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STUDY OF AIRCRAFT IN INTRAURBAN TRANSPORTATION SYSTEMS

Final Report

VOLUME 3

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LOCKHEED-CALIFORNIA COMPANY • BURBANK
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

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FOREWORD

The Study of Aircraft in Intraurban Transportation Systems was conducted under NASA Ames Research Center Contract NAS2-5989. This final report, consisting of four volumes, is submitted in compliance with the requirements of Article IV, Paragraph B-5.0 and presents all of the work accomplished by the Lockheed-California Company during the two-phase study program. This program was initiated in June 1970 and completed in May 1971.

This report is prepared within the framework of the Preliminary Final Report Outline submitted to NASA by Lockheed's letter LAC/01695,dated 26 June 1970, with minor revisions. The report contains an organized and edited version of the work reported in the previously submitted nine Monthly Progress Reports (LR 23820-1 through LR 23820-9) and the formal Phase I Oral Presentation held on 3 December 1970 at the NASA Ames Research Center facility.

This final report is subdivided into four volumes for ease in handling by the reader. Phase I - Aircraft Concepts Selection is contained in Volumes 1 and 2 (CR 114340 and CR 114341). Phase II - Aircraft Concepts Evaluation is presented in Volume 3 (CR 114342). All backup data leading to the summarized conclusions within the main body of the report are to be found in Volume 4 (CR 114343) Appendix. Each figure and table in Volume 4 is identified by the number of the section in the main body of the report that utilizes the basic data. The summary and introduction are presented in Volume 1 and the reference list is shown in Volume 3.

This study was accomplished by the Advanced Design Division, Science and Engineering Branch of the Lockheed-California Company, under the direction of the Engineering Study Manager, E. G. Stout. The principal investigators were P. H. Kesling, H. C. Matteson, D. E. Sherwood, W. R. Tuck, Jr., and L. A. Vaughn.

The work reported herein was administered under the direction of George C. Kenyon, Advanced Concepts and Missions Division, Office of Advanced Research and Technology, NASA Ames Research Center, who was designated the Technical Monitor for the contract.

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2.0 PHASE II - AIRCRAFT CONCEPTS EVALUATION

2.1 ANALYSIS

2.1.1 AIRCRAFT DESIGN

The objectives of the aircraft design elements of Phase II were to define each concept in sufficient detail to:

1) Provide appreciation for the aircraft design-development problems associated with this new mass-transportation vehicle concept

2) Examine the primary effects on vehicle configuration of varying payload and runway lengths for a representative intraurban transport operation, for use in system route/schedule cost analyses.

The aircraft configuration concepts evaluated in Phase I for their adaptability to the intraurban scenario are listed below. Two initial operating capability (IOC) time periods were considered: 1975 and 1985. Contract requirements called for the selection of one VTOL and one STOL concept. For more detailed analysis in Phase II. The concepts evaluated in Phase I are listed below.

CONCEPT	POWER	IOC
1) Tilt Wing VTOL	Propeller	1975, 1985
2) Compound Helicopter VTOL	Turbofan/Rotor	1975, 1985
3) Deflected Slipstream STOL	Propeller	1975, 1985
4) Augmentor Wing STOL	Turbofan	1985
5) Autogyro STOL	Turbofan/Rotor	1985
6) Conventional CTOL	Propeller	1975
7) Conventional CTOL	Turbofan	1985

Concepts 2), 3) and 5) were chosen for the Phase II analysis. The autogyro STOL concept is not a contractual item, but is being studied concurrently as a Lockheed-funded effort.

Each concept was "sized" for at least three payloads (number of passengers) around a single mission. The autogyro was configured aerodynamically and propulsionwise for an FAR field length of 1000 feet since analysis showed that much deviation from this value demanded large increases in gross weight or power. The deflected slipstream STOL concept was configured for three FAR field lengths by varying the power around a fixed aerodynamic configuration. Evaluation of the effects of payload and FAR field length has been extended to include total system cost estimates.

2.1.1.1 Design Requirements and Guidelines

Design requirements and guidelines evolved from the Phase I study for intraurban transport type aircraft were employed in configuring and analyzing the Phase II concepts. These guidelines are as follows:

- Payload - Primary study variable within the following ranges:

	Passengers
Compound Helicopter VTOL	40-80
Autogyro STOL	40-100
Deflected Slipstream STOL	20-100

- Airport Performance - Primary study variable within the following ranges:

	Field Length (ft)
Compound Helicopter	VTOL
Autogyro STOL	1000
Deflected Slipstream STOL	1500-2500

- Design Cruise Speed

Rotary Wing	200 ktas @ 2000 ft
Deflected Slipstream STOL	250 ktas @ 2000 ft

- Design Endurance (fuel required basis) - Eight 22-mile flights (stages) with engines operating continuously under allowance pattern of Table 2.1-1

- Community Noise Limits - The following upper limits on community noise caused by intraurban aircraft operations are considered necessary for public acceptance of the system.

TABLE 2.1-1
FUEL ALLOWANCES AND FLIGHT TIME BASIS

Stage Segment	Configuration	Time Allowance and Fuel Segment Basis
Taxi Out at Low Power	VTOL	- 0.5 minute at 9% rated power fuel flow rate
	STOL's	- 1.0 minutes at 9% rated power fuel flow rate
Takeoff	All	- Actuals to 35 feet altitude, all engines
Climb	All	- MCP climb from 35 to 2000 feet at best R/C speed
Cruise	Hel. VTOL, Autogyro STOL	- 200 kt TAS at 2000 ft altitude
	Fixed Wing STOL	- 250 kt TAS at 2000 ft altitude
Descent	All	- No fuel, time, or distance allowed
Approach Air Maneuvers	All	- 0.5 minute at 50% MCP fuel flow rate
Landing	All	- 1.0 minute at power for level flight
Taxi in at Low Power	VTOL	- 0.5 minute at 9% rated power fuel flow rate
	STOL's	- 1.0 minute at 9% rated power fuel flow rate
Load-Unload	All	- 5 minutes at 9% rated power fuel flow rate

Reserves - 5% initial fuel

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	LIMIT 1975 IOC	PNDB 1985 IOC
Residential - suburban	85	78
- metropolitan	80	73
Suburban park land and research centers	95	88
Metropolitan - high ambient noise, industrial	95	88
Metropolitan - commercial, industrial	90	83
V/STOL commuterport parking, administration service buildings	100	93
V/STOL commuterport load unload area	110	103

The basis for these values is discussed in Section 2.1.1.9.

- Ride Qualities - It is not considered practical to establish quantitative requirements for ride qualities. However, this item is equally as important as community noise in its effect on public acceptance of the system. Factors involved include passenger normal and lateral acceleration and attitude excursions. Gust relieving devices should therefore be included in the configuration development.

- Interior Noise - Voice communications are limited by the amplitude and spectral distribution of the ambient noise and the amplitude and frequency characteristics of the communication. To allow raised-voice communications at two feet and normal-voice communications at one foot, the cabin cruise levels should not exceed 70-73 dB PSIL. The quantity PSIL is equal to the arithmetic average of the octave band sound pressure levels in the 500 Hz, 1 K Hz and 2 K Hz octave bands, and it is referred to as the preferred frequency speech interference Level (SIL).

  "A"-weighted sound pressure level of approximately 85 will be necessary to gain carrier and passenger acceptance of the cabin noise during cruise. The "A"-weighted sound pressure level (dB A) has been shown to be an approximate weighted summation of the octave band sound pressure levels wherein each band is roughly weighted according to its relative annoyance.

- Communication, Navigation, Air Traffic Control - Adequate for FAR category 3b operation for 1975 IOC and 3c for 1985 IOC.

- Performance, Handling Qualities, and Structural Design Basis- 1975, 85 Compound Helicopter VTOL - Per applicable sections of both FAR 29 and August 1970 issue of FAR, "Tentative Airworthiness Standards for Powered Lift Transport Category Aircraft."

  1985 Autogyro STOL - Per applicable sections of both FAR 29 and August 1970 issue of FAR, "Tentative Airworthiness Standards for Powered Lift Transport Category Aircraft."

  1975, 85 Deflected Slipstream STOL - Per applicable sections of both FAR 25, 29, and August 1970 issue of FAR. "Tentative Airworthiness Standards for Powered Lift Transport Category Aircraft."

  Rotor controls and drive system to be designed for infinite life and "fail safe" capability of approximately 300 hours between periodic inspections.

  Single runway operation in 30 kt 90° crosswind and 30 kt wind from the stern.

  Handling qualities of STOL configurations in general accordance with the criteria of NASA TN D-5594, "Air-worthiness Considerations for STOL Aircraft."

- Flight Station Visibility - Flight station visibility to conform to requirements of SAE AS 580A, "Pilot Visibility from the Flight Deck - Design Objectives for Commercial Transport Aircraft." Also, view angle forward and down in STOL's sufficient to allow pilot to see a length of approach lights (three minimum) and/or touchdown zone lights that will provide definite visual reference as to alignment and height with respect to the runway when the aircraft is on a 7 1/2° glide slope and, in addition, for the compound helicopter and autogyro, 15° below the horizontal in the forward quadrant on landing approach.

- Airframe Design -

  Passenger Accommodations - Fuselage interior arrangement of Phase I analysis retained. Interior geometry and variation with payload held constant for all concepts and as shown by Figure 2.1-1 for the deflected slipstream STOL concept and Table 2.1-2.

  It is noted that the double aisle interior was found necessary in Phase I to provide a maximum allowed turnaround time of five minutes (considered necessary as a cost reducing measure). Also, contributing to short turnaround time is the four door load/unload concept illustrated by Figure 2.1-2 which permits simultaneous load/unload operations.

  Crew Accommodations - Two-man crew: pilot and co-pilot with jump seat between and one other seat on flight deck for inspectors, etc.

  Cargo Alternate - Provide capability for all-cargo alternate, via quick removal of passenger interior

  Fixed Landing Gear

  Ram Air Pressurization

  No on-board APU

  General arrangement to include means to permit quick off-load/on-load without stopping engines

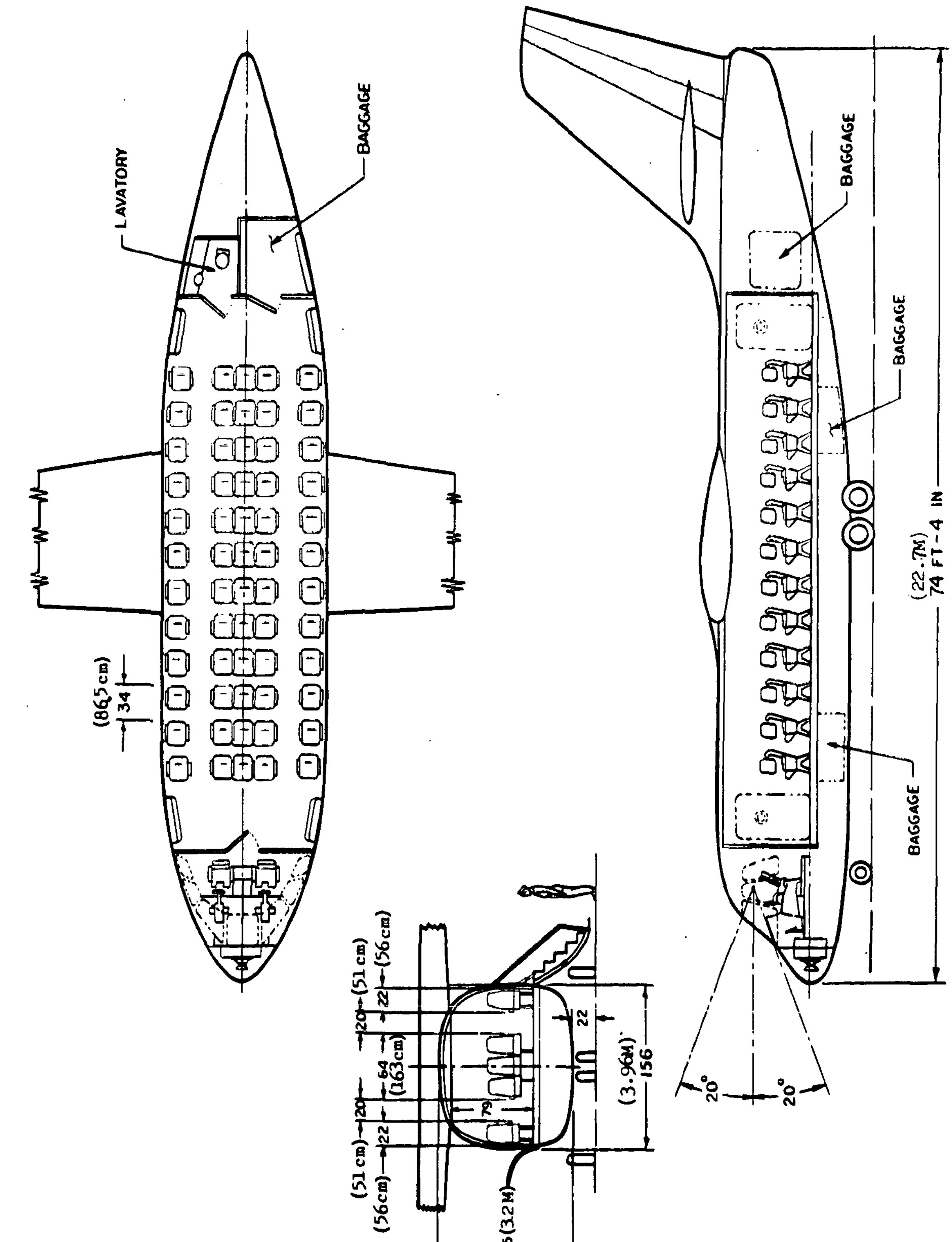

Figure 2.1-1. Interior Arrangement - 60 Passenger - All Configurations

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TABLE 2.1-2. FUSELAGE INTERIOR LOAD-UNLOAD TIME VS CAPACITY

Interior Arrangement	Passenger Capacity			
	40	60	80	100
CABIN WIDTH, IN.	156	156	156	184
APPROX. CABIN LENGTH, IN.	405	530	655	710
SEAT ROW CONFIGURATION	2-1-2	2-1-2	2-1-2	2-2-2
SEAT WIDTH, IN.	22	22	22	22
SEAT PITCH, IN.	34	34	34	34
NUMBER OF AISLES	2	2	2	2
AISLE WIDTH, IN.	20	20	20	20
NUMBER OF DOORS	4	4	4	4
DOOR WIDTH	42	42	42	42
TIME AT ENROUTE STOP WITH 100% PASSENGER TRANSFER	3:13	3:50	4:27	5:07

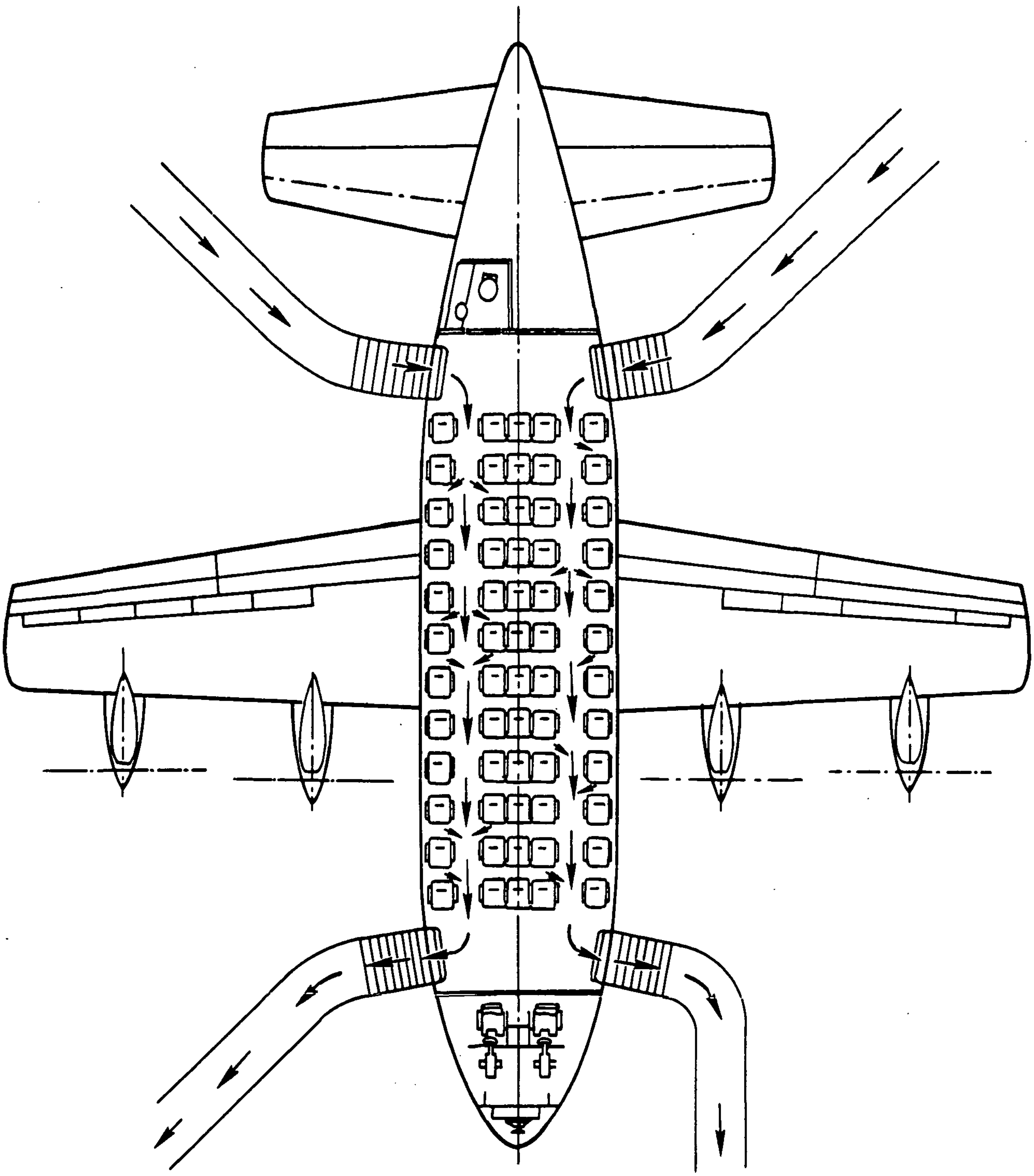


Figure 2.1-2 Onload/Offload Traffic Pattern

Built-in stairs

Passenger axial acceleration limits for performance analysis -

Takeoff acceleration - 0.5g
Takeoff, landing deceleration - 0.35g

All fuel in wing outboard of fuselage half-breadth

Quick release passenger seat and **shoulder constraints**

- Structures - Detail consideration of structural design of the several concepts was beyond the scope of the present study. Reference is made to the discussion presented in Volume 1, Section 1.1.2.4.
- Maintainability and Reliability - No limitations were employed, since treatment of this element of the total design problem is beyond scope of present study. This element does, however, have a large effect on total costs and thus warrants further analysis (see Section 2.1.3.3).
- Propulsion - Capability to leave engines running with propellers and/or rotors stopped during unload-load operations. This will increase safety and extend engine life by reducing the adverse effects of frequent engine stop-start cycles (thermal shock).

2.1.1.2 Technology Application

Primary technology applications employed in Phase II to define the Phase II configurations, are discussed below.

2.1.1.2.1 Aero-Propulsion

No significant advances in 1985 aerodynamics technology have been employed in this analysis. Improved lift and drag performance will likely be through more sophisticated mechanical systems, probably not appropriate to a simple, rugged, intraurban transport type.

Propulsion advances forecast for 1985 IOC technology show a five percent reduction in engine specific fuel consumption and a 20 percent reduction in engine weight. These were employed in the analysis. The rotor tip nozzle drive system used on the 1985 compound helicopter (see 2.1.1.3) will be firm state-of-the-art by then, and this is the most significant factor in the large weight reduction of the 1985 vs. 1975 configurations.

Rotary wing propulsion systems were treated in more depth in Phase II employing information contained in Reference 2.1-5 through 2.1-21. Working data included Figures 2.1-1 through 2.1-12 of the Appendix, Volume 4.

2.1.1.2.2 Structures, Materials

The forecasted structures and materials benefits due to application of 1985 technology were applied consistently to all concepts and to approximately the same degree as in Phase I. The corresponding weight reductions shown (sec. 2.1.1.6) are considered to be a reasonable compromise between a minimum weight maximum cost design and a minimum cost maximum weight approach. The propulsion concept employed on the 1985 compound helicopter is an exception and, as shown, gives a large step-function weight reduction.

2.1.1.2.3 Aircraft Systems

No effort was made to evaluate the benefits of aircraft systems technology developments. These were considered second order in this study.

2.1.1.2.4 Acoustics Technology

Forecasts of acoustics technology developments through 1985 were not considered sufficiently reliable or through to evaluate specifically in Phase II, (See also Section 2.1.1.9).

2.1.1.3 Compound Helicopter VTOL Configuration

The compound helicopter is a hybrid configuration capable of being operated as either a helicopter or a STOL airplane. It is normally operated in a manner that takes advantage of the best characteristics of each of these machines, making the takeoff and landing as a helicopter and the remainder of the flight as an airplane. The concept provides a good balance between the requirements for a high lift capability for takeoff and landing, and low cruise fuel consumption.

These two objectives require some measure of preference for the selection of the design parameters, since the optimum system is usually composed of suboptimum parts. The measure of preference used for this design study was minimum gross aircraft weight while meeting the criteria established.

The design for the 1975 compound helicopter uses the present state of the art. The 1985 compound helicopter uses advanced state of the art, particularly in the rotor drive system, where rotor torque is supplied by a tip nozzle drive system since test experience indicates the possibility of an acceptable noise/weight/fuel consumption tradeoff by 1985.

Both the 1975 and 1985 compound helicopter are designed for an "in-ground-effect" VTOL takeoff, requiring a 500 to 600 foot field length. Pure VTOL operation would require about 23% increase in power to accommodate an engine failure from hover and a subsequent climbout, maintaining at least 35 ft altitude. This capability was considered unnecessarily severe for the intraurban operation.

2.1.1.3.1 General Arrangement

The 1975 and 1985 general arrangement drawings are shown in Figure 2.1-3 and 2.1-4. Both use a single main rotor for low speed lift and control. They have a fan-in-fin arrangement to provide the antitorque moment required by the main rotor and all directional control. Small fixed wing surfaces provide approximately 90% of the required lift in cruise flight. All fuel is contained in the wing outboard of the wing joints. The turbofan engines provide the power needed for both vertical lift and horizontal thrust.

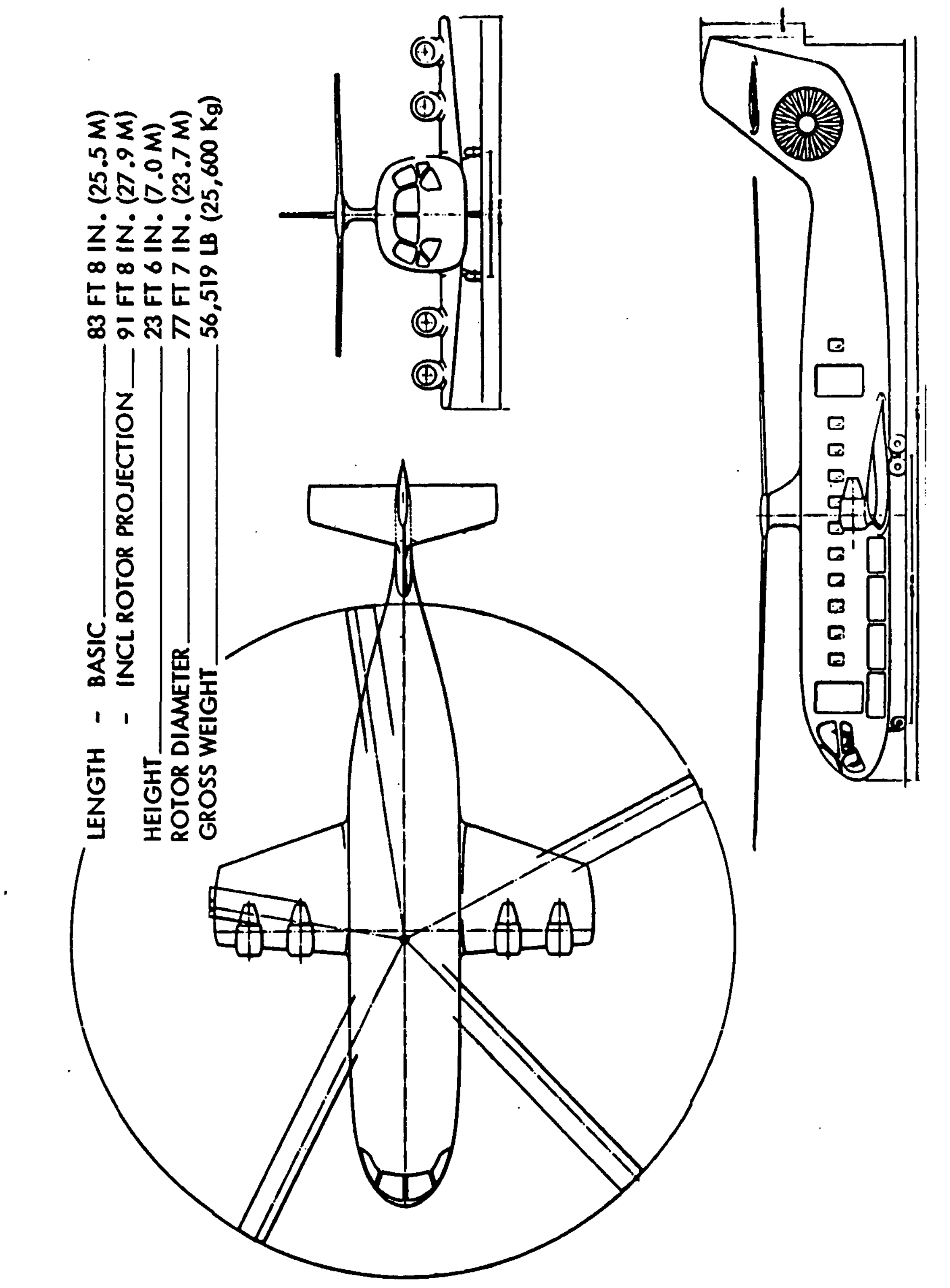
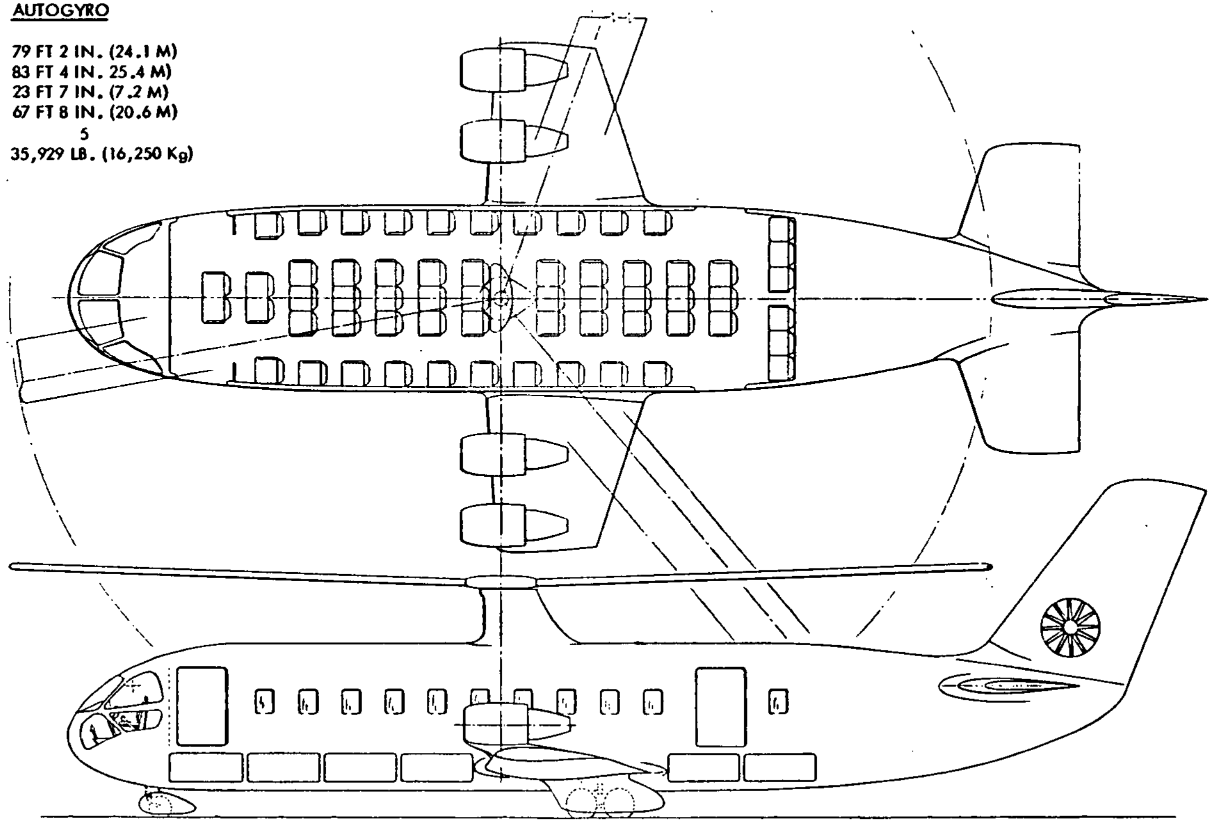


Figure 2.1-3. 1975 General Arrangement Compound Helicopter VTOL

	HELICOPTER	AUTOGYRO
LENGTH - BASIC	79 FT 2 IN. (24.1 M)	79 FT 2 IN. (24.1 M)
- INCL. ROTOR PROJECTION	80 FT 2 IN. (24.4 M)	83 FT 4 IN. 25.4 M)
HEIGHT	23 FT 7 IN. (7.2 M)	23 FT 7 IN. (7.2 M)
ROTOR DIAMETER	62 FT 1 IN. (18.9 M)	67 FT 8 IN. (20.6 M)
NUMBER MAIN ROTOR BLADES	3	5
GROSS WEIGHT	36,278 LB. (16.450 Kg)	35,929 LB. (16,250 Kg)



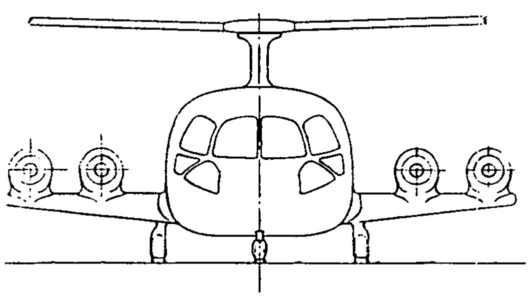


Figure 2.1-4. General Arrangement 1985 Autogyro STOL and 1985 Compound Helicopter

Major items in selecting the configuration general arrangement are wing and engine locations. Factors considered in making these selections include the following:

- Protection of passengers on emergency landing
- External noise environment
- Passenger comfort - vibration
- Internal noise environment
- Servicing accessibility
- Maintenance accessibility
- Hovering performance and aircraft size
- Aircraft drag

Reconsideration of the Phase I high wing, engine-under-wing configurations led to a change to the low wing, engine-over-wing configurations shown. This new arrangement has the following advantages:

- Under-floor gearbox reduces passenger hazard in crash landing
- Under-floor gearbox provides separated work area for inspection and service
- Under-floor gearbox simplifies gearbox noise insulation
- Ground-land fuel and oil service keeps fuel lines away from passengers
- Rotor blade passage produces less severe pressure pulses on wing
- Transmission of wing and main gearbox loads to landing gear requires less structural weight

2.1.1.3.2 Interior Arrangement

The interior arrangement of the helicopters is as described in Section 2.1.1.1 except for a minor seating rearrangement to accommodate the rotor shaft, which passes directly through the passenger compartment from the under-floor gearbox. The existence of the large concentrated rotor-hub mass directly above the middle of the passenger compartment will require added structural support for the case of a hard emergency landing. A review of the applicable and proposed FARs shows the requirement for supporting 4.5 g vertically for this condition. It has been the practice of the rotary wing industry to provide structure to support items of equipment mounted above the passengers through any survivable landing. The criterion that this suggests becomes 20 g. To support this load directly, a vertical support column has been installed in the passenger compartment as shown. This required a slight rearrangement of the seating.

The seating arrangements are in general accordance with the guidelines of Sec. 2.1.1.1.

2.1.1.3.3 Aerodynamic Arrangement

The aerodynamic design involves selection of rotor and wing design parameters in an optimal fashion. The primary function of the rotor is to produce all lift in hover, with the load being gradually shifted to the wing (to about 90%) as speed is increased. Selection of the lift sharing at high speed is dependent on the capability of the rotor to provide lift without excessive vibration and loads. A review of existing data has provided the basis for determining this lift as shown in Figure 2.1-5. This figure provides a boundary of maximum blade loading (C_T/σ)*with advance ratio (μ). The C_T/σ is a nondimentional representation of the rotor blade mean lift coefficient and μ is the forward speed divided by blade tip speed. The rotor load is limited to provide a margin for cyclic control to maneuver the aircraft. The wing is designed to carry the excess. Benefits in cruise flight can be realized by slowing the rotor to reduce the profile power required to maintain rotor speed, but this must be traded against wing-induced power increases due to a higher wing span loading.

---

* $C_T = \frac{T}{\rho(R\sigma)^2\pi R^2}$

$T = \frac{bC}{\pi R}$

$\mu = \frac{V}{R}$

where:

T = Rotor thrust (lb)

ρ = Air density

R = Rotor radius (ft)

= Rotation speed rad/sec

b = Number of blades

C = Blade chord (ft)

V = Airspeed, ft/sec

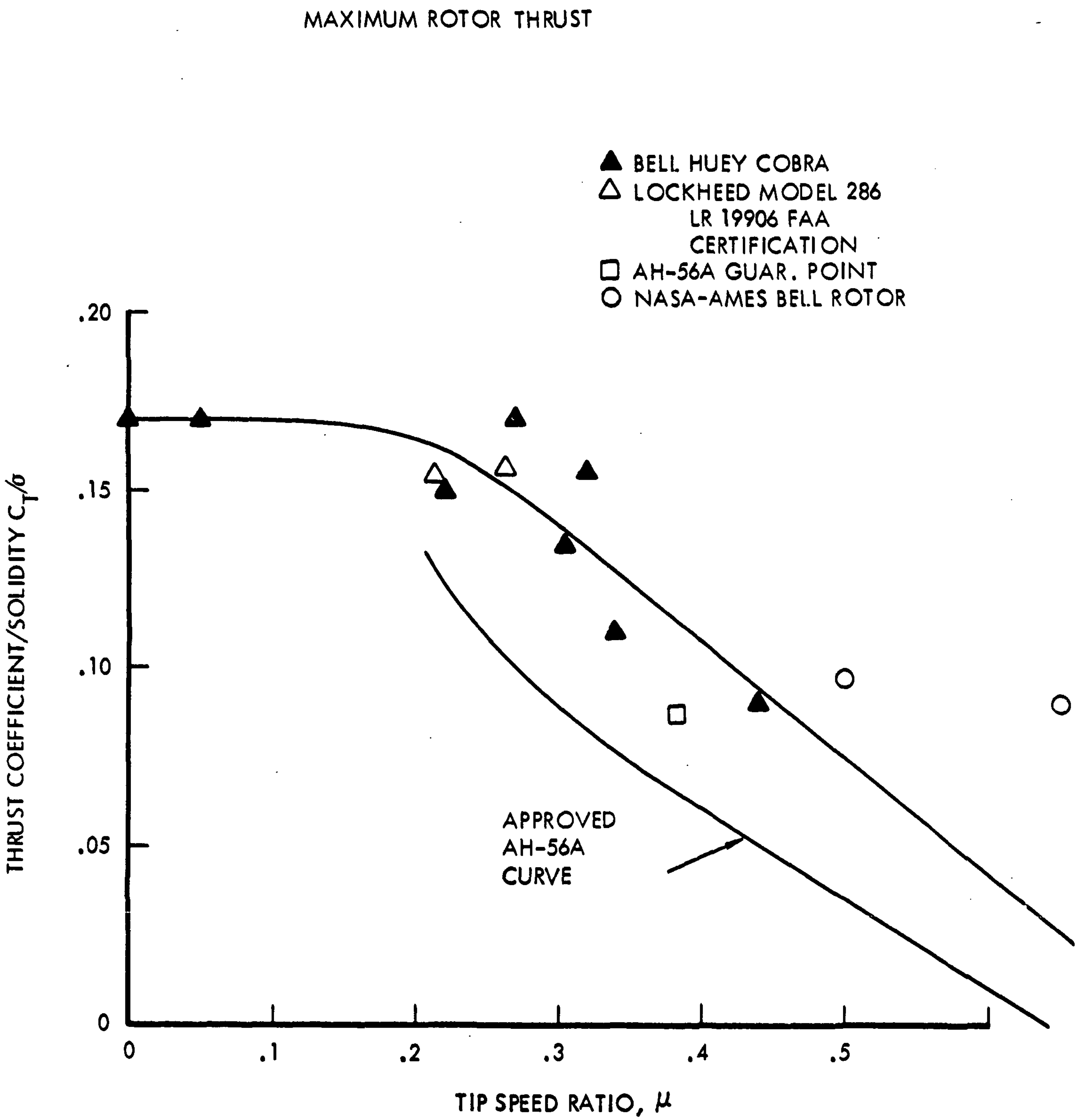


Figure 2.1-5 Blade Loading vs Advance Ratio

The principal design parameter for the rotor is disk loading. Choice of disk loading to use on a rotorcraft is analogous to the choice of span loading on a wing. Higher disk loading, while improving the rotor weight fraction, degrades the rotor efficiency in hovering flight due to an increase in induced power and an increase in the download it causes on the fuselage and wing. The wing must then be limited in span, which in turn, causes the wing-induced power in cruise flight to increase. The tradeoff made in this study shows a near optimum disk loading to be 12.5 psf.

Generalized rotor design constraints employed in consideration of the external noise problem are:

Blade Solidity	=	0.115 to 0.118
Blade loading	=	75 psf (normal TOGW)
	=	90 psf (maximum TOGW)
Tip Speed	=	625 ft/sec maximum

These are "judgement" values chosen to permit configuration definition. A great deal of additional study and analysis would be needed to throughly define an optimum combination of rotor geometry, engine size, etc, for the intraurban transport. Further treatment of the noise problem is presented in Section 2.1.1.9.

The number of rotor blades and blade chord are interdependent. A five-bladed rotor is used on the 1975 concept for reduced weight. A three-bladed rotor is used on the 1985 concept to improve the propulsive efficiency of the rotor tip nozzle drive system. Airfoil sections employed are the NACA 0012, tapered to NACA 0006 over the outboard 20% of the span.

The wing was sized to provide the necessary fuel capacity outboard of the fuselage. The resulting wing loading is approximately 100 psf. A wing span of 60% of the rotor diameter is used.

2.1.1.2.4 Propulsion

The propulsion system for a compound helicopter provides the torque to drive the rotor system which gives the low-speed lift and control, and the thrust for forward flight. Turbofan engines were selected as the basic propulsion units.

The 1975 aircraft uses mechanical shafting to couple the rotor system to the engines. One-way clutches are provided at the engines to disengage a failed engine from the drive train. Figure 2.1-6 shows this arrangement. The "fan-in-fin" is also mechanically driven.

The 1975 propulsion system employs existing state-of-the-art with low development risk. The engine selected has a 7.5 bypass ratio fan with variable pitch fan blades (similar to those being developed by Dowty-Rotal in England). This variable-pitch fan is driven at constant speed with the rotor drive train. The fan shroud is treated for sound absorption, and when operated in flat pitch for helicopter takeoffs it has a low noise level. The rotor drive output shaft is connected through a free-wheeling clutch to shafting routed through the wing leading edge to the main gear box. This gear box is insulated from the aircraft through elastomer mounts, and its compartment is insulated with sound proofing materials. The main rotor is driven by a shaft routed through the vertical structure column and the fan-in-fin is driven by shafting routed through the lower fuselage.

Pratt and Whitney STF/S351 convertible engines are employed (study engine) with power, thrust, and fuel flow characteristics as shown in the Appendix. These engine data were scaled to meet the power requirements of the various sized aircraft. The combined effective static (power + thrust)/engine weight is 9.1. Corresponding static shaft horsepower and thrust specific fuel consumption values are 0.44 and 0.38, respectively. A five minute takeoff power rating of 26 percent above the continuous rating was assumed.

The 1985 propulsion concept also employs a convertible high bypass turbofan engine. The gas generated can be used either to drive the thrust fan through a power turbine in the conventional manner, or it can be diverted to drive the rotor via sonic nozzles located at the rotor blade tips. Gas is

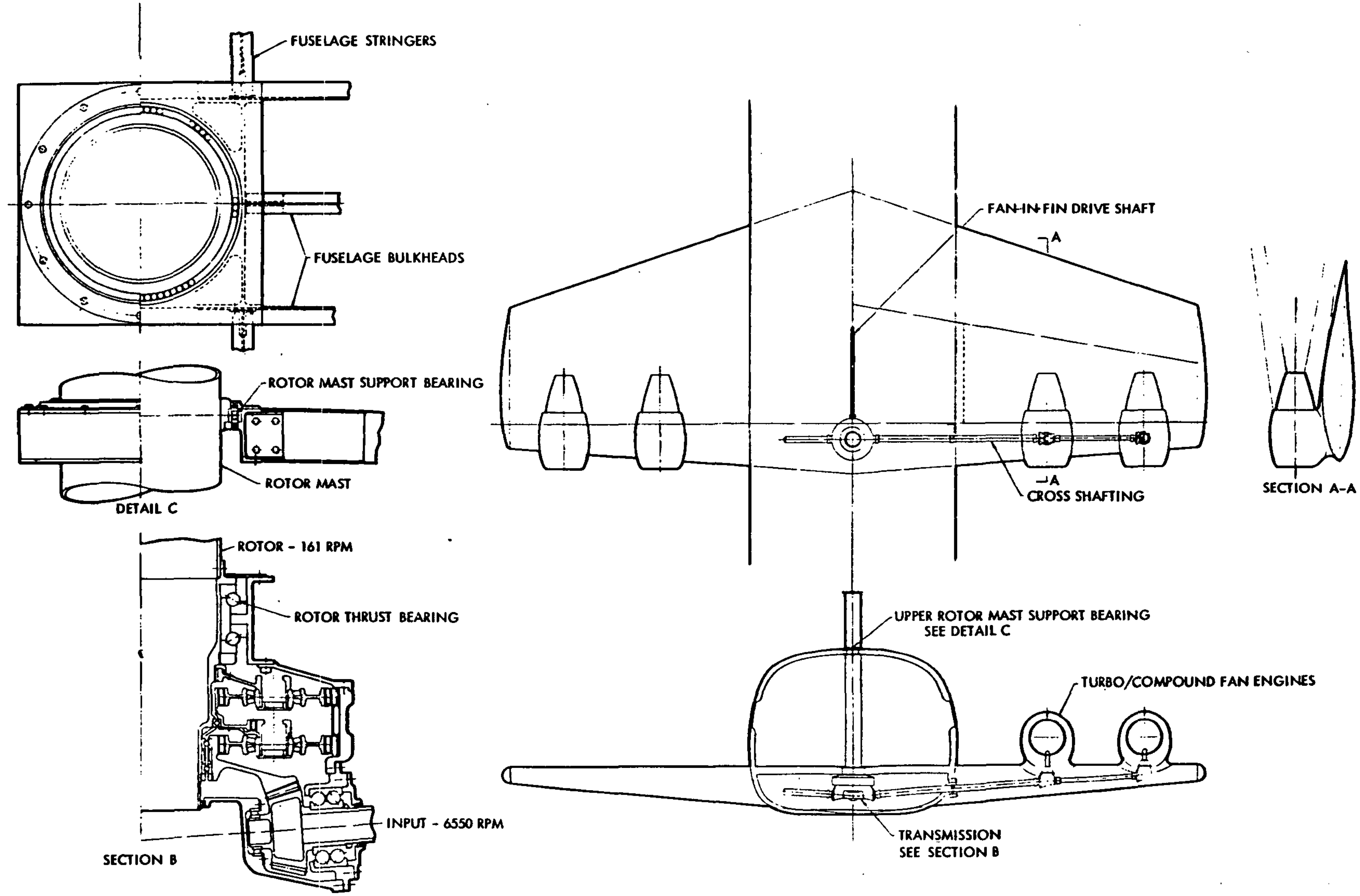


Figure 2.1-6. 1975 Compound Helicopter Mechanical Main Rotor System

supplied to the nozzles through the ducting system shown in Figure 2.1-7. A diverter valve system is employed to divide the flow between the rotor and the fan power turbine. During hover and low speed flight most of the gas is used to drive the rotor. During cruise the rotor is unloaded and slowed to 40 percent design RPM and the gas is used to power the thrust fan. The ducting system is insulated to minimize temperature drop.

The characteristics of this system provide a propulsive efficiency of 0.47 for the rotor drive. The propulsive efficiency for the thrust mode is shown as a function of nozzle pressure ratio, gas temperature, and tip speed in the Appendix. An engine thrust to weight ratio is 9.1. The static thrust specific fuel consumption, TSFC is 0.33 pounds per hour per pound of thrust. The resulting cruise TSFC is approximately 0.45.

The propulsion arrangement includes a clutching/braking system (or in the case of gas propulsion, a valving/braking system) for ground operation which permits the rotors to be decoupled and stopped for load/unload operations while the engines remain idling.

The 1985 propulsion system provides essentially torqueless rotor lift. The fan-in-fin is thus smaller than for the 1975 geared configuration. It is driven by an air turbine motor supplied by engine compressor bleed.

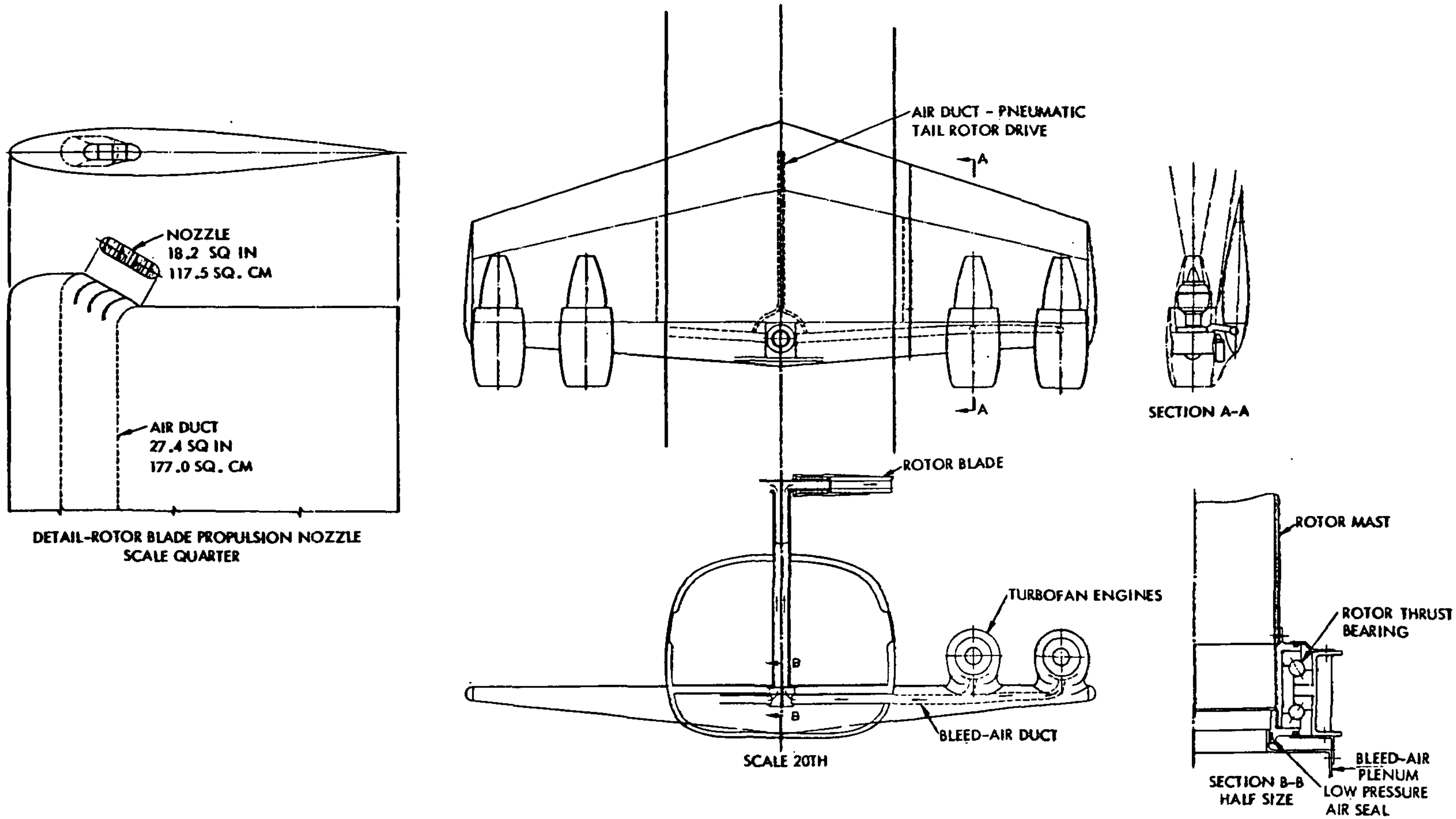


Figure 2.1-7. 1985 Compound Helicopter Pneumatic Rotor Drive System

2.1.1.4 Autogyro STOL Configuration

The autogyro STOL configuration was included in the study to provide an intermediate field length STOL (1000 ft). In the search for a vehicle to operate in this distance, while meeting the safety requirements for engine failure on takeoff and landing, the autogyro concept of the 1930's was considered. Investigation showed this STOL concept to have been dropped after the successful achievement of VTOL helicopter flight. As technology has developed and national priorities have changed, it has become evident that this older concept should be investigated to determine its potential as an intraurban transport. Modern helicopter technology has been applied to this original STOL concept to provide a simpler, more efficient rotorcraft with both very short takeoff and landing distances and a high cruising speed.

The autogyro is outwardly the same as the compound helicopter. The rotor drive system is, however, much lighter and simpler since its only function is to transmit sufficient power from the engines prior to takeoff to spin up the rotor. In flight rotor speed is maintained by operation in the windmilling mode. The takeoff maneuver is accomplished by powering the rotor to an overspeed, then accelerating on the ground to a forward speed sufficient for the rotor to windmill. Collective pitch is applied to use the excess rotor kinetic energy for liftoff. All lift at low speed is derived from the windmilling rotor; at high speed, lift is shared between the wing and rotor. The final approach and landing are made at near zero speed, with the rotor rotational energy expended in deriving low airspeed lift.

The configuration is refined over that reported in the Phase I Interim Report. A study of the power required for takeoff acceleration, climb, and 200-knot cruise was conducted to determine the sensitivity of performance to the rotor disk loading. A study was also conducted to determine the sensitivity of the aircraft weight to the power and disk loading. Minimum gross weight was used as the measure of preference in the selection of these design parameters. (It is noted here that a more detailed aerodynamic analysis of rotor performance at takeoff speed is needed for selection of power and disk loading).

2.1.1.4.1 General Arrangement

The autogyro STOL general arrangement is shown in Figure 2.1-4. The single main rotor provides all lift at low speed and all pitch, roll, and direct lift control. The fixed wing surface provides approximately 90% of the lift during high speed cruise flight. The fan-in-fin provides all directional control for balancing asymmetric thrust and normal aircraft control over the broad range of operating speeds. Turbofan engines provide the forward thrust and the extracted power for rotor speed management. The location of the wing and engines is consistent with that chosen for the compound helicopters, i.e., a low wing with the engines mounted above it on short pylons. The fuselage and empennage are the same as for the compound helicopter.

