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A STUDY OF POTENTIAL ROLES OF SUPERSONIC TRANSPORT CREWS AND SOME IMPLICATIONS FOR THE FLIGHT DECK

VOLUME II:

FEASIBLE AUTOMATED AND MANUAL IMPLEMENTATION CONCEPTS FOR SST ACTIVITIES AND FUNCTIONS

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FOREWORD

This is the second volume of a two volume final report titled "Potential Roles of Supersonic Transport Crews and Some Implications for the Flight Deck". Volume I is concerned with Workload, Crew Roles, Flight Deck Concepts, and Conclusions. This volume is concerned with Feasible Automated and Manual Implementation Concepts for SST Activities and Functions. It is published as a separate volume because of the large amount of material it contains. It should be noted for continuity purposes that Volume I identified seven major activities for the operation of an SST and this volume presents the results of the derivation of functions within each activity and analysis of these functions to develop implementation concepts. The seven major activities from Volume I are:

1. Flight management
2. Phase-oriented system checks
3. Communication
4. Power plant operation
5. Flight control
6. Inlet nozzle configuration
7. Navigation.

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SST FUNCTION DERIVATION/ANALYSIS

In order to identify potential crew roles in the implementation of SST operations, it was necessary to derive specific functions within each activity and these functions were then analyzed with respect to different concepts for their implementation and potential crew participation. The functions were derived in a systematic, a priori analysis. Each activity was partitioned into smaller performance units until it was believed that the performance units represented individual functions. The general method for both doing and documenting this was the development of a flow-logic diagram of SST operations.

Figures 1A, 1B, and 1C show portions of the flow-logic diagram derived for SST operational functions.[1] The dependencies, contingencies, alternatives or interrelationships between functions are shown by the use of logic symbols. Each function is bounded or delineated in terms of relative parameters, and sequential functions are separated on the basis of changes of state of any critical parameter. Since the functions are delineated in parametric terms, they represent performance requirements rather than means although the performance requirements are practically constrained by the design concepts for the SST. During the derivation of the functions and the development of the flow-logic diagram, the flight management concept evolved principally in order to handle automatic and manual implementation of the decision making or management type functions.

The flow-logic diagram of the SST operational functions had several other uses in addition to specifying the basic performance units which were analyzed with respect to crew role. First, it provided the information necessary to develop a time line analysis in which each function was programmed on a real time basis, and this in turn became the basis for our

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[1] The complete flow-logic diagram is quite long and is not included here. Readers who feel they may want the complete diagram should contact the author.

crew workload analysis. Second, the diagram presents the general interrelationships between functions that must be considered when simulation programs are carried out. If specific phases or functions rather than a complete mission are to be simulated, the diagram depicts the functions which are interactive so that they may be simulated to include a true workload situation. Third, the output parameters of each function are essentially criterion parameters which can be used to establish evaluation criteria during simulation. Most of these parameters do not have specific values, but once a specific aircraft configuration is settled upon, these parameters acquire values and become criterion measures.

The functions in the diagram are consistently arranged from the top to the bottom of the diagram. Those functions associated with navigation activity are near the top of the diagram, communications functions are next, flight management functions are near the center, and under flight management are flight control, power plant operation and inlet nozzle configuration functions, in that order. To simplify the diagrammatic presentation somewhat, functions associated with flight management and navigation activity are presented in their entirety and enclosed by a dotted line when they first appear on the diagram. The next time these groups of functions appear, usually in the following phase, they are not repeated in detail, but are represented by a box labeled flight management or navigation. The flow-logic diagram is an overall representation of the operational functions, and details concerning each activity and the functions included within that activity are presented in separate chapters.

Each function identified on the flow-logic diagram and each activity class to which the function belongs was analyzed and an activity/function description prepared. Basically, the activity and function descriptions are the same except for the level of generality used. Activity descriptions are more gross than function descriptions and contain background information pertinent to all of the functions within that activity.

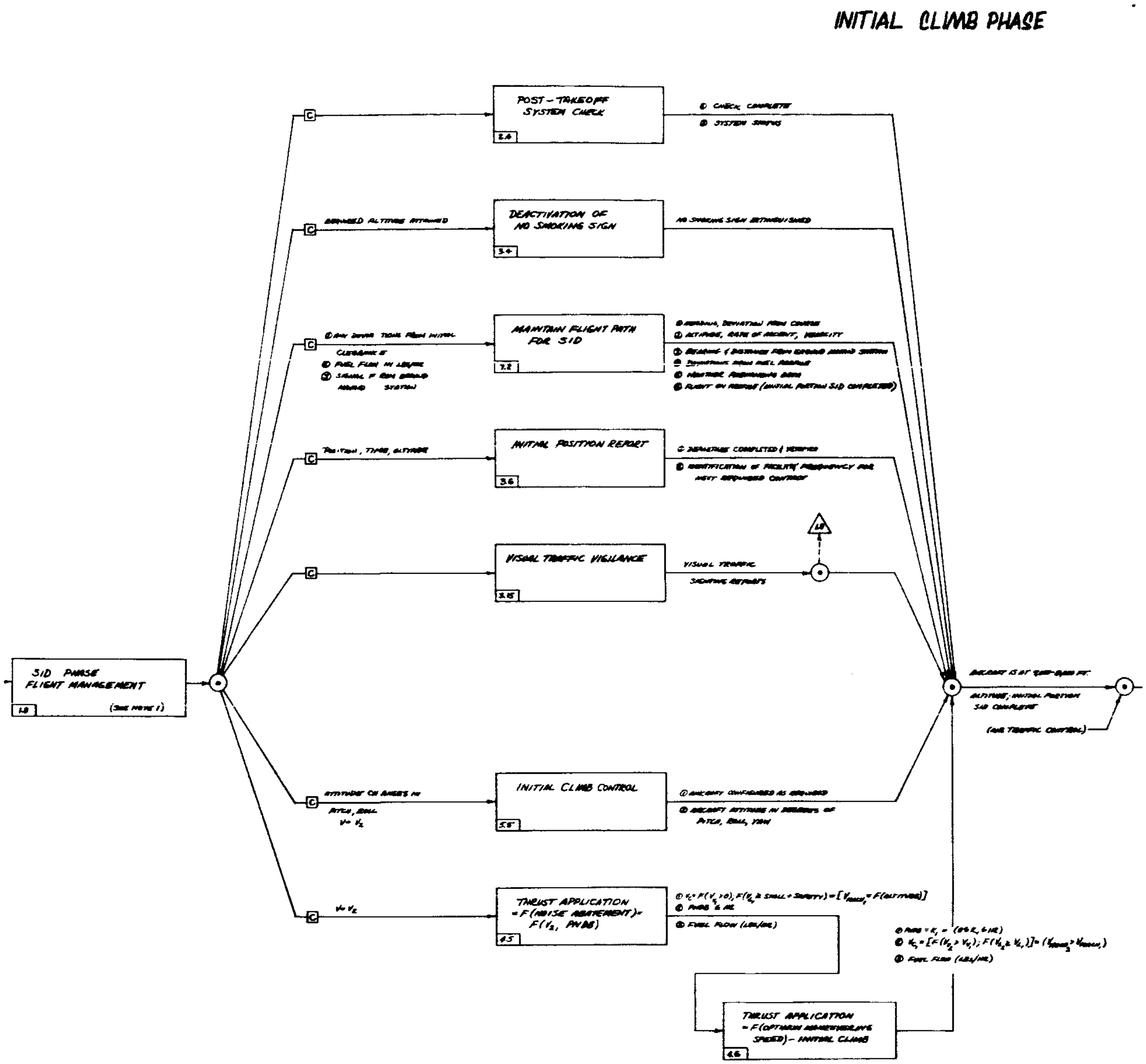

Figure 1A. Sample of flow-logic diagram of SST operational functions (initial climb phase)

TRANSONIC ACCELERATION PHASE

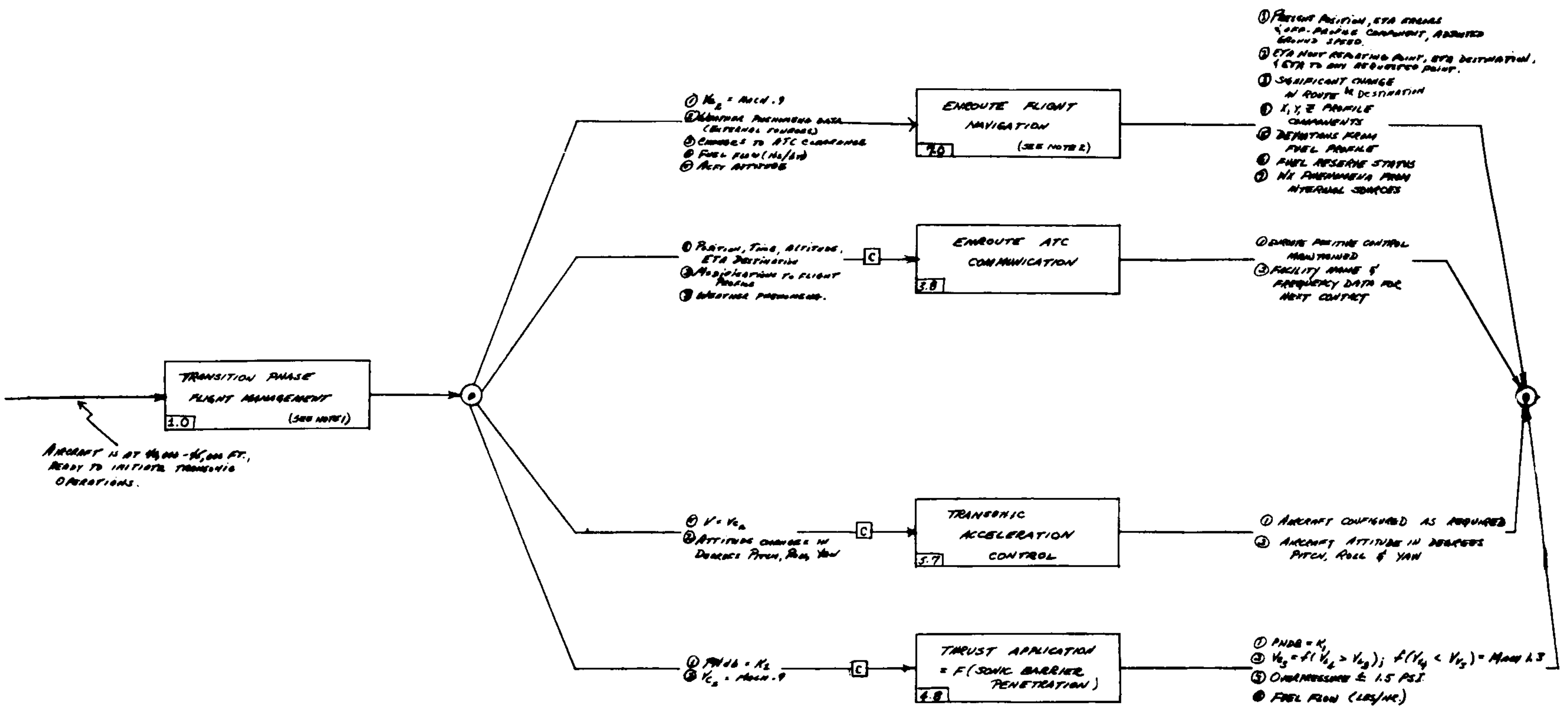

Figure 1B. Sample of flow-logic diagram of SST operational functions (transonic acceleration phase)

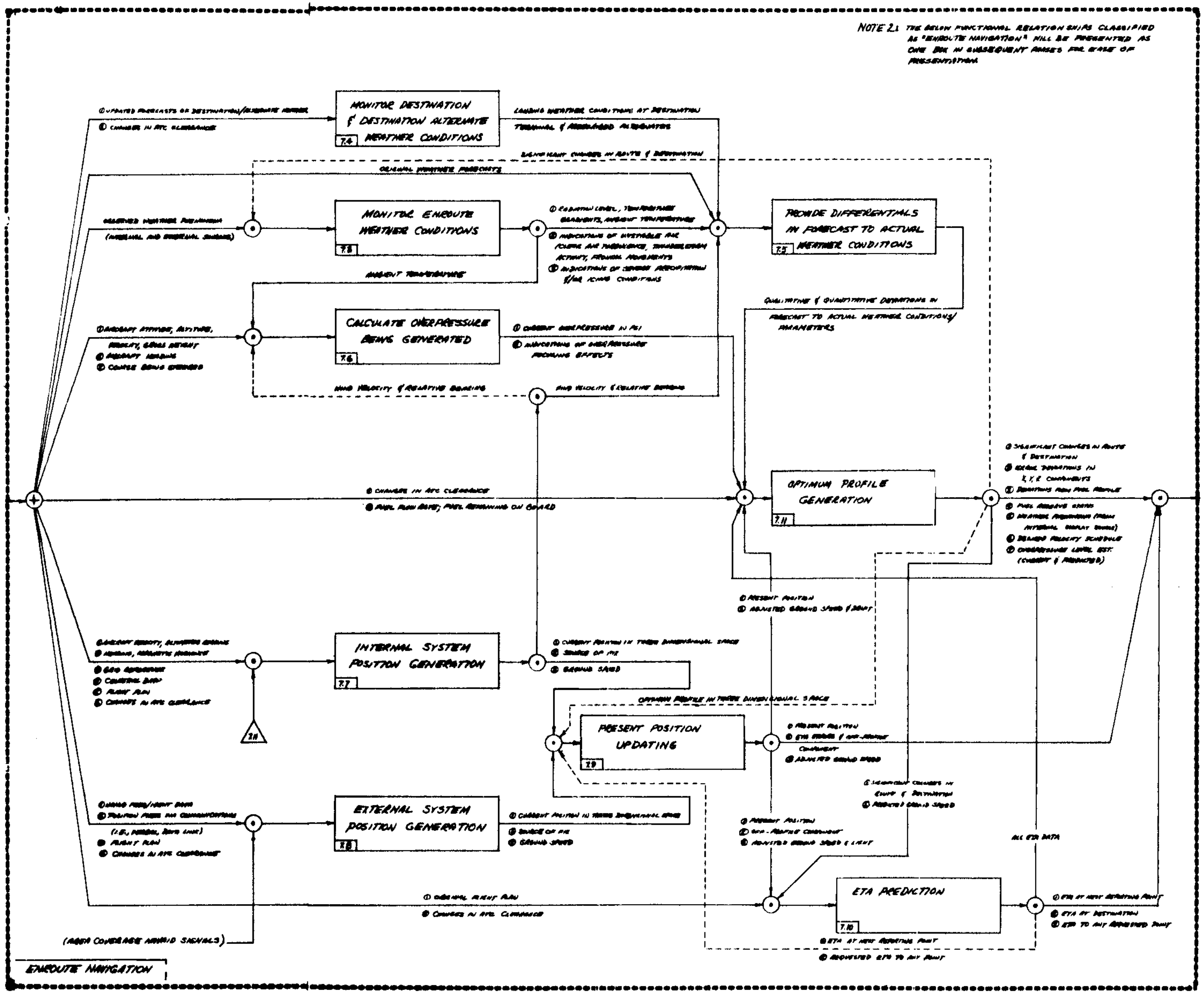

Figure 1C. Sample of flow-logic diagram of SST operational functions (enroute navigation function)

Some of the information contained in the activity descriptions may even be considered elementary by the sophisticated reader with experience in aviation research and development. Each activity and function description consists of six parts which make up that description. These parts and the kinds of information they include are described below:

Purpose. The basic requirements and constraints of the activity or function as well as the general rationale or need are presented here.

Current jet operational requirements and constraints. This part includes International and Federal Air Regulations, or comments about these regulations. No attempt was made to be exhaustive and include all regulations which applied to a function, rather, those regulations which have some effect on the operations and crew requirements of current jets, were generally included. Specifically not included were regulations dealing with certification and air worthiness. Regulations were included for both International (flag) and domestic commercial air carriers and were from two principal sources: (1) the Federal Aviation Regulations (FAR) issued by the Federal Aviation Agency of the United States with which all U.S. domestic air carriers and international carriers (whether U.S. or other) must comply when operating within the Continental boundaries of the United States, and (2) International Standards issued by the International Congress of Aviation (ICAO) which apply to all international carriers which are members of the ICAO when operating outside the boundaries of their country. (Note: Since this report is photographically reproduced, the actual regulations were utilized whenever possible to prevent possible misquotes.)

Current jet implementation concepts. This is a description of the means whereby the activity or function is implemented in current jet aircraft. There is, of course, no standardization throughout current jet operations, and in general, we have presented or discussed several different concepts for implementing the activity or function and frequently integrated these into a typical concept for our purpose. This part is included for two principal reasons, namely, (1) to enable useful comparison between SST concepts for this function and current jet concepts for the specific functions, and (2) because the manual implementation concepts for SST are frequently very similar or the same as current jet implementation concepts. The information in this part in general focused on the equipment involved, the crew responsibility, the crew equipment interface (display and controls), any job aids used, and procedures.

SST potential operational requirements and constraints. This is a discussion of requirements and constraints which may have to be changed in order to accommodate the SST. Further, some discussion of new requirements and constraints necessary for SST operation is presented. The discussion here sometimes refers to a specific regulation and sometimes to an area of operation which affects the crew.

Feasible automated implementation concepts for SST. This is a description of automated means or techniques for implementing the function of concern for the SST. Automation, as used here, means that the function may be initiated, terminated, or have data inserted, and that the crew may monitor the process without participating in the actual processing per se. Feasibility, as used here, is primarily a qualification based on concepts which were available in the technical literature. No attempt was made by the authors to invent new concepts, although some of the existing concepts were extended or integrated to develop what may be considered new concepts. While no rigid format was followed, the same general factors discussed under current jet implementation concepts were also discussed here. These were equipment, crew responsibility, crew interface (controls and displays, job aids) and appropriate procedures. Frequently several alternative automatic concepts were presented.

Feasible manual implementation concepts for SST. This part is similar to the previous one with the exception that it includes feasible manual implementation concepts rather than automated concepts. The term, feasible manual concepts, was used to imply mechanized means or some level of aidedness for implementing the functions in an operational situation. Thus, the concepts described do not imply the maximum or limit of human capability, but concepts which may be considered realistic in the routine, non-emergency operation of the SST. Generally, the concepts are no more "manual" than concepts in current jet operations and in many cases they are the same. In some cases it has been stated that no feasible manual implementation concepts exist for a particular function. This statement means that no manual concepts are deemed feasible if the aircraft is to remain within the intended flight plan and accomplish the cruise phase supersonically. Occasionally, manual implementation concepts have been considered feasible if the aircraft descends from supersonic cruise altitude and continues the flight subsonically. Most planned flights for the SST could probably be completed subsonically within the planned fuel reserve criteria, but obviously this would have a severe economic impact because of loss of utilization of the aircraft. Thus, throughout this report SST operational functions refers to those functions necessary for a flight profile involving supersonic cruise.

Volume I contains a set of summary tables which presents function versus implementation concepts for current operations, SST manual operations, and SST automatic operations.

APPENDIX 1.0 FLIGHT MANAGEMENT

PURPOSE

The purpose of this activity is to ensure safe, reliable, efficient and economic operation of the SST flight during the enroute phases of operations. The activity is visualized as identical to line management functions in any profit-motivated operation. Pilots when functioning as flight-crew captains have long been delegated the responsibility and authority to exercise final judgments as to the course of action demanded by any given operational or emergency situation. Thus, in effect the Captain operates as a flight manager. He has responsibility for assessing the situation, evaluating the situation, and the responsibility and final authority for deciding the course of action required. Although it is true that erroneous judgments may be cause for dismissal or demotion from command, these consequences are always "after the fact" in an operational sense.

As general aviation has progressed, the performance capabilities of aircraft have vastly improved, speeds have increased, and systems have become more complex. This has all served to heighten the complexity of the management activity, and lessen the time available for performance. Moreover, as the complexity has increased and time compressed, the margin for error has decreased proportionately, and many decisions have to be made which are essentially irrevocable. With increasing complexity and decreasing error margins, there have been corresponding increases in available tools designed to extend man's capabilities to cope with the situations. However, progress in this area has been slow relative to the progress in aircraft performance capabilities, and has been evolutionary rather than revolutionary. The impact has been essentially the retention of each set of basic tools, plus the continuous addition of other tools as parameters become more operationally significant; the outgrowth of this development process is the cockpit in a current jet transport. This seems to be due largely to the reluctance on the part of flight crews to accept integrated instrumentation and displays. Research has proven that crew acceptance is the dominating force in the evolutionary nature of cockpit instrumentation. The significant result as far as this discussion is concerned is that flight crews on the decks of current subsonic jet transports are surrounded with a myriad of instrumentation which provides the data necessary to perform the flight management functions either directly or through inference.

The lag in integrated instrumentation behind aircraft performance improvements as well as the compression of time, has significantly increased the cockpit workload. As a result, there have been corresponding increases in cockpit automation. However, this automation has proceeded very slowly, and primarily in piece-meal fashion. The flight management activity may be even more demanding in SST operations and new concepts must be considered.

The flight management activity is comprised of six basic functions as depicted in Figure 1D. A brief description of each function follows:

Data Record. This function satisfies the requirement for keeping records of the various factors associated with flight operations. Basically, three types of record keeping are required: (1) temporary data records which may be required later during the actual flight, (2) permanent data records designed to facilitate flight management at a higher management echelon, and (3) temporary records of pertinent factors during the progress of a flight which may provide insight into accident causes.

Data Monitoring. This function consists of both system performance monitoring and input credibility monitoring. The monitoring task involves comparison of a parameter dimension or characteristic to a criterion referent which may be a magnitude, an envelope boundary, or a condition. Performance monitoring comparisons generally use the desired output conditions and parameters as a referent. An example might be the monitoring of the performance of a simple transformer designed to convert 50 cycle power to 60 cycle power. The transformer performance specification might be an output of 60 cycles ± 1.5 cycles. Performance monitoring would be accomplished by measuring the output frequency to ensure that the criteria envelope is not exceeded.

Input credibility monitoring is concerned with ascertaining that the system receives the necessary qualitative and quantitative ingredients. In the case of [illegible] transformer, input credibility monitoring would be the determination that the input frequency was within some acceptable limits from which it could be inferred that the output would be credible at least in terms of the input parameter. Any out-of-tolerance fluctuations determined by output monitoring would be indicative of non-normal performance and in this case the transformer would be suspect.

In large, complex systems, there are many cases in which system performance monitoring may be construed to satisfy both types of monitoring to an extent. This is due to the cascading effect of functions (or pieces of performance) such that the output of a given function may be the total, or some part of the input to a succeeding function in time. Adding a radio receiver to the transformer above results in a "system" comprising an external power source, a transformer, and a radio receiver. Overall system performance may be measured by certain characteristics of the receiver output, such as volume or fidelity. In this case, system performance monitoring of the transformer performance may also be viewed as input credibility monitoring for radio receiver performance, and so on.

The last example is a highly simplified description of the monitoring problem that exists in the cockpit of a modern day jet transport. Barring some rather revolutionary concepts in instrumentation, the monitoring problem promises to become even more severe in the SST.

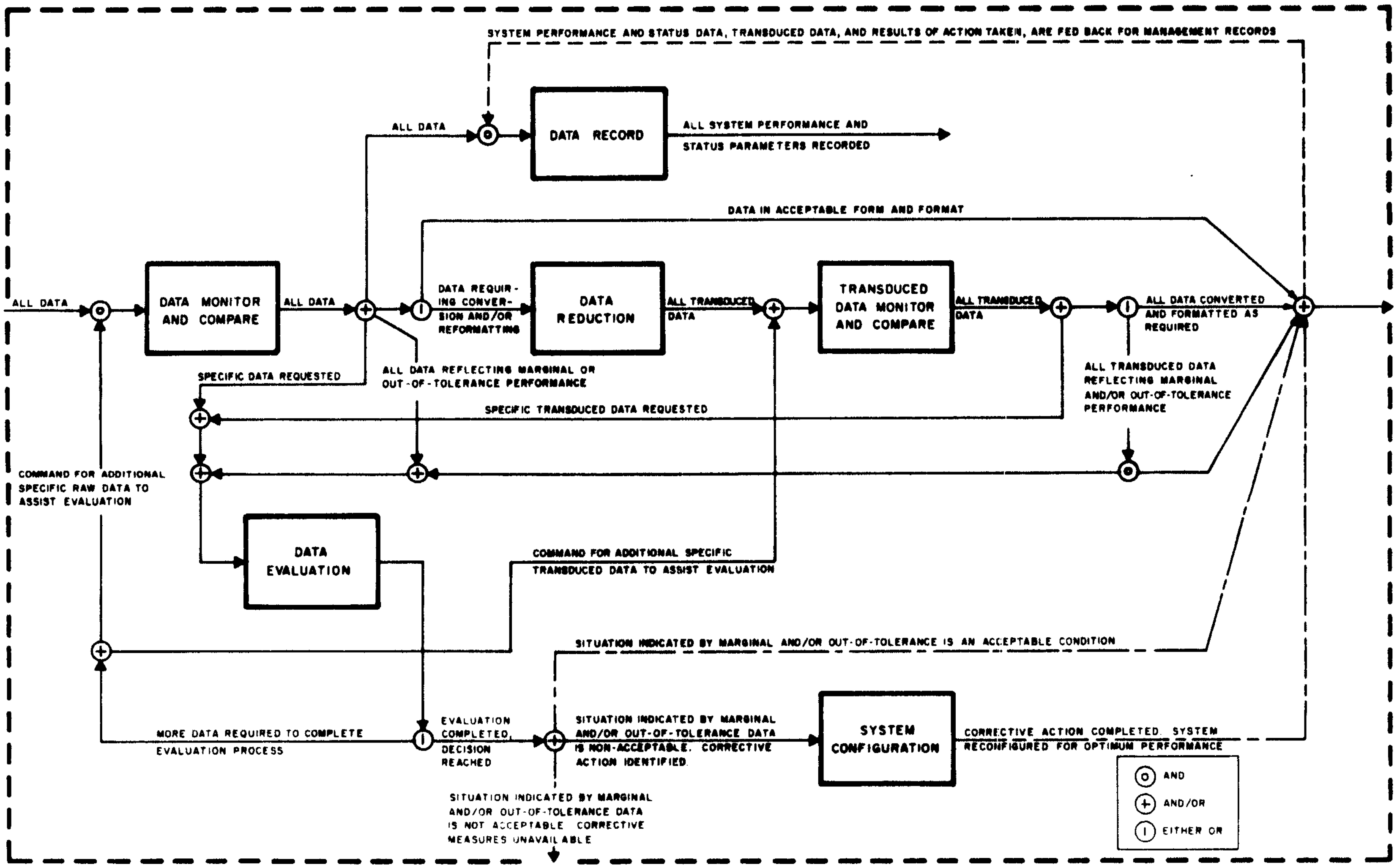

Figure 1D. Six basic functions of flight management

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Data Transduction. This is the conversion of information into the form and format required for subsequent utilization. Data transduction may be construed to occur almost anywhere within a system, if the definition above is not qualified. For purposes of this discussion, the limiting factor is the system level at which flight management is either directly or indirectly involved in the conversion process. A typical example of direct involvement would be the conversion of a cross-track error component into a proportionate heading change command where the autopilot is not engaged and the navigation system output is mentally transduced into an appropriate flight control system input. With the autopilot coupled in, the transduction is accomplished automatically and the crew involvement is indirect in that only the monitoring function is performed.

There are two types of data transduction visualized by this analysis, transduction by design and transduction by inference. The former simply means that system design calls for a direct or indirect conversion process by providing all the essential qualitative and quantitative parameters necessary to provide the desired output in an appropriate form and format. Further, that the system design provides for whatever integration of the input parameters may be required. Transduction by inference directly implies that a crew member is in the conversion loop to provide part or all of the conversion process output. The crew member's involvement is dictated by the need to infer an element or characteristic of any pertinent parameter either by integrating certain parameters for which mechanization has not provided the means, or by focussing skills and knowledge on the problem, or both.

Transduced Data Monitor. This function is the same as that described previously under "Data Monitor." The definition of the two types of data monitoring is equally applicable here. The only change is that the data have been converted into other forms.

Data Evaluation. This function is to provide the capability for situation assessment and decision-making for all normal operating problems and problems of a non-routine and/or emergency nature. Performance in this function will include, in addition to normal operational decisions, (1) evaluation of trouble symptoms, to include the application of cause/effect logic, (2) determination of the impact of the trouble on the overall system in terms of safety, reliability, efficiency and economy, (3) determination of alternative courses of remedial action, and (4) decision-making in the selection of the most appropriate course of action.

System Reconfiguration. This concerns the implementation of the decision resulting from the "Data Evaluation"-function, when that decision calls for some remedial action involving a physical change in the system avionics, or total performance, which will permit the SST to proceed to its destination in accordance with the original flight plan. An example of an avionics change may be simply selecting an alternate sensor when the situation assessment indicates that the on-line sensor is malfunctioning or suspect. Another example may be the insertion of a man into a previously automated servo-loop when it is determined that the mechanization is suspect, there are no alternates, and man's performance would not degrade system performance below an acceptable level. In all of these cases, there is a degree of physical change in the total system.

To discuss the flight management activity on the basis of those functions just described is at present unmanageable for the current jet transports and exceedingly difficult, if not impossible, for the SST. Current jet operations vary greatly in terms of: (1) aircraft design and performance characteristics, instrumentation concepts, operations for which certificated, etc. (2) crew complement and composition, (3) routes flown, and (4) individual airline operator management requirements. The degree of variation is such that a discussion of the flight management function at that level of detail could not possibly reflect all of the pertinent requirements, constraints, and other considerations.

The converse is true with the SST, i.e., at present the information base available is insufficient to permit the degree of specificity indicated in the function descriptions outlined above. It is believed that the purposes of this analysis are best met by combining several of the functions into a single function where a more general discussion will avoid redundancy in the case of the SST, and retain meaning if not specificity in the case of present jet fleets. Therefore, "Data Monitor," "Data Transduction," "Transduced Data Monitor," and "Data Evaluation" will be discussed as one function, namely "Data Monitor and Evaluation." "Data Record" and "System Reconfiguration" will constitute the remainder of the functional descriptions of the flight management activity.

CURRENT JET OPERATIONAL REQUIREMENTS AND CONSTRAINTS

The flight management activity is provided for on current jet transports by FAA Regulations which designate the complement and composition of the flight crew which must be available on each flight, or specify proven means which must be available in the event the crew complement and composition are altered from the standards. Airmen and crew member requirements are specified under FAR Manual (ref. 11), Subpart M. Flight management responsibilities are tacitly designated in the description of the required crew composition. Crew qualifications are also specified. FAR 121.557 specifically assigns the responsibility for final judgment to the pilot in command and provides him with the authority to deviate from any prescribed procedures, regulations, etc. to the extent required in his judgment, in the interests of safety. These crew requirements are meant to provide the means for executing the flight management activities labeled "Data Monitor and Evaluation" and "System Reconfiguration."

Some specific regulations affecting flight management follow:

FAR 121.383, ref. 11:

Airman: limitations on use of services.

(a) No certificate holder may use a person as an airman unless that person—

(1) Holds an appropriate current airman certificate issued by the FAA;

(2) Has any required appropriate current airman and medical certificates in his possession while engaged in operations under this part; and

(3) Is otherwise qualified for the operation for which he is to be used.

(b) Each airman covered by paragraph (a) (2) of this section shall present either or both certificates for inspection upon the request of the Administrator.

(c) No certificate holder may use the services of any person as a pilot on an airplane engaged in operations under this part if that person has reached his 60th birthday. No person may serve as a pilot on an airplane engaged in operations under this part if that person has reached his 60th birthday.

FAR 121.385, ref. 11:

Composition of flight crew.

(a) No certificate holder may operate an aircraft with less than the minimum flight crew in the airworthiness certificate or the Aircraft Flight Manual approved for that type aircraft and required by this part for the kind of operation being conducted.

(b) In any case in which this part requires the performance of two or more functions for which an airman certificate is necessary, that requirement is not satisfied by the performance of multiple functions at the same time by one airman.

(c) The following minimum pilot crews apply:

(1) *Domestic air carriers.* If a domestic air carrier is authorized to operate under IFR, or if it operates large aircraft, the

minimum pilot crew is two pilots and the air carrier shall designate one pilot as pilot in command and the other second in command.

(2) *Flag air carriers.* If a flag air carrier is authorized to operate under IFR, or if it operates large aircraft, the minimum pilot crew is two pilots.

(3) *Supplemental air carriers and commercial operators.* If a supplemental air carrier or commercial operator is authorized to operate helicopters under IFR, or if it operates large aircraft, the minimum pilot crew is two pilots and the supplemental air carrier or commercial operator shall designate one pilot as pilot in command and the other second in command.

(d) On each flight requiring a flight engineer at least one flight crewmember, other than the flight engineer, must be qualified to provide emergency performance of the flight engineer's functions for the safe completion of the flight if the flight engineer becomes ill or is otherwise incapacitated. A pilot need not hold a flight engineer's certificate to perform the flight engineer's functions in such a situation.

FAR 121.387, ref. 11:

Flight engineer.

(a) No certificate holder may operate an airplane having a maximum certificated takeoff weight of more than 80,000 pounds without a flight crewmember holding a current flight engineer certificate.

(b) Such a flight crewmember is also required on each four-engine airplane having a maximum certificated takeoff weight of more than 30,000 pounds, if the Administrator determines that the design of the airplane or the kind of operation requires a flight engineer for safe operation.

FAR 121.389, ref. 11:

Flight navigator: flag and supplemental air carriers and commercial operators.

(a) No flag or supplemental air carrier or commercial operator may operate an airplane over any area, route, or route segment that is outside the 48 contiguous States and the District of Columbia, without a flight crewmember holding a current flight navigator certificate, whenever the Administrator determines that celestial navigation is necessary or other specialized means of navigation necessary to obtain a reliable fix for the safety of the flight cannot be adequately accomplished from the pilot station for a period of more than one hour. However, the Administrator may also require a certificated flight navigator when those specialized means of navigation are necessary for one hour or less. In making that determination the Administrator considers—

(1) The speed of the airplane;

(2) Normal weather conditions en route;

(3) Extent of air traffic control;

(4) Traffic congestion;

(5) Area of land at destination;

(6) Fuel requirements;

(7) Fuel available for return to point of departure or alternates; and

(8) Predication of flight upon operation beyond the point-of-no-return.

(b) The areas, routes, or route segments over which a navigator is required are specified in the operations specifications of the air carrier or commercial operator.

FAR 121.391, ref. 11:

Flight attendants: domestic air carriers.

Each domestic air carrier conducting a passenger operation shall provide at least one flight attendant on each airplane with a capacity of more than nine passengers.

FAR 121.393, ref. 11:

Flight attendants: flag and supplemental air carriers and commercial operators.

(a) Except as provided in paragraph (b) of this section, each flag and supplemental air carrier and each commercial operator conducting a passenger operation shall provide at least the following flight attendants on each airplane used:

(1) For airplanes having a seating capacity of at least 10 but less than 45 passengers—one flight attendant.

(2) For airplanes having a seating capacity of at least 45 but less than 101 passengers—two flight attendants.

(3) For airplanes having a seating capacity of more than 100 passengers—three flight attendants.

(b) Upon application by the air carrier or commercial operator, the Administrator may approve the use of an airplane in a particular operation with less than the number of flight attendants required by paragraph (a) of this section, if the air carrier or commercial operator shows that, based on the following, safety and emergency procedures and functions established under § 121.397 for the particular type of airplane and operation can be adequately performed by fewer flight attendants:

(1) Kind of operation.
(2) The number of passenger seats.
(3) The number of compartments.
(4) The number of emergency exits.
(5) Emergency equipment.
(6) The presence of other trained flight crewmembers, not on flight deck duty, whose services may be used in emergencies.

FAR 121.395, ref. 11:

Aircraft dispatcher: domestic and flag air carriers.

Each domestic and flag air carrier shall provide enough qualified aircraft dispatchers at each dispatch center to ensure proper operational control of each flight.

FAR 121.397, ref. 11:

Emergency and emergency evacuation duties: flag and supplemental air carriers and commercial operators.

[(a) Each certificate holder shall, for each type and model of airplane, assign to each category of required crewmember, as appropriate, the necessary functions to be performed in an emergency or a situation requiring emergency evacuation. The certificate holder shall show those functions are realistic, can be practically accomplished, and will meet any reasonably anticipated emergency including the possible incapacitation of individual crewmembers or their inability to reach the passenger cabin because of shifting cargo in combination cargo-passenger airplanes.

[(b) The certificate holder shall describe in its manual the functions of each category of required crewmembers under paragraph (a) of this section.

[(c) The certificate holder shall train each required crewmember in his functions under paragraph (a) of this section during the emergency training part of the approved training program prescribed in § 121.411.]

FAR 121.543, ref. 11:

Flight crew members at controls.

Each required flight crewmember on flight deck duty shall remain at his station while the aircraft is taking off or landing, and while it is en route unless the absence of one member is necessary for the performance of duties in connection with the operation of the aircraft. Each flight crewmember shall keep his seat belt fastened when at his station.

FAR 121.545, ref. 11:

Manipulation of controls.

No person may manipulate the flight controls of an aircraft during flight unless he is—

(a) A qualified pilot of the certificate holder operating that aircraft;

(b) An authorized pilot safety representative of the Administrator or of the Civil Aeronautics Board who has the permission of the pilot in command, is qualified in the aircraft, and is checking flight operations; or

(c) A pilot of another certificate holder who has the permission of the pilot in command, is qualified in the aircraft, and is authorized by the certificate holder operating the aircraft.

FAR 121.557, ref. 11:

Emergencies: domestic and flag carriers.

(a) In an emergency situation that requires immediate decision and action the pilot in command may take any action that he considers necessary under the circumstances. In such a case he may deviate from prescribed operations procedures and methods, weather minimums, and this chapter, to the extent required in the interests of safety.

(c) Whenever a pilot in command or dispatcher exercises emergency authority, he shall keep the appropriate ATC facility and dispatch centers fully informed of the progress of the flight.

FAR 121.561, ref. 11:

(Similar to ICAO Reg. 4.4.3, ref. 8)

(a) Whenever he encounters a meteorological condition or an irregularity in a ground or navigational facility, in flight, the knowledge of which he considers essential to the safety of other flights, the pilot in command shall notify an appropriate ground station as soon as practicable.

(b) The ground radio station that is notified under paragraph (a) of this section shall report the information to the agency directly responsible for operating the facility.

FAR 121.565, ref. 11:

Engine inoperative: landing: reporting.

(a) Except as provided in paragraph (b) of this section, whenever an engine of an airplane fails or whenever the rotation of an engine is stopped to prevent possible damage, the pilot in command shall land the airplane at the nearest suitable airport, in point of time, at which a safe landing can be made.

(b) If not more than one engine of an airplane that has three or more engines fails or its rotation is stopped, the pilot in command may proceed to an airport that he selects if, after considering the following, he decides that proceeding to that airport is as safe as landing at the nearest suitable airport:

(1) The nature of the malfunction and the possible mechanical difficulties that may occur if flight is continued.

(2) The altitude, weight, and usable fuel at the time of engine stoppage.

(3) The weather conditions en route and at possible landing points.

(4) The air traffic congestion.

(5) The kind of terrain.

(6) His familiarity with the airport to be used.

(c) The pilot in command shall report each stoppage of engine rotation in flight to the appropriate ground radio station as soon as practicable and shall keep that station fully informed of the progress of the flight.

FAR 121.645, ref. 11:

Fuel supply: turbine engine powered airplanes, other than turbo propeller: flag and supplemental air carriers and commercial operators.

(a) For any flag air carrier operation and for a supplemental air carrier or commercial operator operation outside the 48 contiguous States and the District of Columbia, no person may release for flight or take off a turbine-engine powered airplane (other than a turbo-propeller airplane) unless, considering wind and other weather conditions expected, it has enough fuel—

(1) To fly to and land at the airport to which it is released;

(2) Thereafter, to fly for a period of 10 percent of the total time required to fly from the airport of departure to, and land at, the airport to which it was released;

(3) Thereafter, to fly to and land at the most distant alternate airport specified in the flight release, if an alternate is required; and

(4) Thereafter, to fly for 30 minutes at holding speed at 1,500 feet above the alternate airport (or the destination airport if no alternate is required) under standard temperature conditions.

(c) The Administrator may amend the operations specifications of a flag or supplemental air carrier or commercial operator to require more fuel than any of the minimums stated in paragraph (a) or (b) of this section if he finds that additional fuel is necessary on a particular route in the interest of safety.

FAR 121.587, ref. 11:

Closing and locking of flight crew compartment door.

(a) Except as provided in paragraph (b) of this section, the pilot in command of a large airplane carrying passengers shall ensure that the door separating the flight crew compartment from the passenger compartment is closed and locked during flight.

(b) The provisions of paragraph (a) of this section do not apply—

(1) During takeoff and landing if the crew compartment door is the means of access to a required passenger emergency exit; or

(2) At any time that it is necessary to provide access to the flight crew or passenger compartment, to a crewmember in the performance of his duties or for a person authorized admission to the flight crew compartment under § 121.547.

FAR 91.23, ref. 13:

Fuel requirements for flight in IFR conditions.

No person may operate a civil aircraft in IFR conditions unless it carries enough fuel (considering weather reports and forecasts, and weather conditions) to complete the flight to the first intended point of landing, to fly from that point to the alternate airport, and to fly thereafter for 45 minutes at normal cruising speed.

FAR 91.67, ref. 13: (Similar to ICAO 3.22, ref. 14:)

Right-of-way rules; except water operations.

(a) *General.* Except when, because of restrictions to visibility beyond the pilot's control, another aircraft cannot be seen, each person operating an aircraft shall comply with this section. When a rule of this section gives another aircraft the right of way, he shall give way to that aircraft and may not pass over, under, or ahead of it, unless well clear.

(b) *In distress.* An aircraft in distress has the right of way over all other air traffic.

(c) *Converging.* When aircraft of the same category are converging at approximately the same altitude (except head-on, or nearly so) the aircraft to the other's right has the right of way. If the aircraft are of different categories—

(1) A balloon has the right of way over any other category of aircraft;

(2) A glider has the right of way over an airship, airplane or rotorcraft; and

(3) An airship has the right of way over an airplane or rotorcraft.

However, an aircraft towing or refueling other aircraft has the right of way over all other engine-driven aircraft.

(d) *Approaching head-on.* When aircraft are approaching each other head-on, or nearly so, each pilot of each aircraft shall alter course to the right.

(e) *Overtaking.* Each aircraft that is being overtaken has the right of way and each pilot of an overtaking aircraft shall alter course to the right to pass well clear.

(f) *Landing.* Aircraft, while on final approach to land, or while landing, have the right of way over other aircraft in flight or operating on the surface. When two or more aircraft are approaching an airport for the purpose of landing, the aircraft at the lower altitude has the right of way, but it shall not take advantage of this rule to cut in front of another which is on final approach to land, or to overtake that aircraft.

(g) *Inapplicability.* This section does not apply to the operation of an aircraft on water.

FAR 91.87, ref. 13:

Operation of airports with operating control towers.

(g) *Preferential runway system.* When landing or taking off from an airport with an operating control tower and for which a preferential runway system has been established by the FAA, each pilot of a large airplane, assigned a preferential runway by ATC, shall use that runway. However, each pilot has final authority and responsibility for the safe operation of his airplane and if he determines that another runway should be used, ATC will assign that runway (air traffic and other conditions permitting). Each pilot not using the preferential runway assigned shall, if requested by ATC, submit within 48 hours of that request a written report of the reasons therefor to the Chief Airport Traffic Controller of the airport at which the deviation occurred.

FAR 91.127, ref. 13: (Similar to ICAO Reg. 5.3.42, ref. 14)

IFR operations; two-way radio communications failure.

(a) *General.* Unless otherwise authorized by ATC, each pilot who has two-way radio communications failure when operating under IFR shall comply with the rules of this section.

(b) *VFR conditions.* If the failure occurs in VFR conditions, or if VFR conditions are encountered after the failure, each pilot shall continue the flight under VFR and land as soon as practicable.

(c) *IFR conditions.* If the failure occurs in IFR conditions, or if paragraph (b) of this section cannot be complied with, each pilot shall continue the flight to the original destination and shall—

(1) Continue the flight along the route specified in the last ATC clearance received, or, if no route has been specified, along the planned route;

(2) Continue the flight at the highest of the following altitudes or flight levels:

(i) The altitude or flight level specified in the last ATC clearance received;

(ii) The minimum safe altitude; or

(iii) The lowest cardinal altitude or flight level at or above the MEA of the highest planned route structure;

(3) When climb to a higher altitude is required by subparagraph (2)(iii) of this section, begin that climb 10 minutes after passing the first compulsory reporting point over which the failure prevented communications with ATC;

(4) If holding instructions have been received, depart the holding fix at the expected further clearance time received, or, if an expected approach clearance time has been received, depart the holding fix so as to arrive over the radio facility to be used for the approach at the destination as close as possible to the expected approach clearance time; and

(5) Begin descent from the en route altitude or flight level at the radio facility to be used for the approach at the destination at the latest of the following times:

(i) The expected approach clearance time (if received).

(ii) The estimated time of arrival shown on the flight plan, as amended with ATC.

(iii) The actual time of arrival over the facility.

FAR 91.75, ref. 13:

Compliance with ATC clearances and instructions.

(a) When an ATC clearance has been obtained, no pilot in command may deviate from that clearance, except in an emergency, unless he obtains an amended clearance. However, except in positive controlled airspace, this paragraph does not prohibit him from cancelling an IFR flight plan if he is operating in VFR weather conditions.

(b) Except in an emergency, no person may, in an area in which air traffic control is exercised, operate an aircraft contrary to an ATC instruction.

(c) Each pilot in command who deviates, in an emergency, from an ATC clearance or instruction shall notify ATC of that deviation as soon as possible.

(d) Each pilot in command who (though not deviating from a rule of this subpart) is given priority by ATC in an emergency, shall submit, within 48 hours after the emergency, a detailed report of the emergency to the nearest FAA Regional Office.

FAR 91.79, ref. 13:

Minimum safe altitudes; general.

Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes:

(a) *Anywhere.* An altitude allowing, if a power unit fails, an emergency landing without undue hazard to persons or property on the surface.

(b) *Over congested areas.* Over any congested area of a city, town, or settlement, or over any open air assembly of persons, an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft.

(c) *Over other than congested areas.* An altitude of 500 feet above the surface, except over open water or sparsely populated areas. In that case, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure.

FAR 91.129, ref. 13:

Operation under IFR in controlled airspace; malfunction reports.

(a) The pilot in command of each aircraft operated in controlled airspace under IFR, shall report immediately to ATC any of the following malfunctions of equipment occurring in flight:

(1) Loss of VOR, TACAN, ADF, or low frequency navigation receiver capability.

(2) Complete or partial loss of ILS receiver capability.

(3) Impairment of air/ground communications capability.

(b) In each report required by paragraph (a) of this section, the pilot in command shall include the—

(1) Aircraft identification;

(2) Equipment affected;

(3) Degree to which the capability of the pilot to operate under IFR in the ATC system is impaired; and

(4) Nature and extent of assistance he desires from ATC.

ICAO Reg. 3.2.2.4, ref. 14:

Landing.

An aircraft in flight, or operating on the ground or water, shall give way to other aircraft landing or on final approach to land.

When two or more heavier-than-air aircraft are approaching an aerodrome for the purpose of landing, aircraft at the higher altitude shall give way to aircraft at the lower altitude, but the latter shall not take advantage of this rule to cut in in front of another which is on final approach to land, or to overtake that aircraft. Nevertheless, power-driven heavier-than-air aircraft shall give way to gliders.

Emergency landing. An aircraft that is aware that another is compelled to land shall give way to that aircraft.

ICAO Reg. 3.5.1.1, ref. 14:

Air Traffic Control clearances.

An aircraft shall be operated in compliance with air traffic control clearances received.

ICAO Reg. 4.3.3.1, ref. 12:

All aircraft. (Fuel and oil supply)

A flight shall not be commenced unless, taking into account both the meteorological conditions and any delays that are expected in flight, the aircraft carries sufficient fuel and oil to ensure that it can safely complete the flight. In addition, a reserve shall be carried to provide for contingencies, and to enable the aircraft to reach the alternate aerodrome when such is included in the flight plan in accordance with 4.3.1.1.

Note.—Nothing in 4.3.3 precludes an aircraft from amending its flight plan while in flight in order to re-plan the flight to another aerodrome provided that from the point at which the flight is re-planned the requirements of 4.3.3 can be complied with.

ICAO Reg. 4.4.1, ref. 12:
Aerodrome Meteorological Minima

S A flight shall not be continued towards the aerodrome of intended landing unless the latest available meteorological information indicates that conditions at that aerodrome, or at least one alternate aerodrome, will, at the expected times of arrival, be at or above the meteorological minima specified for such aerodromes in the Operations Manual.

S Except in case of emergency an aircraft shall not continue its approach-to-land at any aerodrome beyond a point at which the limits of the meteorological minima specified for that aerodrome in the Operations Manual would be infringed.

NS A flight shall not be continued towards the aerodrome of intended landing unless the latest available meteorological information indicates that conditions at that aerodrome or at least one alternate aerodrome, will, at the expected times of arrival, be at or above the meteorological minima specified for such aerodromes.

NS Except in case of emergency, an aircraft shall not continue its approach-to-land at any aerodrome beyond a point at which the limits of the meteorological minima specified for that aerodrome would be infringed.

ICAO Reg. 4.4.4, ref. 12:
Pilots at Controls.

At least one pilot shall remain at the controls at all times during flight. Two pilots shall remain at the controls during take-off and landing if the certificate of airworthiness or other documents associated with the certificate of airworthiness of the aircraft require the carriage of two pilots.

ICAO Reg. 4.6, ref. 14:

Change from VFR flight to IFR flight.

An aircraft operated in accordance with the visual flight rules which wishes to change to compliance with the instrument flight rules shall:

a) if a flight plan was submitted, communicate the necessary changes to be effected to its current flight plan, or

b) when so required by 3.3.1.1.2.1, submit a flight plan to the appropriate air traffic services unit and obtain a clearance prior to proceeding IFR when in controlled airspace.

ICAO Reg. 5.1.2, ref. 14:

Minimum Heights.

Except when necessary for take-off or landing, or except when specifically authorized by the appropriate authority, aircraft shall be flown at a height of at least 300 metres (1,000 feet) above the highest obstacle located within 8 km (5 miles) of the estimated position of the aircraft in flight.

ICAO Reg. 5.1.3.1, ref. 14:

Change from IFR flight to VFR flight.

An aircraft electing to change the conduct of its flight from compliance with the instrument flight rules to compliance with the visual flight rules shall, if a flight plan was submitted, notify the appropriate air traffic services unit specifically that the IFR flight is cancelled and communicate thereto the changes to be made to its current flight plan.

ICAO Reg. 5.3.1.2.1, ref. 14:

Changes to a flight plan.

5.3.1.2.1 Except as provided for in 5.3.1.2.2 no change shall be made to the current flight plan submitted for an IFR flight within controlled airspace, unless a request for such change has been made and clearance obtained from air traffic control, or unless an emergency situation arises which necessitates immediate action by the aircraft, in which event as soon as circumstances permit, after such emergency authority is exercised, the appropriate air traffic services unit shall be notified of the action taken and if necessary obtain clearance for any change effected.

ICAO Reg. 5.3.3, ref. 14:

Termination of control.

When an IFR flight operating under the air traffic control service has landed, or leaves a controlled airspace and it is no longer subject to air traffic control service, the appropriate air traffic control unit shall be notified as soon as possible.

ICAO Reg. 5.1.3.2, ref. 14:

Change from IFR flight to VFR flight.

5.1.3.2 When an aircraft operating under the instrument flight rules is flown in or encounters visual meteorological conditions it shall not cancel its IFR flight unless it is anticipated, and intended, that the flight will be continued for a reasonable period of time in uninterrupted visual meteorological conditions.

CURRENT JET IMPLEMENTATION CONCEPTS

The implementation of flight management activity varies widely on current jet transports and can be generalized only in terms of typical crew composition and equipment. (Typical cockpit instrumentation for a current jet transport is shown in Figures 4-10.) For example, flights originating in the United States and bound for destinations outside of the continental United States, usually carry a cockpit crew of four members consisting of: one captain, aircraft commander and pilot, one copilot, one flight engineer, and one navigator. This is standard specified by FAA, and deviations must have prior FAA approval.

Crew composition and qualifications for a given flight are based upon consideration of such factors as cockpit workload (normal operations), system reliability, special skills and knowledge requirements, safety factors, and emergency situations. Each air carrier operating along a given route must comply with a specific set of requirements for his operation alone. Although some common denominator may exist in the form of a minimum standard, such a standard would still be subject to variation among carriers depending upon their individual requirements. In essence, the data monitor and evaluation and system reconfiguration flight management functions are provided for by designating an appropriate crew complement which includes the necessary numbers and qualifications applicable to a specific operation. The crew members also provide the means for maintaining specific records and logs required by the FAA and individual airline companies. This excludes, of course, the accident analysis data provided by encapsulated flight recorders which maintain continuous performance records of selected flight parameters throughout the entire flight. These recorders are automatic and only require activation and deactivation by the crew.

SST POTENTIAL OPERATIONAL REQUIREMENTS AND CONSTRAINTS

Essentially, flight management activity for the SST will be concerned with problems similar to those on today's subsonic jets. Some new parameters associated with some of these problems will undoubtedly require the development of specific management techniques, e. g., enroute management of the sonic boom phenomenon. Even though the navigational system will offer control solutions for this problem, flight management will still be required to assess the practicality of the solution.

The paramount differences between today's jets and the SST are potential constraints, such as the severity of time compression and the resultant time available to perform the management activity, and the increased criticality of making an erroneous judgment or decision. It has been stated time and again in the literature that less than optimum performance may well relegate the SST to an extremely unprofitable role. There is unanimous agreement that this factor must be faced and its potential causes minimized to the extent possible and practical through good management as well as design. There is no doubt that higher echelon management will make every attempt to resolve as many of the operational problems as is possible on the ground. However, it goes without saying that enroute flight management must be able to solve problems on a real-time basis, and must be provided the tools, methods, and techniques required to minimize the probability of exercising erroneous judgment.

An error in judgment for SST flight management may be considerably more serious from an economic point of view than it is for current jet operations. This is due primarily to the alternative subsonic flight regime which may permit completing a flight within adequate safety criteria, but at a considerable economic penalty due to decreased utilization. Essentially three types of errors can be committed:

Type 1 Error: A judgment that there is a malfunction when in fact there is not and the flight is aborted or returned to subsonic regime.

Type 2 Error: Failure to recognize a malfunction and continuing to operate in an unsafe situation.

Type 3 Error: Recognition of a malfunction, but selection of an alternative which is unnecessarily penalizing, e.g., going subsonic when it is unnecessary.

Enroute flight management will undoubtedly require some modifications in existing practices and procedures from the viewpoint of ground-based facilities. There may be a need for ATC, for example, to establish some minimum clearance change for the enroute portion of the flight, and possibly some priority handling scheme in the terminal areas. There will undoubtedly be a requirement for reliable, efficient, and faster coordination between all ground facilities and the SST flight management. There are some research programs looking into some of these problem areas, but as yet, recommendations have not been formulated which would permit the specification of practical requirements. However, the potential operational characteristics of the SST, along with the operating environment, permit the generalization of potential effects on the flight management activity. These effects are described in as much detail as is now possible in the discussion of the individual flight management functions.

With respect to automatic implementation of the flight management activity, there is an underlying premise which must be given initial consideration, i. e., man will have a major role in the execution of SST flight management functions, and in this role he is an absolute necessity. Available evidence indicates that it is not a question of whether man is necessary to successful SST flight management, but of the degree of automation necessary to extend man's capabilities sufficiently to perform the functions involved. First of all, it is important to point out that at present there are no machines available which can duplicate man's capability in the areas of computation and judgment (ref. 15). Moreover, even if such a machine were available which could also meet the exacting requirements for size, weight, reliability, adaptiveness, and all of the other constraints and requirements, there is a final authority which would rule out complete automation, or in a broader sense, the absence of man in the system, and that authority is the traveling public. Price, Behan, and Ereneta (ref. 1) point out that "The public has a deep-seated fear of air transport that is independent of objective safety data, and therefore may be termed irrational ... ", and "... to partially cope with this fear, the airplane must be under the control of a force which the public will perceive as competent. Today's public will not so perceive a machine, regardless of the objective facts." An even more basic acceptance factor is concerned with survival needs. While the public will draw some degree of comfort in knowing that the ultimate agent responsible for their safety is governed by the same natural instinct to survive, they also recognize that one cannot so endow a machine.

Regardless of the degree of automation provided within the total system concept, the flight deck will provide for man's (generic here, meaning crew) role in the system. In the first report under this contract (ref. 1), Price, Behan, and Ereneta point out many considerations which are directly applicable conceptually to the definition of implementation concepts to satisfy performance requirements for flight management functions. It is concluded that the implementation concept for the most automatic means feasible for performing the flight management activity will still involve direct participation by the crew. More specific data concerning the degree of crew participation and some possible avenues for satisfying performance requirements are given in the discussions of the specific functions involved.

Donald W. Richardson of Hughes Aircraft Company has written several papers regarding a Central Electronic Management System Concept (CEMS) for SST. Since it is an inclusive concept referred to throughout this report, a brief description of CEMS is presented here reproduced from "VECTORS," a Hughes Aircraft Company Quarterly Publication (ref. 16). Some of the CEMS features are applicable to activities other than flight management, but for continuity the complete CEMS description is included here.

> With dramatic changes in air transport operations, the public is rapidly becoming indoctrinated in the ways of the jet age. We have already geared our thinking in terms of delivery of mail, cargo and people at the 600 m. p. h. range presently being achieved by the major airlines throughout the world. Obviously, jet aircraft transportation is here on a permanent basis. However, not so obvious to the general public--but glaringly evident to the manufacturers and users of these aircraft, the designers and pilots, the engineers and control tower operators--is the entire new family of operational and traffic control problems created by the universal acceptance of these aircraft. The ever-increasing numbers of turbojet transports in the Mach 0. 8-0. 9 speed range operating at altitudes up to 40, 000 ft., are already of such magnitude as to cause considerable concern among the personnel responsible for the safe and economical operation and control of these aircraft. The mere thought of the transition to Mach 3 and 70, 000 feet staggers the imagination.

The basic problems for supersonic air transportation in the Mach 3 range include: how may these aircraft be operated in the most efficient, safe and economical manner possible ? This and other questions airline operators and the passenger public jointly will ask, and in effect are now asking. In answer to these problems, Hughes Aircraft Company has advanced a radically new concept of air transportation control, called the Central Electronic Management System or CEMS for short.

CEMS system consists of two basic elements: a small, highly reliable, general-purpose digital computer --and a multi-purpose central display station. The computer ties together all of the various subsystems required by the aircraft for navigation, communications and flight control. It processes their output and controls them in accordance with instructions from the flight crew or--in some instances the ground controller. (See Figure 2.) * To anyone familiar with the extreme versatility of a digital computer, it becomes almost a case in self-hypnosis to allow it to absorb more and more functions until, without one realizing it, the supersonic transport will seemingly become a pilotless drone--almost a guided missile with human passengers. It therefore becomes necessary to apply judicious restraint to such enthusiasm, realizing that there must be a reasonable trade-off between the exact capabilities of a computer and interpretative ability of the human. Nowhere will the pilot become more important than in the cockpit of a supersonic transport.

The second element of CEMS is the central display station, a TV-like screen which is the link between the computer and the flight crew. The display would include a cathode ray tube capable of presenting super-imposed electronic and optically projected displays. (See Figure 3.)* The presentation of optical and electronic information on the same screen eliminates viewing parallax (the apparent displacement or the difference in apparent direction of an object, as seen from two different points.) Symbols of aircraft present position and heading, fuel circle and homing points can be projected electronically, and navigation and instructional charts projected on the screen by an optical projection system.

CEMS has the flexibility to perform a variety of basic and essential functions; such as: Takeoff Monitoring, Navigation, Automatic Position Reporting, Cruise

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* Parenthetic insertion ours

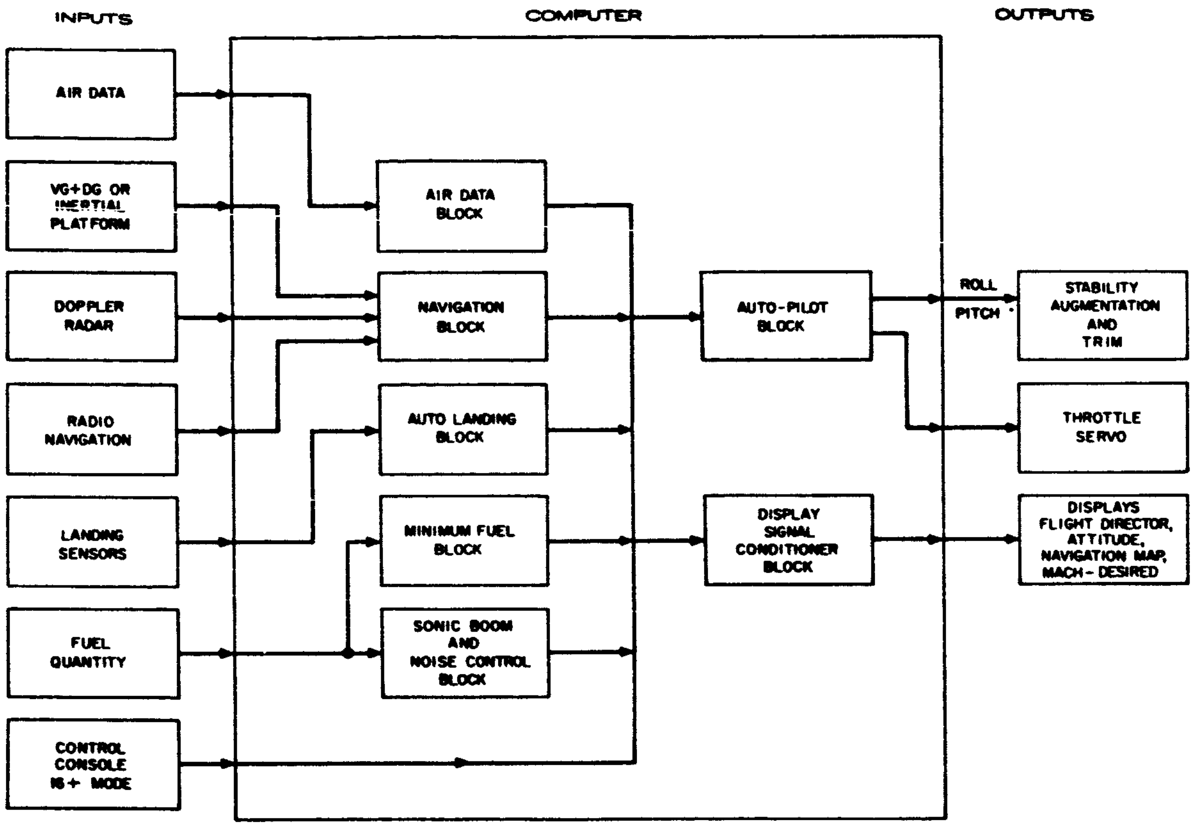


Figure 2. CEMS operational block diagram
(Courtesy Hughes Aircraft Company)

TYPICAL DISPLAY & CONTROL INSTALLATION

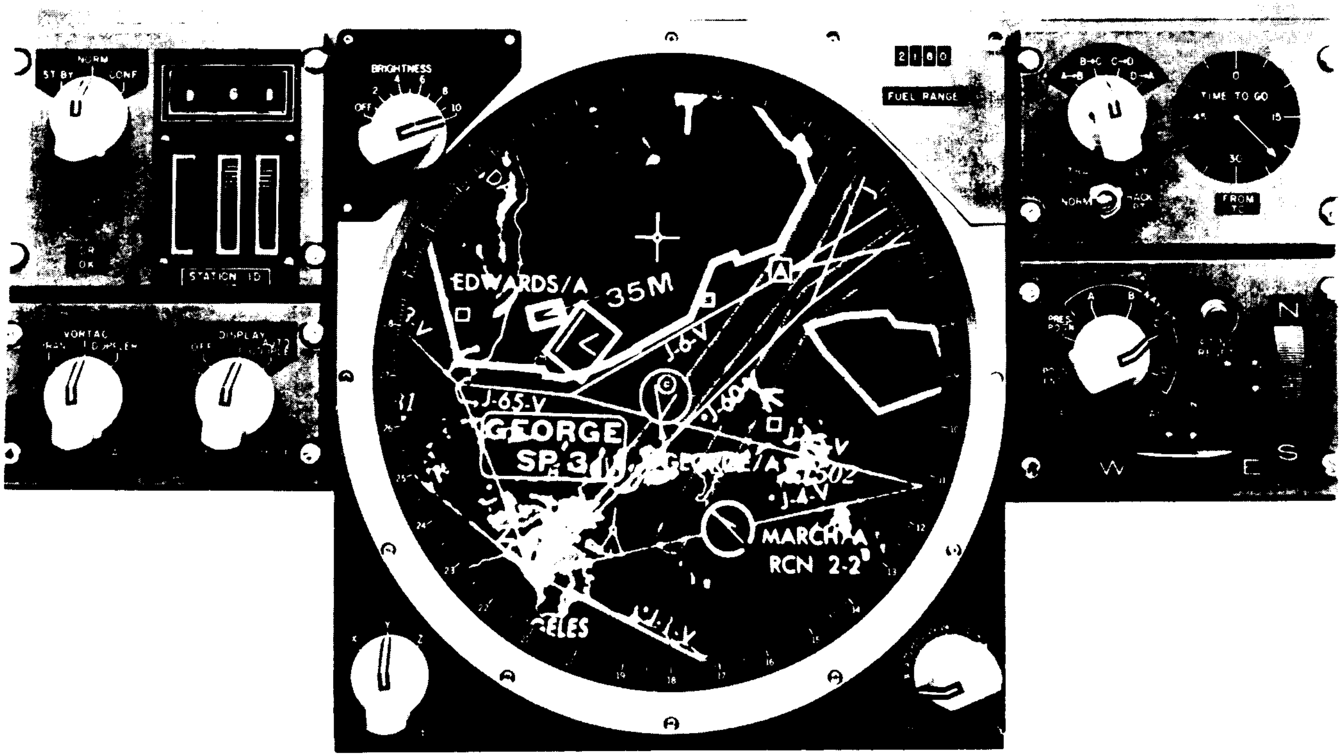


Figure 3. CEMS display and control concept (Courtesy Hughes Aircraft Company)

Control, Terminal Navigation, System Checkout and Self-Test.

Examine each of these briefly: first, takeoff monitoring. The problem of safely taking off a supersonic transport will be complicated by the aircraft's tremendous gross weight and the sensitivity of its engines to changes in atmospheric conditions. If the aircraft is to be operated efficiently, it must take off with the maximum safe load. However, assuming the aircraft has the optimum safe load, but the air temperature increases by as little as 20 degrees over standard atmospheric conditions, a safe takeoff may not be achieved. Therefore, an important function CEMS might perform is monitoring the conditions affecting takeoff safety. Prior to takeoff, CEMS could compute the maximum allowable gross takeoff weight on the basis of runway characteristics, wind, temperature and so on. The computed weight would be indicated to the flight crew on the central display console. Once the aircraft was loaded and started down the runway, CEMS would monitor the aircraft's acceleration and compare it with the predicted acceleration for a safe takeoff. At the critical acceleration stop-point, CEMS would inform the pilot whether or not to proceed.

A more critical function will be navigation. The supersonic transport will cross the United States in an hour and a half; a flight from New York to Chicago will take less than 30 minutes. At these short flying times, precise navigation and accurate position reporting are of paramount importance. It is necessary for each aircraft to maintain an assigned ground track. In order to provide adequate airspace and ensure continuous compliance to assigned ground tracks, area navigation is necessary. Finally, the aircraft's position changes so rapidly that the present techniques of indicating position will be unsatsifactory. CEMS will continuously indicate the aircraft's present position and heading on a pictorial map display. The operator will be able to select maps of different scales for planning enroute navigation and flight terminal areas. If ever the flow of information data to CEMS is interrupted, the system will dead-reckon the aircraft's position. In addition to computing position, CEMS will navigate the aircraft along any desired ground track. Once the flight plan has been entered, CEMS will compute the ground track from any one point to the next. The track will be indicated on the map display by a line joining the two points. CEMS will generate precise commands for directing the aircraft onto the track. These may either be displayed visually to the pilot or coupled directly to the autopilot. CEMS will also compute such pertinent navigational information as the time-to-go till the next navigation point will be reached and the maximum range that can be flown at the present ground speed with the fuel remaining.

Another function which might be performed by CEMS is cruise control to minimize fuel costs. Present jet transports on domestic and shorter range flights have little need for this function. In the case of the Mach-3 aircraft a maximum-speed flight leaving New York at 7:00 a. m. would arrive in Los Angeles at 8:30 a. m. ; a minimum cost flight might arrive at 8:35 a. m. This difference would be of little concern to the average passenger; yet, the difference in fuel cost between the two flights would be approximately $500. Minimum-cost operation, will be highly attractive.

System checkout and self-test may in the end prove more valuable than all the rest. Studies indicate that to be economically practical, a supersonic transport must actually be in flight an average of 10 hours a day; consequently, between flights little time would be available for trouble-shooting and repair. To alleviate this situation, CEMS would perform self-test functions of two types. The first would be to monitor the operation of all elements of the aircraft system. --The engines, hydraulic system, control system, electrical system, electronic system and so on. Should a failure occur, CEMS would notify the flight crew and indicate which item during the self-test checkout had failed; the flight crew in turn would make the necessary arrangements to correct the failure.

The second type of self-testing which CEMS would perform is failure prediction. For example, the r. p. m. of an aircraft engine will, from time to time, exceed the controlled value. The duration of the engine's overspeeds can be correlated with the engine's wear. By monitoring the overspeeds, CEMS could predict when the engine rotor should be replaced. Data such as this would be used in scheduling maintenance operations, and greatly reduce the amount of downtime required.

The complicated CEMS computer will be similar in operation to other Hughes-produced digital computers performing similar functions in advanced military aircraft. However, the CEMS computer will be radically different. Whereas present computers employ etched circuits and conventional circuit elements, the CEMS computer will employ thin-film circuitry. This circuitry has two outstanding advantages: first, its extremely small size. The CEMS computer will occupy no more than one-half of a cubic foot. The second advantage of thin-film circuitry is its extremely high reliability. For every 100 planes flying regular schedules, it is estimated that no more than two computer failures will occur in 10 years.

The other basic element of CEMS, the central display station, presents two somewhat conflicting requirements. It must present a tremendous amount of static information, charts, instructions, and it must present simultaneously a variety of dynamic information such as positions, headings, courses and ranges. The two requirements have been met by combining a slide projector with an electronic display tube. Static information is recorded on a 35mm film strip for optical projection, and dynamic information is presented by electronically controlling the beam of the cathode ray tube. The result is a single, integrated display of not only static, but also dynamic information.

While the concept of CEMS was conceived by its inventors as a specific solution to the operational problems of Mach-3 aircraft, in perhaps slightly different form the CEMS concept could very well be the answer to the operational problems of manned spacecraft.

FEASIBLE MANUAL IMPLEMENTATION CONCEPTS FOR SST

It has been stated that the cockpit workload on current jet transports is at the saturation point. More and more, as aviation technology has progressed, man has been forced into an activity for which he is not particularly suited, i. e., monitoring. It can be concluded, moreover, that the monitoring requirements for the SST will increase in complexity and criticality. Any implementation concept, then, which considers manual feasibility should consider these two aspects along with the pertinent ramifications. Increased complexity and criticality of the monitoring task, along with the unsuitability of the human operator for task performance, would appear to significantly increase the probability of a serious error. It follows that a feasible manual implementation concept should be concerned initially with potential techniques for decreasing the monitoring load on the human being, thus freeing him to perform other functions at which he excels, e. g., situation assessment and making judgments.

It seems reasonable to assume that crews are not going to increase significantly in size, nor undergo any radical changes in composition, although further research may indicate increased requirements for interchangeability. The degree to which crew members will be able to devote themselves to flight management activity will depend in large part on the specification of means for performing the remainder of the system-oriented activities. This analysis has pointed out and substantiated by reference to a broad authoritative base, the requirement for a high degree of automation in the vast majority of other system-oriented activities. Although the justification for automation in each activity will involve a widely varying set of requirements, the ultimate objective has been to attain a balanced man-machine relationship. The exploitation of the crew in the flight management role is a natural outgrowth of such a complementary arrangement. There are tasks associated with flight management which are either beyond man's capabilities or are representative of areas where man is inferior to machines, e. g., continuous recording of numerous flight parameters associated with accident analysis. Conversely, it appears that a large portion of the flight management activity is of a nature that the optimum configuration must surely exploit man's capabilities. Details may be found in the specific function description associated with this activity.

1. 1 FUNCTION 1. 1 DATA MONITORING AND EVALUATION

Purpose

The purposes of this function are to:

1. Provide input credibility and system performance monitoring on all individual parameters indicative of the degree or extent of safety, economy, reliability, and efficiency being achieved by the flight.

2. Provide for data transduction where flight management is directly or indirectly involved, so that the required information is available in the form and format needed for subsequent utilization.

3. Provide input credibility and system performance monitoring on all transduced information.

4. Provide for situation assessment and decision-making for all normal operating problems and problems of a non-routine and/or emergency nature.

It is evident that this function embraces the majority of flight management tasks. Webster defines management as "... judicious use of means to accomplish an end; skillful treatment" and "the collective body of those who manage any enterprise or interest." Judicious use of means implies discerning and sound judgment based on being cognizant and informed. Cognizance or awareness is an obvious result of a good monitoring scheme; being informed implies working knowledge and skills, plus experience. The point is that the performance of this function by the flight crew of a commercial jet transport involves management in every sense of the word.

Current Jet Operational Requirements and Constraints

Requirements and constraints for this function are as numerous as the different aircraft, avionics, crew complements and composition, airline company operations, specific company procedures for individual routes and so on that exist today. Basic regulations for flight management have been included under the activity description. The following are some general requirement and constraint considerations.

1. Cognizance of the progress of the flight relative to the flight plan must be maintained, and appropriate control over flight progress must be exercised.

2. Cognizance of the operating condition of the total system and individual subsystems must be maintained, and appropriate control over system/subsystem operation must be exercised.

3. Detection and isolation of system/subsystem failures and decisions as to whether reconfiguration is possible or whether the aircraft must deviate from the original flight plan must be made.

4. The impact of other perturbations in total system operation must be assessed in terms of continuing the flight safely, reliably, economically, and

efficiently; some typical perturbations might result from:

a. Alteration in the ATC clearance

b. Unfavorable flight conditions enroute

c. Any deterioration in crew capability

d. Non-system oriented incidents (e. g., passenger emergency).

Although certain courses of action are specified by procedures, and advice may be available through communication, there are essentially no constraints on the aircraft commander as far as exercising judgment in any situation and selecting the most appropriate course of action. There are constraints which, although not directly involved in the performance *per se*, may be construed as regulatory for purposes of *facilitating* performance. Generally, these constraints are concerned with minimum standard equipment requirements and minimum standard crew complement and composition requirements. These constraints are manifested in FAA and/or ICAO certification of airline operations along specific routes when these aircraft possess the minimum standard cockpit instrumentation, equipment and crew.

Current Jet Implementation Concepts

As is the case with the other flight management functions, current jet transports provide for data monitoring and evaluation by the cockpit instrumentation together with present standards for crew complement and composition. Although there are many variations in cockpit instrumentation depending on specific aircraft types, equipment manufacturers, or company specifications, Figures 4 through 10 illustrate typical, current jet transport cockpit instrumentation concepts. Figures 4 through 9 are from an early (1960) Boeing 707 operations manual (ref. 17). Figure 10 is a later Boeing 707 pilot and copilot panel presented in life size. It can be seen that many instruments provide the crew with information and that the instruments are not simple meters or lights, but are rather complex. These instrument panel illustrations are for an aircraft with a crew complement of four consisting of pilot, copilot, flight engineer and navigator.

With variations according to specific requirements, the instrumentation presented in Figures 4 through 10 is representative of current jet concepts for the implementation of data monitoring and evaluation. Input credibility and system performance monitoring on all required parameters is facilitated by the displays. In the absence of a specific parameter display, the monitoring is accomplished by inference from displayed data. Some provisions for automated data transduction and system control are available in most cockpit instrumentation schemes, e. g., auto-pilot or flight director systems. Auto-throttling and integrated all-weather landing systems are expected to be in wide use in the near future. Cockpit navigation techniques employing semi-automatic dead-reckoning devices, such as doppler radar and inertial navigator systems, are already being used and are on the increase. Such innovations will have an impact on credibility and performance monitoring as well as on situation assessment and the exercise of good judgment.

SST Potential Operational Requirements and Constraints

The generalized requirements indicated under "Current Jet Operational Requirements and Constraints" are equally valid for SST data monitoring and evaluation. There is no doubt that specific requirements

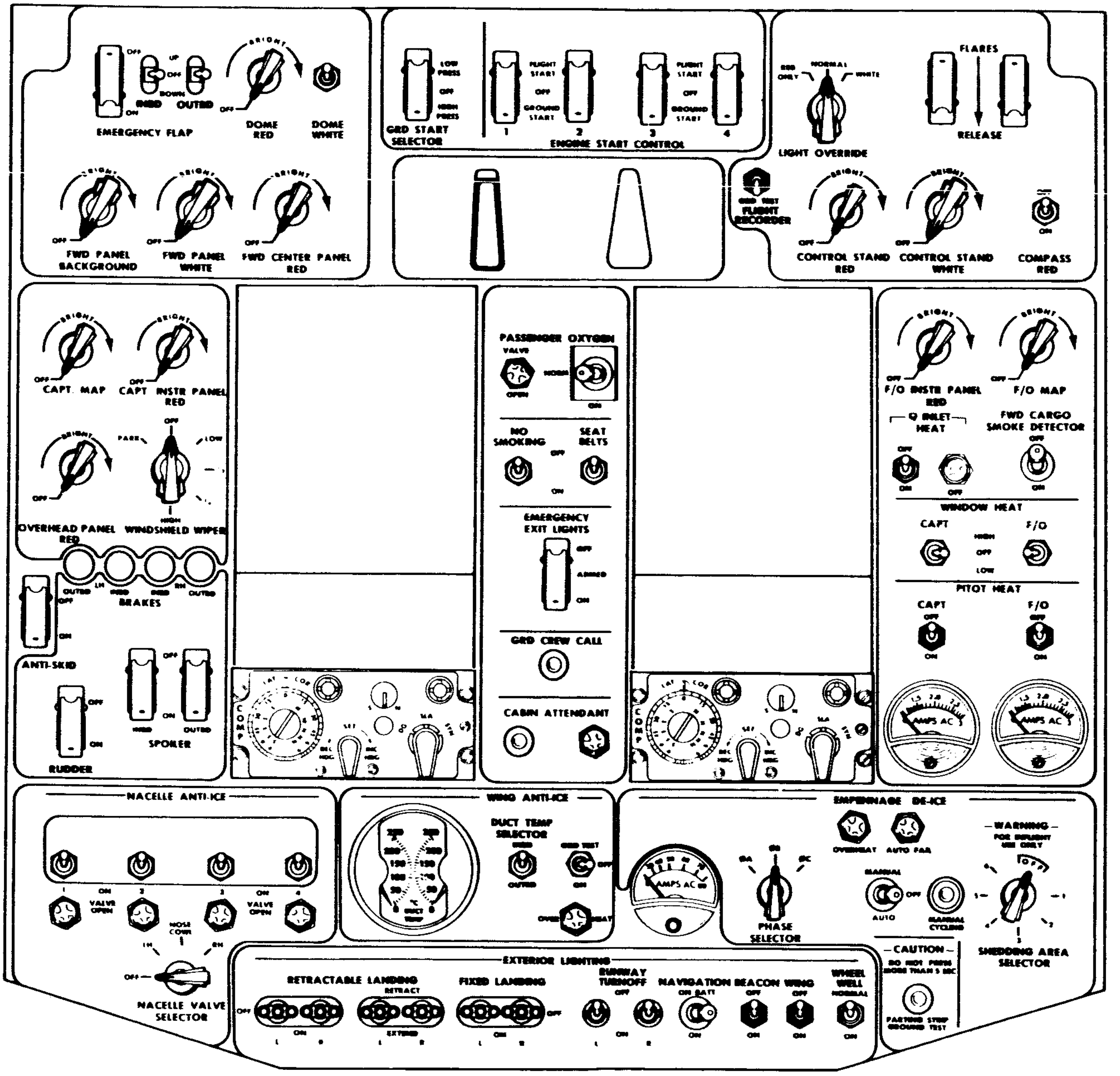


Figure 4. Overhead panel (From ref. 17).

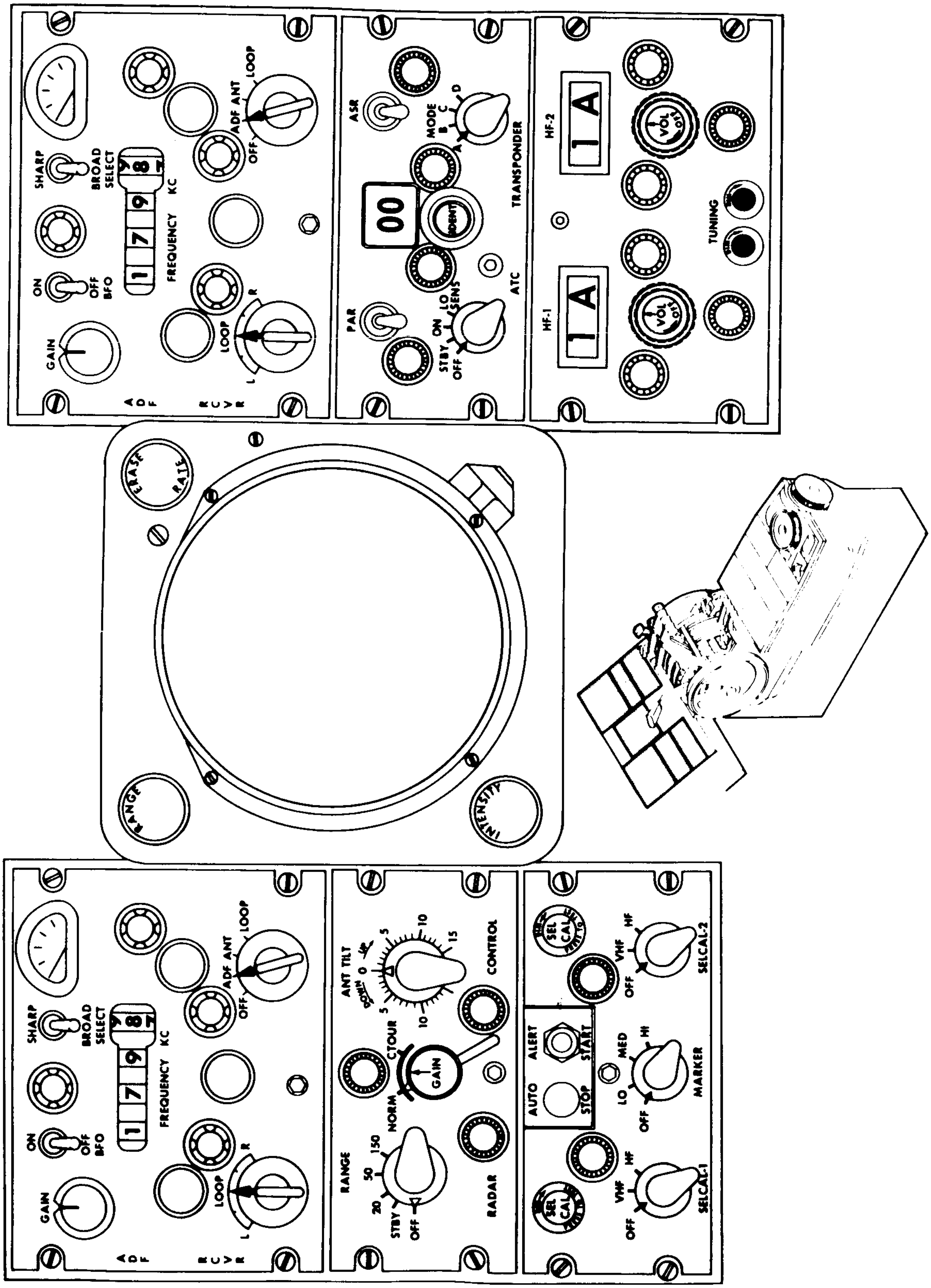


Figure 5. Forward electronic control panel (From ref. 17).

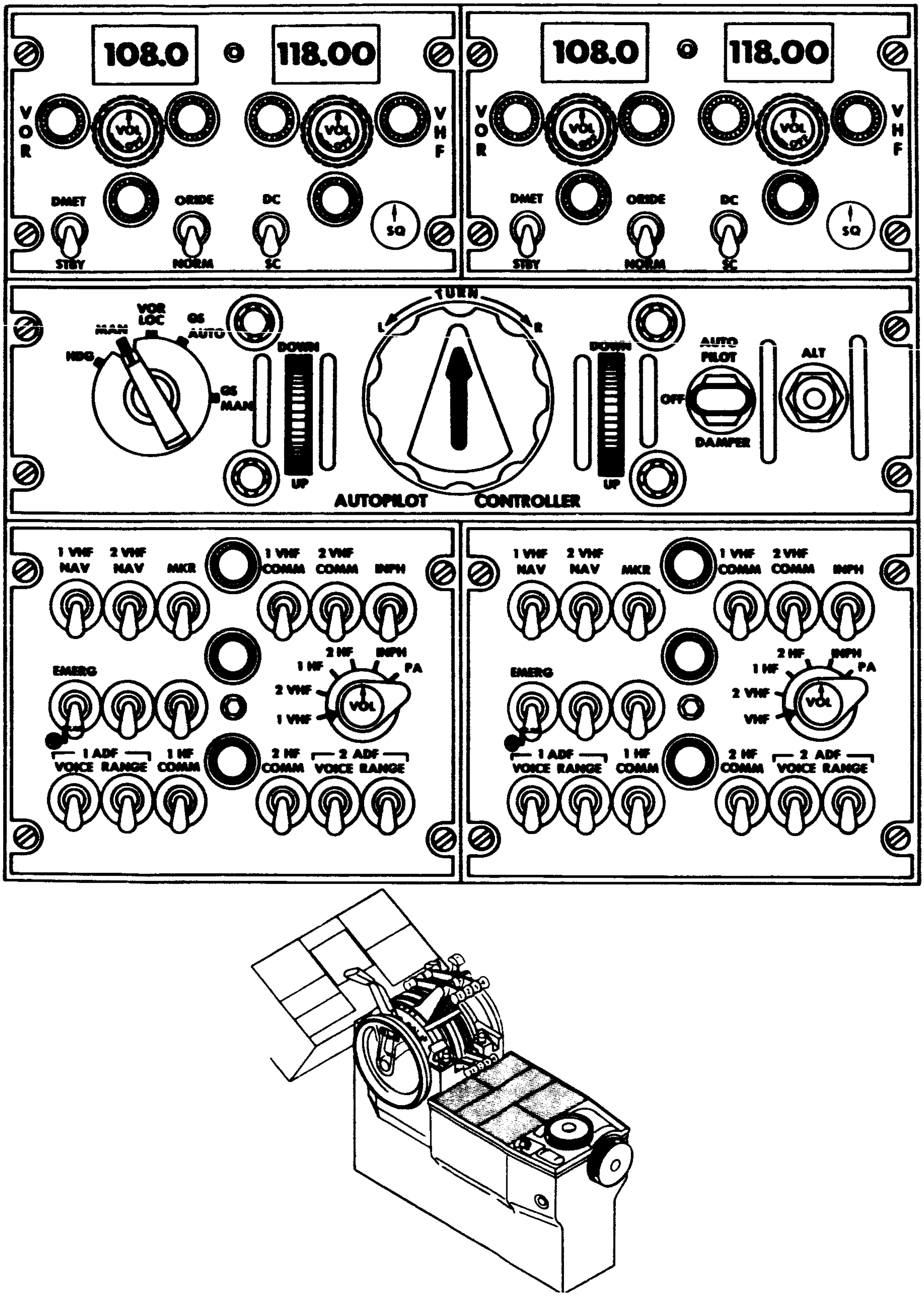


Figure 6. AFT Electronic control panel (from ref. 17).

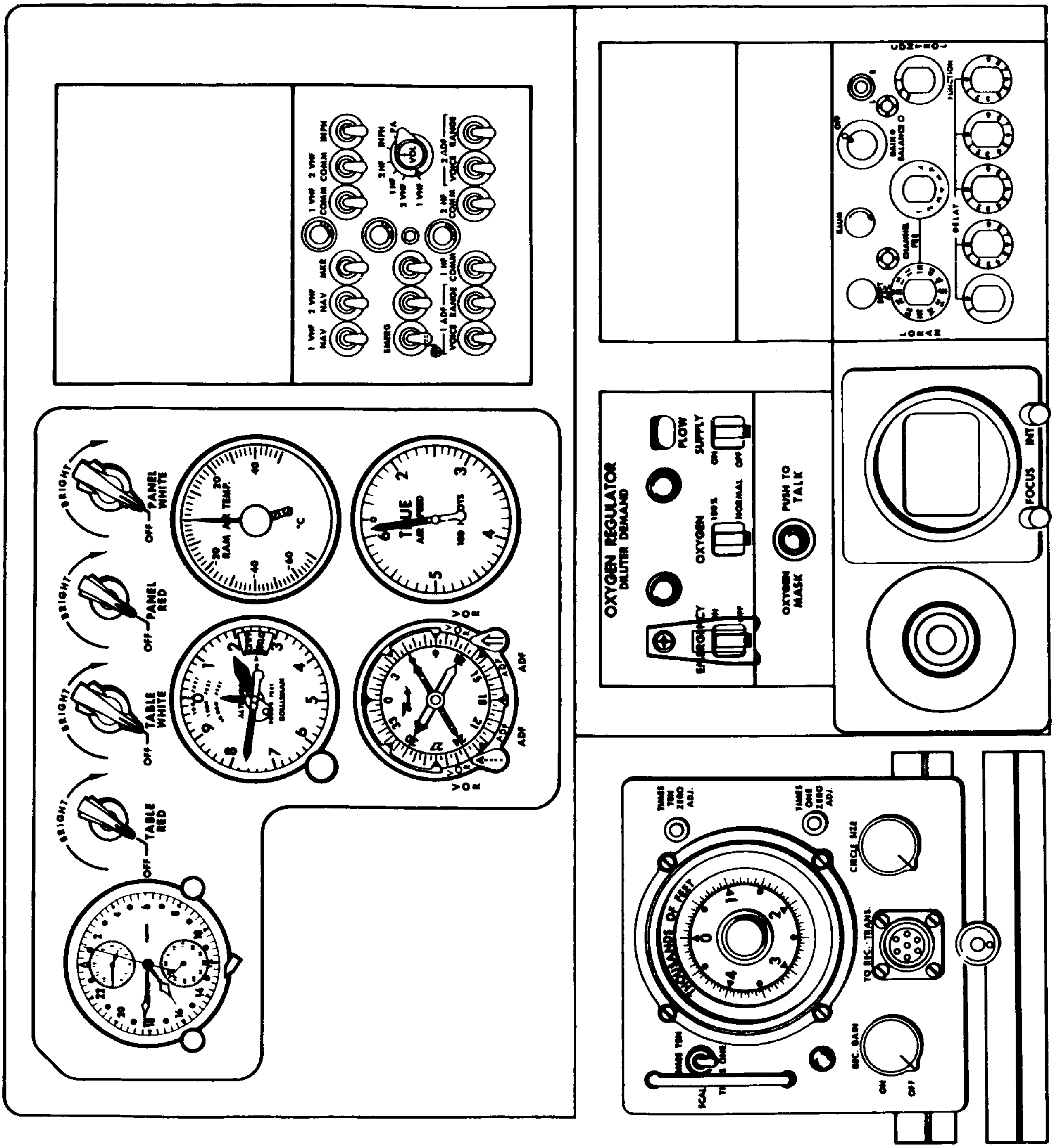


Figure 7. Navigation station panel (from ref. 17).

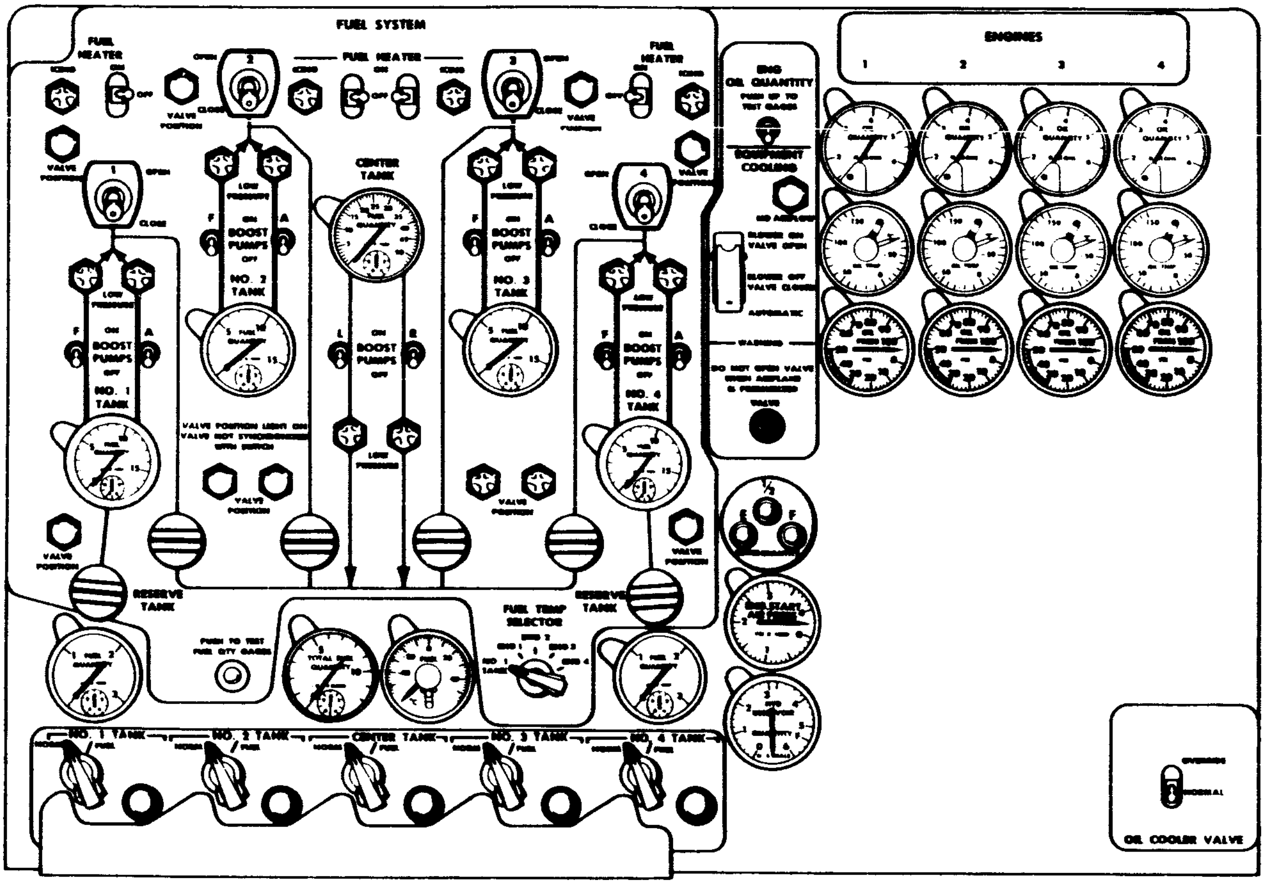
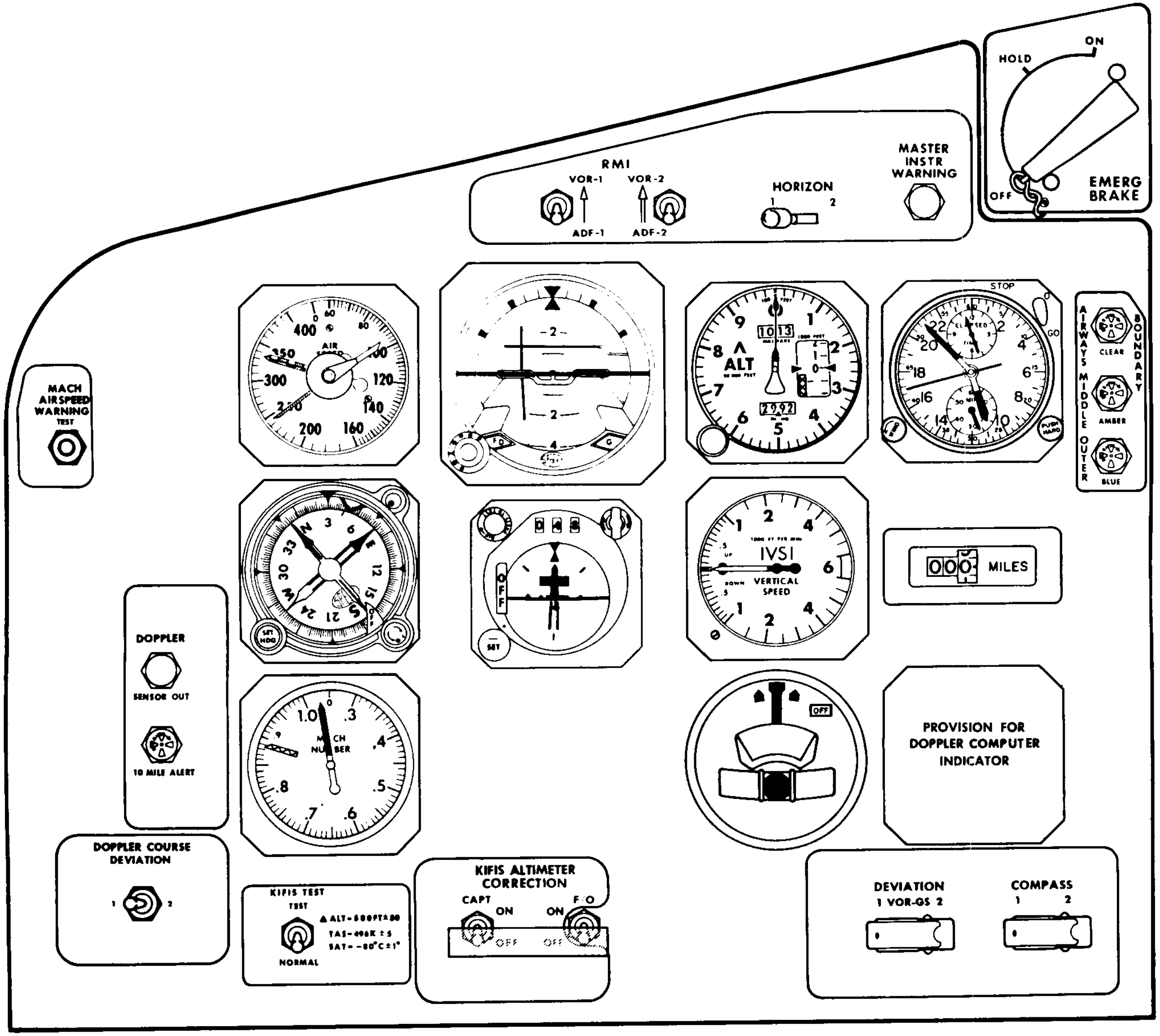


Figure 8. Flight engineer's lower panel (from ref. 17)



Left Panel

Figure 10A. B-707 pilot and copilot instrument panel (courtesy Boeing Airplane Co.)

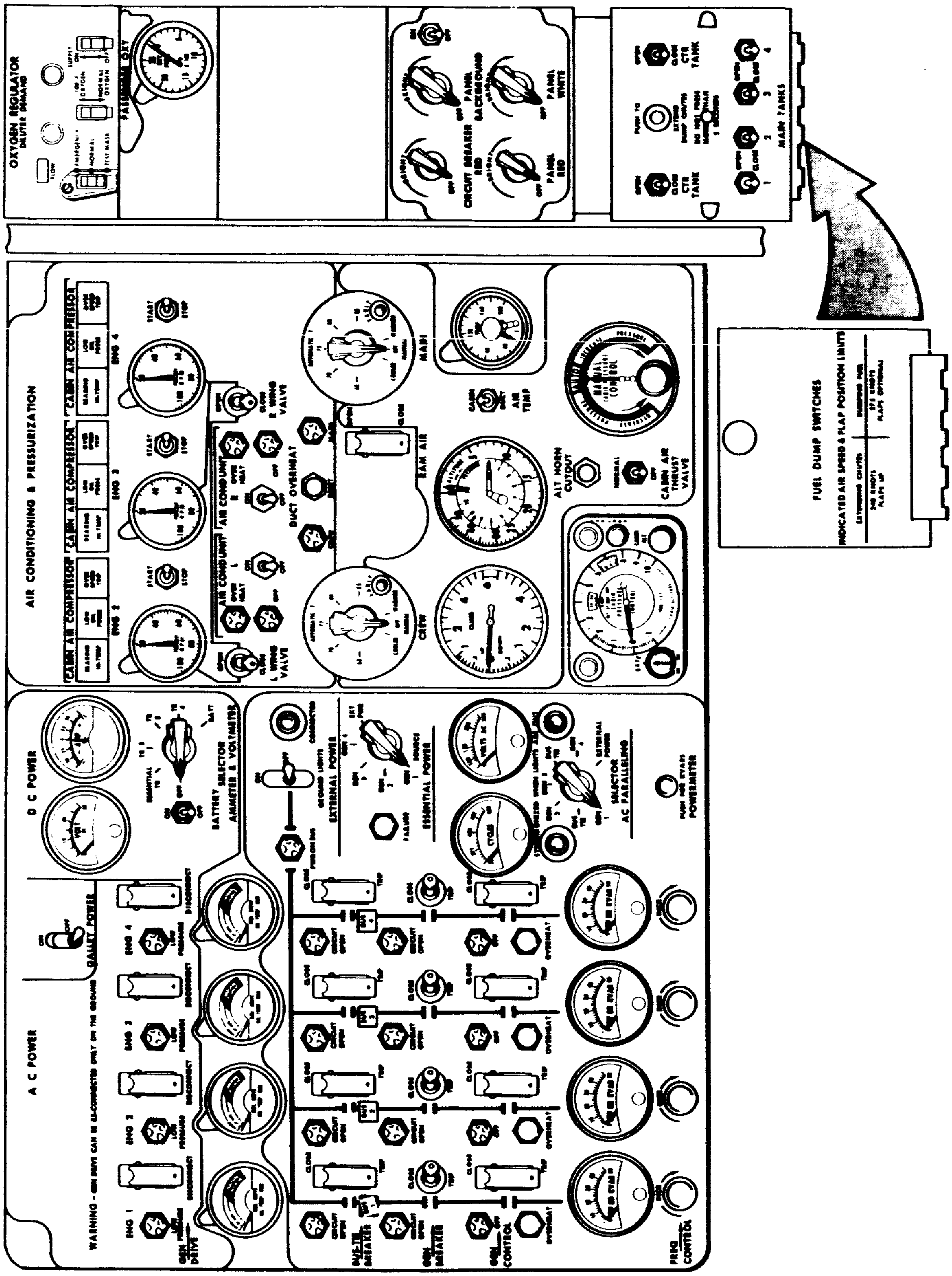
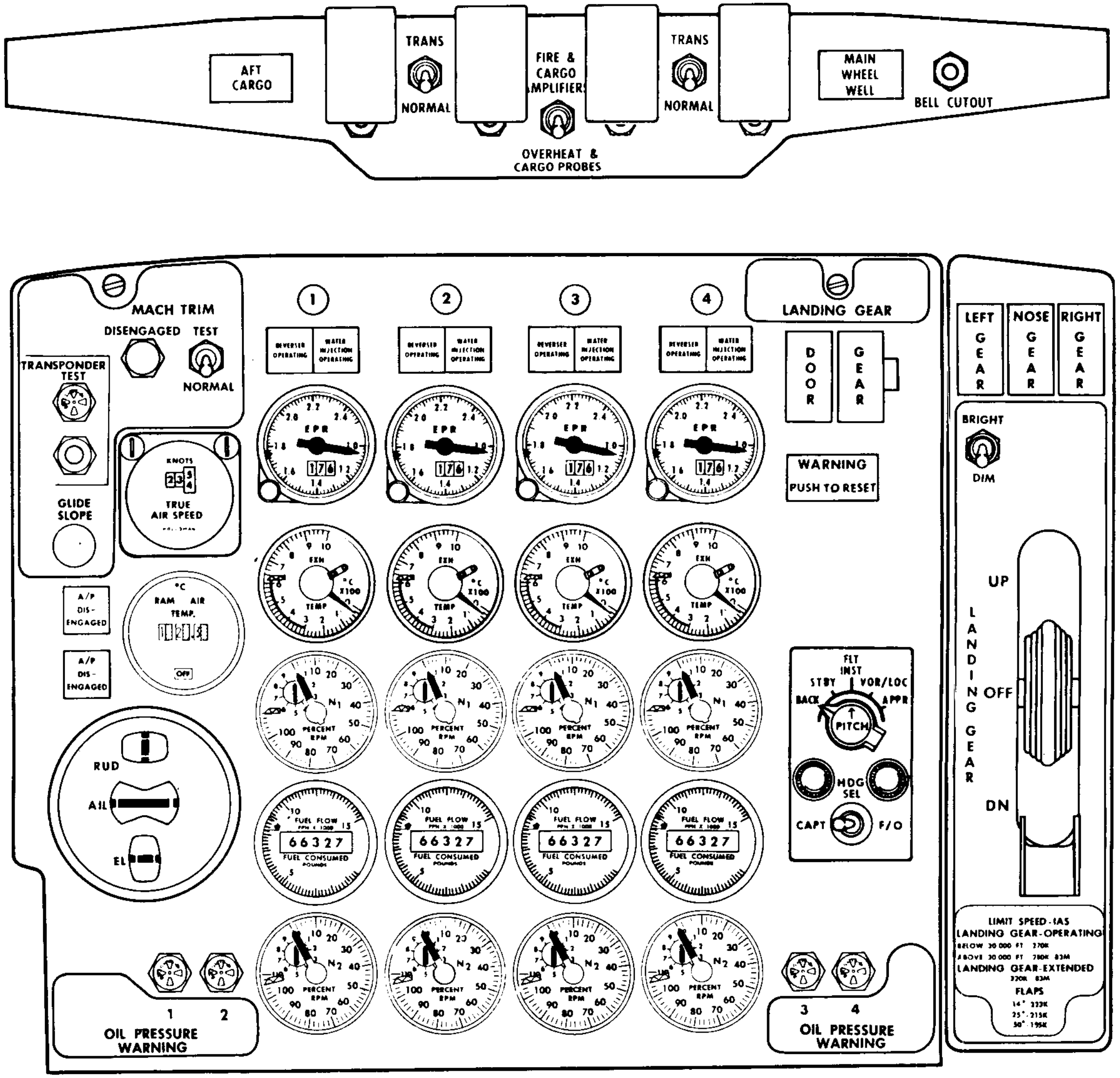
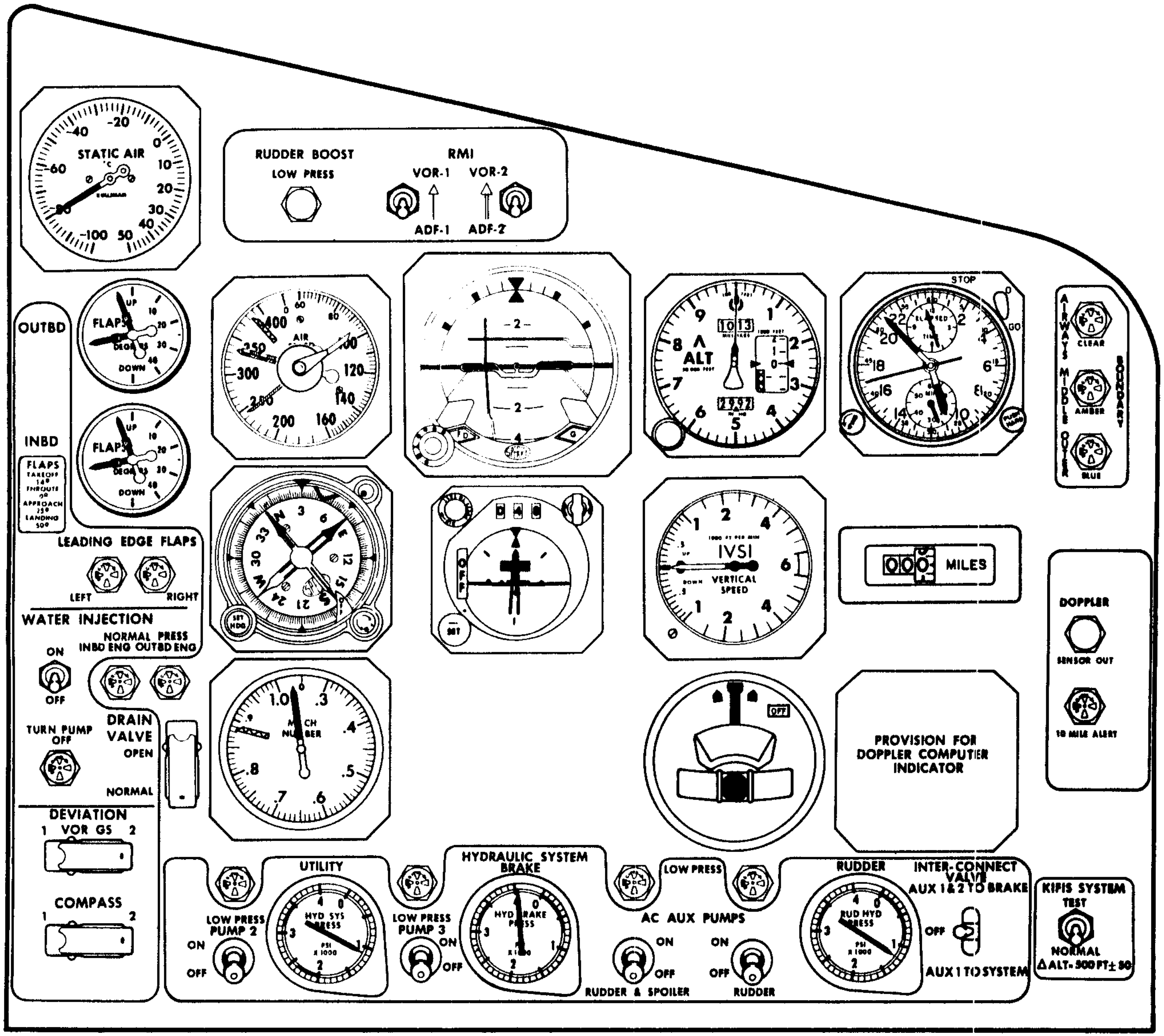


Figure 9. Flight engineer's upper panel (from ref. 17)



Center Panel

Figure 10A. continued B-707 pilot and copilot instrument panel (courtesy Boeing Airplane Co.)



