Department of AERONAUTICS and ASTRONAUTICS
STANFORD UNIVERSITY

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A DESIGN STUDY

OF A

METROPOLITAN AIR TRANSIT SYSTEM

MAT

PREPARED UNDER NASA—ASEE SUMMER FACULTY
FELLOWSHIP PROGRAM IN
ENGINEERING SYSTEMS DESIGN

NASA CONTRACT NSR 05-020-151

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Prepared under NASA Contract NSR 05-020-151 under the NASA-ASEE Summer Faculty Fellowship Program in Engineering Systems Design, 16 June-29 August, 1969.

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Chapter One

INTRODUCTION

The 1969 NASA-ASEE Engineering Systems Design Program was manned by a group of nineteen aeronautical, civil, electrical, industrial, and mechanical engineers. These faculty participants, representing 14 states and 17 universities, spent eleven weeks on the project. In order to obtain knowledge of the current state-of-the-art and research trends in areas pertinent to commuter air transportation, an accelerated learning program was required. Background information for the study was obtained from current literature and from 27 guest speakers representing a cross-section of the airframe, propulsion, avionics, systems management, and transportation industries.

In addition to the copious amount of information obtained from literature and speakers, the study group made trips to manufacturers, research agencies, airlines, and airtraffic control centers. A team of six, headed by Dr. Bollay, visited the McCulloch Aircraft Company and the Hughes Tool Company in the Los Angeles area early in July to obtain data on such VTOL aircraft as autogyros and helicopters. The facilities of United Airlines at San Francisco International Airport were visited for a view of a large scale airline operation, with particular emphasis on maintenance. The Federal Air Traffic Control Centers at Fremont and Oakland International Airport were inspected, giving the group first-hand knowledge of the scope of current local air traffic control.

Investigation of aircraft operations was not limited to the ground. SFO Helicopter, Inc. provided the group with the opportunity to observe present helicopter operations and helicopter passenger environment by supplying complimentary "observer" tickets. The six licensed pilots in the study group contributed their general knowledge of aircraft handling characteristics and their specific experience on local conditions to the group as a whole, both by word and by having project members as passengers. In the course of the project, virtually all of the group members had direct flight experience in the Bay area. A large portion of this experience was with general aviation flying at low altitudes and included some night flying.

The subject of noise assumed a large role in the course of studying a commuter air transportation system, and precipitated investigation of noise levels at various locations in the Bay area. Measurements of ambient noise levels were made at sites considered suitable for the location of air terminals and in areas which would be in the noise field of proposed commuter air lanes.

The proposed air transportation system conceived by the group is summarized in the next chapter. The detailed aspects of the system subsystem designs, and cost analysis are presented in the succeeding chapters.

Chapter 2

DESIGN SUMMARY

2.1 MAT Location

The Metropolitan Air Transit System is designed specifically for the San Francisco Bay area, although the concept is adaptable to any metropolitan area. Proximity of the study group to the Bay area and its particular transportation needs dictated this choice. The MAT System serves a 13-county region bordered on the north by Santa Rosa, on the south by Monterey, and on the east by Sacramento and Stockton. The 24 terminals established within this area and served by the MAT System are located in city centers, the major Bay area airports, and in suburban population centers.

2.2 Market and Routes

The MAT System is to begin operation in 1980 and reach full-scale operation by 1990. Population forecasts for the Bay area indicate a 50% increase in the nine-county region by 1990 with the largest gains in the area north of the Bay and in the Newark-Fremont area. Air commuter traffic is expected to grow with Bay area population. Airline arrivals and departures are expected to grow at a rate faster than the population, reaching a level of 520,000 passengesr daily by 1990. The MAT System is designed to serve both airline connection customers and commuters with the percentage of commuter traffic being about 30% of the total MAT System volume in 1990. Airport customers will be served by providing rapid transportation, including baggage, on a seven-day-per-week basis. While the airport traffic is expected to be significantly larger in the day than at night, airport traffic is expected to be relatively free of the tremendous morning and evening surges characteristic of commuter traffic. Commuter traffic almost exclusively composed of suburbs to city center routes will be offered on a five-day-per-week basis with no baggage provisions. Both commuter and airport customer service will be offered on a scheduled basis.

2.3 Avionics

The MAT aircraft, flying at altitudes no more than 2,000 feet above ground level will be fully automatic from start up to shut down. In areas of dense air traffic such as near airports, either commercial or general aviation, tubelike air traffic corridors will be reserved for exclusive use by MAT aircraft. With a fully automatic system the pilot assumes a role of flight manager or monitor and retains flight proficiency by making a small number of landings and takeoffs daily at outlying terminals. With such a system the capacity is virtually independent of weather conditions. This high speed, totally disciplined system is controlled by a central computer with multiple data links which allow real-time aircraft control. Aircraft guidance and navigation is accomplished by equipment on board the individual aircraft. This onboard equipment does receive some information from the ground, but has the capability of completing a mission without any external signals. This is possible due to the parallel combination of an inertial system and a radio navigation system. The approach and landing system is also a redundant combination of two separate systems which allow ground minotiring of aircraft performance by means of a track-while-scan radar.

2.4 Aircraft

The aircraft selected for the system was an 80 passenger compound helicopter with a gross weight of about 60,000 pounds. This aircraft utilizes the rotor for takeoff and landing. Under crusing conditions the lift is provided by a standard wing and forward propulsion by 2 high by-pass ratio turbofan engines especially designed for low noise level. The rotor is driven by three gas turbines of sufficient power that the craft can safely land and take off even with one engine out. The crusing speed of the aircraft is 250 mph. Since mean stage length of flight is only 35 miles, rapid entry and exit are essential for efficient utilization of the aircraft. For a four-minute stop at each terminal this results in a mean block speed of 150 mph. Turnaround time for the vehicles is reduced by quick loading and unloading design that houses passengers in ten-seat units, similar to European railway cars. Doors are situated on both sides of each seating unit allowing rapid passenger speed. Noise, which is a major constraint on MAT system operation is held to 95 PNdB at ground level, 500 feet from the aircraft during the takeoff and landing phases and below 80 PNdB for overflight.

As the aircraft is capable of high rates of climb, partial pressurization (1 psi) is provided to give cabin pressure change rates which are compatible with passenger comfort.

2.5 Terminals

The 24 MAT System terminals are designed to handle 100,000 commuter trips and 50,000 airline connection trips per day, with a peak hourly load of 9,300 people. Emphasis is placed on designs which promote fast, efficient flows of both passengers and aircraft. Although a novel design of a STOL port is given, it is clearly shown that in order to accommodate such high density flows VTOL ports must be used. Three different classes of VTOL ports are proposed, (1) a Metro terminal, which is principally a high density commuter port, (2) a Suburban terminal which is a lower density commuter port, and (3) an Airline terminal, which is a high density airline port. Commuters and airline passengers gain entrance to the MAT system through the use of magnetic cards. These cards permit the implementation of automatic billing procedures together with providing the scheduling computer with real time demand data. Airline passengers place their baggage into the MAT system as soon as they arrive at the terminals. Automatic baggage handling procedures are then used to route the luggage to the proper MAT flight and the commercial airline connection. In this way the passenger does not pick up his luggage until he reaches his final destination. A system of dual queueing at the terminals is proposed which permits 80 passengers to be loaded and 80 unloaded in less than two minutes.

2.6 Costs and Benefits

It was concluded that such a high speed Metropolitan Air Transit System (MAT) is technically and economically feasible provided that the aircraft are utilized at least 2,000 hours per year assuming a load factor of 50%. At this utilization rate the total cost of operation of the full system is estimated at about $0.17 per passenger mile. For a private operation a fair profit would have to be added. If this system were operated by a public corporation with a subsidy comparable to BART (equivalent to about $0.09 per passenger mile), then the cost to a passenger would be brought down to the cost of automobile transportation.

The major market for this system is believed to be the transportation of passengers to and from the three major San Francisco Airports. In view of the increasing air traffic, it is assumed that by 1980 about 20% of airport passengers will utilize the MAT system to and from the main airports. In addition it is estimated that by 1980 10% of the MAT traffic will consist of professional and business commuters and skilled technicians whose time is worth more than the additional cost of transportation. It is estimated that by 1990 about 40% of airport passengers will utilize the MAT system, and that 30% of the MAT traffic will consist of non-airport traffic. On this basis, during the latter 1980's a total of 260 aircraft will be required at a total system cost of about $1.3 billion, with a total annual capacity 3,120 million passenger miles.

This compares with a cost of the BART surface transportation system by 1980 of about one billion dollars and an annual passenger capacity of about 800 million passenger miles. The mean block speed of the BART system is about one-third that of MAT, or 50 miles per hour. Its equivalent cost of transportation if it were unsubsidized would be about $0.123 per passenger mile. Surface transportation systems such as BART show this cost advantage of about 30%, however, only for very high density traffic. For longer range trips, such as San Francisco to Sacramento, the cost of a MAT round trip would be about one-tenth that of a BART round trip for a traffic flow which requires only about one or two cars per hour. The breakeven point in costs occurs when the traffic flow is about 6,500 passenger round trips per day.

Chapter 3

AIRCRAFT

3.1 General Configuration

3.1.1 Design Criteria

Based on the requirements established by the overall MAT system concept, the criteria for design of the aircraft was established to be the following:

Low operational altitude	1000-2000 ft above local terrain (below ATC)
Low noise	95 PNdB at 500 ft during takeoff and climb
	80 PNdB on flyover (residential area)
Safety	Speed < 250 mph
	Multiple engines
	Coupled propulsion system
	Low gust sensitivity
Minimum non-productive time	Short maneuvering time
	Rapid passenger handling
Low cost configuration	Design for rapid egress and ingress of passengers rather than aerodynamic cleanliness
	Partial pressurization only, as needed for rapid climb and descent
Short range	250 miles
Reasonable operating cost	

3.1.2 Possible Designs

In the initial considerations for aircraft and terminal configurations for this system, an unrestricted "blue-sky" approach was used. Some ideas which were put forth were

(1) Catapult-launched and arrested conventional aircraft

(2) Ground-launched gliders,

(3) Ballistic missiles with paraglider landing,

(4) Cable-guided aircraft,

(5) Aircraft flying into wind tunnels in the terminals,

(6) Underground runways with aircraft flying into a slot, and

(7) Aircraft carrying "People Pods."

The first of these received a great deal of consideration. It was finally decided that for passenger comfort the accelerations and decelerations had to be limited to less than one g, preferably less than 0.5 g. For such low accelerations and decelerations this system had no great advantages over the Short Take-Off and Landing (STOL) aircraft, and the disadvantage of greater time and cost for the engaging of the catapult and disengaging from the arresting gear.

Many of the others were discarded from a safety standpoint, considering factors like ground gusts and crosswind effects on control response and accuracy. Othere were ruled out from the standpoint of operational time on the ground. The remaining schemes were considered to be technically infeasible.

The attention was then turned to the more or less standard STOL, VTOL (Vertical Take-Off and Landing) and V/STOL (Vertical or

Short Take-Off and Landing) aircraft. The general types that were considered in the various categories were

VTOL

- Helicopter
- Compound helicopter
- Tilt rotor

STOL

- Low wing loading aircraft
- Deflected slipstream turboprop
- Propulsive wing
- Autogyro

V/STOL

- Tilt-wing turboprop
- Lift-fan
- Lift-jet

The low wing loading aircraft was quickly discarded because of the tremendous physical size involved for a large payload. The other designs were examined in a qualitative and semi-quantitative fashion, using some of the data presented in References 3-1 to 3-8, with particular regard to the following items:

(1) Noise
(2) Direct operating costs
(3) Terminal time
(4) Block times, and
(5) Operating characteristics.

A summary is presented in Table 3-1.

Table 3-1

SUMMARY OF VARIOUS CONFIGURATION CHARACTERISTICS

	Configurations	Anticipated Noise PNdB at 500 ft Takeoff	Approximate Block Time Min. at 40 Mi.	Non-Productive Time Min./Operation	Cost (Millions of Dollars)	Cruise Efficiency 250 mph at 2000'	Gust Sensitivity	Major Technical Problems
VTOL	Pure Helicopter	90 Acceptable	16	2	3.0	Poor	Low	Few
	Compound Helicopter	93 Acceptable	14	2	3.2	Fair	Low	Several
	Tilt Rotor	95 Marginal	14	2	3.5	Good	Average	Many
STOL	Deflected S.S. Turboprop	95 Marginal	15	4	2.8	Fair	High	None
	Propulsive Wing	100 Unacceptable	15	4	2.8	Poor	Average	Several
	Autogyro	95 Marginal	16	4	2.8	Good	Average	Few
V/STOL	Tilt-wing Turboprop	96 Marginal	14 VTOL	2	3.2	Fair	Average	Few
	Lift Fan	99 Unacceptable	14 VTOL	2	3.4	Poor	Low	Several
	Lift Jet	102 Unacceptable	14 VTOL	2	3.6	Poor	Low	Few

It was concluded that each of these types of aircraft has advantages and disadvantages and may be useful for various short-haul missions, depending upon the desired cruising speed and altitude and the desired range. The so-called "Direct Operating Costs" vary only by a small amount for flight stages of the order of 50 to 100 miles [3-1 to 3-8].

The all-important factor which determined whether our proposed aircraft will be permitted to land at all in city centers, or in quiet communities like Palo Alto, is the noise level of the aircraft. The most critical design conditions in this respect are the takeoff, climb, and final landing maneuver. For a VTOL aircraft weighing in the order of 60,000 pounds the noise level during takeoff at a distance of 500 feet is estimated to be approximately 125 PNdB with present turbojets. Turbojet-propelled types of VTOL aircraft are therefore obviously not suitable for our mission.

Since the noise level from the jet is proportional to V_j^8, where V_j is the jet velocity, it is evident that lower jet velocities are necessary for our mission. The present turbofans provide much reduced jet velocities, and thus a 60,000-pound VTOL aircraft using present turbofans would have a reduced noise level of about 120 PNdB at 500 feet, or with the so-called GE "lift-fan" the level would be about 122 PNdB at 500 feet. A major noise reduction program is underway by all of the powerplant manufacturers, and currently they are optimistic about achieving major noise reductions. Rolls-Royce [3-] quotes anticipated reduction of turbofans to 98 PNdB for an 80,000-pound VTOL. This would correspond to a noise level of about 97 PNdB for a 60,000-

pound VTOL aircraft at 500 feet. It is not clear whether this Rolls-Royce prediction is for a height of 500 feet or a horizontal distance of 500 feet. If their prediction is for a height of 500 feet, then the noise level at takeoff at a 500 feet distance would be 100 PNdB due to a doubling as a result of ground reflection.

The General Electric Company is also optimistic about reducing the noise level of their lift-fans. This is a more difficult problem because of the short axial length of the lift-fans. Even so, G.E. predicts [3-10] that the noise of a 25,000 to 30,000-pound lift-fan engine can be reduced to a level of 99 PNdB at 500 feet. Thus for 60,000-pounds a VTOL aircraft would produce a noise level of 102 PNdB at 500 feet altitude or 105 PNdB at 500 feet from the takeoff point. These noise levels are still too high for city center operations. Similarly, the jet propelled and turbofan-propelled STOL aircraft, which have a thrust/weight ratio of the order of 0.5, have only 3 PNdB less noise than the above quoted values for VTOL aircraft. It is estimated that a compound helicopter of 60,000-pound weight will be able to achieve a noise level at takeoff of 93 PNdB. It is estimated that a tilt-wing powered turboprop VTOL aircraft with large propellers, turning at a low tip Mach number, may be able to achieve about 96 PNdB at takeoff by using 7 or 8 bladed propellers of a type described in Reference 3-11. The titl-rotor with its somewhat higher disk-loading is estimated to produce about 95 PNdB at takeoff.

It is concluded that from a noise standpoint either the helicopter, compound helicopter, or tilt-rotor can be designed to meet the 95 PNdB noise criterion at takeoff, and the tilt-wing turboprop (96 PNdB) would be marginally acceptable.

3.1.3 VTOL vs. STOL

In examining the factors that make up the Direct Operating Cost from the standard ATA Formula [3-12] and actual experience in airline operation, it soon becomes apparent that the two main factors are depreciation and maintenance. The aerodynamic performance, from the standpoint of fuel used for cruise, is a very minor item for the short stage lengths required in this system.

Figure 3-1 shows curves of block time for typical STOL and high-speed VTOL operating over the stage lengths of interest in this system. Since the productive time is the main factor in depreciation and maintenance costs, it illustrates why the VTOL generally shows lower DOC at shorter stage lengths.

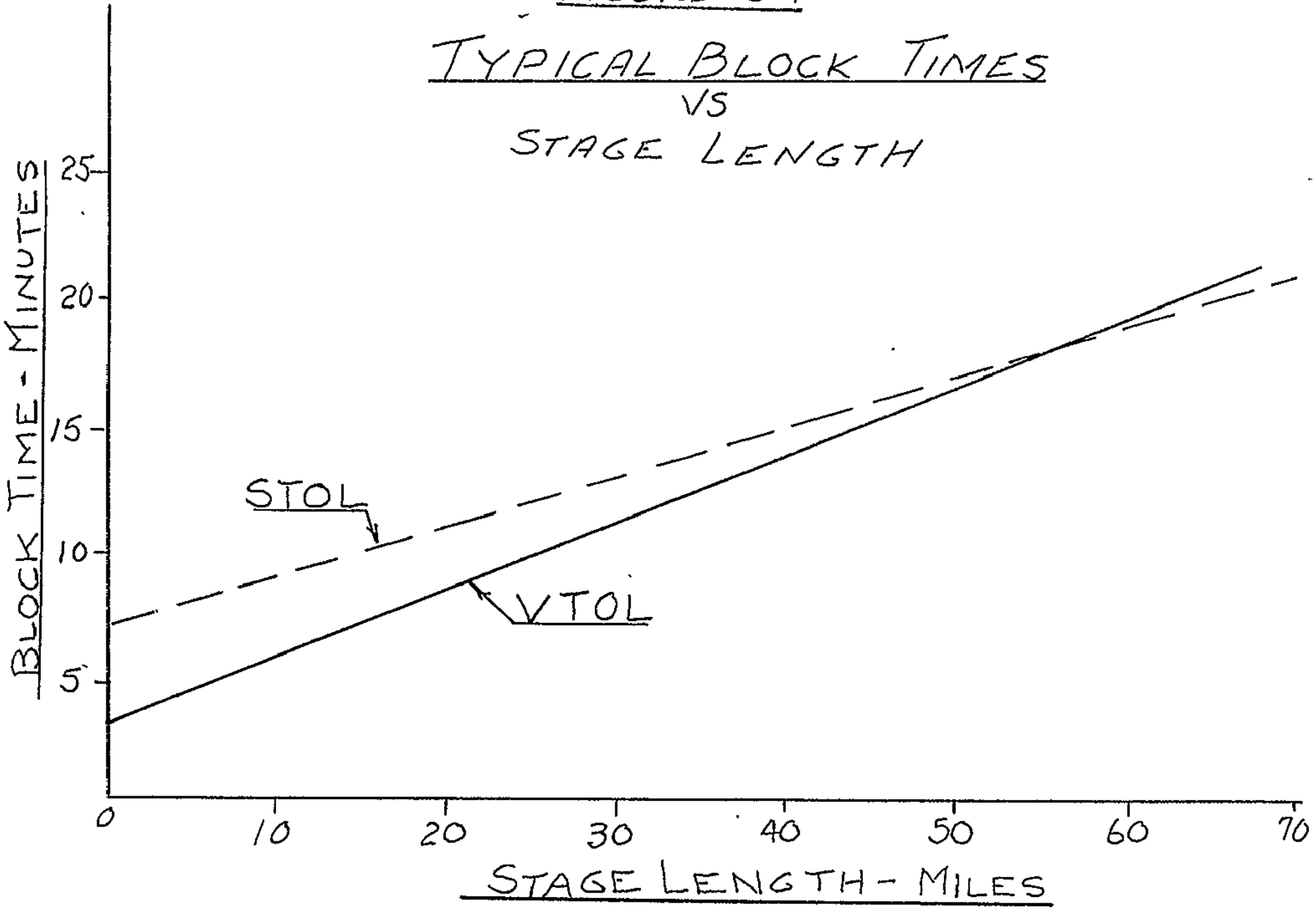
Considering that the mean stage length for this system is about 40 miles (see Chapter 7), it is indicated that the VTOL has a shorter block time than the STOL type (due to the longer ground maneuver time for the STOL), which means more rapid service and a favorable effect on DOC.

The STOL also has a characteristically high gust sensitivity due to its low wing loading necessary to achieve short field lengths.

These facts, coupled with the greater terminal requirements for the STOL (see Chapter 5) and its more restrictive approach and takeoff characteristics (see Section 3.2.1), led to the elimination of the STOL aircraft from further consideration in this study. This conclusion included the consideration that the VTOL aircraft have in general a higher initial cost, but this must be weighed against terminal cost.

FIGURE 3-1

TYPICAL BLOCK TIMES VS STAGE LENGTH



The V/STOL design represents a good compromise which would allow use of existing and planned STOL runways and conventional small airfields with VTOL ports constructed in congested areas, so that on the shorter stage lengths the mode of operations would be VTOL and on longer intercity stages the high speed capability of the STOL configuration would become advantageous (higher altitude of cruise). The DOC, terminal design, and passenger loading considerations also favor the V/STOL craft.

3.1.4 Final Candidate Designs

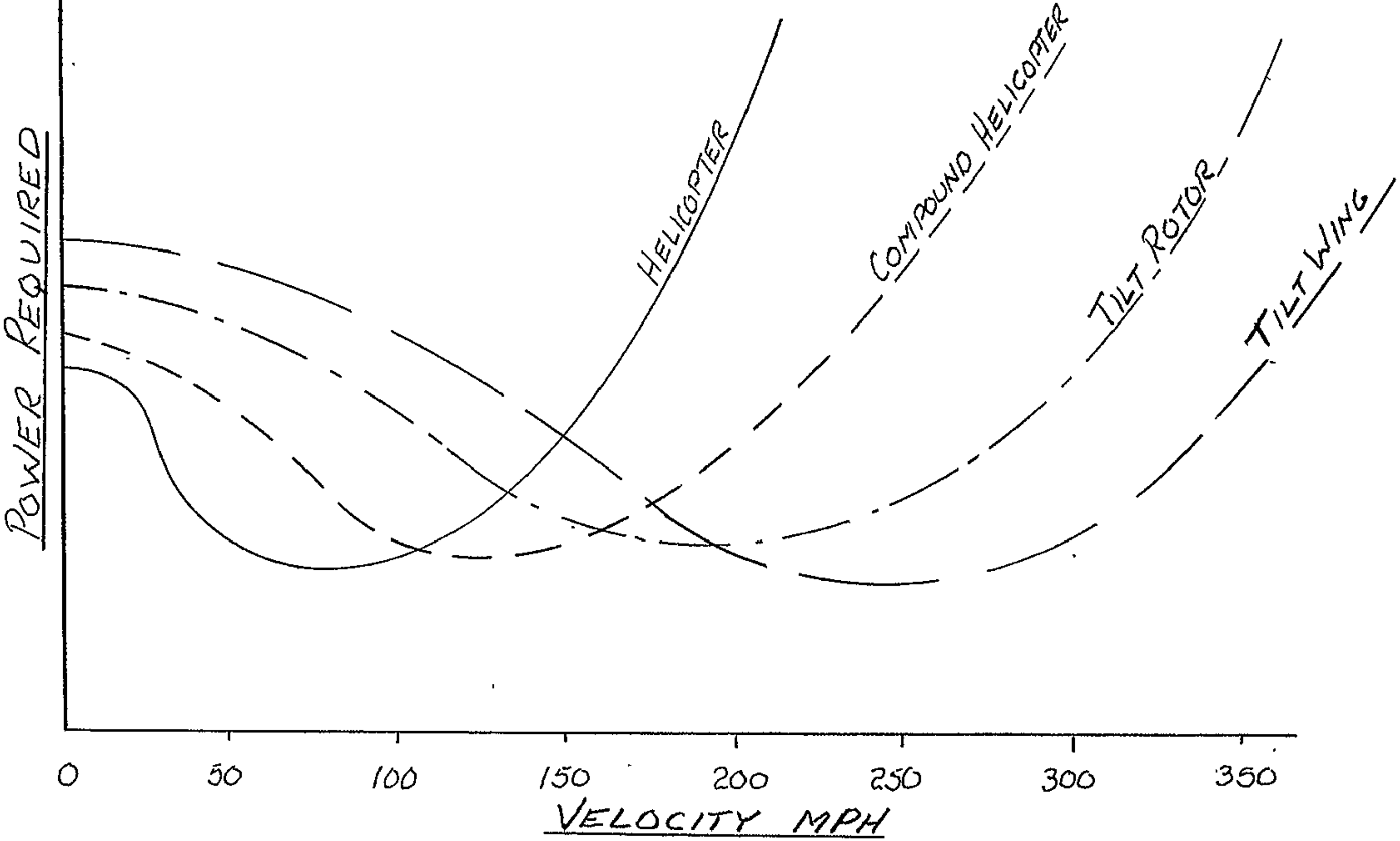
The most promising designs remaining are the pure helicopter, compound helicopter, tilt-rotor, and tilt-wing.

These configurations were evaluated on the basis of gross performance efficiency by comparing their approximate "Power Required" curves. This comparison is shown in Figure 3-2. These curves show the typical shape for VTOL type aircraft, i.e. at zero velocity; a large amount of power is required to hover. This required power drops off as some forward velocity is attained. After reaching a minimum, the required power increases, approximately as the cube of velocity, due to the increasing drag at increasing speed.

The differences in the curves for the various configurations occur primarily due to power loading and the amount of weight carried by the wing on the compound, tilt-rotor, and tilt-wing designs. The differences at zero velocity are due to the induced power (smaller disk area), requiring more hovering power for the same gross weight. The wing lift contributes to the shifting of the minimum point to a higher speed and flattening of the high speed portion.

FIGURE 3-2

TYPICAL POWER REQUIRED
VARIOUS CONFIGURATIONS



Since the minimum power point of the curve generally represents the minimum fuel flow rate, it would be advantageous, from an operating cost standpoint, to have this occur at the maximum speed for this system (250 mph).

Because of the severe vibration and gust sensitivity at high speeds the pure helicopter cannot safely or economically fly at 250 mph, and can be eliminated on that basis.

The tilt-wing propeller type of VTOL has probably the least development difficulties. It provides a smooth flight at all flight conditions, but has a much heavier propeller system than the tilt-rotor particularly if it uses 7 or 8 bladed propellers for noise reduction. Its payload with these low noise propellers will probably be about 10% to 15% less than that of the tilt-rotor or compound helicopter system.

The tilt-rotor configuration combines the advantages of the compound helicopter in vertical takeoff and the advantage of low noise and efficient forward propulsion. It also involves a minimum of vibratory excitation of the rotor due to retreating blade stall such as is encountered by all helicopters in forward flight. Thus it may have a lower vibration level and maintenance than the compound helicopter. On the other hand, the large rotors pose formidable technical problems in the detailed dynamic design of the blades and in coping with the effects of gusts on the rotor at high forward speeds. An energetic research and development program is recommended for tilt-rotor systems, and if this is successful the tilt-rotor configuration may prove superior to the compound helicopter, particularly for speeds up to about 400 mph. But for the flight regime up to about 250 mph the advantage would not be great. Thus for our mission the compound helicopter, at the present time, appears as the preferable type of configuration.

3.1.5 Selected Design

On the basis of the preceding considerations, and because of its acceptable vibration and aerodynamic characteristics [3-13], it was concluded that the compound helicopter represents, at the present time, the most conservative choice from the standpoint of meeting the MAT requirements of low noise level at takeoff and 250 mph cruising speed.

For the purposes of further performance studies, the Sikorsky S-65-200 compound helicopter [3-14] was chosen as a model for our system. The detailed calculations found in the remainder of this chapter center around this or similar designs.

The forward propulsion system may be either low noise propellers or future high by-pass ratio turbofan engines, such as described in Reference 3-9. For purposes of illustration we have shown turbofans (Figure 3-3).

If a turboprop is selected for forward propulsion it is mechanically interconnected with three gas turbines driving the main rotor. Such a system is proposed by Sikorsky in their Model S-65-200 compound helicopter. If a turbofan is selected for forward propulsion, the most straightforward design would be to select two separate engines for the forward propulsion and three standard gas turbines for driving the rotor.

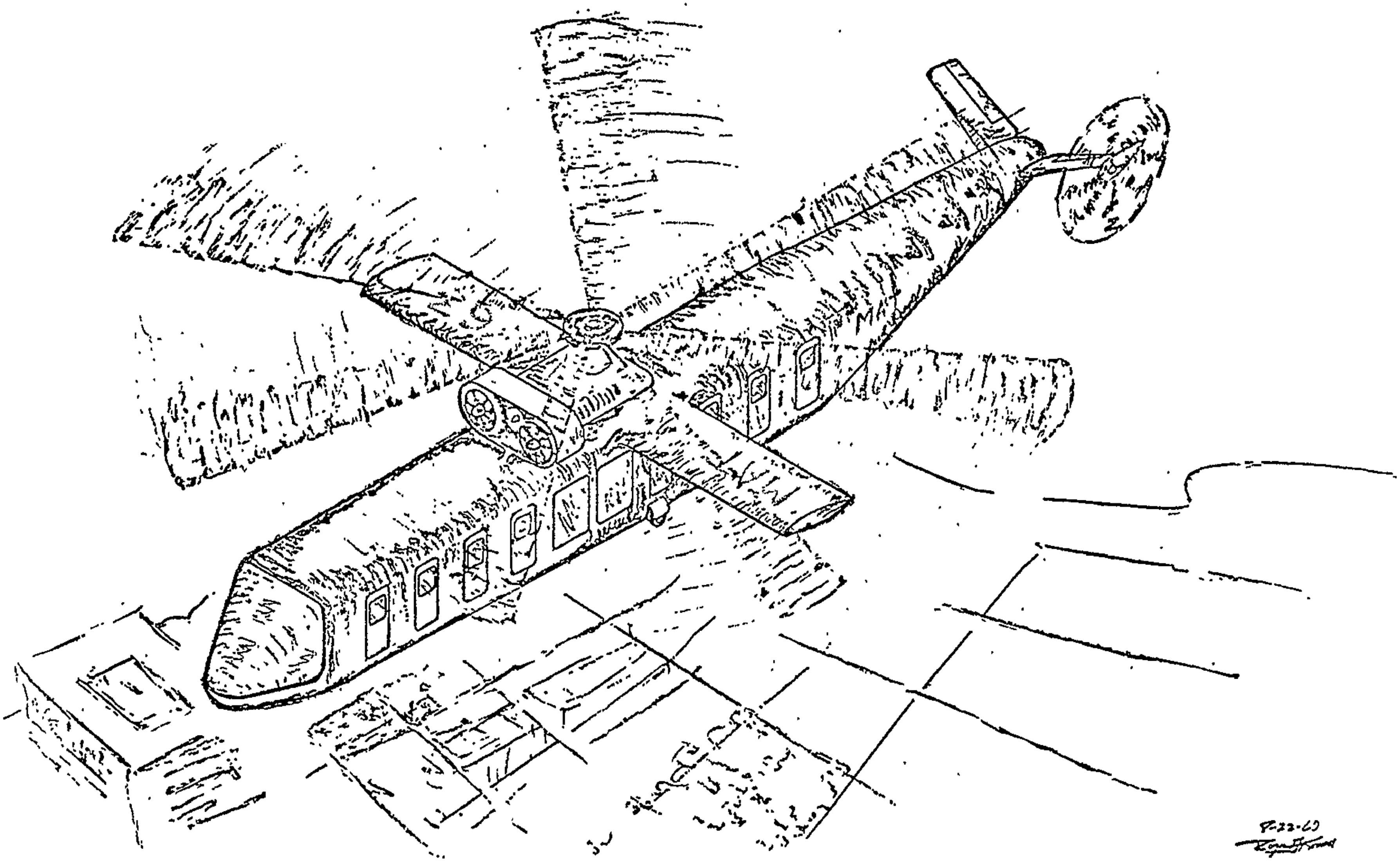


FIG. 3-3 PROPOSED MAT AIRCRAFT

9-22-60

An alternate system, but requiring more expensive research and development program, would be to interconnect the high by-pass ratio turbofan for forward propulsion with a shaft to the rotor, and to idle the turbofan system while the rotor is power driven; such a system has been proposed by Lycoming.

Another possible alternate propulsion system for the compound helicopter would combine a low by-pass ratio turbofan (or tip-driven cruise fan) for forward propulsion with a "warm-jet" propelled helicopter rotor [3-15]; such a system has been proposed by Hughes. This system mixes air from the turbofan (pressure ratio about 2) with the discharge jet gases and ducts the mixed gases to the helicopter tips. This combination low by-pass ratio turbofan and tip-jet reaction system is noisier than the mechanically driven compound helicopter, but it has the advantage of eliminating the troublesome and noisy tail rotors. Probably this configuration provides a higher payload ratio than the mechanically driven compound helicopter on short flights [3-16]. In our system, because of the overriding necessity for low noise levels, we have selected the mechanically driven compound helicopter. If future research tests on sound levels of tip-jet propelled rotors should demonstrate practical methods for reducing the noise level of such rotors, then this decision should be reviewed.

One particularly appealing possibility for future research should be the "circulation controlled" rotor which may promise substantial reduction in rotor noise level by reducing the rotor tip speed to say one-half, and increasing the local rotor blade lift coefficient to about fourfold [3-17]. (See Appendix C.)

3.1.6 Fuselage Design

Although a complete aircraft design was not developed from this study it is felt that a great deal of attention should be given to the fuselage layout, in that the usual aerodynamically aesthetic shape must give way to a more functional shaped dictated primarily by rapid passenger handling capability.

The fuselage cross-section is quite often dictated by pressurization requirements. Since the operational altitude of this aircraft is far below that normally required for pressurization, the only concern that remains is from a rate of climb pressure change consideration (see Chapter 6). It was decided that a programmed control of pressure change rate compatible with passenger comfort would be provided, with a maximum cabin differential of 1.0 psia (about 2,000 feet) being provided by engine compressor bleed air. This also allows the aircraft to be used on higher altitude flights on longer stage lengths.

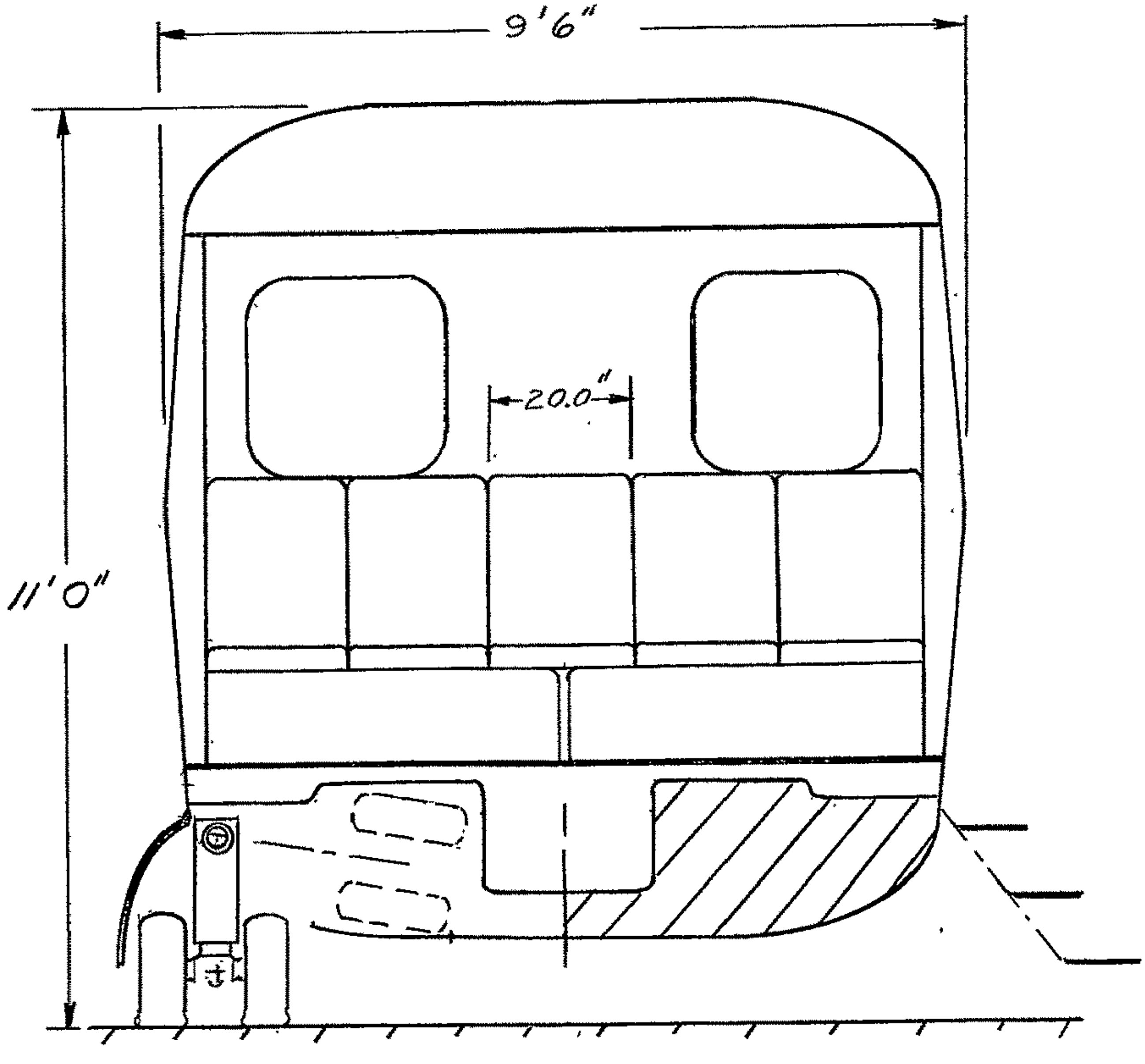
The decision to eliminate the requirement of full cabin pressurization removes the design restraint of a circular cross-section. This allows a rectangular section which provides a full-width, full-heighth cabin without the reduced heat and shoulder room near the windows in conventional airliner design (Figure 3-4).

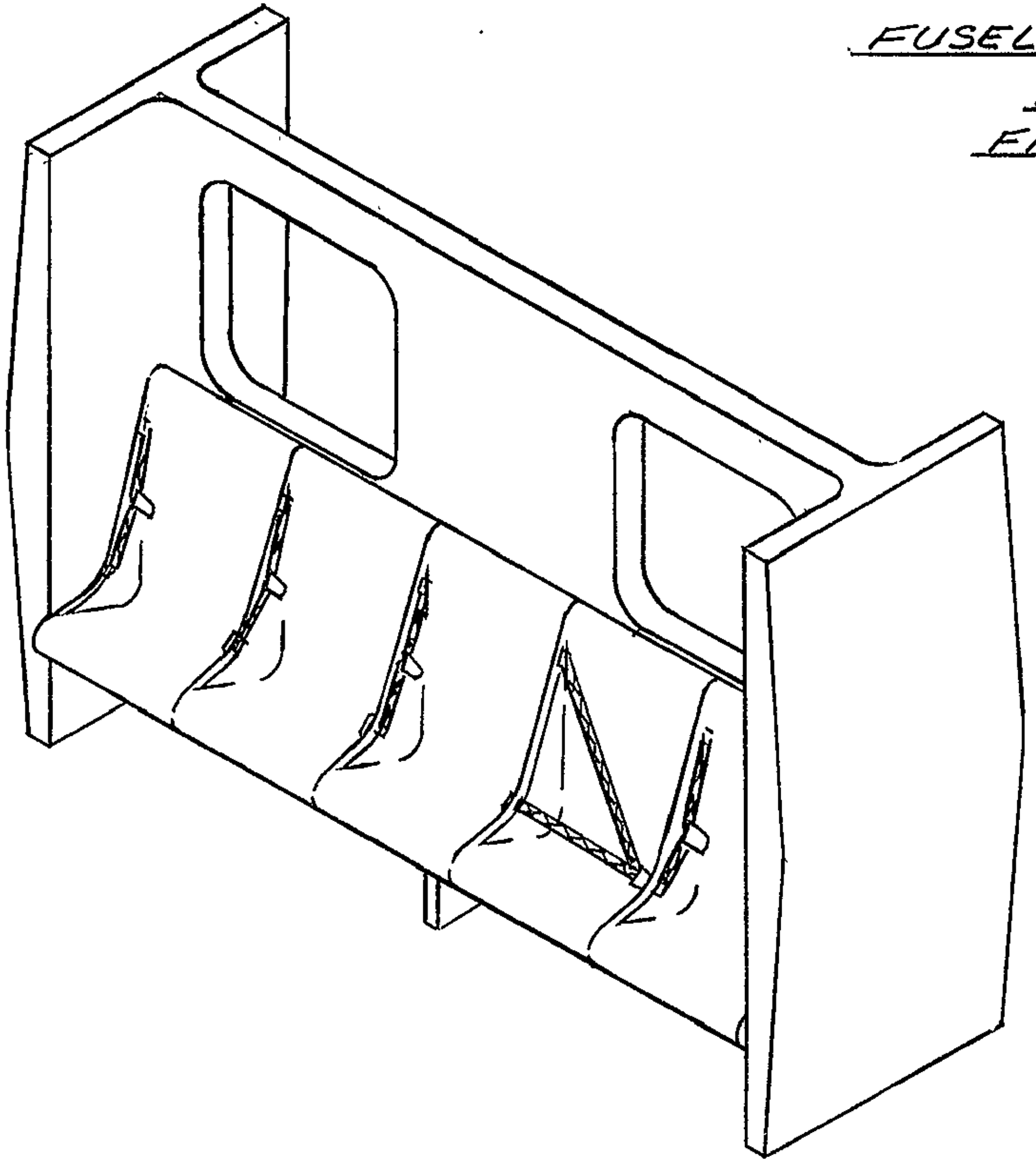
The cabin configuration chosen is a modular concept (Figure 3-5) that allows commonality in major structural components--a cost reduction technique--and provides a future stretched design with a minimum amount of additional engineering effort.

An 80-passenger cabin was chosen as the initial size for

FUSELAGE CROSS SECTION

FIG. 3-4





FUSELAGE SEAT/BULKHEAD MODULE

FIG. 3-5

this design, and is made up of eight 10-passenger modules (Figure 3-6). Each module contains 10 seats in a double pitch of 33.0 inches per pitch--a standard high density seating dimension. The double pitched seats are oriented face to face (Figure 3-7) so that effective leg room is increased, and the space between empty seats provides relatively wide, short aisles. Seat width is 20 inches.

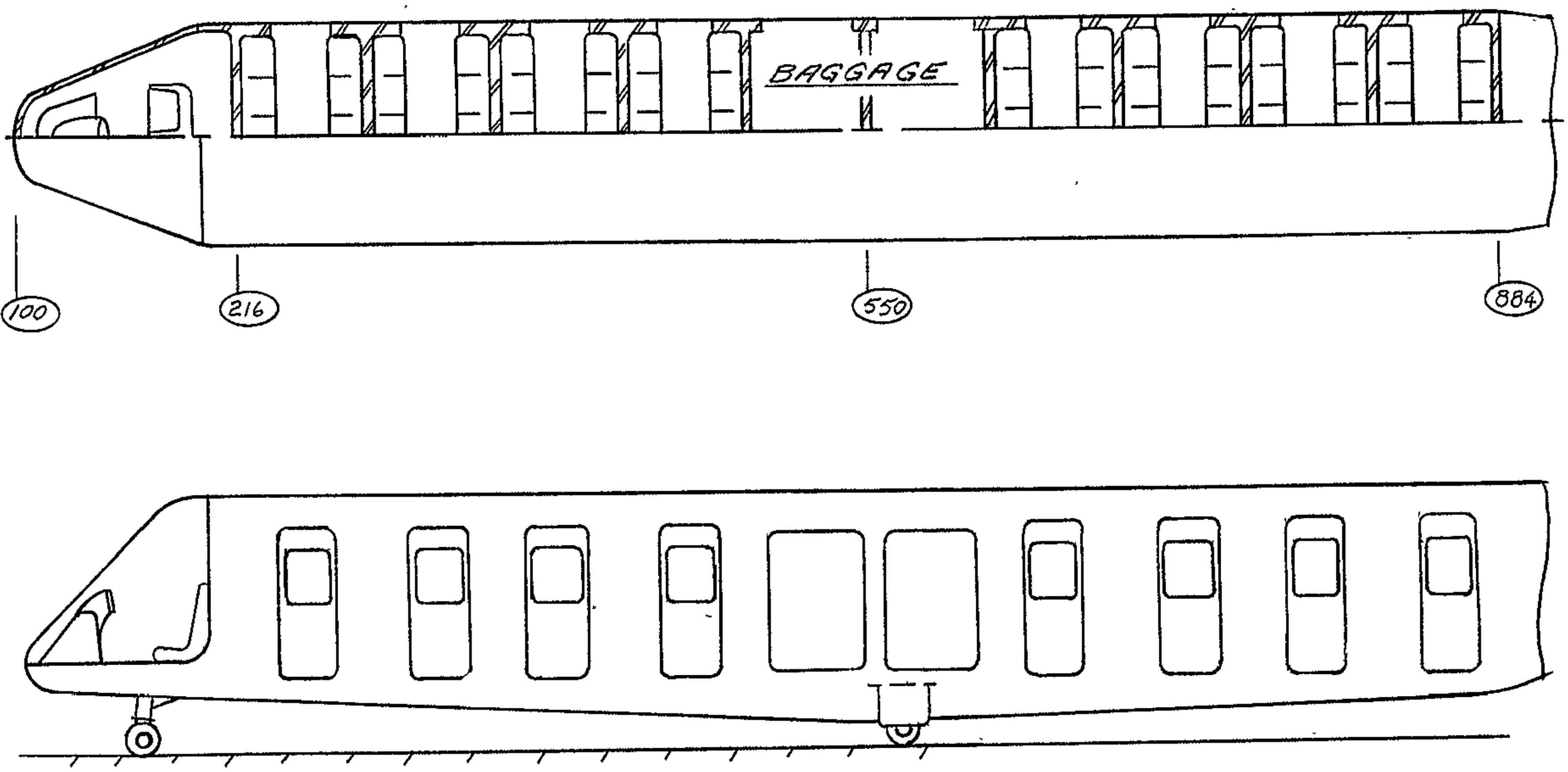
Each 10-passenger module has two doors for entry and exit for rapid loading. The doors, as shown in Figure 3-8, are arranged with a sideways sliding motion external to the main fuselage line. Under each door in the lower fuselage is a set of deployable fold-out steps, thereby eliminating the need for ground stairway equipment at outlying airports.

This cabin design may be used for either VTOL or V/STOL aircraft. In a helicopter the entire vehicle is tilted in the direction of acceleration. This minimizes the effects of "g" loading on passengers in a face to face seating arrangement--a fact substantiated during evaluation flights of SFO Helicopter, Inc.'s Sikorsky S-61 helicopters. In STOL operations, however, high longitudinal accelerations and decelerations would require effective passenger restraining devices. It is suggested that the conventional belt and shoulder harness could perhaps be replaced with simpler restraining mechanisms similar in design to those used in carnival thrill rides, with rapid deployment inflating barriers to be used only in emergency situations.

The basic fuselage design also allows utilization of the aircraft for cargo by sliding special 27" x 75" x 90" cargo containers into the area between the seats on rails mounted in the floor and

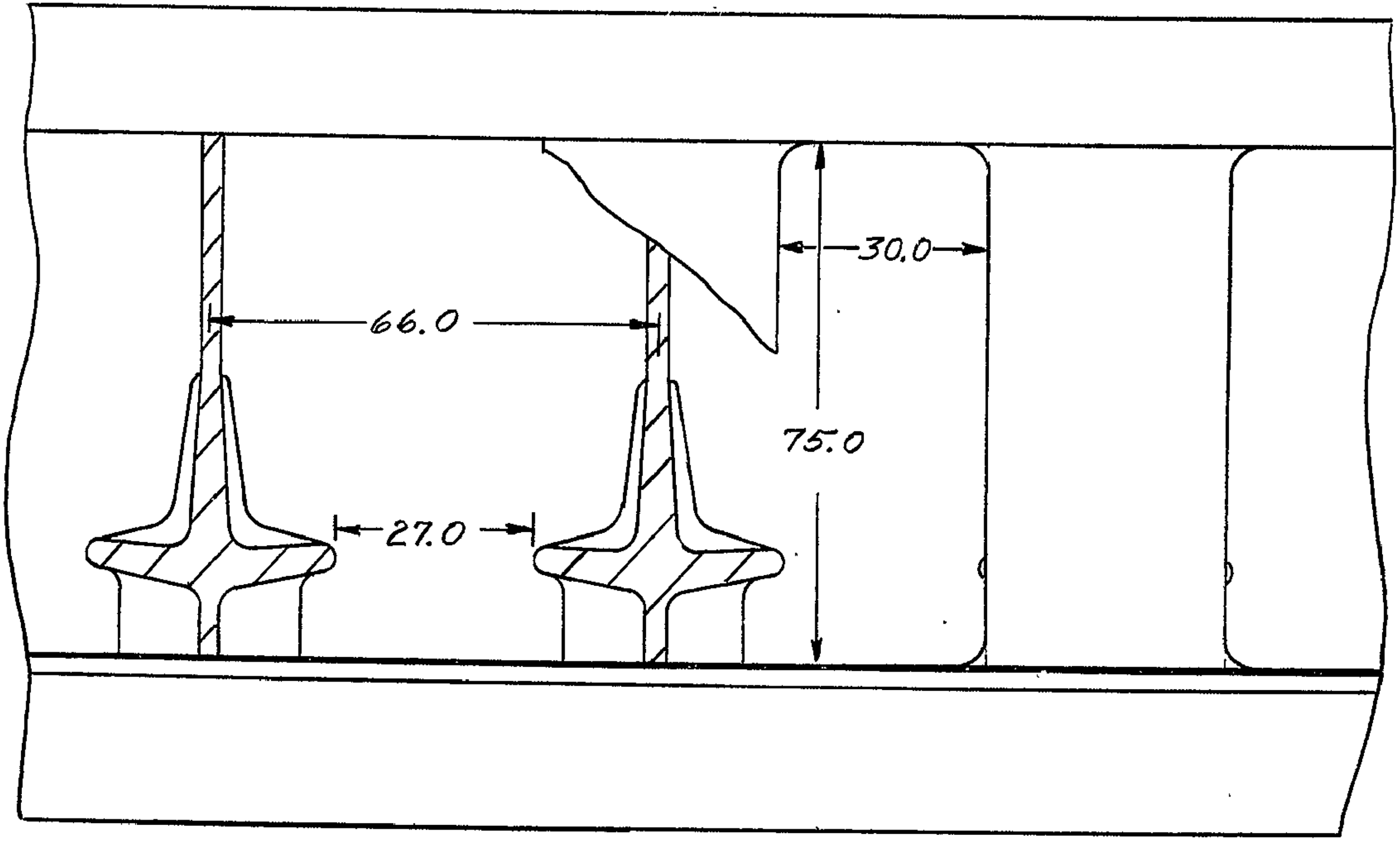
FUSELAGE (80 PASSENGERS)
PLAN AND SIDE VIEWS

FIG. 3-6



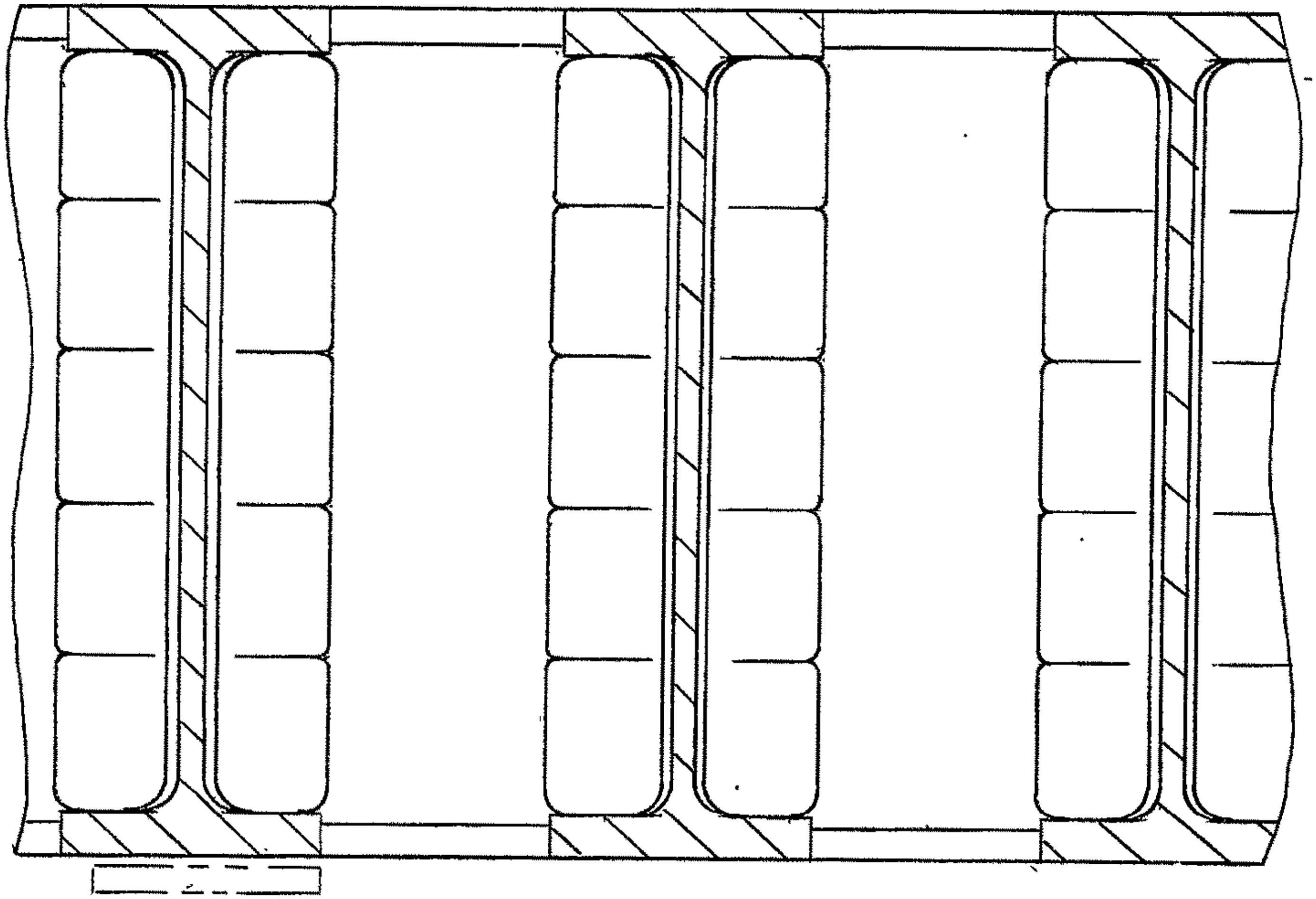
FUSELAGE SIDE SECTION

FIG. 3-7



FUSELAGE TOP SECTION

FIG. 3-8



SLIDING DOORS

ceiling. The seats would not be removed for the cargo function.

The opening in the bulkheads provide a feeling of open space in the compartments as well as a means of emergency egress through other compartments.

The lack of a central aisle in the aircraft is a point of departure from convention. The approach was not only to reduce air-carft fuselage weight and cost, but to eliminate the need for a flight attendant whose primary functions in such aircraft are to help passengers in getting seated, controlling the center of gravity, opening and closing doors, checking seat belts, administering first aid, and helping in onboard contingencies. It is realized that at present there is an FAA requirement for a flight attendant on aircraft carrying 19 or more passengers, but it is felt that it can be demonstrated that these functions can effectively be served in other ways. The doors are operated automatically. The seats are simply arranged and passengers generally require no aid, but a ground attendant at the terminals can serve in special cases. The C.G. is controlled in loading, and by compartmentizing is kept in control. It is felt that passengers will usually fasten seat belts almost instinctively in such aircraft, but with audio and visual reminders such as "Not Responsible..." signs, complete compliance would be obtained. Audio communication from the compartments to the Flight Manager would be supplied so that passengers could notify him in case of emergencies. In these very rare cases, flights could be very easily and quickly diverted to medical or other facilities. For example, in the Bay area it is estimated that a hospital is never more than about 3 minutes away, providing easier access than any other means of conveyance. Fire extinguishers, oxygen masks, and emergency instructions in each compartment would serve the passengers in the case of other contingencies. It is expected that in general ill, incapacitated, or extremely elderly passengers would not ride the MAT system, but in special cases attendants could be supplied to accompany these people (see Chapter 5).

3.2 Performance

3.2.1 Terminal Area

The landing and takeoff phase of the vehicle flight envelope is the most critical from a number of aspects,

(1) Safety,
(2) Guidance,
(3) Facility space,
(4) Noise, and
(5) Block time

The interplay of each of the above relative to the vehicle for the landing takeoff phase will be discussed as it pertains to the choice of VTOL over STOL.

The main aspect of safety considered here is the operation of the vehicle following the loss of a propulsion unit during the landing or takeoff maneuver. Handling qualities during these phases are, of course, of prime importance, especially as affected by gusts and crosswinds, and these will be given consideration

Large commercial aircraft are of necessity multi-engined to handle the contingency of one-engine-out operation. The two-engined aircraft tend to have the largest thrust-to-weight ratio, and consequently very good climb and takeoff performance. To a large extent, the power required at the high flight speeds, desired for the relatively large stage lengths of CTOL aircraft, dictate the installed power, and satisfactory one-engine-out performance can be obtained with either two-, three- or four-engined aircraft.

On the other end of the spectrum, the VTOL aircraft is designed for very short stage length where top speed is not of significant importance, and is required to carry on board a disproportionately large amount of power for one-engine-out capability. This penalty compounds the already existing power penalty required to accomplish the vertical phases of the ascent or descent. For diminishing stage lengths, top speed becomes less significant; relief from the high power/weight problem is afforded by lower disk loading or larger number of engines, with the adverse effects of complexity and higher maintenance costs. Also associated with the large rotored vehicles, are the vibration problems.

The tilt-wing and tilt-prop/rotor vehicles are attractive for the stage lengths under consideration. Through the use of multiple powerplants and cross-shafting of engine and propellers, a high degree of safety should be realized. An essential difference between tilt-wing and tilt-rotor vehicles is the capability of autorotation. In general, tilt-wing vehicles use small diameter propellers to produce a high velocity slipstream over the wing. Thus at moderate tilt angles the aircraft can fly at low speeds much like a deflected slipstream STOL, and for even lower speeds more wing tilt and vertical thrust component is used. The tilt-wing at the higher disk loading does not have the autorotation capability of the lower disk-loading helicopter or tilt-rotor. This is no significant disadvantage for the tilt-wing provided a sufficient number of engines are used, as can be noted from the "dead man's curve" for the 4-engine XC-142A (with a 4-engine thrust to weight ratio of only 1.15, see Figure 3-9).

Because of its autorotation capability the helicopter or compound helicopter could be produced in a single engine configuration with reasonable safety, provided operation is restricted from the avoid region of the altitude-velocity map. With the use of multiple engines the avoid region near the hover boundary can be made much smaller, and hence operational flexibility is increased. It is, of course, desirable from a maximum safety standpoint to install sufficient power such that the avoid region is eliminated completely for one-engine-out operation, as in the MAT aircraft.

Guidance. The only aspect of the terminal guidance phase of interest here is from the standpoint of the limitations in regard to takeoff and landing profiles. A fan-beam system is to be used and the guidance imposes no restrictions on the profile. The most efficient profile is thus determined by the airplane characteristics and community noise acceptance criteria.

Facility Space. The facility space as dictated by the landing and takeoff requirements for both STOL and VTOL aircraft were considered and, to a major extent, dictated the choice of a VTOL rather than STOL system. A discussion of STOL field requirements is, therefore, in order. It should be emphasized that this evaluation does not consider

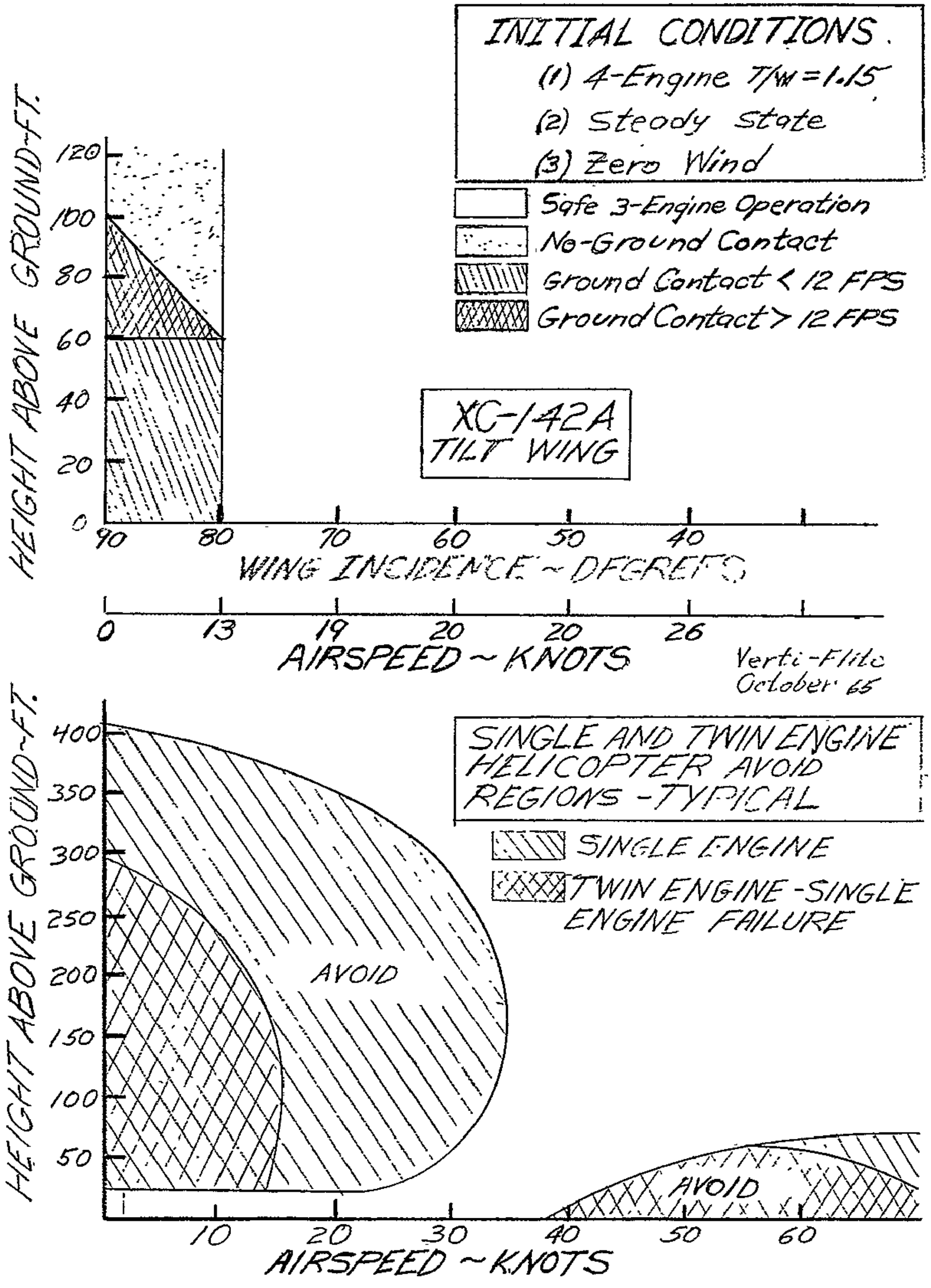

INITIAL CONDITIONS.
(1) 4-Engine T/W = 1.15
(2) Steody State
(3) Zero Wind
Safe 3-Engine Operation
No-Ground Contact
Ground Contact < 12 FPS
Ground Contact > 12 FPS
XC-142A
TILT WING
HEIGHT ABOVE GROUND~FT.
120
100
80
60
40
20
0
90
80
70
60
50
40
WING INCIDENCE ~ DEGREES
0
13
19
20
20
26
AIRSPEED ~ KNOTS
Verti-Flite
October 65
SINGLE AND TWIN ENGINE HELICOPTER AVOID REGIONS - TYPICAL
SINGLE ENGINE
TWIN ENGINE - SINGLE ENGINE FAILURE
HEIGHT ABOVE GROUND~FT.
400
350
300
250
200
150
100
50
AVOID
AVOID
10
20
30
40
50
60
AIRSPEED ~ KNOTS

FIGURE 3-9

the criteria proposed, by the FAA and other investigators, as necessary for STOL fields.

First considering the takeoff distance of a STOL aircraft, the ideal takeoff distance [3-18] is compiled in the following table:

	W/S (lb/ft^2)	P* (hp)	C_L^*	S (ft^2)
Wright Flyer	1.47	12	1.00	78
Piper Cub	8.5	150	1.80	200
Helio Courier	11.0	250	4.10	83
Twin Otter	14.7	1160	1.40	350
Typical deflected slipstream vehicle	50	8000	7	115

where P* and C_L^* are the power and lift coefficient as lift-off.

