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STUDY OF FLIGHT MANAGEMENT REQUIREMENTS DURING SST LOW VISIBILITY APPROACH AND LANDING OPERATIONS

VOLUME II:

DELINEATION OF POTENTIAL PROBLEMS IN SUPPORTING THE PERFORMANCE OF FLIGHT MANAGEMENT TASKS

January 1968

Prepared by:
Walter B. Gartner
Richard E. Shoemaker

NASA TECHNICAL EDITOR
Charles C. Kubokawa

Prepared under Contract No. NAS2-4406 by

SERENDIPITY ASSOCIATES
Los Altos, California

For:

Ames Research Center
National Aeronautics and Space Administration

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SUMMARY

This report identifies potential flight management problems which might arise during low visibility landings in the projected United States Supersonic Transport. Flight management tasks required during critical phases of the approach and landing which were determined to place high cognitive demands on SST command pilots were delineated along with potential human engineering and pilot acceptance problems.

Many of the problems derived in the analysis are directly related to the projected airborne landing system configuration which was defined in Phase I of this study (ref. 3). Others stem from assumptions regarding operational procedures, environmental conditions, and the characteristics of ground based components of the SST low visibility landing system.

As expected, most problems were found during the later phases of the approach and landing due to the decrease both in time available and allowable margin for error. Significant potential problems were identified in: (1) judging the success of the approach, (2) resolving the landing commitment decision, (3) assessing initiation and execution of the landing maneuver, (4) initiation and execution of the go-around maneuver, and (5) assessing equipment operating status and resolving override, reconfiguration and disengagement decisions.

No solution concepts are advanced in this report. The problem statements drawn from the body of the report and assembled in the final section will form the basis for simulation design recommendations to be developed in the next phase of the study.

INTRODUCTION

One of the principal conclusions of a recent analysis of system concepts and operational problems in the development of an all weather landing capability for advanced SST's (ref. 1) was that the main impediments to the introduction of all weather landing involved operational procedures rather than individual technical problems. The role of the pilot in managing the aircraft was cited as a major source of controversy and it was concluded that methods of using the crew to monitor performance of the automatic equipment and a definition of crew procedures for various failure situations are critical problems which remain to be worked out for low visibility approach and landing operations. A clear statement of the importance of resolving the many outstanding issues with respect to the pilot's role in all weather landing operations is given by Beck in the conclusion to a comprehensive overview of crew factor problems in achieving Category II operational goals (ref. 2):

> Beginning with the initiation of a Category II approach, the success of each segment of the flight, as it progresses toward the touchdown and rollout, depends on a compatible pilot/aircraft relationship that can react properly to and take cognizance of each of the multitudinous factors that will be involved in making this approach consistent, reliable, of high quality, and above all operationally safe. In October, 1965 the All-Weather Study Group of the International Federation of Air Line Pilots made the following statement: "It is the Study Group's view that, in the very low minima envisaged, it is no longer possible to compromise and make exceptions to accommodate unique circumstances. The operation is too critical for that. Standardization now becomes essential. If ALL requirements cannot be met, the operation should not take place".

What are some of these outstanding issues and how are they to be resolved? An attempt is being made, in the study reported in this document, to explicate some of the more significant problem areas by focusing on the flight management task requirements imposed upon the pilot-in-command during low visibility approach and landing operations. The ultimate intent is to translate some of the more significant issues into research questions which can be resolved using piloted flight simulation equipment available at the NASA Ames Research Center.

In the first phase of the current study, the principal components and design features of the landing system envisioned for the SST were delineated and the distinguishing characteristics of flight management functions were discussed. This material was presented in Volume I (ref. 3) together with assumptions regarding crew roles and mechanization concepts for satisfying flight management task requirements during a projected SST approach and landing sequence.

This report presents the results of the second phase of the study which was directed toward an identification of potential problems in supporting SST command pilots in carrying out flight management responsibilities. The central concern of this phase of the study was to identify potential problems in the performance of flight management tasks during low visibility SST approach and landing operations, considering projected SST landing system design concepts and operational procedures. The general procedure for identifying these problems entailed an analysis of the cognitive task loading or information processing demands imposed on the Captain, the one crew member who will be solely responsible for SST flight management. In the course of this analysis, consideration was also given to more specific crew acceptance and human engineering problems which could be referred to particular aspects of the Captain's role or to system design concepts and features.

This analytic procedure is briefly outlined in the next section to indicate the manner in which flight management activities were examined and to identify and clarify the criteria applied in distinguishing excessive cognitive demands. The results of this analysis are then presented as a discussion of selected flight management tasks which were found to impose unrealistic information processing demands on the Captain or to be especially vulnerable to such factors as time constraints on task performance or limitations in the quality of available information. The identification, in the analysis, of anticipated difficulties, uncertainties, and lack of clear structure in the information processing descriptions of component diagnostic and action decision tasks provided a direct basis for distinguishing inadequately supported flight management activities. Insofar as possible, the specific SST landing system design features, operational procedures, and/or environmental conditions which are suspected to be sources of flight management difficulties are identified in the discussion of potential problems.

In the next and final phase of the present study, some of the problems discussed in this report will be developed into specific simulation research objectives and submitted to the NASA Ames Research Center as candidate projects for the SST simulation facilities now under development. The selection of problems for development into proposed simulation studies will be based on an examination of commonalities in problem sources and/or solution concepts, a review of current simulation capabilities at the Center, and an appraisal of the projected impact of the problems on the safety, effectiveness, and economics of SST approach and landing operations.

OVERVIEW OF THE ANALYTIC PROCEDURE

A fundamental assumption underlying the analysis is that the development of effective means for supporting the performance of flight management tasks must be based upon a clear appreciation of the information processing demands of component cognitive processes. The general intent of the analytic procedure was to identify potential difficulties in crew information processing in such a way as to provide a direct basis for specifying the SST design features, crew factors, environmental conditions, operating procedures, etc., which appear to be the source of these difficulties. Products of the analysis should thus serve to identify a number of potential simulation research objectives concerned with confirming or infirming the hypothesized difficulties and/or with developing and testing solution concepts.

Flight management requirements outlined in the first project report are the point of departure for the analysis. The first step in the analysis was to adopt a generalized information processing schema as a cognitive process model of crew performance in flight management activities. In this schema (see Figure 1), the crew is understood to be in contact with the objects, events, processes, etc., which define the ongoing SST flight situation through either direct perceptual contact or a display system, i.e., all of the visual and auditory displays available to him in the projected SST operational situation. For the purposes of this analysis, it is useful to distinguish three components of the crew information processing task associated with flight management. Of these, the central component, identified in Figure 1 as Diagnosis, is considered to be the key to the subsequent identification and appreciation of information processing task demands.

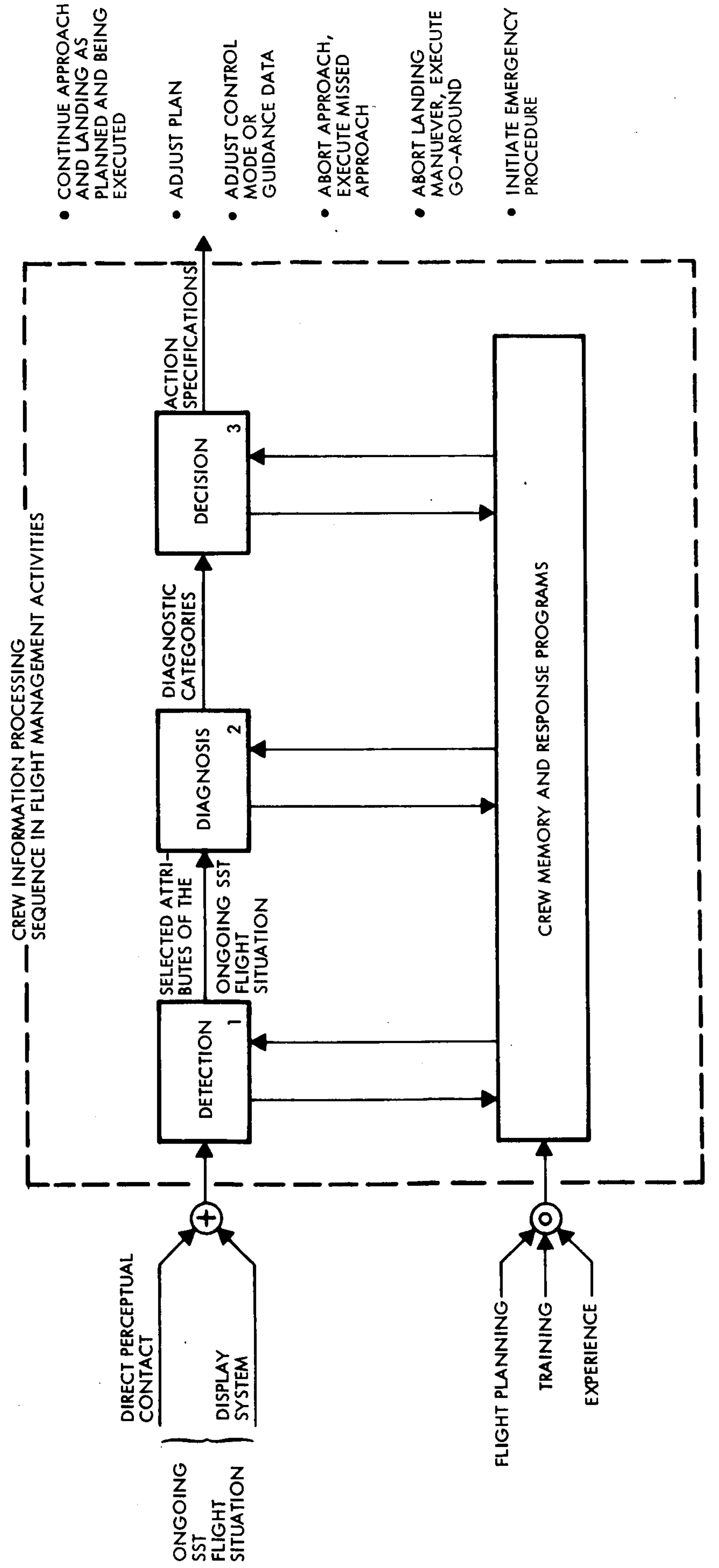

Figure 1. Schematic Overview of Key Cognitive Process in SST Flight Management Activities.

As indicated, the diagnostic component must generate the "awareness" of certain states of the ongoing SST flight situation which, in turn, initiate the flight management decisions related to the major action alternatives available to the Captain during the approach and landing sequence. Such states are referred to in the information processing schema as "Diagnostic Categories" and in general they are to be understood as perceived or inferred states of the aircraft, its subsystems, or the operating environment which indicate that the SST operations control functions being managed are exceeding flight management tolerance or are tending in that direction.

The term "diagnostic" is used here in the most general sense of resolving any uncertainties which may arise with respect to the identity, character, or significance of selected aspects of the ongoing flight situation. For example, a determination that the speed or rate-of-sink of the aircraft is "excessive" or "increasing too rapidly" would entail diagnostic activity. In the schema adopted, diagnostic activity is understood as a form of "categorizing" of the objects and events which define the flight situation, based on certain defining or criterial attributes, and the outputs of this activity are thus referred to as diagnostic categories.

The key role of diagnostic activities in initiating subsequent action decisions has already been mentioned and it can now be seen that the identifications of diagnostic categories is also the key to establishing requirements for the data input or "Detection" function. Diagnostic categorizations are defined by "criterial values" on designated parameters (attributes) of the ongoing flight situation; relevant inputs to the diagnostic function are thus derived from a consideration of the parameters and values actually used by the Captain or those he "should" use in exercising "good judgment". The "Detection" function can be understood, then, as a directed monitoring or scanning (data sampling) of the actual flight environment, when direct perceptual contact is possible, and/or of the flight instruments, communications channels, flight deck reference material, etc. which comprise the projected SST crew information environment (display system).

In applying this schema to projected SST flight management requirements, each of the assessments and decision problems identified in the first report were examined in order to determine the judgments involved, the flight management consequences associated with negative assessments, the immediate bases for the judgments in terms of the information expected to be available to the SST Captain, and the information processing considered necessary to arrive at the judgments. The cognitive process schema just outlined was used to guide this analysis in that judgments were identified by distinguishing the diagnostic categories assumed to underly the major flight management decisions. Information processing demands on the Captain could then be identified by considering the defining or criterial attributes of the flight situation which were expected to determine these categorizations and by an examination of how this information could be derived in the projected SST system.

As the analysis proceeded, potential problems in supporting the Captain in the performance of flight management tasks were noted whenever the following conditions were found to apply to the projected SST operational situation:

1. Significant conditions and events, which must be assessed within severe time constraints, are not directly represented in the SST display system.