Right Panel

Figure 10A. concluded B-707 pilot and copilot instrument panel (courtesy Boeing Airplane Co.)

will change, if for no other reason because there will be a considerable increase in parameters to monitor and in the resultant system performance control required. Examples are the sonic boom problem, engine intake air flow control, and environmental control.

There are factors which will radically alter performance of this function in the SST and necessitate a critical re-evaluation of the present underlying premises. Of these, the most severe will be time compression and the resulting reduced working time in the air, both total time and decision-making time. Another severe factor is the irrevocability of certain critical decisions. To further complicate matters, there is some concern that the SST may be only marginally profitable and some question as to public acceptance, both the riding public and the walking public, so to speak; it also seems, however, that both of these concerns may be minimized by continued research.

The significance of these factors is evident in the position of responsible authorities in both government and industry that mistakes cannot be afforded in the design and development of the SST (Shank, ref. 18). Our analysis concludes that the quoted criterion is generally applicable to the performance of this function particularly in the exercising of good judgment and decision-making. Clearly, this criterion will vary in applicability as a function of the seriousness of the mistake, which of course is proportional to the magnitude of the resultant costs or price of the mistake.

Feasible Automated Implementation Concepts for SST

There is no doubt that the implementation concept for this function in the SST will be a man-machine solution as in current jets. The paramount differences are to be expected in the allocation of specific performance to man or machine, and the resultant interface.

Previous reference was made to the first report of this contract (ref. 1) which discusses at length the problems inherent in optimizing man-machine relationships. Some generalized conclusions may be reached regarding the optimum man-machine relationship for the performance of this function. Supporting detail is available in the first report.

It is apparent that, with time compression and the resultant performance time available, the first consideration must be the conservation of man's time for performance in those areas where man is known to excel. Task automation to conserve man's time should be considered if man is currently performing tasks which for example are:

1. In given areas where man is known to exhibit weaknesses.
2. Relatively time consuming; (both elapsed time and frequency).
3. Repetitive or boring in nature.
4. Easily definable in concrete terms.
5. Basically non-intellectual in nature.

Monitoring can be described by all five statements above and it appears that a good deal of the monitoring performance on the SST will be automated. One possible solution to the cognizance problem has been suggested by Hunn (ref. 19):

> To summarize, the supersonic transport of the future will, I believe, utilize duplicate general purpose digital computers designed to monitor themselves and other equipment in the aircraft. These computers will, at least in the early days, perform an advisory function in a way which does not increase the visual and interpretive task of the crew. I believe, also, that even though this is a relatively modest technical advance, resting as it does on much military and civil automation experience, it is sufficiently advanced for use in the aviation field provided we continue to use well proven instruments as stand-bys and give the aircrews something familiar to fall back on.

Man's weakness in the monitoring performance area has been attributed both to a decrease in motivation with time, and negative adaptation with time. When man's effectiveness in a monitoring role is plotted as a function of elapsed time, the performance curve obtained has a mean negative slope and has been termed the vigilance decrement.

In addition to his poor continuous monitoring capability, man's cognitive processing capability is relatively slow compared to a computer. Man may be capable of functioning as a servo-mechanism where time is not a constraint and the tolerable accuracy is within his performance envelope. However, if either or both constraints (i. e., response time and accuracy) exceed man's capabilities, there is an obvious requirement to provide means for either extending man's capabilities to perform the tasks, or automating the tasks. Since extending man's capabilities so that his performance is adequate retains man as a component of the servo-loop, no conservation of time is obtained. It follows, however, that if the objective is conservation of man's time, consideration should be given to the feasibility and practicality of automation in some areas of performance; data transduction requirements exemplify this situation.

An awareness of man's limitations in response time (this includes perception, assessment, decision and action) is apparent in performance innovations on current subsonic jets. A specific example is the provision for a fully automatic landing capability for all-weather landing systems designed to operate in Category IIIa conditions. Aircraft performance characteristics may be such that the aircraft's response time is too large to permit compliance with an overriding command to abort the landing made at a breakout altitude of 50 feet. However, it is doubtful even if the landing were reversible, that man could effect the transfer from instruments to the contact situation quickly enough to perceive the need to abort the landing and react to that need. As a result, the automatic landing capability is being provided.

The data transduction process of the monitoring and evaluation function is also likely to be automated. For purposes of this analysis, the transduction process includes the capability to:

1. Accept the input data and recognize its qualitative and quantitative characteristics.

2. Perform the necessary computations on the input data to translate it into appropriate qualitative and quantitative values required for its subsequent usage.

3. Translate these values into the form and format required by those components which must accept and utilize them.

4. Route the information to the appropriate receptors.

Man's performance in the transduction process can be seen by examining the comparatively simple task of correcting the aircraft heading under manual control. The pilot first accepts the input data and recognizes its characteristics by perceiving the readout of the heading indicator or course deviation indicator. Then he performs the necessary computations by comparing the input to a referent (i. e., desired course), and deducing the magnitude and direction of the error component. The pilot translates error values into a turning command which has magnitude and direction, and routes the information by exercising the motor control required to implement a turn of the magnitude and direction desired. In this particular case, man is acting as a servo-mechanism in that he receives feedback from his actions in the form of a decreasing error magnitude, if the task is being performed correctly. He will compensate for over-correction and terminate the corrective action when the error component nulls out. Clearly, the introduction of the auto-pilot was a highly significant contribution to the conservation of man's time, even though that was only one consideration in developing the auto-pilot. Other considerations would certainly have included pilot fatigue and the vigilance decrement.

In the areas of fault isolation, situation assessment, and decision-making, instrumentation must be designed primarily to facilitate man's capabilities and therefore provide an optimum interface of displays and means for communicating with the system. It is the interface design area which must provide the solution to the problem of keeping man cognizant and informed while automating the monitoring load.

Feasible Manual Implementation Concepts for SST

In reality, the discussion of automated concepts is equally applicable here. There is no doubt that the SST implementation concept will involve both man and machine components and the potential relationship already discussed considers both. What can be said here, however, is that current practices would probably be acceptable if the SST were to return to the subsonic speed regime. This would, of course, assume that at least the same degree of automation would be provided in the SST as in the most advanced subsonics, and that the crew complement and composition would be essentially the same as on today's subsonics.

1.2 FUNCTION 1.2 DATA RECORD

Purpose

The purpose of the data record function is to provide:

1. A temporary record of selected system performance parameters which are in terms of goal objectives and which can be made available to the flight crew upon demand.

2. A permanent record of selected aircraft performance parameters which would be indicative of probable accident causes or would assist in the determination of accident causes.

3. An historical record of selected aircraft performance parameters, individual system parameters, actions taken, etc., which higher echelon airline management may use to effect more efficient flight operations by conducting empirical analyses.

Current Jet Operational Requirements and Constraints

Data recording requirements for the enroute operation of current subsonic jets include a minimum standard established by FAR's and wider data base requirements of individual airline companies. The latter vary among airline companies, but are described below in general terms in the following FAR's:

FAR 121.343, ref. 11:

Flight recorders.

(a) No person may operate any of the following airplanes unless it is equipped with an approved flight recorder that records at least time, altitude, airspeed, vertical acceleration, and heading:

(1) A large airplane that is certificated for operations above 25,000 feet altitude.

(2) Any large turbine engine powered airplane.

(b) Whenever an approved flight recorder is installed, it must be operated continuously from the instant the airplane begins the takeoff roll until it has completed the landing roll at an airport.

(c) Each certificate holder shall keep the recorded information for at least 60 days and for a longer period upon the request of the Administrator or the Civil Aeronautics Board for a particular flight or series of flights.

FAR 121.711, ref. 11:

Communication records: domestic and flag air carriers.

Each domestic and flag air carrier shall record each en route radio contact between the air carrier and its pilots and shall keep that record for at least 30 days.

FAR Subpart V--Records and reports, establishes the minimum FAA requirements for preparation of reports, aircraft logs, etc., and stipulates the required distribution and tenure of such documents. These reports and records are primarily those required prior to aircraft departure (e. g., load manifest, flight release, flight plan, airworthiness release, etc.), prior to a given operation, or between successive operations (e. g., maintenance logs, maintenance records, etc.).

There are also enroute record keeping requirements which are mostly established by company management. Some typical company forms for enroute record keeping are shown in Figures 11, 12 and 13. Although these forms will vary from company to company depending upon individual needs, procedures utilized, equipment utilized, etc., these are considered typical of the enroute record keeping required of the crew on current subsonic jet transports.

Current Jet Implementation Concepts

The recording of incident and accident analysis data is currently being accomplished by the use of "crash recorders" or aircraft flight performance recorders. Holkstra and Hoover (ref. 20) describe the current recorders and indicate further development efforts in this area as follows:

> The aircraft flight performance recorder, generally referred to as a crash recorder and required for all turbine transports, has proved to be a valuable tool in incident and accident investigations. The present recorders were designed and tested to withstand crash conditions of 100 g, and 1100° C (2012° F) for 30 min, and to record speed, altitude, acceleration (normal g), and heading against time on tape. Two production recorders employ metal tape and one employs magnetic tape. CAB (Civil Aeronautics Board)* information indicates that the recordings have been found usable in 24 out of 28 major accidents. In the remaining 4 cases, either the recorder was not operating or it was destroyed in the crash.

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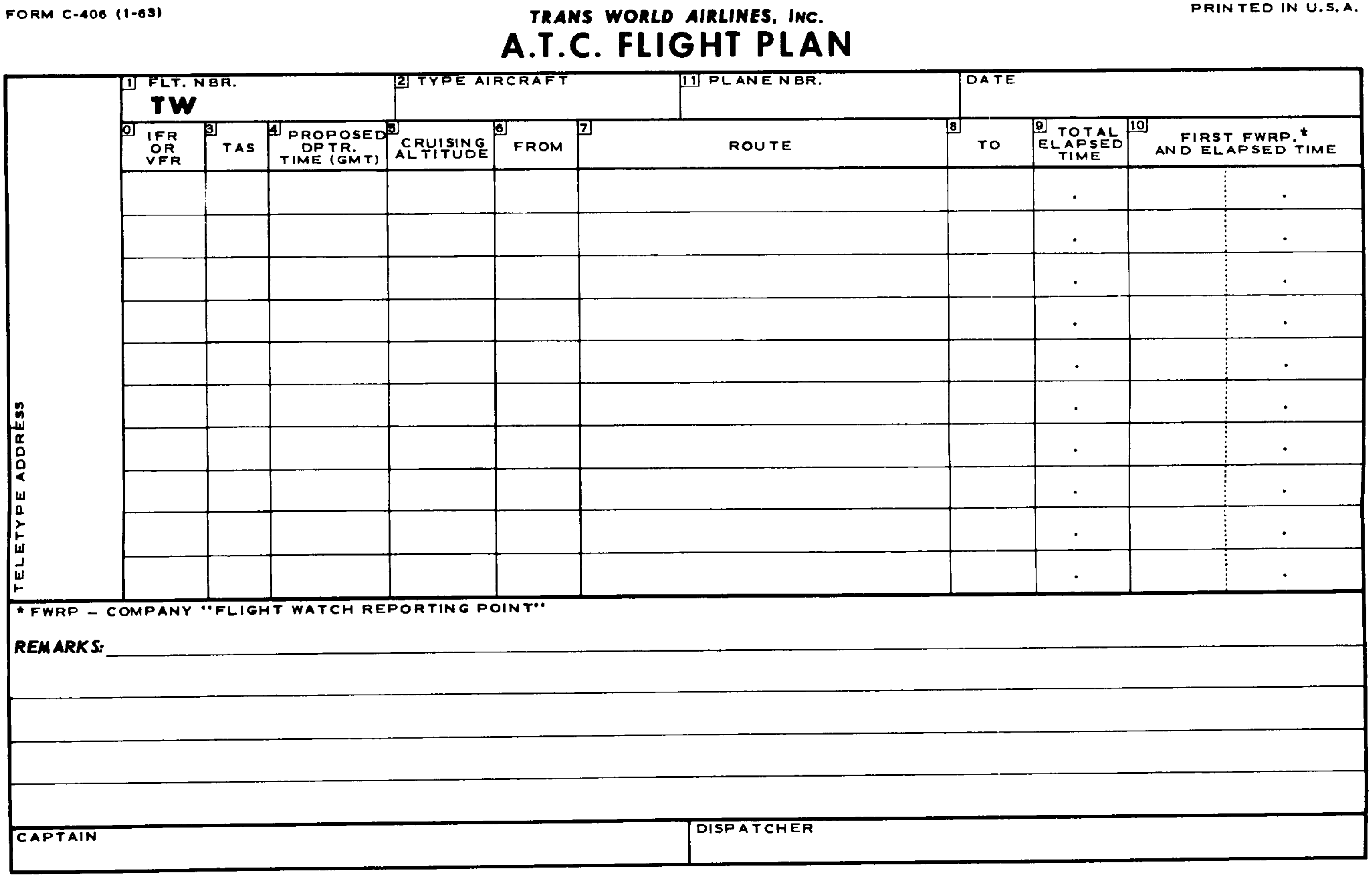
* Insertion by authors



FORM C-406 (1-63)

PRINTED IN U.S.A.

TRANS WORLD AIRLINES, INC.

A.T.C. FLIGHT PLAN

TELETYPE ADDRESS

1 FLT. NBR. TW			2 TYPE AIRCRAFT		11 PLANE NBR.		DATE		
0 IFR OR VFR	3 TAS	4 PROPOSED DPTR. TIME (GMT)	5 CRUISING ALTITUDE	6 FROM	7 ROUTE	8 TO	9 TOTAL ELAPSED TIME	10 FIRST FWRP.* AND ELAPSED TIME	
							.		.
							.		.
							.		.
							.		.
							.		.
							.		.
							.		.
							.		.
							.		.
							.		.

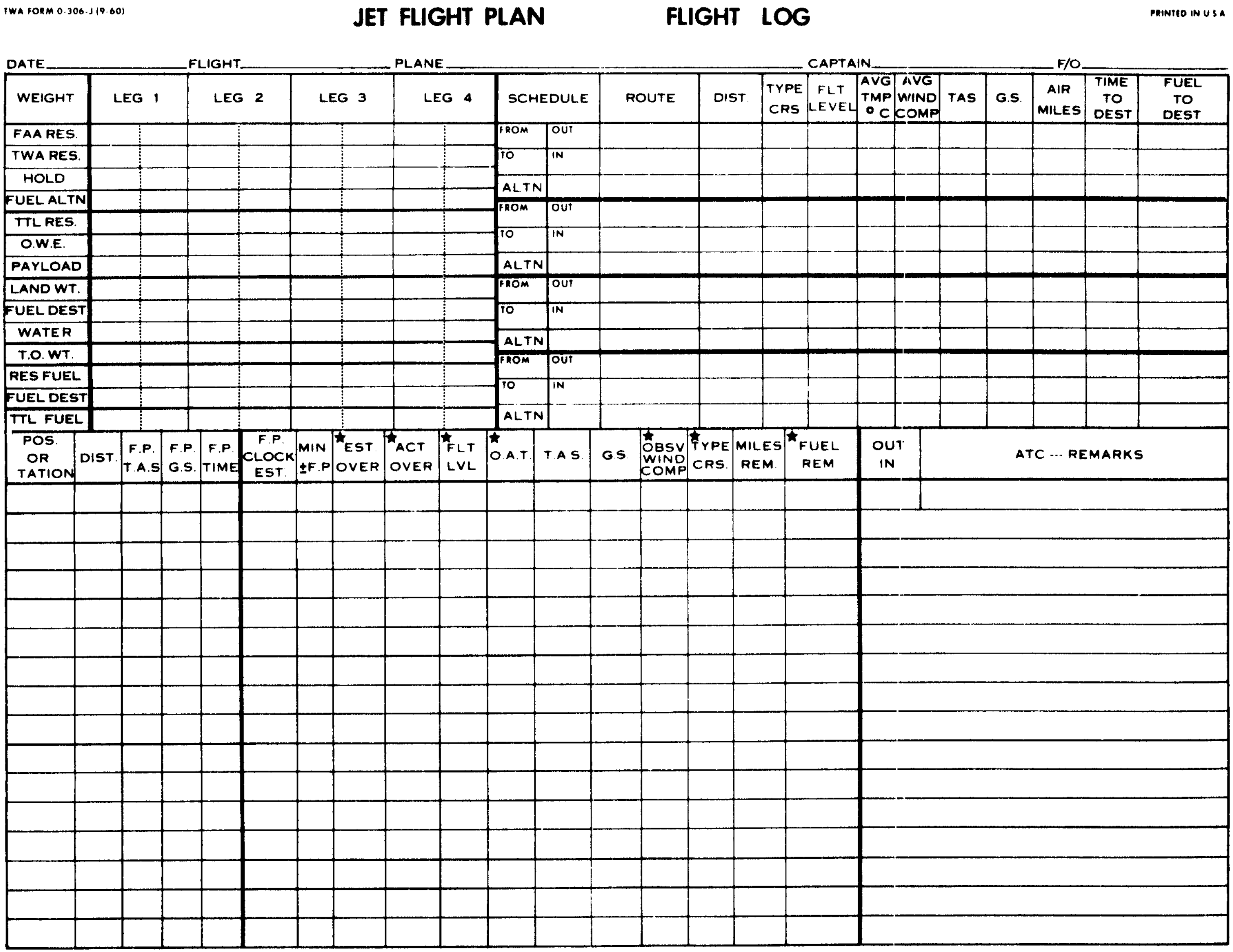
* FWRP – COMPANY "FLIGHT WATCH REPORTING POINT"

REMARKS: ____________________

CAPTAIN

DISPATCHER

Figure 11. Sample of TWA flight plan form



TWA FORM 0-306-J (9-60)

JET FLIGHT PLAN FLIGHT LOG

PRINTED IN U S A

DATE________ FLIGHT________ PLANE________ CAPTAIN________ F/O________

WEIGHT	LEG 1	LEG 2	LEG 3	LEG 4
FAA RES.				
TWA RES.				
HOLD				
FUEL ALTN				
TTL RES.				
O.W.E.				
PAYLOAD				
LAND WT.				
FUEL DEST				
WATER				
T.O. WT.				
RES FUEL				
FUEL DEST				
TTL FUEL				

SCHEDULE		ROUTE	DIST.	TYPE CRS	FLT LEVEL	AVG TMP ° C	AVG WIND COMP	TAS	G.S.	AIR MILES	TIME TO DEST	FUEL TO DEST
FROM	OUT											
TO	IN											
ALTN												
FROM	OUT											
TO	IN											
ALTN												
FROM	OUT											
TO	IN											
ALTN												
FROM	OUT											
TO	IN											
ALTN												

POS. OR TATION	DIST.	F.P. T.A.S	F.P. G.S.	F.P. TIME	F.P. CLOCK EST.	MIN ±F.P	★EST. OVER	★ACT OVER	★FLT LVL	★O.A.T.	T.A.S.	G.S.	★OBSV WIND COMP	★TYPE CRS.	MILES REM.	★FUEL REM	OUT IN	ATC ... REMARKS

Figure 12. Sample of TWA jet flight log.

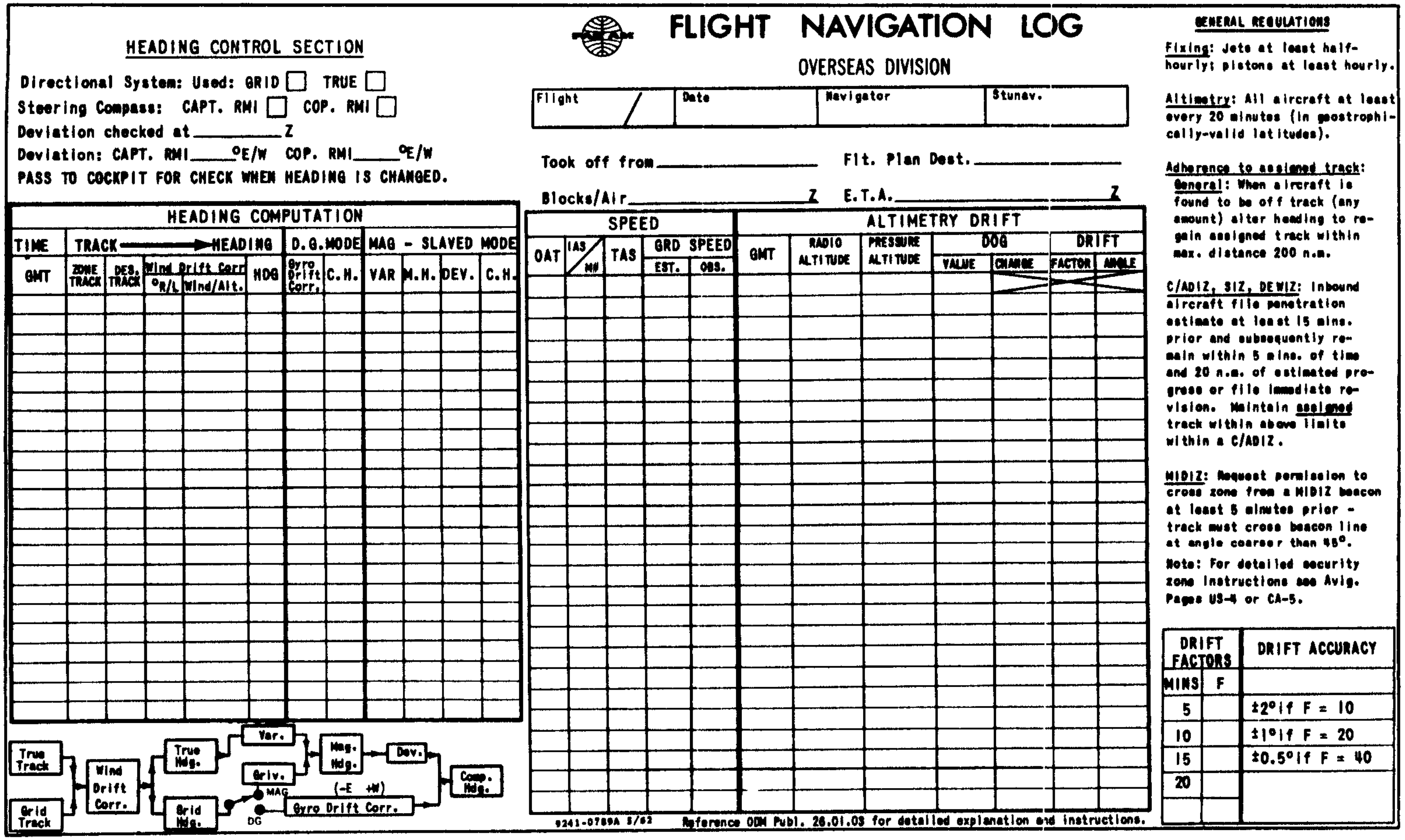
JET FLIGHT LOG

POS'N OR STATION	DIST.	F.P. TAS	F.P. G.S.	F.P. TIME	F.P. CLOCK EST.	MIN. ±F.P.	★EST. OVER	★ ACT. OVER	★FLT. LEVEL	★ OAT	TAS	G.S.	★OBSV WIND COMP	★TYPE CRS	NAUT. MILES REM.	★ FUEL REM.	OUT IN	ATC -----REMARKS

★ REPORT STARRED ITEMS TO THE COMPANY AT TOP OF CLIMB AND WHEN OVER A FLIGHT WATCH REPORTING POINT. REPORT TURBULENCE WHEN OBSERVED!

AIR MILE FORMULA $\frac{TAS}{GS} = \frac{\text{AIR MILES}}{\text{GND MILES}}$

Figure 12. Sample of TWA jet flight log (Cont.)



FLIGHT NAVIGATION LOG

OVERSEAS DIVISION

Flight /	Date	Navigator	Stunav.

Took off from __________ Flt. Plan Dest. __________

Blocks/Air __________ Z E.T.A. __________ Z

HEADING CONTROL SECTION

Directional System: Used: GRID ☐ TRUE ☐
Steering Compass: CAPT. RMI ☐ COP. RMI ☐
Deviation checked at ________ Z
Deviation: CAPT. RMI ____ °E/W COP. RMI ____ °E/W
PASS TO COCKPIT FOR CHECK WHEN HEADING IS CHANGED.

HEADING COMPUTATION

TIME	TRACK ——▶ HEADING					D.G. MODE		MAG - SLAVED MODE			
GMT	ZONE TRACK	DES. TRACK	Wind Drift Corr °R/L	Wind Drift Corr Wind/Alt.	HDG	Gyro Drift Corr.	C.H.	VAR	M.H.	DEV.	C.H.

SPEED					ALTIMETRY DRIFT						
OAT	IAS / M#	TAS	GRD SPEED EST.	GRD SPEED OBS.	GMT	RADIO ALTITUDE	PRESSURE ALTITUDE	DOG VALUE	DOG CHANGE	DRIFT FACTOR	DRIFT ANGLE

9241-0789A 8/62 Reference ODM Publ. 26.01.03 for detailed explanation and instructions.

GENERAL REGULATIONS

Fixing: Jets at least half-hourly; pistons at least hourly.

Altimetry: All aircraft at least every 20 minutes (in geostrophically-valid latitudes).

Adherence to assigned track:
General: When aircraft is found to be off track (any amount) alter heading to regain assigned track within max. distance 200 n.m.

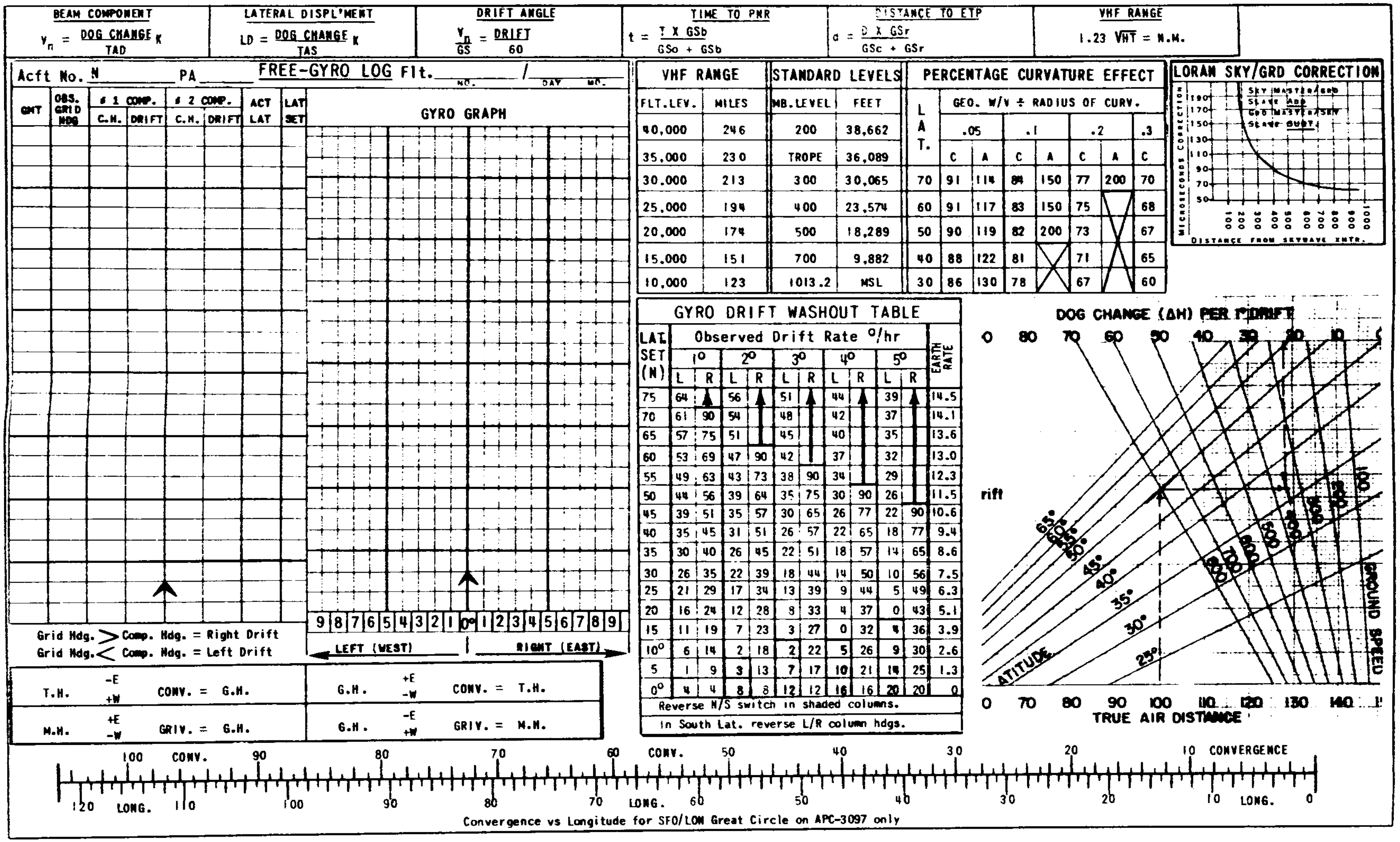
C/ADIZ, SIZ, DEWIZ: Inbound aircraft file penetration estimate at least 15 mins. prior and subsequently remain within 5 mins. of time and 20 n.m. of estimated progress or file immediate revision. Maintain assigned track within above limits within a C/ADIZ.

MIDIZ: Request permission to cross zone from a MIDIZ beacon at least 5 minutes prior - track must cross beacon line at angle coarser than 45°.

Note: For detailed security zone instructions see Avig. Pages US-4 or CA-5.

DRIFT FACTORS		DRIFT ACCURACY
MINS	F	
5		±2° if F = 10
10		±1° if F = 20
15		±0.5° if F = 40
20		

Figure 13. Sample of PAA flight navigation log



BEAM COMPONENT	LATERAL DISPL'MENT	DRIFT ANGLE	TIME TO PNR	DISTANCE TO ETP	VHF RANGE
$V_n = \frac{\text{DOG CHANGE}}{\text{TAD}} K$	$LD = \frac{\text{DOG CHANGE}}{\text{TAS}} K$	$\frac{V_n}{GS} = \frac{\text{DRIFT}}{60}$	$t = \frac{T \times GSb}{GSo + GSb}$	$d = \frac{D \times GSr}{GSc + GSr}$	$1.23\sqrt{HT}$ = N.M.

Acft No. N________ PA______ FREE-GYRO LOG Flt.______ / ______
NO. DAY MO.

GMT	OBS. GRID HDG	# 1 COMP.		# 2 COMP.		ACT LAT	LAT SET	GYRO GRAPH
		C.H.	DRIFT	C.H.	DRIFT			

9 8 7 6 5 4 3 2 1 0° 1 2 3 4 5 6 7 8 9

LEFT (WEST) | RIGHT (EAST)

Grid Hdg. > Comp. Hdg. = Right Drift
Grid Hdg. < Comp. Hdg. = Left Drift

T.H. -E +W CONV. = G.H.	G.H. +E -W CONV. = T.H.
M.H. +E -W GRIV. = G.H.	G.H. -E +W GRIV. = M.H.

VHF RANGE	
FLT.LEV.	MILES
40,000	246
35,000	230
30,000	213
25,000	194
20,000	174
15,000	151
10,000	123

STANDARD LEVELS	
MB.LEVEL	FEET
200	38,662
TROPE	36,089
300	30,065
400	23,574
500	18,289
700	9,882
1013.2	MSL

PERCENTAGE CURVATURE EFFECT							
LAT.	GEO. W/V ÷ RADIUS OF CURV.						
	.05		.1		.2		.3
	C	A	C	A	C	A	C
70	91	114	84	150	77	200	70
60	91	117	83	150	75	☒	68
50	90	119	82	200	73	☒	67
40	88	122	81	☒	71	☒	65
30	86	130	78	☒	67	☒	60

LORAN SKY/GRD CORRECTION

GYRO DRIFT WASHOUT TABLE											
LAT SET (N)	Observed Drift Rate °/hr										EARTH RATE
	1°		2°		3°		4°		5°		
	L	R	L	R	L	R	L	R	L	R	
75	64	↑	56	↑	51	↑	44	↑	39	↑	14.5
70	61	90	54		48		42		37		14.1
65	57	75	51		45		40		35		13.6
60	53	69	47	90	42		37		32		13.0
55	49	63	43	73	38	90	34		29		12.3
50	44	56	39	64	35	75	30	90	26		11.5
45	39	51	35	57	30	65	26	77	22	90	10.6
40	35	45	31	51	26	57	22	65	18	77	9.4
35	30	40	26	45	22	51	18	57	14	65	8.6
30	26	35	22	39	18	44	14	50	10	56	7.5
25	21	29	17	34	13	39	9	44	5	49	6.3
20	16	24	12	28	8	33	4	37	0	43	5.1
15	11	19	7	23	3	27	0	32	4	36	3.9
10°	6	14	2	18	2	22	5	26	9	30	2.6
5	1	9	3	13	7	17	10	21	14	25	1.3
0°	4	4	8	8	12	12	16	16	20	20	0

Reverse N/S switch in shaded columns.

In South Lat. reverse L/R column hdgs.

DOG CHANGE (ΔH) PER 1° DRIFT

Convergence vs Longitude for SFO/LON Great Circle on APC-3097 only

Figure 13. Sample of PAA flight navigation log (Cont.)

> The present FAA development effort, based upon study of past experiences and consultation with CAB and FAA investigators and industry, is intended to provide additional recording channels, easier readout, greater ruggedness against crushing and puncturing loads, better positioning within the aircraft, and locating devices.

Further development efforts are underway by the FAA to obtain a flight-deck voice recorder which would provide supplementary information for incident/accident analysis. Holkstra and Hoover (ref. 20) describe this effort and evaluate a potential maintenance recorder as follows:

> A flight-deck voice recorder may be of value in certain accidents to supplement the information provided by the flight data recorder. Different makes of recorders are intended to record all flight deck crew conversation, continuously "erase" all but the last 30 min of record, withstand the crash conditions listed in the foregoing, and operate for 500 hr without maintenance attention.
>
> Several maintenance recorders have been developed by industry, and there is considerable interest on the part of maintenance people regarding their use in regular airline operation as a means of keeping an accurate check on many powerplant and airframe variables.
>
> At this time FAA development interest lies in the installation of an available recorder in one of the FAA jet transports with the objective of gaining experience on its usefulness as a maintenance aid.

Appropriate flight logs and records are maintained manually by the crew during the enroute phase of current jet operations. This record keeping is facilitated by the provision of forms designed to permit pencil entries of the required data (see Figures 11, 12, 13). The delineation of crew complement and composition for given routes will generally relegate the responsibility for maintaining such forms to appropriate crew members. For example, the flight engineer's log is designed for use on those flights and routes where either the FAA or the company has required one crew member in the position of flight engineer. The same is true of the flight navigator's log, except that this form, or a less detailed version, may be maintained by pilot/copilot personnel when "cockpit navigation" techniques are employed. The flight log is normally maintained by the pilot/copilot personnel.

Clearly, record keeping during the enroute phase of flight operations is a considerable chore. It can be assumed that personnel manning the flight decks of current jet transports are essentially no different from other highly skilled, technically competent personnel, and such individuals have long regarded these kinds of tasks as drudgery. The exception is in those instances where the data maintained in the records can be operationally utilized in problem solving on a real-time basis. However, the majority of record-keeping requirements concern routine operations and require highly repetitive data entries, which have little, if any, operational significance on a real-time basis. In any event, manual data logging is the present means for satisfying both the need for data on a real-time basis (obviously in conjunction with cockpit instrumentation readouts) and for data to be utilized by higher echelon management analyses.

SST Potential Operational Requirements and Constraints

The requirements for data recording in SST operations satisfy the basic needs identified in the discussion of function purpose, i. e., incident/accident analysis, real-time situation assessment, and higher echelon management analyses.

INCIDENT/ACCIDENT ANALYSIS DATA

There would appear to be a possibly increased need for incident/accident data in the SST compared with current jets, even if present day situations include the cockpit voice recorder as a reality. This possibility is based on the tremendous differences in performance characteristics and performance envelope, and the totally new operational strata for the SST. The prime argument for increasing the parameters recorded is the potential for crew/passenger disablement due to an undetected or explosive malfunction in one or more of the environmental control mechanisms. Operational altitudes of present jet transports are such that only comparatively minor consideration and provision have been necessary for the physiological status of passengers and crew. A virtually new problem complex of environmental control must be considered in the SST design. Potential hazards and their physiological effects were discussed in some detail in the first report under this contract (ref. 1). Even with the attempt to "design out" these problems in the SST, there still would appear to be a possibility that the crew could become totally or partially incapacitated through undue exposure to environmental factors. This would appear to be a good reason for continuous recording of cockpit instrumentation readouts concerning these parameters. Furthermore, it would appear to be necessary to record samples of several factors (e. g., ozone levels, radiation levels, etc.) in order to maintain cumulative exposure records at least for the crew, if not for the passengers.

REAL-TIME SITUATION ASSESSMENT DATA

A pilot's primary source of information is the instrument panel and his method of scanning will depend on piloting technique developed from experience. In addition to his instruments, the pilot receives information from the flight engineer and navigator. The pilot then infers the present situation and mentally relates to the desired progress and planned situation, and to the appropriateness of the system operating conditions. This is a periodic check function as opposed to active attempts to isolate a fault. Essentially, the data available for making such an assessment are obtained from dynamic displays usually reflecting a single parameter for a given system (e. g., #1 EGT, #2 EGT, etc., #1 % RPM, #2 % RPM, etc.).

Anyone familiar with the cockpit instrumentation of a modern-day jet transport is aware that real-time situation assessment involves considerable information readout, integration of that data with the information available at other crew stations, and a significant amount of inference. A data recording and display concept is required which would permit logical, functional grouping of sets of parameters. Such a concept should insure that the flight management requirement could be met in a manner which would significantly reduce the scanning and integration requirements, and could possibly replace some, if not all, of the requirement for manual data entries in flight logs.

In this same vein, periodic recording of certain parameters may be necessary to enable detection of a trend. Inside cabin pressure is an example. If it were discovered that the inside cabin pressurization altitude had increased to 12 000 feet from 8,000 feet, sampled readings available on call-up would enable flight management to determine immediately whether the change was abrupt or slow. A slow increasing trend might be indicative of a slow pressure leak. The abrupt change might be attributable to an equipment transient, a slow leak which was not noticed due to the sampling cycle, or a fast leak. For such critical parameters it would appear reasonable to provide as much information as would be practical in assisting in situation-assessment and decision-making processes.

HIGHER ECHELON MANAGEMENT ANALYSES

Even though airline companies have many years of experience and data analysis incorporated into their current management techniques, it would appear that the SST will present new management problems and more critical requirements for current management problems. It will be a requirement of the flight management data recording function to insure that the appropriate quality and quantity of information is collected during each operation. Certainly, a new management headache in the SST era will be the sonic boom damage lawsuit problem. For just such eventualities, it would appear highly desirable to have a record of time, location, altitude, and estimated ground shockwave magnitude. There undoubtedly will be many other areas in which higher echelon management will require new data. In addition, data which is currently recorded will probably need to be increased in quantity and improved in quality to shore up any indicated weaknesses in SST operations.

Feasible Automated Implementation Concepts for SST

Initially, those data required by the FAA or other authoritative sources for incident/accident analyses will continue to be provided by protected crash recorders. The nature of the requirement dictates the means. There is no reason to believe that any additional information beyond that required today will not be provided for in an identical manner.

There are some interesting possibilities for real-time situation assessment data and those data required for higher echelon management analysis. It seems reasonable to assume that there is a high degree of commonality in the data base required for both levels of the management function. And, due to the real-time nature of the enroute flight management function, a combination of these data recording requirements would necessarily ascribe first priority to the enroute aspect. This does not mean to imply that the common data base is essentially all-inclusive for both levels. What it does mean is that if the two requirements are viewed as one, the data records required by enroute flight management should take precedent and should not be compromised in form or format to satisfy higher echelon management needs at the expense of enroute management. Rather, the ground-based management activity would alter its techniques to accept the output of the enroute recording function.

Enroute recording assumes that a parametric analysis has been conducted which would indicate the kinds of data required for the flight management activity, the form and format in which the data should be recorded, how often it should be recorded, and whether updating or serial readout is more appropriate. Functionally related data groupings could be temporarily stored, updated or serialized, and displayed to flight management upon demand. One such scheme which deals primarily with flight progress data, has been described by Hunn, (ref. 19) who states:

> However, as aircraft speeds increase, so does the dependence on avionic equipment. It has been mentioned elsewhere that the captain of a supersonic transport will be the boss of a 5 million dollar industry and he must be given every assistance to make the proper decisions in discharging this onerous responsibility.
>
> All these problems that I have somewhat loosely described suggest the need for more sophisticated avionic systems. However, one must beware of introducing added complexity in such a way that it adds to, rather than detracts from, the already exceedingly complicated data processing problem presented to the aircrew. It has already been suggested that a significant number of accidents arise from the pilot's error in interpreting his mass of instruments.
>
> What kind of equipment is needed? In my opinion, it is sensible to aim at a system which can do a great

> deal of data processing for the crew, relieve them of the routine repetitive tasks and assist them to make critical decision when necessary. However, in doing so, the crew must not be denied the opportunity of taking over the task of this equipment satisfactorily in the event that it fails or when they feel that there is some element of doubt.
>
> An airborne digital computer is admirably suited to this problem if it has adequate speed and capacity, for it is capable of taking on many independent tasks simultaneously on a time-shared basis. To satisfy the general requirements of the system I believe it is desirable to use such a computer as a situation monitor. In other words it displays to the crew a qualitative picture of how the aircraft is performing in relation to plan and will, on request, supply quantitative data on flight management. *

The two figures within Figure 14 are reproduced from Hunn's article and are shown here to illustrate the kind of data recording and call-up scheme which, in an expanded version, would permit handling the temporary recording of SST real-time situation assessment data. The amount of data recorded for subsequent call-up would depend upon the storage capacity of the computer and whatever other functions were assigned to the same hardware. The computer could also be used to drive recording equipment and to provide a hard-copy output which would preserve the data generated by each computation cycle. Thus the recording device could be the means for supplying flight management with a broad base of parametric data recorded continuously every machine cycle or sampled at some predetermined rate. Upon demand, the computer would address the recording device, and provide flight management with an immediate display of the data accumulated up to the time of the demand. If desired, the computer could also drive a hard-copy printer to produce a complete record of the parameters selected during the flight. The record would be available for analysis by higher echelon management. Means for implementing such a concept

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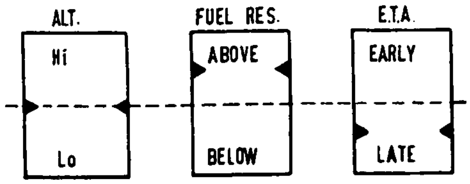
* Underscored by authors



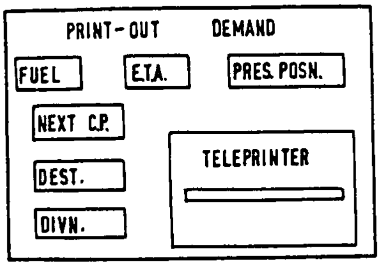


Fig. 1: The airborne computer used as a situation monitor could display information showing how the aircraft is performing relative to the flight plan, and would, on request, supply quantitative flight management data. *Above*: quick-look displays. *Right*: Data demand and print-out panel.

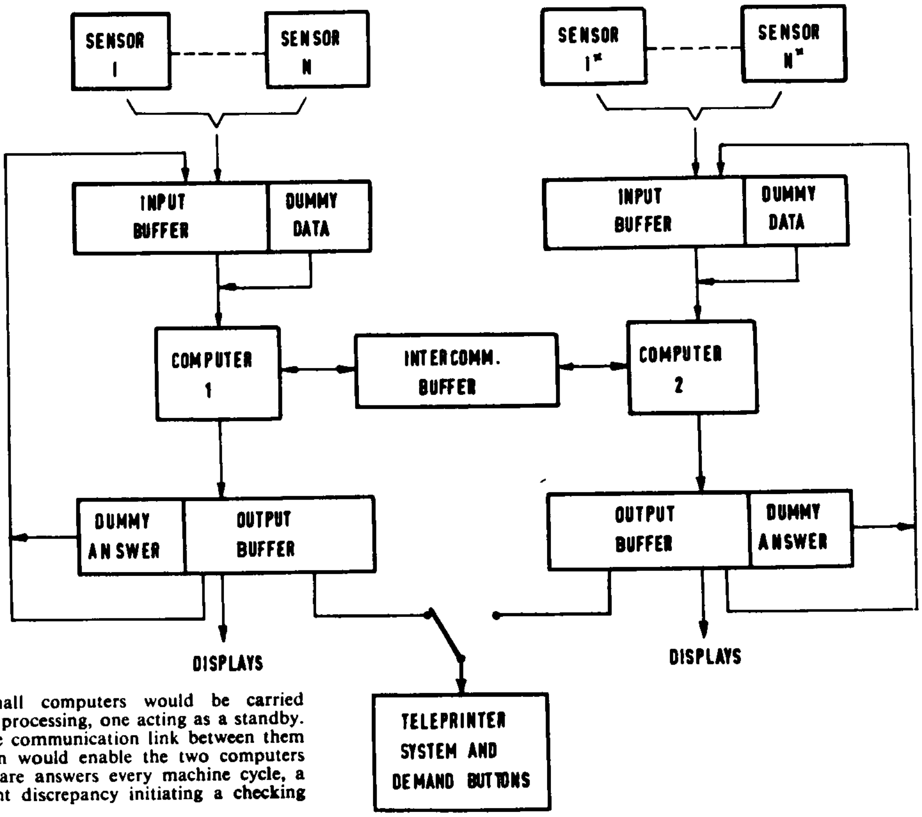


Fig. 2:
Two small computers would be carried for data processing, one acting as a standby. A simple communication link between them as shown would enable the two computers to compare answers every machine cycle, a significant discrepancy initiating a checking routine.

Figure 14. A flight management data recording scheme (from ref. 19)

are as numerous as the number of manufacturers of automatic computation, recording, and display devices. The system illustrated is only one typical method suggested in the literature and should not be construed to be recommended. In conclusion, automatic recording of data which serves the purpose defined for this function, could be accomplished easily within the current state-of-the-art. There is no reason to believe that cost and reliability requirements could not be met by any number of equipment manufacturers.

Feasible Manual Implementation Concepts for SST

In considering a manual implementation concept for satisfying the requirements for this function, it must be recognized initially that the crash recorders are established as a firm requirement by the FAA. Therefore, that requirement can be deleted from any manual system considered. It seems reasonable to assume that the present method of log keeping on current jets is considered by airline operators to be the optimum method utilizing available means. In this scheme, each crew member maintains a log of required data on those aspects of the aircraft performance with which he is particularly concerned. In the event that manual log keeping is implemented for the SST, it would seem logical to maintain such a scheme. However, this raises some important considerations. For example, working time in the air will be reduced by a factor of approximately one-half to two-thirds. As has already been pointed out, the current cockpit workload may be at the saturation point. Maintaining the ratio of effort which currently exists would result in one-half to two-thirds fewer entries in the data logs. In reality, however, it appears that the manually recorded data would decrease even more significantly in quantity because of the potential requirement to maintain records on a broader base of parameters. Time compression, current workload, and criticality of other functions, are real-time constraints on manual record keeping and would appear to relegate such a concept to "last resort" consideration.

On the other hand, Price et al. (ref. 1) raised the issue of keeping the crew sufficiently involved in the aircraft situation so that they are physiologically and psychologically prepared to handle the requirement for manual intervention when required. Put into context, this discussion was considering the interface problem between man and machine with the assumption that considerable automation would be employed in implementing the system-oriented activities and that man would be primarily concerned with monitoring the resulting performance. It is suggested that considerable thought, and possibly empirical research, be invested in considering data recording techniques designed to provide the necessary records. By including man in the recording loop, this function could serve to provide the necessary depth in awareness of the situation and flight progress. Such might be accomplished by several techniques involving mechanized recording rather than completely automated recording. Man may, for example, be required to initiate the recording command according to some well-designed procedures which would assure his awareness of the situation prior to initiating the command. Various schemes could be researched until the appropriate man-procedure-mechanism relationship is determined. What is being suggested here, in essence, is a concept which would provide the necessary data recording, and at the same time, offer a solution to a potential problem area which will be significant for the SST due to the increased complexity of the monitoring task visualized, as well as the inherent danger in oversimplifying the performance means.

1.3 FUNCTION 1.3 SYSTEM RECONFIGURATION

Purpose

This function provides for the implementation of a decision reached in the "Data Monitor and Evaluation" function to go to an alternate mode of operation. The alternate mode would: (1) affect some modification to the total system for purposes of correcting a malfunction or marginal performance situation which threatens to further degrade system performance; and (2) ensure that the resultant total system output is adequate and sufficiently reliable to continue the flight to its destination within the original flight plan. The decision reached in the evaluative process will not necessarily be couched in a specific course of action regarding system reconfiguration. It may merely be in terms of the three basic alternatives, i. e., (1) the problem is noted and is insignificant in terms of overall system performance, (2) the problem is catastrophic in nature and the only recourse is mission abort, and (3) the problem is sufficiently acute that it must be rectified, at least partially, and there are some available alternatives for effecting that rectification. It is the last decision which initiates the system reconfiguration function. Performance of this function includes:

1. Recognition of the classes of alternatives available, such as
    a. Primary system redundancy exploitation
    b. Secondary or back-up system exploitation
    c. Alternate off-line hardware exploitation
    d. Exploitation of man's capabilities
    e. Airborne maintenance provisions and applicability
    f. Aircraft performance envelope exploitation

2. Derivation of each alternative within the classes, such as

    a. Primary system redundancy may be duplex, or triplex, at the entity level (for example, dual inertial platforms) and may offer two or more operational modes for each system, not all of which are necessarily affected by a malfunction or marginal performance in one of the alternative modes.

    b. Secondary, or back-up systems, for the primary system may be able to serve as the primary system without a significant loss of accuracy. In this situation, reliability must be on a "one mission, one aircraft" basis as opposed to MTBF (mean time between failures) as a function of hours per month, or year.

    c. Alternate, off-line hardware may offer various solutions, particularly if exploited in conjunction with man's capabilities.

    d. The potential use of a skilled crew member's capabilities in trouble situations provides an extremely powerful and versatile tool for flight management.

    e. The inclusion of airborne maintenance provisions presumes that some basic corrective maintenance will be provided for in terms of both capability (skills and knowledge) and means (e. g., spare parts, components, plug-in modules). If such is not the case, this class must be deleted from the potential alternatives.

f. The tremendous range of the aircraft operational envelope is offered as a potential class of possible alternatives, however, it would appear desirable to consider this alternative as the last resort in the hierarchy since it is highly probable that exploiting this alternative would usually incur below optimum performance penalties.

3. Selecting that alternative which is optimum in terms of the overall situation and the goal objectives.

4. Effecting the modifications required to implement the selected alternative.

Current Jet Operational Requirements and Constraints

To specify operational requirements and constraints in this area would involve delineating all the possible individual and conjunctive malfunctions and/or marginal performance which could occur within the total system. Moreover, a wide range of different systems employed on modern jet transport fleets would have to be considered. The impracticality of this approach is immediately obvious. Some of the more common occurrences have been translated into required procedures by the FAA. For example, airworthiness certification of the aircraft and pilot qualification procedures require demonstrating adequate handling qualities and piloting technique when an engine is lost on takeoff.

Another example is the specific procedure to be followed when trouble symptoms develop before or after the "point of no return" on a transoceanic flight. Still another example is the three-leg or triangle pattern an aircraft flies when certain equipment is lost and the crew is uncertain of the aircraft's position, or when the aircraft is unable to comply with the last clearance given by ATC. There are many such procedures covering relatively common occurrences and difficulties. The requirements and constraints in this area can best be summarized by the requirement for the aircraft commander to exercise his best judgment in any situation. This most certainly would include the decision to use any and all of the available system components in any manner which would, in the pilot's judgment, maximize safety, reliability, economy, and efficiency, as well as the probability of the aircraft's completing its flight to the scheduled destination.

Current Jet Implementation Concepts

Current jet transports are instrumented and manned so as to provide for considerable system reconfiguration. As a result, they have achieved a high degree of reliability in schedule integrity. The first order of redundancy is the pilot/copilot manning concept. The second order of redundancy is the combined concept of instrumentation and independent equipment which enables the aircraft to be piloted from either of the front two seats and provides for system reliability through the use of redundant instrumentation. Both controls and displays are in many instances driven by independent sensors, power supplies, or control systems.

The inclusion of a flight engineer leads to even greater reliability by providing the skills and knowledge required to quickly detect a trouble symptom, isolate the fault, and take appropriate corrective action. Such action may simply be to advise the aircraft commander of the situation, inform him of the impact, and suggest corrective procedures.

The addition of a navigator and instrumentation for various methods of navigation, provides an inherent capability for system reconfiguration insofar as the navigational activity is concerned. The availability of the navigator's skills and knowledge plus equipment such as VOR/DME, ADF, LORAN, periscopic sextant, doppler and inertial dead reckoning systems, probably offer the widest range of possibilities for system reconfiguration in current jet transports. However, it can be concluded that present day aircraft show considerable evidence of the requirement for system reconfiguration and have gone to some length to provide the necessary means.

SST Potential Operational Requirements and Constraints

All of the specific requirements for SST system reconfiguration capabilities are as impossible to project as are the identification of entire current jet requirements. It is reasonable to assume that the reconfiguration scheme employed will be based in part on obtaining at least the overall system reliability currently enjoyed by jet transports. Total system reliability requirements will probably be considerably more stringent for the SST than for current jets, in view of the increased concern with economics and the expanded realm of potential hazards. The requirement for reliability to a large extent governs the range of potential system reconfigurations that can be conceived, and undoubtedly will dictate the crew complement and composition as well as the cockpit instrumentation concept. Rather than attempt to specify potential requirements at this stage of system development, it would appear more useful, and indeed more practical, to point out some potential problem areas for consideration in arriving at the final man-machine relationship.

A current trend in modern jet transport manning and instrumentation offers a useful framework for discussing potential problem areas, namely, the trend away from navigator personnel to semi-automatic dead reckoning systems operated by pilot/copilot personnel, labeled "cockpit navigation." With this concept, specialist navigator and/or pilot/navigator personnel who have had special training in the necessary skills and knowledge required to employ conventional navigation techniques, are being replaced by semi-automatic devices such as doppler-radar systems and inertial navigation systems, commonly referred to as "present position navigators."

To achieve the required reliability, dual installations of such navigational systems are being provided. The significance of this in terms of the present discussion is simply that the loss of a single installation plus the absence of the capability to employ conventional techniques and tools (e. g., sextant) results in a reconfiguration which may not meet minimum navigation standards in an adequate manner.

Dual equipment installation is not always without problems. For example, a large divergence in dual outputs requires the capability to determine which output is more nearly correct and implies that a sufficiently reliable means for solution is provided. In the case at hand, there is evidence that possibly a third installation will be necessary in the SST to monitor the dual installation and resolve the divergence problem. The significance here is that the reconfiguration capability must provide the necessary overall system reliability.

For purposes of this discussion, the next requirement is in the area of accuracy. Agreement between solutions from two or more installations of a given problem-solver which have essentially identical operating characteristics, does not necessarily mean the required accuracy is being achieved. Repeatability ensures reliability, not accuracy. Present position navigators are known to be subject to both random and systematic error components, and in some equipment, the systematic error components are known to be cumulative in nature. It is presumed that in reconfiguring the total system by utilizing primary system redundancy (selection of an alternate sensor), the probability that the arbitrating system of a triplex installation would tend to agree with the less accurate of the other two installations would approach zero. This presumption must be made if arbitration is to be automated because of the absence of a crewmember with the necessary skills and knowledge to exercise judgment.

Such a problem might be illustrated by considering a triplex inertial installation where System #1 of the two on-line sensors which are being checked against one another to satisfy the input credibility monitoring function, has diverged from System #2 by more than the specified tolerance, but in reality is the more accurate of the two installations. System #3, the arbiter, is consulted, and due to the phase relationships of its Schuler period with the other two installations (e. g., 180° out of phase with System #1 and in phase with System #2) the output of System #2 is selected as the more accurate. The selection would be based on the repeatability of systems known to have phase-oriented divergence as well as differing degrees of cumulative error. The probability of the systems being in phase is undoubtedly less than 1. 0 unless it can be demonstrated that the three gyro-stabilizing platforms have attained precisely identical alignment following gyro-stabilizing platform erection and north alignment. This example, as remote as it may be in the practical world, illustrates the kinds of problems with which the development program for the SST must cope so that the system reconfiguration function can select the most reliable means with a positive assurance of the accuracy attainable.

The use of the navigational sensors to illustrate problems in system reconfiguration does not necessarily mean that this kind of problem would exist in the final installation concept, nor should it be considered an exclusive area where such problems may be applicable. It is typical of the kinds of problems which will be researched and resolved in a practical manner prior to the definition of the cockpit instrumentation concept. The extent to which this analysis can indicate requirements for reconfiguration is necessarily limited to the statement that the means must exist for achieving the necessary overall system reliability and accuracy. Anything less than this capability is assumed by this analysis to be a sufficient basis for aborting the flight and landing at the nearest adequate facility.

Feasible Automated Implementation Concepts for SST

By definition, automatic system reconfiguration is only feasible when hardware redundancy or back-up is available. Therefore, any reconfiguration concept or scheme which would result in man performing as a replacement for some system component defines a class of alternatives for which automation is not feasible. An additional limiting factor or constraint on the feasibility of automatic system reconfiguration is the degree to which criteria for system failures and/or inadequate performance can be specified and programmed into comparator circuits or self-checking circuitry so that the system is able to recognize the need to reconfigure itself. The provision of automatic switching circuitry and self-check/comparator circuitry would depend on considerations of resultant reliability, size, weight, cost factors, and so forth. Clearly, trade-off analyses are required to establish the exact needs in this area.

It is important that such trade-off analyses consider a great many factors, not the least of which is the criticality of response time between failure detection and remedial action. For example, it would appear obvious to provide for immediate automatic switching from the on-line control system to the off-line redundancy capability (assumed to be an equivalent control system) in the event of a definite failure of the control system concerned with adjusting the configuration geometry of the engine intake air ducts. Such a provision is particularly crucial in phases of the operation where erroneous configuration could result in engine failure due to unacceptable air flow rates. This situation of course, assumes that (1) the time lapse between failure detection, display to the crew, recognition by the crew, and execution of remedial action by the crew, would represent a response lag large enough to result in engine failure, and/or (2) an engine failure at high Mach numbers produces effects such that other engines may likewise fail.

In summary, the following might be a criterion statement for automatic reconfiguration: if the system is capable of recognizing the criteria denoting system failure and the obvious requirement to switch to alternate equipments, then the design should allow such to be the criteria for automatic switching. The crew should be warned immediately, or perhaps even simultaneously about the suspected malfunction and informed that alternate equipment has been switched on. The crew could then assess the situation and override the system if in the judgment of flight management that would be the more appropriate action. The advantage gained would be off-line assessment of the trouble symptom which could clearly be highly critical to safe operations.

Feasible Manual Implementation Concepts for SST

The primary limiting factor for automatic system configuration as just discussed is the availability of alternate equipment. However, it is improbable that automation would be employed solely because of hardware feasibility. There would appear to be two prime factors involved in trade-off analyses which will influence the use of manual reconfiguration concepts, i. e., cost and reliability factors for automation, and criticality of response time. To this, an additional factor can be added, i. e., the limitations of the hardware in detecting insidious malfunctions and exercising judgment. This analysis has also indicated a related argument regarding optimization of the monitoring process to compensate for man's weakness in this area, and at the same time to avoid over-simplification of the monitoring interface so that manual intervention is adversely affected.

Although these arguments are not in a specific manual implementation concept context, they do support the premise that man will undoubtedly be involved in a considerable role in the system reconfiguration process. In his discussion of the use of digital computers as situation monitors and providers of flight management information, (Function 1. 2, "Data Record"). Hunn (ref. 19) further states with regards to a specific navigation equipment scheme that:

> I believe it is highly desirable for the crew rather than the computers to decide when equipment should not be used and to choose which reversionary method of operation is to be utilized. To do this it is first necessary to display to them the state of the system. With the system I have described, a warning light would show when a significant discrepancy occurred. When the computers had finished self checks, by means of sums done on dummy inputs compared with dummy answers, and sensor checks by similar means, a remedial action panel would show the result of the check. (See Fig. 15). Associated crew-operated switches would then command as necessary the cross feed of sensor data through the communication link without the need for extra wires.

In summary, it appears reasonable to assume the following concept for manual system reconfiguration:

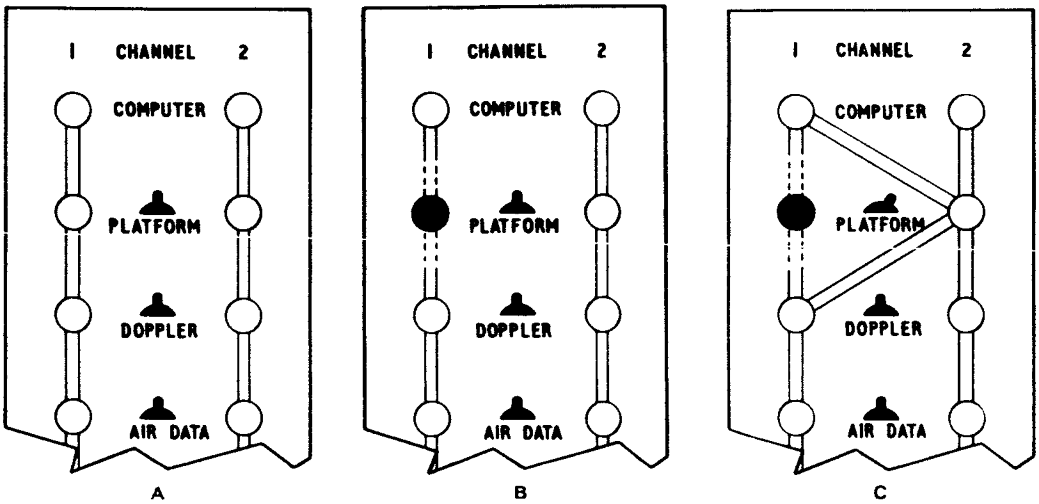


Fig. 3 : Diagram showing use of the remedial action panel. (A) Normal, all lights on. Illuminated strips indicate continuity of channels. (B) Platform 1 failed: platform 1 light extinguished. (C) Reversion—channel 2 platform selected. Diagonal strips lit to indicate restoration of channel continuity. Channel 1 now using platform data from channel 2 transmitted through the intercommunication link.

Figure 15. Navigation reconfiguration display (from ref. 19)

1. Obvious failures detected by the equipment will result in automatic reversion to standby equipment where trade-off analyses have dictated the requirement for such provisions.

2. All other system reconfiguration requirements will involve the crew directly. Broadly stated, this will include:

    a. Checkout of automatic reversion for appropriateness.

    b. Where no automation is provided, derivation of all alternates, assessment of each alternate, and selection of the most appropriate alternate.

    c. Establishing the required man-machine set-up and relationship which is indicated by the alternate selected.

It seems clear that a great deal of decision making will be required in the performance of this function. Although a computer may select from various pre-programmed alternatives, it is felt that decision making _per se_ is reserved for the crew complement, and is not the same type of choice selection exercised by the computer. And it then follows that the exercising of good judgment dictates significant requirements for experience, skills and knowledge which must be met in the crew complement and which will undoubtedly have considerable impact on the ultimate crew composition.

ACTIVITY 2.0 PHASE-ORIENTED SYSTEM CHECKS AND PREPARATION

PURPOSE

These activities are to set up equipment, verify performance, and insure that the overall system is readied to enter a given flight phase. To insure system integrity, all significant parameters must be surveyed and evaluated. Monitoring and evaluating functions are part of the flight management activities, while the step-by-step procedures are the requirements of the phase-oriented checks.

CURRENT JET OPERATIONAL REQUIREMENTS AND CONSTRAINTS

Although regulations do not outline specific system checks, the following do apply:

FAR 121.315, ref. 11:

Cockpit check procedure

> (a) Each certificate holder shall provide an approved cockpit check procedure for each type of aircraft.
>
> (b) The approved procedures must include each item necessary for flight crewmembers to check for safety before starting engines, taking off, or landing, and in engine and systems emergencies. The procedures must be designed so that a flight crewmember will not need to rely upon his memory for items to be checked.
>
> (c) The approved procedures must be readily usable in the cockpit of each aircraft and the flight crew shall follow them when operating the aircraft.

ICAO Reg. 4.2.3, ref. 12:

Flight check system

> An operator shall establish a check system to be used by flight crew prior to and on take-off, in flight, on landing, and in emergency, to ensure that the operating procedures contained in the Operations Manual and the Aeroplane Flight Manual or other documents associated with the certificate of airworthiness are followed exactly.

It is evident in these regulations that the FAA is aware of the capabilities of the human operator. The regulations are intended to insure optimum crew performance. Moreover, the complexities of modern systems generate requirements for systematic performance evaluation.

CURRENT JET IMPLEMENTATION CONCEPTS

In order to conform to FAA regulations and comply with airline operating policies, crews perform system checks and preparations at prescribed times, using checklists to insure sequential and complete performance. In general, these checks are performed prior to engine start, after engine start, prior to takeoff, after takeoff, prior to descent, prior to landing, and after landing. Separate checklists are used which provide sequential procedures to aid the crew in complying with standard operating procedures. A sample flight engineer's checklist is shown in Figure 16.

ENGINEER'S PRE-FLIGHT

COCKPIT I

① Maint. Log, File Folder-CKD
② Check Lists, Spare Forms, Maint & Wiring Manuals-ABOARD
③ Ext pwr, DC pwr, Battery-CKD, ON
④ Ess Bus, CB Panels, Galley-PWR ON
⑤ CBs & Fuses-ON, CKD
6. Radio Master Switches-ON
7. Equipm Cooling-OPERATING
8. Yaw Rate Gyro Selector-NORM
9. CrewO2 Hoses, Goggles(5)-ABOARD
10. Gear Handle-DOWN
11. Q Heater-CKD & OFF
12. Temp Probe Heater-OFF -300B/C
13. Window Heat-OFF
14. Pitot Heat-CKD; OFF
15. Tail Deice-OFF -100
16. Landing & Turnoff Lites(if reqd)CKD OFF
⑰ Beacon, Wing & Nav Lites-ON
18. Wing Anti-ice-OFF
⑲ Emerg Exit Lites-CKD & OFF
⑳ Emerg Flap-SWITCHES OFF, GUARD DOWN
21. Anti-Skid-CKD & OFF
㉒ Spoiler Switches-GUARDS DOWN
23. Nacelle Anti-ice-CKD & OFF
24. Overhead Panel Warn Lites-CKD
25. Mach Airspeed Warn-TEST
26. Flight & Engine Inst-CKD
27. Horizon Selector-#1
28. L.H. Kifis System-CKD (Except -139)
29. Emerg Air Brakes-OFF, SAFTIED
30. Marker Lites-CKD
31. Inst Warn System-CKD (Except -139)
32. Fire Exting Handles-FULL FWD
33. Fire Warn-TEST, TRANSFER NORMAL
34. Gear Warn Lites-CKD
35. Center Panel Warn Lites-CKD
36. Transponder-TEST
37. Engine Hyd Pumps-ON
38. Water Inj Drain Switch-OFF
39. Door Warn Lites-CKD
40. F/O Warn & Marker Lites-CKD
41. F/O Kifis-CKD (Except -139)
42. Mach Trim, Autopilot-CKD
43. Air Brake Press -1000-1400 PSI
44. Pitot Isolation Valve-ON
45. Aldis Lamp-STOWED
46. Eng Start Levers - CUT-OFF
47. Control Stand Warn Lites-CKD
48. Stick Shaker-CKD
49. Warning Horns-CKD
50. Control & Flap (Cockpit)-CKD
51. Life Jackets(5)-ABOARD
52. Fire Axe, CO2, Gloves-CKD
53. Portable O2 & Mask-ABOARD
㊹ Emerg Gear Handle-STOWED
55. Gear Ext. Access Doors-LATCHED-720B
56. Bulbs, Fuses, VHF, F/A Kit-STOWED
57. Nav Sextant-STOWED
58. Spare O2 Masks-ABOARD
㊾ Selcal - SET (Except -121)
60. Control & Flap (visual)(if reqd)-COMPLETE

LOWER NOSE

1. Fwd Cargo Int. Door-CLOSED
2. Radio Rack Equip & CBs-CKD, ON
3. Nose Gear RED PIN-RESET
4. J-9 Panel CBs-ON
5. Nose Gear Emerg Lever-STOWED
⑥ Selcal - SET -121

PAX COMPARTMENT

1. Doors, Slides, Airbottles-CKD
2. Washroom, Galley Equip - CKD
3. Crew O2 Bottle-ON (Except 300B/C)
4. Battery & C.B. - SECURE, ON (Except-139/331/720B
5. Gibson Girl, Spare Vests-ABOARD
6. Water Tank Quantities (2)-CKD
7. Rafts, Polar Equip if reqd-STOWED
8. Fire Extinguishers-CKD
9. Portable O2-CKD
10. Top Wing Surfaces-VISUAL
11. Windows, Wing Exits, Service Units-SECURE
12. First Aid Kit-STOWED
13. O2 Release Valves - CLOSED -121
14. O2 Pax Bottles - CKD & ON -121

FORWARD FUSELAGE

① Main Cargo Press Doors-CLOSED -300C
② L.H. Static Ports-CLEAR
3. L.H. Pitot Mast-COVER OFF
④ Nose Gear & Door-CKD, Gnd Lock-IN
5. Gear Inspect Window & Lite-CKD, OFF
6. Battery-SECURE -139/-331/720B
7. Radome-SECURE
8. R.H. Pitot Mast-COVER OFF
9. Temp Probe-CKD 300B/C
10. Water & Toilet Panels-SECURE
11. Water Drain Mast & Heater-CKD
⑫ R.H. Static Ports-CLEAR
13. Crew O2 Bottles-ON -300B/-300C
14. Fwd Outflow Valve-CLOSED
15. Equip Cooling Exhaust-CLEAR
16. Pack & Antenna Bay Doors-SECURE

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Figure 16. Sample flight engineer's checklist.

ENGINEER'S PRE-FLIGHT

RIGHT WING

1. Pack Air Inlet-CLEAR
2. Stall Warn Sensor-CKD
3. Fire Bottles, Plugs & Press-CKD

----------#3 ENGINE------------

④ Tail Pipe Inspection-COMPLETE
⑤ Strut, Access Plates, Cowling, Latches-CKD
6. Surge Bleed 100/300B/300C/720B-AS REQ
⑦ Intake Inspection-COMPLETE

----

8. Fueling Bay Door-SECURE

#4 ENGINE - SAME AS #3 ENGINE

----

⑨ Wing Tip & Lite-CKD
⑩. Control Surfaces & Flaps, Cove Lip Doors-CKD
⑪. Gear, Brakes, Leveler, Snubber & Tires-CKD
12. Gear Lock, Window, Lite-CKD, OFF
13. Deboosters-CKD
14. Hyd Bypass Valve-SAFETIED
15. Accumulator Press (3)-CKD
16. Pack Exhaust Fans & Doors -100/-300/-300B/-300C/030B)-CKD
17. Cond Fan Dampers(2)-OPEN-331/-023B

AFT FUSELAGE & TAIL

1. Center Outflow Valve-CLOSED
2. Sliding Rear Fillet-CKD 720B
3. 02 Release Valves-CLOSED(except-121)
4. 02 Pax Bottles-CKD & ON(except -121)
5. Aft Outflow Valve-CLOSED
6. Water & Toilet Panels-SECURE
7. Water Drain Mast & Heater-CKD
⑧ Tail & De-icing Boots-CKD
⑨ Tail Nav Lite-CKD
10. Q Inlet-CKD

LEFT WING

① Hyd Fluid Quantity-CKD
2. Gear Lock, Window, Lite-CKD, OFF
3. Deboosters-CKD
④ Gear, Brakes, Leveler, Snubbers, Tires-CKD
⑤ Control Surfaces, Flaps, Cove Lip Doors-CKD
⑥ Wing Tip & Lite-CKD
⑦ Rotating Beacons(2)-CKD

#1 ENGINE - SAME AS #3 ENGINE

----

8. Fueling Bay-CKD

#2 ENGINE - SAME AS #3 ENGINE

----

9. Fire Bottles, Plugs & Press-CKD
10. Stall Warn Sensor-CKD
11. Pack Air Inlet-CLEAR
⑫. Eng Ferry Pod (if used)-CKD

COCKPIT II

① Ext Lites & Beacon-AS REQ'D
② Crew 02-ON, CKD
3. Flight Recorder-TEST
4. Flowmeter Power Selector-NORMAL
5. Gen Disconnects-GUARDS DOWN
6. Elect Panel Warn Lites-CKD
7. Wing Valves-OPEN
8. Recirc Control-NORMAL -331/023B
9. Air Cond Packs-OFF
10. Eng Air Bleeds-OFF(except -100)
11. Ram Air-GUARD DOWN
12. Cabin Press Override-NORMAL -300B/300C
13. Thrust Recovery Valves-NORMAL(exc.-720B)
14. Air Cond Panel Warn Lites-CKD
15. Fuel Heaters-OFF
16. Condenser Fan O'ride-NORMAL-331/023B
17. Air Cond O'ride-AS REQD-331/023B
18. Programmer Bypass-NORMAL-023B
19. Condenser Dampers-AUTO-331
20. Freon Reset Switches-AS REQD-023B
21. Hyd Shut-Off Valve-OPEN
22. Start Air/Compressor Control-AS REQD-300B/300C
23. Vibration Monitor-TEST
24. Fuel Flow Meters-ZEROED(except 100/023B)
25. Fuel Dump Sw & Lights-CHECKED
㉖. Fuel Panel-CK & SET
27. Engine Fuel Valves-OPEN
28. Pre-set Fuel Controls-NORMAL
29. Lower Panel Warning Lights-CKD
30. Starter Air Pressure-CKD
㉛. Hyd & Water Quantity-CKD & RECORD
㉜. Fuel & Oil Quantity-TEST & RECORD
㉝. Pax 02 Press-CKD
34. Coolant Air System-OFF-300B/300C
35. Crew Aux Heat Valve-CLOSED-300C
36. Smoke Detector-CKD-300C

○Items performed at intransit stops.

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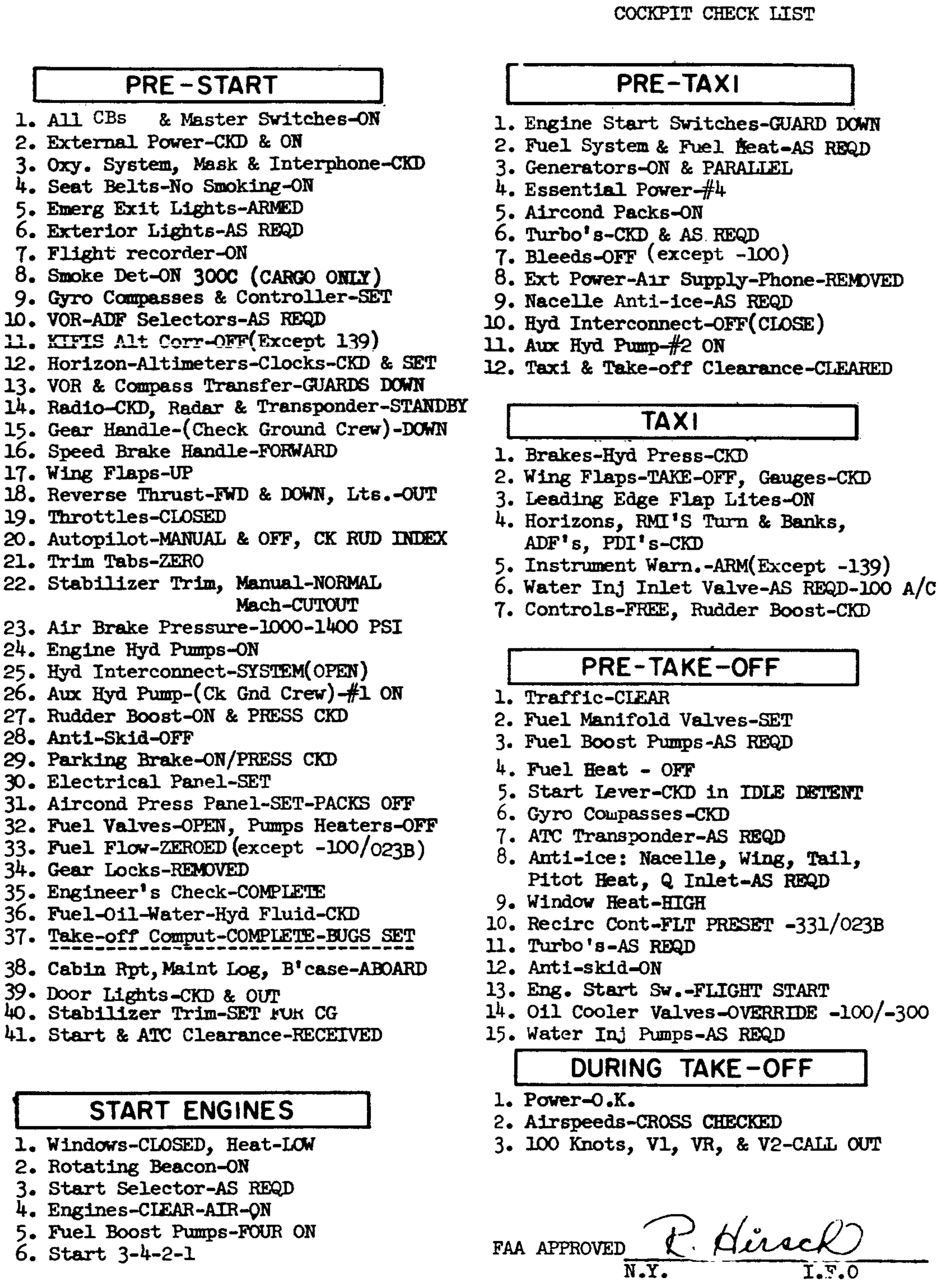
Figure 16. Sample flight engineer's checklist (continued).



COCKPIT CHECK LIST

PRE-START

1. All CBs & Master Switches-ON
2. External Power-CKD & ON
3. Oxy. System, Mask & Interphone-CKD
4. Seat Belts-No Smoking-ON
5. Emerg Exit Lights-ARMED
6. Exterior Lights-AS REQD
7. Flight recorder-ON
8. Smoke Det-ON 300C (CARGO ONLY)
9. Gyro Compasses & Controller-SET
10. VOR-ADF Selectors-AS REQD
11. KIFIS Alt Corr-OFF(Except 139)
12. Horizon-Altimeters-Clocks-CKD & SET
13. VOR & Compass Transfer-GUARDS DOWN
14. Radio-CKD, Radar & Transponder-STANDBY
15. Gear Handle-(Check Ground Crew)-DOWN
16. Speed Brake Handle-FORWARD
17. Wing Flaps-UP
18. Reverse Thrust-FWD & DOWN, Lts.-OUT
19. Throttles-CLOSED
20. Autopilot-MANUAL & OFF, CK RUD INDEX
21. Trim Tabs-ZERO
22. Stabilizer Trim, Manual-NORMAL
    Mach-CUTOUT
23. Air Brake Pressure-1000-1400 PSI
24. Engine Hyd Pumps-ON
25. Hyd Interconnect-SYSTEM(OPEN)
26. Aux Hyd Pump-(Ck Gnd Crew)-#1 ON
27. Rudder Boost-ON & PRESS CKD
28. Anti-Skid-OFF
29. Parking Brake-ON/PRESS CKD
30. Electrical Panel-SET
31. Aircond Press Panel-SET-PACKS OFF
32. Fuel Valves-OPEN, Pumps Heaters-OFF
33. Fuel Flow-ZEROED (except -100/023B)
34. Gear Locks-REMOVED
35. Engineer's Check-COMPLETE
36. Fuel-Oil-Water-Hyd Fluid-CKD
37. Take-off Comput-COMPLETE-BUGS SET
38. Cabin Rpt, Maint Log, B'case-ABOARD
39. Door Lights-CKD & OUT
40. Stabilizer Trim-SET FOR CG
41. Start & ATC Clearance-RECEIVED

START ENGINES

1. Windows-CLOSED, Heat-LOW
2. Rotating Beacon-ON
3. Start Selector-AS REQD
4. Engines-CLEAR-AIR-ON
5. Fuel Boost Pumps-FOUR ON
6. Start 3-4-2-1

PRE-TAXI

1. Engine Start Switches-GUARD DOWN
2. Fuel System & Fuel Heat-AS REQD
3. Generators-ON & PARALLEL
4. Essential Power-#4
5. Aircond Packs-ON
6. Turbo's-CKD & AS REQD
7. Bleeds-OFF (except -100)
8. Ext Power-Air Supply-Phone-REMOVED
9. Nacelle Anti-ice-AS REQD
10. Hyd Interconnect-OFF(CLOSE)
11. Aux Hyd Pump-#2 ON
12. Taxi & Take-off Clearance-CLEARED

TAXI

1. Brakes-Hyd Press-CKD
2. Wing Flaps-TAKE-OFF, Gauges-CKD
3. Leading Edge Flap Lites-ON
4. Horizons, RMI'S Turn & Banks,
   ADF's, PDI's-CKD
5. Instrument Warn.-ARM(Except -139)
6. Water Inj Inlet Valve-AS REQD-100 A/C
7. Controls-FREE, Rudder Boost-CKD

PRE-TAKE-OFF

1. Traffic-CLEAR
2. Fuel Manifold Valves-SET
3. Fuel Boost Pumps-AS REQD
4. Fuel Heat - OFF
5. Start Lever-CKD in IDLE DETENT
6. Gyro Compasses-CKD
7. ATC Transponder-AS REQD
8. Anti-ice: Nacelle, Wing, Tail,
   Pitot Heat, Q Inlet-AS REQD
9. Window Heat-HIGH
10. Recirc Cont-FLT PRESET -331/023B
11. Turbo's-AS REQD
12. Anti-skid-ON
13. Eng. Start Sw.-FLIGHT START
14. Oil Cooler Valves-OVERRIDE -100/-300
15. Water Inj Pumps-AS REQD

DURING TAKE-OFF

1. Power-O.K.
2. Airspeeds-CROSS CHECKED
3. 100 Knots, V1, VR, & V2-CALL OUT

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Figure 16. Sample flight engineer's checklist (continued).

COCKPIT CHECK LIST

AFTER TAKE-OFF

1. Turbo's & Bleeds-AS REQD
2. Cabin Press-SET
3. Pack Valve CB -PULLED -331/-023B
4. Galley Power-AS REQD
5. Engine Start Switches-OFF
6. Gear Handle-UP & OFF
7. Wing Flaps-UP, Leading Edge Lts-OUT
8. Water Inj Pumps-OFF, Drain-OPEN
9. Water Inlet Valve-CLOSED-100 A/C
10. Eng Hyd Pumps-AS REQD
11. Aux Hyd Pump-#2 OFF
12. Mach Trim-ON
13. Yaw Damper-AS REQD
14. Landing Lights-UP & OFF
15. KIFIS Alt Corr-ON (except 139)
16. Rudder Boost Press-1000 PSI
17. Seat Belts-NO Smoking-AS REQD

Water Inj Drain-CLOSED(after 10 min)

PRE-LANDING

Before Descent

1. Instr Warn-ARMED-CKD-OFF(Exc.139)
2. Fuel Heater-AS REQD
3. Air Brake Press-1000-1400 PSI
4. Fire Warning-CKD
5. Window Heat-AS REQD
6. Engine Hyd Pumps-BOTH ON
7. Aux Hyd Pump-#2 ON
8. Brakes-CKD, Press-UP
9. Coolant Air Valves-OPEN-300B/300C

During Descent

1. Seat Belts-ON
2. Pressurization-SET
3. Fuel, Oil, Hyd Quantity-CKD
4. Fuel Panel-TANK TO ENGINE
5. Fuel Boost Pumps-EIGHT ON
6. LGW, Vthresh, EPR -CKD-BUG-SET
7. Recirc Cont-FLT PRESET -331/-023B
8. Landing Lights-AS REQD
9. KIFIS Alt Corr-OFF(Except 139)
10. Press Altimeters-SET & CROSS CKD
11. Mach Trim-OFF

APPROACH

1. Rudder Boost-ON, PRESS CKD
2. Wing Flaps-AS REQD; Leading Edge LTS-ON
3. Instrument Warn-ARM(Except 139)
4. No Smoking-ON
5. Gear-DOWN
6. 3 Green Lts, Hyd Press/Qty-CKD
7. Anti-Skid-ON, CK 4-RELEASES
8. Engine Start Sw's-AS REQD
9. Speed Brake Handle-FORWARD
10. Yaw Damper-OFF WHEN CONTACT
11. Turbos-AS REQD

AFTER LANDING

1. Anti-skid-OFF
2. Engine Start Switches-OFF
3. Wing Flaps-UP
4. Speed Brake Handle-FORWARD
5. Anti-ice: Wing, Tail, Window, Pitot, Temp Probe & Q Inlet-OFF
6. Trim Tabs & Stab -ZERO & NORMAL
7. Radar & Transponder-STANDBY, DME-OFF
8. Fuel Boost Pumps-FOUR OFF
9. Pack Valve CB-IN -331/-023B
10. Recirc Cont-NORMAL -331/-023B
11. Temp Override-AS REQD -331/-023B
12. Freon System-BOTH OFF -331/-023B
13. Turbo's & Packs-OFF
14. Emerg Exit Lights-OFF (before A/C power OFF)

BLOCKS TRANSIT

1. Seat Belts-OFF
2. Nacelle Anti-ice-OFF
3. Ext. Lights-AS REQD
4. Flight Recorder-TEST & OFF
5. Smoke Detector-OFF -300C
6. Aux Hyd Pumps 1 & 2-OFF
7. External Power-AS REQD
8. Engine Start Levers-CUT OFF
9. Rotating Beacon-OFF
10. Fuel Boost Pumps-OFF
11. Chocks in Place-BRAKES OFF

BLOCKS TERMINAL

1. Blocks Transit-COMPLETE
2. Radio Master Switches-OFF
3. White Marked CBs - PULLED
4. Crew 02 Supply-OFF
5. Battery Switch-OFF
6. Gasper Fan-OFF
7. Heating Blankets-OFF -300C

RADIO CHECK LIST

1. All Radio CBs. Ground Power-ON
2. Check HF's, VHF's, ADF's, VOR's REQUIRED ROUTE, LOCAL FREQUENCY & SELCAL
3. VOR 1 and 2-CKD. ON LOCALIZER
4. Cross Functions-CHECKED

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Figure 16. Sample flight engineer's checklist (concluded).

SST POTENTIAL OPERATIONAL REQUIREMENTS AND CONSTRAINTS

For the most part, the SST requirements for checking and insuring system integrity throughout the flight profile will be the same as those on current jets. The SST requirements will probably be even more stringent and will need to be completed in a timely manner. The fact that the SST will be experiencing new aerodynamic phenomena, and operating in a strange and adverse environment, will mean that the crew will be responsible for insuring that all systems are set up and operating as required.

FEASIBLE AUTOMATED IMPLEMENTATION CONCEPTS FOR SST

As was described above, requirements for systematic checks have become more stringent with the increased complexities of aircraft systems. No longer is the crew able to rely upon memory to insure that all parameters are checked; today, lengthy checklists must be used which contribute to the crew's workload and introduce a severe degree of restrictiveness in the cockpit.

Many experts agree that the lengthy, involved, checking process can be optimized by introducing a combined computer-man concept. In his article, "The Feasibility of Cockpit Automation as Applied to the Supersonic Transport" (ref. 21), Richardson points out that:

> The basic problem is this; given a supersonic passenger carrying aircraft of, at the moment, somewhat flexible physical characteristics, how may this craft be operated in the most efficient, safe, and economical manner possible. This is a question which the airline operators and the passenger public jointly will ask, and in effect are now asking. This is the same question which industry must answer, and soon.

> One concept which has been advanced as a means of achieving these goals is the central electronic management system (CEMS). Stripped to its bare essentials, the CEMS proposes the use of a central airborne digital computer to integrate all or many of the varied functions presently being performed on subsonic aircraft by a variety of subsystems, requiring assistance from human flight crew personnel in some cases. Some of these functions include navigation, cruise control, vertical and horizontal profile scheduling, communications, systems test and checkout, auxiliary systems monitor and control, and malfunction detection and identification. In effect the CEMS acts as an overall systems manager, providing either command or control functions as specified by the flight crew.

Due to the complexity and the sophistication of SST systems, it appears that the crew will be more involved in operating the aircraft than it is currently. Supersonic flight and uninhabitable environment will require almost flawless performance by aircraft systems as well as the crew. Although the requirements and responsibilities will become more stringent, it appears that additional means will be available to assist the crew in obtaining optimum performance.

It would appear that the crew will be able to utilize the proposed on-line computer to assist them in determining system status, and in some cases to set up systems through solenoid activation. However, this will not be a completely automatic function; the crew will perform many of the set-ups and verify system status and procedures with the computer.

FEASIBLE MANUAL IMPLEMENTATION CONCEPTS FOR SST

In the event of a malfunction in the automatic portion of the systems checkout, the crew would be required to check critical parameters first, and then attempt to complete the remaining items.

It must be remembered that the SST has introduced what might be called "time compression," so that although more time is needed to complete the checkout manually, there is less time available.

In some segments of the flight profile the implications of using only manual procedures--as in current operations--are insignificant, because the procedures are of short duration. However, elsewhere (e.g., post-start checks) time is an important factor. Within the following functional descriptions an attempt will be made to show the criticality introduced by employing a manual implementation of a particular function.

The manual concept is generally feasible, although it affects the economy and efficiency of operations. With the sophistication of the systems proposed for the SST, efforts will probably be made to incorporate system status parameters into some integrated display which can be easily evaluated by the crew.

2.1 FUNCTION 2.1 PRE-START SYSTEM CHECKOUT

Purpose

Pre-start system checkout entails determining the status of the aircraft prior to engine start, and insuring that all systems necessary for power plant activation are set up as required. Moreover, the exterior portions of the aircraft must be checked to insure that all are functioning normally.

Current Jet Operational Requirements and Constraints

Federal regulations, safety, and airline procedures specify that the aircraft must be completely checked, within the capabilities of the crew. Even though aircraft are checked by maintenance and ground handling personnel prior to each flight, the crew's responsibility is still to insure that all systems appear to be functioning normally.

Current Jet Implementation Concepts

Crews rely on lists of sequential procedures to assess the state of the aircraft. Before boarding, the crew inspects the aircraft exterior examining all those accessible places that would have some influence on the flight.

Once the crew is in the cockpit it can be assumed that the exterior pre-flight check has been successfully completed. With power externally applied to the aircraft, the crew will determine if cockpit systems are functioning normally, and will be ready for the engine start. Of course, not all systems can be completely checked prior to engine start, since full power is required for a complete systems check.

In most cases, electrical power and blown air are the external energy sources applied to the aircraft. The crew must insure that the fuel system and electrical system are ready to furnish power to the engines for start.

When system checks and preparations have been completed, the system is ready for power plant activation.

SST Potential Operational Requirements and Constraints

Several new factors will be introduced with the SST: the sophistication of the systems, the size of the aircraft, and most importantly the need to hold ground handling time to a minimum. As a result, SST pre-start checkout will involve the same number or even more parameters to check as in current jets, and less time to do it in.

Feasible Automated Implementation Concepts for SST

The procedure utilized in the SST will make the greatest possible use of automatic checkout equipment, but will still require strictly manual means in certain areas. Checking the external portions of the aircraft will in all likelihood combine automatic system checkout equipment with the crew's normal exterior inspection or "walk around." The advantages of such a procedure will be a savings in time and the use of ground handling equipment which will not add to the weight of the aircraft.

Within the cockpit, the crew could possibly utilize the proposed on-line computer to check out all systems and actually set up the systems (solenoid actuated). However, it appears more likely that the crew will utilize the computer for a system status check, and will continue as in today's operations to follow sequential procedures in readying the aircraft for takeoff.

Feasible Manual Implementation Concepts for SST

In general, the crew will be able to utilize procedures similar to those in current use. Although these checkout procedures are time consuming, they occur prior to engine start so that high fuel consumption rates need not be considered. The procedures used would assist the crew to insure an optimum engine start. Manual performance is well within the capability of the crew and SST operations should not introduce any training or transition problems.

2.2 FUNCTION 2.2 POST-START SYSTEM CHECKOUT

Purpose

This function is the aircraft status check made after energy is supplied by the power plants. Once an aircraft is no longer on external power, but is receiving its energy from the power plants and associated systems, it is good operating procedure to check the status of all important subsystems. In most cases, it is only possible to ascertain that system output is within tolerances (e. g., the pneumatic and hydraulic systems pressure).

The greatest attention must be given to those systems which are the most critical during the flight because of safety or operating efficiency. For this reason the performance necessary to activate and check out the communications system, the flight control system, the navigation system, and the environmental control system are expanded to show their importance.

Current Jet Operational Requirements and Constraints

Once internal power is applied to the aircraft systems, it is necessary to determine if these systems are operating in accordance with their specified output requirements. In the case of certain systems, such as the pneumatic, hydraulic, and electrical, system parameters (i. e., pressures and voltages) are displayed as soon as the power plants are activated. In some other systems, especially those employing avionics, initial set-up is required to energize the systems before status can be checked (e. g., communications or navigation). Thus, to insure that the entire aircraft is performing within tolerances, all systems must be checked after engine start and prior to takeoff.

Current Jet Implementation Concepts

In current operations, once the power plants have been activated and checked out the crew determines the status of the rest of the system. For the most part this is a standard sequential procedure divided among the crew members according to their locations. The crew examines the various systems using a checklist and insures that outputs are within certain limits. An out-of-tolerance system would be brought to the attention of the crew member responsible for evaluation and decision.

SST Potential Operational Requirements and Constraints

Even if the SST incorporates the amount of automation being advocated, there will still be the requirement to insure normal system functioning prior to takeoff. However, the amount of time available constrains performance of this task. Any delays due to ground lingering could be costly both in terms of economics and safety. Because of high fuel consumption rates, delays cause the aircraft to draw on fuel reserves thus reducing the possible flight distance and safety.

The sophistication of systems may necessitate additional supporting subsystems which would generate more checks and system set-ups. In general, however, the same parameters which currently indicate system performance will be used to measure performance in the SST cockpit. To decrease the checkout time required, better display methods will need to be developed so that system status can be displayed in its entirety.

Feasible Automated Implementation Concepts for SST

The procedures to be followed in the major subsystems, (i. e., flight control, communications, environmental control, and navigation) will be described in the appropriate functional descriptions included in this section. The other systems involved in post-start operations (e. g., hydraulic, pneumatic, fuel system, electrical) will be handled by a joint man-machine procedure. The on-line computer will be used to compare the inputs and outputs to these systems, and indicate the resultant status; the crew will be concerned with activating systems and regulating the outputs of others.

As was pointed out previously, the amount of post-start checking is becoming unwieldy. Steps within a checklist can easily be overlooked, and may not be caught until a critical moment in flight. It is evident that much effort should be devoted to establishing a man-machine procedure which will keep the workload at least at the current level. One such method might be the development of a flow-logic diagram display which would permit completeness in such preparation procedures.

Feasible Manual Implementation Concepts for SST

A procedure similar to that employed in current operations does not seem consistent with the proposed sophistication of the SST. However, it is a feasible concept to have the crew determine the aircraft systems status and set-up equipment in accordance with some sequential procedure. Using such a procedure the crew will usually check all critical systems first, and having ascertained that the aircraft is functioning normally will proceed with the equipment preparation.

General descriptions of checkout for the communications flight control and environmental systems are presented in the remainder of this section.

COMMUNICATION SYSTEM ACTIVATION AND CHECKOUT

Purpose

The purpose of this activity is to bring about activation of the communications system, and then to insure that its operational capability fulfills basic system requirements. During the operation of the SST there will be a requirement to coordinate and convey information to: (1) other members of the crew within the cockpit, (2) members of the crew in other areas of the aircraft, (3) the passengers, (4) external parties in close proximity to the aircraft, e. g., ground handling crews, (5) external parties concerned with control (separation) of aircraft, e. g., Air Traffic Control facilities; and (6) external parties concerned with the operation of the aircraft, e. g., the dispatcher. In most cases the means provided for coordinating and conveying this information will be different for each of the parties or agencies listed. Therefore, during the activation and checkout of the communications systems each means of communication will need to be tested. As will be discussed later, malfunction of portions of this system will vary in criticality.

Current Jet Implementation Concepts

Once the engines have been activated and the electrical bus set to supply power to communication and navigation equipment, the crew follows a checklist or some sequential pattern in setting up and checking the equipment. The HF, VHF/UHF, intercom and public address systems must be activated, tuned as necessary, and monitored to ascertain operation. Total system status of some equipment cannot be completely known until the equipment is actually utilized (e. g., the receiver may be working, but the transmitter may be inoperative even though it is activated).

Feasible Automated Implementation Concepts for SST

The SST designers are forecasting the use of the on-line computer for communications system checkouts, with displayed checklists to be available as a back-up. Richardson points out (ref. 21) the feasibility of automating many cockpit functions using the central electronic management systems (CEMS), one such function being system checkout.

To illustrate how the on-line computer might be used in system checkout, consider the situation in which the SST is parked at the loading area, external checkout of the system has been completed, the crew have taken their places in the cockpit, and the power plants have been activated supplying energy to all subsystems. The communications system is in an unenergized state, i. e., the switches are all off. The crew's role is to insure that sufficient electrical power is available for the communications system, and then to energize the system in the SOP sequence. If the activating sequence is lengthy, a displayed checklist will in all likelihood be utilized. Once all of the switches have been properly positioned, the on-line computer can measure the status of the system and display this information to the crew. Although the crew will be involved in the actual activation and subsequent checkout procedures, the evaluation of the system status is made in the flight management function (ground handling phase).

Feasible Manual Implementation Concepts for SST

If the crew is required to utilize a strictly manual checkout and set-up, the procedure will be similar to that used today. The crew would set switches and evaluate system status in accordance with steps on a checklist. The major objection to this method of set-up and checkout is the length of time necessary to complete it. Present estimates indicate that the time factor involved would be unacceptable.

FLIGHT CONTROL SYSTEM ACTIVATION AND CHECKOUT

Purpose

This function insures that the flight control system (s) is operating within tolerances, i. e., responding to the control signals furnished both by the yoke, and the autopilot.

Current Jet Implementation Concepts

Currently it is standard operating procedure to visually check the control surfaces prior to boarding. Then, after the power plants have been activated and hydraulic and electrical power supplied, movement of the control surfaces is checked in response to yoke or autopilot control. The other control surfaces are also checked, as is the operation of the hydraulic system. The most common form of flight control system in operation today is typified by that found on the Boeing 720. According to the Boeing Operations Manual (ref. 22),

> ...the primary control surfaces consist of ailerons, elevator and rudder. These surfaces are aerodynamically balanced and are actuated by means of cable controlled tabs. The flaps and spoilers are hydraulically operated. In addition to aiding in lateral control, the spoilers can also be used as speed brakes. The horizontal stabilizer angle of incidence may be varied electrically, manually or by the autopilot. The primary flight controls incorporate control systems for both manual and automatic (autopilot) operation of inboard ailerons, rudder and elevator. Hydraulic rudder boost is incorporated. The automatic flight control system consists of an Autopilot which includes an automatic VOR-ILS beam coupler. The Autopilot provides sensitive, automatic, coordinated control of the airplane at any desired altitude, attitude, and heading ...

The various components of the flight control system are checked in coordination with a ground handler, by following a sequential procedure.

Usually the crew will move the controls through their limits, and the ground handler will ascertain that movement corresponds.

Feasible Automated Implementation Concepts for SST

Depending upon the complexity of the systems which will be utilized by the flight control system (e. g., autopilot, all-weather landing, trim, and stability augmentation), crew functions will be similar to those in current operations. However, since time is a factor every effort will probably be made either to complete the checks prior to engine start by utilizing some form of external power, or to use the proposed on-line computer to check system integrity. The latter can probably indicate subsystem status, but the crew will still need to coordinate with ground handlers to ascertain proper control surface movement. This man-machine procedure will probably keep time within acceptable limits.