The last entry shows the type of vehicle being considered for modern STOL aircraft of about 60,000 pounds gross weight. It appears that the large, very high powered deflected slipstream aircraft has a minimum takeoff distance not unlike common light wing loading aircraft. On the other hand, if the allowable acceleration during the takeoff run is limited to 0.5 g, takeoff distance becomes 193 feet with liftoff at stall speed. If a 20% velocity margin above stall is used for the takeoff, the required distance becomes 278 feet.

Allowance to clear a 35-foot obstacle adds an additional 130 feet (assumed climb angle for passenger comfort) for a total distance of 408 feet. On the other hand, when a takeoff abort is necessary, a total runway of the order of 700 feet would be required. Nevertheless, for a very high performance STOL aircraft, an 800-foot runway length could well be adequate for takeoff.

Landing of the high-performance STOL aircraft is somewhat more of a problem. The main difficulty is the dependence of lift on power setting. In order to fly slow the lift coefficient must be increased. Beyond the increase obtained with changes in angle of attack, further increases must be obtained by the addition of power, resulting in a decreased glide path angle. A reference to Figure 3-10 illustrates many aspects of the problem. For the type of system under consideration it is desirable to fly a STOL aircraft onto the field without flare; the maximum sink speed for such an operation would be about 10 ft/sec. On this basis a maximum descent flight path angle of about 8° and a speed of about 60-80 knots seems to be a limitation on the descent capability. Using reversed pitch propellers to decelerate the aircraft at 0.5 g, and clearing a 50-foot obstacle results in a landing distance of 700 feet (522 feet if a 25-foot obstacle is considered). This type of approach, when made from a high altitude, would take considerable time and materially affect the block speed for short stage lengths. Some gains could be made by using deceleration on the descent profile but would be dependent on the type of guidance being used.

Figures 3-11 and 3-12 from Reference 3-19 summarize in detail the many facets of the problem and clearly show the additional length of runway required under contingencies of failed brakes, etc.

In conclusion, it is seen that even with aircraft designed for a landing and takeoff roll of 100 to 200 feet, the required STOL port size is of the order of 800 to 1,000 feet. Aside from catapult

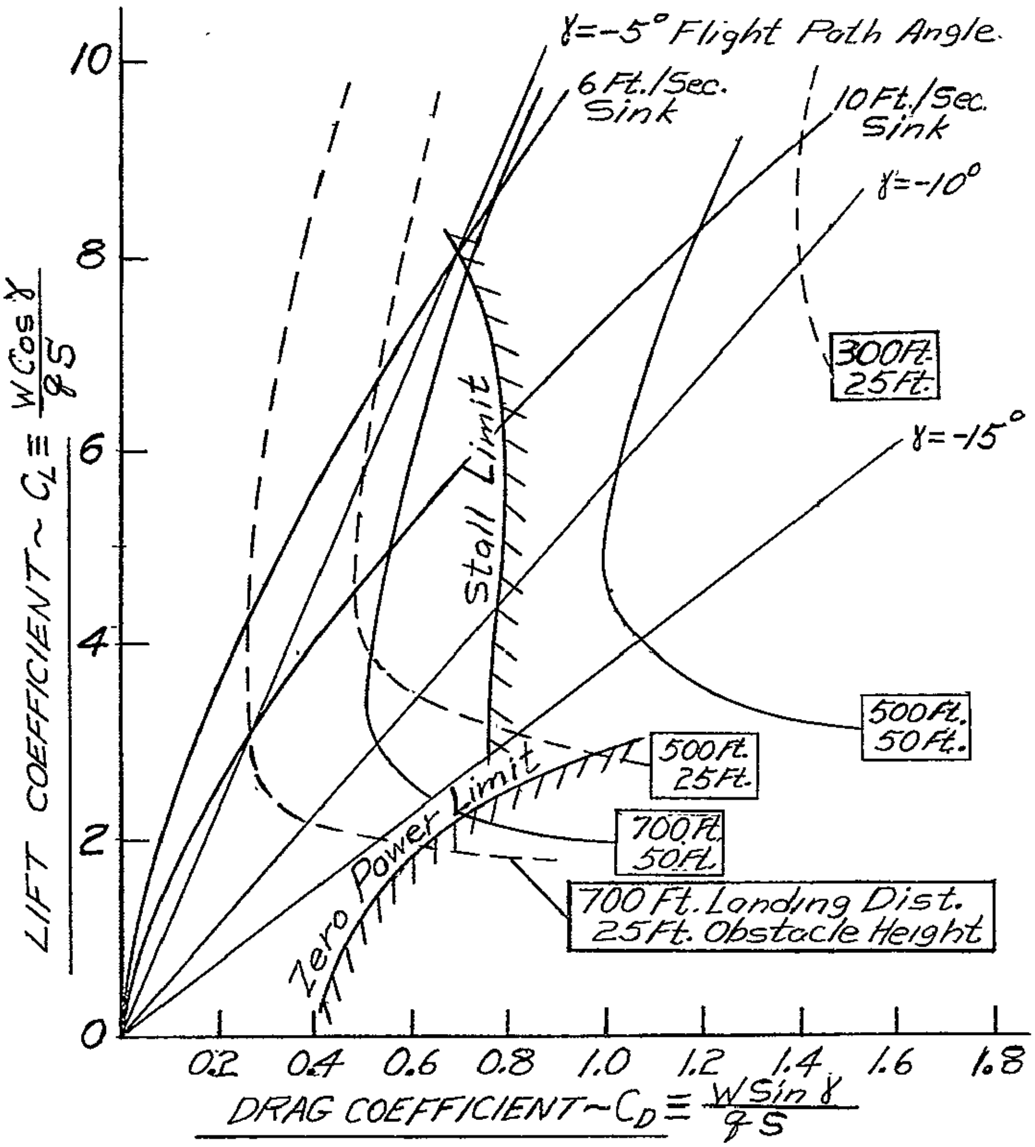
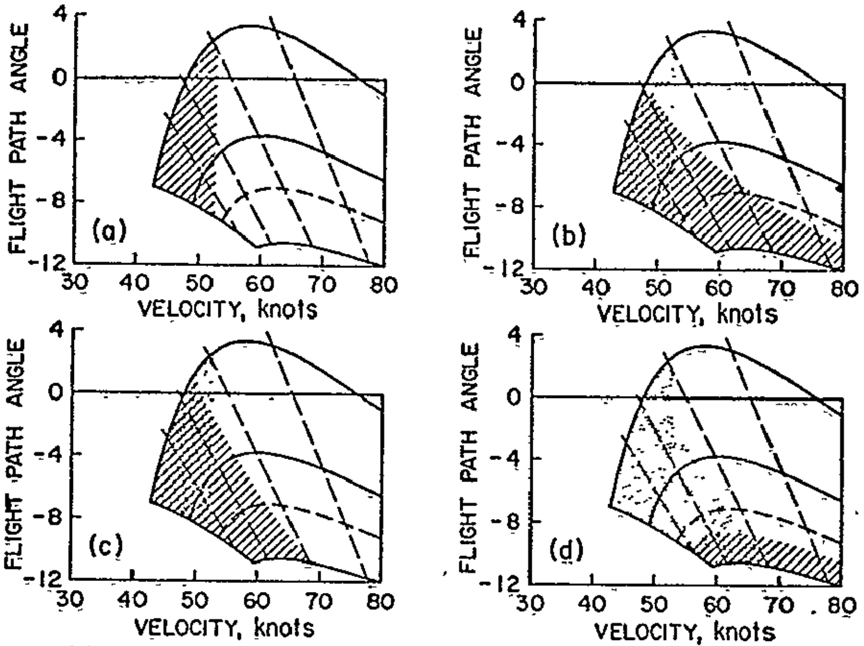


FIG. 3-10 LANDING DISTANCE OVER 25 Ft. AND 50 Ft. OBSTACLES. LANDING ROLL DECELERATION OF 0.5 g. TYPICAL DEFLECTED SLIPSTREAM STOL WITH 48.5 PSF WING LOADING.

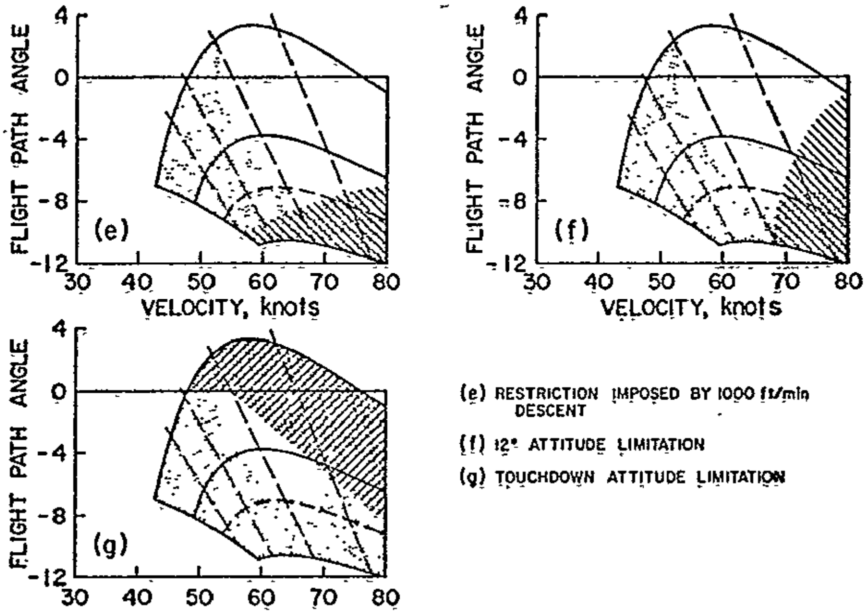


(a) REQUIREMENT TO ACHIEVE LEVEL FLIGHT

(b) MARGIN IF FLARE REQUIRED

(c) 15% SPEED MARGIN

(d) MARGIN TO ADJUST MAXIMUM FLIGHT PATH



(e) RESTRICTION IMPOSED BY 1000 ft/min DESCENT

(f) 12° ATTITUDE LIMITATION

(g) TOUCHDOWN ATTITUDE LIMITATION

Figure 3-11

VARIOUS RESTRICTIONS IMPOSED ON LANDING OPERATIONAL ENVELOPE FOR SAFETY, COMFORT, AND SYSTEM FAILURES

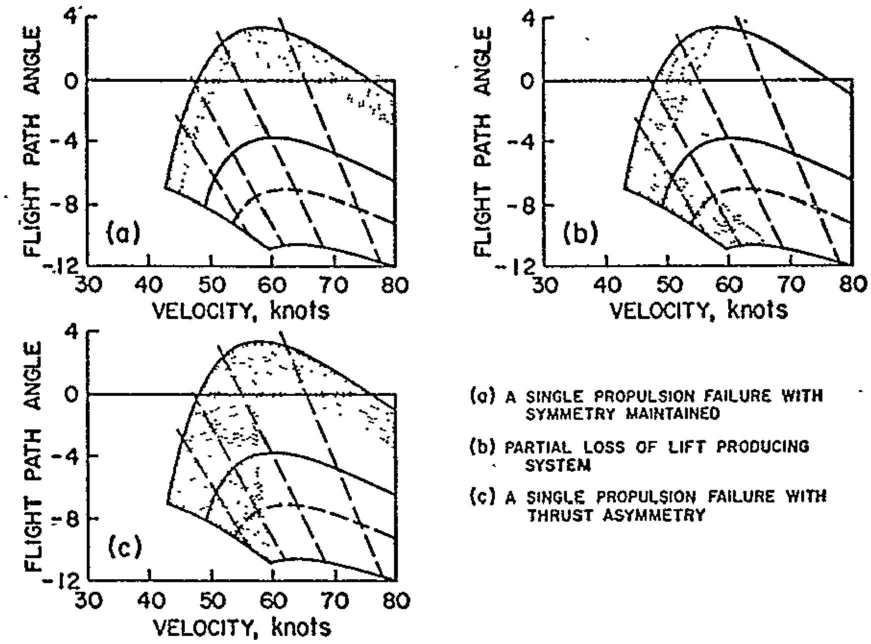


Figure 3-11 (cont.)

VARIOUS RESTRICTIONS IMPOSED ON LANDING OPERATIONAL ENVELOPE FOR SAFETY, COMFORT, AND SYSTEM FAILURES

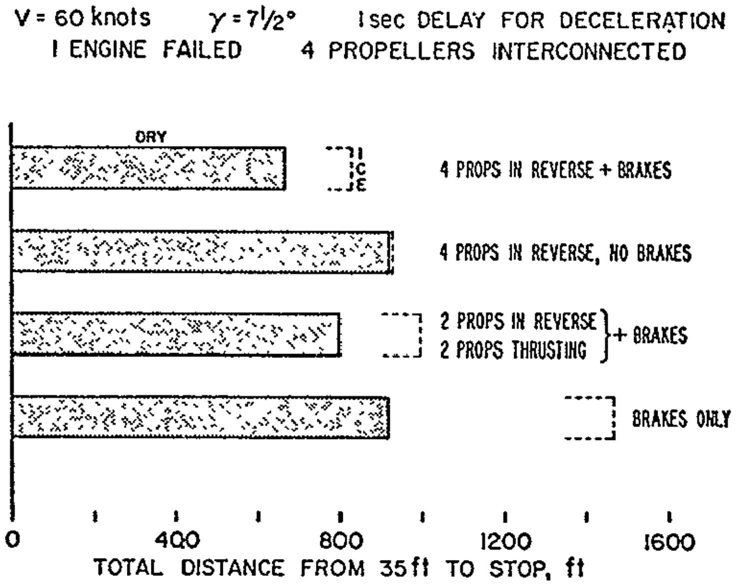


Figure 3-12

EFFECT OF FAILURES AND RUNWAY CONDITIONS ON LANDING PERFORMANCE launch and arresting gear type operation, the only solution to shorter field length appears to be VTOL. Further details of facility space not related to actual landing and takeoff may be found in Chapter 5.

Noise, hazard, and block time: To minimize noise and hazard to the community adjacent to the terminals a maximum angle of climb and descent were selected. In the case of the STOL aircraft, the steepest descent angle of about 8° appeared desirable from the standpoint of both noise and rapid descent. For climbout, 15° with 150 mph is possible and seems a good compromise for both noise alleviation and good block time. This is, however, a climb rate of 3,500 fpm and would require compartment pressurization.

For VTOL vehicles the ascend-descend space was taken as a cone with its apex at the facility. The cone extends radially 1 mile for each 1,000 feet at altitude (an angle of 10.8° with respect to the vertical). The vehicle exits the cone at the desired altitude of the stage length. The details of this cone are given in Section 3.2.3. This is within the criteria suggested by Reference 3-10.

The sound criteria the vehicle is required to meet was established as follows: (1) for flyovers in residential areas 80 PNdB, (2) for landing and takeoff operations (aircraft airborne or during roll-out for landing or takeoff roll = 95 PNdB at 500 feet, (3) run up or taxi operation 100 PNdB at 500 feet.

In addition to the higher noise levels associated with low altitude operation, there is the community reaction to vehicles, especially very large ones, flying at low levels. From the standpoint of operating costs, it would be advantageous to use the lowest altitudes possible, especially for the shorter stage lengths, as this procedure minimizes the block time (which is strongly dependent on the climb and descend portion of the trajectory). Further considerations were that in many areas a good part of the route structure could be placed over water, and the high-density traffic of the system suggested staying out of airspace being currently used by commercial and private aviation. The airspace from 500 to 2,000 feet appeared to be the most attractive.

Without pressurization climb and descent rates of 1,000 and 500 ft/min were considered maximum. As STOL and VTOL vehicles tend to have a large amount of excess horsepower at intermediate forward speeds, the limitation of 1,000 ft/min is highly restrictive on climb rate, and some amount of pressurization is necessary from this standpoint.

<u>Crosswind landing and gusts</u>: Without a doubt the STOL port is at a disadvantage. An attempt to reduce landing speed of the STOL enlarges both the crosswind and the gust problems. The crosswind problem can be alleviated somewhat by using a crosswind landing gear provided the landing speed is not reduced too far. As an attempt is made to reduce landing speeds control surfaces must become larger, or other forms of controls must come into play such as propeller pitch changes and lift spoilers.

On the other hand, the VTOL vehicle can always land into the wind at the terminal. Landing and taking off into the wind with a VTOL vehicle (for which hover with one engine out is not possible) reduces the size of the "avoid" area on the altitude-velocity diagram.

Helicopter-like vehicles are also relatively insensitive to wind gusts and have very good control characteristics at near zero speed.

3.2.2 Cruise Performance

The MAT aircraft is a compound helicopter design using the L/D curve shown in Figure 3-13 and the following rotor unloading profile:

(1) Below 100 mph

$$\frac{T_R}{T_H} = 1.0$$

T_R = Rotor Thrust

T_H = Hovering Thrust

(2) Above 100 mph

$$\frac{T_R}{T_H} = \frac{275 - V_{mph}}{175}$$

With use of the above relationship for the thrust supplied by the rotor, the power required curve (Figure 3-14) was developed.

At the cruise speed of 250 mph the following breakdown of the total power required of 8,262 hp was obtained: (a) Total to rotor 1,944 hp, (b) Total to wings 2,278, (c) Total rest of aircraft 4,040.

The specific fuel consumption best estimate was 0.5 lbs/shaft hp which gives a cruise fuel consumption of 4,131 lbs/hr.

Figure 3-15 shows "Cruise Time vs stage length." With this information a curve of "Cruise Fuel Required vs stage length" is plotted, as shown in Figure 3-16.

3.2.3 Stage Profiles

The basic flight profile for takeoff and landing is shown in Figure 3-17. This profile was determined using the following boundaries:

(1) Average climb rate of 1,000 ft/min with a minimum flight angle of 10.8°, so that for each 1,000 feet of altitude gain the distance covered in flight direction was one mile,

FIGURE 3-13

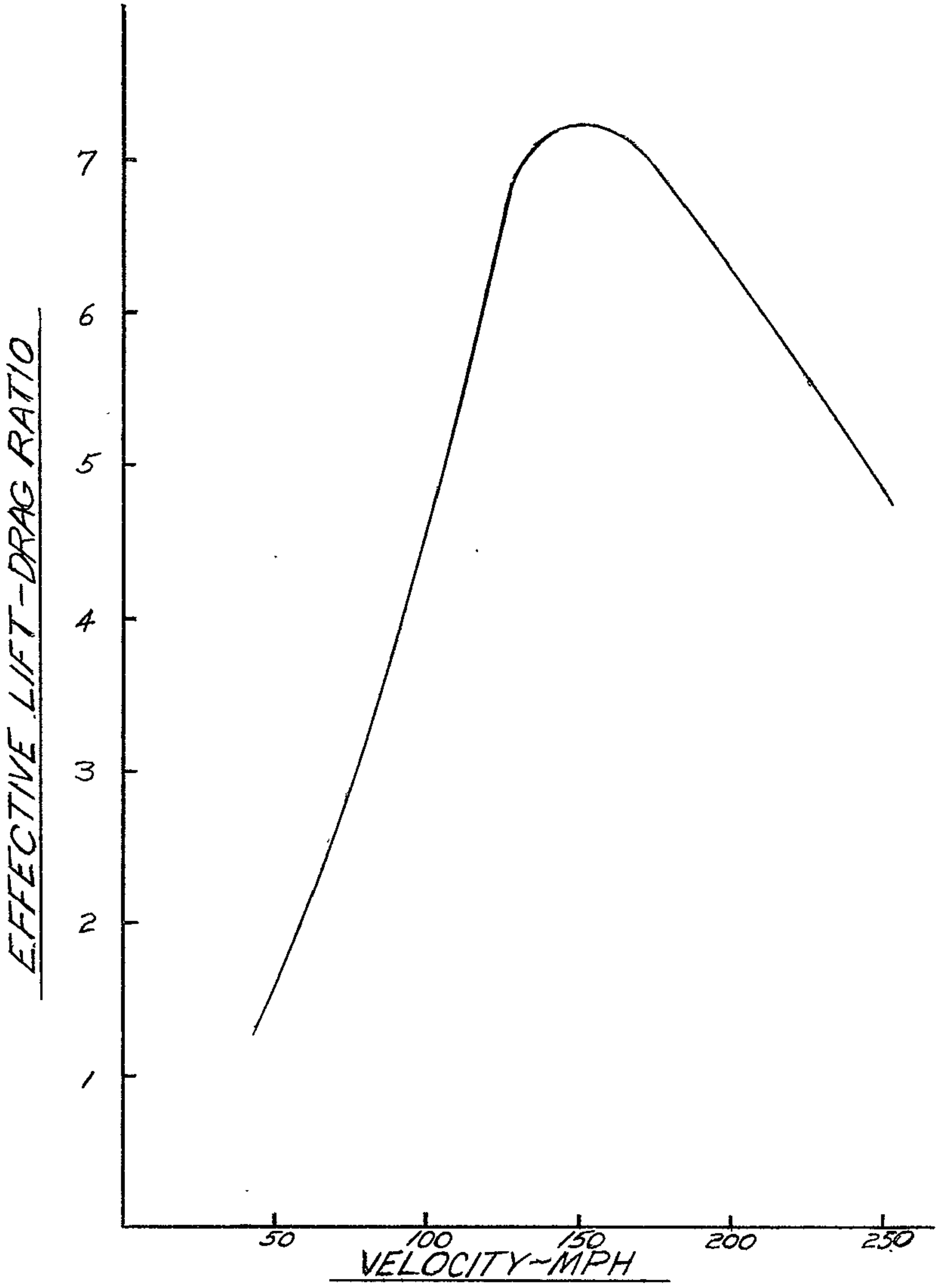

EFFECTIVE LIFT-DRAG RATIO
1
2
3
4
5
6
7
50
100
150
200
250
VELOCITY~MPH

FIGURE 3-14

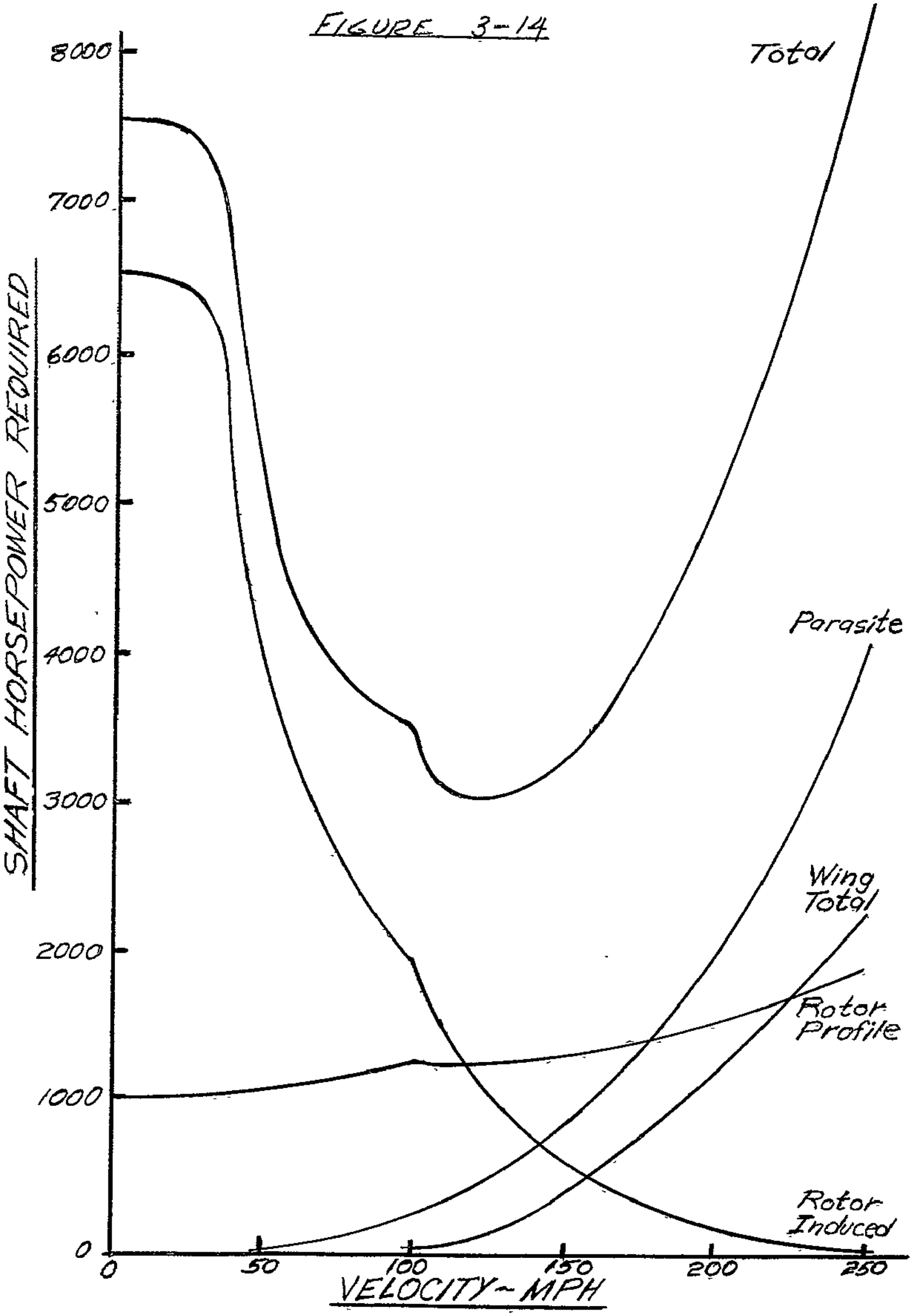
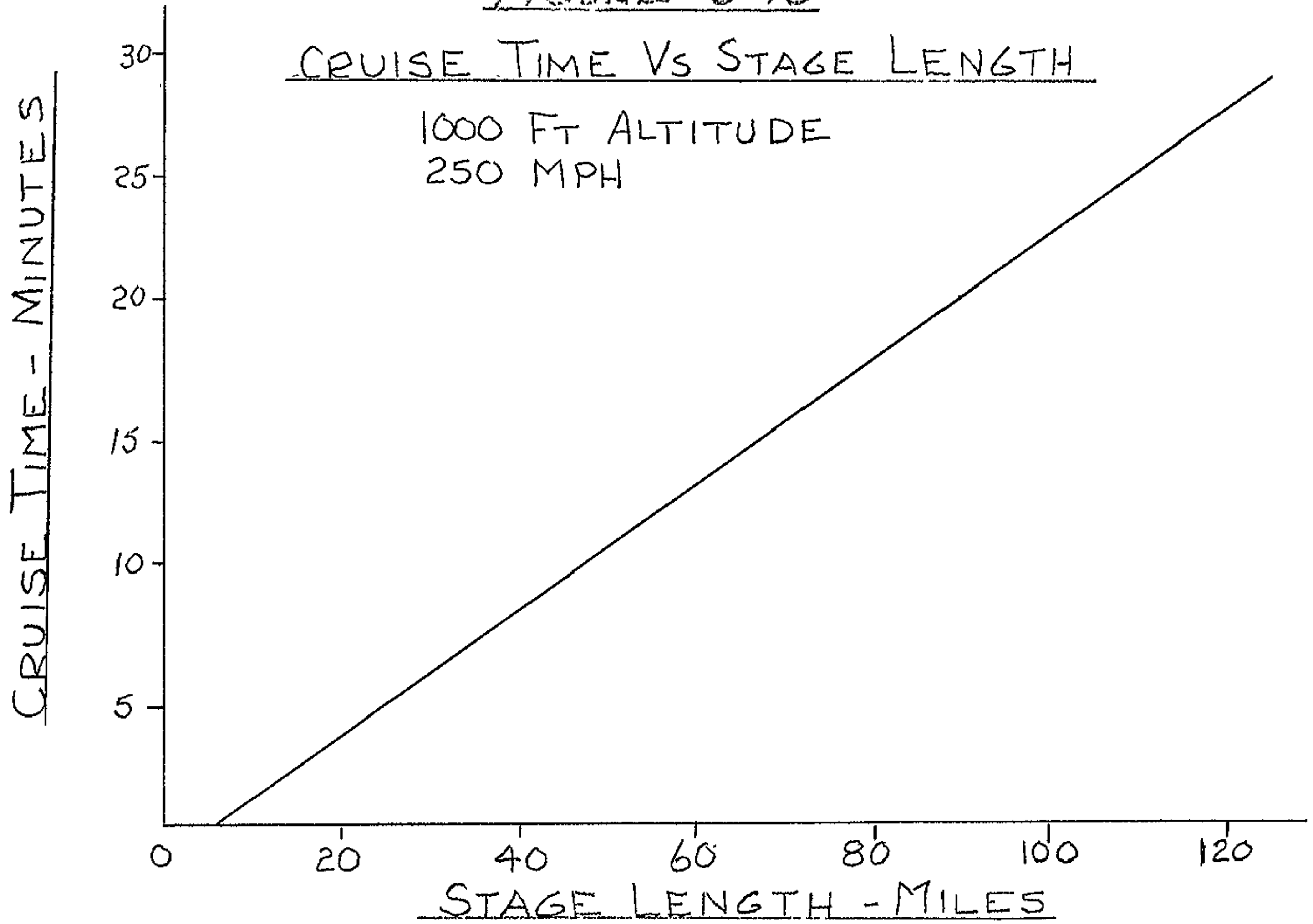

Total
Parasite
Wing Total
Rotor Profile
Rotor Induced
8000
7000
6000
5000
4000
3000
2000
1000
0
SHAFT HORSEPOWER REQUIRED
0
50
100
150
200
250
VELOCITY ~ MPH

FIGURE 3-15


CRUISE TIME VS STAGE LENGTH

1000 FT ALTITUDE
250 MPH

FIGURE 3-16

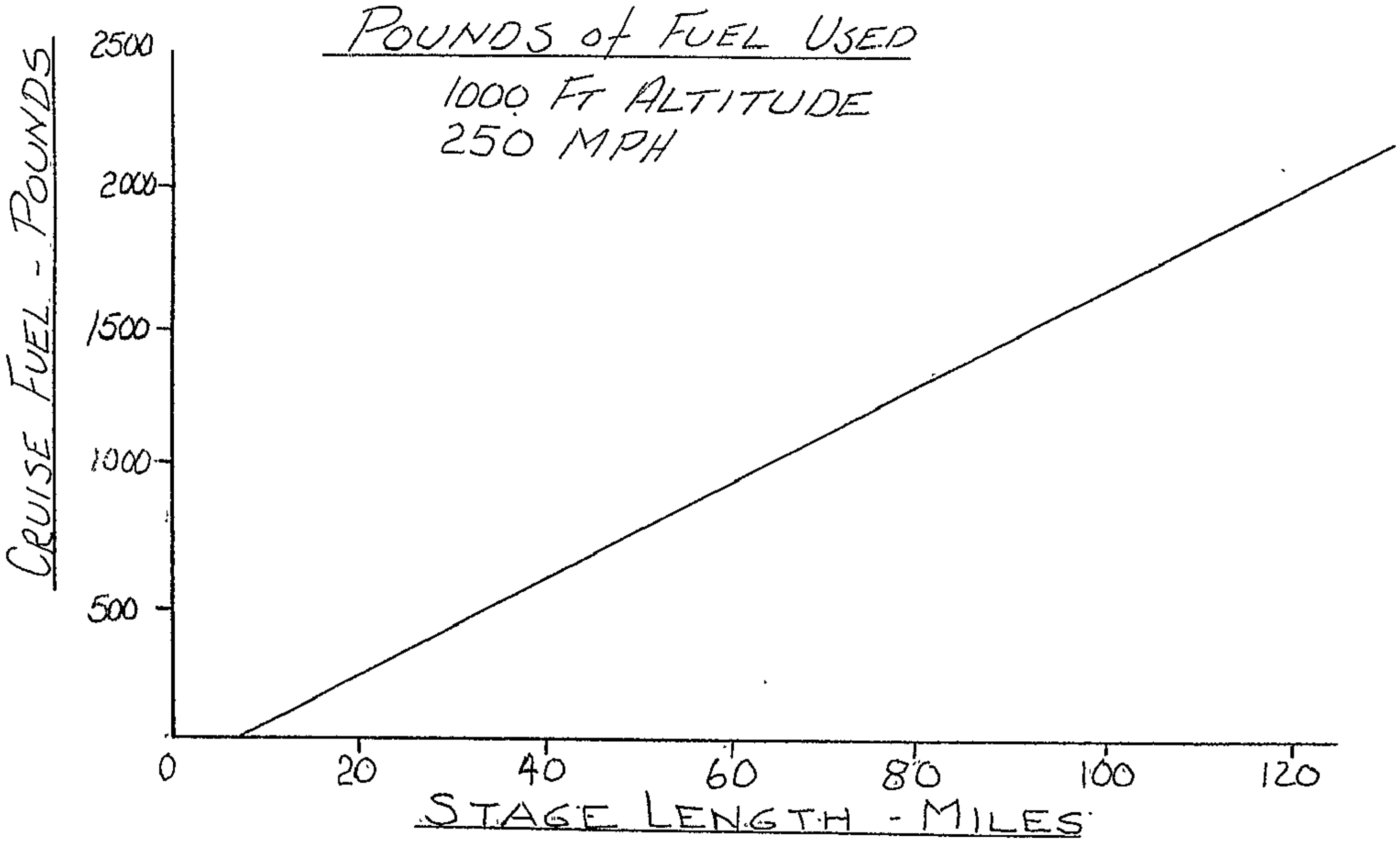
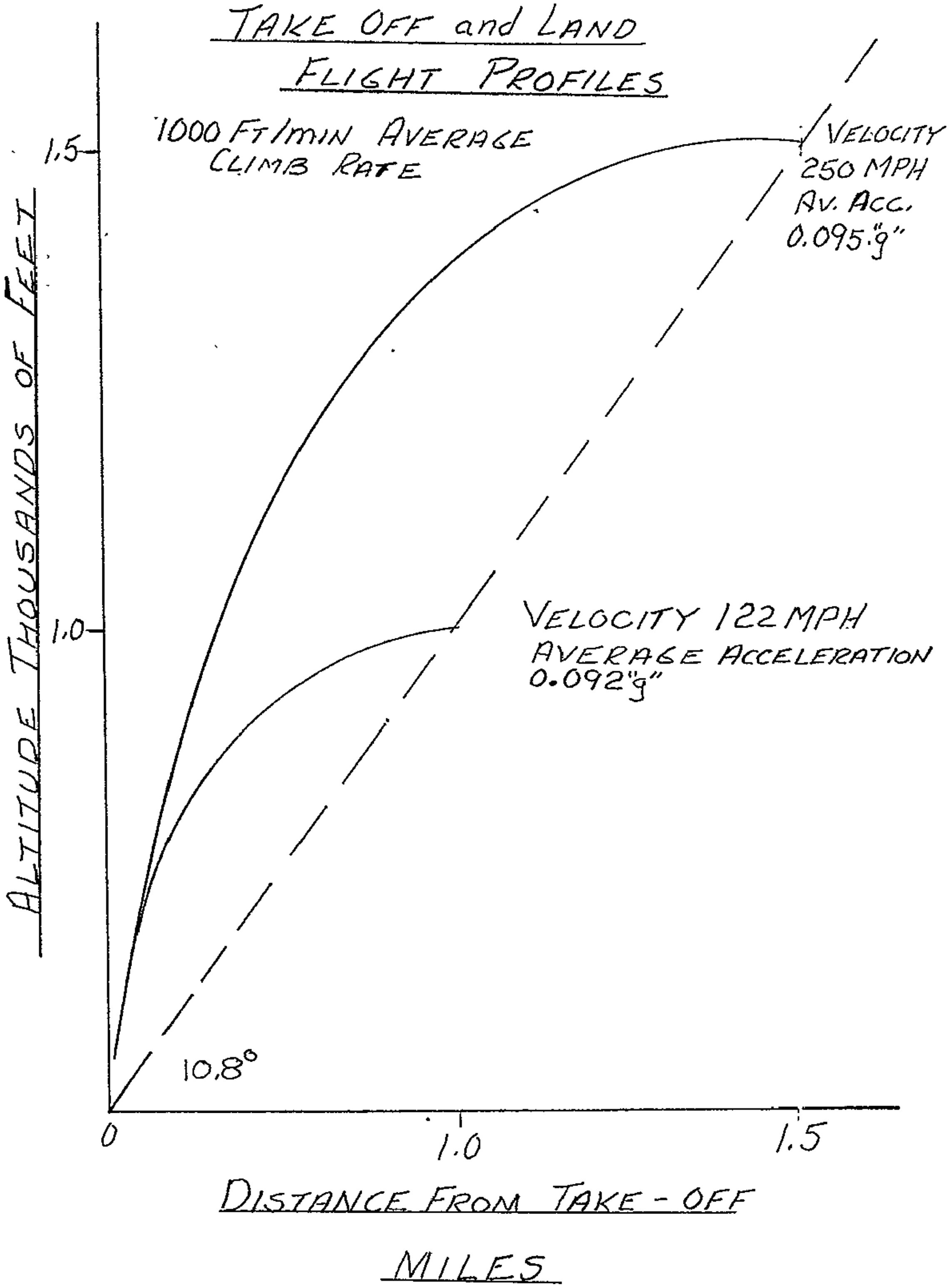

POUNDS of FUEL USED
1000 FT ALTITUDE
250 MPH
CRUISE FUEL - POUNDS
2500
2000
1500
1000
500
0
20
40
60
80
100
120
STAGE LENGTH - MILES

FIGURE 3-17


TAKE OFF and LAND
FLIGHT PROFILES
1000 FT/min AVERAGE
CLIMB RATE
VELOCITY
250 MPH
AV. ACC.
0.095 "g"
VELOCITY 122 MPH
AVERAGE ACCELERATION
0.092 "g"
10.8°
ALTITUDE THOUSANDS OF FEET
1.5
1.0
0
1.0
1.5
DISTANCE FROM TAKE-OFF
MILES

(2) The average acceleration was 0.15 g or below.

These values were picked for the following reasons:

(1) Climb to altitude to be near the terminal with climb and acceleration rates chosen to keep noise within reasonable limits,

(2) To provide easy transition to the flight paths picked for navigation, i.e. 1,000 feet and 1,500 feet,

(3) To have final acceleration to cruise speed take place at cruise altitude, which will reduce noise at portions of flight path which may be over populated areas,

(4) The cruise velocity of 250 mph was picked as the best compromise between the performance for a compound helicopter and safe operation at the low altitude of 1,000 feet.

With this climb and descent profile, calculations were made for average flight speeds and flight times for the various trip distances. These results are shown in Figure 3-18 and 3-19.

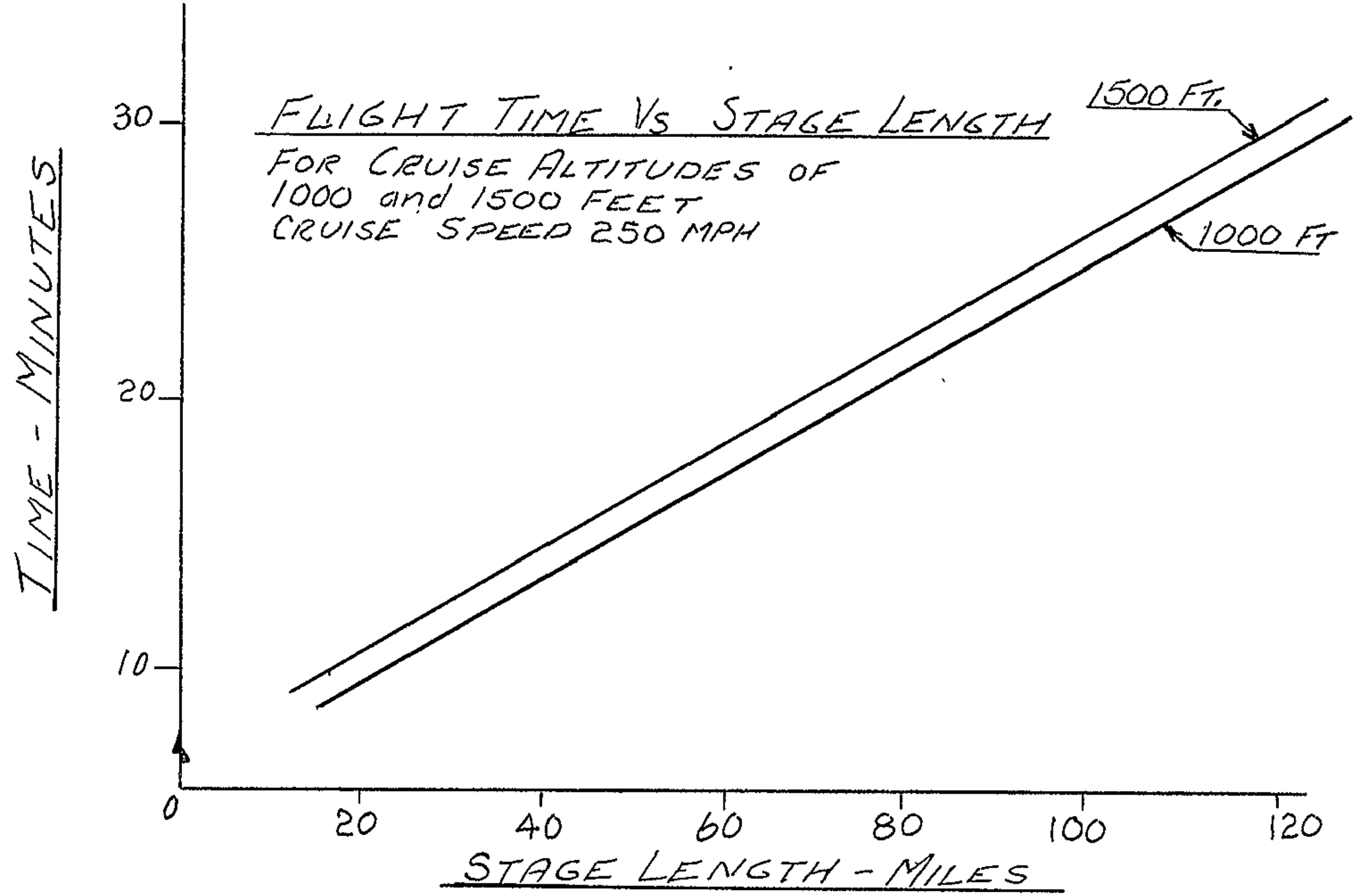
Information was also calculated for a mean stage length of 35 miles, and Table 3-2 shows the change in average flight speed for changes in flight altitude. Figure 3-20 shows the stage profile for a 35 mile flight distance flown at an altitude of 1,000 feet.

Table 3-2

CHANGES IN FLIGHT SPEED AND FLIGHT TIME FOR A 35 MILE STAGE LENGTH DUE TO FLIGHT ALTITUDE

Altitude (Ft)	Flight Speed (MPH)	Time (Min)
500	215	9.77
1000	205	10.26
1500	193	10.85
2000	184	11.44

FIGURE 3-18


FLIGHT TIME VS STAGE LENGTH
FOR CRUISE ALTITUDES OF
1000 and 1500 FEET
CRUISE SPEED 250 MPH
1500 FT.
1000 FT
TIME - MINUTES
30
20
10
0
20
40
60
80
100
120
STAGE LENGTH - MILES

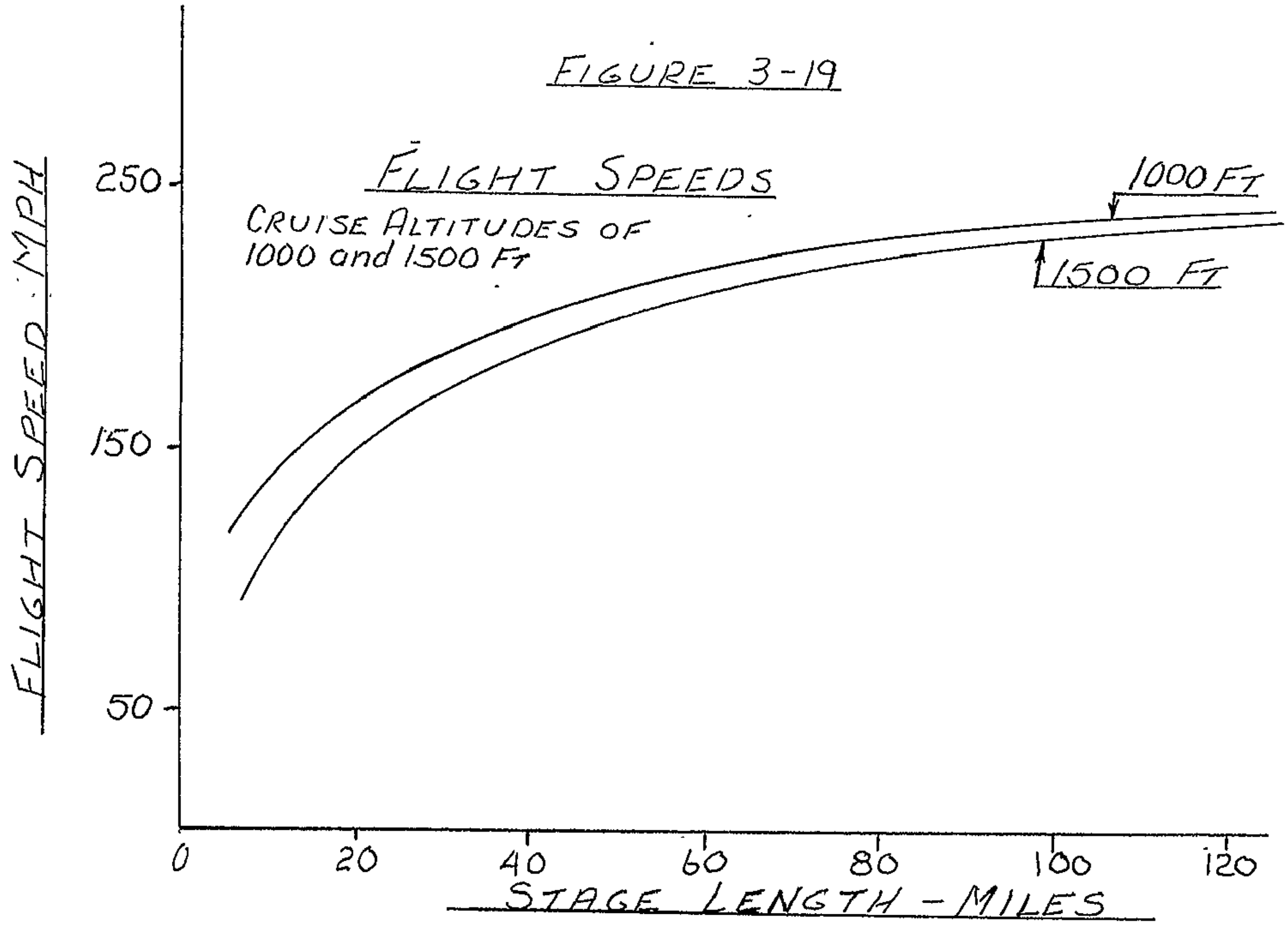


FIGURE 3-19

FLIGHT SPEEDS

CRUISE ALTITUDES OF 1000 and 1500 FT

FIGURE 3-20

FLIGHT PROFILE - 35 MILE STAGE

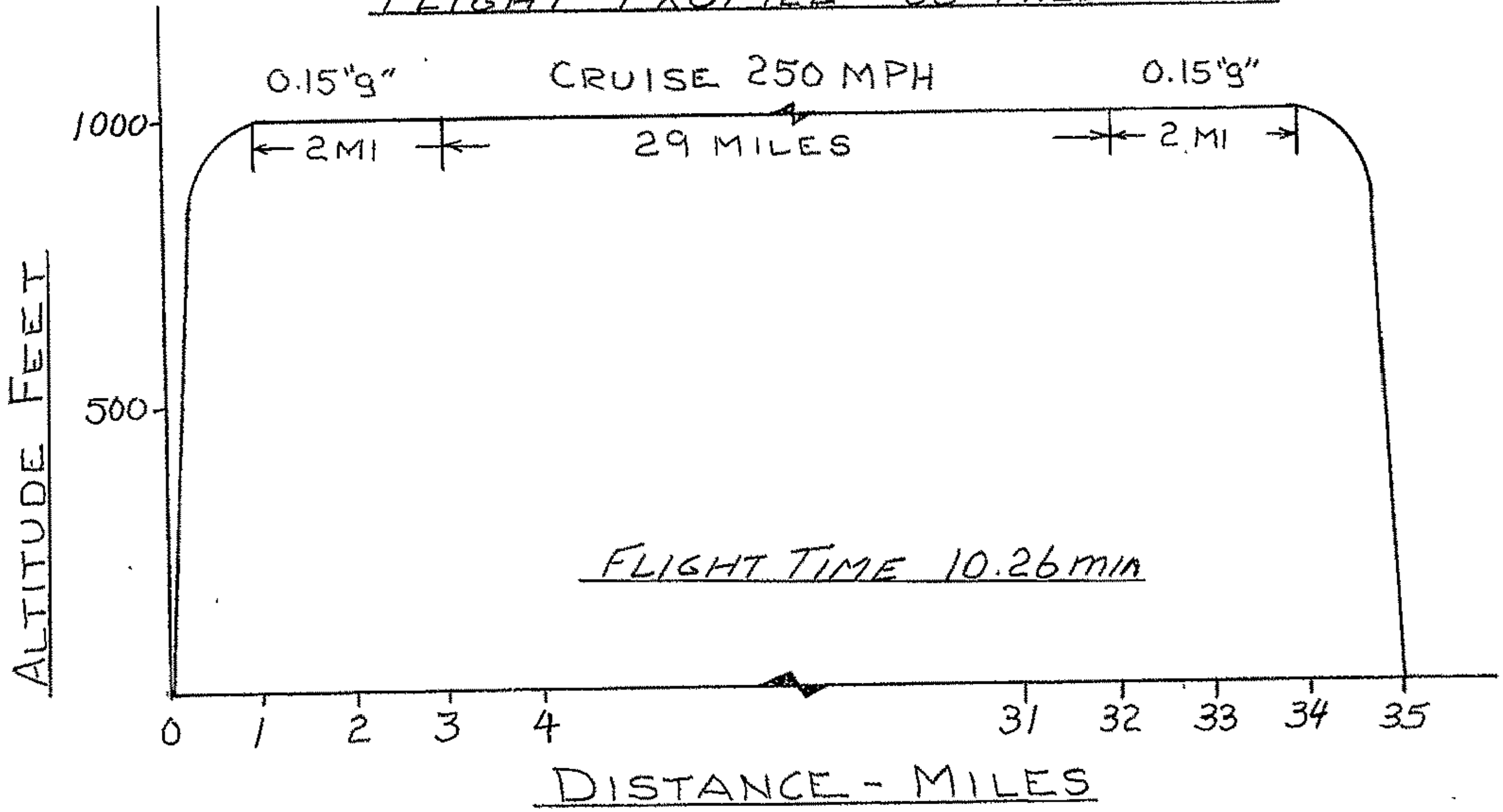


Table 3-3 shows values of time, distance, and fuel for the 35 mile mission at a flight altitude of 1,000 feet.

Table 3-3

MAT BLOCK ANALYSIS

(35 mile stage length)

Altitude 1,000 ft	Flight Speed 205 mph
Flight Time 10.26 min	Block Speed 150 mph
Block Time 14 min	

FLIGHT PROFILE

	Time (min)	Fuel (lb)	Distance (miles)
Start up & taxi	.2	13	0
Climb to altitude	1.0	64	1.0
Accelerate	.66	45	2.0
Cruise	6.95	477	29.0
Decelerate	.66	25	2.0
Descend	1.0	32	1.0
Taxi & stop	.2	13	0
Ground time	3.33	75	
	14.00	744	35.00

3.2.4 Performance Summary

Preliminary design considerations and results are as follows for the MAT compound helicopter:

(1) Safety--There is no "avoid" region. Maximum safety is obtained by using an engine-power combination that results in hover capability with one engine out. Climb rate with zero forward velocity and full power must be at least 2,000 fpm.

(2) Maintenance--The least number of engines possible to accomplish the task in a safe manner is desirable.

(3) Altitude--For low density routes the vehicle should be capable of 400 fpm vertical climb at 10,000 feet. This allows for special purpose operation into ski areas and charter use. The "avoid" boundaries in the operational envelope must be observed for this operation.

From Figure 3-14, the shaft horsepower curve for the vehicle, the necessary requirements at standard sea level conditions seem to be

(1) 8,250 horsepower are required to cruise at the design speed of 250 mi/hr.

(2) 7,500 horsepower are required for hover. This must be accomplished with one engine out.

(3) 11,130 horsepower are required to meet the condition of 2,000 fpm climb with zero forward velocity.

(4) 11,800 horsepower are required to meet the condition of 400 fpm climb at 10,000 feet above sea level.

The above conditions leads to the selection of a three-engine configuration with total of 12,000 hp. One engine is idled during cruise. This has a direct advantage in terms of maintenance and fuel costs. Fuel consumption at the 250 mph cruise on two engines is 4,130 lbs/hr. At the most economical cruise speed (best range) of 150 mph, the fuel consumption is 1,750 lbs/hr and the aircraft can fly on one of its three engines.

The vehicle is operational up to about 10,000 feet of altitude for takeoff and landing. This allows operation into the near-lying mountain areas. The cabin pressure differential of one pound per square inch provides for a 7,500-foot cabin altitude while operating at 10,000 feet. The primary purpose of the 1 psi pressurization of the cabin is to provide passenger comfort during takeoff and landing profiles. A rate of cabin pressure change corresponding to 500 ft/min is maintained independent of the climb or descent rate of the aircraft.

A summary of characteristics is shown in Table 3-4.

Table 3-4

MAT AIRCRAFT SUMMARY CHARACTERISTICS

Weights	
Maximum takeoff weight	60,000 lb
Maximum landing weight	60,000 lb
Empty weight	37,200 lb
Payload at design range (80 passengers)	16,000 lb
Fuel capacity 1 hour cruise, 1/2 hour hold, 1000-lb reserve	6,000 lb
Trapped fuel and oil	600 lb
Crew (1 pilot)	200 lb
Performance	
Cruise speed (2 engines)	250 mph
Cruise fuel consumption	4130 lbs/hr
Holding fuel consumption	1550 lbs/hr
Ground idle fuel consumption	900 lbs/hr
Best rate of climb at sea level	4900 ft/min
Vertical rate of climb at sea level	2480 ft/min
Thrust/weight ratio (1 engine out)	1.06
Vertical rate of climb at 10,000 ft (Std. Day)	500 ft/min
Power loading (max. power)	5 lbs/hp

Table 3-4 (Cont)

Ferry range	800 mi
Ferry range with added fuel tanks	2300 mi
Operational altitude maximum	10,000 ft
Characteristics	
Overall length	90 ft
Rotor diameter	87 ft
Wing area	420 ft^2
Wing aspect ratio	5.95
Rotor solidity	.125
Disc loading (hover)	10 lbs/ft^2
Blade loading	80 lbs/ft^2
Equivalent parasite area (less rotor)	35 ft^2
Landing gear	tricycle
Engines	3 at 4,000 hp each, cross-shafted with de-clutch capability

3.3 Structures and Weights

3.3.1 Materials and Fabrication

Both the cost and weight of any aircraft are extremely sensitive to choice of materials and the manner in which they are formed and assembled. A brief summary of the projected states of materials and manufacturing technology expected to be available for the MAT aircraft is outlined in Table 3-5.

Table 3-5

PROJECTED AIRFRAME TECHNOLOGY (1980)

	Material	Fabrication	Assembly
Primary Structure	Dense, aligned Boron fibers in alum. matrix	Pressure molded	Fabric seam joints
Secondary Structure	Aligned Boron fibers, epoxy matrix	Molded	Adhesive bonding
Non-Structural Shapes	Fiberglass honeycomb		Contact adhesive

A major advantage of the composite fiber materials just now coming into use is that the density and strength levels can be distributed and optimized for any particular section and thereby more efficiently matched to the applied loads. Direct weight savings of 10% to 40% are projected for typical airframe structural components [3-21].

Fabrication costs are historically sensitive to unit quantities. This is going to be even more of a problem in manufacturing airframes in the future, in that composite materials require expensive precision molds (dies). These are necessary to obtain uniform properties and smooth, dimensionally accurate contours.

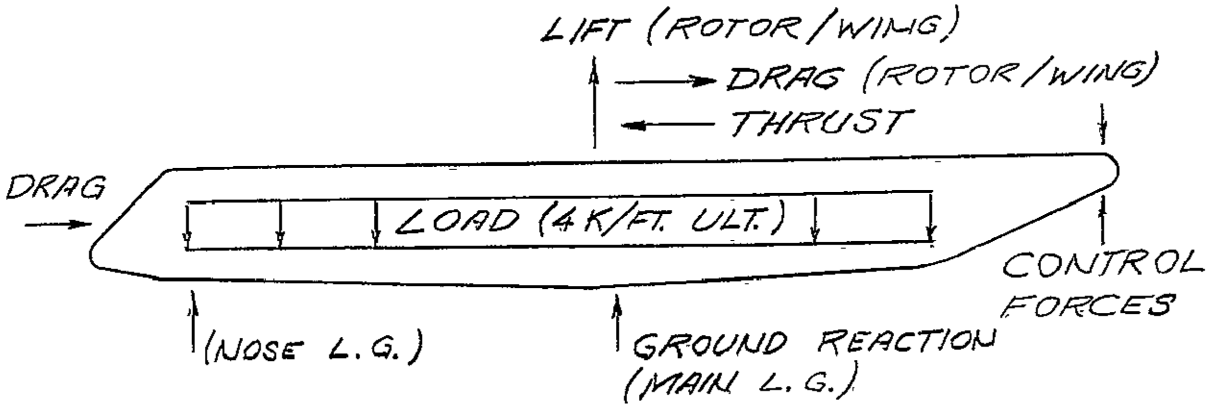
There is a current trend in smaller aircraft to reduce the number of different parts as well as the total quantity. American Aircraft Corporation, for example, uses identical parts for the right and left hand horizontal stabilizer, as well as the vertical stabilizer. Right and left hand parts are made identical rather than mirror images wherever possible. An extension of this design philosophy is a hope for economic utilization of composite materials.

Using this philosophy, the fuselage previously shown in Figures 3-4 through 3-8 is made up of a large number of identical structural sections. The upper and lower sections are continuous to allow extruding techniques.

3.3.2 Fuselage

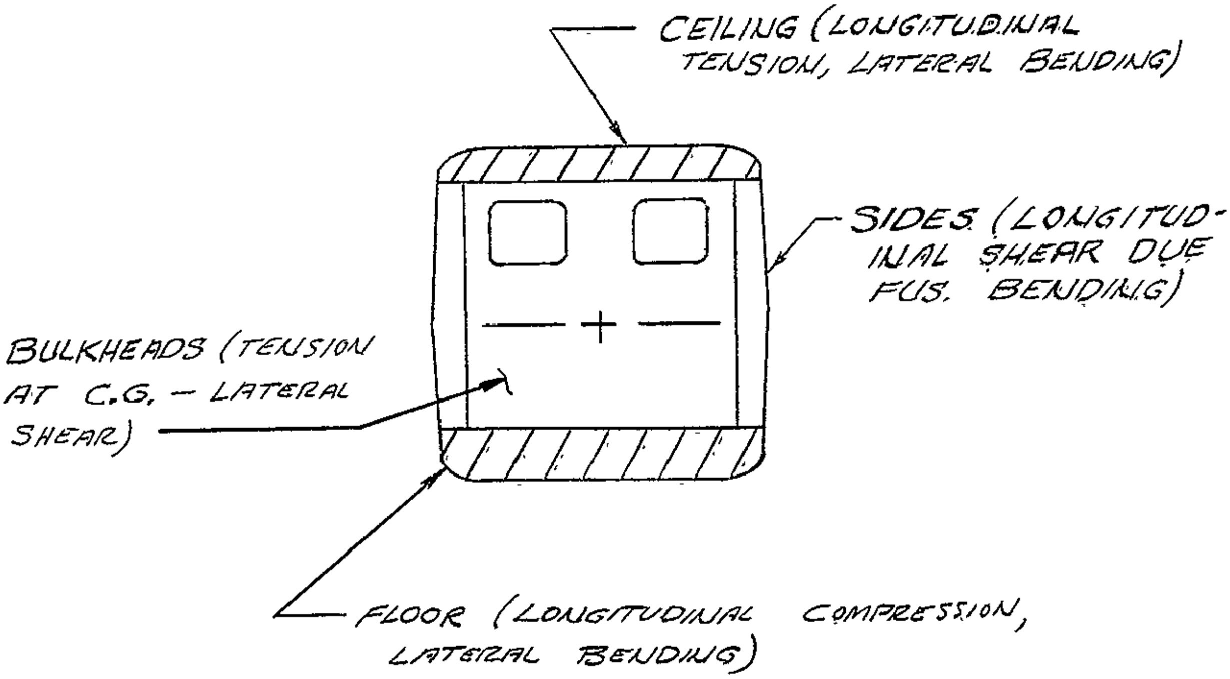
Since the constraint of a circular fuselage was eliminated, the floor has been integrated into the load bearing structure. The benefit of this configuration may be appreciated by referring to the structural loading diagram in Figure 3-21. In a circular fuselage the floor is located in close proximity to the neutral axis, and thereby contributes little to the section modulus. The rectangular fuselage allows the heavy floor section to be located considerably below the neutral axis and thereby loaded heavily in compression (Figure 3-22). This combined loading will result in a cost and weight savings over the commercial design studies of References 3-1 to 3-8.

The major innovation in the fuselage is the bulkhead/seat module previously shown in Figure 3-5. Seven full units of identical dimensions are sandwiched between the ceiling and floor structural sections. This allows a single-molding die for composite material construction. The density of the boron fibers may be varied, however, to match the load at any particular bulkhead station in the fuselage. The module directly beneath the wing and rotor, for example, will require a high density laminate in order to transmit the full flight loads to the structural floor. Conversely, the module adjacent to the empennage could include a considerable amount of lightweight filler material (i.e. foamed resins) since it only transmits control forces



LOADING DIAGRAM

FIG. 3-21



SECTIONAL COMPONENTS

FIG. 3-22

from the tail.

The seats are molded in rows of five from a polyvinyl plastic and are mounted on hard points in the bulkhead/seat module. Seat belts and/or other restraining devices would also be anchored to these hard points.

The space below the structural floor is primarily filled with energy-absorbing cellular material for crash safety, as well as serving for floatation in emergency water landings. Deployable floatation bags for stability would also be mounted in the wings when the bulk of the routes are over water.

3.3.3 Wing Structure

Since wing structures have received considerable attention from industrial design teams there is small room for major improvement. The cruise wing used in the compound helicopter is strictly conventional in design with integral fuel cells.

3.3.4 Weights

Table 3-6 shows a weight breakdown on the MAT aircraft.

It should be pointed out that the majority of the weights are based on present day materials and manufacturing technology [3-1, 3-6, and 3-14] and as such represents a very conservative approach. From the previous discussions it is expected that with present trends, the empty weight would be reduced by about 15%.

3.4 Power Plants

Based on the power required (see Section 3.2.2), the choice of three engines was influenced not only by the safety aspects, engine

Table 3-6

WEIGHT DISTRIBUTION

Item	Weight (lbs)
Fuselage	5,600
Wing	2,400
Engines installed	2,200
Propulsion	3,000
Transmission	6,000
Main rotor	5,200
Tail rotor	1,900
Empennage	1,700
Landing gear	1,200
Air conditioning	1,200
Furnishings	2,000
Controls	1,200
Hydraulics	500
Electrical	700
Anti-ice	600
Electronics	500
Instruments	300
Contingency	1,000
Empty	37,200
Crew	200
Oil and trapped fuel	600
Payload	16,000
Fuel	6,000
	60,000

initial and maintenance cost, but also by the present development of shaft engines in the 4,000 to 5,000 hp range. It is felt that in the 1980 to 1990 time period, a reliable, commercially-rated production engine of 4,000 hp will be available.

The pertinent information assumed on the basic engine is shown below in Table 3-7 [3-22].

Table 3-7

1980 ENGINE DATA

Rated power (S.L. Static)	4,000 hp
SFC	0.50 lb/hp
Installed weight (0.18 lb/hp)	720 lbs
Cost	$200,000

It is also felt that in that time period engines will be designed for use of engine components for units with a multitude of shaft arrangements, use as a gas generator for tip driven fan, gas rotor, or remote turbine supply. This would then provide a thoroughly flexible engine design, which could be used in either a turboprop, ducted propeller, or cruise fan configuration.

For the performance calculations in the normal flight conditions ($h < 2{,}000$ ft, $v < 250$ mph), the output power and specific fuel consumption were considered to be constant over the altitude and velocity range.

Air Pollution. There is little doubt that a transportation vehicle of the 1975-1985 era must emanate considerably less noxious products than the equivalent vehicle today. This is especially true in an area such as the Bay area where a low level inversion exists and tends to retard convection of the pollutants.

At the 250 mph cruise condition, the 80 passenger aircraft consumes 4,000 pounds per hour. Based on a 50% average load factor this amount to 0.4 pounds per passenger mile. On the other hand, an automobile which travels 15 miles on a gallon of gas carries on the average of 1.2 passengers. The fuel consumption rate is thus of the order 0.25 pounds per passenger mile. As both the aircraft and automobile of the 1980 period will most likely utilize the turbine engine, one must conclude that no advantage over the automobile exists. However, the turbine engine of that period will produce considerably less than the equivalent number of automobiles of today.