2. Displays are available from which significant conditions and events can be inferred, but the information processing involved:

    a. would take too long;

   b. would be subject to unacceptable error probabilities due to inaccuracies in source data or the low reliability of processing steps;
   c. would be subject to distortion or bias due to the stress of task conditions.

3. Criterial information, required to assess the significance or character of available information on actual aircraft and environmental states, is not expected to be available.

4. Criterial information is available but not with necessary precision or in the appropriate form for direct application to the assessment task.

5. Concurrent flight management or other operations control tasks may be degraded or attention to them may compromise performance of the primary task.

6. Low or negative pilot acceptance of an information source or task condition can be anticipated.

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DISCUSSION OF POTENTIAL CREW FACTOR PROBLEMS

Suspect flight management tasks, i.e., those found to impose unrealistic information processing demands on the Captain or to be especially vulnerable to the effects of time constraints or limitations in the quality of available information, are identified and discussed in this section. Operational procedures or situations which might reduce pilot acceptance of the landing system are also considered. A more complete identification of flight management requirements during each phase segment of the SST approach and landing sequence is given in Volume I of this study (ref. 3). The general intent of this discussion is to document the apparent inadequacies in supporting flight management in the landing system design, operational employment concepts, and operating environments assumed for SST. No attempt has been made to identify or evaluate solution concepts for the problems considered.

For convenience, the problems discussed are related to five major flight management activities and are considered, generally, in the order in which these activities would occur in the approach and landing sequence. As already indicated, only those flight management tasks which entail suspect cognitive processing demands or related crew acceptance problems are considered. In the discussion, the relevant flight management task requirements are cited, assumptions regarding the manner in which the task will be performed in the SST are stated, and then the potential problems are introduced. Where appropriate, references are given to supporting statements and analyses in the literature. In many instances, supporting technical analyses are somewhat lengthy and complex and are not fully reconstructed in this report. The references given should therefore be consulted by the interested reader for a more complete explication of the problem area.

Potential Problems in Judging the Success of the Approach

An appreciation of the performance objectives of "landing" systems developed to satisfy Category II operating requirements suggests that these systems might be better understood and referred to as "approach" systems. Under such conditions, landing maneuvers are initiated only after the approach is judged to be successful and then only when external visual reference is considered acceptable to the pilot-in-command for subsequent control of the flare and touchdown. Approach systems can also be distinguished from landing systems for Category III conditions, since a positive assessment of the approach will also be necessary before automatic control of the landing sequence is initiated. The general concern in this section is with flight management problems in determining the success of the approach to pre-established minimum altitudes where the landing commitment decision is finally taken.

Consideration must first be given to the defining characteristics of a "successful" approach. As a point of departure, the following excerpt from FAA Advisory Circular 120-20, dated June 6, 1966, which outlines criteria for the approach of Category II landing systems, is given:

> Definition of a Successful Approach. For the purpose of the airborne system evaluation, a successful approach is one in which, at the 100' point:
>
> (1) The airplane is in trim so as to allow for continuation of normal approach and landing.
>
> (2) The indicated airspeed and heading are satisfactory for a normal flare and landing. If an auto throttle control system is used, speed must be ±5 knots of programmed airspeed but may not be less than computed threshold speed.
>
> (3) The airplane is positioned so that the cockpit is within, and tracking so as to remain within, the lateral confines of the runway extended.

(4) Deviation from the glide slope does not exceed ±75 microamps as displayed on the ILS indicator.

(5) No unusual roughness or excessive attitude changes occur after leaving the middle marker.

The 100-foot point in the foregoing definition is, of course, the established decision height for Category II operations. At this point a missed approach must be initiated if the approach is judged unsuccessful or when certain ground and/or airborne equipment operating requirements cannot be satisfied. For Category III operations, no formal minimum approach altitude has yet been established but it can be assumed that a decision height based on minimum altitude requirements for executing a go-around will be determined. The key requirements to be satisfied in achieving a successful approach are taken as those dealing with the aircraft's position and tracking velocities relative to the intended touchdown area on the runway as the descent to the established decision height proceeds. Discussions of these requirements are frequently expressed in terms of an "approach gate" or "window", defined by lateral and vertical flight path displacement limits, from which a "soft" landing (i.e., a touchdown rate-of-descent of about two feet per second) can be achieved within a tightly defined touchdown area without exceeding autopilot authority limits or imposing excessive demands on pilot skills in manually controlling the aircraft.

Assessing Relative Altitude as the Aircraft Approaches the Authorized Decision Height.

Relative altitude is the present elevation of the aircraft relative to the elevation of the intended touchdown area on the runway. The appraisal of approach success and, under Category II conditions, of the adequacy of external visual reference for controlling the subsequent landing maneuver must be completed before the wheels of the aircraft reach a specified relative altitude, i. e., the decision height. As the aircraft approaches the decision height, then, the Captain must monitor and assess relative altitude to ensure that the aircraft does not proceed below the decision height unless the approach is judged successful.

In the projected SST landing system, relative altitude is not directly represented. Dual low-range radio altimeter systems will be available and it is assumed that relative altitude judgments must be derived from several radio altitude displays. Scalar indications of radio altitude, resolvable to about five feet, will be continuously available below 300 feet. Based on information given in approach charts, an index on the radio altimeter can be set to correspond to the relative altitude at the decision height. Below 200 feet, radio altitude is displayed qualitatively on the Attitude Director Indicator (ADI) using a "rising runway" symbol. In addition, arrival at a pilot-selected radio altitude is indicated by both a legend light component of the approach progress display and an auditory signal. Conventional readouts of barometric altitude will also be available and could be used to cross-check or supplement radio altitude information.

During the approach to the decision height, it is assumed that the Captain will simply monitor the scalar radio altitude indicator and/or have the First Officer call out altitude at 200 feet. When arrival at the decision height is imminent, i. e., at approximately 200 feet or over the middle marker, the Captain will direct primary attention to external visual reference and passively monitor the pre-set aural signal. The First Officer will continue to monitor radio altitude displays and may also report arrival at the decision height using established crew communication conventions.

The principal difficulty in this assessment is that the absolute altitude indications available from the radio altimeter systems can differ significantly from relative altitude due to irregularities in terrain features along the approach path. As Litchford reported several years ago (ref. 4):

> The pilot wants to know his height above his touchdown, which is some 3300 feet in front of him if he is indeed at 100 feet. But the terrain leading to the approaches of many of our major airports is usually very irregular, and this is becoming more common as runways are extended out over tidal waters and ravines to provide suffcient length for landing jets.

This point was illustrated by the terrain profiles schematized in Figure 2 for twelve major United States airports. It should be clear that considerable uncertainty regarding actual height above the intended touchdown surface can occur when radar altimeters are used over approaches such as those shown for the Pittsburgh and Dallas airports. The use of a pre-set relative altitude on the radio altimeter will provide a discrete indication of arrival at the decision height, but the problem of anticipating arrival at the decision height when approaching over uneven terrain remains. False discrete indications of arrival at the decision height are possible when the approach terrain is higher than the runway elevation. The use of currently operational barometric altimeters to supplement or cross-check radio altitude displays does not seem promising. Their use under Category II conditions is considered "basically unsafe" by the ALPA All-Weather Flying Committee (ref. 2) and in FAA tests of various methods for determining the 100 foot point on the glide slope, barometric altimeters were found to be the least accurate technique. Reported difficulties include inaccurate pressure settings, effects of rapid pressure changes due to wind conditions, inadequate provisions for detecting instrument errors, and instrument readability problems.

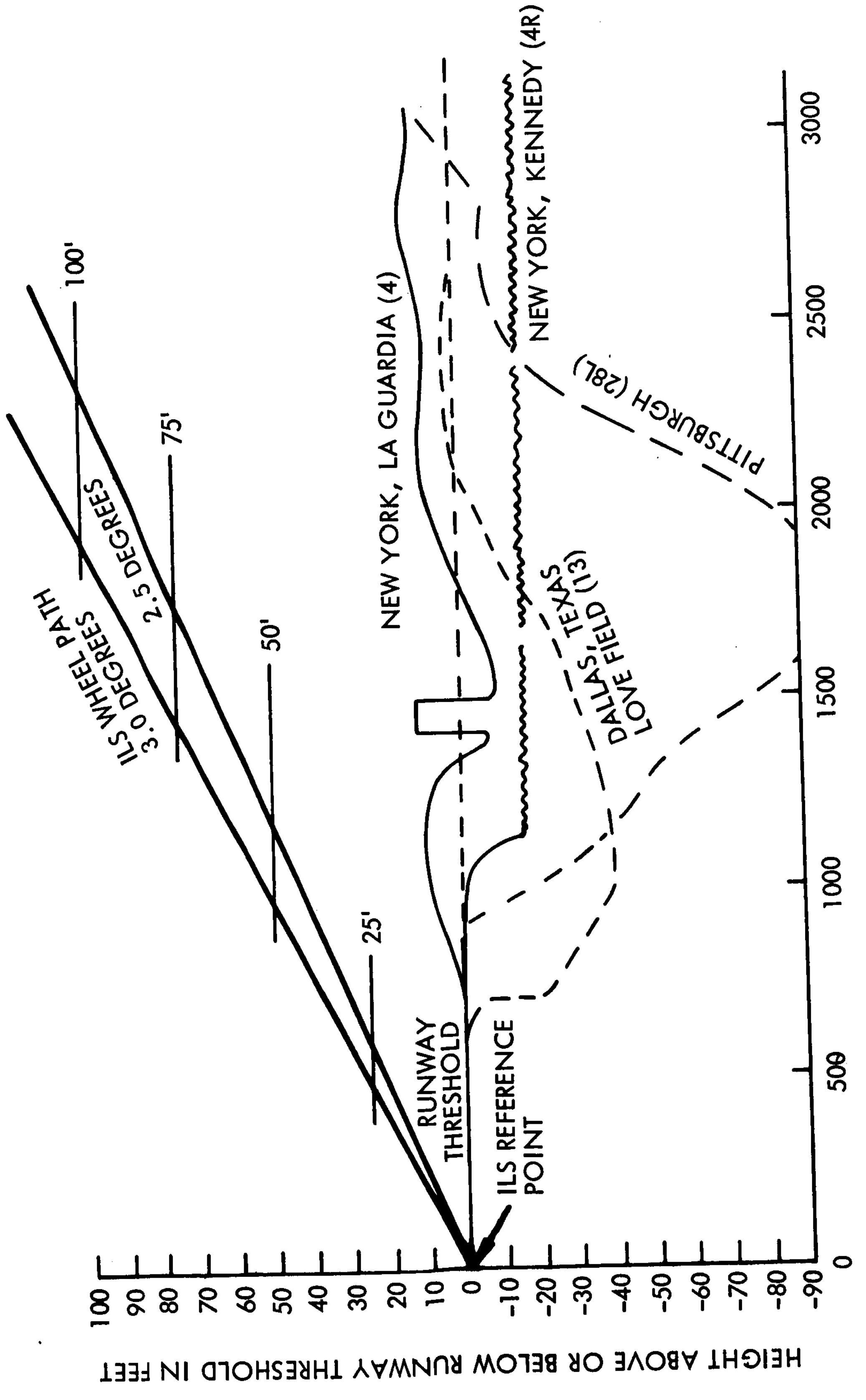

Figure 2. Terrain Profiles (Various Airports)
(from Ref. 1)

Assessing Flight Path Alignment with the Runway

As indicated earlier, one of the key requirements to be satisfied in a successful approach is that the aircraft's position and velocity vectors at the decision height are such that a "soft" landing within a well-defined touchdown area on the runway can be accomplished without exceeding autopilot authority and/or pilot-defined maneuvering limits. Most analyses of tolerable lateral offset limits suggest that lateral flight path alignment at the 100-foot decision height should be within 50 feet of the runway centerline extended and that velocity vectors (flight path projections) should be parallel or converging with respect to this reference line. Approaching the decision height, the Captain must judge flight path alignment to be within these limits or to be correcting so as to arrive within these limits by the time the decision height is reached.

In the projected landing system, flight path alignment with the runway centerline is not directly represented. The principal basis for judging flight path alignment is assumed to be the expanded localizer deviation indicator. Boeing design goals for localizer tracking during the final approach are to maintain the aircraft within ±20 microamps of the localizer beam, an indicated deviation of about one-quarter dot (ref. 5). As the aircraft closes to the decision height, visual cues will "fade in" and may also be used by the Captain to judge flight path alignment and tracking tendencies. The First Officer will continue to monitor the localizer deviation indicator and report excessive cross-track error and/or divergent tracking tendencies when the aircraft arrives at the decision height.

Some mention should also be made of the "approach gate monitor" cited in the B-2707 Model Specification (ref. 6). It is called out as a requirement to ". . . warn the crew if the airplane exceeds the boundaries of a pre-established 'gate' or 'window' through which a safe landing can normally be accomplished". Since no subsequent identification or description of this indicator is provided in the B-2707 proposal documents, this display was not included in the landing system design concepts adopted in this study.