Feasible Manual Implementation Concepts for SST

Whatever the final flight control system (s) chosen, crew requirements in checking operational performance will not change significantly from what is required of today's subsonic jet crews. Since many of the checks are lengthy and complex, some form of checklist should be provided to insure that all important parameters are checked. No problems are anticipated in this area of operations.

The major disadvantage of using a strictly manual procedure in checking the flight control system is that coupled with the other system checkouts the time factor becomes monumental. This area of checkout and set-up might be more amenable to a manual implementation concept, if the other systems were automatically checked.

ENVIRONMENTAL CONTROL SYSTEM ACTIVATION, CHECKOUT AND PREPARATION

Purpose

This function is to check and insure the normal operation of the habitability maintenance systems. The main factors to be considered in an environmental control system are pressure, temperature, humidity, radiation and lighting. The effects that these systems and their controlled parameters have on the passengers, directly affect the operation of the flight. Since safety and passenger comfort are underlying goals in any flight, every effort must be made to provide high reliability in this area. Because these systems are so important, they must be checked prior to takeoff.

The primary functions of an aircraft air conditioning and pressurization system are:

1. Maintain cabin air and wall temperature at a comfortable level.

2. Maintain a comfortable cabin pressure level.

3. Provide sufficient ventilation.

In most instances these are automatic systems which require little crew control to function properly. However, since these systems play such an important role for passengers and crew, every effort must be made to insure that the systems and their backups will perform within tolerances throughout the flight.

Generally, the parameters to be maintained include passenger and crew compartment temperatures between approximately 59.9° F and 81.5° F (15.5° C and 17.5° C), cabin pressures no greater than 8,000 feet equivalent altitude with changes due to ascents or descents being less than 300 feet/minute. The air conditioning system must provide a fairly uniform temperature balance, a feeling of freshness, and freedom from disagreeable odors.

Current Jet Implementation Concepts

Almost all the environmental control system parameters are maintained by the air conditioning and pressurization systems. In both systems an automatic mode of operation is provided which keeps the temperature, pressure and all associated parameters within tolerances. Rates of pressure change, humidity levels, and constant temperatures are automatically compensated for by the systems. In both these major systems provisions are made for a manual mode of operation in the event of a malfunction in either of the systems.

Feasible Automated Implementation Concepts for SST

Coupling the outputs of the environmental control systems to the on-line computer and comparing with required outputs will give the status of system capability. The crew may be required to "set-in" such parameters as airport altitude, desired temperatures or rates of pressure change. In most cases these can be set prior to engine start which would save time. System status would be checked after power plant activation. As with all system checkouts, time must be kept to a minimum to be consistent with proposed ground operations.

Feasible Manual Implementation Concepts for SST

The crew will comply with procedures in much the same manner as in today's operations. Some of the environmental systems will be set up on external inputs prior to engine start. Once the engines have been activated the systems must be switched to internal power and checked for adequate output. The use of a sequential procedure will aid the crew by insuring an encompassing procedure.

2.3 FUNCTION 2.3 SYSTEM PREPARATION FOR TAKEOFF

Purpose

This function is to prepare all systems for takeoff. This might be considered the final overall system check and as such the resulting evaluation should be either "ready for takeoff" or "abort."

Current Jet Operational Requirements and Constraints

Once the aircraft's power plants have been activated, the subsystems supplied with internal power, and the general status of the aircraft found to be normal, some of the aircraft subsystems are positioned for takeoff. These last minute checks and preparations are necessary to insure optimum performance during takeoff.

Current Jet Implementation Concepts

Standard current procedures entail examining aircraft systems prior to takeoff to check for such things as:

Electrical System:	Warning lights OFF Generators checked Circuit breakers all in
Fuel System:	Boost pump switches ON Distribution and flow
Engine System:	Oil pressure Oil temperature Oil quantity

Air Conditioning System:	Turbocompressors checked Automatic function checked
Hydraulic System:	Pressure Hydraulic pumps ON Warning lights OFF
Flight Control System:	Flaps set as required Speed brakes at 0° Trim set as required Autostabilization normal Controls free moving Antiskid ON
Miscellaneous:	External and internal lighting set as required Flight and navigation instruments set as required Engine instruments read normal Altimeters set Takeoff data reviewed

This list is not meant to be comprehensive, but rather indicates the nature of the tasks performed by the crew prior to takeoff. Procedures would vary slightly depending upon equipment chosen by a particular airline.

Generally speaking, the crew will divide the tasks using location in the cockpit as a criterion for assignment. Then a checklist will be utilized to insure that all sequential steps are performed.

SST Potential Operational Requirements and Constraints

The SST will not bring any revolutionary procedures to the cockpit in equipment set-up and checkout. The same basic parameters indicated above will need to be checked. Moreover, the SST's use of new and sophisticated systems may require additional set-up and checkouts. The greatest constraint will be the time element.

Feasible Automated Implementation Concepts for SST

The crew will be able to utilize the proposed on-line computer to check the status of systems as well as their outputs. However, it would appear that equipment set-up will continue to be performed manually. To conserve time, procedures may be changed to perform as many of these set-ups as possible prior to engine activation, and perform the system checks during taxi. The crew will continue to be responsible for insuring that the aircraft is in its optimum configuration when ready for takeoff.

Feasible Manual Implementation Concepts for SST

Current operational procedures would provide the manual mode of operation. It varies only slightly from the automatic mode, chiefly in determining system status. Warning lights and other instrumentation make this performance by the crew relatively non-restrictive, and thus the workload will not increase appreciably. The crew's responsibility would not change to any extent. The use of checklists in addition to the aforementioned lights and instruments would assist the crew is setting up for takeoff.

2.4 FUNCTION 2.4 POST-TAKEOFF CHECK

Purpose

This function is to ascertain status after takeoff, reconfigure as necessary for the climb, and set up equipment for climb-out requirements.

Current Jet Operational Requirements and Constraints

Once the aircraft has completed takeoff, new requirements exist for completion of the climb-out. Systems must be rechecked and equipment reset. These checks and set-ups are necessary to insure optimum equipment performance during the climb profile.

Current Jet Implementation Concepts

After takeoff (i. e., once the aircraft has established an acceptable rate of ascent), the crew must redistribute system loads channeled for takeoff requirements. They accomplish this by performing certain checks and set-ups for such things as:

Flight Control System:	Landing Gear UP Landing Gear Warning lights normal Flaps reset as required Autopilot set as required
Engine System:	RPM, fuel flow, and EPR set as required
Air Conditioning/Pressurization System:	Pressure rate of change set as required ($\approx$ 500 feet/min.)

	Desired altitude selected Turbocompressors activated as feasible
Miscellaneous:	Lights as required Warning signs as required

These are but a few of the system parameters which are checked immediately after takeoff. Depending on the equipment utilized, the procedure could be lengthy and complex. However, these checks can usually be spread out over the climb schedule. The crew, in most cases, will use a checklist to assist in completing the sequential procedure required.

SST Potential Operational Requirements and Constraints

Compared with current jets, the SST will bring higher performance characteristics to the cockpit which will create a greater degree of restrictiveness for the crew. In addition, new equipment concepts may add further set-up requirements to the crew's procedure. Also, because of the SST's fuel sensitivity at low altitudes, the crew will be required to ready the aircraft and get it on climb profile as soon as possible after takeoff.

Feasible Automated Implementation Concepts for SST

Systems which must be checked to verify performance can be checked automatically using the on-line computer. However, for the few systems which require changes, the crew will continue to manually set up the equipment. The time saved in automating this performance area would be insignificant when compared to the complexity of the system needed.

Feasible Manual Implementation Concepts for SST

Those parameters mentioned for jets will continue to draw attention in SST operations, and in all likelihood, the crew will function in much the same manner as currently.

Immediately after takeoff the crew must reconfigure the aircraft, redistribute the loads, and pick up the assigned climb profile. A checklist will probably be used to insure a complete sequential procedure.

2.5 FUNCTION 2.5 PRE-TRANSITION PHASE SYSTEM CHECKOUT

Purpose

This function is to ascertain the status of the aircraft prior to transonic acceleration, and to set up equipment and/or systems for the supersonic phase. The transitional acceleration phase will commence at the upper extremities of the current subsonic aircraft environment and terminate somewhere in that region which is adverse to current operations. Because of this entrance into the unfavorable environment, it must be ascertained that all artificial environment systems are functioning normally.

Current Jet Operational Requirements and Constraints

Since current aircraft are not concerned with transonic accelerations, this is not a requirement for current subsonic jets.

Current Jet Implementation Concepts

Not applicable in current operations.

SST Potential Operational Requirements and Constraints

Because of the adverse conditions the aircraft will encounter after passing the sonic barrier, a complete system status report is required prior to transonic acceleration. The integrity of the aircraft must be assured and all equipment set-ups must be made before continuing with the flight phase. All systems which will provide either artificial environment, or artificial stability throughout the supersonic portions of the flight must be checked to insure normal functioning. The inlet nozzle system will begin to play an important role in the output of the power plants, and its automatic mode of operation must be engaged and checked out. (Note: The automatic system used in the XB-70 is presenting technical problems.)

Feasible Automated Implementation Concepts for SST

Somewhere within the subsonic climb phase the crew will commence system checkout and equipment set-up necessary for the transonic acceleration. They will check such parameters as:

Flight Control System:	Autopilot set as required Variable incidence set as required Automatic stabilization checked and operating as required
Engine System:	RPM, fuel flow, and EPR set as required Lubrication system operating normally Inlet duct system's automatic mode checked as required
Air Conditioning/Pressurization System:	Temperature normal Pressure as desired Air mixture within tolerances Radiation level normal
Miscellaneous:	Warning signs as required Intercom announcements as necessary

Almost all the parameters above and many others which would also give an indication of system status, will be able to be checked automatically via the proposed on-line computer. Since all parameters will be monitored and evaluated, a continuous watch will be available on the system status. For the other areas, the crew will reset equipment, reconfigure the aircraft, and make whatever decisions are necessary to ready the aircraft for transonic acceleration. As in the case of any checkout or system set-up, checklists will be used by the crew to assist in providing sequential procedures.

Feasible Manual Implementation Concepts for SST

The only difference between the manual procedure and the one described above is the checking of system status by the crew instead of by the computer. Manual checking is usually done anyway, so there should be no appreciable workload difference between the two concepts. The crew would continue to function as currently, following sequential procedures as dictated by checklists.

2.6 FUNCTION 2.6 PRE-DECELERATION/DESCENT PHASE SYSTEM CHECKOUT

Purpose

This function is to ascertain the status of the aircraft, reconfigure as required, and to employ any subsystems necessary to fulfill the descent requirements.

Current Jet Operational Requirements and Constraints

In this phase, aircraft checkout and utilization of new subsystems is not specified by Federal regulation, but by safety and economic factors.

The two systems of chief concern are the pressurization system, and the anti-icing and window heating systems. As the aircraft begins its descent it is necessary to insure that the pressure change in the cabin is limited to 300 feet per minute. It should be pointed out that if bleed air (i.e., air from one of the engine compressor stages) is used to pressurize the aircraft as well as to heat the windows and for anti-icing, then a specific power plant RPM is necessary to keep below pressure change limits during descent.

Current Jet Implementation Concepts

The type of descent profile desired would dictate any changes necessary in the flight control or basic configuration systems. Prior to descent the crew checks such parameters as:

Engine System:	Fuel quantity for computing landing gross weight
	Bleed air as required

Pressurization/Air Conditioning System:	Airport altitude set in pressure system Rate of change set to about 300 feet/minute
Miscellaneous:	Hydraulic pump ON Altimeters set Air speed instruments checked Window heat ON Anti-icing system ON Warning lights as required

The parameters above are only a few of those which are checked prior to any descent of appreciable altitude. Of course, the parameters included depend upon the type of aircraft and airline, however, in most cases the procedure would remain the same. The crew utilizes a checklist to assure completeness in the sequential procedures. Assignment of the task to a crew member is usually based on the location of either the crew member or the display for the required parameter.

SST Potential Operational Requirements and Constraints

In general, requirements will remain the same as in current operations. Of course, the sophistication of the entire system, plus the new implementation concepts may generate the need to closely monitor specific parameters during descent. One area of concern may be temperature control during descent. Since the fuel system will probably be used as a heat sink, the decreased fuel flow associated with the descent may introduce some heat dissipation problems.

Feasible Automated Implementation Concepts for SST

As described in previous sections, the monitoring and evaluating of the SST systems and their associated parameters will be a continuous function of the on-line computer. Therefore, the crew's role becomes one of monitoring the operation of the "data monitor," and performing any equipment set-ups or system reconfigurations necessary to fulfill descent requirements. The crew's tasks would all be accomplished in much the same manner as is used today.

Feasible Manual Implementation Concepts for SST

Unless concepts change drastically, the crew will continue to perform these periodic system checkouts and equipment set-ups in the present manner. Of course, in a purely manual mode of operation the crew would need to be cognizant of the status of the major systems at all times. However, this would be no more than is currently expected. The crew's responsibility would be to insure that the aircraft was configured to meet the demands of the descent profile. A checklist would be used to insure completeness in assessing system status.

2.7 FUNCTION 2.7 PRE-LANDING SYSTEM CHECKOUT AND PREPARATION

Purpose

This procedure is conducted to ascertain the status of the aircraft and its systems, re-set equipment, and reconfigure the aircraft as necessary to meet approach and landing requirements. Prior to landing, the aircraft operates in a high density traffic area which requires that slower and more maneuverable speeds be maintained. This can only be accomplished by some form of aircraft configuration change. Also, all systems used primarily for landing must be checked for normal operation.

Current Jet Operational Requirements and Constraints

Federal regulations state that the system will be checked prior to landing and that adequate checklists must be provided. In addition, every effort must be made to optimize performance in this region. The sophistication and complexity of high performance aircraft have brought about the need for sequential procedures which would be quite inclusive.

Current Jet Implementation Concepts

As has been previously described, the crew utilizes checklists during critical portions of the flight to set up equipment and reconfigure the aircraft to meet the demands of the particular flight phase. During the approach the crew must check the aircraft and set up equipment paying particular attention to such parameters as:

Flight Control System:	Speed brakes 0° or as required Flaps set as required Trim system as required Gear DOWN and checked
Hydraulic System:	Pressure checked Anti-skid system checked Parking brake OFF
Engine System:	Fuel boost pumps ON Fuel checked
Miscellaneous:	Passenger warning lights as required Anti-icing system as required Emergency braking system checked Landing lights as necessary

There are more parameters which must be checked, but their inclusion is dependent to a large degree on the equipment utilized. In most cases those things not mentioned will be performed as a portion of the required performance associated with a particular function (e.g., flight control system will check flaps, gear, and any other high lift devices required).

The crew's role is to assure that a complete preparation has taken place. Most of these checks can be made during the let down and initial portions of the approach, leaving very few items for the final approach.

SST Potential Operational Requirements and Constraints

The specific configuration chosen for SST may influence procedures slightly during the pre-landing check, but not sufficiently to warrant concern. Generally speaking the same parameters which draw attention in current operations will do so in SST operations. New equipment and new automated systems will require some setting up during this check.

Feasible Automated Implementation Concepts for SST

Although portions of the approach and landing patterns are slated for automatic operations, the crew will continue to have the primary role in equipment preparation and aircraft reconfiguration. One reason is that many variables may be introduced during these operations and the crew is quite capable of responding to them. A computer would have to be huge to compensate for all possible variants. Therefore, although general system status will be automatically evaluated and displayed continuously, the crew will continue to perform the rest of the required set-ups and reconfigurations.

Feasible Manual Implementation Concepts for SST

As in today's operations, a checklist will be employed by the SST crew in readying the aircraft for landing. Crew responsibility will be largely what it is today. However, with the added automatic systems needing actuation during landing a lengthier check may be required. This will be primarily dependent upon the equipment used.

The crew should not require any revolutionary training to achieve optimum performance.

2.8 FUNCTION 2.8 SYSTEM DEACTIVATION PROCEDURES

Purpose

This function is to de-energize all the systems and equipment which draw their power from the aircraft power plants, note any malfunctions or discrepancies in performance, and generally ready the aircraft for power plant deactivation. As the aircraft completes its landing rollout and clears the runway, the crew will deactivate those systems which will no longer be utilized. Most of these steps will be completed during the taxi to the assigned unloading area so that all that remains is engine deactivation.

Current Jet Operational Requirements and Constraints

Federal regulations are concerned with takeoff and landing checklists, while airline management and maintenance are concerned with optimum equipment usage. In an attempt to obtain maximum performance from systems and equipment, procedures have been set up which assist in maintaining high service rates.

Current Jet Implementation Concepts

As the aircraft is moved towards the unloading area the crew deactivates such systems as:

Flight Control:	Speed brakes at 0° Flaps at 0° Trim at 0° Nose gear straight or as required

Pressurization/Air Conditioning System:	Cabin pressure checked Air conditioning unit switches OFF
Hydraulic System:	Pressure checked Quantity of fluid checked Auxiliary hydraulic pumps OFF
Electrical System:	Set for external power External power of: Frequency 400 ± 8 cps Voltage 200 ± 8 v
Miscellaneous:	Landing lights OFF Pilot heat OFF Anti-icing system deactivated Weather radar and transponder OFF Passenger warning lights OFF

Although it is not entirely inclusive, this list illustrates the deactivation procedure by the crew upon landing and parking. In addition communications and navigation equipment must be de-energized. Descriptions of deactivation procedures for the communications and navigation systems are in the succeeding sections of this appendix.

Crew members will usually follow checklists which are specific to each location within the cockpit. Once all other systems have been checked and external power is applied to the aircraft, the crew will deactivate the engine system and its associated subsystems.

SST Potential Operational Requirements and Constraints

The same considerations listed for current jet aircraft should concern operations in the SST era. However, from an economics point of view the SST will need a short "turn-around" time (i. e., the time to ready the aircraft for the next flight). This means that all discrepancies in performance will need to be noted, reported, and repaired in a short time.

Feasible Automated Implementation Concepts for SST

Almost all the deactivation procedure will consist of "switch flicking" and notation of any discrepancies. For this reason it appears that automatic means are not necessary or practical during this stage.

Feasible Manual Implementation Concepts for SST

No new concepts will be introduced at this point to implement the crew's performance in the deactivation procedures. The crew will continue to utilize the checklist as an aid to being inclusive in their procedures. It should be stressed that every effort must be made to discover discrepancies so that turn-around time can be kept to a minimum.

COMMUNICATIONS SYSTEM DEACTIVATION

This procedure insures that the communications system is de-energized and that any discrepancies are noted and reported for repair. This function is the reverse of Function 2. 2. Once the crew has completed all the required communication functions, and the aircraft is in the process of being de-energized (power plant deactivated), the communication system should be deactivated. As has been pointed out previously, power surges and electrical transients can decrease the reliability of electrical equipment. To preclude this, standard operating procedures call for deactivation.

As in present operations, the SST crew will comply with standardized checklists to make sure that all the equipment is utilized in accordance with manufacturers' specifications. The system can be automatically checked prior to deactivation by some form of CEMS, and then deactivated manually by the crew.

Operating procedures pertaining to activation and deactivation of the various systems and subsystems will be quite similar to those in existence for current operations. Therefore, it is not anticipated that SST crews will require any specialized training, nor will any real automation occur in this phase.

FLIGHT CONTROL SYSTEM DEACTIVATION

This function insures that the flight control system is deactivated in accordance with the standard operating procedures of the particular carrier and/or the subsystem manufacturer. The actual procedures to be followed by the SST crew in deactivating the flight control system will be a portion of the phase-oriented checkout functions and are described under current implementation concepts. However, these procedures should include such items as raising flaps, neutralizing trim systems, deactivating the autopilot system, and checking the general operational performance of the flight control system.

When the power plants are deactivated, most of the electrical and hydraulic power will be absent from the system. Therefore, it is usually standard operating procedure to deactivate the separate subsystems so that upon subsequent activation, energy surges or transients will not cause damage.

This function is not actually required for the successful completion of the flight, but from an economics standpoint it is essential. The crew will not need any new training to deactivate the flight control system, nor will performing the task increase their workload. In all likelihood some form of checklist will be utilized to insure that all systems are shut down.

ACTIVITY 3.0 COMMUNICATIONS

PURPOSE

This group of functions provides the coordination and information flow needed for effective utilization of the SST. The communications of the future are not envisioned to be revolutionary, but rather, evolutionary. That is to say, the areas which need coordination today will continue into the SST era, but new means will be developed to establish better coordination.

There are four major areas of communications which are of concern:

1. Air Traffic Control communications
2. Company communications (i. e., ground handlers and dispatchers)
3. Intra-crew communications
4. Crew-passenger communications

These types of communications vary in their requirements, and vary as to the degree of restrictiveness which they impose on the crew throughout the flight profile.

Since the SST will be moving at 30 miles a minute, current methods of communications will need to be re-evaluated to see if they provide the capability necessary for such high speed, high altitude operations. The role of the crew will be primarily the same, as a coordinator. The sophistication of the SST and the Air Traffic Control structure within which it will be operating would appear to create lower workload levels, but with new methods of operation. The crew's involvement should change from that of operator to that of monitor. However, a shift in crew involvement will not bring a corresponding shift in responsibility.

CURRENT JET OPERATIONAL REQUIREMENTS AND CONSTRAINTS

In all areas of aircraft operation there exists the requirement for coordination and flow of information. These requirements are the same four types of communications listed on the preceding page. The information which must be conveyed is dictated in part by Federal regulations, by efficient operating procedures, and by concern for safety. Some specific existing regulations follow:

FAR 121.557, ref. 11:

Emergencies: domestic and flag air carriers.

> (c) Whenever a pilot in command or dispatcher exercises emergency authority, he shall keep the appropriate ATC facility and dispatch centers fully informed of the progress of the flight.

FAR 121.561, ref. 11 (Similar to ICAO Reg. 4.4.3, ref. 12:)

Reporting potentially hazardous meteorological conditions and irregularities of ground and navigation facilities.

> (a) Whenever he encounters a meteorological condition or an irregularity in a ground or navigational facility, in flight, the knowledge of which he considers essential to the safety of other flights, the pilot in command shall notify an appropriate ground station as soon as practicable.
>
> (b) The ground radio station that is notified under paragraph (a) of this section shall report the information to the agency directly responsible for operating the facility.

FAR 121. 565, ref. 11:

Engine inoperative: landing; reporting.

(c) The pilot in command shall report each stoppage of engine rotation in flight to the appropriate ground radio station as soon as practicable and shall keep that station fully informed of the progress of the flight.

FAR 91. 87, ref. 9: (Similar to ICAO Reg. 3. 5. 2. 1, ref. 14)

Operation at airports with operating control towers.

(a) *General.* Unless otherwise authorized or required by ATC, each person operating an aircraft to, from, or on an airport with an operating control tower shall comply with the applicable provisions of this section.

(b) *Communications with control towers operated by the United States.* No person may, within an airport traffic area, operate an aircraft to, from, or on an airport having a control tower operated by the United States unless two-way radio communications are maintained between that aircraft and the control tower. However, if the aircraft radio fails in flight, he may operate that aircraft and land if weather conditions are at or above basic VFR weather minimums, he maintains visual contact with the tower, and he receives a clearance to land. If the aircraft radio fails while in flight under IFR, he must comply with § 91.127.

(c) *Communications with other control towers.* No person may, within an airport traffic area, operate an aircraft to, from, or on an airport having a control tower that is operated by any person other than the United States unless—

(1) If that aircraft's radio equipment so allows, two-way radio communications are maintained between the aircraft and the tower; or

(2) If that aircraft's radio equipment allows only reception from the tower, the pilot has the tower's frequency monitored.

FAR 121.349, ref. 11:

Radio equipment for operations under VFR over routes not navigated by pilotage or for operations under IFR or over-the-top.

(a) No person may operate an airplane under VFR over routes that cannot be navigated by pilotage or for operations conducted under IFR or over-the-top, unless the airplane is equipped with that radio equipment necessary under normal operating conditions to fulfill the functions specified in § 121.347(a) and to receive satisfactorily by either of two independent systems, radio navigational signals from all primary en route and approach navigational facilities intended to be used. However, only one marker beacon receiver providing visual and aural signals and one ILS receiver need be provided. Equipment provided to receive signals en route may be used to receive signals on approach, if it is capable of receiving both signals.

(b) In the case of operation over routes on which navigation is based on low frequency radio range or automatic direction finding, only one low frequency radio range or ADF receiver need be installed if the airplane is equipped with two VOR receivers, and VOR navigational aids are so located and the airplane is so fueled that, in the case of failure of the low frequency radio range receiver or ADF receiver, the flight may proceed safely to a suitable airport, by means of VOR aids, and complete an instrument approach by use of the remaining airplane radio system.

(c) Whenever VOR navigational receivers are required by paragraph (a) or (b) of this section, at least one approved distance measuring equipment unit (DME), capable of receiving and indicating distance information from VORTAC facilities, must be installed on each airplane when operated within the 48 contiguous States and the District of Columbia at and above 24,000 feet MSL and must be installed on each of the following airplanes, regardless of the altitude flown, when operating within the 48 contiguous States and the District of Columbia after the indicated dates:

(1) Turbojet airplanes—June 30, 1963.

(2) Turboprop airplanes—December 31, 1963.

(3) Pressurized reciprocating engine airplanes—June 30, 1964.

(4) Other large airplanes—February 28, 1966.

(d) If the distance measuring equipment (DME) becomes inoperative en route, the pilot shall notify ATC of that failure as soon as it occurs.

FAR 91. 125, ref. 13: (Similar to ICAO Regs. 5. 3. 4 and 5. 3. 2, ref. 14)

IFR, radio communications.

The pilot in command of each aircraft operated under IFR in controlled airspace shall have a continuous watch maintained on the appropriate frequency and shall report by radio as soon as possible—

(a) The time and altitude of passing each designated reporting point, or the reporting points specified by ATC;

(b) Any unforecast weather conditions encountered; and

(c) Any other information relating to the safety of flight.

FAR 91. 127, ref. 13: (Similar to ICAO Reg. 5. 3. 4. 2, ref. 14)

IFR operations; two-way radio communications failure.

(a) *General.* Unless otherwise authorized by ATC, each pilot who has two-way radio communications failure when operating under IFR shall comply with the rules of this section.

(b) *VFR conditions.* If the failure occurs in VFR conditions, or if VFR conditions are encountered after the failure, each pilot shall continue the flight under VFR and land as soon as practicable.

(c) *IFR conditions.* If the failure occurs in IFR conditions, or if paragraph (b) of this section cannot be complied with, each pilot shall continue the flight [according to the following:

[(1) *Route.*

[(i) By the route assigned in the last ATC clearance received;

[(ii) If being radar vectored, by the direct route from the point of radio failure to the fix, route, or airway specified in the vector clearance;

[(iii) In the absence of an assigned route, by the route that ATC has advised may be expected in a further clearance; or

[(iv) In the absence of an assigned route or a route that ATC has advised may be expected in a further clearance, by the route filed in the flight plan.

[(2) *Altitude.* At the highest of the following altitudes or flight levels:

[(i) The altitude or flight level assigned in the last ATC clearance received;

[(ii) The minimum altitude (converted, if appropriate, to minimum flight level as prescribed in § 91.81(c)) for IFR operations; or

[(iii) The altitude or flight level ATC has advised may be expected in a further clearance.

[(3) *Climb.* When it is necessary to climb in order to comply with subparagraph (2) of this paragraph, the following applies:

[(i) Climb to the assigned altitude or flight level in accordance with the last ATC clearance received;

[(ii) Climb to the minimum altitude for IFR operation at the time or place necessary to comply with that minimum; or

[(iii) Climb to the altitude or flight level ATC has advised may be expected in a further clearance at the time or place included in the expect-further-clearance.

[(4) *Leave holding fix.* If holding instructions have been received, leave the holding fix at the expect-further-clearance time received, or, if an expected approach clearance time has been received, leave the holding fix in order to arrive over the fix from which the approach begins as close as possible to the expected approach clearance time.

[(5) *Descent.* Begin descent from the en route altitude or flight level upon reaching the fix from which the approach begins, but not before—

[(i) The expect-approach-clearance time (if received); or

[(ii) If no expect-approach-clearance time has been received, at the estimated time of arrival, shown on the flight plan, as amended with ATC.]

ICAO Reg. 3. 3. 1. 5, ref. 14:
Closing a flight plan.

3.3.1.5.1 A report of arrival shall be made, either in person or by radio at the earliest practicable moment after landing, to the appropriate air traffic services unit at the aerodrome of arrival, normally the aerodrome reporting office, by any flight for which a flight plan has been submitted.

3.3.1.5.2 When no air traffic services unit exists at the aerodrome of arrival, the arrival report shall be made as soon as practicable after landing and by the quickest means available to the nearest air traffic services unit.

3.3.1.5.3 When communication facilities at the aerodrome of arrival are known to be inadequate and alternate arrangements for the handling of arrival reports on the ground are not available, the aircraft shall, if practicable, transmit by radio immediately prior to landing a message comparable to an arrival report, to an appropriate air traffic services unit, normally the air-ground communication station serving the air traffic services unit in charge of the flight information region in which the aircraft is flying.

Note.—Failure to comply with these provisions may cause serious disruption in the air traffic services and incur great expense in carrying out unnecessary search and rescue operations.

ICAO Reg. 4. 6, ref. 14:

Change from VFR flight to IFR flight.

An aircraft operated in accordance with the visual flight rules which wishes to change to compliance with the instrument flight rules shall:

a) if a flight plan was submitted, communicate the necessary changes to be effected to its current flight plan, or

b) when so required by 3.3.1.1.2.1, submit a flight plan to the appropriate air traffic services unit and obtain a clearance prior to proceeding IFR when in controlled airspace.

ICAO Reg. 5.1.3.1, ref. 14:

Change from IFR flight to VFR flight.

> An aircraft electing to change the conduct of its flight from compliance with the instrument flight rules to compliance with the visual flight rules shall, if a flight plan was submitted, notify the appropriate air traffic services unit specifically that the IFR flight is cancelled and communicate thereto the changes to be made to its current flight plan.

ICAO Reg. 5.3.3, ref. 14:

Termination of Control

> When an IFR flight operating under the air traffic control service has landed, or leaves a controlled airspace and it is no longer subject to air traffic control service, the appropriate air traffic control unit shall be notified as soon as possible.

CURRENT JET IMPLEMENTATION CONCEPTS

Generally speaking, the categories of communications will utilize different pieces of equipment, and will be redundant to the extent required by necessary reliability factors. The specific uses and procedures employed by the crew will be covered in the functional descriptions.

In general, company communications (i. e., ground handlers and dispatchers) are handled via HF communication nets with selected calling features and via intercom when conducting system activation and deactivation procedures. The crew utilizes direct voice communications and intercom to obtain necessary coordination and information flow within the cockpit during all phases of the flight. To keep the passengers up-to-date with flight highlights and safety procedures, the crew utilizes both the public address system, and the series of lighted signs (e. g., No Smoking).

For ATC communications, the crew uses VHF/UHF voice communications and coded transponder beacons. Early in aviation the increase in traffic density was accompanied by a steady increase in workload due to communications. Fortunately, the trend has reversed, and the workload due to communications is decreasing. Just what implications this will have on supersonic flight will be discussed under SST Implementation Concepts.

A block diagram of present aviation communication networks is shown in Figure 17 (from ref. 23). Communications equipment consoles in a current jet transport are shown in Figures 5 and 6 of Activity 1.

SST Potential Operational Requirements and Constraints

For both company and crew communications there do not appear to be any major modifications required by the SST. However, because of the newness of the SST and its inherent flight characteristics, there will, in all likelihood, be a requirement for increased crew-passenger communications. With respect to Air Traffic Control, the basic concept will change and different procedures will be utilized. This in turn will generate requirements for different information flow. The Bureau of Flight Standards, Federal Aviation Agency, describes the new communications requirements in the report, "Supersonic Transports," (ref. 24):

> ...present voice communications between air traffic controllers and aircraft may not be adequate, because of high speed of the aircraft as well as the great increase in volume of air traffic communications.

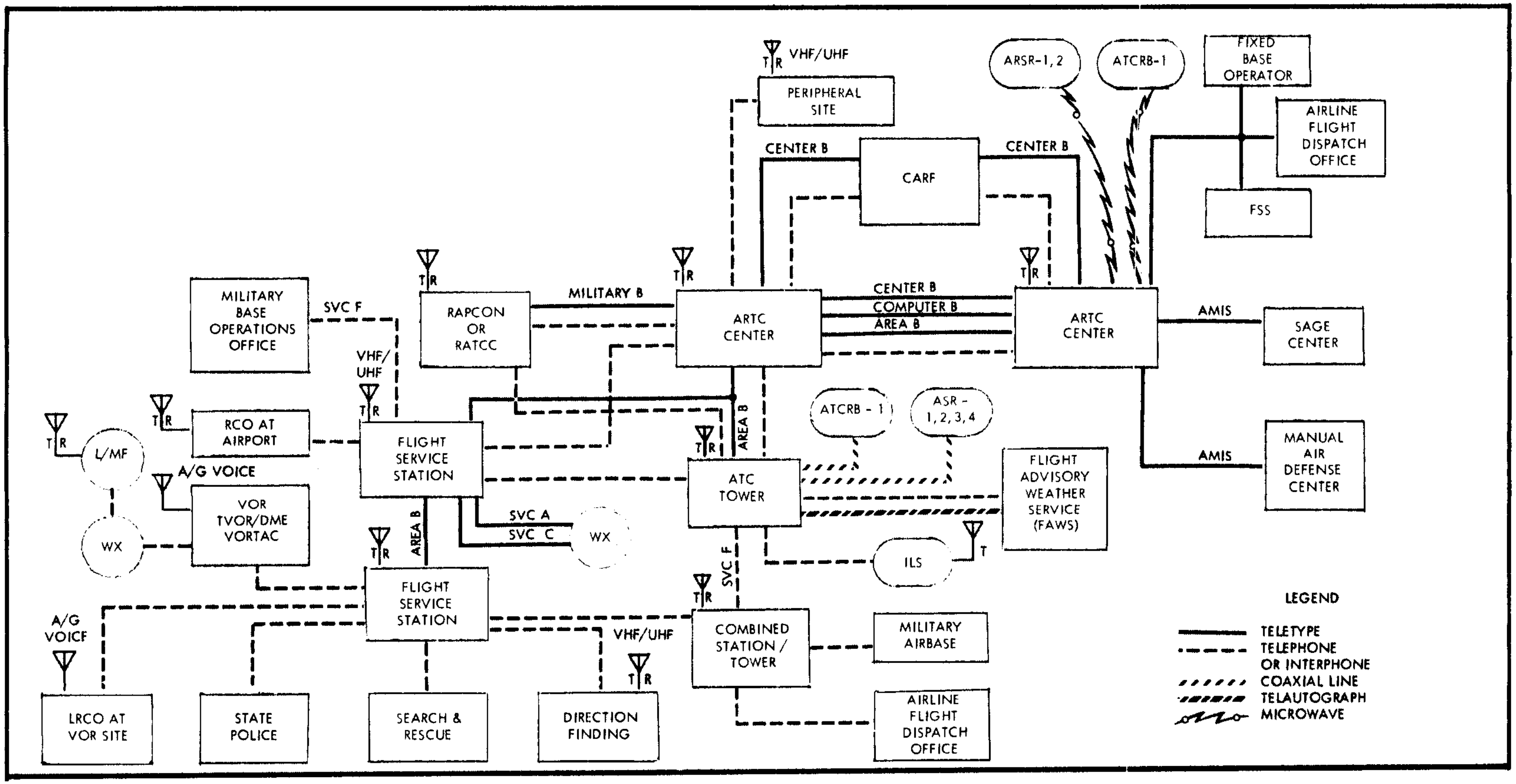

Figure 17. Present aviation communications networks (taken from Reference 23)

> An automatic data link system to transmit information from ground to air and air to ground (AGACS* or equivalent) will be required to relieve air crew members and air traffic controllers of the heavy burden of communications. The data link system should also be capable of providing to ground controllers, on a continuous basis, the aircraft's position, velocity, altitude, and any other pertinent data necessary for air traffic control purposes. It is likely that only communications of an emergency nature will be handled on voice channels in order to relieve traffic congestion and to expedite the handling of communications. . . .

The major changes to be introduced with the SST, appear to be in the area of ATC communications. However, most of these changes will result in a decrease in crew and controller workload.

FEASIBLE AUTOMATED IMPLEMENTATION CONCEPTS FOR SST

An extension of the coded transponder beacon, automatic ground/air data link will be utilized in the SST era for conveying all information of a general nature. A printer used in combination with this system would present an available read-out for the crew. Non-routine or emergency information would be conveyed via the usual VHF/UHF communications links (HF or satellite links on transoceanic flights), but would have a selected call-up feature which would eliminate the requirement for constant monitoring of frequencies. (Pilots are still apprehensive, however, about not being able to monitor what is happening around them. They generally like to monitor frequencies to cross-check control procedures.) Most of the other communication areas will continue to utilize equipment and concepts similar to those currently used, and there does not appear to be a practical reason for attempting to automate these areas of communications.

---

* Automatic ground air communications system

The main areas of concern will be the integration of automatic systems into the cockpit, and the establishment of optimum utilization procedures. Richardson (ref. 21), an advocate of the central electronic management system (CEMS), points out that such a system could be utilized to perform those communications functions which are time consuming. He indicates that in one mode of operations automatic two-way (ground-to-air-to-ground) data link is quite feasible, and that it would provide for "computer decoded ground-to-air data link and displays data on an integrated navigational display. The computer also assembles messages automatically or through manual insertion, and transmits pertinent position and flight plan data to ground control center." He goes on to point out that,

> . . . in an automatic ground-air-ground communications system such as the RCA AGACS presently undergoing development by the FAA, incoming ground-to-air data must be translated into displays in the cockpit. Information inserted either by the pilot or the navigation system must also be translated into a format suitable for transmission from air-to-ground. In an integrated system containing a digital computer, these functions can readily and economically be absorbed by the computer, thus eliminating the need for a special external digital data converter . . .
>
> Although the present AGACS project is planned to be integrated with the ground based data processing central system for ATC, its major utilization is in the area of automatic position reporting. Considering the capability and utilization of the CEMS, it is now feasible to transmit much more information in the air-to-ground message than has heretofore been possible. For instance, such data as present and future destinations or course change points, ETA to these points, present course, speed, and altitude are all items of information continually being computed and used in the computer program. . . .

The description and requirements given in the foregoing paragraphs pertain to communications which involve coordination and control with exterior systems. It is in these areas of communication that supersonic flight will introduce the major problems to be solved by the designers. Since the overall SST concept has incorporated a large amount of automation, it seems likely that the communication system will also use as much automation as is feasible and within the state of the art. Beacon control, data-link system, and SELCAL (selected calling) systems will do much to fulfill coordination requirements. Improved UHF, VHF, HF, and in some instances satellite relay will provide the means for supplementing the automated systems.

Figure 18 shows in simplified form, the various Air Traffic Control functions during a flight in the system to be used by 1975. The diagram indicates how the following design objectives are satisfied:

1. Flight plans may be entered into the computer from remote points such as an operations office.
2. Tabular displays provide a method of automating the control transfer function.
3. Sector size is increased through the separation of planning and active control functions.

FEASIBLE MANUAL IMPLEMENTATION CONCEPTS FOR SST

The entire crew involvement may be quite different from that on today's subsonic aircraft. However, these changes in procedures are expected to be "evolutionary," which means that they may be introduced into service with subsonic carriers before the advent of the SST. Even today, the need for frequent position reports has been eliminated on continental flights. Because of radar coverage over the entire route, crews have been able to substantially reduce their workload due to the reduced communications. As Hill points out (ref. 25),

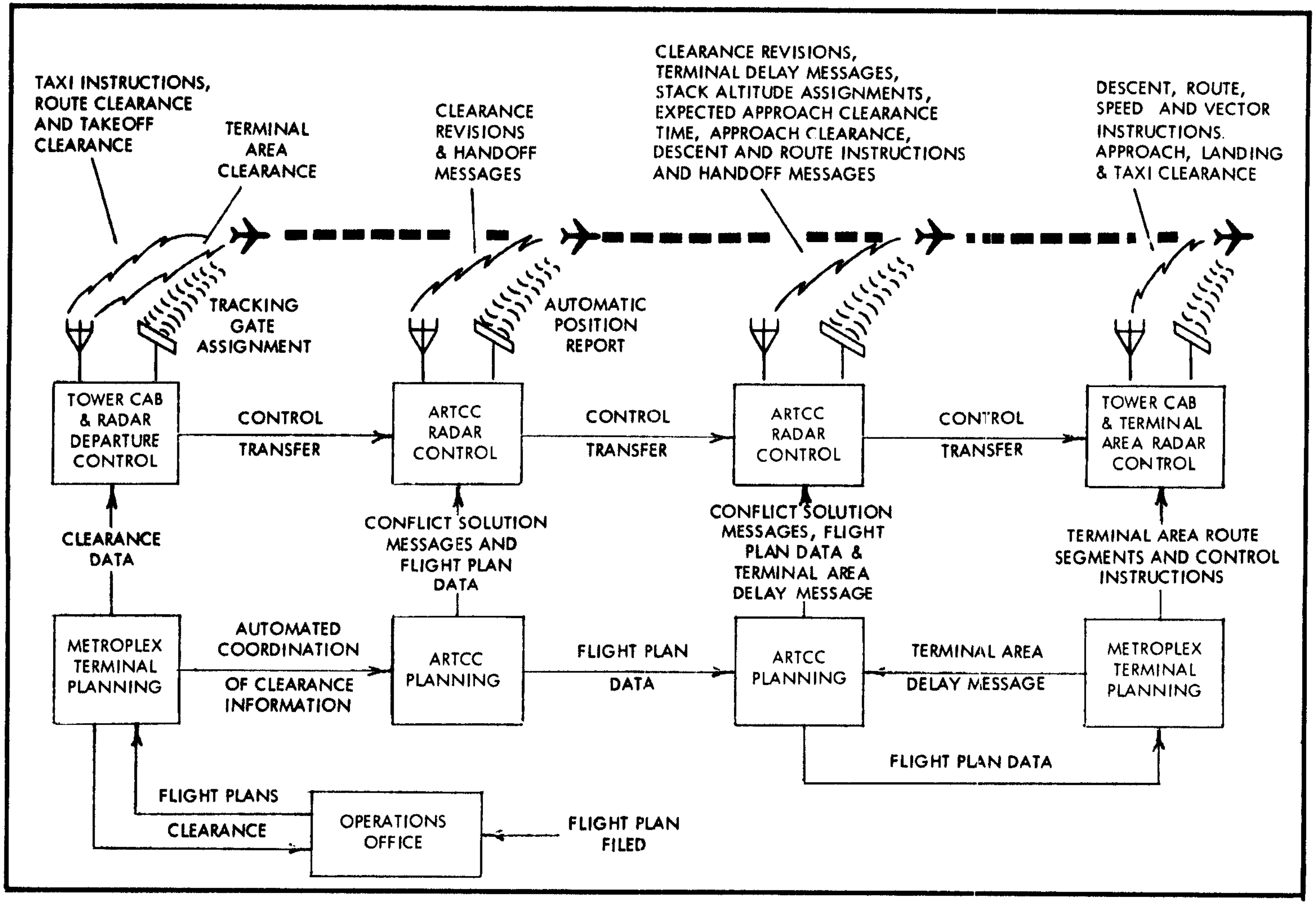

Figure 18. Summary of the handling of a flight in the ATC subsystem (taken from Reference 23)

> . . . the communications systems will largely be quite conventional, but there will be more complex peripheral equipment to provide a greater degree of automaticity. The first step in this direction is being taken in the introduction of more complex reply codes from secondary radar transponders. We will shortly be introducing an altitude-reporting code, and this will be followed by additional modes which will provide information of value to Air Traffic Control.
>
> Extension of this approach to routine messages can result in a considerable reduction of work-load on the crew which will be extremely significant. On certain routes today's aircraft saddle their pilots with a work-load which is about 50 percent communications duties. . .

Many of the new and forthcoming procedures are the result of the Beacon Report. Brady (ref. 26) summarizes some implications of the report as follows,

> . . . the Beacon Report concluded that identity, altitude, and position information provided by altitude coded transponder beacons would reduce communications workload to a tolerable level, at least for the foreseeable future. The report recognized that automatic air/ground data link might some time in the future be an important system adjunct. . . .

Whatever communications system is chosen for the SST, there will always be a requirement to convey information outside the capability of the automatic system. To meet this need the crew will in all likelihood use communications techniques in much the same way as they do today. Until now the amount of work connected with the communications system has increased with the expansion of the aviation field. Now that other systems have been perfected, it is time to reduce loading, and there is no obvious reason why a sizeable reduction can not be made.

3.1 FUNCTION 3.1 GROUND HANDLING PHASE COMMUNICATIONS

Purpose

This function provides the necessary coordination and exchange of information required to change aircraft status from off-line (i. e., parked in the loading area) to readiness for takeoff (i. e., on the operational runway with a takeoff clearance). The communications necessary for this function include those with ATC, the company, among the crew, and between the crew and passengers.

Current Jet Operational Requirements and Constraints

Most of the requirements in this area are concerned with Air Traffic Control; others are generated by the need for safe and efficient ground operations. To ready the aircraft for takeoff, there must be coordination between the aircraft and the ground handling crews, coordination between the aircraft crew and the flight attendants, intra-crew coordination, crew and passenger coordination, and finally coordination with ATC facilities (i. e., both ground and local control).

Current Jet Implementation Concepts

Current communication techniques may best be described by considering again the different types of communications.

Crew-Ground Handlers Communications. When the aircraft is operating on internally generated power, and communications systems have been activated and are in go condition, the crew proceeds with the post-start and pre-takeoff system readiness checks. The intercom system is used to establish coordination and information exchange with ground handling crews. Once the aircraft has completed these checks and has been cleared to taxi (described in the paragraph on ATC communications) the crew resorts to visual signals (e. g., hand signals or light signals) to receive obstruction clearance directions as the aircraft moves away from the loading area. The ground handlers job is usually completed once the aircraft has acquired a taxi guideline.

Intra-Crew Communications. Intra-crew communications involve those coordinated procedures which establish an efficient working team. During the activation and subsequent checkout of the aircraft system, there is a constant need for conveying status information to the Captain for final evaluation and decision making. In most cases direct verbal communication, or perhaps, the intercom would be used. The basic purpose of these communications is to keep the Captain aware of the total status of the aircraft so that he can make appropriate decisions. Although different crew members may be responsible for activating and checking out particular subsystems, the Captain requires such responses as, "ready for taxi," and "ready for takeoff."

Crew-Passenger Communications. The crew's communication with the passengers is limited in the early portion of the flight, and in most cases is performed by the flight attendants. In current operations the flight attendants make sure that passengers comply with safety regulations, remind the passengers of the seat belt and no smoking signs, and inform the Captain when the passengers are ready for takeoff. On some airlines the flight attendants also describe the flight in general, and at a later time the Captain or a member of his staff gives a more detailed description.

Crew-ATC Communications. The bulk of the communications workload is in fulfilling coordination requirements with Air Traffic Control. Initially, the flight plan is filed with the Air Traffic Control Center. This is actually accomplished prior to entering the aircraft.

Currently a scheduled block of time with a canned flight plan help to expedite operations.

Once the checkouts have been satisfactorily completed, clearance must be obtained from local ground control to taxi from the loading area to the operational runway. (Refer to Flight Control and Power Plant Operation for a description of the taxi performance.) In many cases, the crew not only receives clearance to taxi, but also information as to the operational runway in use (in the case of multiple runways), and directions for getting there. Other types of information which can be obtained by the crew include ground traffic advisements and any amendments to previous clearances.

When the aircraft has taxied to the end of the operational runway, by regulation it must obtain clearance to roll onto the runway for take-off. Local ground control gives this clearance in addition to giving a change of frequency to the next ATC controller. At this point the communications frequency must be changed and initial contact and identification made. If the local controller wants to warn the aircraft of some impending danger once the aircraft had changed frequencies, a series of light signals may be utilized, or, since the local controller coordinates with the departure controller, the information may be passed through him.

SST Potential Operational Requirements and Constraints

The major constraint to be introduced by SST aircraft will be the economics involved in long ground handling times. Every effort must be made to shorten this time, and yet not degrade performance by insufficient coordination. The current ground communications requirements should also apply to SST operations.

Feasible Automated Implementation Concepts for SST

Only one segment of the ground handling communication function seems compatible with automated systems, i. e., ATC clearance reception and copying. The communications outputs can be either in the form of an automatic print-out or an approved pre-punched flight plan. For the most part, the means of communication will remain the same with the biggest changes occurring in operating procedures. The shifting of tasks currently accomplished after engine start, to the time period prior to engine start, can also significantly decrease the ground operation time.

Feasible Manual Implementation Concepts for SST

The SST should not increase workload or require a change in technique in the coordination with ground handling crews. Similarly, intra-crew communications should not significantly change and the crew should not be required to perform any more intercom tasks than in today's operations. In fact, the use of the on-line computer to check out system status should cause a decrease in cockpit coordination.

In the initial days of SST flights, public apprehension may necessitate some sort of early communication from the Captain or a member of the crew, but the current procedure would be used, i. e., lighted signs for safety information and public address for other communiques. It is understood that present commercial jet operations encourage the captain to use the public address systems to inform passengers of details of flight.

With the SST it may not be practical to file a flight plan far in advance due to the significance of atmospheric parameters on the SST operation. It is likely that the SST crew will submit the flight plan just prior to the flight, and receive final clearance just prior to boarding the aircraft. The crew will receive the latest local weather, and a clearance for engine start by contacting the local ground control. This clearance for start should be predicated on any estimated delays, so that once the power plants are activated and the system checked out, there will be no delays in obtaining clearance for takeoff. With the SST such delays could be very costly, from the standpoint of economics as well as fuel reserves. In a complex and busy terminal, ATC communications tasks could generate workloads inconsistent with the sophistication of the rest of the aircraft system. Efforts will have to be made to reduce this conflict by means of new procedures and succinct communications. Crew tasks should not radically change from those of today's flight crews, except that the increased traffic may further congest an already overloaded system.

Figure 19 illustrates the typical initial portion of a flight in the automatic ATC environment and the various equipment consoles.

Console 1:	A data entry device which accepts the pilot's filed flight plan.
Console 2:	Marshalling Controller's console which assigns departure times for filed flights.
Console 3:	Departure planning controller's console which examines the terminal area departure route.
Console 5:	A printer for delivering clearances.
Console 6:	Ground Controller's console for clearance delivery.
Console 8:	Ground Controller's console for ground operations.

Console 9: Local control's console.

Console 10: Departure radar control's console.

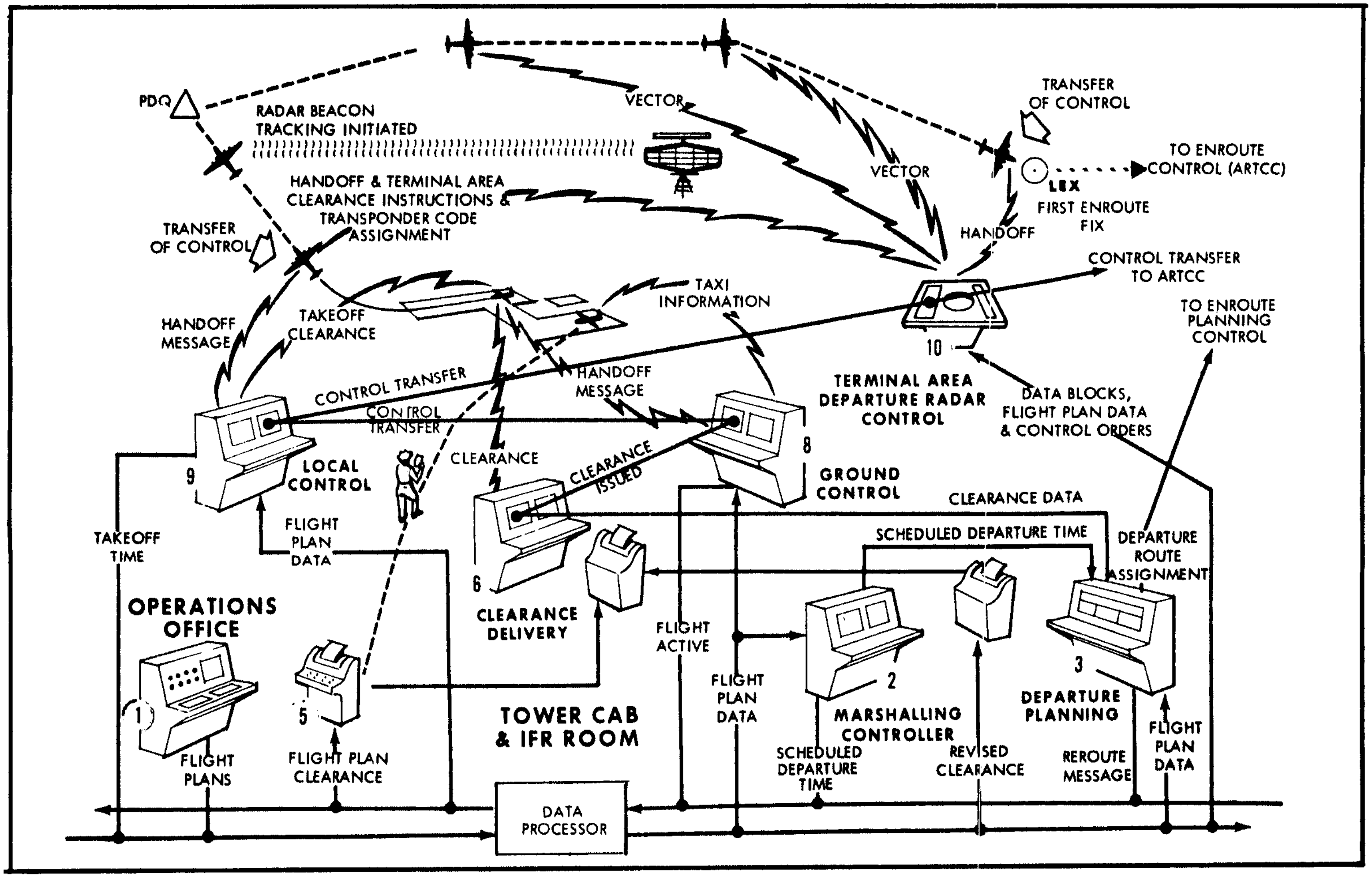

Figure 19. Departure terminal operation (taken from Reference 23)

3.2 FUNCTION 3.2 COCKPIT COMMUNICATIONS FOR TAKEOFF

Purpose

This function provides the necessary internal coordination and dissemination of information during the takeoff roll and subsequent operations which pertain either to takeoff or abort. These will be intra-crew communications primarily concerned with keeping the Captain informed about aircraft status and takeoff performance. Although SST systems and subsystems are checked prior to leaving the loading area, maximum loads are not placed upon the systems until the takeoff commences. Probably the greatest concern of the crew will be the performance of the power plant system, and of the subsystems which support its efficient operation.

Current Jet Operational Requirements and Constraints

During pre-flight planning certain speeds are calculated which take into consideration the gross weight of the aircraft, the runway conditions, and weather conditions. These speeds are an indication of power plant system performance, and are compared to the usable runway remaining to determine the aircraft's acceleration. They serve as guides for the crew in determining whether to continue a takeoff or abort. During periods of marginal weather when the visibility is low, the Captain will require additional information during takeoff to insure optimum performance. Thus, there is a requirement for an airspeed-versus-runway-remaining input to check on the acceleration. Once V_1 speed has been attained, the aircraft is committed to takeoff, and the input is no longer necessary.

In the event that the acceleration is not achieved and the decision is made to abort the takeoff, there must be coordination among the crew to decelerate the aircraft in the remaining runway. This will introduce a new communications task similar to the communications necessary during the landing roll-out. Thus, while abort communications may be considered to be non-routine, the required performance is similar to communications Function 3. 13.

Current Jet Implementation Concepts

During takeoff, the crew is involved in many checks and evaluation processes. The results of these evaluations must be passed to the crew member responsible for making decisions. In standard practice, certain performance values must be met. The evaluation then results in a "go" or "no go" statement. These evaluations are passed via oral communication, intercom, or perhaps warning lights.

SST Potential Operational Requirements and Constraints

The same coordination required in current operations will be required in the SST, with the added need for more timely information. The SST will be accelerating faster than current aircraft, and decisions will of necessity have to be made and communicated as quickly as possible. Since it does not appear feasible for one person to have the entire responsibility for the whole system, it seems likely that areas of responsibility will be divided among the crew as in current operations. Each crew member will then communicate his evaluation of a certain portion of the system as a "go" or "no go" statement.

Feasible Automated Implementation Concepts

Cockpit communications in the SST will be similar to those in current jet aircraft during the takeoff. However, with any system which requires close coordination for optimum performance, the decision-maker must have timely inputs. To meet this need, a takeoff monitor has been suggested for incorporation into the SST. This would present in a timely manner, all parameters critical for optimum takeoff performance. Although such a monitor is not strictly a piece of communications equipment, it is a method of conveying information which is the purpose of this function. The use of a takeoff monitor would aid in cockpit coordination, and decrease the need for many cockpit communications during takeoff. All vital systems and subsystems would be automatically monitored and evaluated, and the Captain given an aircraft status report during the takeoff.

Feasible Manual Implementation Concepts for SST

Without the implementation of a monitor, the crew would perform in much the same way as they do today (i. e. , information as to the status of the various systems and the performance of the aircraft would be exchanged via direct oral communication or intercom). The division of responsibility among the crew members would continue to exist, with the ultimate responsibility belonging to the Captain.

3.3 FUNCTION 3.3 DEPARTURE CONTROL COMMUNICATIONS

Purpose

This function establishes and maintains coordination and information transfer with the first Air Traffic Control facility which concerns the airborne system (i.e., departure control). In looking at the overall Air Traffic Control system, it is quite obvious that in terminal areas (i.e., in the vicinity of the airports) the aircraft density increases, resulting in the requirement for stricter control and closer coordination.

In current operations it is necessary for the crew to establish contact with the departure controller, verify responding to assigned transponder code, and verify radar contact. Once these initial contacts have been made, the crew must monitor the assigned frequencies for any further instructions or traffic advisories. Because of the increase in air traffic, the greatest problem in departure control is congestion on the frequencies, and the need to continually change frequencies in changing from one controller to another.

Current Jet Operational Requirements and Constraints

Coordinated control of aircraft in high traffic density, terminal areas is the chief concern of departure control. Aircraft operating in this airspace are required to maintain a communications link with the facility and pass information as requested, or to comply with ATC instructions. This allows ATC to effect the appropriate separations for departing aircraft.

Current Jet Implementation Concepts

As aircraft are cleared onto the runway for takeoff, they are usually switched from local control to departure control. This is accomplished via the VHF communications equipment. The crew must dial in the new frequency, or if using channelized equipment, select the appropriate channel. The crew conveys information concerning identification, position, and compliance with transponder code instructions. The ATC facility will usually indicate radar surveillance (i. e., radar contact and identification) and any maneuver instructions or other pertinent information.

SST Potential Operational Requirements and Constraints

For the most part, the same type of information requirements will exist for SST flight as for current jets. In "The Role of Communications in SST Flight Path Management," Polhemus (ref. 27) points out some additional SST requirements,

> We presently employ the air/ground communications system to ensure safe separation and control of aircraft using the airspace; to determine terminal and enroute weather conditions; to indicate aircrew intentions as regards track, position, and planned time of arrival when ground facilities require this information; and to select and evaluate alternate routes of flight in cooperation with company operated performance, computers, etc. However, each of these functions presently exists independent of the other. The manager or coordinator of the various data required in operation of the aircraft is the aircrew member. In subsonic jet aircraft the range of alternative courses of action is small and the penalties for mismanagement of the coordination function is not too severe. In supersonic aircraft, the compression of time in which a decision may be made is significantly shorter and the consequences of a poor decision may be great enough to turn an otherwise profitable flight into a costly blooper. . .

It is also necessary that the ATC controller note any conflicts at the earliest possible moment, so that the SST crew will be able to level off without subjecting passengers to unnecessary g loading.

Feasible Automated Implementation Concepts for SST

The SST crew should be relieved of many communications by the coded transponder (beacon) and the utilization of the air/ground data link. A look at a forecasted ATC system may be helpful in estimating the workload which ATC will place upon the SST crew. This will help identify those areas where actual voice communications will be necessary to coordinate and pass information.

A paper presented at the IATA Fourteenth Technical Conference, on "Air Traffic Control for the Supersonic Transport," (ref. 28) describes one conception of the future ATC system.

> ... it is assumed that the supersonic transport will be automatically controlled during most of its flight profile, especially during the climbout phase. Therefore, since air traffic control will have the complete flight profile submitted in the form of a flight plan, a clear takeoff route and climbout profile in the form of a clearance can be given to the aircraft with a high degree of assurance that the aircraft will be capable of making such a profile good. With the available data gathering equipment mentioned previously, the climbout can be monitored by traffic control to assure that the aircraft is following its clearance. With three-dimensional radar information available, it will be possible to provide vectoring when required. The supersonic transport will climb out on standard types of routes which will be established to minimize the noise problems and control problems inherent in integrating it with other traffic movements. Control will be based primarily on radar information to minimize horizontal separation distances and by the use of radar height information to provide vertical separation from other aircraft on crossing paths...

It would appear from the foregoing discussion that the major portion of the forecasted communications workload can be absorbed by automatic systems. All routine communications would be handled automatically and only in the case of clearance changes or non-routine messages would stand-by voice communications be utilized. Even these situations would be automated to the extent that much of the frequency monitoring could be eliminated, and the selected calling method of operation utilized. Such changes would reduce the communications workload, as well as the restrictiveness of such monitoring tasks. It would appear that under ideal conditions the workload created in the cockpit by present communications requirements, would be considerably reduced. This relief in workload could be put to good use in optimizing the SST flight profile.

As was previously discussed, new equipment and procedures will be introduced in an evolutionary manner. As a result, subsonic jet crews may experience the new system before the SST becomes operational.

Feasible Manual Implementation Concepts for SST

In a manual concept the crew is responsible for complying with ATC regulations, making any reports as required and passing all requested information. Voice communications will continue to be the backup communications capability. All non-routine messages will be passed by this means. The major disadvantages of using voice communications alone are the over-crowded frequencies and the requirement for constant frequency monitoring.

It would appear that with the new control procedures and equipment being utilized by ATC, the number of required communications is decreasing. However, the manual concept will still be more restricted and more demanding of the crew than the proposed automatic implementation concepts.

3.4 FUNCTION 3.4 ACTIVATE/DEACTIVATE NO SMOKING SIGNS

Purpose

The purpose of this function is to establish crew-passenger communications so as to insure compliance with safety and standard operating procedures. At specific times during the flight the crew will be required to inform passengers of any restrictions pertaining to smoking. These times are usually specified by regulation and/or company standard operating procedures.

Current Jet Operational Requirements and Constraints

Federal aviation regulations specify that aircraft must be equipped with visual signs operated by the crew to advise passengers of any restrictions pertaining to smoking:

> FAR 121.317, ref. 11:
>
> Passenger Information.
>
> (a) No person may operate an airplane unless it is equipped with signs that are visible to passengers and cabin attendants to notify them when smoking is prohibited and when safety belts should be fastened. The signs must be so constructed that the crew can turn them on and off. They must be turned on for each takeoff and each landing and when otherwise considered to be necessary by the pilot in command.
>
> (b) No passenger or cabin attendant may smoke while the no smoking sign is lighted and each passenger shall fasten his seat belt and keep it fastened while the seat belt sign is lighted.

Current Jet Implementation Concepts

As specified in the regulations, lighted signs operated by the crew are utilized to inform both passengers and attendants of any restrictions placed on smoking. Usually these signs are activated prior to takeoff (during ground handling activities) and then again prior to landing. Once the aircraft is airborne and operating normally, the signs are deactivated.

SST Potential Operational Requirements and Constraints

At the present time there do not appear to be any potential constraints. However, if at a later date it appears that during flight at cruise altitude, the air conditioning system is overtaxed providing for ozone control, some provision may have to be made to make this a no smoking phase of flight.

Feasible Automated Implementation Concepts for SST

Since this is merely the activation or deactivation of a lighted sign, automated performance does not seem necessary.

Feasible Manual Implementation Concepts for SST

The crew must insure that passengers are made aware of the no smoking sign and comply with regulations.

In most cases the means for conveying this information is a lighted sign, activated and deactivated by the cockpit crew at certain established points in the flight (e. g. , takeoff and landing). For the crew the task is merely moving a switch to energize or de-energize the sign. Then, depending on airline operating procedures flight attendants usually advise passengers of the sign and insure compliance with the regulation.

These small tasks can usually be incorporated as a step in a phase-oriented check (see Phase-Oriented System Checks) and would not be considered a function. However, in those cases where the requirements preclude incorporation within a check procedure, the activation and deactivation of no-smoking signs must be called out separately.

3.5 FUNCTION 3.5 ACTIVATE/DEACTIVATE FASTEN SEAT BELT

Purpose

This function establishes crew-passenger communications to insure compliance with safety procedures requiring the use of the fasten seat belt sign. During those phases of flight which could adversely affect the passengers, it is the crew's responsibility to insure that the passengers comply with this requirement. Although the flight profile would only seem to indicate two periods for seat belt use, (i. e., the takeoff and the landing), the fasten seat belt sign must be turned on whenever the pilot considers it necessary because of weather or any other reason.

Current Jet Operational Requirements and Constraints

Federal aviation regulations, standard operating procedures, and passenger safety dictate the use of warning signs throughout specific portions of the flight. The applicable FAA regulation is presented in the section on Function 3.4.

Current Jet Implementation Concepts

As specified in regulations, aircraft are equipped with warning signs to advise passengers when seat belts are warranted. During ground handling, takeoff, and landing when there is always the possibility of some abrupt maneuver, the crew must make sure that these signs are lighted and complied with. In most situations the activation of these signs is merely a step in a phase-oriented check and system set-up. However, there are situations (e. g., enroute turbulence) when this becomes a discrete segment of performance.

SST Potential Operational Requirements and Constraints

The SST may bring with it restrictions on passenger mobility because of higher accelerations, steeper climb/descent angles, and higher speeds than on current aircraft. The steep climb angles may preclude any movement by passengers away from their seats until cruise altitude is attained; and at the other end of the flight, no movement once the cruise altitude has been left.

Feasible Automated Implementation Concepts for SST

As has been pointed out, regulations require a lighted warning sign which must be activated and deactivated by the crew at specific times. This will be handled manually as in current operations.

Feasible Manual Implementation Concepts for SST

The activation and deactivation of a lighted sign will be the means employed by the SST crew to comply with regulations and to insure passenger awareness of safety procedures. The high performance characteristics of the SST will require that passengers have their seat belts fastened for longer periods of time than at present. The crew will need to consider this as a factor in maneuvering at supersonic speeds.

3.6 FUNCTION 3.6 INITIAL POSITION REPORT

Purpose

This function establishes informational flow to provide Air Traffic Control with sufficient information to optimize control procedures and traffic separation. These communications can actually be considered a part of the departure communications. However, the initial position report is described separately to differentiate between those communiques necessary during the initial minutes of flight and those necessary during departure maneuvers.

In terms of today's operations, the initial position phase of the flight would be concerned with either the first communications with an ATC facility after being released by departure, or in a large control sector, with the original departure controller. In any case the aircraft would be clear of the terminal area, and more than likely, would be involved in the subsonic climb portion of the instrument departure. During this phase the crew might be required to change frequencies, and to report completion of a portion of the standard instrument departure.

Current Jet Operational Requirements and Constraints

In areas that lack surveillance radar coverage, much reliance is placed on manual separation procedures, however, these procedures increase the amount of communication required. To resolve any possible conflicts and ascertain that appropriate separations are being provided, the ATC controller needs reassurance that clearances are being followed. He obtains this information from the crew in the form of a position report (e.g., over some fix at some altitude and time), and is then able to establish a three-dimensional image of his traffic.

Current Jet Implementation Concepts

Shortly after takeoff the crew becomes involved in a series of communications which include amendments to clearances, radar vectors, traffic information, and requests for information. Since all this data is passed via common VHF/UHF frequencies, the possible congestion problem is evident. As control procedures become more reliable, the number of necessary communiques will decrease and in fact, today, the number of necessary communications is already decreasing.

SST Potential Operational Requirements and Constraints

The SST will be operating in the subsonic environment for as short a time as possible. The speed and high performance characteristics of the aircraft will necessitate timely communications. It would appear that with the equipment and radar coverage envisioned by ATC, problems of timeliness will be eliminated because the data will be automatically obtained and displayed.

Feasible Automated Implementation Concepts for SST

The role of communications in aircraft operation is changing constantly and as a result the role of the crew is also changing. By the time the SST commences operations most communications concerned with air traffic control are expected to be handled by automatic systems. Data from aircraft will be in a form acceptable to ground computers which will in turn present visual displays to the controllers. This situation display will give the controller the capability of forecasting traffic conflicts far enough in advance to resolve them within the maneuvering capabilities of the SST. The automated ATC structure is depicted in Figure 20 for the initial portion of the enroute operation. The four consoles shown are:

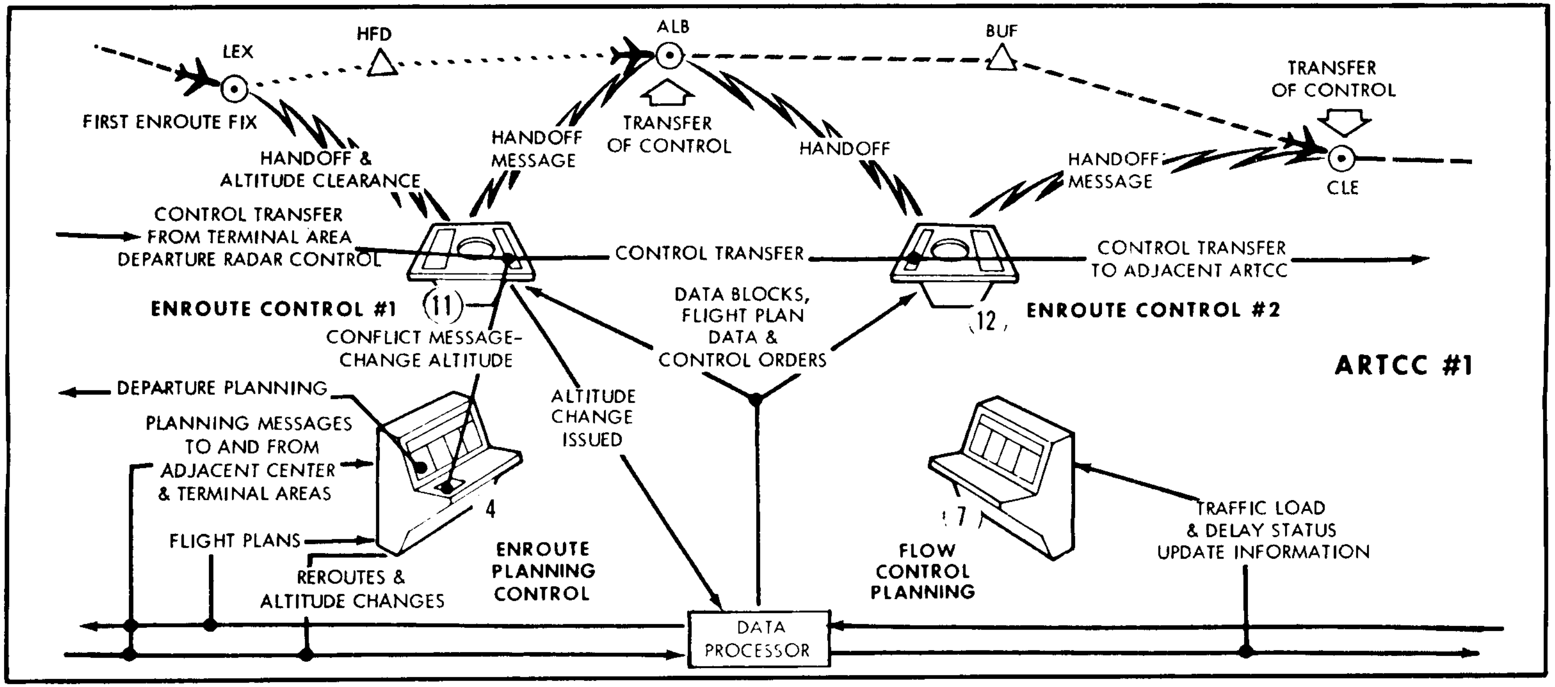

Figure 20. Initial enroute operation (taken from Reference 23)

Console 4:	Enroute planning controller's console which maintains coordination throughout the enroute portion of the flight.
Console 11:	Enroute controller's console which is used to accept control from departure control and maintain control throughout sector.
Console 12:	Subsequent enroute controller's console.
Console 7:	Flow control console maintains data on future flight for possible conflicts.

It should be emphasized that information concerning altitude, position, airspeed, and so on, is essential for proper functioning of the control system. If the aircraft were to lose its automatic capability, or the ground presentation system were to malfunction, then it would be necessary to obtain this information by other techniques. So, although it appears that routine communications could be handled automatically from takeoff to landing, the possibility of reverting to a manual system must not be overlooked.

On an automatic system such as the one described, the crew's role would be to monitor the system operation, and to convey any information requested which cannot be passed via the automatic system (e. g. , visual observation of traffic).

Feasible Manual Implementation Concepts for SST

VHF/UHF voice communications would continue to provide backup for automatic systems. It is interesting to note that because of the increased sophistication of the ATC structure, the crew's communications workload is decreasing as less coordination is necessary to achieve the same or greater degrees of control reliability. This appears to indicate that a manual implementation concept could be both practical and feasible.

3.7 FUNCTION 3.7 AIR TRAFFIC CONTROL COMMUNICATIONS FOR HAND-OFF

Purpose

This function is to establish communications with a new ATC control facility after release from the preceding control sector. ATC hand-off is the procedure in which the controller of one sector transfers an aircraft under his control to the controller of another ATC control sector. This involves identifying the aircraft, and transferring all important control information. For the aircraft crew, this involves receipt of a new frequency, release from the original operating frequency, initial contact with the new control sector, verification of position, and provision of any other requested information.

The Air Traffic Control structure is complex, and is divided into sectors which coordinate the movement of air traffic within the system. In the early days of aviation the control sector boundaries represented large blocks of time, and there was no problem of repeated frequency shifts. However, with today's subsonic carriers and especially with future supersonic aircraft these sectors are not realistic. Since modern aircraft pass quickly through several control sectors, compliance with the old communications requirements results in heavy communications tasks.

Current Jet Operational Requirements and Constraints

In a typical scheduled flight an aircraft crosses several control sectors and is required to maintain coordination with each of them so that information can be conveyed in a timely fashion and the aircraft can be under constant radar surveillance.

Current Jet Implementation Concepts

As an aircraft enters a new area of control, the ATC controller from the previous control sector clears the aircraft from his frequency and instructs the crew to contact the next facility on a given frequency. Once the new facility controller has identified the aircraft and its route of flight, there are usually no further requirements for communications until the aircraft is ready to enter still another area of control at which time new hand-off instructions would be provided.

SST Potential Operational Requirements and Constraints

Supersonic aircraft, traveling at 30 miles per minute, would traverse control sectors rapidly, and if required to establish contact with them all, would be overwhelmed with communications. Fortunately, the ATC structure is changing to handle this coordination problem. Although current distances between reports are not realistic for the SST, changes are already being incorporated into ATC procedures which will alleviate this situation and keep control communications down to a minimum.

Feasible Automated Implementation Concepts for SST

The advent of the SST will bring about new ATC concepts and a completely automatic system that will permit automatic hand-off and ground controlled frequency changes of the aircraft's equipment. Thus the automatic system will fulfill the requirement to change frequencies, make initial contact, establish radar contact, pass along position information, and acknowledge instructions. These are routine communications which currently clutter radio frequencies. In addition, a form of SELCAL (selected calling) will eliminate the present need to continually monitor all communications.

With the completely automatic system envisioned for the SST, the crew will be able to monitor other parameters of flight and concentrate efforts on obtaining an efficient and economical SST flight, rather than worrying about control communications. The crew will still be responsible for insuring that the data link equipment is functioning normally, and that control information is conveyed as required.

In the event of malfunction, the crew would in all likelihood experience workloads comparable to those in today's operations. ATC requires the same information whether it is transmitted by voice communications or the automatic system. Automatic data is faster, relieves congestion on over-crowded frequencies, and can be fed into ground based data processors for easy display.

Feasible Manual Implementation Concepts for SST

The use of VHF/UHF voice communications, as in today's operations, would serve to fulfill hand-off requirements in the event of malfunction of the automatic systems. The crew's responsibility would be to comply with ATC controller instructions and to convey any requested information.

3.8 FUNCTION 3.8 ENROUTE ATC COMMUNICATIONS

Purpose

This function provides informational flow as necessary throughout the cruise portion of the flight so that ATC can maintain safe and expeditious flow of air traffic. These communications consist of such information as position of the aircraft in three-dimensional space, requests for changes in original clearances, unpredicted weather phenomena, and non-routine information. The crew also requires information concerning other traffic, amendments to clearances, unforecasted weather and anything else which might affect the flight.

Current Jet Operational Requirements and Constraints

An aircraft operating within the Air Traffic Control structure is required to maintain informational flow with ATC to optimize coordination. With the advent of jet aircraft, communications during the enroute portion of the flight started to become quite heavy. The small sectors of control coupled with the faster aircraft speeds created tremendous communications workload. New procedures have reduced the communications necessary, but the basic requirement to supply information as requested still exists.

Current Jet Implementation Concepts

The VHF/UHF voice communications and the transponder beacon are the methods of providing the coordination necessary during enroute portions of the flight. Sectors of control for high altitude subsonic jets have been expanded, and scheduled reporting points have almost been completely eliminated. In the event some conflict arises, or information needs to be passed (e. g., pilot observed weather phenomena), voice communications are used.

SST Potential Operational Requirements and Constraints

The means of communications available and the types of information needed by the SST crew will differ slightly from those on current jets. Additional information will also be required. For example, the SST's sensitivity to weather, and the ever-prevailing problem of sonic boom generation makes timely weather data essential for the efficient accomplishment of the SST profile. Although some data will be internally generated by sensors, there will be a need for other parameters best conveyed via the communications link.

Feasible Automated Implementation Concepts for SST

Although the need exists for increased informational flow, the implementation concepts envisioned seem to forecast a lighter crew workload. Automatic data link with a printer, selected call-up, and ground initiated frequency shifts will relieve the crew of many of the routine tasks performed by today's crews. The crew's main function will be to monitor the automatic system and insure that proper informational flow is maintained. The use of the coded transponder beacon will furnish the ATC controller with most of the information he needs to provide safe and expeditious control. In most cases few if any voice communications will be necessary.

Feasible Manual Implementation Concepts for SST

It appears that the use of VHF/UHF voice communications for fulfilling the enroute ATC requirements is feasible, although because of increased workload this might require a larger crew.

As the aircraft operates within the enroute portion of the automated ATC environment, various functions may occur. Some of these are shown in Figure 21, and include such things as revisions to clearances, let down instructions, and hand-off instructions.

These control consoles indicated are:

Console 13: Flow control planner coordinates traffic in the terminal area.

Console 14: Enroute planning controller detects conflicts within an area and resolves them.

Console 15: Enroute controller within a new control sector.

Console 18: Enroute controller within subsequent control sector.

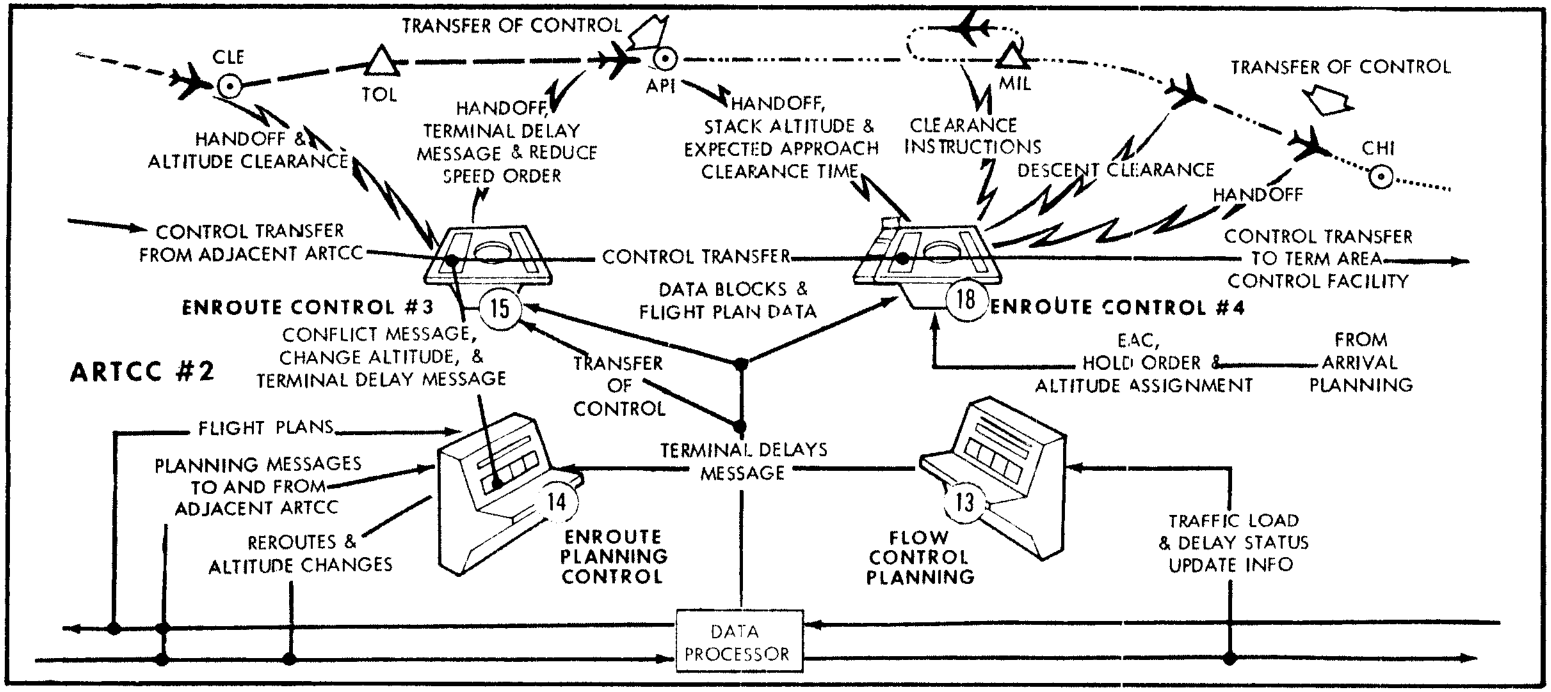

Figure 21. Enroute operation (taken from Reference 23)

3.9 FUNCTION 3.9 INTERCOM ANNOUNCEMENTS

Purpose

This function entails keeping the passengers informed of the progress of the flight and of any noteworthy highlights. The frequency of such communications is primarily dependent upon the Captain, company policies, and Federal regulations. Except for safety information these communiques are scarcely a passenger requirement. Such communications began in the early days of aviation when people were quite apprehensive about flying. To alleviate these tensions, the crew tried to establish rapport by keeping passengers aware of the weather, the route of flight, landmarks, and so forth. The SST will introduce a new era of aviation to the public, and once again such rapport may be important in quieting apprehensions. Passengers will want to be advised of safety procedures and characteristics of the flight profile.

Current Jet Requirements and Constraints

For the most part, intercom announcements are limited to items of interest and safety. The cockpit crew, or in some cases the cabin attendants, communicate any required information to the passengers. The following regulations apply:

FAR 121.571, ref. 11: (Similar to ICAO Regs. 4.2.8.1 and 4.2.8.2, ref. 12)

Briefing passengers; extended over-water flights.

> (a) Each certificate holder operating an airplane in extended overwater operations shall ensure that all passengers are orally briefed on—
>
> (1) The location and operation of emergency exits;

(2) The location and operation of life preservers, including a demonstration of donning and inflating a life preserver; and

(3) The location of liferafts.

(b) The certificate holder shall describe the procedure to be followed in the briefing in its manual.

(c) If the airplane proceeds directly over water after takeoff, the briefing on locations of life preservers and emergency exits must be done before takeoff, and the rest of the briefing must be done as soon as practicable after takeoff.

(d) If the airplane does not proceed directly over water after takeoff, no part of the briefing has to be given before takeoff but the entire briefing must be given before reaching the over water part of the flight.

ICAO Reg. 4. 2. 8, ref. 12:

Passengers.

An operator shall ensure that passengers are made familiar with the location and use of:

a) safety belts;

b) emergency exits;

c) life jackets, if the carriage of life jackets is prescribed;

d) oxygen dispensing equipment, if the provision of oxygen for the use of passengers is prescribed; and

e) other emergency equipment provided for individual use.

Current Jet Implementation Concepts

Subsonic carrier crews use the public address system to greet the passengers, advise them of any safety instructions, and point out any highlights of the flight. Once the initial remarks have been made, cabin attendants instruct the passengers in the use of any safety equipment or procedures.

SST Potential Operational Requirements and Constraints

The SST will be a new aircraft operating in a new environment. The public will want to know as much as possible about the flight and the aircraft environment. Passengers will be experiencing more restraints than on current carriers and will want to be reassured about their safety. Current requirements will continue into SST operations with the added need for more complete information.

Feasible Automated Implementation Concepts for SST

Since one of the main purposes of this function is to establish a relationship between the passengers and the crew, it does not appear feasible to think in terms of an automatic implementation concept. Therefore, current operations would be continued, at least with regard to equipment.

Feasible Manual Implementation Concepts for SST

As in current operations, the crew will be required to inform passengers of anything that might be of interest. Any information which would help to alleviate passenger apprehension should be conveyed at the appropriate time (i. e. , during climb-out, transonic acceleration, descent, etc.). These detailed communications will be particularly important in the initial SST operations when the public will be curious about the SST characteristics and the new operational environment.

Although this type of communication is beneficial to airline-passenger relationships, it is a non-essential function. Obviously, the SST could depart on a scheduled flight, complete its profile, and arrive at its destination without any intercom announcements. The operation of the system would be unaffected. It is not anticipated that the SST crew will be required to increase concern for this area of communications. The intercom-public address system will continue to be used for most such informational transfer, although reading matter might also help to stimulate passenger interest and confidence.

3.10 FUNCTION 3.10 ENROUTE COMPANY COMMUNICATIONS

Purpose

This function is the coordination and informational flow to the company for use by management in scheduling and other decisions. Information concerning operating efficiency and deviations from the scheduled profile is also conveyed.

The main purpose of ATC communications is the safe and expeditious flow of air traffic, and as a result it constitutes the majority of communication activities. Company communications are used to gather operational data and to anticipate changes in any scheduling. Accordingly, they make up a small portion of the communications workload.

Current Jet Operational Requirements and Constraints

Airline policies and standard operating procedures dictate when and what kind of communications are necessary to fulfill requirements. Management often needs to make timely decisions based upon information provided by aircraft crews.

In current operations at least the following company communications are necessary: (1) immediately after takeoff the time off and the fuel on board must be reported; (2) flight watch reports may be required, and estimates to subsequent reporting points; (3) terminal area communications with the dispatcher are necessary to find out about weather in the terminal area, and for reporting ETA (estimated time of arrival) and fuel. Any change in the alternate would also be discussed with the dispatcher; and (4) after landing and being cleared off the runway, the crew switches to company gate control for a gate assignment.

Current Jet Implementation Concepts

The crew's responsibility is to convey information as necessary, and to insure that the company is kept advised of any non-scheduled performance (e. g., diverting to an alternate, non-routine performance of some system, etc.). HF voice communications are used in current operations to fulfill the requirement for enroute company communication. In most cases, a separate piece of equipment is fitted with a selected calling (SELCAL) feature which eliminates the need for the crew to continually monitor company frequencies.

SST Potential Operational Requirements and Constraints

It would appear that with the advent of SST operations, management will require closer coordination with airborne crews to insure economy of operation. This may mean that either more, or lengthier communications will be required. In particular, communications coordination will be required with maintenance so that turn around time can be kept to a minimum.

Feasible Automated Implementation Concepts for SST

There is the possibility that the company can utilize a form of ground air data link to obtain routine information, and the selected calling voice communications to pass non-routine information, in much the same manner envisioned for normal ATC communications. It has also been suggested that much of the profile generation information be processed by company computers and conveyed via data link to the aircraft. The aircraft would receive and process the raw data to obtain an optimum flight profile.

All indications seem to point to an increase in informational flow between the company and the airborne aircraft during all phases of the flight profile. However, it is also evident that the majority of this information will be carried via automatic communication channels. Coded interrogation signals will initiate a "data dump" from the aircraft's memory core. Non-routine information will be transmitted via print-out or selected calling methods.

Feasible Manual Implementation Concepts for SST

Operations similar to current techniques will be used to manually implement this functional performance.

3.11 FUNCTION 3.11 ATC COMMUNICATIONS FOR DECELERATION/INITIAL DESCENT

Purpose

This function is the receipt of information and clearances from Air Traffic Control for coordination of the deceleration and supersonic descent of the SST. Prior to starting this phase of operations, it would be beneficial if clearance straight through to touchdown is obtained. This assurance will be predicated on the traffic situation, the current weather parameters, and the performance characteristics of the particular aircraft.

Current Jet Operational Requirements and Constraints

The basic requirement for subsonic operations is that clearance be obtained for departing cruise altitude. As aircraft near their destination, begin to leave cruise altitudes, and are funneled towards the final landing, more stringent control must be placed upon aircraft maneuvers. It must also be remembered that jet aircraft operate more efficiently at higher altitudes; therefore, all delays should be absorbed while the aircraft is still at altitude.

Current Jet Implementation Concepts

As the aircraft approaches its terminal area, it will require a descent clearance, an approach fix, and an expected approach clearance time (EAC). These procedural parameters are obtained by a clearance from ATC. Current jet crews utilize normal VHF/UHF communication channels to obtain this information and to coordinate their maneuvers with other ATC traffic.

SST Potential Operational Requirements and Constraints

As in current operations, the need will exist to coordinate passage through various altitude layers during the descent and deceleration. This coordination may need to be more rigid if the SST is less maneuverable than current aircraft while it is decelerating, and because care must be taken to control possible sonic boom overpressure generation. There will also be the requirement to consider fuel consumption of the SST during subsonic operations. If at all feasible, all delays should be absorbed prior to descent clearance.

Feasible Automated Implementation Concepts for SST

In this phase of the flight profile there will be no new equipment to perform the communications function. The basic ground-air data link will continue to furnish all routine data and information, while non-routine and emergency data will be conveyed via voice communications. Under completely ideal conditions the pre-flight filed flight plan in its final clearance form will continue to be in effect. As the destination is neared, the descent would be initiated automatically in accordance with the original clearance. Only in those situations where revisions were necessary would the crew be required to feed new clearance data into their navigational equipment.

Feasible Manual Implementation Concepts for SST

The crew's utilization of VHF/UHF voice communications will be sufficient to fulfill requirements of this function. In this mode of operation, the crew's performance will be similar to that on current aircraft. The crew will be responsible for obtaining a descent clearance, and any other clearance information necessary for them to complete the subsequent phases of flight in an optimum manner.

3.12 FUNCTION 3.12 ATC APPROACH CONTROL COMMUNICATIONS

Purpose

This function establishes coordination and informational flow with the facility controlling air traffic in the terminal control area (i. e., the area containing the destination terminal).

The area in and around air terminals is highly saturated with both departing and arriving aircraft. For this reason control and coordination requirements become very strict as one nears the destination terminal. Informational flow must be timely, both to the controller and to the air crew, to resolve any traffic conflicts which might arise.

Current Jet Operational Requirements and Constraints

The number of communiques in this phase is high because of high traffic density terminal areas, and the coordination necessary to provide sequencing and spacing for both arriving and departing aircraft. The crew needs to obtain specific control information (e. g., holding instructions, expected approach, weather, etc.). The ATC controller needs confirmation that the aircraft is complying with instructions (i. e., holding as instructed, commenced approach, maintaining specified altitudes, etc.). A large amount of information must be exchanged between aircraft and controller. In addition, there are numerous aircraft in the terminal area, and they often use the same frequencies. The congestion problem which exists as a result, should be evident.

Current Jet Implementation Concepts

As aircraft approach the terminal area, the enroute ATC controller usually initiates a hand-off (see Function 3.7) to the approach control facility handling the destination terminal. Once contact has been established, a clearance is usually issued which contains all necessary approach information for the crew. The crew usually indicates their compliance with instructions to approach control.

Any amendments to the clearance are also communicated. These communications continue until the aircraft has completed all approach maneuvers, and has been turned onto final approach. At that time a control hand-off is made to local control.

SST Potential Operational Requirements and Constraints

The SST may be very sensitive to unscheduled delays in the subsonic environment. Holds and rerouting will need to be kept to a minimum. Other than the requirement for terse and precise procedures and communiques, all current requirements should exist in the SST era.

Feasible Automated Implementation Concepts for SST

The use of the data link, printer, and transponder beacon will assist in making control decisions, and maintaining appropriate separations. However, it does not appear feasible at this time to think in terms of complete automatic implementation of this function.

Feasible Manual Implementation Concepts for SST

The FAA report, "Design for the National Airspace Utilization System," (ref. 23) indicates that aircraft in the approach phase of flight will be involved in communications concerning approach clearance, hand-off, terminal route, descent clearance, runway and terminal weather, speed reduction, and many other factors. Most of these communiques must be considered as non-routine (i. e. , not readily handled by data link) and would be conveyed via voice communications as in current operations. However, it does not appear that there will be an increase over current communications control. In general, current subsonic aircraft crews indicate that communications, although bothersome, are relatively unrestrictive in the approach phase of flight.

It is anticipated that the SST crew involvement will be less than that currently, and that the workload will decrease slightly, primarily due to the new equipment and procedures which will be utilized by ATC facilities.

The same type of information will be needed for the SST as for current aircraft, but because of greater internal coordination conflicts will be resolved earlier which will preclude having to make amendment communiques. Tighter control and coordination should decrease the amount of necessary communiques and thus the workload for both the controller and the crew.

An aircraft operating within the automated ATC environment will be handled in a manner similar to that depicted in Figure 22 as it enters the terminal control area.

Those control consoles shown include:

Console 16:	Marshalling controller's console where landing times are assigned.
Console 17:	Arrival planning controller's console where hold orders and altitudes are issued.
Console 19:	Sequence controller's console where initial approach instructions are issued.

Console 20: Final spacing controller's console where where final approach instructions are issued.

Console 21: Local controller's console where landing clearance is issued.

Console 22: Ground controller's console where taxi instructions are issued and the flight plan is closed.

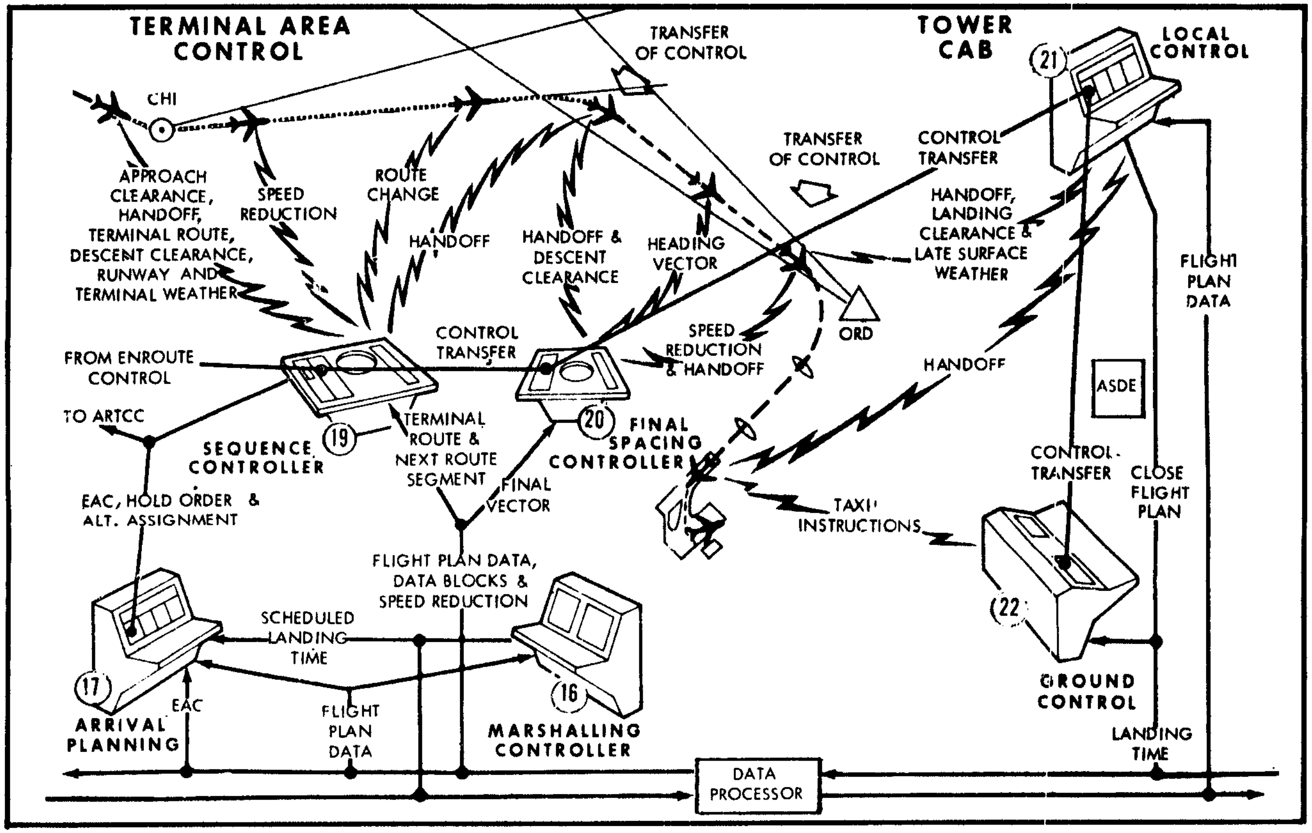

Figure 22. Arrival terminal operations (taken from Reference 23)

3. 13 FUNCTION 3. 13 FINAL APPROACH COMMUNICATIONS

Purpose

This function provides coordination and informational flow to the ATC controller during the final approach to landing, to insure safe spacing, sequencing, and landing clearance. Final approach communications are usually exchanges concerned with that portion of the flight in which the aircraft has intercepted the localizer on the ILS final approach course, and communications control has been handed off to the local controller. Final approach communications continue until such time as the aircraft has landed and taxied clear of the operational runway.

Current Jet Operational Requirements and Constraints

During the later portions of the approach to landing, both the crew and the ATC controller require certain information. The crew needs assurance that the runway is clear, information concerning runway conditions (e. g. , runway surface weather conditions), and a landing clearance. The controller requires information about the aircraft's configuration (e. g. , landing gear extended), and any information about missed approach. Current procedures in the final approach phase have been described by the FAA (ref. 23) as follows:

> ...After the pilot has turned on final approach and reduced to final approach speed, the final spacing controller executes a control transfer to local control.
>
> Local control clears the flight to land and issues present surface weather information to the pilot. After the aircraft has landed and turned off the runway, the local controller executes a control transfer to the ground controller who issues taxi clearance. ...

Current Jet Implementation Concepts

In current operations, VHF/UHF voice communications are used to convey all required information both to the crew and ATC controller.

Feasible Automated Implementation Concepts for SST

In this phase the crew is concerned with the shifting of frequencies which accompanies hand-off from one controller to another, landing clearance, and the prevailing surface weather. As in current operations, the increased traffic density within the terminal area gives rise to increased communications. It does not appear that use of transponders or the air-ground data link will decrease the workload of either the aircrew or the ATC controller. The types of communications required appear to be outside the routine classification and thus voice communications will be required.

Feasible Manual Implementation Concepts for SST

It appears that the communications activity required of the crew during final approach will not change appreciably from current operations with the advent of SST.

3. 14 FUNCTION 3. 14 DESTINATION GROUND HANDLING COMMUNICATIONS

Purpose

Upon completion of landing rollout, this function provides the necessary coordination and exchange of information required to move the aircraft from the end of the operational runway to its designated unloading area, and then insures compliance with company policies in unloading passengers and deactivating the aircraft system. In general, the communications tasks will involve ATC ground control communications, company communications with the gate assigner and ground handling crews, as well as intra-crew and crew-passenger communications.

Current Jet Operational Requirements and Constraints

A matter of prime concern of the major air terminals is the safe and expeditious movement of aircraft and other vehicles along the taxiways, ramps, and parking areas of the facility. To fulfill this requirement, coordination must be established between the aircraft crew and the ground controller. Instructions in the form of a clearance are passed to the aircraft, once the ground controller has been informed of its assigned gate. The primary reason for ATC communications is the receipt of appropriate taxi clearance and instruction. This particular aircraft-ATC coordination has been described as follows (ref. 23):

> . . . After the aircraft has landed and turned off the runway, the local controller executes a control transfer to the ground controller who issues taxi instructions.

Next in importance are those company communications concerning dispatcher coordination with ground handling crews. The crew obtains an unloading area from the gate assigner. Once the unloading area has been assigned and any other urgent information is conveyed, remaining communications are with the ground handling crew regarding parking the aircraft and deactivating the system.

Communications and coordination tasks involving system status increase in the cockpit right after the landing. Post landing checks, pre-deactivation equipment set-ups, systems evaluations for possible maintenance reports, and deactivation procedures all require intra-crew communication and coordination to some degree.

Also during this final phase of the flight information concerning safety or items of interest must be conveyed to the passengers, e. g., local time and weather.

Current Jet Implementation Concepts

The tasks performed by the crew will be very similar to those described in Function 3. 1 Ground Handling Communications as will the implementation concepts, requirements and constraints. Initially, the crew contacts the company dispatcher to receive a gate assignment, conveys this information to ATC ground control via VHF/UHF voice communications and receives a taxi clearance and instructions.

Most of the cockpit coordination needed to perform system shutdown procedures is handled by direct voice communications. For those areas outside normal voice range, intercom equipment is utilized.

The crew informs the passengers about continuing to observe the fasten seat belts and no smoking signs. Further amplifying remarks are usually communicated by the flight attendants. The flight attendants remind the passengers about hand carried articles, procedures of the particular terminal, and any other noteworthy items.

Once the aircraft has been parked, external power attached to the aircraft, and the engines deactivated, ground handling communications are considered complete. It is essential that the aircraft crew be in communication with the ground handling crews during power plants shut down, in the event of some malfunction, (e. g. , fire). For the most part, communication required during ground handling operations at the destination is comparable to communications during the initial ground handling operations.

SST Potential Operational Requirements and Constraints

It would appear that no new areas of concern will be generated by the introduction of the SST into commercial aviation. The only possible exception to this might be different coordination due to potentially restricted visibility from the SST cockpit.

Feasible Automated Implementation Concepts for SST

There does not appear to be a need for automating this particular function. Performance will be quite similar to current operations, and the equipment used will likewise be similar.

Feasible Manual Implementation Concepts for SST

All operations will be quite similar to current operational procedures, and in general the means employed will be VHF/UHF communications (ATC communications), HF communications (company communications), intercom (intra-crew and ground handling), public address (crew-passenger).

ATC communications will be similar to current operations. However, it is likely that because of the decreased visibility characteristics of the SST, more coordination will be necessary so that the SST will clear all obstructions. This may mean that the ATC communications workload will increase in this phase of the flight. (See the description of taxiing, Function 5. 21, to find the requirements of the crew in regard to obstruction clearance information.)

As was stated in the description of Function 3. 1, many of the lengthy system checks will be accomplished via the on-line computer, which will also display a checklist for crew to cross-check. The computer system check should decrease the workload associated at present with procedures verification, preclude the use of lengthy checklists, and decrease intra-crew communication requirements. Crew-passenger communications and the coordination with ground handling crews should remain the same as in current operations.

3. 15 FUNCTION 3. 15 VISUAL TRAFFIC VIGILANCE

Purpose

This function provides information concerning any visual sightings of other air traffic which might have some bearing on the safety or integrity of the SST. Generally speaking, the crew is responsible for clearing obstructions when operating on the ground, and for being constantly alert for conflicting traffic while airborne. Although ATC provides separation for all aircraft under control, the crew is not relieved of the responsibility to scan the area in the proximity of the flight path for any possible conflicting traffic.

Current Jet Operational Requirements and Constraints

The increase in traffic density has created the requirement for constant vigilance to maintain safe separation distances. Even on the ground, the requirement for obstruction clearance makes it necessary for the crew to maintain inspection of the area in close proximity to the aircraft. The following specific regulations apply:

FAR 91. 65, ref. 13: (Similar to ICAO Reg. 3. 2. 1, ref. 14)

Operating near other aircraft

(a) No person may operate an aircraft so close to another aircraft as to create a collision hazard.

(b) No person may operate an aircraft in formation flight except by arrangement with the pilot in command of each aircraft in the formation.

(c) No person may operate an aircraft, carrying passengers for hire, in formation flight.

ICAO Reg. 3. 2. 2. 5, ref. 14:

Taking off.

An aircraft about to take off shall not attempt to do so until there is no apparent risk of collision with other aircraft.

ICAO Reg. 3. 2. 6. 1, ref. 14:

Operation on and in the vicinity of an aerodrome.