2.1.1.4.2 Interior Arrangement

The interior arrangement of the autogyro is the same as that of the compound helicopter.

2.1.1.4.3 Aerodynamics

The aerodynamic design of the autogyro STOL requires the determination of the low speed drag of an autorotating rotor. Existing data, based on very low disk loaded machines of the 1930s, describe lower tip speed and lower airspeed machines than those of interest in this study. A brief study to optimize the disk loading, using unsophisticated extrapolated data, indicates the choice of a 10-psf disk loading. At the 65 knot takeoff speed used, the thrust/weight ratio was less than 0.5. Lower disk loading would reduce this ratio and might be even more cost effective although somewhat heavier. (It is noted here that an automated program for use in determining the rotor drag at low airspeeds is available at Lockheed, but lack of time and resources prevented its use). Additional study is needed for a thorough determination of the rotor inflow and associated elemental blade aerodynamic lift and drag to provide a higher confidence in takeoff thrust and provide and optimum disk loading. In lieu of this, a conservative calculation of low speed performance was made.

Lift sharing in high-speed forward flight is selected in the same manner that it is for the compound helicopter. Figure 2.1-5 is used to determine the allowable rotor C_T/σ versus μ. Sufficient margin is allocated for the cyclic control needed to maneuver, then the wing is sized to provide the remainder. Slowing of the rotor in cruise flight reduces the rotor drag, but it also increases the C_T/σ and the μ, which reduces the allowable rotor lift.

The wing span used on the autogyro is not constrained by the hovering download, as it is on the compound helicopter, but it does complicate the flow field of the rotor. This interaction of the wing and rotor needs further investigation*. For simplicity, the same wing span as employed on the 1985 compound helicopter is used. The rotor blade loading, tip speed and airfoil data used are the same as that of the compound helicopter.

2.1.1.4.4 Propulsion

The propulsion system used for the autogyro STOL is comparatively simple. The turbofan engines have a high air bleed capability for use with air turbine motors that spin up the rotor prior to takeoff. The takeoff speed, and consequently the installed power, could be appreciably reduced by continuing the rotor drive throughout takeoff, but time did not permit examining this factor. Additional study would show the optimal mix of rotor system drive and forward propulsion.

The concept employed is shown in Figure 2.1-18. It has a 7.5 bypass ratio fan with compressor bleed air used for the rotor spinup motors and the fan-in-fin used for directional control. In forward flight, the main rotor drive is used only for rpm control. No reverse thrust is needed for the short field landings, since the uunpowered main rotor acts as a drag chute to provide aerodynamic braking.

Since the rotor is powered only during rotor spinup prior to flight, its power requirements are very small (roughly 650 shp for the 60 passenger configuration compared with the 5000 shp for the compound). The augmentor-wing turbofan engine concept discussed in the Phase I Report is also a possible prototype of the engine for this vehicle. The bleed from each engine is ducted to four

* The aforementioned Lockheed computer program also has this capability

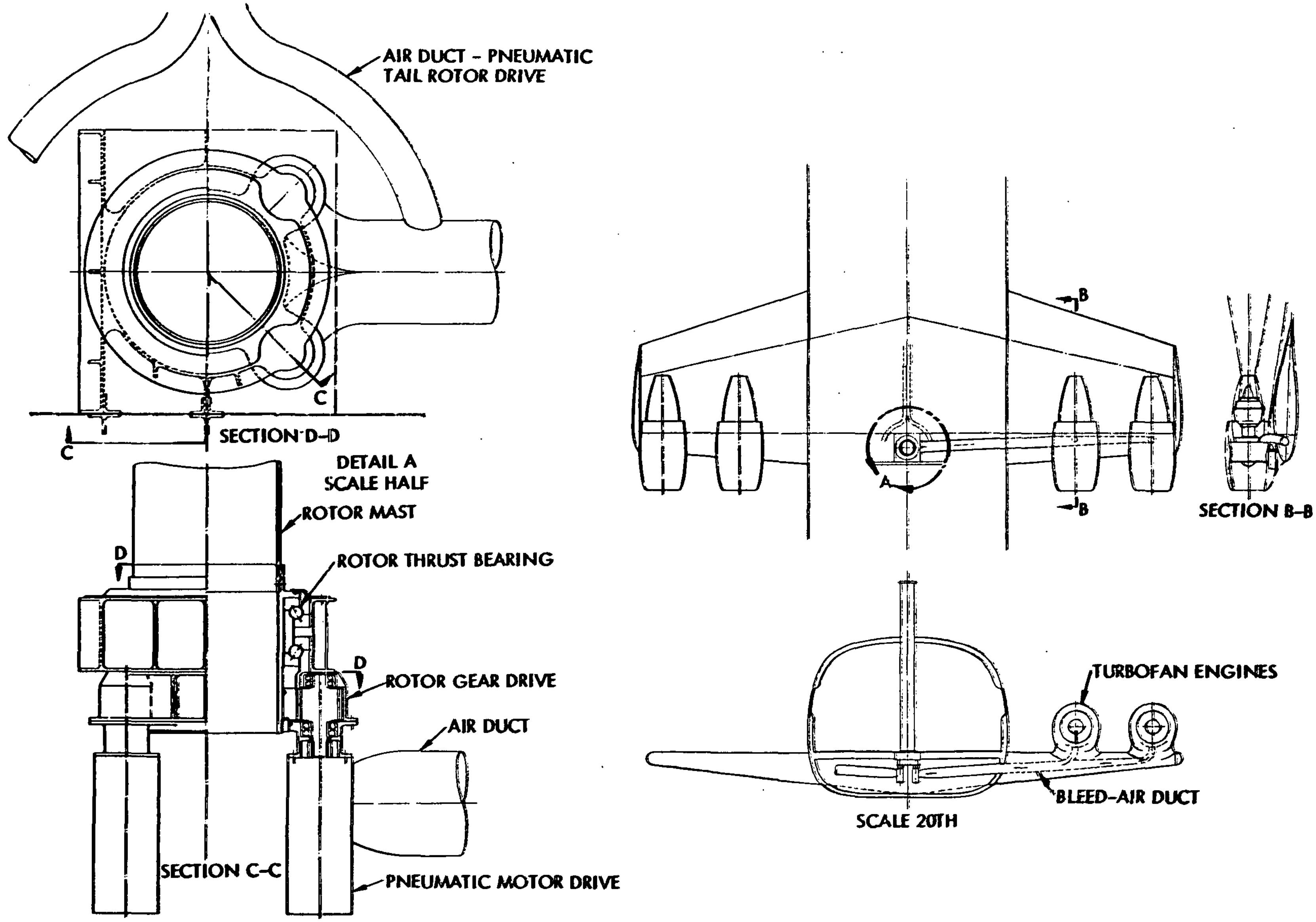


Figure 2.1-8. 1985 Autogyro Rotor Spinup Pneumatic Drive System

individual air turbine drives coupled to the main rotor. Past Lockheed work on this drive scheme led to the choice of four individual drives rather than the use of a single remote turbine.

The rotor systems include a decoupling/braking arrangement to permit the rotor to be stopped quickly for load/unload operations while the engines remain idling. This will relieve, the adverse thermal shock effects on maintenance of having a shutdown-startup cycle at every stop.

2.1.1.5 Deflected Slipstream STOL Configuration

The deflected slipstream STOL Configuration arrangement defined below is considered representative of both the 1975 and 1985 time periods. The benefits of technology are manifested in this concept only in reduced structural and propulsion system weights and improved engine performance.

2.1.1.5.1 General Arrangement

The general arrangement is illustrated by Figure 2.1-9. It has four advanced turboprop engines and is generally similar to the French Brequet 941 STOL. This STOL concept has been tested extensively by NASA and several airlines and is regarded as a feasible approach to a commercial STOL aircraft. The design emphasis is on providing a means of vectoring the propeller thrust and thereby augmenting the wing circulation lift to achieve the reduced speeds required for short takeoff and landing distances.

2.1.1.5.2 Interior Arrangement

The interior arrangement is the same as that shown in Figure 2.1-1.

2.1.1.5.3 Aerodynamics

The wing loading is held to a modest 60 psf as a compromise between a low value for good airport performance and a high value for good ride qualities. The high lift system is similar to that of the Brequet 941 configuration which has the following unique features:

(1) Most of the wing is immersed in the propeller slipstream which is equipped with a large chord, full-span, triple-slotted, trailing edge flap and a cambered leading edge, and

(2) Four propellers, interconnected by a cross shafting system and having opposite rotation, i.e., the left inboard and the right outboard turn

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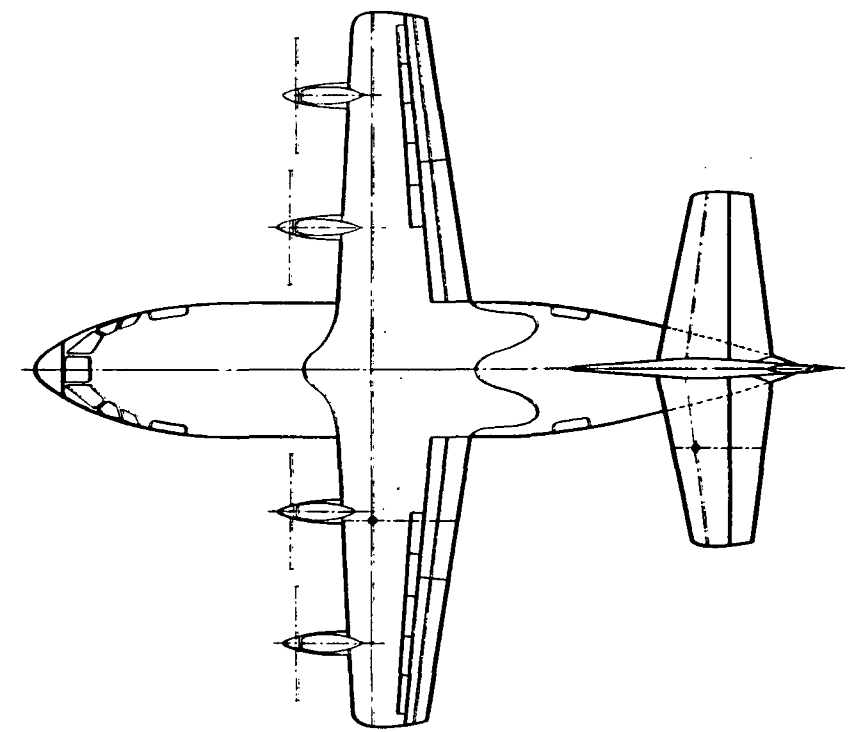
CHARACTERISTICS	WING	HORIZ.	VERT
AREA (SQ FT)	726	291	182
ASPECT RATIO	6.5	4.0	1.4
SPAN (FT)	68.7	34.2	16
ROOT CHORD (IN)	169	136	195
TIP CHORD (IN)	84.5	68	78
TAPER RATIO	.50	.50	.40
MAC (IN)	133	105	145
SWEEP (DEG)	0	7.5	35
T/C ROOT (%)	18	10	12
T/C TIP (%)	12	10	10

POWER PLANT — 4 ADVANCED TURBO-PROP ENGINES
PROPELLER — HAM. STD. 4 BLADE VARIABLE CAMBER TYPE
INSTALLED POWER AND GROSS WEIGHT VARIABLE WITH DESIGN FIELD LENGTH



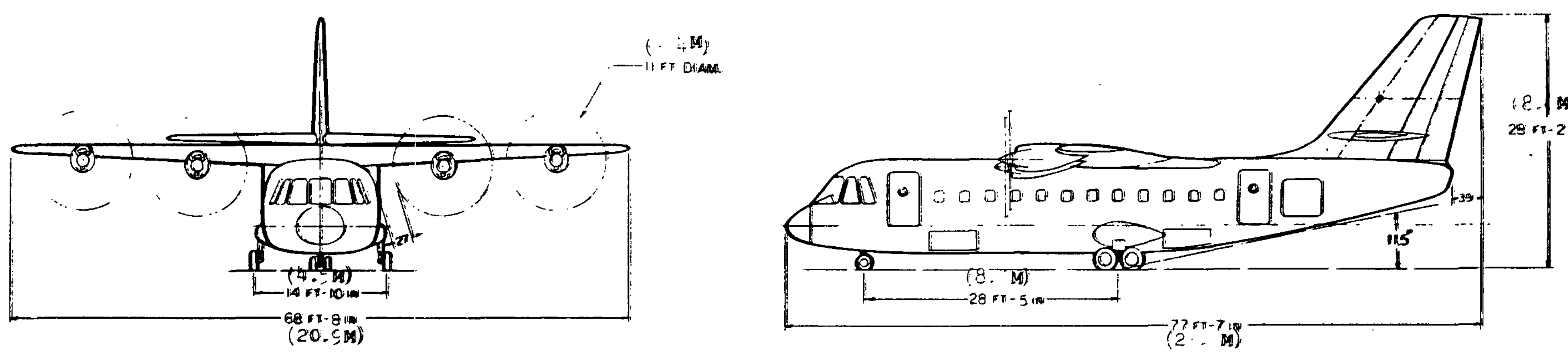


Figure 2.1-9 General Arrangement, Deflected Slipstream STOL Configuration

clockwise and the left outboard and the right inboard turn counterclockwise

(3) Differential outboard propeller pitch to augment lateral and directional control, and

(4) The pilot's controls include a conventional stick for lateral and elevator control, and a single throttle for the pilot's left hand for all four engines. The system is designed to provide lift augmentation at takeoff and landing speeds by vectoring the thrust with the flaps.

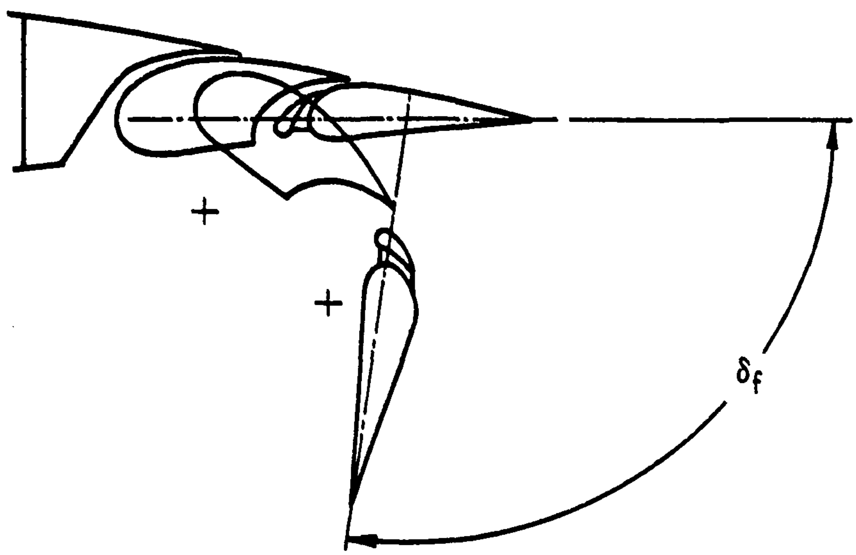
The flap chord is 32-36% of the wing chord, and it is composed of three chordwise and four spanwise segments with the aft section of the outboard flap providing partial lateral control. Conventional spoilers, along with the differential outboard propeller thrust, augment the aileron control at low speeds. Typical flap sections are shown in Figure 2.1-10.

The sophisticated high-lift system is applied to the 60 psf wing loading to provide the low takeoff and landing speeds necessary for 1500-2500 ft FAR-type airport performance (70-80 kt).

The empennage is conventional, except that the surface areas are large to provide extra pitch and directional control power for the low speeds employed during takeoff and landing. An all movable, veri-cam, horizontal tail and a double-hinged rudder are also used to further augment control power.

2.1.1.5.4 Propulsion

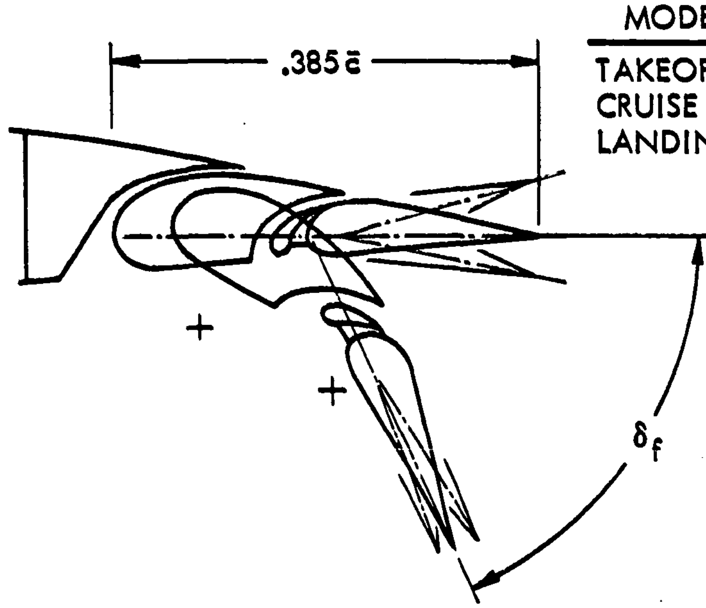
The propulsion system for the deflected slipstream STOL concept includes a Pratt and Whitney study turboprop engine based on currently available technology. The configuration consists of a two-stage, single shaft, centrifugal compressor, an annular reverse flow burner, a two-stage, air cooled, axial turbine driving the compressor, followed by a two-stage free turbine that provides power to the propeller. The exhaust system assumed for performance calculations was sized to optimize the split of propeller power and jet thrust for low altitude, low Mach cruise conditons. The engine provides advanced performance with rugged simplicity, ease of maintenance, and simplified diagnostics. At sea level static, the engine will produce 4.4 shp/lb and rated power fuel flow is 0.435 lb/hr/shp.



(A) INBOARD FLAP

APPX. FLAP SETTINGS

MODE	FLAP DEFLECTION, δ_f, DEG. INB'D	OUTB'D
TAKEOFF	45	30
CRUISE	0	0
LANDING	105	65



(B) OUTBOARD-FLAP AILERON

Fig. 2.1-10 Cross Section of Trailing Edge Flap

An eight-blade, lightweight, Hamilton Standard variable-camber propeller was selected as the thruster. The propeller is designed to operate at low tip speed, low power disk loading, and high static thrust per horsepower - conditions that are favorable for low noise levels. Also, the variable-camber propeller is quieter than a conventional propeller at low speeds due to its favorable blade stall characteristics. The maximum propeller tip speed has been held to 625 ft/sec and was dictated by community noise considerations. The power disk loading of the propeller is 11.8 hp/ft^2, the thrust disk loading is 45 lb/ft^2, at sea level static. Installed performance and sizing data for this engine/propeller combination are presented in Volume IV. The thrusts shown have been reduced by 5 percent to provide for installation losses.

The propulsion system for the 1985 technology deflected slipstream STOL concept includes an advanced Pratt and Whitney turboprop engine which could be available for 1985. Engineering judgment based upon available advanced technology estimates indicates that fuel flows can be reduced by 5 percent and engine weight by 20 percent with the application of 1985 technology at a practical level. Installed propulsion system performance can be obtained by applying these factors to the data noted above.

Possible problem areas for either the 1975 or the 1985 propulsion system include maintenance, development timing, reliability, and noise. Advanced monitoring techniques for engine parameters should reduce engine maintenance costs and improve the propulsion system operational relaibility. Timing of the development of the Pratt and Whitney engine for the 1975 technology aircraft could be a problem.

The propulsion system is provided with a propeller decoupling/braking arrangement that will permit the propellers to be decoupled and stopped for load/unload operations while the engines remain idling. As with the rotary wing concepts, this will relieve thermal shock effects of an engine shutdown/startup at every stop. It also improves safety.

2.1.1.6 Weight Analysis

The Phase II weight analysis include a re-examination of the weight basis employed in Phase I. In general, the Phase I methodology is considered satisfactory and is applied to the more thoroughly defined Phase II vehicles.

The Phase II weight elements are the same as that employed in Phase I except that the Phase I rotory wing tail rotors are replaced by the fan-in-fin concept and the auxiliary power unit has been deleted from all configurations.

Technology factors were applied to 1975 weight estimates at approx. the same level in both fixed and rotary wing concepts to derive 1985 weights, with one exception. This was in the area of rotary wing power transmission from the engines to the main rotor and the fan-in-fin rotor. Here, a completely different concept was employed for 1985, as discussed in Section 2.1.1.2 and 2.1.1.3. The 1975 rotor mechanical drive system was replaced with a pneumatic drive system for 1985. A large weight benefit is anticipated from this development.

Comparative weight breakdowns for each configuration at 60 passenger payload are presented in Tables 2.1-3 and 2.1-4. The variation of gross weight with payload, field length and technology is shown in Figure 2.1-13 to complete the weight comparisons.

Inspection of this weight picture shows the following points of interest:

- Gross weights for the deflected slipstream STOL concept are the same for both 2000 and 2500 ft FAR field lengths. This is because the engine size on the 2500 ft version was set by the 250 kt cruise requirement rather than field length.
- An 8% penalty in gross weight for the deflected slipstream STOL types results from reducing the field length from 2000-2500 ft to 1500 ft, caused by the required increase in T/W.
- Application of 1985 technology to the deflected slipstream STOL types reduces the gross weight by about 15%
- Application of 1985 technology to the compound helicopter VTOL can provide a gross weight reduction of as much as 35%, with approximately half of this reduction coming from the pneumatic rotor drive concept. All rotary wing configurations then become competitive weightwise with the fixed wing types, and all have shorter field lengths.
- The 1985 compound helicopter VTOL and the 1985 1000 ft autogyro STOL are estimated to have nearly the same gross weight (the latter has less complexity, however).

2.1.1.7 Performance Analysis

The performance bases and estimates presented below have been developed in consideration of the existing and proposed Federal Air Regulations noted in Section 2.1.1.1. However, the analysis has necessarily been simplified to meet the time and budget constraints of the study.

2.1.1.7.1 Rotary Wing Configurations

Simplified takeoff and landing operational concepts have been employed in this analysis. They are summarized as follows:

- One speed is employed, "Takeoff Safety Speed" (V_{TOSS}) which is the speed at which a 300 ft/min rate of climb can be maintained with one engine inoperative.
- "Takeoff distance" is defined as that distance required to accelerate to the critical decision point (CDP), at which point the critical

Table 2.1-3 Weight Breakdown 60 Passenger Rotary Wing

ITEM	1975 COMP. HEL. VTOL	1985 COMP. HEL. VTOL	1985 AUTOGYRO STOL
Main Rotor	5729	2998	2801
Wing	1387	788	728
Tail Fan	455	65	60
Empennage	625	325	300
Fuselage	4839	3188	3169
Landing Gear	1854	1144	1058
Flight Controls	2174	1250	1250
Nacelles	967	575	676
Engines	3200	1810	2170
Propulsion Systems	871	665	719
Drive System	6799	1000	270
Instruments	454	321	310
Hydraulics	280	182	181
Electrical	1012	733	733
Electronics	1178	875	875
Furnichings	3190	2552	2550
Air Cond. & Anti-Ice	1497	1140	1128
EMPTY WEIGHT	365511	19611	18978
Operating Equipment	45	45	45
Crew	380	380	380
Oil, Etc.	133	152	84
OPERATING WEIGHT	37069	20188	19487
Payload	11400	11400	11400
ZERO FUEL WEIGHT	48469	31588	30887
Fuel	8050	4690	5042
GROSS WEIGHT	56519	36278	35929

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Table 2.1-4 Weight Breakdown 60-Passenger Deflected Slipstream STOL

Technology	1975	1975	1975	1985	1985	1985
F.A.R. Field Length, Ft	1500	2000	2500	1500	2000	2500
ITEM	WEIGHT					
Wing	4230	3940	3917	2785	2641	2629
Tail	1633	1474	1462	1043	963	956
Fuselage	4923	4826	4818	3693	3638	3633
Landing Gear	1932	1813	1803	1455	1385	1379
Surface Controls	911	888	887	864	848	847
Nacelles	1968	1051	1022	1147	821	799
Engines	1619	1245	1221	1258	1012	996
Propellers	1697	1128	1092	1143	771	747
Fire Ext.	162	125	122	126	101	100
Exhaust	89	68	67	69	56	55
Cross Shafting	1431	1107	1085	1291	1014	994
Cooling	81	62	61	63	51	50
Oil System	81	62	61	63	51	50
Engine Controls	76	59	57	59	48	47
Starting	113	87	85	88	71	70
Fuel System	436	436	436	436	436	436
Instruments	421	410	409	398	390	390
Hydraulics	304	303	303	302	302	302
Electrical	1379	1360	1359	1339	1326	1324
Electronics	1178	1178	1178	875	875	875
Furnishings	4186	4186	4186	4186	4186	4186
Air-Conditioning	1553	1553	1553	1553	1553	1553
Anti-Icing	259	238	236	216	202	201
Weight Empty	30181	27601	27421	24450	22738	22617
Operation Items	493	485	485	477	472	472
Standard Items	196	170	168	171	153	152
Operating Weight Empty	30870	28257	28074	25098	23364	23241
Payload	11400	11400	11400	11400	11400	11400
Zero Fuel Weight	42270	39657	39474	36498	34764	34641
Fuel	2574	2198	2139	2221	1925	1875
Takeoff Gross Weight	44843	41855	41613	38719	36689	36516

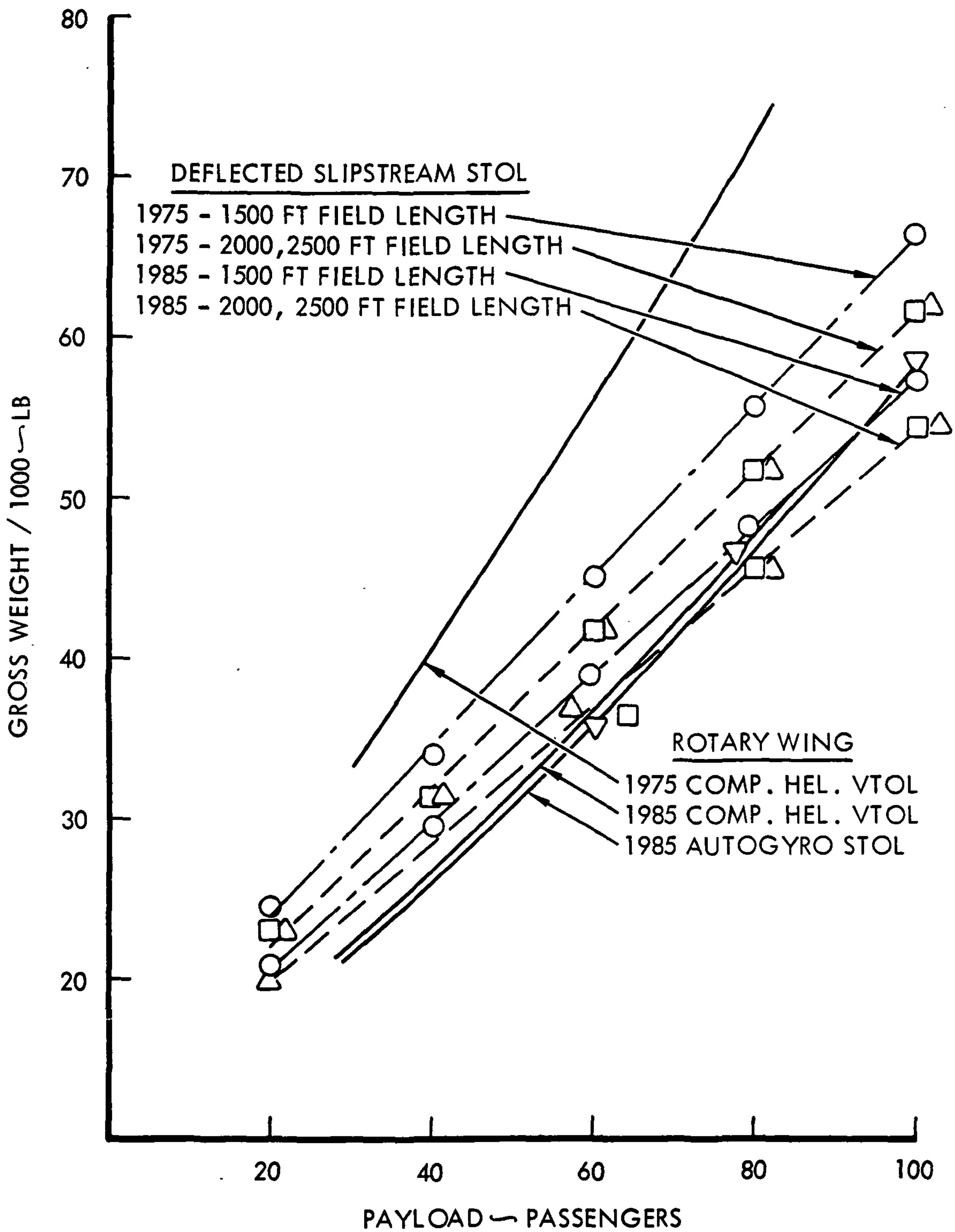

Figure 2.1-11. Takeoff Weight Vs. Payload

engine fails, and either the aircraft is braked to a stop or the take-off is continued to clear a 35-foot obstacle while at V_{TOSS}

- "Landing distance" is defined as the distance required to land and come to a braked stop after clearing a 35-foot obstacle
- "Minimum operating speed" cannot be defined for a rotary wing aircraft as it is for a fixed wing aircraft since the aircraft can be operated at speeds on the back side of the power curve with complete safety so long as there is sufficient rotational energy available to check the rate of descent of the aircraft. A limiting height/velocity relationship (H-V diagram) is normally defined with one engine inoperative (OEI).

Helicopter Takeoff - Safe takeoff operation of a compound helicopter may vary between the extremes of a pure vertical liftoff to altitude and a conventional airplane takeoff. The vertical takeoff would increase the design gross weight appreciably. A form of this VTOL profile is employed by New York Airways and other operators on small roof-top heliports. A conventional rolling takeoff (STOL) permits the maximum takeoff gross weight.

The helicopter takeoff profile typically employed in today's commercial operations permits weights between these extremes. The helicopter VTOL configurations and their takeoff distance estimates described herein are based on operation according to this commercial profile, in the following segments:

1. Vertical takeoff to "in ground effect height," all engines operative (AEO)
2. Accelerate to V_{TOSS}* and 35 feet altitude. The approximate CDP* is 35 kt.
3. If an engine fails before CDP is reached, flare, land, and brake to a stop.
4. If an engine fails after CDP, continue climbout.

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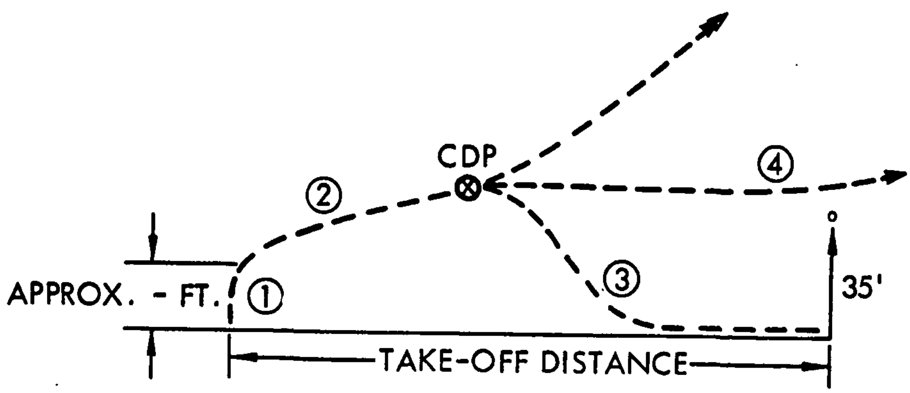
*V_{TOSS} = Takeoff safety speed

CDP = Critical decision point

These points are illustrated in the sketch below:



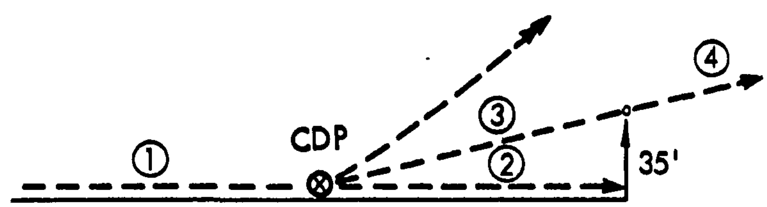
Autogyro Takeoff - The autogyro is operated as an STOL aircraft. Low speed performance is limited by the thrust available to balance the drag of the rotor. Safe descents and landings can be made at near VTOL speeds using rotor rotational energy to derive lift. Autogyro takeoff operations have traditionally been accomplished by powering the rotor to an "overspeed" condition before the takeoff run, then using the excess rotor energy to achieve the required altitude after V_{TOSS} is attained. Flight is sustained by extracting energy from the air to windmill the rotor, thereby maintaining sufficient rotational speed to produce the required lift. Segments are as follows:

1. From a standing start, with the rotor maintained at overspeed in flat pitch, accelerate on the ground to approximately V_{TOSS}. This is the CDP for take-off. V_{TOSS} = 65 kt approximately. (Horizontal acceleration in an autogyro is limited to h_z = 0.5 kt for passenger comfort).

2. If the engine fails, either brake to a stop; or

3. Increase the collective pitch to take-off position. This provides 35 feet altitude and normal operating rotor speed at the field boundary.

4. Continue climbout to the desired altitude while attaining a clean configuration.



Compound Helicopter and Autogyro Landings - Both the helicopter and autogyro use the same approach and landing techniques; the only difference being in the V_{TOSS}. Both types use minimum power approach speed. The aircraft is first decelerated to V_{TOSS} at the obstacle, then flared for a minimum touchdown speed. The segments of this approach and landing, as shown in the sketch, are:

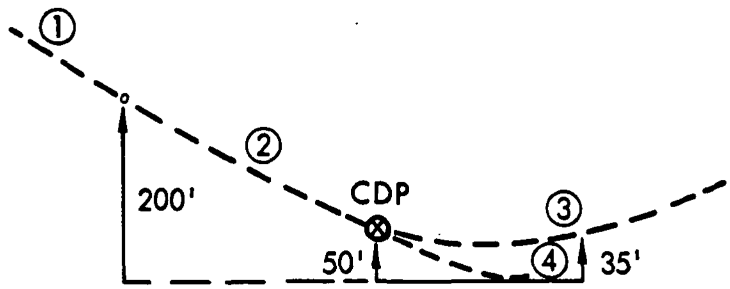
1. Approach along the glide slope at partial power, and decelerate to the speed for minimum power required (approximately 90 kt) at 200 ft altitude.

2. Decelerate from 90 kt to V_{TOSS} and 35 ft altitude at the field boundary. This is the landing CDP.

3. If a safe landing is not assured, the landing may be rejected assuring a 35-ft altitude at the end of the landing field, or,

4. If a safe landing is assured, the aircraft is flared to near zero speed for touchdown.

The touchdown speed is limited by the deceleration capability with an acceptable flare attitude. The energy required to maintain rotor speed is



available from the loss of forward speed. The landing distance is not considered critical for this study.

The estimated flat plate drag of the rotary wing vehicles is presented in Table 2.1-5. The reduced values shown for 1985 result largely from the reduced size of the rotor mast-hub assembly required with the reduced gross weights shown in 1985.

Helicopter power requirements for the one engine inoperative takeoff-climb regime are shown in the Appendix, Figure A2.1-12 and -13.

The 1985 autogyro propulsion system was sized for an FAR field length of 1000 ft. This distance was selected primarily to keep longitudinal accelerations on takeoff below 0.5 g (see Appendix) and also because this value falls midway between the minimum field length for the deflected slipstream STOL configuration and the compound helicopter in ground effect distance of 500-600 ft. The resulting total thrust requirements, assuming the same yaw control power requirements as for the helicopter, are shown in Table 2.1-6.

Table 2.1-5. Equivalent Flat Plate Area

Aircraft →	1975 Compound			1985 Compound			1985 Autogyro			
Number of Passenger	40	60	80	40	60	80	40	60	80	100
Drag Item										
Fuselage	9.0	10.7	12.5	8.1	9.8	11.2	8.2	10.0	11.7	13.5
Main Rotor Hub	11.1	15.1	19.2	7.8	10.8	13.8	8.8	12.0	15.9	20.4
Horiz plus Vert Tail	1.2	1.7	2.2	1.1	1.5	1.9	1.0	1.4	1.9	2.4
Four Nacelles	1.8	2.5	3.2	1.5	2.1	2.7	1.5	2.0	2.7	3.4
Protruding & Misc.	5.1	6.0	7.0	3.5	4.3	4.8	3.3	4.0	4.7	5.4
Tail Fan	0.7	0.9	1.1	0.2	0.3	0.4	0.2	0.3	0.4	0.5
Nacelle/Wing/Fus Interf	0.9	1.2	1.5	0.7	1.0	1.3	0.7	1.0	1.3	1.7
Rotor/Fus Interf.	0.9	1.2	1.5	0.7	1.0	1.3	0.7	1.0	1.3	1.7
Total, sq. ft	30.9	39.3	48.2	23.6	30.8	37.4	24.4	31.7	39.9	49.0

Table 2.1-6. 1985 Autogyro STOL Thrust Requirements

- 1000 ft Takeoff Field Length
- 90° ft
- Sea Level

Payload	Gross Weight lb.	4-Engine Thrust Req'd, lb.
40	26,231	11,600
60	35,927	15,600
80	46,814	20,800
100	58,585	26,400

Approximate values for lift/drag ratio (L/D) and cruise thrust required are as follows:

Configuration	Effective L/D (Approx)	Thrust Req'd/Thrust Avail. 200 kt, 2000 ft Cruise
1975 Compound Helicopter	4.0	100%
1985 Compound Helicopter	4.0	75%
1985 Autogyro	4.6	75%

The fuel required to meet the design mission specified in Section 2.1.1.1 varies from 12 to 15% of the takeoff gross weight.

Stage time and fuel-required information is shown below in comparison with the deflected slipstream STOL configuration.

The all engine climb gradient capability of the compound helicopters is approximately 20° at 70-80 kt. Corresponding values for the 1985 autogyro STOL are approximately 15° at 70-80 kt.

Normal landing approach on the compound helicopters and autogyros will be conducted near the minimum power speed (80-90 kt) at low power to achieve approach angles as high as 20°. The engine power is not normally increased until immediately prior to touchdown since the kinetic energy of forward flight is used to partially power the rotor in the landing flare.

2.1.1.7.2 Deflected Slipstream STOL Configuration

The basis for the deflected slipstream STOL configuration performance estimates is essentially the same as that employed in the Phase I analysis, i.e.,

- Clean aircraft drag - $C_D = 0.0234 + 0.0612\ C_L^2$ - which provides an $(L/D)_{max} = 13.2$ at 170 kts, and $(L/D)_{cruise} = 10.0$ for 250 kt cruise at 2000 ft.

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- Power-on STOL type takeoff and landing lift and drag characteristics estimated from analysis of appropriate power-on wind tunnel test results and flight test results of similar configurations.
- Directional control power adequate to balance any FAR required single element propulsion system failure during takeoff.

Thrust requirements were established to give 1500, 2000 and 2500 ft field lengths, or the required 250 kt at 2000 ft cruise speed, whichever was critical. Takeoff thrust requirements were based on Lockheed's judgment of the takeoff requirements of the final FAR STOL regualtions and the aerodynamic capability of this concept. The resulting T/W required employing both 1975 and 1985 technologies, are as estimated below.

STOL Field Length, Ft.	Required Static Thrust/Weight		Critical Factor
	1975 Tech	1985 Tech	
1500	.52	.50	Takeoff Field Length*
2000	.37	.36	Takeoff Field Length
2500	.37	.36	250 kt Cruise Speed

The comparatively large static T/W required to meet the 250 kt cruise speed requirement comes from the fact that low disk loading, high static recovery propellers are employed to provide the required takeoff thrust with low horse power engines. The resulting lack of power limits the speed accordingly. The 1975 compound helicopter suffers likewise. This implies that power requirements for intraurban aircraft should therefore include a margin to provide emergency maneuver capability, etc., without reducing speed since these aircraft will continually be flying in cramped airspace.

The fuel requirements in terms of fuel weight to gross weight W_f/W_g ratio are only dependent on design field length (installed power). Values required to meet the design mission are shown below.

---

* Critical over landing

STOL Field Length, Ft.	W_f/W_g 1975 Tech.	1985 Tech.
1500	.0570	.0535
2000	.0521	.0494
2500	.0518	.0494

2.1.1.7.3 Route Time-Distance Performance

The stage time-distance performance for each vehcile concept is shown in Figure 2.1-12 for 2000 ft cruise. Increasing the cruise altitude to 4000 ft shows but a slight increase in time with slight reduction in fuel required. This higher altitude operation may be necessary from a ride comfort standpoint.

2.1.1.7.4 Takeoff Climb Performance

The all engine takeoff climb performance for each configuration is shown in Figure 2.1-13. These values were employed in the exterior noise analysis of Sec. 2.1.1.9.

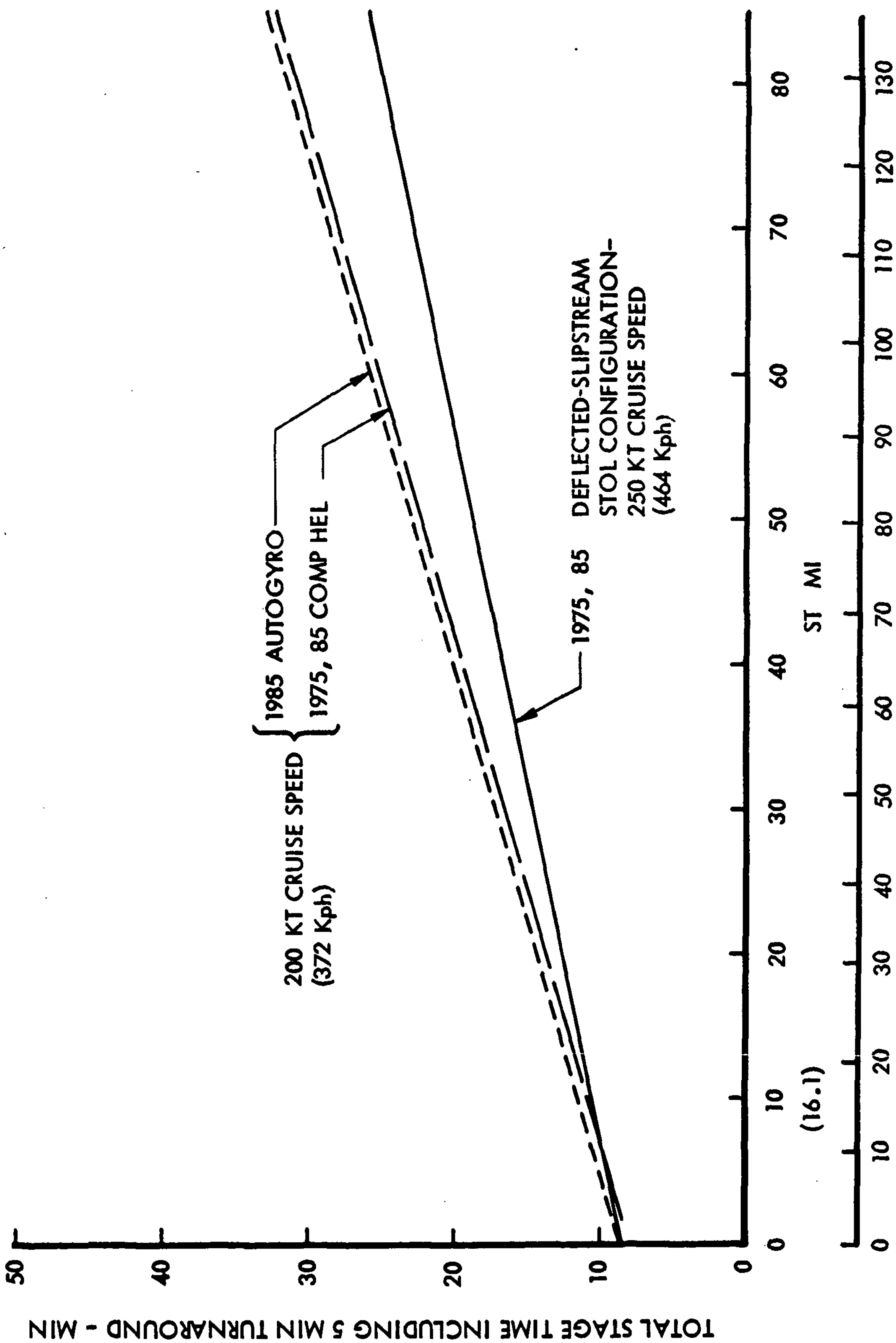

Figure 2-1.12. Stage Time vs Stage Length

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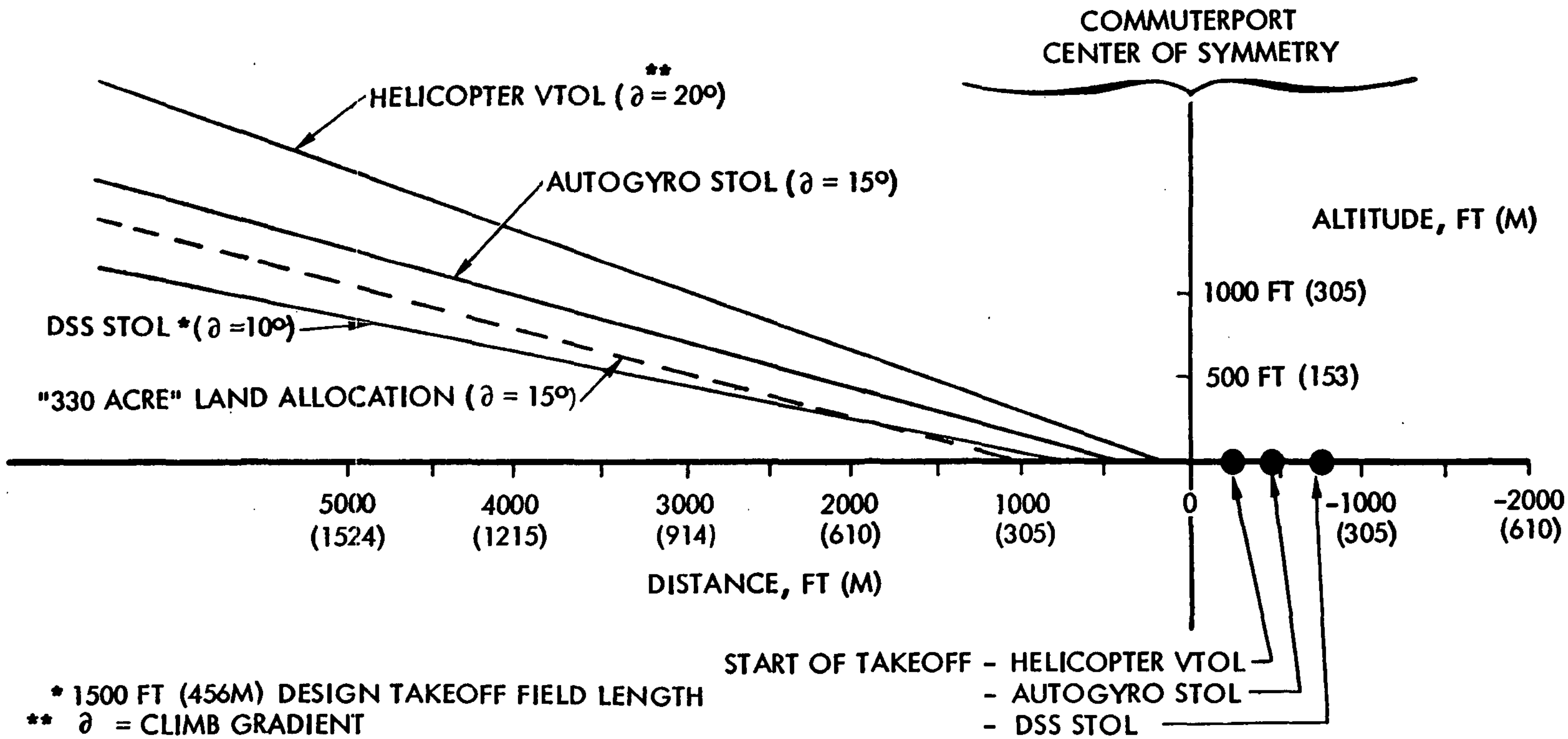

Figure 2.1-13. Comparative all Engine Takeoff Flight Profiles

2.1.1.8 Flight Characteristics

Quantitative estimates of the flight characteristics of the Phase II aircraft concepts are outside the limits of this study. However, the subject is of significance when considering the applicability of aircraft to intraurban mass transportation. A review of V/STOL flight characteristics literature (including Ref. 2.1-1 through 2.1-4) has therefore been carried out to ascertain the more important factors affecting vehicle design and operation. The following discussion was developed from this review.

2.1.1.8.1 Flying Qualities

To be acceptable, intraurban transport operation must be "on schedule" to an order of magnitude greater than today's intercity air transport operations.

Airport performance of both VTOL and STOL aircraft requires slow approach and liftoff speeds, generally less than 80 kt. Detroit's weather spectrum, as noted in Phase I, involves frequent change, with severe winds at times, as well as rain and snow. The intraurban transport operation in this environment will encounter random wind direction changes and large shifts in "free stream q" (free stream dynmaic pressure). During takeoff and landing, this will make it difficult for the pilot to follow the required three-dimensional course with precision. His ability here is a complex function of his own response capability plus the aircraft aerodynamic stability, damping, control response, and inertia characteristics.

In consideration of the above, it is judged that the intraurban transport will require an extensive, reliable, full-time, automatic flight control system (AFCS) to fly the aircraft essentially 100% during scheduled operations in adverse weather. (The AFCS is discussed in Section 2.1.2.5.) This implies a substantial degree of system redundancy for safety. In addition, the pilot must be able at least to get the aircraft back on the ground safely in the event of failure of one or more of the aircraft-electronics system.

By extension, this leads to the question of the proper "quality" of the flight characteristics with the AFCS system 100% off. To change the aero-mechanical configuration so that the pilot would not have to rely on any AFCS elements, even to fly off-schedule good weather operations, would increase aircraft size and complexity, as well as development and maintenance costs.

The above is intended to illustrate the "different" nature of the intraurban transports flight characteristics requirements in comparison with current intercity aircraft. Flight loads, fatigue, system reliability, etc. likewise will require a "different" approach for intraurban transports.

Compound Helicopter VTOL - From a flight characteristics standpoint, the compound helicopter VTOL is considered the most readily adaptable to the intraurban transport operations. The fund of experience with the pure helicopter in limited intracity operations affords a good base for developing design and operating limitations. The compound helicopter VTOL is inherently capable of good low speed control due to the high effective "q" of the rotors at takeoff and landing speeds. It is considered to have no serious flight characteristics drawbacks.

Autogyro STOL - The autogyro STOL concept is not backed by any direct operational experience. However, as noted in Section 2.1.1.4, it operates principally like the compound helicopter after liftoff and during cruise, approach, and landing. It has good transient low speed control power. Helicopter operational experience is also directly applicable to the development of design and operating limitations. It is likewise considered to have no serious flight characteristics drawbacks.

Deflected Slipstream STOL - The deflected slipstream STOL employs the same powered lift principal as the French Brequet 941. This aircraft has been flow extensively by U.S. airlines and NASA flight crews. NASA pilots have judged it to be basically satisfactory for both VFR and IFR operation. However, an all weather "hard schedule" intraurban operation acceptable to FAR may require an augmentation of the low speed, lateral-directional control power -- especially for 1500 ft length operation.

