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STUDY OF AIRCRAFT IN INTRAURBAN TRANSPORTATION SYSTEMS

Final Report

VOLUME 1

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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.

Submitted by

E. G. STOUT
Engineering Study Manager

APPROVED

D. L. Kelly, Dept. Engineer
Advanced Systems Design
Science and Engineering

APPROVED

G. L. Arnold, Acting Division Engineer
Advanced Design
Science and Engineering

LOCKHEED
CALIFORNIA COMPANY

estimates. The reference distance used herein of 1000 feet is one of several being considered as an evaluation distance for noise level certification of STOL aircraft, and is therefore used as a resonable representative distance.

The PNL rating method units, PNdB's, are logarithmic in nature and are expressed in such a manner that a change of 10 PNdB represents either a doubling or halving of the annoyance level. It should be recognized at the outset that excessive noise levels could rule out certain configurations or sizes of vehicles which would otherwise be of practical use as intraurban transports.

The primary thrusting devices used on the aircraft being studied can be classified as rotors, propellers, and turbofans. The noise generated by these various propulsion systems may be rank ordered by means of a parameter called the "disk loading," which is simply the thrust developed divided by the thrusting area. For example, considering vehicles in a 60 000 lb. category, Figure 1.1-22 presents a plot of perceived noise level versus disc loading for the range encompassed by the aforementioned aircraft propulsion systems. The perceived noise levels used in the development of Figure 1.1-22 are based on measured noise levels of current transports having a T/W of 0.25 to 0.3, typically, with necessary adjustments applied to obtain noise levels equivalent to a 60 000 lb. gross weight aircraft at a distance of 500 feet. The data are for engines without acoustical treatment operating in a takeoff mode.

The noise generated by rotors is characterized by a very low frequency blade passage, or rotational, nose, and a higher frequency peaked broadband "vortex" noise. Propeller noise is essentially the same as rotor noise but with both the rotational noise and "vortex" noise occurring at higher frequencies. Power for both the rotors and propellers employed in this study comes from turboshaft engines. Turbofan engine noise is composed of both the fan noise and the turboshaft engine noise. The fan noise is similar to rotor and propeller noise but the associated frequencies are very much higher. The noise of the turboshaft engine used to drive the rotors, propellers and fans is composed of inlet and exhaust noise. Inlet noise is generally characterized by the high-pitched discrete frequency compressor blade passage noise along with a lower level peaked broadband noise spectrum, while the

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INTRODUCTION

Studies of intraurban transportation systems, as opposed to interurban, have concentrated on approaches derived from established systems of commuter service; i.e., ground transportation related to automobile, train, subway, monorail concepts, and their advanced derivatives.

Traditional as these approaches may be, they are all characterized by relatively complex and expensive facility installations such as freeways, road, and rail networks. Consequently, their potential in terms of speed, flexibility of operational routes, and network expansion is hindered. In most urban areas, the presence of geographical or other inflexible considerations further compounds the surface transportation problem by channeling traffic to a few corridors.

Due to the burgeoning expansion of the megalopoleis of the world, studies of future intraurban metropolitan transportation systems always emphasize the need for speed and flexibility. However, these studies do not usually include consideration of aircraft which inherently have these characteristics. Recent preliminary studies by NASA's Advanced Concepts and Missions Division, and others, have analyzed the use of aircraft for this short range, high density, commuter transportation. The results of these cursory studies indicate a potential for aircraft in this scenario. This study is an in-depth followup to the NASA preliminary analysis.

The basic purpose of this study is to conduct a quantitative technical and cost analysis of the potential for the employment of aircraft to provide effective short range, intracity mass transportation.

In response to the NASA request to select a "representative" United States city upon which to base a real-world market scenario for an intraurban air transportation system, Lockheed conducted a cursory examination of the major metropolitan areas outside of the heavily studied Northeast Corridor. Of primary importance was not only the "representativeness" of the study area, but the availability of a satisfactory transportation and land use data base in an urban area that is experiencing growth and transportation problems not unique to itself, but common to most regions.

Upon the approval of NASA, Lockheed selected the seven-county Transportation and Land Use Study (TALUS) region of the Detroit Metropolitan Area (see pocket, inside front cover, Volume 1) as its prime area of interest for this study.

The intraurban (short range, high density) commuter market is characterized by the following basic requirements:

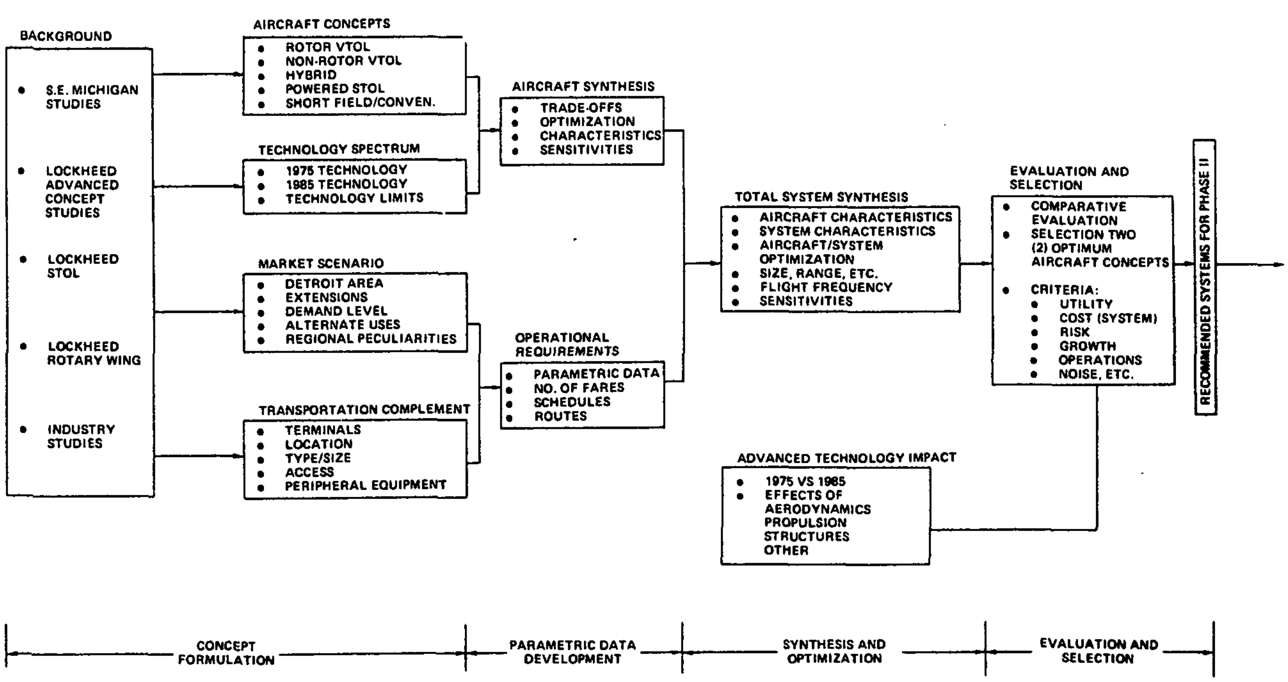
- Efficient service during "peak" hours
- Operation in a variety of environments (downtown, suburbs, new communities, etc.)
- Ability to adjust to changes in demand trends, land usage patterns, technology advances, etc., with a minimum disruption to service and maximum preservation of effectiveness of capital investment
- Ability to expand rapidly to undeveloped areas and thus encourage city growth

It follows then, that the basic features of aircraft; i.e., speed and flexibility, may be uniquely suited to satisfying a significant portion of the needs of the potential intraurban transportation market. Other factors favoring the use of aircraft include:

- Initial land investment may be relatively modest (short field terminals, "commuterports," heliports), tailored to the specific application, and expanded as the need arises
- Routing structure is extremely flexible, compared with that for ground systems
- The aircraft vehicle itself may be used for alternative purposes (mail, cargo, recreation) during off-peak hours

From an advanced technology and systems planning standpoint, certain key items require study to enable formulation of a viable intraurban air transportation system. First, an optimum flight vehicle (VTOL, STOL, etc.) must be conceptually defined, based on major parameters of size, speed, range, and field length. Second, special emphasis must be placed on the terminal in relation to location, passenger management techniques, aircraft turnaround concepts, and passenger access systems (buses, autos, etc.). Finally, a detailed definition of the economic potential or liability of the system must be made. It would include funding, acquisition costs, operating costs (direct and indirect), tariffs, and subsidies.

Lockheed's approach is to divide the study into two phases: (1) Aircraft Concepts Selection, and (2) Aircraft Concepts Evaluation for two time frames: 1975 and 1985. The Detroit metropolitan area was chosen for the real-world scenario, but the approach, logic, and computer models used are adaptable to any intraurban or interurban area. Each phase is described briefly in the following paragraphs.



PHASE I SUMMARY FLOW CHART - AIRCRAFT CONCEPTS SELECTION

As indicated along the bottom line of the above flow chart, this phase comprises four stages: concept formulation, parametric data development, synthesis and optimization, and evaluation and selection.

1. Concept Formulation is designed to consider the total spectrum of candidate aircraft alternatives; to define the 1975 and 1985 technology; to develop the market scenario, thus providing the basis for projecting total transportation requirements and traffic demands in terms of volume, distance, and time; and to define the nature and cost of the elements (in addition to the aircraft) that are necessary to provide an effective total system.

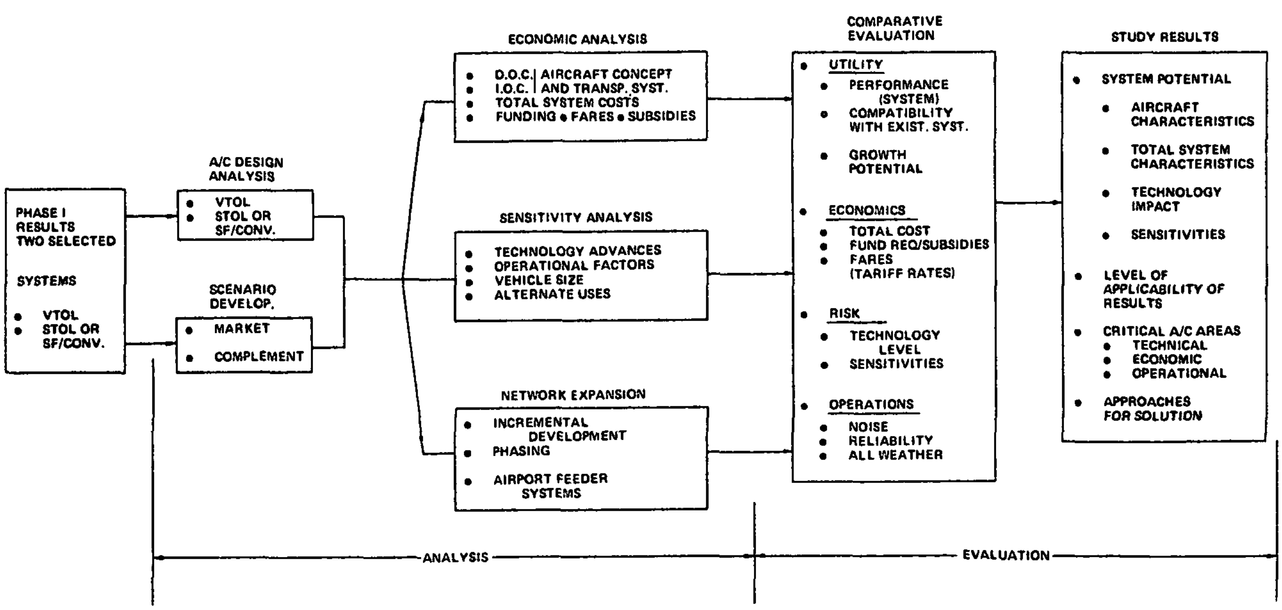
2. Parametric Data Development concentrates on development of a bank of parametric data from which sensitivity of the major aircraft variables such as wing loading/disk loading, thrust-to-weight ratio, aspect ratio, gross weight, passenger capacity, field length, flyaway cost, direct operating cost, etc., can be optimized on the basis of the operational parameters involved. The aircraft synthesis process is performed by integrating these data in the Lockheed Advanced System Synthesis and Evaluation Technique (ASSET) computer model, which can handle all physical and costing parameters required in the optimization process. From these data and the parametric definition of operational requirements, the ASSET computer model generates schedules and parametric operational data such as utilization, fleet size, load factors, turnaround time, and flight times, for each aircraft concept.

3. Synthesis and Optimization yields the ability to: (1) synthesize the total transportation system by combining the parametric vehicle design data with operational/market data of the previous tasks; (2) establish for each aircraft concept the optimum values of passenger capacity, range, speed, and field length (when applicable) on the basis of total system

suitability and total system cost; (3) determine the impact of advanced technology on system characteristics and effectiveness; and, (4) specify, for each of the aircraft concepts:

- Passenger capacity/fleet size
- Terminal location and landing field size
- Range/endurance and trip distance
- Fares vs operating subsidies
- Frequency of service and load factors
- Speed (if applicable), turnaround time, and total trip time

4. Evaluation and Selection is the comparative study of the optimized transportation systems derived in the previous synthesis for each of the conceptual classes -- VTOL rotor, VTOL non-rotor, Hybrid, Powered STOL and Short-field Conventional aircraft, resulting in the selection of at least one VTOL and one STOL aircraft concept for further detailed analysis in Phase II.



PHASE II SUMMARY FLOW CHART - AIRCRAFT CONCEPT EVALUATION

As illustrated in the above flow chart, this phase of the study comprises two parts: analysis and evaluation.

1. Analysis consists in redefining, in depth, the aircraft concepts and transportation systems selected in Phase I. Analyses are conducted in such areas as:

   - Aircraft Design - To provide final data for the economic and sensitivity analyses, the selected aircraft concepts are point designed, final weight statements are prepared, and detailed performance data are generated for each concept mission profile. A baseline system and aircraft avionics suite are developed, and noise levels are computed for takeoff, cruise, and landing including the construction of applicable noise contours.

   - Scenario Development - Based upon the cursory analyses of Phase I, the final transportation system is defined with regard to the selection of the commuterports, routing, transportation complement, and allocation of the demand data to the applicable zones of service.

   - Economic Analysis - Detailed economic analyses are made for the selected transportation systems. These studies include all elements of direct and indirect costs for both the aircraft and the corresponding transportation complement, and they produce detailed breakdowns for the systems studied. Tariffs are established, and the potential necessity of subsidies for both fares and facility acquisition is considered. Total costs for the complete systems are determined.

   - Sensitivity Analysis - A series of comprehensive sensitivity analyses are made on the selected systems. These studies establish the effects of (1) advanced technology in such areas as aerodynamics, electronics, structures, propulsion, etc., (2) operational factors such as acceptable noise levels, vehicle sizes, alternative use for mail or freight, turnaround requirements, etc., and (3) assumptions in the generation of basic input data such as demand levels, cost factors, and design features.

- Network Expansion - In conjunction with the economic and sensitivity analyses, a plan of network expansion is shown. This includes a logical progression from inception to full projected service in the scenario, and the effects of such factors as incremental development, phasing, and airport feeder systems.

2. Evaluation consists in the comparative appraisal of the selected systems and the study results such as:

   - Each conept's potential for intraurban transportation in terms of aircraft and systems characteristics technology level, cost, and operational factors
   - Sensitivity of aircraft performance to aircraft design parameters and to system operational characteristics
   - Observations on the applicability of the intraurban systems of this study to the generalized intraurban transportation problem and the possible limiting boundaries of technical or economic feasibility
   - Recommendations identifying key problem areas where additional research may result in significant improvements in intraurban aircraft transportation systems

Past Lockheed in-house studies have shown a potential for a modern technology autogyro STOL in the short haul scenario. Therefore, Lockheed evaluated this concept alongside the contract required concepts as a parallel study during Phase I, and since it showed interesting potential it was added to the vehicle concepts selected for further in-depth study in Phase II.

The Phase I detailed flow chart shown on the following page is reproduced from the original Lockheed proposal. It depicts the scope, content, sequence, and output of the Phase I study. Inasmuch as Phase II is an in-depth iteration of Phase I, and deviations from this plan during the course of the study were minimal, it is included as a comprehensive guide (or road map) of the total study effort.

Flow Diagram for NASA Intraurban Transportation System Study

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SUMMARY

The results of the Lockheed-California Company's work in compliance with a two Phase NASA Contract, "A Study of Aircraft in Intraurban Transportation Systems," is summarized below. The work was started in June 1970 and was completed in May 1971.

This study was undertaken following cursory studies by the NASA Advanced Concepts and Missions Division which indicated a potential for application of aircraft to provide effective short range intraurban mass transportation.

The objectives of this study were:

- Define the technical, economic, and operational characteristics of an aircraft transportation system for short-range intracity commuter operations
- Assess the impact of advanced technology on the system
- Determine the sensitivity of mission performance to changes in aircraft characteristics and system operations
- Identify key problem areas where additional research may result in significant improvement in short haul aircraft transportation systems.

The seven-county Detroit, Michigan, Metropolitan Area, considered typical of many large metropolitan centers, was utilized as the scenario for the analysis.

The Phase I study consisted of an analysis and forecast of the Detroit metropolitan market through 1985, a parametric analysis of appropriate short haul aircraft concepts and associated ground systems, and a preliminary overall economic analysis of a simplified total system designed to evaluate the candidate vehicles and select the most promising VTOL and STOL for further detailed analysis in Phase II.

The aircraft concepts evaluated in Phase I for two time frames were as follows:

Category	1975	1985
Rotor VTOL	Compound Helicopter	Compound Helicopter
Non-rotor VTOL	Tilt-Wing	Tilt-Wing
Powered STOL	Deflected Slipstream	1) Deflected Slipstream
		2) Augmentor Wing
		3) Autogyro
Short Field Conventional	Turboprop high thrust low wing loading CTOL	Turbofan high thrust low wing loading CTOL

For 1985 the deflected slipstream and augmentor wing powered STOL were initially considered to have about equal potential, and both were analyzed, while the autogyro concept was carried alongside as a Lockheed parallel study.

Analysis of greater Detroit's commuter travel patterns led to the choice of nine appropriately located "commuterports." The demand data, furnished by the Southeast Michigan Council of Governments (SEMCOG) in their Transportation and Land Use Study (TALUS), indicated that there are approximately seven million person-trips a day in this region for those earning $5000, or more, a year. Of this total, approximately 1.8 million are work-trip oriented. The demand for this study covered a parametric capture of 10 to 30% of those person-trips considered potentially eligible for an airborne intraurban transportation system after due consideration and allowance for reasonable service zones, distance travelled, and travel purpose.

A parametric synthesis-analysis using Lockheed's ASSET computer program established for each aircraft concept the relative values of passenger capacity, block speed, field length (when applicable), direct operating cost, and flyaway cost, on the basis of total system suitability and cost when impressed upon the Detroit region scenario.

The significant findings from the Phase I study were:

- The preferred aircraft concepts for detailed analysis in Phase II are:
  - VTOL - Compound Helicopter
  - STOL - Deflected Slipstream and/or Autogyro
- The operating costs of the aircraft and ground facilities dominate the final total system costs
- STOL total system costs are relatively insensitive to design runway length due to relatively low land costs in the Detroit area
- Optimum design payload, fares, and schedule frequency vary grossly with traffic volume
- Noise of the system may be the primary factor affecting community acceptance.

Phase II study was an in-depth reiteration of the analyses of Phase I wherein the preferred aircraft designs were refined and a more precise definition of the transportation complement was introduced. This included commuterports, air traffic control, noise, routes and schedules, ground access, etc. with their detailed attendant costs.

The general results and findings of the simplified Phase I aircraft concept selection study were found to be valid in the more precise, real world evaluation of Phase II. The introduction of realistic routing, schedules, and utilization (including deadhead and standby flights) did not change the relative values of the parameters selected in Phase I, but provided a much higher level of confidence in the derived level of fares, size of vehicles, fleet size, and total system cost.

The optimum vehicle size for the fully developed transportation system in 1985 centered around 100 to 120 passengers for the deflected slipstream STOL and between 60 and 70 passengers for both the compound helicopter and the STOL autogyro. As one would expect, the vehicle size decreased rapidly, and the fare increased correspondingly with decreasing number of passengers to be served. For a constant demand, particularly at the higher values representing a fully developed system, the fares are less sensitive to variations in schedule frequency and corresponding passenger capacity. Load factors between 40 and 50 percent prevail for the total systems of this study which are excellent for any commuter type operation. The analysis showed the optimum schedule frequency to be four flights an hour, at the prime commuterports, for the deflected slipstream STOL, increasing to five to six flights per hour for the smaller rotary wing vehicles.

Within the premises and scope of the study, it is concluded that the preferred vehicle to perform the intraurban mission in the Detroit Metropolitian area is the deflected slipstream STOL.

The conventional compound helicopter, with a gear driven rotor, showed the highest fare, with the STOL autogyro falling roughly half way between. If the relatively high development risk advanced compound helicopter, with the pneumatically driven rotor, could be available in 1985 it would show only slight improvement over the low risk autogyro. It should be noted that in a different scenario, where the unusually low land costs of the Detroit area do not prevail, the 1000 foot optimum field length STOL autogyro may approach, or even improve, the low fare level of the 2000 foot optimum field length deflected slipstream STOL of this study.

Noise continues to be one of the prime problems for aircraft intended for operation in metropolitan and suburban areas. Due to the short ranges (low fuel fractions) of intraurban concepts, an appreciable amount of the potential weight saving has been applied to the vehicles of this study in design areas susceptible of noise reduction devices such as, very low rotational speeds, liners, batting, diffusers, etc. A prime recommendation of the NASA short haul transport aircraft studies of 1967 was the establishment of acceptable noise level requirements for various community V/STOL airport locations to better provide design criteria for future vehicles. The study summarized here has made a significant approach in this direction.

The computer program developed for the analysis of complex mass transportation networks has proved to be an effective tool for the rapid assessment, operational, and cost parameters. The use of this methodology and technique has led this study to the conclusion that a feasible intraurban air transportation system can be developed in many viable situations. Since this study is parametric in nature, it is applicable to generalization.

To continue to develop solutions to the key problem areas of urban mass transportation, where additional research may result in significant improvements, recommendations have been identified in this report. The most important research subjects exposed by this study are (1) Noise prediction and reduction, (2) Detailed definition of the preferred vehicles, (3) Transportation network simulation and demand, (4) Improved maintenance techniques for short haul, and (5) Continued development of computer techniques.

1.0 PHASE I - AIRCRAFT CONCEPTS SELECTION

1.1 CONCEPT FORMULATION

1.1.1 AIRCRAFT CONCEPTS

Aircraft concept selections were made at the beginning of the study following a review of applicable NASA, Lockheed, and other pertinent literature.

1.1.1.1 Selection Rationale

The concept for each aircraft category called for by the NASA RFP (Ref 1.1-1), selected from the options listed (Ref 1.1-2) and shown in Table 1.1-1, are listed below with the basis for its selection. In addition, the hybrid class, shown in the table but not called for by NASA, has been included, since it is believed to be a candidate for this mission.

1.1.1.1.1 1975 Rotor VTOL

Selection: Compound helicopter

Basis: Cumulative benefit of factors shown in Table 1.1-2 favor compound helicopter.

1.1.1.1.2 1985 Rotor VTOL

Selection: Compound helicopter

Basis:

- Table 1.1-2 comparison is considered applicable to both 1975 and 1985 technology, and shows compound helicopter to be superior to both simple-helicopter and stowed-rotor concepts.
- Reference 1.1-3 indicates no advantage in the tilt-rotor concept over the helicopter.

TABLE 1.1-1 CONCEPT MATRIX

CLASS	1975	CONFIGURATION EXAMPLE	1985
VTOL (ROTOR)	HELICOPTER COMPOUND HELICOPTER	LOCKHEED 286 LOCKHEED CHEYENNE	HELICOPTER COMPOUND HELICOPTER STOWED ROTOR TILT ROTOR
VTOL (NON-ROTOR)	TILT WING TILT PROPELLER DEFLECTED THRUST	LTV C-142A VFW VC-500 CW MODEL 200 BELL X-22A HARRIER LOCKHEED HUMMINGBIRD	TILT WING TILT PROPELLER TILT ENGINE DEFLECTED THRUST DIRECT LIFT ENGINE
HYBRID	AUTOGYRO		AUTOGYRO
POWERED STOL	DEFLECTED SLIPSTREAM JET FLAP (BLC) DEFLECTED THRUST	DHC-7 DO 231 GRUMMAN AGA LOCKHEED FUSE-FAN	DEFLECTED SLIPSTREAM JET FLAP (BLC) DEFLECTED THRUST DIRECT LIFT ENGINE
SHORT FIELD CONVENTIONAL (SF/CONV)	HIGH C_L - LOW W/S	DE HAVILLAND OTTER	HIGH C_L - LOW W/S

- o Insufficient flight test experience is available with tilt rotor concept to judge feasibility in intraurban scenario.

- o Retention of same configuration concept for 1975 and 1985 will make assessment of 1985 technology benefit more direct.

1.1.1.1.3 1975 Non-Rotor

Selection: Four Engine Tilt Wing

Basis:

- o Analysis of alternate non-rotor VTOL concepts (tilt wing, lift fan, lift jet) in 60-120 passenger, 500 n.mi., short haul scenario, Reference 1.1-3, shows tilt wing concept requires lightest gross weight and is competitive from a Direct Operating Cost (DOC) standpoint. In intraurban scenario (where total fuel requirement is dominated by takeoff, landing, and hover fuel), propeller configurations, with their superior hover lift/fuel flow rate, will therefore show a reduction in comparative DOC over lift fan and lift jet. Deflected thrust concept is considered approximately equivalent to lift fan concept and is thus judged inferior to tilt wing.

TABLE 1.1-2 COMPARISON - PURE, COMPOUND, AND STOWED ROTOR HELICOPTER CONCEPTS

(Applicable to 1975 and 1985 Technology)

	Pure Helicopter	Compound Helicopter	Stowed Rotor Helicopter
Useful Load Gross Weight	Good	Fair	Fair-
Cruise Efficiency, Equiv. (L/D) Cr. Cruise Fuel Flow	Fair-	Fair+	Good
Rotor Maintenance	Poor	Good	Excellent
Block Speed Over 20-40 Mile Stage	Good	Excellent	Fair (1)
Community Noise Takeoff, Landing Cruise	 Fair Fair	 Fair Good	 Fair Good
Flight Test Experience	Good	Good	None
Terminal Ground Maneuverability	Poor	Good	Good
Ride Comfort	Fair	Good	Good
STOL Overload Potential	Poor	Good	Good
Flexibility, Growth Potential	Fair	Good	Fair
Modified DOC Comparison (2) (Pure Hel. = 1.0)	1.0	0.98	---
Feasibility in Intraurban Scenario	Good	Good	Poor

(1) Assuming Rotor fold-stow-unstow-unfold cycle is employed

(2) Per method of Reference 1.1-4

- Tilt propeller concept is considered to have insufficient wind tunnel and flight test background to properly assess its feasibility.
- Relative attenuation of perceived noise levels, PNdB, favors propeller in critical near field.
- Near-field noise problem of tilt engine and direct-lift engine concepts is considered more difficult than that of tilt wing.

1.1.1.1.4 1985 Non-Rotor VTOL

Selection: Four Engine Tilt Wing

Basis:

- 1985 technology will provide essentially the same benefits to either 1975 tilt wing, tilt propeller, or deflected-thrust concepts. Tilt wing choice is thus retained.
- Tilt engine (turbofan) concept, and direct-lift engine concepts (wherein a portion of the hover lift is supplied by direct-lift engines) are considered inferior to tilt wing due to their high hover fuel flow rates and attendant adverse effect on required fuel fraction.
- Retention of the same concept for 1975 and 1985 will make assessment of the 1985 technology benefit more direct.

1.1.1.1.5 1985 Hybrid STOL

Selection: Autogyro

Basis:

- Preliminary Lockheed studies show a 1000-foot STOL autogyro to be competitive with fixed-wing STOL concepts in intraurban scenario from considerations of gross weight, DOC, and noise.

  NOTE: 1975 considered too near-term for this concept.

1.1.1.1.6 1975 Powered STOL

Selection: Propeller-Powered Deflected Slipstream STOL

Basis:

- Analysis of alternative STOL concepts in 500 n.mi., 60-120 passenger short-haul scenario (Ref 1.1-3) shows propeller deflected-slipstream STOL to have a lower gross weight than either turbofan deflected-slipstream or lift fan-cruise fan (approximately equivalent to deflected-thrust concept).

- Although the propeller deflected-slipstream concept has somewhat lower T/W, it has much higher thrust per pound of fuel in hover, as well as lower cruise S.F.C.'s, as indicated below.

ITEM	DEFLECTED SLIPSTREAM	DEFLECTED THRUST
Approximate Thrust/Weight	7	10
Approximate Thrust/Fuel Flow Rate (lb/lb/hr)		
Takeoff/Landing	6.6	2.9
Cruise	2.5	1.8

Reduced fuel flow rate in takeoff/landing mode offers a gain for propeller deflected-slipstream concept (6-8 takeoff/landing cycles between refueling).

- The lift augmentation capability of propeller deflected-slipstream concept is generally superior to high bypass fan deflected-thrust concept in takeoff/approach/landing speed regime.
- Critical near-field noise level is lower for propeller deflected-thrust concept.
- Augmentor wing concept is not considered sufficiently developed for 1975 Initial Operating Capability (IOC) in intraurban scenario.

1.1.1.1.7 1985 Powered STOL

<u>Selection</u>: Augmentor Wing Concept

<u>Basis</u>: Initial wind tunnel tests and working papers by NASA indicate sufficient potential gain in lift augmentation per pound of thrust for this concept, compared with a conventional flap-deflected-thrust concept, to warrant its consideration for 1985 time period.

1.1.1.1.8 1975 Short Field CTOL

Selection: Four Engine Turboprop powered high T/W, low W/S configuration.

Basis: Propeller power is chosen over turbofan power for the near term due to the noise problem.

1.1.1.1.9 1985 Short Field CTOL

Selection: Four engine turbofan powered high T/W, low W/S configuration.

Basis: Turbofan is expected to be suitably quieted for 1985 time period.

1.1.1.2 Aircraft Design Requirements

1.1.1.2.1 Mission Performance

- Payload. - Primary study variable over 40-120 passenger range.
- Takeoff/landing field length (STOL and CTOL configuration). - Primary study variable over 500 - 4000 foot range as a function of wing loading (W/S) and thrust loading (T/W).
- Design endurance (mission fuel basis). - Two hours engine running time utilized in eight equal-length stages including taxi-out, takeoff, climb, cruise, landing, and taxi-in, with the following fuel allowances:

Segment	Configuration	Time, minutes
Taxi out @ low power (2% rated fuel flow)	VTOL STOL/CTOL	0.5 1.0
Takeoff @ T.O. power	ALL	0.5
Climb to 2000 feet @ max. cont. power	ALL	As required
Cruise @ 2000 feet Fixed wing - 250 knot Rotary wing - 200 knot	ALL	As available
Descent	ALL	0
Approach Air Maneuvers @ approach flap	VTOL STOL/CTOL	0 0.5
Landing @ full flap, power for level flight	ALL	1.0
Taxi in @ low power (2% rated fuel flow)	VTOL STOL/CTOL	0.5 1.0

- Takeoff and landing at 90° F. @ S.L.
- Climb/cruise at 60° F.
- 10% fuel reserves
- 5 minute ground time allowance with engines inoperative
- Two man crew
- High wing arrangement on all configurations
- Unpressurized fuselage
- All weather capability (see avionics - Section 1.1.2.6)
- Reverse thrust on all configurations
- Standard fuselage concept for all configurations
- Structural and operational design cruise speed/altitude

  Fixed wing - 250 knot/2000 feet

  Rotary wing - 200 knot/2000 feet

- Structural design requirements for CTOL and helicopters to conform to existing FAR's; non-rotor VTOL and powered STOL configurations based on consideration of tentative requirements of Ref 1.1-5

The above mission and aircraft design requirements are established as representative for aircraft designed specifically for the intraurban role. Here the emphasis is on being able to maintain a rigid schedule in all weather with an operation that is dominated by the load-takeoff-land-unload elements. It is possible, however, that when the time comes, these aircraft may be designed to fill the intraurban role and other roles. These other roles could include 100-400 mile short-haul, stage lengths where cruise speed would be significant, pressurization would be required, passenger accommodations would need to be embellished, etc. Designing to such a multi purpose mission would, of course, complicate the aircraft and increase its manufacturing and operating costs.

The mission fuel requirement is based on the logic that the vehicles should be able to operate through the rush hour without refueling. The design speed/altitude relationship is a compromise between ride qualities, structural weight, and block speed factors. It is notable here that the cruise mode time is nominally a small portion of the block time over the 20 statute mile average stage as indicated below.