An aircraft operated on or in the vicinity of an aerodrome shall, whether or not within an aerodrome traffic zone:

a) observe other aerodrome traffic for the purpose of avoiding collision;

b) conform with or avoid the pattern of traffic formed by other aircraft in operation;

c) make all turns to the left, when approaching for a landing and after taking off, unless otherwise instructed;

d) land and take off into the wind unless safety or air traffic considerations determine that a different direction is preferable.

Current Jet Implementation Concepts

Even though Air Traffic Control procedures endeavor to remove all possible conflicts through the use of radar and manual separations, aircraft not under ATC control can cause conflicts. As a result, the crew is responsible for being constantly vigilant. The amount of crew involvement will vary among airlines and crews. Generally speaking, though, any time other tasks permit, a constant scan is maintained by all crew members. It should be pointed out that this is becoming an increasingly more difficult task, because airspeeds are increasing (closing rates are very high) and visibility in the environment of the subsonic jet is such that aircraft are difficult to see.

SST Potential Operational Requirements and Constraints

The basic jet requirements will continue to exist in SST operations. The safety of the aircraft will dictate that the crew maintain all possible vigilance with regards to ground obstructions and airborne traffic. It appears that ATC is becoming more stringent, with the result that all traffic which might influence flight safety should be under their control. This should reduce the involvement of the crew in maintaining such vigilance.

Feasible Automated Implementation Concepts for SST

At the present time there are no strongly advocated concepts which use a completely automatic implementation. Some experts have advocated an automatic anti-collision system, but even this may not be feasible for the aircraft during Mach 3 flight.

In general, the major vigilance problems will exist while the SST is operating in the subsonic regime and within areas of high traffic density. A purely manual concept is advocated to supplement the control provided by ATC.

Feasible Manual Implementation Concepts for SST

As in current operations, all available eyes will be scanning the vicinity of the aircraft during ground operations, and the skies for possible conflicting traffic while airborne. This means that the crew will continue to have final responsibility for the aircraft's safety, even though ATC is providing all possible separation through their procedures and equipment.

ACTIVITY 4.0 POWER PLANT OPERATION

PURPOSE

The requirements placed upon the SST pose some monumental problems for power plant design personnel. The power plant system must be able to maintain a 400,000 to 500,000 pound aircraft at speeds of Mach 3.0, and altitudes of 70,000 to 80,000 feet. However, they must also be capable of operating economically in the subsonic regime and environment, and operating outside of the critical sonic boom overpressure envelope.

The specific engine design has not yet been selected, and as a result the exact crew involvement cannot be specified. However, regardless of the engine design, there will be only minor differences in crew roles, so that for all practical purposes the functional descriptions on the following pages will portray the relationships of the crew in utilizing the power plant system.

Those factors which will influence the final design choice include such things as noise problems (both ground noise and sonic boom), specific fuel consumption (SFC), size, weight, and acceleration properties. These are problem areas which must be solved by the engine designers.

Those factors which will influence the crew will be reliability of the basic system, adequate thrust/weight capabilities, and controllability of performance. All these factors will also pertain to the various back-up subsystems (e.g., fuel, lubrication, heat transfer, etc.). The type of engine to be used (i.e., turbofan or turbojet), the need for optimizing inlet duct and exhaust nozzle configurations, and the need to control the output while operating at maximum RPM, will all introduce new procedures into the cockpit of the SST.

Without question the SST power plant must dwarf present subsonic engines. Assuming gross takeoff weights of approximately 400,000 pounds and four engines per aircraft, each SST engine would develop a sea-level thrust of 40,000 to 55,000 pounds. Diameter of a typical engine will be such that a man could actually stand up inside it (5-6 feet), and its overall length could easily be more than 20 feet, a good part of this accounted for by inlet-outlet geometry.

In a sense, the SST power plant designer will be called upon to build two engines in one--a subsonic engine and a supersonic engine. As a subsonic mechanism, the SST engine will operate as a straightforward compressor-turbine gas generator. As a supersonic mechanism, the power plant will not only exist as a gas generator, but will have to handle extraordinarily large masses of air at extremely high velocities, pressures, and temperatures.

The solution to this particular problem is discussed in Activity 6 which deals with the Inlet Nozzle Configuration. Basically, the inlet must be reconfigured in order to decelerate the incoming airflow so that the engine can accept it. Once energy has been added to the airflow, the outlet nozzle must be configured so as to control gas expansion and eliminate power losses resulting from uncontrolled expansion to ambient conditions.

Conventionally, throttling of an engine is considered to be a function of fuel flow and engine RPM's. In the SST engine, however, the engine may be an automated variable in an integrated inlet-engine-outlet schedule. And, optimum design may require that engine speeds and airflows be kept constant at aircraft speeds above Mach 1.5, so that thrust variations would be accomplished by changing the specific thrust (thrust per pound of airflow).

CURRENT JET OPERATIONAL REQUIREMENTS AND CONSTRAINTS

Regulations stipulate power plant performance under both normal and non-routine conditions. These regulations pertain primarily to the basic system design, and must be complied with if the aircraft is to be certified. The crew is affected to the extent that any performance dictated by the rules must be within the capability of the crew.

Another area of concern to the crew is the control of both ground and airport noise. At present, no definite sound level has been put forth as acceptable, although the value of 112 Pndb at 3.5 miles is utilized in many cases. This noise factor influences the design of the power plant and also the operational performance of the crew. Certain ground areas must be designated as "high power turnup" areas. Also, power reductions after takeoff are being introduced into procedures in an attempt to stay within the 112 Pndb level at 3.5 miles. These power reductions occur in that critical area right after takeoff, when the aircraft is heavily loaded and probably initiating a turn to comply with ATC procedures. Accompanying these power reductions are attitude readjustments which can introduce discomforting negative g loading on the aircraft and its passengers.

CURRENT JET IMPLEMENTATION CONCEPTS

Power plants are handled manually in current operations by manipulating the throttles. The throttle provides linkage through an automatic fuel control, which controls the engines. The crew operates the throttles to obtain a certain RPM and fuel flow which in turn results in a certain thrust output. Thrust output coupled with the changes in attitude made by flight control activities, results in specific airspeeds and aircraft states (e.g., climbing, descending, level, etc.).

Thrust can also be used to decelerate the aircraft by changing the direction of the thrust using thrust reversers. This is an extremely useful mechanism for providing acceptable landing rollout capability, aborted takeoff capability, and if necessary, airborne deceleration. It must be noted that to obtain FAA certification, aircraft must be able to come to safe stops without the use of thrust reversers. Once certified the thrust reversers extend the capabilities of the aircraft and provide a larger safety margin.

The crew's responsibility is to utilize the power plants as required, while staying within engine performance envelopes. Safety, passenger comfort, and economics should all be considerations in the utilization of the power plants. The crew should follow as closely as possible,the operating procedures set up for the specific aircraft with regard to take-off, climb, cruise, approach and landing speeds.

SST POTENTIAL OPERATIONAL REQUIREMENTS AND CONSTRAINTS

The SST will be operating in a new environment, and for a major portion of the flight, in a new speed regime. For those portions in which it is operating with subsonic carriers it will need to conform to requirements and constraints set up for these carriers.

In the new areas, new requirements and constraints exist which will greatly influence the performance of the SST crew. One consideration throughout the entire profile is noise (i. e., ground noise and sonic boom overpressures). For the present, the SST will have to conform to a flight profile which limits the overpressures to 1. 5 psi throughout the flight, with possible 2. 0 psi excursions during the transonic acceleration. Since the SST will be appreciably affected by variations in temperature, another area of concern will be the economic effect of variations in predicted weather parameters on operations.

The new flight regime will introduce new concepts in power plant operation and control. As the speed of the aircraft increases, even at maximum RPM the engine would be unable to accept the high speed compressed airflow. This introduces a requirement for an inlet duct system which can be varied to decelerate the airflow and make it acceptable to the engine. Because the engines would be operating at maximum RPM in the supersonic regime, varying RPM to control the power plant output is not feasible. Therefore, fuel must be controlled to obtain necessary requirements. Finally, the expanding gases leaving the engine must be controlled if optimum performance is required. Unrestricted expansion results in sizeable power losses. For this reason an inlet duct and exhaust nozzle reconfiguration system is a necessary additive to power plant operations.

FEASIBLE AUTOMATED IMPLEMENTATION CONCEPTS FOR SST

During ground handling operations the crew will vary the output of the power plants in much the same way as in current operations. However, once airborne, sophisticated automatic throttle systems coupled to either an on-line computer, or to an "optimum profile generator" will be utilized to realize system energy requirements. This concept varies with each particular flight phase, and is discussed in each of the functional descriptions. In most cases the equipment utilized will be the same, with only crew involvement changing.

The crew's responsibility in the manual areas of operation will continue to be the same as it is currently. In those areas of automatic operation, the crew's task will shift to that of primarily a monitor, but crew responsibility will continue to be the same.

Because power plants are sensitive to many rapidly changing parameters in order to optimize economic considerations it may be necessary to automate the throttle system. Automation in this area will relieve workload and allow the crew more time to evaluate and manage the overall flight. New instrumentation will be necessary to display the current situation to the crew in enough definition to allow them to override the automatic system without delay.

FEASIBLE MANUAL IMPLEMENTATION CONCEPTS FOR SST

Manipulation of the fuel control will be the means provided the crew for controlling the output of the power plants. In most respects the concept is similar to current operations. The crew would be responsible for varying the throttle so as to maintain sufficient power outputs for whatever maneuver required.

An automatic concept is being advocated chiefly for economic reasons. The SST will be "fuel sensitive," and every effort should be made to optimize performance in this area. Without automatic operation, the crew would have to evaluate a myriad of parameters, and then vary the output of the power plants to meet requirements. This can result in large fuel consumption rates and less economical operation.

4.1 FUNCTION 4.1 ENGINE START AND CHECKOUT

Purpose

This function is to ready the power plant system, coordinate with ground handling crews, and activate the power plant.

Current Jet Operational Requirements and Constraints

Before starting any engines, it must be ascertained that all procedural steps have been taken which of necessity precede engine activation. This includes clearing the external area in the vicinity of the aircraft, and completing any required checklists.

Current Jet Implementation Concepts

In current operations, a checklist is utilized to insure that the procedural sequences have been followed. Once these have been completed, and the engine start procedures initiated, performance data must be monitored to insure that the engine starts normally. Such malfunctions as cold starts, hot starts, or fires must be anticipated so that the power plant system will not incur damage. If none of these occur, and the RPM, EGT, fuel flow, pressure ratio, and oil pressure are within limits, then the engine start has been performed.

It must be remembered that the power plant system provides energy to many of the critical subsystems. The electrical generators, the turbocompressors, and many of the pressure pumps are driven by the power plant. Thus in many cases it will be necessary to have the power plants operating before subsystem status can be determined. Although external power may be supplied to the aircraft, at times it is insufficient to supply the needs of all of the subsystems.

SST Potential Operational Requirements and Constraints

It does not appear that there will be any modification to current requirements with the entry of the SST into commercial aviation.

Feasible Automated Implementation Concepts For SST

The SST will require a more precise procedure than current jets, so that the time involved in the ground handling phase will be held to a minimum. Many of the system checkouts will be via an on-line computer which will have a "go" or "no go" display. However, no changes are anticipated in the actual performance required in power plant activation and checkout (i.e., the power plants will be manually activated).

Once the system has been activated, and the external power sources have been removed, the entire system must be checked to determine if the power requirements of the entire system will be met. This particular phase of the flight should not change with the advent of the SST. As in current operations, the crew will follow certain procedural sequences to ascertain that the power plant is ready for activation. Then, in conjunction with the ground handling crews who provide the aircraft with external electrical power and a compressed air source, the crew will start the power plant system. During start, indications of RPM, fuel flow, and then EGT will be the important parameters to monitor. Once these instruments indicate a suitable start, the oil pressure will also be monitored.

The crew will be responsible for clearing the area in the vicinity of the aircraft (even if the ground crew actually clear the area), making sure the aircraft is set-up for engine start, and then insuring that engine start procedures result in a normally functioning system.

Even while utilizing a machine to perform some of the checkout functions, the crew will fall back on the use of a start checklist, to insure compliance with procedures.

Feasible Manual Implementation Concepts For SST

The only difference in this concept is the set-up and checkout of equipment prior to engine start. This is a time consuming task, and becomes more complex with sophisticated systems. In a purely manual concept, these checks prior to engine start would be performed by the crew utilizing a checklist. The engine start and subsequent checkout would be the same for both concepts.

The crew's responsibility would not change in this situation. However, the restrictiveness of the task would tend to be greater in this manual mode.

4.2 FUNCTION 4.2 THRUST APPLICATION = F(SURFACE SPEED); TAXI

Purpose

This function is to vary the power plants so that sufficient energy is supplied the system to move from the original parking location to any specified ground location (for this case, to the end of the operational runway). The power required will be a function of the gross weight of the aircraft and the desired surface speed consistent with safe ground control procedures.

Since the aircraft is loaded away from the operational runway, it is necessary to move the aircraft from this point, along taxiways to the operational runway. This can be accomplished by towing the aircraft to the end of the runway, or by using the power plants to move the aircraft. This last method is usually the one employed and will more than likely be used with the SST.

For our purposes the aircraft will start with a velocity, $V = 0$, and will be parked in the loading area. Upon completion of the function, it will be on the operational runway, ready for takeoff, and the velocity will again be $V = 0$. The only change which will have transpired will be the movement of the entire system from one ground location to another within the limitations placed on the aircraft by the Air Traffic Control ground procedures.

A major point which must be remembered is that with the SST, any lengthy delays on the ground will result in the consumption of fuel reserves. The power plants which will be ultimately selected for the SST will give optimum performance at altitudes above 40,000 ft. To increase the available payload, and remain within the safety requirements established by the FAA, ground handling time must be reduced to a minimum.

Current Jet Operational Requirements and Constraints

The chief constraints placed on current aircraft during taxi are based on safety. Surface speeds must be consistent with traffic safety.

Current Jet Implementation Concepts

To accomplish the performance required, the engine RPM and fuel flow settings are changed so as to start the aircraft moving. Once momentum has been gained, auxiliary subsystems are utilized to direct the aircraft in accordance with ground handling procedures. The amount of thrust necessary to start the aircraft moving and maintain a safe ground speed, is a function of the throttle setting, which in turn is a direct link through the fuel control to the engine RPM. Thus, the usual procedure is to use certain RPM settings for ground handling.

In current operations, when an aircraft has received clearance to move from its parking area to the end of the operational runway, just enough power is added to start the aircraft moving. This is usually X% for the time necessary to gain some small increment of momentum. Then this is reduced to some Y% RPM to maintain a desired taxi speed. In any case, the position of the throttle will be a function of the desired RPM and will result in a certain fuel flow. RPM and fuel flow can be visually monitored.

SST Potential Operational Requirements and Constraints

Because ground handling time in the SST will be critical, it appears that every effort will be made to insure ATC procedures which will almost guarantee non-restricted ground movement from loading area to the end of the runway.

Poor visibility may make the crew's use of visual cues to estimate taxi speeds impractical. Other means may need to be devised.

Feasible Automated Implementation Concept for SST

This function should not be automated because of many constantly changing variables. The crew is better qualified to assimilate the data and put it to use.

Feasible Manual Implementation Concepts for SST

There are no reasons to suspect that the ground handling operations of the SST will differ radically from current operations. The crew will still be responsible for controlling the system on the ground, and will be responsible for establishing a safe taxi speed. It must be remembered that the taxi maneuver as such is an integrated task, and that the power plants only serve as energy suppliers. Inputs concerning speed, obstructions, and directions are all directed to the flight management function where an evaluation is made and some change is made to the system so that it conforms to a certain pattern. In this sense, power plant operations become a means for performing an integrated task with the entire system.

Manual manipulations of the throttle will continue to be the method for obtaining required energy increases, similar to current procedures. Once the inertia of the system is overcome, a lower RPM will provide sufficient taxi speed. At too great a speed the heavily loaded SST may be difficult to stop.

4. 3 FUNCTION 4. 3 THRUST APPLICATION = F (MAXIMUM POWER); TAKEOFF THRUST

Purpose

This function is to vary the output of the power plants such that a certain acceleration and thus a certain rotation speed is attained which is consistent with the gross weight of the aircraft, atmospheric conditions, amount of usable runway, and requirements established by FAA to insure safety margins in the event of a malfunction of the power plant. The performance usually only involves the initial setting of the throttle, and the monitoring of the resulting performance parameters (RPM, oil pressure, EGT, pressure ratios, and fuel flow). If performance parameters are within the operating envelope, and if the system accelerates in accordance with the pre-planned schedule, no further action is necessary as the rotation speed V_R will be attained. Since the power plants do furnish the energy for the system, an initial velocity, V_1, versus runway remaining is used as a check for the acceleration being developed by the power plants.

Current Jet Operational Requirements and Constraints

None are applicable.

Current Jet Implementation Concepts

Current aircraft power plant systems are sized for takeoff, and as a result, maximum power is utilized then. Thus, the crew merely applies full throttle, and then monitors instrumentation to ascertain that sufficient power is being generated to accomplish the takeoff within prescribed limits.

According to the Boeing 720 Operations Manual (ref. 22):

> Four engine take-off procedures: Prior to takeoff, review stabilizer setting, engine thrust setting, V_1 speed, V_R speed, and required field length for the ambient conditions of the particular takeoff.
>
> Apply takeoff thrust prior to brake release or rapidly accelerate the engines to takeoff thrust as the airplane is turned onto the runway.
>
> During the takeoff roll, monitor engine performance and airspeed indications. Nose wheel steering is used for directional control on the runway until the airspeed has increased to approximately 80 knots, above which directional control is obtained by use of rudder.
>
> At V_R speed, rotate the airplane smoothly to the takeoff attitude, reaching V_2 speed at a height of 35 feet above the runway. If the takeoff is limited by obstacles, do not permit the maximum speed during the takeoff climb to exceed V_2 + 10 knots. Maintain this speed to the height above the runway selected for the three engine level flight acceleration where flap retraction shall be initiated. Accelerate to the final takeoff climb speed and continue climb until reaching 1, 500 feet or obstacle clearance limits have been exceeded. Above 1, 500 feet follow normal enroute procedures.

In current operations ground noise is becoming a larger factor, and many design concepts are being studied to see if these levels can be lowered. However, at the present time, since engines are sized for takeoff, maximum power must be utilized.

SST Potential Operational Requirements and Constraints

Ground noise will continue to play an important factor in the operations of the power plants. Depending upon the final design chosen, noise levels would vary.

A Space/Aeronautics Staff Report (ref. 29) points out that,

> . . . takeoff noise is a particularly troublesome problem. FAA has suggested that noise during takeoff at a point on the ground one statute mile from the departure end of a 10, 500 ft runway (three miles from start of roll) be less

> than 112 PNdb. (PNdb is the "perceivable noise," in which the conventional decibel measure of loudness is corrected to compensate for the varying reaction of the human ear to noise amplitude at different frequencies.)
>
> Engine noise at takeoff is generated by the shearing action between the high velocity jetstream and the surrounding air. By reducing the velocity of the propulsion jetstream relative to that of the surrounding air, noise can be greatly reduced.
>
> An early NASA comparison of various engines in optimum airframes shows that an afterburning turbojet would not reach the acceptable level of ground noise until it has traveled approximately six miles from the start of ground roll. An SST with a straight turbojet engine at full thrust would reach the 112 PNdb level somewhere about four and a half miles. The turbofan engine, on the other hand, would reach acceptable noise level within the required three miles. ...

The other factors which affect the power plant operations in current operations will continue into SST operations.

Feasible Automated Implementation Concepts for SST

At the current time there is no automatic concept being offered to perform this particular function.

Feasible Manual Implementation Concepts for SST

In SST subsonic operations thrust will be controlled via the throttle as in current operations. Jet and SST operations will differ if the SST engines are sized for transitional acceleration instead of takeoff. In this case the high thrust/weight ratios may dictate the use of other than maximum RPM to reduce takeoff noise.

The crew's responsibility will be to insure that the throttles are manipulated to obtain required power, and that power plant performance is normal. With the SST it may also be necessary to operate the power plants so as to reduce noise. Procedurally, the crew would move the throttles to obtain the required RPM. Then as V_1, V_R, and V_2 were attained, the crew would no longer manipulate the throttles.

If less than maximum power were utilized, in the event of a partial power failure (loss of an engine) the crew would add power as necessary to comply with regulations and standard power failure procedures.

Because of the higher acceleration which will be associated with the SST, the decision speed, V_1, should be as low as possible. Outside this, there do not appear to be any other areas of major concern to the crew.

Bateman points out in his description of a hypothetical flight of the SST (ref. 30):

> ... the actual take-off, once cleared, will be slightly difficult because the power available presumably will preclude running up to full power on the brakes. This means that the power will have to be applied after one has started to roll and this will mean a certain amount of time scatter in the application of take-off power. A pleasant problem here possibly might be the setting of take-off power which may be less than the maximum. Normally everybody gets at the throttles and pushes and waits to get off the ground; with the SST we can possibly take off with less than the available power, this depending, of course, on the individual design of the aircraft. Every time we take off we have at least to consider that we may have to abandon it a short way down and the problems here will be slightly different; the acceleration will be much greater than--at least we hope it will be much greater than--the present-day subsonic jets; so the point at which one will need to abandon the take-off will be noticeably earlier. The actual engine failure problem will possibly revolve around the time it takes the pilot to recognize he has a power loss and to take action to remedy this...

4.4 FUNCTION 4.4 THRUST APPLICATION = F (SURFACE SPEED); THRUST REVERSAL

Purpose

This function is to provide a source of braking for the accelerated aircraft through the variation of the power plant output. If for any reason a decision is made to abort the takeoff roll, a means must be provided to do so with safety. In other words, the aircraft must be decelerated to a safe taxi speed in the runway remaining. Brakes will be utilized when the speed of the aircraft is low enough to safely use them. If the braking system alone were used while the aircraft is moving at high speeds, there would be the possibility of blowing out the tires. Thus a means has been provided to reverse the direction of the thrust from the power plant. This reversal will cause a deceleration which will allow the aircraft to attain the required speeds within the surface limits remaining.

Current Jet Operational Requirements and Constraints

With the evolution of high performance aircraft a need was generated for new braking methods. This need was due to high aircraft energy states, and runway length restrictions.

Current Jet Implementation Concepts

In current jet aircraft the jet engine thrust reversing and sound suppression are accomplished by means of a combination unit, which replaces the standard tailpipe. The thrust reverser consists, essentially, of a pair of internal reversing gates or clamshells mounted just aft of the turbine section. When closed by pneumatically-operated actuators, the reversing gates block normal turbine exhaust flow to deflect the gases forward through circumferential cascade vane openings. A reverse thrust lever mounted on each thrust lever provides cockpit control. The engine will return nearly to the idle thrust position automatically in the event that the doors open during reverse thrust operation, or in the event the doors close during forward thrust operation. This prevents the engine from supplying high thrust opposite to the selected direction.

In current operations thrust reversal is a manual function. If acceleration is insufficient, or the crew decides that takeoff should be aborted, the throttle is usually reduced from the maximum RPM setting to the idle RPM position. Then as needed the thrust reverser levers are actuated, and the throttles are again manipulated to give the desired deceleration rate. In selecting a rate of deceleration, safety is the primary factor, followed closely by passenger comfort.

SST Potential Operational Requirements and Constraints

There appear to be no modifications necessary. The SST will be required to have some type of thrust reversing capability to cope with adverse weather conditions, loss of brakes, and aborted takeoffs.

Feasible Automated Implementation Concepts for SST

In a completely automatic system utilizing auto-throttle on takeoff, it might be feasible to program an abort procedure with subsequent thrust reversal. However, at present it appears more practical to consider a manual mode of operation (i. e., leaving all decisions with the crew).

Feasible Manual Implementation Concepts for SST

The performance required in the abort phase of the takeoff roll will consist of reducing the power plant system to its idle position, and utilizing the thrust reversers as needed to assist the braking system. Operations will be very similar to current procedures, and the means provided should be consistent with current equipment. Although the engines will be designed for transonic acceleration, it must be remembered that on takeoff the gross weight of the SST will be greater than that of current jets. As a consequence the aircraft will be more difficult to stop once a high speed has been attained. The thrust reversers chosen will have to demonstrate the capability of decelerating the aircraft to acceptable taxi speeds within runway limitations. As far as the crew is concerned, there should be no significant alterations of present abort procedures. Because of the increased gross weight, (assuming no further increases in runway length) when a decision is made to abort, procedures will have to be initiated immediately. Safety margins will be very small and any delays in response could result in the aircraft going off the end of the runway, or the crew losing control of the aircraft.

Once the thrust reversing system has been actuated, the crew will manipulate the throttle to obtain RPM settings in the same manner as in other power plant operations.

4.5 FUNCTION 4.5 THRUST APPLICATION = F (NOISE ABATEMENT); (V_c, PNdb)

Purpose

This function is to vary the output of the power plants so as to comply with FAA regulations or local airport noise restrictions. This function usually integrates several of the flight activities, but is quite consistent with the basic aerodynamics of flight. Since standard operating procedures usually dictate the climbing speed (V_c) of the aircraft, any change in the power available will necessitate a change in the aircraft's attitude, so as to maintain the airspeed, V_c, but decrease the vertical speed (rate of climb). In high performance aircraft this is marginal performance because the aircraft has just become airborne, is heavily loaded, and will usually have to make a turn away from the operational runway to assist in the expedient flow of inbound and departing aircraft; and when on instruments a transition to "image interpretation flying" will have to be made. Another factor to consider is the comfort of the passengers. It must be remembered that any significant nose-down attitude change will generate uncomfortable negative g (just as would be experienced in an express elevator).

Current Jet Operational Requirements and Constraints

A paper on the performance requirements for the SST (ref. 31) points out that:

> ... the problem of airport noise has not been adequately defined as yet, and recourse is generally made to the criteria defined by the Port of New York authority, which states that the perceived noise level (PNdb) at a point 3.5 miles from start of takeoff shall not exceed 112.

The problem of airport noise is under close scrutiny in an effort to reach some agreement concerning a standard. Until such time most airlines are performing noise abatement procedures whenever conditions deem it safe.

Current Jet Implementation Concepts

In current operations, a combined power reduction and attitude change is initiated at the 3. 5 mile point to meet noise requirements. In effect, this maintains the airspeed, but reduces the rate of ascent. This procedure is not without problems. Takeoffs that require a reduction in power at the 3. 5 mile point to meet noise requirements, may present a problem of passenger comfort because of the resulting nose over to a lower climb angle. Current jet transports experience a change in climb angle when power is reduced at the 3. 5 mile point, but to a lesser degree than would be experienced by the SST.

The crew's main responsibility is to obtain a noise level acceptable to the public, while at the same time keeping the aircraft at a safe flying speed.

SST Potential Operational Requirements and Constraints

The trend is for stricter regulations than at present; the public is demanding improvements. It would appear that even if the SST is not required to make a maximum power takeoff, some noise abatement procedure would still be required.

Feasible Automated Implementation Concepts for SST

At this time no provisions are being made for automatically implementing this function.

Feasible Manual Implementation Concepts for SST

While local residential noise is a significant problem on current subsonic jets, both local noise and sonic boom are major design considerations for the SST, affecting wing and engine size and vehicle configuration. Residential noise during takeoff may be alleviated by reduction of power during the later stages of climb-out, but passenger comfort may be affected by the significant attitude changes introduced. However, there is some feeling that because the engines will be sized for the acceleration phase, maximum power would not be necessary for the takeoff. Also, because of the great thrust-to-weight ratios, the SST will be at a high altitude at the 3. 5 mile point, which in itself would attenuate the noise. Empirical studies will have to be conducted to determine the noise levels of the chosen power plant systems, and if the need still exists, procedures can be stipulated which would take these factors into consideration.

The desired noise level will be obtained by manual manipulation of the throttle to reduce RPM. The reduction in RPM will generate a requirement for a change in vertical attitude (pitch change) to maintain the desired airspeed.

The crew's responsibility will be to comply with existing noise level regulations, while not jeopardizing the safety of the SST. This is similar to current operations, and should only vary to the extent that the SST is a higher performance aircraft.

4.6 FUNCTION 4.6 THRUST APPLICATION = F (OPTIMUM MANEUVER SPEED); INITIAL CLIMB

Purpose

Power plant output is varied in this function to provide the necessary energy for the system to maintain a constant airspeed (with a corresponding constant rate of ascent). Once the aircraft is airborne and has completed its noise abatement procedures, it complies with its departure instructions. Since the SST will be operating in the same environment as subsonic aircraft, it will be required to maintain an initial climb speed which is consistent with ATC procedures (approximately 300 kts.), until it is clear of the dense traffic. The SST profile will indicate constant speed climbs followed by constant Mach climb, and then return to constant airspeed and finally back to constant Mach. This particular portion of the flight phase deals with maintaining a constant airspeed until reaching Mach 0.9.

Current Jet Operational Requirements and Constraints

Climb speeds are the result of economics and compliance with ATC procedures. In the design and development of any aircraft, schedules are developed to take all these factors into consideration (e.g., maximum climb speed, most economical climb speed, etc.). In planning a flight the crew selects that profile which best conforms to the scheduled flight.

In current operations the speed selected must be low enough to provide adequate maneuvering ability. Around the terminal control areas traffic density is high, and an aircraft operating at an excessive speed would conflict with other traffic.

Current Jet Implementation Concepts

In current aircraft a procedure similar to that described above is followed, but at proportionally lower airspeeds. The selection of climb speeds, and climb Mach is determined during the pre-flight planning phase, and takes into consideration such things as atmospheric conditions, flight endurance, and flight economics.

The crew's role is relatively small in this portion of the profile. This flight phase (initial climb) is of very short duration, and consists primarily of maneuvering the aircraft out of the terminal and high density traffic areas. The crew makes the initial power setting to maintain a certain climb profile (both airspeed and rate of ascent), and then makes those power changes necessary to hold the desired airspeed.

SST Potential Operational Requirements and Constraints

The factors in selecting jet climb speeds will carry over into SST operations, but will be more critical. That is to say, since the best operating environment for the SST is at altitude, climb speeds will be chosen which will give the aircraft the best economic advantage. Although an unrestricted climb would be economically the best, other traffic considerations will prevent using this. Another factor which must be considered will be the generation of sonic boom overpressures. In order to alleviate this problem, the SST will be required to maintain subsonic speeds throughout its initial climb.

Feasible Automated Implementation Concepts for SST

An auto-throttle concept will be utilized which will receive commands from either the crew or the computer. The system will operate the throttle to hold the required speed automatically. The crew will be required to command speed, and in one proposed concept, would be required to set the throttle to some quadrant. The automatic system would then make all the necessary minor corrections.

In its most automatic mode of operation the navigation function of the computer would generate speed commands which would in turn be transmitted to the auto-throttle system. The crew would monitor the operation.

Feasible Manual Implementation Concepts for SST

Manipulation of the throttle to obtain required airspeed will be similar to current operations. In the initial climb phase both the airspeed and the rate of ascent will be restricted by ATC procedures. The crew will establish the airspeed and the rate of ascent, and then vary power so as to maintain these as constants. Although this may not be the most economical mode of operation, the SST must be able to operate in areas of high density subsonic traffic.

The task will be similar to current operations with regards to maintaining a constant airspeed/constant rate of ascent climb schedule. All such operations are tied to flight control operations in that a change in power results in a change in trim (thus attitude).

4.7 FUNCTION 4.7 THRUST APPLICATION = F (OPTIMUM MANEUVER SPEED); SUBSONIC CLIMB

Purpose

This function is to vary the power output to intercept an optimum Mach speed and maintain this in a constant Mach climb (subsonically). The choice of the Mach climb speed will be dependent upon the gross weight of the aircraft, atmospheric conditions, and the climb procedures authorized by ATC. The performance demanded will consist of changing from the airspeed indicator to the Mach indicator as the aircraft attains a predetermined airspeed. As the aircraft gains altitude, constant airspeed will result in an increasing Mach. Once the desired Mach has been attained, the power and/or the attitude of the aircraft must be changed to maintain this speed and the desired rate of climb.

Current Jet Operational Requirements and Constraints

Jet operations in low, dense altitude environments result in high rates of fuel consumption. Thus, within the restrictions of air traffic control, the aircraft must choose a climb schedule which will carry it to its optimum operating environment along an optimum climb placard. Another factor to consider is that as altitude increases it is more difficult to hold a constant airspeed, because at altitude a constant sea level EAS may be well above the maximum operating speed of the aircraft. Thus, a constant Mach is utilized instead.

Current Jet Implementation Concepts

In current subsonic operations, the pilot usually sets the throttles to obtain a rough estimate of what is necessary to maintain a constant Mach climb schedule consistent with pre-planned data. It is then the responsibility of the flight engineer to readjust the throttles as necessary to conform to the pre-planned schedule and the fuel management fuel derivatives.

SST Potential Operational Requirements and Constraints

With respect to fuel consumption, low altitude flight will be even more critical for the SST than for current jets. However, the problem of sonic boom now plagues the designers. In order to obtain public acceptance of sonic boom effects, it will be necessary to accelerate the SST at transonic and supersonic speeds at much higher altitudes than minimum fuel consumption considerations would dictate.

A comparison of current military climb schedules (unrestricted by sonic boom considerations) with those for the SST reveals a large effect on climb and acceleration schedules due to consideration of sonic boom. The effect is pronounced and causes considerable increases in climb fuel and climb time. The primary reason for the altitude sensitivity is that the vehicle must fly at a higher lift coefficient due to the reduced dynamic pressure at the higher altitude. The increased lift coefficient produces an increased drag due to lift, and thereby a relatively lower excess thrust. This situation places great emphasis on being able to realize high airframe efficiency or high engine thrust in this speed region in order to alleviate the aforementioned performance penalties.

Feasible Automated Implementation Concepts For SST

The SST will to some degree do away with manual manipulation of the throttles. Auto-throttle has been advocated for the SST by most of the experts. It is generally believed that it will be necessary to utilize the on-line computer in conjunction with the power control. The crew would set the throttle in the appropriate quadrant, command a specific climb speed (Mach speed), and set the appropriate attitude of the aircraft on the auto-pilot . Then the on-line computer would maintain the appropriate climb speed. Data in the form of temperature differentials, atmospheric conditions, and fuel consumption would be analyzed and the appropriate power setting would be electromechanically set. The crew's task would be to monitor the resultant climb schedule, and make any changes as determined by the navigational function. With the use of an on-line computer the SST would, within the limitations placed upon it by ATC regulations, fly the most economical profile consistent with all constraints (i.e., the optimum profile).

The crew's main responsibility would be to insure that the automatic system was operating normally, and that speeds were consistent with tolerable overpressure generation.

Feasible Manual Implementation Concepts For SST

Keeping the attitude such that a certain rate of ascent is constant (Flight Control Function) and maintaining a constant Mach speed leaves only the manipulation of the power plants as a variable. Manipulation of the throttles by the crew to maintain either optimally generated speeds or pre-flight computed climb schedules will be similar to current procedures. The crew's main responsibility will be to insure operation of the power plants in a manner consistent with economy, sonic boom considerations, and ATC restrictions.

It must be pointed out that as the aircraft attains greater altitude, its EAS will continue to decrease, even though the aircraft is maintaining a constant Mach climb speed. Since the SST will be constrained by the sonic boom consideration, it will be forced to attain that altitude corridor which sufficiently attenuates the generated overpressures. In doing this the aircraft will be forced to fly on the backside of the power curve, i.e., more power will be required to maintain a slower speed. This type of flying is not foreign to present crews, but does require more diligence than is currently required.

Proper power operations during this phase of the flight are mandatory if the SST is to prove an economic reality. The greatest portion of the fuel is utilized in the subsonic climb-transition phases, and the crew's performance during this period could determine the operational feasibility of the SST. Any unwarranted fuel waste or mismanagement could cancel the flight at this point.

4.8 FUNCTION 4.8 THRUST APPLICATION = F (SONIC BARRIER PENETRATION); TRANSONIC ACCELERATION

Purpose

This function is to vary the power plants so as to accelerate the aircraft through the high drag phenomenon associated with the sonic speed region. This phase of flight has come to be known as the "sonic barrier penetration." This of course is a phase of flight which does not cause concern for present subsonic jet crews. New phenomena will be encountered, and new procedures will need to be learned to cope with problems which may arise. Years of experience in military aviation have provided the answers to many of the questions and training can acquaint the unfamiliar with the new problems.

When the decision is made to start transonic acceleration, based on atmospheric conditions, traffic conditions, and sonic boom considerations, the SST will probably reduce or even eliminate its climb attitude in favor of a slight descent. Then, depending upon the power plant system chosen, maximum power would be applied so as to gain the acceleration necessary to penetrate the barrier. With those power plant systems utilizing augmentation, it is quite probable that full augmentation would be used. The higher the altitude, the more difficult it is to attain high accelerations. Therefore, maximum power must be utilized for as short a period of time as possible.

Current Jet Operational Requirements and Constraints

There are none applicable.

Current Jet Implementation Concepts

There are none applicable.

SST Potential Operational Requirements and Constraints

Because of sonic boom considerations, the SST will have to accelerate to its high speeds at altitudes higher than would normally be considered optimum. Since the excess of thrust over drag decreases with increases in altitude, every effort will have to be made to optimize the output performance of the power plant (e. g. , notching of the inlet and nozzle to the engine). Slaiby and Staubach describe the problem (ref. 32):

> ... consideration of potential ground annoyance and damage factors from "sonic boom" has dictated that acceleration to supersonic speeds for the supersonic transport must be at altitudes higher than normally would be optimum for a long-range supersonic aircraft. What acceleration altitude will be required for public acceptance of the "sonic boom" is still a matter of speculation, but altitudes above 40, 000 feet seem likely at this time. This requirement results in the propulsion-system thrust being critical in the transonic-Mach-number region and hence is the condition for selecting powerplant size. The critical thrust margin is in the region of Mach number 1. 2-1. 3. Unfortunately, this is also the Mach-number region in which the losses in thrust due to inlet and nozzle are large. It can be seen that these losses can approach the thrust margin (thrust-drag) in magnitude. They are primarily a function of the relationship between inlet flow capacity and the engine flow requirements. Reduction of these losses by matching the inlet and engine flow characteristics is obviously very important since they can directly influence the propulsion-system size and base weight....

Feasible Automated Implementation Concepts for SST

Either the computer coupled auto-throttle or crew commanded speed auto-throttle will control the power plants during transonic acceleration. In this mode, the crew will be responsible for monitoring the system. As the preplanned acceleration altitude is approached the crew will either move the throttle into the specific quadrant and command a speed, or will check to ascertain that the profile generator is indicating readiness to start the transition phase.

In any case the maximum available power will usually be utilized to obtain advantage of excess thrust/drag at the specific altitude. (The Concorde designers are studying the feasibility of a lower-powered, slower acceleration type of profile to cope both with sonic boom and engine sizing considerations).

Feasible Manual Implementation Concepts for SST

The crew will manipulate the throttles and the fuel control. Since the transitional acceleration will be at maximum power, there does not appear to be any other performance required of the crew but the monitoring of parameters. Manipulation of the fuel control will be necessary because at supersonic speeds the SST engine will in all likelihood be operating at maximum RPM. Thus, one way to control the energy output will be to increase or decrease fuel (this is assuming an optimally configured inlet duct and exhaust nozzle).

The crew's responsibility will be to initiate transonic acceleration procedures at the time determined either by the optimum profile generator or preflight computed data. Once maximum power has been applied, the crew's responsibility will be to monitor system performance, and vary the fuel input as necessary to achieve required accelerations. This operation is well within the capability of the crew as long as the inlet duct and exhaust nozzle are automatically positioned. A failure in that system may generate a requirement to halt acceleration and return to the subsonic regime.

4.9 FUNCTION 4.9 THRUST APPLICATION = F (OPTIMUM AIR SPEED); SUPERSONIC CLIMB

Purpose

The output of the power plants is varied in this function to provide the energy necessary for the SST to continue acceleration to speeds of Mach 3.0, and to sustain speed during the subsequent climb to its operating environment. It has not been determined exactly what kind of profile would be flown by the SST, but it has been suggested that the initial climb and departure would be conducted at a constant airspeed; the following climb would be at some increase in Mach speed; and finally, a constant airspeed would again be followed which would result in an increasing Mach speed with the altitude increase. Whatever the climb schedule proposed, the resulting family of curves would have to be corrected for changes in atmospheric conditions.

The builders of the Concorde are anticipating that the crew's responsibility during the climb phase will be to actually fly the desired climb placard. In so doing, they will be required to assess all available data, and make appropriate changes in a timely fashion.

U.S. builders are thinking in terms of an on-line computer/autothrottle which will, as the result of instantaneous calculations, maintain the optimum profile to reduce the probability of undesirable sonic boom.

All experts agree that the transitional acceleration and the supersonic climb will have to take place at a higher altitude than necessary, in an attempt to control the sonic boom effects.

Current Jet Operational Requirements and Constraints

This is not a current function.

Current Jet Implementation Concepts

This function does not occur in current operations.

SST Potential Operational Requirements and Constraints

The major constraints throughout the supersonic portion of the flight profile will concern the control of sonic boom overpressures. This restriction placed upon the climb portion of the flight will result in high fuel consumption rates which will, depending on atmospheric conditions, determine whether the specific flight will have sufficient fuel to continue as scheduled.

In most cases, once the initial high drag area is passed, the aircraft will start a climb acceleration which will probably vary Mach speed linearly with increases in altitude until the desired Mach is attained. At that point the rate of ascent will be increased until the assigned cruise altitude is reached.

Feasible Automated Implementation Concepts for SST

The computer and coupled auto-throttle will be utilized in an automated concept. Either a pre-programmed climb schedule, or an optimally generated profile will feed speed and energy commands to the auto-throttle. These commands will be the result of environmental parameter sampling and analysis, and will approach optimum performance.

The crew's role in this function will be to monitor the operation of the system, and to enter data as necessary and available. Their main responsibility will be to insure that power plant performance is being monitored, and that automatic performance seems consistent with pre-computed data. It does not appear that any revolutionary type of training will be necessary to acquaint the crews with the system's operation. This concept is an extension of the present auto-pilot system.

Feasible Manual Implementation Concepts for SST

The crew's manipulation of the fuel control to maintain or obtain desired speeds will be in the manual mode of operation. In these operations the RPM will be kept constant, and the fuel flow varied to obtain a desired energy output.

This operation, although rough by comparison to the automatic mode, is well within the capabilities of the crew. The major concern will be whether the crew can make the operation economically feasible. The designers of the Concorde believe that man can do so. They envision a climb schedule made up of a series of constant speed and Mach climb segments, such as the following:

1. Accelerate and climb from 200 knots CAS at sea level to 375 knots CAS at 5,000 feet.
2. Climb at a constant CAS of 375 kts from 5,000 feet to 39,000 feet, where M = 1.147.
3. Climb and accelerate to 45,300 feet, M = 1.8 (530 kts CAS).
4. Climb at 530 kts CAS until the cruise Mach number is reached.
5. Climb to cruising height at cruise Mach number.

In the manual mode of operation the crew would continue to be responsible for controlling the generation of sonic boom overpressures. Similarly, the crew would be responsible for insuring economical operation of the power plants. New instrumentation may be required to indicate to the crew the implications of fuel flow changes on the energy output of the power plants.

4.10 FUNCTION 4.10 THRUST APPLICATION = F (TRANSITION TO CRUISE)

Purpose

This function is to vary the output of the power plants in order to assist in the attitude change associated with termination of the climb phase and initiation of the cruise phase. Although this can be thought of in terms of an automatic function, the builders of the Concorde are leaving this performance to the crew. What is involved primarily is maintaining a constant Mach speed, but decreasing the vertical vector of that speed. This maneuver will be similar to level-off maneuvers with older aircraft, except that more care will have to be taken to keep positive g loading on the aircraft. The power plants are utilized in conjunction with the flight controls to obtain this smooth transition.

Current Jet Operational Requirements and Constraints

Although current jets do not make the transition from supersonic climbs to cruise altitudes of 70,000 to 80,000 feet, they are concerned with transitions from climb to cruise attitudes. The nature of the task is the same, as is the importance of passenger comfort. In leveling off at an assigned altitude, too rapid a rate of change in the rate of ascent will result in the generation of negative g loads. If possible, a positive g loading should be maintained throughout this maneuver.

Current Jet Implementation Concepts

Again, although not specifically the same operation which will be found in the SST, the subsonic carrier performs a transition to cruise maneuver (i.e., a level-off from a climb maneuver). Currently the crew starts the transition several thousand feet prior to the assigned altitude. The aircraft's attitude is changed slowly and power is reduced as necessary to maintain a desired airspeed. Optimally the aircraft reaches the assigned altitude with a rate of ascent equal to zero, with the aircraft trimmed and at the desired speed, and with sufficient power to just hold this speed.

SST Potential Operational Requirements and Constraints

Because of the higher performance characteristics of the SST compared to current jets, even greater anticipation will be needed for this maneuver to preclude the generation of unwanted negative g loading. Air traffic controllers will have to give the crew sufficient warning for altitude holds, or the aircraft will overshoot the assigned altitude.

Feasible Automated Implementation Concepts for SST

In the completely automatic mode the computer would feed commands to the auto-throttle which would be consistent with a level-off maneuver. These commands would be predicated on altitude and airspeed data entered by the crew, pre-computed level-off data (which would take into account passenger comfort), and optimum profile generated parameters. The crew's responsibility would be to insure that the system was functioning normally, and that the transition was initiated at an altitude consistent with optimum g loading profiles. The crew would use either pre-computed data, or displayed loading placards to check on the system performance.

Feasible Manual Implementation Concepts for SST

This function will continue to be performed by means of the throttle. However, in all likelihood, the amount of thrust needed will no longer be obtained by the RPM setting. Most experts agree that the power plant chosen for the SST will be run at maximum constant speed during supersonic operations, and that thrust will be varied by varying the amount of energy added to the airflow.

This is an integrated flight control/power plant operation, and the quality of performance will be a function of the coordination of the maneuver. At extremely high speeds control in the vertical plane is quite sensitive, so that poor performance in that area coupled with too large a decrease in power could generate excessive negative g. Because of the high performance characteristics which will be associated with the SST, it is clear that empirical data should be collected on the amount of anticipation necessary to obtain a trajectory consistent with the desired flight path, assigned altitude, and passenger comfort.

As in current operations, crew involvement will be to insure that passengers are not subjected to any prolonged discomfort. It is clear that some form of instrumentation could be furnished the crew which would present a tracking task both as concerns altitude and acceleration.

4.11 FUNCTION 4.11 THRUST APPLICATION = F (CONSTANT MACH); CRUISE

Purpose

This function is to vary the output of the power plants to provide the SST with a constant Mach cruise speed. It is anticipated that the final cruise speed will be attained during the supersonic climb phase, and as the SST approaches its assigned flight level, the attitude will be altered to maintain a nearly level cruise attitude. At that time the amount of energy supplied to the system will be set so as to maintain a constant Mach speed consistent with altitude and atmospheric conditions.

As the aircraft loses weight due to fuel burn-off it will, within the limitations placed upon it by the Air Traffic Control system, accept an increase in altitude instead of an increase in speed for the same fuel flow setting. As was pointed out earlier, thrust will probably be controlled by varying the amount of fuel injected into the airflow (which will be held constant), rather than varying the amount of airflow available to the engine. Thus, keeping both the RPM and the fuel flow constant would result in an increase in airspeed (considering a constant flight level) as the fuel burns off. However, it can be shown that the acceptance of a slight increase in altitude rather than the increase in airspeed will provide the more economical operation. This slight increase in altitude with burn-off (approximately 100 ft. per minute) is called "cruise climbing."

Current Jet Operational Requirements and Constraints

Current aircraft are required to maintain a constant altitude while flying under ATC control, or to utilize a series of step climbs. Both of these maneuvers restrict efficiency to some degree. The optimum profile accepts the trade-off of weight decrease for altitude increase.

However, because of traffic separation considerations, aircraft must use an available altitude, rather than the optimum.

Current Jet Implementation Concepts

As was pointed out in earlier functional descriptions, this portion of the flight profile can be compared to the current subsonic operational cruise phase with respect to the functions performed by the crew. However, with the SST total cruise time will be less, and fuel will become a critical factor. The main responsibility of the crew will be to monitor the auto-throttle and in case of malfunction, to manually meter the fuel so as to obtain the cruise schedule consistent with economic operations and the capabilities of the crew.

In current operations there is no provision for auto-throttle, at least during the cruise phase, so the crew is responsible for manually maintaining a required airspeed. This is usually done either by setting a certain fuel flow and accepting the airspeed, or by varying the fuel flow to maintain a constant airspeed. It should also be pointed out that in current operations the fuel flow is usually some function of the RPM and environmental conditions. Thus, the crew would set a certain pressure ratio, or RPM, and as a result receive a certain fuel flow.

SST Potential Operational Requirements and Constraints

With the improvements in the state-of-the-art of navigational and tracking systems, and because of the relatively low traffic densities in the SST cruise environment, there appears little reason why the SST should be restricted to one specific cruise altitude. Since the SST will be restricted in other areas (e. g. , sonic boom considerations, unfavorable atmospheric conditions, etc.), every means should be used to optimize its performance.

Feasible Automated Implementation Concepts for SST

As for the crew, their primary responsibility will be to monitor the operation of the automated equipment to insure that constant Mach cruise is maintained, and that the cruise climb schedule is adhered to. Actually, once the transition to cruise has been made, and the power plant set for the constant Mach speed, no further performance will be required by the crew. The various parameters will have to be monitored to insure their position within operating envelopes.

The cruise climb profile could be entered by either the crew, or by the optimum profile generator and the auto-throttle varied as necessary to maintain the constant Mach cruise speed.

Feasible Manual Implementation Concepts for SST

In the manual mode, the fuel control will be set to maintain a constant Mach speed and the fuel flow will be kept constant throughout the cruise phase. As fuel is burned off, the excess resulting energy will be accepted as either an increase in altitude or an increase in Mach. Due to the supersonic flow of air to the SST engine, in all likelihood, the engine will be accepting maximum airflow and will be operating at maximum RPM. In this situation the amount of thrust required will become a function of the fuel flow which will be manually varied (in the most manual mode) to change the energy content of the exhausted airflow.

The crew's responsibility will be to insure economic operation of the power plant. If a cruise climb is allowed, the crew will be required to set a certain fuel flow based on pre-computed or aircraft computer data, and then to maintain this fuel flow profile. If the cruise climb is not allowed, the crew's responsibility would be to maintain either a constant Mach speed or accept the increase in energy as a speed addition. This decision would be dependent upon an analysis of all flight parameters.

SUBSONIC SPEED REGIME

If for some reason other than power plant failure the SST were required to descend to lower altitudes (40,000 to 45,000 feet) and complete the flight subsonically, the crew should not encounter any appreciable increases in workload due to power plant operation. The duct system would have to be reconfigured for optimum subsonic operations. Speed would also have to be recomputed to give the best performance taking into consideration the fuel and distance remaining, and trying to optimize the time factor. However, once these new factors have been computed, the automated system would still function as it did at altitude and supersonic speeds. Thus, there would be no new requirements placed upon the crew other than added endurance.

In the case where the automatic system were to malfunction, the crew would be required to manually control the speed and/or fuel flow very much like current subsonic operations. Again, this is well within the capabilities of the crew and it is not anticipated that any appreciable work load factor other than fatigue would be introduced.

If, however, a failure of a portion of the power plant system (e.g., an engine failure) is the reason for the subsonic profile, then fuel remaining factors versus range must be analyzed to determine the implications of diverting to an alternate, or continuing to the designated destination.

4.12 FUNCTION 4.12 THRUST APPLICATION = F (OPTIMUM AIR SPEED); DECELERATION/DESCENT

Purpose

The output of the power plants is varied in this function to decrease the power available to the SST in such a fashion as to both provide an economical profile and be consistent with passenger comfort and tolerance. When the decision has been made to descend, sufficient energy must be available to control the descent profile of the aircraft. There are many different descent profiles which may be utilized, but generally speaking a minimum fuel flow schedule should be adhered to.

Current Jet Operational Requirements and Constraints

Power and airspeed are two factors which allow the aircraft to maintain altitude. Accordingly, power reduction results in a lower altitude and a lower speed. The rate at which these occur must be regulated to allow for passenger comfort, both with regard to acceptable deceleration and acceptable rates of change of cabin pressure.

Current Jet Specific Implementation Concepts

Current subsonic aircraft have a descent schedule consistent with economical operation, ATC procedures, and the specific destination area. In most cases the descent will be an idle RPM descent with the aircraft either in a clean configuration, or some degree of "dirty" configuration. The dirty configuration induces a higher drag resulting in higher rates of descent, and consequently in steeper angles of descent. In either case, the rate at which the aircraft descends is constrained by other factors such as passenger comfort and the operation of subsystems (e. g., pressurization).

SST Potential Operational Requirements and Constraints

Those areas of concern which dictate operations in current aircraft will continue into SST operations. Added to these factors will be at least two others, sonic boom generation and fuel heat sink overheating. The implications of this last factor have yet to be determined.

Throughout the flight the fuel will be used as a heat sink for the engine to assist in dissipating some of the critical structural heat. As the descent phase is started, fuel flow is decreased. Because of the latent heat of the engine materials, the heat input to the fuel does not change immediately and there is a high, transient temperature rise. Since this rise acts to increase energy output at the same time that lesser energies are required, it presents a real problem in engine control.

Feasible Automated Implementation Concepts for SST

SST operations will be similar in nature to those on current jet aircraft. A fuel flow will be selected which will cause the SST to decelerate at some acceptable rate. Next, the speed of the engine will be changed to further induce deceleration. The rate of deceleration will be primarily dependent upon the rate of descent desired. Of course all this will be accomplished automatically via the computer coupled auto-throttle.

The crew's role will be to obtain ATC clearance, and then feed initiation data into the system. At the prescribed point in space, the system will start descent procedures, sending appropriate commands through the auto-throttle system to the power plants. The crew's responsibility will be to verify the rate of deceleration and to insure a descent/deceleration profile consistent with passenger comfort, ATC procedures, and other subsystem operation. No new equipment will be utilized, and the crew's main aid will be either the preflight computed data, or airborne computer data.

Feasible Manual Implementation Concepts for SST

The crew's adherence to a descent/deceleration profile in a manner similar to that in current operations is quite feasible. The crew would manipulate the fuel flow and accept a linear Mach/altitude deceleration. Their responsibility would not be changed from that stated in the previous section.

In most cases, the descent/deceleration profiles would be predicated on optimum, economical performance. However, in the event of an emergency which warrants rapid deceleration and descent, the crew has the capability of using dirty configuration descents and airborne thrust reversal. These two procedures should only be considered as imminent disaster maneuvers.

4.13 FUNCTION 4.13 THRUST APPLICATION = F (SONIC BARRIER PENETRATION); DECELERATION

Purpose

This function is to vary the output of the power plants so as to insure compliance with the deceleration schedule. As the SST approaches the sonic barrier the high associated drag will increase appreciably, which will in turn cause a more rapid deceleration. As the aircraft approaches its subsonic descent speed it will be necessary to establish a new angle of descent, and to readjust the output of the power plants. Most proposed schedules indicate the flying of a constant Mach descent until such time as a predetermined airspeed is indicated, and then continuing with a constant airspeed descent.

While this particular performance is not experienced in current subsonic operations, there has been extensive military experience in these areas. As a result, no particular problems are foreseen during this phase of the flight, at least with regard to the operation of the power plants. The main concern of the SST crew will be to insure that the inlet duct system is positioned for subsonic flight, and that the fuel control system reverts back to the automatic system which operates as a function of the engine RPM. As has been pointed out, in supersonic flight variations in the fuel control determine the thrust output, since the speed of the engine is held constant at maximum RPM. In subsonic regimes, however, the engines are able to accept the air masses introduced at the intake, so that thrust is varied by varying the air mass flow and accepting the fuel flow obtained. Most current subsonic aircraft are outfitted with an automatic fuel control which takes into account environmental conditions and provides the optimum fuel flow for any selected RPM setting.

Current Jet Operational Requirements and Constraints

This is not an area of concern for current subsonic air carriers.

Current Jet Implementation Concepts. None.

This is not applicable to current air carriers.

SST Potential Operational Requirements and Constraints

The only real constraint is the reduction of sonic boom overpressures. This will be accomplished by performing the transonic deceleration at a high enough altitude to attenuate sonic effects.

Feasible Automated Implementation Concepts for SST

The pre-programmed descent/deceleration profile will control the output of the power plants through the auto-throttle. The commanded speeds will be the result of analyzing data with regard to sonic boom considerations, atmospheric conditions, and economics. The crew will monitor the operation of the automatic system. The crew's responsibility will be to insure that the power plants are performing normally, that untolerable sonic boom overpressures are not being generated, and that upon passing through the sonic barrier, the power plant control changes back from a variable fuel control to a variable air flow/fuel flow operation.

Feasible Manual Implementation Concepts for SST

The crew's manipulation of the fuel control, and later the repositioning of the throttle to a lower RPM, will be the means for performing this transonic deceleration. In most cases, the fuel control would be set to provide minimum thrust, and a decreasing Mach versus altitude deceleration profile would be followed. As the aircraft enters the subsonic speed regime, and the inlet duct is again reconfigured for low speed operations, the crew will be able to vary the RPM to control the power plant output even more.

The crew will be responsible for complying with descent/deceleration profiles which are either computed prior to flight or instantaneously generated and displayed for the crew. In the first case, a family of curves could compensate for variations in forecasted conditions. The instantaneously generated profile would take all existing conditions into consideration. The manual performance should be well within the capabilities of the crew, and should not really be any more restrictive than following current descent/deceleration profiles.

4.14 FUNCTION 4.14 THRUST APPLICATION = F (OPTIMUM MANEUVER SPEED); SUBSONIC HIGH ALTITUDE MANEUVERS

Purpose

The output of the power plants is varied in this function to provide energy to the SST system so that it can perform in high altitude subsonic regions (45,000 to 30,000 ft.) and between Mach .95 and Mach .9. Once the aircraft has decelerated through the sonic barrier, there will still be an altitude region which it must cross and perhaps maneuver in, prior to commencing its standard instrument approach (let-down). This regime is the concern of this section.

In the high altitude regime, the SST is again operating within the environment of subsonic carriers, and may be required to level-off at some altitude, or to establish a holding pattern prior to sequencing into the final approach pattern. Because of the SST fuel consumption rates at low altitudes, any delays or holding patterns necessary for sequencing separation should occur at as high an altitude as is possible.

Current Jet Operational Requirements and Constraints

Currently, aircraft must be able to operate and maneuver effectively in the high altitude regime in response to control commands by ATC. These maneuvers will include changing of altitudes, vectored turns, and standard holding patterns. Almost all of these maneuvers are procedural methods utilized by Air Traffic Control facilities to provide adequate separation between aircraft.

Current Jet Implementation Concepts

The particular regime discussed is equivalent to the cruise portion of the subsonic jet. However, the same activities are involved.

If the aircraft is instructed by ATC to "hold" using some standard holding fix, then the crew manipulates the throttles in a manner so as to comply with published instructions (e. g., airspeed, type of turns, etc.).

SST Potential Operational Requirements and Constraints

There appear to be none, other than, perhaps, consideration by the ATC controller for the altitude sensitivity of the SST. There is no reason to suspect that the SST will have any problems operating in this altitude and speed regime.

Feasible Automated Implementation Concepts for SST

As with most of the other power plant operations, the auto-throttle will usually take care of high altitude maneuvers following a certain schedule. The commanded airspeed will be maintained by the automatic system for level flight, or for some particular selected descent profile.

In those situations which require a constant airspeed, the auto-throttle may be utilized separately to maintain any commanded speed. Any deviation from the pre-programmed descent/deceleration profile would necessitate changing from a completely automatic mode (computer coupled auto-throttle) to a semi-automatic operation (auto-throttle only). The main responsibility of the crew would be to set up the system for some desired airspeed, and monitor it.

Feasible Manual Implementation Concepts for SST

Crew manipulation of the throttles would provide the means for varying the output of the power plants. This performance would be dependent upon the maneuver required (i. e., continued descent, level-off, holding, etc.). This is a straightforward example of power plant utilization to obtain necessary energy for some particular maneuver.

The crew will be responsible for monitoring the performance of the power plant and insuring that sufficient power is available for complying with system demands. The SST crew should not encounter any new problems and should be able to cope with any normal situations which might arise in this regime. Although there is the possibility that this portion of the flight could be completely automated, it is believed that this area is well within the performance capabilities of the crew, and that the additional programming to include such operations as level flight or holding patterns, would be unnecessary.

4.15 FUNCTION 4.15 THRUST APPLICATION = F (OPTIMUM MANEUVER SPEED); LET-DOWN

Purpose

This function is to vary the output of the power plants to maintain an airspeed which is consistent with economic procedures and ATC descent patterns. However, it must be noted that during this let-down phase of flight the power plants will usually be in the idle position. The rate of descent thus is a function of aircraft configuration and airspeed. For our study we will assume that the velocity output required is provided by the power plant operations function. It can be seen that this is really the case because if a constant airspeed is chosen for the idle power situation, then the attitude of the aircraft is determined for any configuration of the aircraft. It must be also noted that the configuration of the aircraft will determine the vertical speed at which the aircraft is descending. Depending on the aerodynamic characteristics of the aircraft the vertical speed determined by the idle power plants and the aircraft clean configuration may be very low. Therefore, to expedite the descent, high drag devices are used to obtain steeper angles of descent (e.g., speed brakes or spoilers). In actuality, during this phase the crew only has to monitor the power plant performance instruments periodically.

Current Jet Operational Requirements and Constraints

Aircraft must possess the means to maneuver in compliance with ATC procedures. In doing this they must have the capability to select those descent profiles which take into consideration passenger comfort, maneuvering for traffic avoidance, and economics. In most current situations aircraft are directed to a specific navigational location (described by position, altitude, and time), from which at a specific time they are directed to follow a standard instrument approach (SIA) which has been published. This SIA furnishes specific instructions with regard to airspeeds, rates of descent and navigational data.

FAR 91.85 (ref. 13) is applicable here:

Operating on or in the vicinity of an airport; general rules.

> (a) Unless otherwise required by Part 93 [New] of this chapter, each person operating an aircraft on or in the vicinity of an airport shall comply with the requirements of this section and of §§ 91.87 and 91.89.
>
> (b) Unless otherwise authorized or required by ATC, no person may operate an aircraft within an airport traffic area except for the purpose of landing at, or taking off from, an airport within that area. ATC authorizations may be given as individual approval of specific operations or may be contained in written agreements between airport users and the tower concerned.
>
> (c) No person may operate—
>
> (1) An arriving aircraft below 10,000 feet MSL within 30 nautical miles of an airport of intended landing (or an airport where a simulated approach is to be made) at an indicated airspeed of more than 250 knots (288 m.p.h.); or
>
> (2) Unless otherwise authorized or required by ATC, any aircraft within an airport traffic area at an indicated airspeed of more than—
>
> (i) In the case of a reciprocating engine aircraft, 156 knots (180 m.p.h.); or
>
> (ii) In the case of a turbine-powered aircraft, 200 knots (230 m.p.h.).
>
> However, if the minimum airspeed required [or recommended in the airplane flight manual to maintain safe maneuverability or required] by military normal operating procedures is greater than the maximum speed prescribed in this paragraph, the aircraft may be operated at that minimum airspeed.

Current Jet Implementation Concepts

Current aircraft performance is similar to that forecast for the SST as the Boeing 707 Operations Manual (ref. 17) indicates:

> A normal descent from a cruise condition may be established in several different configurations. The clean descent can be established merely by reducing power and maintaining any indicated airspeed up to the placard airspeed during a descent. The clean descent is recommended for maximum range considerations provided the descent can be started a suitable distance away from the destination so that arrival at the destination is at a minimum altitude. The descent can also be accomplished by using partial airbrakes and/or with landing gear extended. Extending the gear is generally recommended for conditions where it is desirable to descend in a very short air distance, such as a penetration letdown procedure in weather to a landing approach fix. When letting down with gear extended and/or spoilers extended, care must be exercised to prevent overshooting the desired altitude for leveling off because of the relatively high rates of descent.

SST Potential Operational Requirements and Constraints

With regard to the power plants there does not appear to be any modification necessary to present requirements. Instrument approaches may have to be altered so that the SST can hold and start descent at higher altitudes.

Feasible Automated Implementation Concepts for SST

The computer coupled auto-throttle will furnish the means for following a descent profile which will optimize fuel consumption and comply with ATC procedures. The crew's responsibility would include monitoring the automatic mode of operation and the power plant system performance. In all likelihood, the crew would command a descent speed and the auto-throttle would compensate for pattern characteristics to maintain this airspeed.

Feasible Manual Implementation Concepts for SST

The crew will manipulate the throttle to vary power plant output, so as to comply with let-down procedures. In most cases, an idle RPM let-down will be utilized as in current operations. The crew will be responsible for maintaining a given airspeed, maneuvering ability, and rate of descent consistent with ATC procedures and economic operations. Under normal conditions this particular power plants function is insignificant. The performance required is merely monitoring of power plant instruments. A constant airspeed is maintained and the vertical rate of descent is regulated by the flight control function.

4.16 FUNCTION 4.16 THRUST APPLICATION = F (OPTIMUM MANEUVER SPEED); LEVEL-OFF

Purpose

This function is the varying of power plant output so that energy is available to maintain a straight and level flight altitude at an airspeed consistent with low level maneuvering in the Air Traffic Control system. The preceding phase of the flight, the aircraft descends at a constant airspeed and at a rate of descent consistent with the prescribed approach pattern. As the approach altitude is neared, many operations are required to change the aircraft from a descent pattern to a straight and level state. Other factors must also be taken into consideration in this transition (e.g., the passengers' tolerance to deceleration).

Level-off maneuvers are coordinated flight control/power plant performances. As the assigned altitude is approached, the vertical rate of descent is slowed by retracting the high lift devices and changing the attitude of the aircraft. If an idle power plant operation is used, then as the vertical speed approaches zero and the attitude of the aircraft starts to change, the constant airspeed which was being maintained will start to decrease. When the new desired airspeed is reached, power will have to be applied to maintain it. Optimally, there should be a smooth transition to level flight such that when the assigned altitude is attained, the vertical speed is zero, the aircraft is at the required airspeed, sufficient power is used to maintain the airspeed, and the aircraft is trimmed for the new speed.

Current Jet Specific Operational Requirements and Constraints

In aviation, any transition from one state to another requires a smooth and coordinated maneuver. Square corner maneuvers are not possible thus, anticipation and transition are important factors in smooth flying. Current aircraft must be able to intercept an altitude, either from above or below, without placing undue accelerations on the passengers, and without overshooting, or passing through the altitude. Air Traffic Control separation procedures are predicated on this ability to reach an altitude without overshoot.

Most ATC procedures pertaining to an approach for landing have some type of descent or let-down to an intermediate sequencing pattern altitude (approximately 1,500 to 3,000 feet) where the aircraft is readied for landing as it is maneuvered toward the final approach course. Variations in this pattern increase or decrease the separation between aircraft on final approach (3 miles in current operations).

Current Jet Implementation Concepts

Manipulations of the throttle in conjunction with changes in aircraft attitude are used to accomplish the level-off maneuver. As the assigned altitude is neared the attitude of the aircraft is changed, resulting in a decrease in vertical velocity and a slight decrease in airspeed. Ideally, the assigned altitude is reached as the desired airspeed is attained and the rate of descent reaches zero. The output of the power plants has to be regulated so as to supply sufficient energy to maintain this state (i.e. straight and level flight at a desired airspeed).

SST Potential Operational Implementation Concepts For SST

With the SST there will be the possibility of flying this transition phase of flight via the auto-pilot/auto-throttle/on-line computer. A descent profile can be commanded, so that as a commanded altitude is approached, a signal to the flight control system will change the aircraft attitude, and as a fluctuation is noted in the airspeed, a signal will be transmitted to the auto-throttle for increased power to maintain the commanded airspeed. Although this is a feasible concept, it is probable that a more manual version will be implemented. More than likely the pilot will change the attitude of the aircraft, set the throttle in some quadrant range, and then allow the auto-throttle system to make necessary small corrections.

Whatever the final design, responsibility will be with the crew to maintain proper vigilance of the entire system. This is a critical phase of the flight for the altitude is low and the aircraft is descending at a high rate of speed. If the transition is to be completely automatic, there must be some indication that the system is operating correctly so that the pilot can override the controls if necessary.

Feasible Automated Implementation Concepts For SST

In the subsonic regime, the SST power plants will be operated as are current engines. They will respond to changes in the RPM which will in turn influence fuel control and fuel flow. The main control will keep the throttle control on the power quadrant. While level-off procedures should be the same as that of current operations, the larger dimensions of the SST and the slower control response may necessitate the initiation of such procedures earlier in the descent. However, experience will give the crew sufficient data to make this a routine operation.

The crew's responsibility will continue to be the interception of an assigned altitude with as little overshoot as possible, the comfort of the passengers and the monitoring of power plant performance.

In this particular flight regime the aircraft should operate like any current subsonic aircraft, and the crew should be able to handle it in a manual mode. In fact, until proper training can change pilot thinking, it will be a necessary mode of operation.

4.17 FUNCTION 4.17 THRUST APPLICATION = F (OPTIMUM MANEUVER SPEED); INITIAL APPROACH

Purpose

This function is to vary the output of the power plants so as to maintain an airspeed for the landing sequence. Having reached a final approach altitude, some maneuvering of the aircraft is necessary to intercept the ILS (instrument landing system) final approach course for landing. The airspeed selected for this maneuvering is usually some function of the stall speed. It is usually referred to as the landing reference speed and is a function of the landing gross weight and the aircraft configuration. After the aircraft attains level flight, and has been positioned in the landing pattern, power is decreased to obtain a slower speed. As this speed is attained, the high life devices (i.e., flaps, droop, slots, etc.) are utilized,and as the reference speed is approached, power is readjusted to maintain this speed (straight and level).

Current Jet Operational Requirements and Constraints

The initial approach phase is utilized to provide optimum spacing for traffic on final approach, and for reconfiguring aircraft so that they will be compatible with traffic on final approach. Descent speeds are usually notably higher than those speeds utilized on final approach. Thus, separation distances would be decreasing if some kind of procedure were not set up for shifting to lower speeds.

The initial approach phase is also advantageous for the crew because it permits readying the aircraft for landing while flying straight and level, and prior to intercepting the final approach course.

Current Jet Implementation Concepts

Once the aircraft has leveled-off at the initial approach altitude, the aircraft must be readied for landing. The throttle is manipulated so that available energy is decreased. Since a constant altitude is being maintained, the decrease is manifested as a decrease in airspeed. After the aircraft is reconfigured for landing, and the landing reference speed attained, power is added to maintain this speed throughout the pattern. The throttles are then manipulated as necessary to maintain this reference speed.

SST Potential Operational Requirements and Constraints Modification

There do not appear to be any modifications necessary to present requirements. The SST, as proposed, will have to be capable of conforming to patterns utilized by subsonic carriers, and that implies compatible airspeeds.

Feasible Automated Implementation Concepts For SST

The auto-throttle can be utilized to maintain the constant airspeed, but whether it is easier to dial in a commanded airspeed or to actually fly the required speed is yet to be determined. The use of an auto-throttle would allow the crew to concentrate attention in other areas. Whatever the outcome, the pilot and crew will be responsible for seeing that the required amount of power is available for the speed and configuration desired. The use of power to maintain level flight at a constant altitude is one of the basic concepts of flight. The aerodynamics of the SST might dictate higher approach speeds, and perhaps higher power settings, but the basic underlying principle will be the same.

Feasible Manual Implementation Concepts For SST

Throttle manipulation to obtain energy necessary for a particular maneuver is a feasible concept and is similar to that of current operations. It must be remembered that with high performance aircraft, and swept-winged aircraft in particular, for each configuration of the aircraft there is a set of curves which will give the functional relationship between airspeed and thrust. This is not a completely linear function, and for jet aircraft there is a portion of the power curve called the "back side" of the curve. In this regime more power is needed to obtain a slower airspeed. In some aircraft it may be necessary to fly in this speed regime because of the requirement for a slower approach speed. This may be the case with the SST.

In the SST, the crew will be responsible for insuring that sufficient power is available when needed to maintain any desired airspeed in any particular configuration. Current subsonic jets operate in this manner and so there should be no transfer problems when the SST is introduced.

4.18 FUNCTION 4.18 THRUST APPLICATION = F (OPTIMUM MANEUVER SPEED); FINAL APPROACH

Purpose

This function is to vary the output of the power plants to insure that sufficient power is available to maneuver the SST along the final approach course, and to maintain an approach speed which is consistent with safety factors. The final approach can be assumed to commence at that point in space where the aircraft has reached the final approach altitude, or is in the process of intercepting the ILS final approach course. Once the final approach begins, power will have to be used to keep the SST on its electronic glide path with the desired airspeed. The flight controls will be used with the power plants to maintain the final approach course and to assist in maintaining the desired airspeed.

Almost all experts on the SST insist that in order for it to be an economic reality, it must incorporate some form of all-weather landing system. However, all of the automatic landing techniques under consideration require the pilot to perform several tasks manually. These tasks include:

1. Establishing an initial approach attitude, altitude, and heading.
2. Setting and utilizing flaps as desired.
3. Lowering the landing gear.
4. Establishing an initial approach airspeed.
5. Setting the desired runway heading on the flight director, horizontal situation indicator, or other instruments.

Current Jet Operational Requirements and Constraints

Throughout the final portions of the landing approach, there is a requirement for various energy outputs consistent with the aircraft's configuration and the maneuvers required. These variations in the power plant output will be a function of airspeed requirements, particularly the airspeed control throughout the initial approach pattern, the airspeed control on final approach, and the airspeed control during flare-out. These controls of airspeed are coordinated flight control/ power plant maneuvers.

Current Jet Implementation Concepts

In current operations the crew utilizes the throttle to vary the output of the power plants. As airspeed and maneuver requirements change, the crew manipulates the throttle so as to have sufficient power for the maneuver. Prior to reaching the final approach course, the throttle is varied to obtain an RPM which will provide sufficient energy for level flight in the dirty configuration (i. e., flags and landing gear extended). As the final approach course is reached, and the glide slope approached, the attitude of the aircraft is readjusted to pick up the final approach speed, and the throttle is readjusted to start a rate of descent. Once the glide slope is attained, the throttles are varied to maintain this electronic beam with the smallest possible deviations (both in movement away from glide path and in airspeed).

SST Potential Operational Requirements and Constraints

The requirement to maintain certain airspeeds throughout the final approach pattern will continue into SST operations. One other factor which will be introduced will be noise. If an aircraft makes a nose-down approach, the engine noise will be directed away from the ground and thus attenuated. However, if the aircraft lands nose-up, the engine noise will be directed downward and thus accentuated.

Feasible Automated Implementation Concepts For SST

The use of the auto-throttle through the approach pattern and on the final approach will greatly alleviate some tasks for the crew during this busy flight phase. The responsibility of the crew will be to insure that sufficient power is available to maintain the required airspeeds. This means that the crew will be responsible for commanding certain airspeeds while in the manual portion of the approach, and monitoring the system during final approach in the automatic mode. In the event of some non-routine performance, the manual overriding of the auto-throttle will usually disengage the automatic system.

Because of the time lag between throttle movement and power output, adequate instrumentation will need to be available so that the crew can stay ahead of the aircraft. The optimum flying of high performance aircraft is predicated on this anticipatory ability.

Without a doubt, the final approach in an SST will be a combination of man and machine control. The crew's main function and responsibility on the final approach will be to monitor the functioning of the automated system, and to insure that its performance is within tolerances. Between now and the actual introduction of the SST, crews will be using new landing systems. Each will incorporate a little more automation, but presently there is no indication the crew will be taken out of the loop.

Feasible Manual Implementation Concepts For SST

Manipulation of the throttle in response to airspeed requirements will be the method utilized to manually fly the SST. This performance will be similar to current operations. The crew would continue to be responsible for controlling airspeed throughout the approach pattern, and insuring that sufficient energy was available to perform any required maneuvers.

Assuming that the rest of the automatic system is operating normally, the crew could be kept in the loop by eliminating the auto-throttle concept. The crew's task would be to track the glide slope, a task well within the crew's capability. However, some question could be raised concerning the crew's ability to perform the flareout. If the crew were provided instrumentation which displayed reduced power requirements as automatic flare was initiated, the task would continue to be a tracking task. However, if the flareout is initiated upon the crew's visual contact with the runway, then the same restrictions described in Function 4.20 will hold.

As in current operations the throttle would be adjusted and readjusted as required to control both the airspeed and the rate of descent. Ideal performance would be the maintenance of the glide path at the optimum airspeed (the speed corrected for the aircraft's landing weight).

4.19 FUNCTION 4.19 THRUST APPLICATION = F (MAXIMUM POWER); MISSED APPROACH

Purpose

This function varies power plant output so as to supply energy to the aircraft in sufficient quantity to change its attitude and direction from a descending aircraft to a climbing or level aircraft. At any moment during the final approach, a decision can be made to abort and take another course of action. When this decision is made, the aircraft must be capable of stopping its descent, and in some cases must be able to climb.

Current Jet Operational Requirements and Constraints

It has always been necessary for the crew to be able to abandon an approach at any point if such a decision is made. The advent of jet aircraft brought a few new characteristics to this maneuver. The heavier aircraft, the larger rates of descent, and the power lags (between throttle movement and actual power output) have all influenced the performance requirements of the missed approach.

By regulation the crew is required to execute such a maneuver if the runway is not visually sighted at the minima of the approach. In other words, the aircraft can come down to a particular altitude and then must level-off. If the runway is not sighted, some other procedure must be followed.

Current Jet Implementation Concepts

Crew performance requirements are similar in any type of aircraft, and it is not anticipated that the SST crew will experience any appreciable workload increases. In today's subsonic jets, the crew, upon recognizing the need to abort, will apply takeoff thrust and simultaneously start to change the attitude. Once the aircraft has picked up a climb attitude, it is usually "cleaned up" (gear raised), and the crew will make a decision for further action.

Although noise considerations have played a major role up until this time, most missed approaches, at least at very low altitudes, are predicated on dangerous situations, and might be considered non-routine operations. Thus, the basic concern of the crew will be to perform the maneuver so as to maintain the safety of the aircraft.

SST Potential Operational Requirements and Constraints

If the SST utilizes an all-weather landing system, the missed approach minima will either have to be eliminated, or limited to those aircraft not suitably equipped with adequate systems. Other than that, all other safety considerations will continue into SST operations. Studies of the SST handling characteristics on final approach will have to be reexamined once final designs have been chosen to determine any new characteristics which might adversely affect crew performance.

Feasible Automated Implementation Concepts For SST

Because of all of the variables which would influence the missed approach, and because of the instantaneous performance required, no automatic implementation of this function is currently being advocated. Of course a computer programmed missed approach is feasible and could be actuated instantaneously. Whether the crew would accept such a system is yet to be determined.

Feasible Manual Implementation Concepts For SST

The missed approach maneuver in the SST will in all likelihood continue to be a manual operation. Although many concepts are being presented which rely on an automatic landing system, almost all U.S. companies insist on keeping the pilot in the loop in case there is a missed approach situation. Thus, the pilot's ability to override the automatic system (auto-throttle) is not inconsistent with the landing concept for the

SST. Once the missed approach has been performed by the crew, the automatic system may again be utilized. The crew will continue to be responsible for the safety of the aircraft, and compliance with any ATC instructions.

4.20 FUNCTION 4.20 THRUST APPLICATION = F (FLARE EXECUTION)

Purpose

Output of the power plants is varied in this function in conjunction with the flight control system to reduce the energy of the system in a controlled stall maneuver. Prior to the initiation of the flare maneuver, the aircraft is in a descending attitude (rate of descent of about 600 feet per minute) and maintaining an approach speed which is consistent with the weight of the aircraft and the surrounding weather conditions. In those aircraft requiring flight on the back side of the power curve, sufficient power is supplied to the system to maintain the airspeed and rate of descent required to fly the automatic landing system. When landing is assured, the aircraft's attitude is changed to decrease the rate of descent (to around 200 feet per minute), and the power is set to idle so the aircraft will actually stall as it lands. This prevents the aircraft from floating half way down the runway, and reducing the available roll-out distance.

Current Jet Operational Requirements and Constraints

Larger, faster aircraft approach the runway at extremely high rates of descent, and at angles of attack other than the optimum for main landing gear contact with the runway. Therefore, the aircraft attitude must be changed so as to decrease the rate of descent and obtain a desirable angle of attack for runway contact with the main landing gear. Optimum performance is required in this area to prevent lengthy deviation from the optimum touchdown point and shortening the available roll-out distance.

Price, Smith and Gartner (ref. 33) describe flareout as,

> . . . a maneuver for changing the aircraft attitude and reducing the rate of descent just prior to touchdown in order for the air-

craft to have a desirable angle of attack for runway contact with the main landing gear and to touchdown at an optimum rate of descent. Flareout is usually initiated when the aircraft is in the vicinity of the runway threshold and results in a gradual change in attitude and rate of descent until touchdown.

Present concepts for final approach vertical guidance are to control the aircraft along a straight line path which intercepts the runway in a horizontal plane. The rate of descent of the aircraft is then directly proportional to its approach speed. Current instrument landing system installations include a glide slope beam inclined at an angle of 2.5 to 3 degrees. It is impractical to lower this approach beam any further because of terrain clearance and radiation problems, and in fact with higher performance aircraft it may be desirable to have higher approach angles. Thus the solution to change from a high rate of descent (as much as 60 feet per second for high speed aircraft) to a nominal rate of descent (approximately 2 feet per second) at touchdown is to flare the last segment of the vertical flight path. . . .

Current Jet Implementation Concepts

In today's operations the crew usually performs the flare maneuver manually. That is, the crew makes the decision to flare, starts to change the aircraft's attitude, and decreases power as necessary to initiate a controlled stall. This manually flown maneuver places some restrictions on the landing minima for the aircraft. If the aircraft is descending at a certain rate of descent, and if it takes the crew a certain length of time to visually survey the situation, make a decision, and then initiate the flare maneuver, then this would describe how high above the ground the crew must have visual contact with the runway in order to fulfill the requirements of the performance.

SST Potential Operational Requirements and Constraints

Because of the higher rates of descent associated with the SST, and because of the slower longitudinal response of the control system, it would appear that landing minima using manual means will need to be raised. In the case of automatic all-weather landing systems, the changes will be such as to decrease the existing minima.

The basic consideration will be changing the aircraft's attitude so as to decrease the rate of descent, and optimize the contact attitude of the main landing gear and the runway.

Feasible Automated Implementation Concepts For SST

The performance of the SST crew will be similar to that of today's subsonic aircraft crew. SST operations will find the crew monitoring the final approach and ascertaining that the automatic landing system is functioning properly. The crew will have the prerogative of allowing the automatic system to initiate the flare, or after visual contact overriding the system and performing the maneuver manually.

Even though the flare maneuver will be handled via an automatic function, the crew's responsibility will continue to insure that rates of descents are decreased to acceptable values, and that the aircraft touches down within acceptable deviations from the optimum touchdown point.

Feasible Manual Implementation Concepts For SST

The crew will have the capability to fly the final approach manually, and to perform the flare maneuver as in current operations. However, because of the higher performance characteristics of the SST, in all likelihood the visual minima will probably have to be raised for a manual approach. Because of the higher sink rates and the higher approach speeds, the crew will have less time to make critical decisions. Thus, although the SST may have all-weather landing capability with the automatic system functioning properly, a malfunction of this system will make it necessary to divert to an alternate. It is quite feasible that this will occur even though the destination airport has weather which is acceptable to current subsonic aircraft.

The crew's manipulation of the throttle in conjunction with the aircraft's attitude change will provide the decrease in energy necessary to obtain an optimum landing point.

The crew's responsibility will continue to be optimization of the touchdown point, and acceptable rates of descent on touchdown (both for passenger comfort considerations and for landing gear structural limitations). Large deviations from optimum touchdown point decrease the amount of available roll-out runway.

4.21 FUNCTION 4.21 THRUST APPLICATION = F (SURFACE SPEED); THRUST REVERSAL FOR BRAKING

Purpose

This function is to provide a source of braking for the decelerating aircraft through variation of the power plant output. Depending upon the accuracy of the flare maneuver, the aircraft will touch down at varying distances from the threshold (usable end of runway) which will then leave a certain amount of available runway for rollout. Since there are no immediate plans for lengthening present runways, and since the performance characteristics of the proposed SST on approach and landing are "hotter" than those of current subsonic aircraft, most companies are requiring that the SST have some form of thrust reversing for braking.

A Space/Aeronautics Staff Report (ref. 29) on the SST expresses the general consensus concerning the development and use of thrust reversal:

> . . . the SST will probably have to be capable of thrust reversal. FAA has suggested a maximum of 8000 ft as a landing distance. Some experts' calculations of minimum possible distances for present configurations show a range of values from 8000 to 10,000 ft with idle thrust and brakes only, and 5000 to 6000 ft with 20 percent reverse thrust. Because of the SST's higher ratio of thrust to gross landing weights, the amount of the engine's thrust required to be reversed is more likely to be 20 percent, as assumed here, rather than the 40 percent that is required of present subsonic transports.
>
> Even if one of the three (now two)* configurations proposed for the SST could provide acceptable landing distances without thrust reversal, it is highly probable that the airlines would demand reversers for adverse runway conditions and emergencies such as loss of brakes and takeoff aborts. . . .

---

*Parenthetic insertion by the authors.

Upon completion of the flare maneuver and the subsequent touchdown, the aircraft will still possess some velocity which will be less than landing speed (landing can be considered a controlled stall), and because of its high gross weight, a large amount of kinetic energy. Aerodynamic braking (utilizing the aircraft's surfaces to generate high drag), as well as the friction between the aircraft wheels and the runway will cause a decrease in airspeed and hence in kinetic energy. However, only in the ideal situation where unlimited runway is available will these forms of energy "taps" be sufficient to slow the aircraft to a speed at which the braking system can be effectively utilized. Of course, perfect performance by the crew in attaining the exact landing speed, optimum touchdown point, and a strong headwind will allow the aircraft to slow to taxi speeds within the runway available. However since these factors cannot be considered as constraints, some form of back-up braking system must be provided.

The aircraft must be decelerated to a safe taxi speed in the runway remaining. Brakes will be utilized when the speed of the aircraft is in that regime where it is safe to do so.

For further descriptions of the performance required of the SST crew, and of the current and forecasted implementation concepts, see Function 4. 4.

4.22 FUNCTION 4.22 THRUST APPLICATION = F (SURFACE SPEED); TAXI TO LINE

Purpose

This function is to vary the power plants so that sufficient energy is supplied to move from the end of the operational runway to the designated unloading area. The power required will be a function of the weight of the aircraft and the desired surface speed which, of course, must be consistent with safe ground control procedures.

The description of the crew's performance and involvement will be found under the description of Function 4.2. Function 4.2 deals with the taxi from the loading area to the operational runway. Taxi to line is just the reverse of that performance, and the crew involvement will be the same.

The chief problems which will be encountered in SST operations will not be in the area of power plant operations, but rather in the other areas associated with the taxi phase. The larger aircraft, the pilot's higher position, and the basic configuration of the crew's compartment and amount of visibility will make it quite difficult for the SST to maneuver on the ground.

Current Jet Operational Requirements and Constraints

Requirements are the same as those described for Function 4.2.

Current Jet Implementation Concepts

See Function 4.2.

SST Potential Operational Requirements and Constraints

See Function 4.2.

Feasible Automated Implementation Concepts for SST

See Function 4.2.

Feasible Manual Implementation Concepts for SST

See Function 4.2.

4.23 FUNCTION 4.23 ACCOMPLISH POWER PLANT SYSTEM DEACTIVATION

Purpose

This function is to vary the power plant controls so as to comply with operational procedures concerning shutdown and to insure that power removal will not damage any of the subsystems because of transients or surges. Once the status of the aircraft subsystems has been verified and contact has been made with ground handling crews, the power plants can be deactivated. In most cases this will consist of closing the engine throttles and fuel controls.

Current Jet Operational Requirements and Constraints

Most of the requirements in this area deal with possible malfunctions in the system. Standard operating procedures are usually set up as a guide to optimize the method for deactivating the power plant system. The application of external electrical power is usually a necessity, for in the event of a malfunction or shutdown some source of electrical power must be available to perform malfunction procedures.

Current Jet Implementation Concepts

The Boeing 720 Operations Manual (ref. 22) describes its normal shutdown procedures as follows:

> ...engines must be operated below 85% N_2 rpm for 5 minutes before shutdown to prevent possible engine damage. Any operating time below 85% N_2 rpm may be included in this 5 minute period such as, approach to land, landing, taxiing and parking.
>
> (1) Thrust Lever -- Idle; (2) External Power -- Plugged in; (3) External Power Switch -- On; (4) Essential Power Switch Ext Power; (5) Engine Start Lever -- Cutoff; (6) Engine Fuel Valves -- Close; and (7) Fuel Boost Pumps -- Off...

The crew's main responsibility is to insure that the engines are deactivated in a normal manner in accordance with performance criteria.

SST Potential Operational Requirement and Constraints

There does not appear to be any need for modification from current requirements. The same safety considerations will prevail.

Feasible Automated Implementation Concepts for SST

No automatic concept is envisioned at present for this function. Performance will be manual with perhaps some indication of system status displayed prior to shutdown as a result of the on-line computer check of the system.

Feasible Manual Implementation Concepts for SST

Insuring that electrical power is attached to the aircraft, moving the throttle to the "OFF" position, and closing down the fuel controls will be the means for deactivation for the SST.

The SST's crew's main concern during this particular performance will be to react in case of a malfunction. There is always the possibility of a fire during shutdown procedures, and this must be watched for. Other than that the crew's performance will be very similar to what is found in today's operations. There is no reason to suspect the operational procedures will change with the advent of the SST.

ACTIVITY 5.0 FLIGHT CONTROL

PURPOSE

The static forces of an aircraft, lift, weight, drag, and thrust --all acting in the vertical plane--are assumed in equilibrium, and their effect on the performance of the vehicle is determined by applying Newton's fundamental laws of statics. The ability of a vehicle to maintain its equilibrium is termed its stability; and the influence which the pilot or guidance system can exert on the equilibrium is termed its controllability.

An aircraft has to be able not only to raise itself from the ground, but also, once airborne, to be controllable and able to fly steadily at any desired speed and attitude within the operating range. Moreover, it should preferably be stable; that is to say, if it is accidentally thrown out of its correct flying attitude by a disturbance such as a sudden gust, or by misuse of the controls, it should be able to recover its correct attitude when left to itself, without any corrective action on the part of the pilot. And it should be able to do this regardless of the attitude from which it starts. An airplane that possesses this property is said to be inherently stable.

In the early days of aviation small planes with relatively slow airspeeds caused very few flight control problems. Now, with larger and heavier aircraft and aircraft that operate through a wide spectrum of airspeeds, other factors need to be considered. As the airspeed increases, the dynamic pressures on the aircraft's surfaces increase. This in turn increases the pressure (force) needed to displace the control surfaces. This has resulted in the use of control tab assisted flight controls. However, other problem areas then arise. Since the amount of control needed in various flight phases and speed ranges differs, some compensation must be made so that the aircraft's control system will be within safety limits during all phases of flight. Large aircraft at slow speeds require large control surfaces to obtain the rate of response necessary in these marginal areas of flight. These same aircraft need relatively small amounts of control surface when operating in the multi-Mach ranges.

Assuming that the SST is equipped with a flight control system which will provide the necessary controllability over the entire range of the flight profile, the crew involvement is the concern of the flight control operations. It appears that the final choice for the SST will be an electro-mechanical system into which will be integrated the various automated systems, e. g., auto-pilot, auto-stabilization, and auto-throttle.

Within the entire profile in which the SST will operate, there are various degrees of crew involvement with the flight control system. In fact, there is a changing relationship between man and machine. The functional descriptions which are linked to the various flight phases attempt to distinguish what role the crew will actually play in the required performance. As was suggested by most experts in the over-all description of the SST, many of the tasks will be completely automated, and the crew will act as monitors and will be available to either reconfigure the system in the event of malfunction, or to manually accomplish the required performance.

If all the factors could be forecast, and the SST could be programmed for a completely automatic flight, it could conceivably be thought of as a manned missile flying a particular trajectory. However, various operational constraints limit the extent of possible automation such that the SST is merely a high performance model of today's subsonic carrier. Higher speeds, high altitudes, longer distances, larger aircraft; these are but a few of the changes which the SST introduces into commercial aviation. The new parameters and the sophistication of the systems designed to cope with all the new problems will be the basis for a re-evaluation of current subsonic aircraft by pilots. Performance requirements will change appreciably in some critical flight phases, and the crew must be willing to accept the new responsibilities.

The automated concept is not a new one, but to the SST crew it must not only provide reliable performance, but in the event of a malfunction must provide adequate interface so that the takeover by the crew may be accomplished smoothly and in a timely fashion.

CURRENT JET OPERATIONAL REQUIREMENTS AND CONSTRAINTS

The following regulation applies to flight control.

FAR 121.579, ref. 11:

Minimum altitudes for use of automatic pilot.

(a) *En route operations.* Except as provided in paragraph (b) of this section, no person may use an automatic pilot en route, including climb and descent, at an altitude above the terrain that is less than twice the maximum altitude loss specified in the Airplane Flight Manual for a malfunction of the automatic pilot under cruise conditions, or less than 500 feet, whichever is higher.

(b) *Approaches.* When using an instrument approach facility, no person may use an automatic pilot at an altitude above the terrain that is less than twice the maximum altitude loss specified in the Airplane Flight Manual for a malfunction of the automatic pilot under approach conditions, or less than 50 feet below the approved minimum ceiling for the facility, whichever is higher, except—

(1) When reported weather conditions are less than the basic VFR weather conditions in § 91.105 of this chapter, no person may use an automatic pilot with an approach coupler for ILS approaches at an altitude above the

terrain that is less than 50 feet higher than the maximum altitude loss specified in the Airplane Flight Manual for the malfunction of the automatic pilot with approach coupler under approach conditions; and

(2) When reported weather conditions are equal to or better than the basic VFR minimums in § 91.105 of this chapter, no person may use an automatic pilot with an approach coupler for ILS approaches at an altitude above the terrain that is less than the maximum altitude loss specified in the Airplane Flight Manual for the malfunction of the automatic pilot with approach coupler under approach conditions, or 50 feet, whichever is higher.

CURRENT JET IMPLEMENTATION CONCEPTS

The most common forms of flight control systems in operation today are similar to that found on the Boeing 720. The Boeing Operations Manual (ref. 22) describes the system as follows:

> . . . the primary control surfaces consist of ailerons, elevator and rudder. These surfaces are aerodynamically balanced and are actuated by means of cable controlled tabs. The flaps and spoilers are hydraulically operated. In addition to aiding in lateral control, the spoilers can also be used as speed brakes. The horizontal stabilizer angle of incidence may be varied electrically, manually or by the autopilot. The primary flight controls incorporate control systems for both manual and automatic (autopilot) operation of inboard ailerons, rudder and elevator. Hydraulic rudder boost is incorporated. The automatic flight control system consists of an Autopilot which includes an automatic VOR-ILS beam coupler. The Autopilot provides sensitive, automatic, coordinated control of the airplane at any desired altitude, attitude, and heading. . .

The Boeing 720 flight control system typifies those found in current subsonic aircraft, and is a prime example of the evolution which has taken place in this area of aviation. Looking closely at the flight control system, it can be readily seen that certain distinct areas exist which will influence the crew performance to some extent. The first of these areas are the portions of the aircraft which actually induce the controllability factors; the control surfaces. These are usually outside the influence of the crew and are mainly the responsibility of designers. Although not involved in the control surfaces themselves, the crew becomes quite involved in the systems which transduce their motor actions into desired control surface movement. In current operations these systems are composed of cable actuated control tabs, and electro-mechanical auto-pilot systems.

The use of the cable actuated control tabs might be considered the most manual means of operation utilized by the crews of today's sub-sonic carriers. The traditional yoke and wheel and rudder pedals are mechanically positioned by the crew to obtain the required performance. Back-up systems in the form of trim tabs assist in reducing the forces in the system. The trim tabs aerodynamically balance out these forces, so that the crew is no longer required to exert all of the energy to obtain continued performance.

Today's crews use the cockpit controls in much the same way controls were utilized in early aviation. The yoke is moved to control vertical deviations, and the wheel and the rudder pedals are coordinated to obtain lateral changes. Although the flight characteristics of aircraft have continued to change, and the performance characteristics have become critical, the crew uses essentially the same interface means, for obtaining three dimensional positioning of the aircraft.

Assistance has now been provided by the auto-pilot, which will provide an electro-mechanical means for accomplishing all the required flight control functions. In most instances the auto-pilot offers all degrees of man-machine relationships from a completely automatic system where the crew merely monitors, to an aided system where man accomplishes the complete function using only the electro-mechanical portion of the auto-pilot instead of the straight mechanical flight control system.

Currently the manual system is utilized in those critical areas of flight, e. g., takeoff, rough weather penetration, and landing. Some portion of the automatic system is utilized throughout remaining portions of flight.

SST POTENTIAL OPERATION REQUIREMENTS AND CONSTRAINTS

Many new requirements and constraints will be introduced with the advent of the SST in commercial aviation. However, many of the problem areas which will be encountered by the designers of the SST control systems, have already been solved and tested in associated military systems. The FAA Bureau of Flight Standards (ref. 24) describes some of the requirements and constraints associated with the SST,

> Supersonic transport flight control systems will need to meet a much more complex array of conditions than any of the past or present civil transports. In addition to the present low-to-high subsonic speed controllability with suitable feel characteristics there must be adequate control and pilot feel through the transonic and supersonic ranges. Changes in airframe configuration such as variable sweep, hinged wing tips and other devices may be employed. Automatic flight control, automatic landing systems and other advances may be incorporated in the systems of the aircraft...
>
> The primary control system will be one of the most vital elements of the supersonic transport. Its reliability will be of paramount importance. Because of the variety of conditions to be met and the magnitude of the forces involved, power assist or actuation with secondary and other standby means of operation will be essential. The matter of primary control operation in the event of failure of all engines must be considered. Some preliminary studies indicate that the power demands for even limited

> controllability are beyond the capability of present energy sources such as batteries...

Lee (ref. 34) discusses the type of control system which will in all likelihood be used on the SST,

> ...because of the variation of Mach number experienced in modern aeroplanes, the traditional methods of obtaining aerodynamic balance (such as set-back hinges, aerodynamic servo tabs, etc.) have become inadequate in many cases and manual control has therefore had to be abandoned in favour of power control, usually coupled with artificial feel to replace the natural feel provided by the hinge moments. This has meant putting a servo between the human pilot (or automatic pilot, or autostabiliser servo) and the control surface.
>
> Problems which arise from such a system are those of servo stability, frequency response (that is amplitude ratio, phase lag, threshold, etc.) and the power output; all of these quantities are subject to tolerances, often quite large ones. The high range of E.A.S. to be covered brings with it the problem of resolution, i.e. the precision with which the control surface can be set to the angle required by the pilot...
>
> ...It is now accepted that various forms of 'artificial' aid will probably be built into a modern aeroplane to give it the required stability and control characteristics; this is especially the case for aeroplanes operating over a large range of Mach number. These devices may provide damping, based on gyro principles (e.g. the yaw damper), or may counter movements of neutral point (e.g. a Mach trimmer) or can vary the effective thrust drag speed relationship (e.g. auto-throttle control), and so on.
>
> By accepting such devices, the aeroplane designer obtains more freedom in selecting the aerodynamic characteristics of his aeroplane, for the ability to employ artificial stability aids means that, within limits, some of the derivatives may be permitted to vary considerably and thus it is possible to tolerate a wider range of basic 'aerodynamic' derivatives than would have been possible if stability and control had had to be achieved by the classical means of airframe design (i.e. aerodynamics, mass distribution, structural stiffness) only. Hence, this greater design freedom can be devoted to obtaining a higher aeroplane performance (e.g. more speed, or a lighter structure, etc.) and greater operational efficiency...

It is probably fair to say, therefore, that whereas the modern aeroplane designer is very ready to employ non-aerodynamic solutions to stability and control problems if, by so doing, he can obtain operational advantages, yet there is still a great attraction in trying to retain the old ideal of the naturally stable, manually controlled aeroplane.

Ostgaard (ref. 35) has suggested the following performance requirements for SST flight control systems:

> Before attempting to design a particular system or apply any specific techniques to solving a control problem, the requirements for control must be specified. In the case of supersonic transports the flight control system must provide the dynamic performance, reliability and capability necessary for the vehicle mission with commensurate flight safety. A brief resume of typical dynamic performance requirements as well as systems mechanization requirements are as follows:
>
> A. Dynamic Stability - The transient normal acceleration response which occurs at approximately constant speed by abruptly deflecting and returning the pilots control to trimmed position shall damp to 1/10 amplitude in one cycle or less, and the magnitude of any residual oscillations shall not exceed 0.03 g's at the pilots station. In addition there shall be no sustained or uncontrollable oscillations resulting from efforts of the pilot to maintain steady state flight.
>
> B. Accelerated Stability - The slope of the curve of pilot control input versus normal acceleration shall be stable, increasing aft displacement for increasing of loading throughout the range of attainable load factors and in all conditions of flight. In steady state turning flight and in pull outs, increases in pull force shall be required to produce increases in positive normal acceleration. The variation in force required to produce an incremental increase in acceleration shall be essentially constant up to 85% of maximum attainable or allowable acceleration. Above the 85% of normal acceleration an increase of 50% is allowable in the local force gradient.
>
> C. Speed of Response - The rate of response to a pilot control input shall be such that the pilot shall not be required to command inputs over and above normal steady state input in order to increase the rate of response

during normal maneuvers. There shall be no excessive overshoots or over control tendencies.

D. Speed Stability - For trimmed flight an increase in speed shall result in a nose up pitching moment. The pilot force required to maintain level flight shall be aft for a decrease in speed and forward for an increase in speed. The long period phugoid damping shall be positive at all flight conditions.

E. Augmentation System - The augmentation system shall in addition to its normal function of damping add to or subtract from the pilots input to provide uniform response characteristics without restricting pilot authority. Further the system shall allow maneuver capability up to the limit load, and shall provide the necessary shaping and limiting for automatic hold modes and navigation inputs. The augmentation system shall have adequate authority to adequately control the vehicle in the event of primary control system failure.

F. Gust Disturbances - Definition of gust responses is beyond the scope of this paper but, the system shall have the capability to damp such disturbances to less than 1/4 amplitude in one cycle.

The above represent the basic performance requirements for a supersonic transport flight control system.

FEASIBLE AUTOMATED IMPLEMENTATION CONCEPTS FOR SST

With the increased performance characteristics of the SST consensus seems to indicate the use of automation in large portions of the flight control system. As has been indicated, the basic system will, in all likelihood, be a full powered electro-mechanical system. To this will be added an auto-pilot system similar to that found in today's operations, partial use of an on-line computer to perform in accordance with a pre-programmed flight profile, and an all-weather landing system capability. As in current operations there does not appear to be any off-line equipment which will be utilized to obtain the required flight control performance.

An important area of concern will be the crew-equipment interface. In an automatic mode of operation, the crew will perform primarily as a monitor and will require instrumentation to present a concise picture of system operations. Currently, many flight parameters must be analyzed to gain insight into automatic system operation. This is time consuming and leads to crew error. Research will need to be conducted in this area to develop displays which integrate multiple parameters to give a concise situation picture which can be readily utilized by the crew.

In the automatic mode of operation, the first place in which automation appears is the takeoff roll. An on-line computer analyzing pre-programmed data versus dynamic parameters could abort the takeoff and aid in maintaining directional control. If takeoff is continued, assistance could be given the crew in optimizing their rotation rate and amount of rotation. Once this is completed and air traffic control has given clearance for unrestricted climb, the flight control system could receive commands from either a pre-programmed flight profile, or from an internally generated optimum profile (see Enroute Navigation). Pre-programmed level-off procedures could be utilized to gain optimum performance without great discomfort to the passengers. Finally, in the landing phase, auto-throttle coupled with the auto-pilot could give touchdown capability.

This, to a great extent, is the ideal concept, and must be degraded as snags are encountered. Although the guided missile concept may not be completely realistic, the SST could be almost all automatic.

Ostgaard (ref. 35) describes some typical mechanization characteristics for SST flight control systems. Excerpts from this paper are presented below, but they also apply to manual concepts.

> The flight control system for the supersonic transport is rather impressive in various respects when compared to systems for conventional transports. The most obvious aspects are those associated with the size of the system and related power sources. Approximately 150 foot cable runs can be expected for a typical mechanical system from the pilot control back to the elevon system.

Somewhere in the order of 25-30 hydraulic servo actuators are anticipated for the longitudinal control system. Of these, approximately 20-24 would be elevon actuators which are common to both the pitch and roll controls. Although not as obvious but equally impressive are some of the performance characteristics required in a system of this type. The column friction must be held to not greater than 2 pounds. The average hysteresis bandwidth at the control column must be held to 0.1° equivalent elevon motion or less. To provide the necessary performance, frequency response characteristics of this must approach five cycles per second. To achieve this type of performance, mechanical systems will require hydraulic power boosters in the primary control system at an attendent weight and complexity penalty.

The surface actuators are conventional in design except for temperature requirements, but then hinge moment capabilities will be high. Estimated values for elevon actuators can range as high as 400,000 in. lbs. /actuator with stiffness requirements in the same range. A functional schematic of this typical system is shown in (Figure 23).