The use of fuels other than kerosene could lead to substantially lower pollution levels. In general, however, these other fuels tend to cost more and in many cases are far more difficult to handle. The possibility of generating exhaust constitutients that will chemically combine with existing pollution to produce more inert materials has been proposed but at present, there is no known approach along this line.

3.5 Costs

3.5.1 Aircraft Cost

A new aircraft is normally priced by a manufacturer by referencing data generated from past experience. Since all-metal aircraft from the "DC-3" to the "747" use sheet aluminum-riveted structures of semi-monocoque design, cost data from one generation can be extrapolated to the next by considering only the latest innovations, i.e. chemical milling, heavy press extrusions, etc.

The aircraft considered for the MAT system will include all advances of the next decade, and therefore is difficult to price in a conventional manner. Composite materials are currently flying on a limited basis. A considerable amount of fiberglass has been used in non-structural elements of large military subsonic aircraft. Current Piper designs utilize fiberglass wingtips, engine cowls, and tail cones. Boron filaments are currently being tested in flap and control surfaces on supersonic military jets. Helicopter blades of Boron filaments have been built and tested. All of these show considerable promise for future weight savings.

While the current price of Boron and Carbon filaments is high--$500/lb and up--there is no reason why these materials will not follow the price history of recently adopted materials such as Titanium. Fabrication techniques for composites are now being explored, and it is probable that precision molds or dies are going to be required for maximum uniformity in production.

Jet airliners today are luxuriously furnished for a maximum degree of passenger comfort and appeal. Since flights of three and four hours are not uncommon, long term comfort is a valid design requirement. Conversely, with average flight times of 12 minutes in the MAT system, items like over-stuffed reclining chairs and individual stereo music cannot be justified.

A considerable reduction in passenger area volume has been saved by the elimination of the conventional central aisle. The crosswise aisles require many additional doors, but these are required for rapid loading. Without the central aisle no hostess services may be provided, but short flight times make such service unnecessary. All of this reduces unit costs as well as operating expenses.

The cost of any manufactured item requiring a fixed tooling investment is sensitive to production rates and quantities. One way to increase the number of like units manufactured is to break a design down into identical building blocks or modules. This is the approach used in the MAT aircraft. Tooling is then required for only a fraction of the total configuration. This is offset by increased assembly (fastening) costs, so for each design there would be an optimum number of identical sub-assemblies. For composites, however, there is a promise of much lower assembly cost with a new generation of bonding techniques.

The cost of the MAT aircraft was estimated using the best current information from the feasibility studies conducted for NASA by the various aircraft manufacturers during 1967 [3-1 through 3-8], and updated by Reference 3-14.

The total estimated cost of the aircraft (without electronics) of $3.4 million each is considered to be very conservative in light of the conservative weight and the advances that may be realized from using the fabrication methods that can be used with the fuselage design chosen. This cost is based on a production run of 200 aircraft. It is anticipated that a further reduction in the cost of aircraft might be realized if the initial order of aircraft was such that a production run of 2,000 could be made.

A rule of thumb for reduction of cost with production is:

$$\frac{C}{C_o} \doteq {\frac{N_o}{N}}^{0.303}$$

where C_o is the single unit cost for N_o units and C is the single unit cost for N units [3-23]. For 2,000 units the cost would be about \$1.7 million per aircraft (without electronics).

3.5.2 Maintenance

Maintenance costs represent a large percentage of the direct operating costs. As one would expect, maintenance costs increase with complexity of the machinery and with vibrational environment, and hence helicopter-like vehicles have higher maintenance costs than CTOL vehicles of the same gross weight. On the other hand, there is little doubt that the maintenance costs of any STOL or VTOL vehicle will be considerably higher than the CTOL.

Reference 3-24, which summarizes some of the studies [3-1 through 3-8] performed by outside organizations under contract, gives the maintenance costs of helicopter-like vehicles (stowed rotor) of 60,000-80,000 pound gross weight as 20% to 24% of the total DOC. This is for a 60-passenger stowed-rotor helicopter and 500 mile stage length, with cruise speed of 400 mph. On this basis, the projected DOC of \$0.0285/seat mile and the 24% of total DOC for maintenance gives a maintenance cost of about \$170 per operating hour.

Sikorsky Aircraft [3-14] has predicted maintenance costs of their S-65-200 intercity VTOL at about \$160/hr plus about \$66/hr maintenance burden. This maintenance, not including the maintenance burden, represents about 27% of the total DOC. SFO Airlines, Inc., presently operating Sikorsky S-61 helicopters in the San Francisco-Oakland Bay area, is finding maintenance costs of about $250 per operating hour for the 22-30 passenger aircraft. Undoubtedly part of this high maintenance cost is due to the very small number of these vehicles in service.

Sikorsky contemplates the use of diagnostic maintenance systems such as BITE and AIDS, and in view of the large amount of research that is currently under progress in regard to such systems, it seems that they should be counted upon for significant reductions in costs. Sikorsky predicts the use of BITE will reduce the electronic maintenance man-hours per hour of flight by 60% and that AIDS will reduce them by 8.5%. A further discussion of these systems and associated problems is contained in Chapter 4.

With the use of a diagnostic system and counting on the "Learning Curve" as more VTOL aircraft are used in commercial applications, it is felt that a maintenance cost of $220 per operating hour is a reasonable value for the MAT aircraft. This is based on a TBO of 3,000 hours for the dynamic system, 4,000 hours for engines, and a total of 9.3 maintenance man-hours/flight hour.

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Chapter 4

AVIONICS

4.1 Description of the MAT Avionics System

Avionics generally is defined as airborne electronics equipment, including all of the equipment required for the automatic navigation and control of the aircraft. The MAT avionics system consists of the following subsystems:

(1) Enroute navigation system with sufficient accuracy to fly the MAT aircraft through a corridor or "tube" in the sky with a width of ± 0.25 miles and a height of ± 100 feet.

(2) Terminal guidance system with sufficient precision to land within ± 2 feet longitudinally and laterally with a maximum vertical error of one foot.

(3) A collision avoidance system which is based upon the MAT aircraft flying through a reserved "tube" in the sky with precise control of the position and velocity of each MAT aircraft within the tube, as a function of time. In addition, each MAT aircraft receives an automatic warning from other aircraft flying at the same altitude within a potential collision intercept during the next 40 seconds. It furthermore receives a command to change altitude in the correct direction.

(4) Communication and data handling system: This system automatically keeps track of the position of each MAT aircraft via a data link to each aircraft. In addition, a central computer schedules the routes for successive flights so as to keep a spacing of at least two miles between successive aircraft in the "tube".

(5) Autopilot and control system: The MAT aircraft is automatically stabilized and controlled so as to follow the commands and to stabilize the aircraft against all disturbances. It includes aerodynamic sensors and inertial elements, and an airborne computer to control the position and velocity of the aircraft and to stabilize it about all its axes.

(6) Performance monitoring: A diagnostic system is to be included in the aircraft which will monitor the performance of engines, electronic systems, vibrations, etc. so as to provide warning in case of any impending failures. Monitoring of pilot fitness is also included.

Equipment currently exists which can carry out all of the above functions with the requisite accuracy. British European Airways carries out automatic landings on more than 90% of their current flight operations, with the pilot acting as safety monitor [4-1]. The U.S. Navy has developed an operational system which currently provides for completely automatic landing of high-performance jet fighters on the deck of a moving carrier [4-2].

Thus, the major task in the automatic guidance and control of aircraft for the MAT system is to assemble production versions of types of hardware which have already been invented and either developed or are currently in the process of research and development, and implement the system.

It is concluded that the MAT system will be able to function on a fully automatic basis from start-up to shut-down. This will relieve the pilot of routine repetitious operations which must be carried out with high precision. The automatic system will be capable of greater accuracy and consistency than the human pilots.

The primary functions of the pilot will be to monitor the flight operations and to provide visual surveillance of the immediate airspace in case there are any aircraft which intrude into the MAT airspace. In addition, he can take command of the aircraft if required by any malfunction of the automatic systems. Only a single pilot will be required in view of the already existing redundancy of automatic systems.

The use of an automated flight control system for MAT is considered an essential to the safety of flight operations. With human pilots the statistical fatality rate of one fatal accident per million landings would result in two fatal accidents per year for the MAT operations [4-3]. By use of the automated flight control system it is estimated that this can be reduced by one or two orders of magnitude.

The automated system is independent of weather and visibility conditions, and thus provides more dependable service and increased aircraft utilization.

The various items included in the fully automatic operation include the following:

(1) Automatic start-up, pre-flight check: This will include automatic loading, door operation, and aircraft monitoring.

(2) Automatic route selection: The central computer will inform the pilot of destination and the route over which the aircraft will be automatically flown.

(3) Automatic taxi and takeoff: Information is given to the passengers by a recording concerning actions to be taken in case of an emergency.

(4) Automatic enroute navigation.

(5) Automatic landing: This includes selection of the landing pad.

(6) Automatic post-flight reporting: This will include vital aircraft and engine data, as well as information concerning readiness for additional assignments.

(7) Automatic communications: Communications will be automatic except when it is necessary to interface with non-MAT systems, and during other unusual circumstances. Normally even emergency communications will be automatic.

A more detailed discussion of these systems follows in Sections 4.2 to 4.6.

4.2 Enroute Navigation System

The use of present aircraft navigation systems such as VORTAC require aircraft to fly radial paths emanating from ground transmitters. For the MAT system the routes have to be chosen largely on the basis of

(1) Minimum noise over the residential community.

(2) Avoidance of controlled areas around airports,

(3) Terminal locations, and

(4) Minimum travel time.

Thus, a so-called "area navigation system" must be selected which can use the signals emitted from various fixed radio transmitters but is not restricted to flying radial lines between them.

It should be noted that in order to avoid air traffic congestion in high density areas, a minimum number of "tubes" must be established for the exclusive use of the MAT system.

The present VORTAC [4-4] systems provide the radial distance and angular direction from any one station. For the "area navigation system" it is proposed that the distance and angle from a number of VORTAC stations be measured substantially simultaneously and a computer program continuously determine a best estimate of the position and velocity of the aircraft. Prototypes of such systems are currently under test and have demonstrated an accuracy of ± 0.15 miles [4-5], which exceeds the specified enroute accuracy of ± 0.25 miles.

During the period of the 1980's alternate enroute navigation systems may be installed, such as

(a) DECCA hyperbolic navigation systems [4-6]: This system has the advantage of non-line of sight operation. It has been demonstrated during the past decade to have an error less than half that of the VORTAC system [4-5].

(b) Time frequency system using synchronized clocks [4-7]: Such a system potentially promise less costly aircraft equipment and acceptable accuracy.

Thus, it is concluded that enroute navigation does not present a new or difficult problem but can be carried out with equipment either currently available or under development.

In order to provide high reliability of enroute guidance it was decided to select a redundant navigation system to compare with one of the above primary radio navigation systems. A number of alternatives were explored, including Radar systems, Satellite navigation systems, and Inertial guidance systems.

Radar systems have difficulty in tracking aircraft at low altitudes due to line of sight limitations and ground reflections.

Satellite navigation systems are well-suited for overwater navigation, but probably will involve more costly airborne equipment than other radio systems. Furthermore, they are still sensitive to atmospheric disturbances.

Inertial guidance systems are presently available and have the great advantages of being completely self-contained and using different principles for navigation. For the MAT system with a flight time between successive up-dating of about 15 minutes, such systems provide a drift rate of about 1 mi/hr, and are therefore adequate for our purposes. Current inertial systems used in aircraft cost of the order of $100,000. However, highly miniaturized inertial systems have been demonstrated in the laboratory and the manufacturer estimates that such systems, including their associated digital computer, will be available during the 1980's at a price of about $30,000. This computer is designed at the same time to take care of all airborne navigation functions.

For flight times of more than 15 minutes the drift of the inertial system might exceed our specified accuracy of ± 0.25 miles, and thus updating on the basis of the radio-based navigation aid would be performed at least every 15 minutes. In the event of complete failure of the radio-based navigation system, the inertial system above would still provide ample time for the aircraft to fly to its destination or for the pilot to initiate the emergency plan.

4.3 Terminal Guidance System

Instrument landing systems (ILS) and ground-controlled approach systems (GCA) have been in use at least since World War II. In fact, blind landing systems have been used as early as 1929, when Jimmy Doolittle made a blind landing in an aircraft "under the hood" [4-8].

The ILS system is based on the following principle: A pair of antennas emit radio waves creating two intersecting lobes of radiation. The airborne equipment in the airplane gives a null indication when the aircraft flies along the bisecting radial plane towards the antenna pair. One such pair of antennas is arranged to determine a vertical plane toward the runway. Another pair of antennas is arranged to define a glide slope plane. Whenever the aircraft is off the null line defined by the intersection of these two planes, an error signal is generated giving the direction and magnitude of the error.

The ILS system is subject to errors which arise from reflections (such as metal hangar doors) and distortions from intervening objects such as other aircraft or surface vehicles.

The GCA system consists of a surface-based radar system to track the aircraft during its approach. During the Berlin Air Lift, for example, such GCA radar were used with human controllers to direct the airplane to a safe landing. More recently such GCA systems have been used for the automatic tracking and landing of the aircraft using a surface-based digital computer [4-9].

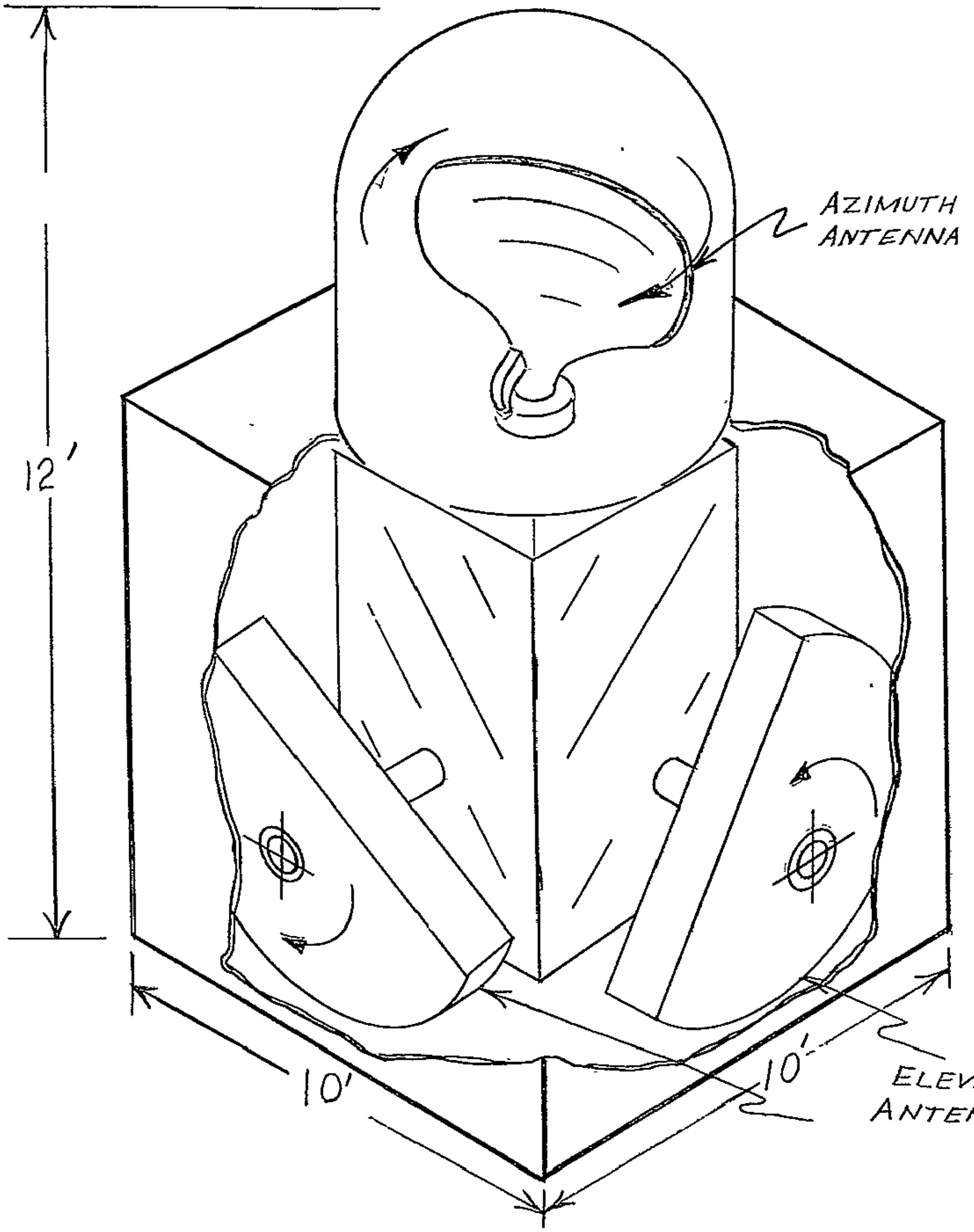
It is proposed that the MAT terminal guidance be carried out by two redundant systems, representing essentially evolutions from the ILS and GCA systems.

The first of these is a scanning beam system and may be described as follows: An antenna rotates about a vertical axis through 360° and sends out a narrow planar beam (about 0.5° beam width) at a rate of at least 5 r/s. This beam carries coded information (such as variable pulse spacing), which indicates the azimuth to a precision of about 0.03°. The same principle is used for determining the angle of elevation in two perpendicular planes (see Figure 4-1 for a typical antenna arrangement). A more detailed description of such a system is given in Reference 4-9. An example of such a system is the AILS system which has been built and tested during the past decade. The manufacturer estimates the cost of two AILS antenna installations at about $100,000 [4-10]. The airborne equipment is estimated to cost about $4,000 per aircraft.

The second system is a track-while-scan radar system. The track-while-scan feature is necessary in order that several aircraft can be controlled simultaneously. To overcome the present problems with track-while-scan radar each aircraft will be equipped with a transponder coded for identification [4-11]. Because of the transponder and the short ranges involved, a peak power of 25 kW should be adequate. It may even prove desirable to reduce this power to reduce background noise and clutter. The primary return of the radar would be used to detect non-MAT aircraft in the area and to provide surveillance of the landing area. An antenna system much like that of the AILS system shown in Figure 4-1 is envisioned for the radar. The radar system would be completely separate from the scanning beam system, having separate transmitters, antennas, receivers, and computers. The radar ground equipment exclusive of the computers is estimated to cost about $100,000. The radar data would be transmitted to the central computer for determining the landing error for each aircraft in the landing beam. Sufficient data would be transmitted to the aircraft to allow comparison with the AILS data, including a quantitative measure of the deviation between the two systems. Much less information will need to be transmitted to the aircraft than would be required for automatic landing via the radar information. The azimuth, elevation, and distance information of the AILS system would be interlaced with the radar elevation and azimuth measurements in a manner similar to that described in Reference 4-9.

In order to maintain pilot proficiency, the pilot should be required to make several simulated emergency manual landings each day. On the other hand, automatic landings would be the normal routine. The manual landings would be made during the slack times of the day and at

FIGURE 4.1 TYPICAL SCANNING BEAM ANTENNA ARRANGEMENT



the small terminals since the pilot would have difficulty following the "tubes" required during high density periods at busy terminals.

Some alternate terminal guidance systems which were analyzed but rejected included the following:

(1) Upgraded ILS, [4-12],

(2) Infrared guidance,

(3) Radioactive guidance (such as the Norwegian Hermes system [4-13]),

(4) Inertial guidance, and

(5) Hyperbolic guidance.

The upgraded ILS system was discarded because it requires large antennas and because it greatly limits the number and shape of landing approach paths. The use of infrared was discarded when it was determined that the transmission of infrared through clouds of fog was only 15% better than that of visible light [4-14].

The Norwegian Hermes radioactive system allows only one approach azimuth, although many glide slopes, and was therefore rejected. An alternate scanning beam system using a rotating radioactive emitter was studied. This system was, however, rejected because it required a prohibitively large rotating shielding device and did not eliminate the need for an electrical power system. Also, the landing area would be swept by a high level of radiation.

Inertial guidance systems would not be accurate enough for the landing operation without continuous updating.

A hyperbolic guidance system using microwave frequencies would in principle have sufficient accuracy. However, it suffers like the ILS system from reflections and was therefore rejected.

4.4 Collision Avoidance

Each of the MAT aircraft will fly through a pre-assigned "tube" in the sky (see Figure 4-2), covering each portion of its flight path with a prescribed velocity and at a prescribed time. Furthermore, the spacing between MAT aircraft within each tube will also be accurately controlled. Such a highly-disciplined flight program is used to prevent collisions between MAT aircraft.

The principal other collision hazards are commercial, military, and general aviation aircraft. Commercial and military aircraft should not interfere with MAT flights, if they observe their own flight procedures, since the MAT "tubes" of flight avoid their takeoff, landing, and flight areas.

It is assumed that by the 1980's the commercial, military, and MAT aircraft will all be equipped with a cooperative collision avoidance system [4-15] based upon the following principle [4-16]: Each aircraft carries a precise clock and is assigned a given time slot when it enters a given region. When it transmits an interrogating pulse, all other aircraft which are similarly equipped respond with a coded signal giving altitude and altitude rate. The range between these aircraft is determined by the total two-way travel time of the signal. The relative radial velocity or range rate is determined by the Doppler effect. If the signal from any of the responding aircraft indicates a hazard in that they are within or will be within ± 200 feet in altitude of each other and either within a range of 4,000 feet or have a range divided by range rate less than 40 seconds then each aircraft changes altitude. For aircraft at the hazard zone the aircraft assigned a time

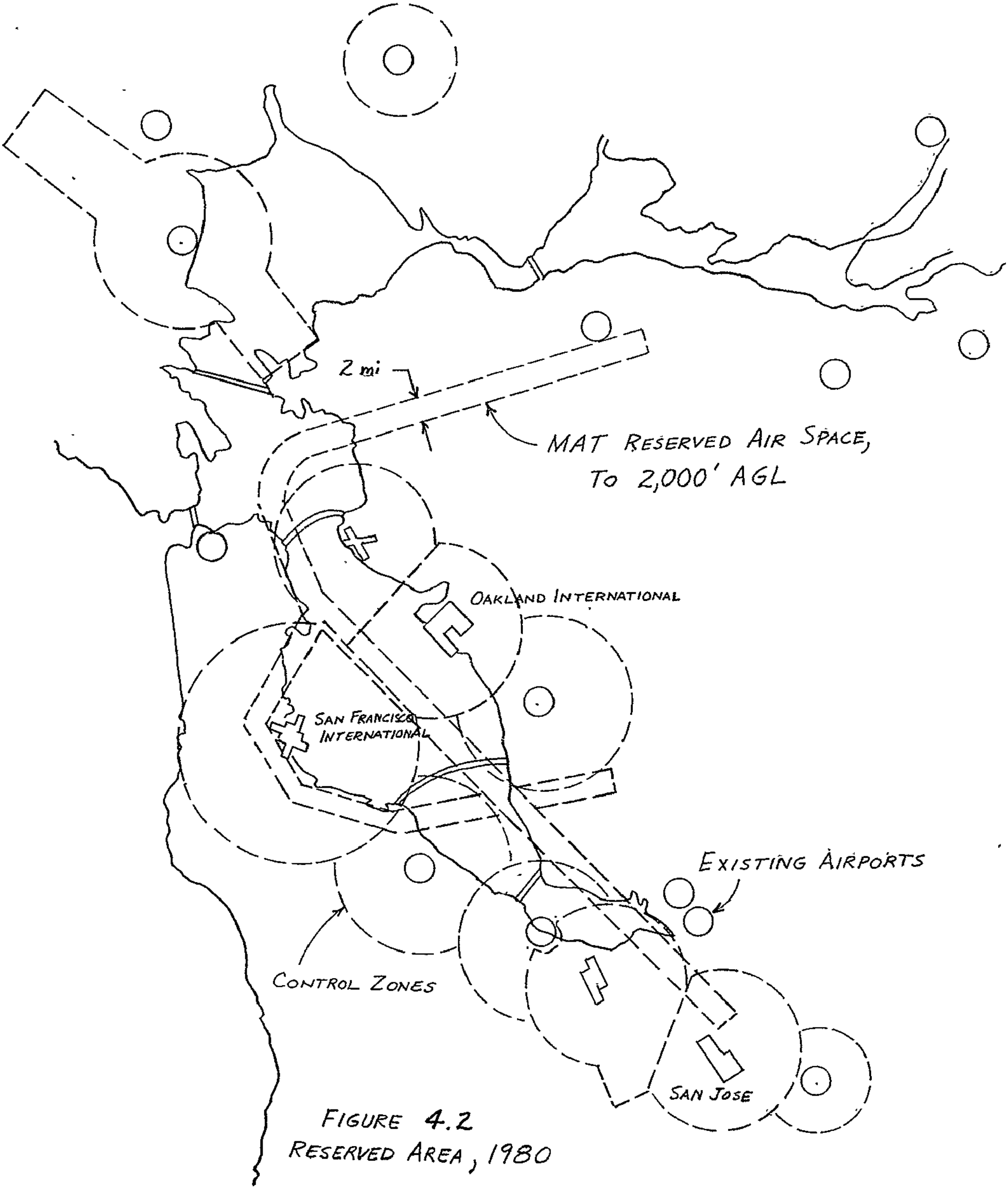


FIGURE 4.2
RESERVED AREA, 1980

slot closest to zero will be told to go up, the other one will be directed to go down.

For any aircraft intruding in VFR condition into the MAT reserved area (see Figure 4-3) it will be the primary responsibility of the pilot to maintain visual surveillance and take evasive action. In view of the fact that the pilot has been relieved of most of the routine flights tasks, he is free to concentrate on this important task.

The entire reserved area of the MAT flight paths would be indicated by day and night markers to caution other aircraft to stay out of this area.

4.5 Communications and Data Processing

The need for information exchange between aircraft and the ground in the MAT system requires a two-way communication link. The information exchanged between a given aircraft and the ground station includes air traffic control data, information to meet scheduling and rerouting needs, as well as needs in emergency situations. In addition, the communication link can aid by providing information to the aircraft for navigation updating, for monitoring the terminal operations, and for collision avoidance (a backup for onboard systems). In order that the MAT system operate efficiently in maintaining schedules, meeting demand while maintaining safe and economical operation, all aircraft in the MAT airspace must be closely watched and accurately controlled in time and space. The air traffic control problem requires having basic information from every MAT aircraft, as well as information about every other aircraft in the airspace such as altitude and position. Also, changes in demand or emergency situations require on-line

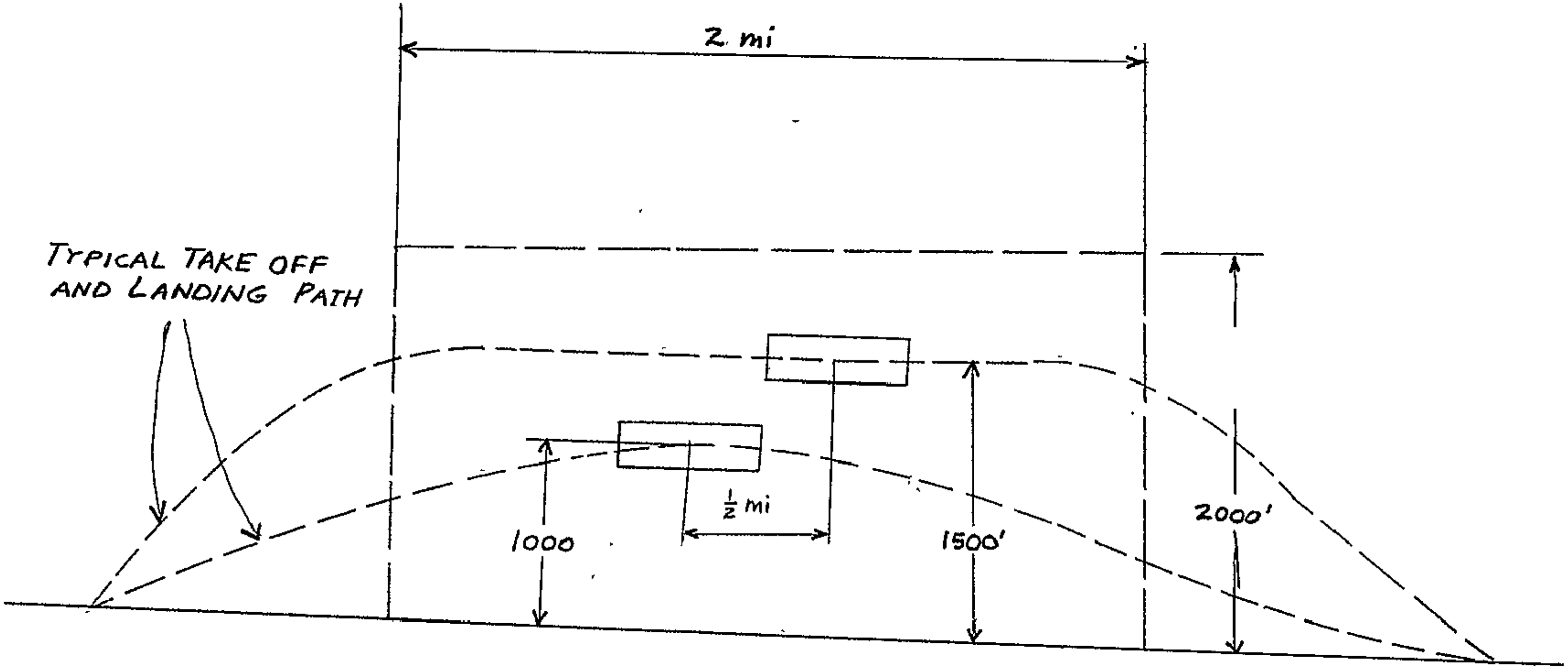


FIGURE 4.3 PROFILE OF MAT RESERVED AREA

rescheduling or rerouting instructions. There are 200 to 300 aircraft in the fully-developed MAT system. Air traffic control and monitoring, as well as initiating scheduling changes, are best performed by centralized ground facilities. One central facility can view the entire system. The overall communication system to implement the communication needs in the MAT system is shown in Figure 4-4. This system consists basically of four different parts which are tied together by three two-way communication links. There is a link between any given aircraft and a communication terminal, between such a terminal and the central control facility, and between the central facility and each air terminal. In addition, there is a one-way link from the air terminal to the aircraft.

4.5.1 Aircraft/Communication Terminal

A communication terminal basically acts as a "relay" for the two-way communications between a given aircraft and the central control facility. Generally, there is more than one communication terminal; each such terminal is stategically located with respect to providing wide coverage for radio transmission and reception (e.g., on a hill) for all MAT aircraft in a given region. Then the set of regions would cover the entire desired airspace.

Data from the aircraft destined for the central facility includes, for example, position and altitude information, while data from the central control facility intended for an aircraft includes, for example, weather conditions and forecasts, rerouting instructions, etc.

4.5.2 Communication Terminal/Central Control Facility

A communication terminal would receive from the central control

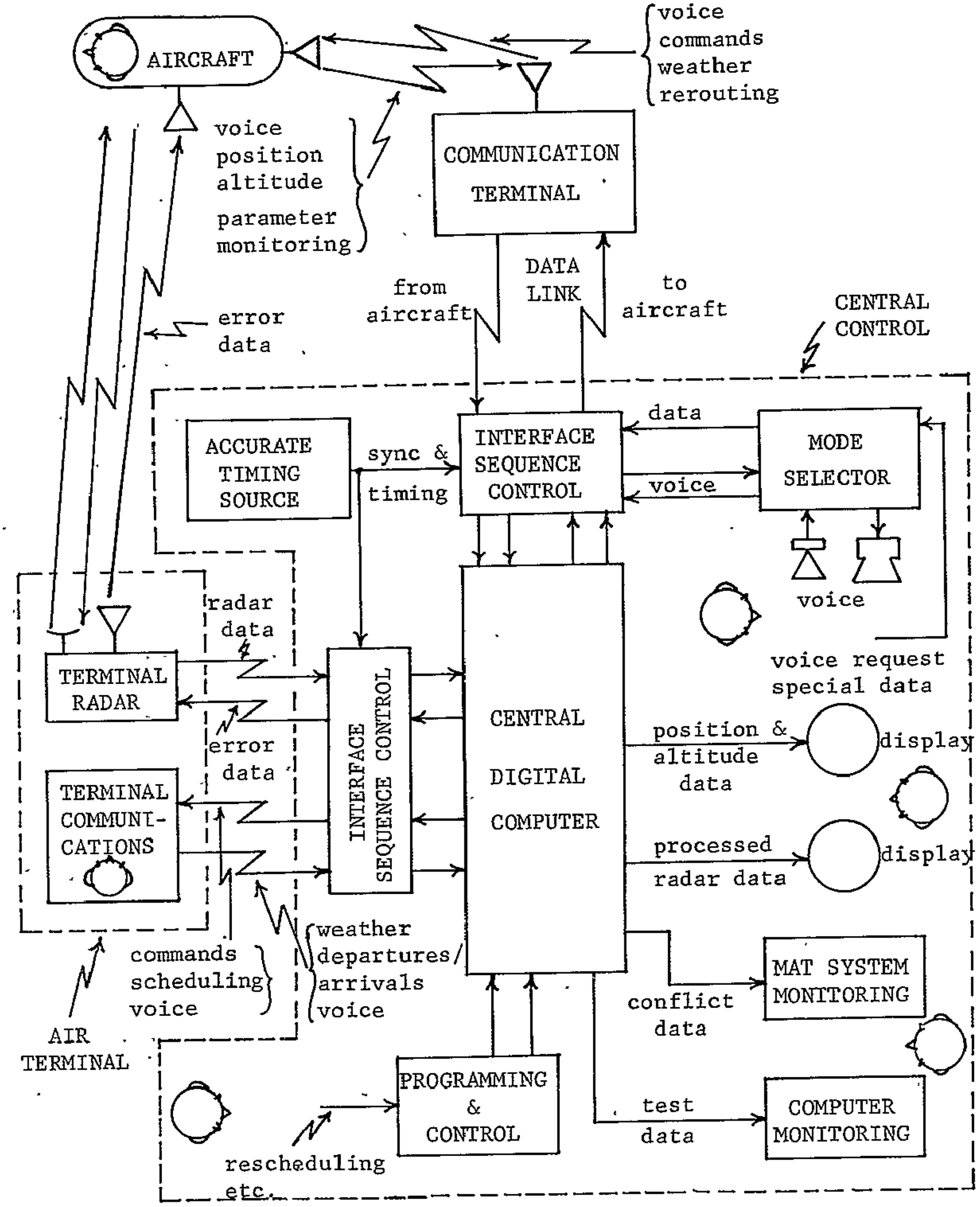


FIGURE 4.4 COMMUNICATIONS AND DATA PROCESSING SYSTEM

facility the information or data intended for a given aircraft and retransmits it to the aircraft. Receivers at the terminal receive information and data from an aircraft which would then be re-transmitted to the central control facility. Communications between such a terminal and the central control facility can be achieved through the use of landlines (telephone-type) or microwave link.

4.5.3 Air Terminal/Central Control Facility

Each air terminal represents one of the 24 terminals in the MAT system. There is two-way communication between a given terminal and the central control facility. Information from the terminal includes basic weather data measured at the terminal and actual arrival and departure times of the aircraft using that terminal. In addition, the information conveyed from the terminal to the central control facility could include seat allocations on departing flights. Moreover, tracking radar located at the terminal provides data for transmission to the central control facility for processing and monitoring. In return the terminal (attended by one person) receives the expected times of arrivals, instructions for special situations, etc. Monitoring information based on the processed radar data is also received from the central control facility for retransmission to the appropriate aircraft. The two-way link would also accommodate emergency requests by the terminal and special instructions to the terminal for the emergencies. Such a communication link can be implemented through the use of a number of landline channels (telephone-type) or a microwave link.

4.5.4 Functions of the Central Facility

The central control facility receives a large amount of data from different locations; the data originates in different aircraft and in different air terminals. This data must be processed not only for the purpose of central monitoring and display, but for providing the appropriate commands and instructions for the aircraft and the air terminals. The data processing needs in terms of reliability, speed, and versatility required at the central facility to perform the necessary calculations, etc., can be best accomplished with the use of a large-scale digital computer, preferably one with time-sharing capabilities. The major tasks to be performed by the central control facility are outlined in the following:

(1) Position and altitude data received from all (active) aircraft in the MAT system is processed in order that

    (a) relative altitudes and positions (MAT aircraft) may be monitored by a ground controller on a display instrument; attention is concentrated on proper stationing and possible conflicts, and

    (b) this data and derived data (velocity, etc.) may be compared with pre-selected desired values (with tolerances) for station-keeping purposes (in the "tubes") and to check automatically for possible conflicts.

(2) If the preselected desired values are not satisfied the necessary changes in speed and direction are calculated and then automatically communicated to the appropriate aircraft. Conflict situations would require a relatively fast response which, along with an aircraft not responding to a command, would give an alarm to a ground controller to initiate voice communications if desired. Such responses by the ground facilities are particularly applicable to aircraft near a given air terminal.

(3) The information received from the air terminals regarding gate arrivals and departures give the central facility a more complete picture regarding conflict situations and

schedule - keeping of all MAT aircraft. Based on inflight data, the expected arrival times are transmitted to the appropriate air terminals. Actual arrival times and expected departure times (for the same aircraft) would be used to change the predicted schedules at subsequent terminal stops. When an aircraft is actually ready to take off, it must be cleared in an automatic fashion; its actual takeoff time (and predicted entrance into the "tube") must fit in with all other active aircraft at that time within the pre-selected tolerance on relative positions and altitudes. It may become necessary that a given aircraft be held up until a "slot" opens up in the tube. The actual departure time of a given aircraft is used to predict its schedule at subsequent terminals.

(4) Data derived from the tracking radar located at a given air terminal is processed by the computer. The processed data drives a display unit which provides a ground controller with a surveillance of the terminal area. In addition, the processed data during the approach, landing, and takeoff phases is compared with preselected approach, landing, and takeoff path data; the results of this comparison are transmitted to the terminal for retransmission to the appropriate aircraft.

(5) From time to time it may be necessary, in order to meet passenger demands which were not accurately predicted in advance, to alter the regular schedule. This may involve adding aircraft to the system from storage areas, removing aircraft from activity, or simply altering the schedules of existing MAT aircraft. Temporary rescheduling of existing active aircraft in the system may arise from unscheduled removal of active aircraft due to maintenance needs. Rescheduling and rerouting would be accomplished by the computer; it should be done in an optimum way according to economics, service, etc. Because it is desired to maintain the published schedules as much as possible, rescheduling of existing aircraft in the system would be minimized. Most scheduling changes are only temporary; these changes occur when failed aircraft are replaced or when additional aircraft are added to the system.

(6) The central control facility must respond to emergencies, preferably in an automatic fashion. If, for example, an aircraft needs to land as soon as possible, the computer would use aircraft data upon which are based appropriate instructions to transmit to the aircraft; such instructions may include the location of the nearest available landing area. Another possibility involves dispatching VTOL type fire-fighting or ambulance equipment

to an air terminal for fires or accidents. Emergencies involving all aircraft in a given area require appropriate instructions to be transmitted to all aircraft involved. Such emergencies as these would give alarms to ground controllers for voice response.

(7) Air terminals would provide basic weather data to the central control facility for the following:

  (a) transmission of terminal weather conditions to aircraft approaching that terminal and to those planning to depart, and

  (b) to be combined with similar data received from other terminals for weather prediction by the computer. Predictions for inflight and terminal weather conditions would be transmitted to the appropriate aircraft.

(8) Because it is proposed to have automatic ticketing procedures at the air terminals, information would be transmitted to the central control facility for calculations whose results would be transmitted to all air terminals for space availability and queueing purposes.

(9) In order to increase safety and reduce maintenance, certain aircraft parameters such as engine parameters, avionics parameters, and parameters from the pilot (e.g., EKG data) would be transmitted to the central control facility for monitoring and analysis. The data would be automatically compared with expected values. The data would also be used to predict possible failures. In case of existing or predicted trouble the aircraft and flight manager would be informed and advised on the action to follow (either automatically and/or by a ground controller). In addition, the data would be used for trend analysis to determine an optimum maintenance schedule for the aircraft systems.

The scheduling of aircraft (as "published") could be changed after longer periods of time in response to slow changes in population densities, etc. Such changes should be accomplished in an optimum manner; this can be done with the aid of the central computer. The same computer center could also be employed to handle reservations and seating assignments for the regularly scheduled airlines for airline users. In reference to item 8 above, procedures for automatic billing could be included as a computational task.

The central computer not only provides the ground controller with the visual displays referred to previously, but provides him with monitoring of conflict data (with alarms) and monitoring of the computer status, resulting from periodic, automatic self-checking. The ground controller can initiate data messages or voice messages to communicate with a given aircraft or air terminal.

To increase the reliability of such important functions as performed by the central control facility, it is recommended that the computer be highly redundant and that there be three such centers established in different locations. Each center would be capable of handling the total functions; however, only one of them would be operative at any given time, with the remaining two centers on standby. Complete failure of the active control center will result in a transfer of control to another center. Complete failure of all three control centers is not catastrophic, because each aircraft carries its own navigation, guidance, and collision avoidance equipment. The computer-oriented functions and tasks outlined above require the use of a highly reliable digital computer. Some of the general desired characteristics of such a computer are as follows: (1) highly parallel operation (time-sharing), (2) programmable in a easy-to-handle language, (3) internal redundancy, (4) automatic, self-checking capability, and (5) conversational modes. As an example of a basic machine, an IBM system 360/67 machine with time-sharing capabilities can be considered; this machine is estimated to cost $40,000 to $50,000/month, including maintenance.

At the other end of the communication system (as described here), the aircraft basically possesses a transceiver. The aircraft receives information from the ground such as weather conditions and instructions, etc. Airborne-derived data from sensors, navigation equipment, or from the onboard computer is converted to a form to transmit to the ground centers.

4.5.5 Operational Requirements for Air/Ground Communication Systems

A number of conditions and requirements are imposed on the operation of the two-way communications systems between aircraft and the ground and between terminals and the central facility. These requirements are based on the needs of the MAT system within the general framework of desirable communication (principally, air/ground) requirements and needs as discussed in [4-17, 18, 19]. Air/ground communications will be emphasized here. In order to automate the air communications as much as possible in the sense of minimizing the intervention and supervision of the human pilot, automatic communication from machine-to-machine is desired. Such an arrangement would provide uniformity in processing the data at the central facility from all MAT aircraft. Consideration of the amount of data generated by the aircraft for transmission to the ground along with the number of aircraft in the system and the ATC requirements reveals the need for high-speed information interchange (compared with voice communication). The communication system should be capable of accommodating simultaneous information interchange between 200 to 300 aircraft and the central ground facility during successive time intervals. In this manner aircraft can be treated uniformly as to processing their data, delivering instructions, etc. A related requirement for the MAT air/ground communication system concerns the use of fixed format messages. Such a message would have a fixed time length consisting of an aircraft identification number, special messages such as message routing, and then routine data on position, altitude, and some critical parameters. Such a message would be transmitted from a given aircraft to ground periodically and during an assigned time slot within a time interval time-shared with other aircraft. A similar requirement holds for ground-to-air messages. It is intended that information based on the processed terminal radar data be transmitted from the air terminal to an aircraft to permit it to monitor its own progress in the approach, landing, and takeoff phases. It is desired that several aircraft be able to do this simultaneously. To accomplish this, a time interval is partitioned into a number of time slots, each slot being assigned to a particular aircraft; these slots, however, are assigned as needed, rather than being preselected. There are many sources of data available on the aircraft which might be considered for transmission to the ground. Position and altitude information is necessary. Sensor data, though basically in analog form, can be converted onboard and processed by the onboard computer before transmission to the ground. Also, particular output data from the computer, resulting from navigation, computations, etc., would also be transmitted. It is desired to achieve a high degree of interface compatibility of the communication link with these sources of airborne data; this would be consistent with recent trends toward "integrated" aircraft functions [4-20, 4-7]. As the processing and display or airborne derived data is performed at the ground end of the communications link, high reliability for the communication system is desired. Specifically, in terms of equivalent information bits, it is desired that there be less than one error per 10^6 bits transmitted, i.e., $p < 10^{-6}$ (probability of error). Equivalently, for a transmission rate of 10,000 bits/sec., one error would occur (on the average) about every minute. This error rate represents a compromise between obtaining the lowest possible rate and power and data rate considerations; it is assumed to be sufficient. Another requirement concerns the efficient use of transmitter power and available channel space. This requirement is closely related with the requirement on error rate and the signaling speed (in bits/sec). The former requirement refers to the choice of the frequency bands available and corresponding power requirements. It is desired that air/ground communication use frequencies which allow for the use of low-to-medium power transmitters to achieve the desired reliability of communications while not complicating the equipment needs. Finally, even if voice communications are not chosen for the main communication link it is desired to retain a voice communication option for use at the discretion and initiation of the pilot and/or a ground controller. In addition, it is desired to have the chosen system be compatible with overall goals of safety (through redundancy) and economy.

4.5.6 Requirements for the Ground Communications

The two-way communication link between a communication terminal and the central control facility must essentially relay and accomodate all of the air/ground data. All of the pertinent requirements and conditions imposed on the air/ground communication link also apply here, except that power requirements and available frequency bands are not as critical here. A similar exception also applies to the two-way communication link between air terminals and the central control. For this case, however, the link would generally not need to carry as much information as the air/ground link. This results in lower data rate and bandwidth requirements. It is desired that the attendant at an air terminal be able to communicate (through the central control facility) with the pilot of a given aircraft.

4.5.7 Alternate Systems and Methods Considered

For the major two-way communication links (the air/ground link, in particular), only voice communications and data communications were considered. Voice communications were assumed to be conveyed by analog signals while data communication in digital form was assumed. Voice communications suffer from (1) inefficient time use, which could be very critical, (2) non-automatic operation, (3) ambiguities and misunderstandings, (4) non-uniformity of messages, (5) difficulty in recording for efficient use at a later time, and (6) inefficient message routing. In contrast, digital data communication (DDC) provides automatic machine-machine communications, high-speed information interchange (an order of magnitude faster than voice communications for the same time-bandwidth product), and a high degree of interface compatibility with airborne data sources and can be readily handled by data processing and display equipment on the ground. Although digital data communication requires more complex equipment, it is not beyond the state-of-the-art. Also, DDC, because of its digital or discrete nature, is much less effected by channel noise and fading than voice communications would be, because they involve waveform transmission. Hence, it is evident that DDC is the answer for the main two-way communication links, particularly for air/ground use.

Once this choice has been made, it is then necessary to decide on many facets of the digital data link such as signaling speed, coding, error correction techniques, modulation, message length, time-sharing techniques, etc. In considering the alternatives, some weight has been given to the results of the thousands of man-hours resulting in the RTCA document SC 110/111 and the so-called USASCII/ISO/ITU/ITU #5 code [4-17, 4-18]. First considered was the form of the digital data; that is, should it be binary or n-ary (i.e., n discrete levels). The binary form, of course, is convenient for almost direct use for computer inputs or computer-to-computer communications. An n-ary form, although requiring more signal power for the same error probability, gives an increase in the signaling rate by a factor of $\log_2 n$ [4-21, 4-22]. Another consideration is the representation of the digital data, that is polar synchronous, unipolar synchronous, and polar return-to-zero. Synchronous refers to the property that all pulses have equal duration with no separation between; polar refers to the polarity of the representation (positive-zero or positive-negative, etc.). Unipolar signals contain a non-zero dc component which is inefficient because it carries no information and requires more power. Synchronous signals, although requiring time coordination at transmitter and receiver are more reliable. The polar return-to-zero signals, although avoiding these two problems, wastes time for the self-clocking spaces. The polar synchronous signal, in addition to being more reliable, is the most efficient timewise. An ideal communication system is capable of error-free transmission at a rate of

$$C = B \log_2 (1 + \frac{S}{N}) \qquad (4\text{-}1)$$

where C is channel capacity, B is the channel bandwidth and S/N is the signal power to noise power ratio at the receiver. However, the impracticality of this lies in the fact that to achieve arbitrarily small error, an infinite encoding (or decoding) time would be required. In addition, if the transmission (and receiving) equipment were linear and distortionless over all frequencies (i.e., infinite bandwidth), a sequence of pulses would undergo no degradation in transmission (and reception); then, one could achieve an arbitrarily high signaling speed by using very short pulses, subject to the channel capacity limitation defined by Equation (4-1). However, a practical system has finite bandwidth and non-ideal frequency response, causing the pulses to spread out and overlap, causing errors. Hence, the output signal should be shaped to minimize intersymbol interference due to overlapping while maximizing the signal rate. An example of the output waveform for a binary (bipolar synchronous) message can be found in Reference 4-21. As a result, the signaling speed is usually lower than the theoretical value of 2 x signal bandwidth. For these reasons, a method for encoding the digital data for a "reasonable" rate of transmission for a given lower bound on the allowable signal-to-noise ratio, and for a given upper bound on error rate must be considered.

The previous factors must be considered in the selection of the type of modulation or method of impressing the information to be transmitted onto a carrier. Because digital data communication has been selected (discussed previously), digital modulation will be employed;

there are three basic forms of digital modulation, amplitude-shift keying (ASK), frequency-shift keying (FSK), and phase-shift keying (PSK). Detailed descriptions of these forms of modulation along with a discussion of the factors involved in communication referred to here can be found in any one of many standard books on communication systems such as in References 4-21 and 4-23. The decisions reached here in regard to the communication link are based in part on such sources. The basic types of digital modulation along with some variations were considered as to performance in noise, i.e., error probabilities as a function of signal-to-noise ratio. For the same noise performance, binary PSK requires 3 to 4 dB less power (4 dB represents a power ratio of about 2.5) than all of the other forms of digital modulation considered, including ASK, FSK, and variations. This is achieved by synchronous detection; synchronous (or coherent) detection here refers to the receiver having available a locally generated sinusoid, synchronized to the carrier. To avoid this synchronization (and resulting complexity), PSK can be modified to DCPSK, differentially coherent PSK. This requires special coding at the transmitter and precludes variable speed data transmission (without alterations) [4-21]. In addition, for the same error rate, 1-2 dB more power is needed for DCPSK compared with ordinary PSK. Another variation of PSK involves the modulation of an audio subcarrier on the carrier; the result is audio PSK or APSK.

4.5.8 Codes

An important consideration in specifying the characteristics of a communication link is the code to be used by the encoder (and decoded at the receiver). Choices considered included block codes such as (m,c) codes, cyclic codes and recurrent or sequential codes. Essentially, only binary codes were considered. A block code defines a binary message as a sequence of blocks or characters (or words), each block being n binarys digit long. Each block can assume any one of 2^n different characters. An (m,c) code is a block code with m message digits and c digits used for error detection and correction. A cyclic code is a block code in which a specific number of successive message digits are grouped together; check or correction digits are arranged such that a shift register with feedback will encode the message [4-24]. Sequential or recurrent codes do not divide the message digits into blocks; such codes have a continuous or sequential encoding/decoding procedure. The choice of a code is coupled with the choice of error correcting capabilities. These are two essential trade-offs here, (1) bandwidth and signal-to-noise ratio (at the receiver) for a given signaling rate, and (2) signaling rate versus error correcting capabilities for a given signal-to-noise ratio.

Error probability in digital communications is a direct function of the signal-to-noise ratio. Assuming that the signal power is limited to some maximum value, the probability of error through a given channel must be controlled by error detection and correction techniques--error control coding. Such coding essentially involves the designed use of redundancy--in the form of adding "check" digits to the transmitted message for error detection and correction (no information content) of the message digits. Though near errorless communication is possible, practical considerations result in a tradeoff of reliability, efficiency (speed), and complexity of the communications equipment. A code which consists of an average of m message digits for a given time and an average of c check digits for the same time will have a speed efficiency factor of

$$\alpha = \frac{m}{m + c} . \qquad (4-2)$$

Practical error control tends to be associated with low data rates. However, by decreasing the data rate and reducing the required bandwidth, the effective S/N is increased; this results in a lower value for the error probability. Or, the same message could be transmitted an odd number, k, of times and then the receiver uses a majority logic decision rule. However, this effectively reduces bandwidth while the speed efficiency factor is $\alpha = 1/k$. Parity-check codes for error detection were given special consideration because the USASCII code recommended by RTCA document SC110/111 represents a parity-check code. A parity check code is a (m,1) block code such that the check digit is used to check for odd or even parity (number of 1's in the block) such that each (m+1) character has, say, odd parity. For such a code, the speed efficiency factor is $\alpha = m/(m+1)$. However, the probability of error with the parity check is

$$P_e \approx m^2 p^2 \qquad (4-3)$$

where m is the number of message digits in the block, p_e is the bit error probability for an m digit message without parity check and P_e is the error probability with parity check. Parity check codes are suitable for applications in which error detection is sufficient, as would be the case when there is two-way communication in which case error detection results in a request for retransmission (i.e., decision feedback). A parity check code represents a low-redundancy code and thus, has a high speed efficiency factor. Such error-detecting codes are satisfactory when the error probability p_e is at a suitable low level (say, 10^{-3} or less). Properly done, a parity check code can be relatively immune to burst errors. Error correction by parity check is not attractive because the achievement of a suitably low probability of error requires a large value of m and results in a relatively low value of speed efficiency. Corrected errors here require substantial decoding equipment. A Hamming code is a block code with good error detection and correction possibilities but the necessary equipment can grow rapidly in complexity when a reasonably high speed efficiency is achieved. In addition, the use of longer words increases the probability of multiple errors. For cyclic codes having short word lengths, encoding/decoding equipment is relatively simple and reliability is high. However, the speed efficiency is low and they are subject to burst error. A variation of this code has better error correcting properties and thus is relatively immune to error bursts. However, a small digital computer is required for error correction.

The use of a sequential code eliminates the need for storage and buffering at the data terminals, thereby reducing equipment requirements. Such codes are usually designed to have a high immunity to burst noise; this gives a low speed efficiency. However, this code has much promise. If a block code were chosen, its length must be selected. Generally, shorter codes (under 10 bits) have a low speed-efficiency but yield reasonably low error rates and require relatively simple equipment. Longer codes increase the efficiency but are subject to multiple errors; such errors can be corrected but with an increase in equipment requirements.

4.5.9 Message Length

Another important factor in the air/ground communication system concerns the length of the message sent by any given aircraft to the ground in its assigned time slot and that of the message sent to the aircraft in an assigned time slot. The message length is determined by the amount and nature of the data to be transmitted in the air/ground communication system. Another influencing factor is how often the data is transmitted. The first part of the aircraft-to-ground or ground-to-aircraft message should be an identification number of the aircraft such as its airframe number (not flight number). Next, the message should contain some words dedicated to special messages such as declaring an emergency or requesting voice communications. Then, the remainder of the message would consist of the necessary "routine" data. From aircraft to ground this data might include position, altitude and critical parameters for ground monitoring and analysis. From ground to the aircraft, this data might include weather data, course correction data, and routing instructions (or special instructions). For the air terminal to aircraft link, this data might assume the form of error information (between actual and desired paths). The message length for any given aircraft is constrained by the number of aircraft sharing a time interval, the length of the time interval (cycling time), and the signaling speed and number of channels. The cycling time need not be the same for all types of data; in fact, the cycling times for the in flight air/ground link and the terminal air/ground link will generally be different.

4.5.10 Voice Communications

It is desirable that voice communications be retained for emergency or unpredictable situations. It can be either on a separate channel from the digital data link or on a data channel. Assigning the voice communications to a separate channel reduces interference and allows simultaneous use of voice and data communications. Basically, because of the number of aircraft in the MAT system, it is desired that the voice communications circuit discipline be controlled by requests via the data link. However, in some cases, it may be desired that air/ground voice communications require only the pilot's decision to begin (ground receiver would always be open). This could lead to overuse.

4.5.11 Frequency Bands

Frequency bands for the data communication link were considered on the basis of reliability, channel space needed, compatibility with other avionics, cost and complexity of equipment. In-flight navigation using VOR is part of a recommendation for the MAT aircraft; because VOR uses the VHF band, the use of VHF for the data link may result in some sharing of equipment or common hardware. The VHF band provides fairly reliable line-of-sight communications with low to moderate power requirements. At higher frequencies, the equipment begins to increase in cost and generally more power is required (because of greater attenuation). However, because of the shorter distances and lower power requirements involved, the UHF band is more suited for the terminal to aircraft link.

4.5.12 Time-Sharing

With some 200 to 300 aircraft in the system, each of which will send data messages to the ground facilities for analysis, some orderly method must be provided to handle the routing and separation of messages from different aircraft. One possibility is for the ground to interogate the aircraft in sequence for data; however, this would appear to be unnecessary in view of the data which a given aircraft would send to the ground facility on a regular basis anyway. Another more feasible solution is to assign a time slot to each aircraft within an overall time interval. The time slots are controlled by an extremely accurate clock; this clock provides timing pulses to the computer for controlling the sequence of messages and selecting particular ones. The clock can also provide synchronization pulses to be transmitted to the aircraft for synchronizing their timing circuits (oscillator). A particular time slot in the overall time interval (cycle time) is allotted for the message from any given aircraft. Such a time slot consists of a fixed maximum time allowed for the message plus a "guard" time to allow for a variable transmission time lag between the aircraft and a given communication terminal, due to the aircraft being different distances from the terminal. This so-called time/frequency system has the advantage that the accurate clock can be used to control accurately timed signals which the aircraft can use for area navigation purposes. In addition, the airborne clocks (synchronized from the ground) can be used as part of a collision avoidance system [4-10]. In this system, the messages from the ground to the aircraft can also be transmitted during assigned time slots. The choice of a basic data rate to accommodate the air/ground communication requirements discussed here can vary over a wide range, anywhere from, say, 600 bits/sec to 10^4 bits/sec or higher. A high information bit/sec rate is desirable, but not at the cost of a high error rate, nor high cost of equipment or of achieving compatibility with ground communication links.

4.5.13 Ground Communication

As mentioned earlier, the communications terminal acts as a relay to relay the aircraft messages to the central control facility and the ground messages to the aircraft. Hence, the communication link between each communications terminal and the central control facility must, in general, accommodate the air/ground communications for all aircraft. However, as noted in the section dealing with the link between the central control facility and a communication terminal, such ground communications do not share the power or frequency band limitations with the air/ground link. The use of either existing telephone lines or a microwave link has been considered. The ground communication link between a given air terminal and the central control facility need only carry information between that terminal and the central control facility; the amount of data is generally less and hence the capacity need not be as high. For this link, also, the use of existing telephone lines or a microwave link was considered.

4.5.14 The System Chosen

In deciding on an optimum communication link, particularly for air/ground communications, some emphasis was placed on the RTCA document SC110/111, [4-1], which adopted the USASCII code. The conclusions reached here are based on consideration of the alternate systems as discussed in the last major section and on considerations of the document referred to above.

4.5.15 Data Form and Modulation

Based on the relative ease of implementation of encoding/decoding procedures and lower power requirements for a given reliability, binary digital data has been selected. The high reliability and time efficiency of the polar synchronous representation of the digital data has led to its being chosen. Because of its lower power requirements for the same noise performance and high reliability, APSK (audio phase shift keying) has been chosen as the digital modulation form. This involves the modulation of an audio subcarrier on the carrier frequency. A second choice which also has many desirable properties is DCPSK (differentially coherent PSK) which does not require synchronization. Based on the general characteristics of available channel frequencies as to reliability, power requirements, compatibility, etc., the use of the VHF band is recommended for the aircraft/communication terminal link. Based on lower power requirements, good line of sight propagation characteristics, and short distance communication characteristics, the UHF band is recommended for the air terminal to aircraft communications link.

4.5.16 Code

In selecting a code and the associated error control methods, consideration was given to the RTCA document SC110/111, speed efficiency, complexity and cost of the encoding/decoding equipment, error rate with error control, and immunity to noise. A compromise selection based on these factors is represented by the choice of the USASCII code. This code is an (m,c) block code with $m = 7$ and $c = 1$; the one check digit is a parity check. Each block of 8 digits represents a character, representing one of $2^m = 2^7 = 128$ different message characters. Such a code possesses a high speed efficiency, moderate equipment requirements, a desirable error rate (if the probability of error is initially low), but its basic form has only a low immunity to burst errors. Another choice is represented by a sequential code; such a code, though possessing a low speed efficiency, has low equipment requirements, a low error rate, and good immunity to burst errors. Serious consideration of such a code is recommended for adoption in Phase II, i.e., later in the design and development of the MAT system.

4.5.17 The Time/Frequency System

The time/frequency system, which was briefly described in a previous section, has been selected to accommodate the data exchange between many aircraft and the ground central facility. The advantage of this sytem lies in its time-sharing properties of assigning a precise time slot to each aircraft for data transmission. Each aircraft and communication terminal possesses an extremely accurate clock controlled by a highly stable crystal oscillator; the clock pulses control the state of the transmitter and receiver and trigger the transmission of the message in the assigned time slot. It is essential that all of the oscillators (clocks) be closely synchronized. This is accomplished through the use of an extremely accurate ground-based master clock (e.g., an atomic clock) which provides sync pulses to synchronize all other clocks in the aircraft and at the communication terminals. A different time/frequency system is proposed for controlling the assignment of time slots for transmitting monitoring information from the air terminal to the aircraft engaged in approach, landing, or takeoff operations. It is proposed that during any one of the three phases, approach, landing, or takeoff, an aircraft would require three numbers, five times/sec. These numbers could be error from desired glide path angle, etc. As before, two characters or 16 bits are assigned to each number. Hence, each aircraft engaged in one of the three operations referred to above would require a 48-bit message five times/sec. In addition, this time/frequency system utilizes the computer to assign the time slots as needed; that is, if an aircraft is cleared for takeoff or is acquired by the landing guidance system, a time slot is assigned to it until no longer needed. It is desired to be able to handle 15 simultaneous operations (aircraft). A detailed description of a time/frequency system as used for collision avoidance can be found in [4-15]. There are several factors which influence the choice of a specific time/frequency system. These factors include the type of communications (one- or two-way), the message length, the cycling time (time between successive message bursts from the same aircraft), the length of the "guard" time, the number of aircraft in the system, and the number of channels, each having a given data rate.

To accommodate two-way communications, the time/frequency system will allow the communication terminal to transmit messages to one or more aircraft while receiving messages from one or more aircraft during the same time slot, provided that all transmission channels have different frequencies than each receiving channel and that each receiving channel receives a message from only one aircraft during that time slot. If the information transfer needs in terms of message length were the same in both directions, then the use of an equal number of transmitting and receiving channels at the terminal would allow for each transmit/receive pair of channels to accommodate two-way communications with only one aircraft during its assigned time slot. A corresponding arrangement occurs on the aircraft. If the message lengths in the two directions are not the same, then, because a common clock is used for sequencing and control, it would be useful if either (1) the message lengths were integral multiples or (2) with equal message lengths, the cycling times (for the two directions) were integral multiples.

In a previous section concerning message length, the first part of a message between aircraft and ground (either way) consists of an identification number for the aircraft. In terms of the USASCII code, two 8-bit characters (including 2 parity check digits) are allocated for identification. The next part of the message is devoted to special messages; one 8-bit character (including one parity-check digit) is allotted for this. The remaining part of the message from the aircraft to the ground facility should consist of the routine data such as altitude, position, and a limited number of critical parameters. One character or 8 bits of this remaining part of the total message could be allotted for informing the receiving equipment how to interpret the data that follows, i.e., the units of the data. Finally, it is assumed that position and altitude information will use a total of 6 characters or 48 bits. Another 10 characters, or 80 bits, can be devoted to a limited number (say five) of critical parameters. Hence, the total length of the message transmitted from an aircraft to the ground facility will be 2(8 bits) + 8 bits + 8 bits + 48 bits + 80 bits = 160 bits. For the message transmitted from the ground facility to the aircraft, after identification, special messages, and an interpretation character (as in the aircraft-to-ground message), an additional message length of 48 bits is proposed, giving a total message length of 80 bits. This number is based upon a lower requirement for the amount of data to be transmitted from the ground to the aircraft. Another method of accommodating this lower requirement is to transmit a 160 bit message to a given aircraft, but only half as often. Based upon experience gained from collision avoidance systems and the needs in the MAT system, a basic cycling time of 2 seconds is recommended [4-15]. Thus, messages would be received from a given aircraft every 2 seconds, during its assigned time slot (and channel). If a set of aircraft send messages in sequential time slots, each message occupying the entire time slot, then the message signals may overlap in time (i.e., out of sequence) at the ground receiver due to different transition times (one microsecond per thousand feet of distance). To avoid this problem, each time slot includes a guard time to allow for the transition time. A two-millisecond guard time will allow for a difference in distance (of different aircraft) from the ground receiver of up to 400 miles. A transmitter message is initiated just after the start of the assigned time slot; it is followed by the guard time, which completes the time slot. Now, for the information to be transmitted from the air terminal to the aircraft, after identification, special message, and interpretation information, the remaining part of the message is 48 bits as previously discussed. Therefore, the message length for the air terminal to aircraft link is 32 bits + 48 bits = 80 bits. However, such a message must be transmitted to each appropriate aircraft (engaged in an operation) five times/sec.