There are three unresolved issues associated with supporting this flight management requirement. Each one is cited below in the form of a question and briefly discussed.

1. What is an appropriate lateral offset limit for the B-2707 at the 100-foot decision height?

Firm criteria for judging excessive cross-track error at the decision height have not been established for the SST. From the previously cited FAA Advisory Circular, absolute limits on the horizontal dimensions of the approach gate, at 100 feet, may be set at ±75 feet from the runway centerline (i.e., tracking within the lateral confines of the runway extended, with a standard runway width of 150 feet assumed). However, somewhat stricter limits must be placed on lateral displacement limits when the pilot's ability to correct for a lateral offset condition is considered. This is illustrated in Figure 3 which shows a shaded region of localizer deviations from which pilots made acceptable manual alignments for proper landings. These data are based on British studies of the ability of airline pilots to execute the "sidestep" maneuver, as reported in reference 1.

Note that lateral offsets in excess of a 20% localizer scale deflection (approximately 75 feet and consistent with the FAA limit) were clearly outside the range of acceptable conditions for manual landing success. Limits on this range of acceptable offsets, begin, however, with localizer scale deflections of about 14% or approximately 50 feet from the runway centerline. The reported range of limits for

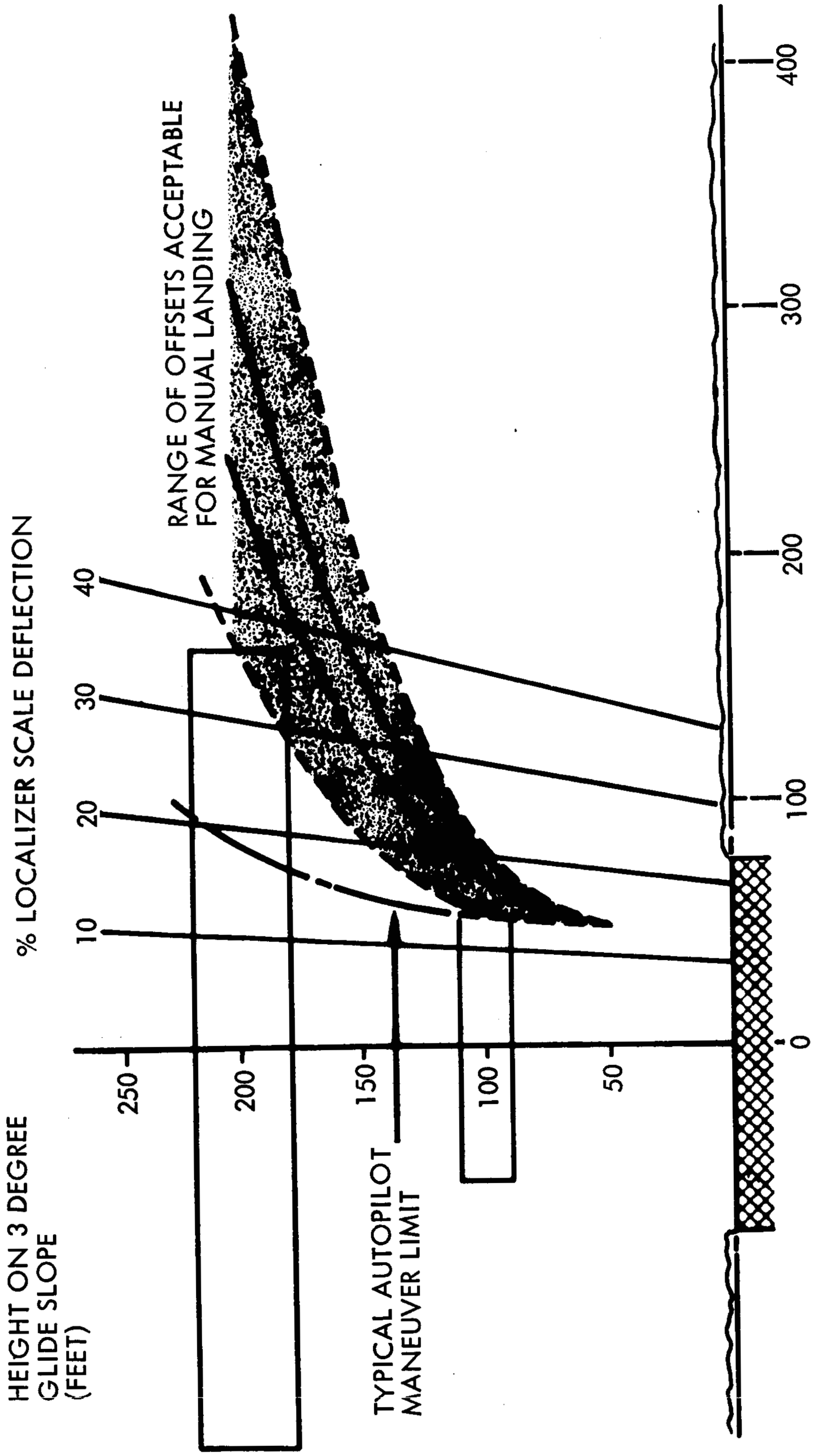

Figure 3. Lateral Displacement from Runway Centerline (Feet), Visual Acceptance Windows (Adapted from Ref. 1, Vol. I)

successful recoveries is due in part to the fact that pilots employed different degrees of roll angle in effecting the re-alignment. Note that a strict offset limit of approximately 50 feet is imposed if corrections are to be made by the autopilot with bank angle commands limited, as is usually the case at this point in the approach, to five degrees.

The pertinent implications of the foregoing are that an offset limit of ±50 feet may be a more appropriate criterial value for judging excessive cross-track error than the FAA standard of ±75 feet, and, perhaps more important, that criterial values should be based on a determination of offset distances from which pilots can comfortably perform lateral correction maneuvers in the SST. The data in Figure 3 were obtained using aircraft representative of conventional subsonic jet transports and should be derived again for the SST.

As Beck has indicated (ref. 2), it may be that pilots would not be willing to accept any degree of lateral displacement which would necessitate a correction at the 100-foot point:

> The first step that must be required to deliver this aircraft to the "success" gate at 100 feet will be the manner in which the crew operates the equipment. This then involves consideration of all the ramifications and techniques that will have to be employed in a mixed automatic/human environment where the airplane is flown to much tighter tolerances, because at the 100-foot point, the airplane must be "in the slot"; that is, aligned with the runway, on glide slope, on speed, at the proper sink rate, and stabilized. There can be practically no side-step adjustment after becoming visual.

Other analyses (ref. 1) have indicated that an uncorrected landing maneuver, committed on the basis of an indicated 20% localizer deviation, could miss the runway completely and that one committed with only a 10% deviation can result in a touchdown dangerously close to the edge of the runway. The problem here, then, is that there is currently considerable uncertainty with respect to the degree of lateral offset which should be judged "excessive" by the SST Captain. It is suggested that criterial values for this assessment be established on the basis of demonstrated pilot ability and willingness to manually execute a lateral correction from the decision height.

2. Can pilots accurately estimate lateral offset and tracking vectors by instrument reference?

This question is applicable to approach success assessments under both Category II and III conditions. It suggests that the expanded ILS localizer deviation information used as the primary basis for this assessment, together with basic flight situation instruments such as the heading indicator which may also be used, will not enable pilots to judge cross-track error and tracking tendencies to the required accuracies. An early indication of this potential problem emerged in Phase II of the joint FAA-USAF Pilot Factors Study of control-display concepts applicable to flying the SST under low visibility conditions (ref. 7). Phase II was conducted, in part, to examine advanced display concepts which would enable the pilot to manually fly the aircraft to the runway threshold on instruments. The following excerpt from the discussion of results provides a clear statement of the basic problem (underlining added):

> Control of the Cross-Track Component The lateral requirements for routine operation inside the middle marker demand more than keeping the aircraft within the center half of the runway. The lateral velocity vector of the aircraft becomes increasingly important to the success of the approach under 200 ft. For a constant approach speed the lateral velocity vector of the aircraft determines the direction and speed that it moves with respect to the runway centerline. As a consequence the cross-track component of the aircraft's lateral velocity vector must be maintained within tolerances about zero so that the aircraft will be moving parallel to the runway centerline upon breakout or, in the case of a touchdown on instruments, straight down the runway for roll-out. Certainly, there are trade-offs involved between displacement and the cross-track rate component. But in any event, there is no question but that both parameters must be controlled for successful operation inside the middle marker.

Localizer deviation showed that the standard flight director displays presented control information which was adequate with respect to lateral displacement inside the middle marker. However, the standard flight director configuration apparently did not provide the proper type of information to the pilot for maintaining the cross-track component of the aircraft's lateral velocity vector within tolerances. Indicative of this inadequacy was the finding that 12% of the coupled touchdowns, 16% of the semi-automatic touchdowns, and 32% of the manual touchdowns had a cross-track component of a magnitude that precluded a safe roll-out. A number of times, the hooded subject pilots expressed surprise upon a quick take-over at touchdown that such a cross-track component existed. Everything "looked good" on the panel.

This is understandable when one considers the information that the flight director presented and the way that it was displayed. The bank steering bar, when centered, was limited to telling the pilot that the aircraft was either on localizer or returning at the proper re-intercept rate. The pilot must necessarily devote a great deal of attention to the steering bars under 200 ft. because they are the primary control elements. On the horizontal situation indicator, displacement from localizer was presented by means of the Course Deviation Indicator (CDI). The rate of movement of the CDI reflected that rate at which the displacement was being incurred or reduced; this was an approximation of the lateral velocity vector. But either the location or the quality or a combination of both might have been the cause for the pilot's apparently not making use of the lateral rate information when he needed it. Heading information was presented by means of a card which rotated and a fixed index. Quite probably the display was too insensitive for presenting the quality of information required.

The problem related to maintaining the cross-track component of the lateral velocity vector within tolerances using just the standard flight director displays did not appear in the T-39 flying until the vertical path information requirements had been resolved. Even then the problem did not become evident until touchdown, because of the quick response of the T-39. The problem undoubtedly would appear further back along the approach with a heavier aircraft. Thus, attention should be devoted to satisfying this information requirement of the pilot in the lateral plane.

In the projected SST landing system, the integration of an expanded scale localizer deviation indicator into the ADI may improve the pilot's ability to estimate offset distance and cross-track velocities, but this possibility should be confirmed. Even with such display improvements, however, difficulties in assessing actual lateral offset and tracking tendencies remain due to localizer beam characteristics and the information processing required to translate indicated localizer deflections to offset distances in feet.

One set of problems stems from the well-documented sources of noise in the localizer signal. These include beam distortions produced by reflectance from large buildings and other objects in the airport surrounds, reflection interference from overflying aircraft, spurious transmissions due to atmosphere effects and interference from remote transmitters, transmitter drift, etc. Considerable effort is being devoted to monitoring such noise sources and to controlling their effects in the improved Category II ILS, but some problems remain. Other problems stem from the fact that information regarding displacement from the beam center is provided via localizer receivers as a signal proportional to angular displacement rather than linear displacement. Thus, a given offset distance from the centerline will produce a variable signal depending on the aircraft's distance from the transmitter. Since transmitters are typically installed at the far end of the instrument runway, the offset distance corresponding to a given beam displacement at any given distance from the runway threshold will vary as a function of runway length.

In order to determine actual offset distance, then, the Captain would require relative transmitter distance information, which will not be available, and would have to recall a complex conversion table for translating qualitative beam deviation indications into microamp displacements and then into offset distance in feet. It is, of course, unreasonable to assume that such data processing will occur. It is likely that deviation indications on the order of one-quarter dot or less will be accepted as providing adequate runway alignment until, under Category II conditions, track alignment and tracking can be confirmed by external visual reference. Potential problems in using visual cues are discussed next; the problem of accurately judging lateral offset and cross-track velocities under Category III conditions remains.

3. Can pilots accurately estimate lateral offset and tracking vectors using external visual cues?

This question is applicable only to an approach under Category II conditions wherein the Captain attempts to assess flight path alignment and tracking relative to the runway by reference to visual cues emerging in the extremely limited time period just prior to arrival at the decision height. It should be noted that the approach success judgment can be made solely on the basis of instrument reference and visual confirmation, strictly speaking, is not required. However, it will be recalled that the Captain is assumed to be "head up" at this point in the approach in order to assess the adequacy of exernal visual reference for the landing and it is further assumed that the compelling character of even fragmentary visual cues is such that they will influence his final judgment regarding flight path alignment. The potential problem here is that information available from these visual cues may prove to be a highly unreliable basis for judging flight path alignment, and, further, that the severe time constraints on resolving the judgment, together with psychological factors which can be expected to bias the judgment in favor of a positive assessment, will increase the already high error probability in this component of the approach success decision.