2.1.1.8.2 Ride Comfort

The intraurban transport's ride qualities are expected to rank equally as important as community noise with regard to public acceptance of the system. The state of the art in airframe design for good ride qualities has not extended much beyond use of high wing loadings and application of lateral-directional dampers, with the latter applied primarily to improve flying qualities. This has happened largely because todays fixed-wing intercity transport operations are mostly at high altitudes where turbulence levels are low and with schedules that allow flying around weather fronts. This approach will not be possible with the tightly scheduled low-altitude intraurban transport operation.

An indication of the powerful adverse effect of low altitude operations atmospheric turbulence (and resultant passenger comfort) is shown in Figure 2.1-14 which has been taken from Reference 2.1-22. This representation is based on extensive Air Force and NASA evaluation of atmospheric properties, and represents a statistical interpretation of available information regarding isotropic turbulence. The format utilized defines the probability density of root-mean-square gust velocity mathematically to obtain a convenient expression for the number of load factor exceedances for any value of aircraft response function at each altitude, i.e.,

$$N(\Delta n_z) = P_1 \exp\left(\frac{\Delta n_{z/\bar{A}}}{B_1}\right) + P_2 \exp\left(-\frac{\Delta n_{z/\bar{A}}}{b_2}\right)$$

where

Δn_z = Transient vertical acceleration, or incremental load factor due to gust, g's

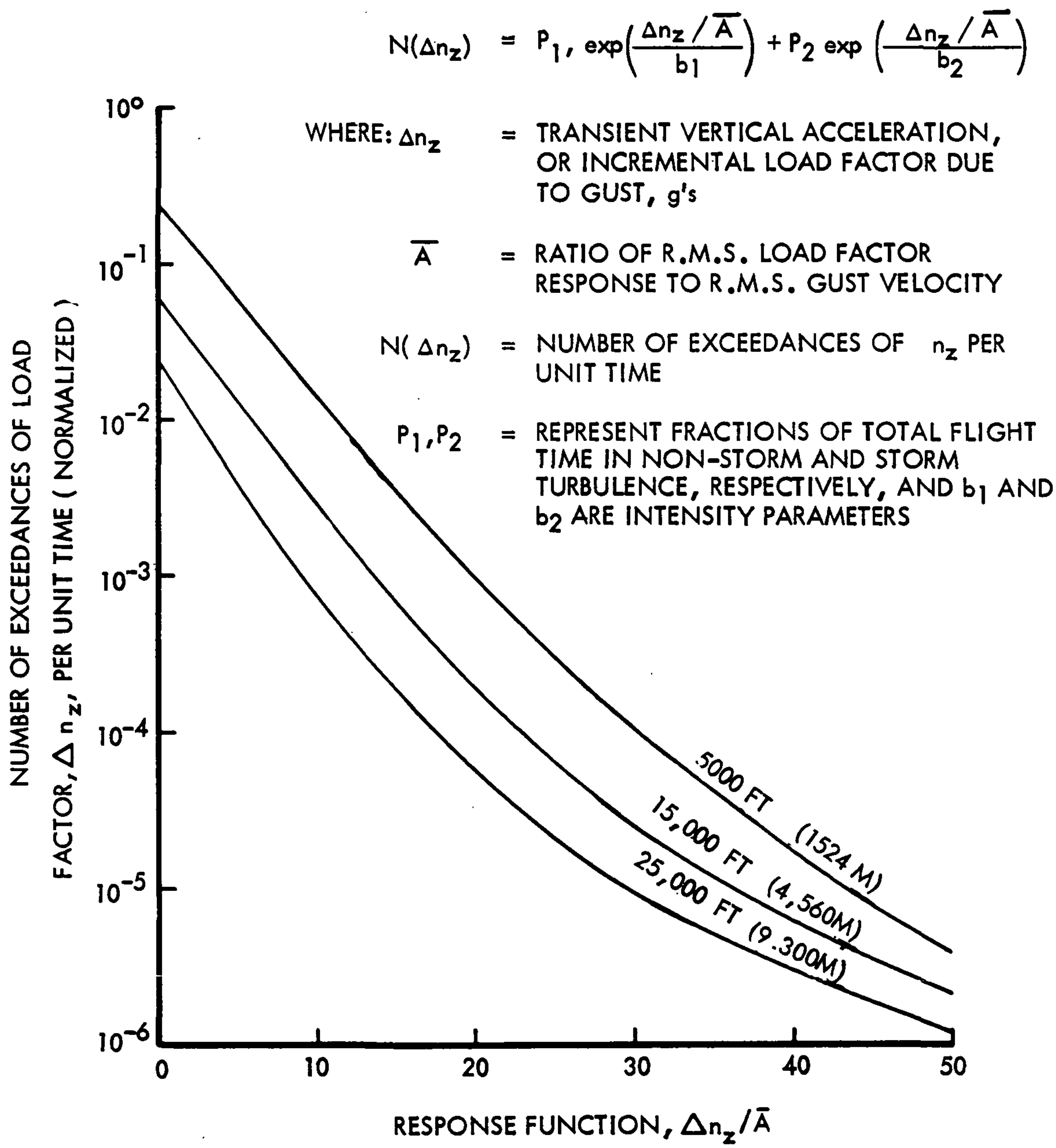

Figure 2.1-14. Generalized Load Factor Exceedance Curve

$\bar{A}$ = Ratio of r.m.s. load factor response to r.m.s. gust velocity

$N(\Delta n_z)$ = the number of exceedances of Δn_z per unit time

P_1 and P_2 represent fractions of total flight time in nonstorm and storm turbulence, respectively, and

b_1 and b_2 are intensity parameters.

Basically, Figure 2.1-14 may be considered as depicting the frequency with which any given load factor will be exceeded at each altitude shown. The order of magnitude difference between 25 000 and 5000 ft is noteworthy.

It is apparent from the above that development of realistic design criteria for ride qualities is essential to the intraurban transport program.

Development of methods to improve ride qualities have been the subject of much statistical and theoretical analysis in recent years, particularly relating to airframe response to nonuniform flow. These analyses have included proposals for application of gust sensing control feedback systems. The all-weather intraurban transport problem will require application and extension of this work to give the vehicles acceptable ride qualities.

The rotary wing vehicles with their comparatively high wing loading flexible rotor blades, and lower cruise speeds, inherently have less response to turbulence than the moderate wing loading, deflected slipstream, STOL concept. The vibration element of the total ride qualities picture is inherently more significant with the rotary wing concepts.

2.1.1.9 Noise Considerations

The success of an airborne intraurban transportation system will depend, in part, on the degree of public acceptance of the system, and this will be strongly influenced by the vehicle exterior and interior noise characteristics.

The approach employed in considering noise is to (1) define the degree of public tolerance to the intraurban transport's noise encroachment as a function of the public's environment, activities, and location; (2) define the resulting commuterport land allocation requirements; and (3) forecast the capability of each configuration/payload combination to meet these noise requirements.

2.1.1.9.1 Community Noise - General

The work presented in the following sections was carried out independently of the preliminary community noise estimates of Phase I. The Phase I analysis, however, served to constrain the Phase II work to a consideration of commuterport vicinity noise only, since it was determined that overhead flight presented no serious noise problems.

The commuterport noise investigation is limited to a consideration of takeoff only since the rotary wing configurations will operate at reduced power on landing to achieve approach gradients approximately the same as for takeoff, and the fixed wing configurations will likewise operate at reduced power on landing (although at limited approach gradients). The takeoff operation is therefore considered the more critical. In the following analysis primary emphasis is given to the far field noise generators since they dominate the community noise scene. These are the main and tail rotors of the rotary wing configurations and the propellers of the fixed wing configurations. Secondary noise sources such as compressors, turbines, and fans, produce lesser noise inputs and are capable of conventional noise suppression treatment. In addition, the work is limited to noise encroachment in the vicinity of the commuterport since the performance analysis shows that possible cruise noise can be relieved if necessary, by increasing the 2000 ft design cruise altitude to at least 4000 ft without appreciable penalty to block performance or cost.

Since noise is unwanted sound, the intraurban aircraft acoustic design problem can be defined as one in which sounds of the aircraft must be so low that they will be considered to be noises by no more than a small percentage of the population, say 10 percent. The design of the aircraft must therefore br related to commuterport area planning. The object of the joint design and planning study is to arrive at a compromise between the economics of quiet aircraft and the economics of land utilization. The first step was to select an aircraft sound characteristic with a numerical value which can be translated into both fundamental aircraft design and land use planning languages.

Aircraft sounds are rated in terms of a subjective annoyance scale called Perceived Noise level (PNL), in units of Perceived Noise Decibels (PndB). Two other rating scales are commonly used for evaluation of sounds in residential areas. The "A" weighted sound pressure level scale, in units of dBA, is used by municipal authorities to judge the levels of traffic noise and other sources of community complaints, such as excessively loud music reproduction systems. Speech Interference Level (SIL) is used in general architectural acoustics and commercial transport aircraft interior design to judge the relative ease or difficulty of face-to-face communication as a function of distance between conversationalists.

Different sounds, judged by different ratings, can be compared with the aid of Figure 2.1-15. The ordinate, PNL, applies to aircraft sounds, and the abscissa to either dBA or SIL equivalences of the PNL's or to description of such common community sounds as those of vehicles or powered lawn mowers. The straight line from lower left to upper right in the figure is generally accepted for discussion pruposes as an equivalence relation. For example, municipal traffic noise laws or regualtions, where they exist, usually specify that vehicle sounds must be exceed 85 dBA at a roadside measurement point. An aircraft sound with a PNL of 98 PNdB is equivalent to a traffic sound at 85 dBA.

The following quotation from page 128 of "Transportation Noise, Pollution: Control And Abatement", NASA Contract NGT 47-003-028, 1970, defines a PNL goal that is widely discussed in current trade literature:

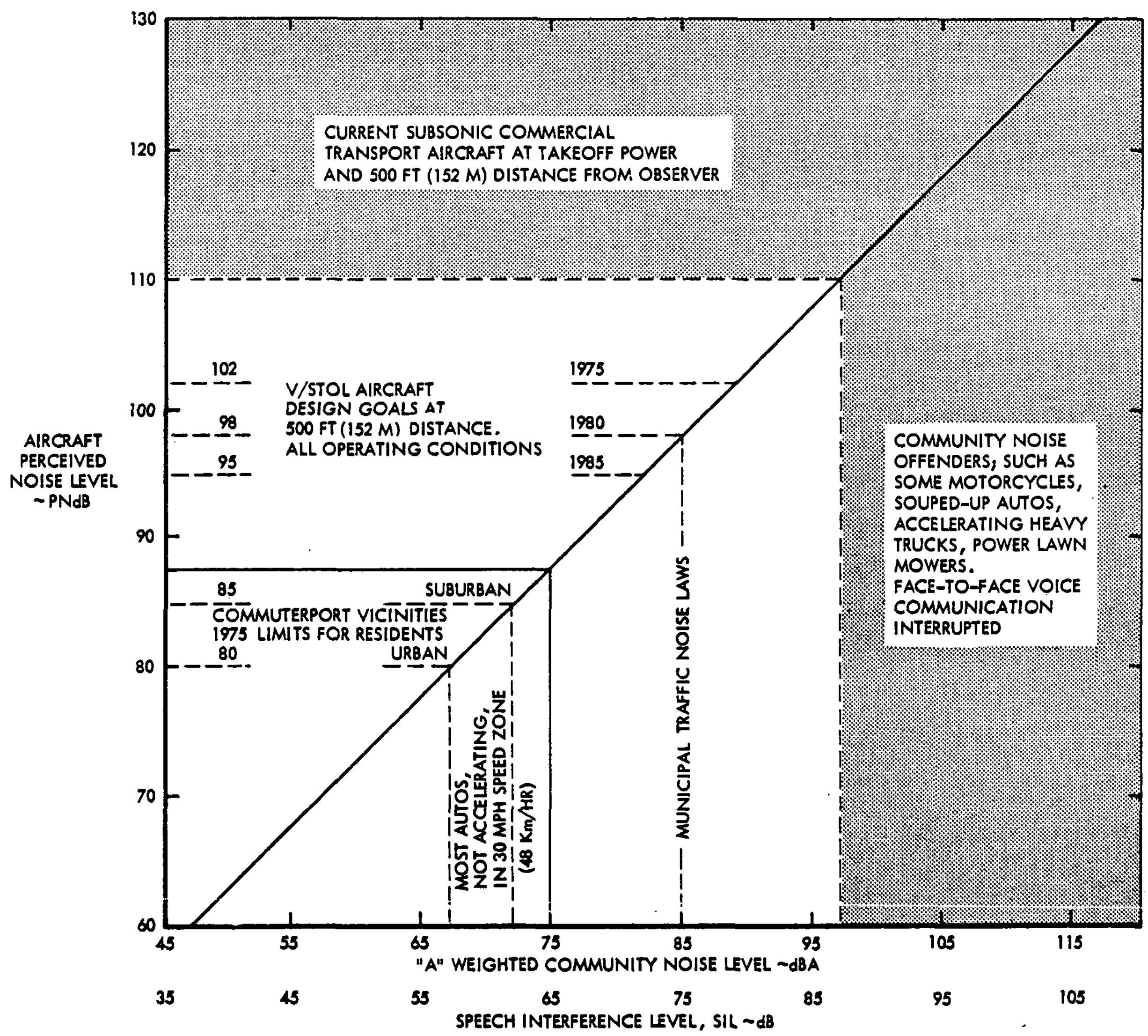

Figure 2.1-15. Comparison of Different Community Noise Rating Scales

"The noise certification levels for V/STOL aircraft should be 95 PNdB at 500 feet. It would be a grave mistake to underestimate the resistance of the communities surrounding a proposed V/STOL port to higher noise levels."

Again, on page 129 of the above reference it is stated that: "A major research effort should be instituted to develop a quiet and economically feasible V/STOL aircraft. A V/STOL aircraft (with perhaps a 150-passenger capacity) should be developed by NASA to ensure that acceptable noise levels can be attained. An engine noise limit of 95 PNdB at 500 feet in all directions should be used."

An objective of the acoustic segment of the study was to provide a basis for establishing relationships between acoustics, aircraft performance, and systems tradeoffs for the aircraft concepts considered. The acoustic design criteria, therefore, were selected with cognizance of the currently discussed 95 PNdB/500 ft limit, but were not necessarily governed by it. Instead, the allowable noise from the intraurban aircraft transportation system was established as a function of the community segment affected, with the limiting values as shown in the "Aircraft Design" section. Corresponding 500 ft values are approximately as follows:

1975 IOC	102 PNdB
1985 IOC	95 PNdB

Residents will unlikely to complain about aircraft sounds that do not disrupt such normal activities as neighborhood socilizing at backyard picnics. An extraneous sound at 75 dBA, with an SIL of 65, corresponds to approximately 85 PNdB per Figure 2.1-15 and this level would cause individuals conversing at normal voice levels to instinctively raise their voices to moderately higher levels. Consideration of this along with a general understanding of the intrusive character of aircraft sounds in an outdoor environment was used as a basis for selecting a design goal limit of 85 PNL for intraurban aircraft sounds perceived in suburban residential areas. As shown by Figure 2.1-15, 85 PNL is no more intrusive than the sounds of most automobiles operating in a 30 MPH speed zone. The surburban residential environment was chosen since it is probable location for some of the communterports and will, therefore, impose the most severe aircraft noise - commuterport land allocation requirements.

For aircraft design purposes it is necessary to translate the 85 PNdB residential design requirement into a unique frequency spectrum representative of the intraurban transport to permit evaluating the noise produced by the candidate propulsion systems. As an aid to the subsequent discussion the PNL calculation procedure is briefly reviewed below.

The portion of the audible frequency range from 50 to 10,000 Hz (hertz: 1Hz = 1 cycle per second) is divided into 24 bands, each covering one-third of an octave. Sound spectra are frequently analyzed in terms of one-third Octave Band Levels (OBL) of sound pressure. Eacn one-third OBL has a subjectively determined annoyance value expressed in units called "NOYS". * The PNL value is determined from the expression:

$$PNL = 40 + 33.3 \log_{10}(NOY_{total}), \text{ PNdB}$$

The design goal of 85 PNdB is equivalent to a NOY_{total} value of 22.6 NOYS. The NOY_{total} calculation makes use of each of the 24 NOY values including the numerically greatest, called NOY_{max}, as follows:

$$NOY_{total} \doteq NOY_{max} + 0.15 \times \text{(the sum of the remaining 23 NOY values)},$$

and it is noted that no unique relationship exists between the NOY_{total} value and the one-third OBL's; i.e., there are a great number of widely different one-third octave band spectra which would yield the same NOY_{total} value.

Perceived noise levels cannot be scaled directly from one aircraft-to-listener sound propagation distance to another. Scaling of aircraft sounds must be accomplished by extrapolation of each of the 24 one-third OBL readings. The extrapolation is performed by considering two type of sound attenuation correction; the first depends on distance between source and receiver independent of sound frequency; the second depends on extra air at attenuation, or atmospheres, the extra air attenuation term is a complex function of atmospheric conditions defined in units of dB/1000 ft of sound path length. The atmospheric absorption can be expressed in simplest terms if extrapolations are performed with reference to a standard day atmosphere in which temperature and absolute humidity are independent of altitude. In practice, a standard day constant temperature of $77^{o}F$ and an absolute humidity of 15.9 gm/m^3, which corresponds to a relative

* Basic unit employed to calculate PNL in PNdB from measured sound pressures.

humidity of 70 percent at a sea level pressure of 29.92 in. Hz, are defined as reference conditions.

An 85 PNdB intraurban transport one-third octave band design goal spectrum, considered appropriate to both rotary and fixed wing types was developed for use in assessing the total noise characteristics of each concept. This development is based largely on analysis of flyover measurements of representative rotary and fixed wing aircraft and includes consideration of noise sources capable of acoustic treatment such as compressor and fan noise, as well as largely untreatable sources such as rotors, propellers and turbine exhaust sounds. Atmospheric attenuation and background noise were also considered. It was developed as follows: An 85 PNdB spectrum in which the one-third octave OBL's each have an annoyance value of 5 NOYS was assigned to the condition of a 2000 ft sideline aircraft-to-listener distance in a surburban residental community (see curve 1 of Figure 2.1-16). The 2000 ft value was chosen following a consideration of Detroit land costs and associated commuterport size costs, as opposed to the cost and risk of providing aircraft having lower noise levels. This spectrum was then extrapolated downward to 250 ft (curve 2 of Figure 2.1-26). This technique provides for the direct comparison between the frequency spectra of the noise criterion and that of a candidate propulsion system with the effects of atmospheric attenuation largely removed from the analysis. The resulting spectrum at the 250 ft reference distance was reshaped, as described above, to obtain a realistic design goal spectrum (curve 3 of Figure 2.1-16). This design goal spectrum was then extrapolated from the 250 ft distance back to the 2000 ft aircraft-to-listener distance (curve 4 of Figure 2.1-16). It is the target spectrum for the intraurban aircraft operating out of a suburban residential commuterport since the 95 PNdB value (22.6 NOY_{total}) is retained.

The establishment of vehicle noise frequency spectrum design criterion and associated reference distance combined with knowledge of the anticipated vehicle performance allows the development of commuterport PNL contours that are then used for land use planning around each commuterport. It was initially assumed that the intraurban transport vehicles would be capable of a 15° all engine climbout gradient from a 2000 ft field length commuterport. Assuming

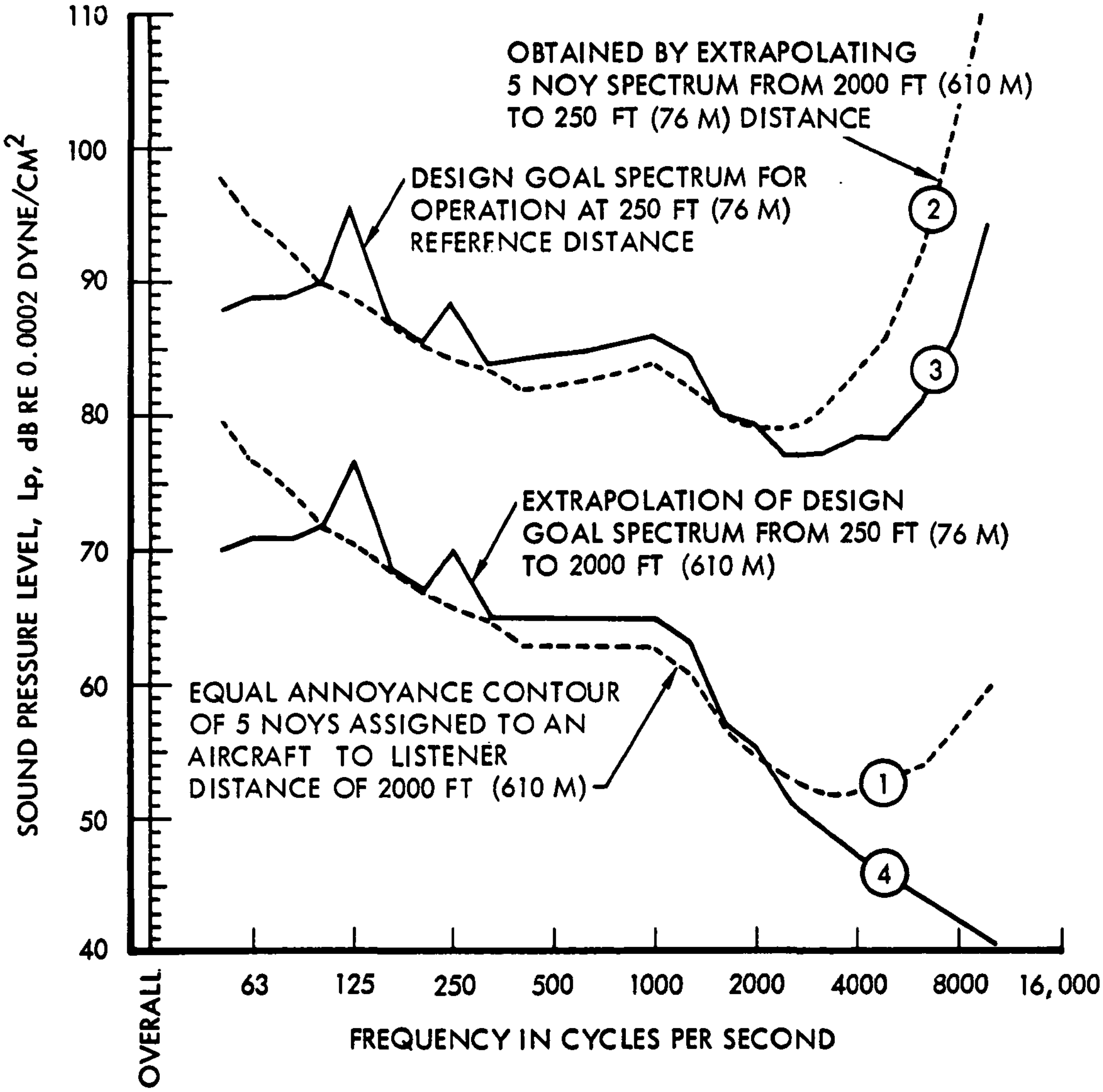

Figure 2.1-16 Derivation of 250 Ft Design Goal Spectrum (PNL = 85 PNDB at 2000 FT)

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85 PNL at 2000 ft, combined with 15 deg. climb performance, and impressing the PNL contours on a suburban area produces the recommended land allocation shown in Figure 2.1-17.

Residential districts would be restricted to areas outside the 85 PNL boundary. The area within the 95 PNdB contour is considered satisfactory for the area immediately adjacent to the commuterport and is approximately 330 acres. Possible uses for the allocated land not required for the commuterport are also shown in the figure. They are based on the logic that higher noise levels are permissible in these areas.

The suggested land allocations of Figure 2.1-17 were made without specifying the flight frequency to and from the heliport. However, in final analysis, acceptable allocations will be a function of this factor - which is included in the Noise Exposure Forecast scale (NEF), and the F.A.R. Effective Perceived Noise Level (EPNL). Scale for the NEF basis doubling or halving the frequency of operation increases or decreases the NEF by five PNdB and will therefore change land allocation requirements. Also, local land use and the associated background noise will also affect these requirements. The land allocations shown in Figure 2.1-17 should be considered accordingly. All engine takeoff flight profiles are shown for each concept in Figure 2.1-13. The rotary wing concept are both shown to have profiles greater than the 15 degree "330-acre" profile while the deflected slipstream STOL, shows lower gradients. The 330 acre land allocation shown in Figure 2.1-17 has been used in the cost analysis of Section 2.1.3.

2.1.1.9.2 Vehicle Exterior Noise-Rotary Wing Configurations

The 1975 and 1985 IOC compound helicopter concepts are basically the same "noisewise" except for the differences in the main rotor drive. The 1975 concept has a conventional mechanical engine to rotor power transmission and the 1985 concept has a hot gas pneumatic system to supply sonic rotor tip jet nozzles. The 1985 IOC autogyro concept is similar "noisewise" to the 1985 helicopter except that the pre-takeoff rotor spinup power is transmitted via engine compressor bleed to air turbine motors which provide the rotor torque. Rotor tip speeds are held to 625 ft/sec in all cases to reduce noise without seriously compromising rotor performance. Rotor blade passage frequency

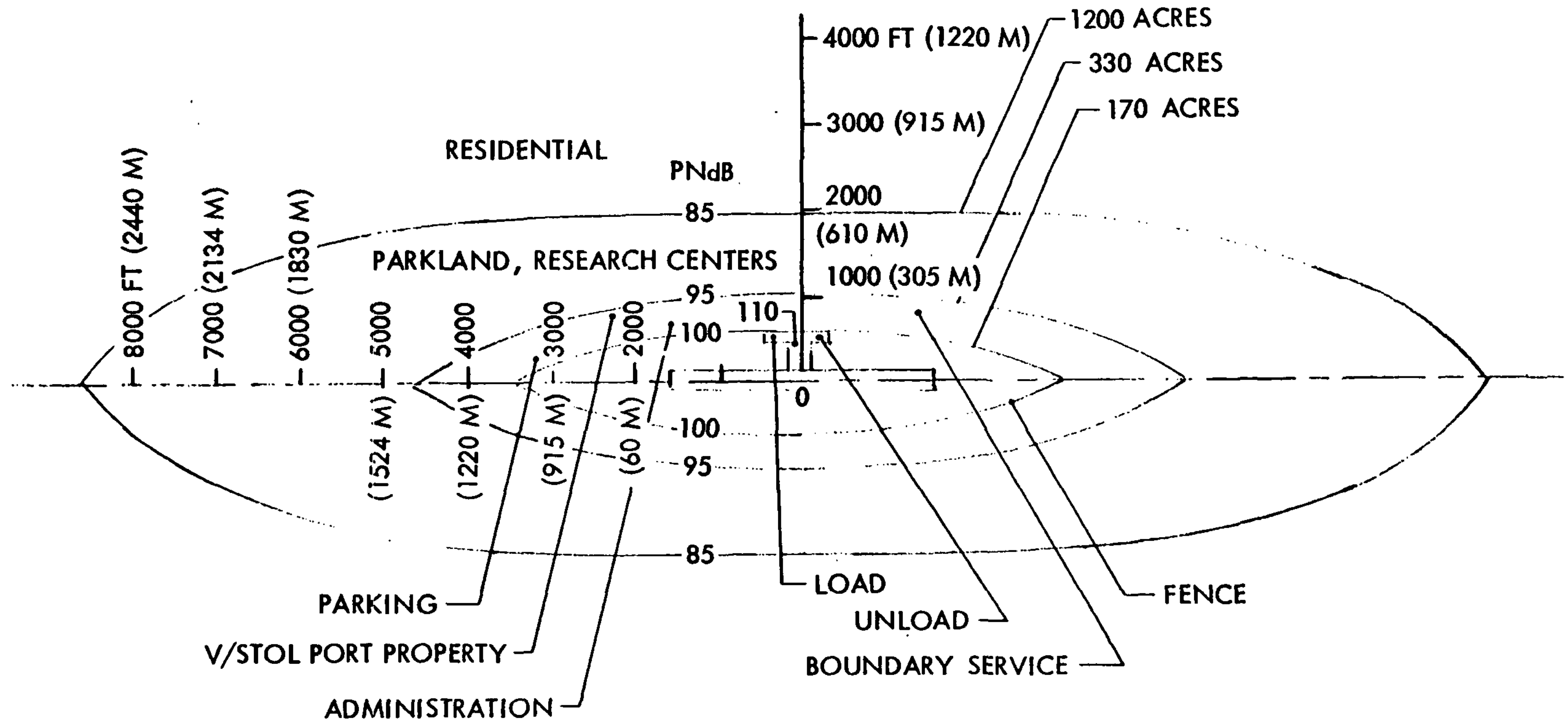

Figure 2.1-17. Suburban Land Allocations to Conform to Community Noise Limits. 1975 IOC

thereby decreases with increasing vehicle size, and this will partially relieve the usual increase in PNL with size since the peak OBL's in the spectrum will be shifted to a lower frequency as the size increases (in general, PNL decreases as frequency decreases for a constant sound pressure level (SPL)).

The 1985 main rotor tip nozzle drive system cannot, with current state-of-the-art, be quieted sufficiently to meet the proposed community noise-land allocation requirements without an excessive weight penalty, particularly in the larger sizes. Nevertheless, this rotor drive concept is retained in the confidence that the combined acoustic and airframe design state-of-the-art will, with ten years to solve under the stimulus of the public demand for less noise, develop sufficiently to provide the art for quieting this concept within the 1985 IOC date without excessive penalties.

The multibladed, lightly load fan-in-fin directional control concept shown for all configurations is not sufficiently defined for quantitative analysis but is selected from a consideration of current attempts to reduce tail rotor noise. Basic noise features are envisioned as follows: tip speed approximately 625 ft/sec, disc load approximately 30 psf; low blade loading possibly with canted blades (non-radial). The required fan-in-fin directional control power during takeoff, and its resulting noise output, will be greatest for the 1975 helicopter since it must overcome the main rotor torque. The 1985 helicopter and autogyro will inherently have lower values since the torqueless main rotor will allow the fan-in-fin to operate near a no load condition.

A real world noise correlation was obtained by utilization of in-house flight test measurements on a large 28,000 lb gross weight current technology helicopter. Fly-by measurements, extrapolated to the 2000 ft reference distance give 80 PNL. At this weight the 1975 intraurban compound helicopter would carry approximately 25 passengers.

2.1.1.9.3 Vehicle Exterior Noise-Fixed Wing Configuration

The primary source of community noise for this concept is the propellers. Propeller noise is basically composed of rotational noise (discrete tones) occurring at the fundamental and harmonics of the blade passage frequency, and "vortex" noise (broadband random frequency noise). A number of parameters influence propeller noise intensity, the most influencial being tip speed. In the proposed configurations, propeller noise intensity will be minimized by holding tip speed to 625 ft/sec.

Most propellers on current and past transport types, such as Lockheed Electra and Douglas DC-7, operate during the early stages of the takeoff with their propeller blades partially stalled, and this results in additional noise. This is alleviated in the proposed concept by using Hamilton-Standard variable camber propellers which provide a wider angle of attack range without stalling.

The propeller noise prediction theory of Gutin, expressed in engineering terms by H.H. Hubbard in Ref. 2.1-23, has proven to be accurate for predict the sound levels for the fundamental of the rotational noise.

For example, agreement within one dB was obtained between measured sound pressure levels for a four engine Lockheed Electra and theoretical SPL's derived from the aforementioned report. Figure 2.1-18 shows a comparison between the Electra spectrum at take-off power and the design goal frequency spectrum for the conditions of a flyover at the reference 250-ft altitude on a standard day. The Electra SPL peak at 63 Hz would require a reduction of 13 dB to meet the 96 dB peak low frequency SPL of the design goal spectrum.

Figure 2.1-19, derived from the above reference, indicates the dependence of SPL at the blade passage frequency, on tip Mach Number for four-bladed propellers at blade diameters of 12, 16 and 20 ft., with total horsepower in the range of 2000-6000SHP as a parameter. The propellers for the deflected slipstream STOL concept must fall within the 96 dB design criterion line to meet the proposed 85 PNdB community noise limit.

The variation of PNL with distance during takeoff is shown in Figure 2.1-20 for the above intraurban transport design goal spectrum and the Electra, where the latter values are based on flight test measurements. Also shown is a calculated value for the French Brequet 941 based on limited flight test measurements. The similarity between the shape of the curves lends substantiation to the intraurban transport design requirements.

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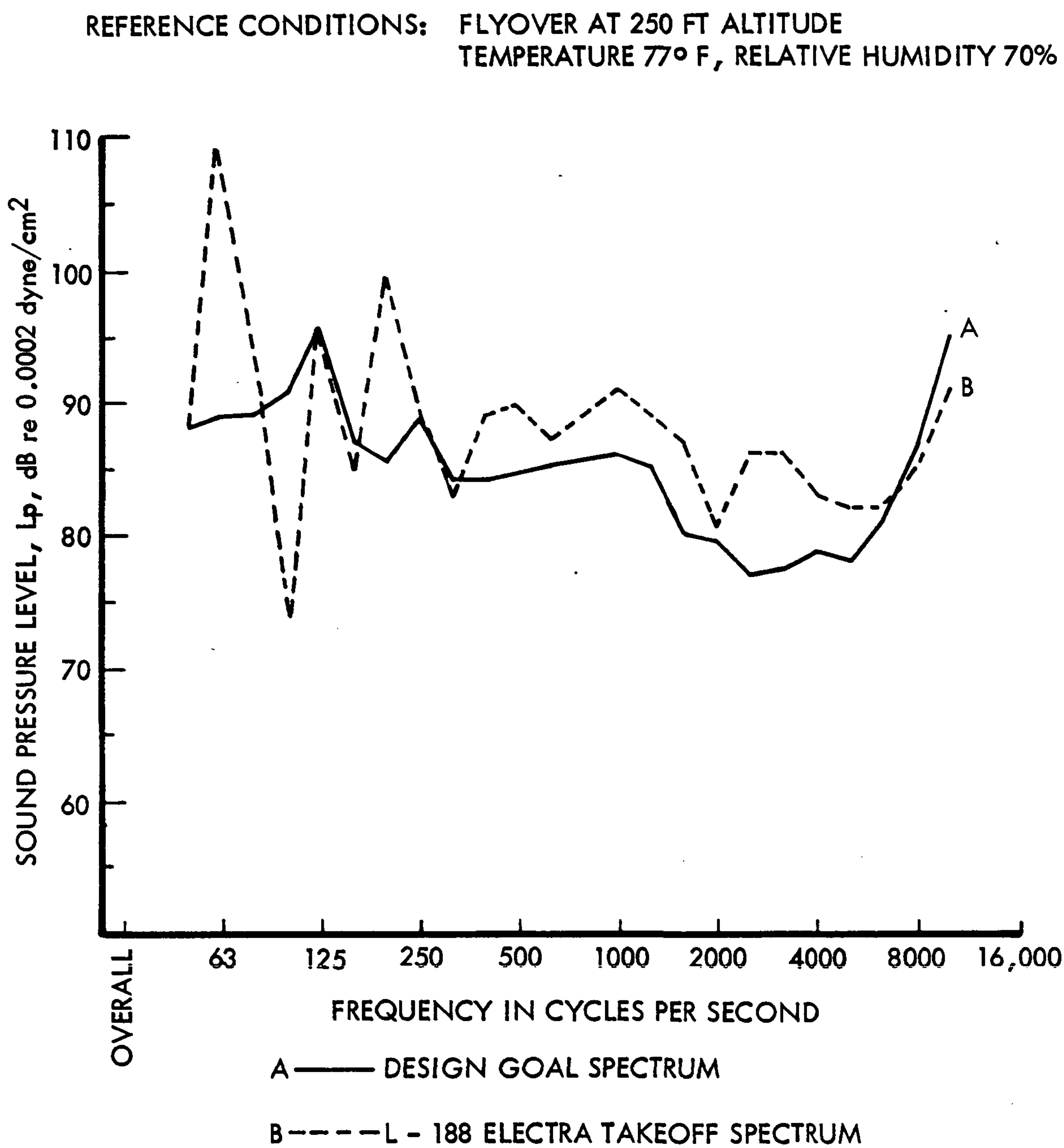


Figure 2.1-18. Comparison of Electra and STOL Design Goal Sound Pressure Levels

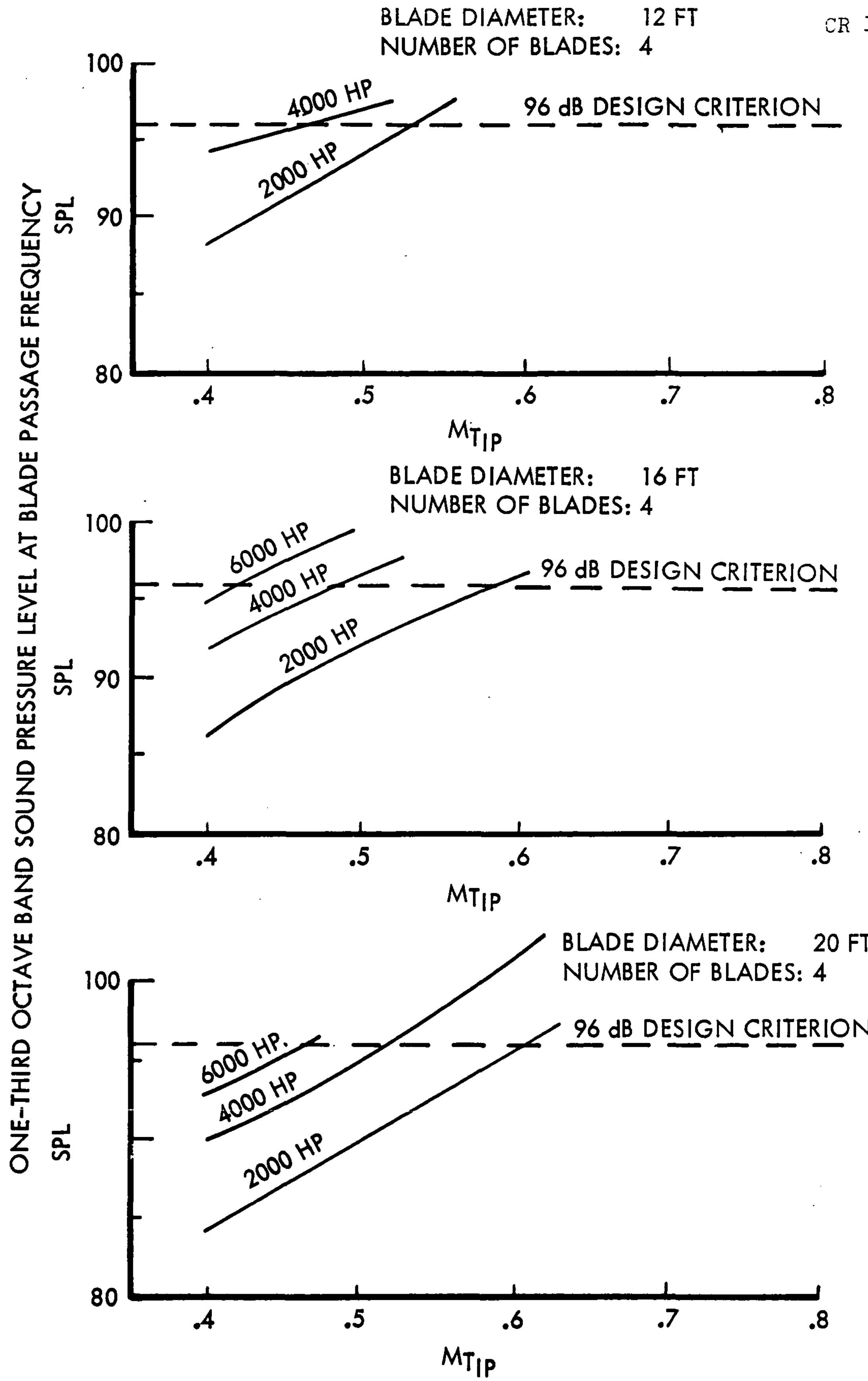


Figure 2.1-19 . Alternative Propeller Characteristics

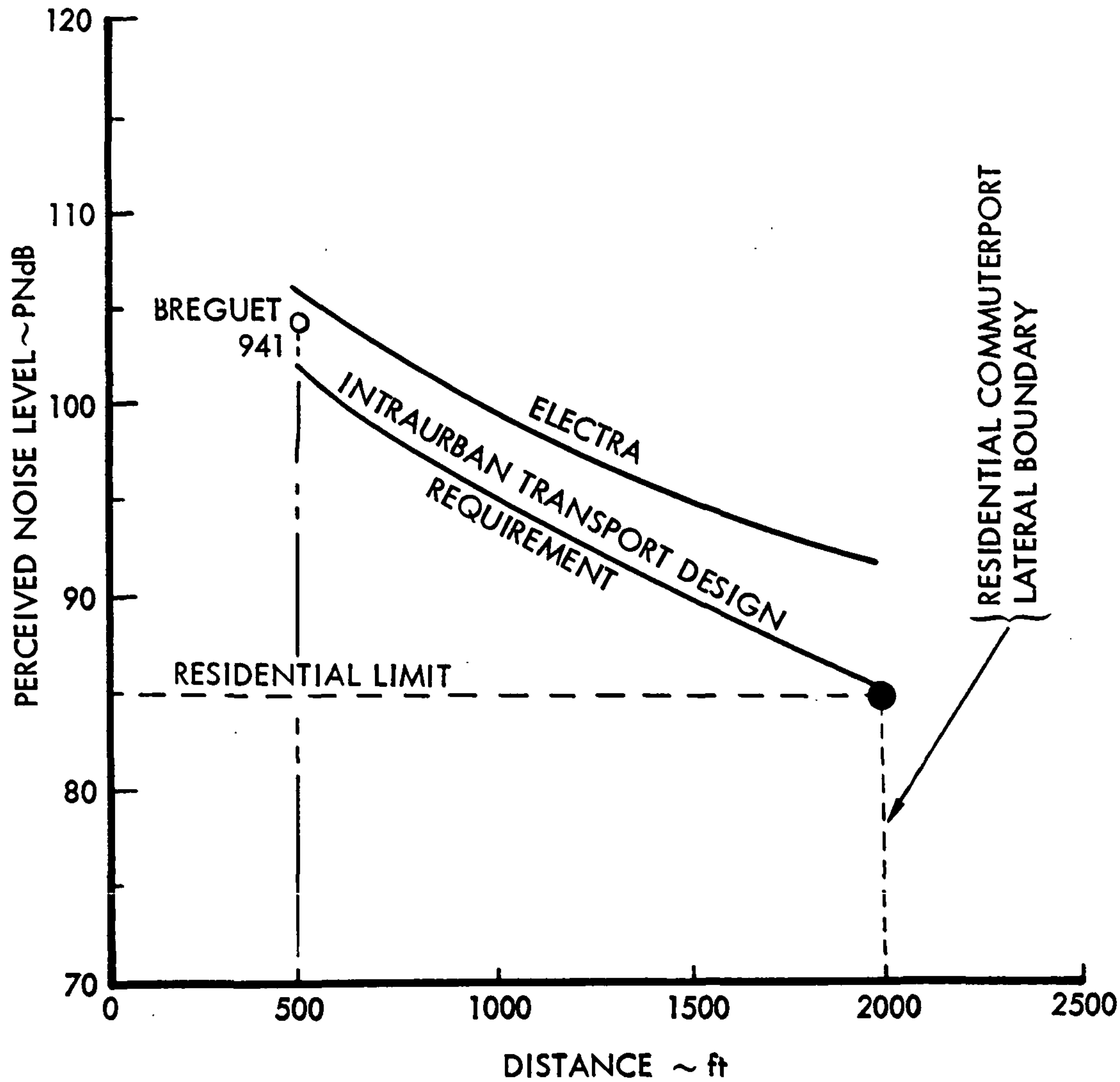


Figure 2.1.20. Comparison of PNL Versus Distance During Takeoff.

The Brequet 941 has approximately 35% of the power of the Electra yet its PNL level at 500 ft is shown to be only 2 PNdB lower than for the Electra. This is attributed to the fact that the Brequet has a propeller tip speed of 925 ft/sec whereas the ocrresponding value for the Electra is but 720 ft/sec. The strong effect of propeller tip speed is thus illustrated.

The Electra is a 116,000 lb gross weight aircraft employing four 3750 hp turboshaft engines driving 13.5 ft diameter four-bladed propellers which develop a total of 15,000 lb of thrust with a tip speed of 720 ft/sec. The largest vehicle in the present study is the 1975 technology, 100-passenger, 1500 ft takeoff field length aircraft whose four propellers develop a total fo 22,150 lb of thrust at takeoff from four 1450 hp engines. The higher total thrust but lower power required to develop this thrust, combined with the variable camber, lower tip speed propellers indicates that this vehicle probably can meet the design goal of 85 PNdB at the 2000 ft reference distance. Therefore, all the remaining DSS STOL vehicles should likewise fall within this design goal.

2.1.1.9.4 Community Noise - Summary

In summary, this exterior noise review indicates that with proper consideration of the noise problem at the outset of an intraurban transport development program, the following capability to meet the exterior noise requirements of section 2.1.1.1 with the commuterport land allocations of Figure 2.1-17 should be attainable.

1) The 20 to 60 passenger 1975 compound helicopter VTOL's could meet the requirements with little compromise. However, at the current state-of-the-art, payloads beyond 60 passengers will require some weight or performance penalties.

2) Assuming a continued public insistence on less noise - with the corresponding necessity for a strong noise research program - it is judged that the acoustic and airframe design art will evolve sufficiently during the coming 10 years to permit development of the suggested 1985 rotor tip nozzle drive compound helicopter to 80 passenger size without significant weight or performance penalties.

3) The 1985 Autogyro STOL concept should have no problem in meeting the requirements up to 80 passenger size.

4) The 1975 and 1985 deflected slipstream STOL concepts should meet the requirements at all sizes.

2.1.1.9.5 Interior Noise

1975 Compound Helicopter VTOL - It is anticipated that the main rotor gearbox, mounted under the cabin floor, will be the major interior noise source. Gearbox noise is characterized by several harmonically related series of discrete frequency tones commencing with the fundamental gear tooth contact frequency of each stage of the transmission. There are two paths for this noise to enter the cabin area. One is the airborne path by which vibration of the gearbox housing radiates noise into the surrounding air space and this noise in turn penetrates sourrounding structure, including the floor, into the cabin area. Application of an acoustical treatment composed of materials such as plastic foam or glass fiber batts and lead-impregnated vinyl fabric can effectively reduce the airborne transmitted noise. The second path is through the structure, whereby the gearbox vibrations pass directly through the attachment points into the airframe. These vibrations cause the wall and floor panels of the cabin to vibrate, thereby radiating noise. Installation of state- of-the-art vibration isolation will minimize this contributor to the interior noise. Effective gearbox noise reduction necessitates the treatment of both noise transmission paths - failure to do so will lead to excessive interior noise levels.

Secondary interior noise sources are the fan engines and the environmental control system (ECS). Tailoring the side wall acoustic treatment to the intensity of the engine noise along the fuselage should effectively control this noise source. Acoustical treatment methods for ECS are well established, and therefore control of this source of cabin noise should not be a problem. In summary, the interior noise of these vehicles can be kept within acceptable limits if priority is given to integrating the acoustical treatment into the overall vehicle design.

1985 Compound Helicopter VTOL - The interior noise from the rotor blade tip nozzle drive system employed in this configuration will not require the extensive noise control measures necessary with drive systems using a gearbox. Any noise generated by the main rotor blade tip nozzles will most likely be high frequency noise which is readily attenuated by relatively lightweight acoustical treatment. The only other potential contributor to the interior noise, that can be attributed to the main rotor drive system, will be airborne engine noise conducted through the main rotor drive air ducts. Careful design of the ducting system and appropriate acoustical treatment should hold the interior noise contributed by this source to a satisfactory level.

The secondary interior noise sources discussed for the 1975 compound helicopters will also be applicable to the 1985 compound helicopter vehicles as well as the associated noise control measures.

1985 Autogyro STOL - Air turbine motors (ATM) drive a below-the-floor gearbox to bring the main rotor up to speed prior to takeoff. This will require 30 to 40 seconds. The noise radiated by typical ATM's is generally high frequency and therefore readily amenable to reduction by an acoustical treatment employing plastic foan of glass fiber batting in combination with lead-impregnated vinyl fabric. Considerable high frequency noise reduction can be obtained by relatively lightweight acoustical treatment; however, this treatment must be used in conjunction with effective vibration isolation. Lack of proper vibration isolation, required to minimize structureborne noise, will result in a "short circuit" of the acoustical treatment used for reduction of the airborne noise. Consequently, control of the interior noise attributable to the ATM's should present no serious technical problems providing the appropriate control measures are followed.

The secondary interior noise sources discussed for the 1975 compound helicopters will also be applicable to the 1985 autogyro configuration as well as the associated noise control measures.

1975 and 1985 Deflected Slipstream STOL - The major contributors to interior noise in the DSS aircraft will be the propellers. Propeller noise, as discussed above, is composed of both discrete frequency tone (occurring at the blade passage frequency and its harmonics), and a broadband random "vortex" noise. The rotational noise is low frequency (60 to 80 Hz) for the fundamental, which makes reduction of the associated noise very difficult.

However, the low tip speed, variable camber propellers used to reduce exterior noise together with low power loadings and large propeller to fuselage clearance are also beneficial with regard to the interior noise problem. Such noise control measures as the use of thick double-or-triple-glazed windows, lead-impregnated vinyl cloth in the side wall acoustical treatment, and the usual damping treatment tailored to the intensity of the propeller noise on the fuselage should keep the propeller noise within acceptable limits; however, low frequency noise reduction measures require the use of relatively heavy acoustical treatment.

The secondary contributors to interior noise (and the measures to control them) will be the same as those discussed for the 1975 compound helicopter.

In summary, means are believed available to provide interior noise levels within the proposed 85 dBA on all of the intruarban transport concepts if the problem is treated as an integral part of the design-development effort.

2.1.2 SCENARIO DEVELOPMENT

The scenario developed in Phase I has been expanded to include more detailed discussions of the regional peculiarities that influence the travel trends and demand forecasts of the Detroit area.

Factors of significance and unique to the total transportation picture in the TALUS region have been defined, broadening the scenario to include a definition of freeway and highway networks, industrial centers, geographic features, existing airports, etc.

2.1.2.1 Economic Development

The future growth of the Detroit area is discussed in Detroit Edison's research project report:

> Urban Detroit Area Research Project - Doxiadis - Emergence and Growth of an Urban Region, Volume 1: Analysis, 1966, The Detroit Edison Company

Parts of the text that apply to Detroit's mass transportation problem are quoted as follows:

> "The Detroit area lies in the heart of the east north central division which has about 20 percent of the national population, personal income and retail sales. Across the border lies the most densely populated part of Canada, with enormous potential for development. The Detroit area is centrally located within the industrial belt running from New York to the west. It is on the main axis of transportation which follows approximately the same direction, although the center is slightly to the north.
>
> "Briefly, the benefits of its location are:
>
> - Because of its central location within the emerging Great Lakes megalopolis, the Detroit area has a tremendous marketing area for consumer goods. Its similarly advantageous position in the industrial belt provides the Detroit area with an excellent market for semiprocessed materials, parts and finished products.
> - The Detroit area has unusual opportunities for developing into an important center for services with high order functions.
> - It has the characteristics of a gateway for United States-Canadian trade as well as for domestic transportation following the east-west route through Canada. This

advantage will be enhanced when the Canadian section of the Great Lakes megalopolis attains higher levels of economic development.

- Because of its location on the lakes and at the intersection of the east-west transportation axis and the two axes heading south through the Mississippi and Ohio valleys, the Detroit area may become the gateway for international trade of the entire north central region of the United States. This position gives Detroit the opportunity for maximum market penetration at low cost.