The RTCA document SC110/111 recommended a nominal signaling speed or data rate of 1,200 bits/sec/channel. However, assuming a reasonable improvement in digital data communications equipment, a data rate of 2,400 bits/sec is proposed as a nominal rate (per channel). This choice of a data rate represents a compromise of signaling rate, equipment complexity and cost, reliability for a given signal-to-noise ratio, and compatibility with system facilities such as telephone lines or standard microwave links.

Now, with a message length of 160 bits to be transmitted to the communication terminal at a nominal data rate of 2,400 bits/sec, one receiving channel can handle (with 0 guard time) $\frac{2400}{160} = 15$ aircraft, each in a different time slot over one second. Over a two-second cycling time, one channel could handle 30 aircraft, or each is allotted 0.067 seconds in time. With a minimum guard time of 2 ms, each aircraft would be allotted about 0.07 seconds or 14 aircraft could be handled in one second by one channel. The relationship between the number of channels needed, N_c, the total number of aircraft to be handled, N_t, and the number of aircraft which can be accommodated over one cycle time (including the guard time), N_o is given by

$$N_c = N_t/N_o \tag{4-4}$$

N_c is rounded off to the next highest integer. For the present system, $N_o = 28$, $N_t = 260$, and thus the number of ground-based receiving channels required is 10. The relationship between N_o, as defined above, the cycle time, T_c, the message length L_m, the data rate R_d, and the desired guard time, t_g, is given by

$$N_o = \frac{T_c}{(L_m/R_d) + t_g} \tag{4-5}$$

in which N_o is rounded off to the next lower integer. Here, for example, $T_c = 2$ sec, $L_m = 160$ bits, $R_d = 2{,}400$ bits/sec, and $t_g \geq 2$ms., $N_o \approx 28$. For a message length of 80 bits for the message from the ground to an aircraft, and with N_t, R_d, t_g, and T_c remaining the same as before, $N_o \approx 56$ aircraft and $N_c = 5$ channels. Hence, each communication terminal has 10 receiving channels and 5 (separate) transmitting channels. Every 28 aircraft are assigned a different transmitter channel and every 56 aircraft are assigned a different receiving channel. For the information to be transmitted from the air terminal to the aircraft (for monitoring operations), each basic time slot will carry an 80 bit message plus a guard time. The time slots associated with different aircraft are interleaved so that all aircraft involved will receive an 80 bit message five times/sec. To handle 15 simultaneous operations, this arrangement is equivalent to communicating an 80 bit message to 5 x 15 = 75 different aircraft with a cycle time of one sec. Using a guard time of 0.5 millisec. (close to terminal) and Eq. (4-5), at a data rate of 2,400 bits/sec, $N_o = 29$. Then using Eq. (4-4), for $N_t = 75$, the number of transmitting channels needed at each air terminal is 3. It is assumed that the aircraft possess redundancy in regard to communications equipment. A similar assumption is made in regard to the terminals (communication and air).

4.5.18 The Communication Terminal System

In order to insure a high reliability of the air/ground communication link, it is proposed that five identical communication terminals be strategically located with respect to providing good reception and transmission characteristics (e.g. located on a hill). All terminals can relay the same messages because they are identical in transmitter and receiver equipment. The total area in which the MAT aircraft are expected to fly is partitioned into five disjoint regions such that one communication terminal is associated with each region. Although all terminals would normally transmit and receive identical information, each terminal will communicate only with the aircraft in the region associated with it. Because the central control facility on the ground knows the position of all aircraft, it can assign, for communication purposes, each aircraft to a particular region at any time. When the assignment of an aircraft to a particular region is made, only the communication terminal in that region will be active in the time slot assigned for the aircraft, all other terminals being blocked during that time slot. This can be accomplished by using the computer to control the sequence of clock pulses at each terminal. The purpose of this system is to avoid multi-path signals while gaining a high reliability for low-to-moderate power requirements, i.e. the aircraft communicates with the "nearest" terminal. In order to add redundancy to this system, a second-closest terminal could be activated by control in case of failure of the closest terminal.

4.5.19 Voice Communications

As inferred in a previous section on the performance requirements for voice communications, the use of a separate channel for voice communications is recommended. In addition, to avoid unnecessary use of such a channel or channels, it is recommended that voice communication circuit discipline be controlled by requests via the data link. As an emergency precaution (failure of data link) an override feature would permit the pilot, by deliberate action, to use an active voice link. For voice communications, a standard FM channel can be used.

4.5.20 Ground Communications

The ground communications between any communication terminal and the central control facility must handle the air/ground data. This ground link must, therefore, handle a data rate of 15 channels x 2,400 bits/sec/channel = 30,000 bits/sec. This can be accommodated by using 15 telephone or microwave links of 2,400 bit/sec capacity. The choice between telephone lines and a microwave link is not acritical one, and is thus left open. Higher signal-to-noise rates are common in ground links; based upon this, it is recommended that the ground link use n-ary digital data to reduce channel bandwidth requirements. Let n = 4. For the ground link between air terminals and the central control facility, the data rate requirements are generally lower; based upon the amount and nature of the data to be interchanged through the link, use of seven channels (of 2,400 bits/sec each) is recommended (four for center to terminal, two for terminal to center, and a voice channel). For all ground links voice communications can be handled by ordinary telephone lines.

4.5.21 Some Performance Characteristics of the Chosen System

Some performance characteristics of the proposed system will now be considered. The use of binary, polar synchronous digital data is compatible with the ground data processing equipment and its compatability with airborne sources is expected to increase in the future. For the chosen binary synchronous APSK system, if the signal power to noise power ratio at the receiver is 7 or higher (8.5 dB or higher), then assuming no fading, the bit probability of error will be less than 10^{-4}, i.e. $p \leq 10^{-4}$. The error rate would then be one part in 10^4 bits. This result can be obtained from a curve of probability of error, p, versus the signal-to-noise ratio for the type of digit modulation (see Reference [4-6], for example). Using the recommended USASCII code, one has an (M,C) block code with $M = 7$ and C Then, with 7 digits of information and a single parity check digit, the probability of error will be, using Equation (4-3),

$$P_e \approx (7)^2 \cdot (10^{-4})^2 \approx 5 \cdot 10^{-7} \qquad (4\text{-}6)$$

which satisfies the original reliability requirement of $p \leq 10^{-6}$. The speed efficiency factor for this code is $\alpha = 7/8$, or about 87%. This means that the effective (information bearing) nominal signaling rate is (7/8) x 2,400 bits/sec = 2,100 bits/sec. Consideration of the use of a sequential code was also recommended. Consider, for example, a Hagelbarger code (a sequential code) with one check digit per message digit. It can correct up to six successive errors (if the preceding 19 digits are correct). Encoding/decoding procedures are easy to implement. For this code the speed efficiency is 1/2, or 50%.

Because of the tradeoff between channel bandwidth and signal-to-noise ratio to yield a given channel capacity, the only way to maintain reliable communications even with low signal-to-noise ratios is to initially specify a wide channel bandwidth. Using the selectivity curve of ARINC Characteristic 546 as a guideline, a 50 kc channel spacing would offer a 13 kc 6 dB pass-band for a 2,400 bit channel. This would mean that fairly reliable communications could still be maintained (channel capacity = 2,400 bits/sec) for signal-to-noise ratios as low as 0.14. Hence, at a communication terminal, 15 channels would require a total spectrum of 15 x 50 = 750 kc on the VHF band. The total spectrum could be cut in half by reducing the channel spacing to 25 kc with a 6.5 kc 6 dB pass-band; a minimum signal-to-noise ratio would then be about 0.3. The use of the VHF band would provide good propagation characteristics along with compatibility with other avionics equipment using the same frequency range (90-110 mc). In addition, expensive or precision hardware is not required. Referring to the previous section concerning the number of channels needed for the aircraft-to-ground message, the required number of channels, from Equation (4-4), is numerically 9.3. With 10 channels, some margin of expansion is obtained. Ten receiving channels can handle 10 x 28 = 280 aircraft, a margin of 20 aircraft. Or, the message could be lengthened by about 20 bits/aircraft. Similarly for the ground to aircraft link, 5 transmitting channels at the terminal could handle 5 x 56 = 280 aircraft, or the basic message could be lengthened by about 8 bits. For the 3 UHF transmitter channels located at the air terminals, a maximum number of 3 x 29 = 87 equivalent aircraft could be handled simultaneously. At five messages/sec about 17 simultaneous operations could be handled (at any given air terminal). These results are based on the use of Equations (4-4) and (4-5). Additional capacity can be added to the system by increasing the signaling rate beyond 2,400 bits/sec. The use of an n-ary code for ground communications, though requiring 2-3 dB more power (or more bandwidth), will increase the data rate by a factor of $\log_2 n$ per channel. An estimate for the cost of the communications terminal is $10,000-$20,000 (not including the site or building) including redundancy. The airborne equipment involved with the proposed data link is estimated to cost about $15,000 to $20,000.

4.5.22 Conclusion

A digital-data communication system has been proposed for the air/ground communication system. Voice communications have been retained as part of the system, but only as a secondary system. The performance characteristics of the proposed system meet the needs of the MAT system communication requirements. In addition, the proposed system is compatible with other electronic systems and enhances their functions such as collision avoidance. The role of communications in the increasing trend toward integrated electronic functions needs additional study.

4.6 Performance Monitoring

Diagnostic equipment to monitor the performance of aircraft, missiles, and space systems is currently being developed at a very high rate [4-18, 4-25, 4-26] and there is little doubt that such equipment will reach a high state of development by the 1980's. Such diagnostic equipment will permit monitoring critical airframe components such as the rotor, the transmission system, the engines, electronic equipment, etc., and will indicate impending failures or the need for maintenance or repair.

Since the MAT aircraft has only one pilot, it is imperative that some warning be provided in case he should become incapacitated. A research program will need to be undertaken to determine what simple measurements can be made that would provide information when the pilot feels ill or gives other signs of impending disability. Most pilots do have at least some warning of impending disability. Most pilots do have at least some warning of impending illness [4-27], such as strokes, heart attack, etc., and if warning occur he would be relieved at the next stop.

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Chapter 5

TERMINALS

5.1 Introduction

It has become increasingly clear in the past few years that airline terminal facilities currently in use cannot handle the ever-increasing numbers of passengers who are using the airplane as a means of transportation. [5-1, 5-2, 5-3] This problem has arisen partly because not enough thought has been given to terminal designs which promote the smooth and rapid flow of passengers and aircraft.

Since the MAT system being proposed in this report must be capable of handling approximately 100,000 commuter trips and 50,000 airline connection trips per day with a peak hourly load of 9,300 people, optimum terminal design is essential if the system is to succeed. It is clear that the solution of the problem of moving such a large number of people in short periods of time requires the setting aside of many of the old ideas in terminal design and the developing of fresh, new ones. [5-4, 5-5]

The MAT system terminals must meet certain basic requirements. In particular, they must:

(1) promote a fast, efficient flow of commuters during the two, 2-hour peak utilization periods each day,

(2) provide for efficient handling of airline passengers and their baggage,

(3) be able to accept and handle both types of passengers without causing a degradation in the system performance, and

(4) provide the necessary support facilities to maintain and service the large fleet of aircraft.

The remainder of this chapter is devoted to identifying the problem areas associated with the design of the MAT system terminals, and making recommendations for their solution.

In Section 5.2 a comparison between VTOL and STOL terminals is made with respect to their functional differences, relative sizes and costs, and need for arresting gear. Although a novel design for a high density STOL port is included, the comparison clearly indicates that a VTOL port is superior.

The MAT system will require several different types of VTOL ports. Section 5.3 is devoted to describing the three classes of ports that are envisioned. Recommendations on the facilities to be included, expansion capabilities, and gate requirements are made for each of the 24 MAT site locations.

The terminal design must optimize passenger and baggage flow. This subject is covered in Section 5.4. The problems of billing, queueing, and having the system keep track of the traveller are discussed, as well as that of system compatibility with airline ticketing and baggage procedures. Recommendations for possible solution of these problems are made.

Aircraft maintenance will be a key factor in the successful operation of the system. Section 5.5 discusses the overhaul and line maintenance (including fueling) schedules, facility requirements, and locations. The final section identifies areas of study which demand extensive additional investigation.

5.2 Comparison of VTOL and STOL Terminals

The function of any air terminal, be it VTOL, STOL or CTOL, is to expedite the flow of aircraft for hauling passengers or cargo. To perform this function the air terminal incorporates several facilities. Among them are

(1) Landing and takeoff area,
(2) Aircraft guidance,
(3) Cargo loading and unloading,
(4) Passenger loading and unloading,
(5) Line maintenance of aircraft, and
(6) Fire prevention and control.

There are, however, certain functional differences in terminal requirements whether one is considering VTOL or STOL. Among the more obvious is the size of the runway required for STOL versus the landing pad size for VTOL. Since these aircraft are to transport people to city centers, the critical terminals are those closest to the central business district. These terminals will experience the highest passenger flow rates and, therefore, will be used in the comparison of VTOL versus STOL terminals. Since land is very expensive in the central business district, the landing and takeoff areas should be located on the roof of a multi-story-structure which will also house the terminal.

The problem then, is to determine a configuration for the terminal which allows a maximum passenger flow rate per unit of land area required. To maximize this flow rate requires the elimination of non-productive time. One of the biggest contributors to non-productive time during the landing-takeoff cycle is the taxiing. The time spent during this maneuver is completely unusable and should be eliminated if possible. The reduction of taxi time is, therefore, a primary goal in the design of the downtown VTOL or STOL terminal. Another bottleneck in the landing-takeoff cycle is loading and unloading and will be considered in Section 5.4. In this section we shall compare the maximum rate at which aircraft can be processed at the respective terminals and the facilities which are unique to either VTOL or STOL terminals.

5.2.1 STOL Terminal

A two-runway STOL terminal is shown in Figure 5-1. One runway is used as a landing strip and the other for takeoff. To reduce the cycle time passenger unloading and loading takes place while the aircraft is taxiing. Note that after the plane has landed it makes a 180° turn and heads into the central corridor. Within the corridor is a moving cable such as is used in an automatic car wash. The craft then mechanically latches onto the cable and proceeds through the corridor at the cable speed of 4 ft/sec. Straddling the airplane on either side within the corridor are walkways also moving at 4 fps which allow passengers to deplane and board simultaneously during the 200 seconds of taxi time. At the other end of the corridor the cable is unlatched, the craft makes a 180° turn, and proceeds down the runway for takeoff. The breakdown of elapsed time is as follows:

Operation	Elapsed Time (Seconds)
Touchdown	0
Landing	10
Turning	15
Load & unload	215
Turning	230
Takeoff	240 = 4 minutes

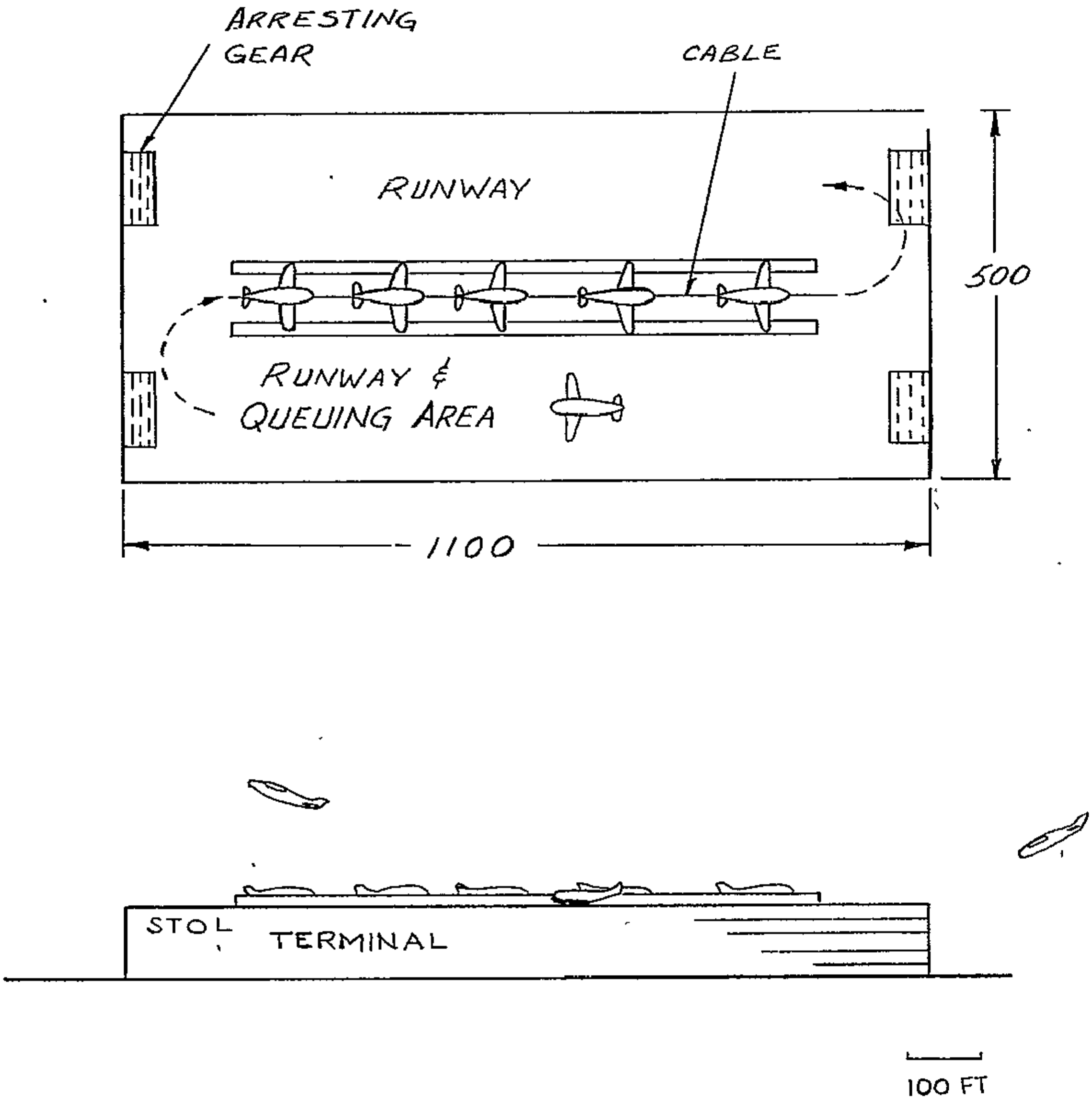


FIG. 5-1 TWO RUNWAY STOL METRO TERMINAL

The turnaround time per craft, then, can be reduced from the current 15 to 30 minutes for CTOL operations to 4 minutes using this terminal design.

A mechanized scheme of loading and unloading is shown in Figure 5-2. To describe the operation of the system consider the flow of passengers through the system. Passengers are queued facing an incrementing belt. Turnstyles at the ends of the queues allow 80 passengers to load the belt in groups of ten for each belt increment. The queueing and loading operation takes place on the level below the landing surface. As a craft begins travelling down the corridor, the incrementing belt begins to load the escalator which then loads the moving walkway. This operation is performed in synchronous fashion so that the passengers are delivered to that portion of the moving belt which is directly in front of the loading doors. The escalator travels at 2 ft/sec, and the moving walkway at 4 ft/sec. The passengers, therefore, experience only a 2 ft/sec difference in velocity at each transition. A similar set of conveyors is mounted on the other side of the plane for unloading passengers. Provision is also made in the design for a roof over the boarding areas to shield the passengers from the weather and noise.

In anticipation of the commuter rush hour, up to 25 planes can be landed and queued on one of the runways. Some time before the rush hour these craft can be flown in, unloaded through the corridor, then stored on the runway. Up to 20 planes can be queued on the runway 2 abreast. During the rush hour these craft would be fed into the corridor, being loaded, and would take off on the other runway. Aircraft flow rates of up to 2 per minute can be accommodated with this terminal design. The land area required is 500 by 1100 ft or 13.75 acres. At a

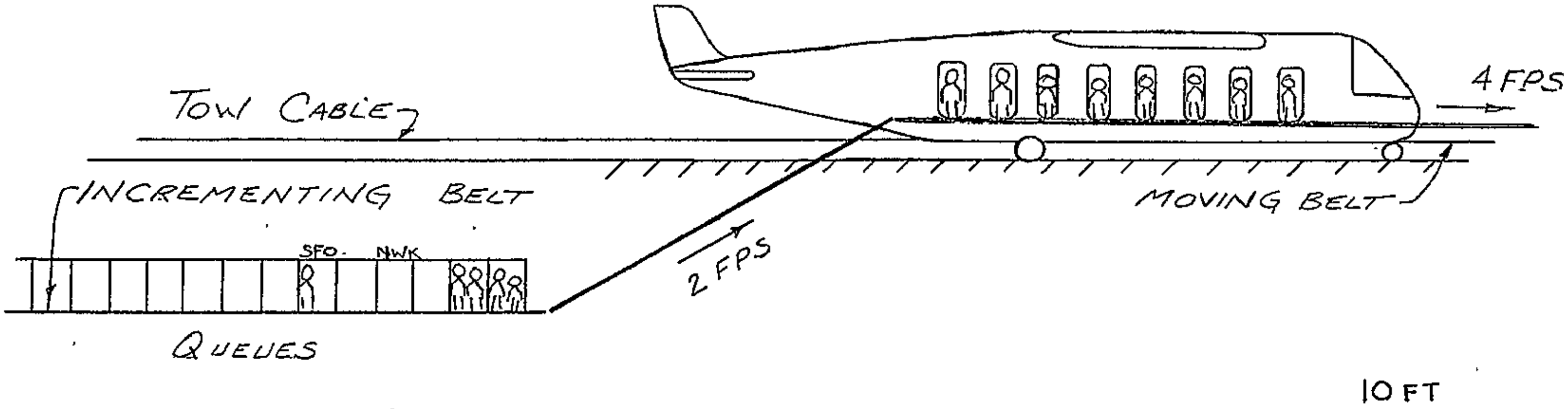


FIG. 5-2 PASSENGER LOADING, STOL TERMINAL

cost of $300,000 per acre [5-6] the cost of land for this terminal is $4,125,000.

One of the major disadvantages of a runway-oriented terminal is the fact that it is a serial system. All craft must use the runway. If a breakdown occurs anywhere in the system, the whole operation shuts down until the situation is rectified. Another major consideration in the design of a STOL terminal is arresting gear to prevent aircraft overshoot of the runway.

5.2.2 Arresting Gear For STOL Runway

Once a STOL aircraft has landed on a runway its rate of deceleration is controlled in possibly three ways,

(1) Brakes on the landing gear,

(2) Spoiler flaps on the airframe, or

(3) Thrust reversal.

In the event that one or more of these systems fails during landing, the aircraft may roll off the end of the runway. This would be particularly disastrous in the case of a rooftop landing strip. To avoid such accidents the use of arresting gear either on the plane or on the runway has been proposed. In 1964 the FAA proposed a program of installing arresting gear (or runway brake) equipment at all the major airports in the United States. In support of this plan the FAA showed that the Air Force saved upwards of 250 aircraft per year with arresting devices [5-7]. In any case, it would seem necessary to provide some provisions for arresting the STOL commuter aircraft in case of an emergency.

Several different arresting schemes have been developed and others are still in development. Among them are,

(1) Hook and Cable. Although there are several variations of it, the most commonly encountered arresting system is the one found on aircraft carriers. Each plane is equipped with a tail hook which may be lowered during the landing maneuver. When the hook touches the deck it scoops up a cable which then transmits a resisting force to the forward motion of the craft. The resisting force may be proportional to velocity or displacement. The earliest arresting gear consisted of sandbags attached to the ends of the cable. The forward motion of the craft then caused the sandbags to be dragged along the surface of the deck and energy was dissipated by friction. Hydraulic cylinders at the cable ends would also provide a velocity dependent resisting force. The resisting force to the craft is proportional to excursion if an elastic cable is tied to the deck at either end. This system could also be used as a takeoff assist device. Neither of these variations, however, seem practical as an emergency device, since this would require the installation of controlled tail hooks in every craft.

In the air commuter system emergency arrest is only necessary if the plane reaches the runway overrun. A system which would perform this emergency operation without the need for a retractable tail hook is currently being evaluated. [5-8] When the nosewheel strikes the runway overrun it actuates a pressure switch which then causes the cable to "pop up" in front of the main landing gear and thereby restrains the vehicle.

(2) Energy-Absorbing Runway Surfaces. In recent years much research has been performed on the design of runway surfaces. Cutting transverse grooves into the pavement has produced an improvement in braking effectiveness. Even more effective, however, is the plastic diaphragm-covered water basin at the runway overrun. [5-9] Such a system can stop all aircraft without damage in 100 to 700 ft with one "g" maximum deceleration.

(3) Energy-Absorbing Barriers. Perhaps the simplest and cheapest arresting scheme to implement is to put up collapsible barriers at the ends of the runway. The kinetic energy of the moving craft is then dissipated by the crash impact. The two obvious disadvantages of this scheme, however, are that the craft may be damaged and that the barrier must be reconstructed after each use. To circumvent these two problems a new type of arresting system is proposed in this report wherein the barriers contact only the tires of the craft and can be reset after each use (see Figure 5-3). Note that the barriers are actually hinged vanes with torsion springs at the hinge. As the landing wheels roll over the vane some slippage occurs between the tire and vane causing a frictional drag. The major portion of the braking force, however, comes from the deflection of the torsion spring as the advancing wheel deflects the vane. As the wheel passes over each vane a

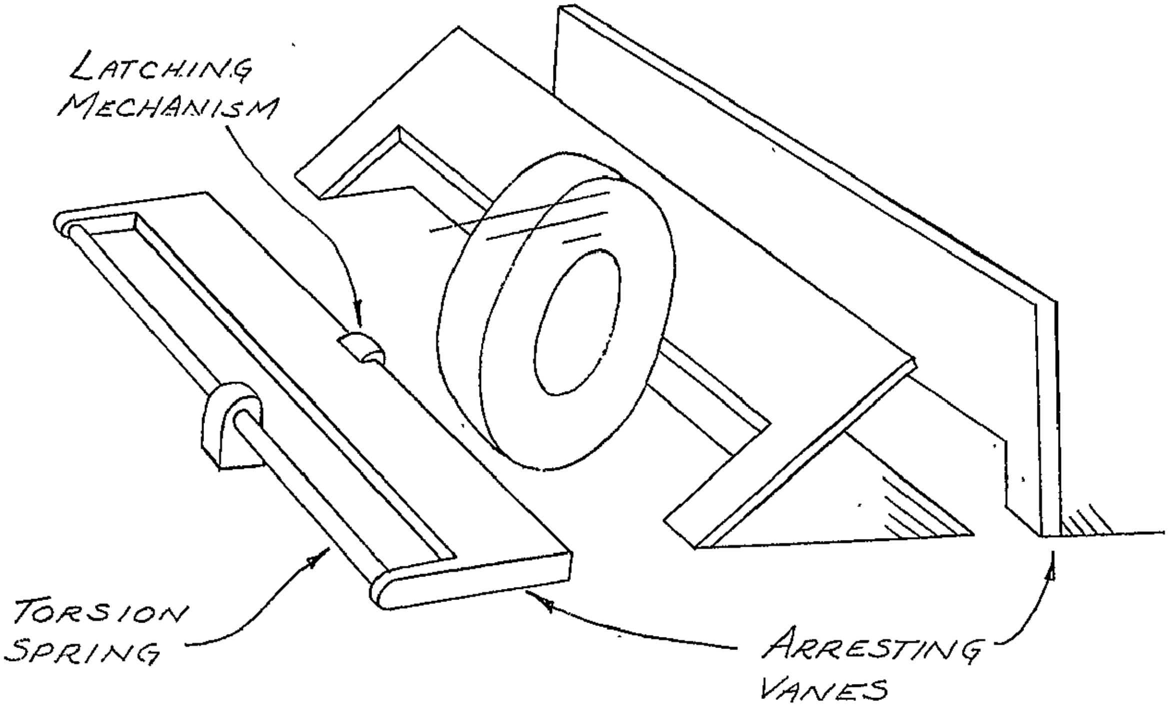


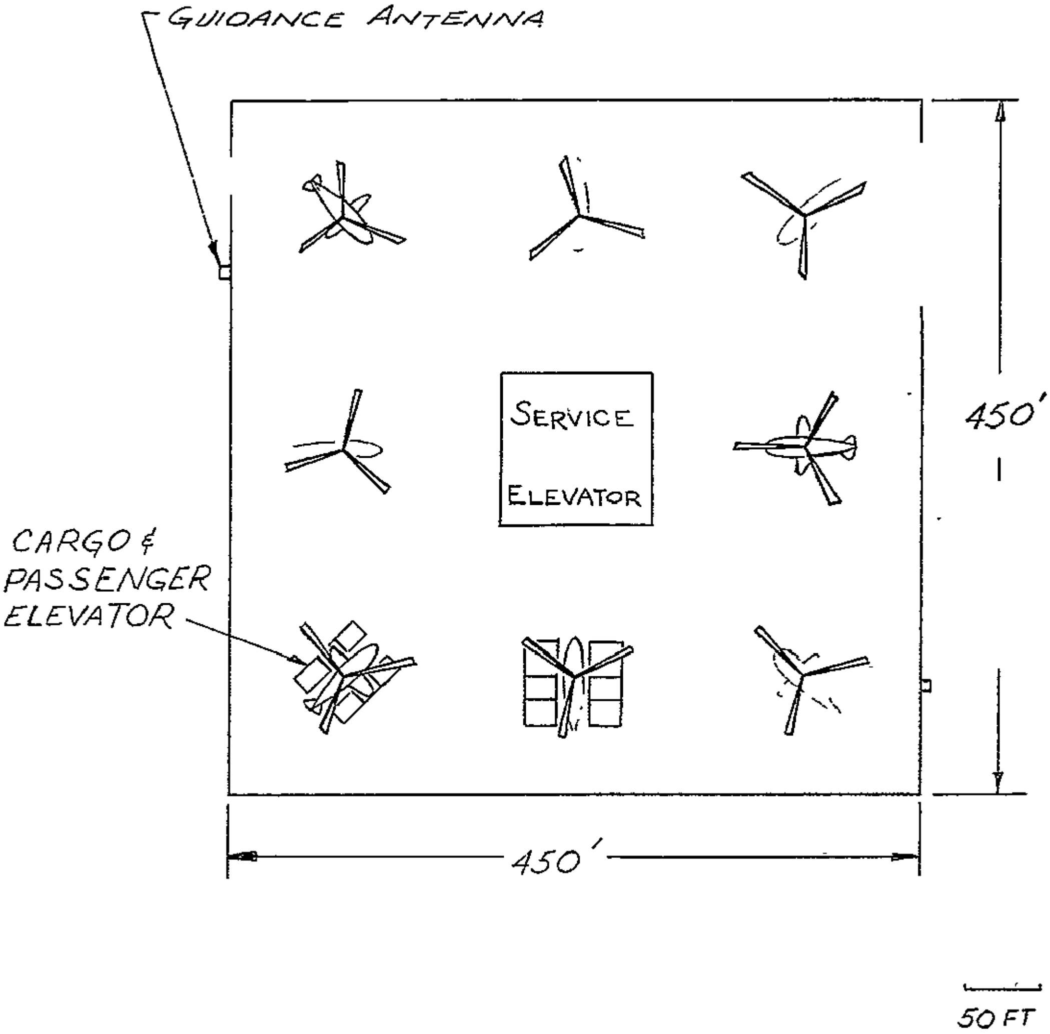
FIG. 5-3 RESETTING VANE ARRESTOR SYSTEM

quantity of the craft's kinetic energy is transformed into potential energy which is stored in the spring. A latching mechanism holds the vane in its deflected position and can be released at a later time. A series of such vanes can then bring the craft to a stop much as a collapsible barrier would, but it has the advantage that it can be reset and also cause no damage to the airframe. A dynamic analysis of arresting systems is included in the Appendix B.

5.2.2 VTOL Terminal

A layout of an 8-gate VTOL terminal is shown in Figure 5-4. This configuration is different from the conventionally envisioned VTOL terminal [5-10] in that no common landing pad is used. In the conventional VTOL port one landing pad is generally common to about 4 gates located some 150 feet from the pad. It is felt that taxi time can be drastically reduced if the VTOL craft lands directly at the gate. The major objection to this scheme is mostly one of passenger safety. However, it is felt that safety is not a factor if the passengers are brought to the craft *after* the landing operation. In addition, the superior down-to-the-deck guidance system at the MAT terminals makes an overflying maneuver feasible.

The scheme, then, is to have a landing area 150 foot square which is devoid of obstructions. When the craft lands it taxis a few feet (due to possible small inaccuracies in the landing phase). At this time two banks of elevators, one on either side of the craft, pop through the pad. These are aligned with the doors of the craft and loading and unloading take place simultaneously (see Section 5.4.2). It is felt that this total operation from touchdown to takeoff can be accomplished in two minutes. During peak hours, then, a single gate can conceivably handle



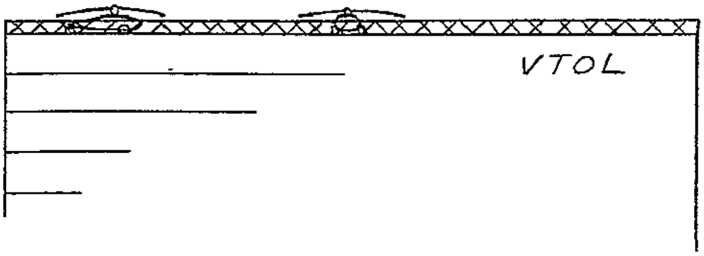


FIG. 5-4 EIGHT GATE VTOL METRO TERMINAL

the flow of 30 aircraft per hour. Multiplying by 8 pads yields a VTOL facility with an aircraft handling capacity of 240 per hour or one aircraft every 15 seconds. The land area required for this type of terminal is 5.06 acres. At the same $300,000 per acre, the cost of land for this terminal is $1,518,000.

5.2.4 VTOL vs. STOL Terminal

In comparing the STOL versus the VTOL terminal there is one primary factor to consider--that is the cost of the installation as a function of the maximum rate of aircraft departure. A summary of the parameters involved in this estimate is shown below.

	2 Runway STOL	8 Gate VTOL
A/C departure rate (max)	1 in 30 seconds	1 in 15 seconds
Land Area	13.75 acres	5.06 acres
Land Cost	$4,125,000	$1,518,000
Terminal Cost [5-11]	$32,300,000	$10,800,000
$/AC/MIN	$18,212,500	$3,079,500

It can be seen that the VTOL terminal has an initial cost of approximately one-sixth the cost of the STOL terminal for the same rate of aircraft flow. Also, the large land area required for the STOL terminal may not be available in high density downtown areas. The conclusion from the terminal study then is that for the downtown MAT terminal the VTOL terminal is to be preferred.

5.3 VTOL Terminals

5.3.1 Classification into Types

The 24 MAT terminals in the greater Bay area can be classified into one of three types, (1) the Metropolitan (or Metro) terminal, (2) the Suburban terminal, and (3) the Airline terminal. The classification is based on the quantity and character of the passengers serviced by the terminal.

Table 5-1 summarizes the morning passenger flow at the various MAT terminals. From this figure it can be seen that only SFO and OAK serve more airline connecting passengers than commuter passengers and are, therefore, classified as Airline terminals. The other 22 terminals have more commuter than airline connecting passengers, and are further subdivided on the basis of traffic density. SJO, FRY, CDP, and NWK are classified as Metro terminals and the remaining ones as Suburban terminals.

The determination of the number of gates per terminal is based on the following assumptions:

(1) The peak hour traffic load is equal to one-half of the total morning traffic.

(2) A gate will handle at least 15 aircraft per hour, or one aircraft every 4 minutes, under the most severe operating conditions. Under favorable conditions a gate can service up to twice this number of aircraft (one landing and departure every 2 minutes). However, the 15 per hour figure represents a lower bound for aircraft service rate, and is used in the calculation of required number of gates.

(3) Morning arriving aircraft, or departing aircraft (whichever constitutes the larger number) operate at an 85% load factor.

(4) If the result of the calculation of the number of required gates is not an integer, it is rounded up to the next integer.

The following formula results:

$$\text{No. of gates} = \frac{\text{Either morning maximum arrivals or evening departures}}{2} \times \frac{1}{80 \times 0.85} \times \frac{1}{15}$$

5.3.2 Metro Terminals

The Metro terminals are high-density, commuter-oriented terminals. Figure 5-4 shows a typical metropolitan terminal and Figures 5-5 and 5-6 and Table 5-2 show some design details of the FRY Metro terminal. Because of the different site locations and somewhat different traffic flows, no two of the Metro terminals will be identical. The detail design of these terminals should not be handled by the MAT system, but should be contracted to architectural firms in the late 1970's. However, all Metro terminals have the following common characteristics:

(1) Because of the high traffic density and consequent land requirements, the Metro ports consist of multi-story, multi-usage buildings with landing pads on the top deck [5-12]

(2) The aircraft guidance system delivers the aircraft to within ±2 feet of a pre-determined position with an angular position accuracy on the ground of ±3° under all weather conditions.

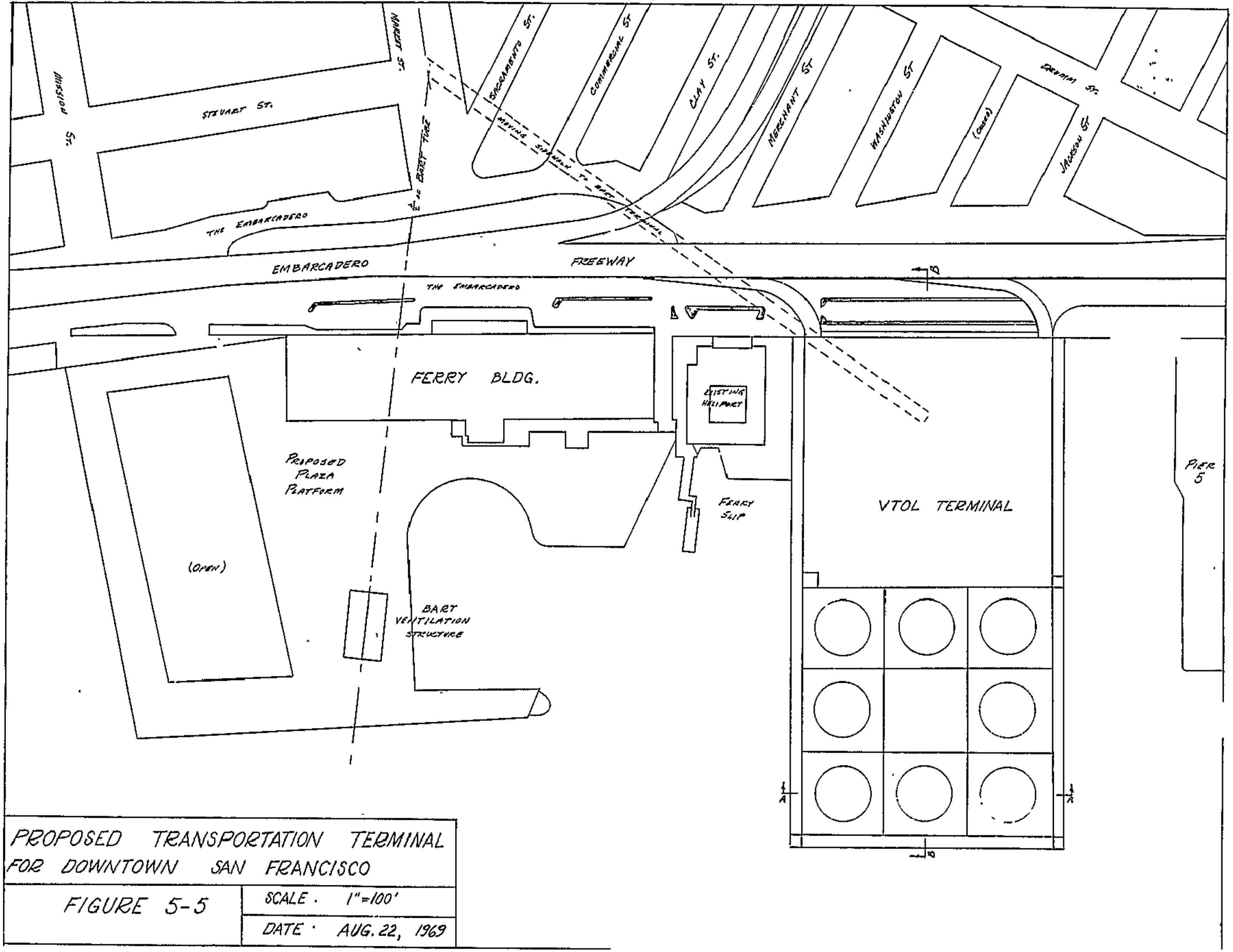
(3) Passenger exit and entrance to and from the aircraft is by compartmentalized elevators with each compartment holding a maximum of 10 passengers. (See Section 5.4.2). The elevators have fronts, capable of extending up to 5 feet, with doors 65" wide to accommodate possible misalignment between the elevator and the aircraft.

As discussed in Section 5.4.2, the elevators serve as passenger queueing areas on a lower level, as well as vertical transportation facilities. They are, therefore, comfortable, well lighted, and contain seats for 10 passengers in each compartment. Figure 5-7 shows a sketch of the interior of an elevator.

Table 5-1

DAILY MORNING PASSENGERS

Terminal	Outgoing			Incoming			Required	Type of Terminal
	Commuter	Airline	Total	Commuter	Airline	Total		
SFO	590	600	1,190	1,670	12,350	14,020	7	A
OAK	610	180	790	1,180	10,380	11,560	6	A
SJO	13,980	1,440	15,420	700	2,460	3,160	8	M
FRY	1,120	2,230	3,350	14,990		14,990	8	M
CDP	870	2,620	349	12,270		12,270	7	M
NWK	8,480	800	9,280	740		740	5	M
OKP	1,780	1,000	2,780	4,500		4,500	3	S
RWC	2,430	1,420	3,850	720		720	2	S
HWD	3,030	700	3,730	530		530	2	S
SRA	780	2,880	3,660	500		500	2	S
SAC	1,790	400	2,190	3,300		3,300	2	S
MTV	2,670	580	3,250	880		880	2	S
SRL	1,070	2,120	3,190	1,270		1,270	2	S
VLJ	1,050	1,900	2,950	1,360		1,360	2	S
PAL	1,780	950	2,730	1,130		1,130	2	S
SKT	1,900	800	2,700	790		790	2	S
CON	2,160	450	2,610	790		790	2	S
BRK	960	450	1,410	2,330		2,330	2	S
SPO	990	1,250	2,240	1,740		1,740	2	S
SCZ	1,290	400	1,690	170		170	1	S
FRF	570	900	1,470	620		620	1	S
MON	710	400	1,110	180		180	1	S
SAL	710	400	1,110	90		90	1	S
ANT	370	320	690	490		490	1	S

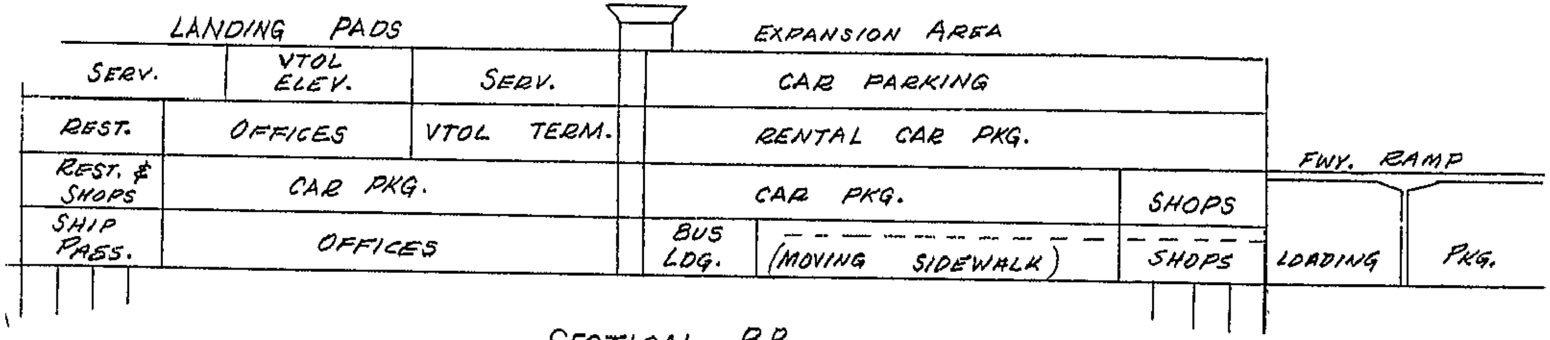


PROPOSED TRANSPORTATION TERMINAL
FOR DOWNTOWN SAN FRANCISCO

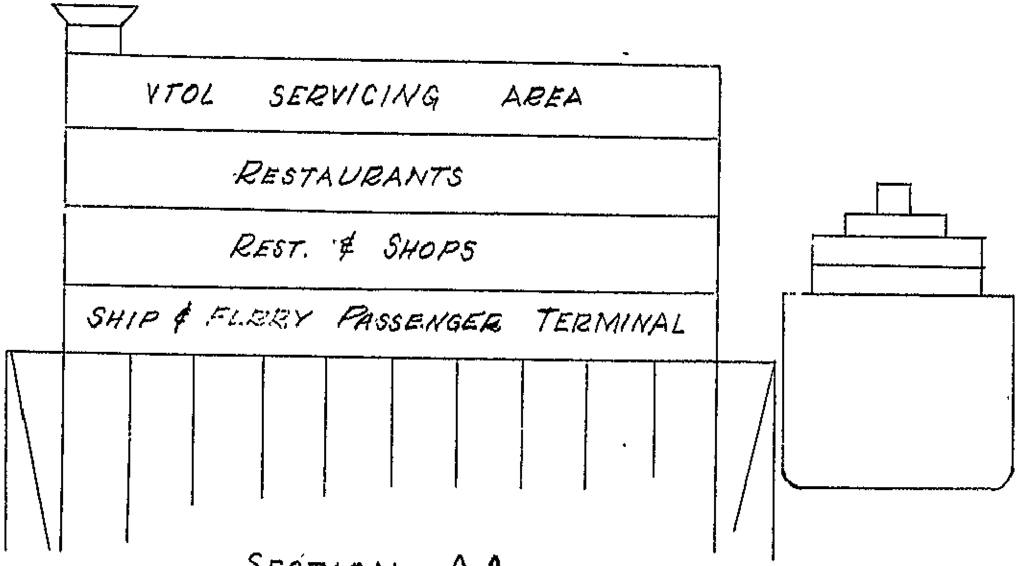
FIGURE 5-5

SCALE · 1"=100'

DATE · AUG. 22, 1969



SECTION BB



SECTION AA

NOT TO SCALE

FIGURE 5-6 CROSS SECTION OF DOWNTOWN TERMINAL

Table 5-2

DETAILS OF DOWNTOWN TERMINAL DESIGN

1. Size: 450 ft x 900 ft, 4 floors plus roof deck
2. Floor Space: 2,025,000 ft^2
3. Entire building supported on piles driven to 120 ft below mean low water level
4. Depth of slips on each side of terminal = 45 ft
5. Pile size = 16" x 16" reinforced concrete
6. Earthquake design for structure
7. Ship berths to accommodate 750 ft + passenger vessels
8. South side of terminal to accommodate smaller passenger ships and ferries
9. Rail spur to handle freight will be constructed on north apron and will connect with San Francisco Belt Line Railway
10. City buses will move into first level of terminal and load passengers as shown
11. Cars can discharge passengers in loading zone in front of terminal or from parking areas in terminal
12. Direct, one-lane vehicular ramps are provided to Embarcadero Freeway
13. Interfloor ramps will permit buses and cars to enter and leave on Levels 1 and 3
14. Passenger waiting room for ships and ferries will be on bay end of first level
15. VTOL passenger waiting room will be in center of third level with special elevator service to landing pads. Transfer to other modes will take place on third level (to autos) and first level (buses or moving sidewalk connection to nearest BART station)
16. VTOL craft will land and take off from 150 ft x 150 ft pad on roof and will be lined up on this pad to receive telescopic loading elevators. A centrally-located aircraft elevator will accommodate craft being moved to fourth level servicing area for fueling and maintenance.
17. In general, waterfront areas of second and third levels will be allocated to restaurants while areas near the entrance on first and second levels will be allocated to ships. Remaining space not accounted for will be used for offices.

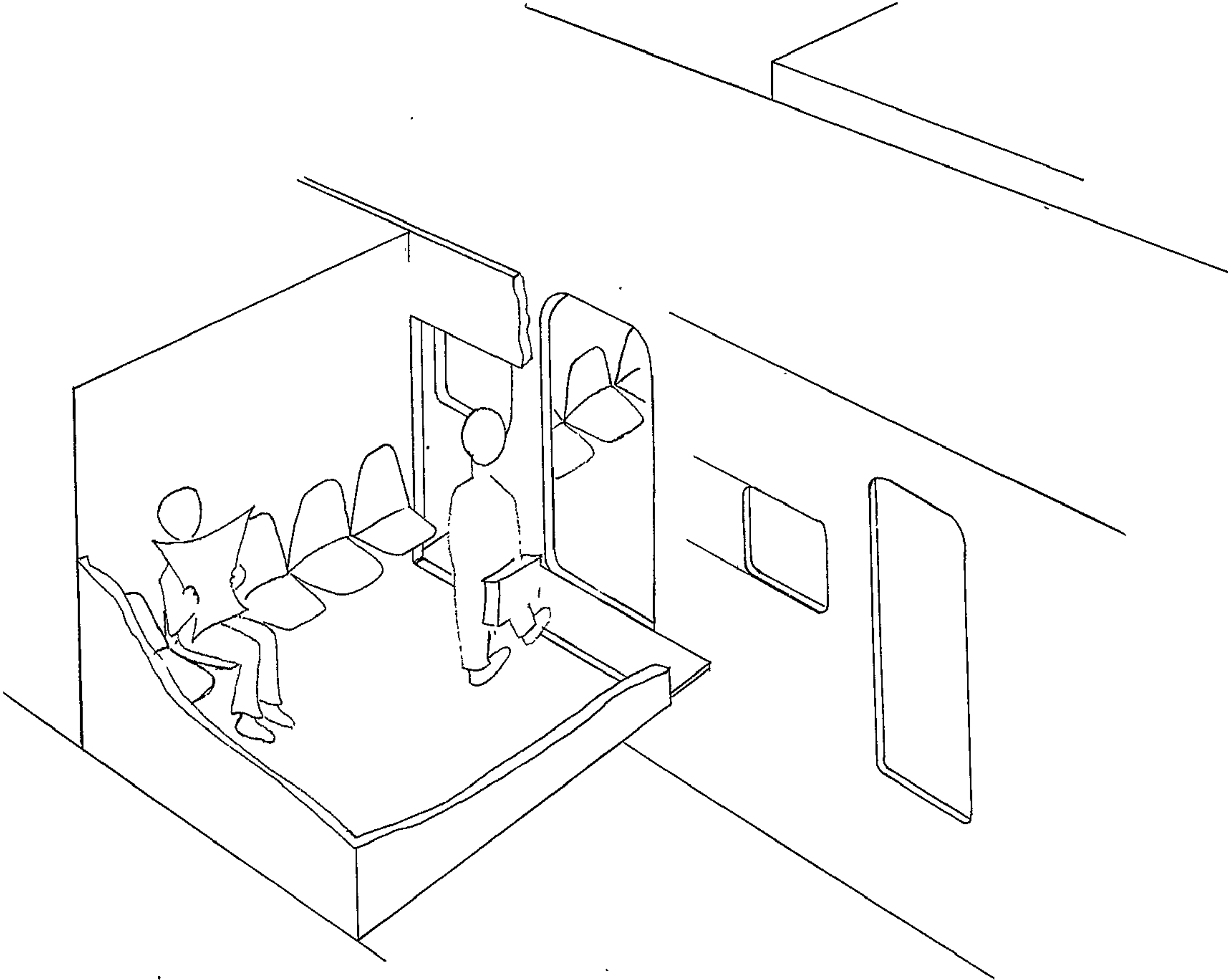


FIG. 5-7 PASSENGER ELEVATOR

(4) Although Metro terminals are primarily commuter-oriented, provisions do exist for baggage handling. Baggage and freight are loaded and unloaded from the airplane's baggage compartment located under the wings, by means of two elevators, one on each side of the fuselage. As in the case of passengers, unloading and loading of baggage is performed on opposite sides of the aircraft. (See Section 5.4.4).

(5) In order to maintain a clear and unobstructed landing area, the passenger and freight elevators occupy space on the landing deck only when in actual use. When they are below the deck no part of the elevator system protrudes above the landing deck level and the elevator shaft is covered by folding doors. Figure 5-8 shows a portion of the deck with elevators deployed.

(6) The passenger lounge areas have minimal service facilities. Food service will consist of a snack bar, vending machines, and a cigar-candy counter. However, extensive restaurant facilities will be available on lower levels of the building. Design details such as rest room facilities, emergency fire exits, fire fighting equipment location, and emergency lighting, will be left to the discretion of the architectural firm, but the passenger facilities should be oriented toward the commuter and not the airline-connecting passenger.

(7) The center section of the landing deck contains a large aircraft carrier type elevator to transport aircraft down one level for maintenance and storage. The dimensions of the elevator will be 100 feet by 100 feet. A small tractor which can be rapidly attached to the aircraft nose gear will be available to transport the aircraft from a landing pad to the elevator and, on the level below, from the elevator to the maintenance area.

(8) The Metro terminals will have minimal aircraft maintenance facilities consisting of emergency service only. The maintenance facility is located one level below the landing area and is accessible to the aircraft by means of the large central aircraft elevator. Only high-replacement rate parts will be stored in the maintenance facility and service personnel will be kept to a minimum number. In the event that major service at a Metro terminal becomes necessary, adequate numbers of service personnel and parts will be transported by plane to the service area on a temporary basis.

The primary use of the maintenance and storage facility is for aircraft storage in anticipation of the morning or evening peak usage period. Although aircraft storage in this facility is not optimal from the viewpoint of accessibility, it will be an important factor in providing the peak number of aircraft.

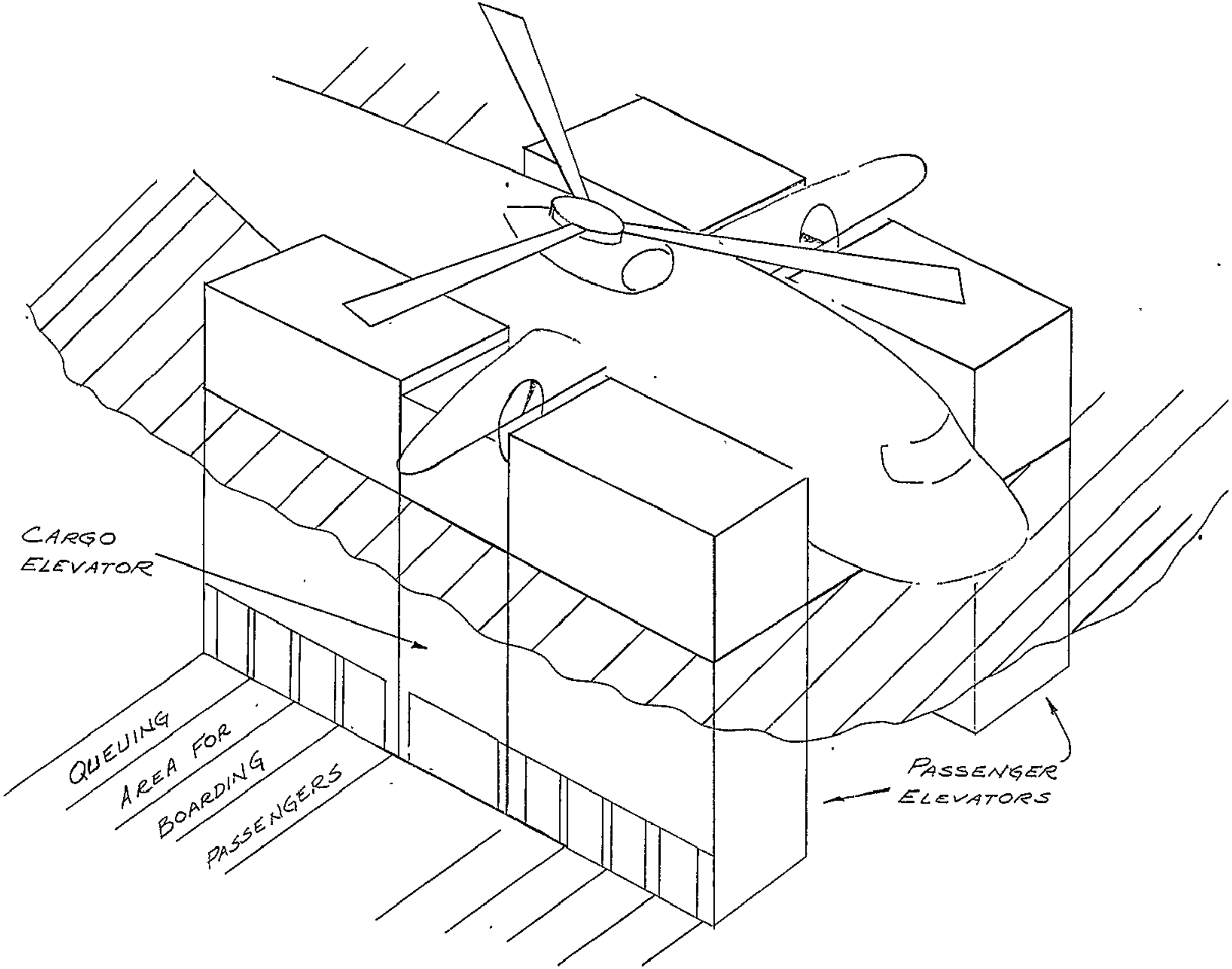


FIG. 5-8. VTOL GATE, PASSENGER ELEVATORS DEPLOYED

(9) Navigation and guidance antennas in 10 ft x 10 ft x 10 ft packages may be mounted on supporting structure at two opposite sides of the landing area as shown in Figure 5-4, or on adjacent buildings or elevated structures, if available, within a few hundred feet of the landing area.

(10) Adequate parking in two or more subterranean levels will be provided. Pedestrian entrances and exits will be at ground level. The Metro terminals will have interconnection facilities with other surface transportation and, in the case of the FRY terminal, with water transportation. Automobile rental facilities will be available.

(11) A substantial portion of each Metro port will be devoted to retail stores, offices, or apartments. As discussed in Chapter 8, all Metro terminal initial costs, except for avionics and queueing, cargo, and aircraft elevator costs, are not chargeable to MAT costs. The terminals are expected to generate sufficient income from space rental to retail stores, offices, and apartments to pay for initial costs, interest on borrowed capital, and facility depreciation. Specific details of this subsidiary business activity should be formulated in the late 1970's and early 1980's as detailed construction plans are made.

5.3.3 Suburban Terminals

Suburban terminals are commuter oriented and vary considerably from site to site. A typical Suburban terminal is shown in Figure 5-9. In general, however, all Suburban terminals have certain characteristics in common:

(1) Since these terminals are commuter oriented, they must provide adequate automobile parking. Adequate parking is defined as at least one parking spot for every two daily departing passengers. In most cases parking will be at ground level. The parking requirements will range from approximately 2000 spaces at RWC to approximately 350 at ANT.

(2) The Suburban terminal consists of a single level building, and landing will be on the ground adjacent to the building. Entrance to and exit from the aircraft shall be on foot over clearly marked walkways.

(3) The Suburban terminals have nightly inspection, washing, maintenance, and storage facilities. Although the number varies among the terminals, the average terminal has the

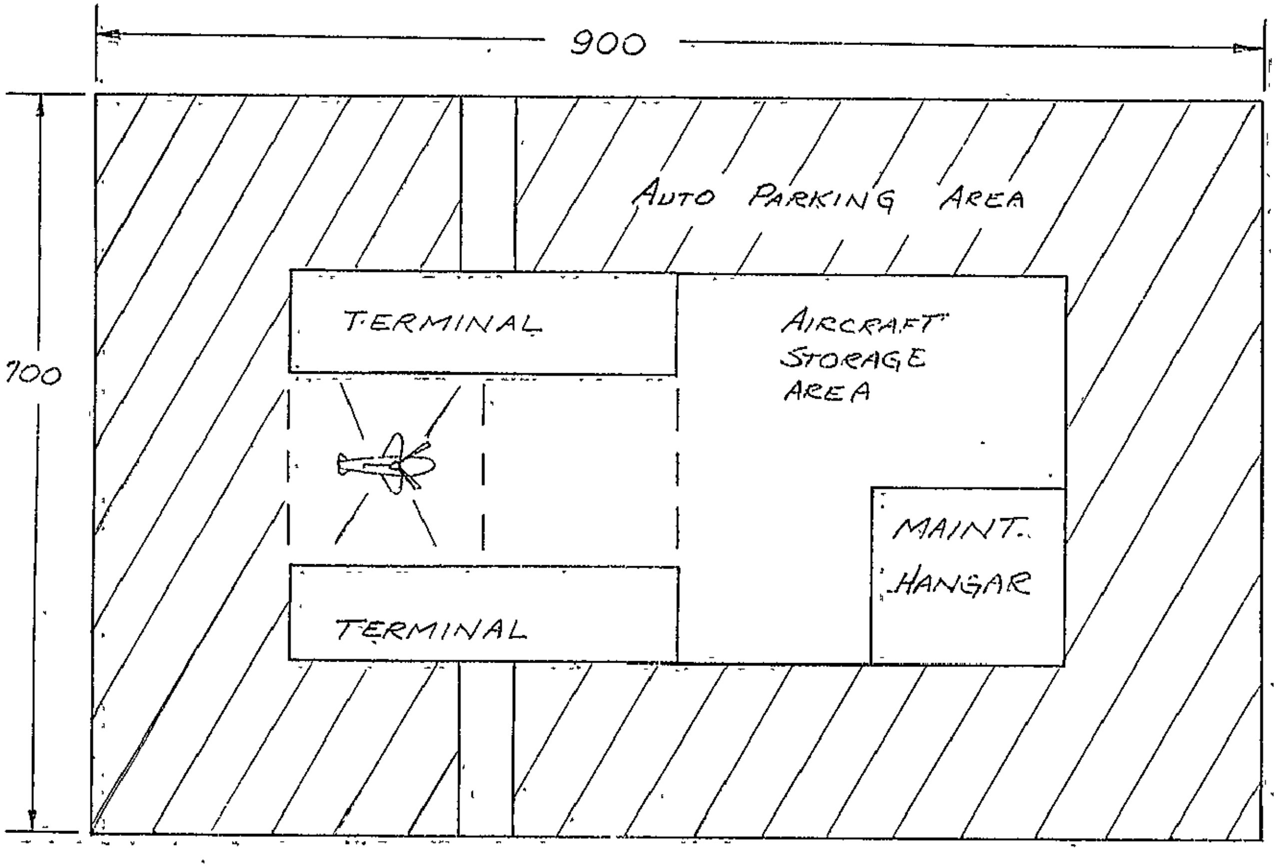


FIG 5·9 MAT SUBURBAN TERMINAL

capability of handling 15 aircraft each night. Inspection, washing, and maintenance is performed within a hangar, typically capable of accommodating 2 to 4 aircraft. Overnight storage is on the ground adjacent to the landing areas.

5.3.4 Airline Terminals

There are two Airline terminals in the MAT system--SFO and OAK. Their primary purpose is to provide passenger and baggage connection service between the airlines and the MAT Suburban terminals, although they also service a small number of commuters. These are high-density terminals and have aircraft landing on new or existing building rooftops, as in the case of the Metro terminals. Also, as in the case of the Metro terminals, passenger and baggage transfer to and from the aircraft is by compartmentalized elevators. No additional parking is provided for these passengers, as their initiation point or final destination point, as the case may be, is another terminal. Figure 5-10 shows a typical Airline terminal.

5.4 Passenger and Baggage Flow

Regardless of whether one talks about the commuter or the airline passenger, one of the major design problems of the MAT terminals will be the rapid movement of up to 80 people at a time from a waiting (i.e. queueing) area to the airplane.