The general character of this problem from the pilot's viewpoint has been briefly outlined by Beck (ref. 2) as follows:

> No pilot under the stress of a Category II approach, should ever be required to mentally process and evaluate what he has seen in order to be able to recognize where he is. The above considerations now lead directly into the basic concept of tracking.
>
> You are doing one of three things: tracking on or parallel to, tracking away from, or tracking toward a desired path over the ground. When you're moving fast at a low altitude and the visibility is restricted, you can only determine where you are by first observing a known object such as a light, for example, then observing another light or series of them and comparing them, basically, with what you first saw.
>
> Experience has shown that, in order to do this, a pilot must see a horizontal segment of lights equivalent to about three seconds of reaction time, and in an aircraft approaching at 140 knots, he will require a length of at least 700 feet. To mentally digest this information, evaluate it, and decide whether you are or are not tracking as you wish to, may take a fraction of a second or it may take several seconds, depending on the clarity, readability and simplicity of your cues. You can even complicate and delay this decision by having your plane in the not uncommon position where it is yawed to the right due to a crosswind and the autopilot has placed the plane to the left of the centerline but is now correcting back to "on course" – you think! The cockpit slant range visibility is 810 feet and, as you approach the 100-foot decision point, your visual cues are appearing outside the window to the left.
>
> Now, are you tracking properly or not? From the 100-foot decision height to the threshold the pilot will have approximately six seconds, then another six seconds to touchdown. During the extremely short interval necessary to make the correct decision in this example, there is grave doubt whether a pilot can positively recognize a tracking tendency.

From British studies of low visibility conditions (ref. 8), it can be concluded that there is a high probability of achieving visual contact and a 500-foot visual segment prior to reaching the 100-foot decision height, with contact occurring in most instances (70%) at altitudes between 200 and 300 feet. These data suggest that the total elapsed time from the first "fade-in" of visual cues to arrival at the Category II decision height will be on the order of 10 to 15 seconds, assuming a nominal rate of descent of about 12 feet per second. During this time interval, which must be reduced to allow the pilot to transition from near-field to far-field viewing conditions and to acquire and recognize usable visual cues, the Captain must also assess his vertical situation and the adequacy of visual conditions for completing the landing maneuver under manual control. Potential problems in performing these assessment tasks are discussed in subsequent sections, but they are cited here to note that some time-sharing among flight management tasks will be necessary during this brief time interval, further reducing the time available for assessing flight path alignment with the runway.

It is anticipated, then, that pilots may experience considerable difficulty in extracting timely and accurate indicators of flight path alignment from visual cues expected to be available in Category II conditions. This problem is related to the problem of the adequacy of visual cues for assessing the vertical situation and the more general issue of what constitutes "adequate" visual reference for resolving the landing commitment decision. Discussions of these issues are given later in this report and are also applicable here.

Assessing Vertical Flight Path Alignment

The second major component of the approach success judgment is the determination that the aircraft's relative altitude (see above), vertical flight path angle, airspeed, and rate of descent are within appropriate limits for effecting a landing within the "touchdown zone". The touchdown zone is defined by the FAA (ref. 9) as the first 3000 feet of runway, beginning at the threshold, and in specifying Category II operating requirements this agency requires that a missed approach be initiated when a touchdown cannot be accomplished within this area. Somewhat more stringent constraints on the desired touchdown point have been suggested by other interested agencies. The Air Transport Association, in a proposed Advisory Circular to the FAA on Automatic Landing System Standards, dated 14 December 1966, calls for longitudinal touchdown dispersion limits of -300 feet to +1000 feet from a line on the runway which is the intersection of the linear extension of the glide slope with the runway. As an indication of preferred touchdown areas in current operations, the mean touchdown point of 1510 feet obtained in an FAA study of hundreds of jet landings by experienced pilots under visual conditions may be cited (ref. 10).

In any event, the Captain must be confident, prior to reaching the established decision height, that the landing can be completed within an acceptable distance from the threshold. On the basis of British studies of the adequacy of external visual reference for vertical flight path control, it is reasonable to assume that this assessment must be made solely by instrument reference. This point has been reiterated by Morrall in a recent paper (ref. 8):

> In making the decision whether to continue with the landing or not after becoming visual the pilot must assess not only his position relative to the ideal flight path but also his velocities, both cross-track and vertical, to determine where the aircraft is going. Whilst it is reasonable to expect a proficient pilot to be able to assess the aircraft's position and velocity in the horizontal plane by looking at a segment of approach lighting which includes only one cross bar, it is more difficult in the absence of the horizon, if not impossible, to make a similar assessment in the pitch plane from the same picture. Even gross errors may be difficult to detect in the time available after visual contact in operations to the lower decision heights of Category II. It is believed that visual control of the aeroplane in pitch begins

> to become reliable when the pilot can see the threshold and does not become really good until he can see the point on the ground at which his approach path is heading. This means that to achieve high standards of safety in these low visibility conditions instrument guidance in pitch is required to heights of at least 100 feet.

In the projected SST landing system, the principal basis for making this judgment will be the glide slope deviation indicator and the direct readouts of airspeed, radio altitude, and vertical speed. Problems associated with the use of radio altitude displays for determining relative altitude have already been discussed. No direct representation of vertical flight path angle is available and no problems are anticipated in monitoring airspeed and vertical speed.

The potential problem associated with the use of these instruments to assess the vertical situation approaching the decision height is that the information provided will not allow the Captain to determine that his touchdown will occur within acceptable limits. Following an analysis of touchdown dispersion outlined by Osder (ref. 1), it can be shown that SST touchdowns can occur well beyond the 3000-foot touchdown zone even when the instruments accurately reflect the fact that the aircraft is precisely on the glide slope, maintaining appropriate airspeed and vertical velocity, and at the appropriate relative altitude as the aircraft arrives at the decision height. The basic elements of this analysis are indicated in Figure 4, which shows the path that would be followed by an aircraft initiating a flare from a 2.5 degree glide slope at approximately 50 feet. Assuming a glide slope intersection with the runway at about 1200 feet, notice that an ideal flare maneuver, executed to reduce sinkrate to about one foot/second, would result in a touchdown over 4000 feet down the runway.

This basic problem is well documented in the literature on proposed Category II landing systems employing existing ILS installations and it is generally conceded that lower minima touchdowns will occur at a

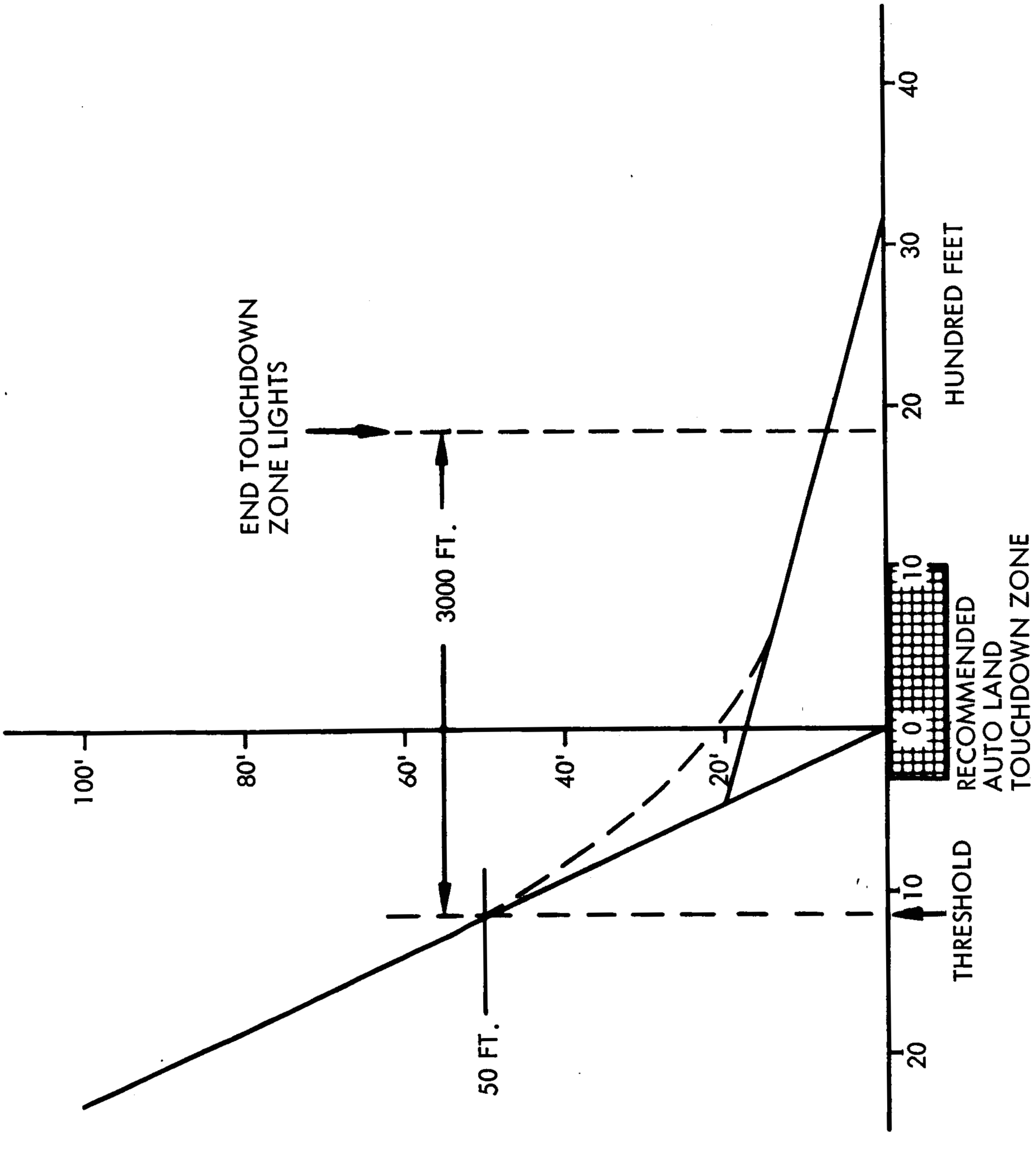

Figure 4. Touchdown Geometry for Soft Landing (from Ref. 1)

considerable distance down range of the glide slope intersection point. Lower minima flareout trajectories start tangent to the glide slope and thereafter always remain above it. Data reported by Litchford (ref. 4) indicates that glide slope intersection points range from about 700 feet to more than 1500 feet past the runway threshold, so the 1200 foot intersection used in Figure 4 is not unrealistic. When it is recalled that flare initiation will occur at 75 feet in the SST, rather than the 50 feet used in Osder's analysis, the present concern for the Captain's ability to assure a touchdown within the touchdown zone can be appreciated.

Pilots, of course, are concerned about stopping distances and prefer to touchdown much closer to the runway threshold, especially under low visibility conditions. In Category I conditions, this has been accomplished by performing a "duck under" maneuver as soon as adequate visual reference is achieved and prior to initiating the flare. As many writers have pointed out (refs. 4, 2, and 1), this maneuver cannot be tolerated under Category II conditions due to the rapid increase in sink rate that would occur close to the ground.

The problem posed here is one of enabling the Captain to determine that he can touchdown within acceptable longitudinal distance limits before he is committed to land. It should be clear, however, that this is one of the major unresolved issues in achieving acceptable low visibility landing objectives and will also affect flight management tasks in assessing the initiation and execution of the landing maneuver. This maneuver and the wind conditions under which it is performed will, of course, finally determine where the aircraft will touchdown. Potential problems associated with its management are outlined in a later section.

Potential Problems in Resolving the Landing Commitment Decision

In the present analysis, it is convenient to distinguish the landing commitment decision from the low approach commitment decision and assessment of approach success which were considered earlier. For operations in marginal weather conditions, the notion of proceeding with an approach to a pre-established decision point prior to finally committing the aircraft to the landing maneuver is deeply ingrained in pilots. The pilot's requirement to approach only as close to the ground as his confidence in the system warrants and "have a look" before committing himself to the landing is, of course, explicitly provided for in the Category II situation. And, although no specific "decision height" has been established, the Category IIIa situation (700 feet RVR) is widely regarded as a "see-to-land" condition at least with respect to last-second assessments of flight path alignment and touchdown attitude.

With the exception of full Category III conditions, then, considerable emphasis is given to a final assessment of the flight situation by reference to external visual cues in resolving the landing commitment decision. Under Category II conditions, and assuming a positive assessment of the approach, the decision to land is taken only when external visual reference is considered adequate for executing a safe and comfortable landing maneuver under manual control. This section will be concerned primarily with potential problems in making this decision at the 100-foot decision height.