TIME BREAKDOWN FOR 20 STATUTE MILE
MISSION FOR NOMINAL FIXED WING VEHICLE

	Minutes	
Taxi out	1.0	
Takeoff	0.5	7.1 total takeoff/landing (Takeoff through Landing)
Climb	0.7	
Cruise	4.4	
Descent	0.0	
Air maneuver	0.5	
Landing	1.0	
Taxi in	1.0	
Ground time	5.0	
Block time	14.0	

The 10 percent fuel reserve allowance is arbitrary and, in retrospect, may be excessive. The five minute ground time allowance is discussed in the following section.

1.1.1.3 Baseline Aircraft Descriptions

The aircraft configuration concepts studied are described below. Features applicable to all concepts include:

- Four engines for all fixed-wing concepts and size. For study consistency, this simplifying approach is used rather than to make the number of engines variable with configuration concept and size. Some cost benefits might be gained in certain concept payload combinations by using fewer engines, but an analysis of these benefits is considered a second order effect in terms of the total study objectives
- Three engines for all helicopters for the above reasons
- Four engines for 1985 autogyroes for above reasons
- Standard fuselage concept (see description below)

- Low sweep wing mounted atop fuselage so as not to interfere with stringer frame continuity
- Two-man crew, no attendant
- Fixed, but carefully faired, fuselage-mounted, tricycle landing gear with emphasis on ruggedness since landing gear usage is extremely heavy compared with contemporary aircraft
- Conventional multiple redundant hydraulic control system
- Forty-five psf, disk-loading, eight-blade Hamilton Standard, low noise propellers on all propeller-powered STOL and CTOL concepts. Tilt wing VTOL disk loading less than 60 psf

It is noted that the rotary wing configurations are point designed at three payload levels, and the following descriptions include weight statements for these configurations. In contrast, the fixed-wing configurations are analyzed parametrically to show the effects of payload, wing loading and thrust loading. Weight information is therefore expressed parametrically as discussed in Section 1.1.2.5.

Fuselage Concept - Fuselage interior arrangement studies included conventional, as well as unconventional, concepts. Considered for possible improvements in construction costs, greater convenience in passenger loading, improved structural arrangement, etc., these unconventional concepts are:

- Passenger capsule
- Compartmentalized fuselage
- Center keel fuselage

The passenger capsule has the advantage that it would be loaded in a protected area, in advance of departure, then wheeled to the aircraft which would be a "flying crane" configuration, where it would be "installed" and ready for takeoff. The mechanical gimmickry and coupling/decoupling time are a decided time and cost disadvantage, to say nothing of the uncertainties of passenger acceptance which puts them in a "can" separate from the basic airplane.

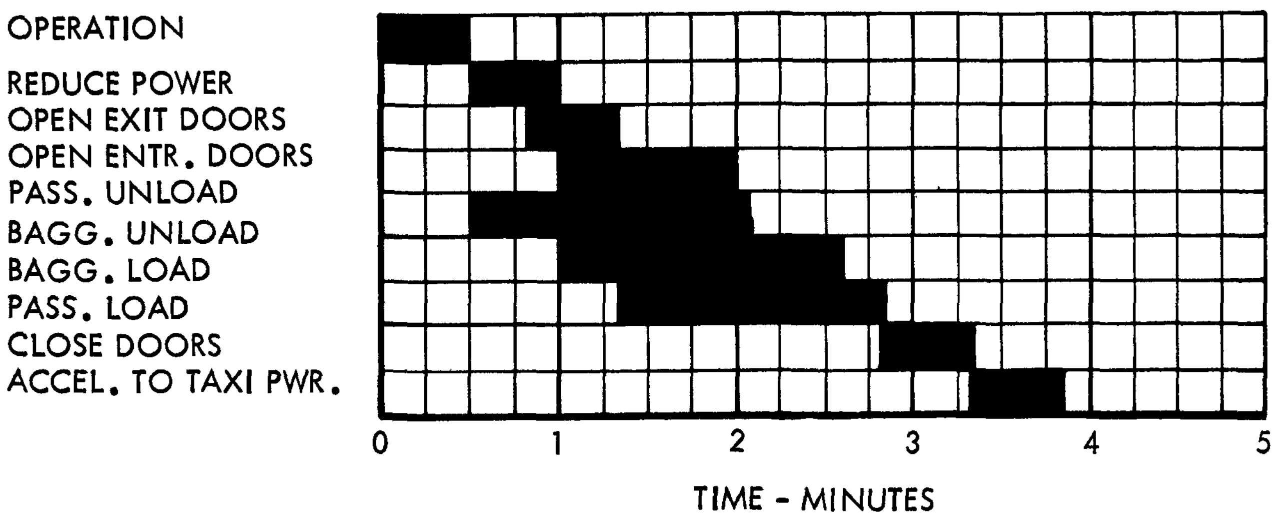
The compartmentalized fuselage, as adopted in the 1969 NASA-Stanford MAT Study (Reference 1.1-6), has its attractions in that the unload/load cycle (U/L) can be accomplished quickly. However, the large number of doors makes it a structural designer's nightmare -- not impossible, but heavier and more expensive than the version chosen. Side entry/exit is also subject to propeller interference.

The central keel concept utilizes a keel or strongback longitudinally through the lower fuselage with a structural tie vertically through the passenger compartment. This produces a horizontal "double-bubble" wide fuselage, an advantage with double aisles and six-across (or more) seating. However, it also has the disadvantage of dividing the cabin and restricting passenger movement laterally unless the keel is compromised.

The most important factor in controlling DOC in the commuter context is utilization. Assuming that passenger demand, passenger capacity, and flight frequency must be balanced for an optimum system, there is an excellent opportunity to increase productivity by reducing ground time to the very minimum. Each aircraft operating during the commuter rush hours will be making many enroute stops. Figure 1.1-1 shows the time line believed achievable in this operation for a 60-passenger payload. Conservatively, the turnaround time is give minutes. Being optimistic, it might be three minutes, since the time line assumes a 100 percent load change at each stop and conservative rates of loading through the doors.

Other concepts considered in arriving at a suitable interior arrangement are based on commuter use as differentiated from long haul. Many of the amenities provided in conventional aircraft can be eliminated in an aircraft intended for commuter use. Passengers will seldom be aboard for more than an hour and generally for a much shorter time. The passenger service aspects of the system -- or lack of them -- will more closely approximate city bus or trolley services. For instance, no coffee bar or galley, lavatories or overhead baggage racks, would be provided. Seats would be nontilt, perhaps even without center arm rests, but footrests would be provided for passenger comfort during approach, when steep deck angles are encountered.

60 PASSENGERS



ASSUMPTIONS ----

- 100% LOAD FACTOR - ARRIVING AND DEPARTING
- 1 PC. CHECKED BAGGABE PER 3 PASSENGERS
- BAGGAGE HANDLER PRODUCTIVITY:

  15 BAGS/MINUTE
  15 SEC TO POSITION EQUIPMENT AND OPEN DOOR

Figure 1.1-1 Timeline - Enroute Stop

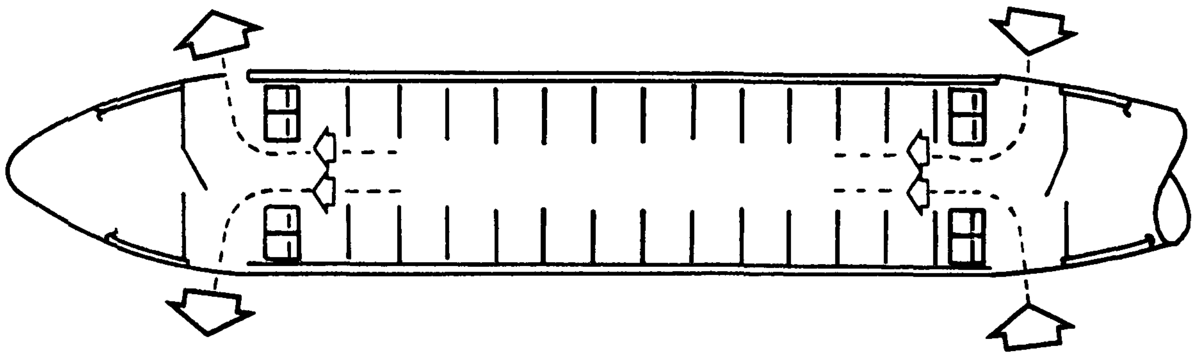
Major consideration must be given to passenger loading, unloading, and seating arrangement so that ground turnaround time can be minimized and productivity improved. One feature that became evident immediately is that passenger flow must be "managed" from the time a passenger enters the terminal waiting area to the time he is located in his seat in the aircraft and from the time he leaves his seat to the time he is deposited in the destination terminal.

Among the aircraft-related factors that affect passenger flow rates are:

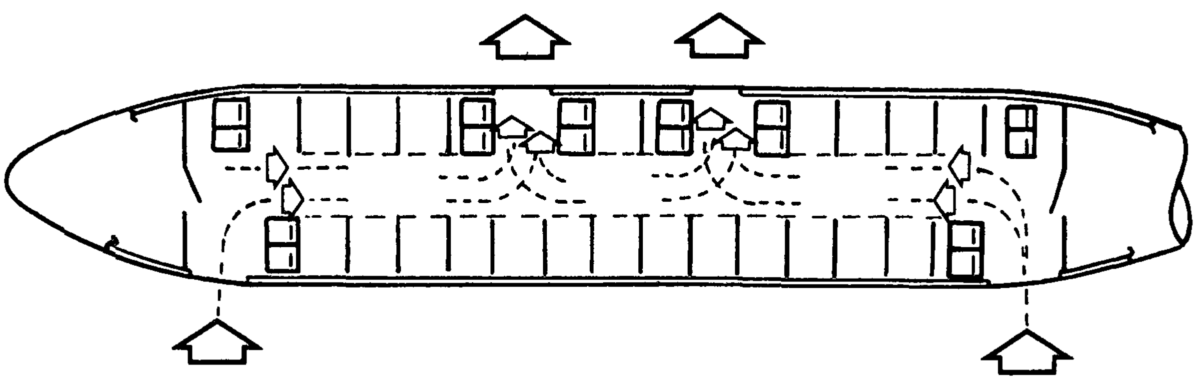
- Aircraft door width
- Service rendered at door; (e.g., gate pass collection, etc.)
- Number of aisles
- Aisle width
- Number of seats per row served by aisle
- Seat pitch
- Passengers' purpose and motivation

Door width, number of aisles and aisle width must be coordinated if there is to be a smooth flow of passengers without congestion. Width or number of doors should be sufficient to pass as many people in a unit of time as the aisles can accommodate. Aisle space must be sufficient to permit easy flow and allow passengers to enter or leave their seats upon enplaning or deplaning. Further, to avoid counterflow in the aisles and permit an overlap of the unloading and loading cycles (very important in reducing ground time), all flow in any aisle, or part of an aisle, must be in a single direction. Figure 1.1-2 shows two versions of a fuselage arrangement utilizing a single aisle and four doors. Assuming aisle width and door size balanced to obviate congestion at either location, a satisfactory arrangement is possible.

The effect of number of doors and door size on U/L time is shown in Figure 1.1-3. This figure does not consider the effect of the flow permitted by the doors on aisle width or number of aisles. It does indicate that with four wide doors, two for unloading, two for loading, a good

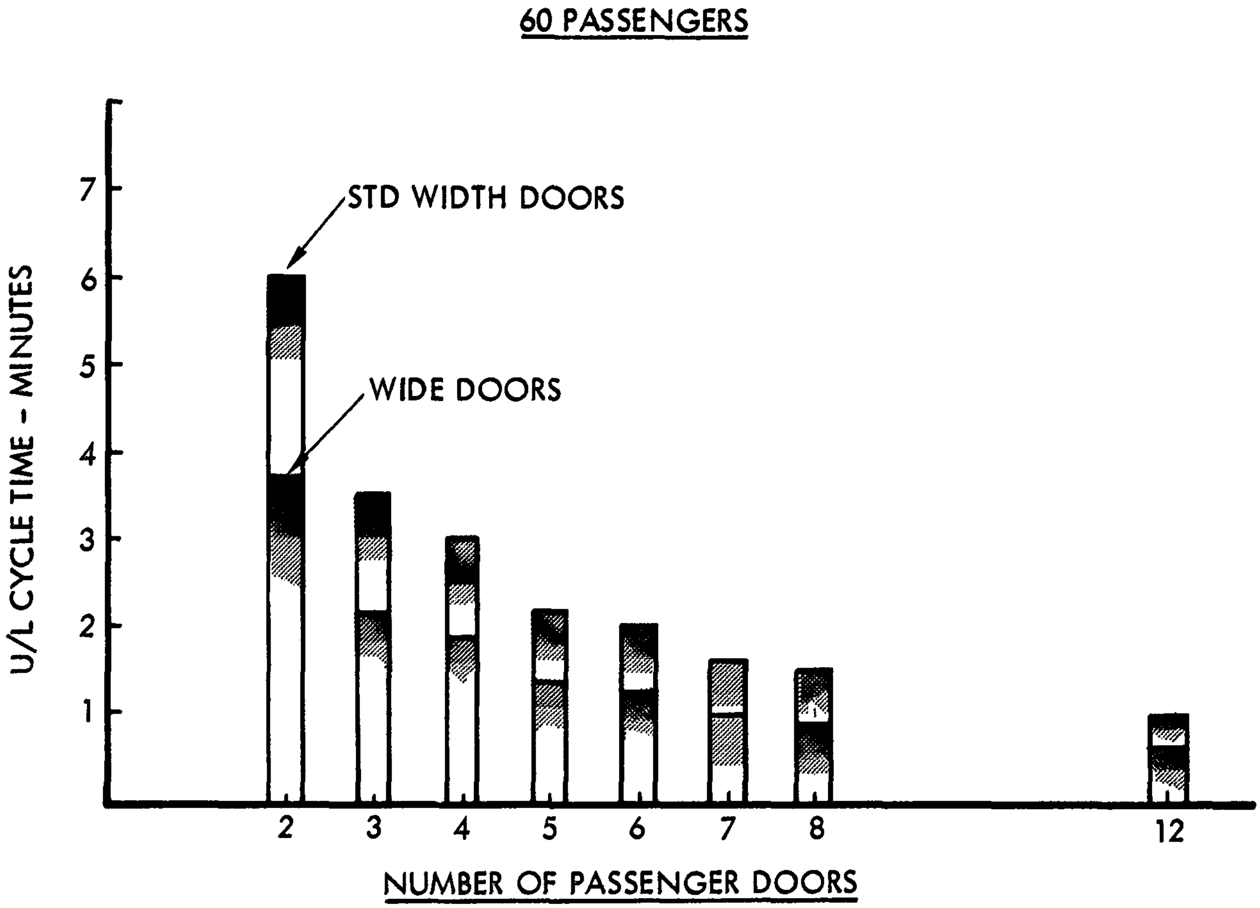


- ENTRANCE AND EXIT MAY BE REVERSED
- AISLE MUST BE WIDE ENOUGH FOR TWO ABREAST TO AVOID CONGESTION
- PROVIDES NON-INTERFERING PASSENGER FLOW
- NEED ACCESS ON BOTH SIDES OF AIRCRAFT



- ENTRANCE AND EXIT MAY BE REVERSED
- ALL DOORS MAY BE ON SAME SIDE IF GROUND FACILITIES CAN SEPARATE PASSENGERS MOVING IN TWO DIRECTIONS
- MAY CAUSE INTERFERENCE WITH L. GEAR, PROPS, ENGINES
- PROVIDES NON-INTERFERING PASSENGER FLOW

Figure 1.1-2 4-Door Interior Arrangements



ASSUMPTIONS

- 100% LOAD FACTOR - ARRIVING AND DEPARTING
- OVERLAPPING UNLOADING AND LOADING CYCLES
- LOADING CYCLE OFFSET (DELAYED) TO PERMIT 33% OF DEBARKING PASSENGERS TO EXIT

Figure 1.1-3 Unload/Load Cycle Time

compromise between U/L time and increased floor area (lost seating space) at each door can be achieved.

Unloading and loading rates have been developed for standard and wide-width aircraft doors as shown in the following table. Standards for door opening sizes do not exist in the industry; manufacturers adopt their own standard widths. Reference 1.1-7 shows that among current commercial aircraft, door widths are 30-35 inches, (Boeing, except 747, 34 inches; Convair, 30 inches; BAC, 33 inches; Douglas, 34.5 inches; Lockheed, 35 inches). Reference 1.1-8 gives Boeing 747 door width as 42 inches. The following table considers standard door width at 30-35 inches and wide door width as 42 inches or greater.

PASSENGERS PER MINUTE THROUGH DOOR

	Std Width	Wide Width
Loading	12	20
Unloading	20	30

The above values are based on References 1.1-9 and 1.1-10. Reference 1.1-9 quotes loading rates in Boeing tests as high as 40-52 passengers per minute (ppm) and unloading rates of 46-70 ppm. However, these rates are derived from nearly ideal conditions and represent maximal flow. Boeing uses a loading rate of 20 ppm. Reference 1.1-10 quotes loading and unloading rates for a Boeing 727 (34 inch wide door), using one door, as 16 and 36 ppm respectively. Further, the same reference quotes a method for determining an "average capacity flow rate." Observed data gave a rate of 14 ppm for loading. The numbers used in the above table for determining passenger loading and unloading cycle time during an enroute stop appear conservative.

Reference 1.1-10 makes a point which seems entirely predictable. "... the constraint in loading was not the size of the aircraft door but the amount of congestion in the aisle." The reason loading rates are less than unloading rates is due, in large part, to the fact that the average passenger has moments of hesitation on boarding while he makes decisions -- whether to sit forward or aft, correlating his preference with the choice of available seats and his assessment of the grouping of the passengers already seated; (e.g., Would he rather sit beside a male or female? Does he want a window seat or an aisle seat? Does he know which will be the shady side of the plane during the flight?) He may even make his choice based on being among the first out on landing. As a debarking passenger he has only one consideration -- to get out quickly -- and usually little hesitation. Therefore, aisle width can be considered critical only during loading. The aisle must be wide enough to allow passage where another passenger has hesitated, partially standing in the aisle, before entering his seat row. A minimum seat pitch of 36 inches and a minimum aisle width of 21 inches will facilitate this. However, both of these dimensions should be considered variable and subject to further study.

The desire for a very short turnaround time has dictated the number of doors on the aircraft (two for loading, two for unloading). But, full advantage cannot be taken of this four-door feature unless there is sufficient aisle space (1) to feed two doors on unloading and (2) to accept passengers boarding from two doors.

For a single-aisle configuration, such as shown in Figure 1.1-4, there needs to be sufficient width to allow two passengers to walk side by side. Forty-two inches was deemed the minimum width to permit this. Two seats to each side of the aisle were considered reasonable in view of the short-haul mission of this craft and the passengers' comfort. To minimize the necessity for passengers to climb over each other to get in or out of a window seat, a single-aisle configuration would have no more than four seats divided by a 42-inch aisle.

To improve this ratio, the single wide aisle was split, and a double aisle configuration with six abreast seating in a 2-2-2 arrangement was considered, Figure 1.1-5. The drawback to this arrangement is that the low fuselage fineness ratio in the plan view may create a drag penalty at low design payloads, and it was concluded that the 2-2-2 arrangement would be too small for 60 passengers. The logical compromise then became five abreast (Figure 1.1-6) with a single row of seats in the middle (2-1-2). This arrangement allows simultaneous loading and unloading. Exiting passengers would leave by the front doors, each door fed by one aisle, and boarding passengers would enter by the rear doors (or vice versa). Either way, the flow in each aisle would always be in one direction without confusion or congestion.

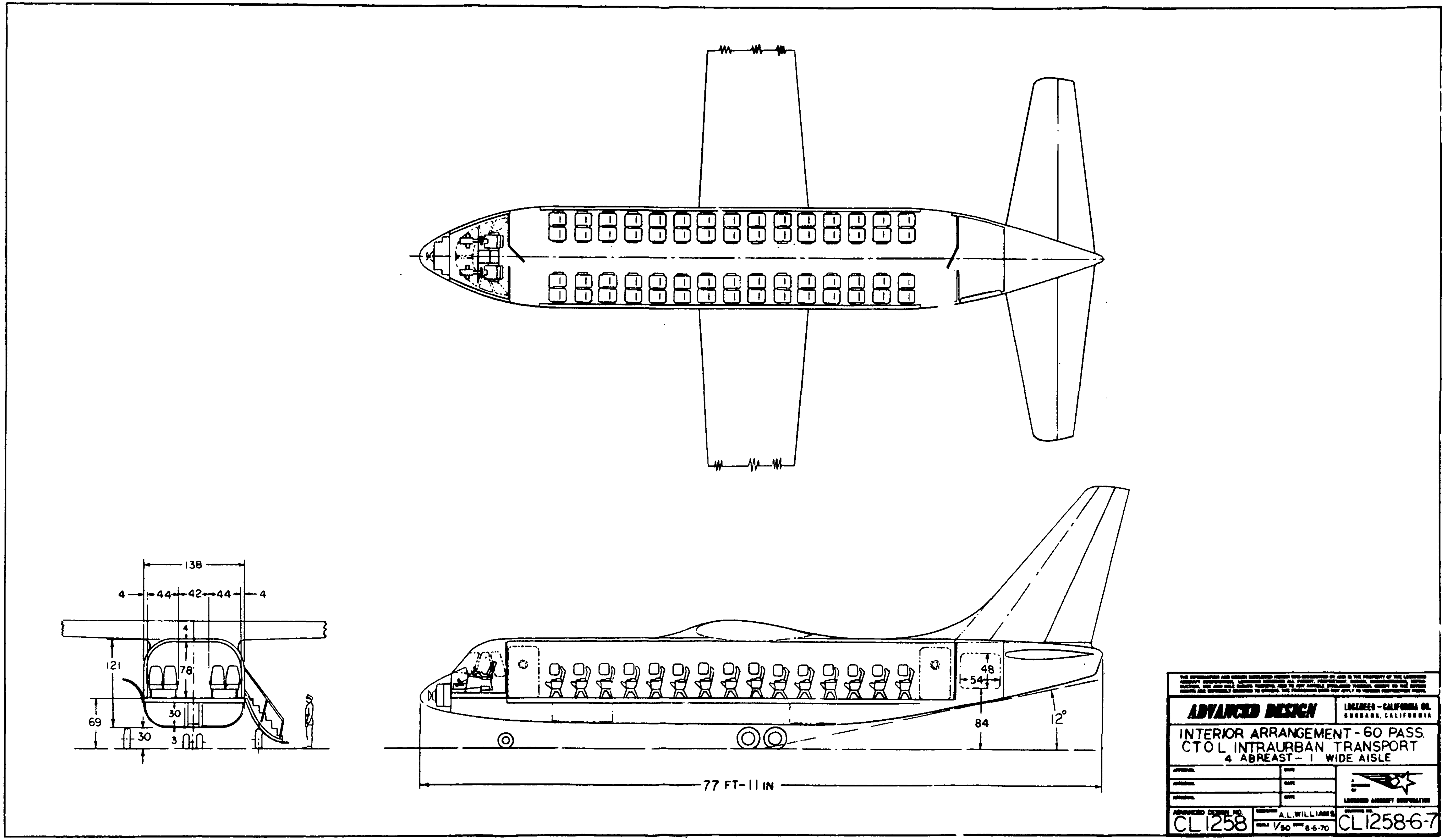


Figure 1.1-4 Interior Arrangement 60-Pass. CTOL Intraurban Transport - 4 Abreast - 1 Wide Aisle

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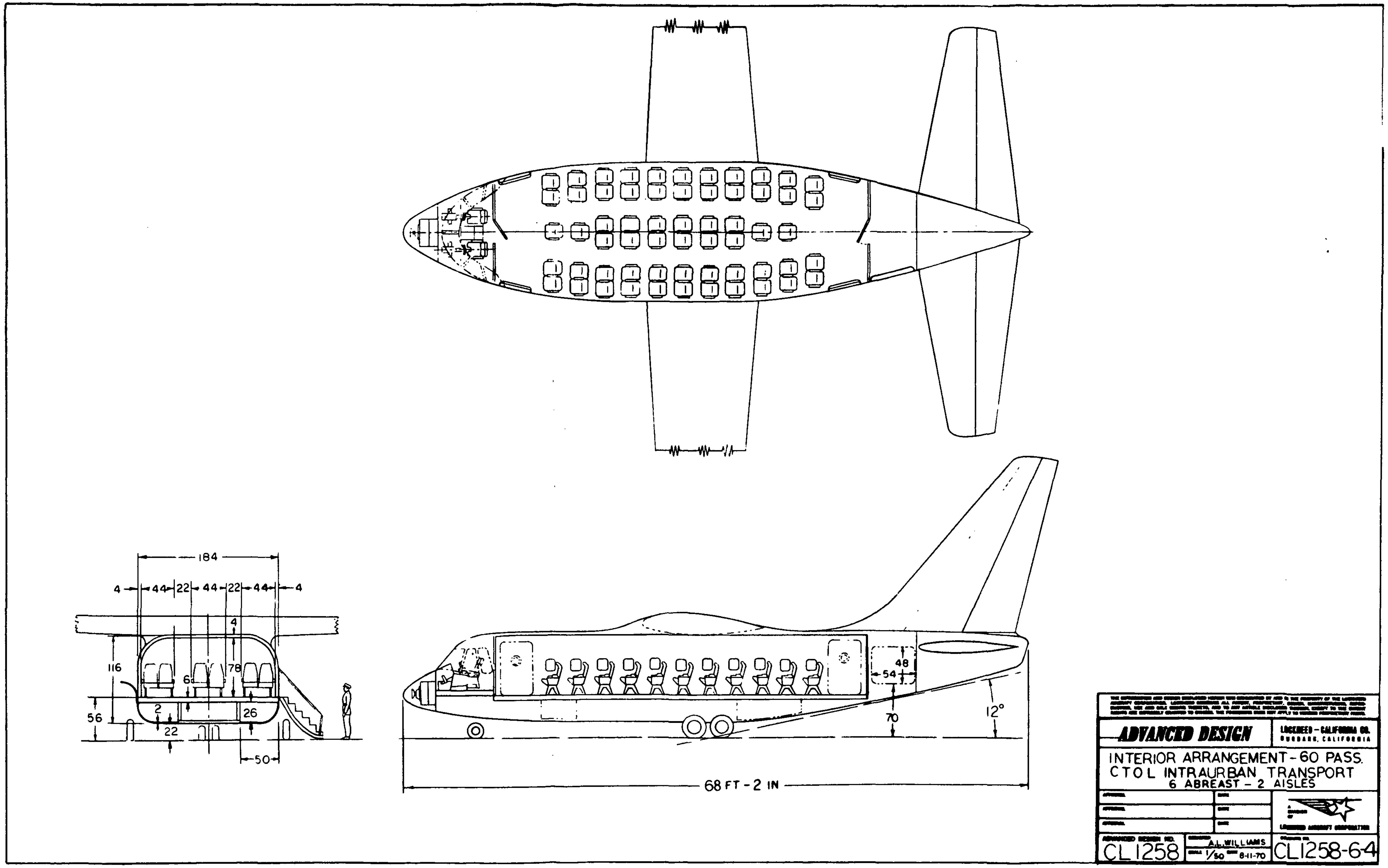

Figure 1.1-5 Interior Arrangement 6C-Pass. CTOL Intraurb. Transport - 6 Abreast - 2 Aisles

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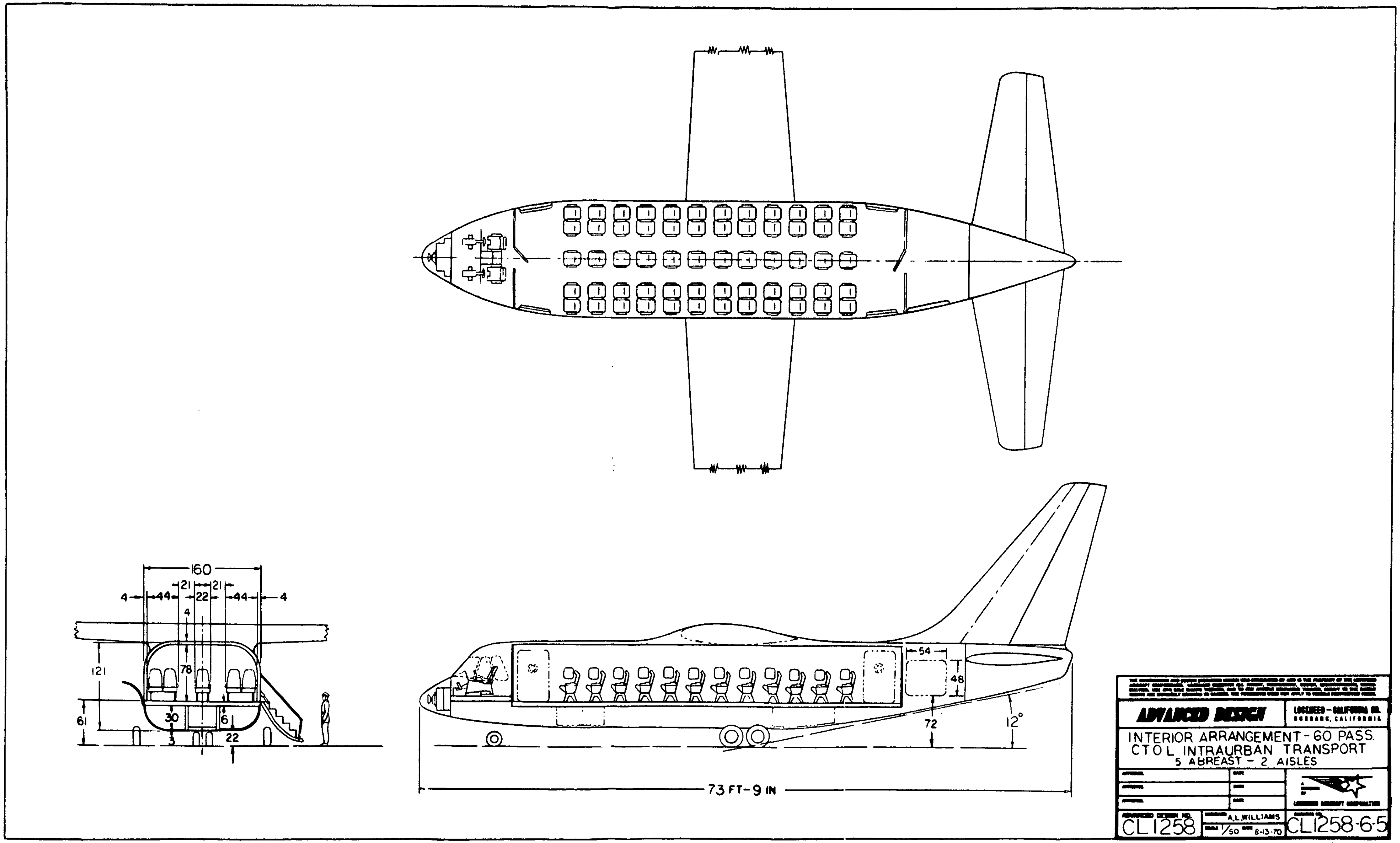

Figure 1.1-6 Interior Arrangement 60-Pass. CTOL Intraurban Transport - 5 Abreast - 2 Aisles

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The five abreast, two aisle seating configuration is amenable to growth from 60 passengers to more than double that figure, if necessary. The fuselage would probably be lengthened as a first move and widening to six abreast is a logical second step.

The fuselage cross section deviates from the familiar circular or nearly circular shape since there is no requirement in the projected type of service for cabin pressurization. Overhead baggage racks have been eliminated since they can only be used for light or soft articles such as items of clothing. It is felt that if passengers are required to keep personal control of these items during the short trip, passenger movement will be speeded. Passenger baggage too big to handle in this manner will be checked and carried in the baggage compartments.

The need for cabin attendants in the intraurban operation is open (none is included in the weight and DOC analysis). Reference 1.1-10 calls for two attendants for aircraft of more than 44 seating capacity and in intraurban operations cabin attendants would serve much the same purpose as on current transport operations. However, to reduce costs, it may be feasible to automate most of the manual safety check, door opening-closing and herding operations performed by today's stewardesses since the average enplane-to-deplane time is only 14 minutes. In such a scheme the co-pilot could perhaps monitor the operation from a suitable display at his flight station. Further study is needed here.

The composition of the passenger traffic in intraurban service will be mostly local, and baggage volume will be very light. However, traffic to and from the airport STOL terminal will carry passengers making connections with longer haul flights at the airport, so a larger volume of baggage can be anticipated. For design purposes, a four-cubic-foot per passenger requirement is used. Checked bags will be carried in four underfloor compartments, two just aft of the forward door and two just aft of the landing gear.

It is believed that even with a full load of baggage to be handled, manual loading and unloading will likely be employed, certainly at the outlying STOLports. The volume projected does not warrant a sophisticated system with automated features and it was decided not to burden the system with the costs of such embellishment. Note, however, that a final review of IOC costs arouses interest in something akin to an automated STOLport at the outlying locations. The operational details of baggage processing must be integrated with the ground facilities but this is considered beyond the scope of this study.