This problem is considerably more difficult to solve than comparable ones usually encountered in other commuter or high density transportation modes (i.e. bus or train). The reasons for this are, in part, due to passenger safety regulations which preclude queueing in aircraft arrival areas (unlike buses and trains where queueing can be adjacent

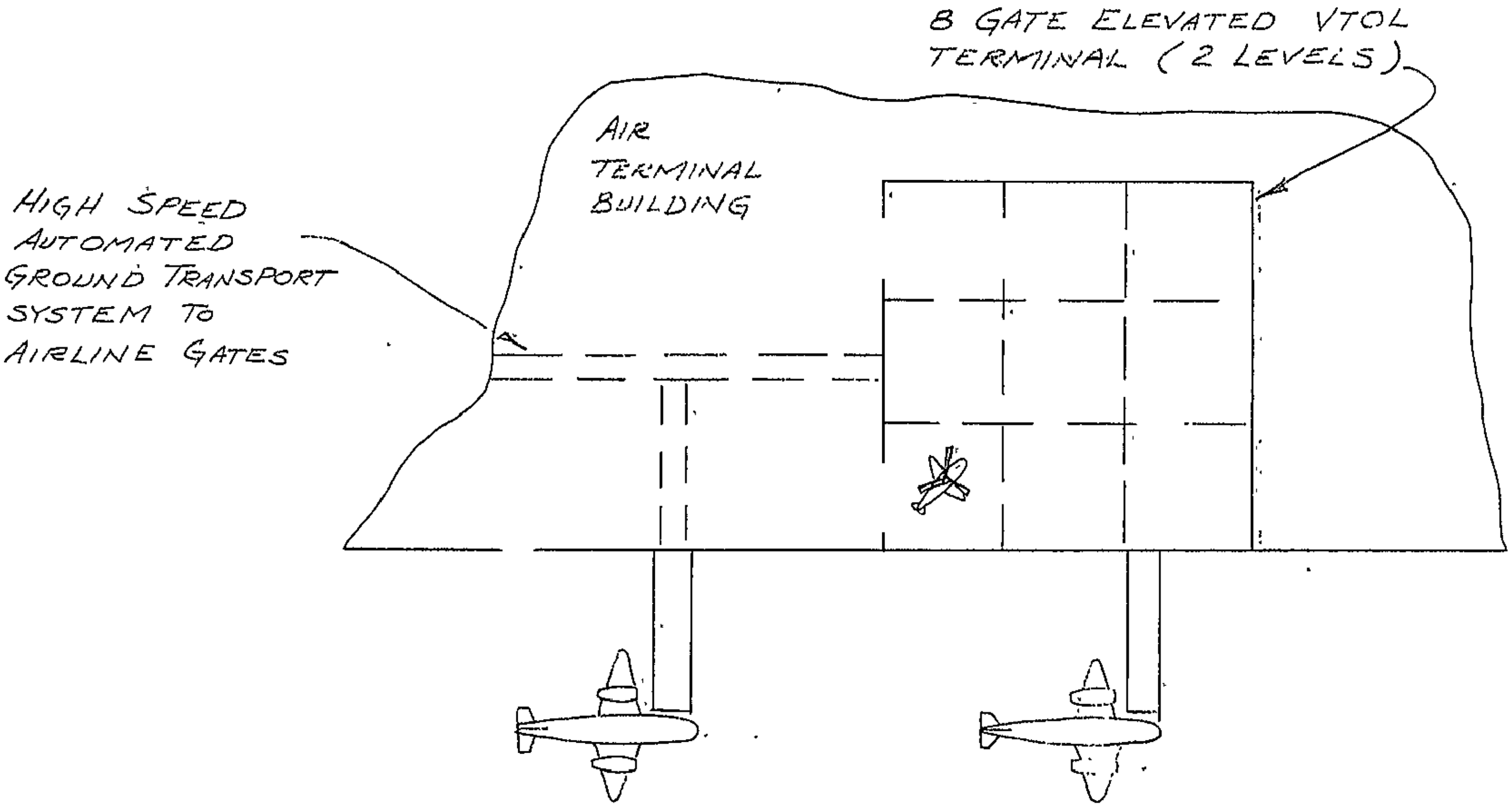


FIG 5-10 MAT AIRLINE TERMINAL

to the vehicle). Passengers must, therefore, be moved long distances from the queueing areas to the plane. Also, standing in aircraft is prohibited during takeoff and landings so that maximum capacities must be rigidly adhered to (also unlike buses and trains). In addition, other modes generally carry larger maximum loads (i.e. trains) or have smaller peak loads to handle (i.e. bus). The problem is further complicated in the case of the airline passenger by the need to carry baggage and to be compatible with airline operations.

Having identified some of the problem areas, we now look in more detail at the various aspects of the flow of people and baggage through the MAT terminals and offer some suggestions for handling the high density of travellers that can be expected to use the system by the 1980's. In what follows we consider the commuter and the airline passenger separately even though there is quite a bit of overlap in handling procedures for the two.

5.4.1 Commuter Handling--Gaining Access to and Leaving the System

As previously defined, the commuter is someone who uses the MAT system to go to work in the morning and to return to his home in the evening. His only "luggage" is an attache case or a small package. Regardless of where he enters or leaves the system his origin and anticipated destination must be known. This information can then be used to adjust schedules on a real-time basis so as to meet one of the MAT system design objectives, i.e. the minimization of overall commuter travel time (including waiting time). In addition, these data can be used to issue periodic bills to commuters.

To permit entry into the system and obtain the above information it is proposed that during the initial system start-up period (during which time, no fares are to be charged) prospective commuters either apply for, or be sent (as a result of a telephone soliciting campaign) MAT commuter cards. Each card is to have the commuter's name and picture on it together with an identifying number. In addition, his anticipated origin-destination is magnetically coded on it. This last piece of information is readily determined for commuters who generally travel between the same two points every day (i.e. locations A & B).

On arriving at a terminal commuters insert their cards into one of several entrance gates. If the card and credit of an individual are acceptable, the gate remains open and he is permitted entry into the active (i.e. waiting or queueing) area of the terminal. The system computer records his entry (at location A, for example) and based on his anticipated destination (location B, for example) adjusts the schedule of the airplanes on a real time basis accordingly. Upon reaching his destination the commuter must insert his card in an exit gate in order to leave the terminal area. The computer uses these data to prepare bills which are sent to each commuter on a monthly basis. (Note that this type of credit card billing without a signature is considered feasible because the users of the MAT system will generally come from the higher socio-economic groups).

If an individual is a first time or a casual user of the system (e.g. a housewife) a temporary pass good for only a limited time (e.g. one week) can be issued by a terminal agent or by a machine which is tied into the computer. The terminal agent is still required in order to clear up any credit problems or difficulties arising from invalid cards. Note that if a card is determined to be invalid for any reason, the entrance gate closes. It also closes if entry is attempted without inserting a card.

Those commuters who desire to change their destination for one trip can do so by entering through one of several special gates. These gates permit him to insert his card and then punch in his new destination (denoted by a number from 1 to 24, representing one of the 24 MAT terminal sites). Billing and real time schedule data are accomplished as with the standard gates.

Computerized entrance gates that can handle 30 to 50 people per minute are currently available and are to be used in the BART system. [5-13, 5-14] If similar gates are used at the MAT system terminals and a uniform distribution of passenger arrivals during an hour is assumed, then the large terminals which must handle peak loads of 9,300 passengers per hour only require six gates (9,300/(60 x 30) = 5.2). Using a gate rate of 30 per minute,* it takes about 52 seconds for the 26 passengers who arrive at each gate every minute to pass through, that is, the maximum wait is 52 seconds. It should be noted that if one assumes an average walking rate of 2.5 ft/sec, and a spacing between people of 2.5 ft., it takes the 26th person 26 seconds to move from the back of the line to the gate. Clearly, the gate is the limiting factor in this instance and thus the passenger flow rate is 30 per minute.

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[*] Special gates are assumed to have a gate rate of 15 per minute.

Since a uniform distribution of arrivals during the hour is not realistic, a triangular distribution shown in Figure 5-11 is used instead. Although the same number of passengers arrive during the hour as before (i.e. 9,300), the peak arrival rate is now 18,600 passengers per hour. Using the same reasoning as above, 11 gates are now required with a maximum waiting time of approximately 58 seconds.

To prevent overly large queues from building up due to a gate malfunction one additional gate is required. This reduces the maximum wait to 52 seconds. Also, two special gates each capable of accepting changes in destination as previously described must be included. Thus, the total number of entrance gates at the high density ports is 14.

Table 5-3 shows the number of entrance gates that are recommended for each of the 24 MAT site locations using a triangular arrival distribution which peaks halfway through the hour.

5.4.2 Commuter Handling—Queueing

Once the commuter passes through an entrance gate a computer-actuated solid state display panel (located on the gate itself) directs him to one of several primary queueing areas in the terminal (at low density terminals the display feature may not be necessary). The decision to set aside a particular queue area for passengers going to destination B is made by the computer in real time and is based on demand data (provided by commuters who have entered the terminal) and the skeleton fixed schedule. The size of any primary queue is flexible and can be controlled by either the computer or by an attendant. In general, such an area is expected to hold from 80 to several hundred people depending

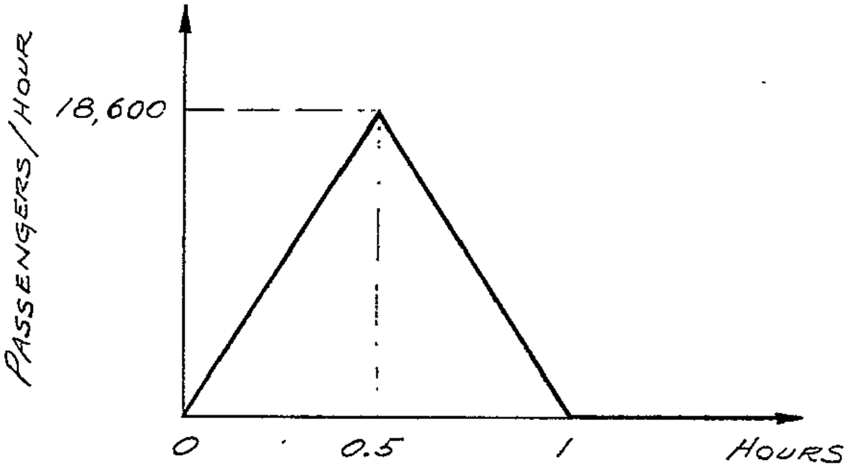

FIG. 5-11 PASSENGER ARRIVALS DURING PEAK HOUR

Table 5-3

AUTOMATIC ENTRANCE GATE REQUIREMENTS

Terminal	Peak Hourly Passenger Flow	Triangular Peak Flow	Standard Gates	Special Gates	Total Gates	Maximum Gate Time (seconds)
SFO*	7,605	15,210	2	19	21	53
OAK*	6,175	12,350	2	16	18	52
SJO	9,290	18,580	12	2	14	52
FRY	9,170	18,340	12	2	14	52
SAC	2,745	5,490	5	1	6	37
CDP	7,880	15,760	10	2	12	53
RWC	2,285	4,570	4	1	5	38
MTV	2,065	4,130	4	1	5	35
PAL	1,930	3,860	4	1	5	33
OKP	3,640	7,280	6	1	7	42
CON	1,700	3,400	3	1	4	38
SAL	600	1,200	1	1	2	40
MON	645	1,290	1	1	2	43
NWK	5,010	10,020	7	1	8	48
HWD	2,130	4,260	4	1	5	36
BRK	1,870	3,740	4	1	5	32
SPO	1,990	3,980	4	1	5	34
SRL	2,230	4,460	4	1	5	38
SKT	1,745	3,490	3	1	4	39
VLJ	2,155	4,310	4	1	5	36
SRA	2,080	4,160	4	1	5	35
FRF	1,045	2,090	2	1	3	35
ANT	590	1,180	1	1	2	39
SCZ	930	1,860	2	1	3	31

*Since SFO and OAK will be mainly for airline passengers, these terminals will be equipped with special gates to handle the different destinations.

on the destination.* At a major terminal (e.g., the Ferry Building) the rapid loading is facilitated by moving 80 people into a secondary queueing area--that is, two 40-passenger elevators (see Fig. 5-8) each subdivided into four ten seat sections and located one or two floors below the landing pads. These elevators are to be loaded approximately two to four minutes prior to the flight departure.

When an airplane is properly positioned the two elevators emerge from the pad deck alongside of the craft and rise until they are both level with the bottom of the plane's doors. A load bearing bottom platform together with non-load bearing side and roof panels extend out from each elevator to provide a short, level, and protected walkway into the plane (see Figure 5-7). To minimize the effects of weather and rotor downwash, the automatically-operated elevator doors remain closed until all of the extension panels are in place. Deplaning passengers, if any, are removed using two similar elevators located on the other side of the fuselage (see Figure 5-8).

As soon as the plane touches down, the four elevators can begin their ascent--a trip taking no more than 20 seconds. During this time the plane is being maneuvered on the ground to position it directly between the elevators. Deplaning passengers are removed first and the plane is then reloaded. Since it is possible to begin loading while passengers are still deplaning (i.e. some overlap of the two processes is possible), it is anticipated that even in the worst case (i.e. loading and unloading 80 passengers) it should take no more than one minute to complete the

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* Queueing areas are determined by allowing 6 ft^2/person. [5-15]

process.* A two minute turnaround time is, therefore, seen to be reasonable although two additional minutes can be allowed for contingencies. Thus, the overall turnaround time is between two and four minutes.

Problems involving an overcrowded aircraft or elevator compartment, or an unbalanced load (which causes the aircraft center of gravity to be in the wrong place) can be remedied by moving passengers from one compartment to another using the load bearing elevator extension panel.

Since many flights arriving to pick up passengers during the morning and evening rush periods may not have any deplaning passengers, both sets of elevators can be used for secondary queueing areas. Even if there are some people who wish to get off the plane, both sets of these elevators can still be used as secondary queueing areas. In this

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* A study of airline passengers has shown [5-16] that 14 people can be moved through a doorway in about one minute. Since only ten people are to move through the doors in the MAT aircraft and overlap is anticipated, the one minute figure is realistic. Moreover, it is reasonable to expect a higher degree of cooperation from commuters than from airline passengers so that this figure of 14/min is probably quite conservative. In fact, if we assume that each person in the elevator walks at an average velocity, v_o, that the distance between passengers is ℓ, and that each person begins to move ℓ/v_o seconds after the person in front of him, then the k^{th} person in any of the 10 seat elevator compartments takes

$$t_k = \frac{d + d_w + k\ell}{v_o} \text{ seconds}$$

to get into the plane. In this equation, d is the distance between the front of the elevator and the fuselage and d_w is the fuselage width. If $v_o = 2.5$ ft/sec, $\ell = 2.5$ ft, $d_w = 9$ ft, and $d = 4$ ft, the tenth and last person in each compartment takes about

$$t_{10} = \frac{4 + 9 + 10 \times 2.5}{2.5} = \frac{38}{2.5} = 15.2 \text{ sec}$$

to enter the plane. The one minute figure is indeed conservative.

case, the loading and unloading sides are alternated (i.e. the first plane unloads from the left, the second one from the right, the third from the left, etc.). By using the above procedure, it is possible to permit two turnaround periods to fill the elevators, i.e. from 4 to 8 minutes.

At terminals where the aircraft are to land at ground level, the secondary queues can be a series of staggered gates (see Figure 5-12). Eighty people who wish to travel to destination B are moved out of a primary queue and into the 8 locations numbered "1". Each of these areas is capable of holding up to 10 passengers, and has a door in the front and one in the back. Passengers for destination C move from their primary queue areas to the secondary queue areas marked "2", etc. When the aircraft for destination B is ready to load, all of the front doors in location "1" are opened and the passengers walk along clearly marked paths to the appropriate compartments. In order to protect the travellers from weather and rotor downwash, a two-section lightweight corrugated awning is extended out from the side of the building at a height of 8 ft so that it fits under the wings and clears the propellors.

Assuming that the distance between the aircraft fuselage and the secondary queueing gates is 25 ft, the <u>maximum</u> distance that any passenger must walk to reach the cabin is 65 ft (see Figure 5-12). Using the equation for walking time for the k^{th} member of a queue (see footnote on page 5-34) with $d_w = 9$ ft, $d = 65$ ft, $\ell = 2.5$ ft, and $v_o = 2.5$ ft/sec,

$$t_{10} = \frac{9 + 65 + 10 \times 2.5}{2.5} = 40 \text{ sec}$$

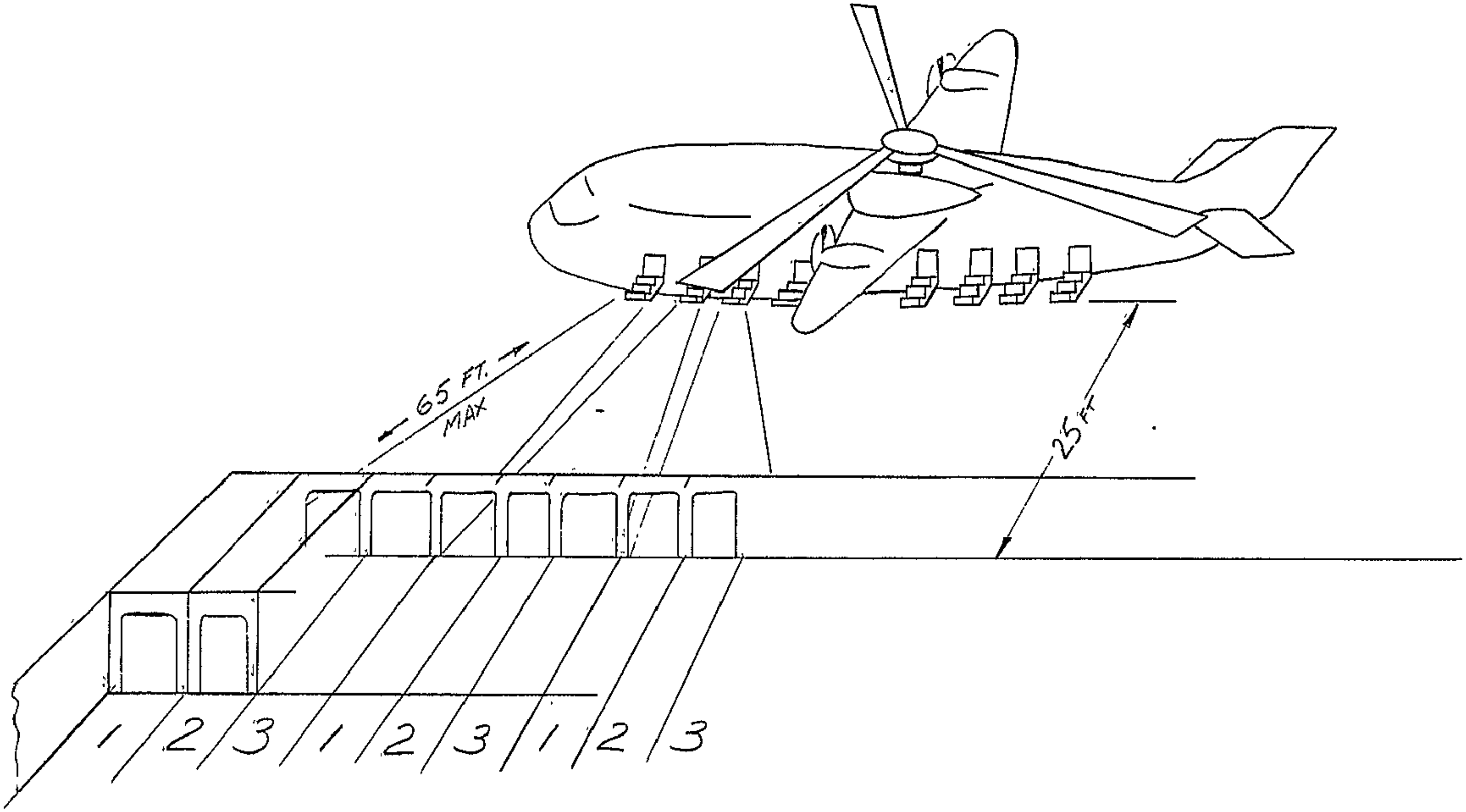

FIG. 5-12 STAGGERED QUEUING

Hence, the maximum time for any passenger to enter the cabin is 40 seconds. Since the unloading and loading processes can overlap somewhat, two minutes is not an unreasonable turnaround time at these terminals. As there are three secondary queueing areas per landing pad, there are at least 5 minutes available for moving 80 people from a primary to a secondary queueing area.

An alternative to the above scheme is the "people carousel" shown in Figure 5-13. Here a 4-section horizontal rotating disk is used as the secondary queueing area. Each sector is subdivided into eight ten-seat parts. When an aircraft is ready to load, the disk rotates 90° moving 80 people outside (and under the protection of a corrugated awning as before). These passengers then walk to their appropriate compartments along clearly marked walkways.

Three sections of the disk remain inside the terminal and are loaded for succeeding flights. Each time the disk rotates an empty section is moved inside and is available for use as a new secondary queue. Again at least 5 minutes is available for loading each of the sections. The primary advantage of this scheme is the added comfort and convenience that it affords the passengers. As such, its primary application might be in the airline terminals of the MAT system (e.g. SFO and OAK).

In either of the above cases, provision is made for limiting the number of people to less than 80 in any of the secondary queues. (This is necessary when, for instance, a plane arrives with several passengers who plan to continue on to another terminal). This information is known to the computer (from the anticipated destination data contained on the commuter cards), which adjusts the secondary queue sizes accordingly.

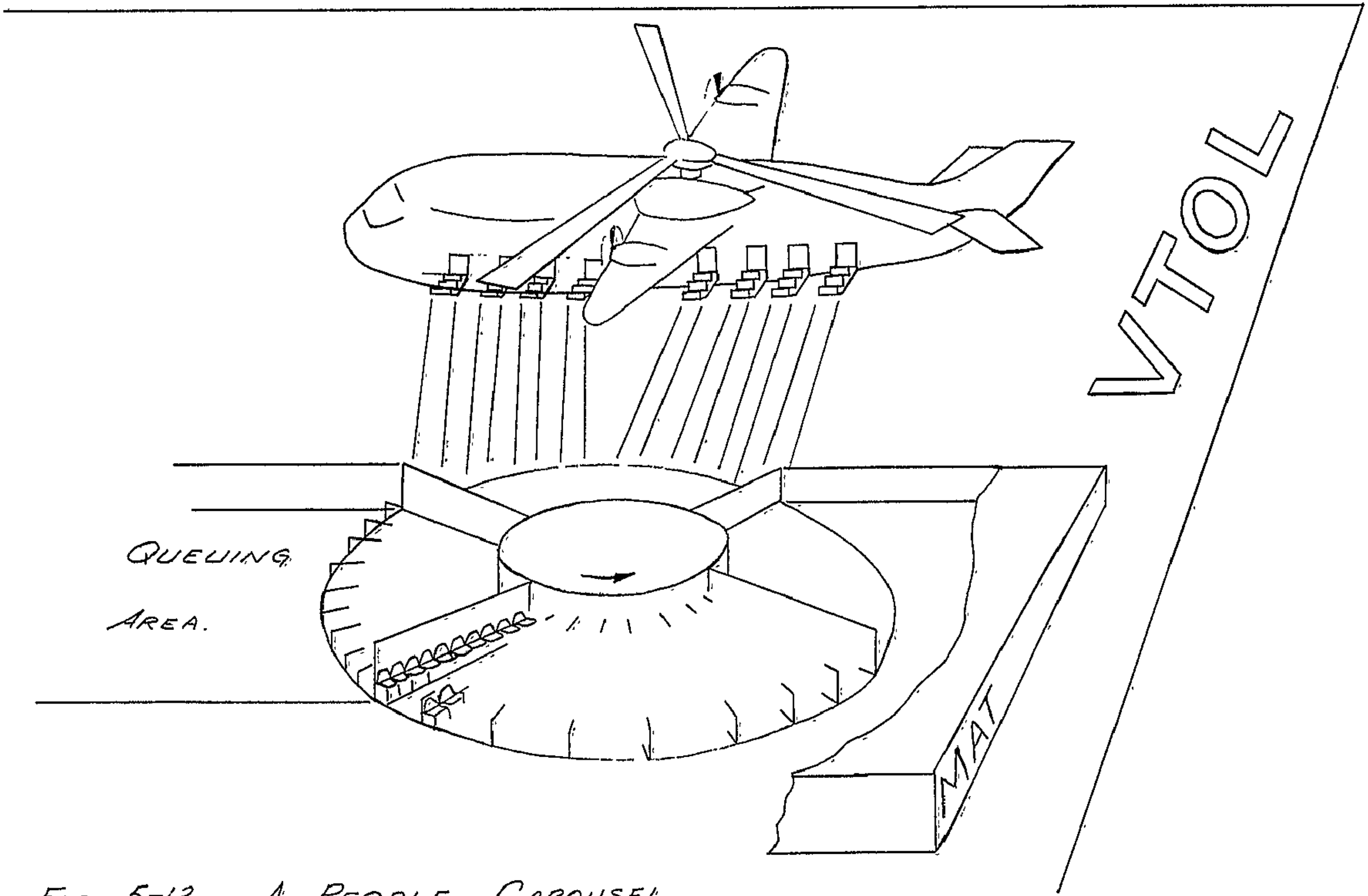

FIG. 5-13 A PEOPLE CAROUSEL

Passengers are informed of this through the use of computer-controlled solid state displays over each of the secondary queueing areas.

5.4.3 Commuter Handling--Center of Gravity Control

Since the aircraft is sensitive to the location of the center of gravity, provision must be made for equally distributing the load. It is proposed that weight-sensing devices be used in all secondary queue areas. The data transmitted from these sensors is fed to the computer which determines whether or not an imbalance condition exists. If one does, this information is given to an attendant along with proposed solution and the appropriate adjustment is made. The attendant is also used to handle the reduction in the maximum secondary queue size resulting from non-deplaning passengers.

5.4.4 Airline Passenger--Baggage Handling

An airline passenger is a traveller who uses the MAT system to go to or from one of the Airport terminals (i.e. SFO, OAK, or SJO). Unlike the daily commuter, he will generally have several pieces of luggage which must also be transported with him.

One of the major annoyances experienced by airline passengers today is that of having to carry their luggage over long distances to check-in areas. The MAT system is designed to eliminate this problem by permitting the traveller to rid himself of his baggage immediately upon entering the system. To accomplish this, an airline passenger arriving at either a MAT Metro or Suburban terminal places his luggage into one of many automatic luggage bins. These bins are conveniently located in parking lots or garages (e.g. two bins per car file) at the higher density Suburban terminals or near entrance doors at the Metro terminals. Walking with luggage is thus reduced to an absolute minimum.

Before a traveller can open a bin door, he must first obtain a magnetic stamp from a machine located above the bin. If he already has a reservation, he punches in the MAT flight number, the commercial airline name, and the number of pieces of luggage. The machine codes these data and issues one stamp for each piece. The passenger then affixes the stamps to the luggage and inserts each piece into the bin. Sensors read the MAT flight number and automatically route the bags over a conveyor belt to a cargo loading area* where they are placed inside a standard cargo container.**

Two of these containers, each resting on a platform equipped with omnidirectional rollers, are loaded onto the plane just before takeoff through side doors located under the wings. At Metro terminals this is accomplished by using a cargo elevator (see Section 5.3.2), which rises out of the deck and permits the containers to be quickly rolled into the plane. A conveyor belt equipped with a hydraulically raised platform is used at Suburban terminals. In either case, only two items need to be transferred, and since the loading is done through the fuselage side rather than the plane's underside (as in the case of CTOL craft), the process can be completed well within the required two to four minutes.

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[*] In order for a system like this to work, a standard luggage size will be required. An additional charge for non-standard luggage will be made.

[**] Each MAT plane is designed to carry two FAA Standard half containers (scheduled for use on the Jumbo Jets). Together they hold 350 ft^3, which is more than adequate to carry the luggage allotment of 80 passengers, i.e. 320 ft^3 assuming 4 ft^3/passenger. [5-17]

If the traveller does not have a reservation or the necessary information on either the MAT flight or airline name, he obtains a magnetic stamp from the machine which indicates this and places his luggage into a bin as before. The luggage conveyor routes his baggage to one of the ticket counters located throughout a section of the terminal. The traveller is directed to proceed to the same counter (e.g. counter "red") through the use of a computer-controlled solid state display panel on the luggage bin. The computer obtains information on current sizes of counter queues and the passenger's distance from any counter in the terminal. By using these data, together with the mean time for a single counter transaction and the average walking speed, it determines the optimal counter location to route the luggage and passenger (i.e. the one where the queue will be the shortest when he arrives).

As an alternative to the terminal counters, ticket issuing machines [5-18] can be located in the parking lots or garages or near Metro terminal entrances. The traveller is able to select his airline destination, and commercial flight time for a single or round trip. The machine issues an airline ticket and indicates to him which MAT flight to take.

Regardless of whether he uses a ticket counter or a machine, a reservation for an <u>entire</u> trip is made and his luggage is then routed as before. Note that the MAT system ticket counters or machines are to be tied in to all of the airline reservation computers.

When the plane arrives at a MAT airline terminal the containers are off-loaded (using the conveyor belt-hydraulic platform arrangement) and the bags are removed and placed on the airport magnetic conveyor system, which automatically routes each one to the appropriate airline. Note that with this system the airline passenger never sees his luggage until he reaches his final destination. A further refinement is possible if the airline flight is also coded on the magnetic stamp. In this case, a sensor located in the airline cargo area allows the bags to be automatically sorted by flight number.

At terminals where airline passenger density is low, the automatic conveyor system may not be required or may be uneconomical to implement. In this case, a magnetic stamp is still affixed to each piece of luggage [The stamp is necessary for automatic delivery at the airline terminal end of the trip]. The passenger must now hand carry and load each bag into a centrally located cargo carrier which is clearly marked with his MAT flight number.

For the airline passenger who is going from an airport to a Suburban or Metro terminal, the bags are sent from the commercial airline via the automatic conveyor to the MAT Airline terminal where they are stored. When the traveller arrives at the MAT terminal (having used the airport high speed ground transportation system to get there if necessary), he inserts his MAT card in a special entrance gate to gain access to the terminal. Besides providing information which can be used to make any scheduling changes, this action automatically extracts his baggage from storage, whereupon it is loaded into the cargo carrier which will be loaded on his MAT Flight. At his final destination the passenger goes to one of the many luggage bins located in a garage near his car or at a taxi or bus stand where he again uses his MAT card. This causes the bags to be routed to that bin. Once again, he never sees his luggage until after he arrives at his final destination.

5.4.5 Airline Passenger--Gaining Access to the System

It is envisioned that an airline passenger will be able to make a reservation to or from his final destination at one of the MAT Suburban or Metro terminals. The commercial airline terminal will, therefore, be used as a transfer point only. Since he will make this transfer without having to worry about his luggage, one of the major annoyances associated with such movements will not be present. Also, high-speed airport transportation will help to make the transfer process more acceptable.

To gain access to the system, the airline passenger who has a reservation obtains a temporary MAT card from machines located above the luggage bins (this is not necessary if he has a regular commuter card). He first punches in the airline name, flight number, and MAT flight number, the computer verifies his reservation, and then issues a card. He enters the active terminal area by inserting the card into one of the special entrance gates (see Section 5.4.1). As before, the destination information is used by the computer to make any schedule adjustments in real time. Billing is also accomplished as before. Prospective airline passengers who do not have reservations make use of the automatic ticketing machines or selling counters previously mentioned.

5.5 Maintenance Facilities

Aircraft maintenance can be classified into three categories, daily line maintenance, major overhaul, and emergency maintenance.

5.5.1 Daily Line Maintenance

At the end of each working day most of the aircraft are in the suburban terminals in approximately the numbers needed to service the next morning's commuter load. At these terminals, on a nightly basis, each aircraft is inspected, cleaned externally and internally, and minor maintenance and fueling is performed as needed.

The inspection and cleaning services are performed within an aircraft hangar at the rate of two aircraft/hour. The hangars will have washing and vacuum cleaning facilities for rapid service. Figure 5-9 shows a typical 2-gate Suburban terminal with hangar and aircraft storage indicated.

Aircraft fueling will be performed at the Suburban terminals during the nightly line maintenance period. Additional fueling will be required during the day, and will also be performed at the Suburban terminals.

5.5.2 Overhaul Facilities

Based on a TBO of 3,000 hours, a yearly utilization rate of 2,000 hrs/aircraft, and a 5-day overhaul period, an aircraft will spend approximately 1% of its calendar life in major overhaul. Translated on a fleet basis, for a fleet of 200-300 aircraft 3 overhaul bays are sufficient.

In addition to the overhaul bays, an engine shop, airframe shop, avionics shop, furnishings shop, and parts warehouse are provided.

The overhaul facility should be located at a Suburban terminal to minimize land costs.

5.5.3 Emergency Maintenance

Emergency maintenance can be performed at any terminal location.

However, replacement parts and service personnel will be available only at the major overhaul facility. Therefore, as the emergency develops, parts and personnel will be transported from the overhaul facility to the emergency point.

Fuel will be available at the Metro terminals on an emergency basis only.

5.6 Future Studies

The MAT system study has identified many interesting areas for further study. Some of these are discussed below.

5.6.1 MAT terminal sites may serve as catalysts for new housing or industrial area development in much the same way that the Federal Interstate Highway system and earlier the railroad networks have done. It is not inconceivable that major changes in urban development patterns could result from a metropolitan air transit system. For example, cities of moderate size might spring up in relatively inexpensive and aesthetically pleasing areas within a 100-150 mile radius of the core area of a large city if MAT terminals were available. Conversely, an industrial park with characteristic pollution and noise problems could be located many miles from residential areas if a MAT terminal were located in the park.

5.6.2 As a possible solution to the growing airport air and ground congestion problem [5-19] a new giant capacity airport could be built in a remote, outlying area, say 100 miles from the central Bay area. This airport could be located where land prices are low and noise problems are unimportant. Service could then be provided to and from this airport to the various MAT terminals by MAT aircraft. Thus, passage could be booked directly from or into a suburban MAT terminal if the passenger so desired. In this way, total block travel time for the airline passenger could be substantially reduced. There are, of course, disadvantages as well as advantages to this proposal, and it is recommended that further study be conducted in this area.

5.6.3 VTOL airport design offers several interesting areas for noise alleviation research [5-20]. For example, dense trees and shrubs can be planted relatively close to the landing pads. Or the landing pads might consist of steel grating with sound absorbing materials below them, or be rough textured, or consist of an improved carpet-like material. That is, the dynamics of vertical landing are different from the dynamics of conventional landing and these differences should be studied and exploited if possible in noise alleviation.

5.6.4 Much work remains to be done in the control schemes for optimal baggage and passenger queueing. Research in this area should yield profitable results not only for the MAT system but for conventional airports as well.

5.6.5 A novel barrier arrest system for STOL airports was described in Section 5.2.2. The system seems sufficiently promising to warrant further research and development.

5.6.6 A problem could develop in the MAT system from passenger identification and billing. It would be desirable for a better identification system to be developed. As a possible area of research, it is proposed that an on-line computerized fingerprint identification system be developed so that a passenger could be identified in a very short time as he laid his hand on an identification plate.

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Chapter 6

ENVIRONMENTAL AND HUMAN FACTORS

Modern commercial airlines strive to provide the passenger with comfort and convenience, and often carry it to a point of luxury. For the MAT system with a mean trip time of less than 15 minutes it has been decided to forego some of the luxury, but to provide reasonable comfort and convenience and high standards of safety. The environmental and human factors essential to the preliminary design of such a system are considered in this chapter. These include noise, acceleration, pressure changes, cabin atmosphere, and isolation.

6.1 Noise

6.1.1 Measurement and Sources

The commonly used definition of the noise level in decibels (dB) is

$$dB = 20 \log_{10} \left(\frac{\text{rms pressure}}{.0002 \text{ Dynes/cm}^2}\right)$$

The human response to noise or "noisiness" is measured in terms of a unit called the NOY. The noisiness is established by the perceived noise level of a given sound that is considered equal to the sound pressure level of a reference sound (1000 HZ band) Figure 6-1 gives the NOY's as functions of sound pressure level (SPL).

The perceived noise level is decibel, PNdB, is defined by the equation

$$PNdB = 10 \log_2[n_{max} + 0.3 (\Sigma n - n_{max})] + 40 \quad ,$$

where n = NOY's. PNdB is presently the number most often used in determining how noisy a sound is. A table giving the conversion from sound pressure level to PNdB is given in Reference 6-1.

In some cases the presence of a strong pure tone is more annoying than that measured by octive band or partial-band dB meters. Figure 6-2 gives a correction to be added to a band containing a pure tone before PNdB is computed.

The "effective perceived noise level" EPNdB is defined by

$$\text{EPNdB} = \text{peak PNdB} + 10 \log_{10}(T/15)$$

where T is time in minutes during which noise is within 10 PNdB of peak. The purpose of EPNdB is to take into account the amount of time one is subjected to a given sound level.

Before concluding on the measurements of sound it should be pointed out that extreme care must be used in interpreting the instrument readings. Figure 6-3 shows three different frequency spectra, all measuring the same PNdB---the only difference is the bandwidth of the instrument. Figure 6-4 shows the effects of temperature and humidity on the 4000 Hz frequency. Clearly, a small error in temperature and humidity causes rather significant errors in dB; a 5° F and 5% humidity error can cause as much as a 6 dB error (a doubling of the sound pressure).

Sound from aerodynamic sources is caused by a motion of the air itself, i.e., fans, jets, nozzles, propellers, etc. Thus, turbulence is the offender and, any reduction of turbulence is a reduction of noise. The noise generated by various aircraft is the sum total of all the

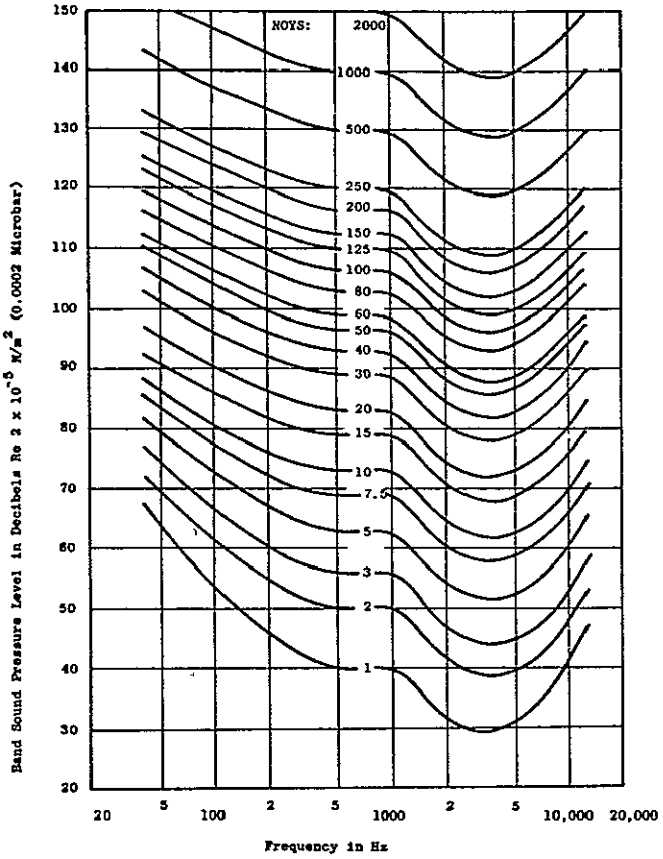
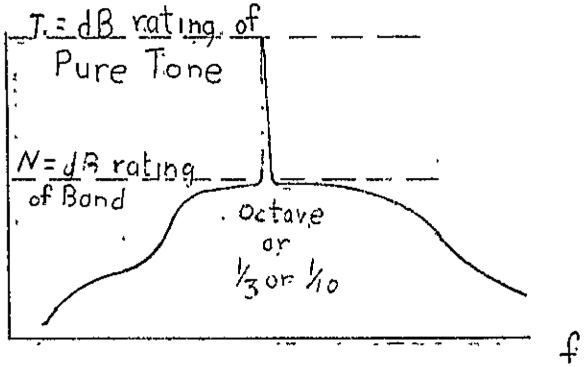


Figure 6-1 Noys as Function of Sound Pressure Level (Reference 6-1)

Octive Width Measured			
	Full Octave	1/3 Octave	1/10 Octave
Number	T/N	T/N	T/N
1	20	25	30
2	10	15	25
3	0	5	10
4	-10	-5	0



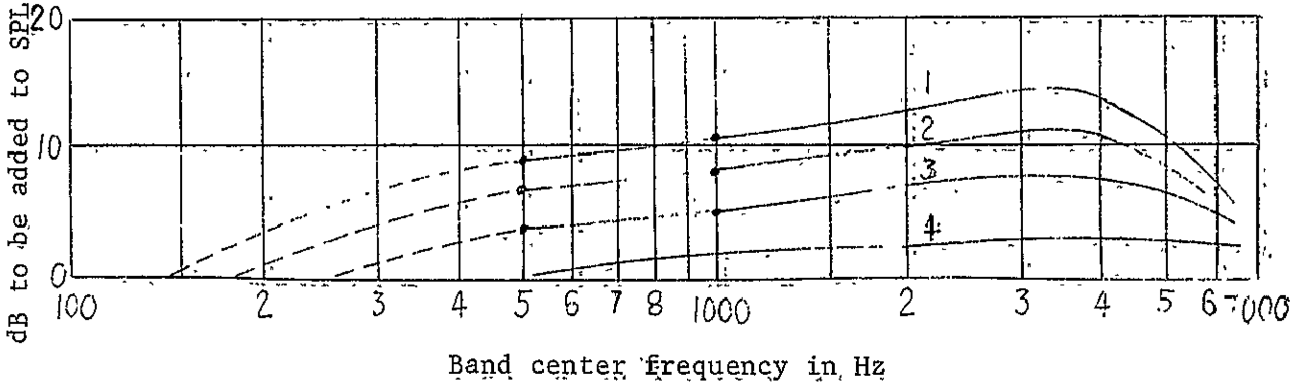


Figure 6-2

DECIBEL CORRECTION TO BE ADDED TO SPL OF BAND CONTAINING THE PURE-TONE COMPONENT PRIOR TO CALCULATING PNdB

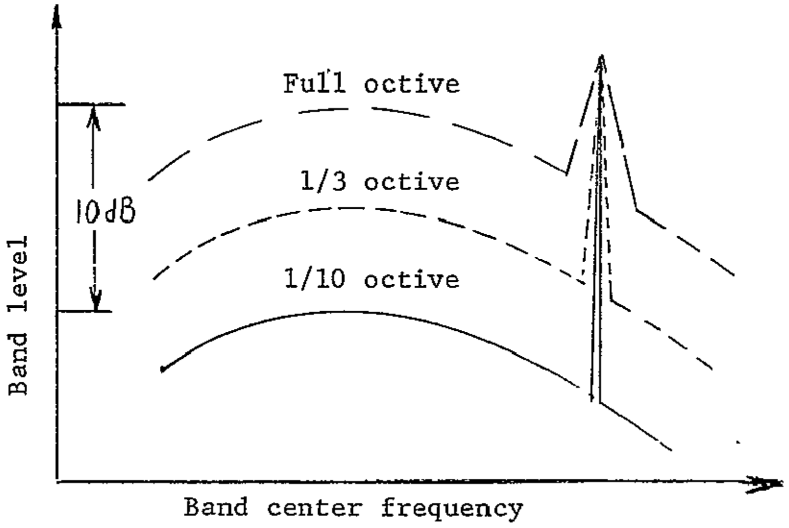


Figure 6-3

EFFECT OF A SINGLE TONE UPON
BROAD BAND MEASUREMENT

Note: All of these result in equivalent value of PNdB if pure tone is not accounted for.

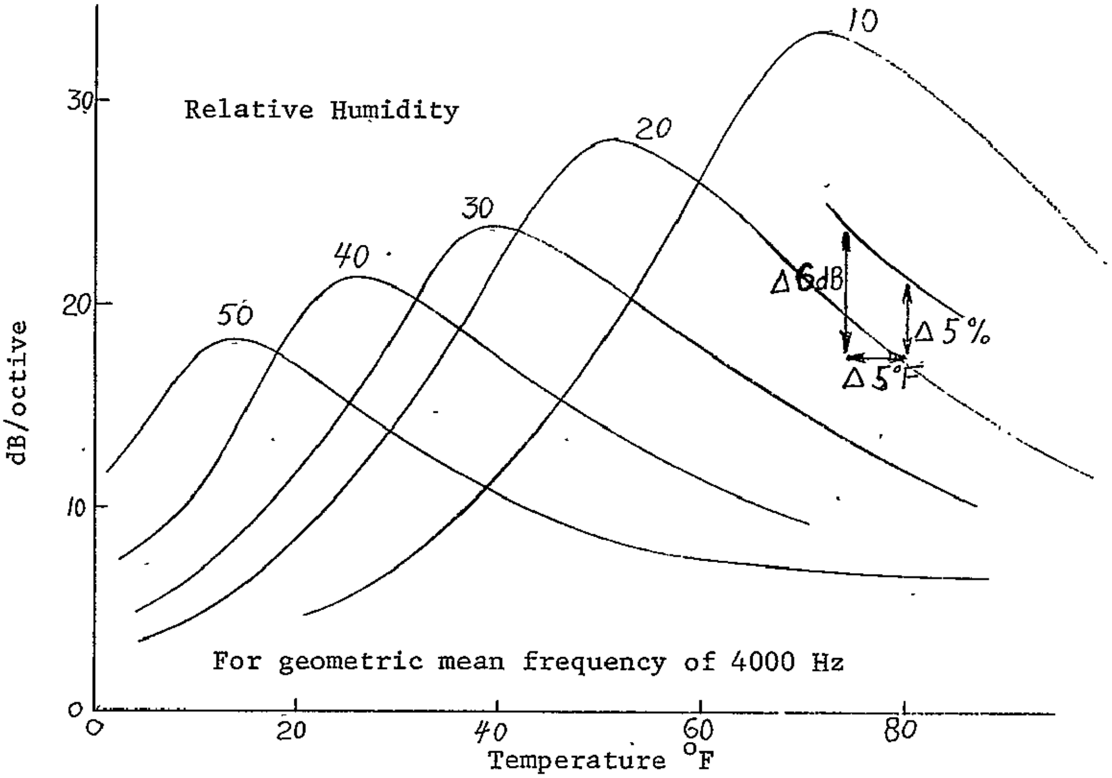
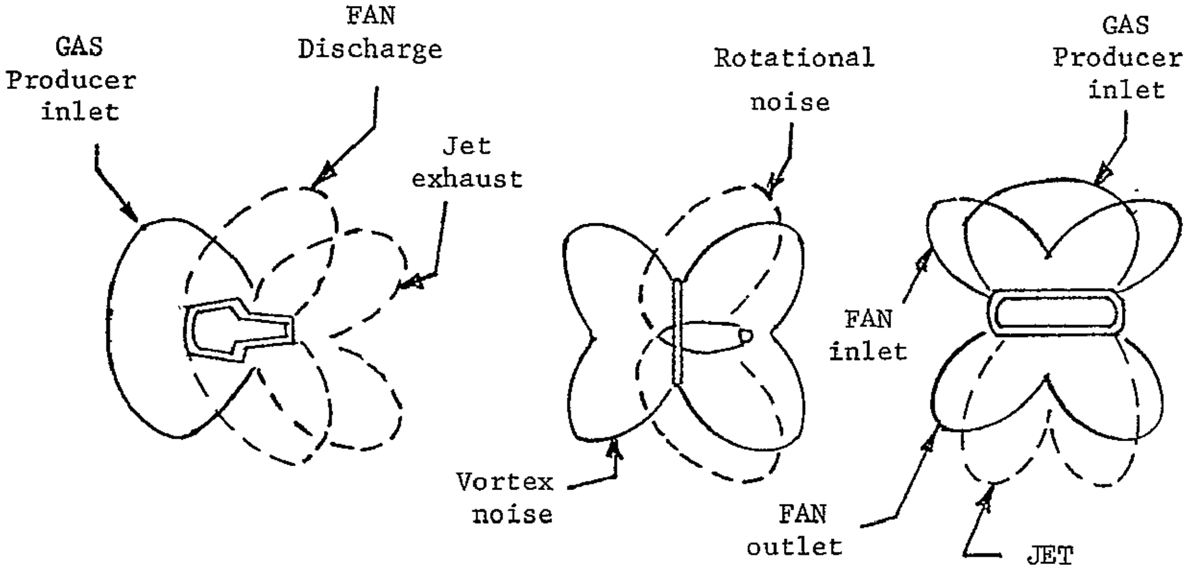


Figure 6-4

ATMOSPHERIC ABSORPTION AS A FUNCTION OF TEMPERATURE AND RELATIVE HUMIDITY various noise-producing elements. For this reason, the various general noise sources are listed and the noise-producing elements of each are discussed. Some of these sources with their main noise elements are shown in Figure 6-5.



(a) Jet engine

(b) Propeller and Rotor

(c) Lift-fan

Figure 6-5

NOISE SOURCE DIRECTIVITY PATTERNS

The exhaust of a gas turbine is a high-velocity hot-air jet which produces noise proportional approximately to the eighth power of the jet velocity (Figure 6-6). As seen in Figure 6-5, other elements that contribute to the noise of gas turbines are compressor, turbine, combustor expansion, and turbine accessories. The exhaust noise has

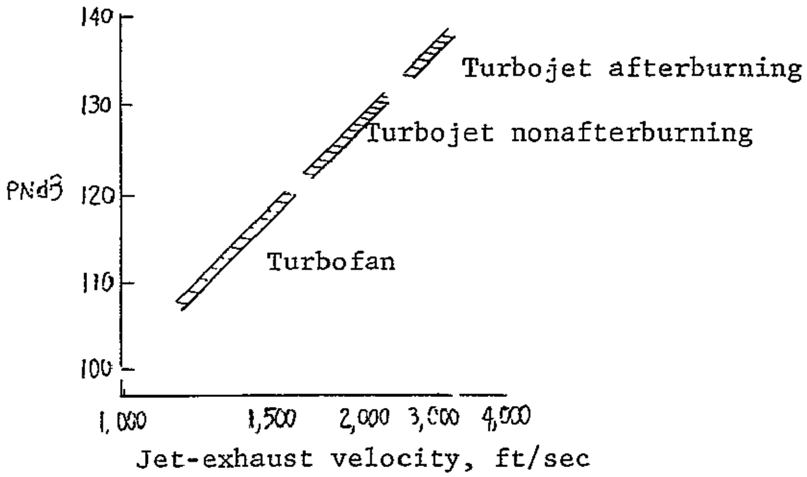


Figure 6-6

EXHAUST NOISE FROM JET ENGINES
AT 500 ft

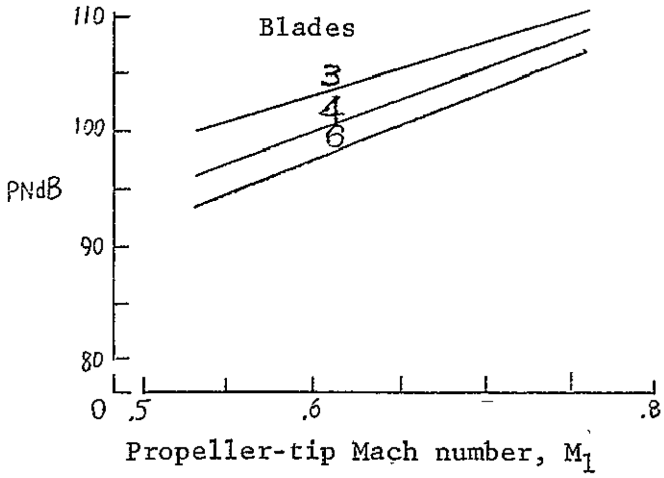


Figure 6-7

TURBOPROP NOISE 8,500 hp,
17 ft diameter prop, 4 blades, at 500 ft

been the dominant source, with the compressor running a poor second.

The main components of propeller noise are rotational noise, vortex noise, and wake noise. Rotor noises include all of those for the propeller plus blade slap and blade bang. The factors effecting prop and rotor noise are tip velocity, power absorbed, number of blades, and diameter of blades. Figure 6-7 shows the effects of tip speed and number of blades on propellers, while Figure 6-8 shows the effect of blade loading and tip speed.

The dominant noise sources of fans are stage interaction, rotational noise, jet mixing, and vortex. Present multi-stage fans are very noisy, however, and intensive research and development program is underway to reduce the noise by developing "high by-pass ratio". Such a "high by-pass ratio" may be acceptable at least for the low thrust levels used in forward propulsion (see Chapter 3). Figure 6-9 shows the effect of the by-pass ratio on noise level.

One other source of noise is that due to air flow around the wing and body. At the speeds of less than 250 mph this is a minor source. Should MAT aircraft someday be designed for higher speeds, then this factor would require more careful investigation.

6.1.2 Human Response to Noise

Physically, sound can incapacitate and even be lethal. As seen in Figure 6-10 pain is experienced at 135 dB, and above that level permanent hearing loss can occur. Recommended maximum levels are given, these clearly depend on the frequency content. Figure 6-11 also shows these maximum values and further indicates when ear protection is required. Figure 6-12 shows the effect of the length of time a person is

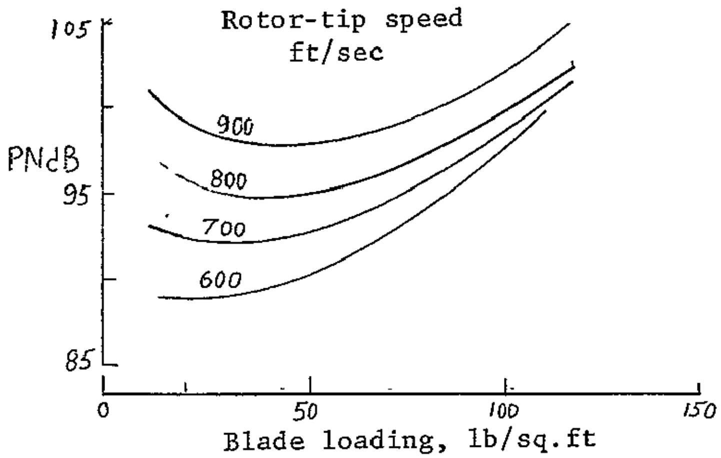


Figure 6-8

HELICOPTER ROTOR NOISE
AT 500 ft

exposed to a given noise level. It is worth noting here that PNdB is not a good method of averaging when considering physical tolerance. Figure 6-13 shows two curves with the same PNdB along with the maximum permissible level indicated in Figure 6-10. It should be noted that though these curves are of the same PNdB the solid curve does not exceed the permissible level, while the dotted durve does.

Another important factor for consideration is the psychological tolerance measuring the annoyance of noise. Figure 6-14 shows the dependence of annoyance on frequency. Because of this frequency dependence, many methods of measuring sound and correlating subjective judgments of noisiness have been established. PNdB has, however been consistently as good a measure as any of the evaluation of noise annoyance.

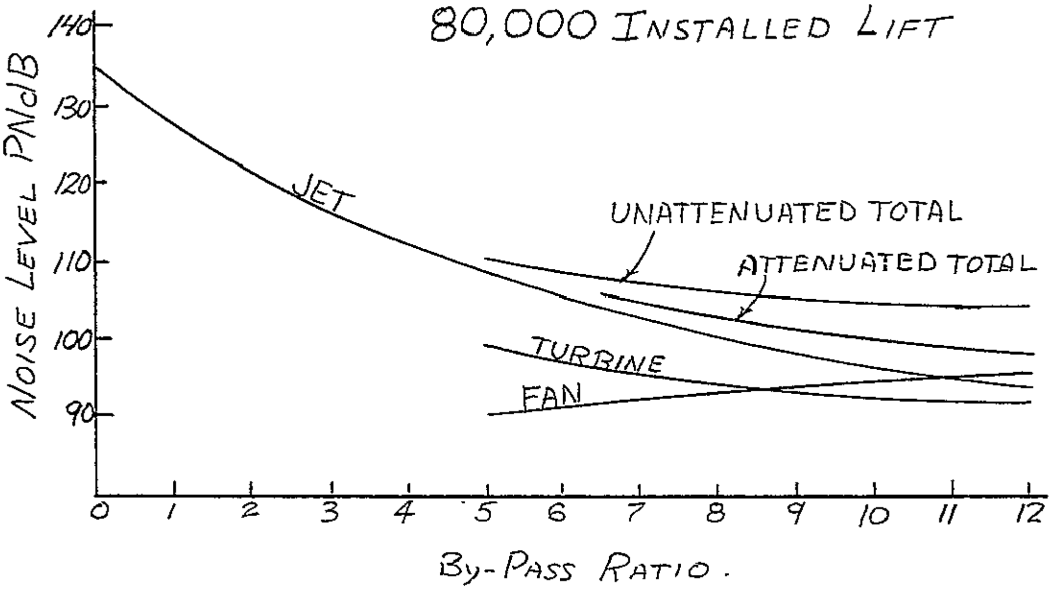


Figure 6-9

EFFECT OF BY-PASS RATIO ON NOISE LEVEL AT 500 FT
(Reference 6-30)

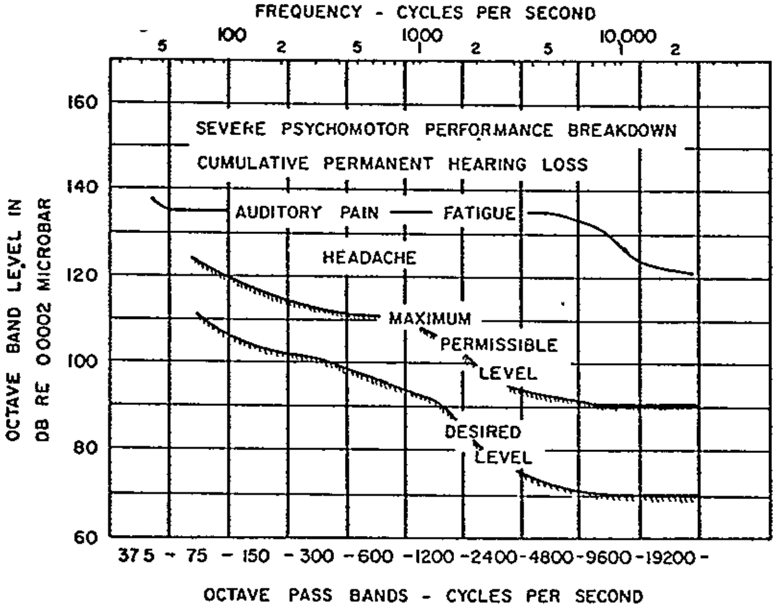


Figure 6-10

RECOMMENDED NOISE LIMITS ON HUMANS IN MANNED VEHICLES

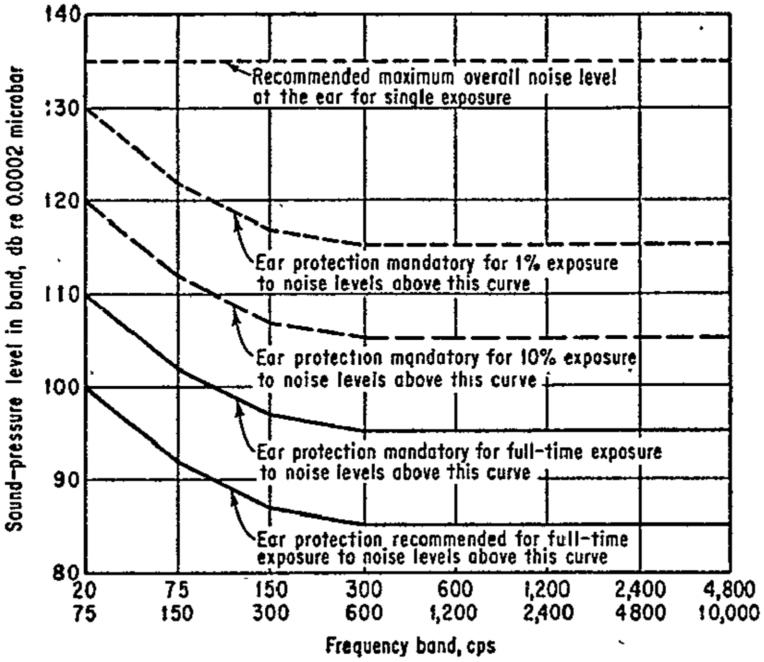


Figure 6-11

BROAD-BAND NOISE LEVEL EXPOSURES FOR WHICH CONSERVATION-OF-HEARING MEASURES ARE RECOMMENDED OR MANDATORY

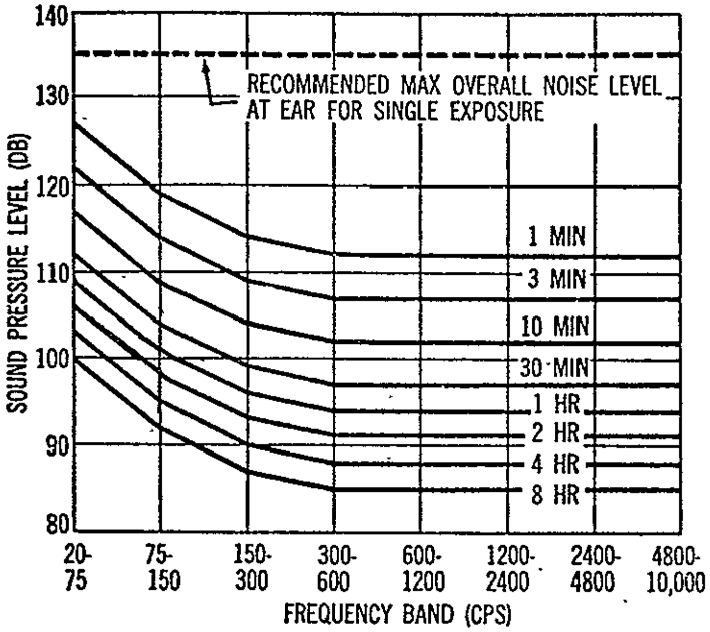


Figure 6-12

RECOMMENDED LIMITS OF CHRONIC EXPOSURE TO NOISE

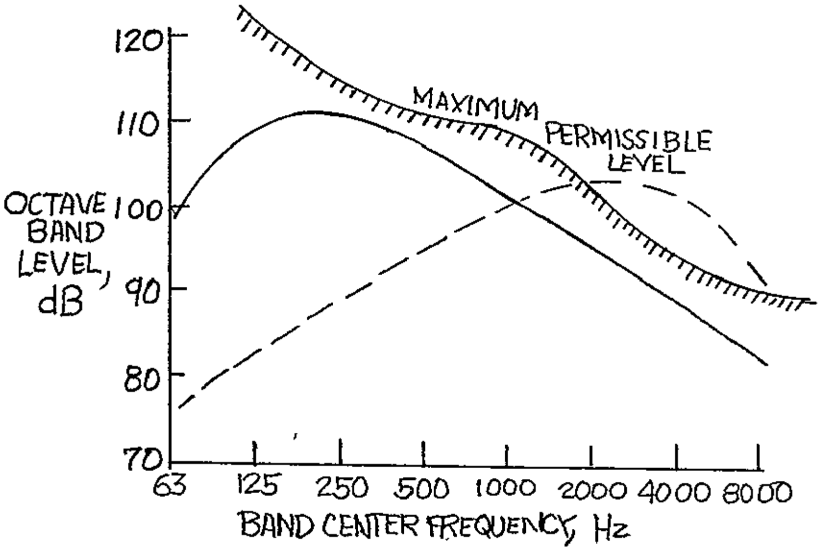


Figure 6-13

SPECTRUM SHAPES HAVING EQUAL PNdB

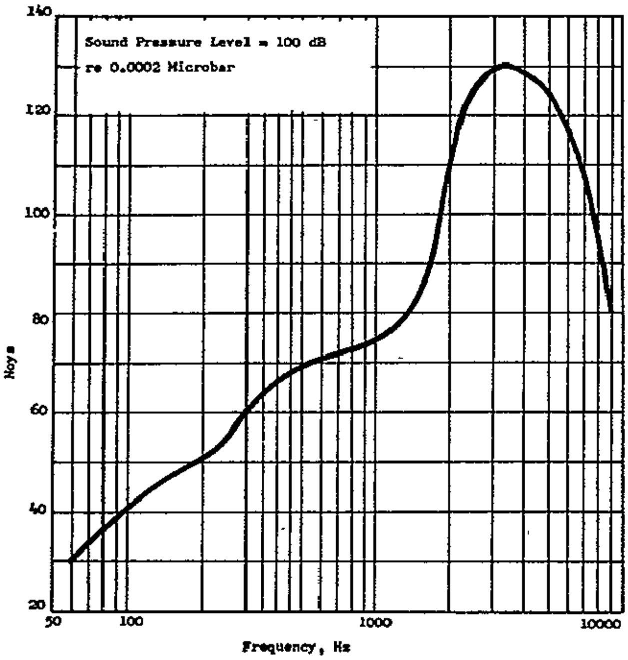


Figure 6-14

FREQUENCY DEPENDENCE OF NOISE ANNOYANCE

Experiments have shown that people exposed to noise judge the annoyance level to be between 40 and 90 PNdB, depending on whether he is an office worker, clerical worker, or what type noise background he is accustomed to. Similar experiments in a community have indicated the annoyance level of intermittent sound, such as that produced by aircraft, to vary between 50 and 90 PNdB. As stated by Kryter [6-2], the problem of community reaction to aircraft is, among other things,

> "(1) A Statistical Question - some people will be annoyed by sounds that others accept, and this in turn is influenced by what these individuals are doing from moment to moment. There is evidence, incidentally, that following an initial adjustment to and learning of the nature and meaning of one's noise environment people become less, rather than more, tolerant of continuous exposure to aircraft noise (Borsky, 4).
>
> (2) A Relative Matter - the seriousness and importance of annoyance due to aircraft noise will undoubtedly be influenced by, if not judged as, a matter of relative magnitude, that is, how does the jet aircraft noise envirnoment compare with the general noise environment or noise environment created by other sources of sound?
>
> (3) A Matter of Equities - this factor cannot be judged on a scientific basis but is a matter of opinion concerning the rights of individuals to be protected from nuisances and the welfare of the community as a whole".