Under Category IIIa conditions, the landing commitment decision prior to initiating the landing maneuver is necessarily made by instrument reference and is thus indistinguishable from the approach success judgment. However, as visual cues emerge during the landing maneuver, they are expected to become a compelling influence on the ultimate decision to continue the maneuver or abort the landing and execute a go-around (as opposed to a missed approach) even when controlled runway contact cannot be averted. But this decision cannot be separated from the ongoing assessment of the landing maneuver and potential problems with this flight management task are covered in a later section.

Since the problems associated with resolving the landing commitment decision are all related to the task of assessing the adequacy of external visual reference for assuming manual control and completing the landing maneuver, no breakdown of component flight management tasks will be necessary in this section. Instead, a number of unresolved issues are stated below as questions and briefly discussed.

1. <u>What consitutes "adequate visual reference" at the 100-foot decision height?</u>

In specifying operating limitations for Category II operations, the FAA (ref. 9) clearly requires that a missed approach be initiated when ". . . the pilot, upon reaching the authorized decision height, has not established adequate visual reference. . ." Thus, there is a formal requirement for the Captain to make this determination, but as yet no further specification of what a pilot must or should see at the decision height to assure adequate visual reference has been developed, i.e., there are no criteria to guide the Captain in making this assessment.

There is, of course, a considerable amount of opinion on this issue and some of it is supported by data. British studies of vertical flight path control by visual reference (ref. 11) suggest the often quoted requirement for seeing both the runway threshold and a flight path aiming point beyond the threshold. Reported approach performance presented in Figure 5 is typical and is interpreted by Morrall as follows:

> The results of (Figure 5a) were taken by J. Cook at London Airport when the visibility was about 1200 metres (Category I). The closure with the runway centreline as the approach proceeds and the deterioration in pitch performance at about 3 to 6000 ft range are quite apparent. The improvement in pitch performance as the aircraft approaches the threshold can also be seen and it is noted that this takes place at the point where the pilot starts to see the runway threshold and beyond at a range of about 3000 ft.
>
> B. L. E. U. have recently completed a flight trial where different approach lighting patterns were investigated. A slant range of about 400 metres was simulated with fog screens. The pilots who took part in this trial had made many landings in low visibility both real and simulated and were also well educated in the problems of this type of operation. The results given in (Figure 5b) again show the deterioration in pitch performance when even these experienced pilots assumed manual control using visual guidance. The pitch performance on this occasion does not improve until after threshold, i. e., when at 400 metres slant range the pilot is able to see the aiming point to which he is going.

Unfortunately, when reported RVR is 1200 feet, it is unlikely that the pilot will be able to see his aiming point and there is some uncertainty regarding his ability to see the threshold. On a glide slope of three degrees with an RVR of 1200 feet, it has been estimated that the pilot's eye would have to be as low as 70 feet in order to see as far as the point on the ground to which his aircraft is heading. And, with respect to the threshold, the ALPA All Weather Flying Committee is convinced, according to Beck (ref. 12), that if 1200 feet RVR is being reported on the ground a pilot should be able to see the final segment of the approach lights and the green threshold lights. Based on observations in the fog chamber at Berkeley, however, they concluded that unless the pilot has been "head up" for some time prior to arrival at the decision height,

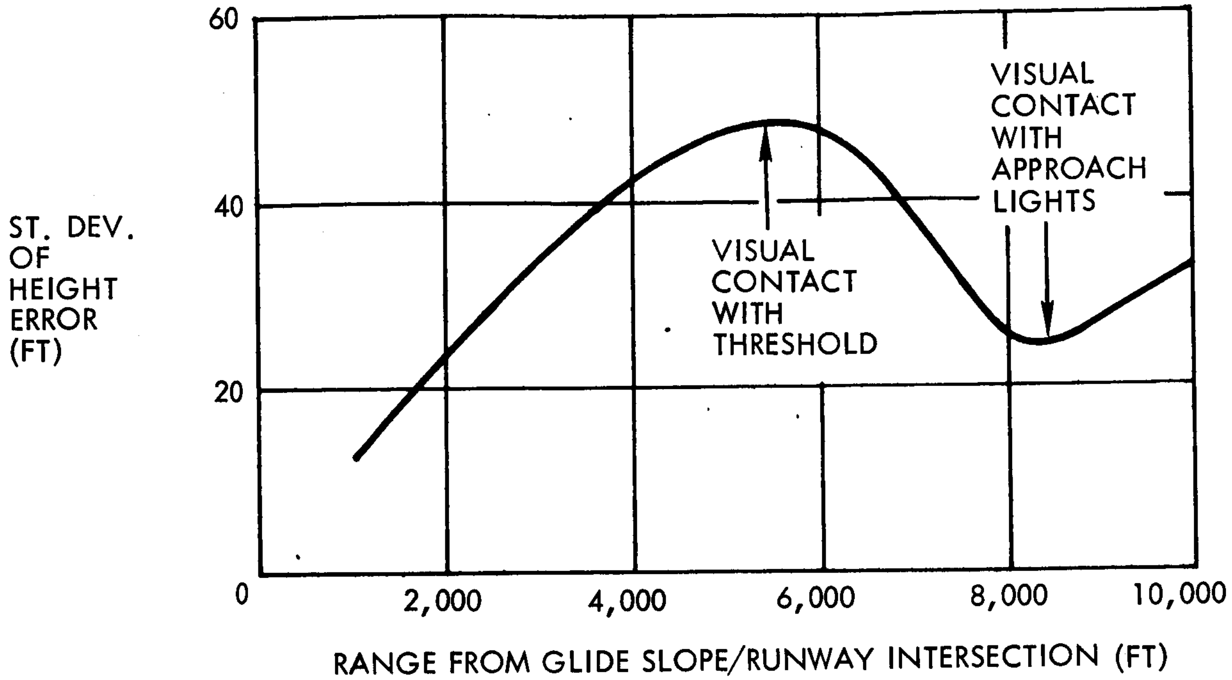

Figure 5a. Approach Performance, London Airport, Average Visual Range 3660 Feet. (From Ref. 11)

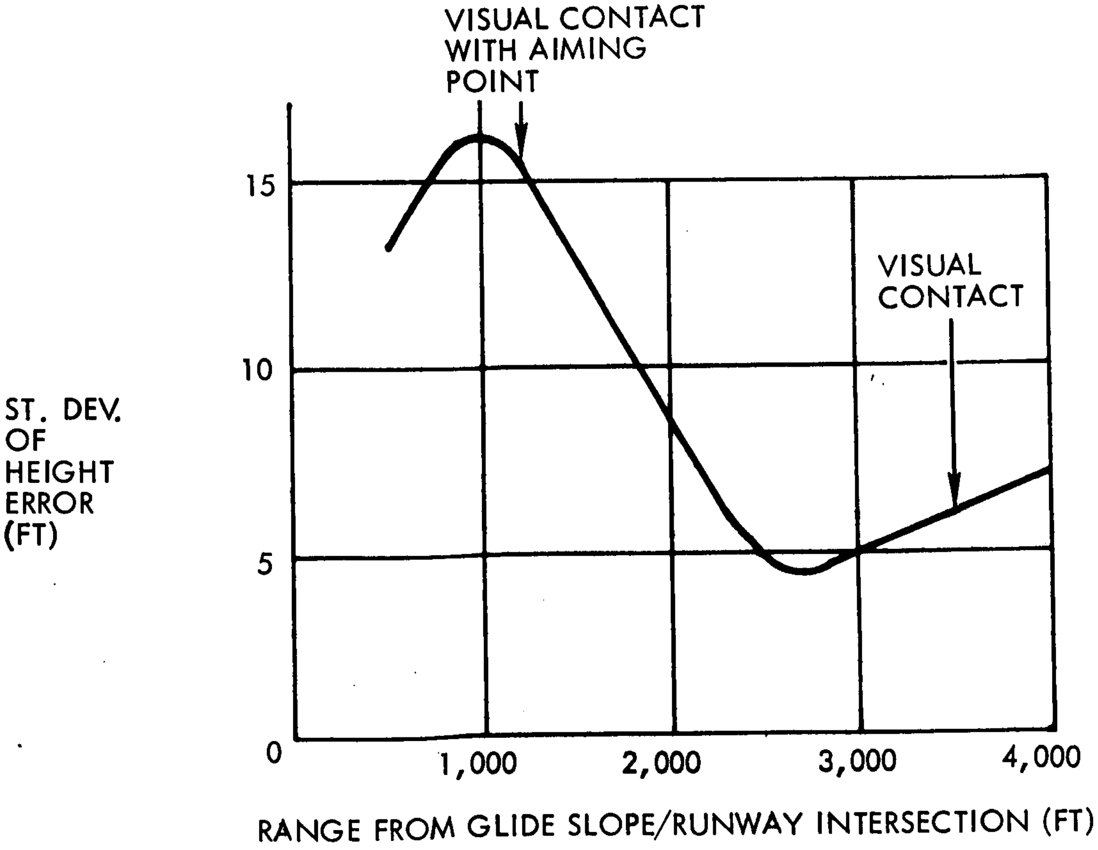

Figure 5b. Approach Performance, B. L. E. U. Trials, Simulated Visual Range 1200 Feet. (From Ref. 11)

completely adjusted to long range vision, and accurately directing his line of sight toward the runway threshold, he will not see the green threshold lights.

The problem of developing criterial information for assessing the adequacy of external visual reference for the landing is complicated by the fact that a satisfactory determination of the visual cues used in controlling the landing maneuver, even under VFR conditions, has never been accomplished. This is indicated in the results of a questionnaire study conducted by Aeronautical Research Laboratories, as reported in reference 13, wherein more than one-third of the 300 responding pilots admitted experiencing uncomfortable incidents on final approach. It was reported that ". . . the pilots were not able to describe clearly how they judged the landing approach, most of them tended to regard it as intuitive".

Other studies also tend to obscure the issue of visual requirements for manual control of the landing. Commenting on the extensive flight test program undertaken to develop the Lear Siegler/SUD All Weather Landing System for the Caravelle, Kramer (ref. 14) suggests that current requirements for Category II operations may be unnecessarily restrictive:

> It was noticed during these tests that the pilot's slant visibility seemed to improve below 100 feet. It was further noted that when the pilot had a slant visibility of 400 meters at 100 feet the landing was always possible, even when disconnecting the autopilot at 50 feet. Thus it appears that a 50 feet decision altitude instead of 100 feet would be adequate for Category II. The pilots were able to make safe manual landings from 50 feet with only 250 meters visibility. Hence, it appears that the present Category II visibility minimums could be reduced.

The foregoing is intended to show that there is considerable difference of opinion in regard to visual reference requirements for Category II operations. No attempt to take a position on this issue or to otherwise suggest solution concepts is implied. With respect to the flight management task the problem remains one of not providing the Captain with criterial information for resolving a formal decision problem.

2. Will pilots experience confusion as visual cues "fade-in" approaching the decision height?

It has been widely reported on the basis of flight tests under low visibility conditions that when slant visual range is less than about 1600 feet, visual cues used to assess the flight situation often "fade-in" rather than emerging suddenly and clearly as they might in the "break-out" phenomena associated with higher minima operations and on training flights when a hood is removed at minimum altitudes. Studies of weather phenomena producing Category II visibility conditions indicate that a number of potentially misleading visual effects may be encountered and there is serious concern for the impact of these effects on human judgment, particularly with respect to assessing the vertical flight situation.

In some instances the pilot will be able to see only a limited roughly conical-shaped region in front of him. This situation is often cited as the basis for the observed tendency of pilots, under Category I conditions, to execute the "duck under" maneuver cited earlier. The fact that the pilot will continue on the glide slope to lower altitudes under Category II conditions before acquiring visual cues will intensify this problem, since an even greater discrepancy can be expected between what the pilot sees and what he expects to see on the basis of extensive past experience in approaching the runway under higher minima conditions.

Assuming present glide slope intersections with the runway, an on-glide slope approach will result in a vertical flight path which crosses the runway threshold at about 50 feet. VFR approach paths typically cross the threshold at about 20 feet as a result of the pilot's effort to touchdown within the first 1000 feet of the runway. On "breaking out" or "fading-in" to visual conditions from an on-glide slope approach, then, the Captain could find himself up to twice as high as he normally approaches under better visibility conditions. In view of the marked differences that can occur in the geometric relationships of the pilot's visual field as a function of relative eye position and line of sight, considerable disagreement may be expected in this situation between what the Captain "sees" and his perceptual expectancies. As Litchford has noted (ref. 4):

> As it is, centerline and crossbar lights extend 3000 feet from the runway threshold into the approach zone of the runway. The pilot uses these lights, and the threshold and border runway lights each time he makes a landing on a clear night. If we ask him to fly under low visibility conditions until he is within 100 feet of the ground (without effectively seeing the lights, and then only a short segment of lights), whatever he sees must coincide with what he usually sees when the visibility is good. Only in this way will the pilot be confident that the landing system is delivering him to his desired and familiar position over threshold.