" . . . Manufacturing in the Detroit area is concentrated in the production of durable goods rather than the many kinds of consumer products it could provide from its central location in a marketing area containing 35 million people. Moreover, the durable-goods production consists mainly of automobiles and allied products and not many of the semi-finished and intermediate products that would meet the demands of other industries. This somewhat one-sided industrial development is due to historical and accidental factors.

"This reliance and emphasis on a single branch of industry may be responsible for the relative underdevelopment of services. In 1960 services accounted for a smaller percentage of employment in the Detroit area than the national or Great Lakes area average despite the fact the Detroit area is a metropolitan area. In a similar way the Detroit area has not developed fully its potential as a major transportation center.

"Since the 1950's Detroit has been passing through a critical phase in its economic history. Several postwar developments, primarily a trend toward the decentralization of the automobile industry, have weakened the employment potential and caused some migration from the area. However, a trend toward more diversification of industry and more intensive growth in services is already evident."

2.1.2.2 Highway and Public Transportation Networks

In May 1969 the TALUS transportation staff issued a working paper entitled, "Preliminary 1990 Transportation Networks for Alternative Testing Highways - Transit."

The following paragraphs are the summary of this working paper and present the basic transit plans Lockheed used in developing its air transportation system routes and V/STOL commuterport locations.

"The highway and public transportation elements of the TALUS Transportation and Land Use Plan will be designed to accomplish two major puposes; first, to serve the travel demands that will be generated by the land use plan; and secondly to encourage growth and development in accordance with the land use plan. Within the framework of these objectives the purpose of the transportation system must be to provide good transportation, that is, an integrated system of facilities that can provide successfullly for the movement of people and goods with a minimum of delay with total cost a major criterion, though by no means the sole determinant.

"Increasing accessibility widens the choice of residence and work opportunities. For employers, this means enlarging the size of the available labor pool; for the employee, a broadened choice of job opportunities for his skills, because existing and new areas would be brought within reasonable commuting time. Good transportation will increase the mobility of people affording greater opportunities to avail themselves of a wider selection of goods and services. This will increase both the volume and variety of demands for these goods and services.

"Good transportation is safe transportation. By eliminating congestion and reducing conflicts among vehicles, it reduces both the costs of policing traffic and the human and financial costs of traffic accidents. Good transportation must be capable of safely moving a large number of people in a short amount of time.

"The first requirement in order to meet total travel demands within the Detroit Metropolitan Region is an extensive and effective highway system. This requires a complex of freeways, major arterials, and collector and distributor roads. Construction, programming and planning of regional freeways in the Southeast Michigan area is already well advanced. The plans to carry these to completion and supplement the system must be strongly supported. In addition, substantial improvements in the arterial system and especially the major mile roads will be required in future years in order to serve total demands. However, if these freeways and highways are to function successfully terminal facilities such as bus terminal and auto parking facilities must be so located and connected by high capacity feeder streets to the arterial system that traffic flows freely to its final destination.

"An additional requirement in order to provide the degree of mobility necessary to serve a metropolitan region such as this is an extensive public transportation system. The level of public transportation service currently provided in the region is not adequate. Extensive improvement is required.

"The total transportation system should comprise a comprehensive network so combining automobile and transit facilities that each can serve that part of the total demand for which it is best suited. The public transportation system, including its rapid transit component, must be designed and operated as an integral part of the total network and must have adequate capacity and service to meet rush hour demands for commuters and other travelers to urban centers and sub-centers. The regional highway system must have the capacity to serve those transportation demands which require the use of the private automobile . . ."

" . . . The TALUS staff then proceeded to develop two alternative 1990 highway networks for testing purposes.

- <u>1990 Test Highway Network I</u>

  A minimal highway plan which relates closely to existing planned levels of freeway and arterial facilities as determined by local and state highway officials with minor adjustments related to the preliminary 1990 land use plan (Figure 2.1-21).

- <u>1990 Test Highway Network II</u>

  A maximal highway plan which includes most of highway network plan I plus substantial freeway facilities that have been identified in context with the 1990 alternative land use plan (Figure 2.1-21).

"These highway networks will be tested with inputs yielded from the preliminary 1990 land use plan which has been approved for testing purposes by the TALUS Administrative Committee. In connection with each of these highway alternatives is a test transit plan.

"The maps which follow this chapter show the 1975 freeway network, 1990 Test Highway Network I, 1990 Test Highway Network II, and the Rapid Transit portion of 1990 Transit Test Network II.

"In 1965, 410 miles of freeway were complete and open to traffic within the seven-county TALUS region. The additional mileage, which is represented by the 1975 network, is 140.3 miles. Test Network I adds 51.6 miles to the 1975 network. Test Network II adds 128.0 miles beyond the additions in Test Network I.

"Thus, a minimal freeway network to serve the needs of the region by 1990 would include some 601.9 miles of freeway. The maximal mileage required, to serve 1990 needs, would be 729.9 miles.

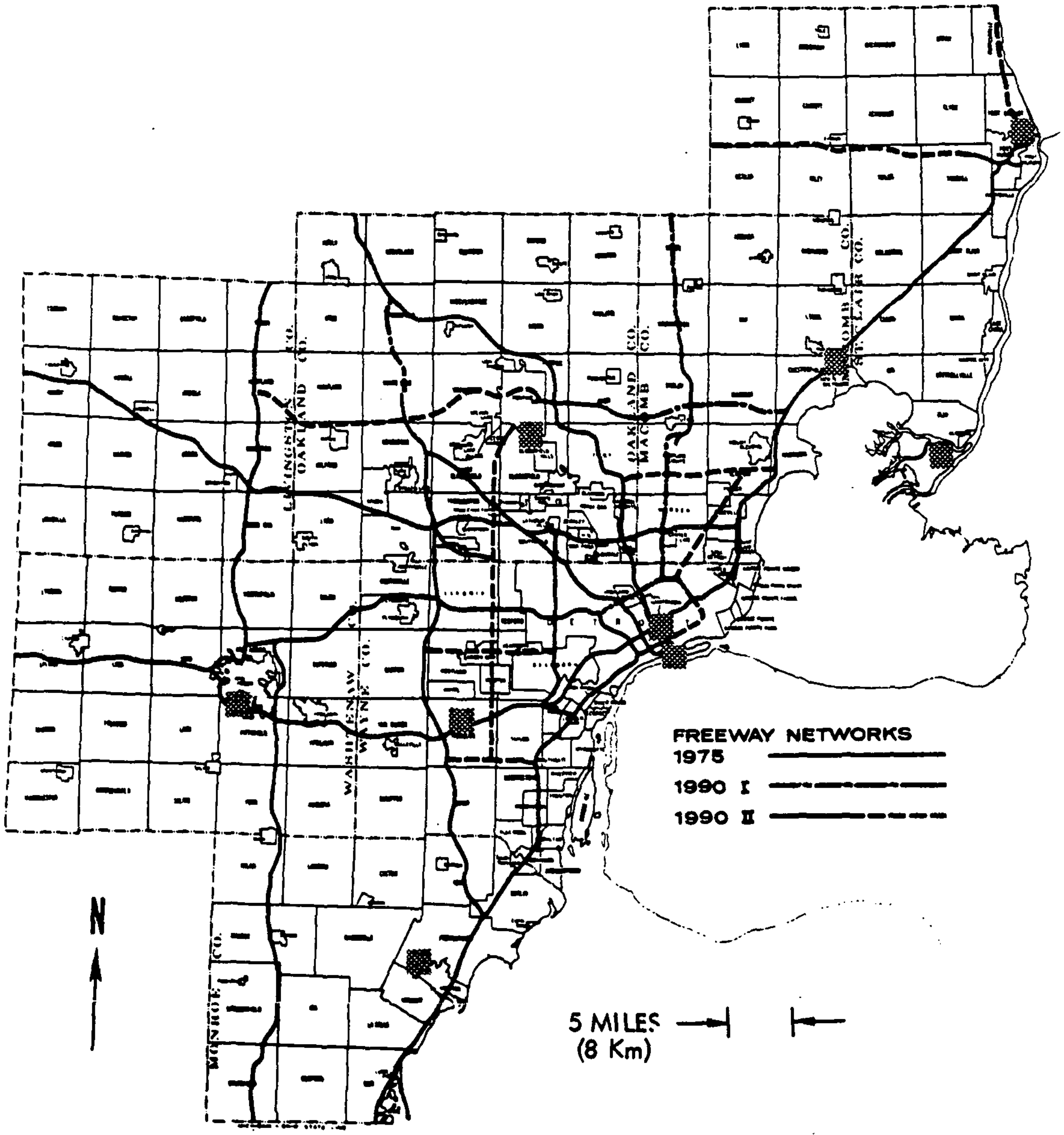


Figure 2.1-21 TALUS - Alternative Test Highway Systems

"TALUS' final recommendations of a highway system to serve 1990 needs will be based on analysis of the vehicular trips assigned to each link in the two alternative 1990 highway systems. This analysis will almost certainly result in the recommendation of a network which lies somewhere between the minimal and maximal networks; with some facilities being deleted, other facilities being shifted somewhat in their location, and the possible addition of some links or facilities not shown on either test network.

"Two alternative 1990 test networks for transit have been developed.

- 1990 Test Transit Network I

  An all bus system characterized by local, express and inter-urban transit routes.

- 1990 Test Transit Network II

  An extensive rapid transit system supported by local bus service and a feeder bus network serving rapid transit stations (Figure 2.1-22)."

"The two transit networks are based on the needs it is assumed will be generated by the preliminary 1990 land use plan which has been approved for testing purposes by the TALUS Administrative Committee. Test Transit Network I, the all bus system, is designed to complement Test Highway Network II, the maximal freeway system; Test Transit Network II, which is based on an extensive rapid transit system, is designed to complement and supplement Test Highway Network I, the minimal freeway network.

"The modeling process and assignment of predicted 1990 travel demands to the two transit networks will provide data for analysis and the development of a third transit network. It is probable that this third transit network will lie somewhere between Test Transit Networks I and II; that is, that it will recommend an extensive bus network for the region and a somewhat less extensive rapid transit network for the region than is contemplated by test network II.

"Test Network I represents an improvement of present-day service levels with substantial extensions of service into additional areas of existing and future urbanization. This network assumes that a single unified system will exist in 1990 allowing for maximum inter-area mobility, integration of systems and scheduling and ease of transfer.

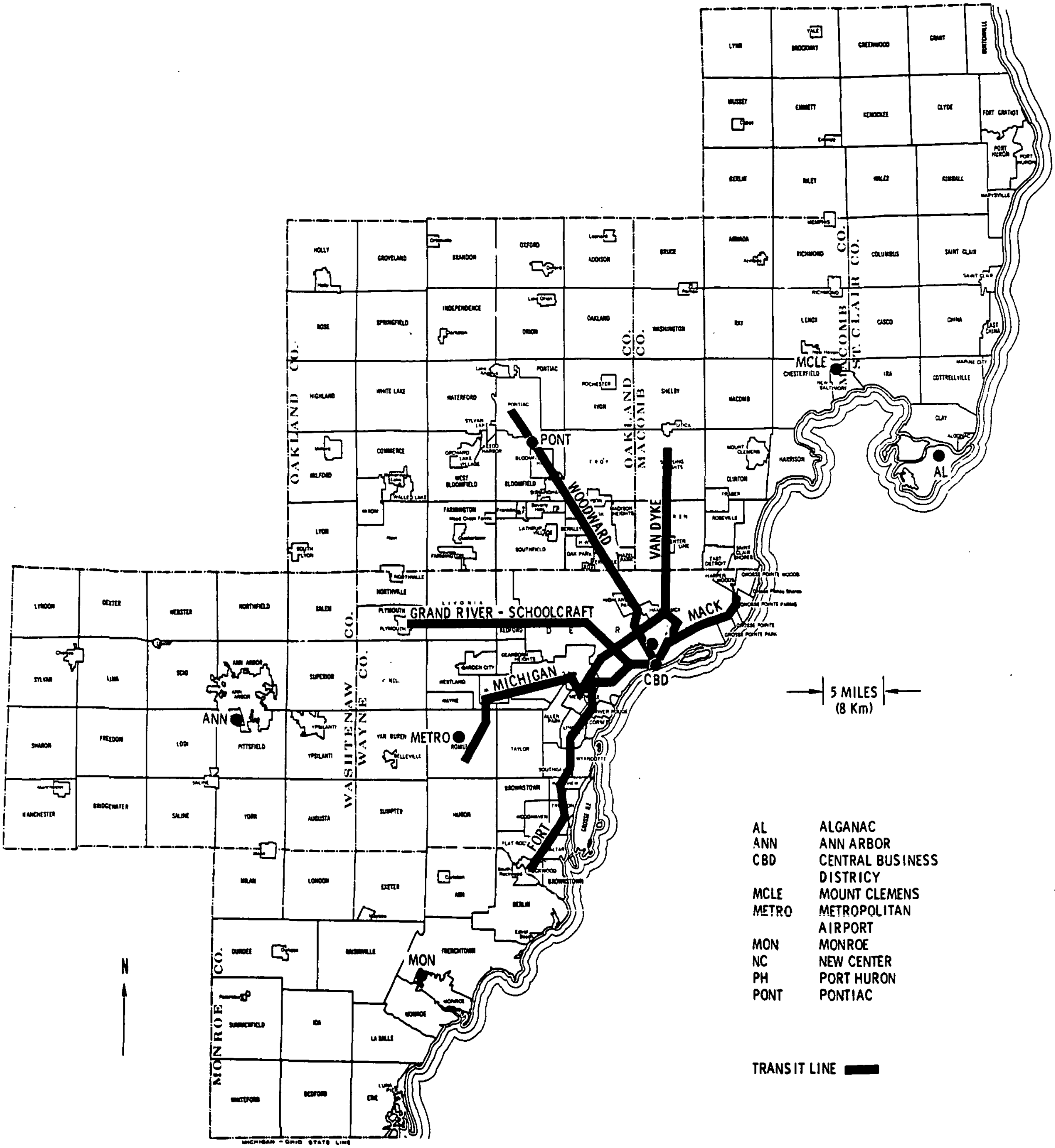


Figure 2.1-22. 1990 Test Rail Rapid Transit System

"Test Network II is characterized primarily by the introduction of an entirely new mode of travel in the Detroit Metropolitan Region. This system is also based on the preliminary 1990 land use plan. Its basic goal is the provision of rapid transit facilities for fast, efficient travel and service to the greatest number of individuals in the region.

"In developing this system, a number of alternative rapid transit corridors were identified and evaluated. Those which were selected for inclusion in Test Transit Plan II are the following:

- Mack Avenue
- Van Dyke
- Woodward Avenue
- Grand River/Schoolcraft
- Michigan Avenue to Detroit Metropolitan Airport
- South Fort Street

"Speeds averaging 40-45 miles an hour with headways of two to ten minutes are assumed for the rapid transit lines. Speeds averaging 10 miles an hour with headways of 10 minutes are assumed for the feeder bus lines and 13 mile an hour speeds with variable headways are assumed for local bus lines.

"A major consideration in making transit location and design decisions must be the level of service provided those people in the population who are largely or completely dependent on public transportation service for mobility. The transit lines and the feeder bus service to these lines are laid out to take into consideration the travel needs of residents of low income, high unemployment and high sub-employment areas; access to areas which provide large numbers of employment opportunities; and access to areas of high levels of activity both currently and in the future as shown on the preliminary 1990 land use plan.

"The feeder bus system is an integral part of the rapid transit system in the inner parts of the region, expanding the potential service area of the transit lines beyond normal walking distance. In the outlying parts of the region, extensive park-ride and kiss-ride facilities would be provided to make the service attractive to trip-makers to whom automobiles are available.

"The bus system in outlying areas would be oriented to the rapid transit system in two ways; providing service along major arterials which would serve to pick up residents of the area destined for the rapid transit system; and providing service between the suburban transit stations and employment centers, both commercial and retail activity centers and places of industrial activity and job opportunities.

"In this manner, the rapid transit system, the feeder bus system and the additional bus service in outlying areas can accomplish several major purposes; providing a high level of transit service as an alternative to the automobile for those suburban residents whose work and shopping places are served by the system; reducing highway travel demands in the center of the region to some extent by the integration of parking facilities with the transit stations so that a portion of the total trip can be made by transit; increasing the mobility of central city residents through the extensive bus feeder and rapid transit system; and increasing the job opportunities of central city residents by providing access to major centers of commercial, retailing and industrial employment in suburban areas through the use of the total system of feeder buses, transit facilities and suburban bus lines.

"Test Transit System I, the all bus system, is based on the following considerations:

- Modification of existing bus service to reflect 1990 land use and transit requirements, using many of the existing line patterns.
- Preservation of service in outlying areas based on 1990 growth patterns and location of activity centers.
- Service in outlying areas with a basic orientation to the various activity centers rather than merely an extension of service of existing routes.
- A system of transit service areas wherein local bus service as well as inter-area express or local service will be developed to serve mass transit needs of the region.

"As outlined above and detailed in the following sections of this report, the highway and transit test systems are designed to provide the data upon which analyses can be conducted to permit the development and further evaluation and testing of a final transportation plan. This balanced plan for highway and transit systems will undoubtedly lie somewhere between the test systems described here.

"Although this report discusses in some detail only the freeway segments of the highway system and the rapid transit portions of the Transit Network, the networks which will be described to the computer and to which travel demands will be assigned include all of the existing major highway and street facilities in the region and the improvements and additions which are anticipated for the planning year; as well as the surface bus systems, both existing and anticipated to be necessary to serve future requirements.

"During the continuing planning process, additional assignments to different combinations of highway and transit networks based on modifications to the preliminary 1990 Land Use Plan will be required to aid in the refinement of the transportation systems and the making of detailed decisions. The transportation planning process is not static. It must be continually responsive to changes in the distribution of people and activities, policy changes relating to the availability of funds for different portions of the transportation system, and to technological change.

"The Preliminary 1990 Land Use Plan will certainly be subject to changes as public hearings are held and the plan is considered for final adoption by the SEMCOG General Assembly.

"These modifications in the plan will affect the output of the Regional Growth Model and thus affect the travel demands generated.

"Legislative changes at the national level relating to the future of the Interstate Highway Program, the degree to which funds will be made available and the highway systems for which these funds can be used, as well as changes in state and local policy will clearly relate to the degree of emphasis which will be possible on different elements of the highway system.

"The United States Congress is currently contemplating the creation of a Transit Trust Fund which would provide significant amounts of money on a 2/3 Federal, 1/3 Local basis for the construction of transit systems. Such legislation would increase substantially the likelihood of TALUS' rapid transit recommendations being implemented. State funds which might also be provided for transit purposes and local governmental policies in this regard will also be major determinants of future system testing.

"The possibility of significant technological development in public transportation systems cannot be ignored. If some of the extensive public and private research currently under way should prove that significant increases in speeds or the development of completely new systems are feasible, additional investigations of these possibilities would have to be conducted through the transportation planning process and the modeling systems."

2.1.2.3 Aviation Facilities

In 1965 there were 45 state-licensed and two military airports in the study area. Since 1950, the number of airports has declined due primarily to urbanization, i.e., the airports were absorbed by urban growth forces for a more demanding land use.

Airports and air activities can be broadly categorized into two general classifications: commercial and general aviation Commercial airports are those that serve or provide scheduled commercial airline traffic, while general aviation is applicable to those fields and activities dealing with business or sport flying by private aircraft. Both types of airports are important in that they provide a definite level of needed service.

From the standpoint of traffic operations and available facilities, i.e., runway length, electronic landing devices, etc., the following are considered to be the major airports in the Study Area:

Detroit Metropolitan Wayne County Airport
Willow Run
Detroit City
Oakland-Pontiac

Others however, such as Mettetal (near Plymouth) and McKinley (Fraser, Macomb County) are extremely important when total general aviation operations are considered.

With the completion of additional terminal and service facilities in 1966; and the transfer of the remaining major scheduled airlines operating from Willow Run, Detroit Metropolitan Wayne County Airport has become the principal airport facility for southeastern Michigan. In 1965, approximately two million passengers enplaned at Detroit.

An analysis of the city pairs between which Detroit passengers travel shows that one traveler in three is going to either Chicago or New York. Seven cities account for over half of all airline passenger trips to and from Detroit: New York, Chicago, Washington, Miami, Los Angeles, Philadelphia, and Boston.

In addition to Detroit Metropolitan, Detroit City Airport located only four miles from downtown Detroit, provides a facility for general aviation (particularly business flying) and for the rapidly growing air-taxi companies that operate aircraft in scheduled service to Cleveland, Columbus, Chicago and other nearby points.

The growth in volume of air cargo has been even more rapid than the growth of passenger traffic. From 1960 to 1965 air cargo volume increased at the rate of 20% per year. Approximately two-thirds of all air carge handled at Detroit is outbound, and the principal commodities include automobile parts and printed matter associated with automobile sales promotion.

Figure 2.1-23 shows the distribution of the 47 airports in the Study Area and Figure 2.1-24 shows the facilities and features at each airport i.e. runway length, control tower, etc.

2.1.2.4 Communterport Design/Operation

The Phase I analysis showed that the commuterport operation contributes a significant portion of the total system cost. The Phase II route-schedule-fleet size analysis showed that the maximum traffic flow at each commuterport could be accomodated with a single loading facility. A conceptual commuterport layout, considering these factors, was therefore developed and is shown in Figure 2.1-25. Commuters pass between the aircraft and the terminal via under ground walkways, using stairs to the surface, as shown, with painted walkways leading to and from the aircraft. This concept should permit unload-load operations within the five minutes allowed in the economic, and route and schedule analyses.

The arrangement assumes a single runway located symmetrically about the loading area. Approximately 5 acres are involved in the runway, loading area, terminal and parking facilities. It is equally applicable to both rotary and fixed wing aircraft and is commensurate with the land allocations of section 2.1.2.9.

Nine operating personal per commuterport were assumed for the cost analysis. However, if a safe reliable operation involving an automatic ticketing arrangement (perhaps on board the aircraft). Coupled with a fenced-off runway - taxiway area could be conceived it might be possible to make a substantial reduction in commuterport operating personnel. Also, it might be possible: to develop a dual purpose installation wherein the terminal facility personnel could perform usefuel non-intraurban transportation system work between intraurban operations.

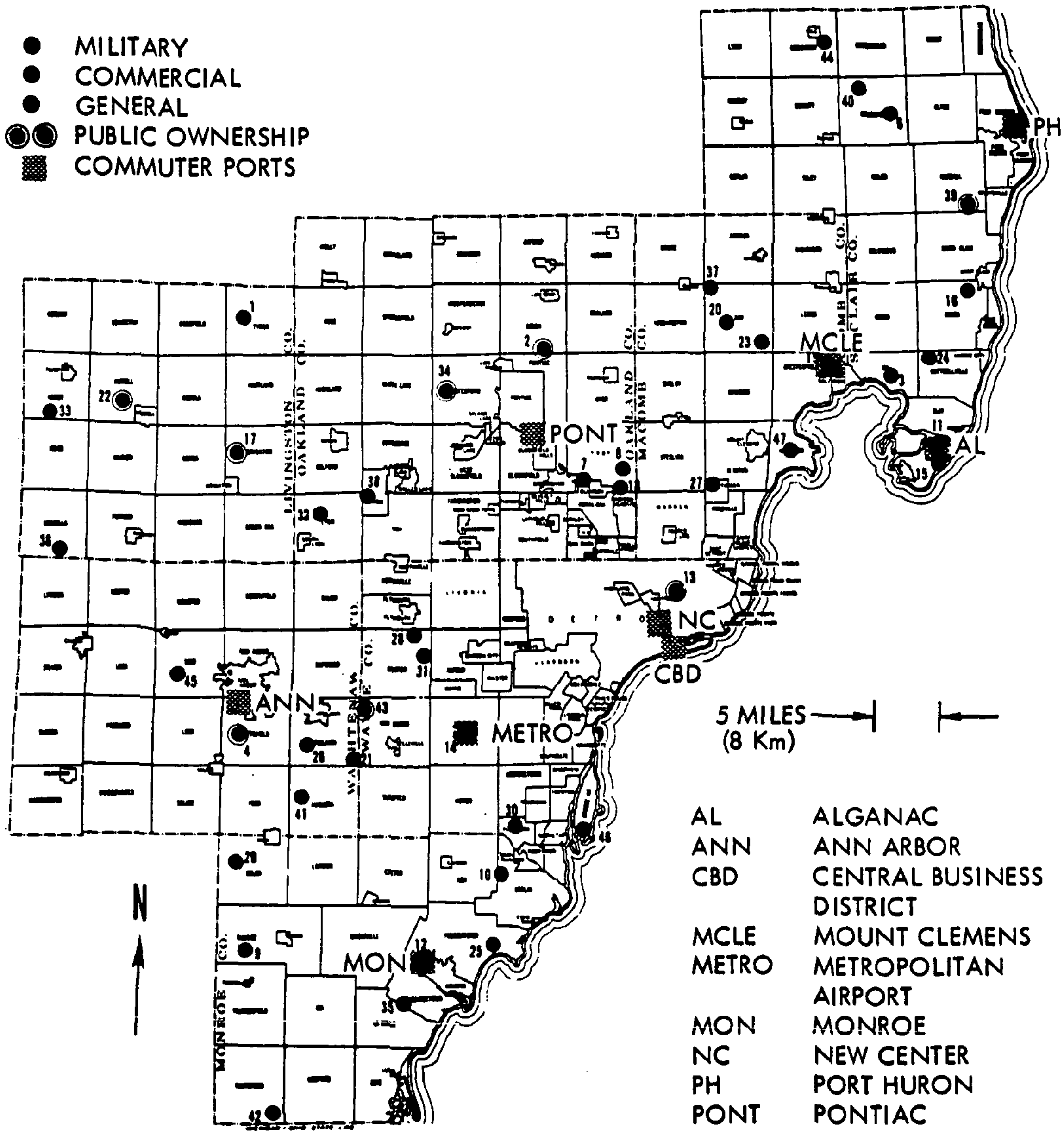
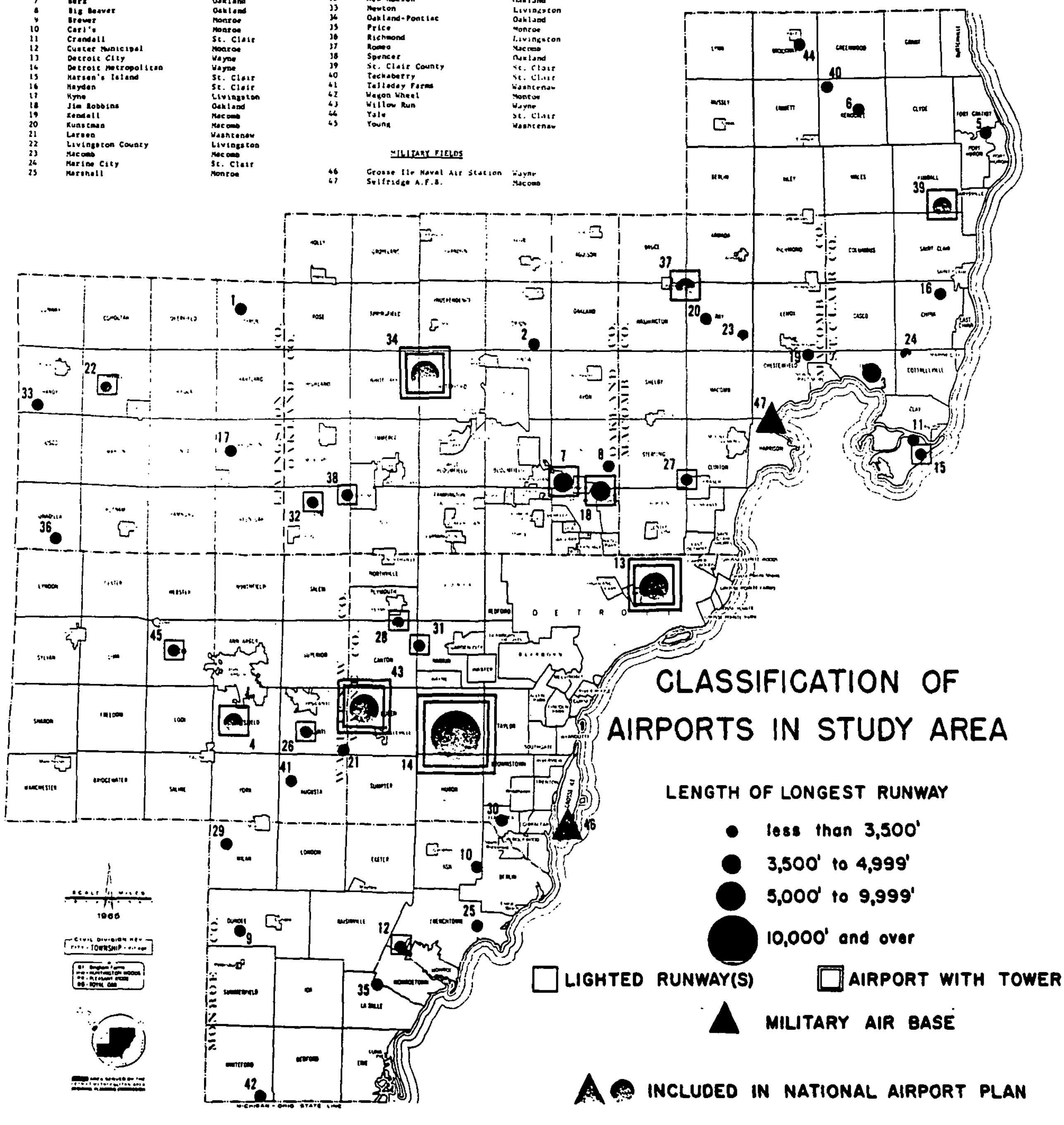


Figure 2.1-23. Airports in Greater Detroit Area

NUMBER	AIRPORT	COUNTY
1	Aero Acres	Livingston
2	Allen	Oakland
3	Anchor Bay	St. Clair
4	Ann Arbor Municipal	Washtenaw
5	Baker's Field	St. Clair
6	Babensee	St. Clair
7	Berz	Oakland
8	Big Beaver	Oakland
9	Brewer	Monroe
10	Carl's	Monroe
11	Crandall	St. Clair
12	Custer Municipal	Monroe
13	Detroit City	Wayne
14	Detroit Metropolitan	Wayne
15	Harsen's Island	St. Clair
16	Hayden	St. Clair
17	Hyne	Livingston
18	Jim Robbins	Oakland
19	Kendall	Macomb
20	Kunstman	Macomb
21	Larsen	Washtenaw
22	Livingston County	Livingston
23	Macomb	Macomb
24	Marine City	St. Clair
25	Marshall	Monroe
26	McEnnan	Washtenaw
27	McKinley	Macomb
28	Mettetal	Wayne
29	Milan	Washtenaw
30	Manber	Wayne
31	National	Wayne
32	New Hudson	Oakland
33	Newton	Livingston
34	Oakland-Pontiac	Oakland
35	Price	Monroe
36	Richmond	Livingston
37	Romeo	Macomb
38	Spencer	Oakland
39	St. Clair County	St. Clair
40	Teckaberry	St. Clair
41	Talladay Farms	Washtenaw
42	Wagon Wheel	Monroe
43	Willow Run	Wayne
44	Yale	St. Clair
45	Young	Washtenaw

MILITARY FIELDS

NUMBER	AIRPORT	COUNTY
46	Grosse Ile Naval Air Station	Wayne
47	Selfridge A.F.B.	Macomb



TALUS

DETROIT REGIONAL TRANSPORTATION AND LAND USE STUDY

THE PREPARATION OF THIS MAP WAS FINANCIALLY AIDED THROUGH A FEDERAL GRANT FROM THE URBAN RENEWAL ADMINISTRATION OF THE DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT UNDER THE URBAN PLANNING ASSISTANCE PROGRAM AUTHORIZED BY SECTION 701 OF THE HOUSING ACT OF 1954, AS AMENDED

TALUS STUDY I-10

PREPARED BY:
WAYNE COUNTY ROAD COMMISSION

FIGURE A-3
JUNE 1967

Figure 2.1-24. Airport Facilities

LOCKHEED CALIFORNIA COMPANY

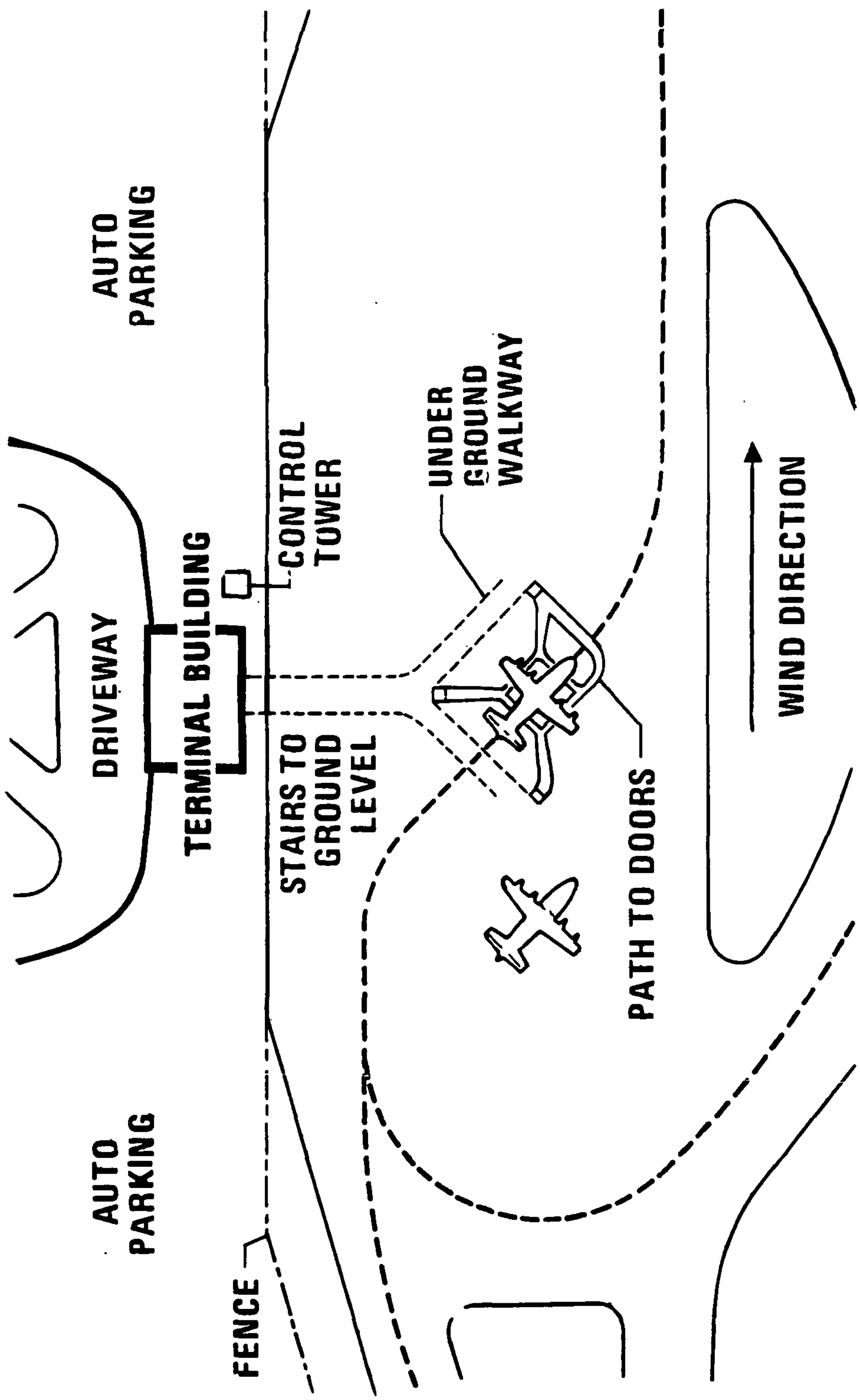


FIGURE 2.1-25. INTRAURBAN COMMUTERPORT TERMINAL AND LOADING AREA

2.1.2.5 Communication, Navigation, and Air Traffic Control

In the conceptual development of the overall traffic control, navigation, and communication network envisioned for intraurban transport operation during the 1975 time frame, extensive utilization of current state-of-the-art technology is employed. Systems currently being used in the L-1011, 747, and DC-10 type aircraft are consistent with the needs of the intraurban transport.

In this 1975 time frame, it is expected that control of the intraurban transport during arrival and departure will be under the direct responsibility of control towers. En route air traffic control for the overall intraurban airways structure will be built upon central contact of all aircraft within the closed system. A central digital data processing computer complex will handle the major share of the day-to-day, long term, flight planning for the total system. Central air traffic controllers, monitoring the overall operation, can handle emergencies such as disabled aircraft, both in the air and on the ground, that might otherwise cause delays and disrupt the smooth flow of the system.

On board each aircraft, precision navigation equipment will provide the basic control and guidance of the individual aircraft and generate the necessary monitoring annunciation to the pilot to aid him in maintaining the aircraft in its "slot" and process any changes in flight plans relayed from the central ground control facility.

A major emphasis must be placed on the inherent problem created by the high traffic densities throughout the route structure. For safety of flight considerations the airspace throughout the intraurban transport routes must be tightly controlled and exclusively reserved for the intraurban aircraft.

Although the intraurban transport route structure, frequency, and tight scheduling, is of specialized nature, the electronics, controls, and procedural standards are advanced to the point where 1975 operation can be expected to function with no major resort to long term development cycles.

In defining these concepts and how they might be integrated into the intraurban operational doctrine, the overall details of the navigation and control concepts for these aircraft are outlined in the following paragraphs.

2.1.2.5.1 Landing, Taxi, and Takeoff Operations

The frequency of operation on a single runway will be limited primarily by the safety criteria selected. Previous studies have shown that the frequency can range from 55 to 166 aircraft landings and takeoffs per hour. Adverse weather conditions should not have a significant influence on these figures, as any control system employed must have a high degree of precision and automation. Collision and hazard avoidance will be ensured by detailed preplanning of the route structure as well as by the inclusion of on-board, self-contained radar and collision avoidance systems, monitored by the central en route ATC board plot, and radar surveillance of the arrival and departure areas of the separate commuterports.

The task of developing individual intraurban transport operational subsystem concepts will be concerned with the following phases of operation:

- Flight planning
- Taxi-out, takeoff
- En route navigation
- Descent, final approach, touchdown
- Rollout, taxi to ramps, turnaround

These operations, of course, influence both the design of the airborne equipment and the design of the associated ground air traffic control and ILS instrumentation.

As a general philosophy, even in the 1975 time frame, the above operations must be carried out with a high degree of automation in both airborne and ground operations. Also, in order to be cost effective, numbers of crews, traffic controllers, and maintenance and terminal operations personnel must be kept minimal consistent with safety regulations and passenger convenience and comfort.

With regard to Weather Minimum Categories (CAT's), current projections indicate that an automatic all-weather landing capability through to CAT III(b) will be available by 1975. By 1985, this will almost certainly have extended through to CAT III(c) (Zero/Zero). These minimums dicate the degree of the instrumentation required both on the ground and in the air.

Table 2.1-7 quantifies the categories for identifying the system requirements. These standards have applied specifically to the CTOL aircraft environment, but will be generally applicable to the intraurban transport operation. Runway visible range (RVR) is, by definition, a horizontal measurement made along the runway. For shallow glide slopes the RVR at the CAT I and II decision heights conforms generally to the actual ground situation. At the steeper glide slopes used by the intraurban type transport, this RVR definition will not be quite so meaningful to the pilot. However, a CAT II(b) requirement for the intraurban transport appears to be absolutely mandatory if satisfactory day-by-day schedules are to be maintained throughout the year.

TABLE 2.1-7 - ICAO STANDARDS FOR WEATHER MINIMUMS AS APPLIED TO INTRAURBAN TRANSPORT OPERATIONS

CAT	RVR (ft)	Decision Ht (ft)	
I	2,400	200	
II-A	1,600	150	
II-B	1,200	100	Current aircraft minimums
III-A	700	See to rollout	
III-B	150	See to taxi - 1975 time period	
III-C	0	Zero/Zero - 1985 time period	

With a CAT III-b capability in the 1975 period, the 150 ft RVR limitation means that the intraurban transport pilot, after touchdown with his auto-land system, will be able to see the first rows of taxi lights which outline the runway boundaries. Taxiing can then be accomplished visually even though at a slow speed. To speed up this taxi process and thus maintain the scheduled turnaround times, the runways and taxiways will have high intensity centerline lighting systems with appropriate identifying symbols at the taxiway exits and ramp locations. A television camera located at the nose wheel of the aircraft could facilitate effective steering control.

The ground instrumentation most suitable for control and automatic landing at the 1975 intraurban commuterport would include a microwave scanning beam ILS system. The standards of operation will be along the lines of the current RTCA (Special Committee 117) recommendations. Figure 2.1-26 illustrates two concepts that could be applicable to the intraurban transport. These systems provide for fully automatic touchdown, broad coverage in both azimuth and elevation, relative freedom from beam bending (which makes them effective even in heavily populated and built-up areas), and utilization with cruved approach and variable glide paths. These features make these systems particularly desirable for intraurban transport operations.

En route Airport Surveillance Radar (ASR) information will be made available for hand-off to control tower personnel. The combination of separate curvilinear approach and departure paths and ASR further enhances collision and hazard avoidance capability, particularly where tall buildings may lie within the commuterport area. **Figure 2.1-27 illustrates this capability.** Wide angular coverage permits acquisition by aircraft well separated in altitude, position, and touchdown time. Obvious advantages in terms of collision and hazard avoidance are apparent in the two views shown. Acquisitions at time t_1 has the aircraft widely separated in position and altitude. Programmed curvilinear paths result in the separation on final approach shown at time t_2.

For the purpose of maintaining high frequency of flight schedules in arrivals and departures, especially during the peak hours (corresponding to the surface "rush hour" periods), flight separation and altitude standards must be rigorously maintained. Since this impacts on tne total intraurban network, rather than on a station-to-station basis, keeping track of and maintaining the steady flow of traffic will be the function of a central intraurban Air Traffic Control Center. Here, by use of air-to-ground data

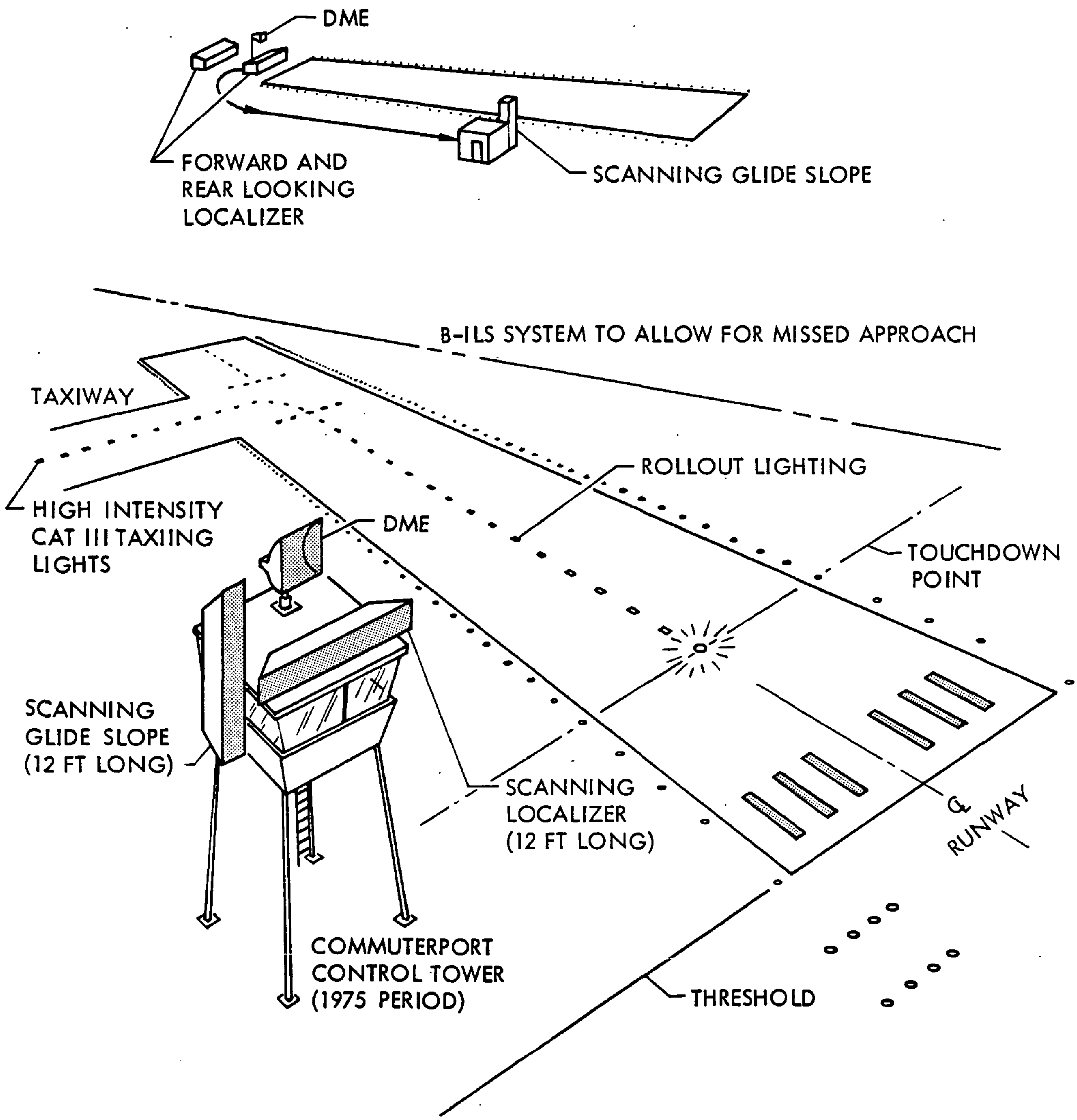


FIGURE 2.1-26. TYPICAL ARRANGEMENTS FOR MICROWAVE ILS SYSTEM

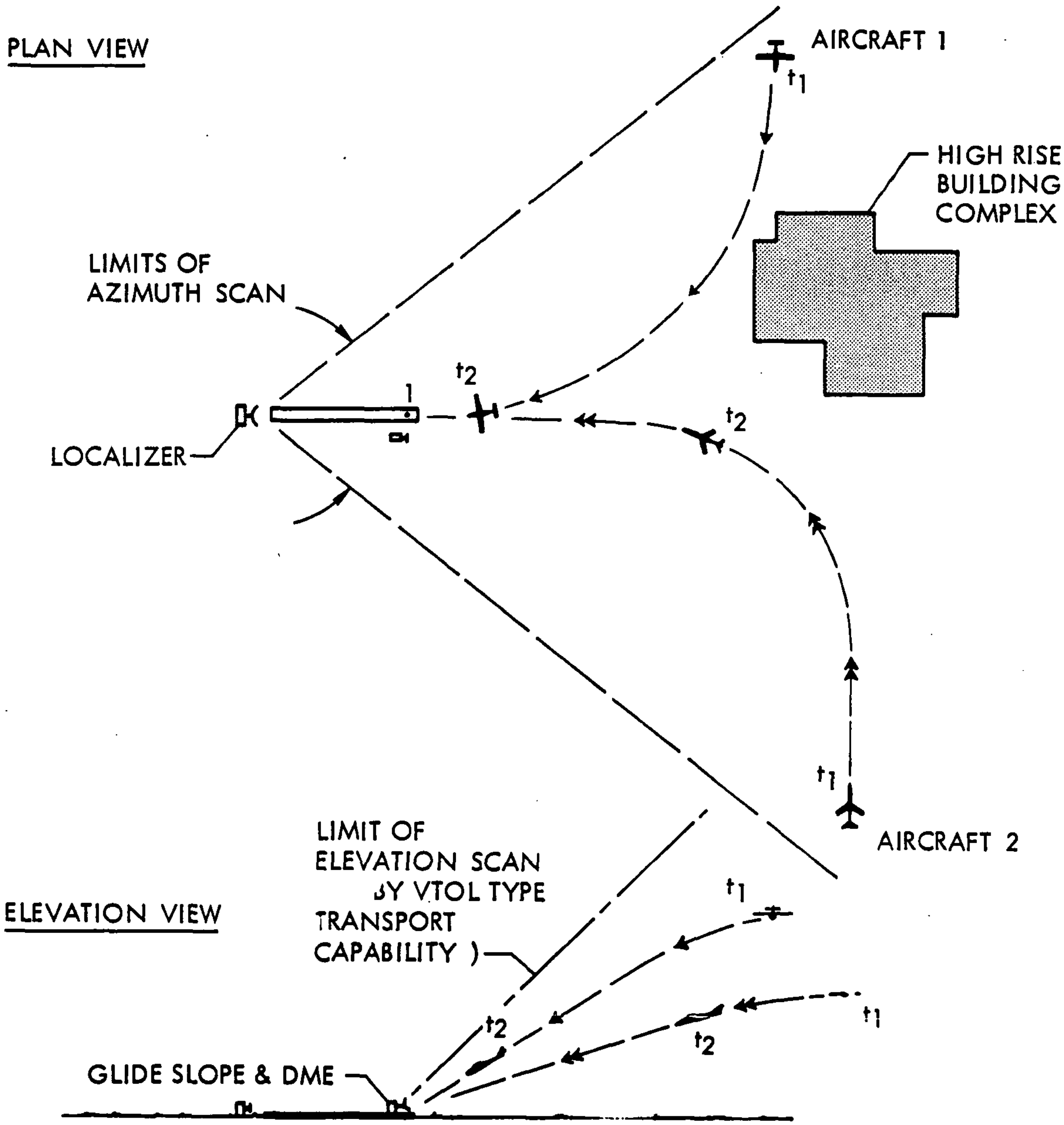


FIGURE 2.1-27. CURVED APPROACH PATHS AND EQUIPMENT LOCATION FOR MICROWAVE ILS

link, surveillance radar, secondary radar, and a cooperative Collision Avoidance System, a ground control digital data processor/computer will track all aircraft in the network and display their tracks on a Traffic Management Display Console.

Intruders would be quickly noted and warning and avoidance instructions could be fed to the affected aircraft. **Figure 2.1-28 depicts a** typical arrangement concept for the 1975 time frame. For the 1985 time frame, the data link system would have to be able essentially to "fly" each aircraft automatically, throughout the route structure and institute landing and takeoff procedures via satellite controls at the terminal areas.

2.1.2.5.2 Navigation Collision Avoidance and Separation Standards

Airborne navigation equipment, as previously defined in the Lockheed Phase I report includes precision area navigation systems, data link, microwave ILS receiver, weather radar, collision avoidance, and other appropriate systems. The basic area navigation (R-Nav) system concept will utilize received signals from existing, as well as supplemental, VOR/DME stations, in conjunction with a computer and stable platform to provide position data. The area navigation feature is obtained through the computer by "moving" the VOR/DME station(s) to points intermediate along the flight path. This gives the crew continuous bearing and distance information in terms of the new "location" of the VOR/DME. Separation of parallel tracks is thus easily obtained. Use of area navigation allows the most flexible routing for the fleet without constraint upon VOR radial tracking and/or high crew workload. Thus, an instant capability would be available for fast route changes extending routing and ferry flights, weather and hazard avoidance. Routes may be coordinated within the intraurban transport structure as well as for flights outside the local system. Standard VHF/UHF ILS receivers/couplers will be included to allow conventional approaches whenever necessary at alternate airports.