(Figure 24) shows a functional block diagram of a typical augmented flight control system. A normal accelerometer and a pitch rate gyro are used as air vehicle feedback transducers for this application. The accelerometer functions to tighten the aerodynamic servo loop resulting in improved aerodynamic stiffness, or speed response, and accelerated stability. Increasing aerodynamic stiffness with the accelerometer however results in a lower dynamic stability. To increase the dynamic stability to an acceptable level a pitch rate gyro is utilized to sense the air vehicle pitch rate thereby providing the loop required for the necessary dynamic stability. In order to achieve the desirable levels in pilot force required per unit of air vehicle response, a transducer or pickoff is connected to the pilot's controls, measuring his maneuvering commands in terms of control displacement. These signals then are electrically summed and amplified in such a manner that the net servo displacement command is the sum of the pilot input less the amount proportional to the air vehicle normal acceleration and pitch rate. In order to achieve optimum performance over the entire flight envelope, the augmentation system electronic gain must be adjusted. This can be adjusted as a function of measured aerodynamic parameters such as mach number, altitude, and so forth, or through adaptive techniques wherein the servo response is used to achieve the proper gain setting. This capability is required in

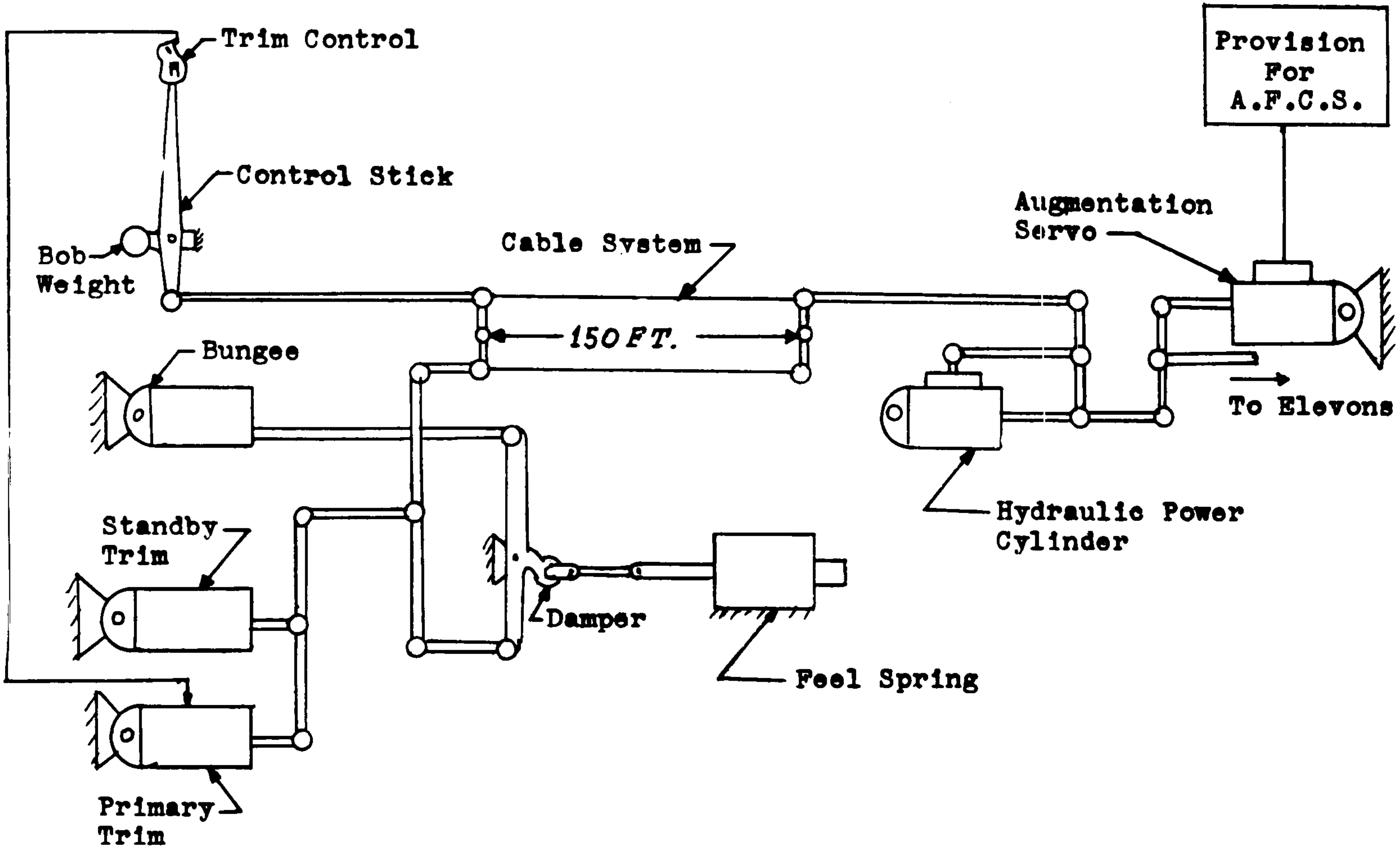

Figure 23. Mechanical primary flight control system (from ref. 35).

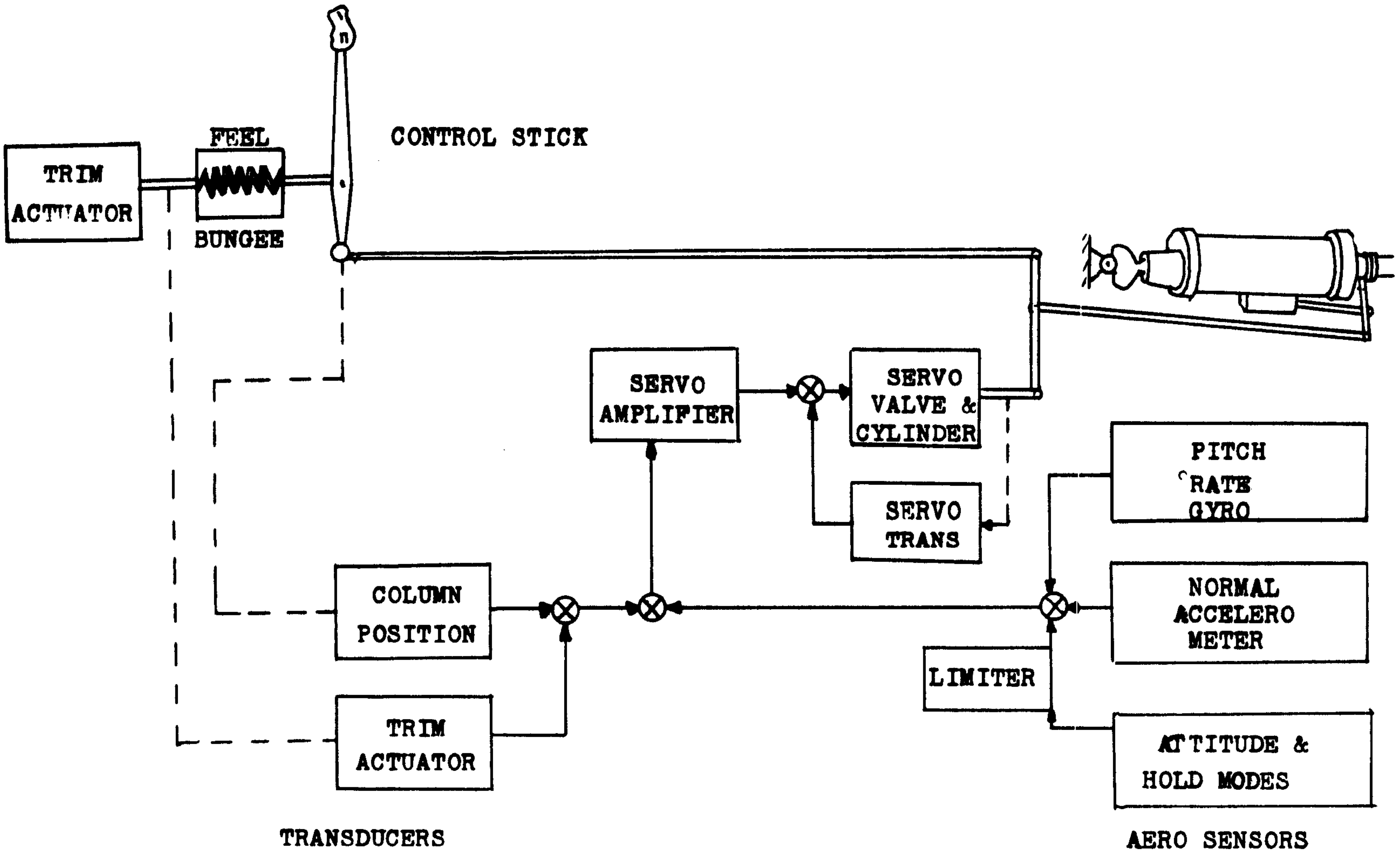

Figure 24. Augmentation system block diagram (from ref. 35).

order to provide constant aerodynamic servo loop gain as the control surface gain varies with altitude, mach number and dynamic pressure...

Since these more modern design concepts have now resorted to using electrical control system as an auxiliary or backup to a mechanical control system, the question now arises as to why cannot this system be designed electrically to overcome the weight and other associated penalties of the mechanical control system. Such a system has been designed and is shown in (Figure 25) for the same problem in which mechanical flight control system has been designed. This configuration is the result of numerous studies and as indicated basically a triple control system. It consists of a three chamber valve and a unit with three separate electrical torque motors mechanically connected in parallel and three mechanically connected second stage spools. Pilot commands are obtained from three separate stick position transducers. Each transducer supplies a high power level signal to one winding of each torque motor. Stability augmentation or automatic flight control inputs are applied to a second winding in each torque motor. The automatic flight control system inputs are thus effectively in series with the pilot inputs; that is, automatic flight control commands produce surface motion with no corresponding stick motion. In the past, it has been generally required that automatic control inputs be parallel; however, recent studies on flight tests indicate that with the increased performance of advanced vehicles this may no longer be required.

FEASIBLE MANUAL IMPLEMENTATION CONCEPTS FOR SST

Manual flight control is feasible for the crew, but at the cost of increased workload. Manual feasibility really means the down-graded automatic mode of operation to the extent that any further decrease in performance capability will result in a man-machine relationship which does not fulfill the basic system requirements. In this condition the crew would be forced to abort the flight or to continue the flight subsonically. In the case of the flight control system and its associated activities, almost any non-destructive malfunction of the automatic system will still leave the system within the capability of the crew. However,

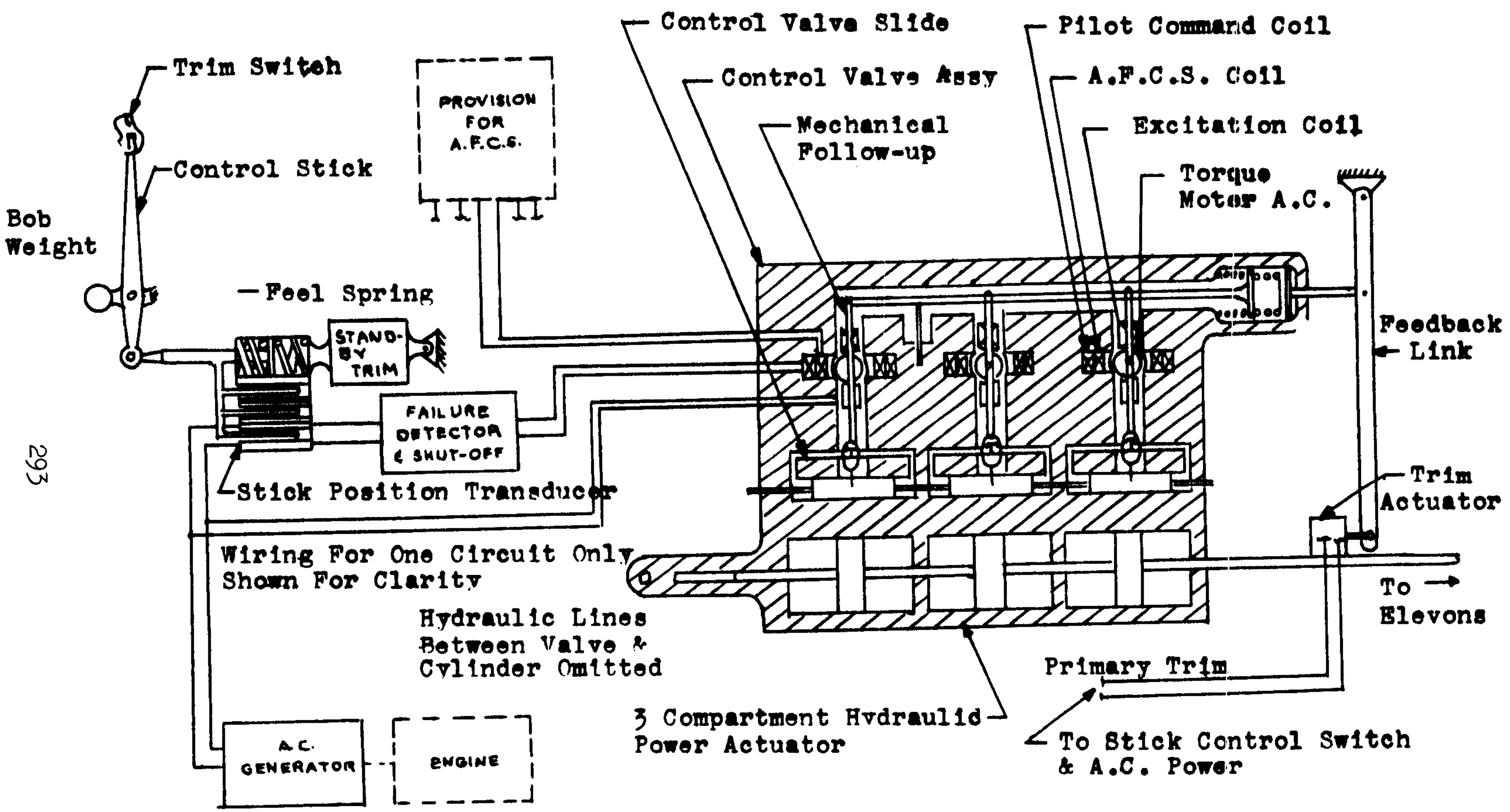

Figure 25. Electrical primary flight control system (from ref. 35).

in certain cases (e. g., runaway trim, loss of auto-stabilization, etc.) safety usually dictates an abort procedure.

The basic system will be the same as that incorporated into the completely automatic system, however, the first order of automation will be eliminated. The crew will have to utilize the conventional yoke, wheel and rudder pedals, and will require a presentation of navigational parameters to fly a flight profile. Without the automatic modes of compensation, gross estimates will have to be used to accomplish the required performance.

Whether a complete malfunction of the automatic mode of operation would be tolerable is still the subject of many simulator studies. It would appear that in order to obtain the navigational tolerances, a portion of the automatic flight control system would need to be operative. If as designers propose, the SST will have the capability of completing the flight subsonically from any point, it may be more feasible to accept this alternative procedure instead of attempting to fly without the automatic mode.

In terms of responsibility nothing will actually change but the restrictiveness to the crew. Whereas the crew participates as a monitor in automatic modes of operation, they are required to become the actor in less automatic modes. This of course increases crew workload. When the manual concept is utilized for supersonic flight control, the crew equipment interface becomes more critical. Methods of presentation will need to be developed and evaluated to give the crew the capability of obtaining acceptable if not optimum performance.

The procedures used by the crew will be essentially comparable to what is experienced by current subsonic carrier crews. Control surfaces are manually positioned, and then aerodynamically held in place (trim tabs). The crew will position and then reposition the control surfaces in response to flight parameters (e. g., airspeed, vertical speed, altitude, direction, etc.). The navigational requirements will also be in terms of such parameters and the crew will attempt to fly acceptable horizontal and vertical profiles. Economics may dictate flying a changing Mach/altitude climb schedule, but the crew would be unable to fly the smooth curve (without special instruments) and would have to resort to a series of approximate segments.

It appears that because of the speeds involved and because of the accuracies required, the automatic mode of operation will be a necessity, at least for operations in the supersonic regime.

5. 1 FUNCTION 5. 1 TAXI FROM LINE

Purpose

The purpose of this function is to supply the directional control needed by the system to move from the loading area to the operational runway. Because of the width of the current taxiways, the aircraft must be almost centered on the taxiway at all times, especially when making turns.

Current Jet Operational Requirements and Constraints

The following specific regulations apply:

FAR 91. 87 (h), ref. 13:

Clearances required.

> No pilot may, at an airport with an operating control tower, taxi an aircraft on a runway, or take off or land an aircraft, unless he has received an appropriate clearance from ATC. A clearance to "taxi to" the runway is a clearance to cross all intersecting runways but is not a clearance to "taxi on" the assigned runway.

ICAO Reg. 3. 2. 6. 1, ref. 14:

Operation On and In the Vicinity of an Aerodrome

> An aircraft operated on or in the vicinity of an aerodrome shall, whether or not within an aerodrome traffic zone:
>
> *a)* observe other aerodrome traffic for the purpose of avoiding collision;
>
> *b)* conform with or avoid the pattern of traffic formed by other aircraft in operation;
>
> *c)* make all turns to the left, when approaching for a landing and after taking off, unless otherwise instructed;
>
> *d)* land and take off into the wind unless safety or air traffic considerations determine that a different direction is preferable.

Current Jet Implementation Concepts

In current operations, once it has been determined that the aircraft system is in a "go" condition and clearance has been obtained from the Air Traffic Control facility (ground control), the crew utilizes the power plant system and the flight control system to maneuver the aircraft from the loading area to the end of the operational runway. The Boeing Operations Manual for the 720 (ref. 22) describes this performance,

> . . . maneuvering the airplane on the ground is accomplished in most respects similarly to other conventional tricycle geared aircraft. Nose wheel steering and engine thrust are used for directional control. Always use the largest radius of turn possible and do not attempt to turn until the airplane is moving. Make all turns at a slow taxi speed to avoid skidding the airplane nose wheel. If the hydraulic system fails while taxiing, the engine reversers and emergency air brakes can be used for stopping the airplane. While taxiing in congested areas the antiskid switch must be turned OFF.
>
> NOTE: Because of the swept wings, the ground crew should watch the wing tips carefully for clearance of equipment on the ramp (loading area)*, especially while making turns.
>
> After a turn has been completed, the airplane should be taxied in a straight line for a short distance to relieve torsional stresses in the main landing gear structure.
>
> CAUTION: Do not use brakes to aid in making a turn while maneuvering the airplane on the ground. The minimum radius turn is made with maximum nose wheel steering and outboard engine thrust only. Any braking will result in excessive scrubbing of main gear and nose gear tires. . .

SST Potential Operational Requirements and Constraints

Current principles should continue into the SST era, with the major change occuring in the nature of the task. The physical dimensions of

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* Parenthetic insertion made by authors.

the proposed SST will make operating out of current facilities (i. e., current ramps and taxiways) more exacting. The major difficulties which will be encountered by the SST crew will be the visibility restrictions coupled with attempting to maneuver this large aircraft in the area provided for today's subsonic aircraft. Horonjeff, in a presentation before the IATA Fourteenth Technical Conferenoe (ref. 36) stated,

> ...In discussions anticipating the advent of supersonic transports, airport authorities have steadfastly maintained that these new aircraft must be able to operate at airports now serving large subsonic jets. Aircraft manufacturers have expressed their optimism that such a requirement can be met...

Figures 26 and 27 (from ref. 36) illustrate a typical SST configuration maneuvering on various existing taxiways. A few of the difficulties due to the aircraft's size are apparent when the aircraft attempts a turn. Figure 28 illustrates the type of taxiway widening which might be utilized to alleviate some of the maneuvering problems.

Feasible Automated Implementation Concepts for SST

No automatic implementation concepts have been introduced in this area.

Feasible Manual Implementation Concepts for SST

In the early days of aviation when aircraft were light weight, maneuvering on the ground was accomplished by the use of the thrust and the basic control surfaces. As the weight increased and the aircraft became larger, differential braking coupled with the control surfaces became the method for taxiing on the ground. Finally, with advent of the large transport, and with improvement in hydraulic systems, nose wheel steering came into practice. There is no indication that the SST will employ any different means of directional control

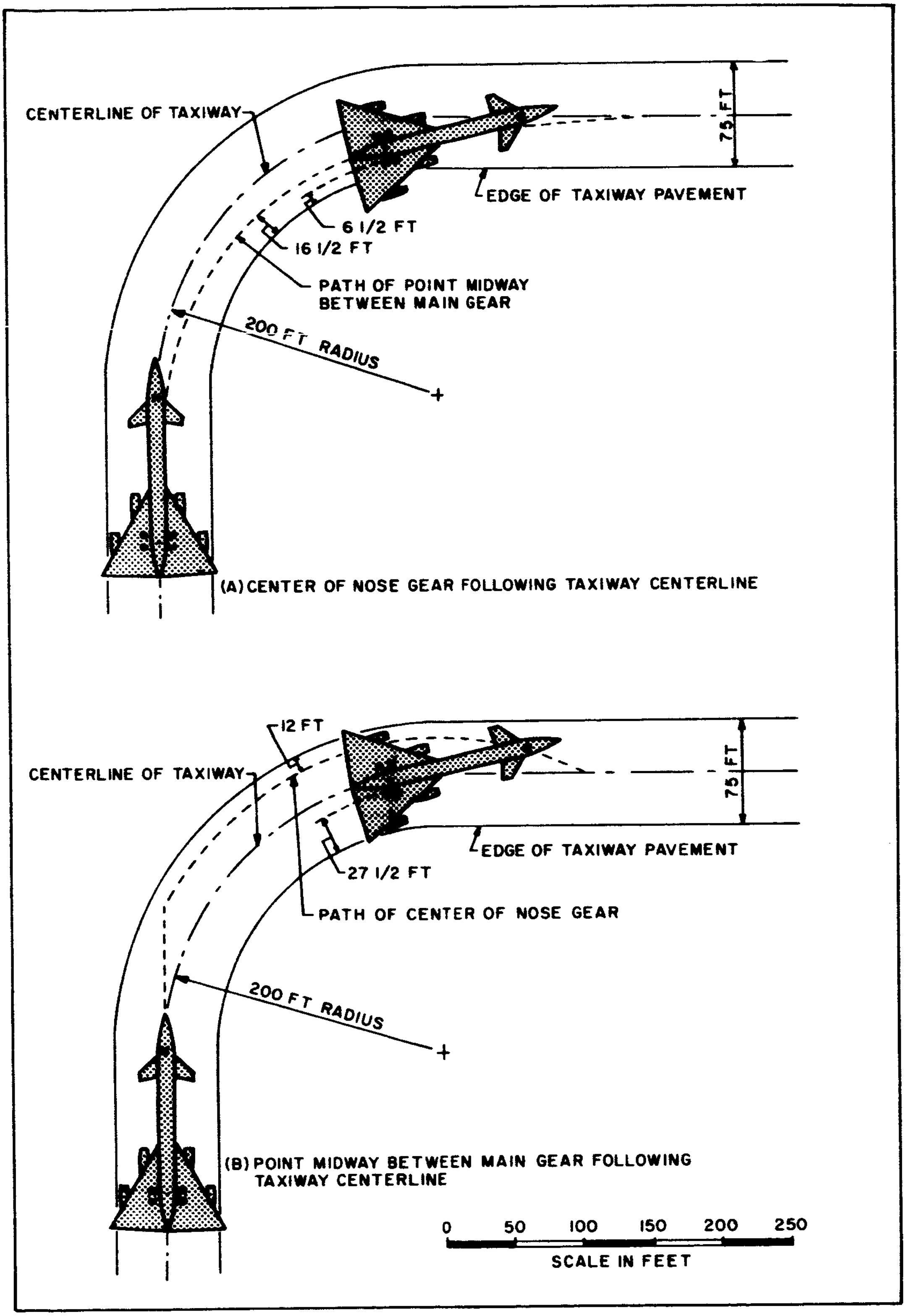

Figure 26. Supersonic transport maneuvering on 200-ft radius taxiway (taken from ref. 36).

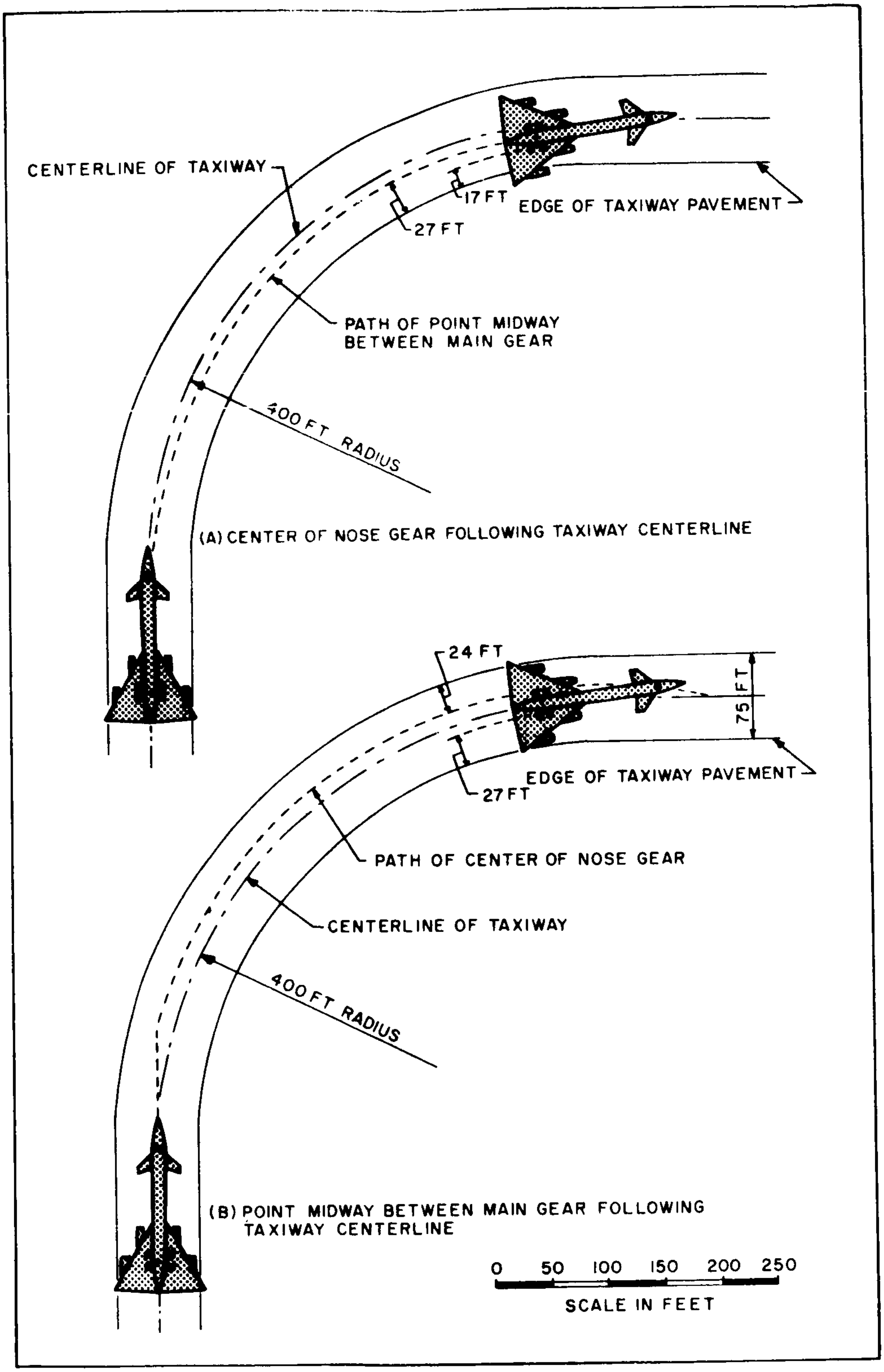

Figure 27. Supersonic **transport maneuvering** on 400-ft radius taxiway **(taken from ref. 36).**

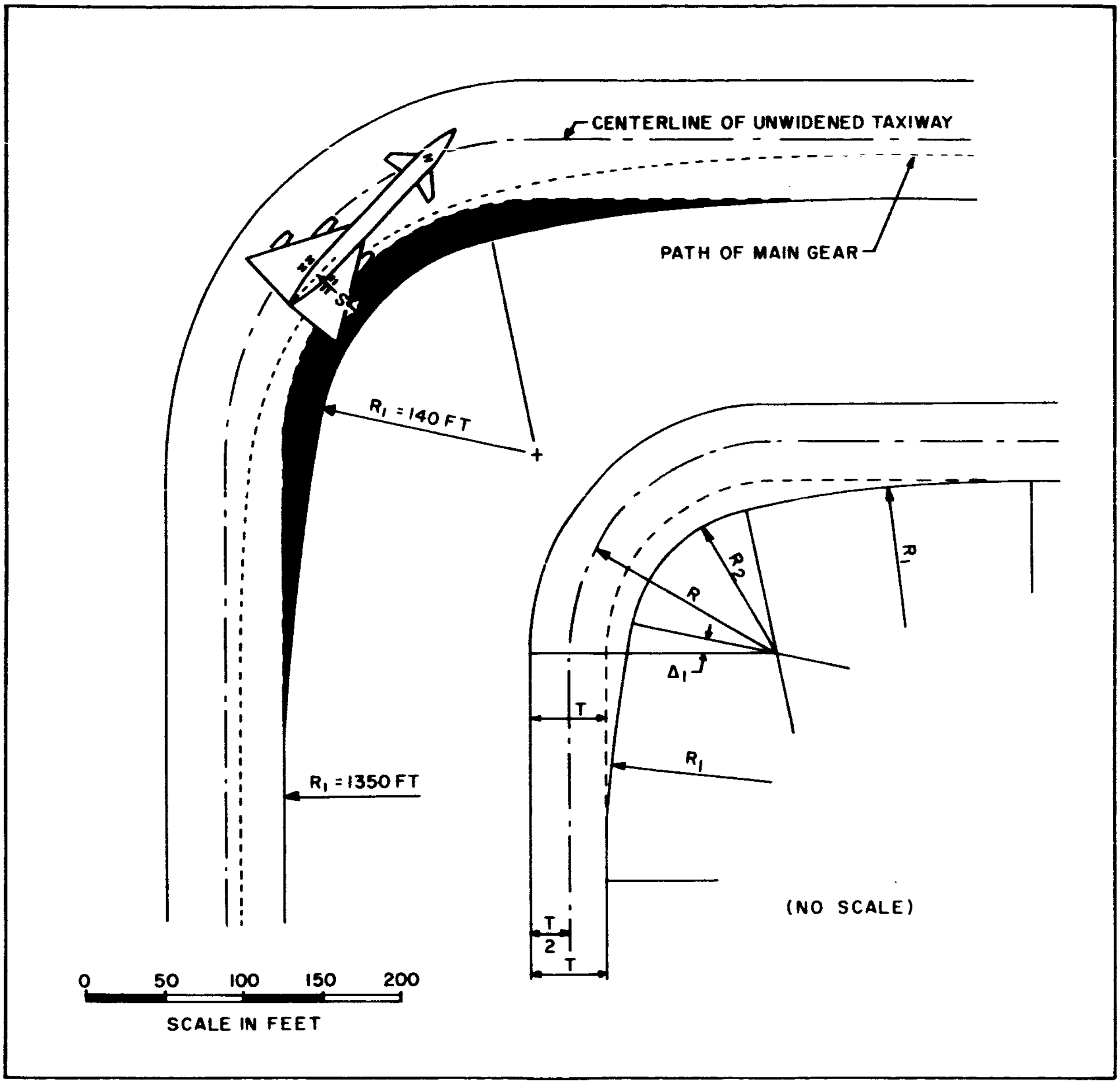

Figure 28. Typical taxiway widening (taken from ref. 36).

for its ground maneuvering operations. The power plants are utilized to overcome inertia and nose wheel steering guides the aircraft.

If nose wheel steering is incorporated into the rudder, it will allow the pilot two-handed operation instead of the three-handed maneuvers caused by some present nose wheel steering mechanisms. One new perceptual problem will be encountered because of the distance from the flight deck to the main gear. Obviously the main gear should track the taxiway centerline and this may result in unusual perspective from the flight deck during turns (Figure 26). In the event that visibility is too poor to allow safe operation, some form of optical system may have to be added to supplement the vision of the crew. It is not anticipated that the introduction of the SST will bring associated problems which are outside the scope of present day subsonic crews, although attention and more care will need to be given to the taxi functions.

5.2 FUNCTION 5.2 INITIAL ROLL CONTROL; TAKEOFF

Purpose

The purpose of this function is to maintain a wings-level attitude, and minimum lateral displacement from the runway centerline during the takeoff roll.

Current Jet Operational Requirements and Constraints

The following specific regulation applies:

ICAO Reg. 4.4.4, ref. 12:

Pilots at controls.

> At least one pilot shall remain at the controls at all times during flight. Two pilots shall remain at the controls during take-off and landing if the certificate of airworthiness or other documents associated with the certificate of airworthiness of the aircraft require the carriage of two pilots.

Current Jet Implementation Concepts

Takeoff is that performance accomplished in the time lapse from release of brakes on the runway, until the predetermined lift-off speed has been attained. During this relatively short period of time the crew is required to make many decisions based on data inputs from both exterior and interior sources. In early aviation the pilot was not concerned with other factors and was able to utilize both kinesthetic and visual cues to achieve the proper aircraft attitude for takeoff. Today, the complexities of the aircraft and the increased weight and speed of the aircraft make this very difficult; in the near future it may be impossible. Nowadays most flights are handled as if they were instrument flights. Directional control, wings-level attitudes, and cross-wind corrections are all maintained by reference to internal instrumentation (e. g., artificial gyro horizon, needle-ball indicator, and radio magnetic compass). This is especially important when the flight will be flown in actual instrument weather conditions. The transition from contact to instrument flying often is accompanied by disorientation, or at least by a time lag during which time the plane could, conceivably, enter a dangerous attitude.

SST Potential Operational Requirements and Constraints

The flight control performance by the crew during the takeoff will be critical, and will require precision. Jameson and Chaplin (ref. 37) argue,

> ... that the distance and height margins that need to be added to this nominal (that is, "when everything is going exactly according to the book") takeoff run and flight path may well be quite inadequate for a supersonic transport, unless great care and ingenuity is taken to avoid or satisfactorily deal with certain pitfalls, which we are going to discuss. We do not believe that it is safe at this stage to assume that, even with greatest care, no increase in margins will be necessary. However, this does not mean that we are necessarily despondent about being able to achieve safe and practical net performances; for example, for factored field lengths.
>
> Let us now consider the causes of variability in takeoff performance, namely, the variations of thrust, drag, weight and center of gravity, and handling (including the effect of instrument errors and other errors)...
>
> It is handling variations to which takeoff field length is most sensitive. ...we should like to summarize some possible characteristics of Mach 2 to Mach 3 SST's. These, though reconcilable with takeoff from existing international airfields with the usual or better than usual clearances, could lead to a bigger dispersion of distances arising from the day-to-day technique when the intended takeoff maneuver is performed exactly:

These contributing characteristics include: (1) Inability to hold a large proportion of the takeoff thrust on the wheel brakes, thus giving rise to greater thrust variability in the early part of the takeoff run; (2) high horizontal acceleration during the takeoff run, giving greater scatter of speed at start of rotation even if the scatter in time, from rotating at the correct moment is no greater; (3) large change of attitude during rotation; (4) unless the cockpit is placed in some highly unorthodox position, a large vertical displacement of the pilots during rotation; (5) pitching inertia at least equal to that of current large jets, and probably greater; (6) unless the canard arrangement is adopted, very possibly a small reserve of elevator power; (7) as a consequence of items 4 and 3 but possibly less important, a larger change of view through the windshield during rotation; (8) more sensitive cross-wind behavior; and (9) possible increase in the likelihood of inadvertent rotation due to variations in runway slope.

In addition to accurate handling being (at least without special aids) more difficult to achieve, the effects of incorrect technique are magnified by the large induced drag coefficient of low aspect ratio airplanes and by the elevator drag effects previously mentioned.

...while we believe that the variabilities of thrust, lift independent drag, and weight and center of gravity are things that will require watching, the aspect requiring most careful watching is the handling variability, also aggravated by induced drag effects. If no special steps are taken to control this variability, then a large increase in field length factors would appear to be necessary. They would also be difficult to predict with exactitude, and of course would not necessarily be the same for different airplanes.

However, we believe that the variability of continued takeoffs can be kept under control by the use of suitable takeoff directors which have the necessary high degree of reliability, taking account of the correct parameters (including loss of thrust) and presenting the information to the pilots in a way they can easily assimilate and which is compatible with the other flight information they must have...

During the takeoff roll many parameters must be assimilated and assayed, and then decisions and control movements must be made. The faster these events occur, the more critical the performance requirements become. Few experts have actually advocated a completely automatic takeoff for the SST, most are thinking in terms of a takeoff monitor and some visual display (flight director) which will optimize the takeoff control performance.

Richardson, in discussing the "Integrated Crew-Computer Team: Its Role in the Supersonic Transport" (ref. 38) points out that,

> ...it should be noted here that the introduction of the central computer system into the supersonic transport is not considered by the writer to be a cure-all or panacea for all of the suggested operational problems. It is, however, considered to be an extremely useful tool, designed to fulfill a specific and unmistakable need in the operation and control of these aircraft...
>
> ...starting, of all places, at the beginning, the problem of safe takeoff operation has been considerably complicated by the increased gross weight of jet transports and the sensitivity of engine thrust to variations in ambient atmospheric conditions such as temperature... For this reason several manufacturers and users are considering different types of takeoff performance being achieved by the aircraft to a selected set of predicted data...

The crew will continue to function primarily in the same manner as at present, but will have an off-line means assisting in decision making. Crew responsibility will not change, nor will the degree of restrictiveness. Greater concentration can be devoted to the actual instrument flying of the SST if some of the data evaluating tasks performed by the crew are taken over by an on-line computer.

Feasible Manual Implementation Concepts for SST

The directional control connected with the takeoff will not vary appreciably from what it has always been. The major changes which have taken place with the advance of aviation have been principally in the means employed. Therefore, the basic performance required by the SST crew will be quite similar to that experienced by the crews of today's subsonic jets. Assuming that the aircraft is lined up with the centerline of the runway, has clearance for takeoff, and that takeoff power is applied, nose wheel steering is utilized to maintain directional control until a speed of approximately 60 knots has been attained. At that time the aerodynamic forces are sufficient so that the rudder can be used to maintain the directional control.

The only differences between this mode of implementation, and the automatic mode will be the use of the takeoff monitor. Without such a capability, the crew will have to depend on pre-flight computed data, as in current operations to make any critical decisions.

5. 3 FUNCTION 5. 3 TAKEOFF ABORT CONTROL

Purpose

The purpose of this function is to provide directional control to the SST in the event a takeoff is aborted, and the aircraft must be decelerated in the runway remaining. The optimum performance is to keep the lateral displacements from the runway centerline to a minimum.

Current Jet Operational Requirements and Constraints

No requirements have been identified.

Current Jet Implementation Concepts

Kinetic energy increases as the square of velocity, and thus the problem of stopping the aircraft in the runway remaining becomes a problem. Current techniques are thrust reversal and the conventional braking system to decelerate the aircraft, but then keeping the aircraft on the runway becomes a critical problem. Unless braking is judicious, the crew could lose all directional control of the aircraft. Just as an automobile might lose its traction on an icy pavement and go into a skid, a heavily loaded aircraft subject to loss of a tire, unsymmetrical thrust reversal, or loss of traction, could conceivably veer away from the runway centerline.

The crew's responsibility is to abort the takeoff roll, and then to decelerate the aircraft to a safe taxi speed within the limitations of the runway remaining.

The decision to abort takes place in the flight management function. Then the flight control system is utilized to obtain abort performance. Some reasons for takeoff aborts and aircraft requirements to optimize the abort function are discussed by Jameson and Chaplin (ref. 37),

> ... in all airplanes, takeoffs may be discontinued for a variety of reasons, and a substantial proportion of discontinued takeoffs arises from causes other than engine failure. In the authors' minds, all discontinued takeoffs can be put in two classes, namely, voluntary stops and involuntary stops.
>
> Voluntary stops are those initiated at or before a decision point (however imperfectly identified; for example, in terms of airspeed) and for which current field length requirements make some provision. Involuntary stops, fortunately more rare, occur sufficiently after the decision point for them not to be allowed for in field length requirements.
>
> Influences on Accelerate Stop Distance Required--The SST may have a higher lift-off speed than the subsonic jet, but there will be pressure to keep the decision speed down as far as possible so as to ease the problem of providing good wheel braking (having regard to both kinetic energy absorption and to the low coefficients of friction on wet runways at high speeds) and to reduce the demands made on the tires. It will, however, be desirable to assess the influence on accelerate stop distance factors of: (1) Greater variability in the acceleration stage (discussed under takeoff without malfunctions); (2) Reduced accuracy in identifying the decision speed, owing to greater acceleration; and (3) Influence, if any, of greater airplane complexity on the frequency of voluntary stops.
>
> It is questionable whether or not depression of the decision speed would cause a significant increase in the frequency of involuntary stops, which are likely to be associated with rotation and lift-off. If emergency thrust (for example, afterburning) is available, emergencies occurring between the decision point and start of rotation may be better covered than on subsonic airplanes.

In time, involuntary decisions to stop may also be catered for (without increase in field length requirements) by arrester gear, research on which has been pursued with some vigor by FAA and should benefit other transport aircraft.

Monitors-- Some form of takeoff monitor has long been advocated for providing pilots of subsonic airplanes with better information on which to decide whether to make a voluntary stop. This function is, of course, distinct from that of a takeoff director, which should give information to assist the pilot to use the elevator control correctly from the start of rotation up through the takeoff climb. While the more recent accidents have suggested that development of a director should have priority over that of a monitor, the case for at least a crude monitor should be examined in relation to the SST, for the following reasons: (1) Variabilities at the start of takeoff may be greater; and (2) Adverse indications from the monitor up to rotation speed could be usefully acted on if emergency thrust (for example, afterburning) is available.

A monitor would, of course, be particularly useful for both subsonic and supersonic airplanes, for takeoffs out of critical airfields in lower visibilities, or for deciding whether or not to make use of arrester gear. For the latter purpose, the monitor should indicate important performance deficiencies even if they occur at the very end of the ground roll.

. . . to maintain current levels of accelerate stop safety, without improved instrumentation or arrester gear, it is possible that margins would need to be increased to cover a greater number of possible causes of stopping and greater performance variability. However, the development of a sufficiently accurate, reliable, and suitably discriminating monitor, in conjunction with earlier decision points made possible by (for example, emergency afterburning) may prevent this affecting net accelerate stop distances. The provision of arrester gear would be advantageous, and not only to SST's. . .

Feasible Automated Implementation Concepts for SST

As of yet, no one advocates automating this function. However, that portion of the proposed landing system which deals with maintaining directional control on the roll-out, could conceivably be utilized to assist the crew in obtaining optimum performance.

Feasible Manual Implementation Concepts for SST

The SST crew should be prepared for the abort directional control and judiciously utilize braking mechanisms in conjunction with directional control devices. Above about 60 knots the rudder system will be effective because of the aerodynamic forces. Below that speed the nose wheel steering mechanism will provide the directional control necessary to maintain the runway centerline.

The crew will continue to utilize that equipment described previously. The particular performance required is similar to any maintenance of ground directional control. The optimum performance will be to avoid lateral deviation from the centerline, and to decelerate the aircraft to taxi speed within the runway remaining at the time abort procedures were initiated.

5.4 FUNCTION 5.4 TAKEOFF CONTROL; ROTATION, CONFIGURATION CHANGE

Purpose

The purpose of this function is to change the attitude of the aircraft so as to change the direction of the force generated by the power plant system, and to take advantage of the lift component of force which is generated. Once the initial attitude change has been accomplished, and the lift vector (less the drag vector) is holding the weight of the system, then the performance requires the elimination of some of the drag producing devices (e.g., the landing gear, and the flaps), so as to obtain an optimum climb speed and profile.

The decision to change the attitude of the aircraft for takeoff is made in the flight management function. Once the command is issued to takeoff, the performance of the crew becomes critical. The rate of rotation and the amount of rotation are important parameters of the takeoff control performance.

Current Jet Operational Requirements and Constraints

No specific requirements have been identified.

Current Jet Implementation Concepts

Current subsonic aircraft operations link their performance on the takeoff to the three precomputed reference speeds, V_1, V_R, and V_2.* According to the Boeing Operations Manual for the 720 (ref. 22),

> ... at V_R speed, rotate the airplane smoothly to the takeoff attitude, reaching V_2 speed at a height of 35 feet above the runway. If the takeoff is limited by obstacles, do not permit the maximum speed during the takeoff climb to exceed V_2 + 10 knots. Maintain this speed to the height above the runway selected for the three engine level flight acceleration where flap retraction shall be initiated. Accelerate to the final takeoff climb speed and continue climb until reaching 1500 feet or obstacle clearance limits have been exceeded.
>
> WARNING: Landing gear must not be retracted until positive rate of climb has been established...

---

* These values are defined as follows: (ref. 22)

> Critical Engine Failure Speed - V_1
>
> Critical engine failure speed V_1 is the speed at which, if an outboard engine fails, the airplane may either continue to accelerate and climb to a 35 foot height on the three remaining engines or it may be brought to a stop on the runway.
>
> Rotation Speed - V_R
>
> Rotation Speed, V_R, is a speed which permits attainment of V_2 speed prior to reaching a height of 35 feet above the runway. V_R can not be less than V_1 and must be equal to or exceed 105 per cent V_{MCA}. (Air Minimum Control Speed.)
>
> Take-Off Speed - V_2
>
> The take-off speed, V_2, is the stabilized speed which can be held in the take-off climbout. V_2 is achieved by the time the airplane is 35 feet above the runway. Certain minimums are specified to insure safety of flight. The first is that V_2 must be at least 120% of the Stall Speed, V_S. The second minimum is that V_2 must be at least 110% of the Air Minimum Control Speed, V_{mca}, to insure that adequate directional control can be maintained during the critical climbout portions of the take-off profile. V_{mca} is the speed at which the airplane heading can be maintained with a 5° bank angle.

The crews of today's subsonic carriers utilize the basic control system to accomplish this takeoff performance. The wings are kept level, and the pitch of the aircraft is changed in accordance with desired rotation rates.

In the event that a portion of the power plant system failed, and it was too late to abort the takeoff, then the performance of the crew will be slightly different than described above. Jameson and Chaplin (ref. 37) discuss this situation,

> ... if the failure of one engine does not lead to large lateral directional handling difficulties (which would be undesirable in their own right), the engine failure case could prove to be noncritical (given factors appropriate to its rare occurrence) because the reduced performance during the flare-up could make the problem of handling the elevator correctly somewhat easier than in the "all engines operating" case.
>
> However, the need to handle the elevator correctly so as to avoid large drag increments will be of much greater importance than in the "all engines operating" case and would place emphasis on choosing a takeoff director that would, without attention from the pilot, give proper guidance during and after any such loss of performance...

SST Potential Operational Requirements and Constraints

The SST will be required to operate out of current sized facilities. Considering the increased size of the aircraft this may bring with it some problems. In order to stay within safety margins as to runway lengths, the rate and amount of rotation during the takeoff must be as close to optimum as possible. Underrotation results in increased runway length requirements, while overrotation generates a considerable amount of induced drag.

One other area of concern which will affect the performance requirements of the SST crew is acceptable acceleration for the passengers. ICAO points out (ref. 39) that,

> . . . the high acceleration during takeoff and the high rate of climb, as compared with subsonic jet aeroplanes, will be noticed by the passengers. Associated with the high rate of climb will be the steep attitude of the aeroplane and the resulting high angle of the floor in the passenger cabin. During the short time of takeoff and initial climb the cabin floor angle may exceed 10° for a period of about three minutes, and the maximum angle is expected to be between 12° and 15°. During descent the maximum floor angle is likely to be between -6° and -10°. During the periods of relatively high acceleration and steep floor angles passengers will have their seat belts fastened and the effects should not be injurious even to those who are aged or not physically fit. While the tolerance of passengers to increased acceleration and steep increase of climb and descent is likely to be function of comfort rather than fitness, it is believed that, once the passengers know what to expect, the particular accelerations and steep angles involved in takeoff, climb or descent will not cause them discomfort or anxiety. During takeoff and climb the maximum acceleration will be of the order of 0. 3 g to 0. 4 g, and most of the time it will be substantially less than this; it has been pointed out that the passenger will be subjected to an acceleration lower and far more regular than would be experienced in some city buses. . .

Feasible Automated Implementation Concepts for SST

Although one or two authorities have hinted that a pre-programmed automatic takeoff is feasible, most feel that this function should be kept in the hands of the crew.

Feasible Manual Implementation Concepts for SST

Most experts agree that with the increased performance characteristics of the SST, the crew will need to have some form of flight director to assist in obtaining rotation rates and amounts during takeoff. The basic flight control system would be used, with the main control being in the vertical (pitch).

Of course the final design of the SST will greatly influence the performance parameters. However, it is anticipated that adequate instrumentation will be made available to the crew to obtain the performance accuracies necessary to operate out of current facilities. With the aid of a takeoff director, the performance required by the crew of the SST should not appreciably change from today's operations.

The variable incidence wing configuration should have handling performance which actually outperforms today's subsonic aircraft. Although some form of takeoff director will probably still be utilized, the criticality of this performance will be greatly reduced.

In describing the implication of performance variations during rotation and flare-up, (ref. 37) it is pointed out,

> ... However, we believe that the variability of continued takeoffs can be kept under control by the use of suitable takeoff directors which have the necessary high degree of reliability, taking account of the correct parameters (including loss of thrust) and presenting the information to the pilots in a way they can easily assimilate and which is compatible with the other flight information they must have...

The crew's main responsibility will be the same as in current operations, namely, rotating the aircraft to a pitch angle consistent with its optimum climb schedule. The performance of the crew will be influenced by the rotation factors, the runway constraints, the available power, and the passengers' tolerance to acceleration forces.

In the situation of a partial power plant failure, the performance of the SST crew will be required to be very exact, but no more so than is expected of today's subsonic aircraft crews. More care will have to be taken to insure that overrotation does not occur, thereby introducing large increments of induced drag. With the engines sized for transonic acceleration there should be no problem with a deficiency of power in the case of a partial failure. However, even though most designers are attempting to locate power plants as close to the longitudinal axis of the aircraft as possible, there will continue to be trim changes associated with the assymmetric thrust. These, however, should not be appreciably greater than those experienced today.

5.5 FUNCTION 5.5 INITIAL CLIMB CONTROL; INITIAL PORTION OF THE STANDARD INSTRUMENT DEPARTURE

Purpose

The purpose of this function is to provide three dimensional control for the aircraft so as to maintain required airspeeds, climb schedules, and any navigational requirements. Jameson and Chaplin (ref. 37) describe the takeoff climb, and point out some of the problems which might be encountered with the introduction of the SST.

> ...the takeoff climb from the end of flare-up may be divided for our purpose into the following major elements: (1) The early climb at high thrust with gear retracted ("second segment"); and (2) The noise-throttled climb.
>
> Either of these two elements may have to include turns, though preferably not at a low height.

Current Jet Operational Requirements and Constraints

Besides those regulations pertaining to the basic control system, the crew must comply with ATC procedures during this initial climb.

Current Jet Implementation Concepts

In current operations once the aircraft is airborne and the necessary configuration changes have been made (e.g., the landing gear raised and the flaps raised), the crew's main concern is to comply with navigational inputs. These inputs will be either in the form of radar vectors or as published in the standard instrument departure (SID) being followed.

All the three dimensional positioning is accomplished by use of the basic flight control system, i.e., the yoke, wheel, and rudder pedals.

Once desired parameters are reached, and are changing in accordance with desired schedule, the crew's responsibility is then to monitor the positioning, and to comply to any extraordinary directions.

In almost all instances this is accomplished manually, with the crew utilizing merely the basic system plus the trim system.

SST Potential Operational Requirements and Constraints

It would appear that the performance requirements of the SST crew during this initial portion of the standard instrument departure (SID) or radar vector as the case may be, will be quite similar to that experienced by the crews of today's subsonic aircraft. It must be remembered that the aircraft is maneuvered from about 1500 ft. to about 8, 000 ft. and is kept at a relatively slow airspeed; one which is consistent with other traffic (subsonic).

Although it would be more economical for the SST to climb unrestrictedly, it must be compatible with the majority of the traffic which will be subsonic. In addition the higher densities of traffic will be found in the terminal areas and at these lower altitudes.

Thus, it appears that the SST will be required to comply with current regulations pertaining to initial climb speeds, and controllability.

Feasible Automated Implementation Concepts for SST

If the SST were not constrained by the Air Traffic Control system, the entire climb-out could conceivably be pre-programmed and the automatic system would control the aircraft during this initial climb phase. Since this will not be the case, the feasibility of such a concept is not being considered.

Feasible Manual Implementation Concepts for SST

Because of the constantly changing traffic situation, a completely automatic implementation concept does not seem feasible. It would appear that portions of the automatic system could be utilized during this initial climb (e. g., the auto-throttle, the course hold, etc.). The amount of the auto-pilot system which could be utilized will vary, and will be dependent upon the particular facility or area in which the aircraft is operating. It should be safe to assume that the performance of the SST crew will change slightly as to the amounts of man-machine utilization, but that the overall workload should not appreciably change over what is currently experienced.

In this particular mode of operation the crew will perform similarly to what is experienced currently. This is a very dynamic flight phase in that the attitude and directional parameters are changing rapidly. For those areas in which the number of variables has been decreased, (i. e., some of the parameters are held constant), the crew can utilize the auto-pilot coupled with an on-line profile generator (see Function 7. 11).

5.6 FUNCTION 5.6 SUBSONIC CLIMB MANEUVERING

Purpose

The purpose of this function is to provide directional control to the SST during the latter portion of the standard instrument departure (SID), through the trim changes accompanying the changes in airspeed, and maintaining the constant Mach airspeed climb schedule demanded by the navigational system.

Current Jet Operational Requirement and Constraints

The main factors which influence current operations are, Air Traffic Control procedures, and operating limitations of the aircraft. Also, as the speed of the aircraft increases, the amount of airspace required to perform a maneuver increases.

Current Jet Implementation Concepts

The equipment which is currently utilized to obtain the subsonic climb maneuvering is the same as has been described for the other flight control functions. The basic system is used to obtain a desired pitch attitude consistent with the desired airspeed and then held steady with the trim system.

In most cases the initial climb is made at a constant indicated airspeed. As altitude is gained equivalent Mach speed increases, until such time as the optimum Mach climb speed is attained. The crew then utilizes this to continue their climb schedule to their assigned cruise altitude.

SST Potential Operational Requirement and Constraints

The SST crew will experience a little more difficulty in obtaining the optimum performance required during the takeoff and subsequent climb. The high performance characteristics of the SST restrained in a subsonic aircraft Air Traffic Control environment, will cause a few problems both for the crew and for the Air Traffic controller. The NASA Flight Research Center at Edwards, using an A5A aircraft as a simulated SST found some interesting problem areas when they tried to introduce the aircraft into the Los Angeles Air Traffic Control area. As they report (ref. 40),

> ... the Air Traffic controllers experienced no difficulty in descending, integrating, and landing the A5A at Los Angeles International Airport along with all other traffic. The takeoff, climbout, and acceleration of an SST presents more of a challenge to the Air Traffic controller because of the tremendously increased performance over present subsonic jets... The only problems encountered in this study concerned the takeoff, climbout, and departure. ATC will have to give special consideration to the SST departure to allow for increased engine noise during acceleration and takeoff, routing of the SST out of metropolitan areas to minimize sonic-boom effects, and critical fuel usage during takeoff, climbout, and acceleration at altitude. Speed restrictions will have to be imposed on the SST, or special instrument departures will have to be devised to properly control the departing SST.

Feasible Automated Implementation Concepts for SST

Coupling of the proposed flight computer with the flight control system can result in an automatic climb-out profile capability. The profile selected could either be based on minimum fuel consumption, or minimum time to climb to altitude.

Richardson (ref. 21) points out that a central electronic management system (CEMS) could be coupled with the flight control system in the SST to provide automatic climb-out control. He feels that the CEMS concept using a computer can perform a system function of "vertical profile (speed/altitude) scheduling," in that it will provide automatic continuous control of climb-out and descent trajectory. With automatic throttle control, both speed versus altitude and distance versus altitude may be controlled. It will also allow accurate airspace assignment.

The crew would be required to select the desired profile, and then to actuate the mode of operation. Once the automatic system was feeding control-commands to the flight controls, the crew's responsibility would be to monitor the performance via the various displays. Any unprogrammed maneuvers could be performed by the crew utilizing some override capability.

If a CEMS type concept is utilized in the cockpit, it is quite feasible to couple it with the flight control system.

Feasible Manual Implementation Concepts for SST

When the SST is introduced into service, the crew's involvement in this particular phase of the flight will be dependent on various situations. In most cases the crew will be required to manually fly this portion of the flight. The term, manually, implies that the entire automatic system will not be able to be utilized, instead only selected modes of operation of the system will be automated, (e.g., Mach hold, course hold, etc.). The major problem to overcome will be the minimization of overshoots with their possible associated negative g. That is to say, while climbing at subsonic speeds, sufficient time will need to be given the crew by the ATC controller if a required maneuver is desired.

In all likelihood the performance and responsibility of the crew will be similar to current operations. The higher performance of the SST will make the vertical component of control a more critical area, but not really outside the capability of present crews.

There will be a need to develop an adequate gauge for the crew to utilize when operating in the manual mode. High rates of ascent plus changing Mach with altitude necessitate an integrated tracking display for the crew, or at least a rough climb schedule to follow. Studies are currently being conducted to determine the type of integrated instrumentation which would optimize crew performance in this manual mode.

5.7 FUNCTION 5.7 TRANSITIONAL ACCELERATION CONTROL

Purpose

The purpose of this function is to provide directional and stability control during transonic acceleration and penetration of the sonic barrier. Also, depending upon the final design configuration selected, it might entail altering the configuration of the aircraft in the case of the variable sweep configuration.

Current Jet Operational Requirement and Constraints

No current requirements are applicable.

Current Jet Implementation Concepts

No current concepts are applicable.

SST Potential Operational Requirements and Constraints

Since there are no regulations currently in effect, requirements and constraints may need to be developed. The major factor which will influence control activities will be the sonic boom problem. The generation of undesirable overpressures must be avoided. This can be most easily accomplished by executing the transition at a higher altitude. However, as the transitional altitude is increased, the acceleration capability of the aircraft decreases because the aircraft must fly at a higher lift coefficient due to the reduced dynamic pressure at the higher altitude. The increased lift coefficient produces an increased drag due to lift, and thereby a relatively lower excess thrust.

The aerodynamic forces experienced during this transition are quite different from those experienced by today's current subsonic aircraft. Thus, for the most part, the SST crews will be dealing with a new factor. Some of the problems which will be experienced are outlined in a Space/Aeronautics Staff Report on the "Supersonic Transport" (ref. 29),

> ...the critical factor in selecting the configuration is not, simply as it has been in the past, providing the optimum system to match the mission profile. Instead, one of the prime considerations must be minimizing the effects of sonic boom. In the long run, in fact, the SST may live or die depending on how well it meets the sonic boom problem.
>
> To minimize boom effects, the FAA proposal set firm limits of 2 psf overpressure during transonic acceleration and 1.5 psf in cruise. This required (sic) that the plane crack the sound barrier at an altitude no lower than 40,000 ft. established the maximum power requirement for the engines...
>
> Aerodynamically, the SST requires a very-hard-to-achieve compromise. The plane must have good handling qualities and reasonable efficiency at subsonic speeds, yet good aerodynamic and propulsion efficiency at supersonic Mach numbers where it will be most of the time.
>
> This means, in effect, that the plane must work in two completely different aerodynamic flow regimes. The main difference is in the character of the drag. At subsonic speeds, two drag components are considered: induced drag due to lift and profile drag which is caused by friction effects between the air and the aircraft surfaces. At supersonic speeds, an additional, very important drag component arises, which is the wave drag due to the shock wave pattern in the air surrounding the vehicle...

Another area of concern will be the rise in trim drag associated with the characteristic shift in aerodynamic center which accompanies increased Mach. If stability management is to be helpful in the low excess thrust region, its full capability must be realized very early in the acceleration. This requirement makes it absolutely necessary that the management system be fail-safe and reversible at all loading conditions so that emergency deceleration speeds do not result in a serious loss of longitudinal stability.

Feasible Automated Implementation Concepts for SST

Those concepts introduced previously for the control of the SST over the entire flight regime will continue to be utilized during this particular portion of the profile (see Function 5. 6). A major portion of transitional acceleration control can be assigned to the automatic control function.

The SST crew will be looking for optimum performance during this particular phase of the flight, since marginal performance could conceivably result in an aborted flight. The extremely high fuel consumption rates during transitional acceleration will require that optimum performance in all areas of operation be the rule rather than the exception.

The crew's responsibility will be to maintain both directional and stability control over the SST during its transonic acceleration. Using the automatic mode of operation the crew will be chiefly involved in monitoring the operation of the computer-flight control coupled system, and insuring compliance with sonic boom constraints.

Feasible Manual Implementation Concepts for SST

Although the consensus of opinion seems to be that stability and control solutions will be built into the system, the crew will still have the capability to manually control the aircraft in the event of some malfunction. This transitional acceleration with its stability and control problems is not familiar to today's subsonic aircraft crews. This may be an initial problem area for the SST crew.

Most indications are for either a level transition, or one with a slight climb attitude. In the manual mode of operation the crew will continue to trim the aircraft as the aerodynamic characteristics change. The chief area of concern will be any maneuvering required while accomplishing this portion of performance. It will be assumed that the portion of the flight control system concerned with the sensitivity of the controls with increased speeds is a portion of the basic system. The main responsibility of the crew will be to maintain a trimmed aircraft over the speed range.

5.8 FUNCTION 5.8 SUPERSONIC CLIMB CONTROL

Purpose

The purpose of this function is to provide three dimensional control for the SST during the supersonic climb phase of the flight profile. The aircraft will be receiving optimum navigational data from Function 7.11, optimum profile generation, which will command three dimensional corrections using the flight control system and the power plants.

Current Jet Operational Requirements and Constraints

None are applicable.

Current Jet Implementation Concepts

No current concepts are applicable.

SST Potential Operational Requirements and Constraints

The climb profile should not cause any unsolvable problems once the desired Mach is attained, but there are still problems in the area of supersonic maneuvering. It will be desirable for ATC to foresee any possible conflicts early in the profile and make provisions for adequate separation.

In the description of transonic acceleration control, it was indicated that only a narrow altitude band was available for the transition, because of the overpressure considerations and the decreases of excess thrust with increased altitude. It should be pointed out that the attainment of the desired Mach will also force adherence to a climb profile which takes these two factors into consideration.

Feasible Automated Implementation Concepts for SST

Use of the computer coupled flight control system seems to be advocated by most experts for flying the climb profile. The computer would receive its data either via a selected family of curves, or from a profile generator (see Function 7. 11). This three dimensional profile would be derived in terms of commands to all axes of the SST flight controls. The crew's responsibility will be to monitor the system, and to override it in the event of a malfunction outside the capability of the automatic system.

Once the climb profile has been selected (if the family of curves concept is utilized), or the profile generator is feeding its commands to the flight controls, the crew will be required to monitor displays to ascertain the adherence to such a climb profile. This display should integrate the data usually used by the crew for routine subsonic climbs with the new parameters introduced by sonic boom considerations. The integrated data should then be displayed in such a manner that the crew would be able to manually duplicate the automatic system's performance.

Feasible Manual Implementation Concepts for SST

Although many U. S. experts rule out the use of manually flown climb schedules (more for economic rather than safety reasons), most airline officials require this back-up feasibility. The Concorde will not utilize an automatic mode of operation, but will depend upon the capability of the crew to follow the climb schedule. Thus there will be provisions for the crew to manually fly this profile, but it is not yet really known how effectively this can be done. Simulator studies are being conducted, but more studies of man's capabilities will have to be completed to determine exactly which portions of the climb profile can be manually flown, and which portions must be flown automatically. In any event it appears that the major problem of concern to the crew, will be the malfunctioning of some portion of the flight control/stability systems.

Flower (ref. 41) indicates that,

> ...for airline operation, it is my opinion that the industry will demand adequate handling qualities for SST's with any single most critical axis damper or stability augmentor inoperative, while flying on its supersonic mach schedule at maximum altitude and carrying passengers. The aircraft must have the ability to complete the trip to its terminal destination through intermediate stops and/or to a schedule stop where repairs can be made, with minimum loss of scheduled time. In fulfilling this requirement consideration must be given to turbulence, engine failure, and the possible loss of an augmentor or damper on another axis as well as a boost control...
>
> A secondary method of achievement of the above requirement, if the basic characteristics are such as to deteriorate passenger comfort at supersonic speed at maximum altitude is descent to, or dispatch at, a lower Mach number and altitude where the flight characteristics are acceptable...
>
> ...Commercial passenger carrying aircraft cannot be subjected to the same acceleration that would be tolerated in military aircraft relative to the motions generated by engine failure or loss of damping augmentation. Therefore, in the interest of passenger comfort, and considering the elderly couple who have the money to travel but who incidently have the susceptibility towards the debilities of advancing age, it is suggested that side forces be limited to approximately 0.2 g or 6 deg/sec^2 yaw rate and vertical forces to 0.3 g for extremely short periods if at all possible. Lower values, of course, will be appreciated.

In summary, the SST crew should not, under normal operating conditions, experience any appreciable increase in workload during the supersonic climb phase of the flight. In all likelihood the climb itself will be automatically flown with the crew functioning as a monitor. The critical areas which will require exact coordination with the ground controller will include any "large" maneuvering, and any traffic avoidance maneuvers.

5.9 FUNCTION 5.9 TRANSITION TO CRUISE CONTROL

Purpose

The purpose of this function is to provide vertical control for the SST during the transition from supersonic climb to the level cruise attitude. As was pointed out earlier, the function of the flight control system is to position the aircraft in three dimensional space so as to comply with navigational commands, and to gain optimum performance from the power plant system. Changing the direction of force of the power plant system results in new performance parameters.

At the end of supersonic climb the SST will have an airspeed close to the cruise Mach number desired, but will have a high rate of climb. As the assigned cruise altitude is approached, the crew must decrease this vertical component of the airspeed to a rate consistent with the cruise climb profile, (i. e., approximately 100 fpm). The major problems here are the amount of negative g which could conceivably be generated if this transitional performance is not anticipated, and the altitude overshoot possibility. Sisk and Andrews (ref. 40) suggest that,

> . . . the SST will have to be given a 4,000- to 5,000-foot altitude advance warning for a hold or level-off during climbout, and even this much warning may produce an overshoot in altitude accompanied by an undesirable amount of negative g imposed on the passengers. It should be pointed out that even though the pilot reduced power during this hold, as evidenced by the decrease in longitudinal acceleration, the altitude requested was passed and the airplane was subjected to a load approaching 0 g. Altitude and speed overshoots can also be experienced during level-off at the acceleration altitude, but these effects will be minimized as the SST pilots gain experience with the new vehicle. . .

Current Jet Operational Requirements and Constraints

Air Traffic Control procedures and passenger comfort dictate the limitations on this performance. Overshoots in altitude (i. e., passing through the assigned altitude and then having to return) cannot be tolerated in areas of high traffic density where only 1000 to 2000 feet of vertical separation is employed. If the crew is late in initiating the transition and complies with the ATC restrictions, then the attitude of the aircraft must be changed abruptly. This results in the generation of negative g which is quite discomforting to the passengers.

Current Jet Implementation Concepts

Although in current operations there is no transition from a supersonic climb to a level cruise attitude, the nature of the performance is quite similar to any level-off maneuver currently utilized. In most cases as the assigned altitude is approached, the angle of attack of the aircraft is changed, (usually accompanied with a decrease in rate of ascent and an increase in airspeed), and the power is readjusted. As the assigned altitude is intercepted, the rate of ascent should equal zero, and the angle of attack of the aircraft should be consistent with the cruise attitude and cruise speed.

SST Potential Operational Requirements and Constraints

Constraints will be the same as at present, but with the increased speed and other performance characteristics of the SST, and the new operating environment, more care will need to be taken to insure performance within tolerable limits.

Feasible Automated Implementation Concepts for SST

It is anticipated that the automatic system will be utilized to obtain the optimum transition to cruise control. The pre-programmed transition will take into account such parameters as, altitude, airspeed, rate of climb, and g loading. A portion of the computer coupled flight control system could be utilized for this transitional performance. The data inputs can either be in the form of a pre-programmed schedule, or inputs from accelerometers which would be transduced into control signals.

The crew's responsibility would be to select a commanded altitude, and then to monitor the performance of the system. It is still their responsibility to comply with ATC instructions, and to operate within an envelope which takes passenger tolerances into consideration.

The transition to cruise for the SST will be slightly different than in current operations. Because of cruise-climb considerations it may be necessary to maintain a vertical ascent of approximately 100 fpm. This will be a function of the burn-off rate. As the fuel is used, the change in aircraft weight will result in an increasing energy state. This energy will be accepted as an altitude increase instead of an airspeed increase.

Feasible Manual Implementation Concepts for SST

The crew should be able to handle this performance, but may not be able to consistently obtain the same degree of accuracy. At the speeds used by the SST, and in the new environment, many parameters must be considered to obtain an optimum transition. However, taking into account only passenger comfort and compliance with ATC instructions, the crew should be able to perform acceptably. The procedure utilized by the crew would be quite similar to current operations. The only noticeable differences would be in initiation point and rates of change of attitude necessitated by the higher performance characteristics of the SST.

This is one area which can be first experienced in the simulator, so that the crew will be aware of the new performance characteristics of the SST, and will be ready to cope with them. From simulator studies being conducted, and from proposed studies, it appears that new forms of instrumentation will be considered to assist the crew in this function.

5.10 FUNCTION 5.10 CRUISE CONTROL

Purpose

This function provides directional control in all three dimensions during the cruise portion of the SST flight profile. Acting with the power plant system, the flight control system is the means for accomplishing the commands from the enroute navigational function.

Current Jet Operational Requirements and Constraints

Current aircraft are required to remain within designated airspace while maneuvering, and to maintain assigned altitudes. Current physical dimensions of airways, holding patterns, and other ATC separation patterns are predicated on the aircraft maneuvering capabilities.

Current Jet Implementation Concepts

Although current subsonic carriers operate at lower speeds and altitudes, the cruise procedures used are similar to those which will be utilized in the SST. Once the assigned altitude is intercepted, the autopilot will provide altitude and course hold. The speed must be set by the crew manually.

SST Potential Operational Requirements and Constraints

In current operations, the high density of traffic, the inaccuracies of navigational equipment, and the constraints of the ATC system require the assignment of specific cruise altitudes. For jet aircraft these strict procedures result in some reduction in range and increase operating costs. With the SST, constant altitude cruise penalties will be even more severe and for this reason either a step climb or constant climb cruise is being considered. If ATC can accept this type of cruise profile then specific new regulations will have to be developed.

Feasible Automated Implementation Concepts for SST

Those systems previously discussed for probable implementation into the SST will also be utilized throughout the cruise portion of the flight profile. The auto-throttle will continue to command a constant Mach cruise speed; the auto-stabilization will maintain the center of gravity and stability of the aircraft throughout the wide speed range; and the auto-pilot will be working in conjunction with the on-line computer to comply with the navigational commands. The crew's main function will be to monitor the automatic performance, and insure operation within tolerable limits.

Feasible Manual Implementation Concepts for SST

In the event of a malfunction of the flight control system (automatic mode), the crew will be responsible for manually controlling the aircraft. If further studies indicate that the crew is unable to effectively control the aircraft at speeds in the vicinity of Mach 3, the final procedure may be to decelerate in the case of a malfunction of the control system, to a speed within the capability of the human controller.

This performance required of the SST crew will be somewhat similar to that performed by current subsonic aircraft crews. The major difference will be in the operational speeds and the sensitivity of the control operations. White (ref. 42) points out that,

> . . . the apparent sensitivity in pitch to which he has referred--the increased effort required to hold altitude accurately--really came about because the pilots of current military high speed aeroplanes did not have adequate information fast enough, and he was definitely of the opinion that, given anticipatory information, the holding of altitude presented no real problem. Simulator experience had shown that, when using altitude control function, pilots made a much better job of maintaining altitude at a much reduced workload. Corrections were made more smoothly and quickly and G loadings were consequently less. . .

The implications of flight control sensitivity based on results of simulator studies are discussed in ref. 43,

> ...one of the impressions that I get from my own Mach 2 flight experience and many hours in our Mach 3 XB-70 simulator is that altitude control becomes increasingly difficult with increasing speed. This is understandable when you consider that for a given error in pitch attitude, you get nearly four times the change in altitude in a given time period at Mach 3 as you do at .8 Mach. (See Figure 29.) This imposes a more stringent requirement on the autopilot, and requires maximum concentration on the part of the pilot if he has to "hand fly" the airplane and maintain a hard altitude using the attitude gyro, rate of climb, or altimeter, or any combination of these. What is really needed, in my opinion, is a flight director computer function that gives vertical steering information to the pilot with sensitivity and lead optimized for the particular type of aircraft and for the speed range in which it is operating.
>
> The secret of precise high-speed flying is anticipation--and this can best come from a flight director computer function which feeds its information to the autopilot and/or to the human pilot via the instrument panel. The airspeed indicator, Mach meter, rate-of-climb indicator, and altimeter are instruments that tell you where you are at any given instant. Good steering information tells you where you should be to accomplish a selected task. This kind of information is extremely important in establishing and maintaining a climb schedule and establishing and maintaining a given altitude--particularly so if step climbs are a requirement for cruise efficiency...

Although it would appear that an automated system will be utilized, the crew will still have the capability of obtaining the required performance. However, whether the crew will be able to keep the aircraft within the navigational limits required by ATC is still to be determined.

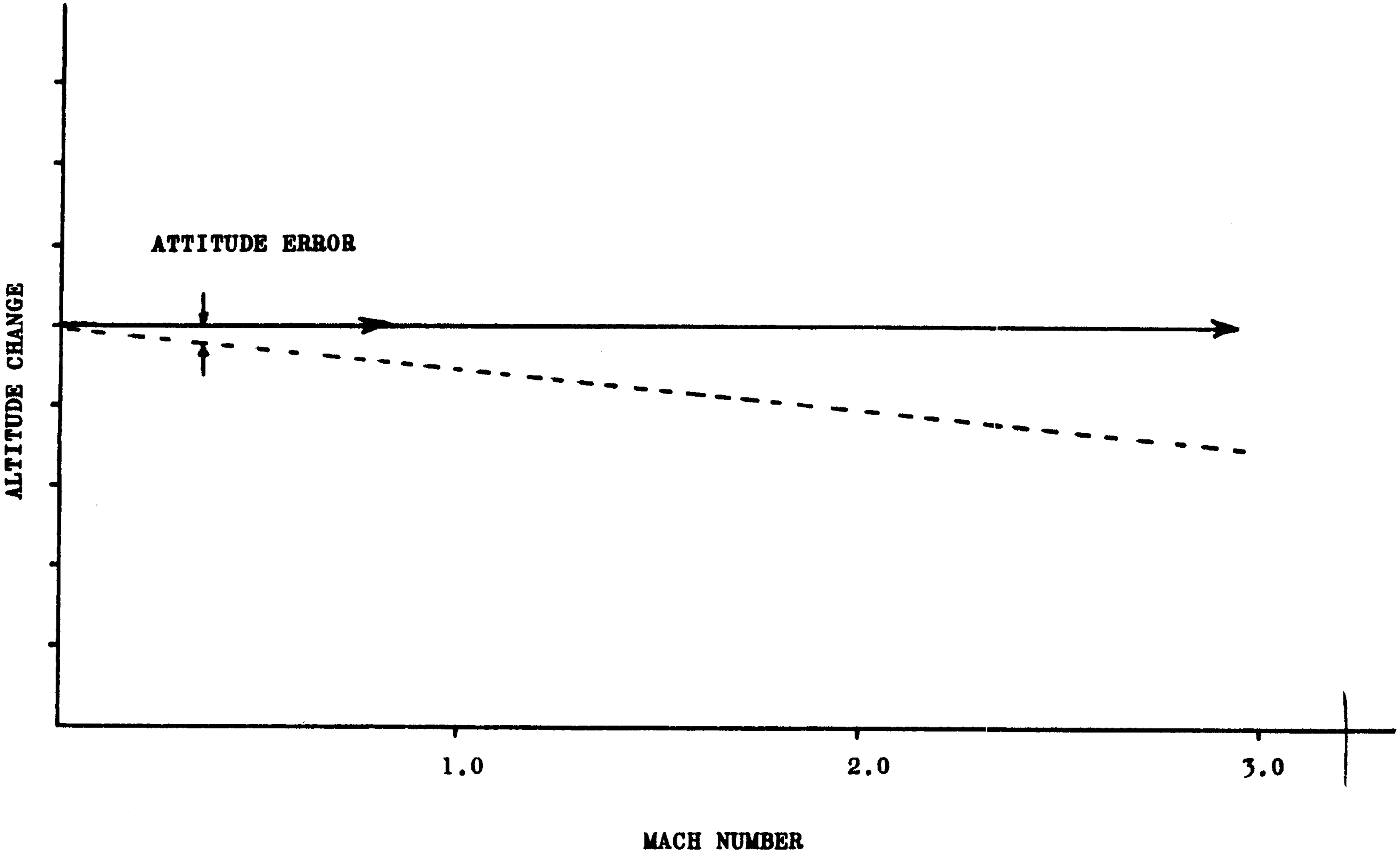

Figure 29. Altitude change vs. Mach number for given altitude error held for given time period (from ref. 43).

5. 11 FUNCTION 5. 11 SUPERSONIC DESCENT CONTROL

Purpose

This function provides three-dimensional control to the SST during deceleration and initial descent portions of the flight profile, and while the aircraft is in the supersonic speed regime.

Current Jet Operational Requirements and Constraints

There are no applicable requirements.

Current Jet Implementation Concepts

This function is not encountered in current operations. However, aside from supersonic speed and its characteristic effect on sensitivity in the control system, performance requirements are similar to those for any descent type flight control activities which are accompanied with rapid speed (and thus trim) changes.

SST Potential Operational Requirements and Constraints

Air Traffic Control procedures, sonic boom considerations and passenger comfort will impose constraints on the SST during its descent performance. The aerodynamics of supersonic flight should pose no new problem area not already discussed in previous functional descriptions. To eliminate passenger discomfort the rate of change of cabin altitude would be limited to about 300 ft/min which then establishes a minimum descent time of about 27 minutes (assuming cabin pressure at 8, 000 ft.). To minimize sonic boom overpressures a descent schedule using a linear variation of Mach with altitude will probably be followed until Mach . 95 at around 55, 000 feet is reached. This constant Mach will probably be maintained until about 300 knots EAS is attained and then this will be held constant.

From an economics standpoint, clearance to descend should be obtained only after assurance is given that an approach to landing is feasible without lengthy delays in low altitude holding patterns.

Feasible Automated Implementation Concepts for SST

The control of the SST during the descent and deceleration phase can be primarily an automated function with the crew participating as a monitor and a back-up system. The descent profile will be very similar to that flown by today's current subsonic aircraft. As has been previously discussed, a combination system which incorporates an on-line computer and the automatic control system will in all likelihood be utilized on the SST. The sophistication of such a system and the final role which the crew will actually play have yet to be determined, but without doubt an economic trade-off will be reached to gain consistently optimum performance. Richardson (ref. 21), describes the automatic descent function of such a system,

> ... considering the descent phase of the vertical profile, a slightly different technique was used. * In order to achieve proper terrain clearance on approach, and to insure accurate spatial positioning of the aircraft, a trajectory of altitude versus distance was used as a control law. Again, for this specific application, the let-down trajectory was stored in the computer memory. As the aircraft passed through the upper homing point, designated by altitude, geographical location (latitude and longitude), and ground track heading, the computer pitched the aircraft over to follow the specified trajectory. As in the climb-out case, the actual control of the vehicle was accomplished by the digital computer driving the autopilot. The only pilot function was the positioning of the throttle to a nominal idle position. In this case the pilot provided a type of vernier adjustment through small manual throttle manipulations. For precise, complete control of the trajectory, automatic throttle control could be used as an airspeed/rate of descent control. A pilot override of automatic throttle

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* See Function 5.6.

> control would provide for immediate takeover by the pilot in the event he visually or otherwise determines the need for a pullout or course change.
>
> In this specific case, as in the previous climb profile, computer inputs from a separate central air data computer subsystem were used. In general the digital computer quantization is such that the input signal accuracy becomes the governing factor in the overall accuracy of the CEMS. The digital computer does not contribute any measurable additional inaccuracies.
>
> The use of the digital computer controlled automatic speed-altitude scheduling of this aircraft has met with complete acceptance by the operational personnel, both traffic controllers and pilots. Automatic climb-outs through restricted climb corridors, and automatic letdowns right to the ILS gate have become standard operating procedures. The requirement for automatic throttle control during these phases of flight is still a matter of some conjecture which probably should be resolved by particular analysis of the SST aerodynamic performance characteristics...

Utilizing the automatic mode of operation the crew, after initial data insertion and system checkout, would function primarily as a monitor to insure that the system was operating within acceptable tolerances. In the event of a malfunction they would be able to override the system immediately with as little transitional delay as possible.

Feasible Manual Implementation Concepts for SST

There is no indication at this time that the crew will be unable to manually fly the SST throughout supersonic deceleration and descent. In fact, most aviation companies are demanding the ability to have a manual back-up to the automatic systems. In the event that a portion of the automatic system were to malfunction, the SST crew should be capable of handling the performance with a basic flight control system. Of course, more attention will have to be given to the area of control sensitivity. To control the SST during its initial descent and deceleration the crew will need some descent placard as a guide to obtaining optimum performance.

Although this concept is feasible, it does not appear to be the best one. The automatic mode of operation seems to be able to handle the myriad of changing parameters which must be considered, in a more efficient manner.

5. 12 FUNCTION 5. 12 TRANSONIC DECELERATION CONTROL

Purpose

The purpose of this function is to provide three dimensional control for the SST vehicle during the transitional deceleration and descent. The required performance will be essentially a reversal of the performance required during the transitional acceleration and subsequent climb. The stability and controllability problem areas associated with the high-drag sonic barrier will again be encountered, but in the reverse direction. The trim speed of the aircraft will be changing rapidly, and with the decrease in speed will come an increase in the available maneuverability.

Current Jet Operational Requirements and Constraints

There are no applicable current requirements.

Current Jet Implementation Concepts

There are no applicable concepts.

SST Potential Operational Requirements and Constraints

One factor which will be considered both in the navigational functions and in the flight control operations, is the problem of sonic boom during the descent phase. More care must be taken during the descent than the ascent because the downward direction of the plane has a tendency to increase the intensity of the overpressures generated. However, navigational outputs should take this factor into consideration when computing the optimum descent flight profile. To minimize sonic boom problems,

> . . . in the deceleration and descent phase of the flight, it is desirable to decelerate to subsonic speeds at as

> high an altitude as possible, and furthermore steep descents at supersonic speeds should be avoided. Maneuvers at supersonic speeds should be avoided in all phases of the flight because of the possibility of intensifying the sonic boom pressures over localized areas on the ground... (ref. 44).

Feasible Automated Implementation Concepts for SST

This particularly short portion of the flight profile can be handled either by the SST crew or by the automatic portion of the flight control system. If the aircraft was cleared all the way into the destination in accordance with a pre-programmed descent profile, the completely automatic mode of operation could be utilized. However, if revisions must be made to the original clearance, or if ATC decides to vector the aircraft via a circuitous route, then the crew has the ability to override the automatic system and to manually control the SST through this portion of the flight.

As the SST decelerates into the transonic speed regime, the high drag characteristic of the area will again appear as discussed in Function 5. 7. This will require compensation from both the auto-stability and the auto-trim systems. The chief concern of the crew will be to attain subsonic flight at an altitude which would preclude the generation of sonic boom.

In the automatic mode of operation, the crew would select the descent/deceleration profile, and the computer would issue control and stability commands to the aircraft. The crew would then be chiefly concerned with monitoring the system and perhaps entering new data into the system.

Feasible Manual Implementation Concepts for SST

The use of descent placards in conjunction with the basic control system is well within the capability of the crew, although it is not quite as precise an operation as the automatic mode. The descent schedule used should minimize the sonic boom effects and should be consistent with the requirements of the other systems (e. g. , pressurization).

In most cases the deceleration and transonic portion of the flight will be performed in a designated area, and will not require any maneuvering by the crew. Thus, the main area of concern will be establishing a vertical profile which is consistent with sonic boom considerations, passenger comfort, and ease of achievement. If the crew is required to fly the descent profile, in all likelihood a constant Mach, then constant airspeed schedule would be utilized.

The descent placard with attainable parameters would serve as a guide to crew performance. (For example, Mach 2. 5 to 60, 000 at a rate of descent of 5, 000 fpm, then 250 knots IAS until reaching 50, 000 ft. and Mach 1. 3). Under normal conditions the use of a descent placard would give the crew the capability of staying within its restriction envelope.

5.13 FUNCTION 5.13 SUBSONIC DESCENT CONTROL

Purpose

This function provides directional control for the SST in that flight regime from the time it passes through the sonic barrier and maneuvers at some subsonic speed, until it is established in its standard instrument approach (SIA). During this particular phase of the flight the SST will be operating in an environment with other subsonic aircraft, and must be able to do so economically.

Current Jet Operational Requirements and Constraints

There are no special requirements and constraints connected with this area of operation, other than compliance with ATC procedures.

Current Jet Implementation Concepts

Current jets cruise at the altitudes slated for the SST's return to subsonic speeds, and start their approaches and let-downs at lower altitudes. When cleared by ATC, a power reduction consistent with the desired rate of descent is utilized to descend. If higher rates of descent are desired, speed brakes and/or spoilers provide this capability. In almost all situations this is a manual operation.

SST Potential Operational Requirements and Constraints

When the SST returns to subsonic operations, it must be compatible with existing regulations for current jets.

Feasible Automated Implementation Concepts for SST

In the case of the straight wing (fixed-wing) configuration, the crew of the SST will operate the aircraft in accordance with procedures which are similar to today's operations. Portions of the automated flight control system may be utilized, or the entire subsonic maneuvering may be manual.

However, if the variable sweep aircraft is the chosen configuration, the crew will be required to reconfigure the aircraft to its optimum subsonic configuration. This should not present any problems for the crew, for in all likelihood reconfiguration will be a pilot initiated, hydraulically actuated function. The Boeing SST design has a single-wing sweep and flap lever on the pedestal with detents at the desirable positions (see Figure 30). The change of configuration will cause some trim changes, but these will be within the capabilities of the flight control system and the crew.

Any problem areas during this and subsequent phases of the flight profile will result largely from the attempt to integrate the SST into Air Traffic Control patterns. It has been pointed out that (ref. 28),

> ... during the subsonic phase of flight, the supersonic transport will have characteristics similar to the present day subsonic jet aircraft. During routine operations, it is expected that the aircraft will be cleared without delay and that holding will not be necessary. Provision must be made, however, for unexpected situations, and some holding capability must be included in the operating characteristics of the aircraft. Holding when necessary will probably be accomplished at altitudes from 30,000 to 40,000 feet. Approach clearance will be issued from this range of altitudes when the aircraft is ready to enter the landing sequence. It should not, however, be cleared to descend below these altitudes unless there is a high probability of landing at the scheduled terminal. Separate inbound tracks should be provided to keep to a minimum the time between approach clearance and landing...

No new equipment will be utilized during this phase of flight. In the most automatic mode of operation, the pre-programmed descent schedule will maintain directional control through the flight control system, and speed control through the auto-throttle subsystem. The

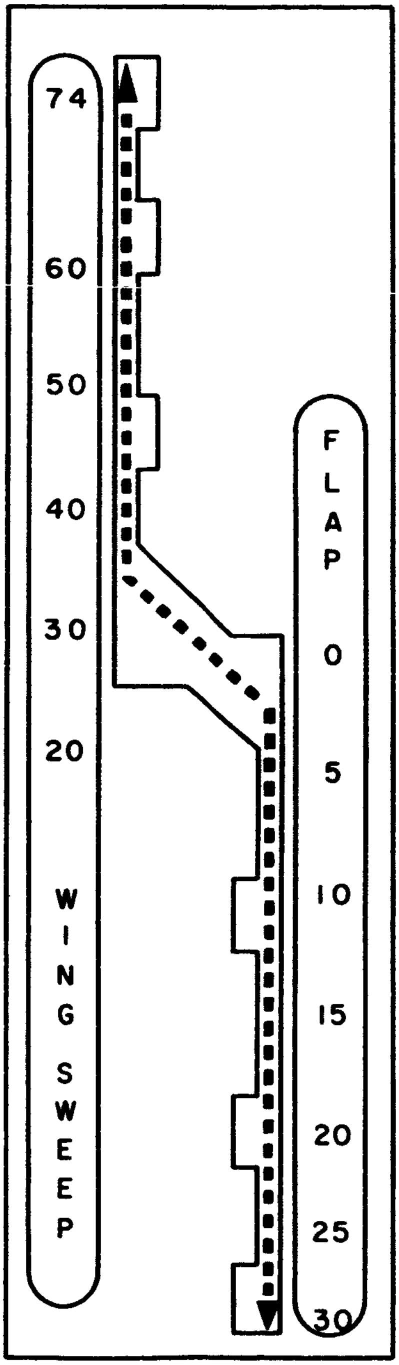


Figure 30. Illustration of detent positions for combined wing sweep and flap lever.

crew's primary function during this phase of the flight will be to monitor performance.

In the event of changes in the original clearance, such as holding, or radar vectoring, the crew can either override the automatic function, or can re-enter the new data into the on-line computer for continued automatic operation. When the automatic mode of operation is overridden by the crew, they will still have the capability for semi-automatic flight operations. In other words portions of the automatic flight control system can still be utilized to fly the holding patterns or to comply with the radar vectoring.

Feasible Manual Implementation Concepts for SST

In the most manual mode of operation the SST crew will have the capability to actually fly the SST throughout its subsonic flight operations. Since the emergency back-up system to the power controls envisioned for the SST will be similar to that found in today's subsonic aircraft, the crew should experience the same degree of restrictiveness that they do today in flying similar patterns. Once the SST has passed through the sonic barrier, aerodynamic characteristics are such that any phase of the flight should be within the capability of the crew. Directional control, pitch control, airspeed and altitude control are all performed in current operations. It will be the crew's responsibility to position the aircraft so as to conform to ATC procedures.

5.14 FUNCTION 5.14 LETDOWN CONTROL

Purpose

This function provides the directional control necessary to position the aircraft in three dimensional space in accordance with the commands of the generated descent profile and in compliance with the instructions of the published standard instrument approach (SIA), or ATC instructions. Within this particular phase of flight there may be the requirement for flying holding patterns and descent maneuvers (e. g., an instrument approach or a radar vectored approach).

Current Jet Operational Requirements and Constraints

The main regulations stem from ATC procedures. Such regulations include obtaining of clearances and complying with published procedures. These procedures indicate methods of flying holding patterns, and information concerning approach patterns which make them consistent for all traffic (e. g., speeds through the patterns, crossing altitudes, minimum altitudes, etc.).

Current Jet Implementation Concepts

Current initial approaches begin at approximately 20,000 feet. However, once a clearance has been received, the aircraft begins the standard instrument approach. The navigational information is found on the SIA plates and the navigational system gives a relative position display. The aircraft descends at a constant airspeed (approximately 300 kts) and a vertical speed of 3,000-5,000 feet per minute. To attain this descent profile, such external devices as speed brakes or spoilers are utilized in conjunction with an idle thrust profile. The letdown varies with the particular facility. Some allow a long descending pattern, while others use penetration type approaches with steeper profiles.

For air traffic control purposes it is necessary to restrict aircraft to certain space areas in their approaches so that minimum traffic separation can be maintained. To attain the type of descent profile required by ATC, high drag devices are utilized so that the aircraft can make a descent at a maneuverable speed (approximately 300 kts) and still remain within a given area. Speed brakes and/or spoilers give this capability; that is, a suitable rate of descent can be attained while maintaining a constant descent speed. (For those unacquainted with descent profiles, it might be interesting to note that if an idle descent is made, and a constant airspeed is selected, then the rate of descent becomes nearly a constant, or a function of the aircraft's configuration.) In current operations most of the SIA is flown manually, and only occasionally will portions of the auto-pilot system be utilized.

SST Potential Operational Requirements and Constraints

Some provision will have to be made to establish holding patterns at as high an altitude as possible because altitude will be critical for the SST as far as fuel burn-off is concerned. In setting up such patterns, the maneuvering space will also need to be recomputed to take into consideration the sensitivity of the SST.

Feasible Automated Implementation Concepts for SST

The equipment and implementation concept described in Function 5.12 would be utilized for this portion of the flight. SIA information could be fed through the computer into the flight control system to obtain required three-dimensional positioning and speed control. In the event of a hold, the crew could utilize portions of the automatic system to obtain speed and altitude control. The crew's main responsibility would be to enter the required data, and then to monitor the performance to insure compliance with the ATC procedures. Although the automated concept is quite feasible, it is more likely that the crew will manually fly this portion of the profile. There are many variables encountered during this phase and the crew would be better able to assimilate and act on this data.

Feasible Manual Implementation Concepts for SST

The following of a constant subsonic descent speed profile should be well within the capabilities of the crew, even using strictly manual means. The procedures will be similar to current operations, and thus the restrictiveness of the task should be similar. In most cases once the descent speed has been trimmed for, the aircraft will almost fly itself and the crew's responsibility will be to comply with approach procedures by utilizing drag devices judiciously.

5.15 FUNCTION 5.15 LEVEL-OFF MANEUVER

Purpose

The purpose of this function is to change the attitude of the aircraft from a descent in compliance with a standard instrument approach or ATC radar vector instructions, to straight and level flight at an altitude consistent with completing the initial landing approach. Aircraft conforming to descent procedures have a constant airspeed (approximately 300 kts. EAS), have a shallow apparent tilt angle with the vertical, and have a rate of descent established of around 3000-5000 feet per minute.

Since neither the aircraft nor the passengers can tolerate square corner transitions, a smooth and gradual transition must be made from the stated vertical descent to level flight. This maneuver requires a coordinated power plant/flight control performance which must take passenger and aircraft limitations and tolerances into consideration.

Current Jet Operational Requirements and Constraints

Although no regulations bind the crew to specific parameter performance, standard operating procedures and aircraft and passenger limitations usually dictate the limits on this performance. ATC procedures require maintenance of assigned altitudes for sufficient separation between aircraft.

Current Jet Implementation Concepts

No equipment not previously mentioned is utilized for this particular phase of flight. As the final approach altitude is neared, the rate of descent is decreased, so that upon arrival at assigned altitude, the attitude of the aircraft will be such as to maintain straight and level flight at the desired airspeed. That is, the established rate of descent of 3000 to

5000 feet per minute is decreased to zero. This maneuver requires coordinated power/flight control performance which must take passenger limitations and tolerances into consideration. The crew is responsible for intercepting an assigned altitude and uses the pitch control either on the primary system (yoke) or on the auto-pilot system to attain the altitude required. This results in directional change of the aerodynamic vector, which in turn decreases airspeed and vertical speed.

SST Potential Operational Requirements and Constraints

The SST will continue to be governed by those factors discussed for current operations.

Feasible Automated Implementation Concepts for SST

In the description of Function 5. 9, Transition to Cruise Control, reference was made to a concept wherein existing parameters were analyzed and an optimum level-off schedule was generated and fed directly into the flight control system. This particular portion of the system could again be utilized for accomplishing a level-off from a descent profile. Data in the form of assigned altitude, airspeed, vertical rate of descent, and passenger tolerances could be called upon to generate a transitional profile which would in turn feed commands to the flight control and auto-throttle systems. The crew would maintain all responsibility, and would need to insure that this mode of operation was functioning normally.

Although this concept is quite feasible, whether any advantage would be gained by utilizing it has still to be determined. The crew is quite capable of performing as well as the automated function.

Feasible Manual Implementation Concepts for SST

As is the case with almost all of the flight control system activities, especially in the subsonic regime, the crew is well within their capability to perform any activity utilizing only the basic system offered. In that sense the procedure would be quite similar to that performed by today's subsonic carrier crews.

The basic control system (yoke) or the pitch control on the autopilot would be utilized to change the attitude of the SST. Data in the form of altitude, altitude assigned, rate of descent, and airspeed, would be analyzed by the crew, and then control commands would be made to obtain a tolerable performance. In these and all cases where the crew will actually fly the aircraft, the need exists for furnishing them with relevant and timely information.

Unless it can be shown that a pre-programmed transition is mandatory, the flying of this portion of the flight profile by the crew appears to be the most practical concept.

5.16 FUNCTION 5.16 INITIAL APPROACH CONTROL

Purpose

The purpose of this function is to provide three-dimensional control and aircraft reconfiguration consistent with the reduced speeds associated with the landing approach. Upon descending from altitude, and leveling at some initial approach altitude, the aircraft is slowed to final approach speed. To accomplish this the aircraft must be reconfigured and then established in an attitude consistent with the new speed. When the aircraft levels at the approach altitude, the attitude of the aircraft continually changes as the excess in airspeed is converted to maintaining constant altitude. As the aircraft's speed decreases it becomes necessary to utilize high lift devices, such as flaps, to obtain adequate low speed flight characteristics.

Once the approach speed has been attained, power is added to maintain the altitude and the airspeed. The flight control task involved is a function of the airspeed and the required angle of attack. It must be remembered that to obtain a certain lift-to-drag ratio (L/D) a certain angle of attack must be maintained, and the only way to establish this is to change the attitude of the aircraft with regard to the relative wind.

The following regulation applies:

FAR 91.117, ref. 13:

Inoperative ILS components.

The components of a complete ILS are localizer, glide slope, outer marker, middle marker, and approach lights. However, a compass locator at an outer or middle marker site may be substituted for the outer or middle marker, respectively. Unless otherwise specified in Part 97 of this chapter, no person may begin an ILS approach when any component of the ILS is inoperative, or the related airborne equipment is inoperative or not utilized, except as follows:

(1) When only one component (other than the localizer) is inoperative and all other components are in normal operation, a straight-in approach may be made if the ceiling and visibility at the airport are at least equal to 300 feet and ¾ statute mile, respectively.

(2) When the localizer and the outer marker are the only components in normal operation—

(i) A circling approach may be made if the ceiling and visibility are equal to or higher than the minimums prescribed for a circling approach; or

(ii) A straight-in approach may be made if the ceiling and visibility at the airport are at least equal to 300 feet and one statute mile, respectively.

(3) In the case of an alternate airport, when only one component (other than the localizer) is inoperative and all other components are in normal operation, a person may make an approach if the ceiling and visibility at the airport are at least equal to the minimums prescribed for use of the airport as an alternate airport.

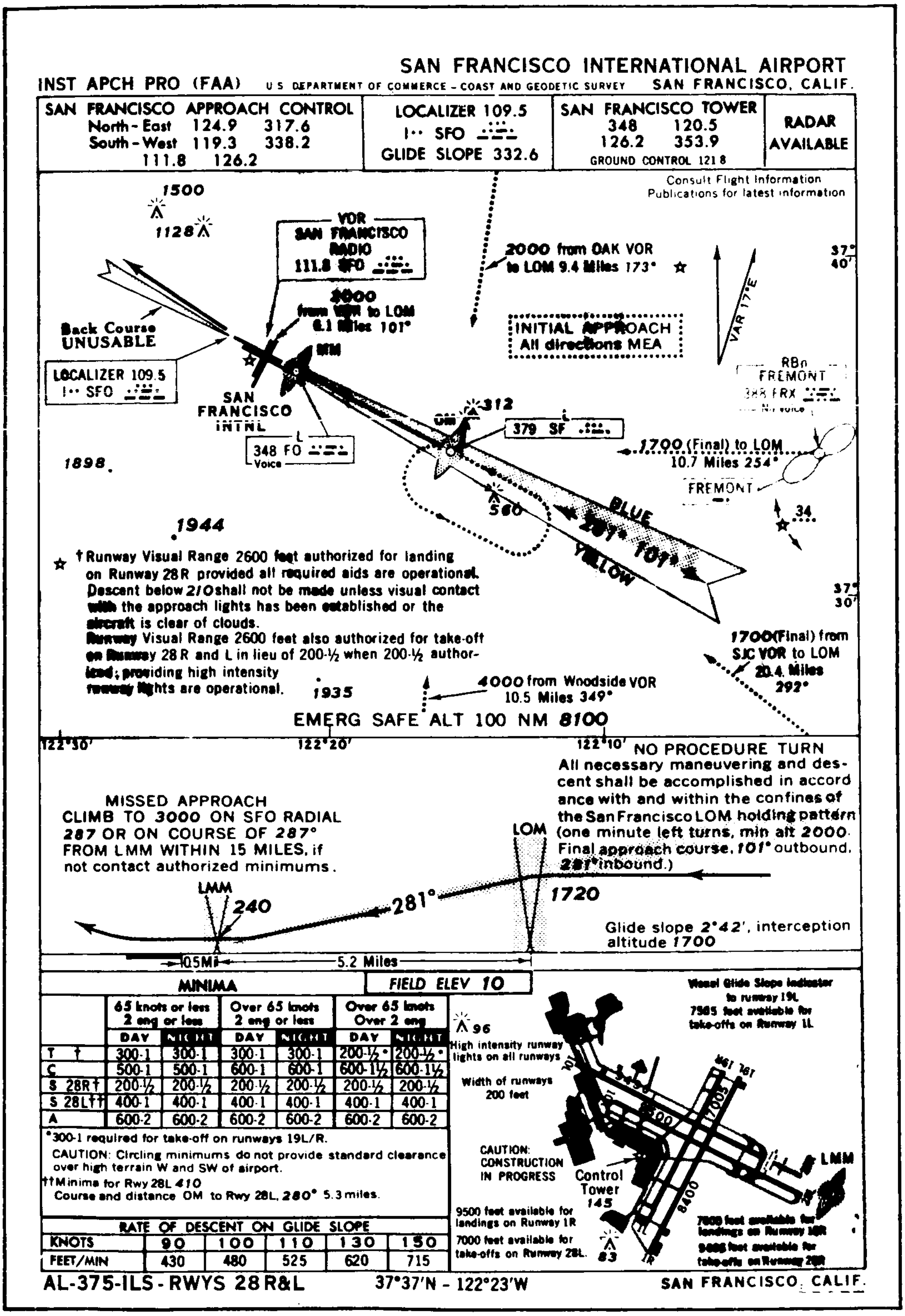
Current Jet Implementation Concepts

In current aircraft this portion of the approach is flown by the pilot. However, in straight and level portions of the pattern, the pilot can activate the auto-pilot and at least utilize the altitude hold and the directional controls. All configuration changes are initiated by the crew in accordance with standard operating procedures and aircraft characteristics relative to certain airspeeds. Landing gear and high lift devices (flaps, droops, boundary layer control, etc.) are used to maintain slow flight. These devices essentially help to increase the L/D ratio (that is, establish a new L/D versus angle of attack curve) whereby a certain desired amount of lift can be obtained at a lower angle of attack.

During this particular phase of the flight (level flight) the airspeed will dictate the vertical attitude of the aircraft (pitch), and the navigational inputs will determine the amount of directional control necessary for the approach (roll and yaw). Directional inputs will probably be in the form of radar vectors given by the local ATC facility, or as directed in the final portion of the standard instrument approach.

Figure 31 depicts the final portion of the standard instrument approach (SIA), and is utilized during the final approach to the landing. Another set of charts depicting the let-down procedures are utilized with these final approach charts to make up the standard instrument approach. These instrument approach procedures are published for each of the usable runways at a facility, and show the minima for each of the approaches.

As in any control maneuvers connected with the three dimensional positioning of the aircraft, the basic flight instrumentation (i. e., the altimeter, airspeed indicator, directional indicator, attitude gyro, etc.) will be utilized to obtain an indication of performance.



INST APCH PRO (FAA) U S DEPARTMENT OF COMMERCE - COAST AND GEODETIC SURVEY

SAN FRANCISCO INTERNATIONAL AIRPORT
SAN FRANCISCO, CALIF.

SAN FRANCISCO APPROACH CONTROL North-East 124.9 317.6 South-West 119.3 338.2 111.8 126.2	LOCALIZER 109.5 I-SFO GLIDE SLOPE 332.6	SAN FRANCISCO TOWER 348 120.5 126.2 353.9 GROUND CONTROL 121.8	RADAR AVAILABLE

Consult Flight Information Publications for latest information

† Runway Visual Range 2600 feet authorized for landing on Runway 28R provided all required aids are operational. Descent below *210* shall not be made unless visual contact with the approach lights has been established or the aircraft is clear of clouds. Runway Visual Range 2600 feet also authorized for take-off on Runway 28R and L in lieu of 200-½ when 200-½ authorized; providing high intensity runway lights are operational.

EMERG SAFE ALT 100 NM *8100*

NO PROCEDURE TURN All necessary maneuvering and descent shall be accomplished in accordance with and within the confines of the San Francisco LOM holding pattern (one minute left turns, min alt *2000*. Final approach course, *101°* outbound, *281°* inbound.)

MISSED APPROACH
CLIMB TO *3000* ON SFO RADIAL *287* OR ON COURSE OF *287°* FROM LMM WITHIN 15 MILES, if not contact authorized minimums.

Glide slope *2°42'*, interception altitude *1700*

MINIMA | *FIELD ELEV 10*

	65 knots or less 2 eng or less		Over 65 knots 2 eng or less		Over 65 knots Over 2 eng	
	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
T †	300-1	300-1	300-1	300-1	200-½ *	200-½ *
C	500-1	500-1	600-1	600-1	600-1½	600-1½
S 28R †	200-½	200-½	200-½	200-½	200-½	200-½
S 28L ††	400-1	400-1	400-1	400-1	400-1	400-1
A	600-2	600-2	600-2	600-2	600-2	600-2

*300-1 required for take-off on runways 19L/R.