Another source of potentially hazardous pilot confusion under low visibility conditions has been identified by Bressey (ref. 15):

> The most dangerous condition occurs when the slant visual range decreases suddenly during the final portion of the approach. If the fog is homogeneous, the pilot's visual segment will increase steadily during his descent along the glide slope, since the length of the obscured segment below the aircraft (due to the cockpit cut-off) decreased with height.
>
> However, if a pilot suddenly flies into a thicker patch of fog, and is unprepared for this, he will imagine that the decrease in his visual segment is due to his having inadvertently "pulled the nose up", and so cut off his view of the nearest lights. In actual fact, it is his view of the lights furthest away which has become obscured. Unfortunately, the "natural tendency" is for the pilot to push forward on the control column to lower the nose, thereby increasing his rate of descent, and so the chances of an undershoot.

> Now those of you who are not pilots, or even those pilots who have not actually experienced this sudden foreshortening of the visual segment under real or simulated conditions, may be saying to themselves "Wot a clot! this could NEVER happen to me." Let me assure you that there is all the difference in the world between viewing this problem in theory, sitting back there in your comfortable chair, full of good Dutch breakfast, than from viewing it in practice, through a smeary windscreen, with several dozen tons of aircraft strapped to your backside, and the end of the runway coming up at more than 200 feet per second...... Under such conditions, seeing is NOT believing, so you must not believe what you think you see.

Additional potential sources of pilot confusion in attempting to assess the flight situation by external visual reference could be cited, such as the misleading effects of viewing the approach from an excessive crab angle. But the point has been made that this sort of confusion can occur and its impact on the Captain's ability to safely commit the aircraft to a landing on the basis of visual judgment must be examined.

3. Will the concurrent requirement to assess both external visual reference and approach success compromise performance of these flight management tasks?

As the aircraft approaches the decision height, the Captain must continue to assess the flight path and velocity vectors against approach success criteria and at the same time evaluate the external visual field for controlling the landing maneuver. Both of these assessments must be resolved before the aircraft leaves the "decision region". This segment of the approach is defined by the FAA as ". . . the region between the middle marker and the 100-foot point where the pilot must decide to either continue his approach or execute a go-around". In the present analysis, the position is taken that ultimate responsibility for the performance of these and other flight management tasks can only be assumed by the pilot-in-command. This position has been expressed by Beck (ref. 12) as follows:

> When the airplane starts down the glide slope, the next assumption must be that the Captain will manage the approach, that any allocation of crew duties will be such that there will be no abrogation of the prerogative of command, and that he, this Captain, will make the decision as to whether the approach is to be continued or a go-around executed.

Potential problems in retaining full command prerogatives are in large measure dependent upon the procedures adopted by the Captain in obtaining the necessary information for this decision. Freed of the demands of continuous manual flight path control by the automatic pilot, the Captain may elect to divide his attention between the flight instruments and external visual reference as soon as fragmentary visual cues become available. The penalty for this procedure is the well-documented information gap of two or more seconds which is estimated to occur whenever the pilot transfers his sight from instruments to the external visual field. The time required to fully transition from instruments to visual reference can vary from a fraction of a second to intervals of 8 to 12 seconds (ref. 16) and even if this transition were completed, cross-checking of flight instruments would still be necessary for assessing approach success.

Information gaps of this sort are clearly unacceptable during the critical time period while the aircraft is in the decision region and crew procedures have been adopted to assure continuous monitoring and assignment of control authority. The two principal techniques have been summarized by Beck (ref. 2) as follows:

> Case I.
>
> The Captain hand flies the plane or, if on automatics, exercises complete control of the entire approach to the DH. At this point, the First Officer, who is looking out the window, indicates whether or not the required visual reference exists. Then the Captain looks up and makes his decision whether to continue or whether a missed approach must be executed. This is the general route toward which most of the U. S. Carriers have directed their plans and thinking.
>
> Case II.
>
> The First Officer flies the plane or, if on automatics, exercises physical control of the approach, while the Captain acts as the approach manager. At some predetermined altitude, the Captain starts looking outside the window for visual cues. When the DH is reached, it is called out by the First Officer (or Pilot-Engineer) and the Captain then decides whether to continue or whether a missed approach must be executed. If the approach is to continue, the Captain physically takes control. If a go-around is to be made, it is commanded by the Captain and executed by the First Officer.

The overriding problem in adopting the Case I procedure is that it clearly entails an "abrogation of the prerogative of command". Notice that at some predetermined point in the approach it is the First Officer who goes "head up" to assess the adequacy of external visual reference. Presumably, if sufficient visual cues are available he will report "Runway in Sight"; otherwise, and assuming he has some way of knowing that the decision height has been reached, he will report "Minimums - No Runway". The probable rejection of this technique by command pilots is clearly indicated in the following quote from reference 12:

> The next point to be again reiterated and emphasized is that there is no question in the minds of anyone in the industry but that the Captain must make the decision to

> land or go-around. If, when the airplane arrives at the 100-foot point, the First Officer says "Runway in Sight" or "Minimums - No Runway", he is judging and making a decision for the Captain. This cannot be!

If the second case is adopted, as it has been by a number of European airlines, the Captain retains command prerogatives with respect to the landing commitment decision, but if he is to avoid the penalties of dividing his attention between the flight instruments and the external visual field, he must now rely on the First Officer to monitor flight path alignment, tracking velocities, airspeed, absolute altitude, vertical velocity, etc., and to report any tendency of the aircraft to exceed "approach gate" limits. Although some problems remain, acceptance of this procedure is expected to be considerably more positive than the first case.

One problem with restricting the Captain to external visual reference during this critical phase of the approach is that as fragmentary visual cues become available, he may attempt to assume manual control too soon. The potential inadequacies in visual information at the decision height for assessing the vertical situation were cited earlier. However, the compelling character of even degraded visual cues and the stress of having to quickly resolve the landing commitment decision before penetrating the decision height can be expected to exert considerable pressure. Difficulties in ignoring visual cues, even if the Captain were inclined to do so, are understandable in view of their acquired value to the pilot, as Gold and Workman have noted (ref. 17):

> Why the importance of the external visual world? Under VFR conditions, the pilot is able to capitalize maximally during approach and landing on many of the visual skills he has been developing all his life. His guidance is excellent, save possibly for some looseness in the elevation channel. His manual flight control capabilities are also good, presuming he had adequate guidance. And for assessment, the external visual world is today literally peerless in the eyes

of the pilot. Under restricted visibility conditions, the pilot also obtains assessment information from the external visual field. The quantity and quality of this information depends on the airport, visual aids, ambient lighting conditions and, of course, the exact weather conditions.

The perceptual capabilities of the pilot make the situation for the assimilation of visual information extremely favorable. Human capabilities for pattern recognition with the type of visual information available during approach and landing are unparalleled. Furthermore, the pilot subjectively has more confidence in what he perceives directly, as contrasted with an instrument display with sensor and processed data inputs. The eyes more often than not believe what they see. This is the reason optical illusions are so compelling when they occur.

Consequently, there are two assessment features which the real world provides the pilot which panel instruments cannot rival. These are perceptual ease of assimilation and subjective confidence that the information is veridical.

Potential Problems in Assessing the Initiation and Execution of the Landing Maneuver

The landing maneuver begins with the initiation of the flare. The objectives of this maneuver are:

1. Maintain runway alignment and control cross-track velocity.
2. Reduce sink rate to about two feet per second at touchdown.
3. Maintain wings level and pitch at approximately plus seven degrees.
4. Contact the runway within the touchdown zone with the longitudinal velocity vector aligned with the runway centerline.

The overall flight management task is to assess whether the objectives are or will be met and thereby decide whether to take corrective action, and/or continue with the landing or abort.

Since some of the potential flight management problems which occur during landing result from crew roles and procedures, those assumed in this analysis are described below.

Category II: The Captain takes control of the aircraft at or above the decision height and uses external visual cues to land the aircraft. The First Officer remains head down to monitor the go-around, if it is initiated by the Captain.

Category IIIa: The aircraft is coupled to the ILS localizer and glide slope and the autopilot controls the final approach. The landing maneuver, including the flare being performed by the autopilot, will be assessed by the Captain by reference to instruments. However, sometime prior to a commitment to the landing it must be determined that the aircraft will touch down within the touchdown zone. Since some visual reference will be possible, it is assumed that the pilot who will control the rollout will be looking out the windscreen in preparation for taking over control at the point of touchdown and that this pilot will determine, by visual reference, whether or not the aircraft will touchdown within the touchdown zone. The question of which crew member will go head up, the Captain or the First Officer, raises qualitatively different problems.

The analysis of system performance during the initiation and execution of the landing maneuver revealed certain potential inadequacies in the support of flight management. These are presented and discussed below.

Assessing Flight Path Alignment During a Category IIIa Landing Maneuver

The flight management task requirement here is to determine that the aircraft is tracking so as to touchdown near the runway centerline and the judgment involved is similar to the earlier discussion of assessing flight path alignment at the Category II decision height. The following discussion questions the pilot's ability to reliably assess runway alignment on the basis of either visual cues or flight instruments during the landing. Under Category IIIa conditions, aircraft performance monitoring will continue to require reference to cockpit instrumentation, though visual cues will be appearing outside. As already indicated, such cues are extremely compelling as they appear to directly represent the aircraft position relative to the ground. Any disparity between perceptual expectancies and observed visual patterns is likely to induce anxiety and possibly, disorientation. Fog, smoke, and haze tend to make objects appear to be farther away, and severely limit or eliminate rate of motion cues (ref. 26). In addition, a crab angle may be established or increased after one of the pilots begins to look outside and this could also produce an unexpected visual pattern. Crab angle changes as great as 17 degrees were experienced in Caravelle flight tests between glide slope capture and 100 feet (ref. 14).

The detection of rate and direction of movement under low visibility is also questionable. To do so accurately requires that the pilot observe one bank of lights approximately normal to his view and then see another bank a short time later (ref. 2). For example, touchdown zone lights in successive parallel banks would be seen as horizontally displaced if the aircraft has a cross-track velocity. The time duration between the first and second sightings and the degree of displacement provides the rate cues.

If the Captain is head up, there is insufficient time for him to look back to the localizer deviation indicator on the instrument panel to verify that an excessive offset or cross-track velocity exists. If the First

Officer is head up, he might report an apparent flight path deviation not represented by the instruments. In either case, the problem for the Captain is to resolve the ambiguity and accept one information source or the other. In the first case, the Captain must accept the First Officer's tacit assessment that localizer deviation is not significant. In the latter case, with the Captain head down, he must weigh the localizer deviation indication against the First Officer's report based on visual reference.

It is assumed that the localizer deviation indicator with the expanded scale is adequate for monitoring runway alignment under Category IIIa conditions. The flight management problem in assessing alignment and cross-track velocity during Category IIIa landings is one of resolving discrepancies between instrument indications and First Officer reports of external cues or, if the Captain is looking out, in using marginal visual cues devoid of rate information to assess runway alignment.

Assessing the Flare

The purpose of the flare is to meet the second objective listed above, i.e., to reduce the rate of descent from a nominal 12 feet per second to about two feet per second. This is accomplished by reducing power and increasing pitch smoothly by one or two degrees (for the SST).

The optimum flare path is not directly represented. It has been shown that variability in glide slope impact points at different airports (ref. 4) will not allow the pilot and/or auto coupler to execute the same approach and flare even though the same glide slope angle is employed. The external view will vary accordingly and compromise the ability of the pilot to assess the landing maneuver on the basis of external cues. In addition, the absence of pitch cues under low visibility does not allow the Captain to assess whether the flare is progressing properly. In this connection, studies indicate that: (1) when flying into gradually thickening fog the pilot looking out feels he is climbing and compensates by descending too low, and (2) a slight bank may cause the pilot to think he is higher than he is (ref. 18).

The inadequacy of visual cues for assessing performance of the flare was also pointed out by Cane (ref. 19):

> It has been shown that both restricted visibilities on break-out and deteriorations thereafter give the pilot the impression that he is high on his approach, causing him to try to duck under what is, in fact, the correct path, or alternatively to maintain power on the engines and fly the aircraft onto the runway. The former is a cause of undershooting and the latter of overshooting; only continuous glide path and flare guidance after the aircraft is under visual control can adequately take care of this major problem.

Indeed, there is evidence that it is difficult for a pilot to adequately assess an auto flare under VFR conditions (ref. 14):

> . . . actual occurrences of improper flare paths during the program definitely demonstrated that the pilot is a very poor monitor of the automatic flare maneuver. The reliability and repeatability of the automatic system soon gives the pilot confidence. . . when the system malfunctions and does not flare the aircraft, the pilot does not realize this soon enough to prevent an excessively hard landing.