Data link exchange with ground terminal sources, including the main Air Traffic Control Center described previously, will allow four-dimensional guidance and monitoring to be maintained consistent with the strategic control plan. Use of an inertial platform, while not considered absolutely necessary

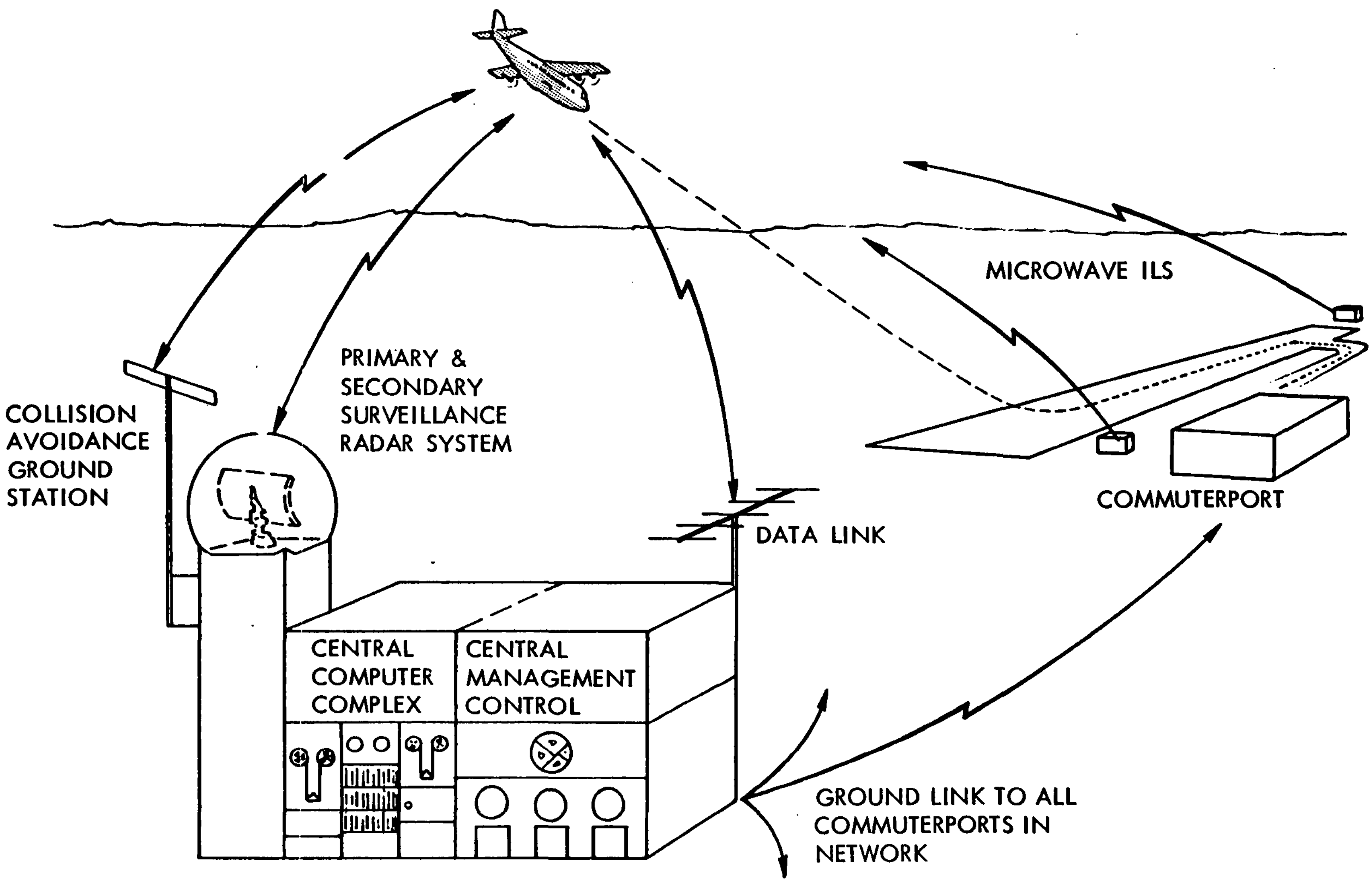


FIGURE 2.1-28. INTRAURBAN TRANSPORT TRAFFIC CONTROL SYSTEM

for navigation and guidance purposes alone, would however be desirable as an aid in effective flight path control during final approach when used in conjunction with the automatic flight control system. Pilot confidence during Category III approaches would also be greatly enhanced by use of a self-contained landing monitor radar system and display. This landing radar would also be of significant value in collision and hazard avoidance with other aircraft or buildings.

The precision demanded of a Category III landing within the intraurban transport system will, of necessity, preclude the pilot from being actively involved in the control loop. Essentially automated flight control is envisioned from takeoff to touchdown. The pilot and copilot will act primarily as vehicle system monitors with the capability to intervene and override the operation of automatic systems in the event of impending or actual malfunction. (The automatic flight control is also discussed in Section 2.1.1.7.)

In navigating between takeoff and landing points with the short separations dictated by the high frequency of service demands, it can be seen that the desired 30-second spacing in cruise flight amounts to about 12 000 feet separation. An on-board collision avoidance system would be mechanized so that other similarly equipped aircraft could never get closer than 6000 feet without an avoidance maneuver being commanded (climb or dive). Aircraft which might have inadvertently drifted into the intraurban system traffic lanes and altitudes must be assumed to be lost or illegally present in this air space. By 1975, legislative standards for the control of airspace will almost certainly have to be adopted to cover this aspect of intraurban transport operations. These intruders would generally be detected by the en route ground radar surveillance system, by visual observation (in VFR situation), and by on-board radar if utilized. High intensity collision lights would be installed on all aircraft in the system.

The on-board R-Nav system, which might also include a moving map display or readout would present not only its own aircraft track but encompass (via its data link/collision avoidance system) those aircraft within a 10-mile radius. This would enable the pilot to adjust his spacing in cases where other aircraft might be experiencing difficulty in maintaining airspeed.

2.1.2.5.3 General Avionic Systems, Communications and Supporting Subsystems

Table 2.1-8 lists those items of avionics that will most likely be used in the intraurban transport of the 1975 time frame. The standard communication equipment listed will be provided as detailed in the Lockheed Phase I report. Air-to-ground voice contact will be primarily used to verify hand-off from departure area to en route and then to arrival area in the 1975 system. It could also be used to report emergency situations, such as equipment failure, on-board mishaps or illness. This complete 1975 system could be compatible with use on VTOL and STOL type aircraft which could utilize up to a 45° maximum glide slope approach.

To bring the 1975 system to full fruition, a complete listing of hardware and software must be properly defined and specified. The several vehicle types under consideration for the intraurban transport have approach and departure characteristic differences that will influence the coordination of guidance system accuracy, precision of command links with the ground environment, and traffic control safety criteria. After these vehicle characteristics have been delineated, the optimization of the avionic equipment and the detailed route structure planning can begin.

Production of the hardware for 1975 is essentially current state-of-the-art; and integration of the hardware, software, and the human operators (ground and airborne) represents the major challenge for immediate development. Figure 2.1-29 presents a block diagram of the aircraft avionic system for the 1975 intraurban aircraft.

2.1.2.5.4 Development Into the 1985 Time Frame

The 1985 intraurban system envisions an even more tightly integrated structure for overall intraurban transport operations. This will take the form of improved computation and data exchange capability and will allow the single centralized Air Traffic Control Center to service the entire extended area. Extension to Category III-c (zero-zero) weather conditions would almost certainly be implemented. Overall equipment weights may lighten somewhat due to advancing technology and increased integration, but this may be offset by the need for utilization of additional functions.

TABLE 2.1-8. AVIONICS WEIGHT SUMMARY*

System	1975		
	Weight per System (lb)	Number of Systems	Total Weight (lb)
VHF Communications	17.5	2	35
Passenger Address	90	1	90
Interphone	20	1	20
Selcal System and Data Link Receivers	10	1	10
Voice Recorder	20	1	20
Flight Data Recorder	25	1	25
Air Traffic Control Transponder	20	2	40
VOR/LOC/Glide Slope (ILS) for use at CTOL ports	20	2	40
Precision Landing Aid (Microwave ILS)	15	2	30
Distance Measuring Equipment (DME) Dual Frequency	40	2	40
Marker Beacon	3	1	3
Independent Landing Monitor Radar	150	1	150
Radar Altimeter	20	2	40
Weather Radar and Display (Multipurpose)	55	1 (2 Ind)	55
Collision Avoidance System	90	1	90
Area Navigation System**	65	1	65
Attitude and Heading Reference System	25	2	50
Air Data System	40	1	40
Flight Director	25	2	50
Instrument Monitoring System	5	1	5

	1975	1985
Subtotal	898	600
Installation	300	275
Total Installed Weight	1,198	875

* Does not include FCS/AFCS

** Computer, Data Storage, Control and Display

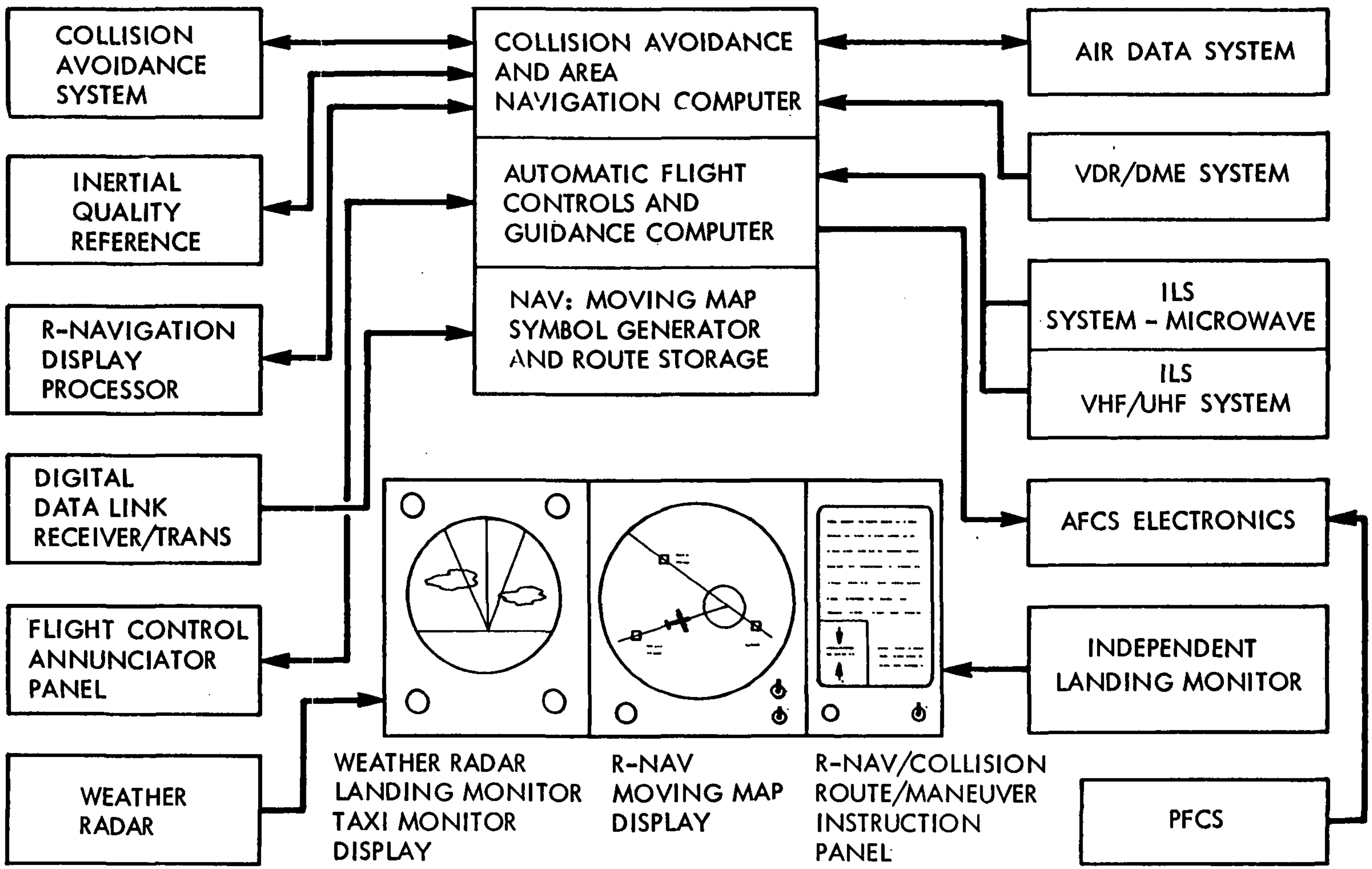


Figure 2.1-29. Central Computer Complex

The areas in which this enhanced and increased automation are most apparent would be in the terminal commuterports. While the basic ILS approach as defined above will be the same, the landing and takeoff scheduled times will be remotely controlled by signals from the Main Air Traffic Control Center. A degree of latitude should be allowed for at the ramp to take into account passenger imponderables and mishaps, but takeoff times will be rigidly controlled. Any minor delay would be made up en route by speed command via the central computer.

The pilot's job will then be that of supervisor of the airborne system part of the overall system. Any deviation in flight paths and schedules would be noted by the ground computer and the pilot would get instructions from the ground control. Failure of the aircraft system to maintain the schedule (due to malfunctions) would require that the aircraft land at a directed point in the network or at another commuterport possibly selected by the pilot. The computer control would readjust speeds, courses, and altitudes to bring the remaining aircraft back into the normal schedule of operations. Likewise, as traffic density demands diminish, as during off-peak loads, aircraft could be redirected or taken out of the system.

Since operation will be required down to CAT III-c, automatic taxiing to the ramp will be mandatory. This could be achieved by buried cable for induction-coil servo guidance control of the nose-wheel steering machanism.

The equipment needs for both the airborne and ground stations will still be quite similar to the 1975 baseline concepts described previously. Since the 1975 system already possesses the capability of automatically landing the aircraft in a hands-off operation, the major differences will be in the area of remote control of the separate terminal operations.

This, however, will add significantly to the software mechanization at the Central Computer. It will also require an order of magnitude increase in system redundancy to avoid temporary havoc upon catastrophic failure of the central traffic control system due to such factors as power failures, lightning, earthquakes, etc. Of course, the pilot will always have the option of complete reversion to manual or semiautomatic control modes, and can operate to any airport under normal navigational procedures.

2.1.2.5.5 Summary of Technological and Economic Factors

In summarizing the impact that the intraurban transport would have upon the basic state-of-the-art in airborne and ground-based facilities and operations, it may be stated that the approaches described previously require no major development efforts to arrive at a viable system for the 1975 time frame. Most of the subsystems concepts utilize existing technology while the specialized needs for the interface of computer/hardware systems would be met by systems design practice.

With regard to economic factors of costs and real estate acquisition requirements, it has been the intent to consider those system concepts that impose a minimum burden on the local airport planning and management agencies. This has been achieved by the heavy utilization of a single, central control and management system approach minimizing major systems complexities at the local intraurban terminal areas.

2.1.2.5.6 Automatic Flight Control System

The systems described above are based on use of an automatic flight control system (AFCS). General characteristics of the system are discussed below.

Operating AFCS Modes - Many of the AFCS modes will be identical to those currently used in conventional jet airline equipment. These mode titles include: Stability Augmentation, Altitude Select and Hold, and AutoNav. Somewhat novel, but state-of-the-art for 1975, are modes such as Auto Throttle (ETA control using navigation data), Auto Land (automatic capture of microwave ILS and path and letdown guidance). Possible system modes and functions for the various phases of flight are listed below.

Stability Augmentation	Improves handling qualities
Control Wheel Steering	Provides uniform vehicle response to pilot input
Altitude Hold and Select	Maintains desired radio or barometric altitude and allows selection of another altitude and climb rate

AutoNav	Maintains ground track as specified by selected navigation source
IAS Hold	Maintains airspeed through conventional surfaces
Auto Throttle	Controls ground speed through navigation inputs for schedule and collision avoidance control
Auto Land	Controls the aircraft by airport referenced inputs: curvilinear approach guidance, letdown, flare and rollout

Design for the modes listed will have to include transition blending of vehicle response characteristics, especially in the takeoff and landing modes.

One of the primary considerations in the design of an automatic flight control system is safety and functional reliability. This is particularly important for the intraurban transport which must make Category III landings. For adequate safety the reliability must be very high. For example, a measure of reliability for an automatic landing system which is currently considered satisfactory in some circles is one landing failure in 10^7 landings. Since it is not possible to design hardware which will experience no more than one failure in 10^7 landings, the system must consequently be designed to permit one or more failures without causing a significant degradation in system performance. This is achieved through redundancy.

The optimum redundancy level is that which achieves the desired reliability at minimum cost. In the design of the automatic flight control system, the redundancy level for each of the several modes of operation is normally selected by means of a trade-off study in which various redundancy models are compared on the basis of reliability and cost.

The redundancy configuration selected for 1975 must be compatible with the following:

- In the automatic landing mode, the system should be fail-operative for the first failure and fail-safe for the second failure.
- After two failures in the normal automatic landing mode, the system should still be fail-operative for a conventional (shallow approach angle) mode of landing.

The above requirements are based upon the belief that after two AFCS failures in an automatic IUT landing, the pilot would elect to revert back to the "conventional" mode of approach and divert to Detroit Metropolitan Airport.

For 1975 period, the use of four instrument landing receivers is assumed. Two will be microwave ILS type, and two will be conventional ILS. In-line monitored, fail-safe ILS receivers are currently available for use with existing ILS systems. These same techniques can be applied to the new microwave ILS receivers. A pair of in-line monitored receivers make a fail-operative combination since any failure in one receiver will cause it to be disconnected while the second receiver continues to function.

To meet the stated requirements, it is necessary that those portions of the AFCS which are used for both automatic landing and automatic cruise operation be quadruplex. This portion of the system would include common sensing and computation equipment and actuators for the aerodynamic controls which are used for all phases of flight.

The redundancy configuration for 1985 must be compatible with the following: in the automatic landing mode, the system should be fail-operative for the first and second failure.

By 1985, the use of microwave ILS will be expanded to include conventional airline operations, and the need for two present day ILS receivers will be gone. One microwave ILS receiver will replace the conventional receivers. The degree of reliability necessary for operation is still maintained. Also, by 1985, means for automatic taxi guidance should exist, and these can be coupled into nose wheel steering actuators for fully automatic Category III-C operations.

Impact of Microelectronics on AFCS Design - The usage of microelectronics in flight controls is quite a recent development, but the interest in this application is growing at a tremendous rate. The projected use indicates that for an AFCS to be operational in 1975 as much as 80% of the electronic functions will be using microcircuits, in one of the various forms, distinguished from discrete components. This prediction is based on the present "analog" type of AFCS. If a digital autopilot has been developed by 1975, the percent usage of microelectronics could be as high at 95%.

It is likely that the equipment/systems will contain microelectronics in more than one of its forms; i.e., monolithic, hybrid, chip or hybrid film circuitry. In general, all digital functions will be accomplished with monolithic (off-the-shelf) circuits and some type of custom Medium-Scale Integration (MSI). The linear functions will be accomplished by monolithic operational amplifiers and custom chip and hybrid film functional elements in addition to a few necessary discrete components.

The reasons why future AFCS will demand the extensive use of microelectronic elements are fairly obvious and can be listed:

- Decreased size and weight
- Increased system reliability
- Lower power drain/less heat rejection
- More effective maintainability
- New system design concepts possible
- Lower purchase costs
- Lower system development costs
- Simplified logistics
- Simplified inventory
- Improved availability
- Improved system effectiveness
- Lower maintenance costs

Many of these factors are interrelated and interdependent. For instance, increased system reliability and more effective maintainability tend to lower maintenance costs, simplify logistics, simplify inventory and ultimately improve availability and system effectiveness.

The important point to note is that microelectronics is not simply to reduce size and weight of the AFCS, but allows the use of whole new avenues of design in terms of redundancy, complex adaptive control, multiplexing, digital control, etc.

Analog vs Digital Mechanization - It is clear from the above discussion on modes and redundancy that the IUT AFCS will be quite complex by today's standards. The level of redundancy required is higher than any currently in operation. Also the combination of flight path control requirements, along with load alleviation, requires additional modes, signal paths and actuators. System complexity makes the digital computer a strong contender for this application since it is generally agreed that while the analog approach is better for simple systems, digital is better for complex. It is difficult to judge where the crossover point occurs without further design refinement.

Several criteria can be used for comparison of the analog and digital approaches. Consider the following:

- Accuracy
- Flexibility
- Cost of ownership
- Reliability

With regard to accuracy it is generally agreed that the digital computer can be made more accurate than the analog. Achieving analog accuracies better than 1% is difficult, but an order of magnitude improvement can be achieved with a digital approach. However, the accuracy of the analog system may be adequate for this application. The absence of drift in the digital computer makes unnecessary the cross-channel balancing which is required in redundant analog systems, especially where series integration is used.

Flexibility is an important feature during the development phases of a flight control system since a number of changes are normally found to be unnecessary as a result of flight test or field experience. The variable-increment digital computer shows a clear advantage in this area since the program can be changed by modifying the plug in programmer board, regardless of the magnitude of the change. Large-magnitude changes in an analog computer might require a complete redesign.

Total cost of ownership depends not only on initial cost but on the cost of maintaining the system during its life. Regarding the initial cost, the digital system is likely to be less expensive primarily because it will be less complex. Cost of maintenance depends on reliability and ease of repair. At this time there is no firm basis for assigning a reliability advantage to either system, except on the basis of parts count. Both systems would make extensive use of microcircuitry and be completely solid state. The analog system would be easier to repair.

It is predicted that if the choice between analog and digital were made purely on the basis of the criteria listed above, the digital computer would be chosen. It is likely, however, that additional factors will be considered in arriving at a choice. One is the fact that the analog system is easier to understand, on an intuitive basis, and flight crews typically feel more comfortable using a system they can understand. Also, analog is the traditional form of mechanization for aircraft automatic flight control systems, and the human natural reluctance to change may delay the introduction of the digital approach until it represents an overwhelming cost effectiveness advantage.

2.1.3 ECONOMIC ANALYSIS

The Phase I effort established the cost elements and the cost estimating relationships for these elements and combined them into computer models for the determination of Direct Operating Cost (DOC), Indirect Operating Cost (IOC), and Total System Cost (TSC). These models are displayed in Volume II, paragraphs 1.2.1.3 and 1.3.1.2. The models are used in the development of the parametric data, and in the system synthesis and selection. The results are found in Volume I.

The cost analysis effort in Phase II is devoted primarily to a more detailed examination of the systems operational parameters and cost factors, and a final evaluation of the vehicles selected in Phase I. The results of the examination of these items are reported in the area of cost where they are used. For instance, the maintenance analysis is reported under DOC cost and the analysis for the personnel for the commuterports is included under IOC. The major items that were examined for their effect on cost are:

- Engineering
- Flight Test
- Maintenance
- Airport land ratio
- Number of system personnel
- Number of work shifts
- Parking area required
- Airport field length for helicopters
- Runway capacity
- Fueling time
- Publicity

A few of the changes resulting from the Phase II effort are direct changes to the cost estimating relationships in the various models, and others are input changes. The input changes are tabulated in Table 2.1-9.

These refinements on costs are noted by comparing the costs resulting from these changes with the costs reported in Phase I. The comparison is based on the same ground rules that were used in Phase I so that the effect

TABLE 2.1-9

INPUT DATA CHANGES

DATA	SYMBOL	UNITS	PHASE I VALUE	PHASE II VALUE
Number of Shifts Worked	SHFT	-	3	2
Airport Land to Runway Ratio	RLAND	-	3	15
Traffic Servicing Personnel	PERST	-	6	4
Fueling Personnel	PERSF	-	2	1
Dispatch & Comm. Personnel	PERSD	-	2	0
Annual Pay for System Personnel	PAY	$/yr	10,000	13,500
Publicity Cost Factor	PCF	$/Pass	.50	.25
Helicopter Field Length	RUN	ft	150	600

of the changes may be noted. The effect of the changes is compiled for all of the cost elements under Total System Cost in paragraph 2.1.3.4.

2.1.3.1 Aircraft Development Cost

The engineering hours for development of the airframe for the aircraft in the Intraurban Transportation Systems Study are projected by the use of an estimating relationship that was developed by the RAND Corporation (see page 146 of LR 23820-6, Volume 2). This device has been used extensively in parametric data analysis of many types and has provided reasonable results.

The estimating relationship estimates the total engineering hours for development, with the exception of the flight test hours for which there is a separate equation. The independent variables in the engineering hour estimating relationship are maximum design speed and total maximum thrust. These variables were changed significantly for each concept. The interrelationships between thrust, weight, and field length are shown in Table 2.1-10. These airplanes, in the deflected slipstream family were chosen because they were the closest in size to the Lockheed Electra and represented the entire range of thrust-to-weight ratios. Since design speed is constant for all cases, the variation in cost is caused by the variation in maximum thrust. Thrust is used as the unit for the parameter because the eshp is converted to thrust in the ASSET program. The same conversion constant is used for all of the turboprop eshp's to thrust. As noted by the comparison of engineering hours in Table 2.1-10, the hours calculated by the estimating relationship are in agreement with the actual hours for the Electra. None of the deflected slipstream aircraft may be directly compared to the Electra because of the size difference, as measured in empty weight and thrust-to-weight ratios. The No. (2) deflected slipstream has approximately the same thrust-to-weight ratio as the Electra, but is only 65% as large as the Electra in terms of weight empty. Ratioing the actual engineering hours of the Electra by the empty weights would give an estimate of 2 800 000 hours for the No. (2) deflected slipstream, whereas the calculated estimate is approximately 13% less than this. This is considered reasonable because of the differences in design requirements between the Electra and the Intraurban aircraft. The intraurban aircraft does not require a pressurized cabin, does not require a

TABLE 2.1-10

ENGINEERING HOURS COMPARISON

DEFLECTED SLIPSTREAM	FIELD LENGTH	T/W	GW	WE	T/ENG	TOTAL THRUST	MAX SPEED	NO. OF PASS	R&D HOURS (CALC)	R&D HOURS (ACTUAL)
(1)	1000 Ft	.74	69,290	43,000	12,813	65.252	345	100	4,520,000	-
(2)	1500 Ft	.52	62,626	37,566	8,217	32,868	345	100	2,470,000	-
(3)	2000 Ft	.36	58,697	34,000	5,352	21,408	345	100	1,725,000	-
(4)	2500 Ft	.23	56,346	32,000	3,238	12,952	345	100	1,090,000	-
Electra		.27	116,000	57,300	13,500	54,000	400	98	4,150,000	4,280,000

galley, and the cabin furnishings are austere. The landing gear is fixed, and the aerodynamic design is straightforward and simple. These factors would tend to reduce the hours for design and ground test.

The No. (1) airplane is smaller than the Electra, in terms of weight empty, but requires more engineering hours because of the higher T/W ratio. The effect of the T/W ratio on cost is shown by examination of the information on Table 2.1-10.

The estimate of the flight test cost is dependent upon the gross weight and maximum speed of the airplane and the number of airplanes assigned to the flight test program. The cost of the flight test program for the intraurban aircraft is determined on the basis of six aircraft in the flight test program. The flight test costs, as determined by the equation in LR 23820-6, Volume 2, are shown in Table 2.1-11. The Electra actuals are given in hours then converted to dollars using the same engineering rate as is used in the design engineering cost.

The comparison indicates that the calculated flight test cost for the Electra is lower than the actuals by 43%. Since the flight test is calculated in dollars rather than hours, the estimate is affected by inflation. The flight test equation was derived from data that is several years old and needs to be adjusted for inflation. The amount of inflation varies by year with the latter years approaching 6%. Modifying the equation by the year of the data base produces an inflation factor of 1.32. Applying the inflation factor to the calculated flight test cost brings the cost to that shown in the last column of Table 2.1-11. The application of the inflation factor brings the calculated flight test cost for the Electra more in line with the actual.

The intraurban aircraft adjusted flight test cost appears reasonable in comparison with that of the Electra. The intraurban aircraft are smaller and less complicated because of the fixed gear and the unpressurized cabin. The intraurban aircraft flight test costs are higher than those of the Electra if size is considered as the scaling factor for computing the relative cost. Moreover, they are proportionately higher because there were six intraurban aircraft assigned to the flight test program whereas there

TABLE 2.1-11

FLIGHT TEST COST COMPARISON

DEFLECTED SLIPSTREAM		T/W	GW	WE	ESHP/ ENGINE	MAX SPEED	NO. OF PASS	CALC FLIGHT TEST COST	ACTUAL	ADJUSTED CALC COST
(1)	1000 Ft	.74	69,290	43,000	3,600	345	100	6,350,000	-	8,400,000
(2)	1500 Ft	.52	62,626	37,566	2,280	345	100	5,820,000	-	7,700,000
(3)	2000 Ft	.36	58,697	34,000	1,490	345	100	5,500,000	-	7,250,000
(4)	2500 Ft	.23	56,346	32,000	900	345	100	5,300,000	-	7,000,000
Electra		.27	116,000	57,300	3,750	400	98	6,300,000	9,000,000	8,300,000

were four Electras. The flight test cost equation is adjusted for inflation for the final economic evaluation of the intraurban aircraft. The adjustment increases the development cost slightly, but the overall effect on the DOC is insignificant.

2.1.3.2 Production Costs

The basic aircraft configurations studied during Phase I and II are listed in Table 2.1-12 and 2.1-13 along with the technology levels assumed and a brief description of their important design features. Several features that are common to all configurations and that have a bearing on the purchase and operating cost are listed below:

- Unpressurized cabin
- Fixed landing gear
- Austere passenger accommodations
- No galley
- No cabin crew

The Phase I activity for estimating the production cost of the aircraft involved the establishment of basic ground rules, development of appropriate cost factors for labor and material, modifying existing computer programs, and establishment of the flyaway cost for the Phase I configurations. The basic ground rules for the airframe cost analysis are:

- These estimates are for engineering analysis purposes only, and no price quotes are implied or intended
- Estimates are in constant 1970 dollars
- An 80% learning curve is used for production labor
- A 95% learning curve is used for materials
- Basic production quantity is assumed to be 300 aircraft
- Composite material for the 1985 technology is assumed to be graphite, and its material cost is estimated at $50 per lb.

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TABLE 2.1-12. PHASE I BASIC AIRCRAFT FEATURES

	CTOL	Augmentor Wing	Deflected Slipstream	Tilt Wing	Compound Helicopter	Autogyro
1975 TECHNOLOGY						
Wing	Hi		Hi	Hi	Hi	
No. of Engines	4		4	4	3	
Engine Location	Pods below wing		Slipper type wing pods	Slipper type wing pods	(2) Below wing (1) Main trans cowling	
Engine Type	Turboprop		Turboprop	Turboprop	Turboprop with rotor powered takeoff	
Advanced Materials	None		None	None	None	
Special Features	Hi lift leading and trailing edge devices		Cross shafting Propeller	Cross shafting Propeller	Cross shafting Main rotor Tail rotor Main transmission	
1985 TECHNOLOGY						
Wing	Low	Hi	Same as 1975	Same as 1975	Same as 1975	Hi
No. of Engines	4	4	Same as 1975	Same as 1975	Same as 1975	4
Engine Location	Top of wing	Pods below wing	Same as 1975	Same as 1975	Same as 1975	Below wing pods
Engine Type	Turbofans	Turbofans	Same as 1975	Same as 1975	Turbofans	Turbofans
Advanced Materials	Composites	Composites	Composites	Composites	Composites	Composites
Special Features	Same as 1975	Spanwise wing ducting for engine bleed air boundary layer control Horizontal stabilizer as for wing	Same as 1975	Same as 1975	Tip nozzle driven main rotor Cross ducting No main transmission	Pneumatic main rotor acceleration drive Cross ducting No main transmission

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TABLE 2.1-13. PHASE II BASIC AIRCRAFT FEATURES

	Deflected Slipstream	Compound Helicopter	Autogyro
	1975 TECHNOLOGY		
Wing	Hi	Low	
No. of Engines	4	4	
Engine Location	Slipper type wing pods	Top of wing	
Engine Type	Turboprop	Turbofan with rotor power takeoff	
Advanced Materials	None	None	
Special Features	Cross shafting	Cross shafting	
	Propeller	Mechanical main transmission	
		Shrouded fan in tail fin	
	1985 TECHNOLOGY		
Wing	Same as 1975	Same as 1975	Low
No. of Engines	Same as 1975	Same as 1975	4
Engine Location	Same as 1975	Same as 1975	Top of wing
Engine Type	Same as 1975	Same as 1975	Fanjets
Advanced Materials	Composites	Composites	Composites
Special Features	Same as 1975	Tip nozzle driven main rotor	Standard rotor blades
		Cross ducting	Pneumatic drive motors for rotor spinup
		Small shrouded fan in tail fin	No main transmission
		No main transmission	

The flyaway costs for the Phase I aircraft are shown in Volume 2 in Tables 1.3-3 and 1.3-6. The flyaway cost information for the Phase II airplanes is tabulated in Tables 2.1-14 through 2.1-17. The flyaway costs shown in these tables are based on a production quantity of 300 for the 60 passenger configuration only. For costs at other production quantities Figure 2.1-30 is provided. For a detailed breakdown of the airframe cost, at the 300 production quantity Tables A2.1-3 through A2.1-10 of the Appendix (Volume 4) are provided.

2.1.3.2.1 Airframe Production Cost

The airframe cost includes all structure and functional systems as well as the installation of engines and avionics, but not the initial cost of these two items. The cost elements included in the production airframe cost are described below.

- Production Labor - This is all labor expended directly for fabrication, assembly, and installation by production groups and organizations. All labor cost includes appropriate direct labor, overhead and general and administrative costs (G & A).
- Quality Assurance Labor - This includes all hours expended for the various inspection and quality assurance functions. A factor of 20% of production labor hours is used.
- Material - Raw materials, purchased parts, major equipment, and subcontracted tiems are included.
- Sustaining Engineering - Costs for maintaining drawings and data, support to production and other organizations, product improvement, and other necessary engineering functions are sustaining engineering costs.
- Sustaining tooling - Cost of tooling changes, and the removal and replacement of worn tooling are sustaining tooling costs.
- Technical Data - Technical orders and manuals, handbooks of instructions, flight and maintenance manuals, vendor handbooks, spares provisioning and certain other data and drawings constitute technical data costs.

TABLE 2.1-14. SUMMARY COMPARISON - 40 PASSENGER CONFIGURATION

40 Passenger Configuration	Deflected Slipstream		Compound Helicopter		Autogyro
Technology Level	1975	1985	1975	1985	1985
Gross Takeoff Weight (lb)	32,158	28,065	40,716	26,539	26,231
Weight Empty (lb)	22,272	18,414	27,589	14,814	14,396
Number of Engines	4	4	4	4	4
Thrust per Engine (lb)	2,970	2,594	3,412	2,880	3,550
Development Cost ($-M)	129.6	144.1	131.8	107.2	120.2
Development Cost/AC ($-M)	0.432	0.480	0.439	0.357	0.401
Production Cost ($-M)					
Airframe	1.222	1.578	1.887	1.492	1.425
Engines	0.244	0.285	0.334	0.288	0.308
Avionics	0.350	0.350	0.350	0.350	0.350
Total Flyaway Cost ($-M)	1.816	2.213	2.571	2.130	2.083
Total Flyaway Cost (incl. Dev.)	2.248	2.693	3.010	2.487	2.484

TABLE 2.1-15. SUMMARY COMPARISON - 60 PASSENGER CONFIGURATION

60 Passenger Configuration	Deflected Slipstream		Compound Helicopter		Autogyro
Technology Level	1975	1985	1975	1985	1985
Gross Takeoff Weight (lb)	42,204	36,969	56,519	36,278	35,929
Weight Empty (lb)	27,951	23,018	36,517	19,611	18,978
Number of Engines	4	4	4	4	4
Thrust per Engine (lb)	3,902	3,417	4,525	3,900	4,875
Development Cost ($-M)	149.1	165.4	160.0	132.8	152.0
Development Cost/AC ($-M)	0.497	0.551	0.533	0.443	0.507
Production Cost ($-M)					
Airframe	1.518	1.971	2.460	1.949	1.853
Engines	0.276	0.324	0.404	0.372	0.428
Avionics	0.350	0.350	0.350	0.350	0.350
Total Flyaway Cost ($-M)	2.144	2.645	3.214	2.671	2.631
Total Flyaway Cost (Incl. Dev.)	2.641	3.196	3.747	3.114	3.138

TABLE 2.1-16. SUMMARY COMPARISON - 80 PASSENGER CONFIGURATION

80 Passenger Configuration	Deflected Slipstream		Compound Helicopter		Autogyro
Technology Level	1975	1985	1975	1985	1985
Gross Takeoff Weight (lb)	52,082	45,721	72,332	46,473	46,814
Weight Empty (lb)	33,473	27,480	45,748	24,544	24,556
Number of Engines	4	4	4	4	4
Thrust per Engine (lb)	4,815	4,227	5,650	4,850	6,430
Development Cost ($-M)	166.7	184.7	190.8	155.9	185.1
Development Cost/AC ($-M)	0.556	0.616	0.636	0.520	0.617
Production Cost ($-M)					
Airframe	1.806	2.363	3.040	2.420	2.407
Engines	0.305	0.357	0.510	0.436	0.564
Avionics	0.350	0.350	0.350	0.350	0.350
Total Flyaway Cost ($-M)	2.461	3.070	3.900	3.206	3.321
Total Flyaway Cost (Incl. Dev.)	3.017	3.686	4.536	3.726	3.938

TABLE 2.1-17. SUMMARY COMPARISON - 100 PASSENGER CONFIGURATION

100 Passenger Configuration	Deflected Slipstream		Compound Helicopter		Autogyro
Technology Level	1975	1985	1975	1985	1985
Gross Takeoff Weight (lb)	62,290	54,684	--	--	58,585
Weight Empty (lb)	39,306	32,139	--	--	30,984
Number of Engines	4	4	-	-	4
Thrust per Engine (lb)	5,759	5,056	--	--	8,150
Development Cost (R-M)	184.0	203.4	--	--	221.9
Development Cost/AC ($-M)	0.613	0.678	--	--	0.740
Production Cost ($-M)					
Airframe	2.110	2.782	--	--	2.971
Engines	0.331	0.388	--	--	0.676
Avionics	0.350	0.350	--	--	0.350
Total Flyaway Cost ($-M)	2.791	3.520	--	--	3.997
Total Flyaway Cost (incl. Dev.)	3.404	4.198	--	--	4.737

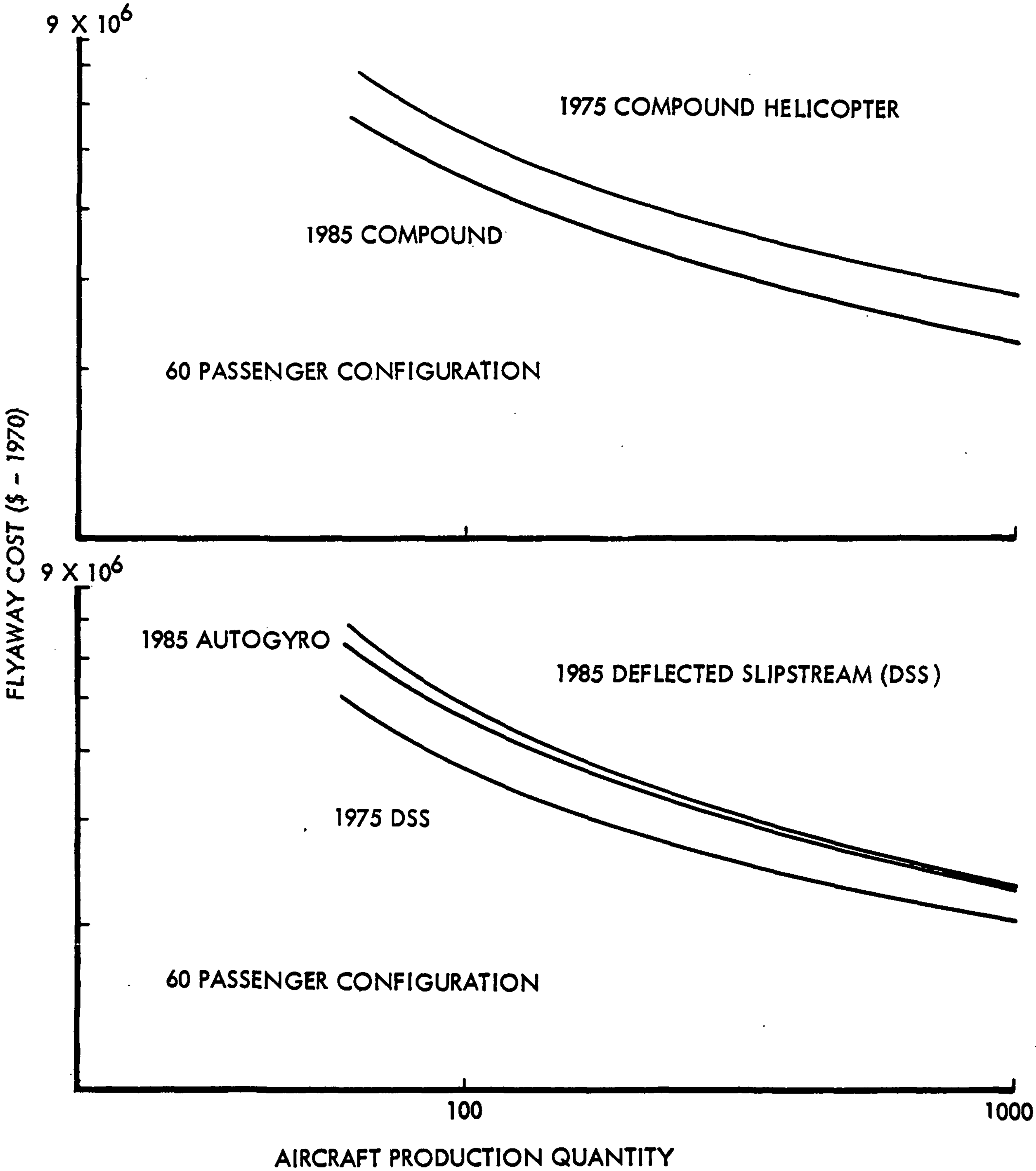


FIGURE 2.1.30. AIRCRAFT FLYAWAY COST VERSUS QUANTITY

- Miscellaneous - Costs associated with production that are not included in any of the other flyaway cost elements are miscellaneous costs.
- Engineering Change Orders (ECO's) - Costs for changes and modifications are ECO costs.
- Warranty - A warranty factor of 5% was applied to all of the above cost elements.
- Profit - A profit factor of 12% was applied to all of the above cost elements.

Basic statistical cost factors were developed in terms of production manhours and material dollars per pound of empty weight for the 1975 conventional takeoff and landing (CTOL), propeller powered configuration. This formed the basis for extrapolation of data representative of the other configurations. Major design differences were analyzed and their cost impact included in the baseline cost factors. The basic cost factors are assumed for a 30 000 pound empty weight vehicle at the 100th cumulative average cost.

The labor hours and material dollars are summed, and a cost sizing factor is applied to the totals to adjust for increases and decreases from the basic 30 000 pound baseline. An analysis of historical aircraft manufacturing costs indicates that as aircraft empty weight increases, the cost per pound decreases. The cost per pound increase approximates a straight line on log-log graph paper, similar to a cost/quantity plot except that dollars are plotted against weights. For this study, it is assumed that typical slopes for aluminum aircraft of 96% for labor and 99% for material can be applied against the total labor and materials.

Straight line, logarithmic, cumulative average learning curves are then applied to arrive at appropriate cost for a given quantity. The basic production quantity for all of these configurations was assumed to be 300 aircraft. The other elements of flyaway costs are then calculated and summed to arrive at the total airframe flyaway cost.

Data for establishing basic cost factors were obtained from such Lockheed military aircraft as the F-104, P-3, C-130, C-141, C-5a, AH-56A, and S-3A as well as commercial aircraft, including the Electra and the L-1011. Extrapolations were made from basic data when required to provide cost data consistent with the overall requirements.

Graphite was selected as the composite material for use in these cost studies. There is practically no agreement within the aircraft and related industries as to either the current or the future price of composites.

Near term projections range from as high as $400 per pound to as low as $26 per pound, while projections for the 1975-80 time period range from $50 to $1 per pound.

The yearly usage plays an important part in determining the cost, and projections of usage vary as much as the price estimates. For purposes of this study, a cost of $50 per pound of graphite was used, based on a production rate of 10 000 to 20 000 pounds per month, although it is recognized that this price may vary with the usage on a specific aircraft as well as usage on other programs. Due to the uncertainty of price projections for graphite composites, it was decided that a variation in the price to correspond with usage was not warranted; therefore, $50 per pound was used throughout the study.

Costs in terms of hours and material dollars per pound were based on a study conducted for another program in the preliminary design phase. An analysis of structural component applications for items such as skins, stringers, formers, and ribs was conducted for each structural weight group (wing, tail, body, etc). Consideration as to whether these components could be layed up by machine, rather than by hand was part of the study. Basic aluminum costs for fabrication, labor and material costs were developed. Appropriate complexity factors for fabrication of components with graphite were developed based on the manufacturing operations involved for each specific component. These complexity factors were multiplied by the basic aluminum costs and were applied against the estimated weights of the components. Summation of costs for both aluminum and composites provided an adjustment factor for the fabrication labor and material costs.

2.1.3.2.2 Propulsion Production Cost

The engine production cost is determined by modified estimating relationships developed by the RAND Corporation (RM-4670-PR, July 1965, and RM-6384/1-PR, September 1970). These equations (turboprop and turbojet/turbofan) were modified to reflect the cost of commercial engines rather than military. These equations are provided in Volume 2, paragraph 1.2.1.3.2.

2.1.3.2.3 Avionics Production Cost

The avionics package is a category II system and is the same for all aircraft in terms of capability and cost. The total procurement cost is $350 000 per aircraft. This does not include the installation cost, which is included under airframe cost.

2.1.3.3 Operations Cost

The operations costs include both DOC and IOC. The elements and cost estimating relationships are given in Volume 2, paragraphs 1.2.1.3 and 1.3.1.2.

2.1.3.3.1 Direct Operations Cost (DOC)

The Phase I analysis shows that maintenance is the largest item of cost in DOC, and is the most promising from the standpoint of cost reduction. The maintenance model is re-examined to determine whether it is producing realistic costs. The justification is based on a maintenance cost comparison between the Fairchild Hiller F-27 and the deflected slipstream intraurban aircraft. The major contributors to maintenance cost are also examined for possible cost reduction. Because a detailed examination is not possible within the scope of this study, such examinations were made in a parametric manner.

The maintenance cost for the fixed and rotary wing aircraft is determined by a number of estimating relationships that are presented in Volume 2, paragraph 1.2.1.3. These relationships are established in terms of labor and material dollars as well as by flight cycle and flight hour. An example of the maintenance cost breakdown is shown in Table 2.1-18. These costs are for the 60-passenger deflected slipstream aircraft operating from a 1500-foot runway.

A gross comparison of the major design parameters reveals that the Deflected Slipstream - 1975 design is similar to the Fairchild Hiller F-27. These characteristics are reflected in Table 2.1-19.

The maintenance cost information contained in Table 2.1-18 was used to determine the maintenance cost per flight hour in terms of flight time per stage length, and compared with the F-27 maintenance cost. This comparison is reflected in Figure 2.1.31. The average flight time per flight for the F-27 is 0.63 hours and its reported maintenance cost is $61.70 per flight hour. This is slightly above the curve generated for the Deflected Slipstream airplane.

TABLE 2.1-18. MAINTENANCE COST

	MAINTENANCE COST					
	DOLLARS PER FLIGHT CYCLE	PERCENT	DOLLARS PER FLIGHT HOUR	PERCENT	TOTAL COST IN DOLLARS	PERCENT
MATERIALS	21.190	49.211	3.334	7.743	24.524	56.953
LABOR	15.235	35.381	3.301	7.666	18.536	43.047
TOTALS					43.060	100.000
MATERIALS MAKE-UP						
EQUIPMENT AND FURNISHINGS	1.453	6.859	0.045	1.357		
LANDING GEAR	2.326	10.978				
TIRES AND BRAKES	3.359	15.851				
OTHER SYSTEMS	1.508	7.118	0.484	14.531		
STRUCTURE	1.544	7.288				
OTHER POWER PLANTS	3.161	14.917	0.641	19.231		
PROPELLERS	0.517	2.439	0.100	2.995		
GEAR AND SHAFTING	0.669	3.159	0.028	0.845		
ENGINES - TURBOJETS	0.0	0.0	0.0	0.0		
ENGINES - TURBOPROPS	6.652	31.392	2.035	61.041		
TOTAL MATERIALS COST	21.190	100.000	3.334	100.000	24.524	56.953
LABOR MAKE-UP						
EQUIPMENT AND FURNISHINGS	1.472	9.659	0.221	6.696		
LANDING GEAR	1.824	11.971				
TIRES AND BRAKES						
OTHER SYSTEMS	1.175	7.715	0.568	17.202		
STRUCTURE	2.659	17.453				
OTHER POWER PLANTS	0.882	5.787	0.341	10.321		
PROPELLERS	2.009	13.189	0.518	15.682		
GEAR AND SHAFTING	0.842	5.526				
ENGINES - TURBOJETS	0.0	0.0	0.0	0.0		
ENGINES - TURBOPROPS	4.372	28.699	1.654	50.098		
TOTAL LABOR COST	15.235	100.000	3.301	100.000	18.536	43.047
TOTAL MAINTENANCE COST	36.425	84.592	6.635	15.408	43.060	100.000

TABLE 2.1-19 DESIGN COMPARISON

PARAMETER	DEFLECTED SLIPSTREAM STOL-75	FAIRCHILD HILLER F-27
Empty Weight	26,516	29,300
Max. Gross Weight	42,566	45,500
Length	82	83
Wing Area	709	754
Shaft Horsepower (total)	6,200	4,600
No. of Engines	4	2
Passengers	60	48

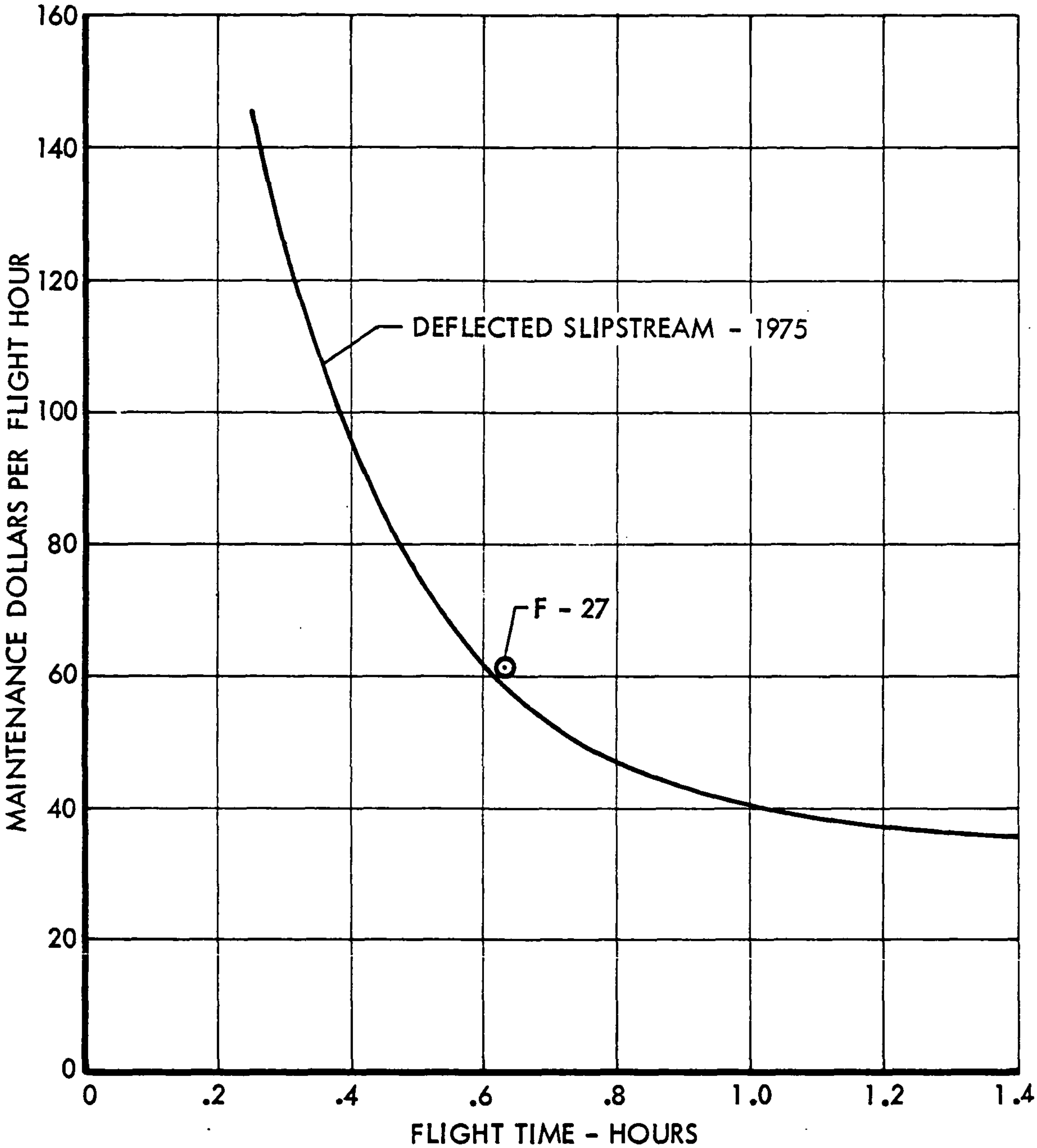


FIGURE 2.1-31. MAINTENANCE COST VS FLIGHT TIME

Examination of the data in Table 2.1-18 indicates that the tires, brakes, landing gear, and engines comprise a large part of the total maintenance cost. The table offers opportunity for design-for-maintenance philosophy. The appearance of the landing gear is not so important as the ruggedness. The drag imposed on the aircraft by the fixed gear is not important for the short stage lengths used in the Detroit scenario, and therefore the gear can be fixed and rugged so as to reduce maintenance. Beefing up the landing gear would impose a weight and cost penalty on the airplane, but this would, no doubt, be offset by the decrease in maintenance cost. For instance, if one-half the maintenance cost on the landing gear, tires, and brakes could be saved by a beef-up, even if it doubled the purchase cost of these items, the total savings in two years would be more than the additional purchase cost. This rough analysis does not include the effects the beefed-up landing gear would have on the other structure of the airplane but even so, the savings over the 12-year operational period would more than offset the cost of the indirect effects.