During enroute stops, in order to achieve the shortest possible aircraft time on ground, engines might not be shut down but left at idle. Such a procedure has an overall advantage to the system although there are also drawbacks. The advantage, in addition to the time saving, is that it reduces a large number of engine starts and stops and thereby reduces engine maintenance time and cost. The disadvantage is that passengers will require protection from rotor or propeller blast, propeller arc, noise and fumes.

Table 1.1-3 presents a summary of the recommended fundamental fuselage interior arrangement as a function of design payload. Enroute stop time estimates are also included.

1.1.1.3.1 1975 Compound Helicopter VTOL

Synthesized around single point design concept with payload variable and having following characteristics:

- Hingeless four blade rotor
- Three cross coupled turboshaft engines, two wing mounted and one mounted in main transmission cowling. Power sufficient to accommodate engine failure on takeoff
- Basic performance parameters

Disk loading	10.2 psf
Power loading	5.14 lb/shp
Design cruise speed	200 kt

- Main rotor aerodynamics

Blade loading coefficient, C_t/σ	0.1
Tip loss factor	0.95
Blade profile drag coefficient	0.0112
Figure of merit	0.803

TABLE 1.1-3 FUSELAGE INTERIOR VS CAPACITY

Interior Arrangement \ Passenger Capacity	40	60	80	102	120
CABIN WIDTH, IN.	160	160	160	184	184
APPROX. CABIN LENGTH, IN.	136	540	684	720	820
SEAT ROW CONFIGURATION	2-1-2	2-1-2	2-1-2	2-2-2	2-2-2
SEAT WIDTH, IN.	21	21	21	21	21
SEAT PITCH, IN.	36	36	36	36	36
NUMBER OF AISLES	2	2	2	2	2
AISLE WIDTH, IN.	21	21	21	21	21
NUMBER OF DOORS	4	4	4	4	4
DOOR WIDTH	42	42	42	42	42
TIME AT ENROUTE STOP WITH 100% PASSENGER TRANSFER	3:13	3:50	4:27	5:07	5:40

Download in hover	1715 lb	
Equivalent parasite drag area	40 sq ft	@ 60 passengers
Power losses	1375 HP	

- Dimensional data @ 60 passengers -

Overall height	24 ft
Overall length	93 ft
Main rotor	
Diameter	32 ft
Disk area	5280 sq ft
Solidity	0.1054
Tip speed	650 fps
Wing	
Area	445 sq ft
Span	37.6
Aspect ratio	3.18
Taper ratio	0.5

Fuselage (in accordance with Section 1.1)

- Propulsion system

Gear driven main and tail rotors from cross-coupled turboshaft engines similar to those employed on tilt wing VTOL per Paragraph 1.1.2.2. Direct cuirse thrust from three engines driving two wing mounted fans or shrouded propellers

Installed power 10,500 SHP @ 60 passengers

- General arrangement - per Figure 1.1-7
- Weight breakdown - per Table 1.1-4

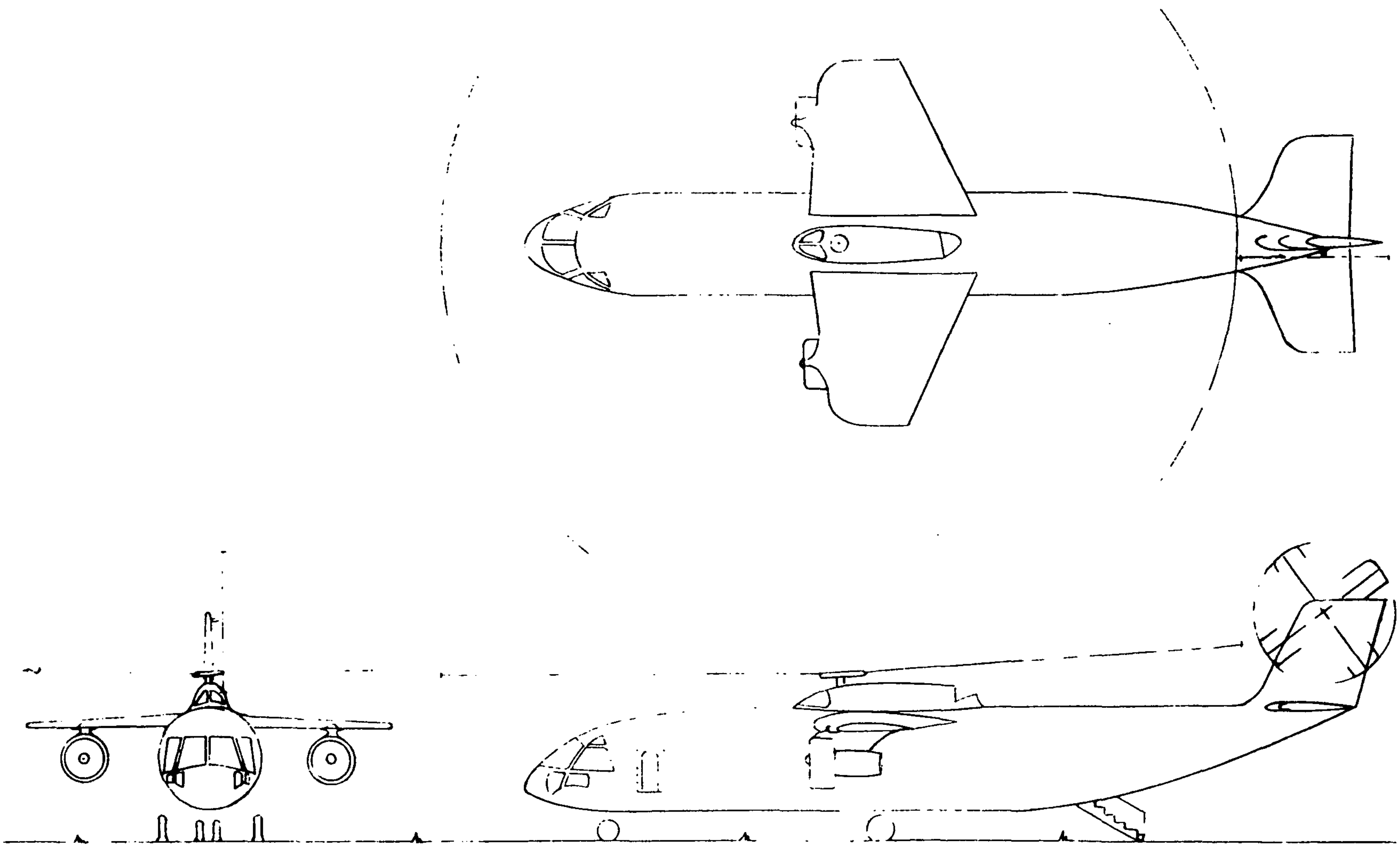

Figure 1.1-7 1975 - 60 Passenger Compound Helicopter

TABLE 1.1-4 1975 COMPOUND HELICOPTER GROUP WEIGHT STATEMENT

GROUP WEIGHT	40 PASSENGER WEIGHT	40 PASSENGER WEIGHT FRACTION - %	60 PASSENGER WEIGHT	60 PASSENGER WEIGHT FRACTION - %	80 PASSENGER WEIGHT	80 PASSENGER WEIGHT FRACTION - %
Main Rotor	4056	.1027	6170	.1143	8493	.1240
Wing	958	.0243	1289	.0239	2130	.0311
Tail Rotor	296	.0075	446	.0083	574	.0084
Empennage	385	.0097	588	.0109	752	.0110
Fuselage	4320	.1094	5380	.0996	6250	.0912
Landing Gear	1306	.0331	1790	.0331	2268	.0331
Flight Controls	1187	.0301	1743	.0323	2133	.0311
Nacelles	521	.0132	628	.0116	724	.0106
Engines	2257	.0571	2764	.0512	3238	.0473
Prop. System	749	.0190	839	.0155	913	.0133
Drive System	4748	.1202	6540	.1211	8524	.1244
APU	350	.0089	350	.0065	350	.0051
Instruments	237	.0060	266	.0049	292	.0043
Hydraulics	285	.0072	342	.0063	388	.0057
Electrical	870	.0220	954	.0177	1024	.0149
Electronics	1178	.0298	1178	.0218	1178	.0172
Furnishings	2190	.0554	3190	.0591	4190	.0612
A/C & A/1	980	.0248	1591	.0295	2204	.0322
Empty Weight	26873	.6803	36048	.6676	45625	.6661
Oper. Equipment	45	.0011	45	.0008	45	.0007
Crew	380	.0096	380	.0070	380	.0055
Oil, etc.	102	.0026	127	.0024	150	.0022
Oper. Empty Weight	27400	.6937	36600	.6778	46200	.6745
Payload	7600	.1924	11400	.2111	15200	.2219
Zero Fuel Weight	35000	.8861	48000	.8889	61400	.8964
Fuel	4500	.1139	6000	.1111	7100	.1036
Gross Weight	39500		54000		68500	
Gross Weight/Pass.	987.5		900		856.3	
Empty Weight/Pass.	671.8		600.1		570.3	

1.1.1.3.2 1985 Compound Helicopter VTOL

Generally similar to 1975 configuration except with reduced size through use of: (1) composite materials in basic structure, and propulsion system; (2) engines with reduced specific fuel consumption, and (3) substitution of a pneumatic rotor drive system for 1975 gear driven system.

- Basic performance parameters -

Disk loading	12.7 psf	
Design	200 knots	
Main rotor aerodynamics		
Blade loading coefficient, C_t/σ	0.1	
Tip loss factor	0.95	
Blade profile drag coefficient	0.010	
Figure of merit	0.806	
Download in hover	2058 lb	@ 60 passengers
Equivalent parasite drag area	30 sq ft	@ 60 passengers
Power losses	653 HP	@ 60 passengers

- Dimensional data @ 60 passengers

Overall height	24.5 ft
Overall length	77 ft
Overall width	60 ft
Main rotor	
Diameter	60 ft
Disk area	2820 sq ft
Solidity	0.109
Tip speed	700 fps

Wing

Area	380 sq ft
Span	30.6 ft
Aspect ratio	3.18
Taper ratio	0.5

- Propulsion system - conceptual

  Torqueless pneumatic main rotor drive system employing dual purpose turbofan engines having a 3 to 3.5 pressure ratio and similar in concept to that proposed for augmentor wing concept as discussed later in Section 1.1.2.2. For the hover mode, essentially all of the multistage fan flow is bypassed from the axial thrust nozzle and routed to the engine cross ducting system through the rotor hub. The air travels through the rotor blade ducts and exhausts from the multistage ejector type tip nozzles. For the cruise mode, the flow is modulated by a valving system to provide both rotor torque and fan thrust. This system is torqueless, with respect to the airframe, and therefore, the required directional control power is minimized. A small pneumatically driven fan mounted in the vertical tail is envisioned to provide the directional control requirements. The thrust requirements for the system are approximately 9000 lb/engine for the 60 passenger size.

- General arrangement, see Figure 1.1-8

- Weight breakdown, see Table 1.1-5

1.1.1.3.3 1975 Tilt Wing VTOL

General arrangement will approximate that shown in Figure 1.1-9, having the following features:

- High wing with approximate 25-30 percent chord full span flap-ailerons for lift and roll control. Wing thickness ratio approximately t/c = 0.18.

- Four underslung wing mounted turboshaft engines with the outboard engines mounted at the wing tips and the inboard engines located so that the entire wing is immersed in propeller slipstream. Taper ratio approximately 0.7, aspect ratio variable with wing loading as shown in Figure 1.1-10. The four engine thrust/weight ratio is 1.35 to provide for engine failure during

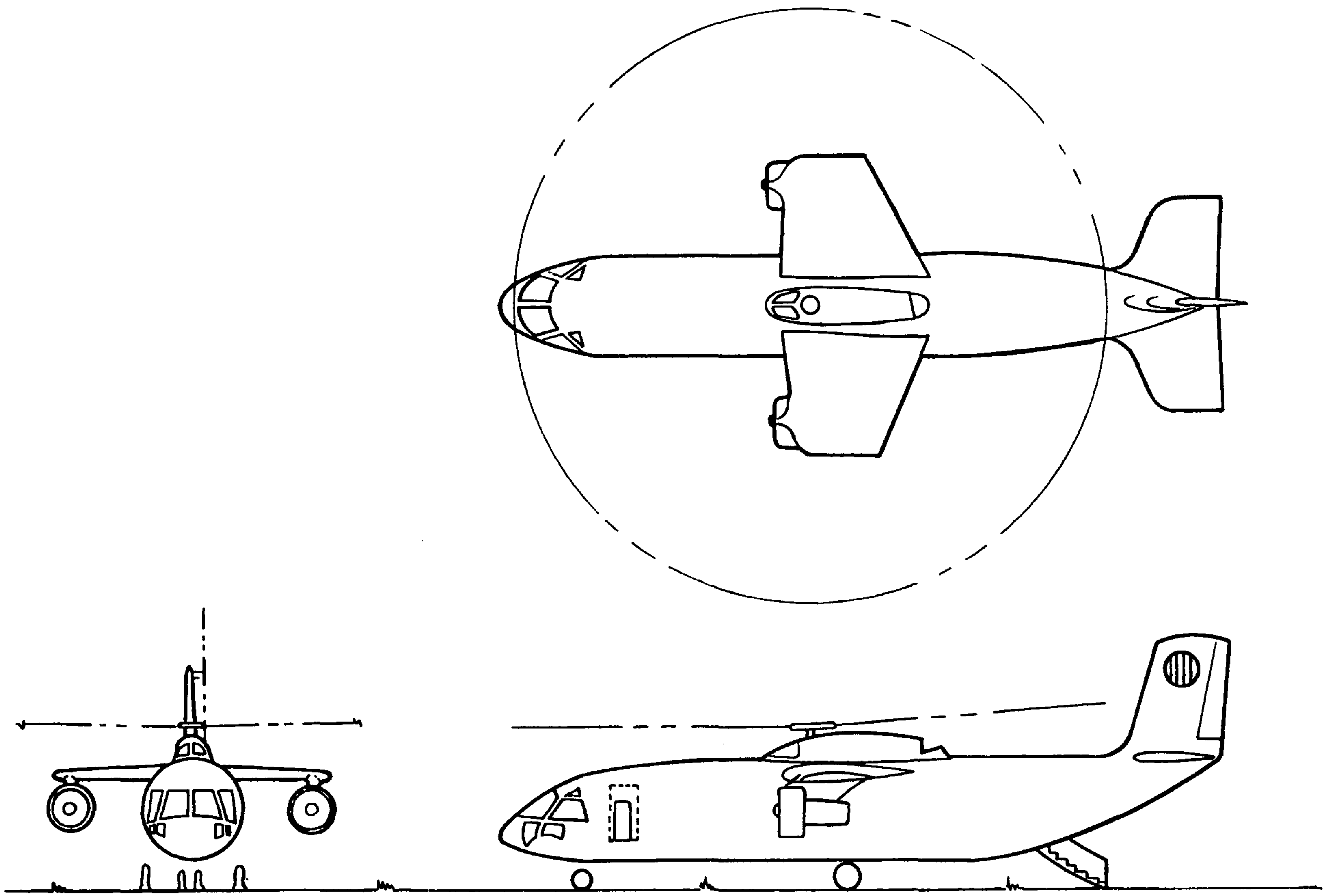

Figure 1.1-8 1985-60 Passenger Compound Helicopter

TABLE 1.1-5 1985 COMPOUND HELICOPTER GROUP WEIGHT STATEMENT

	40 Passenger		60 Passenger		80 Passenger	
Group Weight	Weight	Weight Fraction %	Weight	Weight Fraction %	Weight	Weight Fraction %
Main Rotor	1868	.0718	2810	.0781	3832	.0833
Wing	514	.0198	702	.0195	893	.0194
Tail Rotor	140	.0054	212	.0059	310	.0067
Empennage	200	.0077	293	.0081	395	.0086
Fuselage	2650	.1019	3390	.0942	3970	.0863
Landing Gear	742	.0285	1028	.0286	1313	.0285
Flight Control	509	.0196	785	.0218	949	.0206
Nacelles	453	.0174	527	.0146	629	.0137
Engines	1990	.0765	2360	.0656	2860	.0622
Prop. System	607	.0233	645	.0179	696	.0151
Drive System	650	.0250	900	.0250	1150	.0250
APU	280	.0108	280	.0078	280	.0061
Instruments	181	.0070	205	.0057	225	.0049
Hydraulics	170	.0065	230	.0064	286	.0062
Electrical	585	.0225	693	.0193	720	.0157
Electronics	943	.0363	943	.0262	943	.0205
Furnishings	1750	.0673	2550	.0708	3350	.0728
A/C and A/I	751	.0289	1133	.0315	1506	.0327
Empty Weight	14983	.5763	19686	.5468	24307	.5284
Oper. Equipment	45	.0017	45	.0013	45	.0010
Crew	380	.0146	380	.0106	380	.0083
Oil, etc.	92	.0035	99	.0028	108	.0023
Oper. Empty Weight	15500	.5962	20210	.5614	24840	.5400
Payload	7600	.2923	11400	.3167	15200	.3304
Zero Fuel Weight	23100	.8885	31610	.8781	40040	.8704
Fuel	2900	.1115	4390	.1219	5960	.1296
Gross Weight	26000		36000		46000	

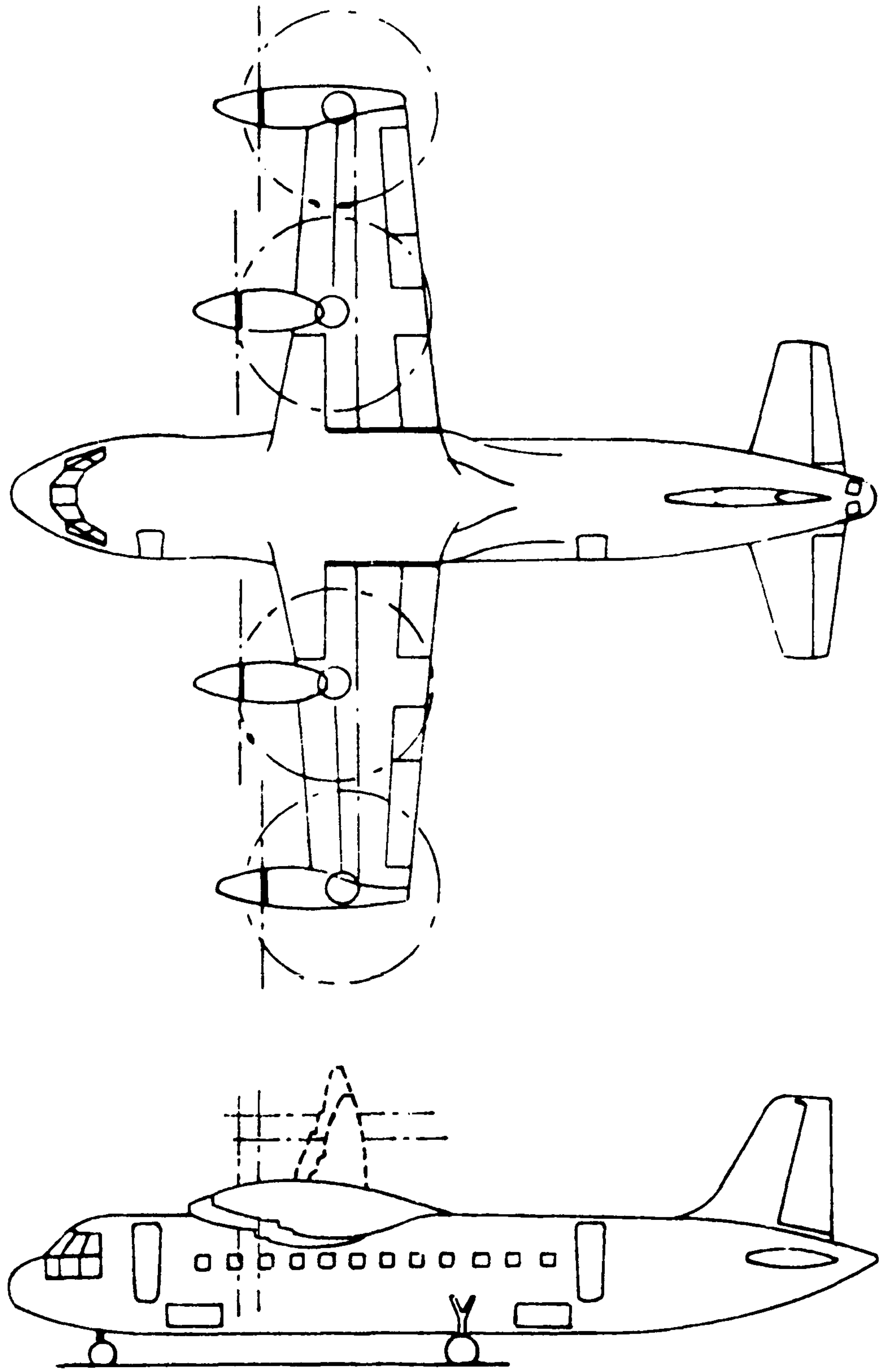

Figure 1.1-9 1975 and 1985 Tilt Wing VTOL

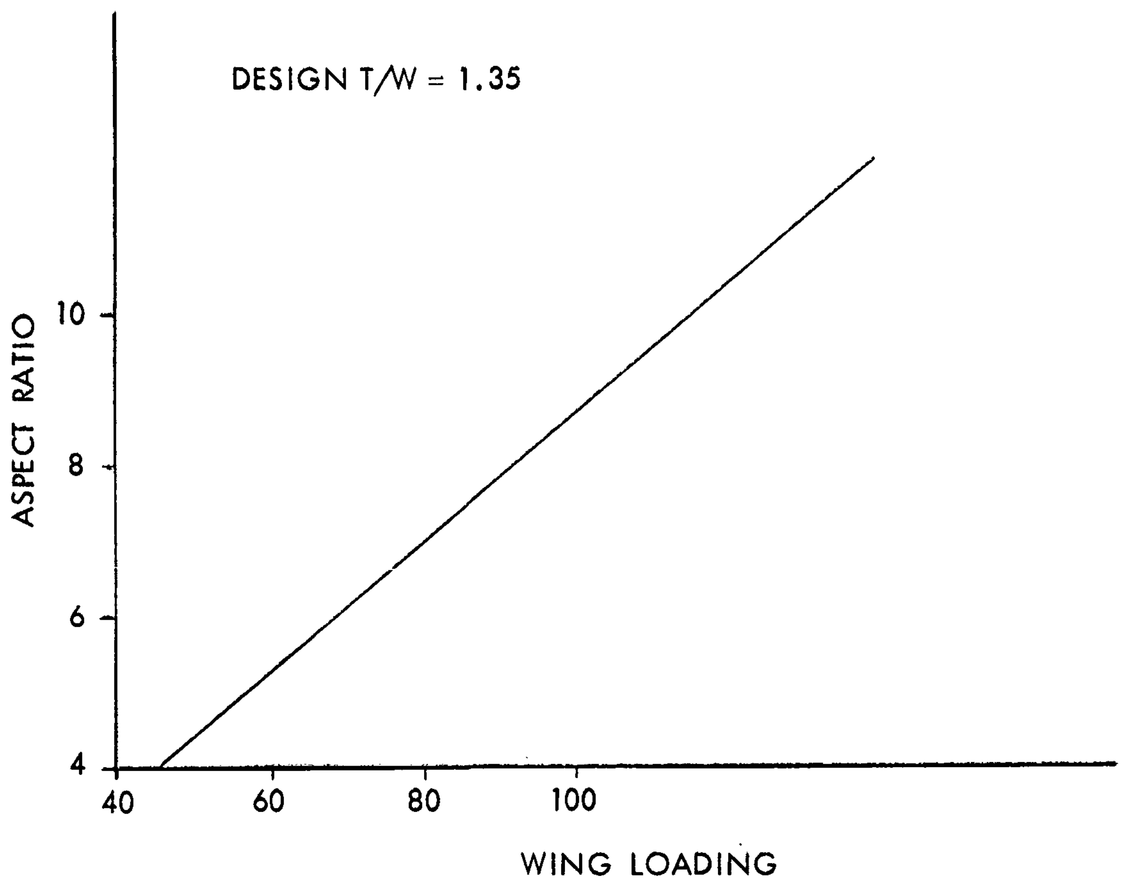

Figure 1.1-10 Aspect Ratio vs Wing Loading
For Tilt Wing Configuration

takeoff and landing. The engines are cross shafted and clutched so as to permit maintaining symmetrical thrust after engine failure. Eight-blade Hamilton Standard Vari-Cam propellers with monocyclic pitch control to provide aircraft pitch control during hover and transition without tail rotor

- Hover roll, pitch and yaw control by differential collective propeller pitch augmented by outboard spoilers
- Conventional empennage and control surface arrangement but with all movable horizontal tail, using approximately $\overline{V}_H = 0.9$ and $\overline{V}_V = 0.1$
- Extensive stability augmentation

1.1.1.3.4 1985 Tilt Wing VTOL

The 1985 tilt wing arrangement is retained for the 1985 arrangement, but is reduced in size as result of expected reduced structural and propulsion weights, due to advanced materials, technology and further reduced by lower engine fuel consumption.

1.1.1.3.5 1985 Autogyro STOL

The conceptual 60-passenger arrangement is shown in Figure 1.1-11, having the following characteristics:

- Hingeless four blade variable speed rotor
- Four under-wing-mounted turboshaft engines driving four shrouded fans or propellers
- Rotor acceleration for takeoff by pneumatic drive system similar to that utilized in 1985 compound helicopter. Rotor driven at low power during cruise for improved specific range
- Disk loading = 10 psf
- Wing loading = 98 psf
- Wing aspect ratio = 3
- Wing taper ratio = 0.5
- Weight empty, fuel weight, gross weight vs payload See Figure 1.1-12

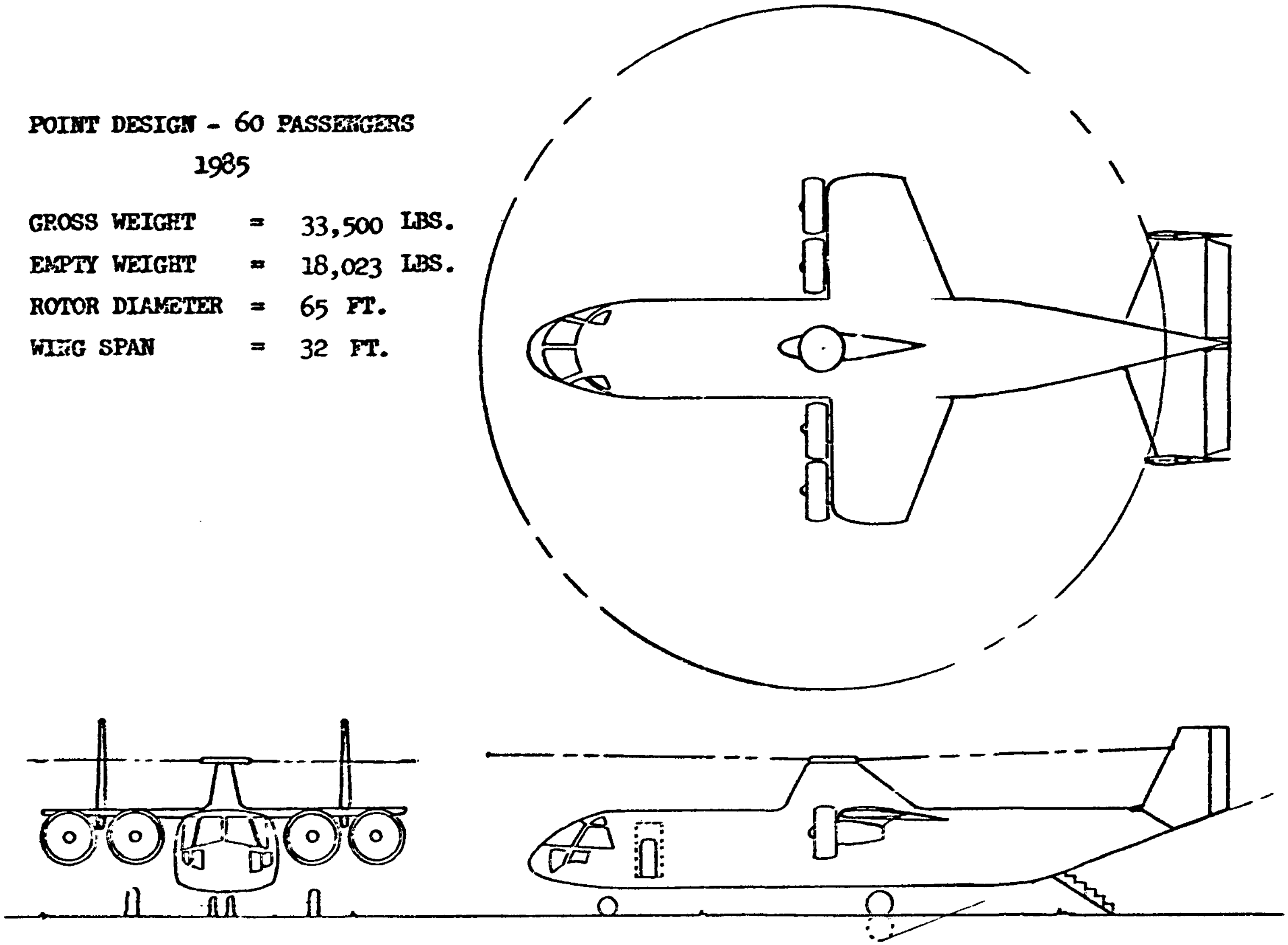

Figure 1.1-11 1985 60-Passenger Autogyro STOL

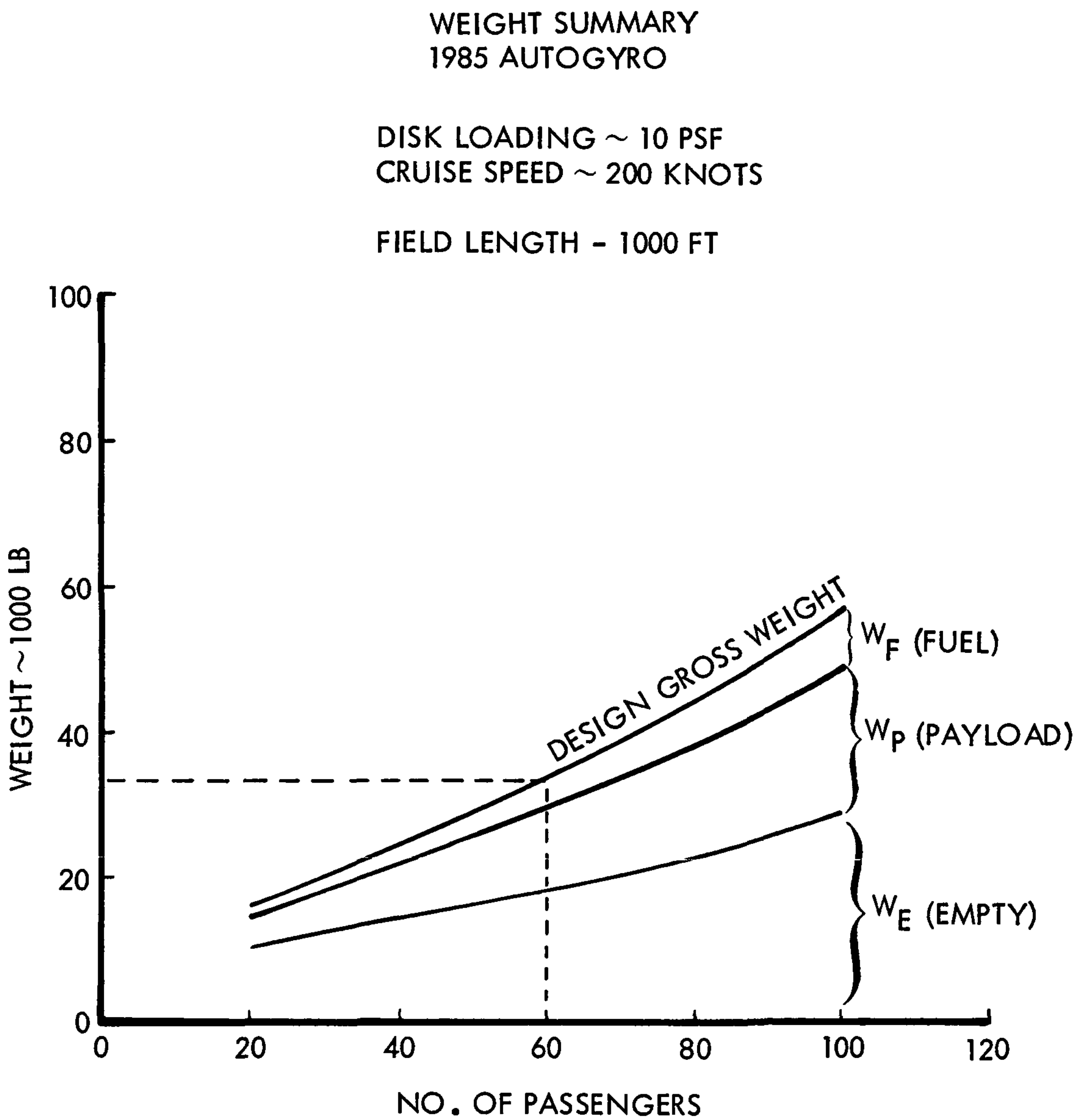

Figure 1.1-12 1985 Autogyro STOL Weight Summary

- Propulsion system - conceptual

  Torqueless pneumatic main rotor drive system employing dual-purpose turbofan engines and similar to that proposed for the 1985 compound helicopter. The rotor torque requirements are reduced however, to approximately 50 percent of those required by the 1985 compound helicopter, through elimination of hover requirements.