Where confidence in the automatic system is not well established the Captain desires that the auto flare system initiate the flare sooner than he might if he were in control. He wishes to anticipate the flare in order to be ready to act if it fails to operate properly. A NASA Technical Report quoted by Litchford (ref. 4) seriously questions the likelihood that an excessively delayed flare maneuver, requiring maximum aircraft performance, will ever be acceptable to pilots for manual or automatic flight.

We have said that outside visual cues are inadequate to assess pitch during flare under low visibility conditions. The pilot apparently needs to see both an initial aiming point and the touchdown point in order to assess the flare on the basis of visual cues. The only means by which the pilot can anticipate the flare using instruments is to monitor the radio altimeter reading as it approaches 75 feet. At that altitude the approach progress annunciator illuminates "green" and the flare is programmed to begin. Lag in aircraft response may momentarily create doubt and anxiety that the flare has been initiated. Auto throttles will begin to retard and sink rate should reduce after a few seconds and assure the pilot that the aircraft is executing the flare. But a few seconds may be too late to recover. At Toulouse, after some 500 automatic landings, a failure occurred in the auto flare and even though the pilot took control he could not avoid an extremely hard contact (ref. 14).

The fact that the flare annunciator is amber means merely that the appropriate control mode has been initiated. The pilot does not know if this is the estimated one in 10^7 landings when the automatic system will fail. It is doubtful that the pilot could assume control and land the aircraft in the event of a failure during the flare, but being able to anticipate a failure would allow more time and altitude in which to execute a go-around.

In assessing the flare, the head down pilot may have difficulty detecting the small change in pitch (one or two degrees) associated with flare initiation. At the same time, the head up pilot may feel that this pitch change is excessive due to concomitant though unrelated changes in visual conditions, e.g., flying into a dense patch of fog. Thus the problem of resolving information discrepancy without adequate support is again introduced.

It may be decreed that because visual cues available in Category IIIa conditions may create invalid perception, the Captain, looking out, must be disciplined to ignore his perceptions and rely on the head down First Officer to monitor the flight instruments. However, it is not inconceivable that something could go wrong with the automatic system and that the Captain, looking out the windscreen, could recover an otherwise dangerous situation. Of course, another danger is to recover an otherwise safe landing or create an unsafe condition by interferring.

Assessing the Touchdown

The importance of the touchdown point is, of course, that it directly affects runway remaining. The FAA Class A runway lighting system has touchdown zone lights which extend 3000 feet down the runway from the threshold independent of runway length. As discussed in a preceding section, regulations state that a pilot must initiate a go-around if he determines that he cannot touchdown within the prescribed touchdown zone. As also pointed out, it is not possible at the decision height to make that determination on the basis of external cues. However, it would appear to follow the intent of the regulation that whenever the pilot using visual cues can judge that his touchdown point will be outside the touchdown zone he should abort the landing and execute a go-around. Problems associated with that assessment are discussed in answering the following question: Can pilots accurately and reliably estimate touchdown point soon enough to execute a safe go-around if this assessment is negative?

Under Category II minimums the Captain should be able to visually assess that the landing will be within the touchdown zone prior to arrival over the threshold. However, with RVR at 700 feet and the aircraft using up runway at a rate of 200 feet per second, the head up pilot has but a few seconds of advance knowledge of where his touchdown will occur.

In the assumed SST landing system, the head down pilot has no direct way of knowing where the aircraft will touchdown,* but he does have better information on when it will occur by virtue of the radio altimeter.

There are several problems associated with assessment of the touchdown point. The many factors which combine to increase the probability of long landings were discussed previously. Certainly pilot acceptance will be difficult to achieve for a system which is likely to land long but not allow him to know about it until he is very close to touchdown.

The Captain, looking out to assess touchdown point, may detect what he considers to be excessive cross-track velocity. Again, he could be wrong and take some control action that might degrade performance of the landing. The Pilot Factors Report (ref. 7) quoted at length earlier showed that pilots under the hood were often unaware that excessive cross-track velocity existed (based upon the flight instruments used in the study). If the B-2707 expanded localizer scale does not adequately represent cross-track velocity, the Captain may doubt the First Officer's ability to detect it and would be encouraged to attempt a visual assessment.

Assessing the Adequacy of Visual Cues for Manual Control of Rollout

When the aircraft touches down on the main landing gear, the flight deck will be 20 to 30 feet high and another five seconds will elapse prior to nosewheel touchdown. Uncorrected crab or lateral velocity may cause the aircraft to veer upon touchdown and the pilot must be ready to apply a correction and keep the aircraft tracking along the runway centerline. The flight management task requirement here, is to assess the visibility conditions sometime prior to or at the point of touchdown as to their

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*Boeing is currently experimenting with a TV display of the landing gear and runway which can be monitored by the pilot.

adequacy for rollout guidance. If the Captain judges that visibility is inadequate for rollout control, he will abort the landing.

The Captain will have received RVR information prior to the approach but the ultimate criterion for what constitutes adequate visual conditions is obtained by looking out the windscreen. As with other assessments which may result in a decision to abort the landing and go-around, the sooner they can be finalized the better. But at low minimums RVR reports do not support the pilot in making his assessment.

A reported RVR of 700 feet is no assurance to the Captain that visual cues are adequate for a safe rollout. The existance of dense fog patches could result in a temporary disappearance of visual cues and loss of control even though reported RVR is equal to or greater than 700 feet. Exactly what RVR value reflects visual conditions which are adequate for rollout guidance is apparently unresolved.

Fog chamber studies indicate that 1200 feet RVR is adequate to control rollout with 50 foot spacing of 5000 candlepower centerline lights (ref. 2). But for lower minimums there is still some question. For example, Kramer states (ref. 14):

> The pilot has no difficulty in rollout after landing until visibilities become less than 150 meters, as long as the landing strip has centerline guidance or narrow gauge lighting.

On the other hand, B. L. E. U., in their discussion of rollout and taxi guidance requirements, conclude that (ref. 20):

> As runway visual range drops below 250 yards the visual guidance provided by runway markings by day and centerline lighting by night becomes insufficient for the pilot to perform safe visual rollout.

Thus, the Captain is inadequately supported in making an assessment that visibility is not adequate for manual control of the rollout until late in the maneuver. He may, as a result, establish his own minimum earlier in the approach and tend toward aborting landings which would have been successful, i.e., visibility would have been adequate.

Potential Problems in Assessing Initiation and Execution of the Go-around or Landing Abort Maneuver

The go-around maneuver is a safety valve operation. It is initiated anytime during the approach and landing that the assessments being performed by the Captain indicate that safety would be compromised were he to continue with the landing.

In the proposed SST landing system, when the go-around button is depressed and throttles advanced, the autopilot initiates a pitch control program designed to minimize altitude loss and establish a safe climb angle. Glide slope and localizer needles center and the Flight Director reflects commands sent to the autopilot.

Considerable controversy appears in the discussion of the missed approach. The questions around which the controversy revolves are presented and discussed below. These questions are important to flight management since the pilot's personal answers to them will affect his assessments.

1. What is the minimum altitude at which a go-around can be safely initiated?

NASA simulation studies show altitude losses up to 70 feet on go-around in jet transport aircraft (ref. 21). Boeing estimates for the SST show a maximum loss of 45 feet on go-around (ref. 22). Apparently, however, these figures are not useful in deriving safe go-around altitude. Flight experience with the Lear Siegler/SUD system in the Caravelle indicates (ref. 14):

> . . . that a safe go-around can be made from any altitude — even down to touchdown. The only requirement is that the aircraft must be aligned with the runway, so that if ground contact is made during the go-around the aircraft will be on the runway and there will be no problem. Because of the fast response of modern jet engines to throttle advance and the power available for the go-around maneuver, go-around is no longer a maneuver of great concern. Automatic go-arounds have been initiated in the Caravelle as low as 6 to 10 feet, and runway contact did not occur.
>
> Of course, at higher initiation altitudes more altitude is lost, so that in the Caravelle at 70 feet altitude, 30 to 40 feet is lost during the go-around. This difference in loss of altitude is due to ground effect to some extent, but primarily it is due to the difference in airplane attitude at initiation of go-around. Prior to the flare altitude, the airplane is descending in a 2^o to 3^o angle; after flare initiation, this angle is continually decreased so that just before touchdown the aircraft is in an attitude where the application of power alone will usually cause the aircraft to begin a climb with no additional aircraft rotation. Thus the closer to the ground, the easier it is to make a go-around.

That optimism is not shared by others in the all weather landing community. Studies are now in progress in the United Kingdom to establish whether the assumption that an overshoot is "entirely safe" in terms of the Air Registration Board safety criteria (ref. 23).

The Caravelle study quoted above specifies that the go-around is safe if the aircraft is aligned with the runway. But suppose the decision to go-around is considered because of mis-alignment? At what altitude can the Captain be assued that the automatic go-around system will prevent ground contact?

2. Will the Captain accept the decision to go-around to be made by the First Officer?

Under Category II, past decision height altitude, the Captain will be controlling the aircraft using visual cues, and for Category IIIa he will be looking out sometime prior to touchdown. On the basis of aircraft instrumentation reflecting aircraft performance or subsystem operation the First Officer may conclude that a go-around should be initiated. Depending upon pre-arranged procedures, the First Officer will announce the out-of-tolerance condition to the Captain or immediately initiate go-around. Time constraints would probably not allow the Captain to receive the information, confirm it and then to take whatever action he deems appropriate, e.g., continue, take manual control or execute a go-around. However, the Captain may be reluctant to permit the First Officer to make the go-around decision.

3. Will the Captain accept the First Officer as monitor of automatic flight control systems during go-around?

Once go-around has been initiated the maneuver must be assessed using flight instruments. The first few seconds of the operation will be monitored by the First Officer since the Captain must readjust to instrument viewing conditions. If the First Officer believes the maneuver is not being performed properly he might override the autopilot using control wheel steering. It is doubtful that Captains will accept exercise of control prerogative by the First Officer under such circumstances.

Potential Problems in Assessing Equipment Operating Status and Resolving Override, Reconfiguration and/or Disengagement Decisions

No requirement is more heavily stressed in current efforts to develop an effective low visibility landing system than the demand for ultra-reliable equipment operation in all subsystems which are essential to the success and safety of the landing. To satisfy safety and legal requirements, the Captain must have continuous assurance that certain system components are operating properly and that possible failures will not have catastrophic consequences. At the same time, the development of an effective failure-monitoring and corrective action system encompassing all of the critical sensors, data processors and computers, displays, servos, actuators, and associated electronics may prove to be the most difficult requirement to satisfy. The detection of system malfunctions and degraded operating conditions must be immediate, comprehensive, continuous, accurate, and itself highly reliable. Significant changes in equipment operating status must be clearly and promptly brought to the Captain's attention in such a way that an appropriate corrective action can be taken or that he may have immediate assurance that it is both safe and legal to continue the approach and landing.

Despite the considerable attention given to this issue, the role of the pilot in fault detection and isolation and in resolving decisions regarding override control and/or disengagement of automatic systems is still largely unresolved. The requirement for automatic fault detection and isolation capability is widely recognized, though much concern remains in regard to the possible interference of such systems with the operation of the systems being monitored and to the possibilities for nuisance warnings or false alarms. The extent to which these systems should be tied-in to an automatic switch-over to redundant control systems and provisions required for various degrees of pilot intervention are more controversial issues. Even in the United Kingdom's position, however, where no reliance is placed on pilot capabilities for fault detection or corrective action in achieving "failure survival" goals below the minimum decision altitude, an active monitoring role for the pilot is still acknowledged, as indicated in the following quote (ref. 24):

> The pilot is there to monitor the system, and to take over as soon as he detects a malfunction. From this spring two research areas. Firstly, anyone who has seen photographs of the cockpit of a modern jet airliner will realise that the terrifying array of dials and lights makes it essential to do some solid thinking about the presentation of failure warnings. It is not sufficient merely to add another flashing red light and hope it will be noticed in time. Industry is already giving close attention to this problem.
>
> Secondly, if the system is to derive its safety in certain cases by using monitors to truncate the error distribution, the risk involved in the pilot's alternative action must be low. No-one really knows at present just how unsafe the overshoot manoeuvre is in blind conditions close to the ground, but it seems that it may not be very safe. A lot of research is needed to define this risk and, if possible, to reduce it.

The foregoing quote also points up the two principal unresolved issues in supporting the Captain in assessing equipment operating status and determining what action to take when malfunctions occur. The first questions the Captain's ability to detect significant conditions and events within the severe time constraints imposed on this task, even when sophisticated monitoring techniques and warning display systems are assumed to be available. His ability to select and implement an effective corrective action without incurring excessive risks is questioned in the second issue. Problems associated with these two issues are discussed in this section.