CAUTION: Circling minimums do not provide standard clearance over high terrain W and SW of airport.

†† Minima for Rwy 28L *410*
Course and distance OM to Rwy 28L, *280°* 5.3 miles.

RATE OF DESCENT ON GLIDE SLOPE					
KNOTS	90	100	110	130	150
FEET/MIN	430	480	525	620	715

High intensity runway lights on all runways

Width of runways 200 feet

CAUTION: CONSTRUCTION IN PROGRESS

Visual Glide Slope Indicator to runway 19L

7565 feet available for take-offs on Runway 1L

9500 feet available for landings on Runway 1R

7000 feet available for take-offs on Runway 28L.

7000 feet available for landings on Runway 10R

9400 feet available for take-offs on Runway 28R

AL-375-ILS-RWYS 28R&L 37°37'N - 122°23'W SAN FRANCISCO, CALIF.

Figure 31. ILS instrument approach procedure plate.

SST Potential Operational Requirements and Constraints

There do not appear to be any modifications necessary to current operational procedures with regards to the SST. However, because of the size of the aircraft and its slower control response, some attention might be paid to establishing procedures which will reduce excessive maneuvering in this regime.

Feasible Automated Implementation Concepts for SST

This phase of flight will be very similar to current operations with the exception that approach speeds may be slightly faster. Also, because of longer proportions, longitudinal response of the SST may be somewhat slower than on current aircraft which will necessitate a little more anticipation by the crew. Depending on the final design chosen, there is the possibility that the approach will be made at high angles of attack, which could make visibility a critical factor.

Aside from these inherent characteristics of the proposed SST, there is no indication that the control activities in this initial approach phase will change significantly with the introduction of the SST. The crew will still be responsible for reconfiguring the aircraft and maneuvering to comply with the approach instructions. The crew will be able to utilize portions of the automatic control system, but will not have a preprogrammed approach pattern feeding command inputs to the control system.

Feasible Manual Implementation Concepts for SST

The concept illustrated above is essentially that which will be employed in the manual feasibility concept. However, in all those portions of the pattern wherein the automatic modes of operation could be utilized (i. e., altitude hold, course hold, etc.) the crew would be required to manually hold the aircraft. This would be quite similar to current jet flight control. Either the flight control system via the control column and rudder pedals will be utilized, or the flight control system via the auto-pilot will be used. In either situation responsibility will remain with the crew. In this particular regime of flight the characteristics of the SST will be comparable to current subsonic jets, and the control necessary will be the same.

5.17 FUNCTION 5.17 FINAL APPROACH CONTROL

Purpose

This function provides directional control to the SST during the final phases of the landing maneuver; in particular, during the portion of the flight that the aircraft has entered the final approach course and has started a descent towards the runway. The main responsibility of the crew will be to insure minimum excursions from the optimum approach profile.

Operational Requirements and Constraints

In most cases the carriers of today are restricted to certain maneuvers because of safety factors and because of demonstrated state-of-the-art concepts. ATC procedures also dictate to some extent the limits of some maneuvers. High traffic density found in terminal areas must be directed in an orderly and precise method. Thus both in visual and instrument conditions, the ILS approach is usually employed. Flying the "beam" requires control in both the vertical and lateral planes, and speed control to operate within structural limits upon landing. The following specific regulation applies:

FAR 91.117, ref. 13:

> Inoperative ILS components
>
> The components of a complete ILS are localizer, glide slope, outer marker, middle marker, and approach lights. However, a compass locator at an outer or middle marker site may be substituted for the outer or middle marker, respectively. Unless otherwise specified in Part 97 [New] of this chapter, no person may begin an ILS approach when any component of the ILS is inoperative, or the related airborne equipment is inoperative or not utilized, except as follows:

(1) When only one component (other than the localizer) is inoperative and all other components are in normal operation, a straight-in approach may be made if the ceiling and visibility at the airport are at least equal to 300 feet and ¾ statute mile, respectively.

(2) When the localizer and the outer marker are the only components in normal operation—

(i) A circling approach may be made if the ceiling and visibility are equal to or higher than the minimums prescribed for a circling approach; or

(ii) A straight-in approach may be made if the ceiling and visibility at the airport are at least equal to 300 feet and one statute mile, respectively.

(3) In the case of an alternate airport, when only one component (other than the localizer) is inoperative and all other components are in normal operation, a person may make an approach if the ceiling and visibility at the airport are at least equal to the minimums prescribed for use of the airport as an alternate airport.

Current Jet Implementation Concepts

Having intercepted the ILS final approach course, the aircraft is slowed to final approach speed. The ILS coupler may be actuated to utilize a portion of the auto-pilot for course and glide slope hold. The crew varies the power to maintain the required airspeed. Current jets also have flight directors which are used to manually fly the aircraft following a computed display (Figure 32). Consideration is being given to a wind screen, heads-up display to assist the crew in making the transition from instrument conditions to visual conditions.

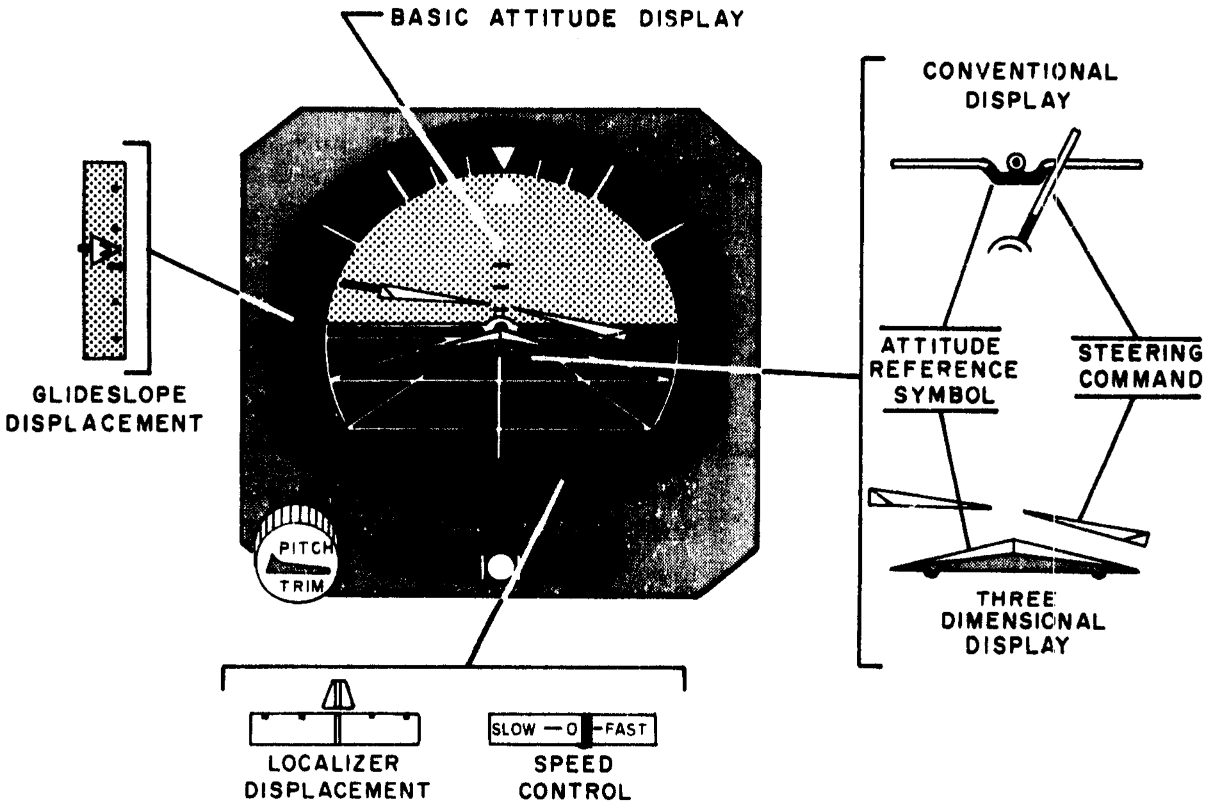


Figure 32. A flight director (from Collins Radio Company).

SST Potential Operational Requirements and Constraints

Some of the problems in trying to integrate the SST into the Air Traffic Control system have already been pointed out (ref. 45) for the approach and landing phase of flight,

> ...approach angles of supersonic transports and touchdown angles will be high which may limit direct vision by the pilot. Wake turbulence due to wing-tip vortices and jet exhaust will be stronger than the commercial subsonic jet. New procedures for spacing of these aircraft in the terminal area and approaches may be necessary.
>
> The terminal area will require an automatic landing system. Go-arounds are costly. In the event of a go-around, a new approach must be set up in the minimum time by ATC...

There have been many attempts to handle the stringent demands of the SST landing and approach in an integrated system which will take advantage of the latest advances in the state-of-the-art, but will maintain the crew somewhere within the loop. The introduction of the SST will bring with it several new flight requirements which will to some degree be foreign to the current subsonic aircraft crews. The SST landing requirements have been described (ref. 31) as follows:

> ...the landing requirements for a supersonic transport can also be extremely critical, although the variable-sweep concept reduces these problems considerably. The landing gross weights for the supersonic transport will be higher than for present turbine-powered transports. Therefore, wing areas for the SST will be greater and/or the available lift coefficient will be increased for landing to prevent the landing distance required from becoming excessive. For the low-aspect-ratio wings required for a fixed-wing SST, it is difficult to obtain sufficiently high usable lift coefficients to reduce the landing speeds to an acceptable level; therefore, it is usually necessary to size the wing larger than otherwise desired for vehicles cruising in the 65,000 to 75,000 foot region.

> ...the rate of descent characteristics during approach for a typical fixed-wing SST are such that the steady state approach condition of 130 knots at 600 feet per minute rate of descent falls well on the "back side" of the (power)* curve. This condition will have an undesirable effect on flareout and touchdown maneuvers. The ability to control approach speed and angle along the glide slope becomes a problem because of the resulting inverse speed-attitude relationship for trim at any given altitude and rate of sink. For example, if the pilot desires to increase speed while holding a given glide slope, he must first drop the nose and increase throttle settings; however, as the transport speed increases, he must reverse the throttle direction to lower and lower power while easing on the wheel until the desired speed is stabilized. Although control motion is essentially normal, operation of the throttle must be reversed to attain the new trim position. Many high performance military aircraft operate in this manner, however, more study is required before this could be considered practical for commercial operations.

In addition to ATC procedures and SST handling characteristics, some thought should also be given to crew and equipment capability. IATA and the FAA are striving for automatic landings. To achieve this a three step program has been devised:

1. Category I -- 200 feet ceiling and runway visual range (RVR) of 1/2 mile.

2. Category II -- 100 feet ceiling and a RVR of 1,200 feet.

3. Category III -- Hands off landing
   a. The landing
   b. The rollout
   c. Taxi

---

*Parenthetic insertion by the authors.

Currently jet aircraft are permitted Category I and in a few cases Category II operation. The SST should be equipped to meet Category III requirements.

Feasible Automated Implementation Concepts for SST

It appears that an automatic landing system will be utilized not only by the SST, but by most subsonic carriers operating in the SST era. The system would provide course hold, glide slope hold, airspeed control, flare initiation and decrab maneuvers. This system would be a portion of the auto-pilot system and would employ data received from the on-line computer, the navigation system, and the ILS system. Since the crew would continue to maintain all responsibility for the approach to landing, displays which would allow instantaneous take over by the crew are essential. This probably means some form of pictorial presentation.

In most concepts the crew may accept whatever degree of involvement it desires. In other words, the overriding of one particular function of the system will not eliminate the capability of the system to perform its other functions.

Although airlines and pilots demand the capability for a manual landing, it appears that the automatic mode of operation will provide the routine method of operation. This is primarily because optimum performance is required at all times.

Feasible Manual Implementation Concepts for SST

The SST will be able to be landed and controlled throughout its approach just like any aircraft currently being flown. However, like current aircraft, higher landing minima may restrict the aircraft under such modes of operation.

If the crew's responsibility is only to maintain three dimensional positioning in accordance with a computer flight director display, then such a tracking task is well within their capability. In that situation the crew would utilize the basic control system to maintain the "bug" on the display placard. The crew would have to maneuver the aircraft into a position to intercept the final approach course. Then as it started inbound towards the runway, they would select a heading which would keep them centered on the localizer course and compensate for any wind components. As the glide slope was intercepted, the crew would need to change the power and altitude of the aircraft so as to maintain the glide path angle.

The performance would be similar to current operations, except that there may be operation on the back side of the power curve. This is certainly new to commercial pilots yet several current military aircraft have to be operated on the back side of the power curve during final approach and they at least do not seem to present a problem.

5.18 FUNCTION 5.18 MISSED APPROACH EXECUTION CONTROL OPERATIONS

Purpose

This function provides directional control for the SST in the event that the landing and/or approach is abandoned for some reason decided upon by the crew. The aircraft on final approach is in all likelihood coupled to an inbound approach course, and descends in accordance with the glide path. Once the decision has been made to abort the landing, the aircraft must be repositioned from its descending trajectory to establish either a level flight or a climbing attitude.

This activity has been part of aviation since the beginning. With the introduction of higher performance aircraft, however, the maneuver has become more critical. Longer aircraft, heavier aircraft, swept-angled configurations, and some of the other characteristics of the high performance aircraft have introduced new problem areas into the missed approach performance requirements. This is particularly true in the latter stages of the landing approach.

Current Jet Operational Requirements and Constraints

Safety is the main underlying factor in the requirements concerning missed approaches. This section on flight control is merely the means for complying with command requirements made in the flight management function. By regulation the crew is required to execute a missed approach if certain weather minima are not met, if the runway is not visible, or if the crew feels that the safety of the aircraft or its passengers is in jeopardy. The following specific regulation applies:

FAR 91.117, ref. 13:

Descent below IFR landing minimums.

No person may operate an aircraft below the applicable minimum landing altitude unless clear of clouds. In addition, no person may operate an aircraft more than 50 feet below that minimum altitude unless—

(1) The landing minimums are at least ceiling 1,000 feet and visibility two statute miles; [or]

(2) The aircraft is in a position from which a normal approach can be made to the runway of intended landing and the approach threshold of that runway or the approach lights or other markings identifiable with that runway are clearly visible to the pilot.

If, after descent below the minimum altitude, the pilot cannot maintain visual reference to the ground or ground lights, he shall immediately execute the appropriate prescribed missed approach procedure.

Current Jet Implementation Concepts

The execution of the missed approach combines a flight control and power plant operation. The performance is actually an extension of the takeoff performance (Function 5.4) and the initial climbout control (Function 5.5). The crew's main responsibility is to abort the landing attempt, and re-establish the aircraft in a safe flying regime. In general, the performance described in the Boeing 707 operations manual (ref. 17) will hold for most missed approach procedures. It states,

> ...the missed approach procedure consists of partially retracting the flaps immediately after takeoff thrust is applied, and then after a positive rate of climb is established, the gear is retracted. The same climbout considerations apply to the missed approach and go-around as were discussed under TAKEOFF AND CLIMBOUT. Speeds should be controlled quite carefully so that the climbout path is assured. Again, after reaching approximately 1,000 feet, airspeed should be increased to the minimum speeds for maneuvering with partial flaps, or the airplane may be accelerated straight ahead to the flap-up configuration, and then pick up the airspeed for maneuvering with flaps up...

In today's jet operations certain operational factors will influence the missed approach performance. One of these is the slower response of jet engines to commands for more power. This in turn affects the decision to abort a landing attempt because a significant amount of altitude can be lost during this maneuver (relative to the height of the aircraft above the ground). Litchford (ref. 46) indicates that,

> Because jet engines usually respond more slowly than propeller engines, the pilot will leave on a few extra knots of speed when the visibility is low ("for the wife and kids"). Then, if the approach must be abandoned near the ground, he is at a more suitable speed to intitate climbout than if he was flying at the lowest permissible speed...
>
> ...Simulation tests by NASA indicate that when the pilot decides he must abandon the approach, he can still lose up to 60 or 70 ft of altitude. Therefore, it is not prudent to postpone such a decision below 100 ft...

SST Potential Operational Requirements and Constraints

The only modification to current procedures would be due to the factor of decreased control responsiveness. This would necessitate a re-evaluation of current thinking with regards to lower limits on a safe missed approach envelope.

Feasible Automated Implementation Concepts for SST

In actuality there does not appear to be an automatic concept being considered. It must be remembered that this performance is the deactivation of the automatic mode of operation or the manual mode as the case may be. So, although a programmed missed approach profile is feasible, it does not appear to be practical.

Feasible Manual Implementation Concepts for SST

At this time no new pieces of equipment will be introduced. Rather, the concepts behind some of these systems will be looked at to determine the role which the crew plays in the landing and the missed approach. It has already been pointed out many times that in all likelihood the SST will incorporate some form of all-weather landing system which will work through the flight control system, and in some cases through the power plant system.

In England a system developed by the Blind Landing Experimental Unit (BLEU) is a triplicated electronic system, which is quite bulky, and "...with the pilot excluded from a say in its operation..." The British group compute the chance of human error at one in 10,000, while the chance of mechanical error, they say, works out to one in 100,000.

"In U.S. systems, the pilot is in effect the commander of the landing," according to Business Week (ref. 47),

> ...he can take over at any time simply by moving the throttles. Meanwhile, both he and the co-pilot are monitoring the autopilot by means of flight directors, hooked on to separate computers, that provide another source of flight data and describe what should be happening...

The crew would use the basic control system (yoke) or a portion of the autopilot system, and would command full power in the same manner as in the takeoff power plants operations (Function 4. 3). The responsibility of the crew would continue to be based on safety, and would not change as a consequence of the means employed to perform this maneuver.

However, there will be a need to augment the flight director system so that the crew will have the capability to take over at any period in the landing approach, and obtain optimum performance. As Manning (ref. 48) points out,

> . . . the need to augment a flight director system to provide stand-by monitor and take-over information for aircraft approach and landing is becoming increasingly important. With the advent of semi-automatic and automatic approach and landing systems the pilots' task has been greatly simplified; however, several obstacles present themselves in the complete utilization of the technical advances now being offered. We must augment the reliability safety factor. It is mandatory that we provide the pilot with sufficient, readily interpretable, easily tracked information so that he has no reservations about the proper functioning of his automatic control equipment. Should he be required to take over because of equipment failure, approach controller directions, or personal desires or intuition, he shall have complete command of his exact condition and position so that the transition from automatic or semi-automatic to full manual control can be accomplished safely, rapidly and calmly. . .

Although the missed approach is not really a phase of the normal flight profile, its frequent occurrence necessitates some discussion of missed approach performance. In a strictly optimum case, this performance could be done away with. However, in considering a system which utilizes both man and machine, the missed approach performance becomes something other than non-routine. Since the landing phase is probably the most critical, the crew will attempt to minimize deviations from what they consider optimum and in the event of a large variance will in most cases choose a missed approach rather than attempt a questionable landing.

The performance characteristics of the SST may need more study to determine just how critical a missed approach will be, especially in the latter portions of the landing maneuver. It must be remembered, that the combination of flying on the back-side of the power curve, heavier aircraft, larger rates of descent, and slower longitudinal response due to the longer aircraft, may mean that once the aircraft has passed a certain altitude on its descent, it is committed to land. This could put a final limit on the landing minima for the SST.

5.19 FUNCTION 5.19 FLARE MANEUVER EXECUTION

Purpose

This function changes the attitude of the aircraft so that the established rate of descent will be altered sufficiently to allow a safe rate of descent upon touchdown, i.e., 2 to 5 feet per second.

Current Jet Operational Requirements and Constraints

Although not constrained by regulation, design and passenger comfort dictate the performance of this operation. Most landing aids utilize a glide angle of approximately 3°, which means that the aircraft must utilize a rate of descent between 500 and 1000 ft./min. (depending upon wind conditions) to touchdown at the desired point on the runway. However, this would result in damage to the landing gear struts, not to mention discomfort to the passengers. Thus, a flare maneuver is necessitated to change the rate of descent to 120-300 ft./min.

Current Jet Implementation Concepts

The basic control system described for current aircraft is used to perform the flare maneuver. The crew, responding to visual cues decides to flare, and initiates a change in the vertical attitude of the aircraft using the yoke. The result is a decrease in the rate of descent. Once the decision has been made to flare, the crew can check the rate of rotation to perform the flare, by checking the verical speed indicator, the airspeed, and the altimeter.

SST Potential Operational Requirements and Constraints

Since for the most part it has been ascertained that the SST will continue to utilize 3° glide slopes, and since heavier weights and faster speeds could result in larger rates of descent during approach, there will definitely be a requirement for a flare maneuver. In fact because of the estimated slower longitudinal control response, and the increased length of the SST, the flare may have to be initiated at a higher altitude than currently.

Feasible Automated Implementation Concepts for SST

One of the functional requirements for the all-weather landing system is an automatic flare. Upon receiving precise altitude information from a radio altimeter, the aircraft would respond with the required change in attitude. This particular form of all-weather landing system has two main concepts. One is the completely automatic system where the crew is not in the loop, and acts only as a monitor. The other, favored by U. S. manufacturers and airlines, retains the crew in the loop, and allows them to utilize whatever portion of the system they require.

Thus, in the SST it would appear that a portion of the all-weather landing system would provide an automatic flare capability. The crew's role would be to act primarily as monitor under routine conditions. It should be pointed out that although the equipment would be performing the approach, the crew would continue to maintain full responsibility for the safety of the aricraft and its passengers. It is also clear that because of this responsibility, the crew will be mentally and perhaps almost manually flying the aircraft in anticipation of a malfunction. This degree of involvement in monitoring will make the task just as restricted as current procedures.

Feasible Manual Implementation Concepts for SST

In performing a manual flare, if the crew were required to respond to visual cues to initiate the flare, then the prevailing weather conditions would need to be at or above 100 feet (ceiling). This would allow time for the crew to react, the controls to respond, and the attitude of the aircraft to change sufficiently prior to touchdown. Thus the weather becomes a constraint. However, it appears feasible for the crew to take over that portion of the all-weather landing system which performs the flare maneuver, and to utilize data from the radio altimeter to accomplish this flare. If the rest of the landing system is functioning normally (i. e., the auto-throttle and the glide slope and localizer holds) then the crew should be able to flare the SST.

If the crew is expected to utilize data from the radio altimeter, instrumentation will need be integrated into the system to give the crew this information along with the other vital landing parameters.

5. 20 FUNCTION 5. 20 ROLLOUT CONTROL

Purpose

This function provides directional control for the SST while it is on the operational runway, decelerating after the completion of its landing. The optimum performance is to keep the lateral displacements from the runway centerline to a minimum.

Performance will be very similar to that described in Function 5. 3, Takeoff Abort Control. In that situation the decision is made not to continue with the takeoff roll and to abort the flight. Since the aircraft will have already gained a certain amount of kinetic energy, the crew's task is to keep the aircraft on the runway as the decelerating devices are employed.

In roll-out control, the aircraft will have just landed and will again have a certain amount of kinetic energy. Depending upon the landing and touchdown, there will be a certain amount of runway in which to decelerate to a suitable taxi speed. With the aircraft no longer airborne, control becomes primarily two-dimensional. As in Function 5. 3, the main responsibility of the crew will be to maintain minimum lateral displacement from the runway centerline during the deceleration.

Current Jet Operational Requirements and Constraints

No specific regulations are applicable.

Current Jet Implementation Concepts

The flight control system is effective with ground speeds above about 50 knots. The crew can maintain directional control by using the rudder system, or can compensate for crosswind using a coordinate rudder-aileron procedure. Below 50 knots the nose wheel steering can be utilized. As a last resort, differential braking can be utilized to maintain directional control of the aircraft.

SST Potential Operational Requirements and Constraints

There are none applicable.

Feasible Automated Implementation Concepts for SST

As was indicated in Function 5. 3, a form of automatic control is feasible for accomplishing roll-out performance. It would be an extension of the all-weather landing system. Business Week (ref. 47) points out,

> ...for the landing, the autopilot is actually programmed to guide the plane a dozen or more feet into the ground. This drops it on the runway at the proper two or three feet per second, so the wheels catch early enough to start the roll-out. "Otherwise", explains a pilot, "we'd run out of roll-out room. Or we might float about three inches off the ground the entire length of the runway."
>
> "During the roll-out, the localizer beam guides the rudder until the plane slows to 50 knots. Below that speed the pilot can steer with the front wheels...

In utilizing such a system, the crew would still maintain the responsibility for keeping the aircraft on the runway.

In 1963 the FAA issued an RFP for a study of "Aircraft Ground Guidance Techniques". This indicates that consideration is at least being given to new techniques for roll-out guidance. The specific tasks listed in the RFP for study were as follows:

1. Aircraft directional gyro systems
2. ILS localizer techniques

3. Infra-red detection
4. Guidance using magnetic fields
5. Aircraft radar
6. Lines and/or line patterns

Feasible Manual Implementation Concepts for SST

As in current operations, during the roll-out control the flight system will be used to control lateral deviations from the optimum line of direction. On the other hand, the power plant system in the form of thrust reversal will be utilized to control the longitudinal deviations.

The crew of the SST should not require any new training in this area, and there should be no appreciable increase in either workload or restrictiveness over what is experienced by today's subsonic carrier crews.

Feasible Automated Implementation Concepts for SST

There are none applicable.

Feasible Manual Implementation Concepts for SST

As pointed out in the description of Function 5. 1, the major problem to be overcome by the SST will be operating on present taxiways and ramps. Reduced visibility, coupled with a larger aircraft will tend to make obstruction clearance most critical. The crew will continue to utilize the nose wheel steering, differential braking, and power plant operation to accomplish the required taxi performance. However, because of the size constraints the crew will have a greater responsibility to avoid obstructions.

5. 21 FUNCTION 5. 21 TAXI TO LINE

Purpose

The purpose of this function is to supply the directional control for the system in moving from the end of the operational runway to the designated unloading area. The performance requirements and implementation concepts will be the same as described in Function 5. 1, Taxi from Line.

To reiterate what has already been discussed, the major problem to be encountered in any ground maneuvering operations will be handling the larger aircraft on present taxiways, and maintaining adequate clearance from all ground obstructions. These problems will increase the restrictiveness of the task, but can be considered to be occurring in a non-critical phase of the flight.

Current Jet Operational Requirements and Constraints

The requirements and constraints will be the same as those listed under Function 5. 1.

Current Jet Implementation Concepts

As discussed in Function 5. 1, the crew utilizes nose wheel steer- and/or differential braking with coordinated power plant operations to move the aircraft from the end of the operational runway to the passenger unloading area.

SST Potential Operational Requirements and Constraints

Potential requirements and constraints will be the same as those listed in Function 5. 1.

ACTIVITY 6.0 INLET DUCT/EXHAUST NOZZLE CONFIGURATION

PURPOSE

The introduction of a supersonic commercial transport will bring several new functional requirements to the crew. One, which is related to the new aerodynamics, is the matching of the inlet duct and exhaust nozzle system to the requirements of the engine.

The critical thrust margin is in the region of Mach 1.2 to 1.3. Unfortunately, this is also the Mach region in which the losses in thrust due to inlet and nozzle are large. These losses can approach the thrust margin (excess thrust/drag) in magnitude. They are primarily a function of the relationship between inlet flow capacity and engine flow requirements. Reduction of these losses by matching the inlet and engine flow characteristics is obviously very important since they can directly influence the propulsion system size and base weight.

The losses attributable to the inlet and nozzle are also of concern during subsonic operation of the propulsion system, for the subsonic-hold and subsonic-cruise-to-an-alternate-field reserve fuel requirements. The amount of reserve fuel required is dependent on many variables, but in general, is approximately 16% of the fuel load or 8% of the airplane takeoff gross weight. This is a dead weight and is of the same order of magnitude as the payload and engine weights. Reductions in the reserve fuel load can therefore be as significant as reductions in propulsion system weight. For a supersonic propulsion system, it can be seen that the inlet and nozzle losses can increase the TSFC (Thrust Specific Fuel Consumption) by as much as 40% at typical cruise-power settings.

For the SST, the cruise fuel weight is 62 to 65% of trip fuel weight. It is therefore important that inlet-engine-nozzle systems operate efficiently during the supersonic cruise. This requires that the inlet capture area and the nozzle area be matched as closely as possible to the requirements of the engine in order to provide minimum propulsion system TSFC during supersonic cruise.

The problem at supersonic speeds is that the intake compressor is unable to accept the high velocity, high pressure airflow. As the Space/Aeronautics Staff Report (ref. 29) indicates,

> At high Mach numbers the speed of the aircraft appreciably precompresses air at the lip of the engine intake (36:1 at Mach 3.0). Axial velocity of this air is essentially equal to airplane speed. At this speed, the air mass cannot be accepted by the engine compressor. The engineer must therefore design the intake to decelerate this air with a minimum loss in the potential energy represented by the original ram pressure.
>
> Deceleration down to Mach 1.0 + speeds is accomplished by inducing a shock pattern--bouncing the shock waves back and forth between the walls of the intake. A contraction at the throat of the intake just beyond the plane of the last shock reduces air axial velocity to slightly below Mach 1.0. The air is then diffused to a velocity which is at the designed acceptance level of the compressor--about Mach 0.5.
>
> The higher the initial airspeed, the more shocks are needed to bring engine pressure down to the optimum level. According to studies made by Bristol-Siddeley, at least five shocks are needed at Mach 3.0...

Thus, the cockpit will have the additional concern of insuring optimum positioning of the shock wave so as to match airflow to the engine.

Just as the inlet duct can be reconfigured to decelerate air, at supersonic speeds the outlet nozzle must effectively translate the high pressures and high temperatures of the exhaust gases into kinetic energy by accelerating these gases from low to high velocities. The convergent nozzle presently used on subsonic aircraft permits airflow velocities only up to sonic speeds. At Mach 3.0, such a nozzle would allow the high pressures to degenerate through uncontained expansion, reducing the possible internal thrust considerably. This loss can be avoided by permitting controlled expansions of airflow to supersonic velocities. Insuring that optimum performance is being achieved via the inlet-engine-exhaust nozzle system will be another area of concern for the SST crew.

CURRENT JET OPERATIONAL REQUIREMENTS AND CONSTRAINTS

In current operations the basic requirements are for an inlet duct configuration and an exhaust nozzle which will optimize the performance of the subsonic engine throughout the entire flight. This requirement is fulfilled by the aircraft and power plant designers, and the crew does not become involved. Thus, the requirements and constraints for this function are associated with supersonic flight, and will need to be developed and set accordingly.

CURRENT JET IMPLEMENTATION CONCEPTS

The only analogous concern for engine airflow requirements in current aircraft is the operation of "blow-in" doors via cockpit switching. However, blow-in doors are rarely used in commercial aircraft. In actuality, there is no concern for reconfiguring inlet ducts or exhaust nozzles, and as a result there is no need for implementation concepts. Since military aircraft use blow-in doors and when utilizing the afterburner reconfigure the exhaust nozzle, crews are at least familiar with the need for such operations.

SST POTENTIAL OPERATIONAL REQUIREMENTS AND CONSTRAINTS

The engine which the designers finally choose for the SST will have to be two engines in one; a subsonic engine and a supersonic engine. As a subsonic mechanism, the engine will operate as a straightforward compressor-turbine gas generator. As a supersonic mechanism, the power plant will not only exist as a gas generator, but will have to handle extraordinarily large masses of air at extremely high velocities, pressures and temperatures.

If anything, the SST inlet is probably misnamed since its function will be much broader than just admitting air to the engine. During flight at three times the speed of sound, the inlet must pre-compress the incoming air to 30 times its original pressure with an efficiency of up to 95%! Studies to date indicate that this can be achieved although the hardware becomes relatively sophisticated and complex.

Unlike a subsonic inlet, the airflow of an efficient supersonic inlet must be held to one specific value for a particular flight altitude and speed. Deviations from this discrete value generally lead to catastrophic results like shock expulsion or swallowing; both of which result in a violent reduction in engine performance. Consequently, it is desirable that the SST engine be closely matched to the inlet with a high degree of reciprocal control. Further, since inlet performance is dependent on the airflow, required thrust variations will need to be made by means other than changes in engine airflow and hence engine speed. Appendix 4.0 discusses means for controlling power plants during the supersonic portion of the flight. In all likelihood, the SST engine will be operated at maximum RPM throughout this regime so as to accommodate the airflow.

The importance of the inlet system cannot be overemphasized. At relatively high supersonic speeds, the thrust of the power plant acts on the internal surfaces of the inlet and the inlet literally pulls the aircraft through the air. The engine's function in this case is just to set up the flow field and inject energy into the passing air. This is typified by today's ramjet which consists only of an inlet, burner, and jet nozzle.

Assuming the inlet duct is reconfigured to recover a large percentage of the high energy pre-compressed airflow, a second source of thrust loss is the exhaust nozzle. If the high pressure, high temperature gases generated in the engine are allowed to expand unrestrictedly to reach ambient levels, drag induced between the differences in velocity will result in appreciable thrust losses. Therefore, reconfiguring of the exhaust nozzle to increase the velocity of the exhaust gases will be necessary. One way to provide optimum exit velocities for Mach 3. 0 operation is by use of a convergent-divergent nozzle which has overlapping fingers at both the throat and exit. These fingers can be closed or opened as appropriate for subsonic or supersonic flow. There are many methods advocated for performing this function, but basically they are all the same; the area of the exhaust nozzle is varied so as to regulate the velocity of the exhaust gases.

FEASIBLE AUTOMATED IMPLEMENTATION CONCEPTS FOR SST

The duct system must maintain an airflow at a degree of constancy acceptable to the engine. To do this the duct must interpose its airflow function between the engine and all external conditions tending to affect airflow. When the aircraft speed is supersonic there will necessarily be a shock wave or system of shock waves in the duct. For best pressure recovery it is desirable that the shock wave pattern be carefully regulated. Atmospheric and aircraft variables such as temperature, turbulence, airspeed, pitch, and yaw tend to disturb the shock wave pattern. The control system should as necessary detect such disturbances and make accommodations for them.

Various groups within the aircraft industry hold the opinion that the operation of the inlet duct variable geometry will have to be automatic.

This position is based on the belief that the variables that must be accommodated are too rapid and numerous for a crew member to be able to handle the task. With an automatic system the crew's responsibility would become one of monitoring the operation of the system and reconfiguring it if possible in the event of a malfunction. In this particular case most designers are hoping for a fail-safe system because economic flight will be predicated on the ability to keep the airflow matched to the engine requirements.

Since it appears that the automatic mode of operation will only be concerned with the supersonic regime, the crew will probably be required to activate the system during transonic acceleration and then deactivate it after transonic deceleration.

FEASIBLE MANUAL IMPLEMENTATION CONCEPTS FOR SST

As has been stated, evaluation of many dynamic parameters to determine the optimum duct and exhaust nozzle configurations appears to be outside the capability of the crew. However, there does appear to be a sort of manual back-up which would allow the crew some degree of control in the event of malfunction. The main function of this manual control would be the maintenance of safety (disregarding economics).

The situation in which the inlet control system malfunctions and allows the normal shock to go out of the inlet is called an "inlet unstart." It changes the pressure field in front of the inlet, changes the air flow around the inlet, and decreases the thrust. Depending on how the inlet and engine are mounted on the aircraft, this can cause pitch, yaw, or roll trim changes, or a combination of any of these. If the position of the normal shock becomes unstable, the inlet will "buzz." An "unstart" allowed to go uncorrected will probably develop into buzz, which can be destructive after some period of time.

The manual manipulation of a lever to control the duct geometry will only allow rough approximations and would be used solely to get the aircraft back to the subsonic environment. To use this means some instrumentation will have to be provided which will show where the shock wave is positioned. It does not appear feasible to use this manual back-up concept for normal operations.

6.1 FUNCTION 6.1 DUCT SYSTEM CONFIGURATION FOR SUPERSONIC CLIMB

Purpose

This function is to insure that the inlet duct and exhaust nozzle systems are appropriately configured to provide acceptable precompressed air to the power plant system and to control exhaust gas expansion. This matching of the inlet system to the engine is a characteristic which accompanies supersonic flight and exhaust.

As the Space/Aeronautics Staff Report (ref. 29) indicates,

> At high Mach numbers the speed of the aircraft appreciably precompresses air at the lip of the engine intake (36:1 at Mach 3.0). Axial velocity of this air is essentially equal to airplane speed. At this speed, the air mass cannot be accepted by the engine compressor. The engineer must therefore design the intake to decelerate this air with a minimum loss in the potential energy represented by the original ram pressure.

Another inherent characteristic of supersonic airflow is the configuration of the nozzle. Just as the inlet duct configuration is in a sense a mechanism for decelerating air, the outlet nozzle at supersonic aircraft speeds must effectively translate the high pressures and high temperatures of the exhaust gases into kinetic energy by accelerating these gases from low to high velocities.

Current Jet Operational Requirements and Constraints

Reconfiguring of the inlet duct and the exhaust nozzle is not a consideration in subsonic operations. Currently the designer must match these designs to the engine requirements, but only for the one regime.

Current Jet Implementation Concepts

Current subsonic aircraft are not concerned with reconfiguration of the intake duct system or the exhaust nozzle system.

SST Potential Operational Requirements and Constraints

Although certain types of engines (e. g., ramjets) can accept high velocity, precompressed air, the axial flow jet engine has its limitations and in most cases these are subsonic velocity airflows. Since the SST will be operating in both subsonic and supersonic speed regimes, the engine must be capable of operation in both regimes. In the case of the axial flow jet engine (i. e., the turbofan or turbojet), the compressors are unable to accept the precompressed air (36:1 at Mach 3) caused by the aircraft's speed. Therefore, some method must be available for decelerating the axial velocity of the airflow without too large a loss in potential energy. This is accomplished by means of an inlet duct system.

Along the same line, the current exhaust nozzles permit airflow velocities only up to sonic speeds. At supersonic speeds this nozzle would allow the high pressures to degenerate through uncontained expansion which would appreciably reduce internal thrust. This loss can be prevented by controlling exhaust expansion.

Thus a system is required which will be able to vary both the inlet duct and the exhaust nozzle configurations throughout the various speed regimes. The system which controls these reconfigurations will need to take into consideration atmospheric and aircraft variables, such as temperature, turbulence, airspeed, pitch and yaw in accomplishing the performance requirements.

Feasible Automated Implementation Concepts for SST

The SST will bring a new procedure to the flight deck which may mean the difference between a successful flight and a failure. The SST crew will be responsible for insuring that the position of the shock wave induced by the precompressed air is focused within limits to cause the required number of shock patterns and the ultimate Mach 0.5 velocity air.

Reference 29 explains that

> ...deceleration down to Mach 1.0 + speeds is accomplished by inducing a shock pattern--bounding the shock waves back and forth between the walls of the intake. A contraction at the throat of the intake just beyond the plane of the last shock reduces air axial velocity to slightly below Mach 1.0. The air is then diffused to a velocity which is at the designed acceptance level of the compressor --about Mach 0.5 ...

Most designers agree that this function will be accomplished automatically with the crew acting primarily as monitors. Many diverse parameters must be analyzed to obtain the optimum position of the shock patterns. These are, at least for the precision required, outside the realm of the human. One manufacturer is making provision for a manual mode, but most are aiming for a fail-safe automatic system. When the shock wave is not positioned correctly, the terminal shock can move away from its normal position at the intake throat as a result of even relatively small variations in airflow. The terminal shock then becomes unstable and is instantly expelled (i. e., "inlet unstart" occurs). Compressor stall can follow unless the shock is quickly repositioned by a rapid change in intake geometry. Thus, to keep the shock pattern focused, it must be possible to vary the cross section of the intake ahead of the throat.

For the SST crew the performance required by this set of functions will be mainly a monitoring function. Temperature and pressure sensors will be located so as to give optimum shock wave positioning.

It is not anticipated that any problems outside the state-of-the-art will arise. Since this particular design area will be critical in the event of malfunction, the final design will be as close to fail-safe as is feasible. And, because of the myriad parameters which affect the ideal positioning of both the inlet duct and the exhaust nozzle, the chosen system will be completely automatic. Some organizations are demanding a manual mode of operation, but due to the severity of the problem it is felt that with the proper presentation this could be eliminated as a basic requirement.

In all probability the duct system which is incorporated will be sensor operated, and will present a certain configuration relative to the existing airspeed requirements. However, for subsonic regions of flight, it will probably be the crew's responsibility to actuate the duct system configuration for one optimum subsonic regime. Then, upon approaching the transonic regime, the automatic mode of the duct system configuration system will be actuated. Once this is performed, the crew's role will be one of monitoring.

Feasible Manual Implementation Concepts for SST

If demands become great enough there will probably be a manual means for varying the inlet duct configuration. However, it appears that this will be an emergency back-up system to alleviate danger to the aircraft. If the automatic mode were to malfunction, the manual positioning might be utilized to reconfigure the aircraft for subsonic flight.

In the event of a malfunction with a resulting inlet unstart it will be the responsibility of the crew to change the attitude of the aircraft and manually vary the inlet capture area so as to recapture the optimum shock wave pattern, and eliminate any compressor stalls. A significant characteristic of this supersonic inlet will be its airflow relationship. Unlike a subsonic inlet, the airflow of an efficient supersonic inlet must be held to one specific value for a particular flight altitude and speed.

Deviations of the airflow from this discrete value generally lead to catastrophic results like shock expulsion or swallowing, both of which result in a violent reduction in engine performance.

For normal operations there does not appear to be manual concept which is feasible.

6.2 FUNCTION 6.2 DUCT SYSTEM CONFIGURATION FOR TRANSITION TO CRUISE

Purpose

This function is to insure that the inlet duct system is matched to the engine airflow requirements, and that the area of the exhaust nozzle is regulated to obtain the most advantageous gas expansion and minimize drag losses.

Since it has been accepted that the configuring of the duct system will be primarily an automatic function, the main reason for calling this out on the flow diagram is to indicate the requirement for such a function, and to indicate what consequences might result if a malfunction occurred in this performance. As was previously stated, once the automatic mode of the system has been actuated, the main responsibility of the crew will be to monitor the performance and to take those steps available to insure that performance is held within normal operating limits. It might be well at this point to indicate that with such an automatic mode of operation, most of these monitoring tasks will be handled by the flight management function. Any decisions concerning the manual manipulation of the duct system configuring would be part of the flight management function. The actual performance would be within the inlet nozzle configuration operations function.

The main task of the crew in such a highly automated system is to act as a monitor. Although most of the systems envisioned will provide a manual back-up to the automated system, the complexity and sophistication of the SST will probably make it almost impossible for the crew to function economically in the manual mode. The manual back-up will give the passengers and crew a safety factor. In most instances the malfunctioning of an automated mode of a major subsystem will require either an aborted flight or a diversion to an alternate for repairs. With this idea in mind it can be seen that this establishes a very strict requirement on the proven reliability of the major subsystems.

Since the positioning of the shock wave to obtain the required airflow is sensitive to attitude changes, the transition to cruise will influence the operation of the automatic system. The automatic concept should be able to handle this performance, but it is still an area of concern to the crew.

Current Jet Operational Requirements and Constraints

There are no current applicable functions.

Current Jet Implementation Concepts

There are none applicable.

SST Potential Operational Requirements and Constraints

The requirements are the same as described in Function 6. 1. For this particular phase of the flight, the major area of concern will be the change of attitude which could possibly disrupt the operation of the automatic system. The system chosen must be able to cope with these variables.

Feasible Automated Implementation Concepts for SST

A sensitive automatic system will be utilized to maintain the configuration of the inlet duct such that acceptable airflow is presented to the engine compressor. The mechanism should be such that the intake will be matched to the engine when operating at full thrust. The position of the variable geometry intake will be controlled solely by the Mach number of the aircraft. A closed-loop system will be used in which the actual position of the variable surfaces is compared to the pre-determined position appropriate to the given Mach number. If the system senses any differences between these positions an error-signal is sent to the control and jacks move the surfaces until the error signal is zero.

The involvement of the crew will be as described in Function 6. 1.

Feasible Manual Implementation Concepts for SST

As pointed out in the activity description and in Function 6. 1, the main function of the manual manipulation of the inlet duct geometry would be to maintain safety. More than likely, the manual mode of the duct system configuring will consist of an integrated flight control-capture area performance. Instrumentation will probably be provided which will indicate the optimum position of the shock wave pattern for any desired Mach speed. The means will probably consist of a positioning lever which will manually (hydraulically actuated) position the apparatus to vary the inlet capture area and allow focusing of the shock wave pattern.

It must be repeated that although a manual means will be available to the crew, this will not give them the capability to operate effectively throughout the entire profile. The manual mode gives the crew a means for reducing possible engine damage, and allows them to return to subsonic operations.

6. 3 FUNCTION 6. 3 DUCT SYSTEM RECONFIGURED AS REQUIRED; CRUISE PHASE

Purpose

This function is to insure the maintenance of low velocity, high potential energy airflow to the engines, and the controlled expansion of the exhaust gases. As was previously stated, the constant reconfiguring of the inlet duct capture area, and the associated exhaust nozzle will, in all likelihood, be a completely automatic function. As such, the performance required by the crew of the SST will be the same as that found in all of the inlet nozzle configuration operations functional descriptions (see Function 6. 1).

Current Jet Operational Requirements and Constraints

There are no current functions which are comparable.

Current Jet Implementation Concepts

As stated in previous functional descriptions, this is not an area of concern with current subsonic carriers.

SST Potential Operational Requirements and Constraints

The parameters which will be changing with the different phases of the profile include altitude, dynamic pressure, temperature, and Mach speed. These all affect the ultimate position of the duct system configuration, and need to be analyzed to maintain the appropriate position.

Any malfunction of the system in this phase of the flight will introduce procedures which may be characteristic of only this area of the flight. This analysis will be presented in another section and will show the relationship of the various systems and the amount of crew involvement associated with the various malfunctions. During the cruise phase of the flight the environment will be the most adverse, and aircraft performance will be approaching the limits of the maximum performance envelope. This seems to indicate that any malfunction occurring at this time would, in all likelihood, introduce the severest constraints into the system.

Feasible Automated Implementation Concepts for SST

The means for insuring this performance will be identical, as will the performance required, as that described in Function 6. 1. An automatic system seems to be the only solution to efficient and practical operation in this speed regime. As with most automatic systems the amount of crew involvement with monitoring tasks will be dependent upon the criticality of the phase and the reliability of the system.

Feasible Manual Implementation Concepts for SST

The manual implementation concept is only discussed as a possible emergency back-up to the automatic system. The crew's role and involvement will be primarily as discussed throughout Function 6. 1. As stated previously there is no manual concept feasible for accomplishing a continuing, acceptable performance.

6.4 FUNCTION 6.4 DUCT SYSTEM CONFIGURATION FOR SUPERSONIC DESCENT/DECELERATION OPERATIONS

Purpose

This function is identical to the inlet nozzle configuration functions in other phases of flight; that is, insuring that the inlet duct configuration reduces the axial velocity of the inlet airflow to an acceptable compressor speed, and that the configuration of the exhaust nozzle is optimized to reduce drag and uncontrolled gas expansion losses. While operating in the supersonic regime it is essential that the power plant system be provided with low velocity, high energy airflow.

The descent phase will be characterized by rapid changes in those parameters which affect the positioning of the duct system capture area. It must be remembered that in anticipating the problems associated with inlet duct systems first consideration must be given to magnitude of the problems that must be resolved by the system. To maintain an airflow at a degree of constancy acceptable to the engine, the duct must interpose its airflow control function between the engine and all external conditions affecting airflow. When the aircraft speed is supersonic there will necessarily be a shock wave or system of shock waves in the duct. For best pressure recovery it is desirable that the shock wave pattern be carefully regulated. Atmospheric and aircraft variables, such as temperature, turbulence, airspeed, pitch, and yaw tend to disturb the shock wave pattern. The control system should detect such disturbances and accommodate them.

As in the other functions dealing with the reconfiguring of the inlet/exhaust systems, the crew's main function will be to act as monitors, and to provide the back-up performance which would be necessary in the event of a malfunction. However, because of its criticality, it is not anticipated that the automatic inlet/exhaust systems would be accepted until reliability studies have proven their fail-safe capabilities.

Current Jet Operational Requirements and Constraints

There is no comparable function in current aircraft.

Current Jet Implementation Concepts

As pointed out previously this is not an area of concern in subsonic aircraft.

SST Potential Operational Requirements and Constraints

While the SST is operating in the supersonic speed regime there will be a continual requirement for matching of the inlet airflow to the requirements of the engine, and for controlling the expansion of the high energy exhaust gases into the ambient air stream. Off performance in either of these areas could result in marked deficiencies in power output and make the SST economically unfeasible.

As the aircraft commences the supersonic descent, attitude changes and changes in atmospheric conditions influence the inlet duct configuring mechanism. These parameter changes must be within the operating capabilities of the system.

Feasible Automated Implementation Concepts for SST

An automatic system responsive to many sensors would provide the means for maintaining the optimum inlet duct and exhaust nozzle configurations. The crew's role would be to monitor the performance. Since the automatic system will have to be a fail-safe system the monitoring function will be very limited.

Feasible Manual Implementation Concepts for SST

As has been discussed in all the previous functional descriptions pertaining to the inlet duct and exhaust nozzle, the only reason for a manual mode would be as an emergency back-up. If a malfunction of the systems were to occur during supersonic flight the crew would require some means for maintaining system integrity as the aircraft is decelerated to the subsonic regime. Most experts agree that a malfunctioning of these particular systems will terminate supersonic operations. Thus, a decision to continue to the planned destination implies continuing subsonically.

6. 5 FUNCTION 6. 5 DUCT SYSTEM CONFIGURATION FOR TRANSONIC DECELERATION/DESCENT

Purpose

Except for the phase of flight and the values of parameters, the performance required in this function will be essentially the same as that for Functions 6. 1, 6. 2, 6. 3 and 6. 4. The automatic system will be able to handle all of those parametric values which will be encountered and reconfigure the duct/exhaust system accordingly. If for some reason the automatic mode is unable to analyze the varying parameters effectively, the crew will have to be able to make the necessary rough settings to maintain a safe system.

Current Jet Operational Requirements and Constraints

There is no comparable function in current aircraft.

Current Jet Implementation Concepts

This area of performance is not a requirement in subsonic operations, but is characteristic of supersonic flight.

SST Potential Operational Requirement and Constraints

During the transonic deceleration and descent the sensors feeding data into the comparator for the automatic reconfiguring mechanism will be recording rapid changes in the critical parameters. The system must be able to handle these rapid parametric changes and continue to supply low velocity airflow to the power plants. The system will need to be able to cope with any adverse yaw which might result from the loss of an engine.

Feasible Automated Implementation Concepts for SST

Automatic reconfiguring of the inlet duct positions the incoming shock wave, and causes a series of reflected shock waves. The last of these is diffused and then accepted by the engine compressor. The crew's chief concern will be to ascertain that the engine is receiving adequate airflow. Instrumentation will in all likelihood be provided to show the position of the initial shock wave relative to its optimum position.

Feasible Manual Implementation Concepts for SST

Feasible concepts which would produce the same performance as the automatic concept do not seem likely. Too many parameters are involved and most of these are highly variable. However, for the sake of safety a method of roughly positioning the shock wave while attempting to decelerate to subsonic speeds is well within the crew's capability.

6.6 FUNCTION 6.6 DUCT SYSTEM RECONFIGURATION FOR SUBSONIC OPERATIONS

Purpose

This function is to deactivate the automatic mode of operation of the inlet duct/exhaust nozzle reconfiguration system, and to lock it in its optimum subsonic position. Once the SST decelerates through the sonic barrier, the requirement for furnishing low velocity, high potential energy airflow to the engine will no longer exist. As a result the inlet configuration which optimizes the power plant performance in the subsonic regime should be chosen.

Since up to this point the crew's main function is to act as a monitor of the automatic system, it can be expected that once the airflow requirement has been eliminated and the inlet configuration set for its optimum subsonic capture operations, the crew's responsibility will also be eliminated. However, as was pointed out, the crew will probably have the responsibility to switch the system from the automatic mode to the off mode. Once this is accomplished and the duct system is configured for subsonic flight, the crew's responsibility will cease.

Current Jet Operational Requirements and Constraints

There are no comparable functions in current aircraft.

Current Jet Implementation Concepts

As was discussed previously, current subsonic carriers have no control over the configuring of the inlet duct geometry or the exhaust nozzle system.

SST Potential Operational Requirements and Constraints

Designers are being pushed to develop two engines in one; one for supersonic and one for subsonic operations. This is best accomplished by matching the engine and its airflow requirements through use of the inlet duct geometry. Once the SST is out of the sonic speed area, and is operating in the subsonic speed regime, the inlet duct system must be optimized for this area of operation.

Feasible Automated Implementation Concepts for SST

Once the aircraft has passed into the subsonic speed range, the automatic inlet duct configuring mechanism will, or at least should be, at the maximum airflow position consistent with subsonic operations. The crew's task is then to deactivate the automatic system to maintain this last position.

Feasible Manual Implementation Concepts for SST

In the event of an emergency in the supersonic portion of the flight, the crew would have the manual capability to roughly position the shock wave so as to lessen the possibility of damage to the aircraft while decelerating to subsonic speed. Once in that speed area they would be able to manually select the optimum subsonic inlet duct geometry. The crew's responsibility would be to insure that the duct system configuration was consistent with the speed of the aircraft.

ACTIVITY 7.0 NAVIGATION

PURPOSE

The purpose of the navigation activity may be viewed as having two primary aspects: (1) conflict avoidance which ensures safety in operation, and (2) getting from the origin point to the destination within some acceptable error limits.

Many parameters affecting navigation stem from either or both of these aspects, since they are not mutually exclusive. The navigation system and navigational accuracy must be such that the operating requirements and constraints associated with both safety and economical airline operation can be adequately met.

Any and all parameters generally associated with the navigation activity can usually be associated with one of two basic requirements listed above, and in many cases with both. For example, the lateral error component in a navigation system can be described in terms of nautical miles displacement from desired track, circular error at way point/destination, or probability of violating assigned air space, depending on the purpose for defining the lateral errors. In any case, lateral errors are associated with both aspects of the basic navigation problem; it is necessary to remain within some tolerable distance from the track to ensure that airline economies are not unduely affected by fuel penalties or schedule degradation, and to minimize the probability of collision. It is sufficient to say that the purpose of the SST navigation activity will be to satisfy these two basic requirements.

Some specific regulations which apply to navigation follow:

FAR 91.79, ref. 13:

Minimum safe altitudes; general.

Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes:

(a) *Anywhere.* An altitude allowing, if a power unit fails, an emergency landing without undue hazard to persons or property on the surface.

(b) *Over congested areas.* Over any congested area of a city, town, or settlement, or over any open air assembly of persons, an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft.

(c) *Over other than congested areas.* An altitude of 500 feet above the surface, except over open water or sparsely populated areas. In that case, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure.

FAR 91.97, ref. 13:

Positive control areas and route segments.

(a) Except as provided in paragraph (b) of this section, no person may operate an aircraft within a positive control area or positive control route segment, designated in Part 71 of this chapter, unless that aircraft is—

(1) Operated under IFR at a specific altitude assigned by ATC;

(2) Equipped with instruments and equipment required for IFR operations and is flown by a pilot rated for instrument flight; and

(3) In the case of a positive control area, equipped with—

(i) A coded radar beacon transponder, having a Mode A (military Mode 3) 64 code capability, replying to Mode 3/A interrogation with the code specified by ATC; and

(ii) A radio providing direct pilot/controller communication on the frequency specified by ATC for the area concerned.

(b) ATC may authorize deviations from the requirements of paragraph (a) of this section for operation in a positive control area. In the case of in-flight failure of a radar beacon transponder, ATC may immediately approve operation within a positive control area. In all other cases, requests for an authorization to deviate must be submitted at least four days before the proposed operation, in writing, to the ATC center having jurisdiction over the positive control area concerned. ATC may authorize deviations on a continuing basis or for an individual flight, as appropriate.

FAR 91. 99, ref. 13:

Jet advisory areas.

(a) No person may operate an aircraft within a radar jet advisory area designated in Part 75 [New] of this chapter unless—

(1) That aircraft is operated under IFR at a specific altitude assigned by ATC; or

(2) If the aircraft is not so operated and—

(i) That aircraft is equipped with a functioning coded radar beacon transponder having a Mode A (military Mode 3) 64 code capability, that transponder is operated to reply to Mode 3/A interrogation with the code specified by ATC;

(ii) If that aircraft is not so equipped, it is operated under specific authorization from ATC; or

(iii) If radio failure prevents the receiving of that authorization, he maintains an appropriate VFR cruising flight level.

(b) No person may pilot an aircraft within a nonradar jet advisory area designated in Part 75 [New] of this chapter unless that aircraft is operated under—

(1) IFR at a specific altitude assigned by ATC; or

(2) Specific authorization from ATC.

FAR 121.121, ref. 11:

En route navigational facilities.

(a) Except as provided in paragraph (b) of this section, no supplemental air carrier or commercial operator may conduct any operation over a route unless nonvisual ground aids are—

(1) Available over the route for navigating airplanes within the degree of accuracy required for ATC; and

(2) Located to allow navigation to any airport of destination, or alternate airport, within the degree of accuracy necessary for the operation involved.

FAR 121. 349, ref. 11:

Radio equipment for operations under VFR over routes not navigated by pilotage or for operations under IFR or over-the-top.

(a) No person may operate an airplane under VFR over routes that cannot be navigated by pilotage or for operations conducted under IFR or over-the-top, unless the airplane is equipped with that radio equipment necessary under normal operating conditions to fulfill the functions specified in § 121.347(a) and to receive satisfactorily by either of two independent systems, radio navigational signals from all primary en route and approach navigational facilities intended to be used. However, only one marker beacon receiver providing visual and aural signals and one ILS receiver need be provided. Equipment provided to receive signals en route may be used to receive signals on approach, if it is capable of receiving both signals.

(b) In the case of operation over routes on which navigation is based on low frequency radio range or automatic direction finding, only one low frequency radio range or ADF receiver need be installed if the airplane is equipped with two VOR receivers, and VOR navigational aids are so located and the airplane is so fueled that, in the case of failure of the low frequency radio range receiver or ADF receiver, the flight may proceed safely to a suitable airport, by means of VOR aids, and complete an instrument approach by use of the remaining airplane radio system.

(c) Whenever VOR navigational receivers are required by paragraph (a) or (b) of this section, at least one approved distance measuring equipment unit (DME), capable of receiving and indicating distance information from VORTAC facilities, must be installed on each airplane when operated within the 48 contiguous States and the District of Columbia at and above 24,000 feet MSL and must be installed on each of the following airplanes, regardless of the altitude flown, when operating within the 48 contiguous States and the District of Columbia after the indicated dates:

(1) Turbojet airplanes—June 30, 1963.

(2) Turboprop airplanes—December 31, 1963.

(3) Pressurized reciprocating engine airplanes—June 30, 1964.

(4) Other large airplanes—February 28, 1966.

(d) If the distance measuring equipment (DME) becomes inoperative en route, the pilot shall notify ATC of that failure as soon as it occurs.

FAR 121. 355, ref. 11:

Equipment for operations on which specialized means of navigation are required: flag and supplemental air carriers and commercial operators.

No flag or supplemental air carrier or commercial operator may conduct an operation for which specialized means of navigation are required unless it shows that adequate airborne equipment is provided for the specialized navigation authorized for the particular route to be operated.

ICAO Reg. 5. 1. 2, ref. 14:

Minimum heights.

> Except when necessary for take-off or landing, or except when specifically authorized by the appropriate authority, aircraft shall be flown at a height of at least 300 metres (1,000 feet) above the highest obstacle located within 8 km (5 miles) of the estimated position of the aircraft in flight.

ICAO Reg. 5. 3. 1. 2. 2. 1, ref. 14:

Inadvertent changes.

> 5.3.1.2.2.1 In the event that an aircraft inadvertently deviates from its current flight plan, the following action shall be taken:
>
> 1) *Deviation from track:* if the aircraft is off track, action shall be taken forthwith to adjust the heading of the aircraft to regain track as soon as practicable.

Additional navigation system requirements for current jets include:

1. The capability to detect the presence of hazardous weather in the flight path and the means to arrange to avoid such weather phenomena.

2. The capability to ascertain the necessity for diversion to an alternate destination, as well as the capability to make the decision to divert. (Necessity in this case is limited to those factors directly associated with navigation, e. g. , landing conditions at the destination, or fuel remaining, etc.)

3. The capability to assess the navigational situation, and those parameters affecting it, and to optimize the flight path accordingly.

4. The capability to provide clear, precise information display of the navigational situation so that the crew is capable of staying ahead of the aircraft at any time during a flight.

CURRENT JET IMPLEMENTATION CONCEPTS

The navigation systems employed on current subsonic jets will vary in implementation as a function both of the routes over which the aircraft is employed, and the availability of ground-based navigational aids along those routes.

Generally, the system must be considered as "bi-functional" in that it must provide for terminal area navigation and enroute navigation, and, as Greenaway (ref. 49) has stated, "... there is no one system common to both enroute and terminal navigation." This may not be entirely true since domestic carriers within the U.S. employ VOR/DME as the basic aid for both terminal area and enroute airways navigation. However, the statement certainly applies to navigation along the majority of transoceanic and intercontinental routes. Departure may be via VOR/DME, enroute via self-contained doppler radar with LORAN A updating, and approach via ADF. The navigation system employed and procedures utilized vary from airline to airline depending upon the particular needs of the airline, and as Powell and Willis (ref. 50) suggest, "There are as many navigation procedures being followed today as there are operators, probably more."

To add to the diversity of navigational procedures, there is some variety in the human element which includes specialist navigators, pilot-navigators, and to coin a phrase, "cockpit navigators." It can be seen that the concepts for accomplishing the navigational activity are highly variable and cannot be accurately and inclusively described here. The discussions which follow attempt to depict typical implementation concepts for both terminal area navigation systems and enroute navigation systems.

Terminal Area. Terminal area navigation is generally accomplished by utilizing short-range, point-source navaids such as VOR/DME, ADF, and LM/F radio ranges, for obtaining range and azimuth, and thereby ascertaining position and determining course to steer commensurate with the ATC controller's clearance. The controller's clearance may be in terms of altitude changes, headings or holding requirements on a real-time basis as the aircraft is radar followed during ascent or descent; or such clearance may be in placard form in the case of standard instrument approaches and departures. In any event, the aircraft is under positive radar control within the terminal areas. The navigation situation is inferred from standard instruments, such as the VOR/DME readouts and the flight director, and correlated with the clearance by checking the data with the approach chart (or placard). Airports certified to accept commercial jet traffic are equipped with ILS which is the primary navigation aid for landings under IFR minimum conditions. The airborne components of this system include the localizer and glide slope receiver which provide azimuth and height information, respectively. Range data is provided by marker-beacon receivers or Distance Measuring Equipment (DME). There are other aids to landing under IFR minimums which can be considered to be navaids, such as high-intensity runway end lights. Moreover, there are imminent all-weather landing systems which will permit significant reductions to the current IFR minimums. These systems will be basically extensions of the current ILS systems as far as navigational data are concerned. The airborne component will still track the ILS localizer for azimuth control, and the glide-slope receiver will be used for altitude data down to a given altitude at which point radar altimetry is to be employed. It appears that complete automation may be feasible by tying navigational inputs directly into auto-pilot and auto-throttle systems such that the aircraft is actually navigated and altitude-speed controlled throughout the landing task including decrab, flare, and touchdown. In any event, provisions will be made for presenting the navigational data (i. e., range, azimuth, height, rate-of-descent, data relative to the runway) by means of cockpit instrumentation.

It is recognized that many airports (particularly outside the U. S.) currently accepting commercial jet traffic are not equipped with operational ILS systems. It is assumed that under these conditions either local traffic control applies, and/or airline procedures are such that VFR or IVFR conditions must prevail for the aircraft to descend for landing.

Enroute. Generally, there are two components of enroute navigation, (i. e., dead reckoning (DR), and position-fixing). Current implementation of DR in the subsonic jets ranges from various manually applied techniques for DR to a semi-automatic DR system such as doppler radar. The manual techniques are too numerous to describe. It is sufficient to say that the use of manual DR techniques is essentially a full-time job and requires specialized skills and knowledge which are generally acquired through specific training programs. Furthermore, airlines employing such techniques provide a crew member with the necessary skills for the job, as well as a special station on the cockpit deck for navigation purposes. Moreover, some airlines retain this station and the crew member even with a semi-automatic DR device installation. In view of the high diversity in concepts in this area, the following paragraphs will briefly describe three typical implementation concepts; enroute cockpit navigation, enroute transoceanic navigation with manual DR, and enroute transoceanic navigation with semi-automatic DR.

1. Enroute Cockpit Navigation. For purposes of this discussion, this concept is limited to enroute navigation within the United States. Today's commercial jets navigate the airways using some of the same basic tools utilized in the terminal areas. Airways are volumetric air space over some ground track generally extending between two standard ground navaids, or passing through radial intersections from standard ground navaids. These airways are clearly defined on charts, and within the U.S. the subsonic jets are given their clearances in terms of numbered airways and altitudes. Azimuth and fix data are obtained from bearing data readout directly in the cockpit which may then be correlated to the appropriate navigation charts. Slant range to the monitored station is also read out directly in the cockpit, and may be translated into distance-to-go to a way point or the destination, depending upon the station being monitored. Deviations from desired course are also directly read out in the cockpit. The availability of such ground navaids (and airborne components) within the United States has completely alleviated the requirement for specialized navigational techniques, such as dead reckoning in the more sophisticated sense, or celestial position fixing. In addition, all commercial subsonic jets are radar followed throughout their flights by ATC which permits ground vectoring for collision avoidance. The crew role is primarily one of navigation receiver channel switching as appropriate, ground station identification, information readout from cockpit instrumentation, and correlation of the displayed information to appropriate navigation charts. There are no highly complex and specialized skills involved, and the availability of this ground/airborne system permits cockpit navigation by pilot/copilot personnel, and consequently, specialist navigators or pilot/navigators are not required as a part of the crew complement. The navigator's station has been deleted from many cockpit deck configurations as a result.

2. Enroute Transoceanic (or Intercontinental) Navigation with Manual DR. The limiting factor in employing the system described above is an appropriate number and spacing of ground stations. Even with long

range ground navaid stations, there are many routes being flown which afford little, if any, effective radio coverage. As a result, the more conventional navigation techniques are employed by the carriers. A typical example would be manual dead reckoning employing grid navigation techniques and utilizing pressure patterns for track keeping accuracy. The DR position is updated as regularly as is both practical and possible by obtaining position fixes from external reference sources such as long range hyperbolic systems (e. g., LORAN A) or celestial fixes. Utilization of these techniques is essentially a full-time job and requires one crew member. Moreover, the skills and knowledge involved in this method of navigation are sufficiently complex and specialized that the crew member must be certified competent to perform the tasks. These skills are generally attained through specialized training programs. When these techniques are employed by the carrier, it is necessary to provide one crew member solely for the navigation task, and a crew member's station on the cockpit deck properly instrumented for facilitating task performance.

3. Enroute Transoceanic (or Intercontinental) Navigation with Semi-Automatic DR. As the speed and overall number of aircraft have continuously increased, the result has been a rather severe compression of time to perform the navigational task, along with a need for navigational accuracy. These requirements have necessitated and motivated the evolution of the semi-automatic dead reckoning navigation system. Although military aircraft employ several types of such systems, there is currently only one used in commercial jet aviation, (i. e., the doppler radar DR system). It should be pointed out, however, that certification of an inertial DR system appears to be imminent. The impact on crew role and complement is not expected to be significantly different regardless of which of the two systems is employed.

The major impact of the advent of semi-automatic DR systems has been the resultant change in crew complement and re-distribution of the navigation task. Airline operators employing these systems distribute the navigational workload between the pilot and copilot and apparently have been able to demonstrate navigational accuracy sufficient to prompt certification for reducing the total crew complement by one member, (i. e., the specialist navigator and/or pilot navigator).

Regardless of the hardware involved in the doppler radar system and the inertial navigator system, the semi-automatic DR systems are very similar in terms of their underlying operational concepts. Operational concept here is defined only in terms of the goals and objectives of the installation, and not in terms of how the equipment is operated externally or how it operates internally. Both systems are the result of a need to automate highly repetitive tasks, where task performance time is increasingly compressed and significant portions of the performance involve high speed computation, high speed data manipulation, and other functions which are highly amenable to automation and highly susceptible to human error when performance time is a constraint.

The semi-automatic DR system is designed to provide continuous cockpit presentation of the aircraft's position either in earth coordinates, or in terms of error components relative to where the aircraft should be. The system is designed to provide this data independent of any external data source. The aircraft crew then has a continuous referent to determine the correctness of aircraft directional movement and provide appropriate steering commands. Such systems, at least to date, are subject to various types of errors, some systematic and cumulative in nature, and some random in nature. As a result, it is present operational procedure to update such systems periodically based on information derived from external sources (e. g., LORAN, celestial fixes, etc.). However, updating is being predicated to an increasing degree on ground-based external radio aids to navigation. This appears to be due primarily to the fact that the classic navigational techniques require highly specialized skills and knowledge generally available only in specialist navigator or pilot/navigator personnel, and these crew members are being eliminated in favor of cockpit navigation.

To provide reliability, it is general procedure to utilize dual installations of the DR systems. Techniques for resolving differences between the two systems are based upon crew judgments. That is to say, a divergence between data readouts from the two installations when indications are that both systems are in proper operating condition may be averaged if the divergence does not exceed some specified magnitude, and the average data is considered the best estimate of present position. This may be improved by an updating fix from external sources. Obviously, a position fix from an external source can be utilized to decide which installation is more nearly correct, and the second, or more errant system can be brought back in line. Another method is to examine readouts from both systems more or less logically on the basis of such information as approximate distances traveled from last good position fix and aircraft heading. This, of course, is conventional or manual dead reckoning.

Differences between the two systems which are difficult or impossible to resolve may force the crew to resort to other navigational techniques which are diverse and depend upon the crew complement. For example, the absence of navigator skills for celestial navigation and the absence of equipment for and/or available effective coverage for obtaining ground radio fixes, may force the crew to utilize rather crude dead reckoning as the navigation means. Conversely, the availability of the navigator skills permits the use of celestial techniques and/or more sophisticated dead reckoning techniques. The availability of airborne equipment and effective coverage, permits navigation by means of position-fixing techniques utilizing externally referenced sources.

A more detailed discussion of these systems, and of the total navigation task, is provided under the descriptions of the individual functions in subsequent sections. In summary, the following conclusions may be drawn:

1. The choice of the navigation system for the subsonic jets is influenced by many factors, some of which are involved in individual airline operator needs, requirements, desires, etc., and there is presently no standard system in use.

2. There is some apparent divergence of opinion as to the required crew complement and composition on the flight deck of today's subsonic jets, and as a result there is no standard crew complement/composition for the navigation task.

SST POTENTIAL OPERATIONAL REQUIREMENTS AND CONSTRAINTS

Estimates of the SST navigational system requirements range widely from relatively simple to highly complex requirements. The full scope of requirements for the navigational system must await the outcome of several basic research programs examining problem areas for which available data are inadequate and inconclusive. Our analysis proceeded on the basis that problem areas would be researched and implementable resolutions found. Moreover, it was assumed that this effort could indicate potentially fruitful empirical research avenues by defining an optimum set of requirements and implementation concepts based on opinions of some navigation experts.

It seems apparent that the absence of standards with respect to present systems, procedures, and crew complement and composition on today's subsonic jets, is a significant contributor to the divergence in expert opinion regarding an optimum navigation system for the SST. Probably the most significant indicator of this divergence is evident in the broad range of means covered in the literature which reflect potential SST navigation systems. It must be concluded that a similar continuum exists with regards to the requirements for SST navigation.

In this study, a combination of present-day navigation requirements were analyzed along with stated problem areas of the SST which either directly or indirectly affect navigation, or are affected by navigation. From this analysis, the SST navigation system requirements have been extrapolated and discussed with a view toward optimizing the system in terms of performance only. Such real-world practical matters as cost analysis and trade-off were not considered.

Summarily, navigation requirements are similar to those of subsonic jets. A major exception in functional requirements is the treatment of sonic boom phenomena. Navigation in the vertical plane could be considered a major exception except for the fact that it is also apparently regarded as highly desirable for the subsonics. All of the remaining functional requirements of the navigation system which were identified and treated by this analysis are, to some extent, requirements for present operations. The paramount difference lies in the accuracy requirements with which the SST system must adequately cope, along with the constraints of severe time compression and economic penalties for less than optimum aircraft performance. The impact of increased accuracy, compressed time, economic penalties, and treatment of sonic boom, is given individual treatment in each appropriate function description where the function is obviously affected.

FEASIBLE AUTOMATED IMPLEMENTATION CONCEPTS FOR SST

Basically, all of the implementation concepts depicting a potential automatic navigation system for the SST, which came under the purview of this analysis, may be discussed conceptually as one concept, or one typical system. Potential candidates for performing a given function are discussed under the individual function descriptions. The following paragraphs represent an extrapolation of a typical automatic navigation system based on the role of each major system component.

Fundamentally, the system is divided into four major components:

1. The primary navigation sensor
2. The secondary, or back-up, system
3. The navigation computer
4. The navigation situation display

The primary navigation sensor (duplex or triplex installation) will provide the necessary data for continuous calculation of present position. This system will either be an inertial system, a doppler radar system, or some marriage of these two designed to minimize the weaknesses of each system, or to perform in a complementary manner. The secondary, or back-up system, will provide the necessary data for updating the information being generated by the primary sensor. The purpose being served is the minimization of cumulative error, and a check against insiduous and/or blunder errors. The navigation computer will accept the inputs of the primary sensor, the secondary system, and coupled with stored information regarding the flight path, real-time information concerning weather parameters and atmospheric conditions, fuel consumption data, and a host of other parameters concerning the overall aircraft situation, will generate an optimum flight profile, off-profile error components in three-dimensional terms, and the required data to define the navigation situation on a continuous basis. The navigation situation display will provide continuous cockpit presentation of the optimum flight profile, updated aircraft present position, and other parameters describing the flight's program and situation, in terms required by the flight management activity for assessing the navigation situation and staying ahead of the aircraft.

This system will be a fully integrated, automatic navigation system with provisions for system monitoring, manual data entry, and manual override. It will provide data suitable for display in the cockpit, and provide required data in a form and format suitable for transmission to appropriate ground stations via an automatic data link system. The navigation computer will either be a central navigation computer, probably incorporating both analog and digital features into some specialized hybrid form, or it will be a part of a central electronic management system. The system would provide for direct tie-in with the flight control and power plant systems through the flight management system for automatic piloting and automatic throttling, during all phases of the flight, including climb-out and acceleration, and descent/deceleration through automatic all-weather landing.

The role of the crew will be primarily that of system monitor and back-up. The interface is visualized as the data display in the cockpit, along with provisions for manual override, data entry, and special data call-up. Essentially, three kinds of displayed information would be involved, i. e., real-time pictorial display, special call-up data, and fault detector display. The pictorial display would provide continuous presentation of the real-time navigation situation on a dynamic basis. The special call-up data display would provide immediate readout of pertinent information regarding one parameter or a logical group of parameters affecting the situation, e. g., flight plan ETA destination, present position, time and distance-to-go, predicted ground speed, and how good is the flight plan ETA. Another example might include fuel remaining on board, fuel flow rate, predicted fuel reserve over destination and any prescribed alternates. The third type of display, fault detection, is self-explanatory. This would be driven by self-check circuitry and a stored test program which the computer would cycle through periodically to test the system, while the system is on-line. Provisions for data entry would include at least the capability for reconfiguring the system, placing the system in standby but on-line, taking the system completely off-line (manual override), and entering commands to the navigation system, such as enroute flight plan changes, diversion action to alternate, and enter information such as visually observed weather phenomena or PIREPS monitored in-flight.

It is important to point out that this system description appears to relegate man's role to that of a monitor, although empirical results indicate man's non-suitability for extended monitoring tasks. However, the appearance is misleading. Man's role in the overall system is visualized as one of managing the flight, and of bringing to bear his evaluative, judgmental, and decision-making capabilities on the overall problems associated with flight management, which certainly include the safety and economic aspects of supersonic travel. Consistent with the flight management concept, the fully integrated, automatic navigation system is visualized as freeing man from the repetitiveness of relatively simple intellectual tasks associated with generating navigation data. Thus, the crew can use the data automatically generated to integrate with the myriad other pertinent parameters in order that the flight management activity may appropriately evaluate, assess and manage the total aircraft as one entity, of which navigation is only a part.

FEASIBLE MANUAL IMPLEMENTATION CONCEPTS FOR SST

It is extremely difficult to visualize anything less than a fully integrated, automatic navigation system for the SST. The requirements for the SST navigation systems as extrapolated by this analysis, and based on a thorough literature research along with the gathering of field data, reflect a workload which seems beyond man's capabilities, if one starts at the lower-most end of the continuum of means which begins with a navigator and conventional tools and techniques. The constraints of the desirable separation minima, the compression of time, and the severity of economic penalties for less than optimum performance also strengthen the argument for automatic navigation concepts. The next consideration is the degree of automation to be provided. This is an area of widely divergent opinions, and obviously, any assumptions made should be subjected to critical empirical research. This analysis has assumed that the inclusion of man in the navigation system loop, per se, would be acceptable only in an emergency situation where either a catastrophic failure in the navigation system precludes reconfiguring for operating in the automatic mode, or the SST must return to the subsonic speed regime to continue its flight. In either of these instances, there are ramifications which must be considered.

Considering the first situation, one of the paramount reasons for automation of the navigation activity is the assumption that the workload for manual implementation under the assumed constraints is beyond the capability of man with standard tools and techniques. The loss of the SST navigation system would make it highly probable that the aircraft would violate the assigned air space. The fact that dual and triplex installations of navigation systems are being contemplated is sufficient evidence of the concern for system reliability. And these efforts to increase reliability are being contemplated prior to any final judgments as to crew complement and composition. It is probable that this navigational redundancy concept is based on assumptions that the SST crew complement will follow the current subsonic jet trend of eliminating the navigator and navigation position in favor of cockpit navigation. However, statements to this effect are lacking in the literature. Our analysis has indicated that if the extrapolated requirements are to be met, redundancy is justifiable for reliability alone, regardless of the crew composition and complement, since the performance of the total navigation task does in fact appear to be unfeasible with conventional techniques. In the event the total automatic system capability is lost, it would appear to be necessary to revert to subsonic speeds in order that acceptable navigation standards could be met. At least, some acceptable procedure would have to be identified to account for the resultant degradation in capability to meet navigation requirements. This is obviously an area for empirical simulation research.

If the SST returns to the subsonic speed regime there would appear to be two major effects, (1) a probability that less stringent separation minima would permit less accurate navigation, and (2) an extremely significant increase in available time to perform navigation activity. Both of these conditions are sufficient to justify the manual navigation concept utilizing techniques in current use on subsonic jet fleets. The adequacy of manual navigation would be even further enhanced by the deletion of the sonic boom control requirement.

This analysis has proceeded on the basis of feasibility, rather than possibility, as far as implementation means are concerned. It should also be pointed out that there may be functions which the analysis has identified as navigation functions which may not be considered as such by other analyses. The decision to place these functions in the realm of the total navigation task was based on the relative effect of the associated parameters on the navigation activity. The net effect is to relegate manual implementation to the concept described above.

7.1 FUNCTION 7.1 MAINTAIN TAKEOFF FLIGHT PATH

Purpose

The purpose of this function is to provide flight management with information describing (1) the desired takeoff heading to be followed by the aircraft such that the execution of the standard instrument departure (SID) is in accordance with the clearance, and (2) the measurement of aircraft deviation from the desired heading along with the corrections required to bring the aircraft back on course.

Current Jet Requirements and Constraints

For purposes of traffic control and conflict avoidance, ATC clears current jets for takeoff on a specific runway, which generally carries a number designator derived from the orientation of the runway to magnetic north. Such clearances consider the weather conditions prevailing at takeoff time, and the SID which the aircraft utilizes for traffic control departure from the terminal area. Aircraft are required to maintain the cleared heading on takeoff until that point specified in their SID for turns. Some specific regulations follow:

FAR 91.87, ref. 13:

Departures.

> (f) *Departures.* No person may operate an aircraft taking off from an airport with an operating control tower except in compliance with the following:
>
> (1) Each pilot shall comply with any departure procedures established for that airport by the FAA.
>
> (2) Unless otherwise required by the departure procedures or applicable distance from clouds criteria, each pilot of a large airplane shall climb to an altitude of 1,500 feet above the surface as rapidly as practicable.

ICAO Reg. 3. 2. 6, ref. 14:

Operation on and in the vicinity of an aerodrome.

An aircraft operated on or in the vicinity of an aerodrome shall, whether or not within an aerodrome traffic zone:

a) observe other aerodrome traffic for the purpose of avoiding collision;

b) conform with or avoid the pattern of traffic formed by other aircraft in operation;

c) make all turns to the left, when approaching for a landing and after taking off, unless otherwise instructed;

d) land and take off into the wind unless safety or air traffic considerations determine that a different direction is preferable.

Current Jet Implementation Concepts

Current jets are equipped with flight director type displays (see Figure 32 in Activity 5). The initial course to fly (in this case designated by the runway orientation) may be dialed into the flight director manually. When the aircraft is lined up at the end of the runway ready for takeoff, the pointer is lined up and indicates the heading of the runway. As the aircraft moves along the runway and becomes airborne, it becomes subject to the prevailing winds which may cause drift. Since the flight director displays the aircraft's position relative to the desired track, the pilot can determine how far off the desired track the aircraft has drifted and the heading of the aircraft relative to the desired course. This information allows the pilot to judge the amount of correction necessary and the direction in which the correction should be applied. Aircraft response is visible by means of the display which enables the pilot to modify any over-correction and maintain the required path.

SST Potential Operational Requirements and Constraints

There are no indications in the literature that the SST requirements for maintaining the takeoff flight path will differ from current subsonic jets requirements. During this portion of the flight, the SST will be in the subsonic speed regime, and while it will be operating at considerably faster speeds than the current jets, there will still be an operational requirement that the SST perform similarly in the terminal control areas. Due to the higher operating speeds there may be a need to modify the SID for such aircraft, however. This possibility is discussed in the following function description (maintain flight path for SID).

Feasible Automated Implementation Concepts for SST

Due to the criticality of the takeoff phase of the flight in terms of fuel consumption, there have been some suggestions that full automation be employed. This is envisioned as a stored computer program (or a punched tape) with the precise speed-altitude schedule for the takeoff run, along with the course to steer. After initial line-up with the runway centerline, the aircraft would be placed under computer control. The computer would exercise full control over the takeoff through automatic throttle control, and auto-pilot control. The computer would supply the necessary signals to the auto-pilot for maintaining the takeoff flight path, and such would be monitored by flight management. An override capability would be provided for manual take-over should the necessity arise.

Feasible Manual Implementation Concepts for SST

Should it be determined that the trade-off between automation and fuel consumption does not warrant automated speed-altitude scheduling and flight control, this function would be performed as described under Current Jet Implementation Concepts above.

7.2 FUNCTION 7.2 MAINTAIN FLIGHT PATH FOR SID

Purpose

The purpose of this function is to:

1. Delineate the optimum flight path from the SID initiation point to the transition area, considering:
    - a. SID cleared by ATC
    - b. Speed-altitude scheduling
    - c. Meteorological conditions

2. Provide continuous presentation of the navigational situation in the following respects:
    - a. Parameters representative of the optimum profile (SID) being followed suitable for pictorial display in the cockpit, and for automatic transmission via data link to appropriate ground installations.
    - b. Parameters representative of off-profile error components in all three planes suitable for transduction into flight control commands and throttle adjustments. These parameters would be optimized in the sense of regaining the track with the most acceptable aircraft manipulation considering the maneuver limits imposed by the aircraft performance envelope and passenger considerations.
    - c. Details of the requirement for track excursion exceeding authorized limits for hazardous weather avoidance, and for optimization of fuel flow considering ambient temperature distribution.

d. Parameters representative of profile modifications for track excursions for reasons in (c) above suitable for transduction into velocity scheduling commands (throttle adjustments) and flight control commands (all attitudes control).

Current Jet Operational Requirements and Constraints

In current subsonic jet operations, each flight is issued a clearance for the SID which includes information necessary for the aircraft to exit from the terminal area on a course consistent with the flight plan and the destination. There are generally several SID's for any given terminal and the assignment of a given SID to a given flight will have considered such parameters as:

1. Flight plan and destination
2. Operational runway in use
3. Weather conditions
4. Aircraft performance characteristics
5. Surrounding terrain, obstructions, etc.
6. Noise abatement considerations
7. Conflict avoidance

The aircraft is required to execute the cleared SID with the greatest possible accuracy and precision because of the relatively high density traffic in terminal control areas. Deviations from the SID are not permitted without prior ATC approval. The sole exception to this rule is the exercise of pilot judgment in an emergency situation such as imminent collision. Flights are under constant radar surveillance and may have their respective SID's altered by radar vectors from ATC, in which case they must follow the vectors assigned.

The fact that an SID is issued and that the flight is under constant radar surveillance does not relieve the crew's responsibility for knowing the location of the aircraft at all times. For example, an SID may include instructions to remain at some fixed altitude on such and such a heading until some low-level airway has been crossed. It is clear that continuous knowledge of aircraft position is an absolute requirement for compliance with such directives.

Some specific regulations follow:

FAR 91.87, ref 13:

Departures.

(f) *Departures.* No person may operate an aircraft taking off from an airport with an operating control tower except in compliance with the following:

(1) Each pilot shall comply with any departure procedures established for that airport by the FAA.

(2) Unless otherwise required by the departure procedures or applicable distance from clouds criteria, each pilot of a large airplane shall climb to an altitude of 1,500 feet above the surface as rapidly as practicable.

ICAO Reg. 3.2.6, ref 14:

Operation on and in the vicinity of an aerodrome.

An aircraft operated on or in the vicinity of an aerodrome shall, whether or not within an aerodrome traffic zone:

a) observe other aerodrome traffic for the purpose of avoiding collision;

b) conform with or avoid the pattern of traffic formed by other aircraft in operation;

> *c)* **make all turns to the left, when approaching for a landing and after taking off, unless otherwise instructed;**
>
> *d)* **land and take off into the wind unless safety or air traffic considerations determine that a different direction is preferable.**

Current Jet Implementation Concepts

Maintaining the assigned flight path in executing an SID involves the use of fairly standard tools in current jet operations. A flight director type display may be used to indicate aircraft heading and relative heading to desired course to steer, as well as position of the aircraft relative to the desired track. A bank indicator may be used to indicate rate-of-turn, and an altimeter used for altitude and rate-of-ascent. Position of the aircraft is obtained from the VOR/DME display read-out. Means are also available for ascertaining fuel consumption rates. With these tools, the pilot manipulates the aircraft in accordance with his displayed navigational data such that the SID track and altitude components are within acceptable limits of the assigned values.

SST Potential Operational Requirements and Constraints

For purposes of this discussion, the SID phase of the SST flight will terminate at that point when the aircraft has achieved cruise speed even though it may have left the terminal area control zone and be under the control of an ATC enroute center. The discussion will refer to that portion of the flight under terminal area control as the "initial phase" of the SID, and that portion of the flight between the exit point from terminal area control and the IP for transonic acceleration as the "second phase" of the SID, although execution of transonic accereration will be included.

The operational requirement for the SST during both phases of the SID is to define precisely, and then attain the transition area with a minimum time aloft and minimum fuel expenditure. The non-ATC constraints, are the same as for other phases of the flight, execution of all maneuvers within the safety margins required, and at those levels of g forces acceptable to the passengers, and avoidance of adverse meteorological conditions, either hazardous weather or unfavorable winds and ambient temperature distribution. ATC-imposed constraints will be the normal constraints currently imposed for conflict avoidance.

In considering possible ATC constraints on this phase of SST operations it is necessary to make two assumptions. Initially, it must be assumed that no major modifications to the current ATC procedures will be adopted. The constraints for the SST will be the same as those discussed earlier for current subsonic jets. This could mean that the SST may not be able to take full advantage of its superior acceleration and rate of climb capabilities (see Figure 33) in the subsonic speed regime in order to (1) assure acceptable g forces, (2) keep off-track lateral displacement following turns at high speed within ATC-imposed limits, and (3) comply with altitude restrictions.

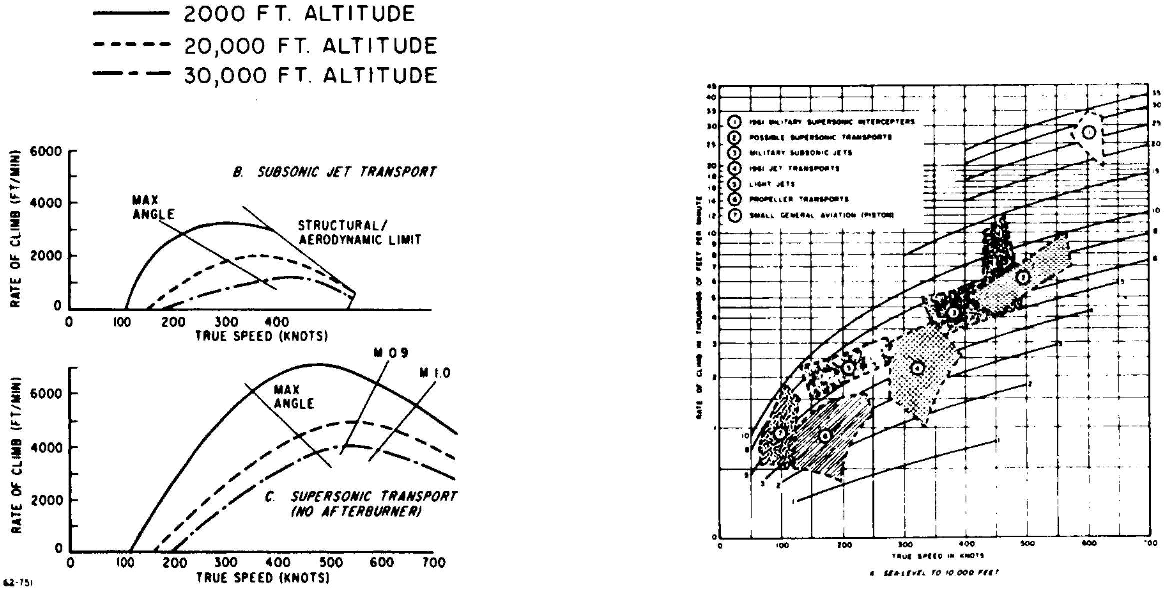


Figure 33. Rate of climb versus true speed for commercial transports (from ref. 51).

It would therefore seem that some penalty in fuel consumption for less than optimum performance could be expected. The restrictions also keep the SST from taking advantage of more acceptable meteorological conditions. (see Figure 34).

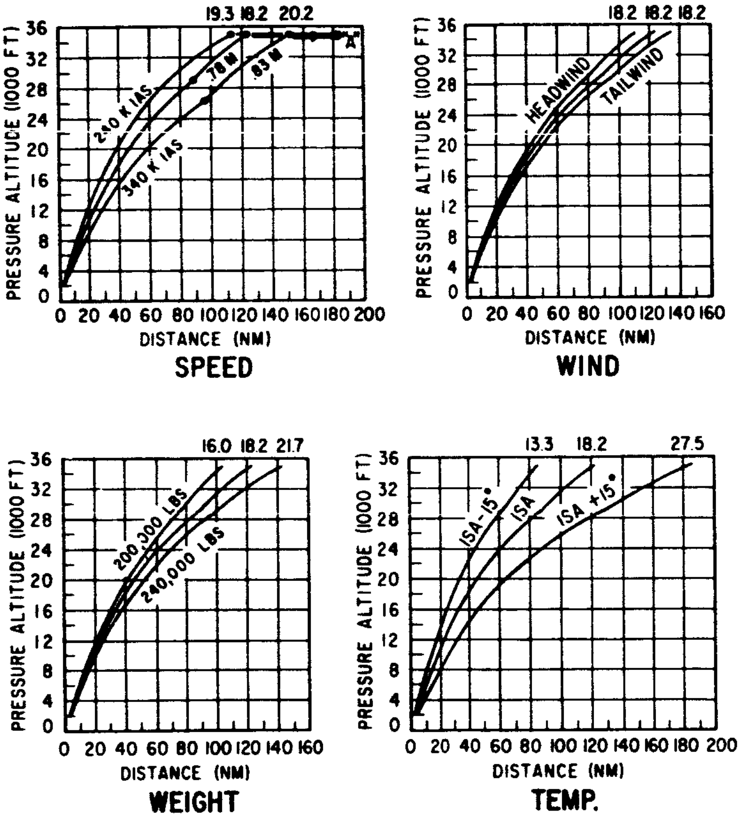


Figure 34. Pressure altitude versus distance (from ref. 51).

The complexity of the SID navigational problem is probably best summarized by Hooton (ref. 51),

> Another aspect is shown in Figure 35. Here are the ideal departure flows out of the three New York airports during northerly wind conditions. Add the arrivals to this, and change the wind direction, and the whole picture would change.

> The point is that we must guard against an oversimplification of the problems involved. For planning purposes one cannot draw a simple climb profile starting at one runway and going out to 40,000 or 80,000 feet and leave it at that. We are faced with turns after takeoff, route deviations, intermeshing of airways and the effects of the weather. Compromises are inevitable but some careful thought should go into this problem.

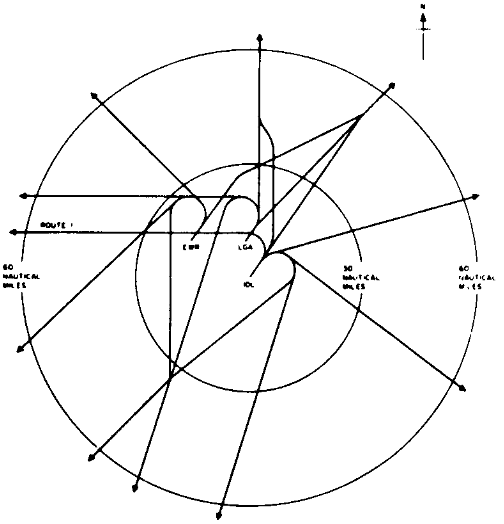


Figure 35. Ideal departure flow-outs of New York Airports (from ref. 51).

Hooton goes on to further define the problem as follows:

> Basically the problem in air traffic control can be summarized as one of prediction. Since this is difficult, traffic control today is done on a basis of airway routes, radar monitoring, and vectoring, within a two-dimensional system.
>
> Figure 36 shows three typical problem areas as they exist today. Figures 36-I and 36-II show two alternatives for westbound departures from airport A which conflict with traffic into and out of airport B.

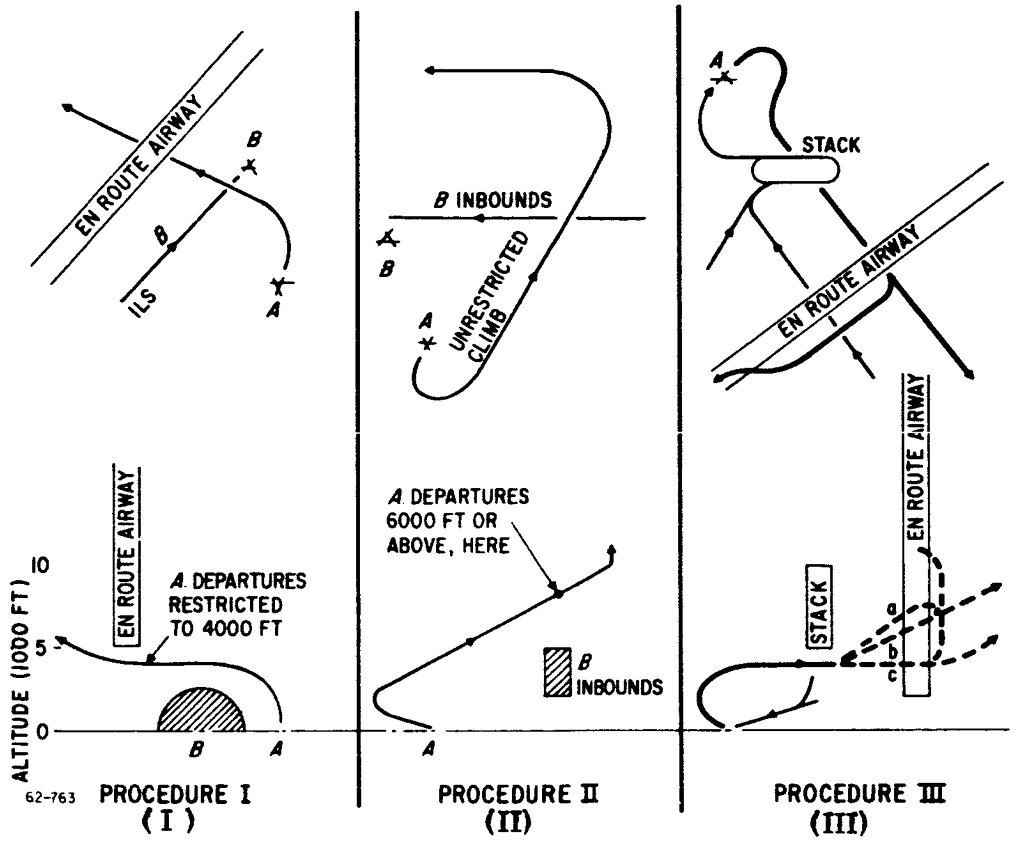


Figure 36. Typical ATC problem areas. (from ref. 51).

In Figure 36-I the departure from airport A must suffer restricted climbs but are allowed to proceed on course immediately after takeoff. In Figure 36-II the climb is not restricted but departures must initially fly away from their intended destination.

Figure 36-III shows a combination of problem areas, the prime difficulty being that of the departures crossing and joining an enroute airway.

Such procedures today are costly in time and fuel and are complicated for pilots and controllers.

Is it practical to think in terms of airways defined in the vertical plane as well as the horizontal plane to overcome some problems? The answer is affirmative, but there are qualifications:

1. "Slant airways" (as they may be called) must be defined and sited very carefully.

2. Since turns are inevitable, such airways will require that navigational information is adequate to define such turns for the pilot.

3. Navaid accuracy will require improvement over present operational navaid standards.

4. Adequate radar monitoring facilities will be necessary for the traffic controllers.

5. Flight planning will require greater accuracy in the climb and descent phases than is presently demanded.

The second assumption regarding ATC constraints on SST operations is that ATC will make modifications in their terminal area control zone procedures for executing an SID. The most extensive modification would be the introduction of area-coverage navigation techniques which would essentially remove the requirement for so-called airways and permit highly flexible navigation even within high density traffic areas.

There appears to be a need for the modification of ATC control procedures, or at least SID layouts, in the terminal area control zones. Further, it seems practical to be able to vary the transonic acceleration area while enroute, depending on meteorological conditions. Area navigation to the transition area with enroute optimization of the profile will be a requirement. This necessitates modifying the present ATC airway concept constraint.

Feasible Automated Implementation Concepts for SST

Although SID has been defined earlier as that portion of the flight from initial takeoff altitude to the IP for transonic acceleration, the discussion of the navigation requirements for this phase is extended to include the acceleration phase to the point at which enroute navigation takes over.

It is clear that navigational system performance in this portion of the total flight may well determine whether or not the SST is to be economically feasible. This, coupled with the fact that for a large portion of this flight phase the SST will be operating in high density traffic areas, constrains the margin for navigational error. This constraint is the basis for the assumption that the SID will be specified in terms of data which can be stored and utilized by an airborne computer which will actually control the aircraft's progress. Computer control will be accomplished by transducing the SID data into appropriate auto-pilot and auto-throttle commands, taking into consideration noise abatement procedures where applicable, and control parameters produced by the navigation system concerning such things as fuel flow rates, safety margins and meteorological conditions.

Optimization of the flight path while enroute to the transition area gives rise to a procedural problem in that deviation from the cleared volumetric air space requires ATC sanction. The navigation situation will be clearly displayed in the cockpit in such a manner that flight management is cognizant of any optimization required, and this same data can be made available via data link to an appropriate ATC facility. The navigation system would proceed with the optimization process as delineated by the displayed navigational situation unless flight management and/or ATC overruled the system.

The navigation system would function to bring the aircraft along the optimized path such that it arrives over the IP for transonic acceleration on course for the destination (or initial checkpoint) at the prescribed altitude. The control law utilized by the computer to accomplish climb-out to the IP for acceleration will probably be as defined by Richardson (ref. 52) in his discussion of a central electronic management system for the SST, wherein he defines such a control law utilized by military supersonic craft as "variation of MACH with altitude, commonly referred to as speed-altitude scheduling." It may be necessary at this point to apply a different control law for the pure acceleration phase. Richardson goes on to say, however, that "transition from one phase of the mission to another, or from one control law to another, was accomplished automatically by the computer with no action required by the pilot whatsoever." It seems reasonable to assume that the initiating signal to the computer to begin the acceleration phase will be verification by the navigation system that the aircraft's position in three-dimensional space and heading is as prescribed earlier by the navigation system in deriving the IP for transonic acceleration while enroute to the transition area. If the computer receives no signal from flight management to delay the acceleration, it will automatically provide flight control and throttle control commands to the auto-pilot and auto-throttle based upon the navigational parameters received which describe the optimum profile for the acceleration phase. This function (i. e., optimum profile generation) is discussed fully under enroute navigation. As performed during this function, it will consider basically the same requirements identified under the enroute navigation description. The justification for such is very well demonstrated by Figure 37 below (from Polhemus, ref. 53) which clearly illustrates the problems confronting the crew in the acceleration phase.

Polhemus describes this situation as follows:

> The acceleration phase is characterized by a call for maximum engine output, extremely high fuel flow (as much as 4000 lb. per minute), rapid change of all the velocity sensors (C. A. S., T. A. S., mach number and G. S. meters), rapid change of altimeter, rate of climb meter near its limit with initial climb values in excess of 6000 ft/min., all of which makes it extremely difficult to get a sense of the correctness of what is going on. Confirmation of forecast or programmed conditions is an urgent requirement both from the point of view of fuel management and from the point of view of navigation accuracy.
>
> Figure 37 illustrates three basic acceleration profiles. The two lower paths are typical of B-58 maneuvers while the upper trajectory depicts the path of a mach 3. 0 S. S. T. as described in Aviation Week, 1 April, 1963. This latter trajectory is designed to minimize the effects of sonic boom

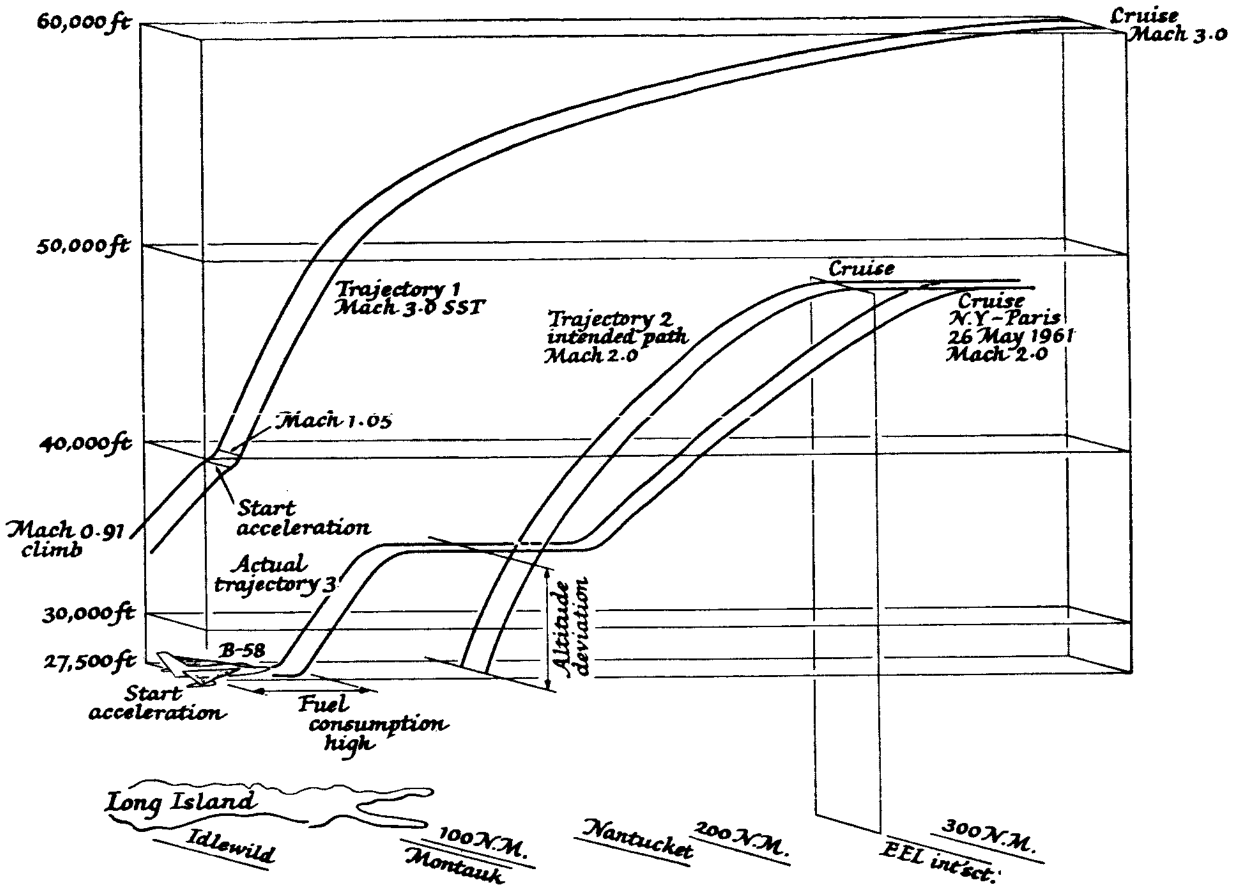


Figure 37. Three basic acceleration profiles (from ref. 53).

disturbance--and appears to be a very demanding schedule to accomplish. The two lower trajectories compare the filed flight path with that actually flown on 26 May, 1961 by the B-58 aircraft which established the 3 hour 19 minute record between New York and Paris. Though the A. T. C. clearance was for the lower trajectory, labelled 2, the two-step path was flown in an effort to minimize what appeared to be an excessive fuel flow. The deviation in altitude and position between the cleared flight path and the path actually flown by the aircraft may be noted. It is this type of in-flight decision that faces the aircrew during the critical first minutes of the acceleration.