1.1.1.3.6 Propeller Powered Deflected Slipstream STOL

1975 General arrangement per Figure 1.1-13 and having the following physical characteristics:

- High wing with large chord high deflection two segment full span flaps for power-on lift augmentation similar to Figure 1.1-14
- Wing thickness ratio approximately t/c = 0.18, Taper ratio approximately 0.5
- Four underslung turboprop engines mounted so as to provide full immersion of wing in slipstream with outboard propeller outermost spanwise station near wing tip. Engines cross shafted and clutched to permit maintaining symmetrical thrust after engine failure
- Aspect ratio variable with wing loading and thrust loading
- Conventional empennage arrangement with adjustable stabilizer and using $\overline{V}_H = 1.1$ and $\overline{V}_V = 0.10$ (approximately)

1985 general arrangements same as 1975 configuration except for size reduction due to use of composites in structure and engines, and reduced engine specific fuel consumption.

1.1.1.3.7 1985 Augmentor Wing Powered STOL

General arrangement similar to 1985 CTOL (see Figure 1.1-17) and with following physical charcteristics.

- Four under-wing-mounted turbofans (no pylons)
- Wing aspect ratio = 8, taper ratio = 0.4, thickness ratio, t/c = 0.18

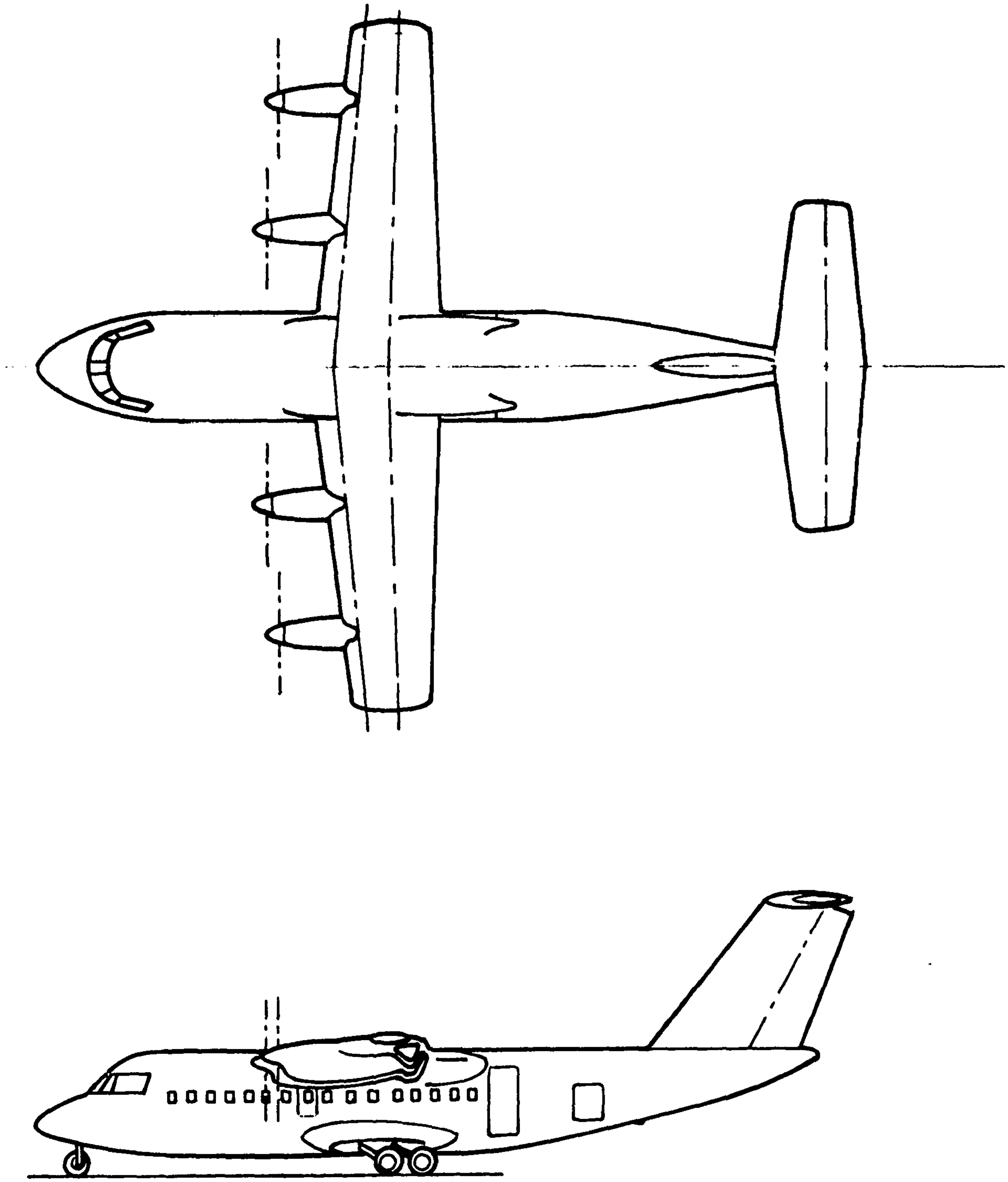

Figure 1.1-13 1975, 1985 Deflected Slipstream STOL Configuration

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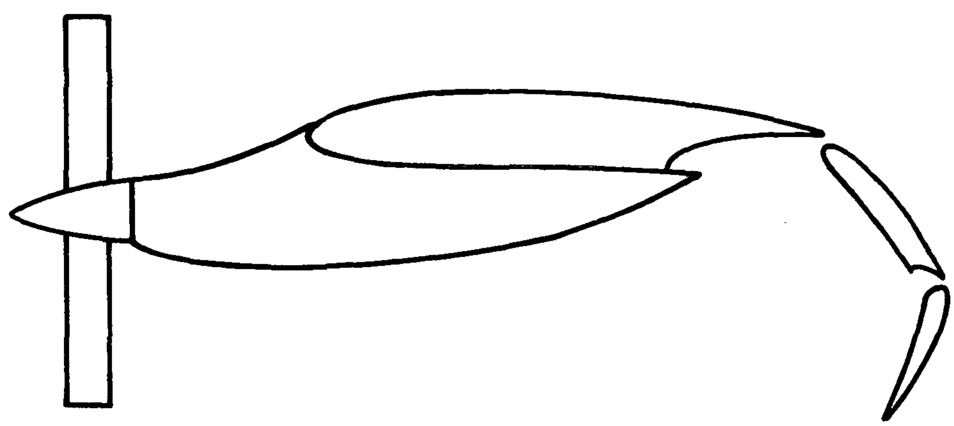

Figure 1.1-14 Deflected Slipstream STOL Flap Configuration

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CALIFORNIA COMPANY

- Thirty percent chord full span augmentor wing type flaps similar to those shown in Reference 1.1-11 and with typical flap section per Figure 1.1-15

- Full span leading edge slats

- Differential flap motion for lateral control

- Wing spoilers for speed control

- Conventional Tee-tail empennage with $\overline{V}_H = 1.1$ and $\overline{V}_V = 0.12$. All movable horizontal, using geared elevator and two-segment double-hinged rudder to augment pitch and yaw control power

- Augmentor wing duct supplied by special fan stages during takeoff and landing. Engine conceptual arrangement per Section 1.1.2.2

1.1.1.3.8 1975 Propeller Powered Short Field CTOL

General arrangement per Figure 1.1-16 and having following physical characteristics:

- Four under-wing-mounted turboprop engines

- Wing aspect ratio - 10, taper ratio = 0.4, t/c = 0.18

- Approx. 33 percent chord, 65 percent span Fowler action double slotted flaps

- Full span leading edge slats

- Conventional ailerons

- 50 percent span spoilers

- Conventional empennage with adjustable stabilizer and two-segment double-hinge vertical and having $V_H = 0.11$ and $V_V = 0.10$ (approx.)

1.1.1.3.9 1985 Turbofan Powered Short Field CTOL

Same general four engine configuration as for 1975 except with bypass fans replacing turboprops as shown in Figure 1.1-17 and with weight benefits due to lower structure and engine weights, and improved engine specifics.

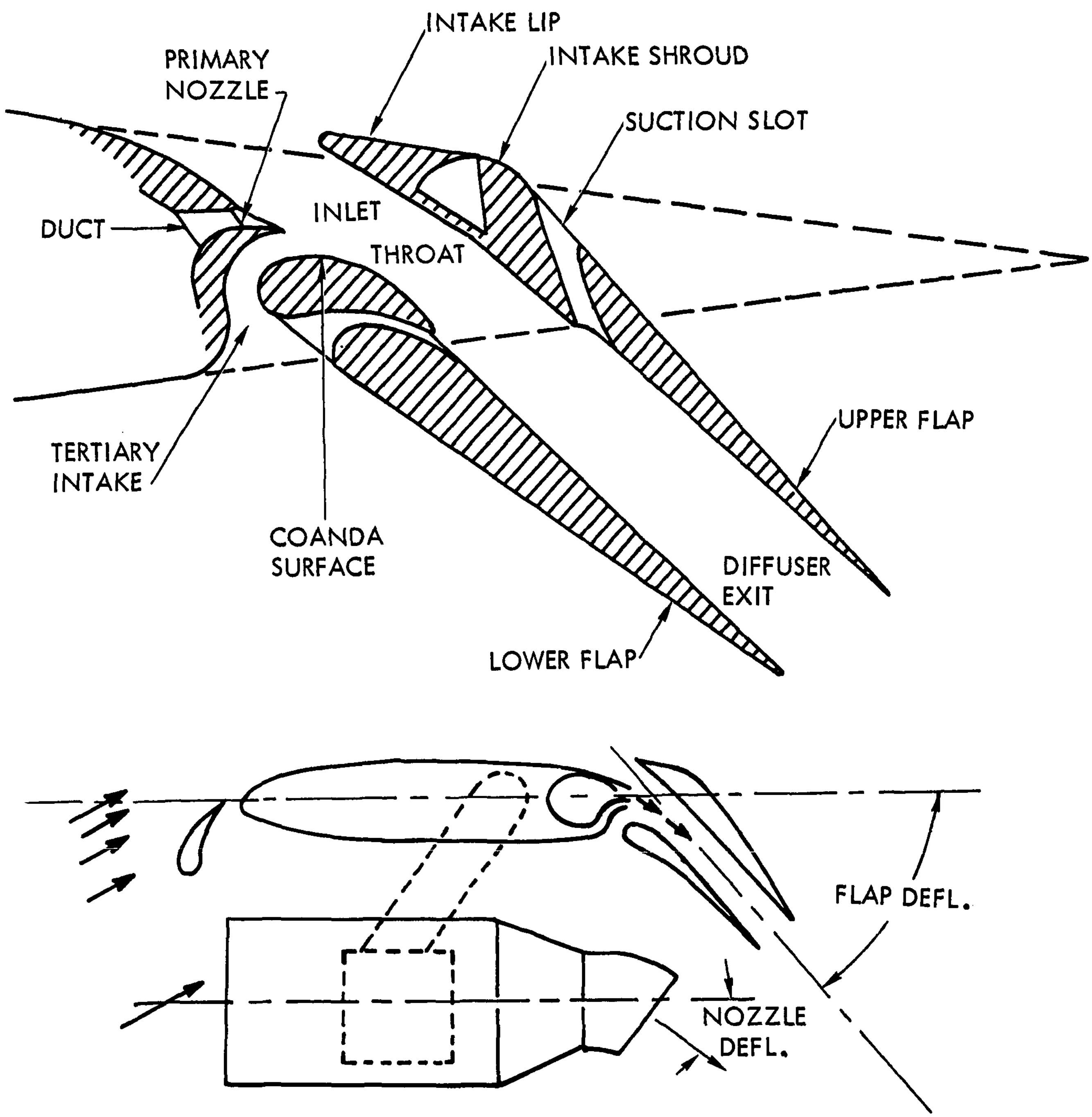

Figure 1.1-15 Augmentor Wing Flap-Propulsion Concept

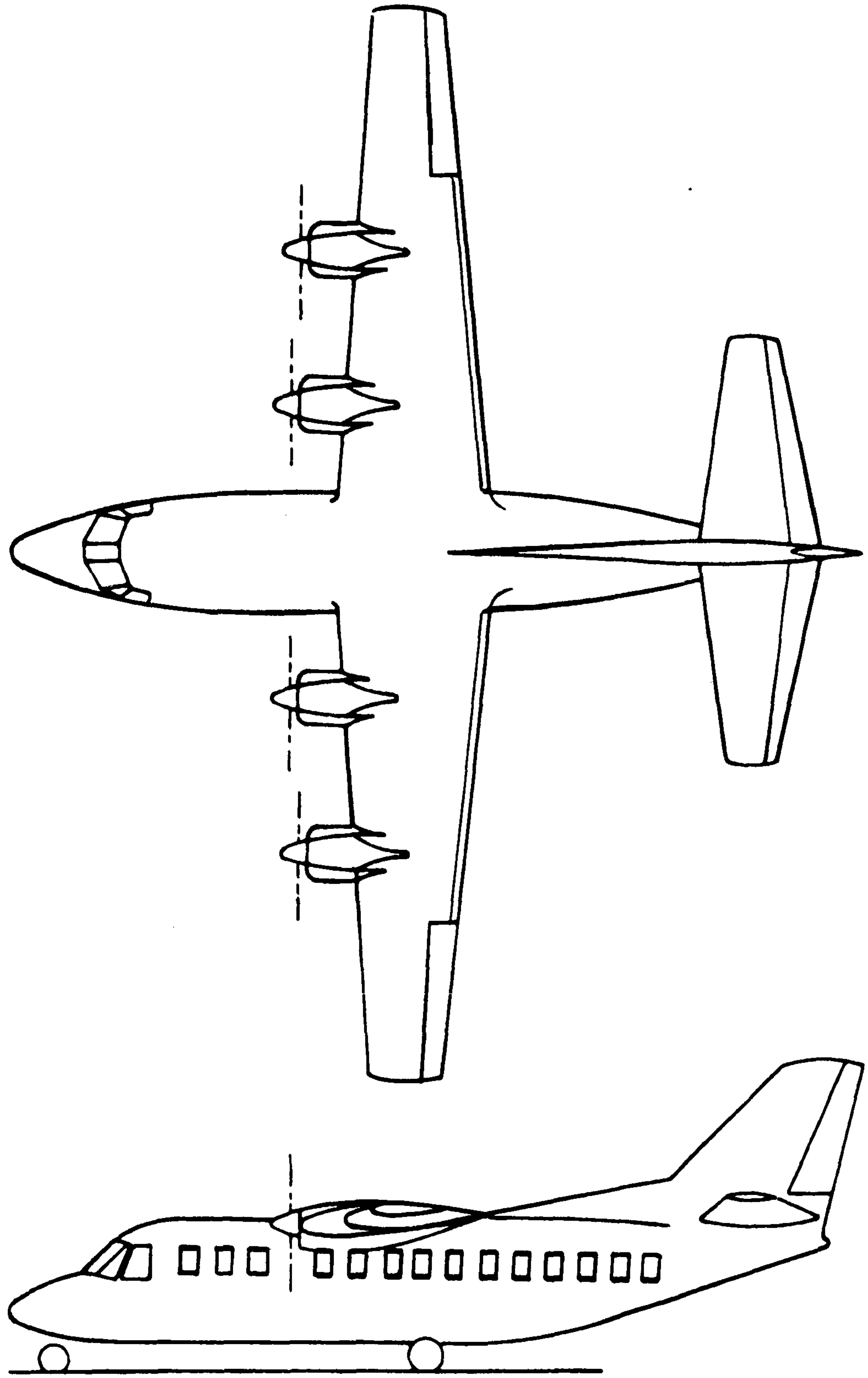

Figure 1.1-16 1975 Propeller Powered Short Field CTOL Configuration

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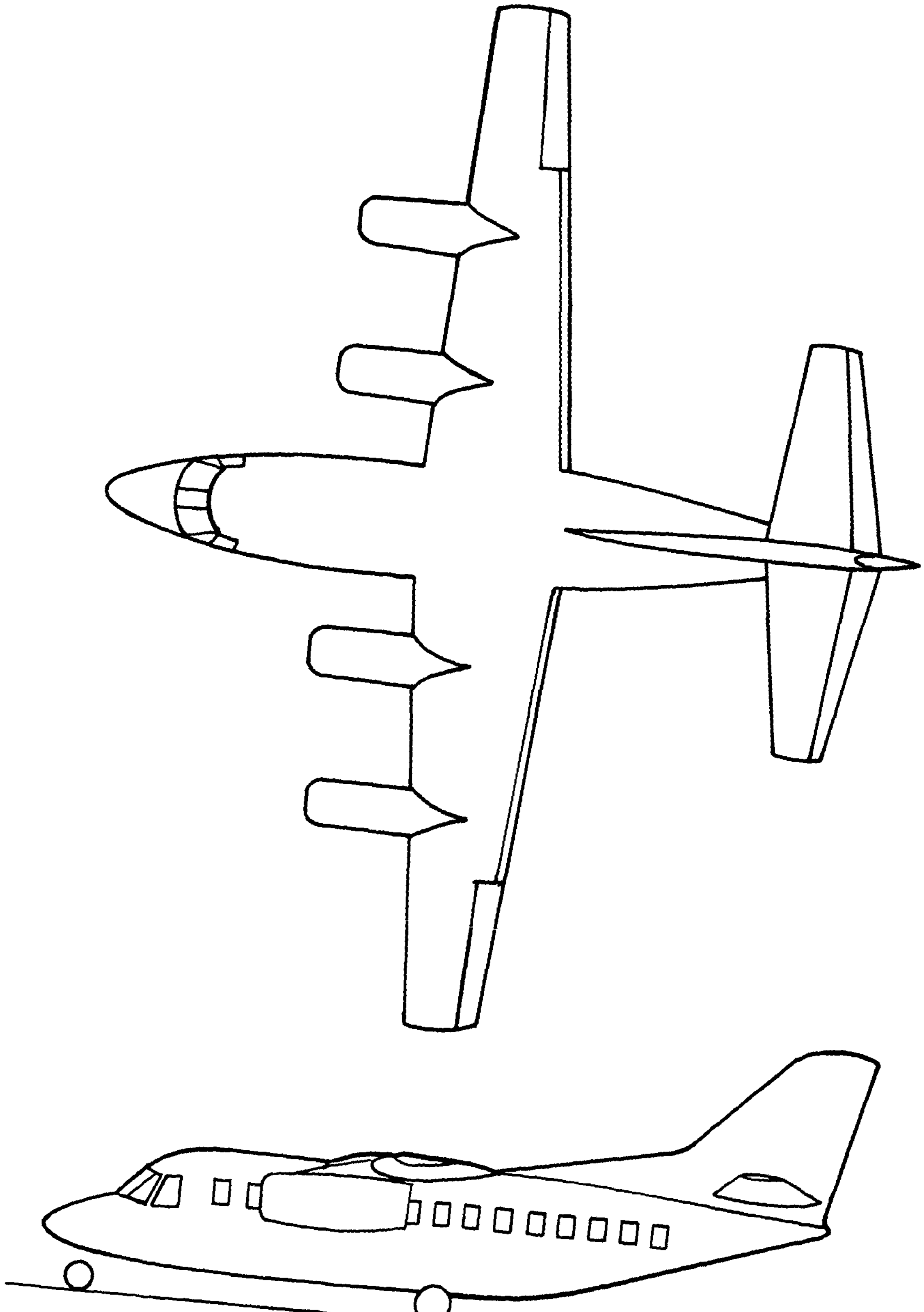

Figure 1.1-17 1985 Fan Powered Short Field CTOL Configuration

1.1.2 TECHNOLOGY SPECTRUM

The technology levels employed in the several disciplines and associated methodologies and assumptions required for the aircraft synthesis-analysis are discussed as follows:

The fixed-wing configurations, aerodynamic, weight, and propulsion information is developed in parametric form for direct application to the Lockheed ASSET synthesis-analysis computer program to show weight, cost, and performance information as a function of payload, wing loading, and thrust loading. The rotary wing configurations are point designed with the payload variables.

1.1.2.1 Aerodynamics

The aerodynamics technology level employed in the analysis along with pertinent performance analysis methodologies are discussed as follows:

An essential requirement of the intraurban transport is that it have a short takeoff and landing capability. This is achieved most simply through low liftoff/touchdown speeds via high lift coefficients. The current and forecasted state of the art in high-lift development, and associated control power, is summarized in Figure 1.1-18. These comparisons are a part of the background used in making the configuration concept selection judgements of Section 1.1.1.1 and are used, where appropriate, in the performance analysis.

The conventional multislotted flap leading edge slat arrangement is employed on the fixed wing STOL and CTOL configurations for both 1975 and 1985 technologies, and the augmented flow flap leading edge slat concept is used on the 1985 augmentor wing configuration. Neither the jet flap nor auxiliary lift engine concept is employed due to their contributions to the noise problem. The estimated lift capabilities shown in Figure 1.1-18 have been employed in the performance analysis.

Preliminary evaluation indicates that acceptable flight characteristics on all fixed wing STOL configurations can likely be achieved down to approximately 1000 feet field length without resorting to reaction control systems. Although some horizontal or vertical tail lift augmentation, using

LIFT AUGMENTATION

METHODS FOR OBTAINING LIFT AT LOW SPEED	AREAS OF CONCERN	POSSIBLE IMPROVEMENTS	1975 IOC 1970 TECHNOLOGY	1985 IOC 1980 TECHNOLOGY	ULTIMATE POTENTIAL	SYSTEM APPLICATION
Multi-Slot Flaps and Leading-Edge Devices (No Power)	• Low L/D for climb • Nose-down pitch moment • Heavy structure	Little additional potential	$C_{L_{MAX}} \approx 3.5$	$C_{L_{MAX}} \approx 4$	$C_{L_{MAX}} \approx 4$	Short field conventional
Jet Flap	• Internal ducting size and weight • Mid-chord stall • Adverse ground eff. • Nose-down pitch mom.	• Cambered wing • Leading edge blowing	$C_{L_{MAX}} - C_\mu \sin(\delta + \alpha) \approx 5$	$C_{L_{MAX}} - C_\mu \sin(\delta + \alpha) \approx 6$	$C_{L_{MAX}} - C_\mu \sin(\delta + \alpha) \approx 7$	STOL
Externally (Prop or Fan) Blown Flap	• Thrust recovery • Loads on flaps • Pitch moment	• High BPR fans	$C_{L_{MAX}} - C_J \sin(\delta + \alpha) \approx 3$	$C_{L_{MAX}} - C_J \sin(\delta + \alpha) \approx 4$	$C_{L_{MAX}} - C_J \sin(\delta + \alpha) \approx 4$	STOL
Suction/Blowing BLC	• Internal ducts • Complexity	Needs development	$C_{L_{MAX}} \approx 5$	$C_{L_{MAX}} \approx 6$	$C_{L_{MAX}} \approx 8$	STOL
Auxiliary Lift Engines (Wing or Fuselage)	• Interference with wing and fuselage • Ground effect • Downwash	• Integrate with wing	Lift due to thrust component magnitude be tailored to specific application. See propulsion matrix for critical parameter evaluation.			VTOL and STOL
Rotors	• Weight • Blade profile • Noise • High L/D ratio	• Improved airfoil sect. • Circulation control	• High advance ratios • Elimination of retreating blade stall • Improved blade tip and planform	• Minimum drag hug • Reduced rotor download • Jet flap rotor blade	• Favorable rotor hub-blade • Root interference drag • High order circulation flow	Rotary wing

CONTROL

METHODS FOR OBTAINING CONTROL FORCES AT LOW FLIGHT SPEEDS	PROBLEM AREAS	POSSIBLE IMPROVEMENT	CRITICAL SYSTEM CONDITIONS	SYSTEM APPLICATION
Surface With Flap	Force decreases as V^2	Increase size or aspect ratio	Flow separation (stall)	STOL + short-field
Flap With BLC (Suction or Blowing)	Force decreases as V^2 (but greater than without BLC)	Increase size, aspect ratio or blowing momentum	Loss of BLC power source	STOL + short-field
Jet Flap	• Internal duct	Integrate with propulsion	Loss of pressure	STOL + VTOL
Jet Reaction Control	• Ducting • Engine thrust loss	Integrate with propulsion	Engine out in hover	VTOL
Auxiliary Thrusters	• Weight • High speed drag	• Integrate with propulsion	Mechanical failure	STOL + VTOL
Rotor Cyclic Pitch	• Dynamics • Anti-torque sys. • Control loads	• Rigid rotor sys. • High order collective and cyclic pitch control • Advanced electronic cont. • Jet flap control sys. • Ducted fan anti-torque	• Vibration • Advancing blade Mach number • Control moments	Rotary wing

Figure 1.1-18. Aerodynamics Technology

one of the concepts shown in Figure 1.1-18, may be required to provide adequate response rates at the low liftoff and approach speeds involved. The potential gains in rotary wing lift capacity through use of rotor blade flaps and/or slats (noted in Figure 1.1-18) are not employed in this analysis because the basis for quantitative estimates is insufficient.

The wide range of configuration concepts, wing loadings, and thrust loadings necessary for the parametric analysis require that the associated performance analysis be simplified. The methods employed are summarized below:

- Fixed wing cruise drag basis

  The cruise drag level for all fixed wing concepts is assumed to be the same as the flight test determined drag of the 1960 Lockheed Electra short haul transport corrected for aspect ratio and wing loading. This value is

$$C_{Do} = 0.0142 + 0.0076\left(\frac{1300}{S_w}\right) + \frac{C_L^2}{\pi ARe}$$

  where:

  S_w = wing area

  AR = aspect ratio

  e = 0.8 (wing efficiency factor)

  A drag penalty of ΔC_{Do} = 0.0050 is added to the 1985 augmentor wing configuration to account for likely profile discontinuities due to the complex flap installation. No change in these basic drag levels is anticipated as the result of technology development between 1975 and 1985.

- Rotary wing drag basis

  The drag basis for the component helicopter VTOL and autogyro STOL configurations is based on flight test drag levels determined by Lockheed on the XH-51A and AH-56A compound helicopters.

- Fixed wing takeoff/landing lift-drag basis

  The deflected slipstream STOL power-on lift-drag basis is established from NASA analytical and power-on wind tunnel test data on various STOL and V/STOL configurations shown typically by references 1.1-12 through 1.1-14.

The dynamic pressure used to correlate aerodynamic data is taken as that in the slipstream. The technique shown in NASA Memo 1-16-59L is used to establish effective lift levels with the resulting values being strongly a function of the slipstream thrust coefficient, C_{TS}, or installed power/wing loading (T/W/W/S). The influence of ground proximity is included in the estimates. A small increase in flap turning effectiveness is assumed for the 1985 technology as compared with 1975 technology via a more sophisticated flap design.

The effective lift/drag during takeoff and landing for the 1985 augmentor wing concept is based on the wind tunnel tests and analysis shown in Reference 1.1-15. At full flap deflection, the augmented circulation lift coefficient, independent of thrust vector effects, is estimated as 4.7 for takeoff and 5.4 for landing with flap deflections of 50 degrees and 75 degrees respectively. The corresponding flap drag increment is estimated to be $\Delta C_{D_P} = 0.135$ with a wing efficiency factor = 1.0.

The CTOL takeoff/landing performance is based on the following power-off lift capability:

	1975	1985
Takeoff $C_{L_{max}}$	2.3	2.3
Landing $C_{L_{max}}$	3.5	4.0

The installed propulsion system characteristics employed in the performance analysis are presented in following Section 1.1.2.2.

- Estimated performance

The fuel fractions required for the mission performance called for in Section 1.1.1.2 are presented in previous Tables 1.1-3 and 1.1-4 at three payload levels for the point design compound helicopter configurations, and in Figure 1.1-12 for the 1985 autogyro. Corresponding block speed versus stage length information is found in Appendix A, Figures A-1.1-1 and -2 for the helicopters. The 1985 autogyro values are approximately the same as for the helicopter.

Fuel requirements for the fixed wing configurations are presented in Appendix A, Figures A-1.1-3 through A-1.1-8 shown as a function of thrust/weight ratio, T/W and wing loading W/S for use in the ASSET program.

Block speed information required for the fixed wing aircraft analysis is not isolated, but simply employed with the ASSET program as part of the total analysis.

The essential elements of the takeoff/landing field length analysis of the STOL and CTOL aircraft are outlined as follows:

- 1985 Autogyro STOL

The STOL autogyro takeoff distance is estimated, assuming an engine failure at liftoff and with the liftoff spaced sufficiently high to provide a climb gradient of five degrees. Rotor acceleration for takeoff via the tip nozzle drive system, utilizes all power and requires 30 to 45 seconds. Power is then shifted to the fans to provide axial thrust for forward acceleration. Near liftoff, power is distributed about evenly between the fans and the rotor. Corresponding values in cruise are approximately 75 percent to fans and 25 percent to rotor.

The variation of design disk loading, liftoff speed and ground run distance are shown as a function of design takeoff distance in the following table.

	Takeoff Distance with Engine Failure, ft.		
	400	1000	3000
Disk loading, psf	4.3	10.0	18.1
Liftoff Speed, kt	90	94	170
Ground run, ft	100	530	1750

The effect of the design takeoff distance on design gross weight is shown in Figure 1.1-19. Landing distances are always less. The very slight reduction in weight at takeoff distances beyond 1000 ft is notable. In addition, at disk loadings corresponding to runway lengths of greater than 1000 ft, the use of autorotation following complete power failure, is not considered practical due to excessive sinking speeds. It is therefore concluded there is no gain to be had by considering the autogyro at field length beyond 1000 ft.

- 1975 and 1985 Deflected slipstream STOL

<u>Takeoff</u>

$$V_{TO} = 1.2\ V_{MIN}$$

V_{MIN} based on three engines operating (one engine out) at takeoff power setting. Flaps are deflected to optimum position, based on wing loading and thrust/weight ratio ($20^\circ \leq \delta_f \leq 60^\circ$).

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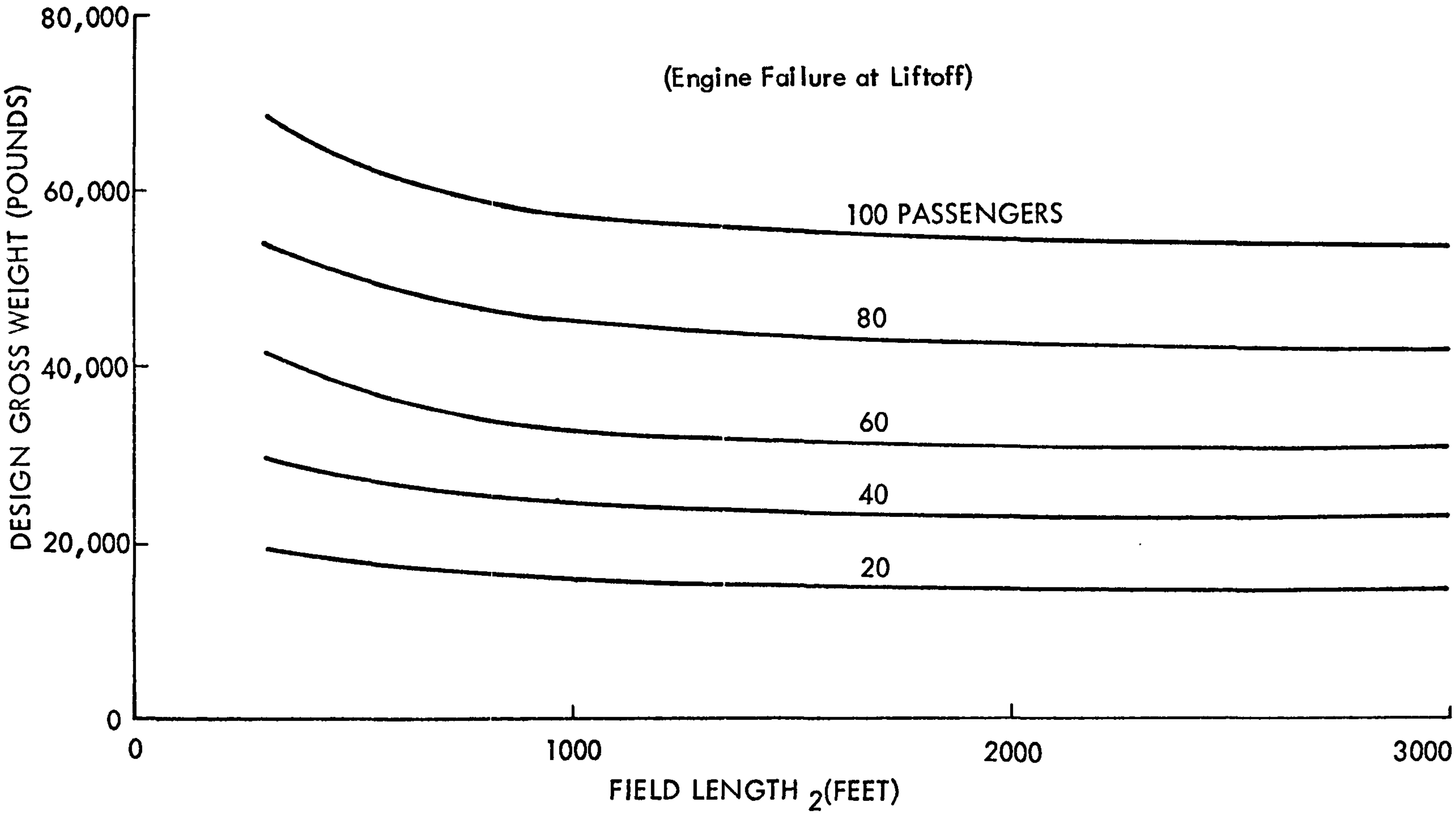

Figure 1.1-19 1985 Autogyro Design Gross Weight vs Field Length

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It is noted that the initial parametric analyses considered all the wing be in the slipstream. In addition, the propeller static thrust loading was maintained at approximately a fixed level to minimize both airport and cabin noise. As a result, aspect ratios as low as AR = 2 and as high as AR = 14 were specified. In order to maintain realistic airplane geometry, aspect ratios were limited as follows: $5 \leq AR \leq 12$; and were used to estimate takeoff and landing performance. Consequently, some airplanes had portions of the wing outside of the propeller slipstream, and some had propellers extending outboard of the wing tips.

$$V_{OBS} = 1.2\ V_{MIN}$$

Obstacle height = 35 ft

Takeoff field length equals sum of four engine ground acceleration distance to V_{TO} plus distance to climb to a height of 35 feet with engine inoperative. Experience with STOL airplanes indicates this distance approximates the appropriate balanced field length.