Assessing Equipment Operating Status

The proposed SST landing system can be characterized as a "fail operational" system. The principal component, the Automatic Flight Control System (AFCS), is comprised of an autopilot equipped with three integrated autopilot/flight director pitch-roll computers, an autothrottle, a continuously operating Stability Augmentation System (SAS), and an angle-of-attack warning and control system (ref. 22). A triple redundant, fail-operational capability is thus provided for initial autopilot failures with a fail-passive capability for a second failure. Dual redundancy is employed in the autothrottle system to provide only a fail-passive capability.

A complete display of AFCS operating status is also proposed. When the first failure occurs, status lights associated with mode selector control for each autopilot axis will indicate trouble in either the servos or the electronics for the designated channel. In addition, the pilot will be informed of this condition by a warning annunciator and the flashing of a master warning indicator on a system warning annunciator panel. No interruption in subsystem performance occurs and the warning indicators can be extinguished by depressing reset buttons. If a second failure of the same type as the first occurs, the malfunction detection system automatically disconnects the control axis involved and the associated displays indicate the disengagement. If the second failure is not the same as the first, disengagement of the axis will not occur. In either case, the malfunction condition is again displayed on the annunciators and master warning light.

Upon automatic disengagement of an axis after two failures, the corresponding autopilot mode selector switch for the defective axis will automatically move to the OFF position. When this occurs the pilot may elect to return the switch to the AUTO position and this action would reset the malfunction detection circuitry. If the second failure was a transient condition, automatic operation would resume; if it was authentic, the malfunction detection system would again disconnect the axis. Provisions for autothrottle monitoring are similar, except that automatic disengagement occurs after the first failure.

An improved flight director system and flight instrument monitoring system is also expected to be available in the SST. The integrated autopilot/flight director computers are connected to the flight director displays on the ADI through voters in the indicators, so that the flight directors are fail-operative for failures occurring in the computers. In addition, the Captain's and First Officer's instruments are monitored by an Instrument Warning System (IWS) as well as conventional flag indicators. A control unit on the IWS provides comparison monitoring of compass heading, calibrated airspeed, and pitch and roll attitude indicators. Flag warning signals are also monitored by this unit for these instruments and also for radio altimeters, vertical speed indicators, pressure altimeters and localizer and glide slope indicators. Identification of discrepancies in indicators and/or the occurrence of flag warning signals is provided on an associated annunciator display panel and a master warning light on the ADI.

The problem here is that even with the considerable effort being made to improve the timeliness and comprehensiveness of critical fault detection and to promptly and clearly display the results of this monitoring to the pilot, the number of parameters which must be monitored and the information processing required to assess the significance of indicated conditions may combine to overload the Captain. Human operators have been shown to be versatile and effective monitors if the number of parameters to be monitored are few and if the monitoring task is of short duration. The severe compression of time available for detection, interpretation and assessment of indicated conditions as the approach and landing proceeds, and the comparatively greater demands of concurrent flight progress and aircraft performance monitoring must also be considered. Detection probabilities for critical system malfunctions under these conditions should be determined emprirically.

Resolving Override Control, Reconfiguration and Disengagement Decisions

Various combinations of visibility conditions, equipment operating states, and the actual time of occurrence of significant state changes (e. g., malfunctions) can interact to produce a complex set of action alternatives which must be considered by the Captain in attempting to satisfy safety-of-flight and legal constraints. In a recent analysis of performance and safety requirements for operations under low minimum conditions (ref. 25), the most likely operational procedure to be followed in the event of failures in the automatic system were estimated; this projection is reproduced in Table 1.

It is reasonable to assume that as operational experience in low visibility operations is gained and crew training programs are developed and refined, clear and simple decision rules can be formulated to enable the Captain to reduce the many contingencies and complexities in action alternatives reflected in Table 1 to a manageable operational procedure. The problem here stems from the fact that a nearly instantaneous response to a potentially complex set of circumstances will be demanded of the Captain. His ability to match the right action alternative to the situation encountered should be examined. Certain combinations of weather conditions and system operating status may occur only very rarely in actual operations, but it is important to determine the Captain's response capability for low probability events to establish boundaries, if any, on the pilot's ability to intervene.

System Status	Antitipated Legal Operational Approach Capability	Type of System Protection	Anticipated Minimum Operational IFR Altitude	Automatic System Capability After First Failure	Automatic System Capability After Second Failure	ACTION REQUIRED WHEN FAILURES OCCUR							
						First Failure				Second Failure			
						Above 200 Ft.	200 to 100 Ft.	100 to 50 Feet	Below 50 Ft.	Above 200 Ft.	200 to 100 Feet	100 to 50 Feet	Below 50 Feet
Three Channels and All Monitors Functioning	Category IIIC	Fail-Operational	Touchdown	Category IIIA (dual channel)	Category II (single Channel)	1. Auto disengage failed channel. 2. Continue with dual channels to 50 feet or go-around manually if field is below Category IIIA minimums. 3. Subsequent approaches may be made to 50 feet under Category IIIA minimums.	1. Auto disengage failed channel. 2. Continue with dual channels to 50 feet or go-around manually if field is below Category IIIA minimums. 3. Subsequent approaches may be made to 50 feet under Category IIIA minimums.	1. Auto disengage failed channel. 2. Continue with dual channels to 50 feet or go-around manually if field is below Category IIIA minimums. 3. Subsequent approaches may be made to 50 feet under Category IIIA minimums.	1. Auto land on dual system with no pilot action.	1. Auto disengage complete axis. 2. Go-around manually or continue to 100 feet on manually selected single channel of AFCS. 3. Subsequent approaches may be made with manually selected selected single channel to 100 feet under Category II minimums.	1. Auto disengage complete axis. 2. Go-around manually. 3. Subsequent approaches may be made with manually selected single channel to 100 ft. under Category II minimums.	1. Auto disengage complete axis. 2. Go-around manually. 3. Subsequent approaches may be made with manually selected single channel to Category II minimums.	1. Auto disengage complete axis. 2. Pilot attempts to make landing manually with adequate display.
Two Channels and Associated Monitors Functioning	Category IIIA	Fail-Safe	50 feet	Category II	None	1. Auto disengage both channels (complete axis). 2. Go-around or continue to 100 feet with manually selected single channel. 3. Subsequent approach with single channel can be made to 100 feet under Category II minimums.	1. Auto disengage both channels (complete axis). 2. Go-around manually. 3. Subsequent approach with single channel can be made to 100 feet under Category II minimums.	1. Auto disengage both channels (complete axis). 2. Go-around manually. 3. Subsequent approach with single channel can be made to 100 feet under Category II minimums.	1. Not legal to be automatically controlled at this altitude with dual system under Category IIIA minimums.	1. Pilot disengages and continues manually on raw ILS data to 200 feet or effects a manual go-around.	1. Pilot disengages and effects a manual go-around.	1. Not legal to be automatically controlled at this altitude after first failure in Category IIIA minimums.	1. Not legal to be automatically controlled at this altitude after first failure in Category IIIA minimums.
Single Channel (No Monitors)	Category II	Servo Authority Limits (Plus in-line monitoring of servo portion of system)	100 feet	None	None	1. Pilot disengages and effects manual go-around or continues manually to 200 feet on raw ILS data. 2. Subsequent manual approach on raw ILS data can be made to 200 feet.	1. Pilot disengages and effects manual go-around. 2. Subsequent manual approach on raw ILS data can be made to 200 feet.	1. Not legal to be automatically controlled at at this altitude in Category II minimums.	1. Not legal to be automatically controlled at this altitude in Category II minimums.	DOES NOT APPLY BECAUSE ONLY ONE OPERABLE CHANNEL INITIALLY EXISTED.			

Table 1. All Weather Landing Operational Procedures (Ref. 1, Vol. II)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Unresolved issues in this problem area include time limits on exercising override control options (e. g., through control wheel steering), time required to confirm indicated failures and reconfigure the system (e. g., select alternate systems or operating modes), absolute altitude limits on assuming manual control, and time required for pilots to enter various control loops and to stabilize out-of-tolerance control parameters. For Category III operations, it is important to determine the risks involved in attempting to assume manual control and complete the landing and touchdown solely by instrument reference. Data on these issues would provide Captains with criteria for deciding when and how to enter various control loops.

CONCLUSIONS

The central concern of the analysis presented in this report was to identify potential problems in the performance of flight management tasks during SST low visibility approach and landing operations, considering projected SST landing system design concepts and operational procedures. Each of the problems identified can be considered as a candidate problem area for investigation in simulation studies at the NASA Ames Research Center. Statements of these problems are reiterated below as the conclusions of this phase of the study. For the reader's convenience, page numbers are cited in parentheses following each problem statement to locate the discussion of the problem in the preceding sections of this report.

1. The assessment of relative altitude, i. e., actual height above the intended touchdown area on the runway, by reference to radio altitude displays, is subject to error due to irregularities in terrain features along the flight path. (p. 13)

2. There is considerable uncertainty with the respect to the degree of lateral offset at the decision height which should be judged "excessive" by the SST Captain. It is suggested that criterial values for this assessment be established on the basis of demonstrated pilot ability and willingness to manually execute a lateral correction from the decision height. (p. 18)

3. The expanded ILS localizer deviation information used as the primary basis for assessing horizontal flight path alignment, together with basic flight situation instruments such as the heading indicator which may also be used, will not enable pilot to judge cross-track error and tracking tendencies to the required accuracies. (p. 21)

4. Information available from external visual cues under Category II conditions may prove to be a highly unreliable basis for judging flight path alignment; the severe time constraints on resolving this judgment, together with psychological factors which can be expected to bias the judgment in favor of a positive assessment, will increase the already high error probability in this component of the approach success decision. (p. 24)

5. The Captain cannot with confidence determine that his touchdown will occur within acceptable longitudinal distance limits by reference to available flight instruments before he is committed to land. (p. 26)

6. There is a formal requirement for the Captain to determine that "adequate visual reference" is available at the decision height, but no specification of what he must or should see at this point has been developed, i.e., there are no criteria to guide the Captain in making this assessment. (p. 32)

7. Studies of weather phenomena producing Category II visibility conditions indicate that a number of potentially misleading visual effects may be encountered and there is serious concern for the impact of these effects on human judgment, particularly with respect to assessing the vertical flight situation. (p. 36)

8. There are potential problems in pilot acceptance of crew coordination procedures in satisfying the concurrent requirements for assessing both external visual reference and approach success while the aircraft is in the decision region due to an abrogation of the prerogative of command. A procedure wherein the Captain elects to divide his attention between flight instruments and external visual reference is considered unacceptable due to the consequent information gap of two or more seconds associated with the transition. (p. 38)

9. There is a flight management problem in assessing flight path alignment and cross-track velocity during Category IIIa landings due to possible ambiguity between emerging visual cues which are largely devoid of rate information and instrument indications. The Captain may be reluctant to accept the First Officer's assessment based upon instruments but will be unable to verify them. (p. 44)

10. The flare annunciator light does not adequately support the Captain in anticipating the onset of the flare, i.e., being sure that manual takeover will be unnecessary. It is seriously questioned whether under low visibilities the pilot is able to assess that the aircraft if following an optimum flare path using either external cues or projected cockpit instrumentation. If "head up", the Captain might, because of optical illusion or a verdical perception, believe that the aircraft is pitching up too much but has insufficient time to verify the First Officer's tacit assessment that it is okay. (p. 45)

11. With RVR at 700 feet, the Captain may be unable to judge that touchdown will occur within the proper zone or that manual control of rollout is feasible until late in the approach. Pilots are unlikely to accept a system which delays a go-around decision until contact with the runway is unavoidable. (p. 48)

12. The minimum altitude at which a go-around can be safely executed in the SST has yet to be established. Computations based upon approach speed, aircraft configuration and gross weight must be performed to establish a minimum go-around decision height. It is also questionable whether Captains will accept the head up situation that precludes their being able to immediately assess execution of the go-around using flight instruments. Nor are they likely to accept the decision to go-round to be made by the First Officer. (p. 49)

13. In assessing the operating status of critical components of the SST landing system, the number of parameters which must be monitored and the information processing required to determine the significance of indicated conditions may combine to overload the Captain. Detection probabilities for critical subsystem malfunctions under realistic conditions of time stress and workload due to concurrent task requirements should be determined empirically. (p. 56)

14. The resolution of override control, reconfiguration and disengagement decisions for automatic systems will demand nearly instanteous responses to potentially complex sets of circumstances and the Captain's ability to satisfy this demand in the later stages of the approach is suspect. Unresolved issues include time limits on initiating override control actions, time required to implement selected corrective actions, absolute altitude limits on assuming manual control, and risks involved in attempting manual control of the landing maneuver solely by instrument reference. (p. 58)

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