A reduction in maintenance cost is also possible by operating with derated engines or using an engine that has more structural material for the same thrust rating. That is, accepting a lower thrust-to-weight ratio for the sake of lower maintenance. Using a heavier engine would compromise the airplane performance, but at these short ranges it would not be significant. A reduction in fuel load does not have a major impact on the economics of the system, whereas maintenance does. A preliminary analysis indicates that a saving of $92 000 per airplane could be obtained for the 12-year period if a 20% increase in engine weight (costing $15 800 per engine) is added to strengthen the high maintenance items assuming a 10% savings in maintenance cost is realized.

The net result in DOC would be an increase of $6700 per year in depreciation and a $40 430 decrease in maintenance for an overall DOC saving of $33 230 per airplane per year.

It is perhaps questionable that doubling the cost of the gear would result in reducing the maintenance cost by one-half. Therefore the assumption is changed to a 20% saving. This would result in a saving of

$15 000 per year, or practically paying off the additional cost of $52 000 for beefing up the landing gear in the first two years of operation. The summary of the analysis with various assumptions as to the percent saving in maintenance cost is presented in Table 2.1-20.

2.1.3.3.2 Indirect Operating Cost (IOC)

The personnel for the operation of the commuterports and the fueling of the aircraft is the predominate cost in the indirect operating cost (IOC). A more detailed examination of the personnel functions during the critical time of loading and unloading is carried out to determine the number of personnel at the commuterports.

The personnel requirements are established on the basis of the five-minute turnaround and the number of flights arriving or leaving during the peak periods of the day. The number of flights vary with the commuter-port location as well as time of day; therefore, each terminal is analyzed separately. The number of personnel is determined by the maximum number of flights per three-hour peak period for each commuterport.

The Phase II analysis includes an evaluation where an operation schedule is met rather than where the schedule is a fallout of the demand and the minimum load criteria. The scheduled operation creates flights with very few passengers as well as fully loaded flights, which imposes a work load consistent with the passenger demand.

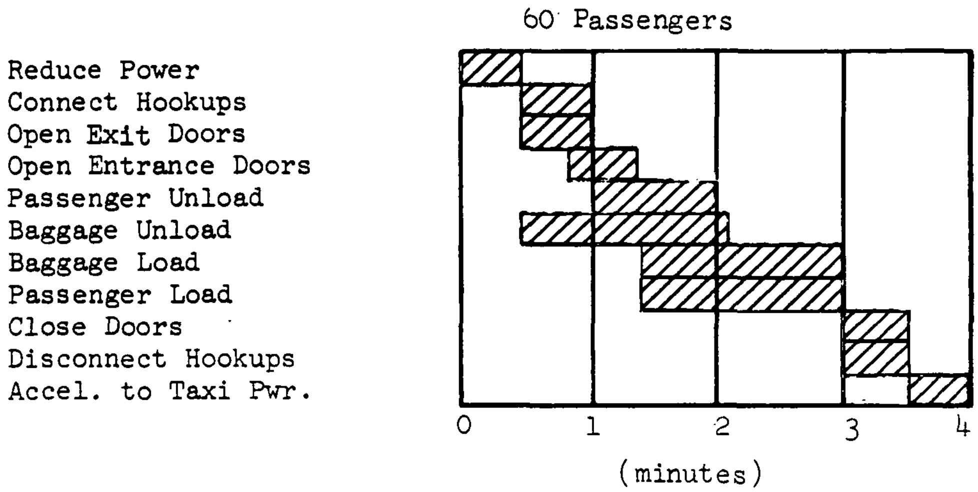
The high demand peaks are from six to nine o'clock in the morning and from three to six in the afternoon. There are no passengers from midnight to six in the morning. This leaves 18 hours when passenger service is required. The passenger demand distribution creates an uneven work load and causes difficulty in maintaining efficiency if three 8-hour shifts are employed. If the 18 hour period is divided into two 9-hour shifts, the number of people may be reduced and the complication of split shifts is avoided. The first shift works from six in the morning to three in the afternoon, and handles 55% of the demand. The second shift works from three in the afternoon to midnight and handles 45 percent of the demand. One hour of overtime payment is required for each shift and the annual wage is raised accordingly. The number of personnel is determined by the physical

TABLE 2.1-20 MAINTENANCE SAVINGS

LANDING GEAR COST INCREASE		DECREASE IN LANDING GEAR MAINTENANCE COST/YEAR		NET SAVING OVER SYSTEM LIFE (12 YR)
PERCENTAGE	DOLLARS	PERCENTAGE	DOLLARS	DOLLARS
10	5,200	10	7,400	83,600
50	26,000	20	14,800	151,600
100	52,000	50	37,000	392,000

ENGINE COST INCREASE		DECREASE IN ENGINE MAINTENANCE COST/YEAR		NET SAVINGS OVER SYSTEM LIFE (12 YR)
PERCENTAGE	DOLLARS	PERCENTAGE	DOLLARS	DOLLARS
5	15,800	5	6,465	61,780
10	31,600	8	10,344	92,528
20	63,200	10	12,930	91,960
20	63,200	15	19,395	169,540

characteristics of the airplane and the various functions that have to be performed. The amount of time spent performing the various functions is shown in the chart below.



<u>Assumptions</u>:

- 100% Load factor - arriving and departing
- One piece checked baggage per three passengers
- Baggage handling rate - 15 bags/minute

The personnel required at the gate positions is determined by the required actions at the gate and the times allocated for each. The personnel stations are noted in Figure 2.1-32. Their responsibilities are noted in the following paragraphs.

The traffic servicing personnel, noted by (A), handle the baggage and passengers. The copilot, (A-1) opens the front doors when the aircraft has parked and watches for any delays in passengers leaving from the front exits. The copilot could unlock the two exit doors manually as the airplane taxis in and then operate the power openers when the plane is docked.

The ramp personnel, noted by (B), dock the airplane and handle the baggage (B1) guiding the aircraft to the proper position in the dock for extending the loading and unloading passenger gates. These gates are extended by the operators (B2) on each side of the aircraft. The sequence is to extend the front gates first and allow the passengers to start exiting

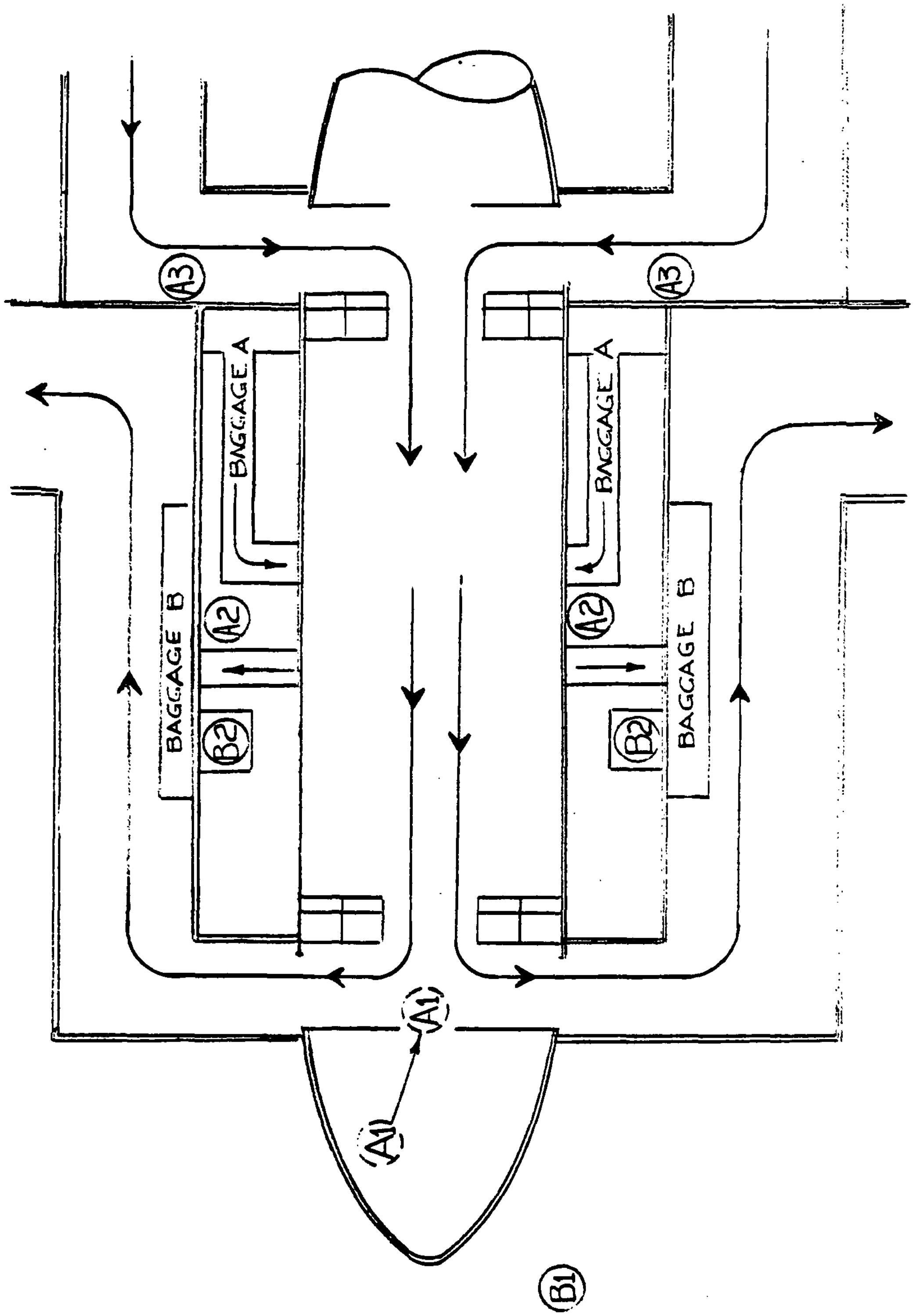


FIGURE 2.1-32 GATE PERSONNEL STATIONS

before the rear doors are opened for passengers entering. When operators (B2) have extended the front gate, they then extend the rear gates and passenger service personnel (A3) open the rear doors for passengers waiting to enter the airplane.

Immediately after the airplane has been positioned in the dock, the baggage handlers (A2) open the baggage compartment and load the baggage onto a mechanical ramp that takes it directly to Baggage B where it is picked up by the passengers as they leave. The personnel who extend the gates (B2) are positioned to see both the front and rear doors of the aircraft and to help expedite the baggage handling for passengers leaving the terminal or catching another airplane. The personnel at the rear doors (A3) see to it that incoming passengers deposit their baggage at baggage (A) where it is rapidly sent to the baggage handlers (A2) by mechanical devices.

Reservations and sales are handled by personnel (A3) in addition to their duty at the rear gates.

The copilot (A1) and the personnel at the rear doors (A3) indicate to the gate operators, via telephone circuits, when the gates may be retracted. Closed circuit TV may also be used to show the gate operators when the gate passageways are clear of passengers.

This Phase II analysis reduces the number of terminal and fueling personnel projected in Phase I (Table 2.1-21).

TABLE 2.1-21 PERSONNEL PER GATE

	Phase I	Phase II
Traffic servicing (A2, A3)	6	4
Ramp servicing (B1, B2)	3	3
Dispatch	2	0
Sales	1	1
Subtotal	12	8
Fueling	2	1
Total	14	9

The fueling personnel are calculated separately from the passenger gate personnel.

Personnel cost has been reduced by cutting the number of shifts from three to two, first keeping the personnel factors the same as in Phase I, then reducing the personnel factors in accordance with the analysis described above. Table 2.1-22 shows the overall results of the two-step reduction in personnel for an 80-passenger deflected slipstream airplane at 20% demand, 75% minimum load factor and 2500 foot runway.

TABLE 2.1-22 IOC COMPARISON

	IOC X $1000		
	Phase I 3 Shifts	Phase 1 2 Shifts	Phase 2 2 Shifts
Facilities depreciation	164.0	164.0	162.1
Personnel	544.0	430.7	285.4
Other expense	379.0	362.1	340.3
Facilities maintenance	215.0	215.0	214.1
Maintenance burden	64.6	64.6	64.2
Ground equipment depreciation	5.5	5.7	5.7
	1,372.1	1,241.9	1,071.8
Fare ($/passenger)	4.94	4.77	4.44

The overall result of using two shifts and decreasing the number of personnel is a 47.5% reduction in personnel cost and an 11% decrease in fare.

Another item of IOC that has been reviewed is the amount of land required for the commuterport. The noise criteria outlined in paragraph 2.1.1.8 have placed certain minimum restrictions on the amount of land surrounding the commuterport, and this is discussed in paragraph 2.1.1.8.1.

The amount of land in relation to the runway area is on the order of 15 to 1. The ratio used in Phase I was 3 to 1. The significance of this change in IOC and TSC is illustrated in the summary cost tables in paragraph 2.1.3.4.

The field length chosen for the helicopter for the Phase I analysis was based on the Heliport Design Guide AC150/5390-1A where the area was defined by the relationship of the length and width of the aircraft. The width being defined by the diameter of the rotor.

$$\text{Area} = (2.0 \times \text{Length})(1.5 \times \text{Width})$$

Applying the expression to the helicopter results in a landing area of approximately 26 000 sq ft. Adding the peripheral area gives a total area of 41 000 sq ft. Since the cost estimating relationship is based on a standard 300-foot width, the length need be only 150 feet to satisfy the minimum requirement.

In Phase II, the emphasis is on reducing helicopter design requirements, not the land area, since the land cost is not a critical item for Detroit. By adding more runway, the danger from engine failure is overcome by forward speed. This reduces the power requirement over that required for the safety factor for hovering, and reduces the overall weight of the helicopter. The length of runway chosen for the helicopter is 600 feet.

Another cost consideration is the amount of parking space allocated at the commuterport. The parking area is sized for the peak three-hour period. The ratio of parking spaces to passengers is taken as one space per passenger, with 250 square feet per space. The square footage allocation is reasonably close to the FAA recommendation (276 square feet) and this factor remains as established during the Phase I effort. The number of parking stalls per auto does not allow for nonpublic space, as would be required for high traffic level intercity airports. The commuterports do not include service other than passenger ticket sales and loading and unloading of passengers. Therefore one stall per passenger is considered adequate.

The fueling of the intraurban aircraft is conducted at only one of the commuterports and not during one of the normal passenger stops. Fueling is a separate activity; it calls for a deadhead flight to the designated fueling port. The tradeoff between the number of deadhead flights and the location of the fueling port is described in Volume 3 paragraph 2.1.4.1. The fueling time is important from the scheduling standpoint; it must be within the system constraints. As indicated in the tabulation below, fueling times are well within the constraints if only a 100 gpm rate is assumed (600 gpm is possible).

	Fueling Time - minutes	
Pumping Rate (gpm)	40 passenger Deflected Slipstream	120 passenger Deflected Slipstream
100	4.3	10.9
300	1.4	3.6
600	0.7	1.8

Another consideration of cost is the number of runways required at each commuterport. The maximum number of operations per hour that can occur on a single runway is a function of the aircraft approach speed and the approach separation distance. The intraurban aircraft has an approach speed of approximately 70 knots. Allowing for two mile separation, a single runway capacity would approach 80 operations per hour (Reference 2.1-24). A comparison of the available peak capacity to the peak load from the demand data contained in Volume I shows that the single runway is sufficient in all cases. The commuterport with the greatest number of flights per three hour peak period is Mount Clemens with the 30% demand for the 40 passenger airplane. The maximum number of flights is 96. This is 32 flights per hour or 64 operations per hour. This is within the 80 operations available with the 70 knot approach speed and the two mile separation distance. All of the commuterports are costed on the basis of a single runway, but with various numbers of gates.

The factor used for the determination of publicity cost, in the IOC model was based on current cost factors for airline operations and is judged to be too high for a commuter system. The intrastate operation does not warrant the publicity effort expended by the trunk lines because they are only interested in attracting people who are in a specific region. The publicity cost factor is reduced to $0.25 per passenger rather than the $0.50 that was used in Phase I.

2.1.3.4 Total System Cost

Total system cost is a combination of the DOC and IOC elements and therefore will also reflect the changes that are recorded in Table 2.1-23. The total system cost model is described in Volume 2, paragraph 1.3.1.2.

The results of the changes are illustrated in Table 2.1-23. The table reflects the difference between the costs as they were reported in Phase I and the cost for the same vehicle with the Phase II changes. The only cost change that caused a change in DOC is in the flight test cost equation, which is a part of the development cost. The overall effect on the insurance and depreciation is insignificant. Most of the major changes had to do with IOC, and TSC. These changes are noted as follows.

- The reduction in the number of work shifts from three to two and the resulting increase in annual pay reduced the personnel cost by 27%. A further reduction in the number of personnel decreases the personnel cost by 47.5%. The reduction in personnel reduces the cost for the headquarters facility and a reduction in depreciation under IOC.

- The increase in the amount of land required because of the noise restraint causes an increase in facilities cost for TSC but not in IOC. Land cost is not included in IOC, whereas it is in TSC. Therefore there is a decrease in facilities depreciation cost due to the reduction in system personnel but an increase in facilities cost in context of total system cost.

- The decrease in facilities operating cost under TSC is due to the reduction in the number of systems personnel.

TABLE 2.1-23 PHASE I AND PHASE II COST COMPARISON

60 Passenger DS Aircraft 20% Demand; 75% Min LF 1500 ft Runway	Phase I Cost	Phase II Cost
DOC		
Flight Crew	49.96	49.96
Fuel and Oil	54.73	54.73
Insurance	78.76	78.90
Depreciation	271.31	271.72
Maintenance	636.26	636.26
Total ($/yr/AC)($-1000)	1,091.02	1,091.57
IOC		
Facilities Depreciation	102.82	99.55
Personnel	385.56	201.75
Other Expense	298.39	150.52
Facilities Maint.	119.10	292.00
Maintenance Burden	35.73	88.23
Ground Equip. Depreciation	5.62	5.62
Total ($/yr/AC)($-1000)	947.22	837.67
Total System Cost		
Aircraft	25.13	25.60
Spares	5.23	5.25
Facilities	18.99	47.70
Ground Equipment	0.65	0.65
Aircraft Operating Cost	94.15	94.15
Facilities Operating Cost	96.34	57.90
Total ($-millions)	240.49	231.25
(1) Fare ($/Passenger)	5.00	4.81
(2) Fare ($/Passenger)	4.97	4.71

- The resulting change in fare is noted. Fare (1) is derived by dividing the total system cost, plus profit, by the total number of passengers served during the 12 year system life. Fare (2) is derived by totalling the DOC plus IOC and profit and dividing by the total annual passengers served by one aircraft.

2.1.3.5 Fare Structure

The fare for the intraurban transportation system is calculated in various ways for comparison purposes. The various methods of calculation allow for different assumptions dealing with ownership and grants. The various fare structures are described below.

- The first method (1) is a calculation of the fare on the basis of total system cost. The fare is determined by dividing total system cost plus profit by the number of passengers served during the 12-year life of the aircraft system.

$$\text{Fare (1)} = \frac{(TSC)(PROF)}{APASS(DA)}$$

- The second method (2) is a calculation of fare on the basis of the DOC and IOC. This method differs from (1) in that it does not include the cost of the land. Land cost is not included in the depreciation of facilities in the determination of IOC, but it is included in the facilities cost in total system cost. Land may be donated by the city at no cost to the operator.

$$\text{Fare (2)} = \frac{(DOC + IOC)PROF}{APASS/XNAC}$$

- The third method (3) is an attempt to derive a fare structure similar to that of current airlines. The cost for the facilities and the facilities maintenance is subtracted from total system cost, and the fare is calculated from the remainder.

$$\text{Fare (3)} = \frac{\text{TSC}-(\text{TRMCST} + \text{XMPROP})}{\text{APASS}(\text{DA})}$$

2.1.3.6 Subsidies/Grants

There are numerous possibilities for some form of subsidy or grant that would affect fare levels. These are considered in the discussion of economics, paragraph 2.2.1.3.

2.1.3.7 Funding

The funding patterns estimated for each aircraft are based on the development and production schedules and the cost for each of the elements within these schedules. The 60 passenger, deflected slipstream compound helicopter, and the autogyro are selected for examples of the funding patterns. The estimated schedules are illustrated in Figure 2.1-33. The corresponding funding patterns are shown in Table 2.1-24.

The schedules and funding are based on the 1985 airplanes. This is done to include the autogyro, which is only considered for the 1985 technology. The airplanes are similar in characteristics and performance, so it follows that the schedules and costs do not have large variations. The patterns shown here for the 1985 technology airplanes would be a close approximation of the airplanes in the 1975 technology as well. The project design and test programs are composed of several tiems. The project design includes.

- Airframe engineering
- Tooling
- Avionics integration
- Special support equipment design
- Operator trainer design
- Maintenance trainer design
- Technical data

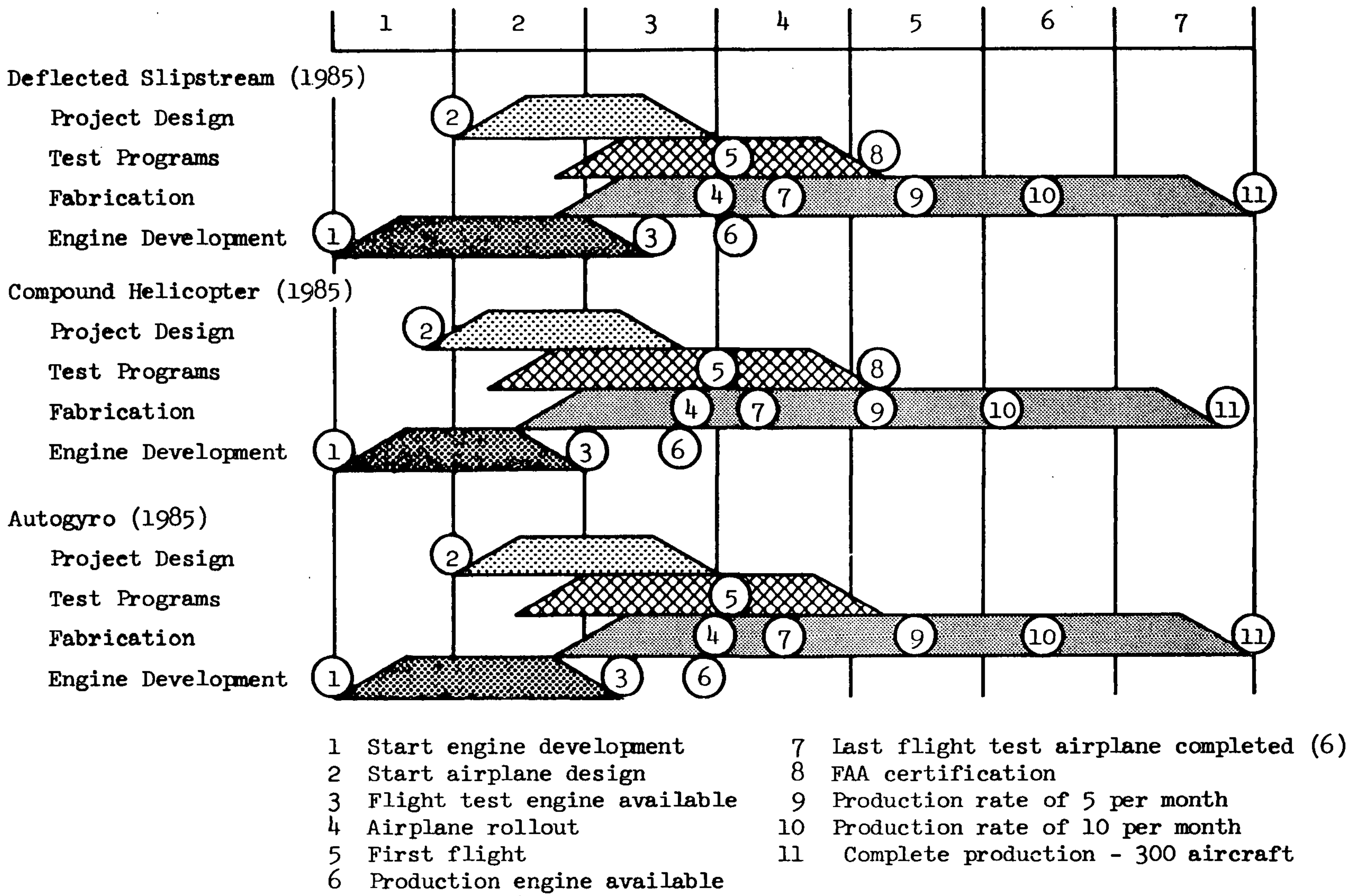


FIGURE 2.1-33 DEVELOPMENT AND PRODUCTION SCHEDULES

TABLE 2.1-24 FUNDING PATTERNS

	1	2	3	4	5	6	7
Deflected Slipstream							
Project Design		29.60	18.20				
Test Programs		0.55	5.00	10.25	0.75		
Fabrication		1.90	13.00	40.64	201.02	275.08	261.85
Engine Development	60.00	40.00	1.00				
Total	60.00	72.05	37.20	50.89	201.77	275.08	261.85
Compound Helicopter							
Project Design	0.82	27.00	18.00				
Test Programs		1.68	6.50	10.00	0.50		
Fabrication		1.03	11.25	76.52	236.81	296.01	185.68
Engine Development	42.00	26.30					
Total	42.82	56.01	35.75	86.52	237.31	296.01	185.68
Autogyro							
Project Design		32.00	19.60				
Test Programs		1.90	6.50	11.00	0.50		
Fabrication		0.78	11.25	43.20	199.88	273.52	260.37
Engine Development	48.0	32.00	0.50				
Total	48.0	66.68	37.85	54.20	200.38	273.52	260.37

Test Programs consist of:

- Flight test
- Ground test
- Spares
- Test articles

Fabrication cost is the cost of producing the 300 airplanes. The first six airplanes are used in the flight test program and then reworked for commuter service.

The engine development cost includes all the items necessary for arriving at a production engine. Engine development cost does not include the continuing cost for product improvement. This will be absorbed in the production cost by the users of the engine.

2.1.4 SYSTEM OPERATION

2.1.4.1 Route and Schedule Development

In phase II, the ASSET route and schedule subroutine (RASP) was employed to generate representative routes and schedules for the Detroit intraurban air transportation system. The addition of this subroutine to ASSET gave the model a total system simulation capability and permitted detailed analyses of the various aircraft system concepts and sensitivities.

The logic flow diagram of the subroutine is presented in Figure 2.1-34. The basic approach is to start a single aircraft at the zone-pair having the highest demand, then routing the aircraft through the network of commuterports by alwsys selecting the destination having the highest demand. This process is repeated iteratively until all the demand is satisfied.

The inputs to the routing and scheduling subroutine are:

- Minimum Permissable Frequency of Service
- Number of passengers per hour from port to port for each hour of the day (demand)
- The times required to go from port to port, including landing and unloading of passengers
- Port to port flight distances
- Minimum time between flights having the same origin and destination
- Minimum time between flights taking off from the same port
- Minimum number of flights before refueling
- Maximum number of flights before refueling
- Refueling location
- Time required to refuel

The routing and scheduling subroutine solves for:

- Route and flight schedule for each of the aircraft
- The number of aircraft needed in the fleet
- The number of flights per aircraft per day
- The number of passengers carried by each aircraft
- Average number of passengers per flight per aircraft

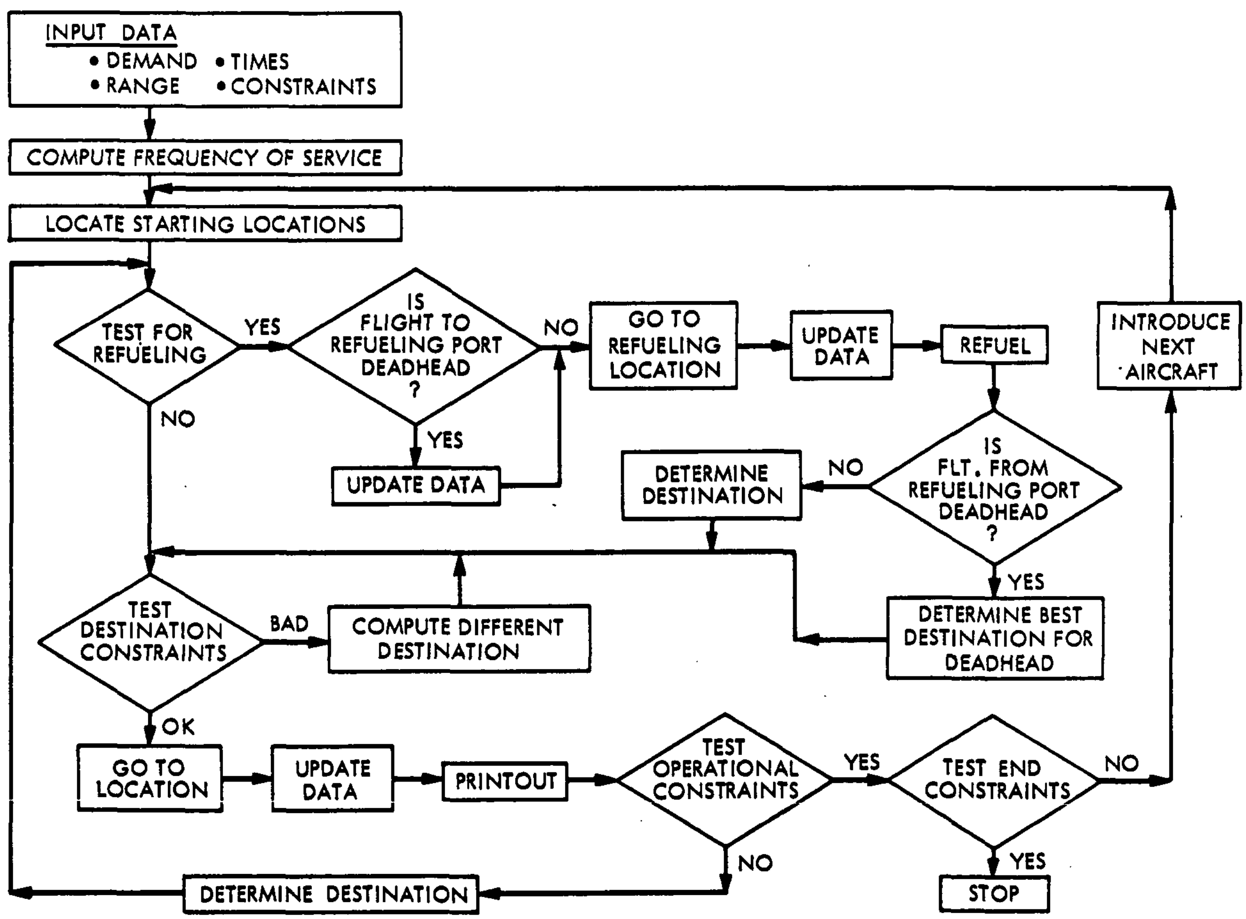


Figure 2.1-34. Routing & Scheduling Logic Flow

- The number of deadhead flights made by each aircraft
- Total number of flights each day by the entire fleet
- Total number of passengers carried by the fleet each day
- Total number of deadhead flights of the entire fleet
- Average number of passengers carried per flight by the fleet
- Total distance flown by fleet per day
- Average flight distance per aircraft per day

Using the combined ASSET model, system sensitivity to changes in demand, variations in the number of commuterports, and changes in the fueling locations was determined. Each of the candidate aircraft concepts was analyzed over the range of passenger capacities considered (20 - 100 passengers)

Figure 2.1-35 presents a map of the TALUS region showing the nine commuterport locations, and the routes between ports. The routes were selected to minimize noise impact on residentail cummunities by making use of existing transportation rights of way, waterways, and agricultural or undeveloped land.

The stage distance/time relation for all route pairs shown in Figure 2.1-35 is presented in Table 2.1-25. These data were employed in the route - schedule analysis.

Table 2.1-26 presents a typical aircraft scheduling summary showing the complete daily schedule for a single aircraft. Table 2.1-27 presents a typical fleet scheduling summary showing daily fleet activity.

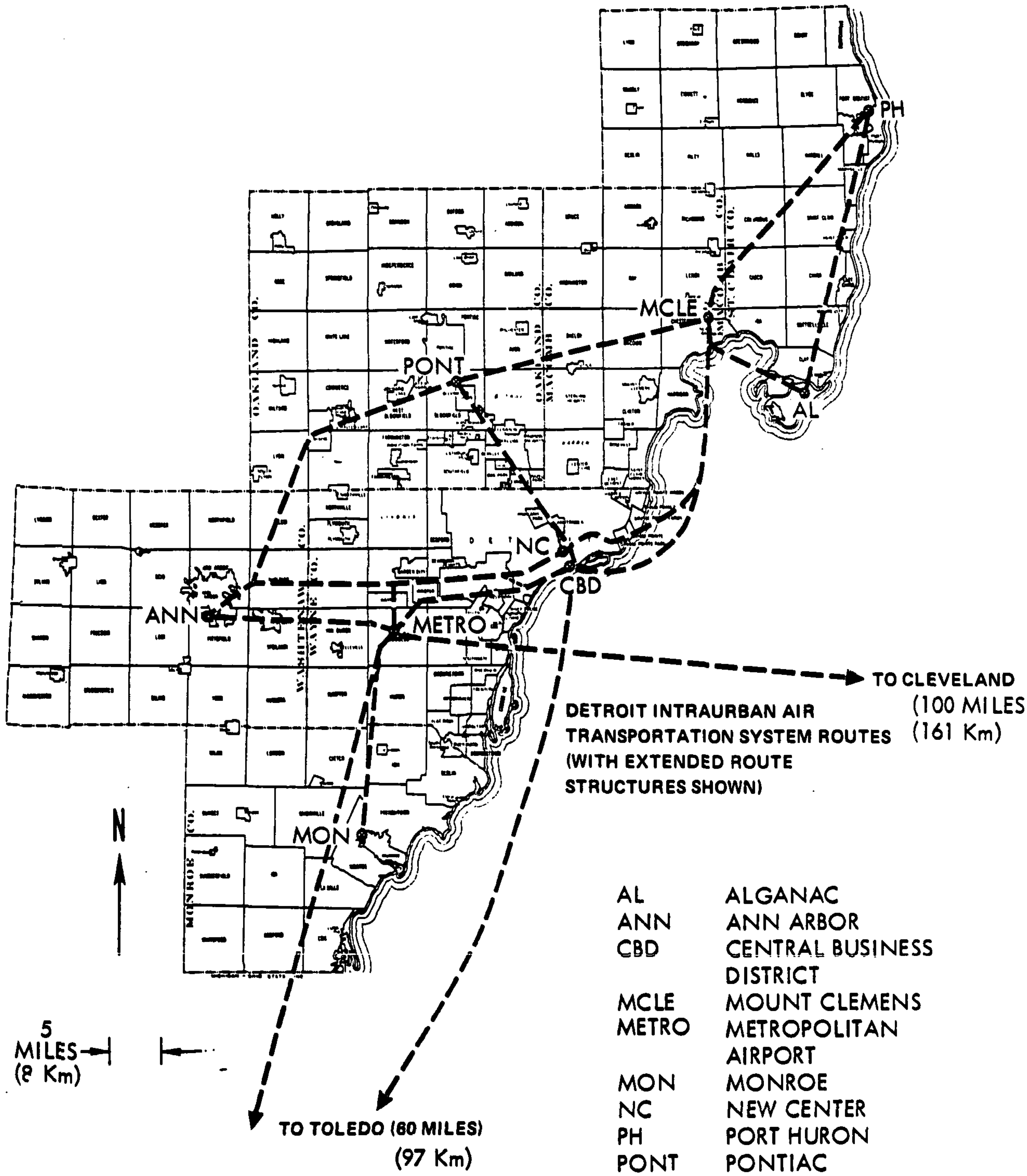


Figure 2.1-35. Commuterport Locations

TABLE 2.1-25 STAGE DISTANCE/TIME

Legend: LENGTH SM / TIME HR. Upper right (diagonally split cells): A.G. (upper) / HEL. (lower) — COMP. HEL. VTOL AUTOGYRO STOL. Lower left (plain cells): DSS STOL.

	ANN	MON	METRO	PONT	CBD	NC	MCLE	AL	PH
ANN		27 / .275 / .270	19 / .235 / .230	37 / .320 / .315	38 / .325 / .320	37 / .320 / .315	58 / .425 / .420	63 / .445	82 / .535
MON	27 / .235		21 / .245 / .240	46 / .370 / .365	34 / .310 / .305	35 / .320	63 / .440	62 / .440	88 / .555
METRO	19 / .205	21 / .220		26 / .270 / .265	20 / .245 / .240	21 / .245 / .240	44 / .360 / .355	48 / .375 / .370	70 / .475 / .470
PONT	37 / .270	46 / .300	26 / .235		21 / .245 / .240	20 / .245 / .240	26 / .270 / .205	34 / .310 / .305	49 / .380 / .375
CBD	38 / .275	34 / .260	20 / .210	21 / .215		34 / .310 / .305	34 / .310 / .305	32 / .310 / .305	54 / .405 / .400
NC	37 / .270	35 / .265	21 / .220	20 / .210	34 / .260		34 / .310 / .305	34 / .310 / .305	54 / .405 / .400
MCLE	59 / .340	63 / .360	44 / .310	26 / .235	34 / .260	34 / .260		15 / .220 / .215	27 / .275 / .220
AL	63 / .360	62 / .360	48 / .225	34 / .260	32 / .250	34 / .260	15 / .190		29 / .285 / .275
PH	82 / .425	86 / .445	70 / .385	49 / .310	54 / .330	54 / .330	27 / .235	29 / .240	

TABLE 2.1-26. TYPICAL AIRCRAFT SCHEDULING SUMMARY

[illegible]

STARTING LOCATION [illegible]

FROM	TO	TIME	FLIGHT NUMBER	NUMBER OF PASSENGERS	DEADHEAD RUNS	FLIGHTS	TOTAL NUMBER OF PASSENGERS	DEADHEAD RUNS	FLIGHT	PASS
[illegible]	[illegible]	[illegible]	1	34.	[illegible]	1100	28239.	147	1	34.
[illegible]	[illegible]	[illegible]	2	66.	[illegible]	1101	28271.	147	2	32.
[illegible]	[illegible]	[illegible]	3	104.	[illegible]	1102	[illegible]	147	3	38.
[illegible]	[illegible]	[illegible]	4	131.	[illegible]	1103	28336.	147	4	27.
[illegible]	[illegible]	[illegible]	5	148.		1104	28352.	147	5	17.
[illegible]	[illegible]	[illegible]	6	176.		1105	28381.	147	6	28.
[illegible]	[illegible]	[illegible]	7	211.		1106	28416.	147	7	35.
[illegible]	[illegible]	[illegible]	8	211.	[illegible]	1107	28416.	148	1	0.
[illegible]	[illegible]	[illegible]	9	243.	[illegible]	1108	28448.	148	2	32.
[illegible]	[illegible]	[illegible]	10	276.	1	1109	28481.	148	3	33.
[illegible]	[illegible]	[illegible]	11	308.	1	1110	28513.	148	4	32.
[illegible]	[illegible]	[illegible]	12	331.	1	1111	28536.	148	5	23.
[illegible]	[illegible]	[illegible]	13	358.	[illegible]	1112	28563.	148	6	27.
[illegible]	[illegible]	[illegible]	14	358.	2	1113	[illegible]	149	7	40.
[illegible]	[illegible]	[illegible]	15	358.	[illegible]	1114	[illegible]	150	1	0.
[illegible]	[illegible]	[illegible]	16	358.	4	1115	[illegible]	151	2	31.
[illegible]	[illegible]	[illegible]	17	390.	4	1116	[illegible]	151	3	22.
[illegible]	[illegible]	[illegible]	18	407.	4	1117	28612.	151	4	27.
[illegible]	[illegible]	[illegible]	19	447.	4	1118	28652.	151	5	40.
[illegible]	[illegible]	[illegible]	20	447.	[illegible]	1119	28652.	152	1	0.
[illegible]	[illegible]	11.775	21	476.	[illegible]	1120	[illegible]	152	2	29.
[illegible]	[illegible]	[illegible]	22	486.	[illegible]	1121	28701.	152	3	20.
[illegible]	[illegible]	12.215	23	486.	[illegible]	1122	[illegible]	153	4	31.
[illegible]	[illegible]	[illegible]	24	518.	[illegible]	1123	28723.	153	5	22.
[illegible]	[illegible]	[illegible]	25	538.	[illegible]	1124	28743.	153	6	20.
[illegible]	[illegible]	[illegible]	26	[illegible]	7	1125	[illegible]	154	7	38.
[illegible]	[illegible]	[illegible]	27	535.	8	1126	28743.	155	1	0.
[illegible]	[illegible]	[illegible]	28	537.	[illegible]	1127	28772.	155	2	29.
[illegible]	[illegible]	[illegible]	29	567.	9	1128	28772.	156	3	27.
[illegible]	[illegible]	[illegible]	30	[illegible]	9	1129	28812.	156	4	40.
[illegible]	[illegible]	[illegible]	31	607.	[illegible]	1130	28812.	157	5	39.
[illegible]	[illegible]	[illegible]	32	627.	[illegible]	1131	28832.	157	6	20.
[illegible]	[illegible]	[illegible]	33	627.	11	1132	[illegible]	158	7	31.
[illegible]	[illegible]	[illegible]	34	627.	12	1133	[illegible]	159	1	33.
[illegible]	[illegible]	[illegible]	35	656.	[illegible]	1134	[illegible]	159	2	29.
[illegible]	[illegible]	[illegible]	36	[illegible]	[illegible]	1135	28935.	159	3	24.
[illegible]	[illegible]	[illegible]	37	712.	[illegible]	1136	[illegible]	159	4	32.
[illegible]	[illegible]	[illegible]	38	735.	[illegible]	1137	[illegible]	159	5	23.
[illegible]	[illegible]	[illegible]	39	768.	[illegible]	1138	[illegible]	159	6	33.
[illegible]	[illegible]	16.747	40	768.	[illegible]	1139	[illegible]	160	7	0.
[illegible]	[illegible]	[illegible]	41	805.	13	1140	29010.	160	1	37.
[illegible]	[illegible]	17.635	42	[illegible]	13	1141	29040.	160	2	30.
[illegible]	[illegible]	17.775	43	835.	14	1142	29040.	161	3	0.
[illegible]	[illegible]	[illegible]	44	835.	[illegible]	1143	29040.	162	4	0.
[illegible]	[illegible]	[illegible]	45	854.	15	1144	29059.	162	5	19.
[illegible]	[illegible]	[illegible]	46	876.	15	1145	29081.	162	6	22.
[illegible]	[illegible]	[illegible]	47	876.	[illegible]	1146	29081.	163	7	38.
[illegible]	[illegible]	[illegible]	48	[illegible]	17	1147	29081.	164	1	35.
[illegible]	[illegible]	[illegible]	49	[illegible]	17	1148	29094.	164	2	13.
[illegible]	[illegible]	[illegible]	50	902.	17	1149	29107.	164	3	13.
[illegible]	[illegible]	[illegible]	51	[illegible]	[illegible]	1150	29107.	165	4	0.
[illegible]	[illegible]	[illegible]	52	921.	[illegible]	1151	29126.	165	5	19.
[illegible]	[illegible]	[illegible]	[illegible]	943.	[illegible]	1152	29148.	165	6	22.
[illegible]	[illegible]	[illegible]	[illegible]	943.	[illegible]	1153	29148.	166	7	38.

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TABLE 2.1-27. TYPICAL FLEET SCHEDULING SUMMARY

FLEET SUMMARY

AIRCRAFT NUMBER	STARTING LOCATION	STARTING TIME	FLIGHTS/DAY	NUMBER OF PASSENGERS/DAY	DEADHEADS/DAY	AVERAGE PASSENGER LOAD/FLIGHT
1	CBD	6.000	58.	1938.	0.	33.
2	PONT	6.000	59.	1896.	1.	32.
3	CBD	6.200	59.	1844.	2.	31.
4	NC	6.000	61.	1789.	3.	29.
5	ANN	6.000	63.	1788.	4.	28.
6	NC	6.200	61.	1884.	1.	31.
7	MTRO	6.000	63.	1738.	2.	28.
8	PONT	6.050	61.	1733.	4.	28.
9	MCLE	6.000	63.	1673.	7.	27.
10	MCLE	6.050	64.	1515.	9.	24.
11	MCLE	6.100	62.	1443.	11.	23.
12	MCLE	6.150	63.	1403.	11.	22.
13	MTRO	6.050	63.	1439.	11.	23.
14	CBD	6.100	63.	1304.	16.	21.
15	CBD	6.400	61.	1253.	14.	21.
16	MCLE	6.200	61.	1241.	17.	20.
17	MCLE	6.200	59.	1213.	17.	21.
18	ANN	6.050	55.	1111.	17.	20.
19	MON	6.000	54.	943.	19.	17.
20	ANN	6.100	47.	733.	18.	16.
21	MTRO	6.100	49.	933.	15.	19.
22	PONT	6.200	46.	912.	15.	20.
23	NC	6.100	40.	714.	15.	18.
24	NC	6.150	41.	669.	17.	16.
25	MCLE	6.400	40.	743.	15.	19.
26	MCLE	6.350	33.	590.	11.	18.
27	AL	6.000	22.	412.	8.	19.
28	CBD	7.000	19.	441.	5.	23.
29	ANN	7.000	18.	392.	5.	22.
30	MTRO	7.000	18.	361.	5.	20.
31	CBD	7.000	18.	410.	5.	23.
32	PONT	7.000	18.	376.	6.	21.
33	ANN	8.000	13.	231.	5.	18.
34	MON	8.000	7.	184.	1.	26.
35	MTRO	8.000	9.	171.	3.	19.
36	CBD	8.000	7.	140.	2.	20.

FLIGHTS/DAY	TOTAL NUMBER OF PASSENGERS/DAY	DEADHEADS/DAY	FLEET AVERAGE PASSENGER LOAD/FLIGHT
1558	37560.	317	24.

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2.1.4.2 Commuter Service Analysis

In Phase II of the study, the operational impact of varying the commuter service offered by an intraurban air transportation system was studied by considering changes in area coverage by (1) decreasing the number of commuterports, and (2) enlarging the commuterport service zones from five mile radii to ten mile radii.

The nine commuterports in the Detroit region were ranked by the daily number of passengers served, from maximum to minimum, as follows:

1) Mount Clemens (MCLE)
2) Central Business District (CBD)
3) New Center (NC)
4) Pontiac (PONT)
5) Metropolitan Airport (METRO)
6) Ann Arbor (ANN)
7) Monroe (MON)
8) Algonac (AL)
9) Port Huron (PH)

To consider the impact of decreasing the number of communterports, two alternate cases were analyzed. They are (1) only the top six commuterports comprized the ground system, and (2) only the top four commuterports were considered (with the further constraint that CBD and NC commuterports were combined into a single port at the central business district). In each case a 60-passenger Deflected Slipstream STOL aircraft having 2500 ft field lengths served as the air vehicle, and the 1985 20 percent demand capture projections established the demand levels. The results of these analyses are presented below.

COMMUTERPORT VARIATION ANALYSIS

	9-PORTS	6-PORTS	3-PORTS
TSC	$ 466 Million	$ 372 Million	$ 230 Million
FARE	$ 8.46	$ 7.97	$ 6.75
Annual Passengers	$ 5.28 Million	$ 4.47 Million	$ 3.26 Million

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As can be seen from these data, a diminishing return is realized in both fare and annual passengers carried when investment (as represented by TSC) is increased to add commuterports from a basic system of three. In other words, to go from three to nine commuterports requires a change in investment from $230 to $466 million (or 102 percent), while fare only decreases 25 percent, and annual passengers carried increases only 62 percent.

The second approach to analyzing the impact of varying area coverage was to increase the radius of the service zones extending around each of the commuterports from five miles to ten miles. Since the average distance between commuterports is 22 miles, the 10 mile service zone radius allowed consideration of commuter trip distances of down to 12 miles (assuming edge-to-edge zone pair travel). An increase in demand results and this was quantified through use of certain elements of the Boeing Company's corresponding Phase I analysis (Reference 2.1-25) as a factor of 1.57 to be applied to the initial market demand to account for the reduced trip distances and increased area of coverage. This increased demand level forms the basis for the Phase II system evaluation.

2.1.4.3 Fueling Location

In Phase I of the study, a tenth port was postulated which would serve as the fueling, maintenance, and service facility and would be separate from the nine commuterports. In Phase II of the study, however, consideration was given to locating the fueling, maintenance, and service facilities at one of the nine commuterports. The RASP subroutine was exercised to study the impact of fueling location on scheduling and subsequently on fleet size requirements. The results of the analysis are summarized in Figure 2.1-36. On the basis of fleet size and percentage of deadhead (empty) flights, the MCLE, NC, and CBD commuterports appear to be the favored locations for the fueling facility. However, if land value enters into the evaluation, the comparatively lower value of land at MCLE than at NC or CBD leads to the conclusion that the MCLE would be the favored location. Consequently, MCLE is employed as the fueling location for the Phase II systems evaluation.