The steady-state second segment climb was checked for selected configurations, and the climb gradient exceeded 0.03 for all cases checked.

<u>Landing</u>

$$V_{OBS} = V_{MIN} + 10 \text{ knots} = V_{TD}$$

V_{MIN} based on three engines operating four propellers at takeoff thrust setting. Flaps are deflected to approach setting ($\delta_f = 90^o$).

Ground roll assumes one second free roll at touchdown speed prior to actuation of deceleration system, and an average deceleration of 0.5 g.

Air distance is taken from a height of 35 ft to touchdown. Average rate of sink during this period is taken as 10 fps.

Field length is the sum of the air distance and the ground roll divided by 0.7.

- 1985 Augmentor Wing Powered STOL

<u>Takeoff</u>

$$V_{TO} = 1.2\ V_{MIN}$$

V_{MIN} based on three engines operating (one engine out) of takeoff setting, at sea level, 90°F. Flap setting is 50 degrees and the tail pipes are undeflected.

$$V_{OBS} = 1.2\ V_{MIN}$$

Obstacle height = 35 ft

Four engine acceleration to V_{TO}; three engine climb out to clear obstacle. On ground roll, conditions at 0.7 V_{TO} are used to represent averaged net acceleration.

$$Sg = \frac{W \cdot V_{TO}^{2}}{22.4\ (F_n - D)}$$ ground roll with V in knots

$$Sa = \frac{35}{\frac{F_n}{W} - \frac{D}{W}}$$ air distance

Field length = Sg + Sa

With the use of these simplified methods and assumptions, the takeoff field lengths will reasonably approximate those computed using more exact and involved data, methods, and the restrictions of the proposed FAR for V/STOL aircraft. These results are considered "first cut" and are felt to be sufficiently accurate for comparison with other configurations in this study.

Figure 1.1-20 presents definitions for overall lift and drag coefficients, which are based on free stream dynamic pressure and wing reference area.

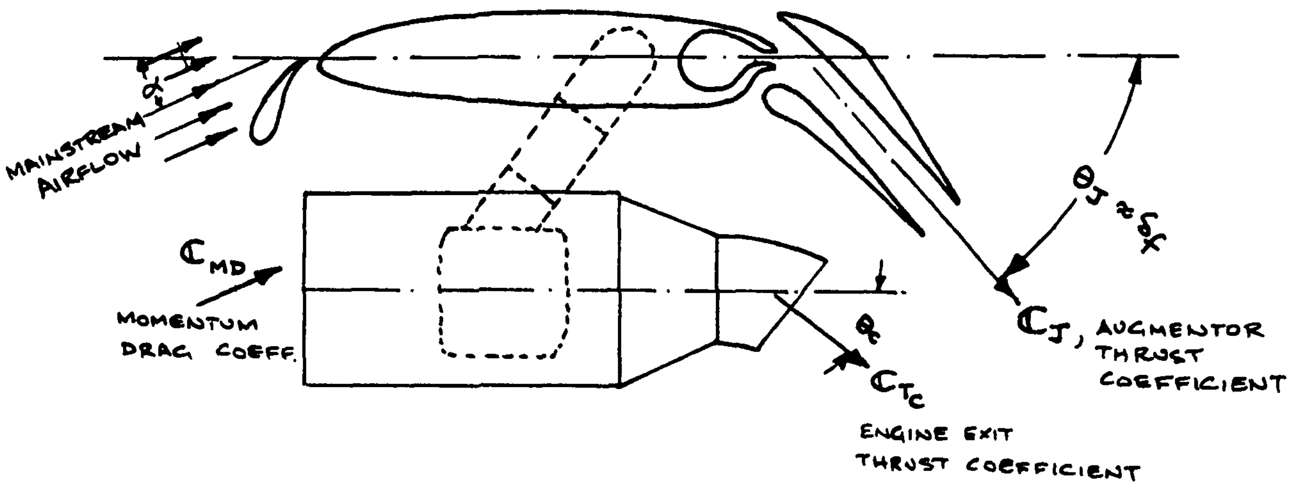
Landing

$$V_{OBS} = V_{MIN} + 10 \text{ knots}$$

V_{MIN} based on three engines operating (one engine out) at takeoff setting, at sea level, 90°F. Flaps and tail pipes are deflected 75 degrees. Values computed in the same manner as in the above example.

Ground roll distance is based on one second of free roll at touchdown speed, equal to obstacle speed, and a deceleration of 0.5 g.

Air distance is based on an obstacle height of 35 feet, V_{OBS}, and an average rate of sink of 10 fps.



OVERALL LIFT COEFFICIENT, ΣC_L

$$\Sigma C_L = C_L^* + C_J \sin(\theta_J + \alpha) + C_{Tc} \sin(\theta_c + \alpha)$$

(NOTE: ASSUME DUCT LOSSES ≈ AUGMENTOR GAINS)
ASSUME STALL AT $\alpha = 20°$

OVERALL DRAG COEFFICIENT, ΣC_D

$$\Sigma C_D = C_{D_{o_{clean}}} + \Delta C_{D_{flap}} + \Delta C_{D_{gear}} + \frac{C_L^{*2}}{\pi A R e} + C_{MOM.DRAG} + - C_J \cos(\theta_J + \alpha) - C_{T_c} \cos(\theta_c + \alpha)$$

(PUT $e = 1.0$)

TAKEOFF: $\theta_J - \delta_f = 50°$; $\theta_c = 0°$

LANDING: $\theta_J - \delta_f = 75°$; $\theta_c = 75°$

Figure 1.1-20 Augmentor Wing Propulsion System

The field length is then the sum of the air and ground distances increased by 1/0.7.

- 1975 and 1985 CTOL

Takeoff

$C_{L_{MAX}} = 2.3$ (flaps 20°)

$V_{TO} = 1.2\ V_S$ (power off)

$V_{OBS} = 1.2\ V_S$

Four engine acceleration to V_{TO}, three engine climb out to clear obstacle. On ground roll, conditions at 0.7 V_{TO} are used to represent averaged net acceleration.

$$Sg = \frac{W \cdot V_{TO}^2}{22.4\ (F_n - D)}$$ ground roll with V in knots

$$Sa = \frac{35}{0.15\ (F_n/W)_{3\ eng}}$$ air distance

Assumed climb gradient equivalent to 0.15 x available three-engine thrust/weight

Field length = Sg + Sa

Landing

$C_{L_{MAX}}$ per Figure 1.1-18

$V_{OBS} = 1.25\ V_S$ (power off)

Ground roll distance is based on one second of free roll at touch-down speed, equal to obstacle speed, and a deceleration of 0.4 g.

Air distance is based on an obstacle height of 50 feet (present FAR), V_{OBS}, and an average rate of sink of 10 fps.

The field length is then the sum of the air and ground distances increased by 1/0.6.

The resulting fixed wing takeoff and landing field length estimates are shown in Appendix A, Figure A-1.1-9 through A-1.1-16.

- Flight Characteristics

Detailed analysis of the flight characteristics of each configuration concept is beyond the scope of this study. However, the aerodynamic geometry of the concepts as defined in Section 1.1.1 is believed sufficient to provide satisfactory flight characteristics. Certain risk factors though, are involved and some of the more important of these are discussed as follows:

Rotary Wing Concept

1) Control system dynamic problems at 200 kt cruise could increase development costs, particularly at larger payload sizes

2) Control system fatigue in heavy, long life commercial usage

3) Development costs and performance of pneumatic rotor drive system on 1985 helicopter and autogyro

Deflected Slipstream Concept

1) Pitch control power for trim at forward c.g. at high power-on lift coefficient during takeoff and landing

2) Development of sufficient flaps down power-on drag to permit use of required high power-on landing approach

Augmentor Wing Concept

1) General development costs assure satisfactory flight characteristics of this new concept (wing flap, engine, ducting system)

1.1.2.2 Propulsion

The propulsion systems consist of either turboprop, turbofan, or turboshaft engines driving propellers and/or rotors and ducted propellers. The basis for the installed performance which includes inlet and drive system losses, and secondary power takeoffs is presented below for each concept. System sizing information is also shown.

- 1975 Technology Prop-powered CTOL

A Pratt and Whitney study turboprop engine based on currently feasible technology is used for this concept. At sea level static, the engine is rated at 2500 equivalent shaft horsepower, and the rated fuel flow is 1086 lb/hr. The sea level static idle fuel flow is estimated to be 98 lb/hr. The engine weighs 570 pounds.

An eight-bladed, lightweight, 16-foot diameter, variable camber propeller is used as the thruster. It is designed to operate at low tip speed, low power disk loading, and high static thrust per horsepower - conditions which are favorable for low noise levels. The estimated propeller weight is 590 pounds. The mated system provides a sea level static thrust rating of 9000 pounds and an overall propulsion system thrust to weight ratio of 7.7.

Installed performance and sizing data are presented in Appendix A, Figures A1.1-17 through A1.1-22. Figure A1-1.17 presents installed net thrust versus Mach number at takeoff power for standard and tropical atmospheres. Figures A1.1-18 and 19 present installed values of net thrust and fuel flow versus Mach number at maximum continuous power. Figures A1.1-20 and 21 present installed specific fuel consumption versus the parameter, F_N/P, installed net thrust divided by ambient pressure, at sea level and 2000 feet for part power operation. Figure A1.1-22 presents propulsion system scaling curves for the purpose of determining propulsion system weight, and engine and propeller dimensions at thrust sizes other than the base point.

- 1975 Technology Deflected Slipstream STOL

The propulsion system selected for this concept is identical to the one described above.

- 1985 Technology Deflected Slipstream STOL

An advanced version of the above engine is used for this aircraft concept. Engineering judgment, based upon available advanced technology estimates, indicates that fuel flows can be reduced by 5 percent and weights by 20 percent for 1985 technology. Applying the weight factor to the propulsion system described above, the heading results in an engine weight of 456 pounds and a propeller weight of 455 pounds. This gives a propulsion system thrust to weight ratio of 9.9. Installed propulsion system performance and sizing can also be obtained by applying the 1985 technology fuel flow and weight factors to the data shown in Figures A1.1-17 through 22.

- 1975 Technology Tilt Wing VTOL

A Pratt and Whitney study turboshaft engine based on currently feasible technology is used for this concept. At sea level static, the engine is rated at 8000 shaft horsepower, and the rated fuel flow is 3172 lb/hr. The estimated sea level static idel fuel flow is 285 lb/hr. The engine weighs 1175 pounds.

A 1975 technology gearbox with provision for cross-shafting transmits power from the engine to the propeller. The gearbox and right angle drive is estimated to weigh 1308 pounds. A gear loss of 1 1/2 percent is included in the analysis.

Thrust is through an eight-bladed, lightweight, 26-foot diameter, variable camber propeller. It is designed to operate at a low tip speed, low power disk loading, and high static thrust per horsepower to favor the noise problem. The propeller is sized at the normal takeoff condition of sea level, standard day, with all engines operating. At this condition, approximately 75 percent power is required for takeoff. Full power is required for the sea level, tropical day, one engine out takeoff condition. The estimated propeller weight is 1480 pounds. The mated system provides a sea level static thrust rating of 23000 pounds and an overall propulsion system thrust to weight ratio of 8.0.

Installed propulsion system performance and sizing data are present in Appendix A, Figures A1.1-23 through 28.

- 1985 Technology Tilt Wing VTOL

An advanced version of the above engine is used for this aircraft. Available advanced technology estimates indicate that fuel flows can be reduced by 5 percent and engine, gearbox, and propeller weights by an average of 23 percent for 1985 propulsion systems. Applying the weight factor to the propulsion system described above results in an engine weight of 905 pounds, a gearbox weight of 1008 pounds, and a propeller weight of 1145 pounds. The propulsion system thrust to weight ratio for 1985 then becomes 10.4.

Installed propulsion system performance and sizing can be obtained by applying the 1985 technology fuel flow and weight factors to the data in Appendix A, Figure A1.1-23 through 28.

- 1985 Technology Fan-powered CTOL

An advanced Pratt and Whitney turbofan engine, which could be available for 1985 technology, is selected for this concept. The advanced engine is a high bypass ratio, low pressure ratio, geared fan based upon the STF-320A-4 P&WA study turbofan proposed for 1975 technology. Engineering judgement indicates that a reduction of fuel flow by 5 percent and weight by 20 percent from the STF-320A-4 design is reasonable for 1985. The engine is selected for its low noise characteristics, high thrust-to-weight ratio, and good cruise fuel consumption. At sea level static, the advanced turbofan is rated at 38170 pounds thrust, and the rated fuel flow is 11750 lb/hr. The sea level static idle fuel is 1060 lb/hr. The engine weighs 3170 pounds, giving a thrust to weight ratio of 12.

Installed performance and sizing data are presented in Appendix A Figures A1.1-29 through 34.

- 1985 Technology Augmentor Wing STOL

A conceptual 1985 technology high-bleed turbofan engine configured by Lockheed is used for the augmentor wing aircraft. A schematic of this engine, which is based on a Pratt and Whitney concept, is shown by Figure 1.1-21. At sea level static, the engine is rated at 10800 pounds thrust, including the thrust of the flap bleed air, and the rated fuel flow is

INTRAURBAN TRANSPORT 1985 HIGH BLEED TURBOFAN

SEA LEVEL STATIC THRUST RATING = 10,800 LB

FPR = 1.4 MAX T.I.T. = 2600°F

WEIGHT = 1200 LB

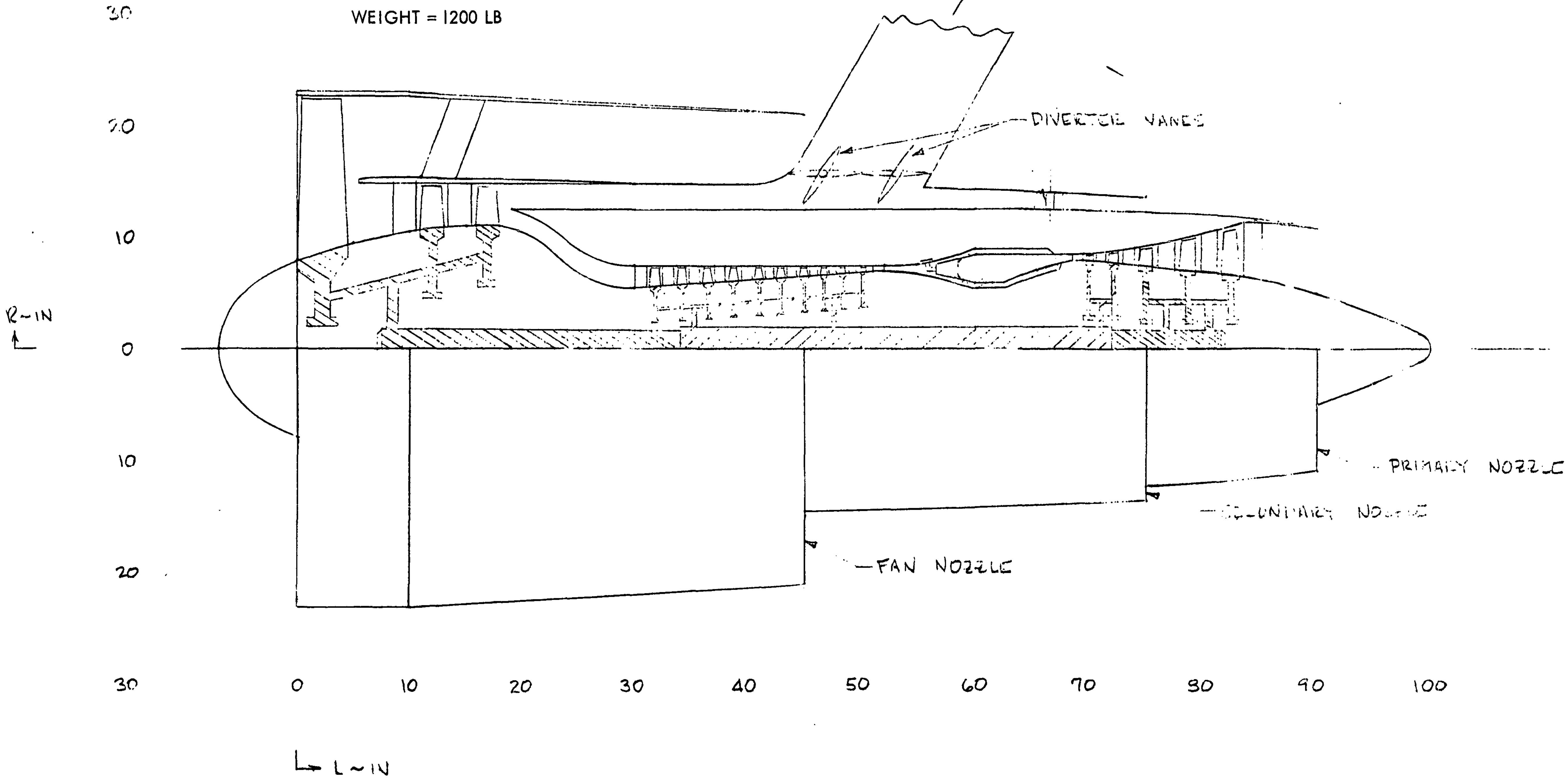


Figure 1.1-21 Augmentor Wing Conceptual Engine Schematic

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3604 lb/hr. The sea level static idle fuel flow is 324 lb/hr. The engine has a fan pressure ratio of 1.4, an overall pressure ratio of 25, and a maximum turbine inlet temperature of 2600° F. In order to minimize the jet noise, the bypass ratio is chosen to achieve a match of fan exhaust and primary exhaust velocities at the sea level static design point. During the STOL takeoff mode on a tropical day, the engine provides flap air at the rate of 62 lb/sec at a pressure ratio of 2.5. During cruise, the vanes diverting bleed air to the wing flaps are closed, and the flow is directed out the secondary nozzle to provide horizontal thrust. The estimated weight of the engine and bleed system is 1200 pounds, giving a thrust to weight ratio of 9. The system provides for stable engine operation during high airflow bleed at a minimum cruise fuel penalty.

Installed performance and sizing data for the system are presented in Appendix A, Figures A1.1-35 through 41. Figure A1.1-35 presents installed horizontal gross thrust, flap gross thrust, and ram drag versus Mach number for STOL takeoff on a tropical day. Figure A1.1-36 presents installed takeoff net thrust versus Mach number for standard day and tropical day during STOL takeoff. Figures A1.1-37 and 38 present installed values of net thrust and fuel flow versus Mach number at maximum continuous power for normal flight. Figures A1.1-39 and 40 present installed specific fuel consumption versus the parameter, F_N/P_{am}, (installed net thrust divided by ambient pressure, at sea level and 2000-feet for part power operation during normal flight). Figure A1.1-41 presents engine scaling curves for the purpose of determining engine weight, length and diameter at a different thrust size than the base point.

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1.1.2.3 Noise Evaluation

The introduction of aircraft in an intraurban transportation system of an established densely populated area could bring with it serious community noise problems. Appropriate steps must be taken to minimize these potential problems by judicious selection of commuterport sites, by adopting proper operational procedures, and by designing vehicles for minimum noise generation and radiation. The selection of the commuterport sites is a prime factor in determining community acceptance of an airborne intraurban transportation system. Sites in or near "high" ambient noise areas, such as industrial and commercial zones, or near modern air conditioned office buildings and apartment houses are less susceptible to community rejection than those in low ambient noise areas, such as strictly private home residential zones. Other factors relating to an intraurban transportation system involve the frequency, or repetition, of flights and the relative ambient noise level. The periods of high vehicle usage are the morning and evening rush hours. During these time periods the aircraft will have the highest flight repetition rate; however, the general ambient noise levels will also be the highest and this will have a tendency to offset, somewhat, the adverse effect of high flight repetition rates. Weather conditions, while generally unaccountable, may also influence the community noise exposure.

There exist, at the present time, a number of rating methods for evaluating the subjective response to noise. One of the most widely used methods, in the aircraft industry, is the "perceived noise level" (PNL) method which relates the subjective response of persons to the "noisiness" of various sounds and is expressed in units of perceived noise decibels or PNdB. A modification to the basic PNL rating, referred to as the "effective perceived noise level" or EPNL, and expressed in units of EPNdB, involves corrections for the presence of pure tones, or very narrow bands of noise, and for the duration of the noise. The current Federal Aviation Agency (FAA) noise certification requirements, FAR Part 36, are in terms of EPNL. It is anticipated that similar requirements will be applied to aircraft operating in densely populated areas. Insufficient vehicle performance and powerplant information is available to allow estimations to be made of vehicle noise in terms of EPNL; therefore, only the basic PNL method is used in the following

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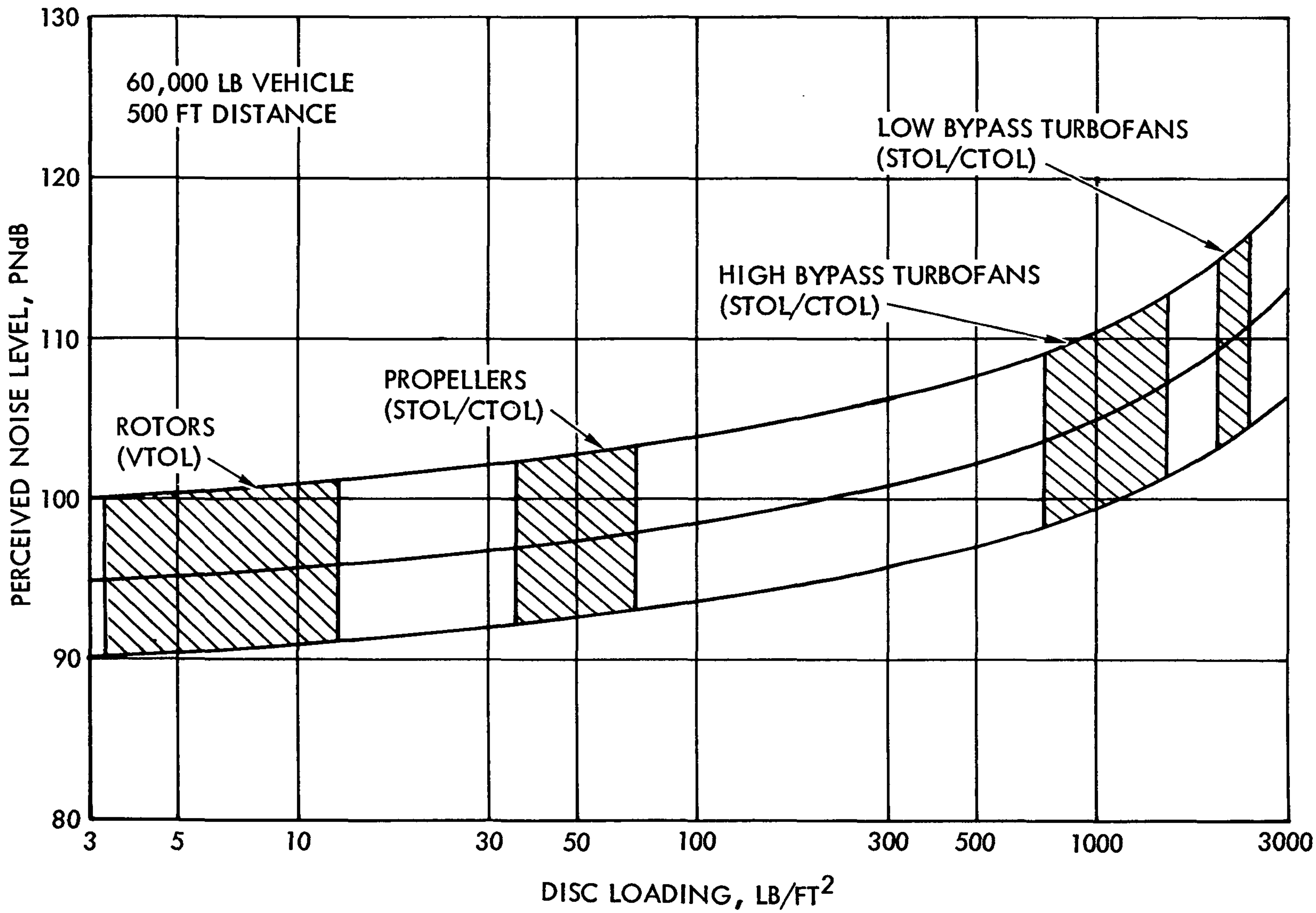

Figure 1.1-22 Noise Variation with Disk Loading For Takeoff Condition

exhaust noise is primarily broadband in nature with some very narrow bands of noise from the power turbine stages. In general, the exhaust velocities are low enough so that any "jet" noise generated is very low level and not a problem source.

The following analysis of the comparative noise characteristics of the alternate configurations is presented to provide an approximate indication of their "noiseness." The emphasis is on comparative accuracy between concepts rather than absolute accuracy. It is limited to the takeoff phase with a general consideration of cruise.

Takeoff - The estimated PNL's at 1000 feet for the study aircraft are presented in Table 1.1-6 as a function of aircraft size, design field length and technology. These levels are based on the mean PNL values for the appropriate source and disk loadings shown in Figure 1.1-22 with adjustments applied for thrust level and distance. 1985 Autogyro STOL values are not included pending further analysis of tip nozzle levels during rotor runup prior to takeoff. In the case where the vehicle being evaluated employs the "low" noise variable camber propellers (all propeller driven vehicles), an additional noise reduction of three PNdB is estimated as the benefit for using these propellers in 1975 and five PNdB for the 1985 versions relative to the levels of Figure 1.1-22. Rotors are attributed with a 1.5 PNdB noise reduction between 1975 and 1985 for progress in rotor design, but a three PNdB penalty from rotor tip drive nozzles. A reduction of six PNdB is used for the increase in distance from 500 feet to 1000 feet for both the propellers and rotors while a reduction of seven PNdB is used for the turbofans which includes one PNdB for extra atmospheric absorption of the high frequency fan noise spectrum. For the turbofans, a total passby noise reduction of five PNdB for the 1975 acoustical treatment and 7.5 PNdB for the 1985 treatment is assumed.

Cruise - Rough cruise noise levels are expressed in terms of a reduction in the sideline values of takeoff shown in Table 1.1-6. The resulting values are shown in the following Table 1.1-7.

TABLE 1.1-6 APPROXIMATE PNL LEVELS

Concept	Payload (Pass)	Req'd Field Length, Ft.	Gross Weight		Estimated PNL (±5 PNdB) at 1000 Ft. Distance on Takeoff	
			1975	1985	1975	1985
Tilt Wing VTOL	40	150	39,500	30,500	96.5	92.5
Tilt Wing VTOL	100	150	87,500	66,000	103.5	99.5
Comp. Hel. VTOL	40	150	40,000	26,000	87	84.5
Comp. Hel. VTOL	100	150	83,000	54,000	93.5	91
Defl. SS STOL	40	1000	31,500	29,000	90	87.5
Defl. SS STOL	40	2000	29,500	26,000	83	80
Defl. SS STOL	40	2500	28,000	25,000	81.5	78.5
Defl. SS STOL	100	1000	69,000	58,000	97	93.5
Defl. SS STOL	100	2000	59,000	52,000	89	86
Defl SS STOL	100	2500	56,000	50,000	87.5	84.5
Aug. Wing STOL	40	1000		39,000		92
Aug. Wing STOL	40	2000		31,500		88.5
Aug. Wing STOL	40	2500		30,500		87.5
Aug. Wing STOL	100	1000		80,000		98
Aug. Wing STOL	100	2000		65,000		95
Aug. Wing STOL	100	2500		62,000		94
Autogyro STOL	40	1000		25,000		
Autogyro STOL	40	2000		23,500		
Autogyro STOL	40	2500		23,000		
Autogyro STOL	100	1000		57,500		
Autogyro STOL	100	2000		54,500		
Autogyro STOL	100	2500		54,000		
CTOL**	40	2000	33,000	30,500	86.5	87.5
CTOL**	40	2500	30,500	28,000	85.5	87
CTOL**	40	3000	29,000	27,000	85.5	87
CTOL**	100	2000	71,500	65,500	93	94
CTOL**	100	2500	63,500	59,500	92	93
CTOL**	100	3000	60,000	56,500	91.5	93

**1975 - Prop Powered
1985 - Fan Powered

TABLE 1.1-7 2000 FT ALTITUDE CRUISE - NOMINAL NOISE REDUCTION OVER TAKEOFF

Configuration	Primary Noise Source	Δ PNL Reduction Over 1000 ft Sideline at Takeoff
1975, 1985 Tilt Wing VTOL	Propellers	16-31
1975, 1985 Comp. Helicopter VTOL	Fans	5-6
1975, 1985 Defl. Slipstream STOL	Propellers	17-24
1985 Augmentor Wing STOL	Fans	22-24
1975 CTOL	Propellers	16-18
1985 CTOL	Fans	22-24

These estimates are based on the following assumptions:

Δ PNL due to increased distance -

6 PNdB-propellers, rotors

8 PNdB-fans (distance plus increased absorption of high frequencies.

Additional reduction may, of course, be gained through use of a high cruise altitude; i.e., approximately seven PNdB for propeller configuration and a PNdB for fans and fan-rotor configurations or cruise altitude is increased from 2000 to 4000 feet.

In passing, it is judged that interior noise levels on all except the tilt wing VTOL can be reduced to acceptable levels for the intraurban transport. However, analysis of XC-142 tilt wing VTOL flight measurements implies that this concept particularly in larger sizes, will pose a severe interior noise problem.

Noise Evaluation

Summary

1) Analysis shows the following rank ordering of the several concepts from community noise considerations in order of noise acceptability.

   1975 - Deflected Slipstream STOL

   - Compound Helicopter VTOL

   - Short Field CTOL

   - Tilt Wing VTOL

   1985 - Deflected Slipstream STOL

   - Compound Helicopter VTOL

   - Tilt Wing VTOL

2) Payload increase from 40 to 100 passengers causes six to seven PNL increase (vs 10 for doubled annoyance) in all concepts.

3) The primary noise problem for the intraurban transport is expected to be STOLport noise rather than overhead cruise noise since the latter may be relieved by using higher cruise altitudes (which may be quickly attained by these high T/W aircraft).

1.1.2.4 Structures/Materials

- Design Load Considerations

New structural design criteria for intraurban type aircraft must be developed since this operating scenario is totally different from today's transport operations. A jumpoff point might be the proposed regulations to cover verticraft/powered lift type transports (reference 1.1-5).

Operational requirements peculiar to the Intraurban Transport scenario dictate several major areas for which definition of special structural criteria will be necessary. These key problem areas and possible approaches toward their solution are reviewed in the following paragraphs.