One further remark by Richardson (ref. 52) in his discussion of the CEMS application further illustrates the versatility of automation to provide high-speed problem solutions at critical moments,

> The MA-1 computer, for instance, will not allow the F-106 to automatically climb to its best cruise altitude if its computations indicate there is not enough fuel on board to climb along its climb schedule from present altitude to cruise conditions and cruise for a specified distance. The ASG-18 computer program has the capability of continuously telling the pilot how far he can cruise towards an alternate base after he reaches his future destination, taking into consideration the fuel and distance required to: (1) accelerate and climb to supersonic cruise conditions; (2) cruise at best cruise altitude for decreasing gross weight or cruise at present conditions of Mach and altitude; (3) descent to subsonic hold pattern over destination; (4) climb from hold conditions to cruise for diversion.

There is obviously already a great deal of precedent in automating navigation functions with integrated information concerning profile optimization. The criticality of the climb-out and acceleration phase would appear such that automatic navigation and flight profile optimization is a certain requirement, and will be implemented in much the same manner as discussed in enroute navigation.

Feasible Manual Implementation Concepts for SST

Maintenance of the flight for the SID and the acceleration phase of the flight could be handled by more conventional techniques such as those discussed under Current Jet Implementation Concepts. However, there are several implications stemming from the use of conventional techniques. An obvious result would be the difficulty in minimizing track excursions in turns due to the higher subsonic speeds. Probably the paramount consideration, however, would be the impact on the on-board capability for optimization. In this area, it is a safe assumption that a considerable degradation in optimum performance may result from a clear-cut decrease in available means. It would appear almost a virtual necessity to rule out requirements for sonic boom control and fuel optimization before anything less than automatic implementation could be justified, even if the conflict avoidance problem is resolved by extremely careful definition and execution

7.4 FUNCTION 7.4 MONITOR DESTINATION/ALTERNATE WEATHER CONDITIONS

Purpose

The purpose of this function is to provide flight management with continuous cognizance of weather conditions affecting SST low-altitude operations at the destination point and all prescribed alternates for that given flight. "Low altitude operations" are defined as those operations from the time the aircraft returns to the subsonic flight regime until roll-out after landing.

It seems important to note that despite an all-weather landing capability, there may be conditions at terminal points which will necessitate diverting aircraft (including the SST) to an alternate. Strictly defined, all-weather landings are all ceilings-all visibility landings. All-weather systems cannot be construed to include a capability for landing an aircraft with wind shears of intolerable magnitude, for example, or severe thunderstorm activity or squall line activity in a terminal area. Therefore, the possibility of diverting to other terminals will continue to exist even though all-weather landing systems are being employed. Hence, monitoring of weather conditions for the destination point and prescribed alternates must also continue.

Current Jet Operational Requirements and Constraints

Current jets are required to prescribe alternates in their flight plans. The following specific regulation applies:

ICAO Reg. 4. 4. 1, ref. 12:

Meteorological Minima

S A flight shall not be continued towards the aerodrome of intended landing unless the latest available meteorological information indicates that conditions at that aerodrome, or at least one alternate aerodrome, will, at the expected times of arrival, be at or above the meteorological minima specified for such aerodromes in the Operations Manual.

S Except in case of emergency an aircraft shall not continue its approach-to-land at any aerodrome beyond a point at which the limits of the meteorological minima specified for that aerodrome in the Operations Manual would be infringed.

NS A flight shall not be continued towards the aerodrome of intended landing unless the latest available meteorological information indicates that conditions at that aerodrome or at least one alternate aerodrome, will, at the expected times of arrival, be at or above the meteorological minima specified for such aerodromes.

NS Except in case of emergency, an aircraft shall not continue its approach-to-land at any aerodrome beyond a point at which the limits of the meteorological minima specified for that aerodrome would be infringed.

Current Jet Implementation Concepts

Currently, weather and landing conditions at destination and alternate terminals are obtained via meteorological forecasts and reports furnished by Flight Service Stations and other Air Traffic Control agencies. Appropriate information is generally passed to the crew verbally via the communications system (VHF/HF radio transceivers). Current weather conditions, the forecast, and the general weather trend, are used in deciding to continue to destination or divert to the alternate.

forecast and taken into consideration during the flight planning stage. An additional consideration, during periods of turbulence is passenger discomfort, either physical or psychological, and its contribution to the overall public acceptance of flying in general and the SST in specific. Weather phenomena of the thunderstorm variety are not anticipated to present many problems to the SST once the cruise/climb profile has been attained. However, since cumulous buildups at altitudes from 50,000 to 75,000 feet have been reported by pilots and weather radar, their possible presence cannot be disregarded.

2. Adverse winds. Adverse winds aloft may be of two varieties: (1) head winds (or lateral cross winds) of relatively high magnitude, and (2) wind velocity and relative bearing such that sonic boom focussing effects may materialize. Although it is generally believed that winds are relatively light above 50,000 feet, there is evidence that high winds can be experienced at SST cruise altitudes (ref. 53). The possibility of experiencing winds aloft of magnitudes such as those indicated in the 30 millibar chart (Figure 38) will have to be considered in maintaining the optimum flight profile. Undoubtedly more significant is the requirement for continuous knowledge of the actual wind velocity and relative bearing so that generation of excessive overpressures can be avoided. Either of these factors could produce a change in the optimum planned profile once the aircraft is airborne.

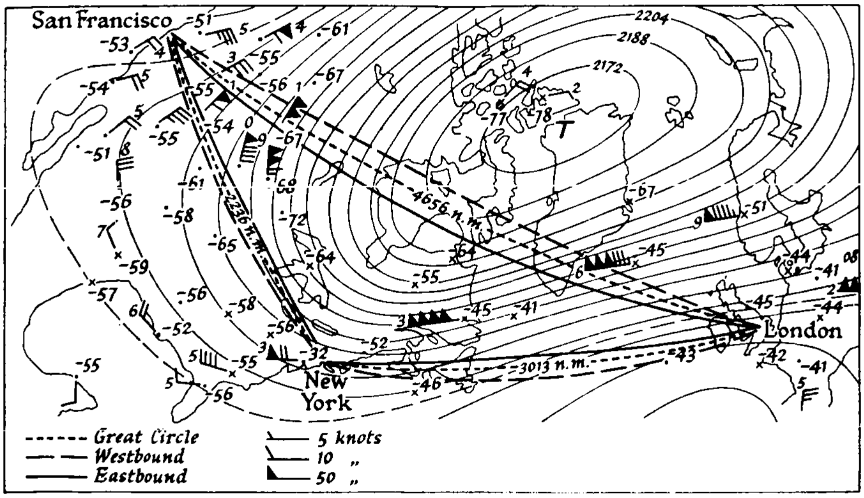


Figure 38. Constant altitude (30 mb) chart (from ref. 53).

3. Adverse temperatures (ambient). It is quite clear in the literature that a parameter of paramount importance in SST operations is the ambient temperature aloft. It has been stated in essence (ref. 54), that during the acceleration phase non-standard atmospheric conditions can affect fuel consumption and rate of acceleration by 20% to 30%, and can in rare instances cause such high rates of fuel flow as to require discontinuing the acceleration. It is evident that continuous availability of ambient temperature data is an absolute requirement and, moreover, that temperature values must be known with the greatest possible precision as far ahead on the aircraft's path as possible. It seems a certainty that temperature alone will be sufficient cause for many modifications to planned optimum profiles if the SST is to keep within fuel reserves and operate economically. It is also obvious that variations between actual and forecasted temperature conditions can greatly affect ETA validity and thus may present a significant

problem in integrating the SST into the ATC system. It has been stated that the SST true airspeed can vary as much as 240 knots in a one hour period due to changing temperatures alone (ref. 54).

4. Radiation hazards. Operational altitudes of the SST will require consideration of altering or modifying the optimum flight profile to avoid radiation hazards. Although radiation levels at altitudes within the cruise envelope for the SST are known and are acceptable, solar storms can cause those levels to increase rather rapidly to levels unacceptable for passenger and crew exposure. Currently solar bursts can be forecasted about 15 minutes in advance. Meteorological services could provide this data for the SST sufficiently before increases in radiation levels occur, so that necessary avoidance measures could be executed. Nevertheless it seems likely that raidation levels will be monitored during flight to insure safety.

The following regulations apply:

FAR 121. 357, ref. 11:
Airborne weather radar equipment requirements: passenger-carrying airplanes.

(a) No person may operate any airplane certificated under the transport category rules (except C-46 type airplanes), in passenger-carrying operations, unless approved airborne weather radar equipment has been installed in the airplane.

ICAO Reg. 4. 4. 2, ref. 12:

Meteorological Observations.

So far as possible, weather observed en route shall be reported at prescribed times or points as requested by the appropriate meteorological authorities.

Note.—The times and points mentioned are usually in accordance with the recommendations of Regional Air Navigation Meetings.

Current Jet Implementation Concepts

Of the aforementioned weather parameters, only severe turbulence significantly affects the capability of subsonic commercial airliners to adhere to a given flight profile. Other factors that accompany thunderstorm activity and other frontal movements, such as severe precipitation and heavy icing are also important for subsonic jets. At the altitudes frequented by these aircraft, radiation hazards are non-existent. Although variations in standard day temperatures affect fuel consumption and economy of engine operation, subsonic jets are capable of maintaining significantly greater fuel reserves since high altitude climb-out and acceleration to supersonic regimes are not a part of their operational profile. Thus, temperature has no appreciable effect on subsonic jet operations as far as schedule maintenance is concerned. Commercial airlines try to plan their flights to take advantage of prevailing jet streams and avoid head-winds. All favorable wind conditions are taken advantage of to the extent that ATC clearance can be obtained. Subsonic jets, obviously, are not concerned with the sonic boom problem.

Meteorological forecasts, PIREPS, and search (WX) radar are the three means available for recognizing turbulence associated with storm activity. Included in PIREPS, of course, are visual sighting and avoidance measures. Avoidance means usually consist of: (1) redirecting the path of the aircraft--most generally used at cruise altitude when storm buildups are broken such that a path can be found through the fringe areas and clearance can be obtained to deviate from the track to the extent necessary; and (2) penetrating the storm front at slower speeds when the turbulence encountered is not considered to be a risk to flight safety, or to cause extreme discomfort (primarily psychological) to the passengers.

Clear air turbulence is of two varieties, that associated with particular terrain characteristics along with weather parameters, and that associated with unstable air at altitude primarily due to mixing of warm and cold air masses. The first type can usually be considered in flight planning because it is relatively constant, (e. g. , updrafts and down drafts over mountainous terrain, or thermal drafts on a hot day over the desert floor). Conditions conducive to the second type of turbulence can be forecast, but there are still occasions when the conditions can be encountered without having been forecasted. The general procedure in penetrating turbulence of both varieties is to decelerate until an acceptable level of turbulence is experienced. There is no instrumentation provided to indicate turbulence severity or, particularly in the case of clear air turbulence, to detect its presence before it is encountered.

SST Potential Operational Requirements and Constraints

In those portions of the SST flight regime which are similar to that for subsonic jets, requirements for monitoring enroute weather phenomena are basically the same. The SST design requirement for capability of operating within terminal areas in the same manner as subsonic jets also dictates consideration of the same weather phenomena and, in all probability, similar avoidance techniques. The severity of the penalties for less than optimum SST performance will undoubtedly necessitate more precise forecasts of certain weather parameters as well as for airborne measurement of some of these parameters. For example, variations in standard day temperatures in the transitional acceleration area are of critical importance and will have to be more precisely forcasted, and undoubtedly will have to be measured in flight. Likewise, wind direction and magnitude will be of primary importance at the transitional acceleration point and thereafter until transitional deceleration has been executed. These parameters will also have to be more accurately forecasted than at present and the SST must be able to obtain accurate measures while in flight. Clear air turbulence and radiation levels at SST cruise altitudes are also weather parameters for which accurate measurements must be available.

Feasible Automated Implementation Concepts for the SST

General weather conditions expected along a given route will be known in terms of detailed meteorological forecasts. The monitoring of enroute conditions will include gathering qualitative and quantitative data suitable for display in the cockpit and comparison against the original forecasts (for purposes of computing differential wind, differential temperature, etc.). Special parameters which affect critical functions (e.g., wind velocity and relative bearing for overpressure control) will have to be known enough in advance to permit correcting or avoiding a given maneuver.

A general concept for SST follows. Temperature gradients would receive more attention in the meteorological forecasting situation. An airborne ambient temperature sensor has been suggested which would detect temperature in the areas adjacent to the aircraft and 10 to 15 miles ahead on the projected flight path (ref. 54). Wind velocity and relative bearing will be calculated from other system sensors, such as the Doppler sensor (indicates drift angle and ground speed), and true heading and true airspeed indicators, as a normal output of Function 7. 7 (see Internal System Position Generation). Greenaway (ref. 49) suggests that "search radar, although not an integral part of the navigation system, will be required primarily for storm avoidance in all supersonic transports." Winick (ref. 55), FAA design team spokesman, has indicated that avionics problem areas for which no solutions are available include "airborne WX radar capable of detecting light rainfall at distances of 250 miles, means for detecting clear air turbulence and sensing temperature gradients for optimum flight paths." King and Groves (ref. 56) indicate a requirement for a suitable air/ground data link. A high speed digital data link would permit rapid updating of the meteorological forecasts along the flight route such that the SST would always have the latest information available, including information on those areas out of range of the on-board weather sensing devices.

The weather parameters discussed will be available to the SST crew in one form or another. Depending upon the sensor design it appears feasible that all these weather parameters could be provided in either analog or digital form suitable for machine calculations. Although it may not be feasible or practical to make the weather radar return signal pattern or ATC reports direct inputs into the navigational computer, this is not the case with temperature and wind velocity and relative bearing. Moreover, temperature and wind are more critical in terms of requirements for immediately available data and continuous accurate measurement.

Feasible Manual Implementation Concepts for SST

Temperature and wind velocity can be measured (or calculated) and read out in the cockpit, as can radiation levels. Obviously, weather radar can be displayed in the cockpit area. Changes in forecasted weather along the flight path which are available at Flight Service Stations along the route may be received in the cockpit by an appropriate verbal communication via VHF net, or hard copy printout via data link. Monitoring enroute weather conditions is certainly amenable to manual or semi-automatic implementation. However, a manual concept limits the rapidity with which these data can be used. For example, consider the time required for a crew member to take readouts of wind velocity and relative bearing, aircraft heading, aircraft gross weight, aircraft altitude and attitude, and aircraft velocity, and compute the overpressure being generated and the conic dispersion of the overpressure with respect to the movement of the aircraft in space. The situation could seriously degenerate before the first calculation was completed.

The point is that measurements of weather parameters, though manually available through readouts or calculations, should be examined in terms of the changing requirements for their utilization, including considerations such as timeliness, accuracy and regenerativeness (or cyclic in nature). These requirements are not in essence compatible with manual means without some degradation in performance. It is probable, however, that there will be some degree of manual implementation in this area, particularly in monitoring weather radar and incoming weather data forecasts, as well as visual sighting of storm clouds.

of SID's at possibly lower speeds than those achievable or optimum for this phase. Slower speeds mean higher block times which lead to fuel penalties. All in all, it appears that the application of conventional techniques during this phase of the flight is questionable.

7. 3 FUNCTION 7. 3 MONITOR ENROUTE WEATHER CONDITIONS

Purpose

This function is the gathering of necessary data concerning weather phenomena along the flight route which may have direct or indirect impact on the flight operations. A direct impact on the operation of the flight is considered to result from individual or sets of weather parameters along the flight route which in and of themselves necessitate altering the optimum profile planned prior to the flight (e. g., radiation hazard avoidance at altitude, thunderstorm avoidance in the transition phase). An indirect impact refers to individual or sets of weather parameters along the flight route which sufficiently affect some other critical operating parameters to the extent that it is necessary to alter the optimum profile planned prior to the flight (e. g., large deviations in temperature from standard atmospheric variations with altitude which result in higher fuel consumption).

At least the following set of weather phenomena may result in the necessity to alter the optimum planned profile for the reasons indicated.

1. Severe turbulence. The unforecasted presence of severe turbulences, both the clear air variety and that normally associated with frontal movements, i. e., thunderstorm and squall lines, usually results in a rather severe modification to the planned flight path for any aircraft, and the SST will apparently be no exception. The most common method for negating the effects of severe turbulence is to avoid it. However, sometimes when the turbulence is moderate to severe, its effects can be minimized by decreasing the speed of the aircraft. In either event, there would appear to be a penalty to the SST in terms of fuel consumption unless the situation were correctly

SST Potential Operational Requirements and Constraints

The SST is not expected to initiate new requirements in this area. However, it seems likely that the decision to divert to an alternate may have to be made earlier in SST operations than in current jets due to the criticality of the fuel reserve problem. Consideration is also being given to the requirement for increased accuracy and frequency of meteorological forecasting and measurement (ref. 57).

Feasible Automated Implementation Concepts for SST

Forecasted weather conditions for destination and prescribed alternates are a required portion of any flight plan. As such, these data will be available in some form for flight management perusal; as written narrative or hard copy, appropriate charts for display, or stored in some central data computer available for retrieval upon demand. Updated forecasts and current measurement of appropriate parameters will be supplied to the SST by Flight Service Stations or other ATC functions via the data link. This information would be in form suitable for direct comparison with the original forecasted conditions such that differentials could be readily calculated. The original data, revised data, and differential solutions would be available for flight management perusal upon demand.

Feasible Manual Implementation Concepts for SST

This function could be performed by manual means much as it is in current jet operations (i. e., the pertinent data is passed verbally and hand recorded).

7. 5 FUNCTION 7. 5 PROVIDE DIFFERENTIALS IN FORECAST TO ACTUAL WEATHER CONDITIONS

The purpose of this function is to provide the essential weather information required for:

1. Insuring the continued integrity of the optimum flight profile being flown (from an acceptable WX conditions viewpoint).
2. Providing the basis for optimum profile modification as a direct result of the weather situation either enroute or at the destination point.
3. Establishing and maintaining the integrity of the optimum profile following its modification for any reasons (from acceptable WX conditions viewpoint).

The input data to this function, in general, consists of "what was expected" and "what is" in the sense of forecast to actual weather conditions, both enroute and at the destination and prescribed alternate terminals. In this function weather parameters are accepted from the monitoring functions, parameter magnitudes being experienced are compared to those which were forecasted, any differential solutions required are calculated, and trends in parameter variance are developed where required. So, in a sense, the function will output a best estimate of "what will be" for specific parameters, based upon the forecast, the actual, and the trend developed. It will also output the instantaneous values of specific parameters being measured along with the difference in forecast, e. g.

$$\Delta \mathrm{Vwind}_{\mathrm{actual}} = \pm 10 \text{ Kts.}, \qquad \mathrm{Vwind} = \mathrm{Vwind}_{\mathrm{actual}} \pm \mathrm{Vwind}_{\mathrm{fcst}}.$$

(The sign of the wind parameter indicates either a quartering tailwind (+) or a quartering headwind (-).)

At least the following parameters will be treated by this function:

1. Wind velocity, relative bearing; (enroute, terminal areas)
2. Ambient temperature, temperature gradient (enroute, terminal areas)
3. Radiation level (cruise altitudes only)
4. Turbulence (clear air, thunderstorm, squall line, hurricane, tornado, etc.) (enroute, terminal areas)
5. Precipitation (rain, sleet, snow, hail) (enroute, terminal areas)
6. Freezing levels (icing conditions) (enroute, terminal areas)
7. Cloud cover, type, etc. (base, height, amount) (enroute, terminal areas)
8. Runway accumulations (type, depth) (terminal areas)
9. Visibility, slant visual range, runway visual range. (terminal areas)
10. Obstructions to vision (smoke, haze, fog) (terminal areas)

These requirements are detailed in ref. 58, "National Aviation Meteorological Requirements through 1975."

Current Jet Operational Requirements and Constraints

Current jets are required to compare the enroute weather conditions with those forecasted and to be cognizant of any and all differences in parameter magnitudes and phenomena to the extent that flight management may request clearance for course deviations should that be required and that flight safety is assured. Destination weather must also be continuously compared with the forecast to determine the necessity for possible deviation to an alternate. (FAR 97 governs the landing minima, and ATC has the authority to close terminals as well as designate specific airways "blocked.")

Current Jet Implementation Concepts

In current jet operations the practice of noting differences in the forecast to actual weather is rather unsophisticated, and often a by-product in the performance of associated functions. For example, if no thunderstorm activity had been forecasted, and yet the crew visually sights heavy cumulus buildups and anvil irons indicative of thunderstorms, no special task was performed in noting this differential. A difference is noted and with that the data is in the appropriate channel for decision making. Also, current practice is to check the destination terminal weather at each reporting point, and in some cases at closer intervals when the weather situation is marginal and forecasted to reach the minima, or below; or when the weather situation is below the minima, but forecasted to improve. So, differences are noted by the crew member receiving and recording the latest weather report regarding the destination and alternate situation, and this is actually a product of weather monitoring.

SST Potential Operational Requirements and Constraints

Weather parameter differentials will have a pronounced effect on SST operations from the viewpoints of fuel management, sonic boom control, schedule maintenance (i. e., ETA validity), air space control, flight safety, and passenger accommodation. Polhemus (reference 53) has stated that "confirmation of forecast or programmed conditions is an urgent requirement both from the viewpoint of fuel management and from the point of view of navigation accuracy." Considerably more emphasis is necessary in this area in view of the many facets of SST operation which weather parameters may affect to a much greater extent than in current jet operations. Hence, the requirements in this area are considered to be significantly more stringent for SST efficiency.

The following paragraphs discuss the specific SST requirements in terms of the parameters needed and their utilization. It is important to keep in mind that this discussion is concerned only with differentials between forecasted and actual weather conditions. For purposes of this discussion, an ideal weather flight is defined as a flight during which no critical weather parameter is encountered which is sufficiently different from that which was forecasted to:

1. Require discontinuation of the acceleration to supersonic speeds.
2. Require returning to the flight origin point.
3. Require diversion of the flight to an alternate destination.
4. Require discontinuation of the flight at supersonic speeds prior to the planned deceleration point.
5. Require immediate landing of the aircraft at the nearest adequate facility while enroute.
6. Require major modification to the planned enroute profile.

In general, the above alternatives are assumed to embrace all facets of flight tactics which may be employed to assure flight safety, passenger accommodation (or passenger acceptance of the SST), and general public acceptance of the SST (e. g. , sonic boom problem). By this definition, it can be stated that in an ideal weather situation, weather parameter differentials are essentially equal to zero plus or minus an acceptable tolerance, and "ideal" may range from minimal (that which was forecasted) to maximal (the best possible combination of weather conditions for a given flight).

1. Wind velocity and relative bearing. This information is necessary in all phases of the flight, including takeoff and landing. The information is necessary during takeoff and landing for safety in directional control of the aircraft. During the climb-out and acceleration phases which are in the pre-transonic speed regimes, this data is necessary for flight control of the aircraft, as well as in predicting fuel consumption rates. During the acceleration and deceleration phases of the flight, and during supersonic cruise, this information is critical for calculating overpressure being generated, for avoidance of sonic boom focussing effects and for predicting fuel consumption rates. During all phases of flight it is also necessary to navigation for schedule maintenance and to assure valid steering commands for the track being flown.

2. Ambient temperature and temperature gradient. This information is necessary in all phases of the flight for the primary purpose of predicting and controlling fuel consumption rates. It is assumed that the SST will maintain schedule integrity by cruising at a constant Mach number. It is also assumed that the SST will fly an airspeed value when operating in the subsonic speed regimes. If airspeed were to be utilized as a back-up for Mach values in the cruise phase in the event of Mach indicator failure, this data would be critical to navigation and flight control for maintaining schedule integrity due to the possible extremes in airspeed variation as a function of ambient temperature.

3. Radiation level. This information is necessary during those phases of the flight where sudden, appreciable changes in the radiation level due to solar storms could produce conditions of overexposure for the crew and passengers. It also seems likely that a record of the radiation level variance during the cruise portion of a given flight would be necessary in determining the cumulative exposure magnitudes for the

crew (and/or passengers) over a period of time, as well as in substantiating radiation level standards.

4. Turbulence magnitudes. This information is necessary during all phases of the flight. It is required to determine the necessity for, and appropriate action for, avoidance of weather hazards to flight safety.

5. Other phenomena. Data concerning weather phenomena, and conditions which are directly attributable to weather phenomena, listed as items 5 through 10 under Purpose will be necessary primarily in the terminal areas and during subsonic operations. These data will be used in assuring flight safety, anticipating possible problem areas and appropriate corrective action for the conditions in which the flight is operating, determining the necessity for diversion to an alternate, and determining the utilization of and potential necessity for override of the all-weather landing capability.

Feasible Automated Implementation Concepts for SST

The task of providing differentials between forecasted and actual weather conditions would appear to be such that some distinctions among requirements are necessary in order to better discuss potential implementation concepts. Some requirements appear to call for a significantly high degree of sophistication, while for others an extension of present methods/techniques may be adequate. For purposes of this discussion, the requirements will be viewed as being of two kinds, and the reader is free to assume some reasonable and practical combinations of the implementation concepts for both kinds. Those requirements for which greater sophistication seems warranted will be discussed in terms of why the sophistication is necessary, and some potential means for obtaining it. It is again useful to present these discussions in terms of individual parameters.

1. Differentials in wind velocity and relative bearing. Although the need for this information has already been presented, it should be stressed that the accuracy and timeliness of these data is of critical importance. Viewed as parameters affecting navigation from the standpoint of schedule maintenance and air space utilization, wind velocity and relative bearing can be treated by present day techniques and hence no new problems are generated for the SST. On the other hand, viewed as significant components of ground overpressure magnitude (focusing effects), they are highly critical, particularly because they are uncontrollable variables for which highly accurate and reliable prognostic techniques are still beyond the scope of meteorological forecasting. An estimate of the operational weather information which will be required by the ATC system by 1975 (ref. 58) indicates that forecasts of enroute winds (assumed to include winds above the tropopause) will need to be accurate to within ± 5 knots or 5% speed, and ± 10^{o} magnetic direction. Figure 39 indicates that these accuracy requirements could present a serious problem to the SST in predicting the likelihood of overpressure focusing. It seems highly likely that the SST navigation system must provide the capability for extrapolating predictive curves of focusing effects. These curves will need to be based in part upon data derived from constant measurement of actual velocity and direction of the winds aloft, a comparison of these curves to the predicted curves, and development of the trend of wind variation. These are the wind data which are to be developed in this function.

It is assumed that any internal system for position fixing adopted for SST use will have the capability to provide either direct values of wind velocity and relative bearing, or the raw data necessary to compute wind velocity and relative bearing values. Since it is obvious that the internal system for position fixing will be continuous in nature, it will be possible to calculate wind velocity and relative bearing values during each (or following each) computational cycle of position. Thus updated values will be available essentially continuously. Further, an

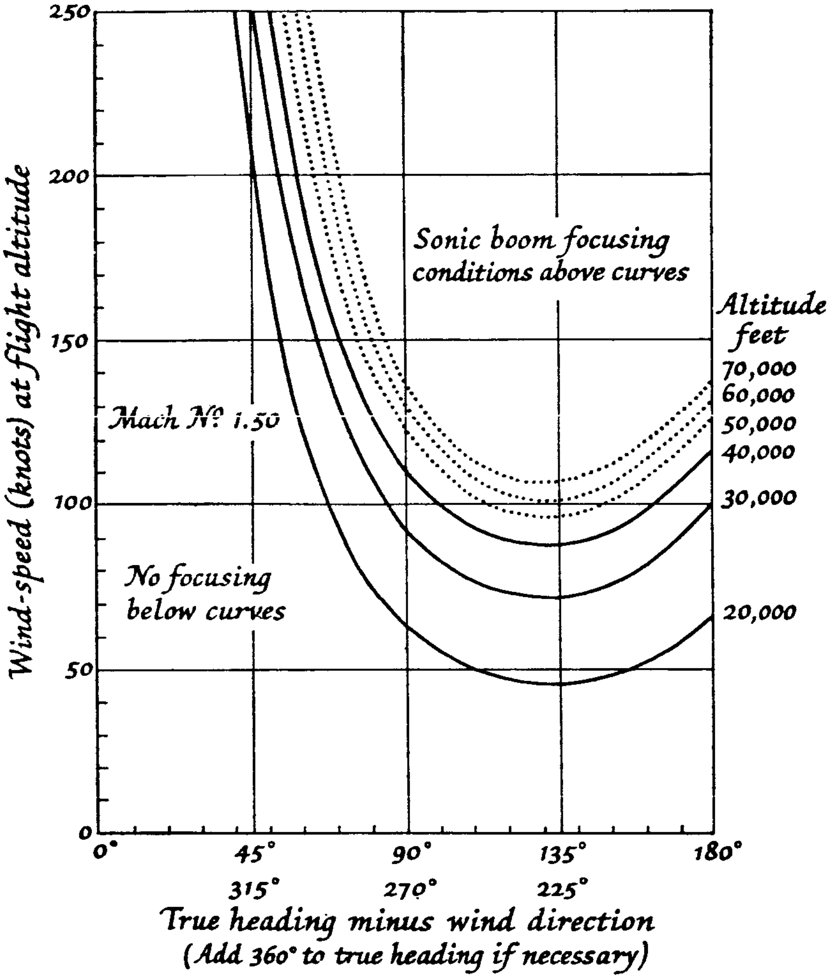


Figure 39. Determination of boom focusing--in standard atmosphere temperatures for various flight altitudes, headings and mach numbers, and wind-speeds and direction. The intersection of relative wind direction from abscissa and wind velocity from ordinate, when above altitude curve, indicates focused boom likely. (From ref. 53.)

externally-referenced system will supply corrective data for the internal system periodically, and some measure of wind data accuracy and reliability from the internal source can thus be determined (assuming that errors associated with both position fixing systems are random with respect to frequency and magnitude, and that some mean error value is available). These wind data values will be inputs to Function 7. 5.

Predicted values will be available from meteorological forecasting services. The wind data in the forecast utilized in the planning stage immediately prior to takeoff would serve as the initial referent for comparison of actual and forecasted conditions. Since it is assumed that data link equipment will be a portion of the SST communications system with ATC, it will be possible for the latest meteorological forecasts to be automatically transmitted and stored in the SST navigation system. The referent then would always represent the latest available forecast (consistent with equipment range).*

Since data points representing wind values will be generated and available at an essentially continuous rate, it would appear feasible to extrapolate trend curves for the wind values, and correct these curves on the basis of PIREPS and up-to-date weather forecasts. The desired output would be such that the relatively more fixed parameters which contribute to sonic booms could be combined with the wind values and used to determine the necessity for altering the flight profile to avoid generating excessive overpressures. This would of necessity involve rather complex and sophisticated calculations at extremely high speeds, and would undoubtedly have to be accomplished by an airborne computer.

A natural product of determining the wind values for sonic boom control will be wind values associated with more classic navigation

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* There would also appear to be a potential data input to this function which could (for some routes) conceivably be the best data available, i. e., PIREPS (or just plain weather monitor reports) for other aircraft operating along essentially the same routes at some short time interval earlier than a given flight. It would appear technically feasible for critical wind values and temperature values to be measured, coded, and transmitted on a certain frequency such that any aircraft operating within equipment (transmission) range that would have a requirement for such data, would have it available essentially instantaneously. And it would also appear to be highly desirable for all SST operators in view of the common problem and criticality for its solution.

problems (i. e., making good the track and maintaining schedule integrity). Differentials in these values from those forecasted will permit flight control to calculate those corrections necessary to bring the flight back to the optimum profile with minimum penalties in fuel consumption. Further, extrapolation of a trend in the wind values will permit continuous and more complete evaluation of the fuel consumption profile from a predictive point of view.

2. Temperature gradient and ambient temperature differentials. Input data will include continuous read-out of the ambient temperature and forecasts of the temperature gradient. Such forecasts would be updated in the same way as the wind data forecasts. (The preceding footnote is also applicable to this parameter.) It is assumed that essentially the same technique discussed for wind velocity and relative bearing would be employed regardless of whether a sensor is developed to measure ambient temperature at some distance (ref. 54, 10 to 15 miles) along the flight path ahead of the aircraft. Such a sensor would undoubtedly permit a higher degree of refinement to the technique.

Whereas the preceding paragraphs attempted to point up the criticality of reliable and accurate wind data for dealing with one of the three most severe constraints on SST operation (i. e., sonic boom control), these paragraphs will attempt to establish the same criticality for reliable and accurate temperature data for dealing with another of those constraints, optimum fuel utilization. This is not to say that this parameter does not also add difficulty to the navigation problem from another point of view, i. e., velocity changes and the attendant ETA problems. Both of these problems are illustrated by the curves in Figure 40. Power (ref. 57) has pointed out that "... the enormous fuel consumption capabilities of the SST must at all times be considered." And Groves (ref. 59) has stated that differences in ambient temperatures from those forecast may entail high fuel penalties, and that "... ambient temperature distribution becomes a decisive factor in defining the transition area

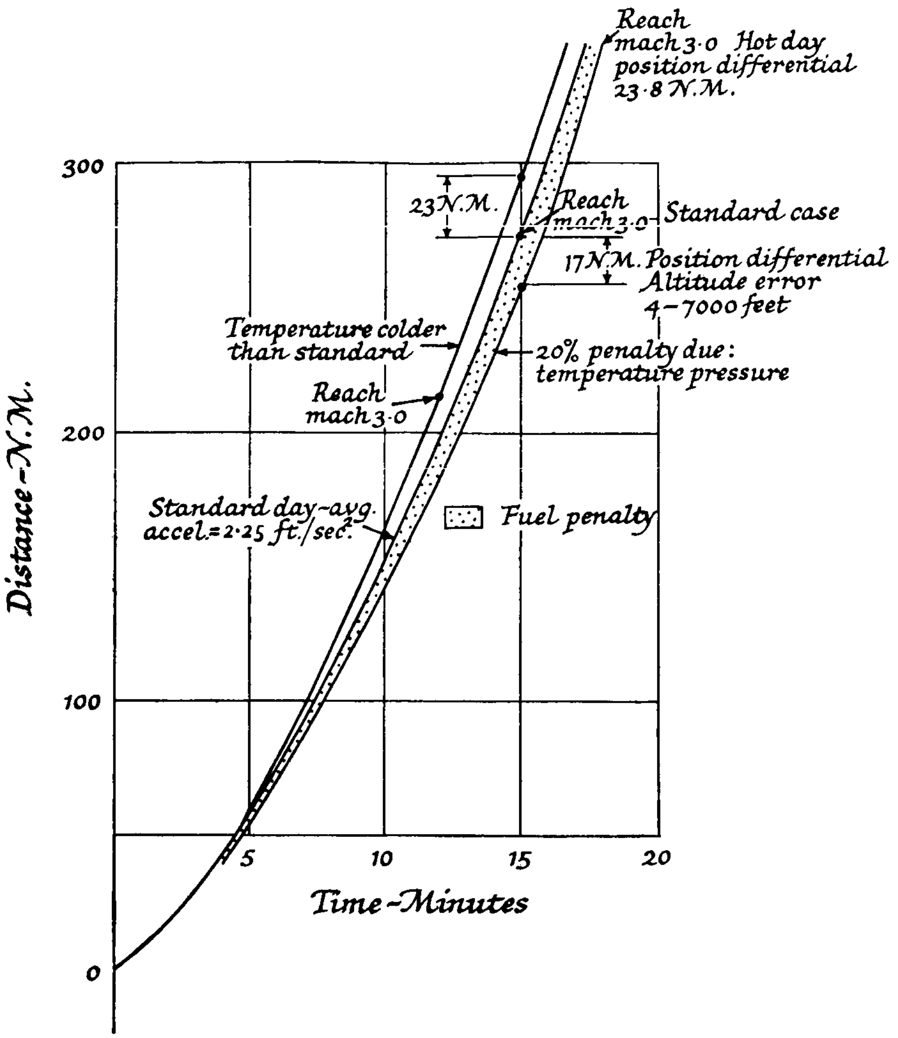

Figure 40. Effect of conditions which produce a 20 per cent reduction in acceleration performance and increase in performance capability (from ref. 53).

with precision and in the need to vary the flight profile accordingly." It can be seen that differential temperature solution is a critical factor in SST operations.

In essence, the approach discussed for dealing with wind data would be feasible for the temperature problem. Considering the absence of a sensor which can measure 10 to 15 miles in front of the aircraft, the approach would be essentially the same. Continuous read-out of ambient temperature is input to the function, and a resulting temperature curve indicates the trend or can form the basis for extrapolation from the trend corrected by the forecast, or vice-versa. The forecast gradient curves could also be corrected by the extrapolated trend. As is the case with the wind data, this would be a dynamic situation in which the predicted gradient would be continuously updated by later forecasts and the extrapolation of the trend. If outputs from the long range sensor mentioned above were introduced into the system, significant refinement could be attained in that a gradient would be established immediately for the next 15 miles of flight. In subsonic regimes this might represent 2 or 3 minutes of flight time, and thus allow adequate time to vary the profile to take advantage of more favorable temperatures. It would still appear desirable to continue trend extrapolation and forecast correction to ascertain even longer range implications for, say, fuel management. Again, as with the wind calculations, the speed, complexity, accuracy, and cyclic nature of these computations are such that they must be made by an airborne computer.

3. Radiation level differentials. Input to this function would be (1) the forecast radiation level magnitude through all appropriate phases of the flight, (2) any prognistication regarding solar storms, and (3) radiation level measurements from an appropriate sensor at whatever intervals are established as minimum or optimum, depending upon the extent of the requirement for the data. It would certainly be feasible to treat these data much the same as the temperature data and wind data. That is, the data can be treated by a curve-fitting process, and an extrapolated radiation level trend can be compared to the forecast curves. Differentials can be noted and recorded automatically over the appropriate portion of the flight to determine cumulative exposure and substantiate the standards. Of course, absolute values can be available in the cockpit at all times, as well as an alarm indicator in the event that the trend appeared to be approaching dangerous zones.

If it is decided that no particular requirement exists for cumulative exposure data or data to substantiate standards, it appears likely that this function would output a danger alarm in the event of a solar flare-up. The handling of this requirement would be covered by the ATC system (ref. 58):

> Past requirements reports have indicated the need for information on upper-air ozone distribution--because of its potential toxic effects on humans--and radiation conditions--because of the hazard to human tissue. It now seems likely that ozone will be chemically decomposed by onboard equipment before entering the SST cabin. Similarly, high radiation levels are easily forecast now by detecting solar flares. The 15-30 minute time required for these flares to enhance the upper-air radiation levels is sufficient for warning SST aircraft and diverting them to lower--safe--flight levels. For these reasons, both ozone distribution and radiation conditions have been stricken from airspace user requirements with the understanding that the occasional solar flares will be reported to the ATC system and SST pilots so that appropriate diversions can be made.

4. Turbulence magnitudes. At the date of this writing, it has been reported (ref. 55) that no sensor available will detect clear air turbulence. Obviously, weather radar can detect the conditions accompanying turbulence depending upon the storm activity at operating ranges. However, there is a requirement for a means of detecting light rainfall at distances of 250 miles; such means are not yet available. There is very little in the literature regarding the SST procedure during turbulence (both clear air and that associated with storm activity) except to assume the current procedure of avoiding it where possible, although NASA is researching this problem. It appears that the inputs to this function will be weather forecasts and airborne weather radar display, and possibly an input from a turbulence-sensing device. The most practical criterion measure for this parameter is an indication of the presence or non-existence of turbulence in the vicinity of the SST flight path, with possibly some estimate of severity, such as light, moderate, or severe. The requirements for

forecasting turbulence (ref. 58),through 1975 indicate that these conditions for the terminal areas and enroute airspace will be forecasted as to occurrence and location on a 0 to 1 hour and 1 to 12 hour basis. Data will also be available on a 2 to 5 minute decision time period for takeoff and landing operations. The location of the turbulence area will be specified with accuracies within ± 1000 feet and ± 0. 5 miles, with forecasts proportionately less accurate as a function of time elapsed since forecast. As with the other parameters, the forecasts will be updated to the extent possible via the data link. Monitoring of the airborne weather radar will be a manual function and hence no automation is envisioned in the provision of differentials (i. e., presence or non-existence) since this will be perceived each time the radar display is sampled (viewed) by a crew member. Reliability, accuracy, and range of any turbulence-sensing device would certainly contribute significantly to any scheme for providing differential turbulence solutions, assuming such to be a requirement. It appears more likely that the sensor-output will be monitored by flight management and differences between actual and forecasted conditions noted by the system monitor.

5. Other phenomena. It appears that other weather phenomena will be treated in much the same manner as the turbulence magnitude parameters (i. e., same as the turbulence-sensing device). The remaining phenomena treated by this function may be generally separated into two categories, enroute and landing conditions. Hazardous weather conditions in both the terminal area and enroute will be forecasted and observed with the same time schedule and accuracies indicated for the turbulence parameters (ref. 58). Runway condition forecasts and observations will include precipitation types, and depth in a range of 0 to 1 inches to ±20% and >2 inches, and will be forecast with the same time schedule indicated for the turbulence parameters. It is further assumed that the function will provide the means for comparing the newest forecasts with those preceding and informing flight management of any differences. It should be pointed out that any of these phenomena which can be described

parametrically, and whose parameters may be measured over some dynamic range, could be included in the above described differential calculation and trend development sequence. The practicality and necessity for such treatment should be subjected to further analysis.

Feasible Manual Implementation Concepts for SST

This function, as this analysis indicates, is essentially not amenable to a manual implementation. That is if the navigation of the SST were to be implemented with man being responsible for many of the tasks which this analysis considers to be more amenable to an on-board data processor, it would appear highly likely that differential weather parameter solution would be reduced to an evaluation of changes in weather forecasts which are based on periodic observations by meteorological agencies. As such, sophisticated techniques for calculating differential solutions for several parameters such as winds and temperature, as well as developing a prognostic trend, would be largely impossible with on-board facilities; and, if practical at all, such calculations would have to be made by ground-based meteorological facilities. Simply put, man is only capable of working at a pace which would reduce this function to noting changes in forecasts and receiving airborne sensor inputs for evaluation over a longer time base than would appear to be optimum. It is true that sensors such as search weather radar with a range of 200 to 250 miles would undoubtedly be monitored to some extent by man. It is also true that the latest weather forecasts would be monitored to some extent by man. However, these data inputs provide the evaluative basis for some action to be taken only a few minutes later. Consequently, sonic boom focusing could be occurring over a significant area when it could at least be minimized, and possibly even eliminated by the use of a more sophisticated technique. In the equally critical area of fuel consumption, the absence of a sophisticated technique for fuel conservation depending on the ambient temperature gradient and the resultant engine efficiencies would appear to impose an unrealistic economic penalty on the SST.

7.6 FUNCTION 7.6 CALCULATION OF OVERPRESSURE BEING GENERATED

Purpose

This function provides the cockpit with an accurate measurement of the location and strength of ground shock-wave patterns being generated (along with predictions for the same data) by the SST during all phases and maneuvers executed in the supersonic speed regime.

Current Jet Operational Requirements and Constraints

There are no applicable requirements or constraints.

Current Jet Implementation Concepts

There are no applicable concepts.

SST Potential Operational Requirements and Constraints

The literature reflects the general consensus that the magnitude of ground overpressure generated by the SST should not exceed some nominal value (generally ≈ 1.5 psf). The FAA RFP (ref. 60) indicates: "Maximum overpressure, during acceleration to supersonic cruise speeds, less than two pounds per square foot. Maximum cruise and deceleration overpressures of 1.5 pounds per square foot." Polhemus (ref. 53) suggests that navigation will have the added task "... of detecting (or in some way acknowledging) the possibility of creating damaging overpressures at the ground, and of displaying the correct flight path modification necessary to minimizing its effect." King and Groves (ref. 56) indicate the criticality of the control requirement:

> . . . transition from subsonic to supersonic speed may occur in the altitude range of 30, 000-40, 000 feet, but, due to the problem of sonic boom, this altitude range may have to be higher, e. g. , between 50, 000-55, 000 feet. The sonic boom problem will almost certainly means that this transition will have to take place either over water or over sparsely populated land areas and will need to be clearly defined geographically.

Further indication of the seriousness of the control problem is borne out by Shaw (ref. 61),

> Like most other airlines, Qantas regards the sonic boom problem as the most serious, uncertain, and inherently intractable problem of the SST. To underscore the seriousness of this problem area, an excerpt is presented from a paper written a year ago:
>
> . . . There are two major uncertainties in this problem, firstly, the precise value of the boom overpressures that will be developed by aircraft of the size of the SST, cruising at SST altitudes, and secondly the magnitude of the booms that will be acceptable to people living on the ground beneath.
>
> There is a considerable body of theory covering the first point. While in the main it is well founded theoretically, it does not include some assumptions that have yet to be fully confirmed.
>
> On the second point, there have been a number of experiments carried out already. However, as with most tests of subjective reactions, the answer is far from definitive. My own tentative view is that boom overpressures of no more than 1 lb/sq. ft. will be acceptable and up to 1-1/2 lb/sq. ft. may be acceptable. I feel certain that boom pressures over 2 lb/sq. ft. will not be acceptable. Unfortunately the predicted boom pressure for the SST fall right in the band of uncertainty between 1 to 2 lb/sq. ft.
>
> The worst overpressures occur during the acceleration which has to be made at altitudes well below the cruise altitude. There is little doubt in our mind that the sonic boom problem will determine the minimum acceleration altitude and consequently exert a decisive influence on the overall design, particularly on the selection of engine size and possibly wing loading.

> The boom pressures are a function of aircraft weight and it is not unlikely that the sonic boom problem will set a practical upper limit to the gross weight of the machine. This is a further and compelling argument for the design of the minimum possible size of the SST.
>
> It is not impossible that the sonic boom problem will preclude the operation of the SST at supersonic speeds except over oceans and deserts of the world. For this reason, Qantas has included in its route studies of the SST the question of alternate operation of sectors over heavily populated areas at subsonic speeds.

A final indication of the problem criticality is evident in the remarks of Power (ref. 57), "In reality, actual flight operations of the SST, both by the flight crew and with consideration of the air traffic control system, may be defined by sonic boom criteria... " With regard to a simulation program to support fuel optimization studies, Power goes on to say that the program is designed such that:

> During every portion of the flight (simulated by computer techniques)* ground overpressure due to sonic boom will be calculated with inputs provided from the Joint FAA-USAF-NASA Program. On the basis of the best information available concerning the operational procedures, design considerations, meteorological effects, and generation of the sonic boom overpressures, the optimum accelerate-climb and decelerate-descend profiles will be constrained to limit overpressures to a nominal maximum value. Similarly in the cruise region, optimum cruise altitudes and Mach numbers will have the same overpressure boundary conditions imposed. In this manner the fuel penalties associated with various sonic boom limits can be evaluated. Overpressure limits can be varied during the flight by operational procedures to take advantage of terrain features, meteorological conditions, and population density wherever possible.

In view of the foregoing, it seems appropriate to state the constraint as follows: overpressure measured at any point on the ground falling in the total dispersion area of the shock-wave generated by an SST passing

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* Parenthetic insertion ours.

through the sonic barrier, and while in the supersonic speed regime, should not exceed the maximum acceptable level (currently established as ≈ 1.5 psf) regardless of the maneuvers being executed and/or unfavorable atmospheric conditions.

The proper execution of certain flight control functions such that established limits of acceptable ground overpressure are not exceeded will require (1) accurate measurement (by estimation techniques) of ground overpressure generated throughout the dispersion area with respect to the flight path; (2) continuous measurement of overpressures reflecting any change as a result of a change in one of the contributing factors; (3) a clear presentation of these measured values so that a useful dynamic range is available to flight management at all times; and (4) data available on a prediction basis such that profile modification may occur as required.

Feasible Automated Implementation Concepts for SST

The calculation of a best estimate of ground overpressure location patterns and magnitudes generated by the SST in all phases of its supersonic operations is by the nature of the contributing variables, a highly complex problem.

Given a specific SST design, several components which contribute to the sonic disturbance can be subjected to analysis such that these components may be fixed with respect to the magnitude of their contribution to the problem under certain conditions. Presumably, some range of variance may also be established for each fixed component as the conditions are varied. Typical fixed components may be generally categorized as aircraft configuration characteristics, because the pressure signature near the aircraft contains shock waves from the airplane nose, wing-fuselage juncture, engines and tail surfaces, and because it has been concluded and corroborated that volume and lift effects contribute to the pressure signature magnitude (ref. 62). Other variables of a more or less controllable (or predictable) nature include aircraft gross weight, altitude, Mach number and attitude. Wind velocity and relative bearing contribute directly to focusing effects and, obviously, are of an uncontrollable nature.

In arriving at an implementation concept for this function, it is worthwhile to consider the real nature of the calculation to be made from the standpoint of the contributing factors. Ideally, in the calculation of overpressures, all contributing configuration characteristics would be known in absolute magnitude and would be assumed to be absolute constants, the aircraft would be assumed to be in straight and level flight with a constant angle of attack and a constant lift coefficient, altitude would be constant, Mach number would be constant, and gross weight would be constant, and the flight would be conducted in standard atmosphere, no-wind conditions. Carlson (ref. 62) states (after Walkden) that

> In the following equation. . . the bow-shock overpressure directly under the flight path of an airplane in level supersonic flight is related to the geometry of the airplane and the flight conditions:

$$\frac{\dfrac{\Delta p_{max}}{p}\left(\dfrac{h}{\ell}\right)^{3/4}}{K_r\ \beta^{1/4}} = \frac{1.19}{\sqrt{\gamma+1}}\sqrt{\int_0^{T_o} F(\tau)\,d\tau}$$

where

Δp_{max} = maximum value of Δp (at bow-shock)
Δp = incremental pressure due to flow field of airplane
p = reference pressure for a uniform atmosphere
h = altitude of aircraft
= airplane reference length
K_r = reflection factor
β = $\sqrt{M^2 - 1}$ (M = Mach number)

γ = ratio of specific heats (1.4 for air)

T = dummy variable of integration measured in same direction and using same units as t

T_0 = value of T giving largest positive value of integral

$$\int_0^T F(T)\,dT$$

t = nondimensionalized distance measured along longitudinal axis from airplane nose, x/ℓ and the function F(T) above depends on the longitudinal distribution of cross-sectional area and of lift and is defined as follows:

$$F(T) = \frac{1}{2\pi}\int_0^T \frac{A''\,t}{\sqrt{T-t}}\,dt + \frac{1}{2\pi}\int_0^T \frac{B''\,(t)}{\sqrt{T-t}}\,dt.$$

where A''(t) represents the second derivative of a distribution along the longitudinal axis of a nondimensionalized airplane cross-sectional area determined by supersonic-area-rule cutting planes and B''(t) represents the second derivative of a distribution of nondimensionalized equivalent area due to lift evaluated through an integration of the lifting force per unit length along the airplane longitudinal axis.

This excerpt is not being offered as proof, nor as a complete, all-inclusive treatment of the sonic boom problem. Rather, this excerpt should make it clear that even under ideal conditions the complexity of computing the problem dictates the use of high-speed computing techniques if the data to be generated are to be useful in exercising control over the problem. The problem is further compounded when so many of the components in the calculation may be changing slowly or rapidly, non-linearly or linearly, and in some unpredictable fashion. Consider a typical example in which altitude is increasing or decreasing relatively rapidly, gross weight is decreasing, Mach number is increasing and meteorological conditions are anything but standard. Wind velocity is double what was forecasted and the relative bearing is off by 30 to 40%. The aircraft is scheduled to execute a climbing turn to a new heading in three minutes. Flight management needs to know immediately if the profile scheduled will generate sonic boom focusing effects and/or the magnitude of the overpressure expected if the profile is followed. And this need must be met with sufficient response time available to alter the profile. It certainly seems within the realm of technical feasibility to provide:

1. Continuous presentation of the best estimate of ground overpressure magnitude being generated by the SST.
2. Continuous presentation of the best estimate of predicted ground overpressure magnitude that will be generated as a given profile is being followed.
3. Continuous presentation (as required) of profile modifications necessary to minimize or control overpressure magnitude such that: (a) the acceptable level is not exceeded unless absolutely necessary; (b) the time duration for exceeding the acceptable level is held to the barest minimum; and (c) insofar as possible, the focusing effects occur in the most sparsely populated regions.

Results of recent studies (refs. 62 and 63) indicate that techniques for measuring and predicting the shock-wave patterns produced by an SST in normal operating maneuvers are under development and hold considerable promise. These techniques are being assessed as to their compatibility for implementation via high-speed computers. And, results also indicate that, to the extent that the sonic boom phenomena theory is developed, the theory correlates well with typical data. It therefore seems reasonable to assume that by the advent of the SST in commercial airline operations, means will be available for implementing this function (i. e., the necessary software and hardware will exist for automatic airborne computation and presentation of the data required by flight management for control of the problem). A sonic boom control concept for the Hughes Aircraft Company's CEMS system (see Activity 1, Flight Management) is presented in Figure 41.

Feasible Manual Implementation Concepts for SST

This function is not considered amenable to manual implementation.

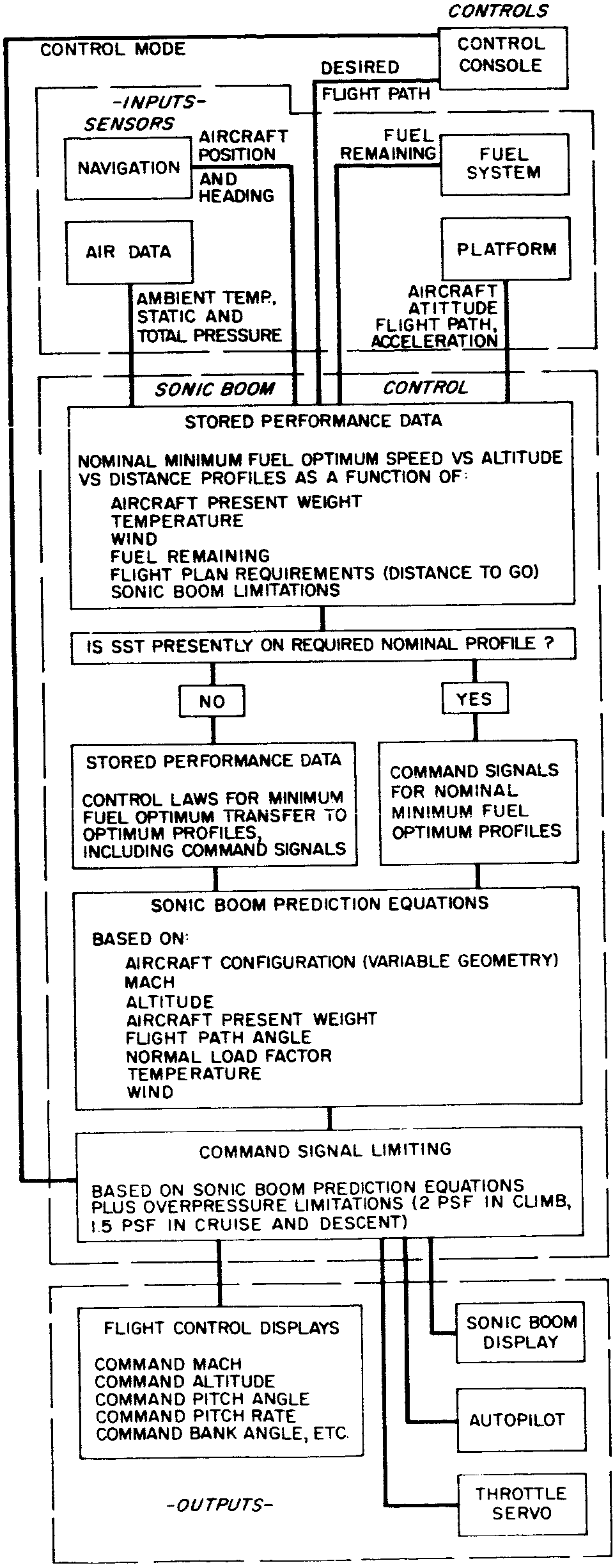

Figure 41. Sonic boom control concept. (Courtesy Hughes Aircraft Company)

7.7 FUNCTION 7.7 INTERNAL SYSTEM POSITION GENERATION

Purpose

This function provides continuous information which reflects the aircraft's position in three-dimensional space relative to any reference system employed by either the aircraft for navigational purposes or by ATC. Such information must be provided reliably and accurately from self-contained sources. Accuracy of these data must be commensurate with the ATC requirements regarding separation minima for commercial SST operations. This information must be in suitable form for:

1. Display in the cockpit relative to the optimum profile for the flight.
2. Expression in terms of off-profile components in the lateral, longitudinal, and vertical planes of the appropriate reference system(s).
3. Utilization by other navigation functions (i.e., present position updating, ETA prediction, optimum profile generation).
4. Transmission to appropriate ground-based facilities (i.e., Air Traffic Control, company facilities).

Current Jet Operational Requirements and Constraints

Current jet commercial airliners are required to carry the necessary navigation equipment which meets the minimum requirements for on-board navigational capability for either domestic or intercontinental flights or both, depending upon the aircraft's utilization. Such equipment must be compatible with present-day capability requirements for maintaining current separation minima in all three planes. This imposes position-fixing accuracy requirements on the self-contained navigation system.

Current Jet Implementation Concepts

Currently, this function has limited applicability to jetliners operating on domestic routes. This is primarily due to the fact that externally referenced systems are much more widely employed within the continental United States than are self-contained systems. The current ATC system within the United States utilizes VOR/DME equipment as the basic navigational tools. Some airlines operate self-contained systems (e.g., TWA uses Doppler on transoceanic routes), however, these systems have yet to be sanctioned by FAA for use in the continental United States as the primary navigation means.

Internal system position generation does have direct application to jetliners operating on intercontinental routes. The use of Doppler radar systems as primary navigation means for transoceanic routes is well established. Moreover, a major intercontinental carrier (PAA) has placed an order for a considerable number of inertial guidance navigation systems. Increasingly, these systems are becoming the primary means of navigation, and externally-referenced systems such as LORAN relegated to a back-up role. The self-contained systems, however, do not eliminate man's role in the present-day situation. In this regard, Powell and Willis (ref. 50) have made very cogent remarks concerning the Doppler system,

> ...we have to accept the fact, so often stated, that the compass-Doppler-computer system can be no better than the man who manipulates it. Compass management is one reason; ignoring this for the moment, one other reason is that Doppler error is not as straightforward as it seems to be.

...On a series of flights, a Doppler operator monitors equipment performance, programs the computer, keeps track of compass errors for each stage of the flight, and later removes to the best of his ability the effects of all factors, including human error, which have deteriorated Doppler performance.

...We believe these results are near the ultimate with present equipment and fixing aids. To achieve them we have found it necessary to follow a fairly intensive in-flight work schedule. Compasses are checked celestially an average of every 45 minutes, with cross-checks between numbers 1 and 2 systems every 10 minutes. Doppler bias in established early in flight and revised as indicated by subsequent fixes. Position is fixed by outside means every 20 to 30 minutes, normally at 3 or 4 lines of position, and the computer is updated fix by fix. Any let-up in this routine has been found to invite errors. However, when our navigators adhere to the routine, results indicate that they have been able to detect and compensate for errors before they become gross.

... There are as many navigational procedures being followed today as there are operators, probably more. No doubt every airline operator thinks his is the best.

... There is danger in the concept we sometimes hear which argues for reduction of separation standards based upon the capabilities of one particular black box, the capability of one component of the whole navigation system. . .Ultimately, however, separation criteria must be reduced if we are to avoid having aircraft sitting on the ground, or accepting grossly uneconomical clearances. Will the standard of North Atlantic navigation be adequate in all cases if, for example, lateral tolerance is reduced by one half (the only figure ATC authorities are presently willing to consider)? We have to say no. We have found it impossible to produce the required results consistently either by navigating without a serviceable Doppler, using existing long range navigation aids, loran, consul, and celestial, or by navigating with Doppler with inadequate fixing or compass-checking programs.

Some discussions of present-day inertial systems indicate that the advent of the "pure inertial" system as a present position navigation system still requires crew involvement. The equipment must still be updated on the basis of external fix data, and equipment performance must be monitored. Regarding present systems, Holm (ref. 64) states, "During this past summer, the Pan American flight tests demonstrated the accuracy of a present position navigator which was an inertial platform." And that, "...a trained observer from the airline operated the equipment and recorded..."

Greenaway (ref. 49) also discusses the crew role in long range navigation of jet transports and points out that,

> Until the introduction of jets, very few transport aircraft were even equipped with elementary dead reckoning computers, such as the air position indicator, let alone with doppler radar. The navigator collected the desired navigation information from various unrelated aids and sources, maintained a manual air or track plot, passed heading alterations to the pilot, and revised times of arrival. The human computer and manual servo loop concept was quite satisfactory for slow flying transports but left much to be desired when applied to the navigation of high speed aircraft. Therefore, it was obvious even some years ago that the basic dead reckoning system for jet transports would be an automatic DR computer receiving inputs from the compass system, and drift and groundspeed from the doppler radar. In actual fact this has occurred, and in jet navigation the automatic position computer has replaced the manual plot. Now the navigator has only to concentrate on checking the DR position with various fixing aids, monitoring the heading, computing the arrival time, and maintaining fuel consumption records.
>
> Automatic computers can be designed to indicate position in a number of ways, such as latitude and longitude, distance and bearing from base or to destination, as x and y co-ordinates on a rectangular grid, or as distance to go and miles off the desired track. Of the above systems, the along- and across-track computer appears to be favoured today by transport operators. This computer, in conjunction with doppler radar, underwent trials on global routes during the mid-1950's, and is now being installed in most jet transports.

It is important to note that internal position fixing has now been largely automated or is in the process of being automated on virtually all jet aircraft equipped for intercontinental and/or transoceanic flights where long range navigation is a requirement and must ensue without the benefit of constantly available external aids to navigation. However, it should be pointed out that, at least in present systems, complete automation of the present position navigator system has not been achieved. Both the doppler systems and the inertial systems still depend on a crew member for certain operating tasks.

SST Potential Operational Requirements and Constraints

Requirements for position fixing by a self-contained system will undoubtedly be more stringent for the SST than for current jets in terms of accuracy and will possibly involve a new dimension--continuous changing of position in the vertical plane. It also appears a certainty that present position must be continuously updated and available in a form and format which can be transmitted and displayed, and must be in terms of all airborne and ground reference systems being employed in the navigation of the flight. With regard to the requirements for automation affecting this function, Greenaway (ref. 49) states that,

> ... automatic dead reckoning systems are approaching reality... Although this automation is not a requirement when navigating current transports flying at 7 to 8 miles per minute, it will be for the MACH 2 - 3 jet transports flying at 25 miles per minute.

He goes on to indicate that,

> Future navigation systems will also use the actual convergency of meridians to automatically correct for transport wander, in addition to an automatic correction for earth rotation. Both corrections are a necessity in supersonic transport systems. Although the directional gyro provides an accurate and stable heading, it must be aligned to a reference and checked at regular intervals.

> The navigator presently carries this out manually by taking a bearing on a planet or star with the periscopic sextant. To guard against errors when attempting to read several dials simultaneously during the heading check, Trans Continental Airlines is installing a synchronous astro compass. The requirement for this refinement is brought about by the need for more accurate heading data...

He further indicates that,

> ...automatic position reporting will probably be employed along the more congested routes. If so, ... there is no reason to suggest that the normal geographical coordinate system is not satisfactory for this purpose.

King and Groves (ref. 56) state that,

> The need for a continuous knowledge of the aircraft's position by the ground organization is also self-evident and indicates a requirement for a suitable air/ground data link for the transmission of navigational information and A. T. C. data necessary for adequate control purposes... Moreover, it will clearly be of the greatest importance for the pilot to be able to establish the precise position of the transition area involved, for both the pilot and A. T. C. to be able to refer to this area in common geographical terms, and for the pilot to be able to execute the transition in strict conformity with the clearance given... Lateral separation minima must be as small as possible, otherwise the spread of flight paths appropriate to a given route will entail some excessive route mileage and tend to offset the advantages of the vertical freedom gained... Navigation data must be continuously presented in the cockpit both to facilitate adherence to cleared flight paths and to avoid the cockpit workload entailed in intermittent position fixing. By the same token, A. T. C. will require a continuous flow of accurate information on flight progress for monitor and control purposes. It is essential that the navigational data should be presented in the cockpit in a manner which will reduce the need for interpretation and provide the pilot with a self-evident and continuous indication of position.

During the November 1963 Symposium of IFALPA, it was suggested that each SST should be equipped with a proven instantaneous self-fixing navigational system so that both the pilot and ground controller could know the unmistakable location in transoceanic and supersonic flight.

With regard to the new dimension in navigation, i.e., the vertical plane, it appears likely that the constant altitude constraint imposed by ATC for collision avoidance will be modified to give the SST freedom in the vertical plane. It follows then that the requirement for continuous position derivation by the self-contained navigation system must include accurate information reflecting the aircraft's position in some reference system which includes all three dimensions. Although the current literature seems to reflect a general consensus that freedom in the vertical plane will be allowed for by the ATC environment existing during the advent of the SST, this has not yet been confirmed by ATC. However, Power (ref. 57) suggests that,

> ...In reality, the entire concept of navigation as it has been practiced in the past may very well be subject to a sweeping change, or rather extension. In addition to the ever present problems of horizontal global navigation at ground speeds of 2,000 miles per hour, a completely new dimension of commercial navigation will be added. The initial flight plan, and enroute perturbations or deviations therefrom will in all probability be considerably more complex in the vertical plane than the horizontal plane. ...As a matter of fact, it should be clearly understood at the outset that SST navigation must always be considered as three dimensional.

And thus, this study considers the self-contained means of present position derivation as one which must satisfy the three dimensional requirement.

One other major constraint that has a direct bearing on present position derivation and which appears likely to be modified is the high-altitude structure of the ATC system. It appears a certainty that airways as we now know them will be non-existent in the ATC altitude structure for the SST, and that the SST will essentially navigate point-to-point using an area-coverage approach and following an optimum flight profile. The reasons for these assumptions are primarily economic, although structuring the SST cruise altitude environment in restrictive airways would in all probability impose severe and undesirable maneuvering requirements on the SST at high speeds.

Feasible Automated Implementation Concepts for SST

Implementation concepts for this function are generally restricted to systems employing either Doppler radar or inertial guidance systems or some marriage of the two. There appears to be general agreement that the two sensors could be employed so that their complementary aspects are exploited. White (ref. 65) states that:

> The "marriage" of doppler radar and inertial systems offers some definite advantages over either system used alone. In the writer's opinion, the self-contained system most attractive for supersonic aircraft use at the time these aircraft become operational will probably be some combination of doppler and inertial techniques in a single system. Significant operational advantages are offered by at least three combinations of doppler and inertial features:
>
> 1. Doppler systems with inertial system heading reference.
> 2. Inertial systems with aircraft velocity computation corrected continuously on a long-term basis by doppler groundspeed output.
> 3. Doppler velocity input to an inertial system to provide fast accurate in-flight north alignment.

There are significant problems associated with both systems, some of which may have a direct bearing on the crew's involvement in the function, and, resultantly, in the skills and knowledge which the crew complement must have available for function performance. Some indications of these problems follow (White, ref. 65), Doppler radar is a proven transport aircraft system today. In February 1962 TWA received FAA approval for using doppler radar as a primary overwater navigation system. Very recently TWA received FAA approval for doppler radar as a primary navigation system on polar routes between the U. S. west coast and the west coast of Europe. The approved route network extends to 72° north latitude. Magnetic heading reference is used from the end points of these routes to check points marking the boundaries of the area where magnetic compasses become too unreliable. The compass system function is changed from magnetic heading reference to gyro heading reference to gyro heading reference (sic) at these points and is changed back again to the magnetic mode after crossing the "unreliable" magnetic field areas.

Several years' flight test experience with commercial doppler radar indicates quite clearly the capabilities and limitations of doppler as installed in TWA long range jet aircraft.

Figure 42 shows system accuracy experience to date together with future accuracy estimates based on automatic groundspeed bias adjustment and more accurate heading inputs. The first line shows experience on 34 transatlantic flights flown without resetting computers or headings on the basis of ground fixes. The reference line 2 shows experience with 64 transatlantic flights on which the computer and heading corrections were made as necessary based on loran and consol fixes.

The 95% probability cross-track errors increased only about 31% when reference to ground facility fixes was eliminated. This was a smaller error increase than we expected.

The third line shows estimated accuracies assuming the use of automatic groundspeed bias adjustment. To my knowledge such a system has never been flown. In brief, this proposed system would adjust the groundspeed bias as a function of signal return level and indicated altitude, thereby tending to compensate for groundspeed errors caused by variations in sea roughness. Since the received signal returned from the water surface is a function of the sea state, it should be entirely possible to adjust the groundspeed bias on the basis of altitude and signal return input

		Along Track Errors		Cross Track Errors		Remarks
Reference Line	Installation	Average	95% (2σ)	Average	95% (2σ)	
1.	Present TWA Installations	±0.5%	±1.2%	±0.88% (±0.5°)	2.2% (±1.26°)	Without resetting Computers and Headings on basis of Loran or Consol Fixes
2.	Present TWA Installations	±0.5%	±1.28%	±0.65% (±0.37°)	±1.69% (±0.96°)	Computers and Headings reset as necessary from Loran and Consol fixes
3.	With Automatic Ground-Speed Bias Compensation	±0.25% (est.)	±0.5% (est.)			
4.	Automatic Ground-Speed Bias Compensation & ±0.25° Heading Input Accuracy	±0.25% (est.)	±0.5% (est.)	±0.87% (±0.2°) (est.)	±0.87% (±0.5°) (est.)	

Figure 42. Doppler capability, based on test data from 98 transatlantic flights (from ref. 65).

> intelligence. Assuming such a system operates with reasonable accuracy, the groundspeed errors could probably be cut approximately in half, as shown in line 3.
>
> Reference line 4 shows the estimated combined effect of the automatic groundspeed bias and a plus or minus .25 degree heading input accuracy. These cross-track errors assume a continuation of our present experience which indicates that drift angle errors in straight and level flight are extremely small--probably some small fraction of one degree. Our best estimates to date indicate, at least roughly, that our drift angle errors are probably something less than plus or minus .2 degree.
>
> In my opinion, the error figures shown in reference line 4 are about the doppler state-of-the-art we can visualize now. Any errors less than these figures are probably crowding the present state-of-the-art. Assuming these error figures would be attainable in actual installations, we could expect along-track errors of plus or minus 17 miles on a 95% probability basis on 2,000-mile flight segments.

An interesting comparison of achievable accuracies may be made by examining the data presented by Powell and Willis (ref. 50) which illustrates the experience of Trans Canada Airlines, using the doppler system with a full time navigator. These accuracies were achieved using the navigational procedures discussed above under "Current Jet Implementation Concepts." The following is also from the same publication (Powell and Willis, ref. 50).

> The data which follow in no way attempt to reflect the capability of doppler, computer, or any other particular piece of equipment. What they illustrate is the navigational accuracy we have been able to achieve in T. C. A. Essentially this is system rather than box accuracy, the accuracy of the whole navigation loop including the human operator and his control of the various components.

> It does not include all error originating in the doppler, computer, or compasses, since much of this will have been compensated for by the navigator, who feeds corrections for the errors he measures back into the system. It does include the results of human errors which are inadvertently fed in from time to time. The figures indicating track-keeping capability further include the effect of occasional steering errors and autopilot malfunctioning.
>
> Results of our most recent analysis, 80 North Atlantic flights available between completion of the fleet modification program and preparation for this paper, follow. Errors are expressed as percentages of distance run, average distance = 1730 nautical miles.

	Cross-Track Error	Along-Track Error
Standard deviation	1.39%	1.38%
50% error	0.93%	0.93%
95% error	2.71%	2.69%

> Track maintenance results on the above flights follow.

Percentage of Flight Time	Nautical Miles of Cleared Track
94.72	10
99.86	20
100	30

> We believe these results are near the ultimate with present equipment and fixing aids. To achieve them we have found it necessary to follow a fairly intensive in-flight work schedule.

Although White gives no specific average distance, it is assumed that the distance would be comparable to that given by Powell and Willis since both studies concerned trans-Atlantic operations. It also should be pointed out that there are data available on blunder type errors, which occur all too frequently.

Although a direct comparison is limited by differences in equipment, procedures, routes flown, data sample size, and so on, it is interesting to note that the TWA figures obtained without updating the system reflect a track-keeping accuracy considerably better than TCA's figures which were obtained while using a fairly stringent fixing and updating schedule. The only significance of such a comparison is in the wide variation of reported achievable accuracy obtained with such obvious extremes in navigational procedures. The fact that such a comparison is completely inconclusive is borne out by the necessity for conducting such programs as Operation Accordion. (Ref. 66.)

One thing seems fairly certain, however, regarding the use of doppler sensors; they are subject to errors which are cumulative with distance flown, and which can apparently become significant in some cases. It follows that with the SST the errors would accumulate much more rapidly, and thus provide much less response time for detection and correction. It is assumed that if the procedure outlined by TCA were to be necessary with, say, dual doppler system installations on the SST, the relative impact on the workload for the crew would be such that the capabilities of at least a full time professional navigator might be required to provide the necessary support and back-up for the system. An additional problem with the doppler system is the necessity to provide an opening in the fuselage for antenna installation. Although this is not a crew complement problem, it is a design problem which could well eliminate doppler from further consideration for the SST due to the impact of the installation on fuselage integrity.

Before leaving the doppler discussion, it should be noted that the literature reflects considerable support for its use, as the following statements made by Greenaway (ref. 49) exemplify:

> It is unlikely that inertial systems will have overcome the lead that doppler has attained by the time the SST's are flying. Although doppler is only just becoming widely used in transport aircraft, the results obtained, both in accuracy and reliability, are very good. It is difficult to imagine operators going to another sensor which will lack the operational background that doppler will have acquired by this time. Moreover, by the time the SST enters service, many refinements will have been added to current doppler systems and their reliability will be comparable to the main electrical system of the aircraft...

And with regard to how this may affect the crew loading, Greenaway goes on to state that,

> The flight crew of an SST will probably consist of three members, and one of the primary tasks during the enroute phase of the flight will be the monitoring of the navigation system and checking on the progress of the flight.

Powell and Willis (ref. 50) state the case for doppler,

> There are doubtless many valuable places for a full "inertial navigator," but we do not believe there is one in civil aviation. The gap between present serviceability performance and that required in civil aviation is tremendous. In-flight failures particularly those in the vertical system, don't just degrade the results; they make them useless. Both initial and maintenance costs are discouraging. So is the allied problem of keeping enough skilled technicians in the right place at the right time. But, perhaps above all, an inertial system, and any hybrid system involving inertial components, would still require in-flight monitoring and the use of back-up aids. Inertial systems might well give increased accuracy for considerable periods, but not enough accuracy plus reliability to permit their performance to go unchecked.
>
> Doppler sensors enjoy an extensive operating background. It is reasonable to expect some refinements in both airborne and ground checking equipment. The incidence of airborne failure is significant, and probably always will be, but it can be minimized by a dual installation. It seems certain that doppler sensors will supply drift and groundspeed for civil supersonic systems, but from everything said so far it is also certain that monitoring and back-up capabilities must be provided.

There have been some interesting developments in the inertial navigation field, however, and the inertial technique appears to be the stronger contender for the primary self-contained aid. White (ref. 65) points out an important problem with this technique,

> One serious limitation of known inertial systems is the requirement for ground alignment by automatic gyro compassing for periods up to 30 minutes in order to attain an adequately accurate true north reference...

Probably the strongest support for use of this technique in the SST may be found in the following excerpts reflecting FAA thinking (ref. 55).

> Inertial navigation systems now appear almost certain to find use in U. S. supersonic transports as a basic en route navigation aid and also for "vertical navigation"--to provide a climb and descent profile which maximizes fuel economy and passenger comfort and minimizes the sonic boom problem... This view was expressed by Federal Aviation Agency representatives speaking here at the Institute of Navigation conference.
>
> All three aircraft companies that submitted bids in the U. S. supersonic transport competition proposed the use of inertial navigation systems, according to an FAA spokesman.
>
> FAA's own studies, and its flight tests last year of a Litton Industries inertial system on a Pan American World Airways jetliner, indicate that inertial systems "have progressed during the long period of military sponsorship to where they are now approaching the stage of commercial utility," according to Alexander B. Winick of the FAA system design team.
>
> The inertial system has an edge over Doppler radar navigation aids, Winick said, in several respects. The external antenna needed by a doppler radar requires a hole in the aircraft belly which involves added structural reinforcement and an inertial system consumes less electric power than a Doppler system.

> If Doppler were used, the supersonic transport probably would require a gyro stabilized platform to provide a sufficiently accurate heading reference for the Doppler system and an accurate attitude reference for climb and descent maneuvers, so that the supersonic transport would have most of the elements of a complete inertial navigation system anyway.
>
> Winick acknowledged that inertial systems still face cost and reliability hurdles. Present FAA thinking is that at least two complete inertial systems will be required, with perhaps a third system carried as a standby.
>
> If an attempt is made to compare automatically the output of the two or three systems to monitor their performance, it will be necessary to develop better monitoring techniques than are now available or else all of the systems will have to be aligned very closely before take-off, posing airline operating problems, Winick said.

There are also numerous discussions in the literature regarding the utilization of a hybrid self-contained system, such as doppler/inertial, doppler/astro, or inertial/astro. Regardless of which system is ultimately employed, it will not be allowed to operate without adequate monitoring, and updating by removing errors detected or known to be cumulating due to equipment characteristics. The final system will probably involve certain tasks on the part of the crew. At this time, estimates of crew involvement must be limited to generalizations of crew requirements and associated skills and knowledge. Detailed determinations of crew involvement must await the selection of the avionics to perform the function, and the actual man/machine relationship designed into the avionics ultimately selected. Generalized task requirements would include the following:

1. <u>System monitoring</u>. Regardless of the system employed, its performance will be monitored. The monitoring is visualized in terms of two requirements, (a) performance monitoring from a credibility point of view to detect blunder type errors, and (b) performance monitoring from an accuracy point of view to detect cumulative and insidious types of errors. It would be desirable to monitor both the system inputs

and outputs. System inputs appear amenable to automatic monitoring from an electrical approach; input voltages could be compared to a reference voltage. And, credibility monitoring on the output side appears feasible by a criteria-envelope approach; given an instantaneous latitude readout as a beginning point, true heading, and velocity, the latitude change computed in each machine cycle would not be allowed to exceed some number representing, say, the change attainable with maximum speed of the aircraft, or be less than, say, the change attainable if the aircraft speed were some fixed percentage less than indicated. Such monitoring would only insure that the computed value lies within a range of possibility. This type of monitoring would catch gross errors in the equipment, such as an analog to digital converter dropping significant digits due to malfunctioning components. These monitoring functions are generally amenable to automation.

Monitoring system outputs for accuracy would undoubtedly involve the crew. This would be true even if triple system installations are employed, since rough agreement among the equipment only ensures reliability, and accuracy is not necessarily a function of reliability. Given three similar installations with similar systematic errors of varying magnitudes, the average output could be less accurate than the output of any one of the systems, or than the average of any two outputs. As a result, monitoring the accuracy of the self-contained system outputs will be a task for a crew member to ensure that the inputs to the Present Position Updating function are within some reasonable limits of the estimated aircraft position where such an estimate is based on the crew member's judgment, given the last updated position, heading, and velocity.

2. System operation. There undoubtedly will be certain operating procedures applicable to any system employed which will involve basic tasks for a crew member. For example, both inertial and doppler systems now utilized employ set-up techniques requiring the manual

insertion of the known coordinates of the destination or the initial checkpoint. If check points are employed in the SST system, a series of these set-up operations will be necessary even though they are menial tasks. Also, if an automatic star tracker is employed for the heading check task, a crew member would still function with the equipment by selecting the appropriate stars. Just what part the crew member might play in an in-flight north alignment scheme is not yet known.

There is, of course, a high probability that other tasks will be required of the crew in the utilization of the self-contained system chosen for the SST. It is not likely, however, that such tasks will be complex as long as the system is functioning properly.

Feasible Manual Implementation Concepts for SST

The performance of this function by conventional methods, or any method less than the system described above is difficult to consider as being feasible for the SST, at least as the primary navigation technique. This seems to be borne out rather conclusively in the literature. Some representative references follow:

> When cruising the Mach 3 aeroplane travels about one mile in every two seconds. Methods of navigation used with slower aircraft will not be suitable. The development of reliable Inertial and Doppler Radar Navigation Systems is expected to result in the installation of airborne Inertial or Inertial/Doppler Navigation Systems on the aircraft. These systems will include small digital computers for continuous presentation of position and velocity information. (Ref. 39.)

> Greenaway (ref. 49) states that,

> The manual linking together of the navigation sensors, computer, and directional element when flying at 25 miles per minute is out of the question, and a fully integrated and automatic navigation system is required.

And, regarding the navigation problem with the Concorde (ref. 25), it has been stated that,

> Navigation computation can no longer be done manually, since the time involved would make the information too stale to be of use.

And (ref. 39),

> Airborne navigational equipment will relieve the crew of what would be an impossible task at speeds of Mach 3 if conventional methods were used.

In summary, it seems a certainty that this function will not involve a crew member to any greater extent than monitoring and, depending upon the system characteristics, perhaps one or more manual insertions of a set of geographical coordinates, such as the destination coordinates and/or checkpoint coordinates. This assumes that (in the event of an inertial system) north alignment will be obtained automatically, and switching from magnetic reference to grid reference will be automatic. The requirement for heading check is discussed under External System Position Generation.

SUBSONIC SPEED REGIME

Assuming that the SST returned to the subsonic speed regime to continue its flight or returned to base for some reason other than failure of the navigation system, present position generation by the internal system would continue as an automated function. However, any increase in flying time would increase the error being accumulated by the system. Since doppler error is cumulative with distance flown, the error rate would tend to be no worse than in the supersonic regime, assuming a doppler system. On the other hand, an inertial system degrades in accuracy with elapsed time. Hence the slower flying speeds would tend to cumulate a proportionate increase in system error, assuming an inertial system and utilization of external fixing aids where possible, and possibly celestial fixes in the absence of other sources.

Although the astro-tracker is visualized as being automated to provide an accurate heading reference, it is assumed that the obtaining of a fix would involve "unlocking" the tracker from the system, and manually operating it to obtain an actual fix. Additionally, the slower speeds would permit more time to establish bias in the doppler system if one were employed. It is apparent that the skills and knowledge involved parallel those required for the application of conventional navigation techniques, and generally found for the most part only among specialist navigators.

If the reason for return to the subsonic speed regime was due to catastrophic failure in the navigation system, and more particularly in total failure of the self-contained system, the result could be one of the two following. The external source information could be utilized with the airborne components to provide adequate navigation, assuming that the aircraft was always in range of a suitable signal source. Alternatively, the aircraft would have to rely on the application of conventional navigation techniques, which generally require the skills and knowledge of the professional navigator. While returning to the subsonic speed regime will have severe economic penalties, the impact will nevertheless be less severe if the aircraft can continue to its destination and not abort the flight entirely. This obviously has some trade-off considerations.

7.8 FUNCTION 7.8 EXTERNAL SYSTEM POSITION GENERATION

Purpose

The purpose of this function is to provide information generated by an externally referenced source which reflects the precise position of the aircraft in three-dimensional space in whatever reference system is compatible with the reference systems employed by the self-contained system position generator and the ATC system. The timeliness and accuracy of these data should be such that:

1. Self-contained dead reckoning systems are not allowed to accumulate errors large enough to put the SST in jeopardy of violating the assigned air space, thus assuring collision avoidance.
2. Self-contained dead reckoning systems are not allowed to promulgate insidious or blunder type errors.
3. Dual installations of self-contained systems are afforded reliable and accurate means for cross-checking purposes.
4. Where required, the initial or origin coordinates stored in the self-contained system(s) may be precisely updated, where these systems rely on the accuracy of such coordinates for total system accuracy.
5. On domestic routes (or wherever ground installations permit) the aircraft may be navigated using the externally referenced source as the primary navigational means.

This information should be in a form suitable for display in the cockpit; utilization by other navigation functions (i. e., Present Position Updating, ETA Prediction, Optimum Profile Generation); and transmission to the ground-based ATC system.

Current Jet Operational Requirements and Constraints

Within the continental United States, jetliners are required to navigate using the high altitude ATC airway structure for the enroute portion of any given flight and to follow standard instrument departure and standard instrument approach patterns for navigation within the origin and destination terminal areas. These airways and standard patterns are structured such that the ATC facilities can maintain maximum control of the air traffic situation. Usually, an airway proceeds from one ground navaid of a certain class to another ground navaid, or to some intersection of lines of bearing from two such navaids, with a maximum distance (e. g., 250 nm) between aids. For given flights, there are mandatory position checkpoints. Present position is then generally determined prior to each checkpoint and given in relation to the checkpoint. Thus the present position derivation by means of an externally-referenced system is performed at required reporting points, and upon request by either ATC or company procedure.

Because the externally-referenced system is used as the primary navigation means in the continental United States, the present position will also be determined by the crew with whatever frequency may be required to insure that the aircraft is maintaining its schedule and keeping within its assigned airspace. Since altitude is generally assigned as a constant value, the principal concern is aircraft deviation in the lateral and longitudinal planes, although altitude is a required report component. Further, since longitudinal deviation is usually more a function of the capability and capacity of the ATC system, aircraft navigation is generally most concerned with lateral deviations, which are largely a function of meteorological conditions.

The requirements for present position derivation by means of an externally-referenced source on intercontinental flights are necessarily limited by the availability of the necessary ground-based aids. Since there is no world-wide standard of long range, ground-based navigational aids, and not all points along intercontinental airways are within the range of available aids, the general requirements for position reporting are met by utilization of the self-contained systems. The self-contained systems are updated by the external systems where the necessary facilities are available. On intercontinental flights then, the requirement is to update the self-contained system by means of a position-fix obtained from an externally-referenced source when the ground-based facilities are available. An obvious constraint is that aircraft may not operate on intercontinental lanes without the appropriate airborne navigation system components compatible with the available ground aids.

Current Jet Specific Implementation

At present, the standard navigational aid within the continental United States is the VOR (very high frequency omni-directional radio range) used in conjunction with DME (distance measuring equipment). When navigating airways within the United States, commercial jets have an essentially continuous read-out of the necessary data that will allow them to plot their position on an appropriate geographical reference. The VOR is used for azimuth indication and the DME for range. By dialing in the appropriate frequency (channel) of a given VORTAC station, the crew member obtains an automatic cockpit display of the range and azimuth from that station. Current jetliners navigate the airways by utilizing two such VOR receivers such that intersecting lines of bearing may be correlated to an appropriate geographical reference (e. g., WAC chart, or sectional chart) and a set of coordinates may be derived which describe the aircraft position, or a distance to or from a given station may be determined. The equipment is also such that the passage over a VORTAC whose signal is being received in the aircraft is visually indicated in the cockpit, and an updated origin point is immediately available. There are presently some 850 VOR and VORTAC stations within the U. S. and programs call for increasing that number to 1100 (ref. 28). The accuracy of a position fix utilizing these navaids is the basis for current high-altitude standards for domestic usage (i. e., 15 minutes in time longitudinally and 30 to 35 nm laterally, ref. 67). VORTAC is also currently the standard navaid for commercial jetliner navigation in terminal areas, even though the aircraft are under radar surveillance and ground control.

During intercontinental flights, the determination of present position by means of externally-referenced systems is governed by availability of means, range of available means, and the type of means. These means are generally referred to as long range and area coverage and generally are designed around hyperbolic line of position and "straight, line-of-bearing" disciplines. Such means include LORAN C, Standard LORAN, and others. Typical basic navigation procedures (transoceanic) in use today call for checking the heading reference and fixing the aircraft's geographical position at half-hourly intervals, plus reporting position to ATC at least once an hour (ref. 68). For example, current ATC procedure in transoceanic flights in the North Atlantic call for reporting of present position at every 10° of longitude (approximately 450 miles at 50° N latitude). However, in many cases the absence of an externally-referenced source for navigational signals means that the position is derived by a navigator, or solely from the self-contained system and may contain those error components which are both random and cumulative since the last updating from an external source position fix.

Where there is such equipment, however, the involvement of a crew member can range from almost an observer to that of actually plotting various LOP's from selected pairs of ground-based stations and extrapolating a position-fix therefrom. Variance in the routine can be caused by several factors. For example, there are systems available today (LORAN C) which provide fixes automatically. Another source of variance can be the audibility of the ground station signal, or presence of anomalies of any sort. When the aircraft is in an area of weak ground signals, or when discontinuity of the signal becomes a factor, it may be necessary for the crew member to take several readings before an accurate and reliable fix can be obtained. And in some cases, if the discontinuity is severe, the process cannot be culminated in a fix until the aircraft is within more suitable range of the ground stations. Additionally, time differentials from two pair of stations (or three separate stations) do not in and of themselves constitute a fix. These data must be correlated with the hyperbolic grid reference charts (LORAN charts) and aircraft velocity so that a position fix can be extrapolated. In the absence of automation, this entire process is performed manually by a skilled crew member.

Heading checks (compass alignment checks) and position fixes, if required in the absence of ground-based aids, are also obtained by celestial techniques which are currently performed manually with the aid of certain equipment. This process involves deriving the actual range and azimuth of the aircraft from selected celestial bodies and comparing these data with the extrapolated range and azimuth from these same celestial bodies derived by the self-contained system. To some extent, the process has been largely automated. These are astro-tracking systems which will provide range and azimuth data on selected celestial bodies automatically, and the crew member's involvement is restricted to selecting one of the stored targets in the astro-tracker memory and recording the results (or equipment read-out). However, in other cases, it is necessary for one of the crew members to be skilled in the use of the periscopic sextant and the appropriate manuals. Obtaining range and azimuth data on selected celestial targets is the preliminary step in performing a heading check or obtaining a position fix by celestial techniques. These data must be correlated with aircraft situation data

(e. g., altitude, heading, velocity) in order to obtain a fix or a compass alignment. The processes of getting from star data to heading error component or present position involves definite skills available in specialist navigators or pilot personnel who have undergone navigation training. Some airlines have deleted the navigator position from the crew complement and other airlines still retain this position. The avionics and job aids undoubtedly vary widely among airlines. It is obvious that the degree of crew involvement varies just as widely, and perhaps this is best borne out by reiterating the statement (ref. 50) that, "There are as many navigational procedures being followed today as there are operators, probably more. No doubt every airline operator thinks his is the best."

SST Potential Operational Requirements and Constraints

Modifications to current navigational accuracy requirements have been discussed under the general activity. These new requirements can be viewed as having considerable impact upon the performance of this function. Although the reduction in separation minima generally reflect performance criteria for both self-contained and externally-referenced systems, there are some indications in the literature that navigational accuracies anticipated for both the doppler and inertial self-contained systems will be such in the 1970's that updating via externally-referenced source aids will not be required.

However, there are also indications in the literature that tend to substantiate a very realistic need for the updating of self-contained systems, even when such systems are duplex or triplex installations. It is important to remember that duplex or triplex installations only provide an insurance factor of reliability and do not necessarily insure accuracy. Considering, moreover, the vagaries of electronic equipment, it seems reasonable to assume that there will be a requirement for, and therefore facilities for, updating the self-contained system by means of an externally-referenced source. There presently is no standard, long range, ground-based navigational aid along the airways of the world. Should one be adopted prior to the advent of the SST, an obvious constraint will be provision of the airborne components compatible with such a system in each SST. Should there be no standard, equipment constraints will vary according to the available means along the airways scheduled to be navigated by any given SST. Generally stated, the SST is constrained by its integration into the air traffic control system.

Feasible Automated Implementation Concepts for SST

It appears that SST navigation within the continental United States (and any other areas where similar coverage is afforded) will be accomplished utilizing VORTAC as the primary means. There is some opinion voiced regarding the use of inertial and/or doppler systems between VORTAC fixes. However, the general consensus is that the VORTAC system with some improvements, would suffice alone. There are problems to be solved first, to be sure. For example, the distance measuring equipment contains an inherent error component in that it measures slant range rather than surface range. This error component increases in magnitude with the increase in SST operational altitudes and can become significant. Another problem is the increased magnitude of the "cone of confusion" at SST operational altitudes, coupled with the possibility for co-channel interference at those altitudes. Nevertheless, it seems a certainty that the VORTAC will be used as either the primary navigation means where adequate coverage permits, or as an updating and back-up system for self-contained systems, or both. As Winick (ref. 69) states, "There is little doubt that the VORTAC system will be the standard ground based navaid through 1975."

Alleviation of some of the problems with the present VORTAC system as it applies to the SST would appear feasible in light of the following remarks by Winick (ref. 69). Referring to altitudes above

45,000 feet, for which the use of the super VORTAC has been proposed, he says,

> There is some question whether or not there must be complete signal coverage throughout the United States at these altitudes. If the answer is yes, it appears that there will be from 24 to 27 Super VORTAC's throughout the country. As has been discussed many times in the past, the concept is that ground based facilities will be available for updating and correcting dopplers and inertial navigators.
>
> ...A second question worth considering is whether these facilities should be VORTAC or whether they might be TACAN only. If they are TACAN only, it will certainly help the frequency allocation problem faced by the FAA. This would place a requirement upon the supersonic transport for use of a TACAN bearing adaptor as an addition to the DME. The associated DME will be capable of providing range out to 300 miles.
>
> As you may be aware, some of us in the FAA, for a considerable time, have been advocating the use of VORTAC rho-theta displays as a means of utilizing the area capability which exists in our system. As part of our reconfiguration of the airways, we will attempt to designate some airways, where airspace permits, which will be suitable for flight by those appropriately equipped with rho-theta pictorial displays. We have found some divergence of pilot opinion concerning such displays, and therefore it is difficult to use such preferences as a basis of decision. To us the pictorial display is something the system needs, and therefore we have repeatedly encouraged its use. The important point to be made on this subject is that VORTAC has an area coverage capability with the appropriate type of cockpit instrumentation. It doesn't need a hyperbolic signal generator to obtain it. In fact, it does a much better display job without the use of the hyperbola.
>
> Taking a broader look at the subject of area coverage, we realize that the doppler navigator is likewise an area coverage device. Therefore, in the period through 1975 we envision the introduction of a pictorial display driven by the outputs of the doppler navigator computer for use in the continental U. S. With this type of instrumentation it should be possible to bring in the ground based VORTAC signal and display it on the same mechanism. It is generally accepted that this type of integration of ground based

> and self-contained aid is the very simplest that could be achieved, and until much more confidence is accumulated in the use of airborne digital computers it will be a simplified way of accomplishing this objective.

As to plans for increased VOR accuracy, Winick goes on to say that,

> The doppler VOR is a highly successful development which has resulted in a VOR ground station suitable for installation at difficult sites where the conventional one could not work properly. Our next step, one which we have just begun and which is aimed at 1970, is to convert the doppler VOR into a multilobe ground station to provide a much higher order of system accuracy.
>
> We would like to see the accuracy of the ground based navaid system be essentially the same as that of the radar surveillance system. The doppler VOR recently developed is completely compatible with current airborne equipment, and this was a major objective. However, the precision VOR will need an additional piece of airborne equipment. We are not advocating this as an essential part of the VORTAC system, but we do feel that the system has the potential of providing bearing information to an accuracy of essential (sic) 1 or 1-1/2 degrees. The precision ground units can be very highly specialized facilities rather than those in general use. They will provide the normal VOR signal to all aircraft carrying the standard VOR airborne receiver, but with the addition of an adaptor unit will provide an increase in instrumental accuracy. This growth potential, with some increase in complexity, coupled with the ability to provide different degrees of service to different users, is the reason why we are sure that the system will be suitable for the time period of interest.
>
> Another system element, DME, will also be refined for use at ILS facilities. There are many uses for distance information associated with the ILS; it can be a monitoring device as well as a means of feeding signals to an autopilot approach coupler and flareout computer for landing. These functions require the highest possible accuracy from the distance measuring system and it is believed that potentially the system can provide an accuracy of ± 250 feet. We are actively undertaking this work and should have test results shortly. DME at ILS sites will be a part of the navigation system starting within a few years.

Another view (ref. 68) is that,

> Area coverage navigation systems with pictorial display, which really permit complete utilization of the airspace, together with extensive utilization of electronic computers for air traffic control, would undoubtedly assist but, as neither of these is likely to be available, it appears that a compromise between the ideal and the attainable will have to be made.
>
> The navigation is not seen to be greatly different from that existing today and is primarily a question of adherence to track, monitoring progress in time and fuel, and regularly reporting this information to A. T. C.
>
> Overland, conventional navigational facilities may be adequate for these purposes. In areas of high traffic density, there exists here also a need for more efficient use of the airspace, which could only be provided by a ground-based area coverage system. VOR and DME, supported by a self-contained aid such as Doppler and perhaps by a proximity warning system, could be sufficient for areas of low traffic density. In areas of higher density traffic, the accuracy of VOR and DME would need to be increased. At supersonic cruise altitudes, the "over station cone" is much wider than at the levels flown today and would not be acceptable as ATC checkpoints or for resetting Doppler or inertial systems. Errors in DME at these altitudes are also large and must be eliminated. For example, when an aircraft flying at 60,000 ft. measures a distance of 16 miles by DME indicator, it is in fact only about 11 miles from the station. Doppler or inertial systems reset according to such erroneous indications would carry this error along with them to the next checkpoint. The large number of checkpoints and turning points on today's airway patterns would also be too great for SST airways, since the time between points will be reduced to one half or one third at these speeds, and at SST flight levels there is a risk of interference between transmissions from different facilities. In order to permit cruise climb procedures, a system of parallel airways may be required to facilitate the work of the pilot and air traffic controller.

White (ref. 65) states that,

> Supersonic transport navigation over the continental United States can probably utilize the present VORTAC

ground station network with some modification. Supersonic aircraft at altitudes in the neighborhood of 60,000 feet cannot use many of the stations at the present VORTAC network because of co-channel interference at these higher altitudes. Therefore, some portion of the VORTAC network should be tailored specifically for optimizing high altitude supersonic aircraft navigation.

Ideally, the supersonic transport should fly the longest possible straight-line segments compatible with meteorological and navigational requirements. Also, since the supersonic aircraft flies more than twice as fast as the present subsonic jets, frequency changes must be made more than twice as often. This is very undesirable, and possibly unacceptable to flight crews.

The proposed "skip-station" scheme would utilize selected VOR stations chosen from the present VORTAC network. These stations should have the necessary co-channel and adjacent-channel radio frequency protection so they can be utilized out to radio line-of-sight distances from the station at supersonic aircraft altitudes.

Figure 43 shows a typical relationship of selected high-altitude VORTAC stations to the low altitude VORTAC network. The widely spaced high altitude stations provide straighter and shorter flight paths between the end points, as shown by comparing the dashed line representing a typical low altitude route and the solid line representing the proposed high altitude route. Conversion of the selected VORTAC to high-altitude facilities would not decrease their utility in the low-altitude network.

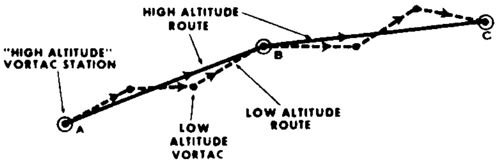

Figure 43. VORTAC "skip-station" scheme (from ref. 65).

The proposed high altitude VORTAC network would provide, in effect, area coverage so that any point on the map within the station coverage could be defined in terms of a bearing and distance from the referenced station. This means a line could be drawn on the map from a VORTAC to any desired check point defined by bearing and distance.

Figure 44 illustrates this navigational scheme. The course line between the lefthand VORTAC station (Station A) and point D can be flown in terms of a bearing and distance from point A to point D. This flight segment could be navigated en route by a VOR-DMET off-course computer, doppler radar or an inertial system.

In effect, the high-altitude network would provide a set of convenient high altitude check points and a means of defining any point on the map in terms of bearing and distance from a referenced VORTAC station. Any one of the three systems mentioned above could be used to navigate between the series of points defined by the area coverage VORTAC system.

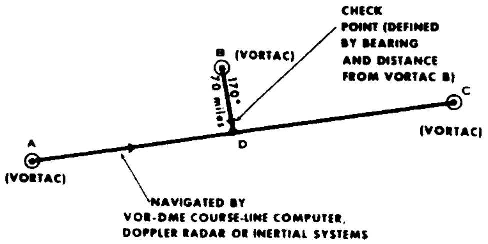

Figure 44. Area-coverage navigation using high-altitude VORTAC facilities as check points (from ref. 65).

At the higher cruise altitudes (60,000-65,000 feet) the over-the-station "cone" is considerably broader than at the lower jet and piston aircraft altitudes. A narrower over-the-station cone is very desirable at the supersonic cruising altitudes so the VOR stations (which probably will be ATC check points) can be marked with greater accuracy.

> Any errors in over-the-station indications impose similar starting point errors in inertial or doppler systems which use over-the-station indications for initiating a flight segment. In any case, the end point navigational accuracy is limited by the starting point accuracy (assuming the system is not corrected en route by some external fixing means).
>
> ...A VORTAC station and airborne course-line computer combination provides, in effect, an area coverage navigation system permitting definition of any chosen flight path with the line-of-sight cover of the VORTAC facility used.
>
> The primary accuracy limitation is probably imposed by VOR system azimuth accuracy. At higher altitudes DME slant range errors become significant when the aircraft is near the ground facility. Example: When the aircraft is 11.3 miles horizontally from the ground facility at 60,000 feet altitude, the DME indicator reads 16 miles, i. e., a plus error of 4.7 miles. Doppler and inertial systems are both capable of accurate navigation between VORTAC network fixes. Accuracy is limited primarily by fix accuracies of the VORTAC system and the over-the-station fix accuracy. The capabilities and limitations of these two systems otherwise are common to both long- and short-range navigation.

It can be seen from these discussions that, in all probability, an area coverage navigational system employing VORTAC will be utilized by the SST on domestic routes for present position determination by externally referenced sources. It seems highly probably that rho-theta computers and pictorial displays will be instrumental in the SST. This would appear to limit the crew involvement to that of selecting appropriate VORTAC channel(s) or frequencies to obtain indications of the display of present position. It is also obvious, however, that this concept will be necessarily limited to those geographical zones or areas where the VORTAC signals are available with the accuracies required for SST navigation. At the time of this analysis, this potential appears to be quite limited in scope and is generally restricted to the continental United States. However, indications that the coverage will become considerably broader are evident in the following quotation (ref. 28).

> ...VORTAC equipment is also the international standard, and as such, is being implemented in many other countries throughout the world. The present plans include a complete airways installation for the United Kingdom, France, Germany, Scandinavia, Switzerland, Italy, and through the Middle East. In the time period under discussion, it is fairly safe to assume that such a system will be implemented along a large majority of high density international routes around the world. Plans also call for experimental installations on U. S. Coast Guard weather ships across the North Atlantic and on various island bases throughout the Pacific.

Concepts for present position derivation via externally referenced sources for intercontinental and/or transoceanic navigation are necessarily based on the ground navaid environment predicted for the SST era, and upon agreement that the requirement actually exists. Some discussions follow. Winick (quoted in ref. 55) indicates that,

> There is less widespread agreement on the question of whether the supersonic transport's navigation system will need to be updated, or corrected for accumulated errors, and if so, what auxiliary navigation aid should be used for this purpose. For supersonic flights of only 2-3 hr. duration, correction may not be necessary, he said.
>
> For the North Atlantic, Loran-A or Loran-C may be the best auxiliary up-dating means. The use of celestial sightings for this purpose seems less desirable. If star trackers were used, they would have to be more fully automatic than those now used in the B-52 and B-58, and such complexity and cost would be difficult to justify if inertial systems develop the reliability that is now expected.

Some substantiating opinion is available (ref. 74) in the following statement:

> While it is too soon to predict exactly what kind of airborne navigation system will be used on the supersonic transport when it is introduced into service, one report made to a government agency by an impartial study group has already expressed the opinion that an inertial guidance system capable of navigating an aircraft

> to within two miles of its destination, with no external aids to navigation, probably will be in production by 1970.

However, there appears to be much more comment to substantiate the use of external aids. Some representative comments follow. King and Groves (ref. 56):

> It has already become generally accepted that an inertial platform will form a basic element in the navigation system of the supersonic transport aircraft. However, where the aircraft are to fit into any systematic air traffic control pattern, which has as its object the rigid control of separation between tracks in the horizontal plane and the precise definition of specific geographical points and areas, it follows that information of the dead-reckoning type must be supplemented by information in which errors are non-cumulative, e. g., from a ground-based radio navigation system having a common-reference characteristic.
>
> Without the updating facility that such a system can provide, separation standards would have to take into account the possibility that the self-contained aid in each aircraft in the traffic complex can accumulate errors of a sign and magnitude which must be regarded as largely random. Given a sufficient degree of updating by a common-reference navigation aid, i. e., by a system in which every aircraft obtains the same reading at a given geographical location, the problem of establishing separation standards is eased and the actual separation values can be markedly reduced since errors of a cumulative nature can be neglected.
>
> In addition to providing this essential common-reference characteristic, it is clear that an accurate ground-based radio aid can contribute more effectively to the navigation and control of air traffic in terminal areas, where traffic density is such as to require the highest possible navigational accuracy, than any device of a dead-reckoning character. Again, the precision which a ground-based radio system can furnish is of value in terminal areas as a means of aligning aircraft accurately with the axis of a guidance pattern established for landing purposes--more especially when a fully automatic landing capability is required.