An example of statistical data is presented in a plot given by Wilson [6-3], Figure 6-15. This data clearly shows that as the number of flights per day increases so does the annoyance. There is a large change in annoyance for 0 to 20 flights/day, and then only a slow asymptotic approach to some level above 20 flights/day.

Kryter offers a comparison between PNdB and scales of acceptability, intrusiveness, and noisiness as indicated in Figure 6-16. Hoehne and Luce [6-4] show that for wideband random noise that recognition level is 1/2 dB change for the SPL range of 30 dB to 100 dB. An interesting

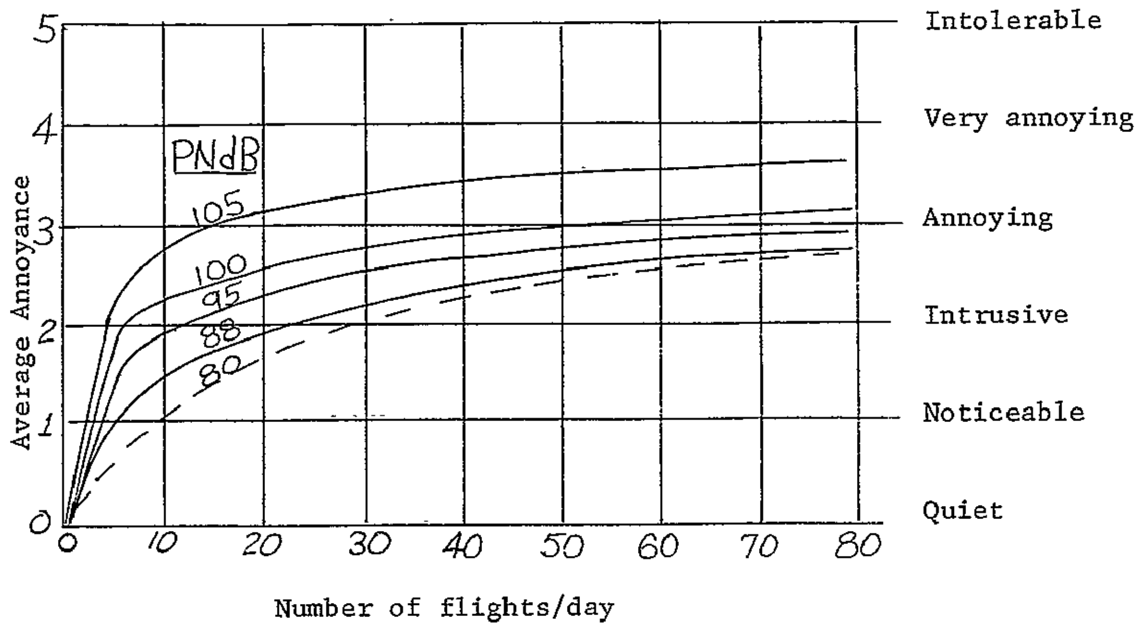


Figure 6-15

RELATIVE ANNOYANCE AS A FUNCTION OF PNdB AND NUMBER OF FLIGHTS/DAY

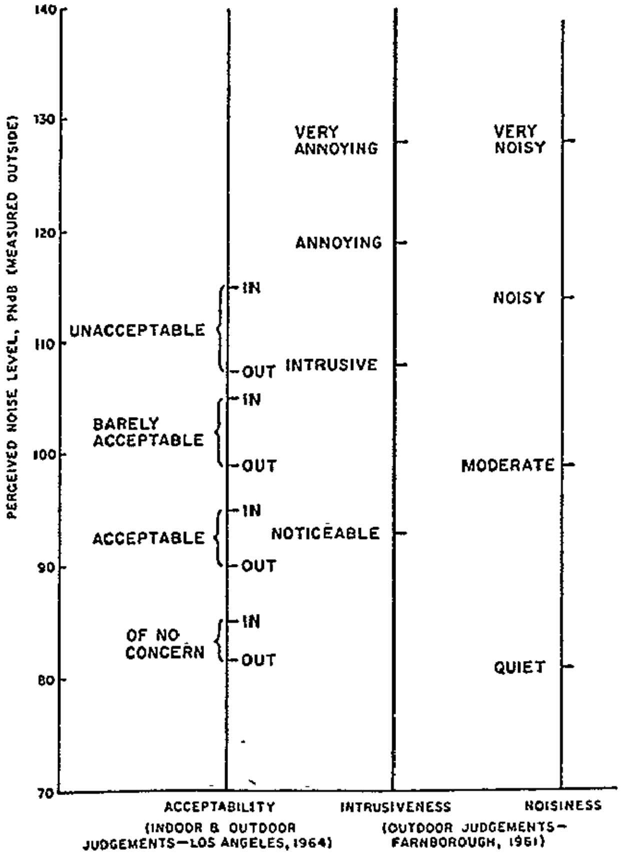


Figure 6-16

COMPARISON BETWEEN PERCIEVED NOISE LEVEL OF AIRCRAFT FLYOVERS WITH SCALES OF ACCEPTABILITY, INTRUSIVENESS, AND NOISE comparison could have been made if Wilson had included in his work the annoyance for various background levels.

Considering the third community reaction listed by Kryter, i.e., that of equities, he writes that the Port of New York Authority has set 112 PNdB as a maximum level for aircraft flyover. Similarly, the British Ministry of Aviation has set 110 PNdB for daytime aircraft operations and 100 PNdB at night.

In establishing the noise criteria for MAT, it was decided that the three criteria given by Kryter need to be met, i.e, (1) the "statistical question", (2) the "relative matter", and (3) the "matter of equities". Figures 6-15 and 6-16 summarize the statistical question. To answer the relative question, an additional 1/2 dB is the recognition level over the everyday noise levels. In order to establish everyday noise levels measurements were made

(a) inside several vehicles (Figure 6-17),

(b) around Bayshore Boulevard and downtown San Francisco (Figure 6-18), and

(c) at the various sites where MAT terminals would be located (Figure 6-19).

It was decided that for the MAT aircraft over flying an urban area a level of 80 PNdB should not be exceeded. Thus, the "statistical question" and "relative matter" are satisfied. The 80 PNdB allows 30 flights/day, and on the basis of the 1/2 dB recognition above background noise, is exceeded only at Oakland-Piedmont and at Berkeley Pier. For both of these locations the increased noise level would not be critical.

On the question of equities no limits have been established, but if the 112 PNdB from New York or the 110 and 100 PNdB from Britain

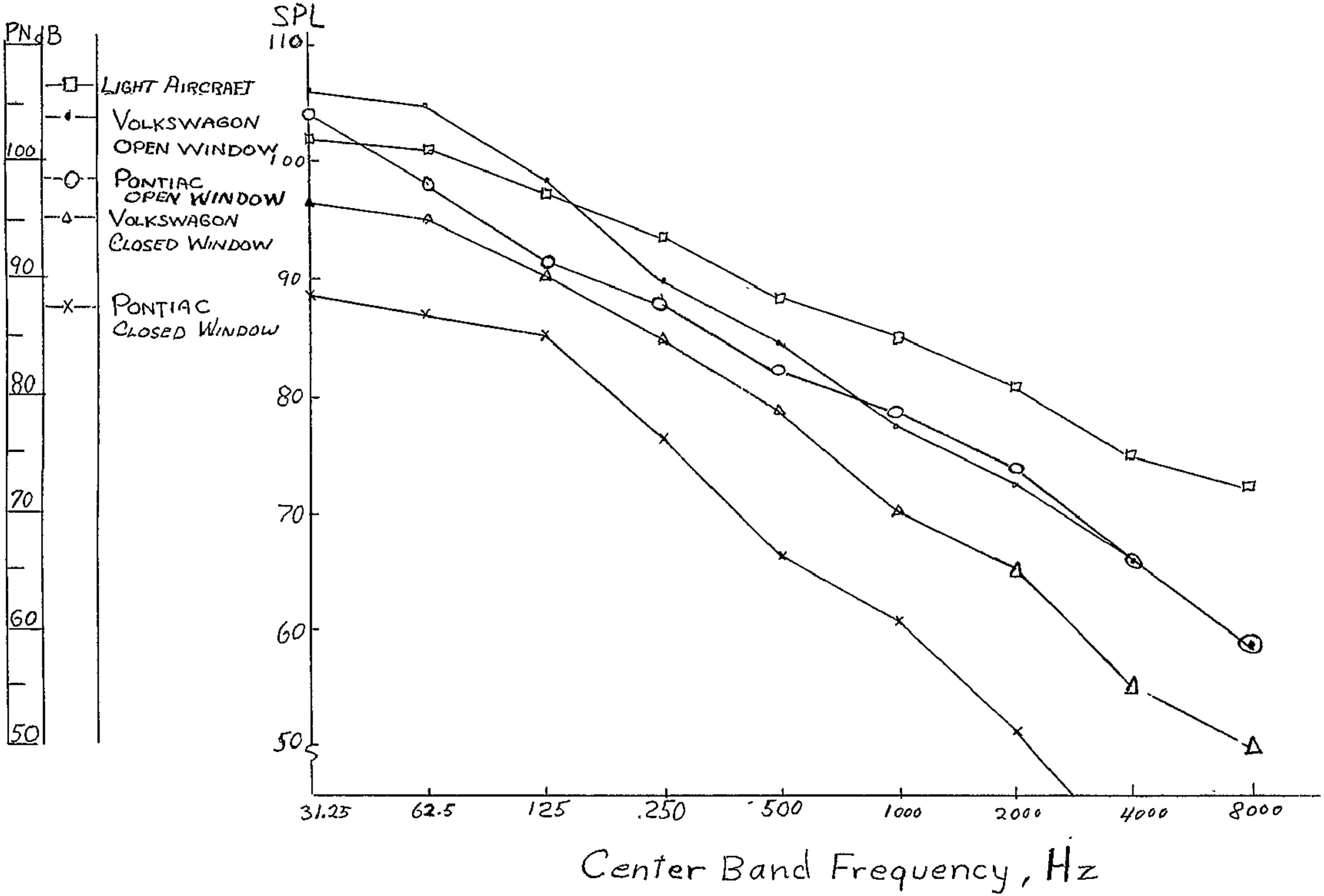


Figure 6-17

MEASURED NOISE LEVELS INSIDE VARIOUS VEHICLES GIVING BOTH FREQUENCY DISTRIBUTION AND PNdB FOR EACH

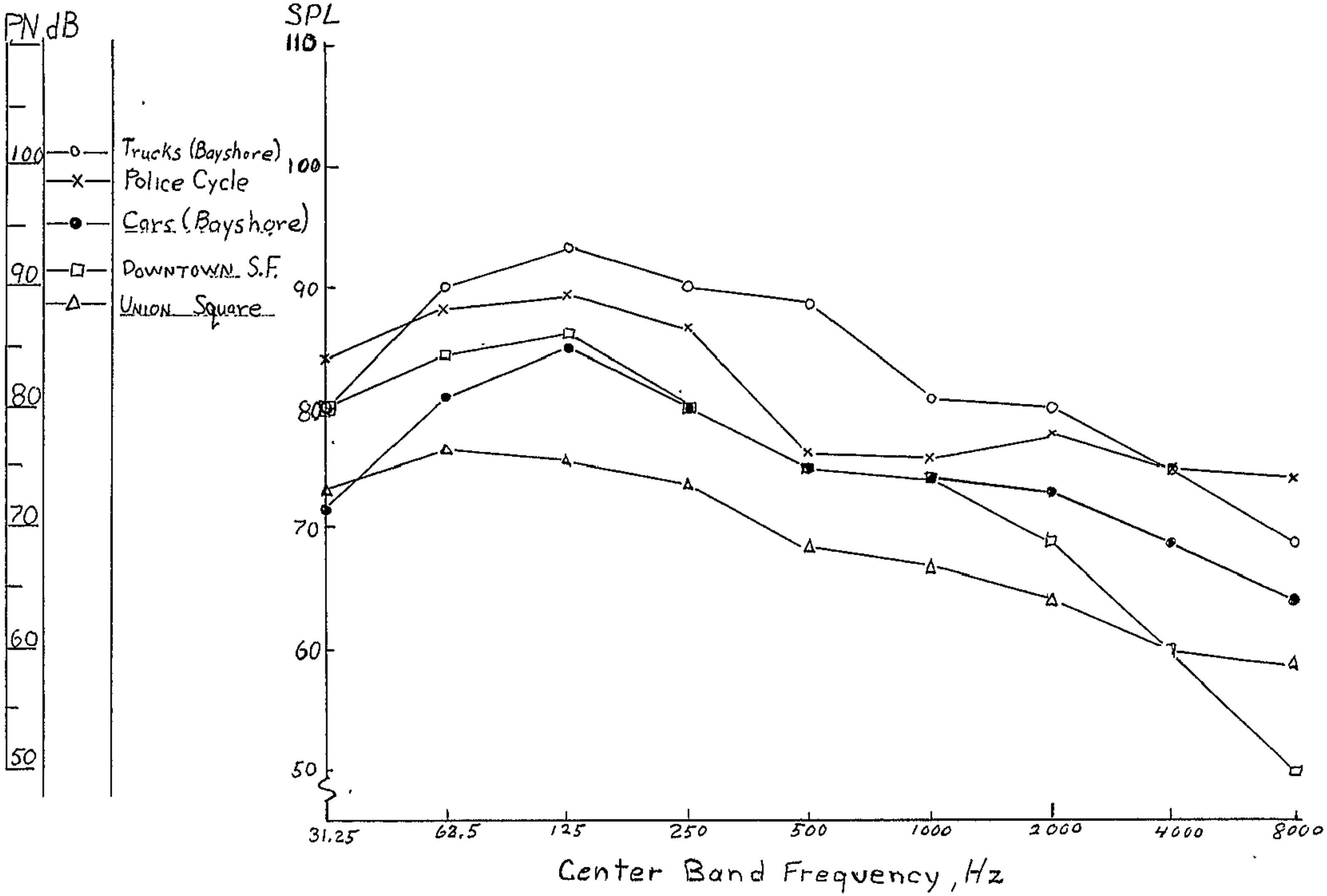


Figure 6-18

NOISE LEVELS AROUND BAYSHORE FREEWAY AND
DOWNTOWN SAN FRANCISCO

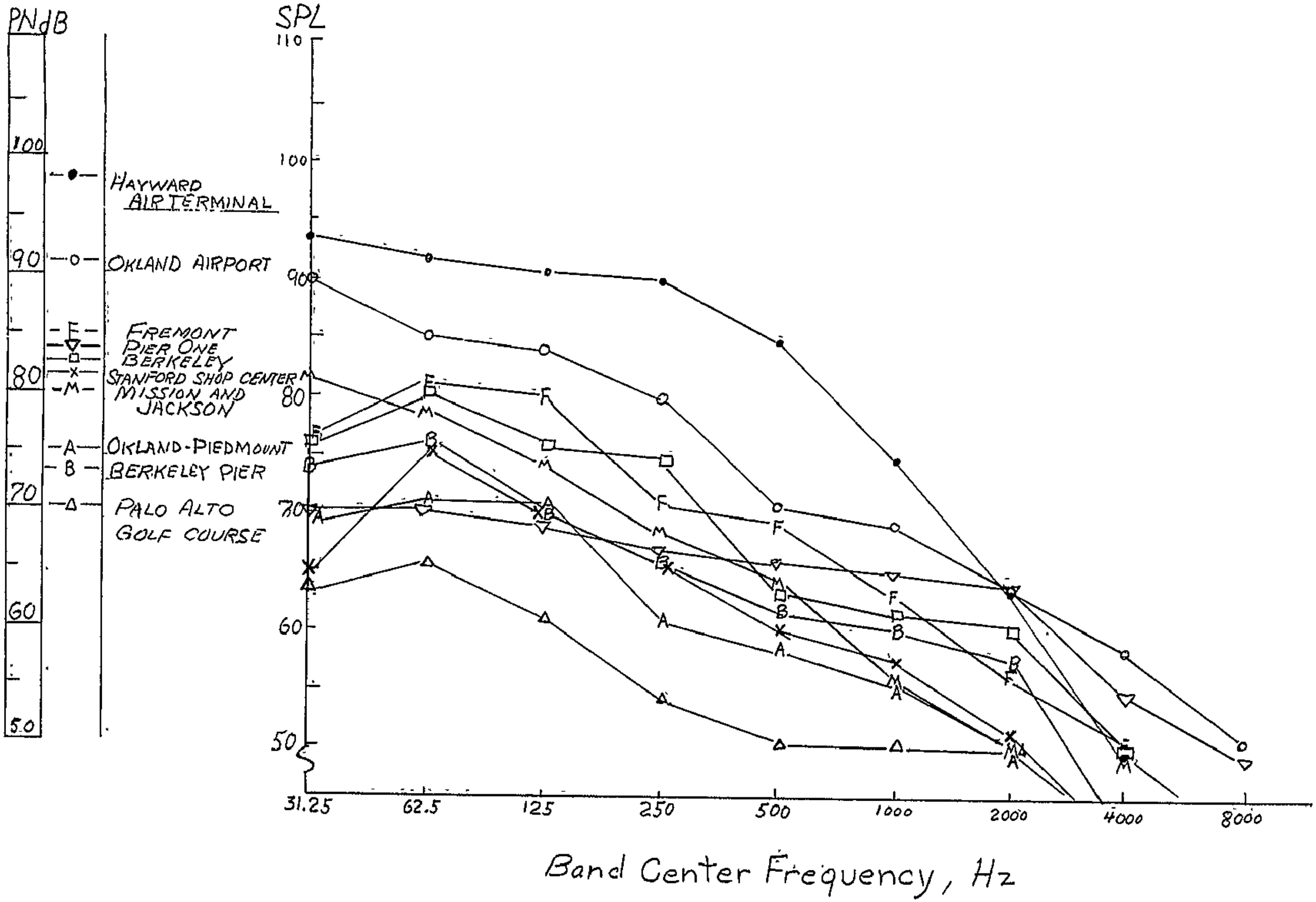


Figure 6-19

NOISE LEVELS AROUND PROPOSED TERMINAL SITES
WITH A GOLF COURSE FOR REFERENCE

are any indicators of such limits, then certainly the MAT level of 80 PNdB would more than suffice.

A critical problem of the MAT system is the noise level in the proximity of the terminals. With current technology it appears that the proposed compound helicopter will have a noise level of about 93 PNdB within 500 feet of its takeoff point and, neglecting atmosphere attenuation, about 87 PNdB at 1,000 feet from its takeoff point. For 50% atmospheric humidity and a mean temperature of 70° F an attenuation is attainable by grass and trees, as shown in Figure 6-20. Figure 6-21 shows some measurements of the attenuation of traffic noises by a small earth ridge parelleling the freeway with an Oleander hedge on top.

If a specification were to be set for the maximum noise level near the takeoff location of MAT aircraft, it is recommended that this be set at 95 PNdB at a horizontal distance of 500 feet from the takeoff point.

6.1.3 Present Noise Levels of Aircraft

In the study of the noise produced by present aircraft there is so much data available that if combined it would be a report itself. In fact, the available information is so scattered that it would indeed be a worthwhile project for some agency to collect and compile all the available technical information on aircraft noise. For the purpose of this report only present V/STOL aircraft will be discussed, and then just briefly. Many of the aircraft companies have written reports for NASA on the subject of short-haul V/STOL aircraft, and most of these reports include the noise aspects. Fry and Zabinsky [6-5] of Boeing

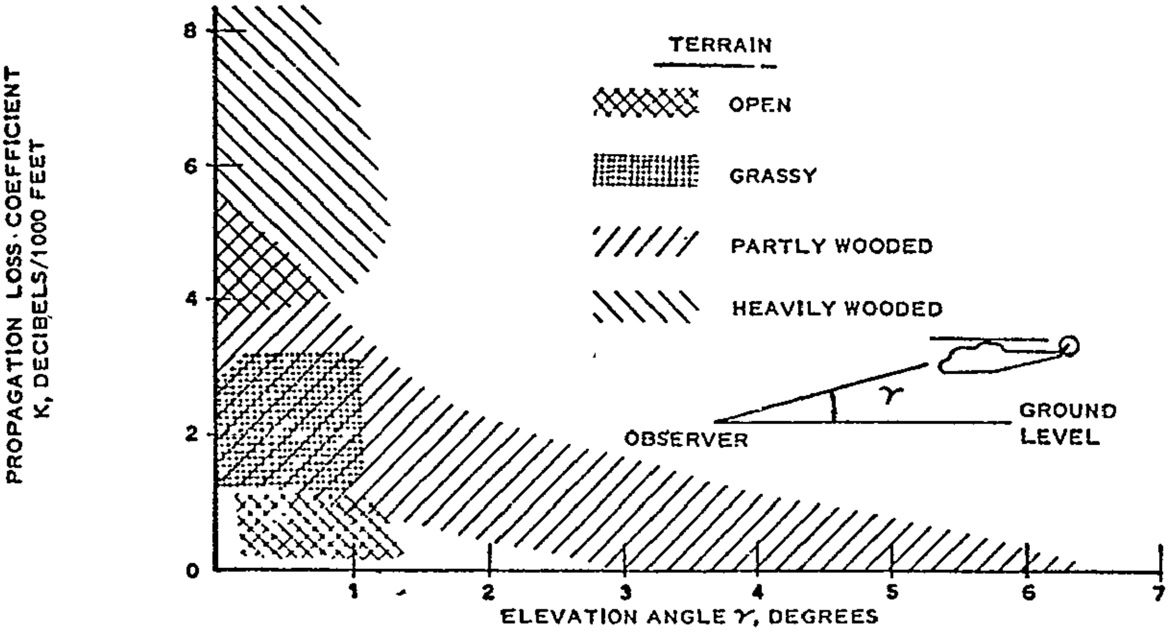


Figure 6-20

EFFECT OF TERRAIN AND ELEVATION ANGLE ON NOISE PROPAGATION

Company give the overall PNdB levels of V/STOL aircraft (Figures 6-22 and 6-23). K. R. Marsh [6-6] of Ling-Temco-Vought, Inc. gives the noise signature-foot of various V/STOL aircraft, both for landing and takeoff. Marsh also gives noise levels for various V/STOL aircraft, but as a function of distance (Figure 6-24). D. Maglieri, D. Hilton, and H. Hubbard [6-7] also give a good account of V/STOL aircraft noise, and give a comparison of noise for various V/STOL configurations (Figure 6-25).

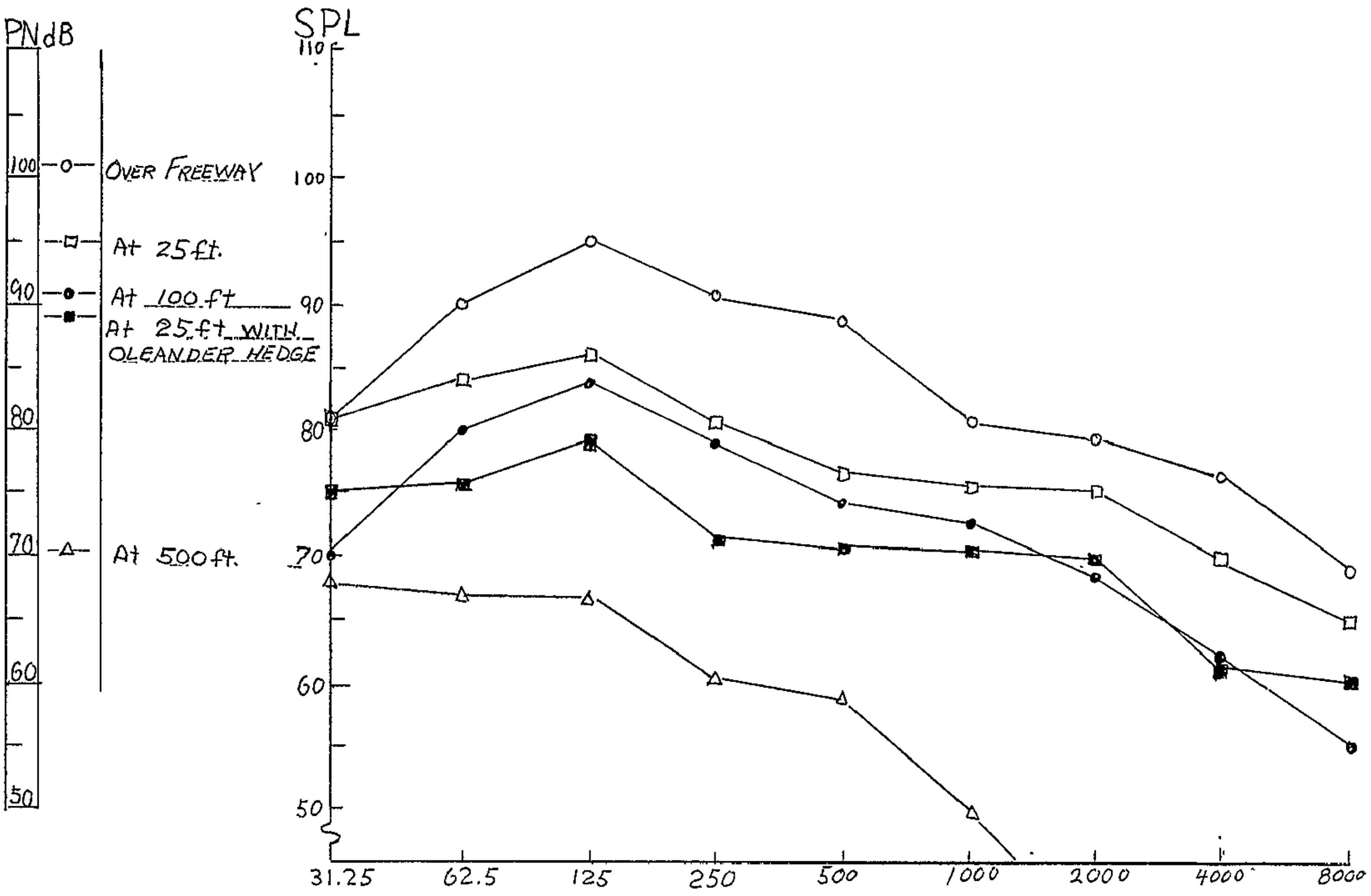


Figure 6-21

EFFECT OF AN EARTH RIDGE OF 6 FT HEIGHT COVERED WITH OLEANDER
(All measurements made around Bayshore Freeway)

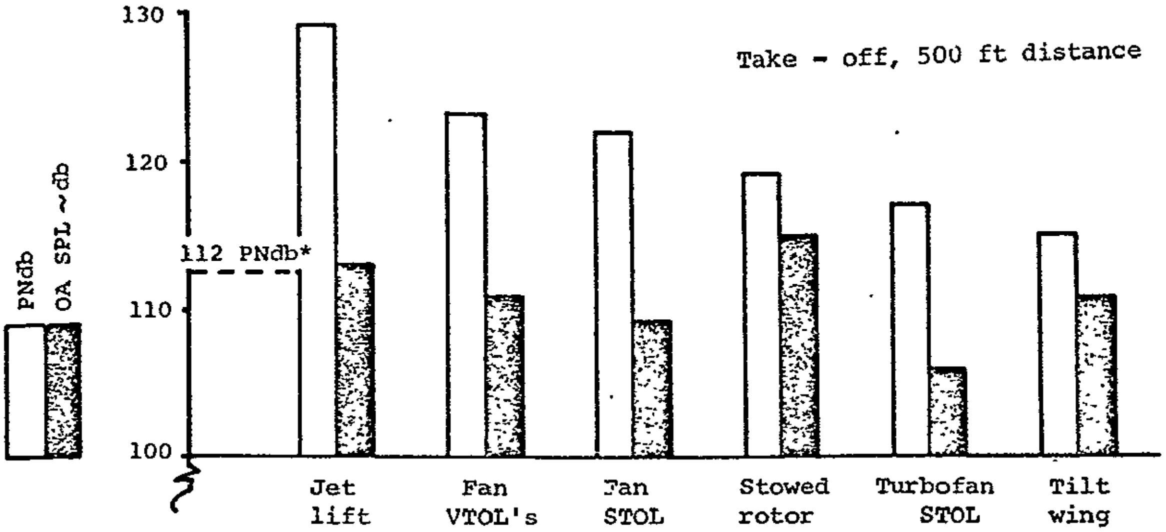


Figure 6-22

OVERALL SOUND PRESSURE LEVELS AND PERCEIVED NOISE LEVELS AT TAKEOFF

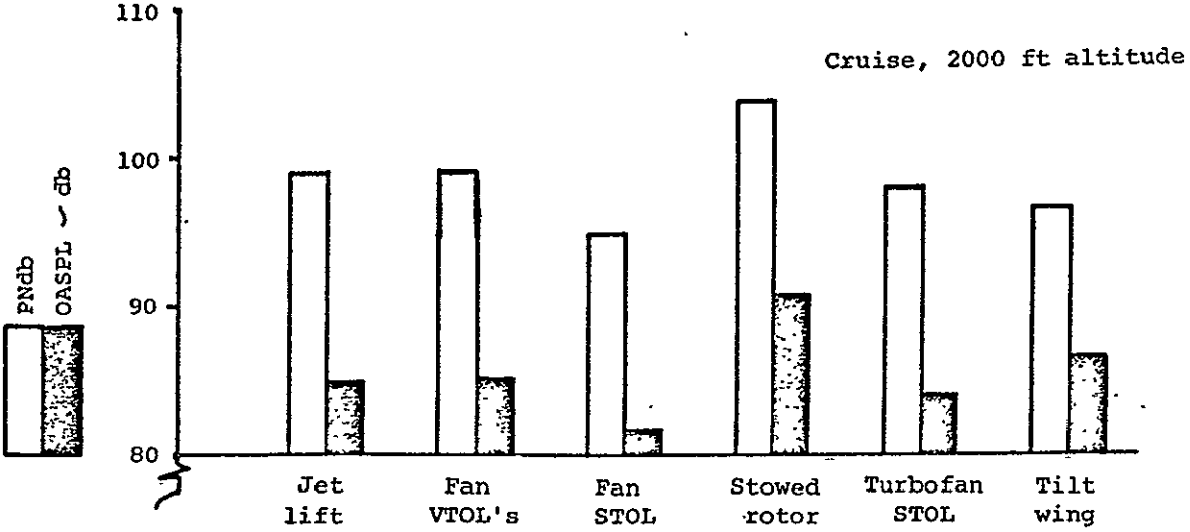


Figure 6-23

OVERALL SOUND PRESSURE LEVELS AND PERCEIVED NOISE LEVEL IN CRUISE

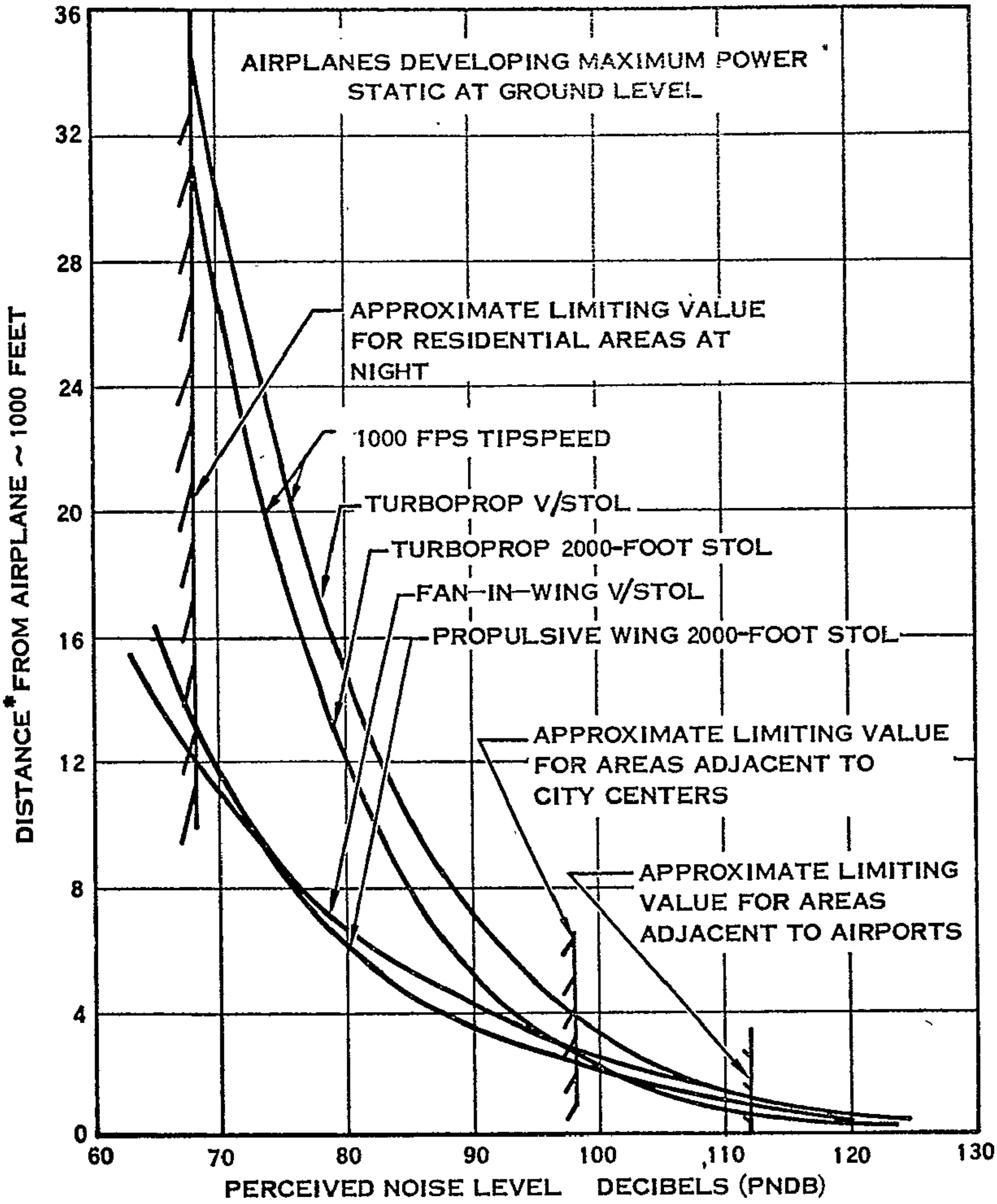


Figure 6-24

PERCEIVED NOISE LEVEL VS DISTANCE*

Note: Distance is measured at the angle at which the maximum PNdB occurs, measured radially from the airplane.

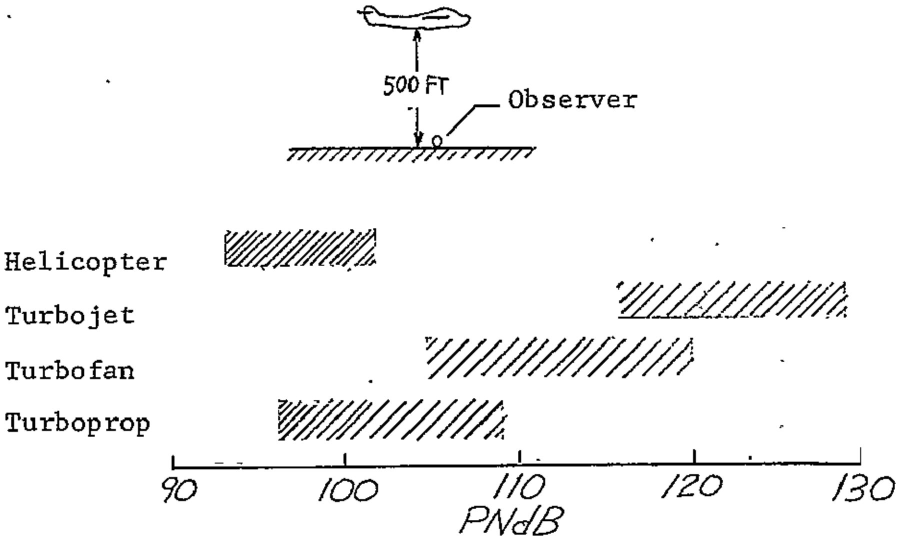


Figure 6-25

RANGE OF NOISE LEVELS OF V/STOL CONFIGURATIONS
(payload = 9,500 lb)

In addition to the work on V/STOL aircraft, there is a great deal of information on each type of aircraft. References 6-8 to 6-14 deal with studies of helicopter noise. References 6-15 to 6-20 deal with rotor, propeller, and fan noise, including methods for calculating the noise levels. Ollderhead and Lawson [6-21] also describe methods of noise estimation and reduction.

Noise Reduction. Perhaps more significant to MAT is not just the present noise of aircraft, but present noise reduction programs which promise major noise reduction in the future.

David Hickey [6-22] describes programs of noise reduction in ducted propellers and fans. Figure 6-26 shows the effects of rotor blade tip shape, and Figure 6-27 shows the effect of owl wing leading

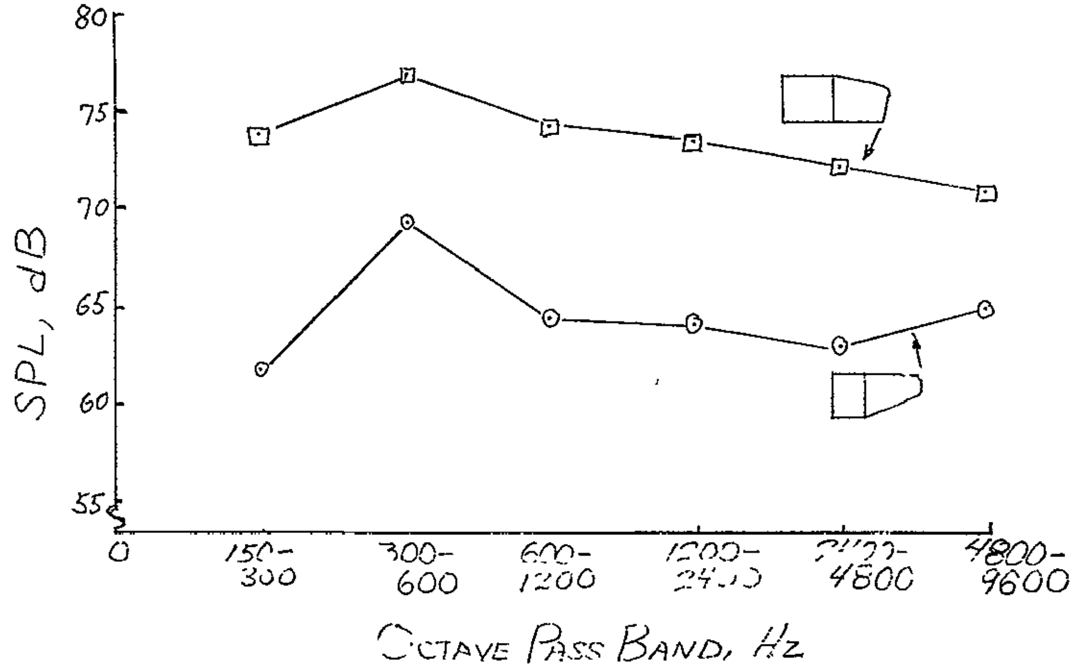


Figure 6-26

EFFECT OF HELICOPTER ROTOR TIP PLANFORM MODIFICATION

edge. The above was for rotors, but Figure 6-28 (effect of stator lean), Figure 6-29 (effect of number of vanes), and Figure 6-30 (effect of rotor-stator spacing) show measures that promise to reduce fan noise. Cheney [6-23] addresses aircraft engine noise and shows work being conducted at Boeing to suppress jet noise. Hochne and Luci [6-4] offer means of reducing noise using present technology through measures such as lower tip speeds and lower jet velocity by using more blades or higher by-pass engines. Hubbard, Maglieri, and Copeland [6-24] also show the noise reductions due to higher by-pass ratios, and show that a 5 dB reduction was obtained by having the wings between the engine and the measuring point.

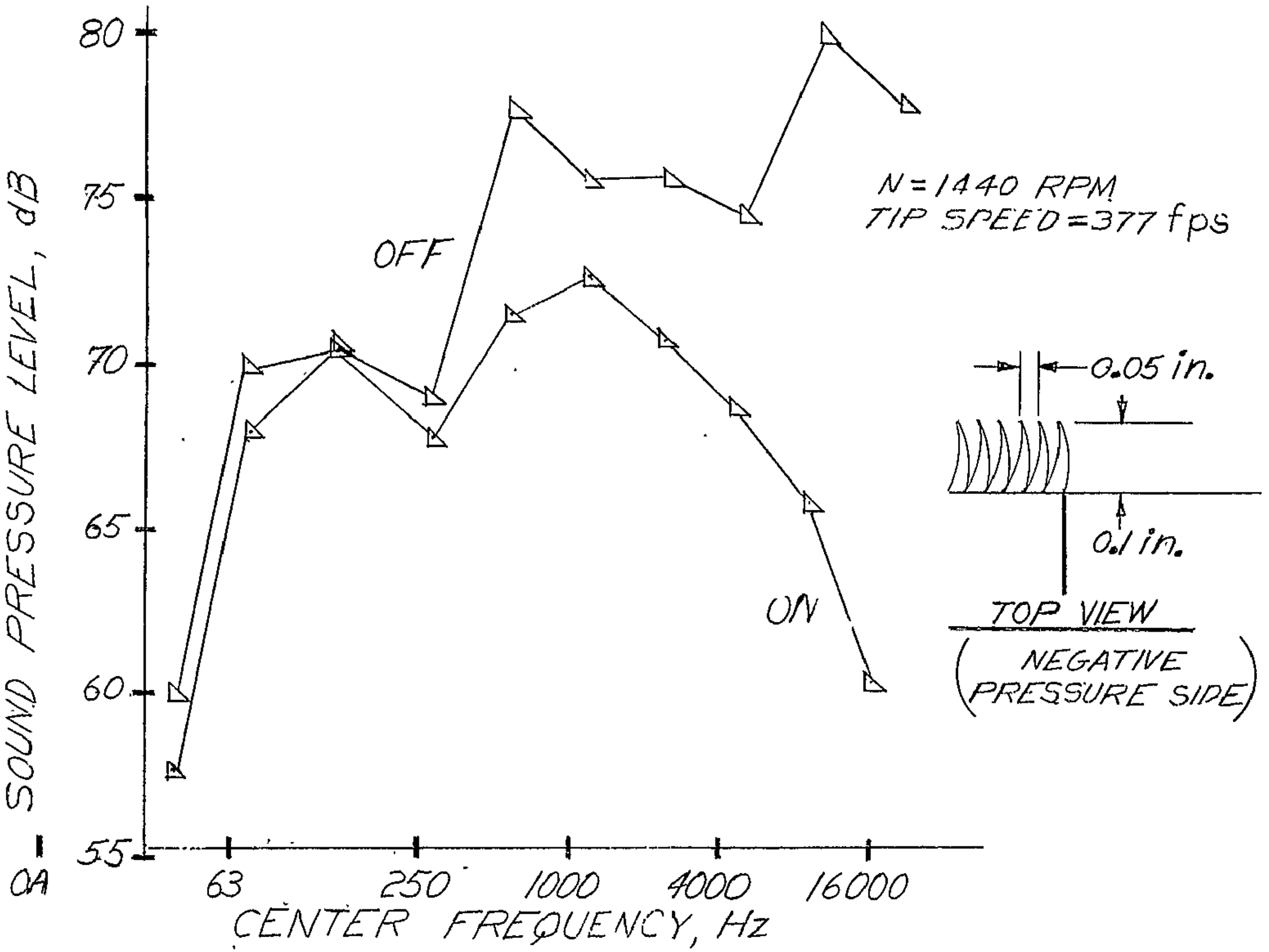


Fig. 27-EFFECT OF OWL WING LEADING EDGE ON NOISE SPECTRUM B=10°

Fig. 6-28 EFFECT OF STATOR LEAN

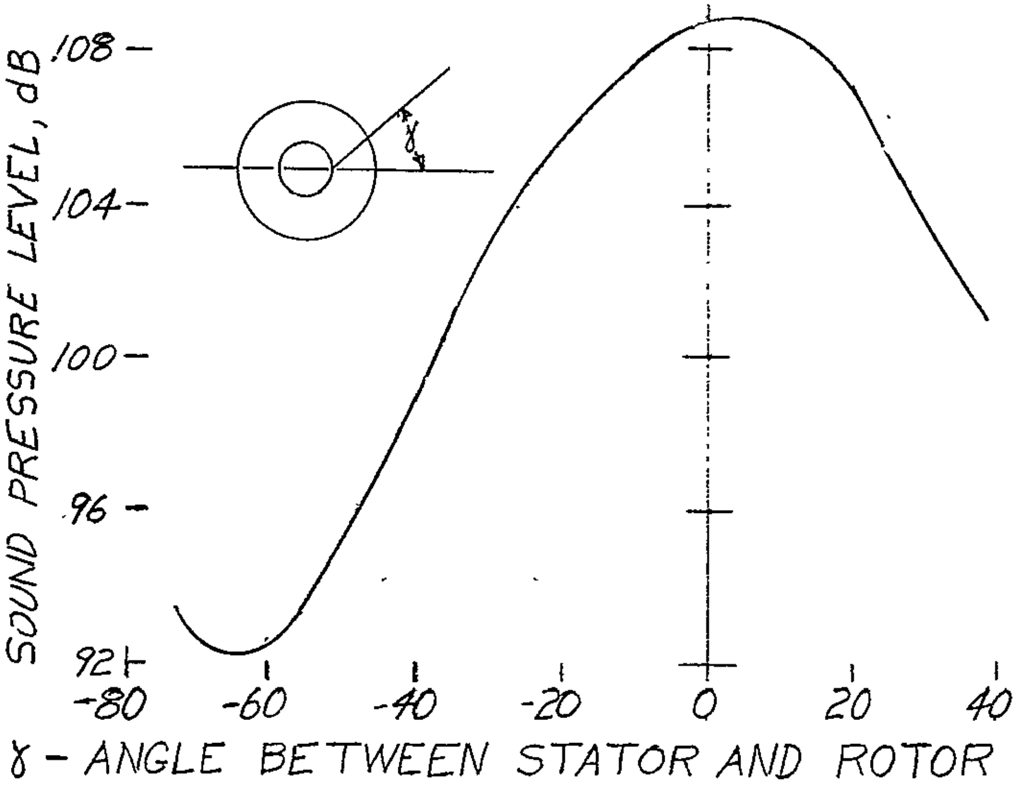
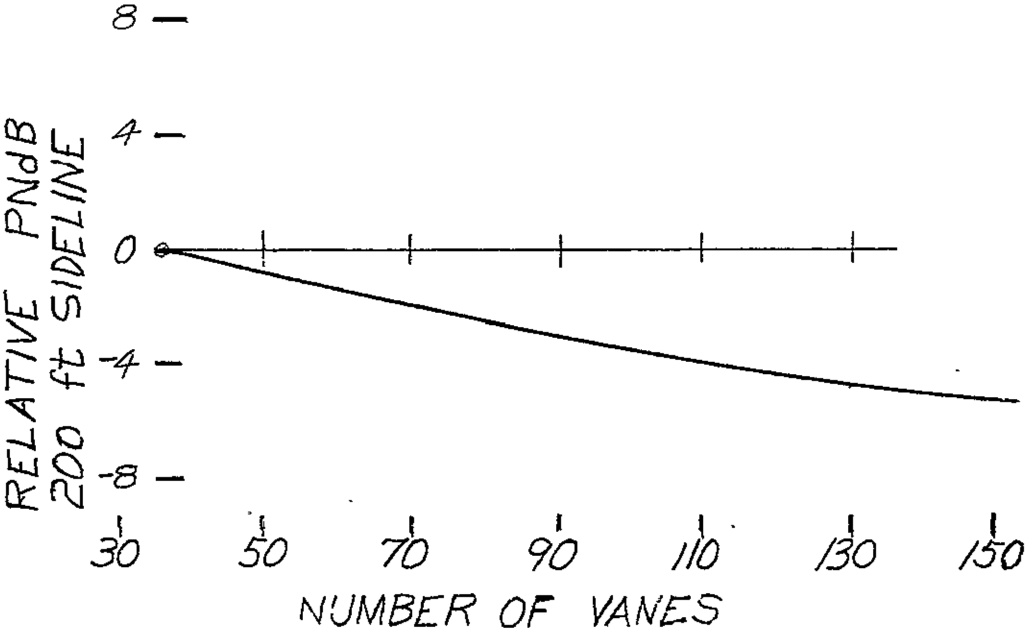


Fig. 6-29 PERCEIVED NOISE LEVELS VS NUMBER OF VANES, DOWNSTREAM STATOR



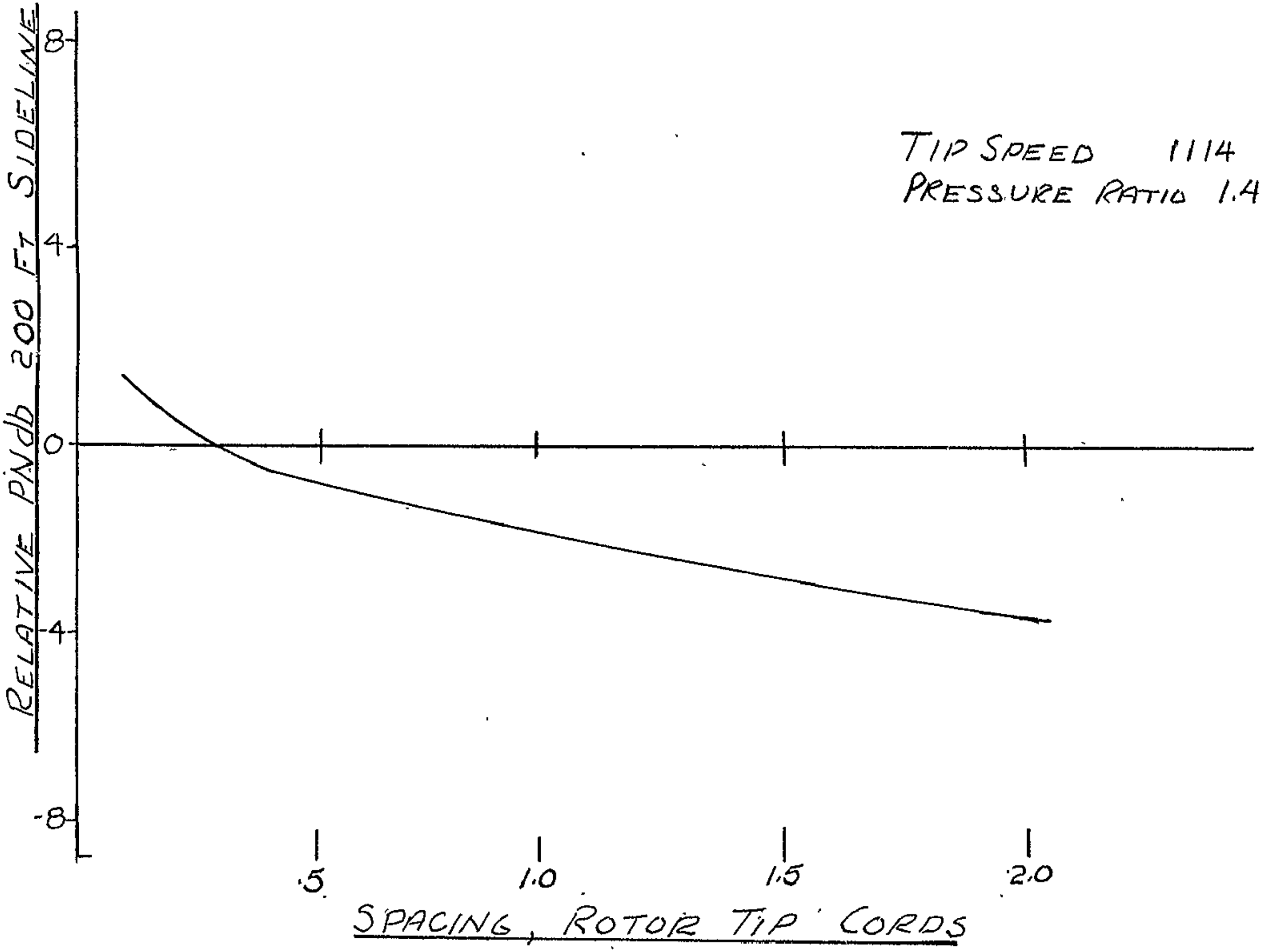


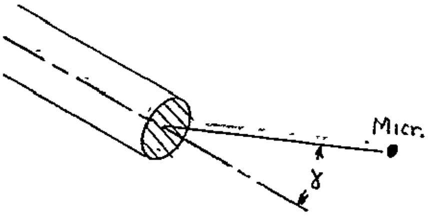
Figure 6-30 Effect of Rotor-Stator Spacing

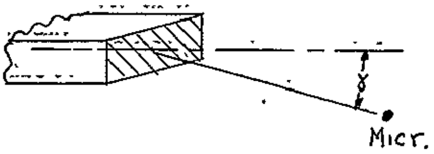
Finally, there is a lot of work being done to eliminate or reduce noise at the terminal (as opposed to that at the source). Parillin and Miller [6-25] discuss the prospects for a quieter metropolitan environment, and Rogers, Lovi, and Hall [6-26] describe ground jet suppression fences.

6.1.4 Needed Research and Development for Further Noise Reduction

It is evident from the preceding discussion that there is a great need for further noise reductions in almost all phases of aircraft. For cruising flight the further needed noise reductions are not as great, but they must be reduced at the source. For the takeoff and landing phase, further research is needed both with noise deflection and absorption systems on the ground, as well as on the aircraft.

One of the promising techniques which needs to be explored further for jet-propelled rotors is to discharge the jet at the tip of the rotor through narrow slits instead of a circular orifice. Maglieri and Hubbard [6-27] give some preliminary measurements of the noise characteristics of jet-augmented flaps. This data was converted to PNdB, and Figure 6-31 shows that by shifting the frequency contents of the jet noise to higher frequency the PNdB level is reduced from 80 PNdB to 75 PNdB for a slit with a width to gap ratio of 200. It is even further reduced to 64 PNdB when the slit is followed by a trailing edge flap. A desirable research project would be to compute the noise level of a jet-propelled helicopter rotor applying the method of sources and doublets pioneered by Gutin [6-28] for propellers. If such theoretical studies indicate promise, a more extensive experimental investigation of jet-propelled rotors for the MAT aircraft would be warranted.





Size	γ = 52°	γ = 90°
D = 1.0	80 PNdB	73 PNdB
w/h = 200	75 PNdB	65 PNdB

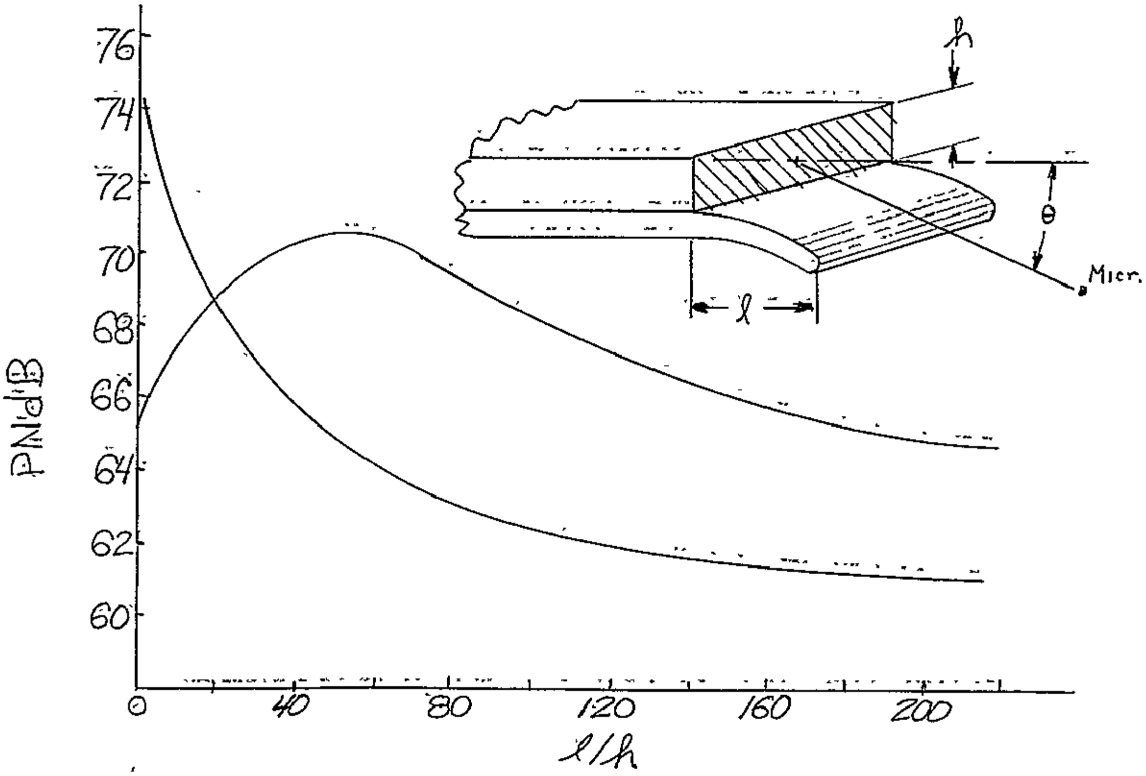


Figure 6-31

EFFECT UPON NOISE LEVEL OF USING THIN RECTANGULAR JETS INSTEAD OF A CIRCULAR JET OF SAME THRUST

Similarly, further theoretical and experimental investigation is needed to gain a better understanding of noise phenomena such as the "owl wing" effect, the effects of tip blade shape, and the acoustical fences for airport boundaries.

Some other "blue-sky" suggestions which have been made include studies of

(1) the feasibility of providing short-circuit acoustical paths through a water spray region to an attenuator, and

(2) gratings under VTOL aircraft takeoff areas to duct the jet and its associated noise to an attenuator region.

Further suggestions for noise research are given in Chapter 3.

6.2 Other Environmental and Human Factors (Accelerations, rate of pressure change, cabin atmosphere, windows)

Current airlines expose passengers to 0.159 to 0.20 g during acceleration, and up to 0.5 g during braking with controlled "jerk" (that is, a small rate of change of acceleration). These same limits are acceptable for the MAT system. It should be noted that the helicopter, during its normal mode of landing and takeoff, inclines its fuselage such that the resultant acceleration (including gravity) is nearly normal to the seats. Thus, the accelerations do not pose any special problem in the MAT system.

The typical MAT flight profile extends to only 2,000 feet of altitude above the surface, and thus there is no need to provide pressurization for breathing purposes. Since the potential rate of climb of the MAT aircraft is up to 2,000 ft/min it is, however, desirable to provide for a pressurization of about 1 psig so as to avoid discomfort during rapid ascents or descents. Above 2,000 feet altitude change it will be necessary to reduce the rate of climb to about 500 ft/min and to limit the descent so that the passengers are not exposed to an apparent rate of pressure change corresponding to 300 ft/min descent.

The cabin will be air-conditioned. In view of the many doors and frequent stops, this system will need to be designed with a larger capacity then normal aircraft. A total of 12 to 15 ft^3/min of fresh air per person will be provided.

To avoid a feeling of isolation, external windows will be provided in the doors. Also, openings will be provided in the partitions to provide through flow of air and visual contact. The openings in the partitions will be large enough to permit emergency egress.

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CHAPTER 7

MARKET AND OPERATIONS ANALYSIS

7.1 Delineation of Study Area

The development of the San Francisco Bay region as a metropolitan center began during the gold rush more than a century ago. While the present commercial district of San Francisco provided most of the needs during the early days, additional settlements soon appeared along the shoreline of the Bay. At one point during the second half of the nineteenth century, San Francisco, Oakland, Alameda, and Berkeley accounted for more than three-fourths of California's urban population.

Such is no longer the case, of course, as urban development has spread over much of the state. Specifically, in the Bay area this development pattern has virtually encircled the Bay, and it is not unusual to find people who work in downtown San Francisco and live 50 or 60 miles away.

The urban core of the area today remains in San Francisco; however, another core is developing around San Jose. Outside these highly developed areas are the rapidly-growing suburban areas--which include the peninsula between San Francisco and San Jose, western Santa Clara County, southern Alameda County, central Contra Costa County, and eastern Marin County. The remaining large urban center, which has developed during the past decade, is the Walnut Creek-Concord area of Contra Costa County.

Although more than a million people have been added to the Bay region's population during the last ten years, the regional pattern of development has not changed substantially. For the next five to ten years, it is anticipated that the nine counties in the Bay area (see Figure 7-1)

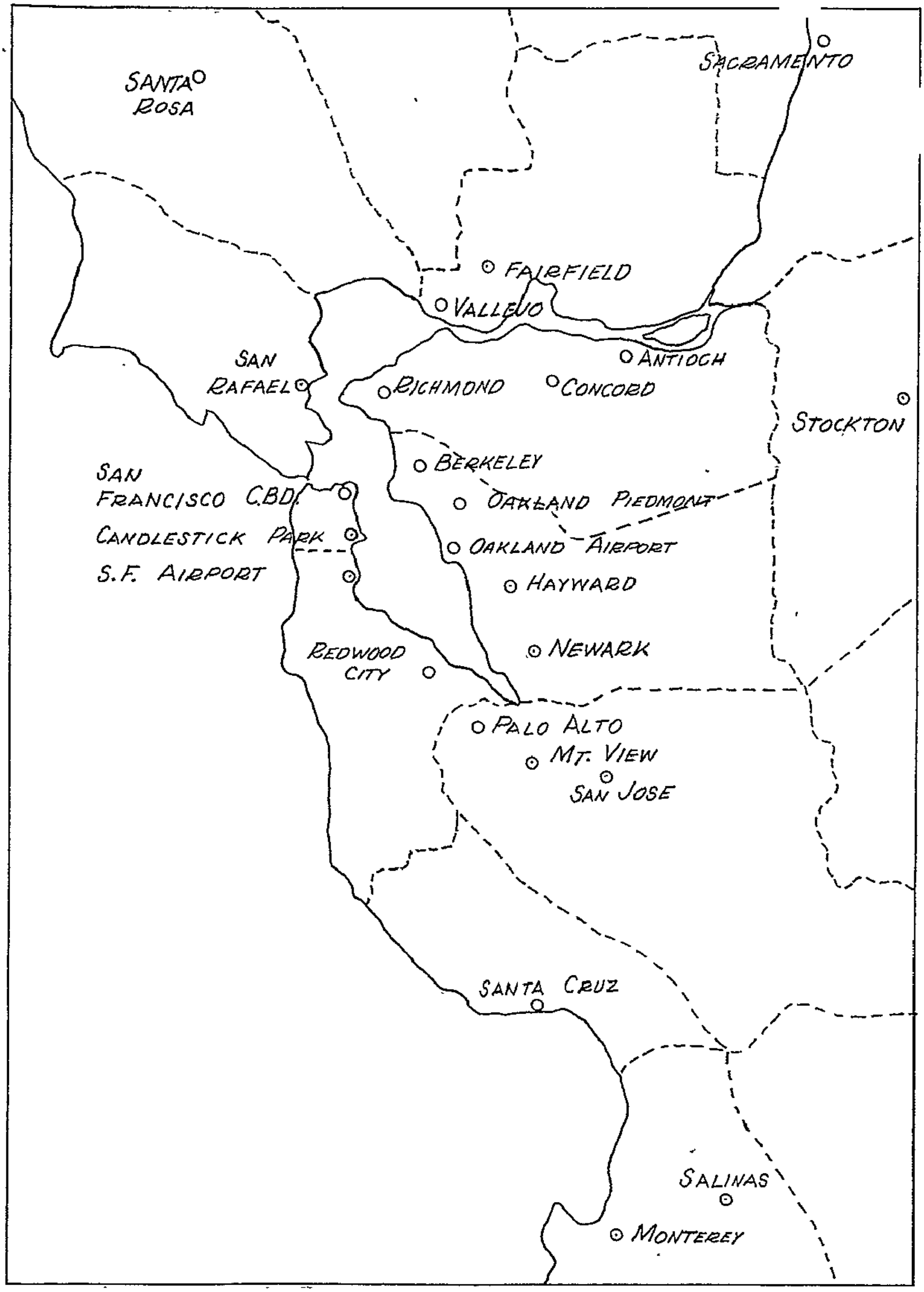

FIGURE 7-1 GENERAL TERMINAL SITES

will continue their growth and development at the present accelerated rates. Starting in the 1980's the bulk of new growth is predicted to shift to the North Bay counties. Forecasts of population growth rates shown in Table 7-1 are based on the Association of Bay Governments' population projections for the entire Bay area and for each of the individual counties.

A look in Table 7-2 at the division of land suitable for urban development indicates there are approximately 7,000 square miles almost equally divided between the North and South Bay areas. Unfortunately, because of location, slope, drainage, elevation, or ownership, only about half of the area is suitable for urban development. Up to the present time the availability of land has had little effect upon population distribution. More than 85% of the population is concentrated in the South Bay counties.

Population and land use data projections suggest that growth of the area beyond 1980 will force many residents to move further from the urban core if they are desirous of residing in relatively low-density areas. To this end it is conceivable that in the 1980's many people will commute to work in the San Francisco central business district (c.b.d.) from as far away as Salinas, Monterey, Stockton, or Sacramento. To accomplish such a trip by automobile or any rapid transit system capable of implementation within the next decade will require a prohibitive amount of time. Indeed, some type of air commuter service may be the only answer for an influence area as widely dispersed and geographically limited as the Bay region.