Low Altitude Operation - The low-altitude operation of the intraurban transport will require that definition of design dive speed include other possible overspeed conditions than the current 20 second shallow dive since the routine low altitude operation where "q" speed (or V_{ind}) and true speed are essentially the same and the aircraft will likely cruise at speeds well below its full throttle value. Accordingly, alternate bases for definition of design dive speed will need to be developed consistent with mission profile and operational environment. Such events as avoidance maneuvers in the high density traffic in which the vehicle will operate, encounter of high intensity head-on turbulence, or inadvertent pilot action must be considered. Since all weather operation is required, the possibility of some combination of these events occurring simultaneously must be considered in developing criteria for definition of required design speeds.

All-weather Flight - Limits loads criteria must also reflect the requirement that the aircraft be operated on schedule under all weather conditions. Present criteria permit reduced speed operation under extreme turbulence; however, it is not likely that this mode of operation will be compatible with the necessity of moving a large number of people in a finite period of time. As a result, gust criteria may be expected to dominate the design. Since much of the flight time will be spent in climb-out or landing approach, the probability of combined maneuver and gust requirements must be considered. These criteria would be based on consideration of the design level gust in normal flight, or a design maneuver with no gust, as limit conditions with combinations of lower intensity gusts and reduced maneuver load factors defined within these extremes.

The multi-directional nature of atmospheric turbulence necessitates that gust effects on all components be included in development of design loadings. Appropriate design criteria reflecting the foregoing considerations must be developed.

Calculation of the response of a typical Intraurban Transport configuration to the current 66 fps specification rough air gust indicates that a positive load factor of 3 to 3.5 may be anticipated. Maneuver load factor requirements of similar magnitude are expected. Exposure to the maneuver/gust environment caused by high density traffic and rough air operation requires that some means of ride smoothness be devised to assure passenger and crew comfort. (The use of small aerodynamic vanes activated by motion sensors for suppression represents a potential approach to such alleviation.) It is to be noted here that the arbitrary operational cruise speeds of 200 and 250 kt respectively, for the rotary and fixed wing types, selected for this study may be excessive in light of ride qualities. Suppression of airplane response to gust and/or maneuver will also be necessary to reduce fatigue criteria to a level compatible with material stress levels.

Fatigue Requirements - The high frequency of takeoffs and landings in the intraurban scenario necessitates that special landing and ground handling criteria be developed to assure adequate structural capabilities under the most adverse operating conditions anticipated during service. High taxi speeds will be employed to reduce block times, and new landing gear design criteria will therefore be needed for these conditions. Fatigue requirements under this kind of operation will impose high stress requirements on the landing gear and associated structure. The requirements that the airframe not sustain major fatigue damage or excessive structural deformation throughout its service life will require that fatigue spectra be representative of the actual service history of this operation.

Total usage of the airplane is anticipated to be three to five times as severe (in terms of total ground - air - ground cycles) as current generation transport aircraft. Specification of fatigue requirements for aircraft design will require that the total life be separated into basic missions, and that each mission be resolved into taxi, takeoff, climb, cruise, descent, and landing requirements. Estimated gust and maneuver spectra within each flight segment, together with takeoff, landing, and taxi spectra must be used to determine frequency of occurrence of various loading levels to which the airframe will be exposed. The cumulative spectra from this analysis can provide the basis for a fatigue criterion.

Materials Considerations

It is envisioned that the 1975 Intraurban Transport would be constructed largely of existing materials and using current fabrication techniques. However, new materials, fabrication methods, and methods of analysis emerging from research and development work offer the opportunity for making sizable improvements in structural and engine weight fractions, and are the basis for the 1985 technology weight estimates shown in Section 1.1.2.5. These materials and fabrication methods are discussed below.

Advanced filamentary composites probably offer the greatest potential for substantially reducing the structural weight. The filaments, have large strength/density and/or stiffness/density ratios and are combined with low-density matrices to yield a highly efficient structural material. The material properties are highly directional (anisotropic), and their efficient utilization depends on proper orientation of the fibers with respect to the load paths. The technological complexities as well as cost factors have limited the large scale usage of composites in the past, but their development is progressing rapidly. This is evidenced by the use of boron flaps on the 707, A-6, and A-4C; the F-111 boron horizontal tail; the F-4 boron rudder; and other experimental component programs. This increasing usage will eventually reduce the cost of both the materials and fabrication.

The advanced composite material systems receiving primary interest currently are the boron/epoxy and graphite/epoxy systems. However, substantial research and development effort continues on strengthened glass, silicon carbide, boron carbide, aluminum oxide and other ceramic whiskers, and beryllium filaments. Plastic matrices include epoxies, polyimides, polyesters, phenolics, and thermoplastics; and metallic matrices include aluminum, titanium, nickel, magnesium, and some refractory metals. Three phase systems such as boron/graphite/epoxy or boron/glass/epoxy and compound composites consisting of boron/epoxy or graphite/epoxy bonded as reinforcement to a metallic substrate are being considered for some applications.

BORON - The boron/epoxy material system has received the bulk of development effort in recent years under the impetus of the Air Force Materials Laboratory. When laminated unidirectionally with a fiber volume of 50%, it has a specific modulus of 4.5×10^8 inches and a specific tensile strength of 2.5×10^6 inches. Typical properties used on the C-5 boron slat program are summarized on Table 1.1-8. Its fatigue properties are rated as superior to metals. Boron/epoxy is most suited as face sheets for honeycomb sandwiches in applications such as flaps, slats, doors, control surfaces and wing surfaces. It does not lend itself to sharply formed structures. Some work has been done on randomly oriented chopped-fiber casting compounds.

In addition to using boron/epoxy as the primary material for a structural element, it is used as a reinforcement to a metallic primary structural element. Control rods have been overwrapped with boron/epoxy to produce compound-composite structures that are very efficient. AVCO produces aluminum extrusions with hollow members filled with boron/epoxy. In other structures the

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TABLE 1.1-8 COMPARISON OF ADVANCED COMPOSITE MATERIAL PROPERTIES

MATERIAL DESIGNATIONS	BORON SP 272 EPOXY		GRAPHITE/EPOXY TYPE I HIGH MODULUS PHM/LHM		GRAPHITE/EPOXY TYPE II HIGH STRENGTH PHS/LHS		GRAPHITE/EPOXY TYPE III LOW MODULUS PLM/LLM	
Fiber Properties - Density, lbs/in.^{3} Diameter, Microns Tensile Strength, ksi Tensile Modulus, psi	0.095 102.5 400 55×10^6	Ratio of Specific Strength (Stiffness) to 7075-T6 Aluminum	0.072 8.0 250 60×10^6	Ratio of Specific Strength (Stiffness) to 7075-T6 Aluminum	0.063 7.5 400 40×10^6	Ratio of Specific Strength (Stiffness) to 7075-T6 Aluminum	0.063 8.7 260 28×10^6	Ratio of Specific Strength (Stiffness) to 7075-T6 Aluminum
Lamina Properties (Unidirectional)								
Fiber Volume Percent	50		50		57		60	
Ultimate Tensile Strength, Axial (ksi)	180	2.4	100	2.2	120	2.8	128	2.9
Ultimate Tensile Strength, Transverse (ksi)	16.7		5.0		9.9		9.7	
Ultimate Compr. Strength, (ksi) Axial	324	4.8	63	1.55	167	4.3	140	3.6
Ultimate Compr. Strength, (ksi) Transverse	34.5		19		32		31.8	
In-Plane Shear Strength (ksi)	14.1	0.32	8	0.30	14	0.55	10.5	0.41
Tensile Modulus, Axial (psi)	30.8×10^6	(3.4)	27×10^6	(4.6)	18.5×10^6	(3.3)	15.8×10^6	(2.8)
Tensile Modulus, Transverse (psi)	3.7×10^6		1.54×10^6		1.54×10^6		1.82×10^6	
Compressive Modulus, Axial (psi)	30.8×10^6	(3.4)	25×10^6	(4.1)	18.0×10^6	(3.2)	15.0×10^6	(2.6)
Compressive Modulus, Transverse (psi)	3.7×10^6		1.55×10^6		1.55×10^6		1.78×10^6	
Shear Modulus (psi)	0.8×10^6	(0.22)	0.75×10^6	(0.33)	0.7×10^6	(0.33)	0.66×10^6	(0.31)
Poisson Ratio	0.36		0.3		0.45		0.41	
Density (lbs/in.^{3})	0.070		0.058		0.055		0.0555	
Average Ply Thickness (inch)	0.0052		0.005		0.005		0.007	

unidirectional boron/epoxy has simply been bonded as local reinforcement to the metallic substrate. The purpose of these approaches is to derive some of the weight reduction benefits of the boron/epoxy over the major length of the element while retaining the ease of attachment of metallic structures.

Metal matrix composites have also been demonstrated to be feasible. The leading candidate appears to be boron/aluminum. A 45% fiber volume yields a specific strength of 2.3×10^6 inches and a specific stiffness of 3.3×10^8 inches. Stringers and other formed sheet metal parts have been fabricated from aluminum/boron. Boron/magnesium and boron/nickel composites have been fabricated. The use of $\text{BORSIC}_{\text{TM}}$ with titanium has been proved feasible. $\text{BORSIC}_{\text{TM}}$ is a silicon carbide coating on a boron substrate that overcomes the incompatibility between boron and titanium. The metal matrix composites are heavier than boron/epoxy composites, and they appear to have their greatest potentials in areas that are subject to high temperatures such as nacelles and thrust reversers.

GRAPHITE - Substantial current research and development effort is being devoted to the graphite/epoxy material system for several reasons. It has a density that is 75 to 80% of the boron/epoxy system; it has a specific strength and specific stiffness that is comparable to the boron/epoxy system; it is easier to fabricate (it allows a smaller bend radius and can be machined with carbide instead of diamond-tipped tools); it can be woven; and it costs less than boron. The interlaminar shear strength has been raised to acceptable levels by fiber surface treatments. Three types of fibers (based on the PAN precursor) are currently available, and their preliminary lamina properties are summarized on Table 1.1-8. Its fatigue properties are rated as superior to metals. The cost of graphite is forecast at approximately $40 to $90 per pound in 1975 with substantial reduction by 1985. The formability of graphite/epoxy allows the fabrication of conventional structural shapes such as angle, Tee, I and J sections. Consequently, most of the conventional aircraft structure fabricated from sheet metal and extrusions can be simulated with graphite/epoxy. Fittings are being developed using chopped-fiber casting compounds. In addition to the three types of filaments described above, laboratory development of filaments with a Young's modulus of 75 to 100 million psi is continuing. Improved resins are also being investigated. In terms of properties, fabricability and cost, the graphite/epoxy material system offers the greatest potential of the advanced composites for large-scale weight reduction for a STOL transport.

OTHER FIBERS - Glass fibers have been strengthened but the Young's modulus is still comparatively low. However, in tension-critical applications where stiffness is not a major design factor glass is shown to be cost effective. Filament-wound pressure vessels are the most likely application. Silicon carbide on a tungsten wire substrate has properties similar to boron, but it is denser. It appears to have its greatest potential utility in metal matrix (aluminum or titanium) composites for turbine blades. Boron carbide filaments are lighter than silicon carbide and have similar properties. Aluminum oxide, single-crystal (sapphire) filaments are being produced with a modulus of 76 million psi and a strength of 380 000 psi by Tyco Laboratories. The current price is $75 000/lb, but they forecast costs of $10/lb within 10 years with increased production.

Weight Reduction Potential - The actual weight reduction that can be achieved by fabricating a component of advanced composites can only be determined by detail design. However, reasonable engineering estimates of the potential are made by comparing reductions achieved on comparable structures or by comparing the composite's specific strength and stiffness with those of aluminum. Account is taken of the influence of the unaffected weight that is composed of fasteners, brackets, clips, etc.; minimum gage restraints; and types of loading. Weight reduction potentials are summarized on Table 1.1-9 for a typical 40 000 lb Intraurban STOL.

Component Application - Advanced composites will be applied to specific airframe components in a sequence so as to provide maximum weight reduction with minimum risk. As design, fabrication, and qualification experience is gained on low-risk secondary structural components, it is applied to more complex structural components. Table 1.1-10 lists a suggested sequence of application. It should be noted that as experience is gained on the performance of composite components of other aircraft, the data obtained will be incorporated to speed the application of composites to similar components on the STOL transport. For example, the data from the flight test of the F-111 boron horizontal tail will be useful for the design of similar structures on the intraurban transports. Several programs are currently under way to flight test other boron control surfaces, and the data from these programs will aid in the early development of graphite control surfaces.

Impact of Reduction of Structural Weight Fraction on Performance - The desirability of incorporating advanced composites and the degree to which they are incorporated must be assessed in terms of aircraft performance, fabrication and maintenance costs over system life. These estimates have been made for the current study and are included in the 1985 system costs shown in Section 1.2.1.3.

TABLE 1.1-9. INTRAURBAN TRANSPORT WEIGHT REDUCTION POTENTIALS

Component	Aluminum Design Weight lbs	Affected Weight lbs	Composite Weight (1985 Tech.) lbs	Weight Reduction lbs	Net Percent Reduction, %, with Composites
WING	(3089)	(2322)	(1633)	(689)	(22.3)
Wing Box Covers and Stringers	1430	1144	808	336	23.5
Shear Webs	201	167	117	50	24.9
Ribs	504	403	252	151	30.0
L.E., T.E., and Secondary	523	253	202	51	9.8
Flaps, Slats, Aileron	431	355	254	101	23.5
FIN	154	127	93	34	22.1
RUDDER	101	84	63	21	20.8
STABILIZER	200	163	124	39	19.5
ELEVATOR	67	52	39	13	19.4
FUSELAGE	(5151)	(3867)	(2749)	(1118)	(21.7)
Skins and Stringers	2790	2222	1587	635	22.8
Frames and Bulkheads	1130	878	628	250	22.1
Substruct. and Doors	1231	767	534	233	18.9
LANDING GEAR STRUCT	1210	605	440	165	13.6
ENGINE INSTALL.	650	245	163	82	12.6
TOTAL	10622	7465	5304	2161	20.3

TABLE 1.1-10 COMPONENT APPLICATION SEQUENCE

Order	Component	Weight Reduction	Cumulative Reduction
1	Fuselage Substructure Floor Supports, Intercostals, etc.	93	93
2	Unpressurized Fuselage Doors	34	127
3	Control Surfaces Flaps, Slats, Spoilers, Rudder, Elevator, Aileron	135	262
4	Wing Secondary and Ribs	202	464
5	Cowls, Ducts, Engine Instal.	82	546
6	Pressure Decks, Doors and Fuselage Substructure	106	652
7	Fuselage Frames and Bulkheads	250	902
8	Landing Gear Structure	165	1067
9	Fin and Stabilizer	73	1140
10	Wing Box	386	1526
11	Fuselage Skin and Stringers	635	2161

1.1.2.5 Weights

The fixed wing aircraft weight analysis made use of the Advanced System Synthesis and Evaluation Technique (ASSET) program. This program has a weight subroutine which calculates the weights of the component elements. Basic input variables consist of the wing loading, thrust to weight ratio, and passenger capacity. Range is essentially treated as a constant. The subroutine converges on the takeoff gross weight, until the calculated gross weight of one iteration equals the gross weight of the previous iteration. Weights are calculated for the structure components, propulsion components, furnishings, equipment systems, and payload items.

The subroutine estimates aircraft weights by using parameterized weight equations. The equations have various parameters, coefficients, and constants as terms. Coefficients and constants are obtained for typical basepoint aircraft. Values of the coefficients and constants vary as a function of the basepoint aircraft type. The parameters vary as a function of the basepoint aircraft type and the input variables.

Coefficients and constants vary with the type of design. The tilt wing aircraft include weight provisions for engine cross shafting, clutches, auxiliary gearboxes, tail rotor, additional support structure, and wing tilt mechanisms. The deflected slipstream aircraft include provisions for engine cross shafting, clutches, auxiliary gearboxes, and heavy flaps. The augmentor wing aircraft allow for exhaust ducting, valves, heavy flaps, high horizontal tail, and boundary layer control on the tail. The conventional takeoff and landing aircraft have a low horizontal tail.

Parameters such as wing thickness ratio, taper ratio, and tail volume are fixed for each base point aircraft configuration. Other parameters in the equations, such as wing area, tail area, and body length are allowed to vary as a function of the chosen input variables. For instance, wing area is calculated using the wing loading input and the gross weight. Tail area is figured as a function of the wing area and body length. Body length varies with the number of passengers.

Structure weight equations are from References 1.1-16 and 1.1-17. The following format is typical for the parameterized weight equation:

$$\text{Weight} = \left[(\text{Coefficient})(V_{\text{Parameter 1}})^{\text{Power 1}} (V_{\text{Parameter 2}})^{\text{Power 2}} (F_{\text{Parameter 3}})^{\text{Power 3}} (1 + F_{\text{Parameter 4}})^{\text{Power 4}} / \cos (F_{\text{Parameter 5}}) + \text{Constant}\right]$$

The basic form of the equation including exponents is derived from analysis of contemporary aircraft. The coefficients, constants, and fixed parameters ($F_{\text{Parameter}}$) are determined by the basepoint aircraft. The variable parameters ($V_{\text{Parameter}}$) change with the variable input data.

Typical variable and fixed input values are shown in Table 1.1-11.

The rotary wing aircraft weights analysis does not utilize the ASSET program, but rather involves a conventional point design approach at three different payload levels. Point design rotary wing aircraft are based on 40, 60, and 80 passenger payloads.

Rotary wing and fixed wing weights analyses are made as consistent as possible for comparison purposes. The same constant weight items such as passengers, baggage, and avionics are used for both the fixed and rotary wing designs (see Table 1.1-12 for constant weight items). The same parametric weight equations are used for compatible items such as the fuselage structure, electrical system, and hydraulic system. Essentially the same 1985 technology weight reduction factors are used on both the fixed and rotary wing aircraft.

Separate approaches are used to determine the weight of items like wings, flight controls, and rotors which have different design concepts for rotary and fixed wings. Weights for these items are determined through the use of parametric equations and analytical calculations based on the extensive Lockheed knowledge of fixed and rotary wing aircraft.

Technology factors are used to reduce the structure, propulsion, furnishings, and systems weights for the 1985 time period. Use of a high percentage of composite materials is assumed to be practical at that date. Composites will reduce the weight of the aircraft structure as shown in Section 1.1.2.4. Improved cooling techniques will reduce the engine weight for a required thrust

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TABLE 1.1-11 VARIABLE AND FIXED INPUT VALUES

Item	Symbol	STOL Deflected Slipstream	VTOL Tilt Wing	STOL Augmentor Wing	CTOL Prop/Fan
Variable Input					
Number of Passengers - 1975	XNPASS	40 to 100	20 to 120	-	20 to 100
Number of Passengers - 1985	XNPASS	20 to 100	20 to 120	20 to 100	20 to 100
Thrust to Weight Ratio	TOVERW	0.4 to 0.9	1.35	0.4 to 0.9	0.2 to 0.6
Wing Loading, lb/ft^2	WOVERS	40 to 100	40 to 100	40 to 100	40 to 100
Technology Date	-	'75 & '85	'75 & '85	1985	'75 & '85
Fixed Basepoint Parameters					
Wing					
Taper Ratio	LTORW	0.5	0.5	0.5	0.4
Thickness Ratio	TCW	17.6	17.6	18.0	17.6
Flap to Chord Ratio	CS/CW	0.30	0.30	0.35	0.25
Wing Sweep Angle, Degrees	LAMDAQ	0	0	0	0
Tail					
Horizontal Volume Coefficient	CUHT	1.00	0.92	1.20	1.00
Vertical Volume Coefficient	CVVT	0.12	0.10	0.12	0.10
Body					
Pressure Differential, psi	DELTAP	0	0	0	0
Number of Aisles	XNAE	2	2	2	2
Aisle Width, in.	EAW	20	20	20	20
Seat Width, in.	ESW	18	18	18	18
Seat Pitch, in.	ESP	32	32	32	32

TABLE 1.1-12 CONSTANT WEIGHT ITEMS

Items	Weight, lbs Fixed and Rotary Wing
Crew, lb/Crew	170.0
Crew Baggage, lb/Crew	20.0
Passenger, lb/Passenger	170.0
Passenger Baggage, lb/Passenger	20.0
Installed Avionics, lb (1975)	1178.0
Auxiliary Power Unit, lb (1975)	350.0
Furnishings, lb/Passenger (1975)	50.0
Standard Items, lbs	45.0

by allowing higher turbine inlet temperatures. Better materials will also reduce the engine weight. The increased engine efficiency will give reduced fuel flow rates which in turn gives a reduction in required fuel. Furnishings weight is generally a function of the desired interior comfort level. However, use of more efficient, lighter items such as insulating material, soundproofing, and trim panels will allow the furnishings weight to decrease in 1985. Weight for systems like the electrical, hydraulics, air conditioning, and avionics will be decreased by 1985 technology. Reductions will come from better design methods such as multiplexing and miniaturization. Also, use of stronger, lighter, and more effective materials will result in lighter systems. In particular, the avionics system weight would be reduced by integrating functions, and through the use of microminiaturized integrated circuitry (reference Section 1.1.2.6). Table 1.1-13 shows the weight savings from advanced technology.

TABLE 1.1-13 ADVANCED 1985 TECHNOLOGY WEIGHT SAVINGS

Item	Percent Weight Savings	
	Fixed Wing	Rotary Wing
Structure	-	-
Wing	22.3	22.0
Horizontal Tail	19.5	20.0
Vertical Tail	21.5	20.0
Body	21.7	21.7
Landing Gears	13.6	13.6
Engine Nacelles	12.6	0.0
Flight Controls	25.0	25.0
Propulsion System - General Items	23.3	20.0
Engines	23.3	20.0
Propellers	22.5	(A)
Main Rotor	A	20.0
Tail Rotor	0.0	20.0
Drive System	(A)	(B)
Cross Shafting	0.0	(A)
Cross Shafting Gear Boxes	0.0	(A)
Furnishings	20.0	20.0
Systems	-	-
Auxiliary Power Unit	20.0	20.0
Instruments	20.0	20.0
Hydraulics	20.0	20.0
Electrical	20.0	20.0
Air Conditioning	20.0	20.0
Anti-Icing	20.0	20.0
Electronics	20.0	20.0

(A) Does Not Apply (B) New Design Approach

1.1.2.6 Aircraft Systems

Factors involved in systems selection for intraurban type of aircraft have been considered and are discussed in the following paragraphs.

- Flight Control System - Flight control systems for the 1975 intraurban will be of conventional mechanical/hydraulic type (assumed for this study). However, for the smaller STOL and CTOL types it could be advantageous costwise to employ a simple, spring tab-type manual system. In either case, however, emphasis will be placed on extensive use of electronics to provide for stability augmentation aid to the pilot and control of the aircraft. Such systems will be an extension of current systems now being employed in the Boeing 747, Lockheed L-1011 and other current transports.

  For the 1985 time period significant changes can be foreseen in flight control system design (specifically, the use of fly-by-wire, side arm controllers and digital computation of flight control functions). All automatic flight, from takeoff to touchdown, is envisioned. All aircraft will be under complete ground control at all times to insure on-time arrivals and departures by eliminating stacking of aircraft by speeding up or slowing down arriving aircraft while they are still en route.

- Navigation/Communication - The extemely short stage lengths involved will require rigid traffic control and collision avoidance procedures. Any maneuvering or deviation from the scheduled flight plan will need to be tightly controlled and monitored.

  As noted above, automatic flight controls will be utilized in conjunction with total ground-controlled instrumentation to develop the basic flight profile. However, due to uncontrolled air traffic - which must be considered, at least in the 1975 era - deviations to established flight plans can occur, necessitating holding patterns at the destination STOL commuterport. Similarly, extreme weather fronts can occur which may require some rerouting in deference to passenger comfort.

- Avionics - Among the avionic needs for the 1975 and 1985 era may be mentioned the following key functions.

  In Navigation requirements Area Navigation (R-Nav) systems will be utilized in the 1975 period similar to those systems (DECCA) utilized by today's STOL operators. In the 1985 period similar R-Nav systems would be used in conjunction with multi-purpose displays to present route progress, ground-derived traffic data, weather and landing instructions. Weather Radar will be a primary dispatch item for 1975 and 1985. However, for the Intraurban Transport it will not be necessary to utilize the long-range (300 n.mi.) ARINC-type systems.

Due to the inherently low-altitude flight profile of the Intraurban Transport which places it always below the cloud base of most dangerous cumulo-nimbus weather fronts, the problem for the radar would be to measure rainfall gradients precisely enough to locate the generally homogeneous rainfall areas rather than those which have violent discontinuities (hence turbulence). Thus the Weather Radar for the Intraurban Transport should have a large antenna with a precise ISO-ECHO contour mode but without the high-powered transmitter of current ARINC systems.

Other key avionic systems would be a Landing Performance Monitor Sensor which would "see" the runway down to a CAT III b and c weather situation (zero/zero), and enable the pilot to land and taxi off the runway. In a 1975 aircraft this would probably be a separate sensor, but by 1985 a combined landing and weather radar would be feasible.

The display of all navigation, traffic and flight control data would be on the cathode-ray tube, multi-function displays in the 1985 time frame. For the immediate 1975 time period, it is probable that a combination of conventional instruments and electronic displays would be utilized.

Table 1.1-14 summarizes the avionics technology status applicable to the Intraurban Transport. As can be seen from this table, the basic difference between the two time frames is the greater capability for operation down to a true "zero-zero" environment typified by CAT III c operation in the 1985 period. This will be made possible by the use of improved microwave Instrument Landing Systems beyond 1975 and the employment of the combined Landing Performance Monitor Sensor as described above. This allows for precise rollout and taxiing to the pickup point even in a zero/zero (heavy fog) situation.

Improved technologies of electronic displays in conjunction with the R-Nav systems and collision-avoidance concepts would allow for a highly precise traffic monitoring system to be made available to the pilot. Traffic along the route structure as well as adjacent routings could display the complete IUT traffic pattern. By 1975 this would allow pilot assessment of traffic and enable him to adjust his progress accordingly. By 1985 a central computer would assess the traffic automatically and develop automatic traffic control procedures for all aircraft while the pilot assumes a monitoring role.

Table 1.1-15 presents a weight breakdown of typical avionics likely to be employed in the 1975-1985 time periods. These values have been used in the aircraft synthesis.

TABLE 1.1-14. AVIONICS TECHNOLOGY

Technology Area	Critical Parameters	1975 IOC 1970 Technology	1985 IOC 1980 Technology	Ultimate Potential	System Application
Area Navigation	Horizontal and Vertical Accuracy	±0.25 mi horizontally, ±100 ft vertically	±0.1 mi horizontally, ±50 ft vertically	Completely automatic and tied in to air traffic control	All-systems concepts
Terminal Guidance Including Automatic Rollout and Taxiing	Horizontal and Vertical Accuracy with Runway	Suitable For Category 3A instrument landings	Suitable For Category 3C landings	Category 3C	All
Air Traffic Control Including Collision Avoidance	Safety	Present technology is marginal	Requires improvements and new approaches over those used by FAA	Completely automatic control	All
Communication	Data Rate and Error Probability	Can be tailored to system requirements. Well within the state of the art.		-	All
Control System and Autopilot	Response Rate, Stability Damping	Within current state of the art	Normal technology growth	-	All
Radar	Weather ILM	Separate systems planned	Combined sensor for all modes	Used for weather, landing, taxi and obstacle detection	All
System Performance Monitor	Selection of and Sensitivity to Performance Parameters	Minimal system now available	Normal tech growth plus failure prediction	-	All
Secondary Power	Hardware Weight per Horsepower	1.7 lb/hp	1.0 lb/hp	-	All

* Technology growth in all areas will include increases in reliability and decreases in weight and cost for comparable equipment.

TABLE 1.1-15. AVIONICS WEIGHT SUMMARY*

System	1975		
	Weight per System	Number of Systems	Total Weight
VHF Communications	17.5	2	35
Passenger Address	90	1	90
Interphone	20	1	20
Selcal System	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)	20	2	40
Precision Landing Aid (Microwave ILS)	15	2	30
Distance Measuring Equipment (DME)	20	1	20
Marker Beacon	3	1	3
Independent Landing Monitor	150	1	150
Radar Altimeter	20	2	40
Weather Radar	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	878	600
Installation	300	275
Total Installed Weight	1178	875

* Does not include FCS/AFCS

** Computer, Data Storage, Control and Display

The weight reduction shown for 1985 results largely from the extensive use of integrated design, as was discussed above. The weather radar would be combined with the landing sensor. The Area Navigation and Collision Avoidance functions would be integrated with the Displays and Monitoring systems. Microminiaturized, integrated circuitry and Large-Scale Integration (LSI) techniques would further aid in accomplishing this weight reduction.

In summary, the avionics technology required for the intraurban aircraft system will be available in both of the considered time periods.

- Hydraulics - A conventional, 3000-lb hydraulic system is envisioned with emphasis on modular assembly (plug in) of basic elements for quick exchange to favor maintenance. For 1985 welded plumbing will likely be employed, along with 4000-psi pressure levels with perhaps some filament-wound valves to favor weight.

- Electrical - A conventional electric system is envisioned for 1975 and 1985, except that in 1985 printed, flat-wire circuits with modular assembly will be used to favor maintenance.

- Auxiliary Power - A conventional, self-contained, auxiliary power system is likely for starting and ground air conditioning. Technology growth is not expected to change this appreciably.

- Air Conditioning - Air conditioning can be supplied by a conventional main engine bleed-heat exchanger arrangement or perhaps as part of an integrated auxiliary-power air-conditioning package. Capacity will need to be sufficient to overcome the heating/cooling effects of the frequent loading/unloading schedule of the intraurban operation (much greater than the current 15-20 cu ft/min/passenger).

- Anti-Icing - The anti-icing system will require special consideration for the intraurban scenario, i.e., frequent exposure to anti-icing conditions, ground anti-icing and the need for high schedule reliability.

- Safety/Survial - The intraurban operation will be grossly different from current transport operations and from passenger safety/survival considerations. The flight operation is dominated by takeoff and landing, with a cycle occuring every few minutes. Statistics show that in today's transport operations, with their comparatively infrequent takeoff-landing cycles, approximately 75 percent of all fatalities still occur during these operations as shown in the following table 1.1-16.

Table 1.1-16 COMMERCIAL AIR TRANSPORT FATALITIES AS A FUNCTION OF FLIGHT PHASE

Flight Phase	Percent of Fatalities
Takeoff	18
Climb	15
Cruise	10
Landing (letdown, Final Approach, Landing)	57

Consideration of intraurban transport safety and survival must, therefore, be primarily concerned with the takeoff and landing phases.

An additional factor is that essentially all of the intraurban operation will be over heavily populated regions with the result that accidents will likely cause ground fatalities and damage at a much higher incidence than for today's operations.

Ameliorating factors in this regard include the fact that mean takeoff and landing speeds will be much lower than for current operations (roughly 100 kt takeoff for average STOL vs 140-200 kt for today's transports, with landing speeds correspondingly lower). In addition, the aircraft will always be under rigid ground control and never more than a few minutes from a V/STOL commuterport.

Minimal design requirements for safety and survival should include the following:

1) All fuel in wing with inboard tank bulkhead well outboard of fuselage half breadth

2) Passenger seat belting to include shoulder harness type arrangement with associated seat strengthening to hold passengers in place during entire flight. This is considered acceptable due to short duration of ride

3) Long stroke "soft" gear to allow for hard landing without failure

4) Fuselage design in passenger cabin area utilizing new structural design criteria developed from analysis of

fuselage failure statistics available from current accident history. The end product here would develop a structural design requirement with passenger safety in mind in the event of structural failure of the main gear and/or its attachments to the fuselage, and the resulting fuselage impact load.

5) Passenger Escape - Escape door design requirements to include criteria concerned with assuring operational doors following fuselage structural failure under certain typical accident assumptions.

6) Passenger/Cargo Handling - See Section 1.1.1.2

1.1.2.7 Operational Factors

Significant operational factors, associated problem areas, and potential benefits of advanced technology are summarized in Table 1.1-17 and expanded by the following remarks.

- Utilization - Many factors which affect utilization can be influenced by the aircraft designer while other influences are operational in nature, such as scheduling of maintenance activities. Administrative procedures can affect utilization, for example, spare parts policies, airspace congestion and regulatory constraints can seriously undermine utilization. Improved utilization will depend on how successfully the problems are identified and analyzed and the system concept tailored to provide the maximum daily usage. Some recommended approaches to the problems of utilization, in addition to those noted in Table 1.1-17 are noted below.