> In other phases of S. S. T. flight, the accuracy factor is scarcely less critical since it is paramount that pilots should be able to execute flight clearances with a very high degree of precision if efficient operation is to be assured. It follows, therefore, that the updating facility is also highly desirable in these phases, both from the A. T. C. and flight viewpoints. Needless to say, the ground-based system must at all points provide the requisite accuracy to compensate for errors accumulating in dead-reckoning systems.

Greenaway (ref. 49):

> Although many of the major intercontinental routes will be covered to some degree by radio aids, these will only be used to supplement the aircraft's self-contained system rather than being an integral part of it. . . . Similarly, there will be other aids installed which will supplement the automatic navigation system but will not actually be part of the system. These aids will be the airborne components of the ground-based systems covering the more congested intercontinental routes and the terminal areas.

Powell and Willis (ref. 50):

> . . . an inertial system, and any hybrid system involving inertial components, would still require in-flight monitoring and the use of back-up aids. . . It seems certain that doppler sensors will supply drift and ground-speed for civil supersonic systems, but from everything said so far, it is also certain that monitoring and back-up capabilities must be provided. . . In any event, such an aid will probably be required as a means of back-up navigation.

Miedzybrodzki (ref. 70):

> . . . The display should be driven from the aircraft navigation computer using self-contained aids and it should be capable of indicating errors of the navigation system by an easy, and preferably continuous, reference to ground radio aids. This, of course, is specially important in or near terminal areas. . . It should be possible to update the navigation system via the display using radio aids such as VOR's and DME's.

Reference 71 regarding the Concorde:

> It is probable that ATC authorities will insist on "updating" aircraft positional information periodically to ensure that there are no gross errors in a self-contained system which might endanger other aircraft.

Groves (ref. 59):

> The requirements for a ground-based fixing aid can be justified solely on the basis that the SST will have to fit into a systematic ATC pattern. . . Information of the dead reckoning type must be updated by information in which errors are non-cumulative, e. g. , from a ground based radio navigation system having a common reference characteristic.

This analysis has assumed that, even on intercontinental flights where there is a paucity of available ground based aids, the self-contained system will be updated as often as is either practically necessary or possible by a fix obtained from externally referenced systems. It seems highly likely that such a system will provide automatic position inputs to the integrated SST navigation system, for the same reasons justifying the automation of the self-contained system (i. e. , the staleness of the data generated and integrated by manual methods). Again, it would appear that crew involvement would be limited to only those operations required by specific equipment characteristics for obtaining the necessary signal source, such as frequency channel selection. The actual integration of the fix obtained from such sources into the self-contained, automatic navigation system is discussed under Function 7. 9, entitled Present Position Updating.

Certainly, another possibility is fixing the position of the aircraft by ground-based equipment, and relaying this position via the data link. Obvious constraints are imposed by available stations.

Feasible Manual Implementation Concepts for SST

The general consensus seems to indicate manual implementation of this function only in terminal areas where the SST will have to operate within the performance envelope of current subsonic jets. Therefore, speeds and altitudes will be such that terminal area navigation will utilize essentially the same procedures as on the subsonic jets with, hopefully, a higher degree of accuracy, particularly for all-weather landing operations. (See Functions 7. 3, 7. 4, 7. 6, and 7. 7.)

During the enroute flight phases, both domestic and transoceanic, performance of this function with any degree of manual implementation is not considered practical with the exception of setting specific dials for proper equipment operation and display read-out, and as an emergency back-up in the event of catastrophic equipment failure.

SUBSONIC SPEED REGIME

In the event the SST reverts to the subsonic speed regime for any reason other than catastrophic failure in the navigation system, external position generation would continue to be an automated function. Should there be catastrophic failure in the navigation system, return to the subsonic speed regime would permit utilization of conventional techniques such as those employed aboard current jet liners for the performance of this function.

7.9 FUNCTION 7.9 PRESENT POSITION UPDATING

Purpose

The purpose of this function is three-fold, including,

1. The integration and processing of all appropriate navigation inputs from the self-contained navigation system(s) (i. e., dual, or triple installations of identical systems, plus any additional dissimilar system) such that the most reliable and accurate indication of present position from these sources is continuously available in appropriate form and format.

2. The integration and processing of all appropriate navigation inputs from the externally-referenced navigational system(s) (e. g., VORTAC, hyperbolic, and communications satellite) such that the present position indicated by the self-contained system(s) contains minimal cumulative error, and is cross-checked for the presence of insidious and blunder errors, and at all times represents the most reliable and accurate indication of present position derivable from all navigation system(s) sources where the complementary capabilities of these systems are fully exploited.

3. The best possible indication of present position is continuously displayed in the cockpit in a form and format consistent with requirements for clarity, accuracy, and correlation with the optimum profile in a manner which permits flight management to

stay ahead of the flight situation (i. e., monitor flight progress with respect to the optimum situation) and is available in appropriate form and format for transmission to ground facilities.

Current Jet Operational Requirements and Constraints

There are no current requirements or constraints applicable.

SST Potential Operational Requirements and Constraints

Actually, the justification for this function is inherent in the justification for externally referenced system position generation. If position-fixing system inputs are required to correct and act as back-up for self-contained systems, then the updating process itself is justified. The justification (or requirements) for the updating process are given more fully under Function 7. 8.

Feasible Automated Implementation Concepts for SST

There are generally two methods discussed in the literature for the integration of data from self-contained and externally-referenced navigation systems such that the best indication of present position is available in the form and format required. The widest variance between these two methods is in their refinement and sophistication.

Using the simplest concept, inputs from the two sources would be integrated in a pictorial display. This display would be designed so that a "roller map" would move through the display at a relatively constant speed set to correspond with the best available estimate of the aircraft's ground speed along the required track. This track would be pre-drawn as a line down the map center. The aircraft would be positioned manually in relation to the track as data is available from the position-fixing component. The display would be driven by the dead-reckoning component. Figure 45 illustrates this arrangement. In this arrangement, the speed of the map (representing ground speed) would be adjusted manually as better estimates become available, and the aircraft position denoted by external sources would provide the basis for manually updating the dead-reckoning component. Three obvious disadvantages of this arrangement for the SST are, (1) probably error magnitudes that would be intolerable, (2) no provision for the vertical plane and profile navigation in three dimensions, and (3) the restrictiveness of the system in terms of its need for rather constant attention, which essentially requires one full-time crew member, a situation which may not be practical or economical.

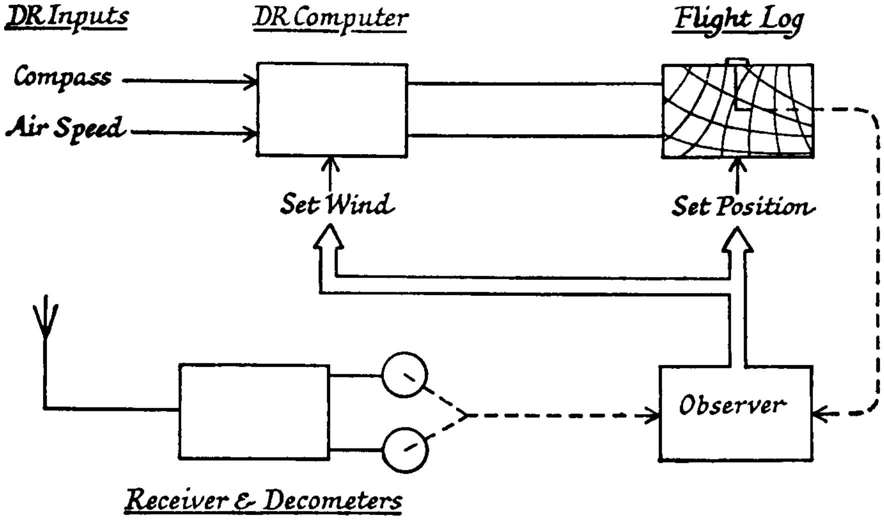

Figure 45. Elementary compound navigation system using a flight log to combine the two inputs.

The second method, and the one appearing most advantageous for the SST, is the use of an airborne digital computer to combine the navigation inputs from both self-contained and externally-referenced systems. The use of the computer offers many advantages over the manual method, but perhaps the most significant improvement would be the capability for data smoothing, that is, continuous combination of the information from both types of systems such that their complementary aspects are exploited fully and their error components minimized. This would permit an output of substantially higher quality than that obtained from either input taken separately. Additionally, the computer permits a greater degree of accuracy because of its capability to make many complex computations in very short time periods, and because adjustments in the flight situation display under computer control are not subject to the gross error magnitudes probable from manual manipulations. The addition of the computer also greatly reduces the workload on the crew in this area by essentially automating the derivation of the best estimate of present position which includes all system inputs.

Computer outputs would be used to drive the pictorial display in the cockpit, and to provide continuous information to the necessary ground facilities regarding the precise position of the aircraft and other desired data, such as aircraft velocity. The computer could even be preprogrammed such that, at specified points along a given flight path, navigation receivers could be automatically switched to receiving channels for the most appropriate radio aids.

Feasible Manual Implementation Concepts for SST

The absence of any indications in the literature regarding crew role in this process, suggests that the updating of the self-contained system by inputs from externally-referenced systems is being considered primarily as an automatic function. Manual implementation is not considered practical if the externally-referenced system is to be employed as the primary navigation means, or as the back-up system in the event the self-contained systems are lost for any reason and the aircraft remains supersonic.

However, manual insertion of a fix obtained from such sources strictly as an updating requirement could be feasible, depending upon the frequency with which the fixes must be obtained and entered into the navigation system, and provisions for the necessary means to enter the data. Manual insertion of fixes would probably be accomplished by providing the means for direct entry of information into the navigation computer, e. g., Lat/Long turning control with time-of-fix data, or buffer storage of key-punched data where the crew member could enter the appropriate information into the buffer, check it for accuracy, and cause the navigation computer to interrogate the buffer and accept the data.

7.10 FUNCTION 7.10 ETA PREDICTION

Purpose

The purpose of this function is to provide the crew and ATC with the most accurate ETA's at checkpoints and destination based on the most recent navigational data. This task has been considered a separate function because of the apparent increase in SST requirements for frequency and accuracy over those for current subsonic jets. Some following comments illustrate the apparent importance being attached to this function.

Polhemus (ref. 53) gives some indications of the difficulty in establishing and maintaining schedule integrity. The effect of temperature differentials on achieving a predicted position and the time necessary to reach that position during the acceleration and climb phase has already been pointed out in the discussion of Function 7. 3. Polhemus states that,

> Ambient temperature aloft may actually result in greater problems for ETA validation and position prediction than will the wind solution. A 25°C change of temperature at Mach 3. 0. . . is equivalent to a 100 knot ground speed change. . . During the cruise phase of flight the atmospheric conditions can invalidate an ETA, vary true airspeed by 240 knots in a one-hour period. . .
>
> It is also evident that the traditional navigation function is complicated by the need to solve for position and ETA during periods when velocity may be changing continuously, and when navigation system performance (accuracy) is difficult to evaluate.

Further. Hooten (ref. 51) states that, "The SST will require that the controller be given much more information than at present on the scheduled flight path and flight times." Also pertinent here is the impact of a statement made during the November 1963 IFALPA Symposium to the effect that prior to acceleration beyond subsonic speed, the pilot must have details of the time, height and location in which the aircraft is due to return to subsonic speeds. It is apparent that such details are merely the accuracy goals for the navigation system for a given flight, and the key to achieving an ETA as scheduled prior to the flight lies in accurate and continuous prediction of time and distance to go based on the most current navigation data. The requirement for the continuous and accurate derivation of present position has already been established. By the same token, the ever-changing navigation situation will demand the same requirements for ETA prediction in order to maintain cognizance of schedule integrity and provide the basis for adequate schedule revision.

Current Jet Operational Requirements and Constraints

In current jet operations, scheduled flights operate with "canned" flight plans which indicate ETA's at all required reporting points and at destination. In transoceanic operations, ETA's at the next reporting point and at the destination point are given verbally as a required portion of the standard position reporting format. This means that between reporting points the crew must calculate ETA at the next reporting point and at the destination point. This is a simple calculation based upon the flight's progress and anticipated meteorological conditions.

Within the continental United States, jet liners are not required to report their ETA at any checkpoint unless specifically requested by ATC or the airline company. Further, ETA at the destination point is not reported unless it becomes apparent that the flight will deviate by more than three minutes from the scheduled ETA. This means that although it may not be necessary to report the ETA at any point during the flight, it is necessary for the crew to remain cognizant at all times of their adherence to the schedule. Hence, ETA must be calculated periodically to ascertain any necessity for revision. The following regulation is applicable:

ICAO Reg. 5.3.1.2.2.1, ref. 14:

Change in estimated elapsed time (EET):

> . . . if the estimated elapsed time to arrival over the next designated reporting point or to the aerodrome of intended landing as given in the flight plan is found to be in error, normally in excess of 3 minutes, unless otherwise prescribed by the appropriate authority or by regional agreement, a revised EET shall be notified as soon as possible to the appropriate air traffic services unit.

Current Jet Implementation Concepts

Generally, the calculation of an ETA to either some checkpoint or to the destination point involves no more than a direct comparison of the distance to go with the established ground speed. The accuracy of the ETA is a function of the accuracy with which the distance to go is known and the accuracy of the ground speed predicted over the remaining distance.

In domestic flights, VOR/DME equipment provides a direct read-out of the distance to go to a VORTAC station lying directly on the flight path or to either side of it. The flight plan provides a "total miles" figure from which the distance flown may be subtracted leaving distance to go. The anticipated ground speed during each leg of the flight is also available and is based on the anticipated meteorological conditions. It is, then, a simple matter to check the ETA at any point in the progress of the flight. The same procedure is utilized during transoceanic flight, the exception being that aircraft equipped with doppler radar have ground speed available as a direct read-out in the cockpit.

SST Potential Operational Requirements and Constraints

It does not appear that the SST will be subject to any requirements for ETA prediction notably different than those for the current subsonic jets, other than increased frequency and accuracy. It does appear, however, that the "time for error" requirement may be necessarily decreased. In other words, if current jets need to report an ETA revision when the flight deviates by more than three minutes from the scheduled ETA, then the SST should probably make such a revision when the crew can predict an ETA deviating by more than one minute from the schedule. The decrease in time would be warranted by the tremendous increase in speed of the SST over that of subsonic jets, which if no changes were made, would cut ATC reaction time by a factor of two-thirds.

The operational characteristics of the SST would also seem to necessitate a much higher degree of accuracy in predicting the ETA. Accuracy would be particularly important in predicting the ETA at the deceleration/descent point where missed ETA's generally result in holding in terminal control areas. The adverse impact of holding for the SST is evident in considering the fuel penalty for such operations and the possibility that these penalties could easily affect payload. It seems obvious that along with more accurate ETA calculations there will probably be more frequent ETA revisions made to maximize ATC response time.

Feasible Automated Implementation Concepts for SST

There seems to be little doubt that the vast majority of the navigation tasks in the SST will be performed by a fully automated, integrated navigation system utilizing data inputs from various navigation sensors as well as stored data and information from the ground-to-air communications system. It is also generally agreed that the heart of this navigation system will be an airborne digital computer capable of performing the entire navigation task as well as many other tasks related to overall SST operations. ETA predictions based on computations performed by the computer would be obviously faster and more accurate than manual calculations. Handling of this function by the computer would insure utilization of the most current navigation data from all appropriate input sources because as each computational cycle for wind, ground speed, and present position is made, updated data would be available for calculation of a more current ETA. In discussing some aspects of SST navigation and the utilization of an airborne digital computer, Groves (ref. 59) states that the computer "would perform the additional task of supplying navigational data... for the provision of accurate ETA." And Richardson (ref. 52) states that "present and future destinations, or course change points, ETA to these points... are all items of information continually being computed and used in the computer program."

Feasible Manual Implementation Concepts for SST

Manual calculation of ETA is a relatively simple task if one has available the distance to go and estimated ground speed values for the remainder of a flight or flight leg or series of flight legs. For the SST, the distance will undoubtedly be in terms of the ground track distance along the great circle path defining the flight path between the points of origin and destination. Monitoring of enroute weather conditions will permit revision of ground speed estimates for the remainder of the flight as meteorological conditions enroute change. Conversion of distance-to-go and estimated ground speed over the track remaining to an estimated time of arrival is a straightforward, simple calculation.

The accuracy in the ETA will be no better than the accuracy with which distance and ground speed may be resolved. However, it should be recognized that changes in the atmospheric conditions may occur rapidly and in magnitudes adequate to invalidate an ETA in a relatively short time span. That is to say, anticipated ground speed may fluctuate considerably as a function of the fluctuation in weather conditions prevailing along the flight route. It is worthwhile to note some remarks of Polhemus (ref. 53) along this line.

(1.) During the cruise phase of the flight the atmospheric conditions can invalidate an ETA, (and) vary true airspeed by 240 knots in a one-hour period of time due to changing temperature alone...

(2.) Figure (40 presented on page 468) shows the effect of conditions which produce both a 20 per cent reduction in acceleration performance and a 20 per cent increase in performance capability. The central curve showing the case for standard day conditions is based on an average acceleration of 2-25 ft. /sec. ^{2}. Time to reach mach 3. 0 from mach 0. 91 is 15 minutes, distance 273 n. m. Conditions which produce an unexpected 20 per cent degradation in performance, such as temperatures significantly higher than standard and the aircraft above its sub-sonic optimum altitude would result in a position error of 17 miles; whereas an aircraft experiencing colder than standard temperatures might be 23 miles further ahead of this standard day position.

(3.) The cruise phase of flight should be characterized by a high degree of schedule reliability as long as meteorological forecasting errors are not unreasonable. The effect of an error in forecast wind velocities is quite small, as can be seen from an analysis of Fig. (46). Errors in forecast or flight plan ground-speed can easily be negated by changing power to achieve a different mach number. The fuel penalty curve in the upper right corner of Fig. (46) indicates the magnitude of the fuel consumption penalty as a function of "off-mach" (at mach 3. 0) operation for a particular engine at present under consideration. Ambient temperatures aloft may actually result in greater problems for E. T. A. validation and position prediction than will the wind solution.

(4.) Some idea of the difficulty which the temperature gradient may have on the navigation problem may be gained from inspection of Fig. (47), which is another of Tewles's cross-sections, lying in proximity to a segment of the great-circle track between Los Angeles and London. Somewhere near Churchill

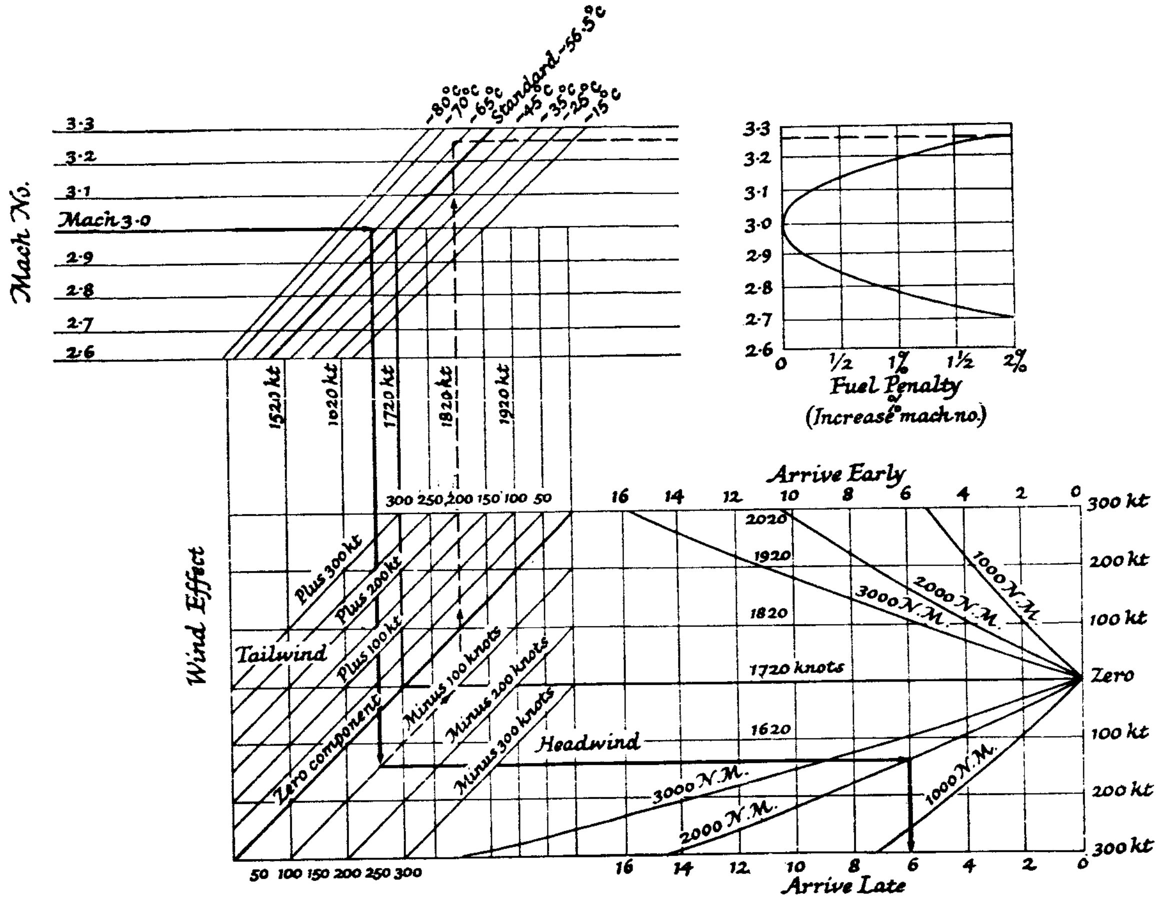

Figure 46. The effect of non-standard temperature (from ref. 53).

the aircraft would cross the stratopause and enter a region of rapid temperature change--between Churchill and Greenland the increase is approximately 1° C/minute of flight--a T. A. S. change of 3. 3 knot/min. For a mach 3. 0 vehicle this temperature change would produce a 160-knot change in velocity in the 48 minute flying time between station 913 and Greenland--and a change in E. T. A. to London of 9 min. if one based his estimate on a time-speed-distance solution completed at the beginning of the leg. Following passage of the -25°C. isotherm over Greenland the true air-speed would begin to decrease at a rate of 3. 0 knot/min. until the aircraft reached the deceleration point off the Scottish coast.

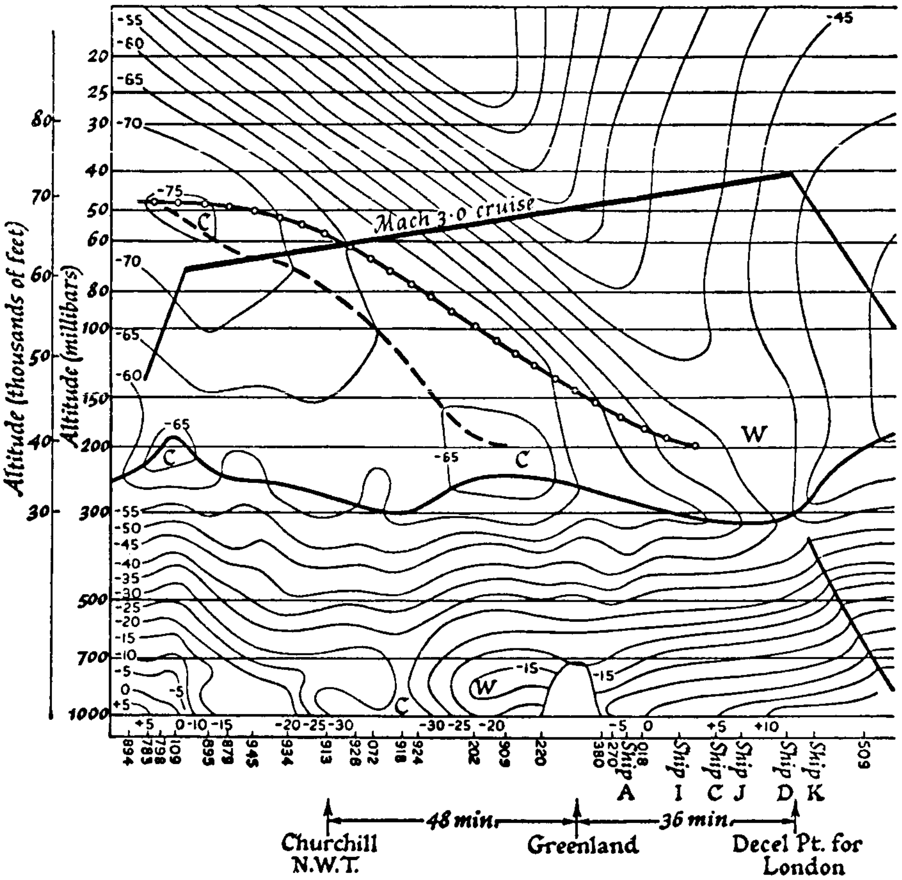

Figure 47. Cross-section for 6 February 1957 from Lajes (Azores) to Salem (Oregon). Heavy line with open circles shows the stratopause and heavy dashed line the lapse rate discontinuity. (From ref. 53.)

It can easily be seen that manually checking and revising ETA as the meteorological conditions vary during the flight could well turn into a task which would occupy much more time than would be warranted. It would therefore seem reasonable to assume that manual implementation of this function would be reserved for emergency or non-routine situations. Some support does exist for manual performance of this function. Greenaway (ref. 49) indicates in his discussion of a possible navigation system for Mach 2 and Mach 3 transports that "An estimated-time-of-arrival meter is not required since it is a simple matter to check the ETA against the actual time of arrival and make adjustments accordingly."

By and large, however, computer calculation and constant revision of ETA as necessitated by changing flight conditions seem to be a reasonable trade-off considering the amount of time required to perform this function manually and the fuel penalties involved in other than optimum operation, particularly in holding situations resulting from missed ETA's. In addition, the computer, representing optimum means, is available.

SUBSONIC SPEED REGIME

Assuming that the SST returned to the subsonic speed regime to continue its flight or return to base for some reason other than failure of the navigation system, the ETA calculation as performed by the automated system would not change. If the reason for return to the subsonic speed regime was catastrophic failure in the navigation system, then the calculation of ETA would be as discussed under manual implementation concepts. This would require varying levels of skills and knowledge depending upon the degree of refinement employed. For gross estimates, it would be a simple matter of calculating:

$\text{ETA} = T_0 + T_1$, where

T_0 = time of calculation and

$$T_1 = \frac{\text{Distance-to-go}}{\text{Average ground speed}}$$

However, the extended flight time in the subsonic regime would undoubtedly call for resumption of some of the more conventional techniques such as position fixing and reporting at fairly regular intervals where ETA's to each reporting point would have to be calculated, compared to ATA's at each point, and the impact of any error component between ETA and ATA at any given point examined in terms of the destination ETA. The accuracy of a series of ETA's would reflect the amount of consideration given to the anticipated meteorological conditions as well as the accuracy of the meteorological forecasts. The technique becomes more involved and the use of standard job aids, such as the E6B computer or Jeppeson computer, would appear to be required. Hence the skills and knowledge required to use these aids would have to be available in the crew complement.

7.11 FUNCTION 7.11 OPTIMUM PROFILE GENERATION

Purpose

The purpose of this function is to assess the entire navigation situation and all related parameters and provide on a continuous basis optimum velocity scheduling and the optimum flight path in all three dimensions. The optimum flight path should allow the aircraft to either complete its original flight plan, or a modified flight plan, such that the operation of the flight from the viewpoint of navigation is executed in the most efficient and economical manner consistent with governing regulations and safety.

The following tasks are inherent in the performance of this function.

1. Optimization of the flight profile in the vertical, lateral, and longitudinal planes taking into consideration all of the applicable constraints and related parameters, and including the following performance:

   a. Minimization of sonic boom--performance of this part-task involves the optimization of the flight profile for minimizing the sonic disturbance. This includes the utilization of techniques for predicting ground shock-wave magnitudes over the entire flight plan schedule considering all the pertinent contributing factors (e.g., Mach number, attitude, altitude, bearing and magnitude of winds aloft, aircraft gross weight, and aircraft design characteristics inherent in the problem solution).

b. Cruise phase optimization for minimization of effects of adverse meteorological conditions--performance of this part-task involves the optimization of the flight profile for minimizing, and delineating where necessary, track excursions for hazardous weather avoidance.

c. Optimization of fuel consumption--performance of this part-task involves the consideration of all parameters affecting the fuel flow rate, including present aircraft position, current flight plan, fuel remaining on board, fuel consumption, fuel reserve requirements, Mach number, predicted and measured local winds and ambient temperatures.

d. Optimization of the flight route--performance of this part-task assumes that area navigation is authorized, and that variations in the desired flight path may be made within specified tolerances of the cleared flight track; performance involves the delineation of required (and/or desired) excursions from the cleared flight track necessary for the optimization of the flight profile considering all critical parameters when such excursions exceed specified tolerances associated with the clearance.

e. Generation of a truly optimum flight profile --performance of this part task involves the derivation of a flight profile truly optimum in that it is the resultant of a thorough and complete trade-off analysis considering profile optimization for all pertinent parameters as a collective body of data.

2. Continuous presentation of the navigational situation in the following respects:

   a. Parameters representative of the optimum profile being followed suitable for pictorial display in the cockpit, and for automatic transmission via data link to appropriate ground installations.

   b. Parameters representative of off-profile error components in all three planes suitable for transduction into flight control commands, and optimum in the sense of regaining the track with the most acceptable aircraft manipulation considering all the constraints mentioned in (1) above with the additional constraint of maneuver limits imposed by aircraft performance envelope and passenger considerations.

   c. Details of the requirement for track excursion exceeding authorized limits to include: the optimum profile assuming the excursion takes place, when and where the excursion is required, and the justification for the excursion requirement (e. g., storm avoidance, or diversion to an alternate due to fuel reserves).

   d. Details of fuel management to include fuel remaining on board, fuel consumption, fuel flow rates experienced and predicted, predicted fuel reserve status over destination and over all prescribed alternates, fuel transfer system monitoring data, and velocity scheduling data suitable for transduction to thrust control commands.

e. Parameters representative of meteorological conditions both current conditions and those predictions being used for profile optimization over the remaining track to be followed.

f. Temporary storage for retrieval and display upon command of a series or sets of parameters representing the profile optimized for any given single, critical consideration (e. g., optimum fuel profile, all other constraints notwithstanding, or optimum velocity scheduling profile, fuel reserves notwithstanding).

Current Jet Operational Requirements and Constraints

Generally, this function is performed by current subsonic jets only in part and only once in the initial specification of an optimum flight plan for a given flight, although parts of the function are performed en-route.

Current Jet Implementation Concepts

For the most part, current jets operate along a flight route between two given points which has been optimized to the extent possible prior to any given operation along that route. This is the use of the so-called canned flight plans. The following specific regulations apply:

FAR 91.23, ref. 13:

Fuel requirements for flight in IFR conditions.

No person may operate a civil aircraft in IFR conditions unless it carries enough fuel (considering weather reports and forecasts, and weather conditions) to complete the flight to the first intended point of landing, to fly from that point to the alternate airport, and to fly thereafter for 45 minutes at normal cruising speed.

FAR 91.81, ref. 13:

Altimeter settings.

(a) Each person operating an aircraft shall maintain [the cruising altitude or flight level of that aircraft,] as the case may be, by reference to an altimeter that is set, when operating—

[(1) Below 18,000 feet MSL, to—]

(i) The current reported altimeter setting of a station along the route and within 100 nautical miles of the aircraft;

(ii) If there is no station within the area prescribed in subdivision (i) of this subparagraph, the current reported altimeter setting of an appropriate available station; or

(iii) In the case of an aircraft not equipped with a radio, the elevation of the departure airport or an appropriate altimeter setting available before departure; or

[(2) At or above 18,000 feet MSL, to 29.92" Hg.]

(b) The lowest usable flight level is determined by the atmospheric pressure in the area of operation, as shown in the following table:

[Current altimeter setting	Lowest usable flight level
29.92 (or higher)	180
29.91 thru 29.42	185
29.41 thru 28.92	190
28.91 thru 28.42	195
28.41 thru 27.92	200
27.91 thru 27.42	205
27.41 thru 26.92	210

[(c) To convert minimum altitude prescribed under §§ 91.79 and 91.119 to the minimum flight level, the pilot shall take the flight-level equivalent of the minimum altitude in feet and add the appropriate number of feet specified below, according to the current reported altimeter setting:

[Current altimeter setting	Adjustment factor
29.92 (or higher)	None
29.91 thru 29.42	500 feet
29.41 thru 28.92	1000 feet
28.91 thru 28.42	1500 feet
28.41 thru 27.92	2000 feet
27.91 thru 27.42	2500 feet
27.41 thru 26.92	3000 feet]

FAR 91. 121, ref. 13:

IFR cruising altitude or flight level.

(a) *In controlled airspace.* Each person operating an aircraft under IFR in level cruising flight in controlled airspace shall maintain the altitude or flight level assigned that aircraft by ATC. However, if the ATC clearance assigns "VFR conditions-on-top," he shall maintain an altitude or flight level as prescribed by § 91.109.

(b) *In uncontrolled airspace.* Except while holding in a [holding] pattern of two minutes or less, or while turning, each person operating an aircraft under IFR in level cruising flight, in uncontrolled airspace, shall maintain an appropriate altitude as follows:

[(1) When operating below 18,000 feet MSL and—]

(i) On a magnetic course of zero degrees through 179 degrees, any odd thousand foot MSL altitude (such as 3,000, 5,000, or 7,000); or

(ii) On a magnetic course of 180 degrees through 359 degrees, any even thousand foot MSL altitude (such as 2,000, 4,000, or 6,000).

[(2) When operating at or above 18,000 feet MSL but below flight level 290, and—]

(i) On a magnetic course of zero degrees through 179 degrees, [any odd flight level (such as 190, 210, or 230); or]

(ii) On a magnetic course of 180 degrees through 359 degrees, [any even flight level (such as 180, 200, or 220).]

(3) When operating at flight level 290 and above, and—

(i) On a magnetic course of zero degrees through 179 degrees, any flight level, at 4,000-foot intervals, beginning at and including flight level 290 (such as flight level 290, 330, or 370); or

(ii) On a magnetic course of 180 degrees through 359 degrees, any flight level, at 4,000-foot intervals, beginning at and including flight level 310 (such as flight level 310, 350, or 390).

FAR 121.645, ref. 11:

Fuel supply: turbine engine-powered airplanes, other than turbo propeller: flag and supplemental air carriers and commercial operators.

(a) For any flag air carrier operation and for a supplemental air carrier or commercial operator operation outside the 48 contiguous States and the District of Columbia, no person may release for flight or take off a turbine-engine powered airplane (other than a turbo-propeller airplane) unless, considering wind and other weather conditions expected, it has enough fuel—

(1) To fly to and land at the airport to which it is released;

(2) Thereafter, to fly for a period of 10 percent of the total time required to fly from the airport of departure to, and land at, the airport to which it was released;

(3) Thereafter, to fly to and land at the most distant alternate airport specified in the flight release, if an alternate is required; and

(4) Thereafter, to fly for 30 minutes at holding speed at 1,500 feet above the alternate airport (or the destination airport if no alternate is required) under standard temperature conditions.

(b) No person may release a turbine-engine-powered airplane (other than a turbo-propeller airplane) to an airport for which an alternate is not specified under § 121.621 (a) (2) or 121.623 (b) unless it has enough fuel, considering wind and other weather conditions expected, to fly to that airport and thereafter to fly for at least two hours at normal cruising fuel consumption.

(c) The Administrator may amend the operations specifications of a flag or supplemental air carrier or commercial operator to require more fuel than any of the minimums stated in paragraph (a) or (b) of this section if he finds that additional fuel is necessary on a particular route in the interest of safety.

Area and route requirements: general.

(a) Each supplemental air carrier or commercial operator seeking route and area approval must show—

(1) That it is able to conduct operations within the United States in accordance with subparagraphs (3) and (4) of this paragraph;

(2) That it is able to conduct operations in accordance with the applicable requirements for each area outside the United States for which authorization is requested;

(3) That it is equipped and able to conduct operations over, and use the navigational facilities associated with, the Federal airways, foreign airways, or advisory routes (ADR's) to be used; and

(4) That it will conduct all IFR and night VFR operations over Federal airways, foreign airways, controlled airspace, or advisory routes (ADR's).

(b) Notwithstanding paragraph (a)(4) of this section, the Administrator may approve a route outside of controlled airspace if the supplemental air carrier or commercial operator shows the route is safe for operations and the Administrator finds that traffic density is such that an adequate level of safety can be assured. The air carrier or commercial operator may not use such a route unless it is approved by the Administrator and is listed in the air carrier's or commercial operator's operations specifications.

FAR 91.119, ref. 13:

Minimum altitudes for IFR operations.

(a) Except when necessary for takeoff or landing, or unless otherwise authorized by the Administrator, no person may operate an aircraft under IFR below—

(1) The applicable minimum altitudes prescribed in Parts 95 and 97 of this chapter; or

(2) If no applicable minimum altitude is prescribed in those Parts—

(i) In the case of operations over an area designated as a mountainous area in Part 95, an altitude of 2,000 feet above the highest obstacle within a horizontal distance of five statute miles from the course to be flown; or

(ii) In any other case, an altitude of 1,000 feet above the highest obstacle within a horizontal distance of five statute miles from the course to be flown.

However, if both a MEA and a MOCA are prescribed for a particular route or route segment, a person may operate an aircraft below the MEA down to, but not below, the MOCA, when within 25 statute miles of the VOR concerned (based on the pilot's reasonable estimate of that distance).

(b) *Climb.* Climb to a higher minimum IFR altitude shall begin immediately after passing the point beyond which that minimum altitude applies, except that, when ground obstructions intervene, the point beyond which the higher minimum altitude applies shall be crossed at or above the applicable MCA.

FAR 91.123, ref. 13:

Course to be flown.

Unless otherwise authorized by ATC, no person may operate an aircraft within controlled airspace, under IFR, except as follows:

(a) On a Federal airway, along the centerline of that airway.

(b) On any other route, along the direct course between the navigational aids or fixes defining that route.

However, this section does not prohibit maneuering the aircraft to pass well clear of other air traffic or the maneuvering of the aircraft, in VFR conditions, to clear the intended flight path both before and during climb or descent.

ICAO Reg. 4.3.3.1, ref. 12:

Fuel and Oil Supply - All aircraft.

A flight shall not be commenced unless, taking into account both the meteorological conditions and any delays that are expected in flight, the aircraft carries sufficient fuel and oil to ensure that it can safely complete the flight. In addition, a reserve shall be carried to provide for contingencies, and to enable the aircraft to reach the alternate aerodrome when such is included in the flight plan in accordance with 4.3.1.1.

Note.—Nothing in 4.3.3 precludes an aircraft from amending its flight plan while in flight in order to re-plan the flight to another aerodrome provided that from the point at which the flight is re-planned the requirements of 4.3.3 can be complied with.

ICAO Reg. 4.4.1, ref. 12:

Aerodrome meteorological minima.

S **A flight shall not be continued towards the aerodrome of intended landing unless the latest available meteorological information indicates that conditions at that aerodrome, or at least one alternate aerodrome, will, at the expected times of arrival, be at or above the meteorological minima specified for such aerodromes in the Operations Manual.**

S **Except in case of emergency an aircraft shall not continue its approach-to-land at any aerodrome beyond a point at which the limits of the meteorological minima specified for that aerodrome in the Operations Manual would be infringed.**

NS **A flight shall not be continued towards the aerodrome of intended landing unless the latest available meteorological information indicates that conditions at that aerodrome or at least one alternate aerodrome, will, at the expected times of arrival, be at or above the meteorological minima specified for such aerodromes.**

NS Except in case of emergency, an aircraft shall not continue its approach-to-land at any aerodrome beyond a point at which the limits of the meteorological minima specified for that aerodrome would be infringed.

ICAO Reg. 4.5, ref. 14:

VFR flights operated in level cruising flight at 900 metres (3,000 feet) or more from the ground or water shall be conducted at a cruising level appropriate to the track as specified in Appendix C, except when otherwise prescribed by the appropriate authority for VFR flights within controlled airspace.

ICAO Reg. 5.2.1, ref. 14:

Cruising levels.

Except when climbing or descending, an IFR flight operating outside controlled airspace shall be flown at a cruising level appropriate to its track as specified in Appendix C.

ICAO Reg. 5.3.1.2.2.1, ref. 14:

2) *Variation in true airspeed:* if the average true airspeed at cruising level between reporting points varies or is expected to vary by plus or minus 5 per cent of the true airspeed, from that given in the flight plan, the appropriate air traffic services unit shall be so informed.

ICAO Reg. 5. 3. 1. 2. 3. 1, ref. 14:

Intended changes.

5.3.1.2.3.1 Requests for flight plan changes shall include information as indicated hereunder:

a) Change of cruising level: aircraft identification; requested new cruising level; revised EET (when applicable) to next designated reporting point.

b) Change of route:

i) Destination unchanged: type of flight plan; aircraft identification; description of new route of flight including related flight plan data beginning with time and position from which requested change of route is to be commenced; estimated elapsed time from point of change to destination; any other pertinent information.

ii) Destination changed: type of flight plan; aircraft identification; description of new route of flight to new destination including related flight plan data, beginning with the time and position from which requested change of route is to be commenced; estimated elapsed time from point of change to destination; alternate airport; any other pertinent information.

The optimization process will usually have considered such factors as:

1. The most appropriate schedule for the flight to depart and arrive where such may be affected by the tastes of the traveling public and noise abatement constraints in the terminal areas.

2. Routing of the flight to include checkpoints.

3. Fuel and payload data (e. g. , gross weight empty, total fuel weight, gross weight taxi, gross takeoff

weight, fuel consumption rate, fuel reserves over destination, and landing weight).

4. Optimum altitudes for fuel consumption and prevailing winds.

Although frequently deviations from the scheduled times are due to traffic control problems, the major constraint in using canned flight plans is the weather condition assuming that the flight departs as scheduled. The canned flight plan must be modified prior to the flight to reflect any necessary changes in such items as fuel requirements, payload, or re-routing, as may be necessitated by the enroute weather. Moreover, along highly congested routes, flights may not be given ATC clearance as requested. For example, the optimum flight path may be the MTP (minimum time path) along with optimum steps in altitude for fuel consumption; however, ATC may clear the flight for the MTP, but not for the altitudes requested, or may clear the altitudes, but not the flight path. Such ATC clearances result in a re-examination of the parameters in order to ascertain what is optimum within the constraints of the clearance specified. Generally, the flight plan is still optimized prior to takeoff. Deviations enroute may be unavoidable due to hazardous weather, changes in ATC clearance, or equipment malfunctions. By and large, however, ATC constraints severely limit enroute optimization of the flight profile, and deviations from the cleared profile, including changes ordered by ATC, are generally issued for the avoidance of traffic and hazardous weather avoidance, rather than for optimum equipment operation.

Changes in the ATC clearance, directed by ATC for whatever reason, only call for compliance by the crew. However, it may be that some optimization of the profile based on the revised clearance is possible, e. g., some change in Mach number may be called for to optimize fuel consumption. The crew must determine this and implement changes as required. Changes in the ATC clearance requested by the aircraft commander usually reflects some sort of profile optimization, such as a change in altitude to take advantage of better winds, or a course change to avoid turbulence. Thus the crew does perform enroute profile optimization to this extent, and it is, or may be construed to be, dynamic. But, the optimization process is generally gross and does not involve all of the necessary considerations required by the SST, as may be seen in the following paragraphs.

SST Potential Operational Requirements and Constraints

Although the SST profile described in the literature is basically optimized for fuel consumption, there are several indications that such a profile may be modified to consider other factors, such as meteorological conditions. This is certainly understandable because of the effects of the weather on the fuel consumed. It is not enough that an optimum fuel profile for a given flight be based strictly on standard-day weather conditions. The following paragraphs will attempt to show the overall requirement for dynamic profile generation optimized over a more inclusive set of parameters.

For purposes of this discussion, optimum profile is defined as, a flight path through three-dimensional space which most nearly meets all operational requirements and most nearly satisfies all applicable constraints for a given flight operation. Since operational requirements and constraints are to a large extent affected by dynamic situations, it follows that the optimum profile must be dynamic in that it must be continuously revised to reflect any pertinent changes in the situation. The optimum profile may then have its origin and termination points defined by the aircraft's instantaneous position relative to its destination. However, the aircraft's path through space in an optimized situation may conceivably depart from the associated great circle path at any point in time as well as utilize both curvature and step-function vertical movement. It seems appropriate next to justify the requirement for generating optimum profiles. King and Groves (ref. 56) have stated that,

> Because of its characteristics, the SST has, whenever possible, to carry out its flight in accordance with an optimum profile. It has been said that this aircraft is like a projectile and that, once launched, it should follow a certain trajectory without deviation, as otherwise it becomes an uneconomical proposition. This projectile analogy is obviously an exaggeration... The problems will in fact arise in attempting to reconcile the ideal operational flight path with any ATC and environmental restrictions... In this context, it is evident that such an analogy has some truth, and a clear operational requirement, therefore, is that the aircraft shall have the means to minimize the need to deviate from its optimum flight path.

Groves (ref. 59) believes that "The common requirement becomes the ability to adhere to the optimum profile." Polhemus (ref. 53) suggests that,

> The two major constraints to be dealt with are those of flight path optimization--fuel predictive and conservation --and sonic boom minimization. It will certainly be a function of the navigation system, both ground and air, to acknowledge these two major considerations in the course of directing the flight of the aircraft.

White (ref. 65) remarks that,

> In brief, we need maximum flight path flexibility in three dimensions available to dispatchers and flight crews so we can tailor the flight path precisely to get the most from the aircraft... Typical ATC procedures today... may impose serious economic penalties on supersonic transports. The optimum flight paths for a given supersonic transport flight should be flexible yet definable rather precisely in three dimensions, preferably for the total length of flight.

It is indicative, also, that authorization was granted for an FAA-sponsored study of the "Optimization of Fuel on Supersonic Transport Vehicles" to be performed by the Hughes Aircraft Company (ref. 57). The following excerpts are from an article by Power (ref. 57) concerning this program, and are presented here to provide insight into the various parameters which affect an optimum fuel profile, and which would therefore be considerations in optimizing an SST flight profile where all pertinent parameters were included.

> Many parameters with sometimes conflicting requirements affect the fuel consumption of the SST. Almost all of these parameters concern some aspect of navigation, either vertical or horizontal. As a matter of fact, it should be clearly understood at the outset that SST navigation must always be considered as three dimensional. Precise speed-altitude scheduling, particularly during the initial climb-to-cruise phase of the flight, is one of the most critical facets of SST operation.
>
> While fuel consumption is markedly affected by speed-altitude scheduling, so also is the ever present "sonic boom" or ground overpressure caused by supersonic flight. In reality, actual flight operation of the SST, both by the flight crew and with considerations of the air traffic control system, may be defined by sonic boom criteria, with fuel consumption so much a function of vertical navigation as well as horizontal navigation the critical reserve fuel problem is being carefully and exhaustively studied by a joint government and industry committee. Serious implications for both the flight crew and the traffic controller, as well as the overall air traffic control system in the SST era, are contained in the fuel penalties concomitant with incorrect or inadequate flight plan scheduling and execution.
>
> This initial study of optimum flight profiles, carried out over a range of route segments, fuel, and payloads, will define the base from which all other modes of operation will be evaluated. As already mentioned, no constraints will be imposed on the flight profiles during the determination of the absolute optimum operating conditions. However, practical considerations of such things as noise or sonic boom effects, air traffic control restrictions, meteorological effects, and emergency conditions will all act to require some compromise from optimum conditions. One major portion of this study therefore will systematically investigate the effects of these parameters both singly and in combination.

It is immediately obvious that the optimization of a flight path prior to SST takeoff will not be sufficient. There is clearly a need for on-board optimization on a real-time basis.

Of the constraints pertinent to flight path optimization while enroute, there appear to be two which are subject to consideration for modification, fuel reserves over destination and step-altitude scheduling. These two constraints can certainly be considered as functionally interrelated, for if fuel reserve numbers are decreased, the more plausible step-altitude scheduling becomes. On the other hand, the more freedom the SST is allowed in the vertical plane, the more likely it is that current fuel reserve requirements could be met. It seems a certainty that the ATC system will aim for vertical plane navigation, and, hence, profile navigation will succeed step-altitude scheduling.

Feasible Automated Implementation Concepts for SST

The literature reflects a general consensus that this function will be implemented in the SST by means of an airborne navigation computer, or by an airborne computer provided for flight management purposes. Power (ref. 57), discussing the FAA-sponsored study of fuel optimization, states that,

> One of the major objectives of this project is to define exactly what types of data are required by the flight crew in order to achieve optimum fuel utilization. It is highly probable that the traditional flight handbooks or even the hand-held type cruise control computers will not be adequate for the SST operation. There are so many interrelated effects of vertical flight profiles, reserve fuel requirements, sonic boom considerations, atmospheric conditions, and ATC constraints that some form of on-board data processor may be required. Although no a priori conclusions have been drawn, the feasibility of performing both vertical and horizontal navigation using a simplified form of the Central Electronic Management System (CEMS) concept will be evaluated.

> The requirement for on-board determination and revision of optimum profiles based on current situations may reflect markedly into the techniques to be developed for ground control of both en route and terminal area traffic, as well as in the area of data transmission both air-to-ground and ground-to-air. Particularly in the case of diversion to an alternative airport, the capability to utilize an optimum fuel profile may have a drastic effect on the amount of reserve fuel carried or expended.

King and Groves (ref. 56) discussing profile navigation, indicate that,

> The use of an airborne digital computer in conjunction with an accurate ground-based radio aid affords a further possibility of providing the means of navigation in three dimensions by the integration of vertical rate of ascent or descent with horizontal progress, already a growing requirement in present-day operations. The operational consequences of climb and descent restrictions for the SST make this requirement essential. The basic difficulty is the present inability of A.T.C. to monitor continuously the altitude of climbing and descending aircraft and thus to determine, within adequate safety tolerances, when specific altitudes are vacated. In consequence, either whole blocks of altitudes have to be reserved for this purpose or aircraft have to proceed in a series of "steps" associated with time and geographical positions for separation purposes. This procedure is wasteful of airspace and imposes a high workload on the controller.
>
> One of the potentials of the type of system described is its capability, coupled with a height sensing element, of accurately defining the slant track which an aircraft should follow. The airborne computer forms the means of combining, for this purpose, navigational information in the horizontal plane with vertical progress. The three-dimensional information thus derived would be utilized to indicate the required action to maintain slant track, or more probably would be fed directly into the autopilot. Furthermore this information in digital form could be fed via an air-to-ground data link into any automatic A.T.C. devices requiring accurate information concerning aircraft flight paths. The inherent advantages of this arrangement are:
>
> a. For the pilot:

    i. Accurate compliance with A. T. C. clearances for altitude changes.

    ii. Immediate indication of the optimum vertical flight profile including commencement of descent.

    iii. Specific indication of the optimum altitude and position for transition from subsonic to supersonic flight and vice versa to minimize the sonic boom effects on the ground.

b. For the A. T. C. organization:

    i. Reduction of longitudinal separation between aircraft during altitude changes.

    ii. The ability to allocate vertically separated slant tracks to climbing or descending aircraft.

    iii. The possibility of combining horizontal and vertical separation to provide a concept of volumetric separation, leading to much more efficient use of the airspace.

    iv. Accurate and continuous updating of three-dimensional flight data, thus providing a realistic basis for conflict avoidance.

Discussing CEMS for the SST, Richardson (ref. 52) states that,

> With an airborne computer tied in to the various aircraft subsystems, it is continuously aware of such pertinent information as aircraft present position, altitude, airspeed, ambient temperature, local wind, fuel remaining on board, fuel consumption, and current flight plan. It is now possible to utilize all of this basic information in conjunction with the cruise control laws to arrive at an optimum vertical and horizontal flight profile. . . The capability of the airborne computer to handle enroute flight plan changes, either selected by the flight crew or commanded by a two-way data link, allows it to render a unique and valuable service presently unavailable in existing or proposed systems.

It is evident that successful control of the ground shock-wave magnitude problem through flight path optimization for this parameter would undoubtedly require availability of a high-speed computing technique capable of predicting an optimum flight profile with this parameter minimized. The degree of concern in both government and industry with this problem, along with the complexity involved in control, would appear to clearly dictate the use of an airborne computer capable of a numerical analysis of the problem, and an extrapolation of a profile to minimize the problem where such a profile is the result of a tradeoff analysis with other critical parameters such as fuel optimization.

The requirement for complete automation of this function is further borne out by the manner in which the product of the function is to be utilized. This function would be quite inefficient if its outputs were in terms of gross increments of track errors in the lateral and longitudinal planes, and velocity errors in the vertical plane. What is evidently much more to be desired is a rather continuous output of error increments in all three planes representing a smoothed error function immediately translatable to similarly smoothed increments for appropriate flight control commands in pitch, roll, and yaw. Such correction increments together with similarly smoothed increments for throttle adjustments, would permit the aircraft to maintain, or regain and maintain, the optimum profile with the <u>optimum</u> number and magnitude of adjustments. Such increments may be beyond the state-of-the-art for useful incremental displays, and will undoubtedly be beyond the capabilities of man to efficiently interpret and execute the required corrective actions at the resolution level achievable by automation. It must be remembered that the optimum profile will be dynamically derived on a real-time basis. The insertion of man in the servo-system would generate a response lag in the loop of a magnitude that over a period of flight time would result in excessive penalties for off-optimum performance.

There is clearly one area of the flight path optimization process in which automation, if feasible, would be clearly unnecessary--the area of significant changes in the route. Such changes are defined as major modifications to the flight path (or flight plan) as a result of (1) changes in ATC clearance for whatever reason, (2) hazardous weather avoidance, and (3) diversions to an alternate destination. When a situation arises which may be the basis for a significant change in the route, there are judgmental and decision-making processes involved in assessing that situation and arriving at the necessary corrective actions. Obviously, these processes are as numerous as are the situations which may arise. In order to automate the correction action for any given situation, every possible combination of contingencies which could generate such a situation would have to be known and defined in numerical terms, given an appropriate series of corrective actions, and properly stored and addressed for immediate retrieval. It is obvious that a computer of practically infinite capacity would be required. Even if that were possible, man would still be required to monitor the action taken, and override the system should there be a blunder in the assessment or in the execution of corrective procedure. Here, the training and experience of man, in both piloting and navigational disciplines, is indispensable.

When significant changes in route are required, the navigation system would continue to function, and the optimum profile generator would continue to exercise control over the three-dimensional progress of the aircraft until human judgmental and decision-making processes resulted in the optimum corrective action to handle the situation. The nature of the situation and of the required corrective action would affect that point at which the automated navigation system could be employed. For example, if ATC were to require a later ETA to avoid a holding situation, the navigation system might certainly be such that flight management could enter a revised destination ETA into the system, and the optimum profile generator would immediately compute a revised profile with all pertinent parameters optimized for the ETA change, and there would be no reason to disengage the navigation system from the flight control and power plant systems. Similarly, for weather avoidance, the manual entry of a set of geographical coordinates representing the height of the chord describing the optimum lateral excursion consistent with the required miss-distance and destination (or possibly the point at which deceleration and descent is to be initiated) may be sufficient information for the navigation system to optimize the flight profile accordingly.

In Figure 48, barring exceeding ATC restrictions on available volumetric airspace, flight path optimization for storm avoidance could conceivably involve beginning the lateral excursion at point 4, which is arbitrarily defined as the last possible point to initiate a turn which would:

1. Insure that the required miss-distance would be achieved.
2. Insure the degree of turn necessary to intercept the point defining minimum miss-distance would not exceed the performance envelope of the aircraft, nor exceed the acceptable g force level for passengers.
3. Insure zero overshoot beyond the minimum miss-distance point.
4. Insure that the degree of turn necessary to regain and maintain the optimum profile in the lateral plane would not exceed the performance envelope of the aircraft, nor exceed the acceptable g force level for passengers.

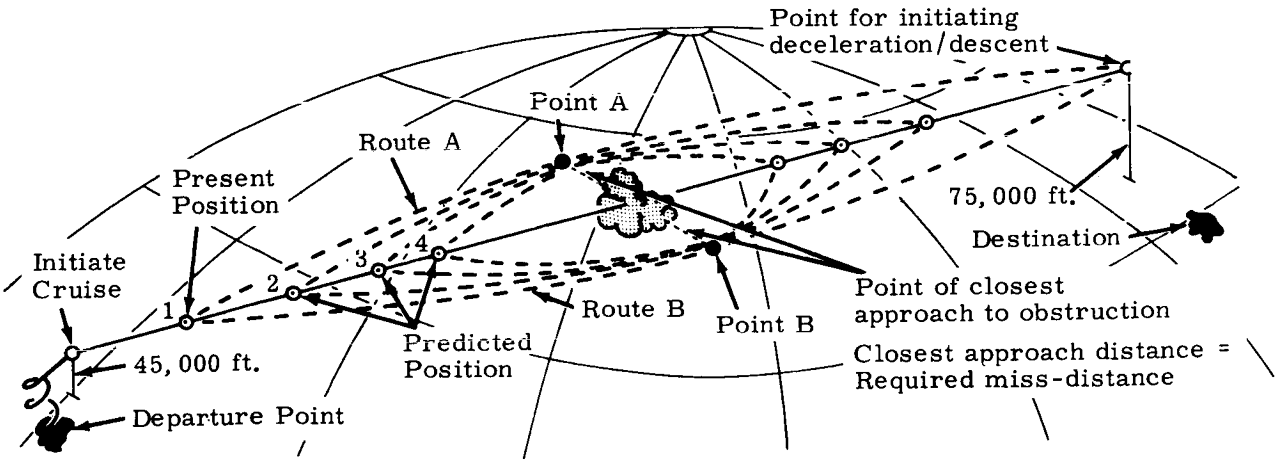

Figure 48. Flight profile optimization problem.

It also seems reasonable to assume that point 1 may be a better initial point for such a maneuver, if a truly optimum profile is derived. The computer, given present position and destination coordinates, and a set of geographical coordinates representing required miss-distance points on either side of the obstruction, could be programmed to derive the optimum flight profile between any such three points in space considering all of the relative parameters and constraints, and could develop the necessary data defining the flight control and power plant operation commands, using essentially the same technique as for any two points in space. Due to its speed and capability to handle complex computations, the computer could perform a series of calculations designed to pick the initial point of the maneuver consistent with the required miss-distance, and to ascertain the relative merit of returning to the original profile in the lateral plane, and if so, at what point the original profile should be regained. Or, if necessary for ATC compliance, the computer could perform the same function, given an IP and a series of two or more vectors.

It would appear then, that man would actually perform the situation assessment, would determine to a lesser or greater degree the fixed parameters defining the necessary corrective action, and would enter these parameters into the navigation system. It is evident, however, that at this point a computer would be much more suited to developing the implementation commands representative of the corrective action and informing flight management of its problem solution in the form of a revised optimum profile and the quantitative impact of this revision on critical parameters such as destination ETA, or fuel reserves over destination. Man could either then accept the solution or override the navigation system based on his judgment of the total impact of the situation on the safety and efficiency of the flight operation.

Feasible Manual Implementation Concepts for SST

Whenever the terms optimum or optimization are used, it is necessary to define them, particularly if a trade-off analysis of means is involved. Optimum implies relationships among involved means or parameters for obtaining some common objective; obviously, the term itself becomes relative when the means or parameters are varied. Given nothing more than a gross estimate of present position, a map showing destination and present position, and a magnetic compass, a pilot optimizes his flight profile by heading corrections, And, in the true sense of the word, he has developed an optimum flight profile, based on the information and means available to him. Now, given drift, he can develop a relatively more optimum profile in the sense of achieving the objective. And, as more parameters are known, and means are available for their interpretation in light of the total situation, the optimization process approaches the objective even more closely. The important point is the the degree of optimization may vary widely along a continuum defined by means.

Flight crews on today's subsonic jets perform the profile optimization function in the cockpit while enroute. The supersonic transport faces essentially the same navigation problems, and its performance is affected by essentially the same parameters, with one or two major exceptions such as sonic boom control, potential exposure to radiation storms, and the like. The case for automating the flight profile optimization function in the SST perhaps best summarized by the following statements made by Groves (ref. 59) in his discussion of area coverage navigation systems. With regards to the operational requirements, Groves remarked that,

> The general characteristics of an SST, be it a Mach 2 or Mach 3 version, have been adequately defined and need no amplification here. Similarly those characteristics which relate to the navigation requirements have been covered, not only at this Symposium but also at numerous international gatherings. Perhaps I may summarize these by reference to the three stages of flight:
>
> a. Subsonic phase from terminal area to the transition area and vice versa.
>
> b. Transition phase of acceleration to supersonic speed and of deceleration from supersonic to subsonic speed.
>
> c. The supersonic phase.
>
> Certain features are obviously common to these various flight stages. A viable and economic operation is very much a function of fuel consumption. The transition phase from the subsonic to supersonic flight is critical in this respect. Difference in ambient temperature from those forecast can entail high fuel penalties. Delayed or interrupted climbs and descents, the assignment of non-optimum Flight Levels and the incidence of holding, all for A. T. C. reasons, can upset the economy of operation. The common requirement becomes the ability to adhere to the optimum profile. *

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* Underscoring throughout this quotation is the authors.

> Mention should also be made of the effects of turbulence, precipitation, jet streams and thunderstorms, all of which raise the need to cater for their avoidance and for the rapid resumption of the planned flight path.
>
> Sonic boom considerations make these (transition) phases most critical, in the selection of areas over which transition may take place. Furthermore the ambient temperature distribution becomes a decisive factor in defining the transition area with precision and in the need to vary the flight profile accordingly. As a corollary, the navigation system must enable the pilot to execute the transition in the defined area and in accordance with the A. T. C. clearance issued for the flight.
>
> The requirement for cruise/climb and cruise/descent becomes the significant factor in the supersonic regime. The use of vertical separation will be highly restrictive, and whilst longitudinal separations must be reduced, close lateral separation becomes essential. The need is for an accurate and flexible navigation system to permit A. T. C. to apply clearances along laterally separated tracks. Changing meteorological conditions or the need to divert may require flight plan modification and the issue of re-clearances by A. T. C. The navigation system must therefore provide clear and continuous position presentation to facilitate adherence to the cleared flight path. Furthermore diversion action should be clearly apparent from the navigational presentation.
>
> The thoughts outlined above concerning the operational requirement for navigation in the SST are by no means revolutionary. With the exception of the need to define transition areas, the requirements apply in most cases to the current breed of subsonic jets. The basic difference becomes apparent in the degree to which the requirement is critical for economic SST operation. More particularly, it is the necessity for accurate profile flying which accentuates the difference.

And in his discussion of a system to meet such requirements, Groves goes on to say that,

> There is of course much sheer common sense in using compound systems. Ideally the two elements should be combined in such a way that the complementary characteristics of each of the data sources are employed to the best possible advantage. For maximum utilization, particularly for SST operations such compound systems must inevitably employ an airborne digital computer. Its function would be to integrate the basic inputs for the provision of a clear and continuous presentation of the navigational situation to the pilot. It would perform the additional task of supplying navigational data to the flight director system, for auto-coupling, for the provision of accurate E. T. A. and to define the slant track or profile which the aircraft should maintain.

While, to be sure, the case made would appear to be for adherence to a fixed optimum profile and for a particular system configuration, this is all the more reason for automating the optimization process in a dynamic situation based on real-time assessment and integration of the pertinent information. In summary, it seems clear that manual implementation of profile optimization would involve essentially the same procedures followed today, already discussed under Current Jet Implementation Concepts above, and that such procedures would be woefully inadequate for SST operations.

SUBSONIC SPEED REGIME

Assuming that the SST returned to the subsonic speed regime to continue its flight or returned to base for some reason other than failure of the navigation system, optimum profile generation would continue to be performed by the automated system.

If the reason for return to the subsonic speed regime was catastrophic failure in the navigation system, then profile optimization would proceed as discussed in Current Jet Implementation Concepts. The most significant impact of this situation is that the return to subsonic operations greatly enhances the feasibility of a manual optimization process due to the following changes in pertinent parameters:

1. Optimization of the profile for sonic boom minimization is no longer a requirement.

2. As a result of (1) above, optimization of the profile for consideration of adverse winds becomes solely a function of fuel consumption, since focusing effects are no longer a consideration.

3. As a result of (1) above, aircraft attitude changes and maneuvers need not consider the focusing problem.

4. The manual profile optimization process for any parameter is considerably enhanced by the increased crew response time for reaction to a given situation brought about by the decrease in aircraft closure with the situation.

5. There is a pronounced increase in the acceptable maneuverability envelope due to the slower speeds resulting in (a) a corresponding decrease in g forces which will allow application of pitch and roll commands of higher magnitudes, and (b) off-track components decreasing in magnitude with corresponding capability for maintaining track accuracy following turns of considerably higher bank angles.

One parameter of the optimization program, fuel consumption, would tend to become extremely critical. This is not to detract from its obvious importance in the supersonic regime. If, however, fuel reserves are based on completing the flight at supersonic speeds, the return to the subsonic regime, even though fuel consumption rates may be somewhat slower, may increase the block time to the extent that inadequate fuel reserves are available over the destination. This problem will undoubtedly be of paramount importance, and consideration should be given to a standby or back-up system, or automated capability for an emergency or non-routine fuel profile optimization process which can both (1) determine the feasibility of making the destination with fuel remaining on board, and (2) develop the necessary velocity scheduling and associated power plant adjustments to execute the optimum profile, such that the destination or a prescribed alternate is reached with the maximum fuel reserves possible.

7.12 FUNCTION 7.12 MAINTAIN FLIGHT PATH FOR SIA

Purpose

The purpose of this function is to:

1. Delineate the optimum flight path from the SIA initiation point to interception of the ILS gates, considering SIA cleared by ATC, speed-altitude scheduling, and meteorological conditions.

2. Provide continuous presentation of the navigational situation in the following respects:

   a. Parameters representative of the optimum profile (SIA) being followed suitable for pictorial display in the cockpit, and for automatic transmission via data link to appropriate ground installations.

   b. Parameters representative of off-profile error components in all three planes suitable for transduction into flight control commands and throttle adjustments, and optimum in the sense of regaining the track with the most acceptable aircraft manipulation considering the maneuver limits imposed by the aircraft performance envelope and passenger considerations.

   c. Details of the requirement for track excursion exceeding authorized limits for hazardous weather avoidance, and for optimization of fuel flow considering ambient temperature distribution.

d. Parameters representative of profile modifications for track excursion for reasons in (c) above suitable for transduction into velocity scheduling commands (throttle adjustments) and flight control commands (all attitude control).

Current Jet Operational Requirements and Constraints

As is the case with SID's, current subsonic jets are issued a clearance for the execution of a Standard Instrument Approach (SIA) which includes the necessary information for the aircraft to enter the terminal area control zone on a course consistent with the designated traffic pattern to be flown for proper interception of the ILS gate. There are several SIA's for any given terminal and the assignment of a given SIA to a given flight will have considered such parameters as:

1. Flight origin point and inbound heading
2. Operational runway in use
3. Weather conditions
4. Aircraft performance characteristics
5. Surrounding terrain, obstructions, etc.
6. Noise abatement considerations
7. Conflict avoidance

The aircraft is required to execute the cleared SIA with the greatest possible accuracy and precision because of the relative high traffic density in terminal control areas. Deviations from the SIA are not permitted without prior ATC approval. The lone exception to this rule is exercise of pilot judgment in an emergency situation such as imminent collision. However, flights are under constant radar surveillance and may have their respective SIA's altered by radar vectors from ATC, in which case they must follow the vectors assigned.

The fact that an SIA is issued and that the flight is under constant radar surveillance does not reduce the crew's responsibility for knowing the location of the aircraft at all times. For example, an SIA may include instructions to remain at some fixed altitude on such and such a heading until some low-level airway has been crossed. It is clear that continuous knowledge of aircraft position is an absolute requirement for compliance with such directives.

The following regulations are applicable:

FAR 91.117, ref. 13:

Takeoff and landing under IFR.

(a) *Instrument approaches to civil airports.* Unless otherwise authorized by the Administrator (including ATC), each person operating an aircraft shall, when an instrument letdown to an airport is necessary, use a standard instrument approach procedure prescribed for that airport in Part 97 [New] of this chapter.

(b) *Use of low or medium frequency simultaneous radio ranges requiring flight check.* When a flight check of a low or medium frequency (200 through 415 KCS) simultaneous radio range is required, a Notice to Airmen will be issued advising that the range is "ground checked only, awaiting flight check" and the range may be used as a homing facility and in addition may be used as an ADF instrument approach aid if an ADF procedure for the airport concerned is prescribed by the Administrator or if an approach is conducted using the same courses and altitudes for the ADF approach as those specified in the approved range procedure.

(c) *Landing minimums.* Unless otherwise authorized by the Administrator, no person operating an aircraft (except a military aircraft of the United States) may land that aircraft using a standard instrument approach procedure prescribed in Part 97 [New] of this chapter unless weather conditions are at or above the landing weather minimums prescribed in that Part for the procedure used.

(d) *Civil airport takeoff minimums.* Unless otherwise authorized by the Administrator, no person operating an aircraft under Part ——, ——, ——, ——, (present Parts 40, 41, 42, 44) or 135 [New] of this chapter may take off from a civil airport under IFR unless weather conditions are at or above the weather minimums for IFR takeoff prescribed for that airport in Part 97 [New] of this chapter.

(e) *Military airports.* Unless otherwise prescribed by the Administrator, each person operating a civil aircraft under IFR into, or out of, a military airport shall comply with the instrument approach procedure and the takeoff and landing minimums prescribed by the military authority having jurisdiction on that airport.

(f) *Use of radar in any instrument approach procedure.* When radar is approved at certain locations for ATC purposes, it may be used not only for surveillance and precision radar approaches, as applicable, but also may be used in conjunction with instrument approach procedures predicated on other types of radio navigational aids. Radar transitions may be authorized from established holding fixes to final approach positions in relation to the ILS or other types of radio navigational aids upon which instrument approach procedures are predicated. Upon reaching a final approach position in relation to these facilities, the pilot will either continue a surveillance or precision approach to a landing or complete his instrument approach in accordance with the procedure approved for the facility in question.

(g) *Limitations on procedure turns.* In the case of a radar initial approach to a final approach position or a timed approach from a holding fix, no pilot may make a procedure turn unless, when he receives his final approach clearance, he so advises ATC.

FAR 121.567, ref. 11:

Instrument approach procedures and IFR landing minimums.

No person may make an instrument approach at an airport except in accordance with IFR weather minimums and instrument approach procedures set forth in the certificate holder's operations specifications.

ICAO Reg. 3.2.6, ref. 14:

Operation on and in the vicinity of an aerodrome.

An aircraft operated on or in the vicinity of an aerodrome shall, whether or not within an aerodrome traffic zone:

a) observe other aerodrome traffic for the purpose of avoiding collision;

b) conform with or avoid the pattern of traffic formed by other aircraft in operation;

c) make all turns to the left, when approaching for a landing and after taking off, unless otherwise instructed;

d) land and take off into the wind unless safety or air traffic considerations determine that a different direction is preferable.

Current Jet Implementation Concepts

Maintaining the assigned flight path in executing an SIA involves the use of fairly standard tools in current jet operations. A flight director display may be used to indicate aircraft heading and relative heading to desired course to steer, as well as position of the aircraft relative to the desired track. A bank indicator may be used to indicate rate-of-turn, and an altimeter used for altitude and rate-of-descent. Position of the aircraft is obtained from the VOR/DME display read-out. Means are also available for ascertaining fuel consumption rates. With these tools, the pilot manipulates the aircraft in accordance with his displayed navigational data such that the SIA track and altitude components are within acceptable limits of the assigned values.

SST Potential Operational Requirements and Constraints

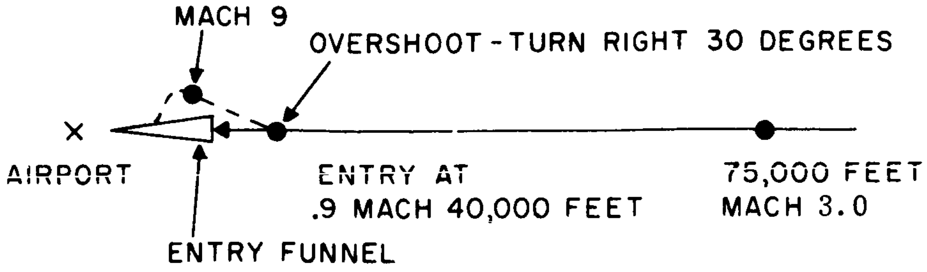
For purposes of clarity, the SIA phase of the SST flight originates at that point where the aircraft re-enters the subsonic speed regime following deceleration/descent, and terminates when the aircraft is at final approach altitude and immediately prior to ILS localizer intercept.

With some possible qualifications, it may be stated that the requirements and constraints discussion for Function 7.2 are the same as those which should be considered in the execution of the SIA. Economy will still be a function of fuel optimization which will depend on both optimized throttle manipulation and block time. Block time can certainly be decreased by allowing the SST to take advantage of its faster speeds. Fuel consumption can also be optimized during the SIA phase by consideration of the ambient temperature distribution, and so on. Current thinking is that the SST must operate, however, as "just another aircraft" during this phase of the flight. The possibility of holding is assumed to be minimized by means of ETA revision through the cruise phase of the flight, but it will still need to be considered. It is conceivable, however, economics notwithstanding, that the requirements and constraints which are ATC-imposed may not be as critical as during the SID phase since the aircraft has essentially met the objective, i. e., arrival at the destination point. This undoubtedly will not be true in all cases since the hold condition may be a function of a possible necessity to divert to an alternate. Much depends on the fuel reserves over destination requirement, and how well the vehicle meets that requirement.

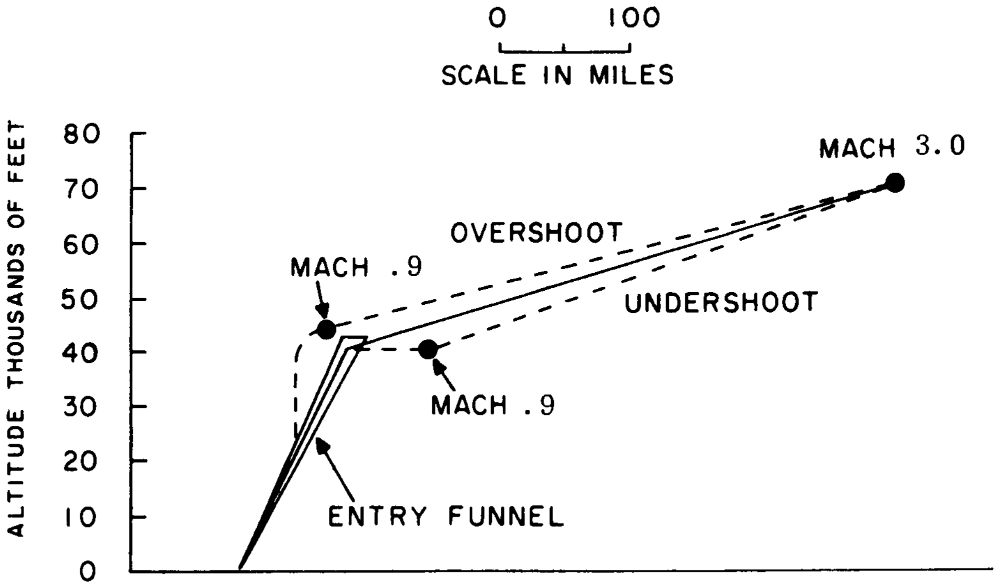
There is an economic difference in the criticality of the SST fuel situation existing, say, at the completion of the SID (through entry into the supersonic speed regime) and at the point where the SIA is to be initiated. Clearly, an SST which has made the transition to the supersonic speed regime, but due to inadequate fuel remaining, must return to its origin point or land for refueling, faces the possibility of revenue loss, or, at best, an extreme increase in aircraft-mile costs for that flight. In contrast, an SST which arrives over its destination with inadequate fuel reserves can declare an emergency and receive special consideration from ATC. It will not experience the same loss of revenue as in the first example, and will have much more tolerable increases in aircraft-mile costs.

Hooton (ref. 51) in a discussion of SST navigation in the vertical plane, discusses this phase of the flight.

> The SST will initially require deceleration from cruising Mach to subsonic flight (probably carried out during a shallow letdown), followed by a steeper descent into the terminal area at speeds below Mach 1. Figure (49) shows such a technique.
>
> The initial descent could start 500 miles from the destination, and in the final subsonic descent, speeds between 300 and 500 knots are likely, flight path angles being between 5^{o} and 10^{o}. These angles are a little steeper than those of most present-day aircraft.
>
> If the air traffic control situation demands that the aircraft enter a terminal area "funnel"--such as shown in Figure 49--we must ensure that the pilot is capable of flying and navigating over the initial deceleration phase such that overshoots or undershoots are reduced to a minimum.
>
> At the present time the en route traffic controller in a busy terminal area usually has the decision as to when a descent may be started--as indeed he should. The SST will require that the controller be given much more information than at present on the scheduled flight path and flight times, very close cooperation with the pilot will be necessary, and the pilot must have the navigation aids to do what is asked of him. If these conditions are not met, the controllers will be faced with unpredictable control situations and airline economics will suffer.



PLAN VIEW



SIDE VIEW

Figure 49. SST deceleration technique (from ref. 51).

It should also be remembered that by the time the SST is in operation, terminal area sequencing systems may have been introduced. If speed control is to be used the aircraft characteristics must be considered, particularly with respect to drag producing devices which allow speeds to be controlled for a given angle of descent. If path-stretching is to be employed, the effects on block time and fuel consumption must be considered.

In any event, provision for means to satisfy the requirements and constraints in maintaining the SID certainly would assure the means for meeting the requirements and constraints imposed during the SIA phase of flight from the viewpoint of navigation.

Feasible Automated Implementation Concepts for SST

The automated concept for executing this function is precisely the same as for that for the execution of the SID phase, with the possible exception of a different control law than speed-altitude scheduling. Richardson (ref. 52) indicates that,

> Considering the descent phase of the vertical profile, a slightly different technique was used. In order to achieve proper terrain clearance on approach, and to insure accurate spatial positioning of the aircraft, a trajectory of altitude-vs. -distance was used as a control law... For precise, complete control of the trajectory, automatic throttle control could be used as an airspeed/rate-of-descent control.

For essentially the same reasons, it would appear highly desirable to have the SIA phase of the flight available in appropriate numerical form. With appropriate computer programming, it could provide the necessary data for transduction into flight control commands to the auto-pilot and throttle adjustment commands to the auto-throttle, so as to provide complete automatic control of the SST throughout the entire SIA phase. Such an arrangement would help assure that the optimization process insures the economic operation required, and at the same time provides the necessary navigational accuracy for meeting ATC requirements.

Feasible Manual Implementation Concepts for SST

The implementation of this function by conventional techniques would incur the same penalties in off-optimum performance as discussed for the SID phase, although there may be a relative decrease in the criticality of such operation from an economics point of view. Hooton (ref. 51) points out some possible weaknesses in the standard navaid to be used at the advent of the SST.

Aircraft height for slant airways can be derived from either pressure altimeters or by some form of angular radar or radio device such as a "long-range ILS." The latter would guarantee altitudes above mean sea level; pressure altimeters do not, because of air density/temperature changes. Since the two are not compatible and pressure altimeters will probably be with us for a long time, let us presume that height information will still be obtained from pressure altimeters.

The logical navaid to examine is VORTAC, that is, the combination of VOR angular information and DME information. Figure (50) shows two VORTAC's in relationship to a desired slant path, shown in both plan and side views.

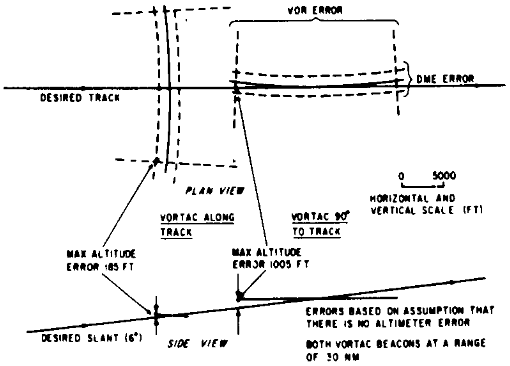


Figure 50. Inherent errors of VORTAC navigation (from ref. 51).

Since ideal siting of VORTAC's would require many more VORTAC's than is practicable, and the amount of airspace used increases as a function of slant airway errors, it appears, after detailed study, that VORTAC in its present form will not meet the requirements for slant airways.

For universal application of the slant airway concept, the following navaid requirements may be necessary:

> 1. Across-track accuracy errors not to exceed ±0.75 n mi.
>
> 2. Along-track accuracy errors not to exceed ±1% of aircraft distance flown. (Greater accuracy is required in the airport vicinity because of conflicting routes and the fact that climb angles are at their maximum. Accuracy may be relaxed at greater ranges and higher flight levels).
>
> 3. These errors not to be exceeded within 200 n mi radius of any given terminal area.
>
> Use of a rho/rho computer using pairs of DME's appears to offer a reasonable solution if VORTAC cannot meet the specifications.
>
> VORTAC alone would allow a limited number of SST descent "funnels" or slant airways, but other types of aircraft could not use them and would require routing around them during their use. If the basis of equal priority for all users of the airspace can be relaxed VORTAC does offer a limited solution for the final descent path of the SST, although it should be emphasized that good accuracy is still required for the initial deceleration phase.
>
> However, questions of flight planning, flexibility of routing, and controller displays still remain and require solution.
>
> None of these problems is insurmountable but they must be faced soon if we are to provide the right facilities for SST operations, from the points of view of both the controllers and of the airlines and their pilots.

A salient remark by Richardson (ref. 52) indicates the impact of navigational accuracy as far as an optimization process is concerned. He states that:

> In general, the digital computer quantization is such that the input signal accuracy becomes the governing accuracy of the CEMS. The digital computer does not contribute any measurable additional inaccuracies.

It is obvious that the price in decreased economy attributable to conventional navigation techniques is solely a function of navigational accuracy.

And, moreover, it appears that manual (or conventional) techniques will be sorely pressed to provide the accuracy required for conflict avoidance, if such is indeed feasible via conventional techniques.

7.13 FUNCTION 7.13 MAINTAIN FLIGHT PATH FOR ALL-WEATHER LANDING

Purpose

The purpose of this function is to provide:

1. Parameters representative of the aircraft's position in three-dimensional space suitable for continuous display in the cockpit;
2. Parameters representative of off-profile error components suitable for:
   - a. Transduction into appropriate commands for the auto-pilot and auto-throttle systems;
   - b. Transmission to the appropriate ground facility;
   - c. Continuous display in the cockpit in order that the relationship between the optimum profile for the landing phase, the present position of the aircraft, and the corrective action to be taken by the system, is clearly understandable by flight management;
3. Parameters representative of the optimum profile for the landing phase suitable for continuous display in the cockpit.
4. Parameters clearly defining the decision-gate for the landing, and parameters indicative of any potential problem associated with the execution of a missed-approach, all appropriate for display in the cockpit.

For purposes of this discussion, this function is initiated with the aircraft at 1500 feet on a constant heading aligned with the runway, when the ILS localizer has been intercepted and the aircraft is configured for final approach and ready to begin its final descent. The function is complete when the aircraft has decelerated to taxi speed and is off the operational runway.

Current Jet Operational Requirements and Constraints

The following specific regulations apply:

FAR 91. 87, ref. 13:

Operation at airports with operating control towers.

> (d) *Minimum altitudes.* When operating to an airport with an operating control tower, each pilot of—
>
> (1) A turbine-powered airplane, shall, unless otherwise required by terrain, obstacles, or applicable distance from clouds criteria, maintain within the airport traffic area an altitude of at least 1,500 feet above the surface of the airport until further descent is required for a safe landing;
>
> (2) A large airplane approaching to land on a runway being served by an ILS, shall, if the airplane is ILS equipped, fly that airplane at an altitude at or above the glide slope between the outer marker (or the point of interception with the glide slope, if compliance with applicable distance from clouds criteria requires interception closer in) and the middle marker; and
>
> (3) An airplane approaching to land on a runway served by a visual approach slope indicator, shall maintain an altitude at or above the glide slope until a lower altitude is necessary for a safe landing.
>
> However, subparagraphs (2) and (3) of this paragraph do not prohibit normal bracketing maneuvers above or below the glide slope that are conducted for the purpose of remaining on the glide slope.

FAR 91.117, ref. 13:

Takeoff and landing under IFR.

(2) The aircraft is in a position from which a normal approach can be made to the runway of intended landing and the approach threshold of that runway or the approach lights or other markings identifiable with that runway are clearly visible to the pilot.

If, after descent below the minimum altitude, the pilot cannot maintain visual reference to the ground or ground lights, he shall immediately execute the appropriate prescribed missed approach procedure.

(c) *Landing minimums.* Unless otherwise authorized by the Administrator, no person operating an aircraft (except a military aircraft of the United States) may land that aircraft using a standard instrument approach procedure prescribed in Part 97 of this chapter unless weather conditions are at or above the landing weather minimums prescribed in that Part for the procedure used.

(h) *Descent below IFR landing minimums.* No person may operate an aircraft below the applicable minimum landing altitude unless clear of clouds. In addition, no person may operate an aircraft more than 50 feet below that minimum altitude unless—

(1) The landing minimums are at least ceiling 1,000 feet and visibility two statute miles; [or]

(i) *Inoperative ILS components.* The components of a complete ILS are localizer, glide slope, outer marker, middle marker, and approach lights. However, a compass locator at an outer or middle marker site may be substituted for the outer or middle marker, respectively. Unless otherwise specified in Part 97 of this chapter, no person may begin an ILS approach when any component of the ILS is inoperative, or the related airborne equipment is inoperative or not utilized, except as follows:

(1) When only one component (other than the localizer) is inoperative and all other components are in normal operation, a straight-in approach may be made if the ceiling and visibility at the airport are at least equal to 300 feet and ¾ statute mile, respectively.

(2) When the localizer and the outer marker are the only components in normal operation—

(i) A circling approach may be made if the ceiling and visibility are equal to or higher than the minimums prescribed for a circling approach; or

(ii) A straight-in approach may be made if the ceiling and visibility at the airport are at least equal to 300 feet and one statute mile, respectively.

(3) In the case of an alternate airport, when only one component (other than the localizer) is inoperative and all other components are in normal operation, a person may make an approach if the ceiling and visibility at the airport are at least equal to the minimums prescribed for use of the airport as an alternate airport.

ICAO Reg. 3. 2. 2. 4, ref. 14:

Landing.

An aircraft in flight, or operating on the ground or water, shall give way to other aircraft landing or on final approach to land.

When two or more heavier-than-air aircraft are approaching an aerodrome for the purpose of landing, aircraft at the higher altitude shall give way to aircraft at the lower altitude, but the latter shall not take advantage of this rule to cut in in front of another which is on final approach to land, or to overtake that aircraft. Nevertheless, power-driven heavier-than-air aircraft shall give way to gliders.

> *Emergency landing.* An aircraft that is aware that another is compelled to land shall give way to that aircraft.

ICAO Reg. 3.2.6, ref. 14: Operation on and in the vicinity of an aerodrome.

> An aircraft operated on or in the vicinity of an aerodrome shall, whether or not within an aerodrome traffic zone:
>
> *a)* observe other aerodrome traffic for the purpose of avoiding collision;
>
> *b)* conform with or avoid the pattern of traffic formed by other aircraft in operation;
>
> *c)* make all turns to the left, when approaching for a landing and after taking off, unless otherwise instructed;
>
> *d)* land and take off into the wind unless safety or air traffic considerations determine that a different direction is preferable.

Current Jet Implementation Concepts

At the date of this writing, there are no existing all-weather landing systems sanctioned for commercial airliner (jetliner) utilization. The data in the preceding paragraph define the constraints under which current subsonic jets must operate. Aids are available for executing IFR approaches. However, airports must have measured ceiling and visibility within the constraints stated above or the aircraft must be diverted to an alternate airport where such minima are not exceeded. The current standard aid for IFR approaches is the Instrument Landing System (ILS). Many current airlines have incorporated coupling systems which permit ILS and auto-pilot integration such that the airborne system, following engagement is essentially automatic, the exception being manual throttle control. However, if the pilot does not have visual contact with the runway at the time the minimum altitude is reached, he must execute a missed approach and request ATC clearance to divert to a prescribed alternate, or hold until better weather conditions exist, based on parameters such as the meteorological forecasts and fuel remaining on board.

There are systems in various stages of development and usage which may be categorized as all-weather, automatic landing systems. Farr and Schmitz (ref. 72) discuss some of the systems currently being evaluated,

> The North American Aviation APN-114 flare-out altimeter system is a precision instrument designed to provide extremely accurate elevation information using a sophisticated airborne flight-control computer which receives azimuth information from ILS ground equipment. With the availability of improved ILS directional localizers, this equipment could be used for near-zero-visibility landings.
>
> NAFEC is testing the British Government's Blind Landing Experimental Unit (BLEU) system. This system utilizes ILS signals until the aircraft reaches an elevation of approximately 300 feet. From this point, azimuth information is received from "leader cables" which are installed in the approach area and alongside the runway to a distance of about 5,000 feet out from the end of the runway while height information is obtained from an airborne flare-out radio altimeter. These altimeter and azimuth data are fed to a special pilot display. The APN-114 and BLEU differ only in flare-out computer philosophy.
>
> Bell has developed a military landing system (GSN-5) which is being tested at NAFEC. The GNS-5 employs directional ground-radar tracking. The system utilizes ground computer-derived signals which are transmitted to the aircraft for automatic (hands-off) approach and landing. The airborne equipment includes an extremely fine auto-coupler, a special function box, and a small aluminum corner reflector mounted on the outside of the aircraft to furnish a good radar return. On the ground (to one side of the runway) a radar scanner and computer in a mobile unit track the aircraft and constantly compare the aircraft track being made good with the optimal track which has

been previously fed into the computer. Deviations are corrected by automatic radio transmissions to the plane's auto-coupler. Considerably more testing at NAFEC will be required before official FAA sanction can be made.

In the long range field, NAFEC is also testing the Gilfillan REGAL (Range and Elevation Guidance for Automatic Landing) system. This system uses a ground-based scanning antenna. Aircraft receives accurate three-dimensional position information again starting at an elevation of about 300 feet on the ILS glide slope. This information is then used to generate the approach and flare-out commensurate with the requirements of the particular aircraft. Aircraft can be brought down manually, or automatically if the system is hooked into the plane's auto-coupler. REGAL may be operational about 1965-66.

The Smith Aviation Division of S. Smith & Sons Ltd. (England), has developed an autopilot, SET. 5 for automatic landing. British European Airways will use it for fully automatic landing. The manufacturer predicts a realistic date for full civil Autoland (automatic landing) as early as 1968, although they feel the system could be reliably used at an earlier date. A multiplex SEP. 5 has been flown in Smith's Dakota aircraft for 2 years and the company has completed over 4,000 automatic landings using the BLEU installation at Bedford, England.

Standard Telephone and Cable of England has developed a radio altimeter (STR-40) for use in automatic landing that has an extremely high accuracy with altitude error at touchdown not exceeding 1 foot. It is hoped that by 1963 an ILS localizer will be in operation that will provide azimuth guidance all the way down to the runway and a new directional glide slope which will be reliable down to 200 feet or even closer.

These are just a few of the systems being developed and tested. The airline companies have made it quite clear they are in the market for a good reliable automatic landing system that will allow them to begin all weather operations. As a result, many electronic companies are just now producing their prototype models of all weather automatic landing systems. NAFEC will continue to test many of these systems; as a result of these tests, FAA will establish safety and reliability criteria which will then permit the production of all weather automatic systems. It seems likely one or more of these systems will be in operational use by the commercial carriers in a few years.

Price, Smith and Gartner (ref. 33) have also discussed many all weather landing concepts and the problems of pilot acceptance.

It is reasonable to assume that any one, or several, of the automatic landing systems which may eventually be sanctioned for use by subsonic jets, will provide the capability required by the SST, or at least provide the basis for the refinement of a system which will meet the SST requirements.

SST Potential Operational Requirements and Constraints

There appears to be general agreement that an all-weather landing system is a necessity for the SST if it is to be an economically profitable operation. The SST must have the capability to land in conditions of zero ceiling and zero visibility. It is important to point out that all-weather landing is in fact synonomous with blind landing since other weather parameters can still preclude SST operation (e. g. , cross winds, shear, precipitation accumulation on the runways, severe thunderstorms, turbulence and icing).

The requirement to land once the deceleration/descent phase has been executed would appear to have long-range implications. It seems a certainty that enough fuel would not be available to permit climb-out and transonic acceleration in the event diversion to an alternate is called for. Because of these conditions, flight management will need to commit the aircraft to landing while it is still in the cruise profile and as much prior to initiating the deceleration/descent as is operationally feasible. It will be noted that the necessary information for decision-making in this area has been specifically called for as a requirement during the enroute navigation phase.

At the moment, no clear representation of weather constraints or SST landing operations has been specified, excluding, of course, zero-zero ceiling-visibility requirements. It is assumed that the final design and resulting operational characteristics of the SST will dictate the specification of such requirements. At present, the general requirement is for an all-weather landing system which will provide for essentially blind landings, and will include provisions for the safe execution of the track-keeping during final descent, decrab, flare-out, touchdown, and roll-out maneuvers with no visual contact with the runway.

Modifications to current constraints could possibly include some changes in weather minima other than ceiling and visibility minima, which will undoubtedly be modified to essentially include zero-zero conditions. Obviously, this modification will have the effect of deleting the constraint that the pilot establish visual contact with the runway at a given altitude.

Feasible Automated Implementation Concepts for SST

The navigation of the SST during the landing phase is characterized by requirements for three-dimensional location of the aircraft, and off-profile error components, with precision accuracy considerably higher than the accuracy requirements during the cruise phase. Winick (ref. 69) has remarked that, "We (FAA Systems Research and Development Service) feel that the landing system which will be used by civil carriers will be a flare-out landing system as an extension of the ILS."

It is useful, then, to examine the ILS as a navaid with a view toward establishing the information it furnishes to flight management during the landing phase. Generally, the ILS localizer is located so that it is aligned with the runway centerline and the aircraft steers the course defined by the radial of the localizer beam. This beam is defined by a null effect caused by overlapping lobes of two transmitted radio waves of different frequency. Drift to either side of the null area causes null dissipation and the resulting reception of only one of the waves as a more defined signal so that only one signal is displayed the cockpit. The display indicates that the aircraft is off the course and the relation of the aircraft to the desired course.

Another component of the ILS system, the glide slope, provides a side view of an azimuth envelope shaped like a vortex. The desired descent path on the glide slope is the center of the envelope and culminates at the impact area of the runway. Rate-of-descent, or sink rate, and deviations from the desired descent path are detected and displayed to flight management as number of feet above or below the desired path. A flight-director type display is used to establish the necessary crab angle to maintain the approach course, with these data flight management can manipulate control surfaces and make throttle adjustments to correct detected error components and maintain the approach profile.

The ILS system has drawbacks. Achievable accuracy is influenced by the ground locations of equipment. ILS is often unusable at certain altitudes above mean sea level. The ground components are often inoperative due to their vulnerability to certain weather phenomena (e. g. , precipitation), and because redundant equipment is unavailable during periods of scheduled or unscheduled maintenance. However, it is expected that the all-weather system for the SST will be an extension of the current ILS system, and it is reasonable to expect improvements in the ILS system components prior to the advent of the SST. It is certainly expected that minimum operating standards will improve along with system reliability, and that more accuracy will be achievable.

Several aspects of all-weather landing systems are currently under study, and some systems are anticipating FAA certification for Category 2 airports in the immediate future. Certification of Category 2 includes landings with a ceiling of 100 feet and RVR of 1, 200 feet. FAA documents AC 120-15 and AC 20-31 list airline operational requirements for Category 2, and equipment requirements for Category 2, respectively. According to Plattner (ref. 73), the decision height is expected to be lowered in Category 3A to 50 feet, and it appears necessary to provide automatic landing capability. This situation relegates the pilot's primary role to that of "monitoring the approach so he can take over immediately in event of a failure in the system." However, whether the landing system is fully automatic, semi-automatic, or completely manual, the requirements for the generation of precise, accurate navigation data will undoubtedly be met by a fully automatic navigation system which may or may not be directly coupled to auto-pilot and auto-throttle systems. It would appear that coupling of the navigation system to auto-pilot and auto-throttle systems has some inherent advantages, and possibly some disadvantages. An extensive discussion of these pros and cons may be found in reference 1, pp. 317 to 320.

Assuming a fully automatic system, it would appear that the following would be typical. ILS localizer would still provide the beam to fly with off-course components transduced and coupled directly to the auto-pilot for lateral control. The primary difference would be in auto-pilot sensitivity to produce a smoother approach with auto-pilot control. This would be accomplished by an amplifier-computer for the auto-pilot which would incorporate gain desensitization by radio altimeter, beam-rate tracking, and approach monitoring capability. Below the usable height range of the glide slope equipment, an automatic flare computer would assume pitch control from the auto-pilot, adjust the rate-of-descent and flare the aircraft to touchdown. The auto-pilot would continue to keep the aircraft tracking the localizer beam down the runway centerline until roll-out has either progressed to the point that flight management can exercise lateral control through braking and power application, or until a high speed turn-off maneuver is executed.

Assuming that the primary role of flight management is system monitoring, systems currently being evaluated, and those under proposed development schedules are incorporating means to facilitate the monitoring function. In a system for the Boeing 707 and 720 aircraft, developed and tested over a two-year period by Boeing and the Bendix Corporation, certain cues are being made available for the monitoring function. The Boeing system has been described by Plattner (ref. 73),

> Breakdown of equipment Boeing is proposing for Category 3A includes:
>
> New amplifier-computer for the auto-pilot. Gain desensitization by radio altimeter, beam-rate tracking and approach monitoring capability have been incorporated. This computer will be available by next September. The Category 2 computer, which will be available this spring, is basically the same with space and wiring provisions for the autopilot monitor. The autopilot system is designed to handle wind shears up to 10 kt. wind change per 100 ft. of altitude although the FAA Category 2 requirement is only 4 kt. /100 ft. This is an order of magnitude improvement over present Bendix 707 equipment.
>
> Self-monitored flare computer.
>
> Throttle control system. This includes a Bendix-supplied amplifier and a Boeing-supplied no-back clutch system which advances or retards the throttles but which may be easily overridden. The Kollsman airspeed indicator also will be modified to include a bug which is remotely set to the desired airspeed by a toggle on the overhead panel.
>
> Approach progress display and cockpit test unit. The approach progress display is a vertical row of five separate annunciator blocks with relief printing reading localizer, glide slope, decision point, flare and abort. A green light shining through the letters indicates that the individual system is armed. The light changes to amber and remains on when the function has been engaged. To insure the equipment is operating prior to the approach, the pilot presses an enroute test button and the system automatically checks itself out with the approach progress display lights illuminating in sequence over a 3-minutes interval.
>
> Component failure is indicated when lights fail to illuminate. The system also checks itself automatically when glide slope is engaged.

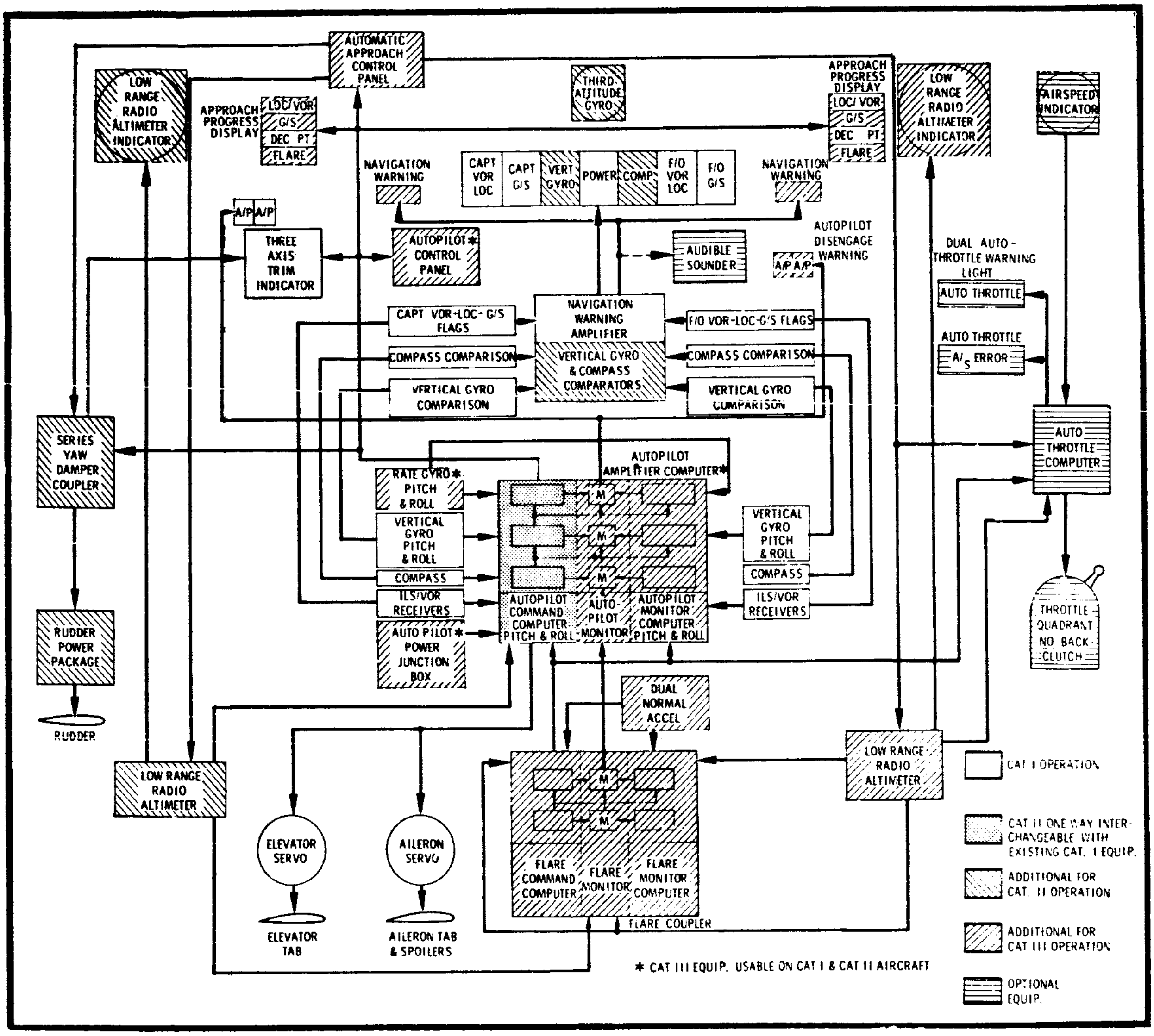


Figure 51. Boeing 707-720 equipment for Category 2 and Category 3A in block diagram. Gear which is optional to airlines is indicated. (From ref. 73.)

Electrically-damped rate gyro package to provide approach monitoring information on pitch, roll and yaw rates.

Dual Emertron radio altimeters.

Standby gyro horizon. This is needed as a voting unit to determine whether the pilot's or copilot's gyro is accurate if a discrepancy occurs and provides a positive reference for go-around.

The Category 3A equipment package assumes installation of a series yaw damper, already certified by the FAA, since the current yaw damper must be turned off during takeoff and landing.

An examination of the system block diagram (Figure 51) shows that some additional monitoring capability for the navigation system has been provided in a navigation warning display at both the pilot and copilot stations. Additionally, a landing phase sequence monitor is incorporated.

Basically, however, current thinking appears to reflect very little, if any, requirements for the navigational components of the all-weather landing system beyond those being evaluated today. One possible exception to this is in the area of visual presentation of the navigational situation so that the manual override of the automatic system does not introduce lag in response due to time to orient to the situation. Such a situation obtains where the various elements of the situation may be individually displayed and may be such that some collection of parameters is necessary before the situation may be inferred accurately and corrective action contemplated. In this regard, Price, Behan, and Ereneta (ref. 1) suggest that,

> . . . the pilot may be both psychologically and physiologically unprepared to take over a complex task if he has been monitoring this task by observing oversimplified displays. There is reason to believe that monitoring should be accomplished in the same dimensions and similar order of complexity as the performance task if the human is to be able to take over effectively.

Feasible Manual Implementation Concepts for SST

During this phase of the flight, the only possible manual navigation would depend upon visual contact with the runway or terrain perturbations from which present position and course to steer could be inferred. Since it would appear that all landings will be executed at least under IFR conditions even in VFR weather, if not all automatically, this function is not considered amenable to implementation via manual techniques. It would, of course, be possible to make a visual approach under the appropriate weather conditions should the occasion arise. However, the utilization of an all-weather landing system implies automatic generation and display of the necessary navigation elements. Execution of flight control and throttle adjustments, even though part of the system, are independent of the navigation data generation and display, and dependent upon navigation data for implementation in and of themselves.

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