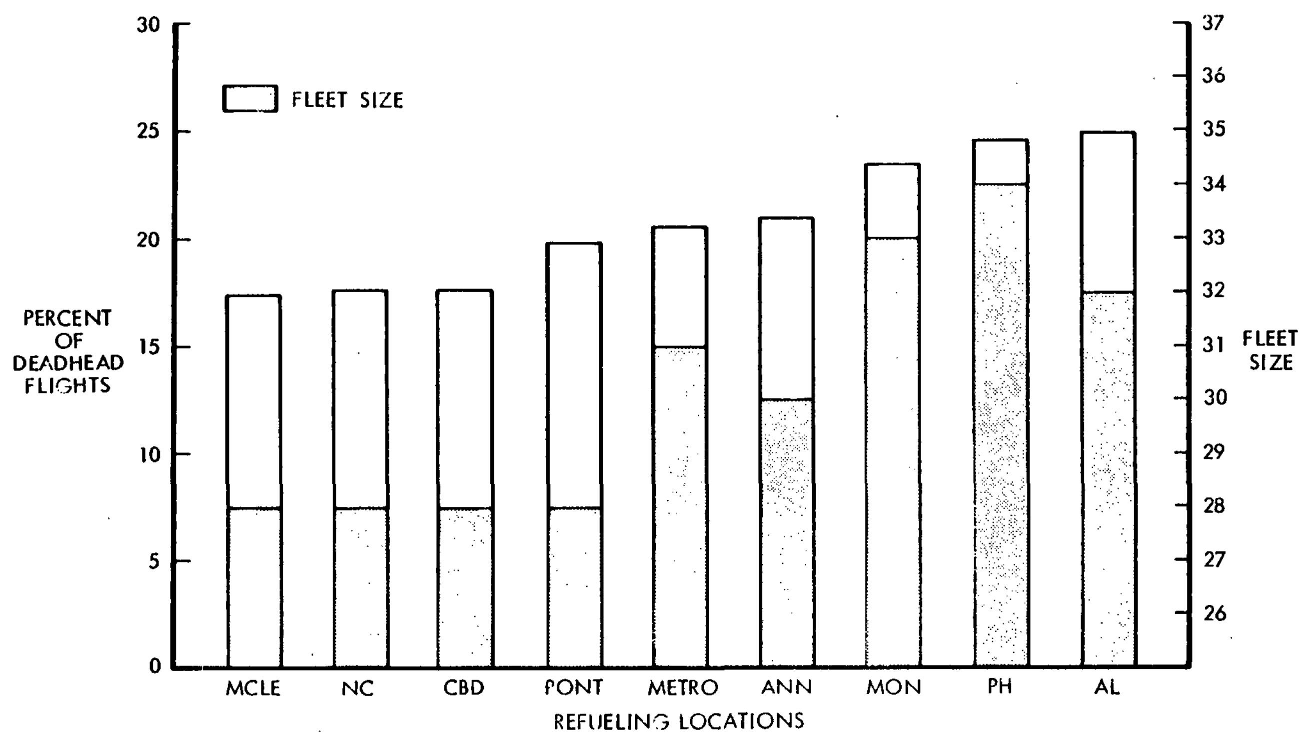

Figure 2.1-36. Effect of Varying Refueling Location

2.1.5 RAPID TRANSIT SYSTEM/AIR TRANSIT SYSTEM INTERFACE

Of prime importance to transportation planners is the interaction and interface between the various transportation modes serving a common market. Historically, and principally due to the U.S. free enterprise system, divergent transportation systems have been viewed, analyzed, and operated as competing systems. Interface was treated only as an economic or operational necessity rather than a desired characteristic. However, as the complexity of transportation systems and their requirements increased, the trend toward total transportation planning and development has become more pronounced.

In the analysis of intraurban transportation systems, Lockheed views fixed-track rapid transit systems and air transportation systems as being complementary in the intraurban role.

In any dynamic metropolitan area, such as Detroit, there exist both stable (or fixed) transportation corridors, and growing or developing corridors. The fixed-track rapid transit concept is ideally suited to serving established corridors with high density traffic. The V/STOL air transportation system is characterized by its flexibility, and the ease with which its operations and routes can be modified to meet the changing requirements of developing corridors.

An interesting phenomenon associated with the introduction of a new, relatively high capacity transportation system along a low density transportation corridor is the acceleration of the corridor's development into a stable, high density corridor.

Another advantage of an air transportation system in a dynamic metropolitan area, is its relatively low installation costs; especially compared with fixed-track systems. An air transportation system serves as an adequate interim system along established routes until the funds or demand become available to warrant construction of rapid transit right of ways.

The primary advantage of an intraurban air transportation system from the passenger point of view is its speed and the resulting in total trip time. The air transportation system maintains this advantage over fixed-track rapid transit systems whose great passenger capacity and comparatively short stage lengths result in slower average speeds (or increased total trip times). For this reason, the demand for an airborne transportation system would not necessarily be reduced for trip lengths in excess of 20 miles by the introduction of a rapid transit system. In some respects, it is possible that a rapid transit system would increase (indirectly) the total air market over the long term, since it would serve to increase the percentage of the population that would use public transit instead of the private automobile. In other words, the introduction of rapid transit would decrease public dependence on private transportation.

Based on these premises, it is probable that an air transportation system would be able to maintain its clientele upon the introduction of rapid transit; although a temporary loss of passengers would result during the initial period of rapid transit service (due to its novelty and initially low load factors).

2.1.6 VEHICLE ALTERNATE USES

The aircraft defined above have been conceived specifically for intraurban mass transportation operations. However; they could, with minor modification or production-line change, be converted to serve other roles. Some possible uses of the Detroit intraurban transport fleet and alternate applications of the basic 60-passenger aircraft model are discussed below.

2.1.6.1 Cargo Capacity

The approximate cargo capacity of the 60-passenger size vehicles is expressed for three levels of modification as follows:

	Change	Approx. Cargo load (lb)
1)	Minimum change - Remove seats to provide cargo area -- no floor beefup. Suitable for light cargo; i.e., mail, light freight, etc.	15,000
2)	Convertible - Remove seats and add floor beefup for heavy cargo with provisions for reinstallation of seats.	13,000
3)	Production cargo configuration	18,000

Door sizes are considered adequate.

2 1.6.2 Performance Limits

The single-stage range capability at design payload varies from 300 to 350 statute miles. The range payload potential of 60-passenger vehicles is shown by Figure 2.1-37 . Long-range cruise speeds are approximately 150 and 190 kt for the rotary and fixed wing aircraft, respectively. The usable high speed capability of the rotary wing vehicles will be limited to the vicinity of the design value of 200 kt. The corresponding value for the deflected slipstream STOL is 275-300 kt as a function of design field length (installed T/W).

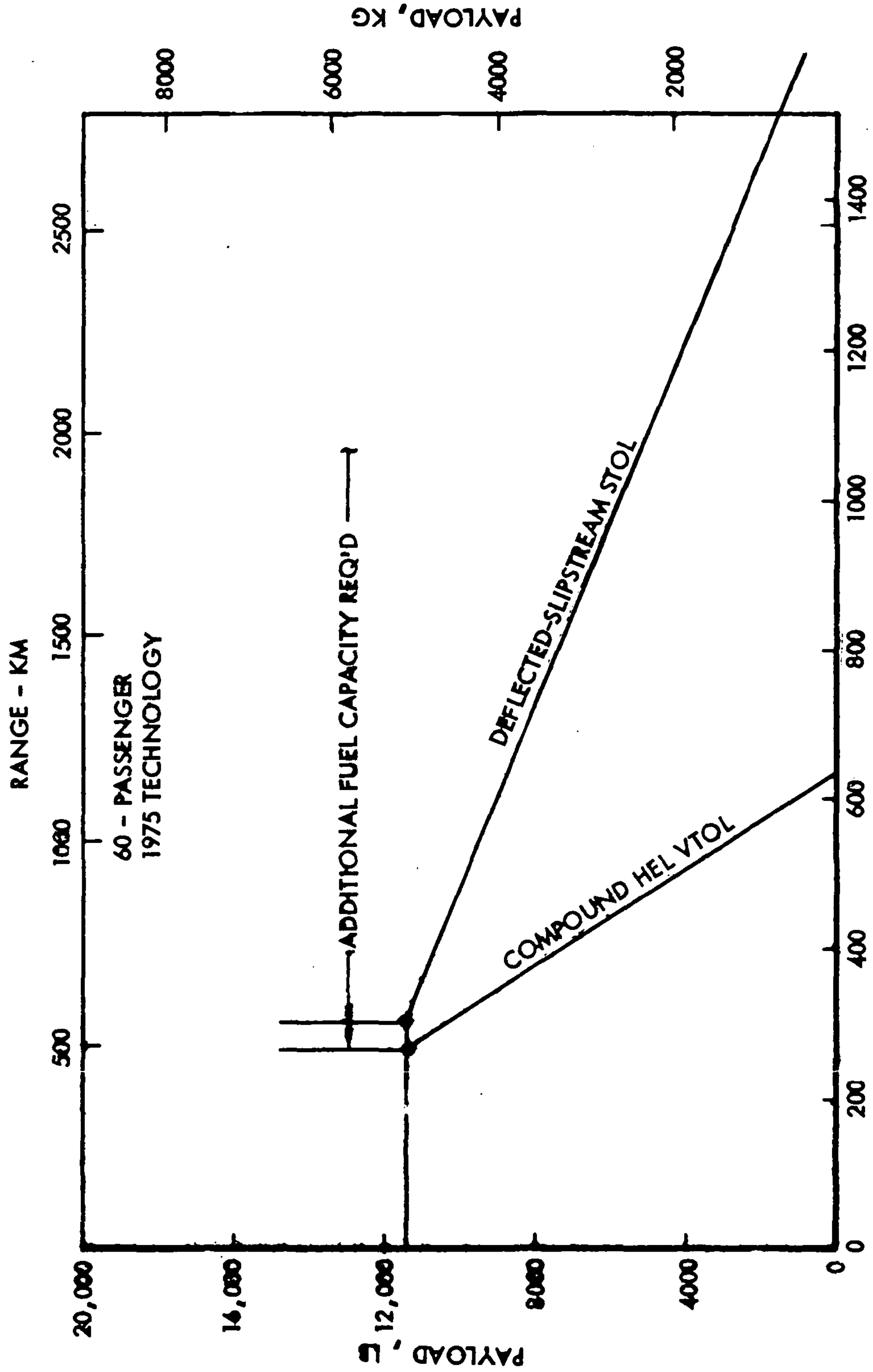

FIGURE 2.1-37. POTENTIAL RANGE/PAYLOAD - 60 PASSENGER 1975 AIRCRAFT

The absence of cabin pressurization will limit cruise altitudes to less than 10 000 ft.

2.1.6.3 Scenarios

Consideration of the intraurban transport potential to serve in other scenes suggests the following possibilities:

- During off peak hours mail and light freight could be carried by removing some of the "quick remove" seats.
- The full payload range capability is adequate to provide good intercity V/STOL service between cities such as Detroit, Lansing, Battle Creek, Traverse City, etc. The modest cruise speed-altitude performance is of little consequence at these short ranges.
- A convertible configuration could give flexibility to the fleet by offering a substantial V/STOL cargo miles per day capacity over short ranges. The large fuselage doors lend feasibility to the convertible configuration.
- The intraurban fleet would provide a useful and available air reserve for use in case of emergency, disaster, military action, etc.
- A production cargo version of the intraurban transport for military use could be produced with little engineering/production-line change. Cargo load capacity up to approximately 32 000 lb is available.

2.1.7 NETWORK EXPANSION

The development of a V/STOL commuter system in the Detroit area should follow a plan of incremental expansion. This expansion should be based on the predicted growth and development of the Detroit region and its associated travel patterns, and the development and growth of rapid transit in the region.

Current estimates indicate that the two primary corridors for travel in Detroit are the Woodward and Michigan corridors (Figure 2.1-22) It will be along these corridors that the first rapid transit lines will be located and service initiated.

An intraurban air transportation system would be ideally suited to serve as an interim transportation system along the two corridors until the rapid transit becomes operational. The Michigan and Woodward corridors would also provide the demand to support the initial V/STOL system.

The next extension of the V/STOL service should be along the Mack corridor (Figure 2.1-22) extending from the CBD to the Grosse Pointe area and on to Mount Clemens.

As the system matures and a clientele is established, the V/STOL service will be expanded so that a network of routes between the nine V/STOL commuterports previously described will be established.

Because a main characteristic or feature of air transportation is flexibility, the network expansion of the intraurban air transportation system will follow a heuristic approach; that is, starting with a simple route structure serving the primary travel corridors, and then expanding the system based on operational experience and self-generating demand.

Along with the growth or expansion of the intraurban service, development of interurban service between Detroit, Toledo, Cleveland, and Buffalo (Figure 2.1-38) should be initiated. These routes are to be established for off-peak utilization of the aircraft. Current commercial air line experience has demonstrated the economic feasibility of this intercity service.

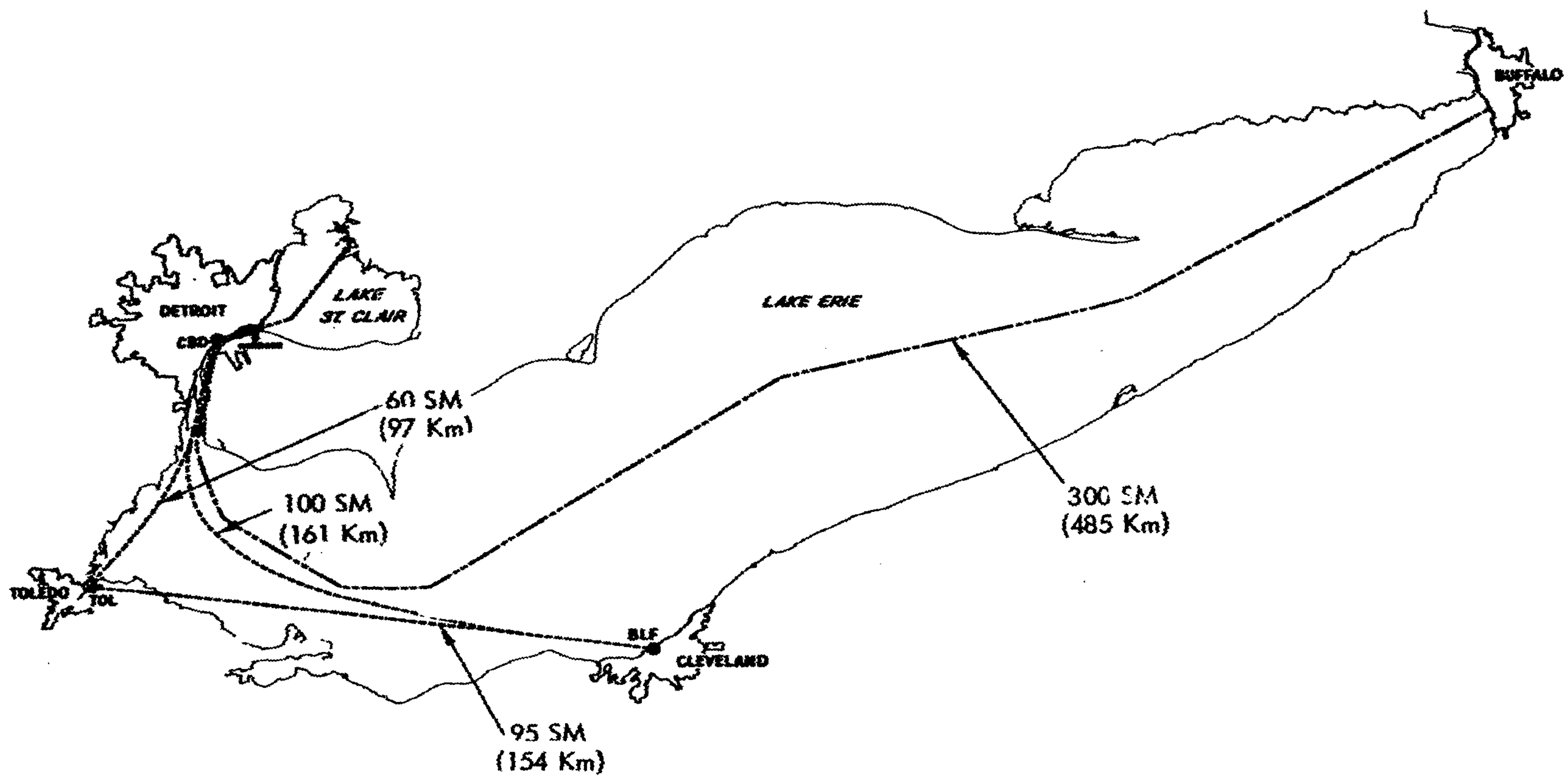

FIGURE 2.1-38. INTERCITY AIR TRANSPORTATION ROUTES

2.2 EVALUATION

2.2.1 COMPARATIVE EVALUATION

In order to evaluate these aircraft concepts in a real world environment it is necessary to determine the effects of varying the aircraft size and then superimposing this aircraft on the market senario of the Detroit area. This encompasses a complete total system synthesis of the aircraft characteristics with that of the movements of the daily commuter. This total system synthesis will solve for the following:

- The total number of flights required to satisfy the commuter demand as a function of the size of aircraft design
- The size of the fleet needed to satisfy this demand as a function of the aircraft size
- The number of commuters who pass through the terminal gates per hour
- The frequency of service per hour at each of the commuter ports
- The total number of dedhead flights made to satisfy the commuter demand
- The actual route and time history each aircraft flys
- The total system cost and fare paid by the commuter

For a given fixed commuter demand, the fleet size is inversely proportional to the design capacity of the aircraft. As the aircraft size is increased, the fleet size is reduced. A smaller fleet size in turn reduces the frequency of service to the commuter. As a basic ground rule to this analysis, at least one flight per hour is provided to the commuter. This means that there is some minimum number of airplanes required to satisfy this constraint. Thus, as the aircraft size is increased, a point of deminishing returns is reached where increasing the aircraft size no longer reduces the total number of airplanes in the fleet.

From the cost analysis it is determined that the direct operating cost of the aircraft is the largest single item in making up the total system cost. Within the direct operating cost, maintenance is the highest cost item. Maintenance cost of an aircraft is made up of the fixed flight cycle cost and the costs per flight hour. In this type of commuter operation, 80 percent of the maintenance cost is of the fixed cycle type. This means that a smaller aircraft which requires a larger fleet size has very high direct operating cost. Increasing the aircraft size reduces the fleet size and thus the total direct operating cost of the fleet. However, a point is reached where the fleet size is no longer reduced and the operating cost increases because of the increased size of the aircraft.

By properly combining the aircraft size with a fixed market demand it is possible to solve for the best mix of aircraft size, fleet size, load factor, frequency of service, in terms of minimum fare or total system cost. Each of the aircraft concepts for both market time periods is subjected to this analysis. By comparing these results, it is then possible to evaluate each concept, relative to each other concept, on a consistent basis. Examples of the associated total system synthesis computer runs for a variation in aircraft size of 60 to 140 passengers are shown on Tables A2.2-1 through A2.2-30 for the 1975 deflected slipstream STOL aircraft operating in the 1975 market scenario of the Detroit area.

2.2.1.1 Utility

2.2.1.1.1 Frequency of Service

In order for a commuter transportation system to be viable and effective, it is necessary to provide some reasonable frequency of service to the commuter. The frequency of service provided between any two of the commuter ports is a direct function of the number of commuters commuting between those ports and the size of the aircraft used. Table 2.2-1 is an example of the frequency of service provided by a 100 passenger deflected slipstream STOL aircraft operating in the 1985 demand time period. The commuter demand for this particular situation varies from 30 passengers per hour to 303 passengers per hour.

The table shows that the frequency of service for this situation varies from one flight to four flights per hour depending on the number of commuters located at each of the commuterports. The 100-passenger aircraft makes four flights/hour to carry the 303 commuters from the Central Business District (CBD) to Mount Clemens. These four flights from CBD to Mount Clemens would have an average load factor of 76 percent. The single flight/hour from Monroe to Ann Arbor, which carries 30 passenger, has a load factor of only 30 percent. This mixing of all of these varying flight frequencies over an 18-hour work day becomes a rather complicated but necessary step of analysis to arrive at a real-world route and schedule for each of the aircraft and commuterports. The frequency of service provided at each commuterport is a function of the aircraft size and the number of commuters to be transported. However, no matter how small the commuter demand is, at least one flight per hour is provided.

2.2.1.1.2 Field Length

At the start of Phase II, all of the basic grounds under which the study was to be conducted were reviewed and modified where necessary. The concepts choosen in Phase I were re-examined in greater detail, and all of the detailed weight, performance, and costing data were modified where required. Because of this, both of the 1975 and 1985 deflected slipstream STOL designs were again investigated from the standpoint of choosing the best FAR field

TABLE 2.2-1. FLIGHTS PER HOUR DURING THE PEAK DEMAND TIME PERIOD FOR 100 PASS. AIRCRAFT

FROM: ANN ARBOR	MONROE	METROPOLITAN AIRPORT	PONTIAC	CENTRAL BUSINESS DISTRICT	NEWS CENTER	MOUNT CLEMENS	ALTOWN	PORT HURON	TO
	1	2	1	1	1				ANN ARBOR
1		2		1	1				MONROE
2	1		1	1	1				METROPOLITAN AIRPORT
1		1		2	1	3			PONTIAC
1	1	1	2			3			CENTRAL BUSINESS DISTRICT
1	1	1	1			3			NEWS CENTER
			3	4	3		2	2	MOUNT CLEMENS
						2		1	ALTOWN
						1	1		PORT HURON

length. Each of the concepts were investigated for 1500, 2000, and 2500 foot FAR field length requirements with varying passenger size and for both market demands.

These designs were run through the total system synthesis analysis; with results per Figure 2.2-1. It was determined that very little change in fare would result from choosing one field length over another. A field length of 2000 feet minimizes the fare for all aircraft sizes in both of the market demand time periods. This effect is primarily due to the low cost of land in the Detroit area as compared with many other major metropolitan areas.

2.2.1.1.3 Growth Potential

A comparison of the growth potential of deflected-slipstream to the compound helicopter concept is presented in Table 2.2-2. The optimum aircraft sizes shown on this table represent the minimum fare designs. Increasing or decreasing the aircrafts size from this minimum fare point increases the fare.

TABLE 2.2-2. AIRCRAFT GROWTH POTENTIAL COMPARISON

AIRCRAFT CONCEPT	OPTIMUM AIRCRAFT SIZE (PASSENGER CAPACITY)		AIRCRAFT GROWTH
	MINIMUM 1975 MARKET DEMAND (15,700 PASS./ DAY)	MAXIMUM 1985 MARKET DEMAND (47,000 PASS./ DAY)	
DEFLECTED-SLIPSTREAM	54	114	111%
COMPOUND HELICOPTER	42	72	72%

The deflected slipstream concept reaches a minimum fare at a design capacity of 54 passengers. The study (based on 1975 market demand) showed that a 20-passenger reduction increased the fare by 7%; a 20-passenger increase likewise increased the fare by 2%. In the case of the compound helicopter concept, a 42-passenger design resulted in minimum fare. The same 20-passenger decrease resulted in a 10% increase in fare; the 20-passenger increase in capacity increased the minimum fare by 8%

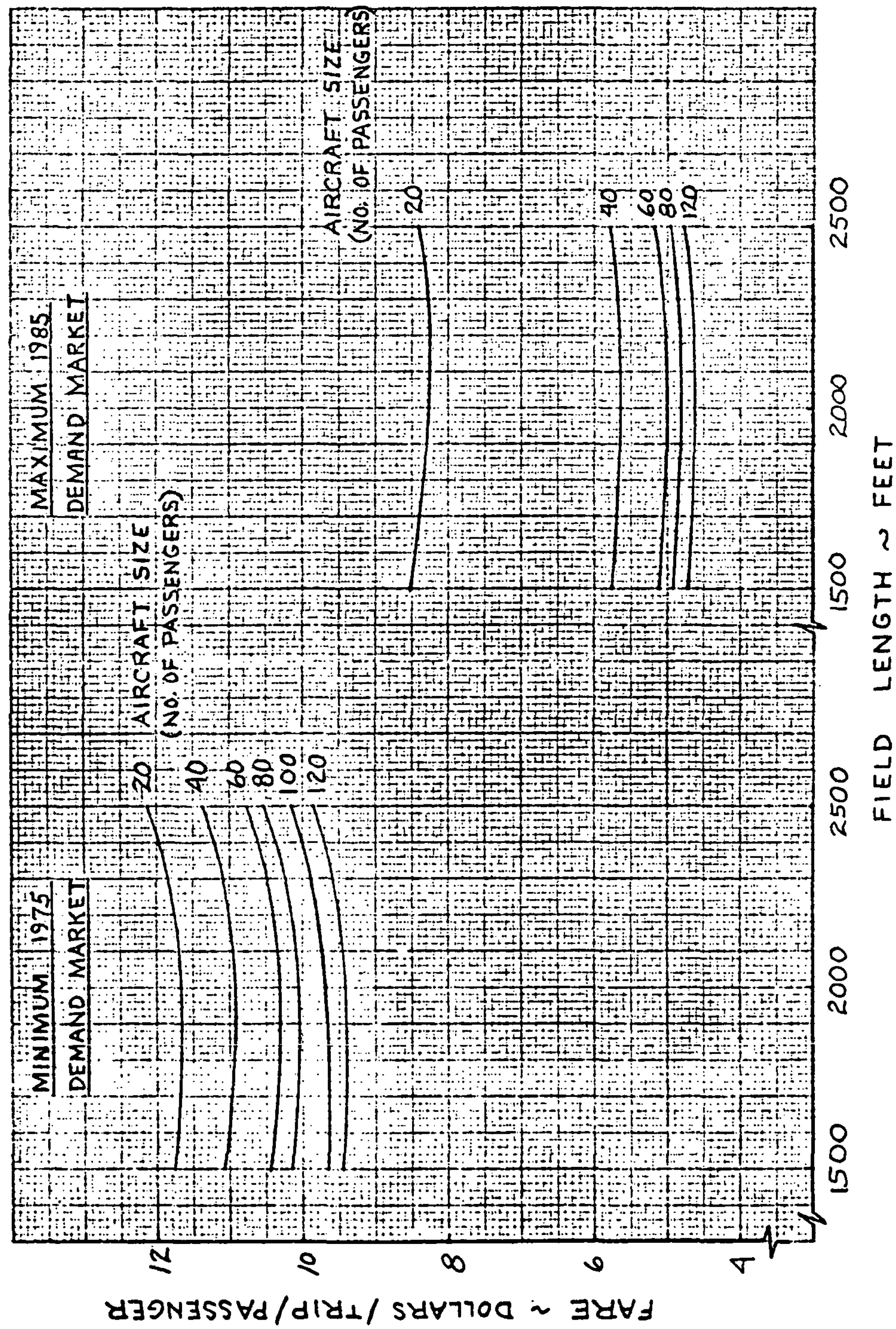

Figure 2.2-1. Effect of Field Length on the Deflected Slipstream STOL

The penalty in terms of increased fare is approximately the same when the aircraft size is reduced for both concepts, but when the aircraft size is increased to accommodate more passengers, the deflected-slipstreams fare increases at one fourth the rate of the compound helicopter. Hence a greater growth potential is possible with the deflected-slipstream concept in terms of minimizing changes in fare.

The table shows what happens if you start with the minimum 1975 market demand and later discover that your market demand is actually much larger than expected. The deflected slipstream design shows a potential growth of 111% as compared with a 72% growth potential for the compound helicopter design.

2.2.1.2 Risk Sensitivities

The technical risk involved in developing 1975 IOC configurations having the characteristics shown herein is judged to be low, except that the larger compound helicopter VTOL may not meet the recommended community noise limitation criteria without some weight/performance/cost penalities.

The technical risk IOC involved in developing 1985 configurations having the characteristics shown herein is judged to be low, assuming continued government and private research activity in materials and fabrication methods, propulsion, and acoustics.

The sensitivity of system costs to technology is relatively low, except that vehicle maintenance costs exert a significant effect.

New regulations and other operational factors associated with the development of an airborne intraurban transportation system are judged to have the same impact on the deflected slipstream and autogyro STOL concepts, but somewhat less for the compound helicopter VTOL which is currently operating in a related scenario.

Passenger appeal and community acceptance are judged to be the same for all concepts.

2.2.1.3 Economics

The overall results of the phase II cost analysis are shown in the Comparative Evaluation section of this report. The information is in parametric form and does not show the breakdown of the various cost items. The cost for each element in the IOC/DOC and TSC are shown in the DOC/IOC/TSC summary sheets, Tables 2.2-3 and 2.2-4. These tables represent the evaluation of each type of airplane for one set of data. The data presented here are for the 60-passenger configurations, with the 30% demand (factored by 1.57), and using the nine commuterports. This is one set of data from among many that are shown in Comparative Evaluation section. It is representative of the aircraft in the area of minimum fare.

As may be noted by the cost breakdown of Tables 2.2-3 and 2.2-4, the predominant costs are maintenance of the aircraft and facilities, depreciation, and other expense which includes publicity and G&A. This is also illustrated in the percentage bar charts which show the breakdown of the cost elements of DOC/IOC and TSC as percentages of the total. The percentage makeup of each type of cost is shown in Figures 2.2-2, 2.2-3, and 2.2-4. Figures 2.2-5 and 2.2-6 shows the TSC/DOC/IOC makeup by cost.

2.2.1.3.1 Subsidies/Grants

There are numerous possibilities for some form of subsidy or grant that would affect the fare level. Four plans (A through D) are listed below, and the effect of each on the fare structure is shown in the Subsidy/Grant Comparison Table (Table 2.2-5).

A. The City or State owns and maintains the commuterport facilities and runways with no cost to the system operator.

B. A general subsidy of 2.0 dollars per passenger is received.

C. A capital Grant is received for 2/3 of the operating cost that cannot reasonably be financed from revenues (urban Mass Transportation Act of 1964). The revenue is predicated on a fare of $1.73. This fare is based on the assumption that the commuter is willing to pay five cents per mile, which is equivelent to the operating cost of his own car but not the depreciation or insurance.

TABLE 2.2-3. DOC/IOC SUMMARY
($-1000 Except As Noted)

PASSENGER CONFIGURATION 30% DEMAND 2000 FT RUNWAY	DEFLECTED	SLIPSTREAM	COMPOUND	HELICOPTER	AUTOGYRO
	1975	1985	1975	1985	1985
DOC					
FLIGHT CREW	97.118	93.182	138.072	125.443	146.506
FUEL AND OIL	44.020	37.760	184.509	99.265	117.317
INSURANCE	79.253	95.891	112.431	93.406	94.139
DEPRECIATION	249.075	301.097	353.640	294.706	298.346
MAINTENANCE	770.758	728.227	979.544	821.791	848.326
TOTAL ($/YR/AC)	1240.225	1256.157	1768.197	1434.611	1504.633
TOTAL (CONTS/SEAT MILE)	5.6	5.8	8.6	7.2	7.4
IOC					
FACILITIES DEPRECIATION	33.570	28.650	26.551	22.486	24.411
PERSONNEL	88.186	74.921	87.871	82.811	85.140
OTHER EXPENSE	107.503	109.904	98.151	102.552	105.597
FACILITIES MAINTENANCE	121.054	102.638	49.277	41.831	58.442
MAINTENANCE BURDEN	36.316	30.791	14.783	12.549	17.533
GRD. EQUIP. DEPR.	6.376	6.397	7.350	5.889	6.014
TOTAL ($/YR/AC)	393.005	353.300	283.984	268.117	297.136
TOTAL (CENTS/SEAT MILE)	1.8	1.6	1.3	1.3	1.4

TABLE 2.2-4. TOTAL SYSTEM COST SUMMARY

($-Millions Except As Noted)

60 PASSENGER CONFIGURATION 30% DEMAND 2000 FT RUNWAY	DEFLECTED 1975	SLIPSTREAM 1985	COMPOUND 1975	HELICOPTER 1985	AUTOGYRO 1985
TOTAL SYSTEM COST					
AIRCRAFT	68.686	99.087	108.684	105.860	103.553
AIRCRAFT SPARES	7.733	11.212	12.836	12.875	12.920
FACILITIES	52.250	52.502	22.305	22.322	31.020
EQUIPMENT	1.989	2.380	2.558	2.403	2.382
AIRCRAFT OPERATING COST	309.239	355.282	492.266	465.081	477.689
FACILITIES OPERATING COST	110.154	118.390	87.029	97.815	105.618
TOTAL	550.052	638.856	725.678	706.355	733.182
FARE (1) ($/PASSENGER	5.38	5.00	7.06	5.52	5.73
FARE (2) ($/PASSENGER)	4.98	4.69	6.94	5.43	5.58
FARE (3) ($/PASSENGER)	4.51	4.30	6.69	5.23	5.32
AIRCRAFT FLYAWAY COST	2.642	3.196	3.748	3.113	3.138
FLEET SIZE (NO. OF AC)	26	31	29	34	33
AIRCRAFT UTILIZATION	1981	1931	1987	1894	2123
LOAD FACTOR (AVERAGE	.51	.56	.50	.55	.55

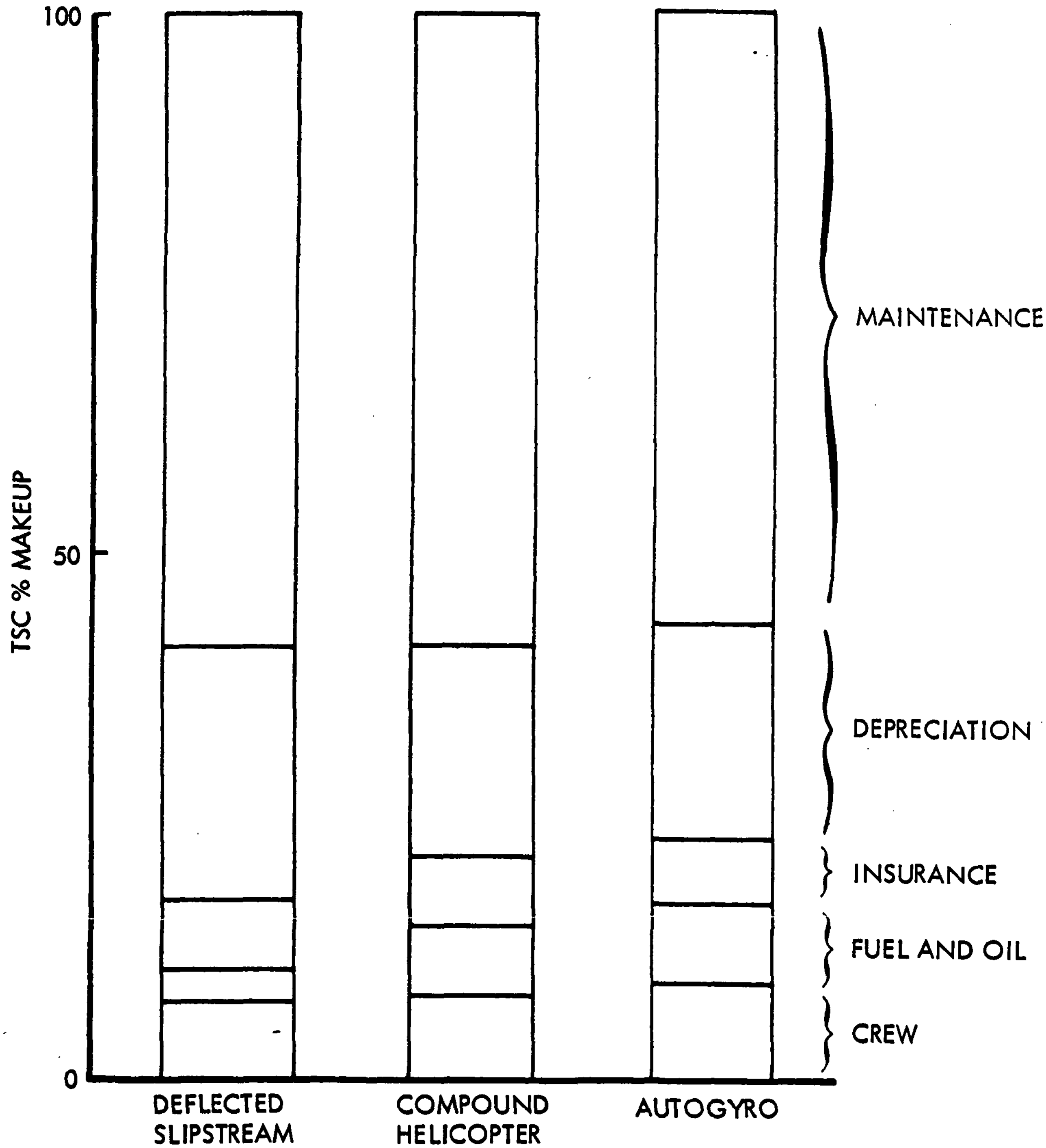

Figure 2.2-2. Percent makeup of DOC

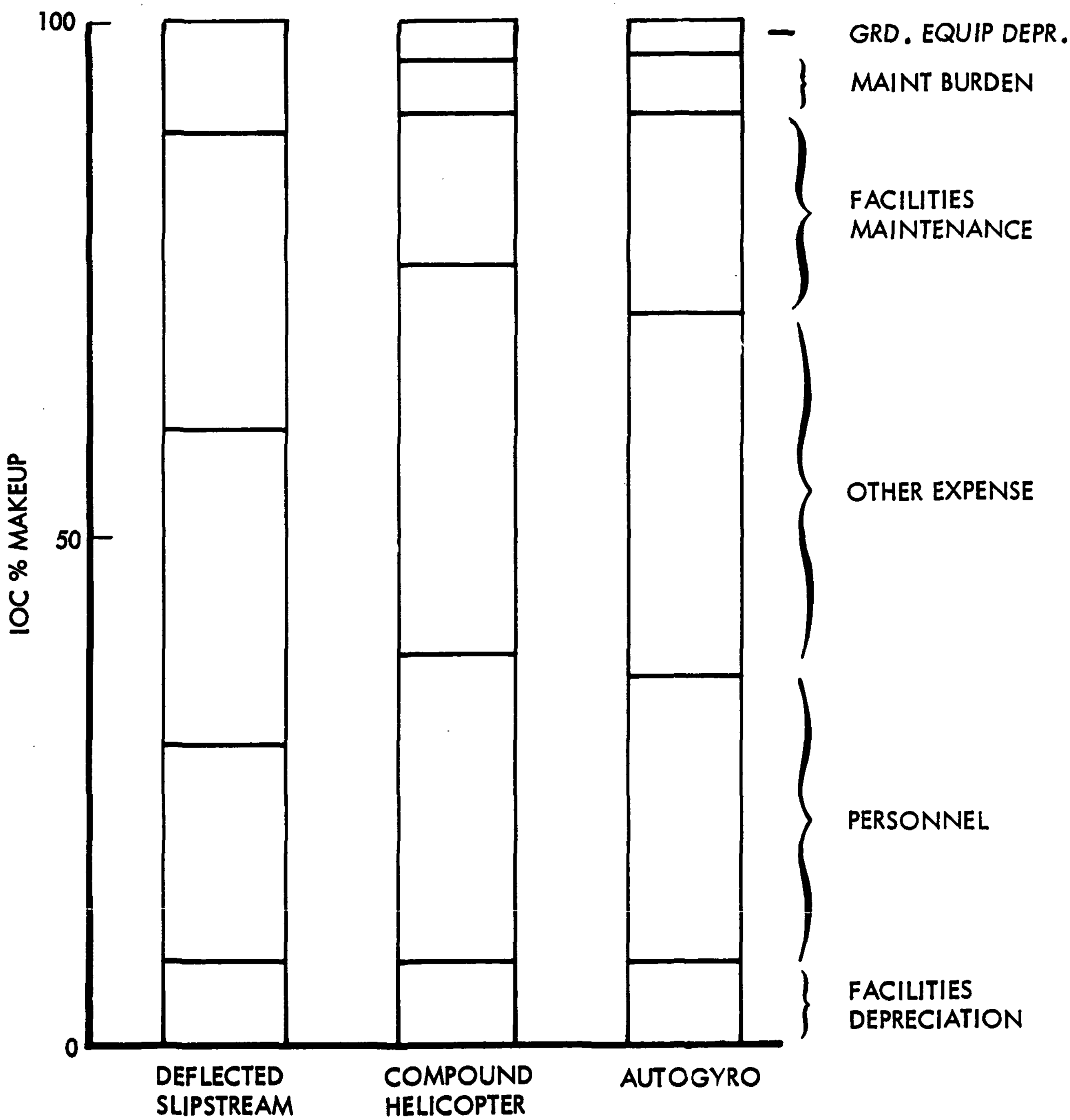

Figure 2.2-3. Percent makeup of IOC

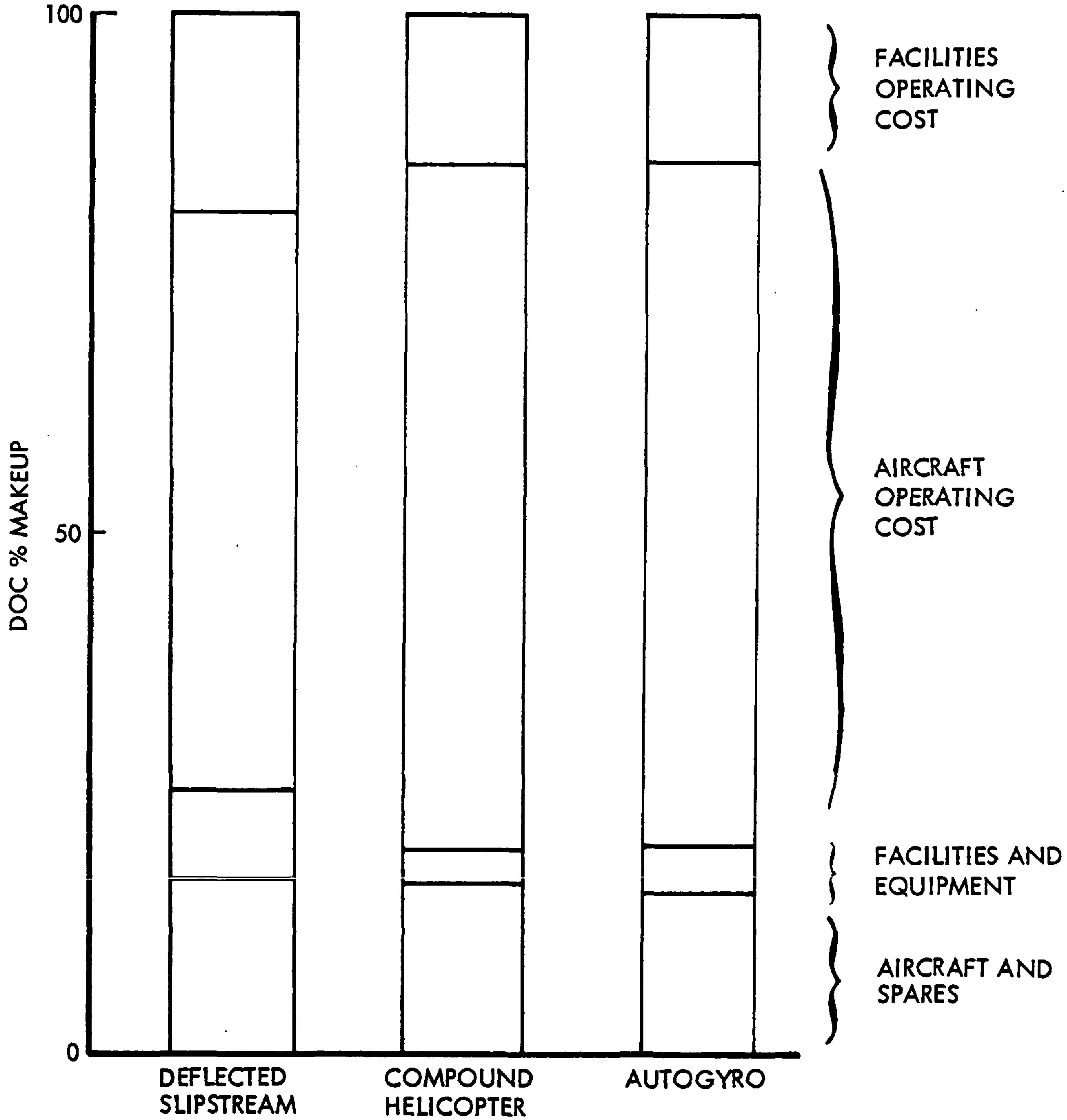

Figure 2.2-4. Percent makeup of TSC

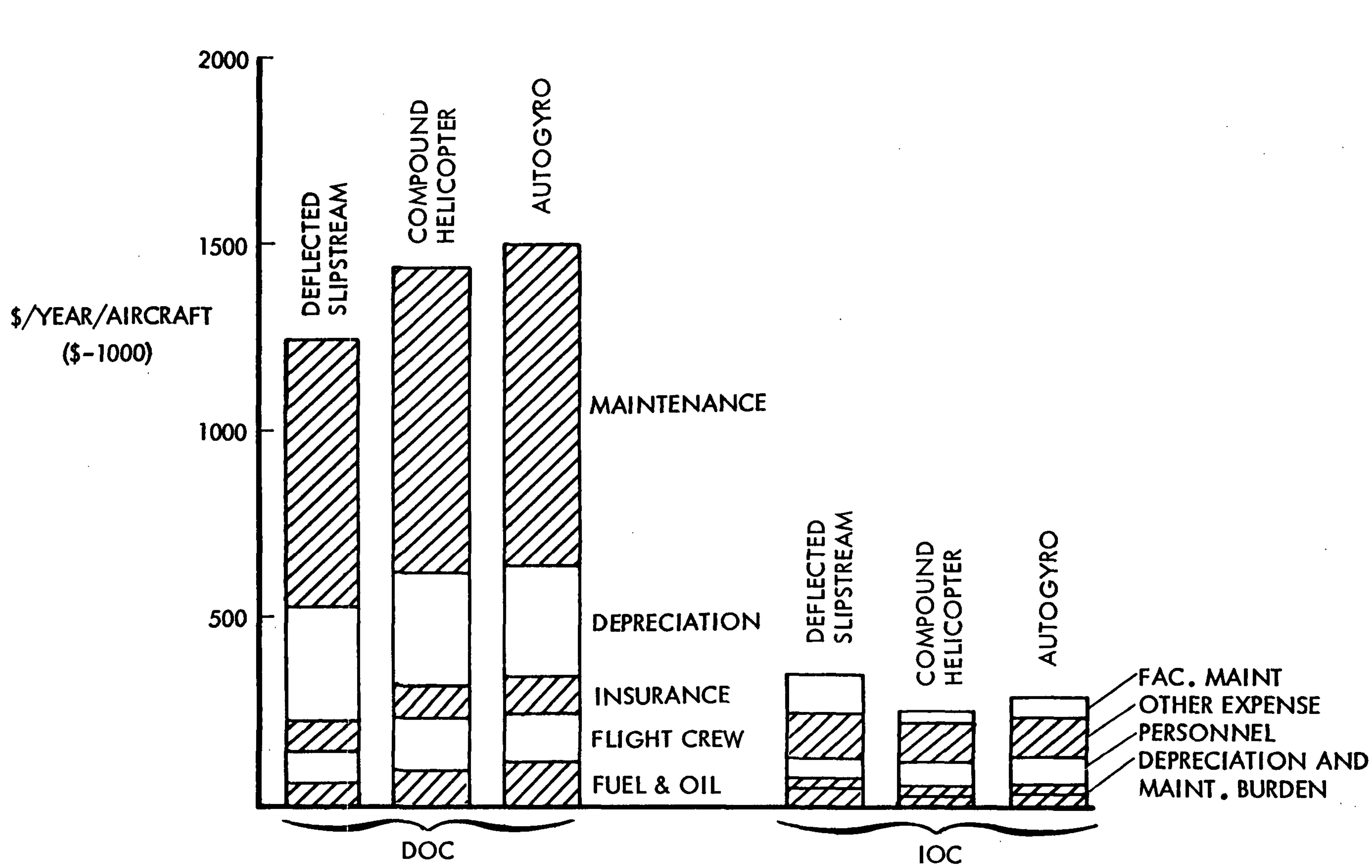

Figure 2.2-5. Comparative Evaluation - DOC/IOC Breakdown

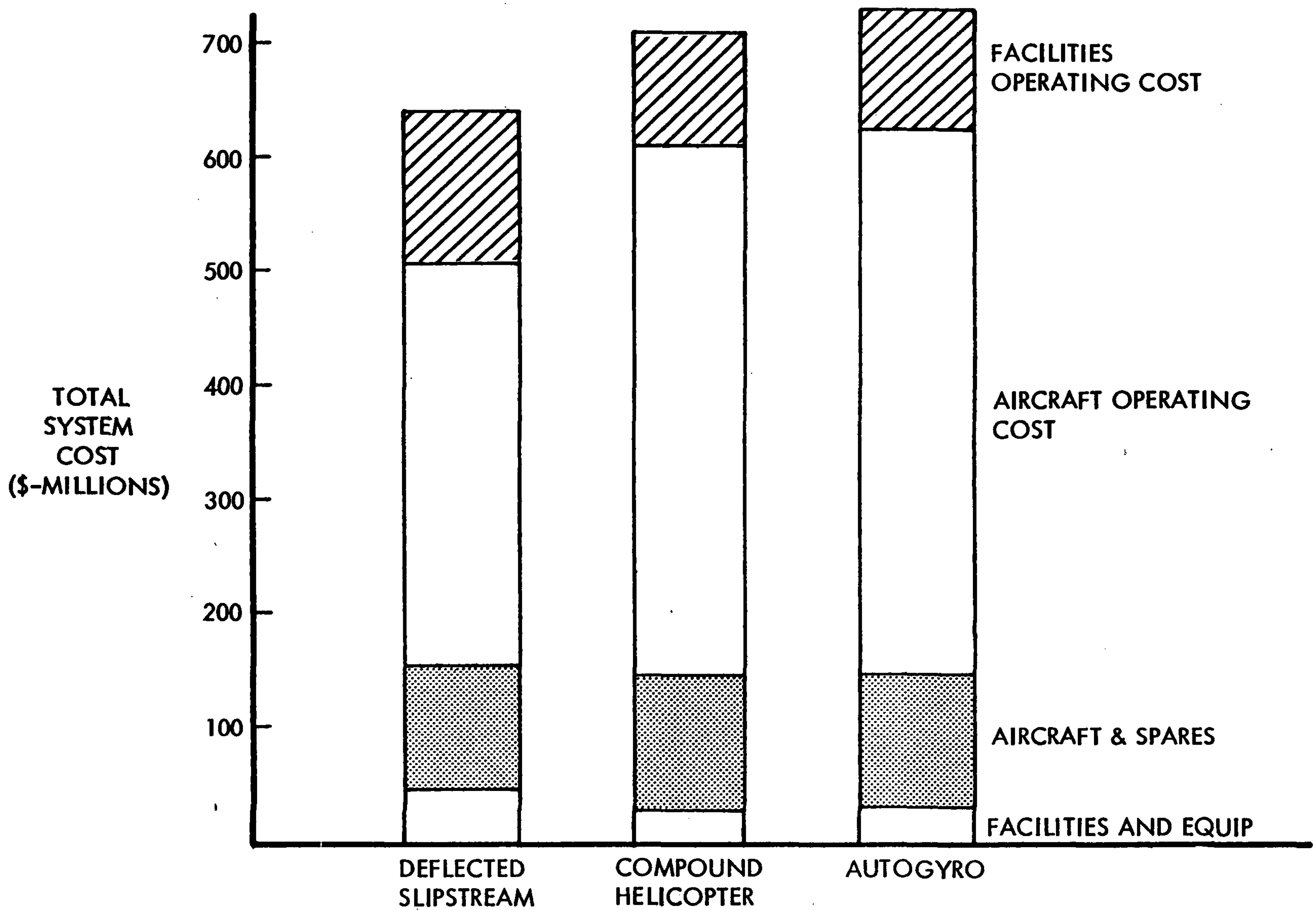

Figure 2.2-6. Comparative Evaluation - Total System Cost

TABLE 2.2-5. SUBSIDY/GRANT COMPARISON
1975 DEFLECTED SLIPSTREAM STOL

SUBSIDY	TOTAL SYSTEM COST ($-MILLIONS)		FARE $ PER PASSENGER		COST PER YEAR FOR SUBSIDY ($-MILLIONS/YEAR)
	WITHOUT SUBSIDY	WITH SUBSIDY	WITHOUT SUBSIDY	WITH SUBSIDY	
A	550	496	5.38	4.51	4.48
B	550	315	5.38	3.38	19.61
C	550	121	5.38	1.73	23.83 11.94 35.77
D	550	323	5.38	3.45	12.6 6.3 18.9

D. The same as subsidy "C" except that the revenue is predicated on a fare of $3.45. The fare is based on the assumption that a commuter is willing to pay this, provided the commuter service makes it possible for him to get rid of his second car.