THE PROBLEM	CAN BE IMPROVED BY:
Turnaround Time	• Better management of passengers and baggage.
	• Minimizing unload and load time with wide aircraft doors, more doors, double aisle, shorter walking distance from queueing area to aircraft.
	• Improved clearance procedures
	• No shut-down of engines during enroute stops
	• Aircraft endurance sufficient for peak hour travel periods. No refueling during enroute stops
	• Adequate gate facilities
Maintenance Downtime	• Greater component reliability (less unscheduled maintenance)
	• Scheduled maintenance during non-service hours
	• Easier maintenance; on-board fault detection, plug-in replaceable modules, automated check-out, maintenance accessibility
	• Spares policies

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TABLE 1.1-17 OPERATIONAL FACTORS

ITEM	PRIMARY ISSUE	REASON FOR INTEREST IN IMPROVEMENT	CAUSES OF CURRENT PROBLEM	KIND OF IMPROVEMENT NEEDED	TECHNOLOGY INVOLVED
Utilization	Number of hours aircraft used per day	DOC (through depreciation per hour of use)	1. High maintenance costs 2. Excessive turn around on short hauls 3. Demand distribution	1. Improved reliability 2. Faster aircraft servicing and maintenance 3. Greater "smoothing" of demand distribution	1. Miniaturization New materials 2(a) i On board fault detection/isolation ii Centralized system checkout parts iii "Plug-in" subsystems 2(b) More doors, wider aisles, etc. 2(c) Improved refueling systems 3. Economic policy
Access	Time and convenience in getting to and from airport	Gross Income (through sales appeal)	1. Airports not located close to customer origin/destinations 2. Transportation to and from airport 3. Intraterminal transportation	1. See terminal location 2. Better integration of local transportation systems 3. Better integration of terminal functions	1. City Planning - System Approach 2. Terminal Planning - System Approach
Airport Operations	Management of airport, particularly, to movement of people and baggage, and movement of ground and air vehicles	IOC Gross income (through sales appeal)	1. Excessive delays 2. Excessively long walking distance 3. Congestion at transfer points 4. Holding of aircraft in traffic patterns or on taxiways are costly delays	1. Improved ticketing and baggage handling 2. Improved intraterminal transportation 3. Improved design of terminal interfaces	1(a) Integrated computer ticketing 1(b) Automated baggage sorting 2. Better terminal design 3. Terminal planning - system approach 4. Automated traffic control 1(c) Computer flight planning 1(f) Transponders in private aircraft 2. Precision sensor/ instruments for true V/STOL blind landing/ takeoff
Airspace Usage	Efficient use of airspace to minimize delays and maximize traffic flow	DOC (through delay costs) and gross income (through sales appeal)	1. En route congestion 2. Weather magnifies congestion problems	1. Improved en route traffic control 2. Improved all weather capability for V/STOL	1(a) Fewer, but larger aircraft 1(b) Greater vehicle speed flexibility 1(c) Collision avoid-ance equipment 1(d) Automated aircraft position tracking equipment 1(e) Computer flight planning 1(f) Transponders in private aircraft 2. Precision sensor/ instruments for true V/STOL blind landing/ takeoff
FAA Regulations	Safety of air vehicles and regulation/control of available air space Rotary access and egress patterns (rotary-wing vehicles)	Procurement and operating costs Rigid rotor advantages over conventional heli-copter and fixed wing aircraft DOC, useful load/gross weight Rotary wing terminal facilities	1. Inefficient use of airspace 2. Need for greater safety in high density/all weather operation 3. Need for fewer losses of life in case of accidents 4. Interim relations and tentative standards	1. See Airspace Usage 2. See Improved All Weather Capability 3(a) Improved emergency landing techniques 3(b) Improved "second accident" control 3(c) Improved emergency exiting 3(d) Improved takeoff and landing requirements for rotary wing	1(a) Vertical thrust/lift redundancy 1(b) Emergency VTOL capability or assignment of many small areas for STOL landing with electronic locating devices 1(c) Improved passenger cushioning 1(d) Larger doors, aisles, auto-matic chutes, etc.
Terminal Location	Location of terminals to optimize customer time/ cost/convenience Rotary wing requires minimum land acquisition	Gross Income (through sales appeal) and total operating cost	1. Placing terminals close to origins of traffic is generally unaccept-able to suburbanites 2. Placing terminals close to business destinations is very expensive.	1. Reduced pollution 2. Reduced total area of terminal	1(a) Engine sound reduction - Combustion/bypass design 1(b) Engine with more complete combustion 1(c) New fuels 2(a) Shorter STOL capability 2(b) More precise landing/ takeoff equipment

Total Demand and Demand Distribution

- More attractive compared to other transportation modes (time, convenience, cost and service)
- Provide frequent short haul mail and freight service in off-peak hours
- Offer off peak fares, group travel rates, commuter discounts
- Include recreational use during off-peak hours and week ends to nearby points of interest and sightseeing tours.

- Terminal Considerations - The operational effectiveness of the system can be maximized if careful attention is paid to terminal location and layout. The purposes of a terminal are to provide:

  1) a point of access to the system;

  2) fast, efficient and simple passenger and baggage flow;

  3) lowest possible operating cost commensurate with the level of service demanded by potential customers.

  Si''ng of the various terminals will require attention to total land required, land availability, land cost, zoning regulations, topographical features and building patterns in the surrounding area, access to present and future ground transportation links, probable origin/destination points for predicted users, compatibility with airspace utilization requirements of the FAA and coordination with the Detroit planning authority and master plan. If Federal funds are contemplated in the project, then it will be necessary to consider the impact of the National Airport Plan and the Federal Aid to Airports Program.

  Passenger processing will necessarily have to be rapid and contribute little or no delay to passengers in order to be attractive. Processing; i.e., baggage handling and ticketing delays add to the user's travel time and present concepts will not suffice if the system is to be competitive with other modes of transportation. Therefore, an automated ticketing and fare collection procedure is mandatory. Several systems are under development at the present time and can be evaluated for use in the intraurban system. Automated baggage handling is further away, but is receiving attention and might become applicable in part, or in total in the next few years.

Apron layout should be closely integrated with the terminal building and handling concepts employed and the facilities designed for rapid turnaround of aircraft.

- Air Pollution - Currently, Michigan's air pollution standards only encompass smoke and particulate emission, setting a maximum allowable emission in pounds of particulates per thousand pounds of exhausted gas (Reference 1.1-18). By implication, no legal limitations have been placed on the emission of gases such as carbon monoxide, unburned hydrocarbons, nitric oxide, and sulfur dioxide. These gases are prime contributors to photo-chemical smog through atmosphere reactions in which ozone, peroxyacetyl nitrates, formaldehyde and nitrogen dioxide are formed. The primary menace to health comes from unburned hydrocarbons and the products of these reactions rather than the exhaust emission. On a nationwide level, transportation vehicles contribute most of the carbon monoxide and a major portion of the nitric oxide and unburned hydrocarbons while industrial sources, power plants, refuse disposal and space heaters contribute most of the particulate matter and sulfur dioxide. For this reason, only the problem of the three gases associated with transportation are discussed. Transportation vehicles are responsible for 60 percent of all pollutants emitted into the atmosphere. Carbon monoxide makes up the major portion and amounts to 46 percent of the total pollutants emitted on a nationwide level (Reference 1.1-18).

  Reported data on the chemical composition of the exhaust from aircraft gas turbine engines show that the contribution to air pollution by these engines is low in comparison with conventional piston engines (Reference 1.1-19).

  In order to compare the amount of pollutants emitted by an automobile, a STOL aircraft and a bus data (Reference 1.1-20, and 1.1-21) is converted to units of grams per passenger mile for each mode of transportation. Certain assumptions must be made about the number of passengers per vehicle. Using average numbers, the following table was prepared.

	Two Passenger Automobile	60 Passenger STOL Aircraft	40 Passenger Bus
Carbon Monoxide	22.0	2.1	1.2
Unburned Hydrocarbons	0.5	0.2	0.05
Nitric Oxide	1.4	0.8	0.04

  The numbers are the weight of pollutant in grams per passenger mile.

The automobile is an average warm automobile travelling at 30 mph. The STOL aircraft is an average taken from an average STOL intraurban aircraft with the average distance runs for an intraurban transportation system. The bus data are extrapolated from automobile data assuming gasoline is used instead of diesel fuel. Diesel-fueled engines would give somewhat higher values for all pollutants.

The carbon monoxide produced by an aircraft is only 10 percent of that which is produced by an automobile on a passenger mile basis. The average traffic flow into the central business district of Detroit is 153,000 cars per week day between 7 AM and 7 PM (Reference 1.1-22). If a STOL aircraft intraurban transportation system were to replace 15 percent of this traffic, there would be a reduction in the pollutants emitted due to the change in traffic But due to the fact that the transportation is responsible for only 60 percent of the total pollutants, the resulting decrease in pollution would be about eight percent. The variation in the average traffic from one year to the next has a standard deviation of three percent. It is therefore concluded that a barely perceptible decrease in pollution would be noted based on use of 1970 automobiles. Between 1975 and 1980 pollution limits will be such that it is not likely that an improvement will be noticed.

In summary, it is concluded that the impression of an airborne intraurban transportation system on the Detroit Metropolitan area would have a negligible effect on pollution levels.

1.1.3 MARKET SCENARIO

The primary objectives of this task are to delineate and quantify those elements of the physical and socio-economic environments of the Detroit region that impact on the design, development, and operations of an intra-urban air transportation system.

During Phase I the primary activity centered on developing an operational market scenario keyed to the requirements of a comparative analysis of the previously described candidate aircraft system concepts. As a result only a cursory physical description of the Detroit region is presented, while a more detailed statement of the potential market demand (in terms of volume, distribution, and direction of movement) is included.

1.1.3.1 Site Selection and Definition

In response to the NASA request to select a "representative" U.S. city upon which to base the market scenario for an intrurban air transportation system, Lockheed conducted a cursory examination of the major U.S. metropolitan areas. Of primary importance was not only the "representativeness" of the study area, but also the availability and accessibility of a transportation data base similar to the Bay Area Transportation Study data, upon which the Lockheed proposed work statement had been based.

It is recognized that the characteristic, "representative," is somewhat nebulous in its application to U.S. cities, but an attempt was made to identify an urban area that is suffering growth and transportation problems that are common to nearly all regions in the U.S. and that are not unique to the region itself.

Lockheed selected Detroit, Michigan as the focal point of the subject study. The next task was to determine the specific bounds of the total area to be studied.

In 1969 the Detroit Regional Transportation and Land Use Study (TALUS) was completed. TALUS was a four-year, 4.5-million-dollar study to produce a comprehensive plan to guide the growth and development of the seven-county (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne), 4500-square-mile southeastern Michigan metropolitan region through 1990. During TALUS an extensive transportation data base was generated, and is now maintained by the Southeast Michigan Council of Governments (SEMCOG).

Upon the approval of NASA, Lockheed selected the seven-county TALUS region as its prime area of interest for the subject study.

1.1.3.2 Environmental Factors

Since Phase I of the study consists primarily of comparative analyses of aircraft concepts, the principle tasks undertaken in the description of the environmental factors were to identify general characteristics of the Detroit region and to determine what, if any, environmental factors would place an unfair advantage or disadvantage on any of the candidate aircraft concepts. The Detroit region is described as follows:

"The waterway, consisting of the Detroit and St. Clair Rivers, Lake St. Clair, and the west end of Lake Erie, lies at an elevation of 568 to 580 feet above sea level. Nearly flat land slopes up gently from the water's edge northwestward for about 10 miles and then gives way to increasingly rolling terrain. The Irish Hills, parallel to and about 40 miles northwest of the waterway, have tops 1000 to 1250 feet above sea level. On the Canadian side of the waterway the land is relatively level.

"The slope of the land dries northwest winds and has an opposite effect on southeast winds. Northwest winds in winter bring snow flurries to all of Michigan. Flurries build up snow accumulations in many places, but in Detroit they rarely cause enough snow to be measured. Summer showers moving from the northwest also weaken and sometimes dissipate as they approach Detroit. On the other hand, much of the heaviest precipitation in winter comes with southeast winds, and this may be heavier in the Detroit area, especially to the northwest of the City, than in other places affected by the same storms.

"Detroit's climate is controlled by (1) its location with respect to major storm tracks and (2) the influence of the Great Lakes. The normal wintertime storm track is south of the City, and most passing storms bring periods of snow or rain. In summer most storms pass to the north, often with brief showers in the area and occasionally with heavy thundershowers or damaging winds. The Great Lakes smooth out most climatic extremes. Precipitation is distributed evenly through all months of the year. The most pronounced lake effect occurs in the colder part of the winter. Arctic air moving across the lakes is warmed and moistened. Cold waves approaching from the northern plains are much reduced in intensity. But the price is an excess of cloudiness and very little sunshine in the winter.

"Summers in Detroit are warm and sunny. Brief showers usually occur every few days, but often fall on only part of the metropolitan area. Extended periods of drought are unusual. Each year sees two or three series of days with temperatures in the nineties. The highest temperatures are often accompanied by high humidity. Most summer days are quite confortable, and air conditioning is required only intermittently. In winter skies are cloudy and temperatures average near the freezing point. Day to day changes are not large. The mercury drops to near or a little below zero once or twice each year. Winter storms may bring rain, snow, or both. Freezing rain and sleet are not unusual. Most wintertime precipitation is more or less steady and continues for several hours. Snowstorms average about 3 inches, but heavier amounts accumulate several times each year.

"Local climatic variations are due largely to (1) the immediate effect of Lake St. Clair and (2) the urban 'heat island.' On warm days in late spring or early summer, lake breezes often lower afternoon temperatures by 10° to 15° in the eastern part of the City and the northeastern suburbs. Less pronounced local lake effects occur at other times of the year. The urban effect shows up mostly at night. Comparative readings show nearly uniform maximum temperatures over the metropolitan area. Minimum readings at Metropolitan Airport, in a semi-rural area, average 2.3° lower than those at City Airport, in a typical residential area, and 4.1° lower than those in downtown Detroit. On humid summer nights or on very cold winter nights, the difference can exceed 10°.

"Air pollution comes primarily from heavy industry spread along both shores of the waterway from Port Huron to Toledo. The most intense source of pollution is along the west bank of the Detroit River from just southwest of the downtown area to opposite Grosse Ile. Although the amount of contamination is very large, air motions both horizontal and vertical are usually sufficient to keep it from becoming a major hazard."[1]

The major climatological factors having impact on air transportation systems are summarized in Figures 1.1-23 through 1.1-27.

[1] "Local Climatological Data; Annual Summary with Comparative Data, 1969, Detroit, Michigan, Metropolitan Airport," U. S. Department of Commerce.

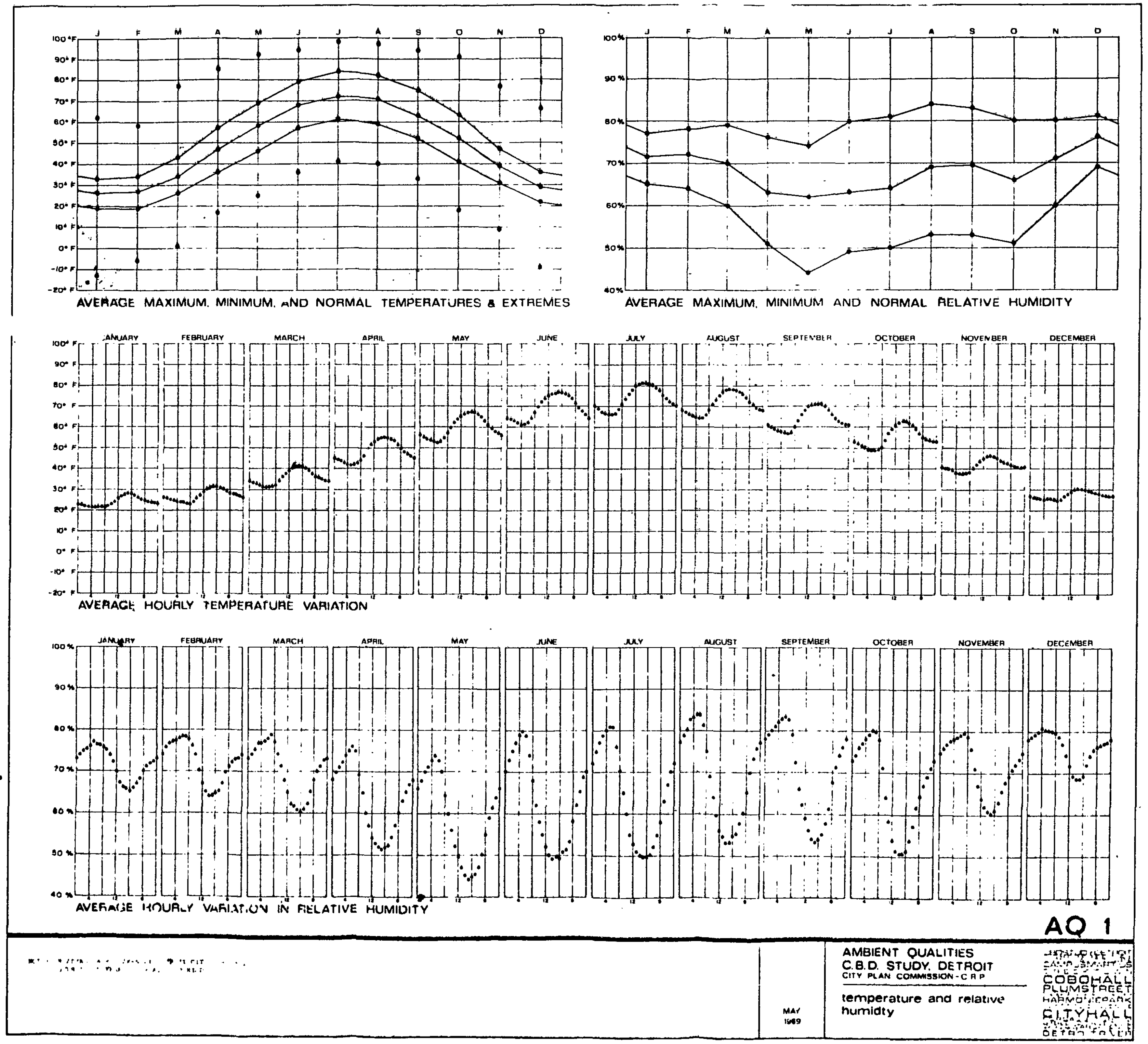

Figure 1.1-23 Temperature and Relative Humidity

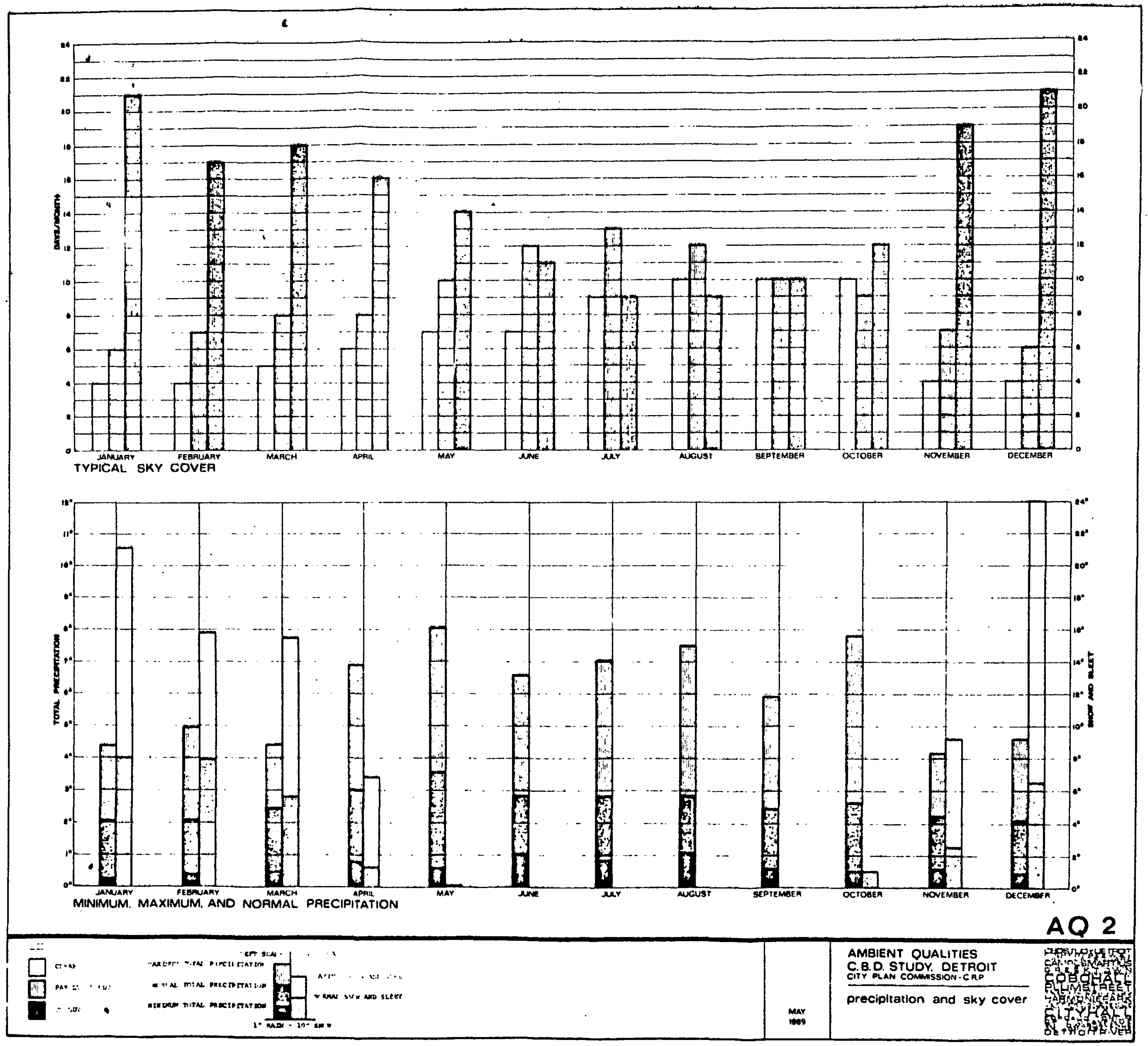

Figure 1.1-24 Precipitation and Sky Cover

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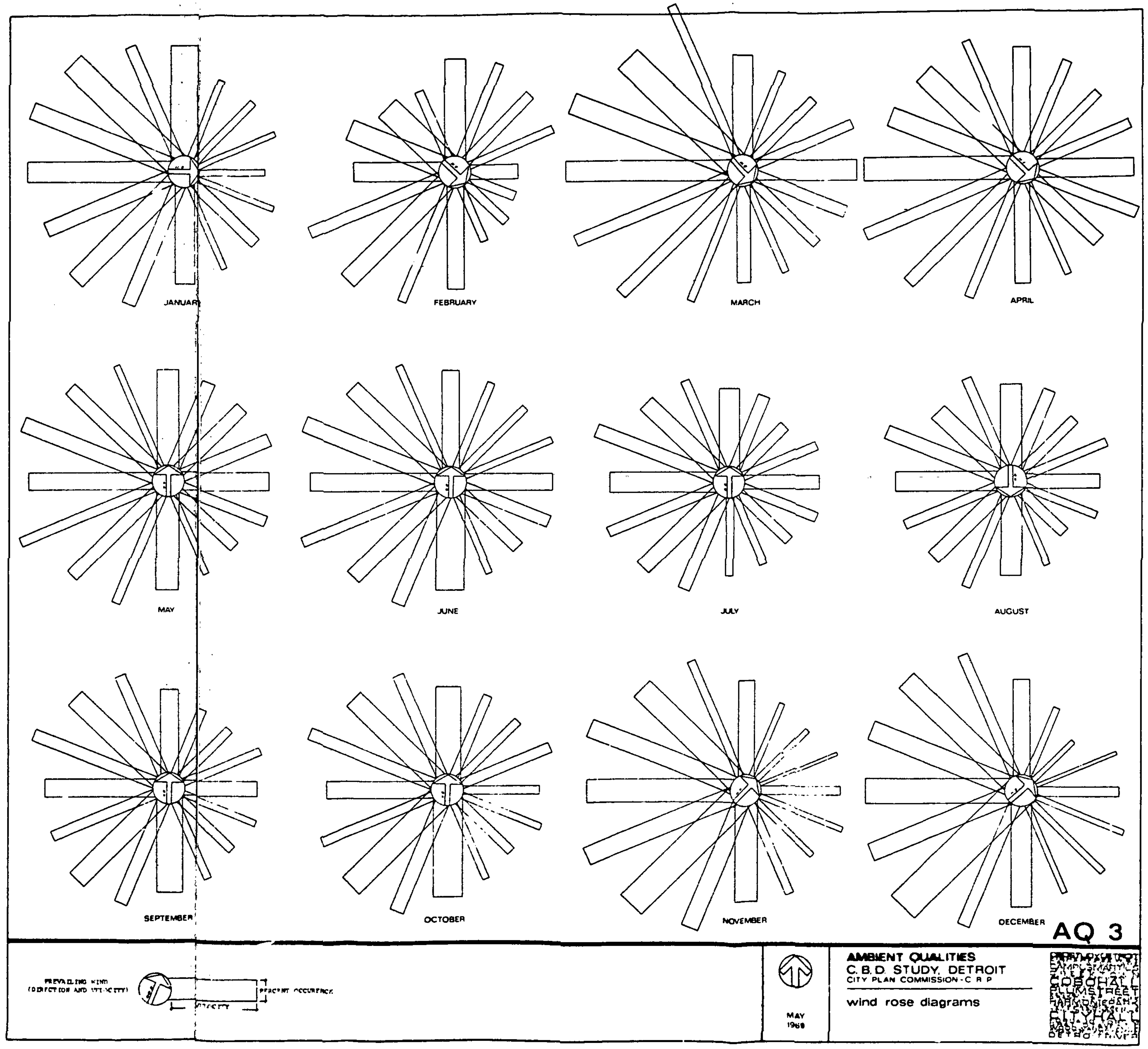

Figure 1.1-25 Wind Rose Diagrams

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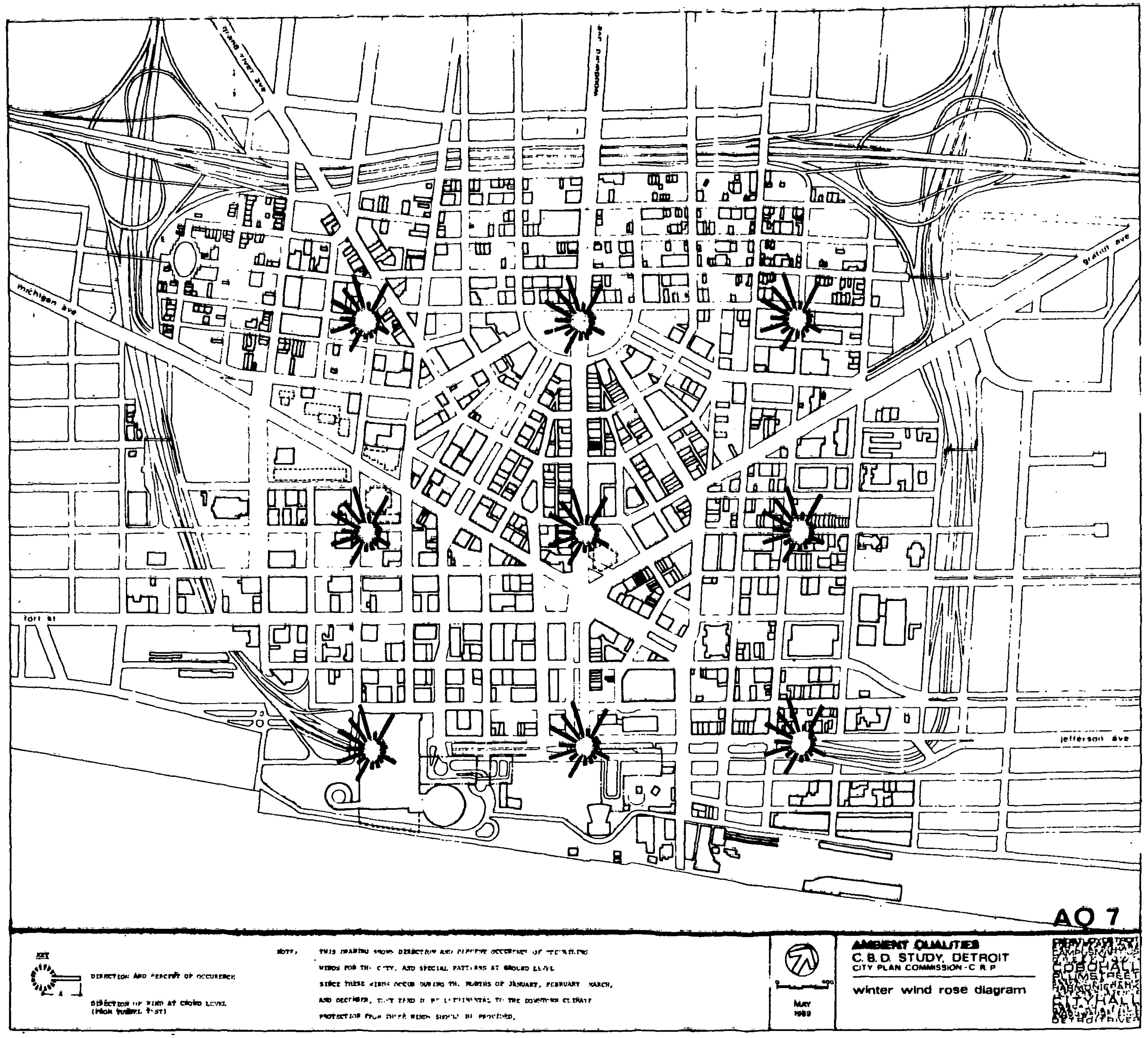

Figure 1.1-26 Winter Wind Rose Diagram

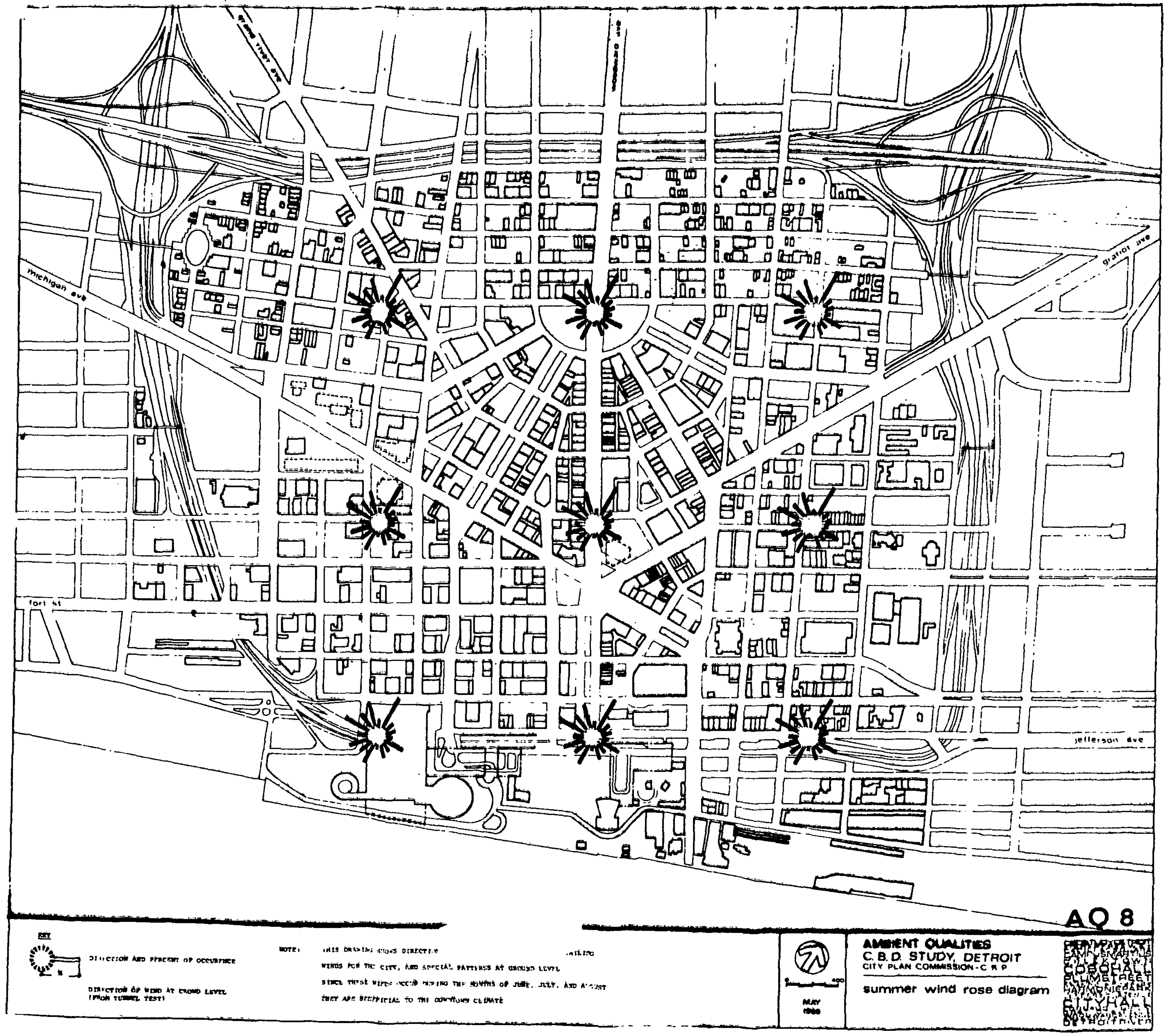

Figure 1.1-27 Summer Wind Rose Diagram

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1.1.3.3 Social Factors

From 1970 to 1985, the population of the Detroit region is expected to increase by approximately 1.6 million people, or 34%. This prediction is based on the Southeast Michigan Council of Governments (SEMCOG) population growth forecasts shown in Figure 1.1-28. Accompanying this growth will be significant changes in the distribution and composition of the population. Figure 1.1-29 presents the forecasted (SEMCOG) changes in the distribution of population shares (percentages) among the seven counties of the TALUS region. County population projections, prepared by the Battelle Institute, are shown in Figure 1.1-30.