Project personnel selected the nine-county Bay area as the

Table 7-1

PROJECTED POPULATION FOR THE BAY REGION

	1970	1980	1990
Alameda	1,150,000	1,350,000	1,505,000
Contra Costa	605,000	860,000	1,138,000
Marin	232,000	330,000	450,000
Napa	87,000	117,000	150,000
San Francisco	760,000	815,000	850,000
San Mateo	600,000	745,000	860,000
Santa Clara	1,033,000	1,290,000	1,500,000
Solano	180,000	220,000	254,000
Sonoma	220,000	344,000	500,000
Bay Region	4,869,000	6,071,000	7,207,000

Table 7-2

BAY AREA LAND SUITABLE FOR URBAN DEVELOPMENT

	Area Sq. Miles	% of Total Land Area	% Bay Area Population
Bay Area	6,976	100.0%	100.00%
South Bay	3,289	47.1	85.7
Alameda	738	10.6	23.2
Contra Costa	740	10.6	12.0
San Francisco	45	.6	16.3
San Mateo	461	6.6	12.0
Santa Clara	1,305	18.7	22.0
North Bay	3,687	52.9	14.2
Marin	521	7.5	4.5
Napa	760	10.9	1.7
Solano	827	11.9	3.7
Sonoma	1,579	22.6	4.2

site for this study for several reasons. In addition to its obvious proximity to the staff's location at Palo Alto, it has the following advantages:

(1) With a population of 4.5 million people it comprises a large enough area to have a unique commuter problem.

(2) Now under construction in three of the nine counties is the only rapid transit system (BART) to be undertaken in this country in the past half century. As a result excellent data, including origin-destination projections to 1975, are available.

(3) Geographically, the Bay area is uniquely unsuited for good land transportation. Because the urban core is surrounded on three sides by water, ground access is limited to a relatively small number of high-capacity transportation facilities.

(4) Participants were able to visit existing transport facilities in the Bay area as well as interview individuals responsible for the planning and operation of these facilities.

(5) If the methodology developed in this study appears to be sound, it could be modified to help solve the growing commuter problem in other metropolitan areas of the nation.

For preliminary planning and design purposes the study area was delineated to include all the cities that might reasonably generate commuters to the San Francisco c.b.d. during the 1980-1990 period--viz., the nine counties listed in Table 7-1 and 7-2 plus Sacramento, San Joaquin, Santa Cruz, and Monterey Counties. General terminal locations, which were selected to serve this 13-county area, are shown in Figure 7-1. In addition to the 23 suburban terminals listed, one or more downtown terminals in the San Francisco c.b.d. were envisioned in the early stages of the study. Selection of the suburban terminals was based upon 1980 trip generation predictions from the 21 major cities in the area.

7.2 Trip Generation Model

In order to estimate the size of the aircraft fleet necessary to serve the needs of a metropolitan area, a reasonable estimate of the demand is required. The number of passengers who wish to go from each terminal to any other terminal, together with the distribution of demand over the day, is required as input to a simulation of the air transit system.

One possible approach to determining the demand is to collect data on the origins and destinations of commuters now travelling in the area and extrapolate this data forward in time to the period of interest. The Bay Area Rapid Transit Authority has made available data derived in this manner for thousands of origin-destination pairs in the Bay area. For several reasons this approach was dropped in favor of a simpler dynamic model: (1) The short time available made digesting the BART data unattractive, (2) most of the BART data is concerned with destinations in the San Francisco central business district and does not provide information on flow between other cities, and (3) the impact of future transportation sustem developments is not clearly delineated.

The trip generation model divides the potential passengers into two classes: (1) persons travelling between their homes and jobs, shopping, entertainment, and (2) persons travelling between their homes and major airports.

The metropolitan area is divided into N centers of residences and M centers of employment. For the commuter part of the model, E_i, the number of people who work at center i and R_j, the number of workers who live at center j is known from predictions on population growth

(Ref. 7-1). In order to determine F_{ij}, the number of people who work at center i and live at center j, imagine a job-hunting process described by the following dynamic model:

$$\dot{e}_i = - \sum_{j=1}^{N} f_{ij} \; , \; e_i(0) = E_i; \; i = 1,2,\ldots,M \qquad (7\text{-}1)$$

$$\dot{r}_j = - \sum_{i=1}^{M} f_{ij} \; , \; r_j(0) = R_j; \; j = 1,2,\ldots,N \qquad (7\text{-}2)$$

$$f_{ij} = e_i a_{ij} r_j \qquad (7\text{-}3)$$

$$F_{ij} = \int_0^\infty f_{ij} dt \qquad (7\text{-}4)$$

where e_i (t) is the number of jobs unfilled at time t at center i

r_j (t) is the number of workers unemployed at time t at center j

f_{ij}(t) is the rate of filling jobs at center i with workers who live at center j

a_{ij} is the "accessibility" of center i from center j.

The a_{ij} are influenced by several factors such as travel time between centers, the relative desirability of centers i, the characteristics of the trip and many other psychological factors. In this simple model the a_{ij} were assumed to be a function of the distance between the centers

$$a_{ij} = c/d_{ij}^{q} \qquad (7\text{-}5)$$

This accessibility function is suggested for use in a static model described by Martin [7-1] with a value for the exponent, q, of 2.2.

The numerical integration of the differential equations (7-1) and (7-2) was accomplished by an error-controlled, variable-interval, predictor-corrector scheme based on the approximations,

Predictor:

$$y(h_2) = y(0)+ah_1y'(-h_1)+bh_1y'(0)+ch_1^2y''(-h\ )+dh_1^2y''(0)+eh_1^5y^v\theta \tag{7-6}$$

$$\rho = h_2/h_1 \tag{7-7}$$

$$a = \rho^3(\rho+2)/2 \tag{7-8}$$

$$b = \rho - a \tag{7-9}$$

$$c = \rho^3(3\rho+4)/12 \tag{7-10}$$

$$d = \rho^2(3\rho^2+8\rho+6)/12 \tag{7-11}$$

$$e = \rho^3(6\rho^2+15\rho+10)/720 \tag{7-12}$$

Corrector:

$$\begin{aligned} y(h) &= y(0)+hy'(h)/2 + hy'(0)/2 + h^2y''(0)/12 - h^2y''(h)/12 \\ &\quad + h^5y^v(\theta)/720 \end{aligned} \tag{7-13}$$

This scheme is very stable, with small truncation error, and provides a good error estimate, properties which are essential for the successful integration of the model.

The center designations, together with their estimated 1980 employment, housing units, and population are shown in Table 7-3. The results of the job-hunting model are shown in Table 7-4. Since the total employment of the area is greater than the number of housing units,

Table 7-3

CHARACTERISTICS OF CENTERS OF POPULATION IN THE BAY AREA

Code		Housing	Employment	Population	d_{ii}
SFO	San Francisco International Airport	31,000	38,568	96,000	5.0
OAK	Oakland International Airport	24,000	49,810	77,338	2.5
SJO	San Jose Municipal Airport	130,000	140,006	446,696	3.0
FRY	Ferry Building, San Francisco	170,000	360,000	405,000	3.0
SAC	Sacramento	113,000	189,145	353,000	8.0
CDP	Candlestick Park, San Francisco	150,000	350,000	400,000	2.6
RWC	Redwood City	36,000	34,755	105,000	4.0
MTV	Mountain View	26,000	40,281	75,000	4.0
PAL	Palo Alto	43,000	74,896	140,000	3.0
OKP	Oakland-Piedmont	134,000	234,142	373,000	3.0
CON	Concord	21,000	18,783	79,000	5.0
SAL	Salinas	6,000	7,000	50,000	3.0
MON	Monterey	5,000	6,000	40,000	5.0
NWK	Newark-Fremont	53,000	28,323	188,000	6.5
HWD	Hayward	46,000	38,380	166,000	3.0
BRK	Berkeley	40,000	68,936	116,000	3.0
SPO	San Pablo-Richmond	29,000	46,178	99,000	3.0
SRL	San Rafael	20,000	25,000	60,000	3.5
SKT	Stockton	41,000	61,469	133,000	4.0
VLJ	Vallejo	21,000	33,977	65,000	3.5
SRA	Santa Rosa	16,500	25,000	50,000	5.0
FRF	Travis AFB--Fairfield	5,000	8,000	25,000	5.0
ANT	Antioch	5,000	9,000	25,000	3.0
SCZ	Santa Cruz	5,000	4,000	40,000	4.5

Table 7-4

TOTAL COMMUTER DAILY FLOW, HOME-TO-JOB (100's per day)

	SFO	OAK	SJO	FRY	SAC	CDP	RWC	MTV	PAL	OKP	CON	SAL	MON	NWC	HWD	BRK	SPO	SRL	SKT	VLJ	SRA	FRF	ANT	SCZ
SFO	170	9	2	83	2	135	24	5	14	28	2	0	0	4	5	7	4	2	1	2	1	0	0	0
OAK	4	198	1	22	1	20	2	1	3	99	2	0	0	2	15	11	3	1	0	1	0	0	0	0
SJO	22	10	1320	220	28	179	12	90	30	47	6	2	3	32	6	25	18	14	4	12	3	6	4	7
FRY	9	9	2	1683	1	912	3	1	3	73	1	0	0	1	3	21	11	7	1	2	0	0	0	0
SAC	2	2	1	13	1750	10	1	1	1	6	3	0	0	1	1	3	3	2	11	4	3	6	3	0
CDP	12	7	2	746	1	1574	3	1	3	46	1	0	0	1	3	10	5	3	0	1	0	0	0	0
RWC	59	8	5	55	2	65	170	17	144	21	2	0	0	11	6	6	3	2	1	2	1	0	1	0
MTV	10	4	24	45	3	42	11	184	49	12	1	0	0	15	3	5	3	2	1	2	1	1	1	1
PAL	18	5	9	32	2	34	80	43	428	13	1	0	0	14	5	4	2	1	1	1	0	0	0	0
OKP	11	98	3	150	3	112	5	3	6	1561	7	0	0	4	14	157	19	5	1	5	1	0	1	0
CON	4	9	1	44	7	31	1	1	2	37	123	0	0	2	3	28	15	4	2	11	1	3	8	0
SAL	0	0	0	7	8	5	0	0	0	1	0	63	5	0	0	1	1	1	0	1	0	1	0	0
MON	0	0	0	8	8	5	0	0	0	1	0	3	48	0	0	1	1	1	0	1	0	1	0	0
MWK	32	26	21	166	12	152	22	44	47	66	9	1	1	161	29	25	13	8	4	7	2	3	4	2
HWD	19	89	5	77	4	74	10	7	14	82	7	0	0	28	285	20	7	3	2	4	1	1	2	0
BRK	3	12	1	61	2	36	1	1	2	182	5	0	0	1	3	294	31	5	1	4	0	0	1	0
SPO	2	4	1	48	2	26	1	1	2	13	4	0	0	1	1	42	274	15	1	13	1	1	1	0
SPL	2	2	0	63	2	32	1	1	1	30	2	0	0	1	1	10	23	159	1	7	1	1	0	0
SKT	1	1	1	14	30	10	0	1	1	4	2	0	0	1	1	3	3	2	580	3	1	2	3	0
VLJ	1	2	0	19	4	12	1	0	1	9	4	0	0	1	1	8	17	6	1	246	2	3	1	0
SRA	1	0	0	11	4	7	0	0	0	2	1	0	0	0	0	2	2	2	0	3	229	1	0	0
FRF	0	0	0	6	7	4	0	0	0	2	1	0	0	0	0	2	2	1	1	4	1	48	1	0
ANT	0	1	0	4	3	3	0	0	0	2	3	0	0	0	0	1	1	0	1	1	0	1	57	0
SCZ	1	0	1	18	6	13	0	1	1	2	0	0	1	0	0	2	2	2	0	2	0	1	0	27

R_j, the number of workers living at center j, was determined from the following formula:

$$R_j = (\sum_i E_i)H_j/(\sum_j H_j) \qquad (7\text{-}14)$$

where H_j is the number of housing units at center

After the number of people who work at center i and live at center j has been determined from the trip generation model, it is necessary to estimate how many of them will ride the air transit system. It is reasonable to assume that the ratio of those using the air transit system to the total travelling between centers is a function of the travel time between centers. This ratio should be low for short distances and nearly 1 for long distances. Such a ratio can be approximated by $1-e^{-(d_{ij}/d_o)^2}$ The conservative assumption is made that even at long distances not all people will ride the air transit service; this is reflected by multiplying the above ratio by $\rho(<1)$. This very approximate procedure could be improved upon but it is surely conservative. In Table 7-5 are shown the estimated number of air transit passengers who live at center j and work at center i, T_{ij}. These numbers have been obtained from Table 7-4 using the formula

$$T_{ij} = \rho(1 - e^{-(d_{ij}/d_0)^2})F_{ij} \qquad (7\text{-}14)$$

where $\rho = 0.25$ and $d_o = 30$ miles.

An additional source of customers for the air transit system is the traveller going to one of the large international airports in the area. Because of the phenomenal growth in air travel expected by 1980

Table 7-5

PASSENGER FLOW HOME-TO-JOB

(TENS PER DAY)

	SFO	OAK	SJO	FRY	SAC	CDP	RWC	MTV	PAL	OKP	CON	SAL	MON	NWK	HWD	BRK	SPO	SRL	SKT	VLJ	SRA	FRF	ANT	SCZ	
SFO	0	6	4	44	5	42	5	5	7	18	3	0	0	4	3	7	5	4	2	3	1	1	1	0	170
OAK	3	0	2	12	2	11	2	2	3	10	1	0	0	2	2	3	2	1	1	2	0	0	0	0	61
SJO	38	18	0	484	69	379	13	24	22	95	14	4	7	19	8	56	43	35	10	29	7	14	10	8	1406
FRY	5	5	4	0	3	36	3	2	5	21	2	0	0	2	3	7	5	3	1	3	1	0	1	0	112
SAC	4	4	2	34	0	26	2	2	3	15	6	0	0	3	2	8	7	5	23	10	7	10	6	0	179
CDP	4	4	4	30	2	0	2	2	4	16	1	0	0	2	2	5	3	2	1	2	1	0	0	0	87
RWC	13	6	6	61	6	57	0	7	11	22	3	0	1	6	4	9	6	4	2	4	2	1	1	1	233
MTV	10	5	6	85	8	72	5	0	8	21	3	1	1	5	3	10	7	5	2	4	1	2	2	1	267
PAL	9	5	7	46	5	42	6	7	0	17	2	0	1	5	3	7	4	3	2	3	1	1	1	1	178
OKP	7	9	6	44	6	38	5	4	8	0	4	0	0	4	6	13	8	4	3	5	2	1	1	0	178
CON	6	6	2	55	16	43	2	2	3	23	0	0	0	3	2	13	10	6	5	9	3	4	4	0	217
SAL	1	0	1	19	19	12	0	0	0	2	0	0	2	0	0	2	3	3	0	3	1	2	0	1	71
MON	1	0	0	20	19	13	0	0	0	2	0	1	0	0	0	2	3	3	0	3	1	2	0	1	71
NWK	31	19	12	265	29	222	12	16	17	74	13	2	3	0	8	37	24	16	10	16	5	7	7	3	848
HWD	13	11	6	76	11	66	6	7	9	34	7	0	1	8	0	15	9	6	5	7	2	2	3	1	305
BRK	3	4	2	21	4	18	2	2	3	15	2	0	0	2	2	0	5	3	2	3	1	1	1	0	96
SPO	3	3	1	24	5	19	2	1	2	13	3	0	0	2	2	7	0	4	2	5	2	1	1	0	102
SRL	4	3	1	29	5	23	1	1	2	11	2	0	0	1	1	6	6	0	1	5	3	1	1	0	107
SPO	3	3	2	36	63	25	1	2	2	11	4	0	0	2	1	7	6	4	0	6	2	5	5	0	190
VLJ	3	3	1	25	10	19	1	1	2	11	3	0	0	1	1	6	6	4	2	0	3	2	1	0	105
SRA	2	1	0	25	10	18	1	0	1	6	2	0	0	1	0	4	4	4	1	5	0	2	1	0	88
FRF	1	1	0	13	12	9	0	0	0	4	2	0	0	0	0	3	3	2	1	3	2	0	1	0	57
ANT	1	1	0	8	6	6	0	0	0	3	1	0	0	1	0	2	1	1	2	2	1	1	0	0	37
SCZ	2	1	1	43	15	31	1	1	1	6	1	1	2	1	0	4	4	5	1	4	1	2	1	0	129
	167	118	70	1499	330	1227	72	88	113	450	79	9	18	74	53	233	174	127	79	136	50	62	49	17	5294

parking around large airports will become more difficult and more expensive. If the air transit system can deliver the traveller and his baggage directly to the main airport from a VTOL terminal with adequate parking near his home or place of business, he should make extensive use of this service.

The projected air travel originating in each of the Bay area counties with Los Angeles as a destination is shown in Table 7-6. These figures were apportioned among the Bay area centers of population on the basis of population. The fraction of the air travellers using the air transit was estimated considering the distance from the center to the major airport. These estimates are shown in Table 7-7.

Table 7-6

SAN FRANCISCO-LOS ANGELES AIR TRAFFIC POTENTIAL--1980

County	1,000 Annual Passengers[1]		Estimated Daily Passengers	
	Pass. Departure for L.A.	Arrivals from L.A.	For L.A.	From L.A.
Alameda	3,382	4,134	11,270	13,780
Contra Costa	1,786	2,184	5,920	7,280
Marin	1,586	1,938	5,290	6,460
San Francisco	4,203	5,138	14,010	17,130
San Mateo	1,978	2,417	6,590	8,057
Santa Clara	3,325	4,063	11,083	13,540
Sonoma				
Napa	2,847	3,479	9,490	11,597
Solano				
Bay area	19,107	23,353	63,643	76,844

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[1] Source: "STOL Passenger Demand Potential in the San Francisco Bay Area 1970--1980," Douglas Aircraft Company Report No. C1-804-SD 1098, January 1968.

Table 7-7

AIRLINE INTER-CONNECTION PASSENGER FLOW TO AIRPORTS PER DAY

From To	SFO	OAK	SJO	ALL MODES[†]	AIR NO.	COMMUTER %
SFO	0	480	120	6,120	600	1
OAK	150	0	30	1,800	180	1
SJO	740	700	0	14,400	1,440	1
FRY	1,110	900	220	14,900	2,230	15
SAC	200	160	40	1,000	400	40
CDP	1,310	1,050	260	13,100	2,620	20
RWC	710	570	140	7,100	1,420	20
MTV	290	230	60	2,880	580	20
PAL	470	380	100	4,750	950	20
OKP	500	400	100	10,000	1,000	10
CON	220	180	50	4,500	450	20
SAL	200	160	40	1,000	400	40
MON	200	160	40	1,000	400	40
NWK	400	320	80	4,000	800	20
HWD	350	280	70	3,500	700	20
BRK	220	180	50	3,000	450	15
SPO	620	500	130	6,250	1,250	20
SRL	,060	850	210	10,600	2,120	20
SKT	400	320	80	2,000	800	40
VLJ	950	760	190	9,500	1,900	20
SRA	,440	1,150	290	7,200	2,880	40
FRF	450	360	90	2,270	900	40
ANT	160	130	30	1,080	320	30
SCZ	200	160	40	1,000	400	40
Total	12,350	10,380	2,460	132,950	25,190	

[†] Data from Table 7-6 adjusted according to following assumptions:

(1) San Francisco-Los Angeles air travel in 1980 will account for one half of all air travel to and from the San Francisco area.

(2) County data from Table 7-6 is divided among the areas served by Air Commuter terminals on the basis of population to get column labeled "ALL MODES."

(3) An assumed percentage of "ALL MODES" is assigned to Air Commuter based upon factors such as distance from residential area to airport and parking convenience at commuter terminal.

(4) Air commuter travel is apportioned to the three airline terminals on the following basis:

SFO - 50%
OAK - 40%
SJO - 10%

A significant characteristic of the passenger demand described above is its non-uniformity over the day. The flow of persons going to work is strongly peaked in the morning while those returning home concentrate in the afternoon. The flow of air travellers is also peaked at certain hours, but with a somewhat different pattern. The time distributions for these two types of flow used in the simulations of Section 7.4 are shown in Table 7-8. The distribution for commuters is plotted in Figure 7-2.

When it appeared that the commuter might be difficult to serve efficiently, because of demand peaking which leaves aircraft unutilized during the middle of the day, alternative sources of customers for the air transit system were investigated. The most promising potential demand is the air traveller going from his home or place of business to a major air terminal to connect with a flight leaving the Bay area. In Figure 7-3 the estimated air passenger arrivals and departures per year are shown together with an estimate of how many of these passengers might use MAT for travel to and from the airport.

This enormous increase in people travelling through airports is going to create unprecedented congestion of parking lots, ticketing facilities and baggage handling areas. It will be essential to decentralize these facilities into suburban terminals served by rapid transportation directly to aircraft loading areas. The MAT system is extremely well suited to this service.

Table 7-9 shows estimates of MAT service required under the assumptions that reasonable percentages of air travellers will use MAT and that the commuter service component will be small at the beginning

Table 7-8

PASSENGER FLOW TIME DISTRIBUTION

Hour	Commuters Home-to-job	Commuters Job-to-home	Air Travellers Home-to-airport	Air Travellers Airport-to-home
0000-0100	.000	.028	.001	.002
0100-0200	.002	.010	.001	.002
0200-0300	.002	.004	.001	.002
0300-0400	.000	.004	.001	.002
0400-0500	.000	.001	.001	.002
0500-0600	.022	.004	.013	.019
0600-0700	.092	.008	.051	.019
0700-0800	.138	.012	.076	.039
0800-0900	.104	.016	.076	.039
0900-1000	.056	.020	.063	.039
1000-1100	.042	.024	.051	.058
1100-1200	.042	.041	.038	.058
1200-1300	.042	.041	.038	.078
1300-1400	.040	.039	.038	.039
1400-1500	.040	.071	.051	.039
1500-1600	.060	.127	.063	.039
1600-1700	.060	.112	.076	.058
1700-1800	.060	.108	.089	.078
1800-1900	.050	.065	.089	.097
1900-2000	.050	.073	.089	.097
2000-2100	.040	.055	.051	.078
2100-2200	.030	.035	.025	.058
2200-2300	.010	.043	.013	.039
2300-2400	.012	.031	.006	.019

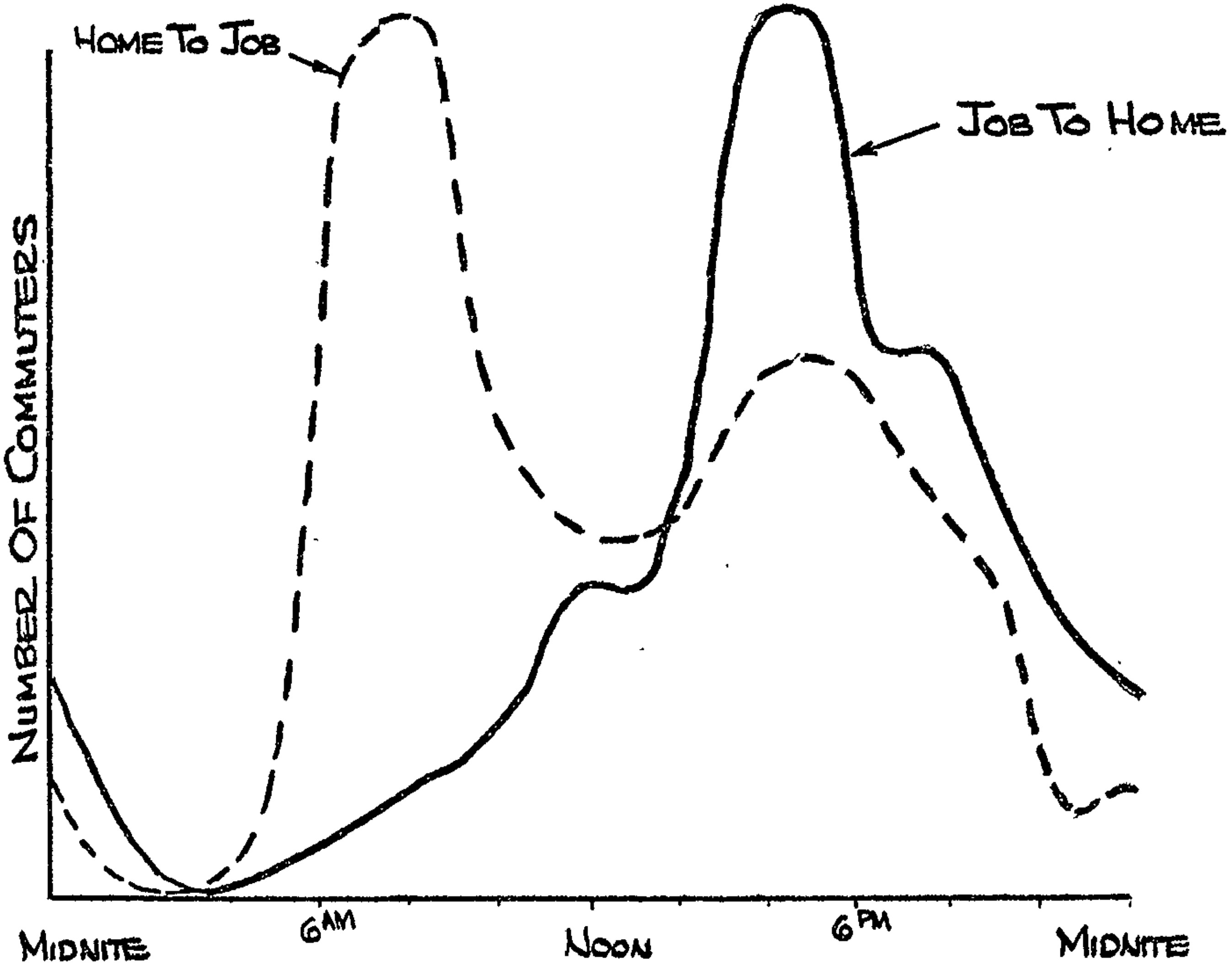


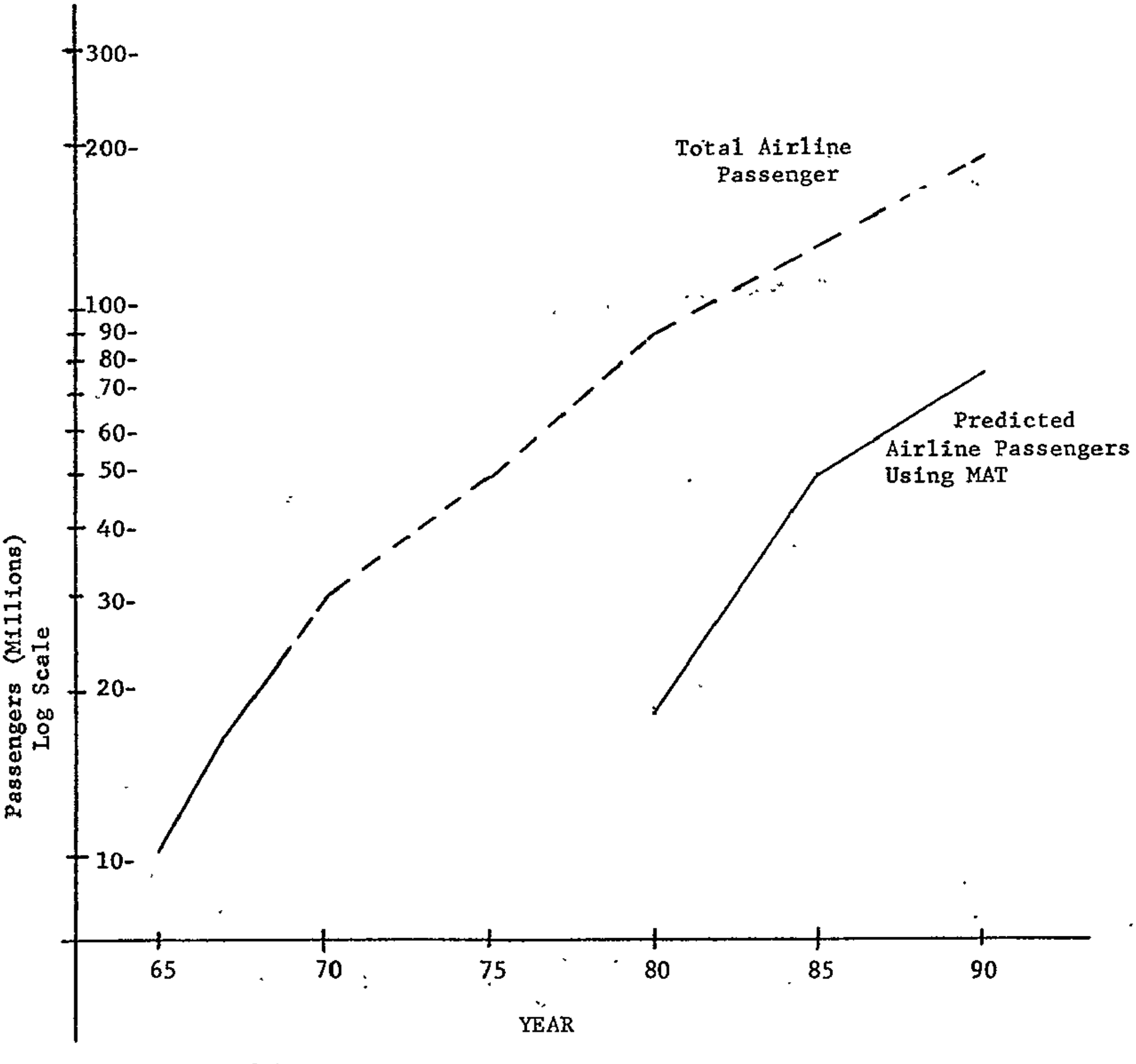
FIGURE 7-2 COMMUTER TIME DISTRIBUTION

Figure 7-3

SAN FRANCISCO BAY AREA

AIR PASSENGER FORECAST

1965 - 1990



Notes: 1. Data For 1965-1980 Taken From McDonnell-Douglas Report "STOL Passenger Demand Potential in the San Francisco Bay Area 1970-1980"

2. 1985 and 1990 Data Based on Assumption of 45% increase every 5 Years

Table 7-9

POTENTIAL MAT AIRLINE TRAVELER MARKET

Year	Annual Airline Traffic 9 Cty. Area Arrivals & Departures Passengers[3,4]	% Using MAT[5]	No. of MAT Passengers	No. of A/C Required[2]	% of MAT Business from Commuters[5]	Total No. of A/C Required	Total Annual Pass-Miles[1] -35 Mile Stage Length
1980	90×10^6	20%	18×10^6	53.5	10	59	693×10^6
1985	130×10^6	30%	49×10^6	146	20	175	2044×10^6
1990	189×10^6	40%	75×10^6	224	30	290	3445×10^6

NOTES:

(1) Average stage length = 35 miles; block speed = 150 mph; 50% load factor

(2) 1 A/C flying 2,000 hours at 50% load factor = 11.8 M passenger miles/year

(3) McDonnell-Douglas Aircraft Company "STOL Passenger Demand Potential in the San Francisco Bay Area 1970-1980"

(4) Assumed 45% increase each 5-year period

(5) Increase due to additional congestion

of MAT but will grow as congestion of other modes of commuting inevitably occurs.

7.3 Selection of Terminal Locations

As discussed in Section 7.1, preliminary terminal locations were based upon 1980 trip predictions from the 21 largest cities in the Bay area, regardless of whether these cities constituted a potential market area for short-haul air service. The trip generation model that was developed in Section 7.2 required some modifications to the tentative terminal locations and these are reflected in the recommended sites specified in Table 7-10.

Table 7-10

RECOMMENDED VTOL TERMINAL LOCATIONS

	TERMINAL CODE	CITY	VTOL TERMINAL LOCATION
1.	SRL	San Rafael	4th and Redwood Highway
2.	SRA	Santa Rosa	California 12 and Redwood Highway
3.	FRF	Fairfield	Air Base Parkway and Walters Road
4.	VLJ	Vallejo	Tennessee Ave. @ Mare Island Shipyard Gate
5.	SPO	Richmond	Contra Costa College Stadium @ Brookside Road and Pablo Avenue
6.	CON	Concord-Walnut Creek	Clayton Road and Monument Blvd.
7.	BRK	Berkeley	Telegraph Avenue and Parker Street
8.	ANT	Antioch	8th Street and Bliss Avenue
9.	OKP	Oakland-Piedmont	Fruitvale Avenue and McArthur Blvd.
10.	OAK	Oakland Airport-San Leandro	Oakland Metropolitan Airport
11.	HWD	Hayward	Foothill Blvd. and Fairview Avenue
12.	NWK	Fremont-Newark	Mowry Avenue and Fremont Blvd.
13.	CDP	Candlestick Park	South end of Parking Lot
14.	SFO	San Mateo-San Francisco Airport	San Francisco International Airport
15.	RWC	Redwood City	El Camino Real and Woodside Road
16.	PAL	Palo Alto	Stanford Shopping Center
17.	MTV	Mountain View-Sunnyvale	Mountain View Shopping Center
18.	SJO	Santa Clara-San Jose	San Jose Municipal Airport
19.	SCZ	Santa Cruz	Mission Street and California (1)
20.	MON	Monterey	Del Monte Avenue and Munras Avenue
21.	SAL	Salinas	Watsonville Highway and California 68
22.	SAC	Sacramento	California State Fairgrounds
23.	SKT	Stockton	Union Pacific Station
24.	FRY	San Francisco CBD	Ferry Building

A number of factors make the San Francisco Bay area a very attractive region for a VTOL service. While air travel in this country is expected to increase by 650% between 1960 and 1985,[1] the air traffic forecast for the nine-country Bay area indicated an even more phenomenal 900% increase for the period from 1965 to 1980 (Reference 7-2). About half, of this 1980 flow will be concentrated on the San Francisco to Los Angeles run. Since this high density corridor is primarily a non-stop, one-hour type of service, it is essential that efforts be made to reduce the door-to-door times of these travellers. The VTOL system proposed herein will have a salutary effect on this problem in several ways,

(1) Travel times from suburban VTOL stations to the three Bay area airports will be reduced drastically over those for existing ground transportation,

(2) Transfer of a sizeable volume of passengers from automobiles will appreciably reduce highway congestion,

(3) Permitting prospective passengers to park at suburban VTOL terminals will greatly reduce congestion of access roads and parking areas at major airport terminals,

(4) Cost of the VTOL portion of the trip may be less than present parking costs, particularly for those having to park for several days, and

(5) The air traveller should welcome the opportunity to check his baggage through to final destination at the suburban terminal.

The other general market available to this system is the home-to-work commuter, especially those living at substantial distances from the central business district. Providing free parking at the suburban terminal and ensuring congestion-free, high-speed air transport (usually non-stop) to the city center should attract many "commuters." In addition, the convenience of a downtown terminal close to the centroid of business destinations assures him additional savings in overall travel time.

7.3.1 Terminal Siting Criteria

During the early stages of the study equal consideration was given to VTOL and STOL operation. From the standpoint of terminal siting this meant that ports had to be located at each of the 24 general locations in Figure 7-1 to accommodate both types of aircraft. As the project evolved the relative advantages of VTOL terminals became apparent, and several criteria for their selection were developed,

(1) Proximity to passenger origins--Because VTOL terminals are small enough to be dispersed throughout a demand area they can be located very close to the centroid of passenger origins and destinations.

(2) Flexibility--As demand grows in a suburban area VTOL terminals can be expanded commensurately. This, of course, will reduce the high initial investment cost until the VTOL system is generating increased revenue.

(3) High level of safety--Non-obstructed, safe approaches to the terminal from several directions are desirable. Since VTOL aircraft are not crosswind limited, this criteria is best satisfied by waterfront VTOL terminals, if available.

(4) Low cost--Based upon size alone STOL ports, provided they are to provide close-in accessibility, would have higher costs for acquisition of right-of-way and higher construction costs.

(5) Environmental compatibility--In terms of noise exposure forecasts, noise is less of a problem with VTOL than fixed-wing aircraft.

(6) Potential for stimulating economic activity--Although difficult to quantify, an important consideration for the terminal location is that it may stimulate economic activity in the immediate area.

(7) Noninterference with other aircraft operations--Because of their small size VTOL terminals can more easily be sited so as to avoid interference with conventional aircraft operations. This is particularly critical in the San Francisco Bay area.

(8) Interconnection with other modes--A final criterion is the desirability of reducing the interface time with

other transport modes. Ideally, this can be accomplished by locating the VTOL terminal above or adjacent to a terminal for one or more other modes. For this reason serious consideration was given to location of terminals over railroad yards, BART stations, etc.

7.3.2 Bay Area Terminal Complex

Obviously, all the criteria stated above cannot be met at each of the terminals. However, especially in the case of the downtown terminal, as many as possible were considered in the selection process.

Initially four alternative downtown locations to serve the central business district of San Francisco were considered,

(1) Crissy Field (Presidio),

(2) Southern Pacific Railroad Station,

(3) Site near Hunter's Point, and

(4) Pier adjacent to Ferry Building.

Because of its adequate size, Crissy Field appeared to hold the greatest promise as a potential STOL site since it is the only existing airport in San Francisco. It was ruled out primarily because it is too far from the high-demand passenger area (generally concentrated along Montgomery Street, Market Street, and around the Civic Center), but also because it is highly doubtful that the Army would release it for other uses. The site near Hunter's Point, which was proposed a few years ago as a possible STOL site, was also eliminated because of its distance from the center of the city. Due to its size and relatively open access from the air, a VTOL or STOL site over the rail yards at the Southern Pacific Station looked very promising. It would, of course, entail higher construction costs because it would be elevated; but its principal disadvantage is that, while much closer to the city center than the first two alternatives, it is still some distance away. Buses are now required in this area to move rail passengers to and from the stationand continuation of such a procedure with increased passenger loads does not look promising. Consideration of some other transit forms to make this connection would make the total system cost prohibitive.

A VTOL terminal in the vicinity of the Ferry Building on the Embarcadero at Market Street was finally selected from the alternatives. This is envisioned as a modern, multi-story building constructed on piers along the waterfront with land facilities on the upper deck. It satisfies most of the previously stated criteria for siting in that it combines a waterfront location with proximity to the city center and an excellent connecting point with other modes. Aircraft can approach this site without difficulty from several directions with no interference to existing glide paths at Alameda Naval Air Station, Oakland International Airport, or San Francisco International Airport. Noise levels along the waterfront would not be a serious problem. Many of the arriving passengers with close destinations could walk or take shuttle buses to work. Those with more distant destinations, e.g., the Civic Center, would have direct access by escalator or moving sidewalk to an Embarcadero Station on the BART system, and could quickly reach other parts of the city. This last feature becomes particularly attractive when one looks at the proposed transit routes for the city beyond 1975 [7-3]. Most bus and trolley routes and all BART routes converge on Market Street and the BART line runs beneath the Ferry Building. Further details of the downtown terminal design are shown in Figures 5-5 and 5-6.

Selection of suburban terminal locations again reflected an effort to place the terminal as close as possible to the center of demand, to minimize initial investment costs by utilizing existing shopping center parking lots or other paved areas with contiguous parking availability, and to reduce the overall travel time. Recommended locations are listed in Table 7-10. In following this approach considerable flexibility is built into the system. For example, the recommended suburban VTOL terminal for the Palo Alto-Menlo Park area might be located in the southeast corner of the Stanford Shopping Center on El Camino Real. This corner is normally unused except for a few peak shopping periods during the year and could easily provide adequate parking spaces. The initial terminal in its most spartan form might consist only of a 200-foot by 400-foot area for landing pad, gate position, and terminal building. Likewise, the terminal building itself may only be a trailer with ticketing and servicing facilities. There is some evidence that similar transportation facilities which attract parkers to excess capacity areas of shopping centers also increase business for stores in the centers. Obviously, as VTOL passenger patronage increases more permanent terminal facilities will be needed. These could be provided by constructing decks or buildings in the same or nearby locations. Indeed, since the growth process of most cities is a dynamic one, the actual location of future suburban terminals may very well shift in the direction of expanding population and an entirely new terminal location may be feasible.

7.4 Routes and Schedules

Routes between terminals have been chosen with the following criteria:

(1) On high density routes reserved airspace will be requested for the sole use of MAT. On these routes MAT aircraft will be passing a given point to frequently that there will be no airspace available for any other use. On other routes MAT aircraft will fly direct under normal FAA flight rules. The reserved routes are shown in Figure 4-2.

(2) Routes should be chosen to minimize the noise perceived from the ground. Routes will be over the water or along areas of high ambient noise. Flights over residential areas will occur at higher altitudes.

(3) Routes should minimize conflict with other airspace users. The routes should remain below 2,000 feet where possible to avoid Air Traffic Control responsibility and outside of airport control areas. Special arrangements for reserved space between airport control areas will be necessary when these control areas touch, for example, San Francisco and Oakland International Airports.

The inter-terminal route distances are shown in Table 7-11.

It is crucial to the success of this system to have available algorithms which construct efficient aircraft schedules that will meet the demand and will minimize the fleet size and operating hours. In a system of this size the construction of efficient schedules is a difficult problem. Ordinary optimization techniques, e.g. dynamic programming, will not suffice because computer capability is not available to implement them. A program has been developed to use heuristic methods to produce efficient, but not optimal, schedules which can then be evaluated by a system simulator for quality of service given and profit gained.

Table 7-11

INTERTERMINAL ROUTE DISTANCES

(in miles)

	SFO	OAK	SJO	FRY	SAC	CDP	RWC	MTV	PAL	OKP	CON	SAL	MON	NWK	HWD	BRK	SPO	SRL	SKT	VLJ	SRA	FRF	ANT	SCZ
SFO	0	19	34	14	85	8	13	22	17	16	41	76	75	24	17	25	27	28	67	38	65	64	44	47
OAK	19	0	45	14	70	12	17	22	19	6	21	79	82	17	8	12	19	25	52	28	60	40	29	53
SJO	34	45	0	40	92	35	18	10	14	25	44	47	50	13	22	41	53	54	61	60	92	69	51	22
FRY	14	14	40	0	75	7	24	32	27	10	26	90	90	30	23	8	12	19	65	25	50	42	38	62
SAC	85	70	92	75	0	78	87	91	89	68	53	132	139	79	72	64	62	69	40	52	68	34	41	115
CDP	8	12	35	7	78	0	20	29	24	11	33	84	85	28	19	13	18	21	64	29	56	47	32	57
RWC	13	17	18	24	87	20	0	9	4	27	36	67	67	14	16	28	35	41	66	45	73	59	46	38
MTV	22	22	10	32	91	29	9	0	5	30	40	54	56	12	20	37	45	48	64	54	85	66	50	27
PAL	17	19	14	27	89	24	4	5	0	29	56	62	63	13	17	35	42	41	64	48	78	61	47	34
OKP	16	6	25	10	68	11	27	30	29	0	16	85	87	23	12	6	12	18	54	23	54	37	29	58
CON	41	21	44	26	53	33	36	40	56	16	0	91	95	29	20	13	16	25	41	18	53	25	13	67
SAL	76	79	47	90	132	84	67	54	62	85	91	0	12	62	73	90	98	103	94	107	139	115	95	29
MON	75	82	50	90	139	85	67	56	63	87	95	12	0	65	75	92	100	104	103	110	141	120	100	23
NWK	24	17	13	30	79	28	14	12	13	23	29	62	65	0	10	28	35	41	53	45	77	54	33	37
HWD	17	8	22	23	72	19	16	20	17	12	20	73	75	10	0	17	25	31	51	34	67	45	31	47
BRK	25	12	41	8	64	13	28	37	35	6	13	90	92	23	17	0	7	15	54	18	49	32	27	64
SPO	27	19	53	12	62	18	35	45	42	12	16	98	100	35	25	7	0	9	56	11	42	28	28	71
SRL	28	25	54	19	69	21	41	48	41	18	25	103	104	41	31	15	9	0	66	16	37	34	38	75
SKT	67	52	61	65	40	64	66	64	64	54	41	94	103	53	51	54	56	66	0	54	85	44	23	82
VLJ	38	28	60	25	52	29	45	54	48	23	18	107	110	45	34	18	11	16	54	0	35	18	26	82
SRA	65	60	92	50	68	56	73	85	78	54	53	139	141	77	67	49	42	37	85	35	0	41	59	112
FRF	64	40	69	42	34	47	59	66	61	37	25	115	120	54	45	32	28	34	44	18	41	0	21	92
ANT	44	29	51	38	41	32	46	50	47	29	13	95	100	33	31	27	28	38	23	26	59	21	0	74
SCZ	47	53	22	62	115	57	38	27	34	58	67	29	23	37	47	64	71	75	82	82	112	92	74	0

The schedule generator is provided with the following data:

(1) The number of terminals,

(2) Code names for the terminals,

(3) The inter-terminal route distances,

(4) The size and time distribution of the passenger demand,

(5) The capacity of an aircraft,

(6) The maximum fleet size, and

(7) Parameters to control the schedule generation.

The steps in the schedule generator program are:

(1) Initialize,

(2) If generation is finished go to system simulator,

(3) Advance the clock and compute new passengers arriving at each terminal,

(4) For each terminal (ID) do steps 5 through 10,

(5) Are there enough passengers waiting to go to terminal, ID, to provide service? If not continue step 4,

(6) Find an origin terminal (Iϕ) which has most passengers bound for destination terminal, ID,

(7) Attempt to schedule a flight from Iϕ to ID. If successful continue step 4,

(8) Find terminal (L) which has most passengers bound for terminal Iϕ,

(9) Attempt to schedule a flight from L to Iϕ to arrive in time to make desired flight from Iϕ to ID. If unsuccessful continue step 4,

(10) Schedule a flight from Iϕ to ID,

(11) Go to step 2.

The flight scheduler called in the above steps, carries out the updating of the system to provide an approximate simulation during the schedule generation process. The steps in this subroutine, which is called by furnishing the desired takeoff time, IT, the original terminal, Iϕ, and the destination terminal, ID, are:

(1) If an aircraft is not available at terminal Iϕ at time IT go to step 8,

(2). Label this aircraft IA and remove it from list of aircraft at Iϕ

(3) Load aircraft with passengers bound for ID and update those waiting accordingly,

(4) If there are seats remaining load other passengers bound for terminal K such that the flight time from Iϕ to K via ID does not exceed the direct flight time from K to ID by more than DEV. Update those waiting accordingly,

(5) Record landing and take off events in schedule,

(6) Add aircraft IA to list of aircraft at ID and set its time available for takeoff to its landing time plus turnaround time,

(7) Return indicating success,

(8) If available aircraft list is empty or blocked return indicating failure,

(9) Remove aircraft from available aircraft list and label it IA,

(10) Go to step 3.

The system simulator is provided with the same data as the schedule generator plus

The schedule of events, each of which is described by giving

(a) event time,

(b) aircraft number,

(c) origin of flight,

(d) destination of flight, and

(e) type of event (landing or takeoff),

parameters which control the simulation and weight such factors as the value of a passenger's time, the cost of operating aircraft, the fare structure, the cost of a fleet, and the penalties for providing poor service in order that a single figure of merit can be determined for comparing two schedules.

The steps of the system simulator are as follows:

(1) Read data and check schedule for consistency

(2) Initialize

(3) If time of current event is greater than current time go to step 16

(4) If event is a takeoff go to step 8

(5) Update passengers waiting and aircraft status

(6) Advance to next event in schedule

(7) Go to step 3

(8) Let aircraft IA be taking off from terminal I0 bound for terminal ID

(9) Load passengers bound from I0 to ID

(10) If no seats are left go to step 14

(11) Determine minimum-time path from I0 to every other mode according to schedule

(12) Assess penalty against system and remove passengers waiting at I0 from system if the time to their destination is excessive

(13) Apportion remaining seats among those passengers whose minimum-time path from I0 to their final destination includes the current flight

(14) Update passengers waiting and aircraft status

(15) Go to step 6

(16) Compute new passengers arriving, record statistics and advance the clock

(17) If finished record statistics and stop

(18) Go to step 3.

Computer time to run the schedule generator and system simulator for the full 24-node network would have exceeded the budget available for this study, therefore, runs were made on smaller systems of two and five terminals both to verify the correctness of the programs and to estimate the load factor and aircraft utilization factor possible with a peaked commuter demand.

The data and results of the two terminal run are summarized below:

Airline Interconnection--0
Commuters Home at Terminal A=52980
Commuters working at Terminal B=52980
Flight time=10 minutes
Turn-around time=4 minutes
Aircraft capacity=80 passengers
Fleet size=43 aircraft
Load factor=0.763
Aircraft Utilization=9.38 hours/aircraft/day
Total passengers carried=105,800

The five-terminal run was made with the following terminals SFO, OAK, SJO, FRY, SAC, and the schedule generator was allowed to run until noon only.

Total Residences=12330
Avg Flight Time=9.95 minutes
Turn-around time=4 minutes
Aircraft capacity=80 passengers
Fleet size=30 aircraft
Load factor=.778
Aircraft Utilization=2.6 hours/aircraft/day
Total passengers carried=10,426
Total number of flights=168

In an attempt to improve the aircraft utilization, the schedule generator was run on the same five terminals but with fleet size restricted to 10. The above results were altered to

Fleet size=10 aircraft
Load factor=.795
Aircraft utilization=7.14 hours/aircraft/day
Total passengers carried=9560
Total number of flights=150

On the basis of these latter figures the fleet size to carry all the estimated commuter and airline load of 156,340 passengers per day is 64 operational aircraft plus spares.

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Chapter 8

SYSTEMS EVALUATION

8.1 Economic Analysis

Initiation of the MAT system will involve a substantial capital investment as many components are required to make a complete network. Stopping points need terminals with landing pads, parking, and at least one building and of course, real estate is required before these terminals can be established. Aircraft will complete the network by connecting the stopping points. Ground personnel and flight crews will have to undergo training programs before beginning service. Acquisition of required capital may be accomplished by any of several means. Many rapid transit systems have been financed by bond issues repaid through taxes and revenues. Airlines are publicly owned through common stock issues, requiring revenues to repay all debts and operating expenditures.

The total cost of this system is a function of several parameters. Aircraft prices vary because of type, size, number produced, and performance. Table 8-1 gives non-recurring and unit costs for the VTOL aircraft selected. Here, the development of the airframe is the primary non-recurring item. Sophisticated avionics for navigation and guidance will be necessary for all-weather reliability. Each aircraft will be equipped with at least one VOR/DME, an autopilot, and a computer for enroute guidance and navigation, plus a microwave terminal guidance system and data link. Table 8-2 summarizes the costs for appropriate airborne and ground equipment, and shows a total of $162,000 of avionics per aircraft. These are included in the estimated aircraft costs of $4.94

Table 8-1

INITIAL AIRCRAFT COSTS

(For 80-passenger, compound helicopter)

Research and Development (non-recurring)	Millions of $
Airframe	120
Engines and gearbox	15
Rotors and propellers	24
Electrical equipment	1
Total	160

Total Aircraft Cost (for a production of 160 aircraft)

Basic aircraft - 260 units at	$3.6 M each*	
Spare parts - 20% =	0.72 M each	
Research and development $\frac{\$160\text{ M}}{260}$ =	0.62 M each	
Total for 260 aircraft at	$4.94 M each =	$1283 M

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[*] Production cost studies indicated a unit cost of $3.6 M each in production quantities of 200 units, and about half this amount if the production quantity is increased tenfold. This suggests that major cost savings would be feasible if a government-coordinated program were organized to include (a) a substantial number of aircraft for Army, Navy, Marine, Air Force, Coast Guard, and other governmental functions and (b) if a number of major cities ordered such aircraft for a MAT system at the same time. For example, for a production order of 2,000 aircraft the costs would then be reduced as follows:

Basic aircraft - 260 units at	$1.80 M each
Spare parts - 20%	0.36 M
Research and development $\frac{\$160\text{ M}}{2{,}000}$	0.08 M each
Total for 260 aircraft	$2.24 M each = $582.4 M

An investment in suitable production facilities for producing such a large number of aircraft would be much more efficient from a national standpoint than to pay a high subsidy for the use of such a transportation system.

Table 8-2

NAVIGATION AND GUIDANCE COSTS

Avionics

Item	Number/plane	Total cost/plane
Voice communications and data link	2	$ 6,000
Radio navigation equipment	2	8,000
Accessories for receivers	2	1,000
DME	1	8,000
Flight monitor	1	31,000
Transponder	1	4,000
Radio altimeter	2	14,000
Peripheral command indicator	2	6,000
Monitor	1	3,800
Compass	2	6,200
Autopilot	1	14,000
Audio control	2	1,200
Electronics controls	2	800
Antenna	1	140
Collision avoidance	1	3,000
Computer	1	50,000
Microwave receiver	1	5,000
Total/aircraft		$162,140

Ground Equipment Required (shown also in Table 8-3)

Terminal microwave	$100,000/location
Terminal radar	$100,000/location
Installation of microwave and radar	$ 50,000/location
Total cost per terminal	$250,000
System control & communication center	$ 30,000

million each in lots of 200 to 260 units.

Each terminal will consist of at least a building, landing pad, parking area, terminal guidance ground equipment, and an assortment of furnishings.

It is further assumed that the costs of real estate, buildings, and construction for the 18 suburban terminals and the 4 major city terminals will be paid for by the associated businesses and/or the local community that benefits from the traffic flow generated by the MAT system. The initial cost of installation of the ground-based electronics and elevators for aircraft and passengers will be financed by the operator of the MAT systems. It is assumed that the two airport terminals will be an integral part of the airport complex and will be leased from the various airport authorities. The cost of operation of these terminals, as well as the other terminals, is expected to be covered by a 25¢ per passenger landing fee at each terminal.

The costs to be financed by MAT are summarized in Table 8-3. Also listed in this table is the estimated cost of systems engineering and organization to implement MAT. Finally, a ground-based computer complex will be required for overall MAT system communication and control. This will be comparable to the one used by BART. Therefore, an estimate of $30 million is provided for this item. Adding the costs of all system components leads to a total initial investment of $1,396.5 million for the conservative case assuming that only a total production run of 260 aircraft will be made, or of $696 million for the optimistic case if the total aircraft production is 2,000.

Operating cost calculations are again made for MAT on two

Table 8-3

INITIAL SYSTEM COSTS
(millions of dollars)

Terminals		
4 major terminals - mechanical equipment	13.6	
electronics equipment	1.0	
18 suburban terminals ($0.25 M)	4.5	
2 airport terminals ($0.25 M)	0.5	
20% spares	3.9	
MAT total terminal investment	23.5	
Other Initial Costs		
System design and start-up	60.0	
Control and communication	30.0	
Total other initial costs	90.0	
Total initial cost except for aircraft	113.5	
Aircraft cost for a total production of 260 aircraft	1,283.0	
Total initial cost	1,396.5	(conservative case)

In case of a national production program involving 2,000 aircraft, these initial costs would be reduced as follows:

Initial cost except for aircraft	$ 113.5 M	
Aircraft cost for 260 units	582.4 M	
Total initial cost	$ 695.9 M	(optimistic case)

viewpoints - a conservative and an optimistic basis. Table 8-4 outlines the different sets of assumptions used to obtain aircraft operating costs. The conservative basis is probably the safest one on which to base present planning. On this basis it is assumed that 80-passenger compound helicopters are developed and produced only for MAT, that the current high interest rate of 8.5% on money remains in effect, that the hull insurance rate is 5%, and that the brokers fee is 1% for arranging financing. For the optimistic case it is assumed that several other MAT-type systems are being set up so that the manufacturer can tool up for producing 2,000 aircraft, that the interest rates have receded to 4%, that the hull insurance rate decreases to 3% as the result of safe operating experience and that no brokerage fees need to be paid. Table 8-5 lists the fixed annual operating costs for aircraft. These figures are based on full system operation with 260 aircraft. The costs shown represent funds required to pay interest, insurance, and depreciation, whether the aircraft are used or not.

As with the aircraft cost computations, operating costs for terminals and ground equipment were calculated using two viewpoints. The assumptions used in obtaining fixed annual operating costs for this equipment are listed in Table 8-6. The resulting costs are given in Table 8-7. The total fixed annual costs for MAT are obtained by adding the above items. Table 8-8 indicates that these fixed annual costs per aircraft are between $0.4 million and $1.2 million.

In addition to fixed costs, there are several variable expenses which depend on actual operation of the MAT system. These are most conveniently listed as costs per aircraft operating hour. Typical

Table 8-4

FIXED ANNUAL OPERATING COSTS AS PERCENTAGE OF INITIAL COSTS

Aircraft

Conservative Basis

Distribute non-recurring and production costs over 260 aircraft

8.5% interest rate

5% hull insurance costs

1% financing fee

12-year, zero residual depreciation policy or 8.33%/yr

Total of 22.83%

Optimistic Basis

Distribute non-recurring and production costs over 2,000 aircraft

4% interest rate

3% hull insurance

No financing fee

12-year, zero residual depreciation policy or 8.33%/yr

Total of 15.33%

Table 8-5

FIXED ANNUAL OPERATING COSTS

Aircraft

	CONSERVATIVE	OPTIMISTIC
Total aircraft costs	$1,283 M	$582.4 M
Annual costs		
Percentage	22.83%	15.33%
Dollars	$ 293 M	$ 89.2 M
Annual fixed cost per aircraft	$1.125 M	$0.343 M

items of concern are aircraft maintenance, fuel and oil, liability insurance, landing fees, personnel salaries, and ticketing. Hourly costs for these items are listed in Table 8-9. The maintenance and fuel and oil costs are based on estimates given in Chapter 3 of this report. Crew costs are based on a one-pilot crew with the pilot earning $24,000 per year (plus an additional 15% in fringe benefits). Pilot flight time was limited to 1,000 hrs/yr. The liability insurance costs are based on a total premium of $1.40 per 1,000 revenue passenger miles. This includes both basic and excess coverage. The $0.25 landing fee was included to help defray terminal costs. Indirect operating costs as given in Table 8-9 are based on an assumption of one cent per revenue passenger mile. This figure corresponds approximately to expenses of current air shuttle operators. It is evident from Table 8-10 that operating cost on the basis of only 1.92 hours of use/day (500 hrs/yr) would be too high for a viable commercial operation. It appears that

Table 8-6

FIXED ANNUAL OPERATING COSTS AS PERCENTAGE OF INITIAL COSTS

Terminals, control, and system engineering

Conservative Basis

Distribute engineering costs over 12-year operation or 8 1/3%/yr

12-year, zero residual equipment depreciation policy or 8 1/3%/yr

Total of 17.83%/yr

8.5% interest rate

1% financing fee

Real estate costs are expected to be borne by the local community and/or building revenue

Optimistic Basis

Distribute engineering costs over 12-year operation or 8 1/3%/yr

12-year, zero residual equipment depreciation policy or 8 1/3%/yr

Total of 12.33%/yr

4.0% interest rate

No financing fee

Real estate costs are expected to be borne by the local community and/or building revenue

Table 8-7

FIXED ANNUAL OPERATING COSTS

TERMINALS, CONTROL, AND SYSTEM ENGINEERING

	Conservative	Optimistic
Initial costs except for aircraft (from Table 8-3)	$113.5 M	$113.5 M
Annual costs		
Percentage	17.83%	12.3%
Dollars	$ 20.3 M	$ 14.03 M
Number of Aircraft	260	260
Allocable cost per aircraft	$ 0.078 M	$ 0.0539 M

Table 8-8

FIXED ANNUAL OPERATING COSTS

TOTAL SYSTEM ANNUAL COSTS

	Conservative	Optimistic
Aircraft annual cost per aircraft	$1.125 M	$0.343 M
Other allocable cost per aircraft (from Table 8-7)	$0.078 M	$0.0539 M
Totals per aircraft	$1.203 M	$0.3969 M

Table 8-9

VARIABLE OPERATING COSTS

Item	Cost/aircraft operating hour
Aircraft maintenance	$220.00
Fuel and oil (average)	$ 81.50
Crew (one pilot)	$ 27.60
Liability insurance	$ 9.18
Landing-fee ($0.25/passenger landing)	$ 42.90
Indirect operating costs (personnel, administration, ticketing, etc.)	$ 60.00
Total variable cost/aircraft-operating hour	$441.18

on the basis of the conservative assumptions the cost of operation for 3.85 hours of use per day (1,000 hr/yr) would be $0.274/passenger mile. If this operation was carried out on a commercial basis with about 10% profit added, this would result in a fare of about $0.30/passenger mile.

nimum target for a commercial operation of the MAT system would appear to be 7.70 hours of operation/day (2,000 hr/yr) in which case on a conservative basis the operating cost would be $0.174/passenger mile and with a 10% profit a fare of about $0.20/passenger mile. This price compares with about $0.10/passenger mile for a businessman travelling by car. If a business traveller with an annual salary of $12,000/year values his time at $6/hr, then in a 35 mile trip he would save approximately 0.5 hours or $3.00 if he travelled by MAT. For the 1980 BART system it is estimated that an initial subsidy of $850 million was required. If this amount had been invested at 8.5% (using similar

Table 8-10

SUMMARY OF OPERATING COSTS

Number of Aircraft Operating Hours/year	Average Aircraft Operating Hours/day (1)	Conservative				Optimistic			
		Fixed Cost ($/hr)	Variable Cost ($/hr)	Total Cost ($/hr)	Total Cost (2) (¢/passenger mile)	Fixed Cost ($/hr)	Variable Cost ($/hr)	Total Cost ($/hr)	Total Cost (2) (¢/passenger mile)
500	1.92	2,405	441	2,846	47.40	795.00	441	1,236.00	20.60
1,000	3.85	1,203	441	1,644	27.40	397.00	441	838.00	14.00
2,000	7.70	602	441	1,043	17.40	198.50	441	639.50	10.65
3,000	11.55	401	441	842	14.00	132.30	441	573.30	9.56

(1) 260 days/year operation

(2) Block speed = 150 mph, 80 passenger, 50% load factor

assumptions as for the MAT cost calculations), then the annual income would have been $850 M x .085 = $72.25 million. If this is considered as the equivalent of an annual subsidy of the 80 million passengers travelling a stage length of about 10 miles, this would represent an equivalent subsidy of $\frac{\$72.25\text{ M}}{80 \times 10}$ = $.09/passenger mile. The BART fare is about $.032/passenger mile. Thus, the equivalent total cost of the 1980 BART systems operation is about $0.122/passenger mile. This is about 70% of the cost of the MAT system based upon 2,000 hr/yr per aircraft operations.

For longer range routes and with lower traffic densities the MAT system shows a considerable cost advantage. This is illustrated in the following analysis for a route between San Francisco and Sacramento. Tables 8-11 and 8-12 give the estimated costs of a BART-like rail system as envisioned for this market. Table 8-13 gives a comparison of these costs with those of MAT operating in the same market. Clearly MAT enjoys a major cost advantage as long as the number of passenger round trips/day are small. If the traffic requires about 6,480 passenger round trips/day, then the costs via the MAT system and the BART system are about the same. For much higher traffic requirements, such as 36,000 passenger round trips/day over a given line, the cost via BART system is about one-third that via the MAT system. The reason for the very high costs of BART transportation at low traffic densities is the very fixed costs of real estate and tracks.

8.2 MAT System Benefits - Components

For the MAT system to become an attractive proposition for

Table 8-11

FACTORS USED IN THE EVALUATION OF BART POTENTIAL IN THE SAN FRANCISCO TO SACRAMENTO MARKET

One-way, distance	90 mi
Block speed	60 mph
Round trip time	3 hrs
Total cost of track, power and control system at per unit cost $1 M/mile	$ 90 M
Annual cost of track, power and control system(1)	$ 11.55 M
Total cost of real estate, grade crossings, etc. at per unit cost $3 M/mile	$270 M
Annual cost of real estate, grade crossings, etc.(2)	$ 22.95 M
Total annual track costs $(11.55 + 22.95) M	$ 34.50 M
Total daily track costs(3)	$ .1325 M
Cost of vehicle (72 seats)	$260,000
Annual fixed cost of vehicle(4)	$ 33.400
Variable cost of operation(5)	$ 46.20

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(1) Amortize over 30 yrs (3 1/3%/yr), interest 8 1/2%/yr, insurance at 1% yr, totaling 12.83%.

(2) 8 1/2%/yr interest

(3) 260 days/year operation

(4) Amortize over 30 yrs (3 1/3%/yr), interest 8 1/2%/yr, insurance 1% yr, totaling 12.83%.

(5) Variable cost of operation estimated at $0.77/car mile.