The subsidy/grant analysis is based on the 1975 60-passenger deflected slipstream airplane. The amount of subsidy required for the other aircraft types would be in proportion to the fares without subsidy. The subsidies or grants are applied against fare (1) as noted in the total system cost summary (Table 2.2-4). In the case of subsidy "C" and "D" the grant aid would be $23.83 million and $12.6 million, respectively per year for 2/3 of the operating cost not covered by revenue. The remainder in each case ($11.94 million and $6.3 million) would have to be subsidized by another agency. The total system cost without subsidy in each case is what the operator would be responsible for and the remainder would be covered by some form of subsidy or grant to bring the fares to the levels shown. The fares include a profit for the operator of the system.

2.2.1.3.2 Fare Structure

The fare for the intraurban transportation system is calculated in various ways for comparison purposes. The various methods of calculation allow for different assumptions dealing with ownership and grants. The various fare structures are described below.

- The first method (1) is a calculation of the fare on the basis of total system cost. The fare is determined by dividing total system cost plus profit by the number of passengers served during the 12-year life of the aircraft system.

$$\text{Fare (1)} = \frac{\text{(TSC) (PROF)}}{\text{APASS(DA)}}$$

- The second method (2) is a calculation of fare on the basis of the DOC and IOC. This method differs from (1) in that it does not include the cost of the land. Land cost is not included in the depreciation of facilities in the determination

- of IOC, but it is included in the facilities cost in TSC. Land may be donated by the city at no cost to the operator.

$$\text{Fare (2)} = \frac{(DOC + IOC)PROF}{APASS/XNAC}$$

- The third method (3) is an attempt to derive a fare structure similar to that of current airlines. The cost for the facilities and the facilities maintenance is subtracted from total system cost, and the fare is calculated from the remainder.

$$\text{Fare (3)} = \frac{TSC-(TRMCST + XMPROP)}{APAS(DA)}$$

The fares, as calculated by the above methods, are shown in Table 2.2-4.

2.2.1.4 Technical, Operational Risks

Comparative risks from a technology viewpoint are judged to be low for all vehicle/time period combinations, except that the acoustics art needed for the 1985 rotor tip nozzle drive system is considered an unknown at this time.

The sensitivity of the several design and operational factors affecting cost are believed to be about the same for all vehicles as noted below.

- Community Noise - Ability to meet design criterion -

1975 Compound helicopter	20 pass - good 40 pass - good 60 pass - marginal 80 pass - marginal
1985 Compound helicopter	Good at all sizes with reasonable level of acoustic research through the 70's
1975, 1985 Deflected Slip-stream STOL	Good at all sizes
1985 Autogyro	Good at all sizes

- Interior Noise - Ability to meet design criterion - Good for all concepts and sizes
- Maintainability reliability - low risk for all vehicles if given proper attention in design stages
- Ride Qualities - Ride quality is a signficant problem, but somewhate less severe for the rotary wing vehicles.
- Flying Qualities - All concepts can be provided with good flying qualities with about the same design effort and aircraft complexity.

2.2.2 RESULTS

The results of exposing each of the aircraft concepts to the total systems synthesis in both the 1975 and 1985 time period can be shown in terms of (1) the number of aircraft of a given size that are needed to satisfy the commuter demand, (2) the frequency of service to be provided, and (3) the resulting fare to be paid for this service.

Two curves make up the resulting analysis for each of the aircraft concepts investigated, namely the fare and fleet variation curves. There is a set of these curves for each of the aircraft concepts investigated.

These results are presented on the following figures:

Figure 2.2-7 1975 Deflected Slipstream STOL Fare Variation
Figure 2.2-8 1975 Deflected Slipstream STOL Fleet Variation
Figure 2.2-9 1975 Compound Helicopter Fare Variation
Figure 2.2-10 1975 Compound Helicopter Fleet Variation
Figure 2.2-11 1985 Deflected Slipstream STOL Fare Variation
Figure 2.2-12 1985 Deflected Slipstream STOL Fleet Variation
Figure 2.2-13 1985 Compound Helicopter Fare Variation
Figure 2.2-14 1985 Compound Helicopter Fleet Variation
Figure 2.2-15 1985 Autogyro Fare Variation
Figure 2.2-16 1985 Autogyro Fleet Variation

For each of these concepts and within the upper and lower limits of the market demand investigated, the optimum combination of aircraft size, load factor, fleet size, and frequency of service has been determined in terms of minimum fare. Using the fleet variation curve in conjunction with the fare variation curve for each of the concepts, it is possible to readily see the effect of changing the fleet size and/or the load factor, or any of the other parameters. For all of the data points shown on these curves a real-world route and flight schedule has been solved for and used in the analysis to determine the total system cost.

The final step consists of cross plotting the minimum fare points against the number of passengers served for each of the concepts in both the 1975 and 1985 time periods. Figure 2.2-17 shows the final stacking of the aircraft concepts for both time periods. In both the 1975 and 1985 time periods, the deflected slipstream STOL concept proves to be the minimum fare system.

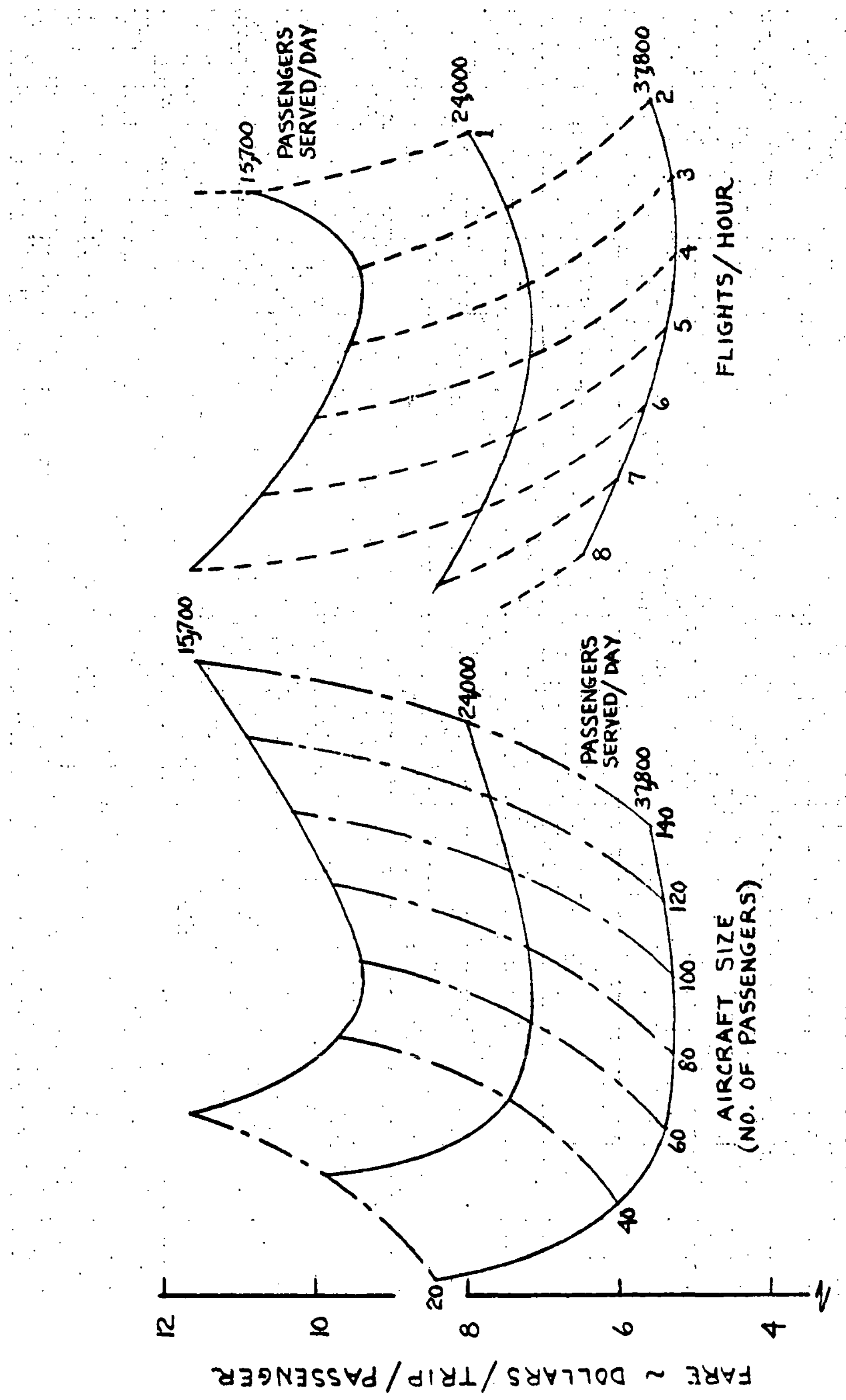

Figure 2.2-7. 1975 Deflected Slipstream STOL Fare Variation

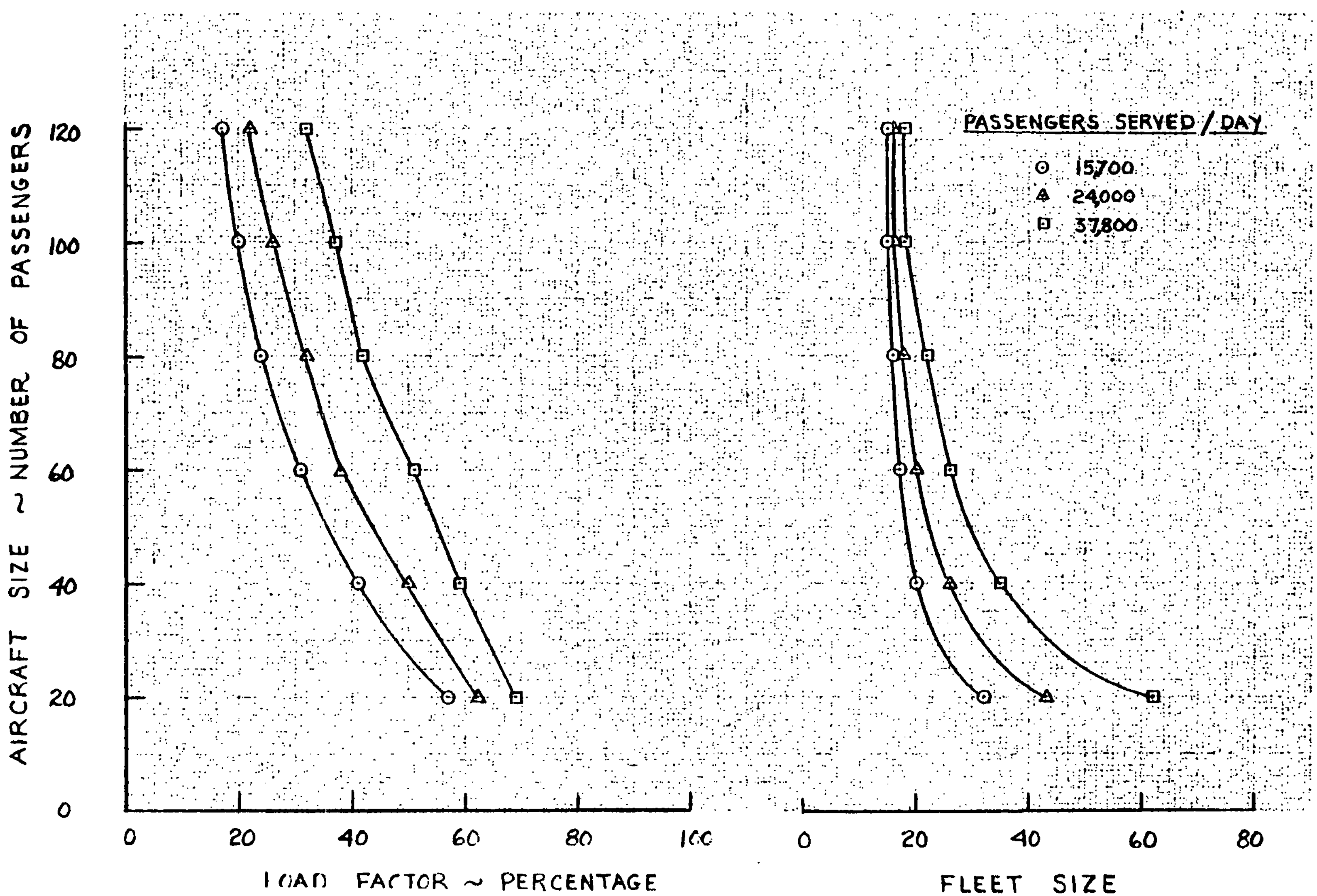

Figure 2.2-8. 1975 Deflected Slipstream STOL Fleet Variation

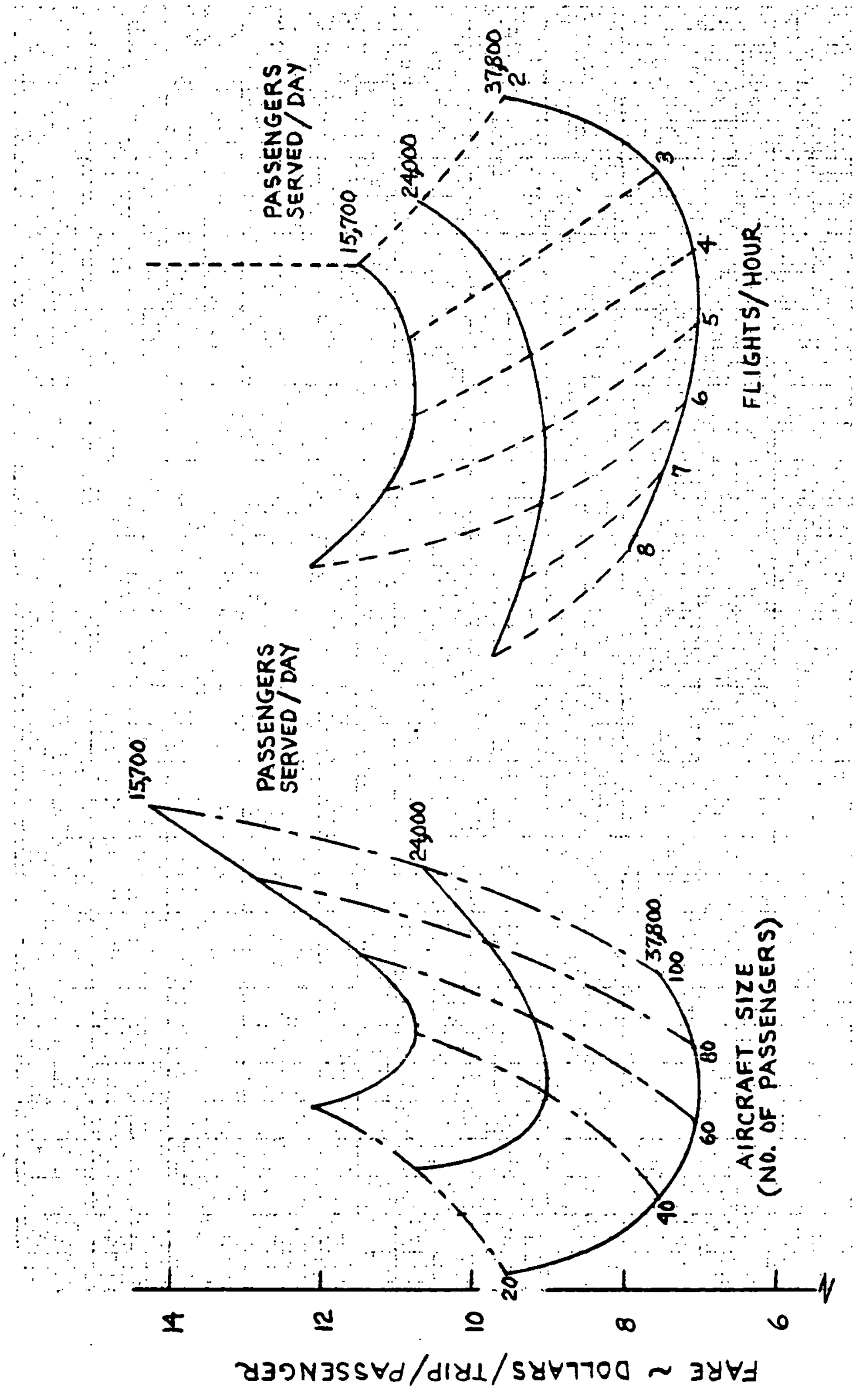

Figure 2.2-9. 1975 Compound Helicopter Fare Variation

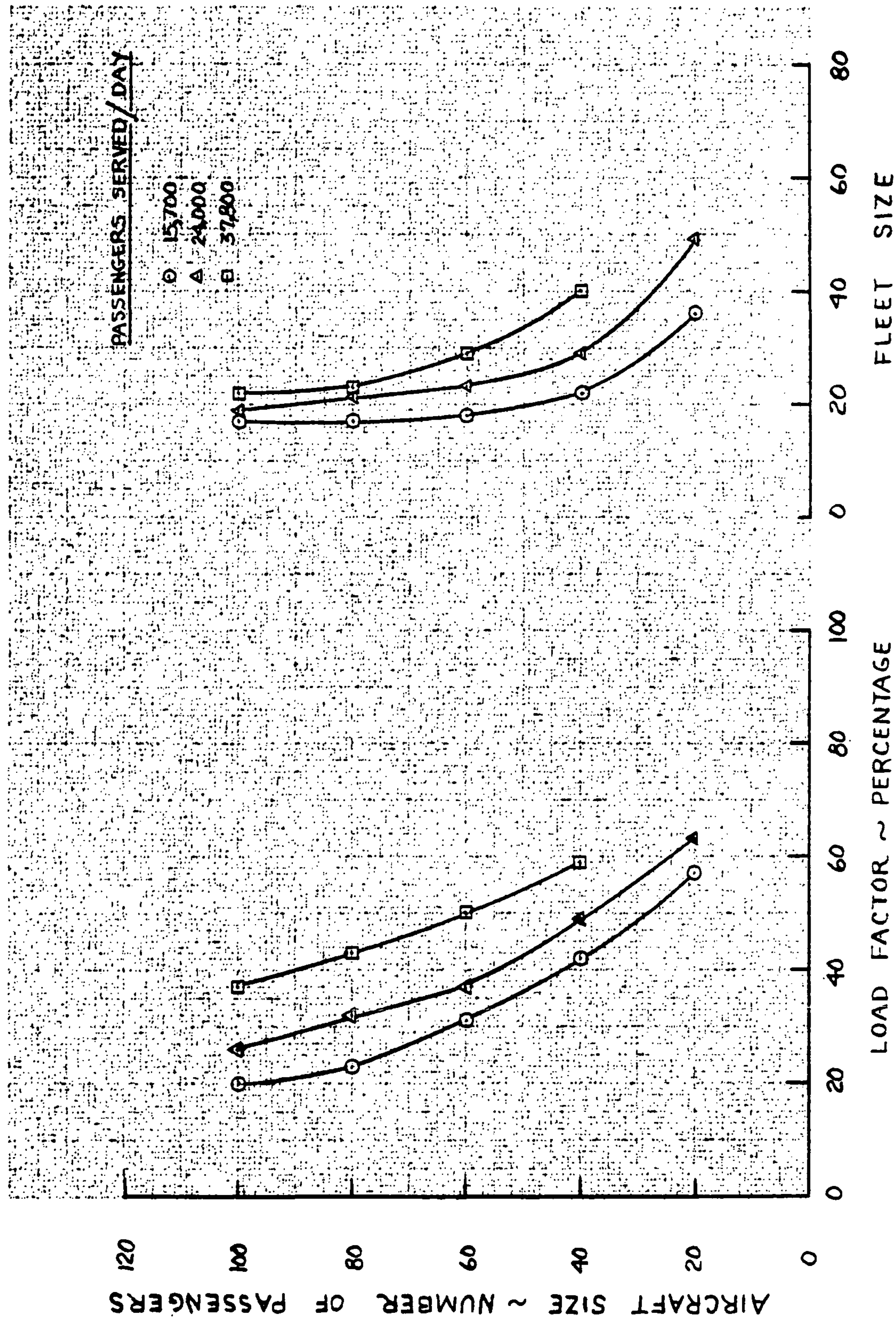

Figure 2.2-10. 1975 Compound Helicopter Fleet Variation

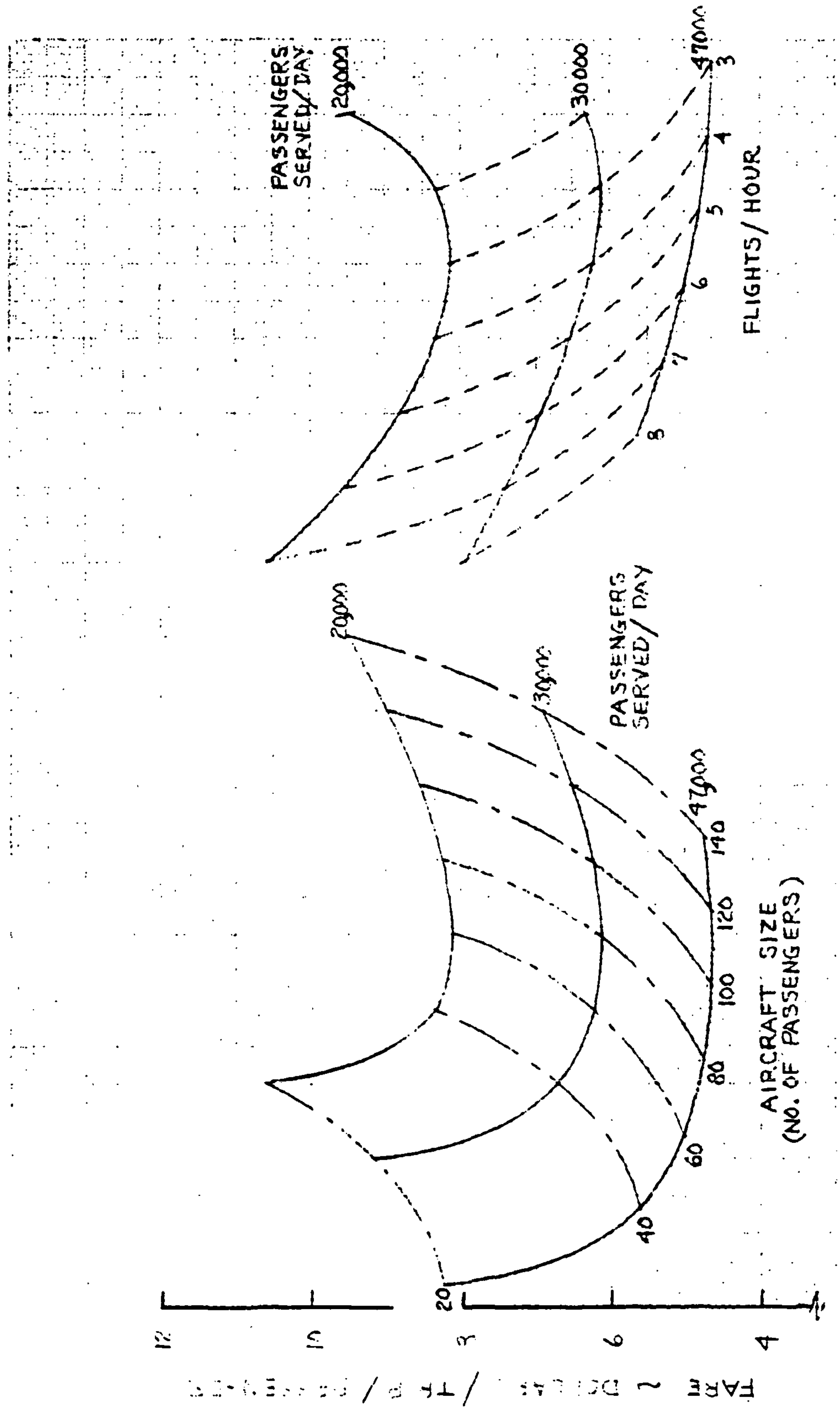

Figure 2.2-11. 1985 Deflected Slipstream STOL Fare Variation

LOCKHEED
CALIFORNIA COMPANY

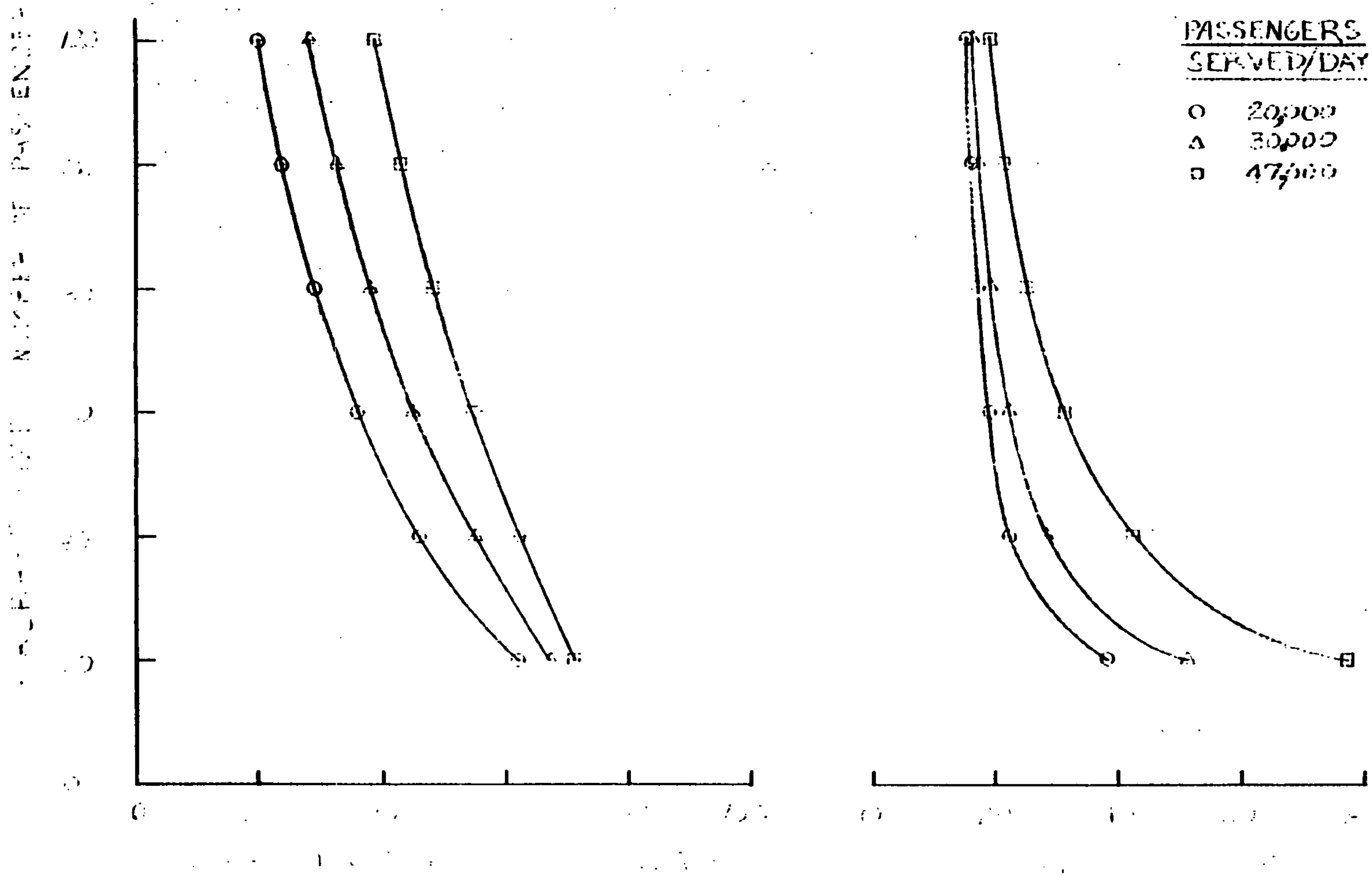

Figure 2.2-12. 1985 Deflected Slipstream STOL Fleet Variation

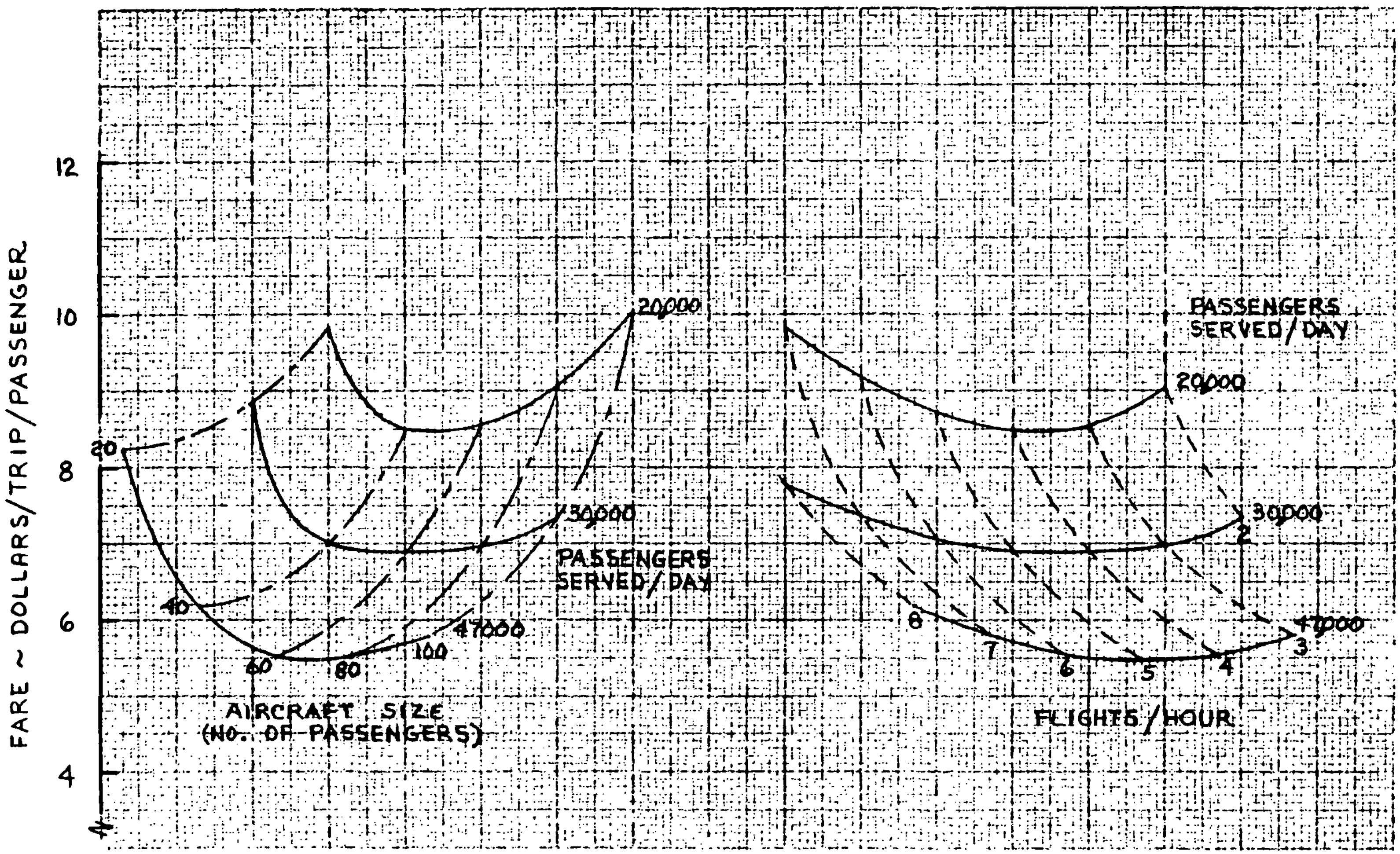

Figure 2.2-13. 1985 Compound Helicopter Fare Variation

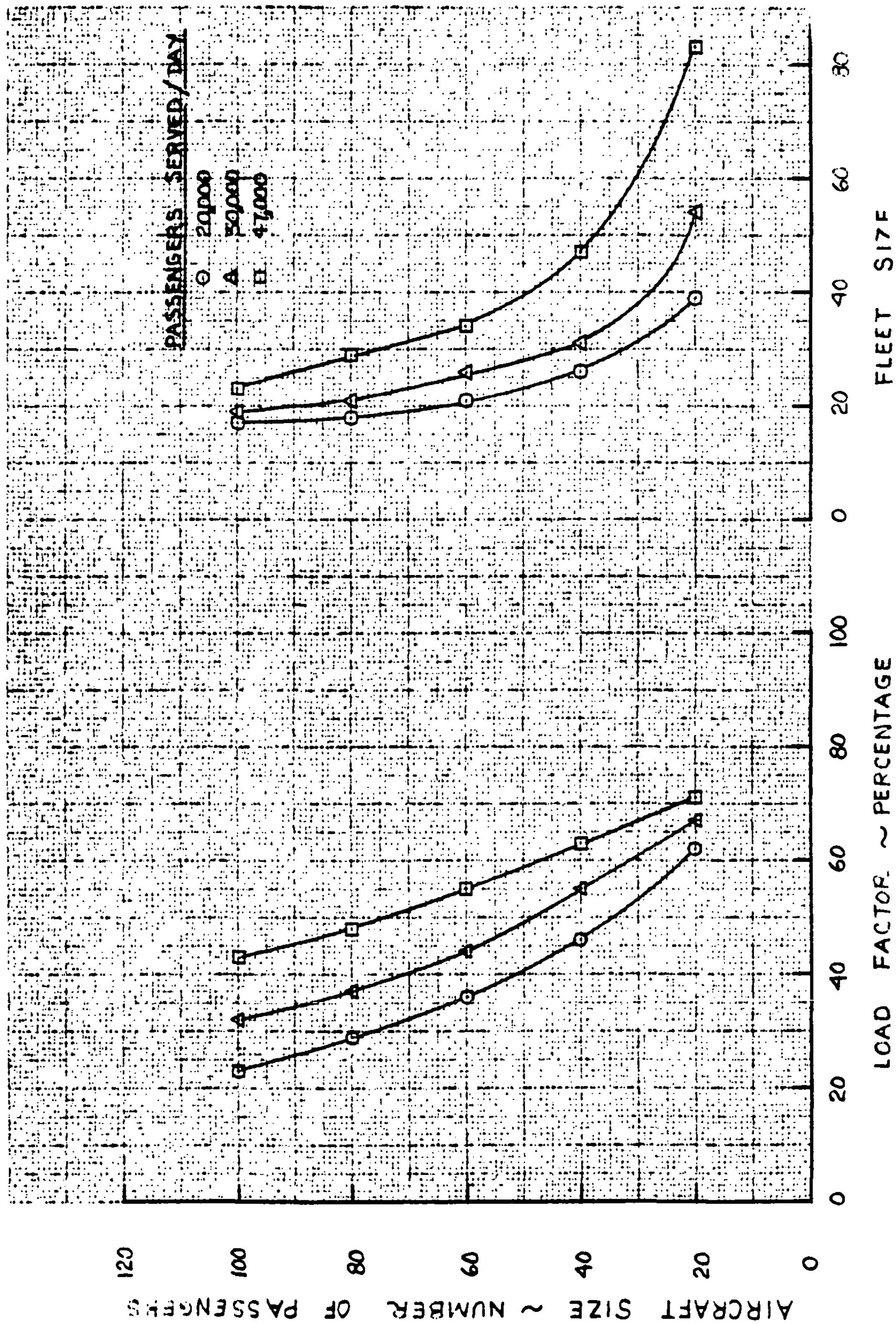

Figure 2.2-14. 1985 Compound Helicopter Fleet Variation

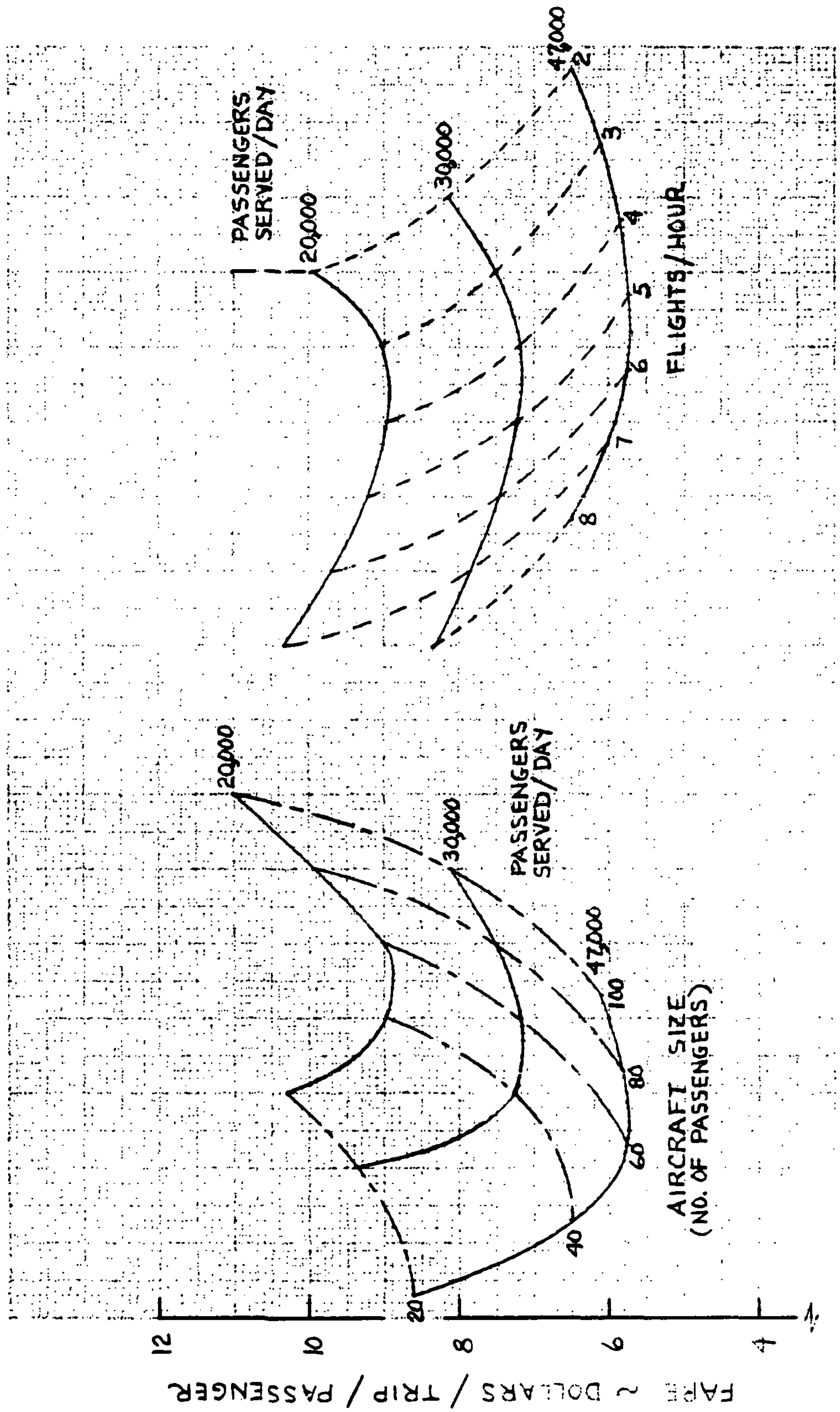

Figure 2.2-15. 1985 Autogyro Fare Variation

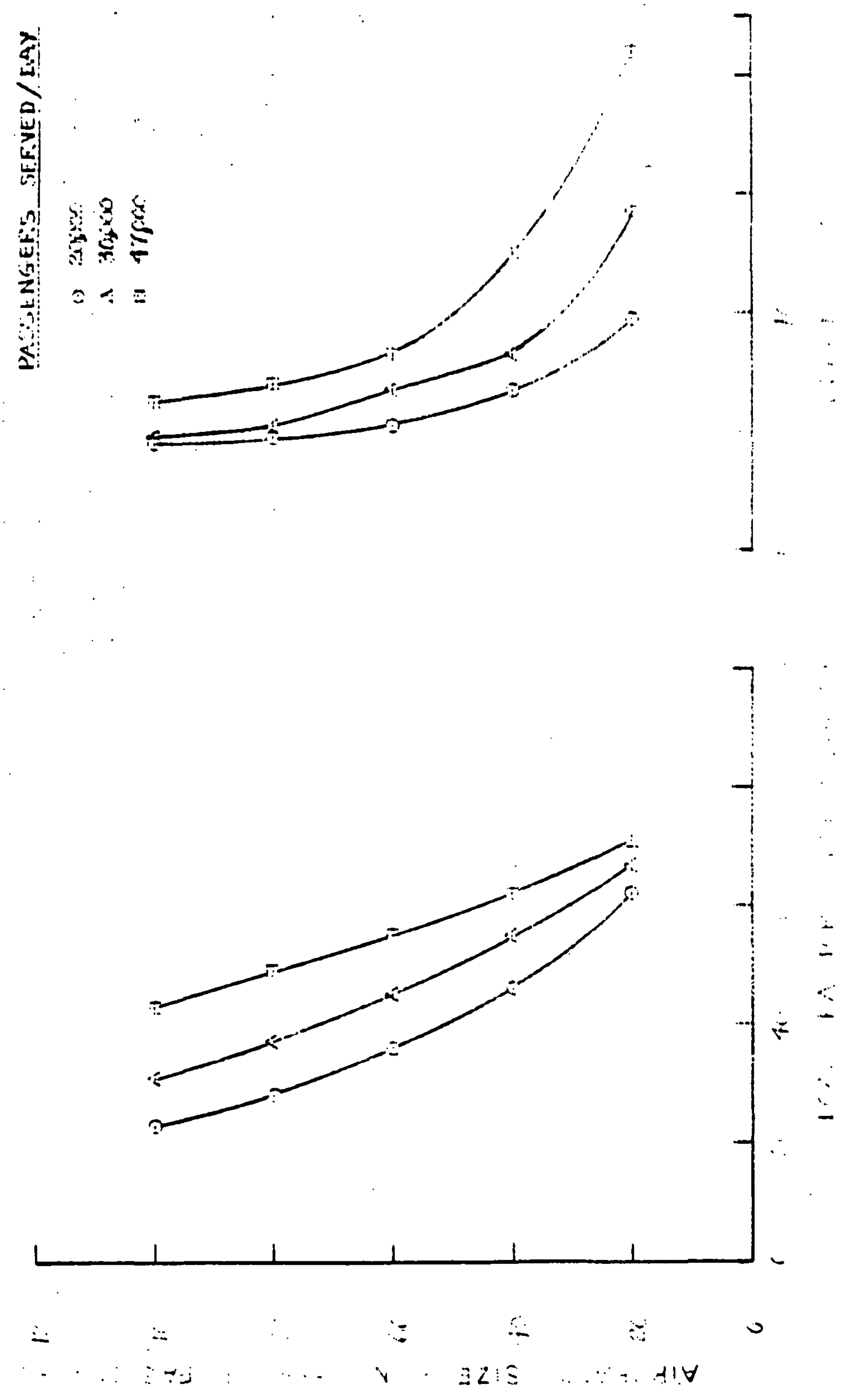

Figure 2.2-16. 1985 Autogyro Fleet Variation

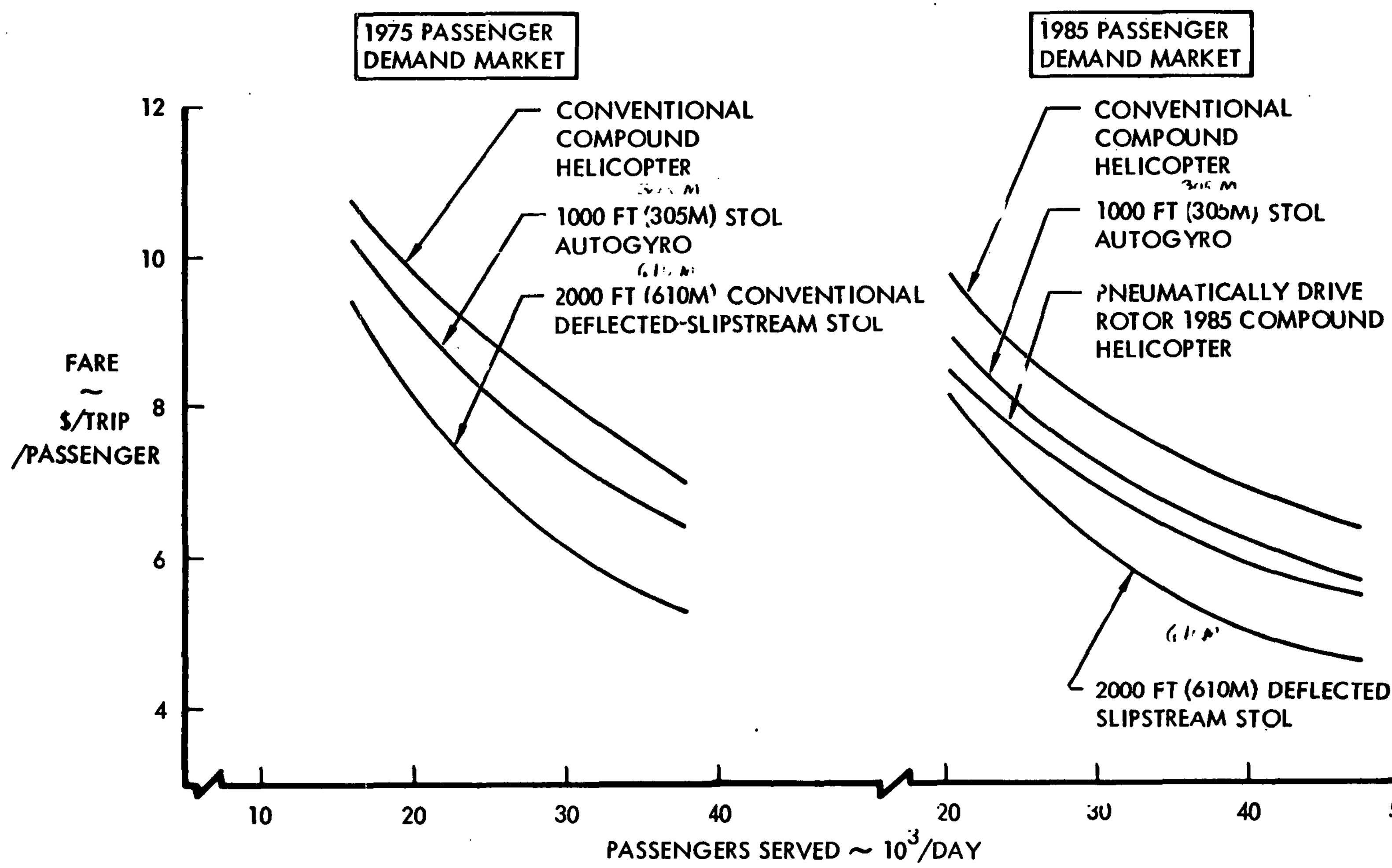

Figure 2.2-17. Fare vs. Demand Comparison for all Concepts

In addition to analyzing the previously described concepts, the 1985 autogyro was projected into the 1975 market and the 1975 conventional compound helicopter was extended into the 1985 market.

The 1000 foot STOL autogyro fares lie half way between the 1975 conventional compound helicopter and the 2000 foot deflected slipstream STOL. However in a high land cost situation the 1000 ft STOL autogyro might well provide the minimum fare.

The conventional compound helicopter extended into the 1985 market shows no advantage over all of the other concepts analyzed in this time period and proves to be the most expensive.

3.0 CONCLUSIONS

3.1 AIRCRAFT DESIGN-DEVELOPMENT-OPERATION

- Current technology is adequate for the development of an intraurban transport aircraft for the 1975 IOC time period.
- Advanced technology appears tc offer largely indirect benefits to the intraurban transport, if., potential for reduced maintenance costs, reduced noise, more reliable automated systems, etc.
- The compound helicopter VTOL, and deflected slipstream STOL concepts are judged to be low design-development risks for both 1975 and 1985 IOC time periods. The 1985 autogyro STOL is likewise considered low risk.
- The autogyro STOL is believed to have more growth potential through configuration development than either the compound helicopter VTOL or the deflected slipstream STOL.
- Aircraft operation in the intraurban scenario is grossly different from intencity operations, and its development will require new design and operational standards.
- Aircraft noise and ride qualities are key elements in the development of an acceptable intraurban transport system
- An aircraft intraurban transport operation will reduce air pollution slightly in the Detroit area.

3.2 COST/FARE/SCHEDULE

- For all of the market demands invesitgated, the 2000 foot deflected slipstream STOL concept is the most cost effective aircraft in terms of minimizing the fare by a margin of 4 to 22 percent, depending on the demand.
- The 1000 foot STOL autogyro shows promise where land is not available for the building of a 2000 foot STOL commuterport
- The optimum aircraft size for the deflected slipstream STOL in this market is 110 passengers and would provide a frequency of

service of three to four flights per hour at the high demand commuterports. A fleet of 20 aircraft would be required to satisfy this demand and would operate with an average load factor of 42 percent.

3.3 GENERAL

This study has shown that the application of aircraft to relieve the Detroit intraurban mass transportation problem is feasible.

None of the three aircraft concepts evaluated is distinctly superior to the others, although indications are that the deflected slipstream STOL may be somewhat better.

4.0 RECOMMENDATIONS

- The autogyro STOL is shown to be generally competitive with the helicopter VTOL and fixed wing STOL concepts. It is therefore recommended that the study be extended to permit a more complete design analysis of this new STOL transport concept. In particular, an invesitgation of the aero-structural rotor geometry for this 100% windmilling mode is needed.
- Using the knowledge gained through this work, a first generation intraurban transport should be defined.
- In consideration of the long calendar time involved in establishing certification standards for aircraft, initial study efforts for the forthcoming, intraurban transport aircraft should commence now.
- Public acceptance of an intraurban transport will depend to a significant degree on its "noise in the neighborhood" and its ride comfort. Both intraurban transport oriented acoustic research studies, and ride comfort studies should be initiated.
- Study results show maintenance to be a predominate cost, and the portion of maintenance sensitive to flight cycles to be responsible for over 80% of the total maintenance cost. Study limits did not permit a detailed design-for-maintenance analysis wherein each major component of the airplane is examined for the tradeoff between cost, maintenance, and performance. The short stage lengths (20 to 30 miles) reduces the sensitivity of the aircraft performance to cost. Additional weight or drag does not significantly affect the overall system cost. Thus, additional weight (at some cost) may be added to the airframe, engine, or subsystems to increase their reliability and decrease maintenance without a large degradation in system performance. In view of the above, it is recommended analysis be undertaken to determine how much cost may be reduced through the design-for-maintenance philosophy, and how much degradation in system performance will result.

- There is a critical need for continued research in the area of modal split analysis, and especially for the development of a simple model or methodology for the generation of gross modal split data based on the origin-destination demand data integral to the various regional transportation studies. It is suggested that such a model be based on the value of time concept that considers the fundamental differences in productive, recreational, and nonproductive time (as defined or determined by the traveler). The output of such a model should be families of generalized curves (functions) that relate dollar value to travel time for various factors such as trip purpose, trip length, income levels, etc. The curves could then be used by all contractors performing demand analyses for government agencies and not requiring high degrees of accuracy. These curves would be especially well-suited to parametric analyses. In addition to this, the relationship between frequency of service and commuter demand should be developed.

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