Table 8-12

SUMMARY OF THE EVALUATION OF BART POTENTIAL IN THE SAN FRANCISCO TO SACRAMENTO MARKET

Number of Car Round-trips Per Day	C_1 Track Costs per Round-trip	N Annual Utilization (hr/yr)	A Variable (1) Cost of Vehicle Operation ($/hr)	B Fixed Operating Cost of Vehicle ($/hr) $\frac{\$33,400}{N}$	A+B Total Operating Cost of Vehicle ($/hr)	$C_2=3(A+B)$ Vehicle Costs (2) per Round Trip ($)	C_1+C_2 Total Cost per Round Trip ($)	$\frac{C_1+C_2}{36}$ Total Cost per Passenger Round Trip (3) ($)
10	$ 13,250	500	$46.20	66.80	113.00	339.00	13,589.00	378.00
		1,000	"	33.40	79.60	238.80	13,488.80	374.50
		2,000	"	16.70	62.90	188.70	13,438.70	373.50
		3,000	"	11.13	57.33	171.99	13,421.99	372.50
100	$,325	500	$46.20	66.80	113.00	339.00	1,664.00	47.20
		1,000	"	33.40	79.60	238.80	1,563.80	43.40
		2,000	"	16.70	62.90	188.70	1,513.70	42.10
		3,000	"	11.13	57.33	171.99	1,469.99	41.60
1,000	$ 132.50	500	$46.20	66.80	113.00	339.00	471.50	13.05
		1,000	"	33.40	79.60	238.80	371.30	10.30
		2,000	"	16.70	62.90	188.70	321.20	8.92
		3,000	"	11.13	57.33	171.99	304.49	8.45

(1) Variable cost of operation at $0.77 per car mile. In one hour car variable costs are 60 mph x $\frac{\$0.77}{\text{mile}}$ = $46.20/hr

(2) Round trip time = 3 hour

(3) Based on a 72-sent vehicle with 50% load factor, i.e., 36 passengers. Thus total cost/passenger $\frac{C_1+C_2}{36}$

Table 8-13

COMPARISON OF TOTAL ROUND TRIP COSTS PER PASSENGER

MAT AND BART

SAN FRANCISCO TO SACRAMENTO

Number of Passenger Round-trips/Day	MAT	BART		$\frac{\text{Cost via BART}}{\text{Cost via MAT}}$
	Conservative Basis (1) 2,000 hrs/yr	Number of Car Roundtrips/Day	Car Utilization 2,000 hrs/yr	
360	26.10	10	373.50	14.3
3,600	26.10	100	42.10	1.61
6,480	26.10	180	25.70	.98
36,000	26.10	1,000	8.92	.34

(1) Based on air round trip distance of 150 miles at $0.174/passenger mile, or a total of $26.10

private investors the users' benefits will have to be large enough to merit fares that will make the operation profitable. The system will have substantial non-user benefits, however, and thus another alternative would be to consider operating MAT as a public utility. These advantages may also be an important factor in gaining public acceptance of MAT if it is implemented by private enterprise.

Among the first public benefits of MAT is the fact that it will remove large numbers of people from the surface congestion picture. In the short run this advantage could be thought of as increasing the speed and safety with which non-MAT users could use the surface systems. There would also be a savings in terms of the cost of traffic control involved in moving these commuters and airline travellers who are now using MAT. In the long run, the freeways and downtown streets will again be congested, causing some observers to conclude that MAT made no difference in the congestion. For this point of view one might look at MAT as providing additional surface capacity, in that increased surface travel equal to the number of surface travellers who convert to MAT can be accommodated without further expenditure for surface systems. As an illustration, consider that 50,000 one-way peak-hours travellers use MAT rather than the freeways. If all of them could have been handled on a single 35-mile section of freeway over a three-hour period, or approximately 16,500/hour, the freeway would have to consist of something in the order of 16,500/1,500 = 11 lanes in each direction.

Increasing public concern over the preservation of the natural appearance of the countryside has made it difficult to use freeway systems for further expansion in many areas. The MAT system involves no change in landscape configuration other than at its terminal sites. Its flexibility means that if flyover patterns prove aesthetically unacceptable, these may easily be changed. Thus MAT fits very well into the modern social value system which insists that the desirability of man's environment be protected and enhanced.

MAT provides another capability which should be of extreme interest to the residents of the Bay area. This capability involves the providing of emergency service without dependence on surface conditions, and making use of the vertical flight possibilities of the aircraft. The Bay area might develop emergency teams and facilities designed to be picked up by a MAT aircraft and delivered to the scene of the emergency. In this way, medical treatment could be taking place at the scene of a freeway accident within minutes after the accident is reported. Rescue for boaters, fast positioning of fire-fighting teams, police observation and deployment for riot control, and other such missions could become a part of the area's public service capability.

The tourist who wishes to see the Bay area in a short time would find that MAT makes this possible at a reasonable price and offers as a bonus the air views of the area. Locations which would have tourist appeal but are now too difficult to reach could be developed to further enhance the attractiveness of the area.

The business and commercial environment of the area would benefit from MAT's introduction. Recruitment of professionals would certainly be aided by the existence of a transportation system that would allow one to live in Monterey or Santa Cruz and commute to downtown San Francisco in considerably less than an hour. The fact that the business visitor would be able to travel rapidly from the airport to any part of the Bay area and back, making a one-day trip a productive possibility, would also be an important factor in the minds of those deciding where to locate a business or industry. MAT also offers the potential for changing the patterns of travel of salesmen and service men who operate over the Bay area, perhaps adding substantially to their productive time. New sources of employees will become available and new locations and types of business may become feasible because of MAT's capability to change the accessability picture of the area.

MAT represents an investment which is not particularly high-risk in terms of dependence on accuracy in the forecast of customer demand patterns and quantities. This problem is inherent in surface systems with large investments in fixed facilities. MAT's flexibility exists in terms of overall size, location of terminals, selection of routes, and selection of frequency of service. MAT can be used as a dynamic tool for the planning and stimulation of area development, with the option of adjusting to a variety of unforeseen trends which may appear over time. The area might, for example, seek to optimize the use of land from the tax revenue point-of-view by placing MAT terminals in accordance with the desired development pattern.

MAT utilization is a key factor in its economic success. In order that the effect of traveller peaking will not unduly reduce the average utilization, MAT will seek non-passenger markets for off-peak periods. There may be many existing markets for limited amounts of vertical lift and/or high speed capability. Delivery of replacement parts for systems whose downtime is costly, delivery of hyper-perishables, delivery and placement of construction materials in remote or congested areas, and delivery to and from ships enroute are examples of uses which might become commonplace. It might also be anticipated that some new markets will develop based on the existence of the MAT-type capabilities. (See Appendix A.)

8.3 MAT System Benefits - Aggregate Evaluation

The previous section itemized and described the potential benefits of MAT. Few quantifiable measures are available for assessing these benefits and aggregating their value. In the Bay area, however, it is possible to get such a measure of aggregate benefit by examining the implied value of similar transportation service. In 1962, BART presented its system to the people for consideration. The information available included the forecast of future system utilization as the system capacity built up to its final size and a schedule of bond retirement timing with the tax levies required. Discounting the scheduled phase-in of service and the scheduled tax support to a common point in time at 6%, the interest rate most often used as the time value of money in 1962, the following was found:*

Discounted cost of future public support of the system	$661.4 M
Discounted quantity of future increments of system utilization in <u>annual passenger miles</u>	783.2 M
Implied present worth of average value of benefits associated with a system which provides one <u>annual passenger mile of utilization</u>	$0.845

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* This analysis represents an alternate approach to the earlier cost estimate of BART and MAT systems with somewhat different assumptions.

Implied benefits of MAT:

1.517 B annual passenger miles
@ 1,000 hrs/yr average
aircraft utilization

x $\frac{\$0.845}{\$1.282\text{ B}}$ Total Benefits

If this amount were supplied as the "purchase price" of the MAT system by the public and invested at 8%, each of the passenger miles flown each year could be supported at the level of $0.067, or the yearly benefit of the system is $0.067/passenger mile.

8.4 Cost-Benefit Comparisons

It appears that a production run of aircraft only for MAT (260 aircraft) and a run of 2,000 aircraft are unreasonable extremes. The following analysis shows what might realistically be expected as alternatives:

If unit cost of aircraft can be reduced to $\frac{(\$4.94 + 2.24)}{2}$ M = $3.59 M,

If patronage and scheduling achieve 1,000 hrs/yr average aircraft utilization at 0.50 load factor for 260 aircraft, and

If cost of borrowing money is 9.5%,

Then cost/passenger mile =	$ 0.21
revenue/passenger mile (fare for 35-mile trip at $1.75 + 0.10/mile) =	0.15
operating deficit/passenger mile =	0.06
implied benefits/passenger mile =	0.067
net system benefits/passenger mile =	0.007
Which gives annual net system benefits = (Public support would be required)	$10.6 M

However, if system utilization can be increased to 2,000 hours with the same return per mile in revenue and benefits,

the cost/passenger mile = $ 0.144
revenue/passenger mile = 0.15
operating profit/passenger mile = 0.006
implied benefits/passenger mile = 0.067
net system benefits/passenger mile = 0.073

Which gives annual net systems benefits = $222.0 M
(System would be self-supporting)

8.5 Implementation Considerations

The MAT system will introduce a new mode of rapid transit to a large potential market. Although SFO Helicopter, Inc. offers a very limited service along some similar routes, the frequency of service and fare structure have prevented a substantial capture of this market. Initiation of a high-frequency, medium-fare air transit system should be executed to attract potential customers on a continuing and increasing basis. The flexible nature of scheduling aircraft flight will allow the system to begin operation with a minimum of routes and vehicles. Growth and increased service will occur as aircraft deliveries permit. Temporary terminals may be used until construction is completed. A ten-year period should be sufficient to implement the system to full capacity. Therefore, 1975 would be the appropriate year to initiate the first regular service. Political, real estate, and financial negotiations should begin as soon as possible.

The most heavily travelled route links appear to be[*] SJO-FRY,

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[*] These terminals are defined in Chapter 7.

SJO-CDP, NWK-FRY, NWK-CDP, FRY-SFO, CDP-SFO, SRL-SFO, SRA-SFO, CDP-OAK, and SRA-OAK. The first aircraft put into service would best be used to cultivate commuter traffic between SJO, FRY, and SFO, because this will serve the most heavily travelled segment. Therefore, the first three terminals put into operation will be SJO, SFO, FRY in 1975. One additional terminal and corresponding routes will go into service at equal one-year intervals. This sequence is based on exponential growth of business and MAT facilities. Table 8-14 summarizes this growth in tabular form, and Figure 8-1 illustrates the exponential profile of MAT implementation. Three aircraft will initiate service on the route in 1975. By 1980 there should be 28 aircraft servicing 8 terminals. Finally, in 1985 there would be 260 planes flying among 24 terminals.

Initial fares should be sufficiently low to attract new customers. A limited period of free fare may be appropriate to promote public acceptance. However, the fare structure should not exceed the predicted full-system levels. This would probably mean deficit operation until at least 1980. Such deficits can be minimized by proper implementation scheduling of maintenance facilities, terminals, and personnel. Only a small number of flight and ground crew need be initially hired and trained. The fare used in Table 8-15 is assumed to be $0.15/passenger mile. The effects of an alternative fare of $0.25/passenger mile are shown in Table 8-15 and Figure 8-2.

When considering implementation of MAT it is interesting to look at analogous situations. The BART system will go into operation in the early 1970's. However, the initial study which eventually led to this system began in 1951 and was completed in 1956 [1]. In 1957

Table 8-14

MAT SYSTEM IMPLEMENTATION SCHEDULE

Year	No. of Aircraft	Aircraft Trips/Day (1)	Aircraft Trips/Yrs (2) $(X10^{-3})$	Passenger Trips/Yr (3) $(X10^{-3})$	Passenger Miles/Yr (4) $(X10^{-6})$
1975	3	100	25	1,000	35.0
1976	5	168	42	1,680	58.8
1977	7	235	58.8	2,350	82.1
1978	11	336	84	3,360	117.5
1979	18	605	151	6,050	212.0
1980	28	940	234	9,400	329.0
1981	42	1,410	352	14,100	494.0
1982	68	2,280	570	22,800	797.0
1983	105	3,520	880	35,200	1,230.0
1984	165	5,550	1,388	55,500	1,940.0
1985	260	8,740	2,180	87,400	3,055.0

(1) Assuming 8 hrs/day aircraft utilization and 150 mph block speed

(2) Assuming 250 days/yr operation

(3) Assuming 50% load factor

(4) Assuming 35 mile average stage length

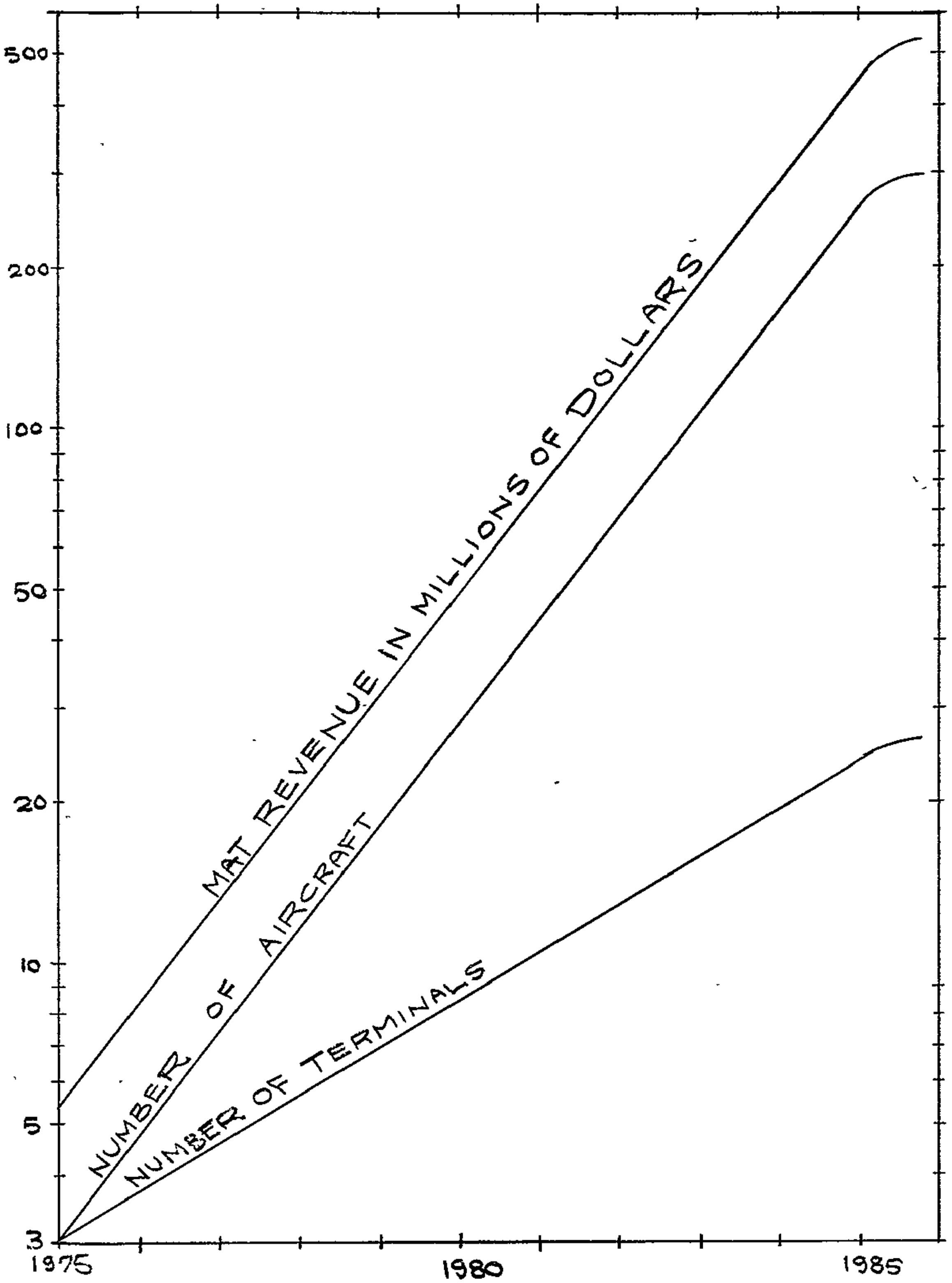

Figure 8-1

MAT IMPLEMENTATION

Table 8-15

TIME-PHASING OF MAT COSTS AND BENEFITS

(All costs and benefits are in millions of dollars, BASED ON $0.15/MILE FARE)

Year	Aircraft in Service	Cost Above Annual Cost per Pass. Mile	Benefits @1,000 hrs/yr 15¢/mile Fare	Benefits Minus Cost	Present Worth @10%	Cumulative Present Worth	Benefits @2,000 hrs/yr 15¢/mile Fare	Benefits Minus Cost	Present Worth @10%	Cumulative Present Worth
1970	0	6	0	- 6.0	-6.0	- 6.00	0	- 6	- 6.	- 6.
1971	0	6	0	- 6.0	-5.45	-11.45	0	- 6	- 5.45	-11.45
1972	0	6	0	- 6.0	-4.95	-16.40	0	- 6	- 4.95	-16.40
1973	0	6	0	- 6.0	-4.51	-20.91	0	- 6	- 4.51	-20.91
1974	0	8	0	- 8.0	-5.45	-26.36	0	- 8	- 5.45	-26.36
1975	3	7	0.12	- 6.88	-4.27	-30.63	2.57	- 4.43	- 2.75	-29.11
1976	5	7	0.200	- 6.80	-3.83	-34.46	4.27	- 2.73	- 1.54	-30.65
1977	7	7	0.29	- 6.71	-3.44	-37.90	5.98	- 1.02	- 0.52	-31.17
1978	11	7	0.45	- 6.55	-3.60	-41.50	9.42	+ 2.42	+ 1.13	-30.04
1979	18	7	0.74	- 6.26	-2.65	-44.15	15.40	8.40	3.56	-26.48
1980	28	0	1.14	+ 1.14	+0.44	-43.71	23.95	23.95	9.22	-15.26
1981	42	0	1.72	1.72	0.60	-43.11	35.9	35.9	12.55	- 2.71
1982	68	0	2.78	2.78	0.88	-42.23	58.1	58.1	18.50	+15.79
1983	105	0	4.29	4.29	1.24	-40.99	89.8	89.8	26.05	41.84
1984	165	0	6.74	6.74	1.77	-39.22	141.0	141.0	37.10	78.94
1985	260	0	10.61	10.61	2.55	-36.67	222.5	222.5	53.50	132.44
..						⋮				
..										
1997						0.0				

Table 8-15 (Cont)

TIME-PHASING OF MAT COSTS AND BENEFITS

(All costs and benefits are in millions of dollars, BASED ON $0.25/MILE FARE)

Year	Aircraft in Service	Cost Above Annual Cost per Passenger Mile	Benefits @1,000 hrs/yr $0.25/ Mile Fare	Benefits Minus Cost	Present Worth @10%	Cumulative Present Worth	Benefits @2,000 hrs/yr $0.25/ Mile Fare	Benefits Minus Cost	Present Worth @10%	Cumulative Present Worth
1970		6	0	- 6.0	- 6.0	- 6.0	0	- 6	- 6.0	- 6.0
1971		6	0	- 6.0	- 5.45	-11.45	0	- 6	- 5.45	-11.45
1972		6	0	- 6.0	- 4.95	-16.40	0	- 6	- 4.95	-16.40
1973		6	0	- 6.0	- 4.51	-20.91	0	- 6	- 4.51	-20.91
1974		8	0	- 8.0	- 5.45	-26.36	0	- 8	- 5.45	-26.36
1975	3	7	1.89	- 5.19	- 3.23	-29.59	6.1	- 0.9	- 0.56	-26.92
1976	5	7	3.14	- 3.86	- 2.18	-31.77	10.3	+ 3.3	+ 1.86	-25.06
1977	7	7	4.40	- 2.60	- 1.33	-33.10	14.2	7.2	3.69	-21.37
1978	11	7	6.92	- 0.08	- 0.40	-33.14	22.3	15.3	7.15	-14.22
1979	18	7	11.33	+ 4.33	+ 1.84	-31.30	36.6	29.6	12.55	- 1.67
1980	28		17.63	17.63	6.8	-24.5	56.8	56.8	21.9	+20.2
1981	42		26.45	26.45	9.3	-15.2	85.4	85.4	32.5	52.7
1982	68		42.8	42.8	13.7	- 1.5	138.0	138.0	44.0	96.7
1983	105		66.0	66.0	19.2	+17.7	211.0	211.0	61.2	157.9
1984	165		104.0	104.0	36.4	54.1	335.0	335.0	88.2	246.1
1985	260		164.0	164.0	39.2	93.3	528.0	528.0	126.0	372.1

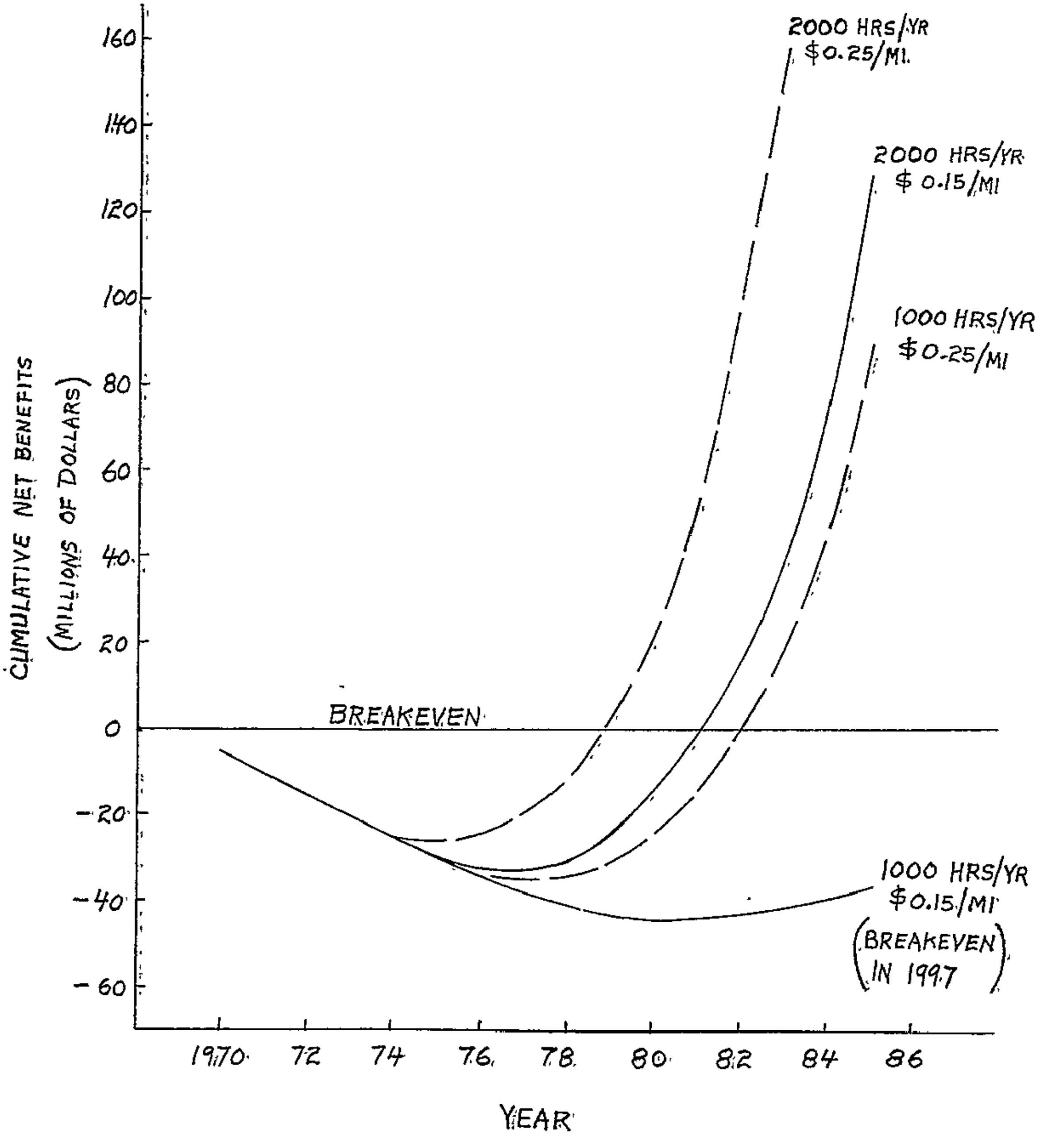

Figure 8-2

BENEFITS-FARE-UTILIZATION RELATIONSHIPS

the California Legislature founded the San Francisco Bay Area Rapid Transit District. Creation of this district was not subject to a vote by the people. Five counties were initially included: San Francisco, Alameda, Contra Costa, San Mateo, and Marin. Additional counties could be annexed if a majority of the voters in such areas approve. Any of the original counties could withdraw from the district merely by a vote of its Board of Supervisors.

A five-county plan for a rapid transit system was proposed in 1961. San Mateo and Marin counties found it unacceptable and withdrew from the district. Finally, a three-county BART network was proposed in mid-1962. The bond election occurred in November of that year. There were 61% affirmative votes, with 60% required to pass. Therefore, a period of over 20 years will elapse from study initiation to system implementation. The MAT system will not have right-of-way problems, but will involve 13 counties. Hence, it seems advisable to begin more definitive studies immediately in order to make implementation possible in a reasonable time period.

8.6 Discussion

MAT can become a serious competitor in the metropolitan transportation picture. Programs involving combined planning by two or more regional areas can make it possible to lower the initial cost of the aircraft. Only limited research success is required to get the utilization above the threshold of acceptance. No large technological problems stand in the way, although noise suppression will be an area of continuing research pressure. Time will remove the psychological resistance to the one-pilot concept, and in time flying to work will be as commonplace as driving.

No planning for area transportation can be considered thorough unless it includes consideration of a MAT-type system. It appears to have reasonable promise for the Bay area and perhaps even more promise for areas which have not yet made substantial commitments to a mass transportation system.

8.7 Conclusions

The relatively high cost of operation (about $0.17/passenger mile when the aircraft utilization rate is about 2,000 hrs/yr) probably restricts the number of commuter customers that the MAT system can attract. However, present forecasts indicate a tremendous increase in the conventional airline passenger traffic in the Bay area by the 1980's (see Chapter 7 for these forecasts). These airline passengers represent a very large market for the MAT system. These passengers will be willing to pay for the high cost of operation for the relatively convenient service that can be provided. If these forecasts are accurate, the congestion around the major airports will forbid the use of private automobiles as the primary means of reaching the airports. MAT can provide the required service by accepting the passenger and his baggage at the outlying terminals and transporting both to the conventional airline terminal. In fact, if the forecasts are correct this class of travellers could easily become MAT's primary customers by the late 1980's or early 1990's. In Chapter 7 an estimate of this market is given that indicates that MAT might attract as much as

2,650 million passenger miles of business from the airline travellers by 1990.

REFERENCE

1. Homburger, W. S., "An Analysis of the Vote on Rapid Transit Bonds in the San Francisco Bay Area," The Institute of Transportation and Traffic Engineering, University of California, Berkeley, Calif., June 1963, pp. 1-4.

Appendix A

INCREASED UTILIZATION

The most effective method for reducing the cost per passenger mile is through increased utilization of the aircraft. This results from the fact that the aircraft represent about 80% of the total system cost, and the high annual amortization costs go on independently of how much the system is used. Increasing aircraft utilization during the non-peak hours was, therefore, identified as a key question early in the program. A number of possible applications have been compiled in the hope of at least partially answering this important question.

Historical and sociological data indicate that the work week has been decreasing and will probably continue to decrease. Most experts agree that the thirty-hour work week may soon be with us. Another observation that can be made is that the investment in production equipment required for each worker is increasing yearly. Obviously the reduction of the normal eight-hour workday will increase the effective cost of the production equipment. One way to overcome this is to establish two six-hour production shifts per day. For example, the forenoon shift could start at 6:00 a.m. and end at noon, with the afternoon shift working from noon until 6:00 p.m. Many people working in professional, service, and administrative positions might work from about 9:00 a.m. to 4:00 p.m. This workday schedule would make all public transportation systems more evenly loaded. The present early morning and late afternoon peakload periods would be replaced with four peak periods all with lower maximums. Two of these peak periods would occur in the middle of the day and would produce flow in the opposite directions. In addition, those people not working the standard forenoon or afternoon periods would tend to use the transportation system during the non-peak hours. All this would increase the overall load factor and therefore reduce costs for all public transportation systems. Of course, this is not a concept that may be implemented by a system like MAT. Rather, it is our purpose here to bring attention to a trend that will make the MAT system more attractive.

We believe that increased utilization of MAT aircraft can be encouraged by establishing a separate division for developing new business which supplements the commuter traffic. This division will develop concepts such as those listed below.

<u>Mail</u>. With the increased emphasis on the improvement of mail service more of the mail traffic has moved to air transportation, and post office people predict that all mail between cities will travel by air in the near future. This means that mail will be collected in the regional and central post offices of each community, transported by truck to a major airport, such as San Francisco International, and then loaded aboard outbound flights. Incoming mail is received at the airport and trucked to the various regional post offices. The MAT system could perform the important task of moving the mail quickly between the airports and the post offices. Due to the vertical motion capability of the aircraft, it will be possible to land at each of the post offices to be served. In the future planning of post office facilities it may prove to be advantageous to locate certain post office facilities at the various MAT terminals.

Air Transport of Prefabricated Houses. One way to reduce the cost of house construction is to fabricate and assemble houses in the factory so that mass production techniques can be applied. Estimates of cost savings range from 30% to 75%. Even if the savings are of the order of 30%, this is a significant amount. Factory production will also make it possible to introduce the application of new materials which should help reduce construction costs, and make homes cheaper to maintain. The vehicles of the MAT system will make it possible to move by air a factory-finished house to the home site, placing it on the prepared foundation, leaving only a minimum number of connections to be made before the house becomes a home. This concept offers a large amount of flexibility to the construction industry and should prove helpful in combating such problems as the decay of our cities. Once houses are built with the potential of being air-lifted, a new capability will exist for refurbishing and removal and replacement when necessary.

Charter Service. With increased leisure time the public will seek to spend more of its non-working hours in removed recreation areas. The MAT vehicles could be operated in a charter operation to supply transportation to these areas on the off hours, i.e., evenings and weekends. An area defined by a radius equal to the compound helicopter's range of 250 miles would be a logical region to serve. Within this region around the Bay area are located a large number of recreation areas Table A-1 along with typical one-way fares. It should be noted that the assumptions used to generate Table A-1 are conservative. If true charter service where used between San Francisco and points listed in the table, the fares could be reduced to the point that the figures shown on the right could actually represent the round trip fare.

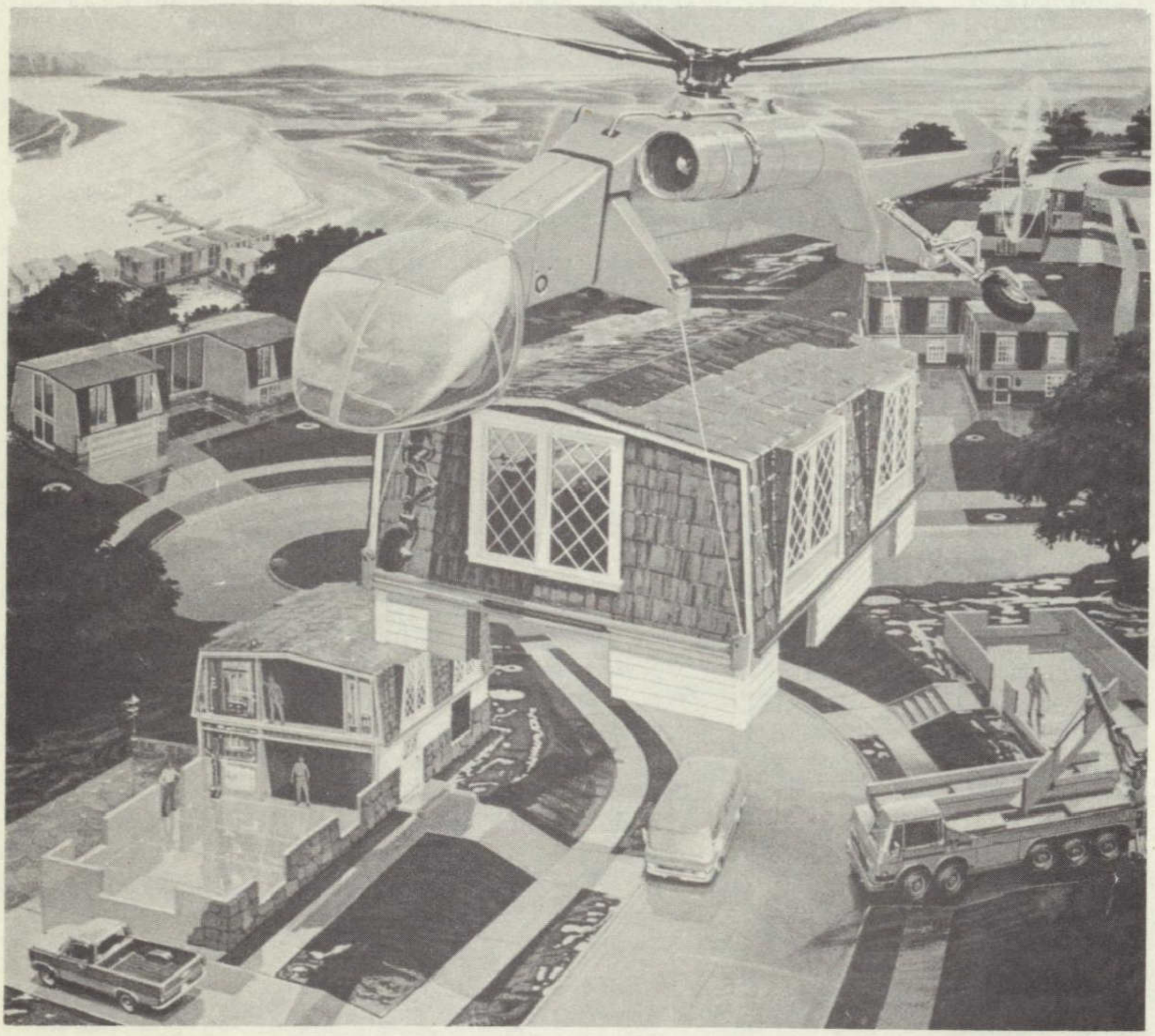

Figure A-1 Air Transportation of Prefabricated Houses

Freight. Due to the quick movement of the MAT vehicles between the communities, in which the 24 terminals are located, it will be possible to move certain goods between these centers in ways not now possible. There is need for rapid movement of certain items in any large metropolitan area. A few examples that quickly come to mind are movement of money, bonds, cancelled checks, and jewelry. The fast movement of many other goods about the metropolitan area could be justified in a number of ways, e.g., time saved or on the basis of the costs saved in reduced warehouse and inventory requirements in branch outlets. All of the branch outlets could be served from a central location with time measured in minutes. To make this type of service more attractive, a fleet of small radio-controlled vans could be operated at each terminal that would transfer the good between the shipper and the terminal. An estimate of the competitive position of the MAT freight service can be obtained by comparing MAT rates with typical truck freight rates (see Table A-2).

Extended Commuter Service. Potential customers for the MAT commuter service could be better attracted if the system offered door-to-door service. At least a first step in this direction could be supplied by a fleet of small vans (ten passenger) operating out of each terminal. The customer would contract for a fixed period of time, say six months, for a mini-bus to pick him up at home each morning, deliver him to the terminal, and then a second bus to take him from his destination terminal to his place of work. This process would be reversed in the afternoon. The vehicles used for this purpose during the morning and afternoon rush hours could be used in the off time for the freight service outlined above.

New Areas. The demand for more living and working space in any metropolitan area typically means a move outward away from the central business district. The movement is usually in the direction of less expensive land. The problem that is encountered is the lack of good transportation to the central business district. Flexibility of the MAT system allows for the service to such areas to be started in a relatively short period of time and for service to be increased more nearly in keeping with the increase in demand. The original design of these housing areas, industrial parks, and towns would incorporate the necessary ground facilities, heliport, parking, etc.

Emergency Applications. The MAT system vehicles may be employed in times of emergency to move people out of regions of potential danger, or to move emergency equipment into a disaster area.

Table A-1

MAT CHARTER RATES

Location	Distance Air Mile From S.F.	Flight Time (min.)	MAT Fare (one-way)		
Santa Cruz	70	24	$ 6.78	to	$10.52
Monterey	90	28	7.90		12.16
Mammoth Lake	200	59	16.68		25.60
June Lake	200	59	16.68		25.60
Squaw Valley Lake Tahoe	160	46	13.00		20.00
Reno	195	57	16.10		24.80
Healdsburg	65	23	6.50		10.10
Clear Lake	90	29	8.18		12.60

Assumptions:

(1) Total price/hour = \$679 to \$1,041 or $\frac{\$8.48}{\text{pass. hr.}}$ to $\frac{\$13.03}{\text{pass. hr.}}$ for each airplane.

(2) Vehicles fly full one direction, empty the other, so the passenger must pay two times the flight time cost (50% load factor).

Table A-2

COMPARISON OF MAT FREIGHT RATES TO TRUCK FREIGHT RATES
(San Francisco to San Jose)

<u>Truck Freight Rates - door-to-door</u>	
Small expensive items (electronic parts, small electrical appliances)	$\frac{\$0.0725}{100\text{ lb mi}}$
Bulk materials (can goods, materials easy to handle)	$\frac{\$0.0467}{100\text{ lb mi}}$
<u>MAT Freight Rate</u>	
Small expensive items (electronic parts, small electrical appliances)	
terminal-to-terminal	$\frac{\$0.056}{100\text{ lb mi}}$
door-to-door	$\frac{\$0.10}{100\text{ lb mi}}$

In effect the MAT system would become an air freight forwarder and air freight operation in a metropolatin area rather than across the country.

Appendix B

DYNAMIC ANALYSIS OF ARRESTING SYSTEMS

To gain some insight into the relative magnitudes of forces, stopping distances, and stopping times involved for different arresting systems the linearized differential equations for each system will be set up and solved. The task for each of the systems is the same: to bring a craft with a mass of 2000 slugs to a stop in 100 ft/sec from an initial velocity of loo ft/sec. The arresting systems will be classified in terms of the energy conversion principle involved.

B.1 Spring Arrest

A spring arrest system converts the kinetic energy of the moving plane to stored kinetic energy in the spring. The differential equation of motion is that of a simple harmonic oscillator with an initial condition

$$m\ddot{x} + kx = 0, \quad \dot{x}(0) = 100 \text{ ft/sec}$$

where k is the spring constant to be determined such that the craft comes to a stop in 100 ft. The solution of the equation is

$$x = 100 \sin \omega t$$

where $\omega = \sqrt{k/m}$.

Differentiating to get velocity and acceleration,

$$\dot{x} = 100\,\omega \cos \omega t$$

$$\ddot{x} = -100\,\omega^2 \sin \omega t$$

Using the initial condition

$$\dot{x}\ (0) = 100 = 100\ \dot{\omega}$$

$$\omega = 1 = k/m$$

$$\text{or}\quad k = m = 2000\ \text{lbs/ft}\ .$$

The maximum deceleration is then

$$\ddot{x}_{max} = 100\ \text{ft/sec}^2 \cong \underline{3g\text{'s}}$$

occurring at a time

$$t = \frac{\pi}{2}\frac{1}{\omega} = \frac{\pi}{2} \cong 1.7\ \text{sec}$$

This is also the time at which the craft comes to a stop.

B.2 Damper Arrest

A damper arrest system will dissipate the kinetic energy of the craft. The differential equation of motion is first order in $\dot{x}$.

$$m\ \ddot{x} + b\ \dot{x} = 0, \qquad \dot{x}\ (0) = 100\ \text{ft/sec}$$

where b is the damping coefficient to be determined. The solution to the equation is

$$\dot{x} = 100\ e^{-(b/m)t}$$

Integrating and differentiating yields

$$x = 100\ (\frac{m}{b})\,[1 - e^{-(b/m)t}]$$

$$\ddot{x} = -100\ (\frac{b}{m})\,e^{-(b/m)t}$$

Using the condition that $x_{max} = 100$ ft (the required stopping distance),

$$x_{max} = 100 = 100\ \frac{m}{b}$$

$$b = m = 2000\ \text{lb sec/ft}.$$

The time constant of the solution is therefore

$$\tau = \frac{m}{b} = 1 \text{ sec}$$

The craft will essentially come to rest within 4 time constants or 4 seconds. The maximum acceleration occurs at t = 0 and is

$$\ddot{x}_{max} = 100 \text{ ft/sec}^2 \cong 3 \text{ g's}$$

B.3 Friction Arrest

A friction arrest system also dissipates the kinetic energy of the craft but the retarding force is constant and not proportional to velocity. The equation of motion is

$$m\ddot{x} + F\frac{\dot{x}}{|\dot{x}|} = 0 \qquad \dot{x}\ (0) = 100 \text{ ft/sec}$$

where F is the retarding force required. The solution is

$$\ddot{x} = -\frac{F}{m}$$

$$\dot{x} = \dot{x}(0) - \frac{F}{m}t$$

$$x = x(0) + \dot{x}(0)t - \frac{F}{2m}t^2$$

If we let the stopping time be 2 seconds, then

$$\dot{x}(2) = 0 = 100 - \frac{F}{2000}(2)$$

$$F = 100{,}000 \text{ lbs}$$

and

$$x(2) = 100(2) - \frac{100{,}000}{4{,}000}(2)^2$$

$$= 100 \text{ ft}$$

$$\ddot{x} = \frac{100{,}000}{2{,}000} = 50 \text{ ft/sec}^2 \cong 1.6\text{g's}$$

The results of this analysis are summarized in Figure B-1. The fact that the deceleration of the craft is less for the friction type of arrest indicates that less inertial damage will occur both to the passengers and the craft with this type of system. An arresting system which provides a uniform arresting force to be applied to the craft therefore is to be preferred. Although the resetting runway vanes provide discrete arresting forces to the craft, when they are spaced closely enough together they will produce a nearly constant arresting force and therefore warrant further investigation.

B.4 Kinematics of the Resetting Runway Vane Arrestor

Figure B-2 shows a geometric diagram of a wheel in contact with a runway vane during the arresting operation. The wheel is rolling along the surface of the runway from left to right. This motion is being resisted by the horizontal component of force at the point of contact with the vane. As the wheel travels to the right this point of contact translates toward the hinge. Slippage also occurs between the wheel and the vane at this point. The retarding torque of the vane is given by

$$T = K\ (\theta_o - \theta)$$

The retarding force in the horizontal direction is then

$$F_H = \frac{K}{L}\ (\theta_o - \theta)\ \sin\theta\ ,$$

where by symmetry $L = r - x$.

θ can be found as a function of x as

$$\theta = 2\ \tan^{-1}\ (\frac{r - x}{r}) \qquad 0 \le x \le r$$

$$F_H = \frac{K}{r - x}\ [\theta_o - 2\ \tan^{-1}\ (\frac{r - x}{r})]\ \sin\ [2\ \tan^{-1}\ (\frac{r - x}{r})]$$

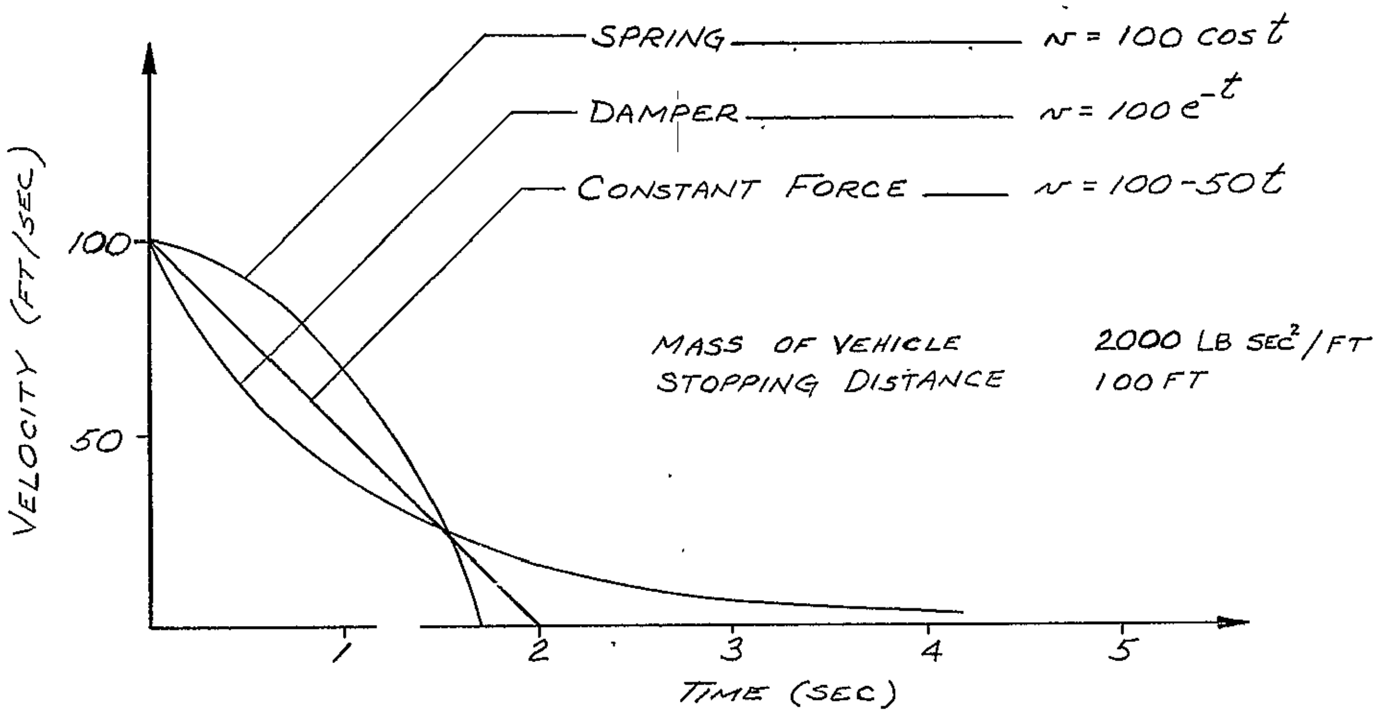

FIG B-1 COMPARISON OF DYNAMICS OF ARRESTING SYSTEM.

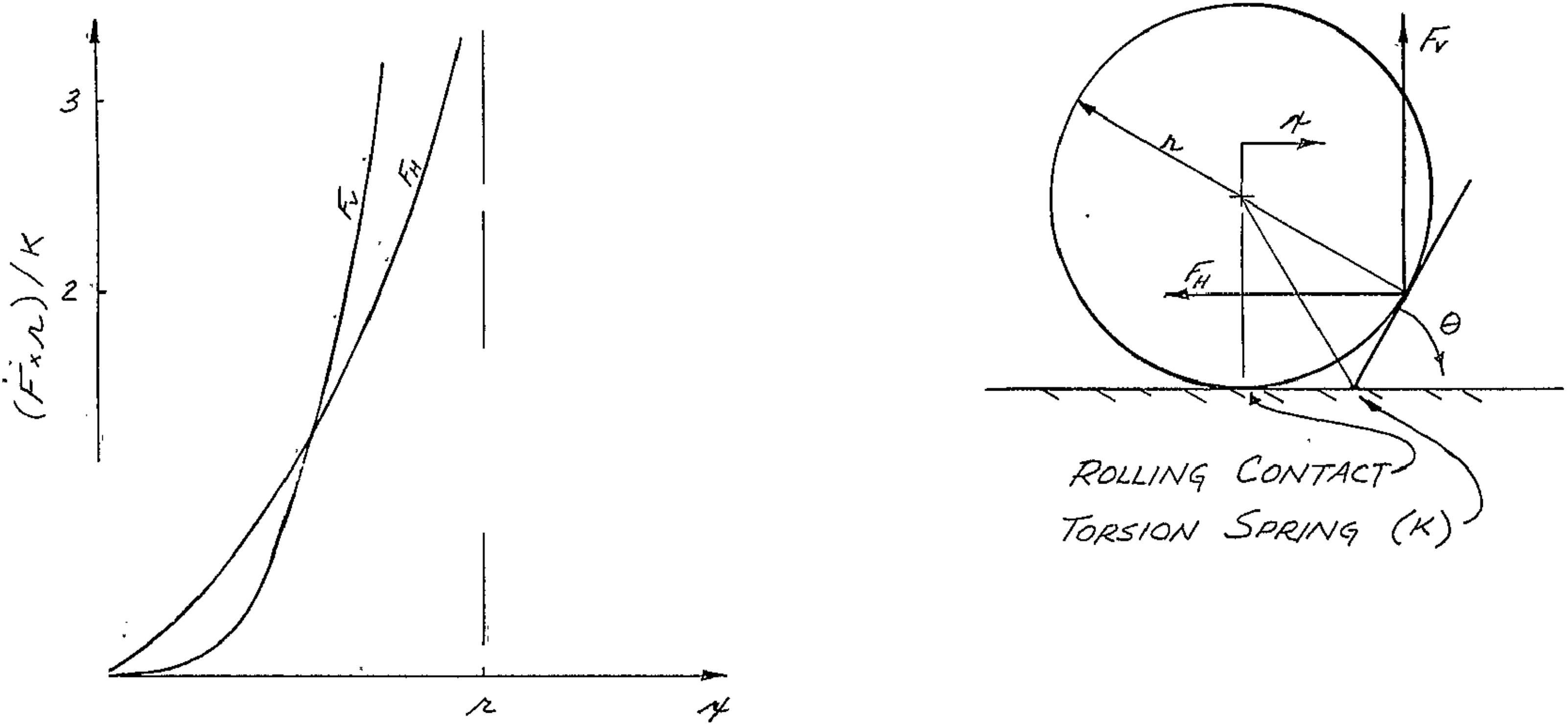

FIG B-2 KINEMATICS OF RESETTING VANE ARRESTOR

Likewise the vertical force at the point of contact is

$$F_V = \frac{K}{r - x} [\theta_o - 2 \tan^{-1} (\frac{r - x}{r})] \cos [2 \tan^{-1} (\frac{r - x}{r})]$$

These functions are plotted in Figure B-2. Note that both the horizontal and vertical forces tend to infinity as the point of contact reaches the hinge. Of course, this would not happen in reality since the rubber wheel is not a true circle, but the forces do get rather high. The horizontal force is desirable but the vertical force will cause the craft to "hop" along the tops of the vanes. This unwanted effect can be avoided if the vanes are modified. If, for instance, the lower half of each vane is cut out except for attachment bars to the hinge, then the point of contact will not reach the hinge and the peaks of the force curves will be clipped. This will also, of course, decrease the effectiveness of the vanes as arrestors. Rough calculations show that a torsional spring constant of 200,000 lbs/rad is required to bring a 60,000-pound craft to a stop in 100 feet. The number of vanes required depends on the size of the landing wheel but would probably be in excess of 50. Much experimental work would be required to evaluate such a scheme and only a first order analysis has here been attempted. A more comprehensive analysis would include the several degrees of freedom of the craft and a more realistic simulation of the gross nonlinearities involved in such a scheme.

APPENDIX C

SUGGESTED RESEARCH--NOISE REDUCTION

In studying the possibility of applying VTOL aircraft to city center transportation one quickly concludes that noise reduction is an area that will require continued research and development effort if the full potential of the vehicle is to be realized. This conclusion is well-supported in the literature (see References C-1, C-2, C-3, and C-4).

From the standpoint of acceptable noise levels for city center operation, the list of lifting systems to be considered may be quickly reduced. Hargest [C-5] presents convincing arguments leading to the conclusion that the two which should be considered are ducted fan systems and rotor systems. Hargest goes on to suggest that even with the projected future noise reductions for the fan systems their noise levels will still be above those of the rotor for comparable performance. This clearly suggests that the rotor systems must be carefully examined for possible noise reduction possibilities.

Rotor rotational noise is a function of the rotor tip speed as is indicated in the Gutin noise theory, which is expressed in mathematical form as

$$P_m = \frac{169.3\ M_t\ R_t}{SA} \left(-T \cos\theta + \frac{.76\ Hp}{M_t^2}\right) mBJ_{mB}(.8mBM_t \sin\theta)$$

where

M_t = tip rotational Mach number

N = angular velocity

R_t = rotor radius ∿ ft

C = speed of sound ∿ ft/sec

S = distance of observer from rotor ∿ ft

A = rotor disk area ∿ ft^2

T = disk static thrust ∿ lbs

θ = angular position of observer ∿ degrees

Hp = horsepower supplied to rotor

B = number of rotor blades

$J_{mB}(\ )$ = Bessel function of first kind, order mB and argument ( )

P_m = sound pressure ∿ $dynes/cm^2$

m = harmonic of sound ($m = 1$ is fundamental tone)

A reduction in rotor tip speed may be obtained if, at the same time, the section lift coefficient is increased so as to maintain a given thrust level. An interesting suggestion for increasing the rotor section lift coefficient was presented by Cheeseman and Seed (see Reference 6). The Cheeseman-Seed circulation control concept offers many advantages along with the possibility of noise-reduction, and therefore deserves further study. Circulation control involves the blowing of air tangential to the surface, in the direction of flow, at the rear of the rotor section. A typical application is shown in Figure C-1.

The amount of circulation is controlled by the relative strength of the two jets. An indication of the amount of noise reduction that may be obtained with this system is shown in Figure C-2, taken from Reference 5.

At the rear of the rotor section a wake region will trail off in the flow. This type of flow generates aerodynamic noise that should be considered. One approach is to remove the wake regon. A possible

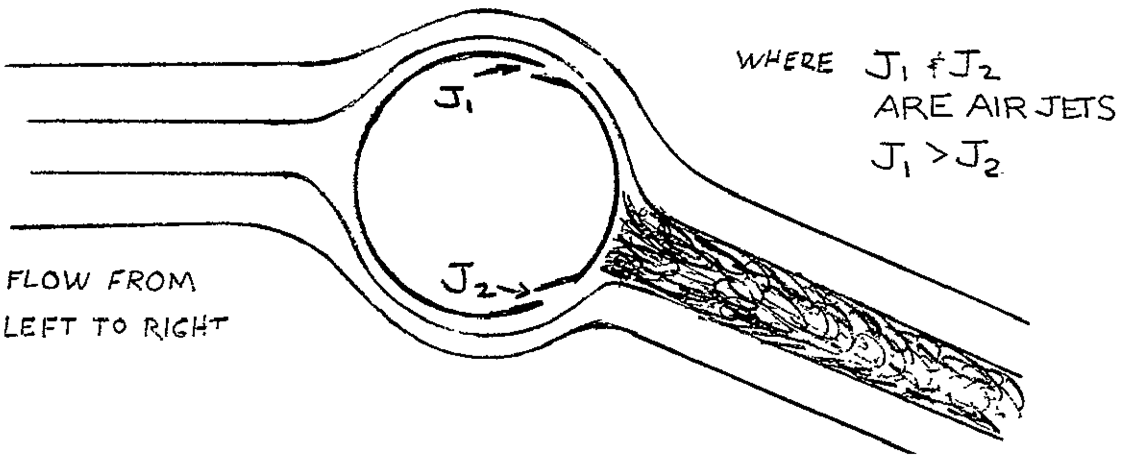

FIGURE C-1 JET-INDUCED CIRCULATION

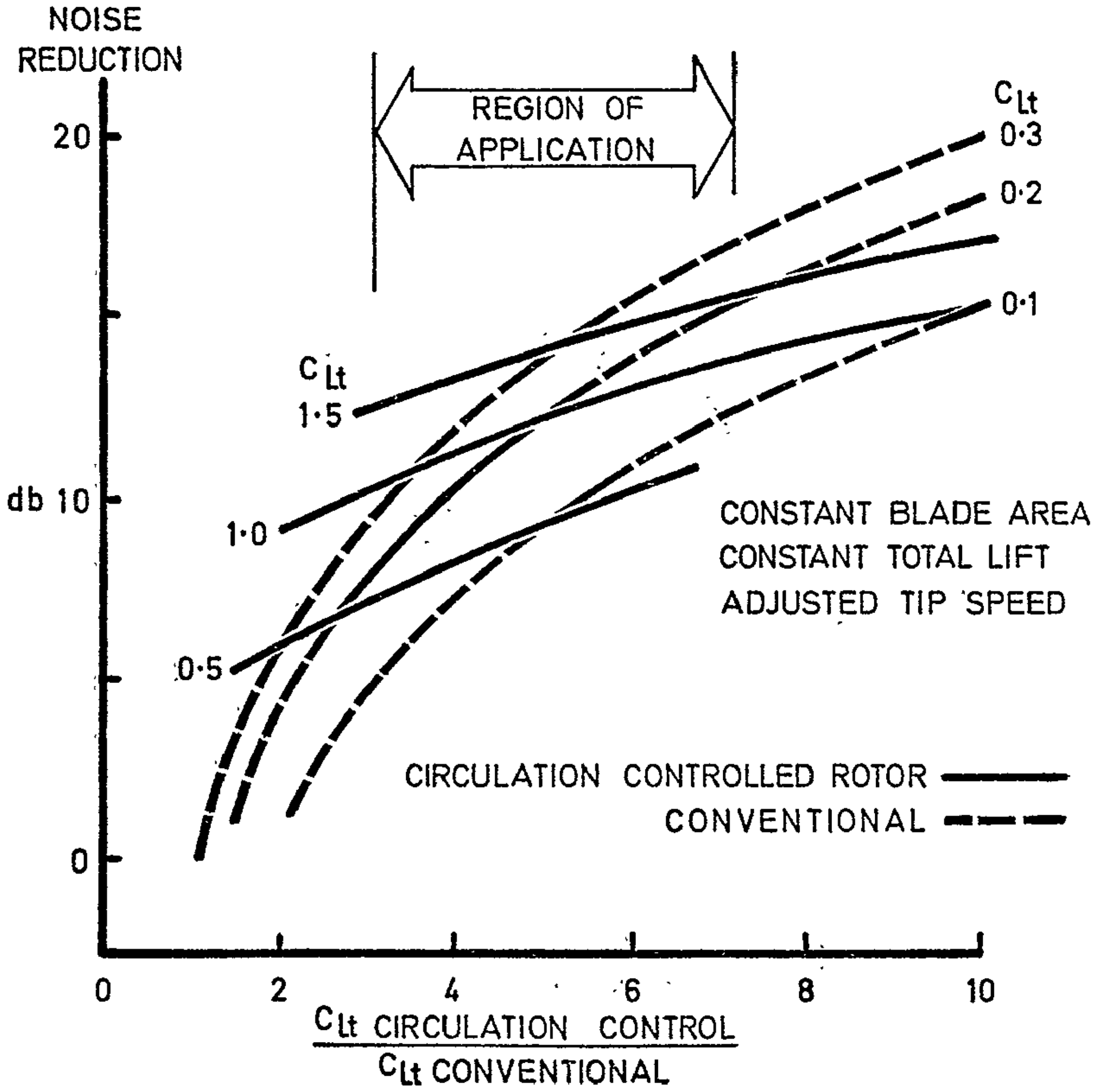

Figure C-2

NOISE REDUCTION BY APPLICATION OF CIRCULATION CONTROL scheme for doing this is indicated in Figure C-3.

The method of introducing the circulation flow will influence the overall noise level, and therefore should be investigated in the study suggested. If the flow is injected through a large number of small holes, it may be possible to increase the frequency of the sound emitted. This could result in an overall noise reduction at locations removed from the rotor. The reason is that atmospheric attenuation is larger on higher frequency noise.

A possible noise reduction of 12 dB more, as is indicated in Figure C-2, warrants a research effort directed to develop this potentially low-noise rotor. Also much, if not all, of the knowledge gained in such studies will apply to propeller design.

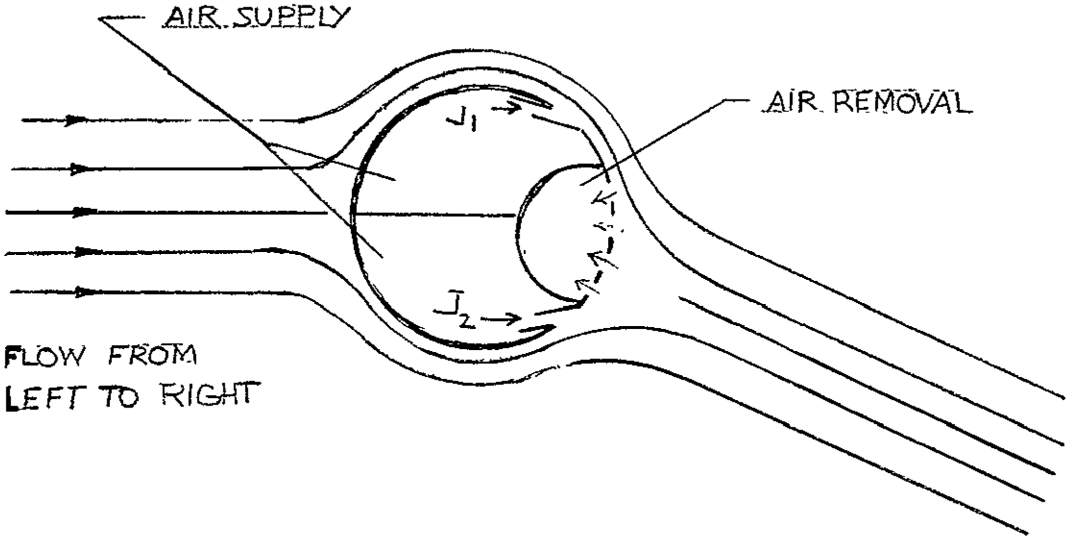

FIGURE C-5 REMOVAL OF WAKE BY SUCTION

REFERENCES

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2. Richards, E. J., "Problems of Noise in Helicopter Design," The Journal of the Helicopter Association of Great Britain.
3. Pickerell, D. J. and Cresswell, R. A., "Powerplant Aspects of High-Speed, Inter-City VTOL Aircraft," Journal of the Aircraft, September-October 1968, pp. 467-472.
4. Maglieri, D. J., Hilton, D. A., and Hubbard, H. H., "Noise Considerations in the Design and Operation of V/STOL Aircraft," NASA Technical Note D-736, 1960.
5. Hargest, T. J., "VTOL Aircraft Noise," AGARD Conference Proceedings, No. 22, September 1967.
6. Cheeseman, I. C. and Seed, A. R. "The Application of Circulation Control by Blowing to Helicopter Rotors.

APPENDIX D

LECTURE PROGRAM

Organization and Speaker	Topic
Stanford University	
Bollay, William	Educational and Technical Objectives of Project Previous System Engineering Projects Proposed Organization of Project
Hall, W. Earl	Dynamics of Large Tilt-Rotors in Forward Flight
Miles, Richard	An STOL Aircraft Design Project
Noton, Bryan	Graduate System Design Projects
Piper, Robert	Methods of Cost Analysis
NASA-Ames	
Anderson, Seth B.	Handling Qualities of V/STOL Aircraft
Drake, Hubert M.	Short-Haul Transportation
Foster, John V.	A Far Out View of V/STOL Transportation Systems
Innis, Robert C.	A Pilot's View of V/STOL Aircraft
Johnson, Norman S.	Navigation and Automated Guidance Systems II
Kelly, Mark W.	Perspective of V/STOL Aircraft
Yaggy, Paul F	Problems and Future Potential of Rotary Wing Aircraft
NASA-Electronics Research Center	
Schuck, O. Hugo	Navigation and Automatic Landing Systems

Other Universities

Andreoli, A. E.	California State Polytechnic College	An Undergraduate System Engineering Project (Proposed System for California State Polytechnic College)
Lissaman, P.B.S.	California Institute of Technology	Studies on Future V/STOL Systems

Research Organizations

Babcock, Dean F.	Stanford Research Institute	Navigation and Automated Landing Systems I
Dodson, E. N.	General Research Corporation	An Operational Analysis of Urban Transportation Systems
Henderson, Clark	Stanford Research Institute	High-Speed Surface Transportation Systems
Hinz, Earl	Aerospace Corporation	The Requirements in the Western States for Commuter and Short-Haul Transportation
Fink, Martin R.	United Aircraft Research Laboratories	Turbofan Engine Noise
Katten, Stanley L.	The RAND Corporation	Air Traffic Control--Truth or Consequences Systems Analysis of V/STOL Operations
Vogt, Richard	Scientia Corporation	Some Design Concept for V/STOL Systems

Airlines and Airports

Cable, Roger B.	Los Angeles Airways	Future Potential for STOL Aircraft--View by a Helicopter Airline Operator
Coykendall, Richard	United Airlines, Inc.	Future Potential for V/STOL Aircraft--View by a Major Airline Operator
Ellison, Thomas	United Airlines, Inc.	Navigation and Instrument Landing Systems

McSherry, George M.	Los Angeles Department of Airports	Large Airports and Future Commuter Systems
Schwind, George	United Airlines, Inc.	Autopilot Systems

Industry

Ashby, Robert M.	Autonetics Division, North American Rockwell Corporation	Inertial Autonavigation
Coty, Ugo	Lockheed-California Company	V/STOL Concepts for Short-Haul and Commuter Systems
Farr, Donald	Autonetics Division, North American Rockwell Corporation	Computers and Micro-electronics
I'Anson, Leonard	Lycoming Engine Division, AVCO	Future Propulsion Systems for V/STOL Aircraft
Irvin, Leslie A.	Parsons-Brinckerhoff-Tudor-Bechtel	The BART Transportation System in San Francisco
Marsh, K. R.	LTV Aerospace Corporation	V/STOL Concepts for Short-Haul Transport Aircraft
Shevell, R.	Douglas Aircraft Corporation	Relative Merits of Turbofan and Turboprop Aircraft
Vickers, T. K.	Decca Systems, Inc.	The Decca Navigator System
Woodward, Joseph E.	Cutler-Hammer Airborne Instruments Laboratory	Landing Guidance Techniques