Population and economic distributions and densities are summarized in the map "Comprehensive 1990 Plan" contained in inside flap of cover.

1.1.3.4 Transportation Factors

At the time that the current contract was awarded to Lockheed to study aircraft in intraurban transportation systems, urban and regional transportation planners in the Detroit region had not considered air transportation as a possible solution to some of the region's intraurban transportation problems. As a result, transportation studies of the region (such as TALUS) did not include the development of a data base directly related to intraurban air transportation. It was necessary, therefore, for Lockheed to identify or develop a methodology to predict intraurban (commuter) air demand from the extensive ground-transportation-oriented TALUS data base.

Initially, Lockheed planned to make use of passenger preference curves to resolve the modal split problem, and to project air demand based on total (all modes) trip demand. While extensive literature is available on the development and application of preference curves for determining modal split and passenger demand for ground transportation systems, very little research has been conducted on their development and application to extremely short-haul, urban air transportation systems. Classically, passenger preference curves are postulated, a posteriori, from observed travel or demand trends. Lockheed had hoped to use the TALUS travel and demand data to develop air transportation passenger preference curves, but the lack of

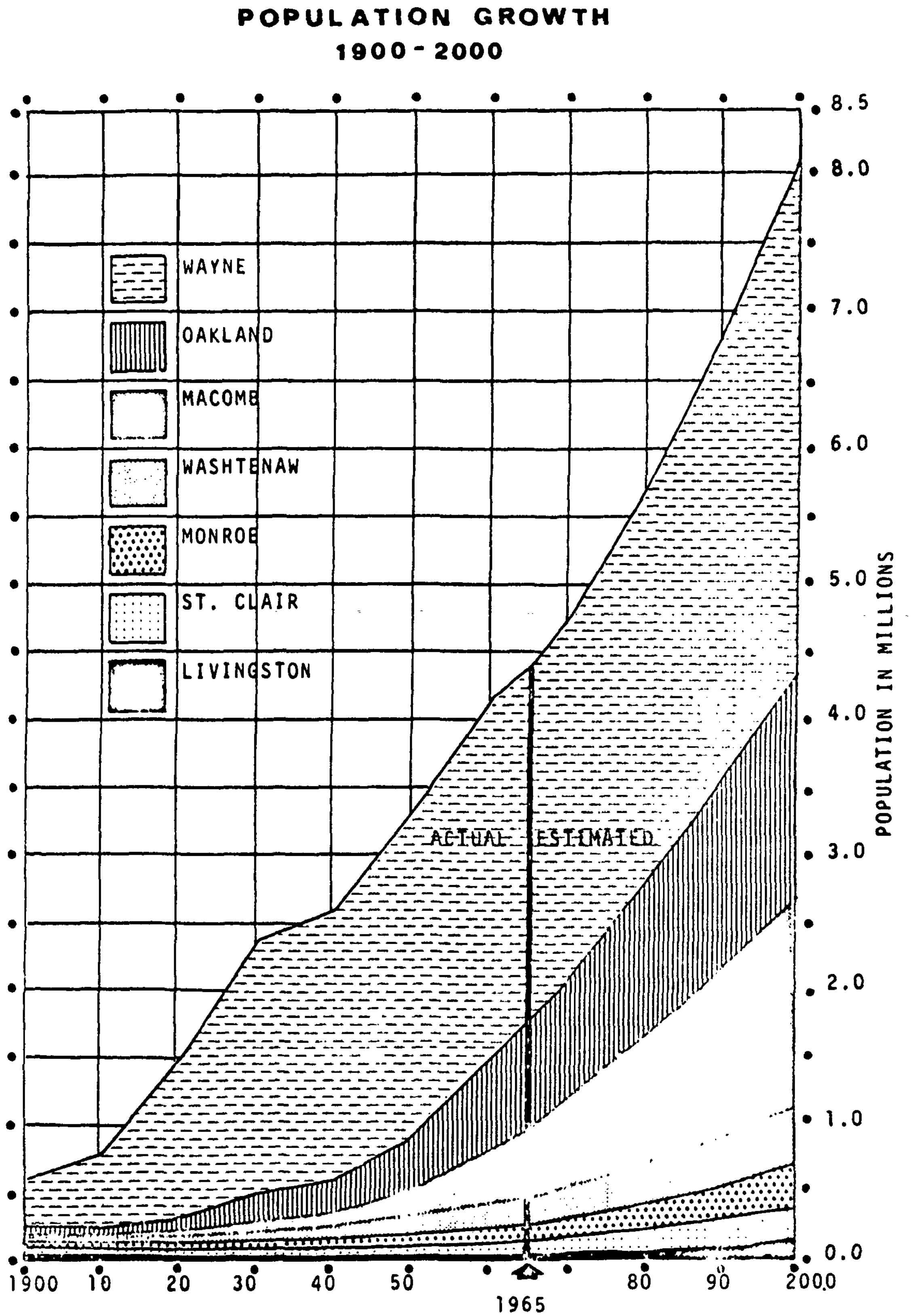

Figure 1.1-28. Population Growth

COUNTIES' SHARE OF THE REGIONAL POPULATION

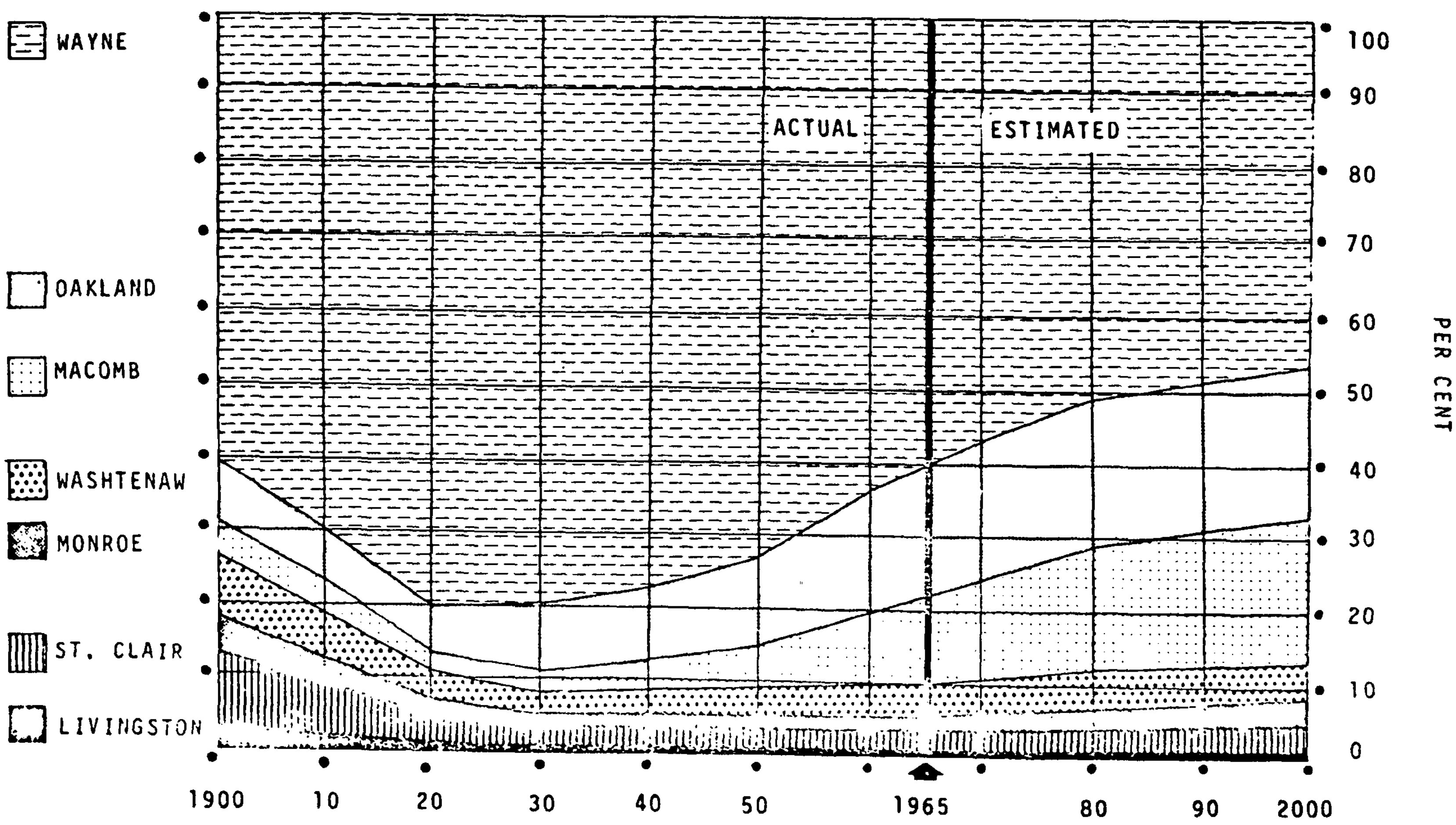

FIGURE 1.1-29. COUNTIES SHARE OF THE REGIONAL POPULATION

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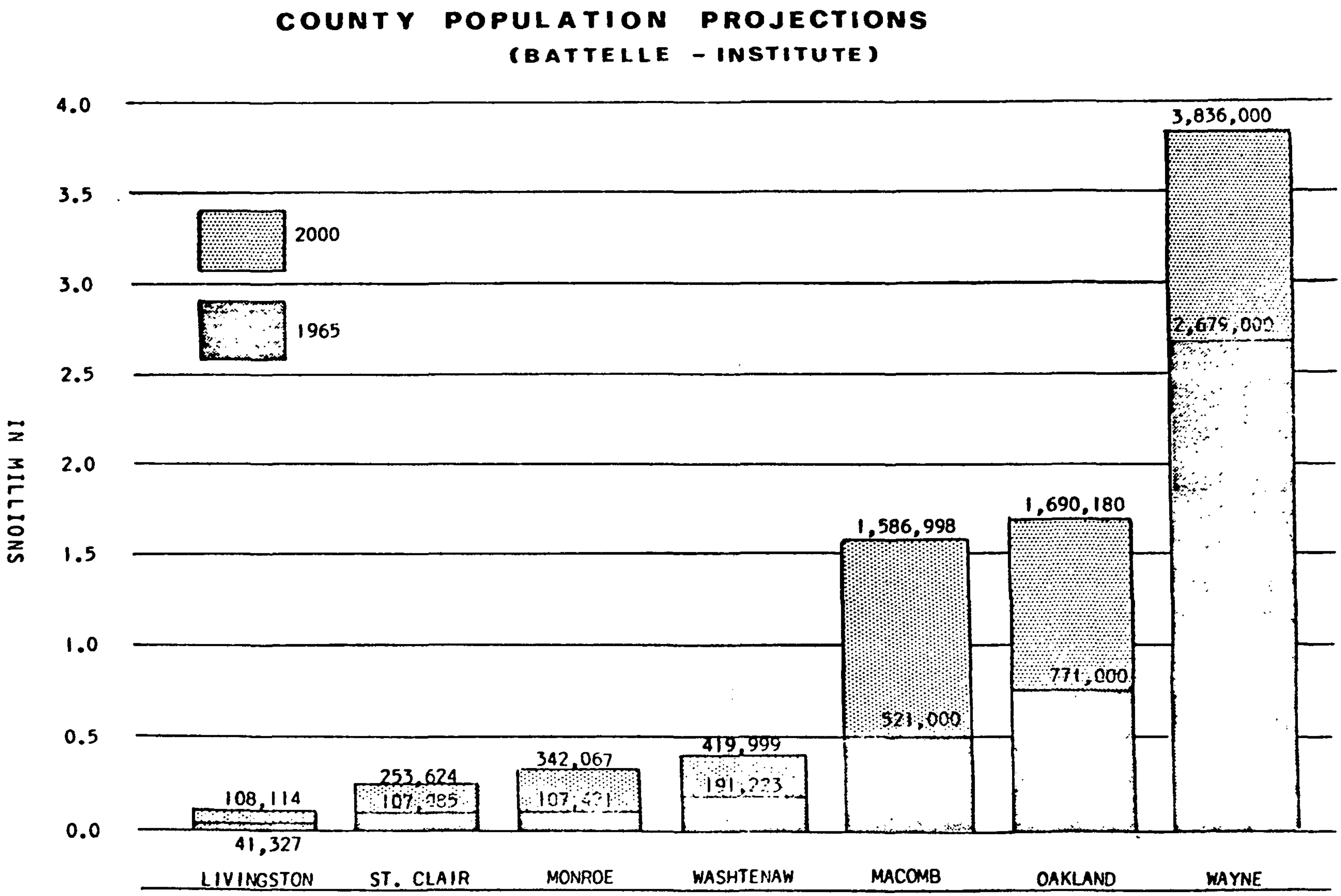

Figure 1.1-30 County Population Projections

direct or indirect air demand data presented a serious obstacle. Further consideration of the problem led to the conclusion that the uncertainties inherent in either a new analytic procedure or a study of Detroit's transportation plans and their impact on passenger travel trends would not produce confidence levels to warrant the development costs of the preference curves and total methodology in this study.

1.1.3.4.1 Demand Analysis Methodology

In attempting to establish a basic philosophy and approach for the Phase I analysis of demand in the Detroit region, Lockheed was guided by two critical factors: (1) that the primary purpose of Phase I was to conduct comparative evaluations of aircraft concepts in intraurban transportation, and (2) that Lockheed, with NASA approval, has elected to conduct parametric analyses of the candidate aircraft concepts. The latter factor suggested a viable and consistent approach to establishing forecasts of market demand in the Detroit region for the years 1975 and 1985; a parametric treatment of demand forecasting.

With NASA concurrence, Lockheed established a range for the percentage of total passenger demand that an air transportation system would capture in the Detroit area. For this study, the primary market has been defined as the daily commuters who travel a minimum of 20 miles one way for business purposes and earn a minimum annual income of $5000. A secondary source of demand would be personal business, shopping, social-recreation, and school trips. Table 1.1-18 summarizes the general travel trends in the Detroit region. The upper bound of the expected demand capture range was set at 30%.

To establish the lower bound of the expected demand capture range, Lockheed considered that the purpose of the Phase I study is to conduct a comparative evaluation of candidate aircraft systems. An implicit basic premise of a comparative evaluation is that the basic concept (intraurban air transportation) is feasible (economically and operationally). To follow this logic, it must be assumed that there exists sufficient demand to support the air transportation system. If the demand does not exist, then a rational comparison of candidate air vehicle concepts is not possible. From a preliminary examination of the base travel data (described in Section

TABLE 1.1-18 GENERAL PURPOSE TRIP FREQUENCIES

Component of Analysis	Person Trips Number	Person Trips Percent	Number of Vehicle Trips
Residents[a]			
Work	2,153,456		
Personal Business	1,387,053		
Shop	1,230,844		
Social-Recreation	1,365,167		
School	682,669		
Non-home-based	1,826,480		
Total	8,645,669	89.0	
Truck Trips	849,440	8.7	849,440
Taxi Trips	71,253	0.7	71,253
Non-Residents			
Auto Cordon Trips	111,126[b]	1.1	65,638
Truck Cordon Trips	18,010[b]	0.3	15,661
Through Trips	15,645[b]	0.2	8,234
Total	9,711,143	100.0	

[a]About 37,000 trips made by persons living in group quarters are excluded from this table. Data are summarized from the unfactored file.

[b]Vehicle occupancy rates are: 1.7 for auto cordon trips; 1.15 for truck cordon trips; 1.9 for through trips

1.1.3.4.2) and based on experience in demand forecasting, Lockheed set the lower bound for the expected demand range at 10%.

It is extremely important to note that the 10% lower bound represents the minimum demand (in Lockheed's best judgement at this time) that would support an air transportation system in the Detroit region, not necessarily the minimum actual demand that might be postulated or encountered.

In summary, for the purposes of the subject study, Lockheed will assume that an intraurban air transportation system would capture between 10% and 30% of the total business commuter travelers (traveling over 20 miles one way and earning a minimum annual salary of $5000) in the Detroit region.

1.1.3.4.2 Base Data

Lockheed received from the Southeast Michigan Council of Governments (SEMCOG) copies of the TALUS data base (which describes the major population characteristics of the study region), and copies of two runs of the trip generation model (described in TALUS report entitled, "A Trip Generation Model for the Detroit Region," December 1969). The trip generation model output presents projections of: (1) the 1990 District to District Total Auto Driver Trips, and (2) the 1990 District to District Total Person Transit Trips. These data formed the base for the Lockheed demand analysis.

1.1.3.4.3 Expected Demand

To determine expected air demand in the Detroit region in the years 1975 and 1985, Lockheed first located terminal service zones in the region to establish origin and destination areas. The terminal service zone locations and the process by which they were determined are discussed in Section 1.1.4.1.

The 1990 District to District Total Auto Driver Trips data is the basis for the demand analysis. After identifying the TALUS districts contained within each of the nine terminal service zones, the 1990 District to District Total Auto Driver Trips data were reduced and consolidated into a 1990 Zone-to-Zone Total Auto Driver Trips matrix.

It was assumed that the total auto trips represent 80% of the total trips within the Detroit region. Furthermore, SEMCOG data indicated that the average load factor for auto driver trips was 1.46 passengers per automobile. Therefore, by multiplying the 1990 zone-to-zone total auto driver trips by a factor of 1.83 (1.46 times 100%/80%) the 1990 zone-to-zone total trips was determined. Using the 10-30% demand capture range assumption, the range of expected (potential) air demand for 1990 was calculated through simple multiplication.

To convert the 1990 air demand data into that for the years 1975 and 1985, Lockheed followed the assumption that the demand changes in direct proportion to changes in population. Therefore, by determining the ratios, 1975 population/1990 population and 1985 population/1990 population, for each of the seven counties, the 1975 and 1985 air demands were calculated.

It is important to note that in Phase I, Lockheed has postulated a fixed, parametrically defined potential demand. That is, the range of potential demand does not vary with changes in system operational characteristics; the parametric nature of the analysis justifies this approach. Because potential demand has been fixed, the percentage of this demand served by an air system is limited only by total system capacity (which is determined by aircraft capacity, fleet size, and schedule and routing).

A range of aircraft capacities of 40-100 passengers was studied for each of the candidate aircraft concepts.

Fleet size and routing and scheduling were based on flight requirements as established by the potential demand, aircraft capacities, and minimum scheduling factors.

As an operational philosophy, Lockheed has elected to maximize system frequency of service. To determine flight frequency, "scheduling factors" over a range of 0.50 to 1.00 were used to establish the upper bound of the number of flights between any given zone-pair during a single three hour period. The equation used is:

$$\text{number of flights} = \frac{\text{potential demand}}{\text{a/c passenger capacity x scheduling factor}}$$

This equation determines the number of passenger carrying flights needed to serve the potential demand between zone-pairs. By setting the lower bound of the range of schedule factors at 0.50, Lockheed ensures that average total load factor (for all flights) does not drop much below 30% upon the introduction of "deadhead" or empty flights necessary or inevitable to real-world scheduling.

In Phase II of the study, Lockheed will exercise the schedule generation model and develop a number of representative system schedules. In Phase I, however, Lockheed will analyze only flight requirements (assuming a perfect schedule requiring no "deadhead" flights) for the purposes of the comparative analysis and aircraft concept selection.

Using the TALUS projection of the distribution of travel as a function of time of day, Lockheed divided the day into three-hour periods and determined the percentage of the total travel that occurred during each period as tabulated below.

Period	% of Demand
0 - 0300	0
0300 - 0600	0
0600 - 0900	25
0900 - 1200	15
1200 - 1500	15
1500 - 1800	25
1800 - 2100	10
2100 - 2400	10

Using this distribution, the expected air demand as a function of time of day was determined. Summing this data yields daily zone-pair demand.

Tables 1.1-19 through 1.1-24 present summaries of the demand analysis. The following variable definitions are presented to aid in interpreting the summary tables.

Variable Definitions

PERCDE	-	Demand
XNPASS	-	Aircraft Passenger Capacity
SF	-	Scheduling Factor

TABLE 1.1-19 DEMAND ANALYSIS SUMMARY

PERCDE = 10% 1975

	XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100			
	SF			SF			SF			SF			
	50	75	100	50	75	100	50	75	100	50	75	100	
DNFLTS	294	156	100	156	76	42	100	42	22	66	22	12	Daily Number of Flights
PNFLTS	84	48	34	48	25	15	34	15	9	21	9	5	Number of Flights in the 3 Hour Peak Period
DPASS	6938	5502	4000	5820	4212	2520	4932	3002	1760	4124	2180	1200	Daily Number of Passengers
DRANGE	6544	3364	2146	3400	1600	890	2566	1014	580	1382	458	250	Daily Total Range

TABLE 1.1-20 DEMAND ANALYSIS SUMMARY

PERCDE = 20% 1975

	XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100			
	SF			SF			SF			SF			
	50	75	100	50	75	100	50	75	100	50	75	100	
DNFLTS	698	422	294	422	236	154	290	154	100	216	106	66	Daily Number of Flights
PNFLTS	184	118	84	118	67	47	83	47	34	61	34	21	Number of Flights in the 3 Hour Peak Period
DPASS	15706	14508	11760	14880	12616	9240	13868	10944	8000	12838	9624	6600	Daily Number of Passengers
DRANGE	15938	9488	6598	9434	5168	3326	7584	3862	2586	4734	2280	1382	Daily Total Range

TABLE 1.1-21 DEMAND ANALYSIS SUMMARY

PERCDE = 30% 1975

	XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100			
	SF			SF			SF			SF			
	50	75	100	50	75	100	50	75	100	50	75	100	
DNFLTS	1100	694	482	694	422	292	490	290	188	380	208	134	Daily Number of Flights
PNFLTS	281	184	132	184	118	84	134	83	57	104	59	41	Number of Flights in the 3 Hour Peak Period
DPASS	24082	23092	19200	23564	21686	17400	22698	20110	15040	22316	18230	13600	Daily Number of Passengers
DRANGE	25280	15820	10746	15820	9488	6492	12904	7584	4838	8580	4564	2886	Daily Total Range

TABLE 1.1-22 DEMAND ANALYSIS SUMMARY

PERCDE = 10% 1985

	XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100			
	SF			SF			SF			SF			
	50	75	100	50	75	100	50	75	100	50	75	100	
DNFLTS	378	210	134	210	110	68	132	68	34	94	38	18	Daily Number of Flights
PNFLTS	105	64	41	64	36	25	40	25	12	29	12	7	Number of Flights in the 3 Hour Peak Period
DPASS	9142	7668	5320	8048	6032	4080	6880	4926	2720	6274	3540	1800	Daily Number of Passengers
DRANGE	8546	4638	2920	4638	2362	1466	2440	1342	604	2038	812	376	Daily Total Range

TABLE 1.1-23 DEMAND ANALYSIS SUMMARY

PERCDE = 20% 1985

	XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100			
	SF			SF			SF			SF			
	50	75	100	50	75	100	50	75	100	50	75	100	
DNFLTS	884	548	380	552	332	210	378	210	132	286	158	90	Daily Number of Flights
PNFLTS	230	146	105	146	91	64	104	64	40	80	47	28	Number of Flights in the 3 Hour Peak Period
DPASS	19838	18830	15120	19110	17344	12600	18380	15216	10560	17180	14014	9400	Daily Number of Passengers
DRANGE	20378	12440	8542	12440	7422	4618	7476	4102	2440	6358	3450	1978	Daily Total Range

TABLE 1.1-24 DEMAND ANALYSIS SUMMARY

PERCDE = 30% 1985

	XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100			
	SF			SF			SF			SF			
	50	75	100	50	75	100	50	75	100	50	75	100	
DNFLTS	1392	884	638	884	546	378	632	378	262	488	284	190	Daily Number of Flights
PNFLTS	355	230	170	230	146	105	168	104	76	131	80	56	Number of Flights in the 3 Hour Peak Period
DPASS	30046	29408	25360	29758	28192	22680	29222	26410	20860	28222	24852	19200	Daily Number of Passengers
DRANGE	32331	20378	14590	20378	12428	8542	12750	7476	5016	11106	6362	4214	Daily Total Range

1.1.3.4.4 Flight Allocation

The purpose of this subtask was to determine the number of flights that would be required to serve the zone-pair demand. The basic assumption followed was that frequency of service would be maximized by flying the maximum number of aircraft, as determined by minimum load factor constraints between zones during a given period, and for the established demand. Tables 1.1-25 through 1.1-30 present the summarization of the number of flights during the three-hour peak period. These data were summarized from the number of flights for the 38 possible terminal pairs. They were also used to determine the number of passenger gates required at each terminal. The detailed data are included in the Appendix as Tables A1.1-1 through A1.1-6.

1.1.3.4.5 Zone-Pair Passengers Served

An interesting phenomenon of the minimum load factor criterion is that for minimum load factors greater than 50%, 100% of the expected demand will not always be served. For example, consider a zone-pair having an expected demand of 85 passengers and a 60-passenger aircraft with a 75% minimum load factor. Clearly, the route can support only one flight during the three-hour period (a second flight would violate the 75% minimum load factor constraint) and hence only 60 of the 85 passengers can be served.

By considering the expected demand and the maximum number of flights for each zone-pair and during each three-hour period, the zone-pair passengers served was determined. The detailed data are included in the Appendix as Tables A1.1-7 through A1.1-12.

maximum number of aircraft, as determined by minimum load factor constraints between zones during a given period, and for the established demand. Tables 1.1-25 through 1.1-30 present the summarization of the number of flights during the three hour peak period. These data were summarized from the number of flights for the 38 possible terminal pairs. They were also used to determine the number of passenger gates required at each terminal. The detailed data are included in Appendix A as Tables A-1.1-1 through A-1.1-6.

1.1.3.4.5 Zone-Pair Passengers Served

An interesting phenomenon of the minimum load factor criterion is that for minimum load factors greater than 50%, 100% of the expected demand will not always be served. For example, consider a zone-pair having an expected demand of 85 passengers and a 60-passenger aircraft with a 75% minimum load factor. Clearly, the route can support only one flight during the three-hour period (a second flight would violate the 75% minimum load factor constraint) and hence only 60 of the 85 passengers can be served.

By considering the expected demand and the maximum number of flights for each zone-pair and during each three hour period, the zone-pair passengers served was determined. The detail data are contained in Appendix A as Tables A-1.1-7 through A-1.1-12.

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TABLE 1.1-25 FLIGHT ALLOCATION SUMMARY

PERCDE = 10% 1975

FLTS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	15	10	6	10	5	3	6	3	2	4	2	1
NC	2	10	6	4	6	3	2	4	2	1	3	1	1
MCLE	3	24	15	12	15	8	6	12	6	4	7	4	3
MON	4	6	4	2	4	1	1	2	1	0	1	0	0
PONT	5	12	7	5	7	4	3	5	3	1	4	1	1
METRO	6	10	6	4	6	4	2	4	2	1	3	1	0
ANN	7	9	3	3	3	1	1	3	1	1	1	1	0
PH	8	2	1	1	1	1	0	1	0	0	0	0	0
AL	9	3	2	1	2	1	0	1	0	0	1	0	0
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TABLE 1.1-26 FLIGHT ALLOCATION SUMMARY

PERCDE = 20% 1975

FLTS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	33	22	15	22	13	10	15	10	6	13	6	4
NC	2	23	15	10	15	9	6	10	6	4	7	4	3
MCLE	3	50	32	24	32	20	15	24	15	12	19	12	7
MON	4	14	9	6	9	4	4	6	4	2	4	2	1
PONT	5	27	17	12	17	9	7	12	7	5	9	5	4
METRO	6	23	15	10	15	8	6	10	6	4	8	4	3
ANN	7	18	10	9	10	6	3	9	3	3	5	3	1
PH	8	5	4	2	4	2	1	2	1	1	1	1	0
AL	9	6	5	3	5	2	1	2	1	1	2	1	1
	10												

TABLE 1.1-27 FLIGHT ALLOCATION SUMMARY

PERCDE = 30% 1975

FLTS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	50	33	23	33	22	15	23	21	11	18	11	8
NC	2	35	23	17	23	15	10	17	10	7	13	7	4
MCLE	3	76	50	37	50	28	24	37	19	17	29	17	14
MON	4	22	14	10	14	9	6	10	6	4	8	4	3
PONT	5	38	27	20	27	17	12	21	12	9	17	9	7
METRO	6	36	23	16	23	15	10	17	10	8	13	8	5
ANN	7	28	18	13	18	10	9	13	9	5	10	5	3
PH	8	9	5	4	5	4	2	4	2	1	3	1	1
AL	9	10	6	4	6	5	3	4	2	2	4	2	2
	10												

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TABLE 1.1-28 FLIGHT ALLOCATION SUMMARY

PERCDE = 10% 1985

FLTS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	17	11	7	11	6	4	7	4	2	5	2	1
NC	2	11	7	4	7	4	3	4	3	1	3	1	1
MCLE	3	30	19	14	19	13	9	14	9	6	9	6	3
MON	4	7	4	3	4	2	1	3	1	0	2	0	0
PONT	5	14	8	5	8	5	4	5	4	1	4	1	1
METRO	6	11	8	4	8	4	3	4	3	1	3	1	1
ANN	7	10	5	3	5	3	1	3	1	1	3	1	1
PH	8	5	3	2	3	1	1	2	1	1	1	1	0
AL	9	5	4	2	4	2	1	2	1	1	1	1	0
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TABLE 1.1-29 FLIGHT ALLOCATION SUMMARY

PERCDE = 20% 1985

FLTS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	38	23	17	23	15	11	17	11	7	13	8	5
NC	2	25	17	11	17	10	7	11	7	4	9	5	3
MCLE	3	63	41	30	41	27	19	30	19	14	23	15	9
MON	4	17	10	7	10	6	4	7	4	3	5	3	2
PONT	5	30	19	14	19	12	8	14	8	7	10	5	4
METRO	6	26	17	11	17	10	8	11	8	4	8	5	3
ANN	7	23	14	10	14	10	5	10	5	3	9	5	3
PH	8	11	7	5	7	4	3	5	3	2	4	3	1
AL	9	12	8	5	8	5	4	5	4	2	4	3	1
	10												

TABLE 1.1-30 FLIGHT ALLOCATION SUMMARY

PERCDE = 30% 1985

FLTS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	57	38	28	38	23	17	28	17	13	21	13	10
NC	2	39	25	18	25	17	11	18	11	8	15	9	6
MCLE	3	96	63	47	63	41	30	47	30	23	36	23	17
MON	4	26	17	13	17	10	7	13	7	5	10	5	4
PONT	5	46	30	22	30	19	14	22	14	10	17	10	7
METRO	6	40	26	19	26	17	11	19	11	8	15	8	6
ANN	7	37	23	18	23	14	10	18	10	9	13	9	5
PH	8	18	11	8	11	7	5	8	5	4	7	4	3
AL	9	19	12	9	12	8	5	9	5	4	7	4	3
	10												

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1.1.4 TRANSPORTATION COMPLEMENT

The objective of this task was to identify those elements of an intraurban air transportation system that complement the air vehicle: the terminals, ground support equipment, and air traffic control facilities. The data generated by this task were primarily used as input to the Indirect Operating Cost Model described in Section 1.3.1.2.

1.1.4.1 Terminal Requirements and Characteristics

1.1.4.1.1 Terminal Locations

Based on the population and economic distribution data contained in the TALUS base data (see map entitled "Comprehensive 1990 Plan" in inside flap of cover), nine locations for commuterports were selected for analysis (see Figure 1.1-31). A service zone for each commuterport was then determined based on an approximately 10 minute transfer time to or from the terminal.

A tenth terminal is postulated which will contain facilities for servicing, maintaining, fueling, and storing aircraft. It will not be a passenger terminal, and hence has no service zone. It has been assumed that this maintenance terminal will be located an average 22 miles from the other terminals.

It will be noted from Figure 1.1-31 that the entire TALUS region is not covered by commuterport service zones. Based on the socio-economic distributions and densities of the region, Lockheed judged that only the nine locations previously shown would support STOL operations, and that diminishing returns would be realized by adding more commuterports or increasing the area coverage.

1.1.4.1.2 General Characteristics

During Phase I of the subject study, only those terminal characteristics used in the determination of facility costs were identified. However, some basic assumptions were followed:

- All terminals would be ground level (not elevated)
- Each terminal would have a single runway

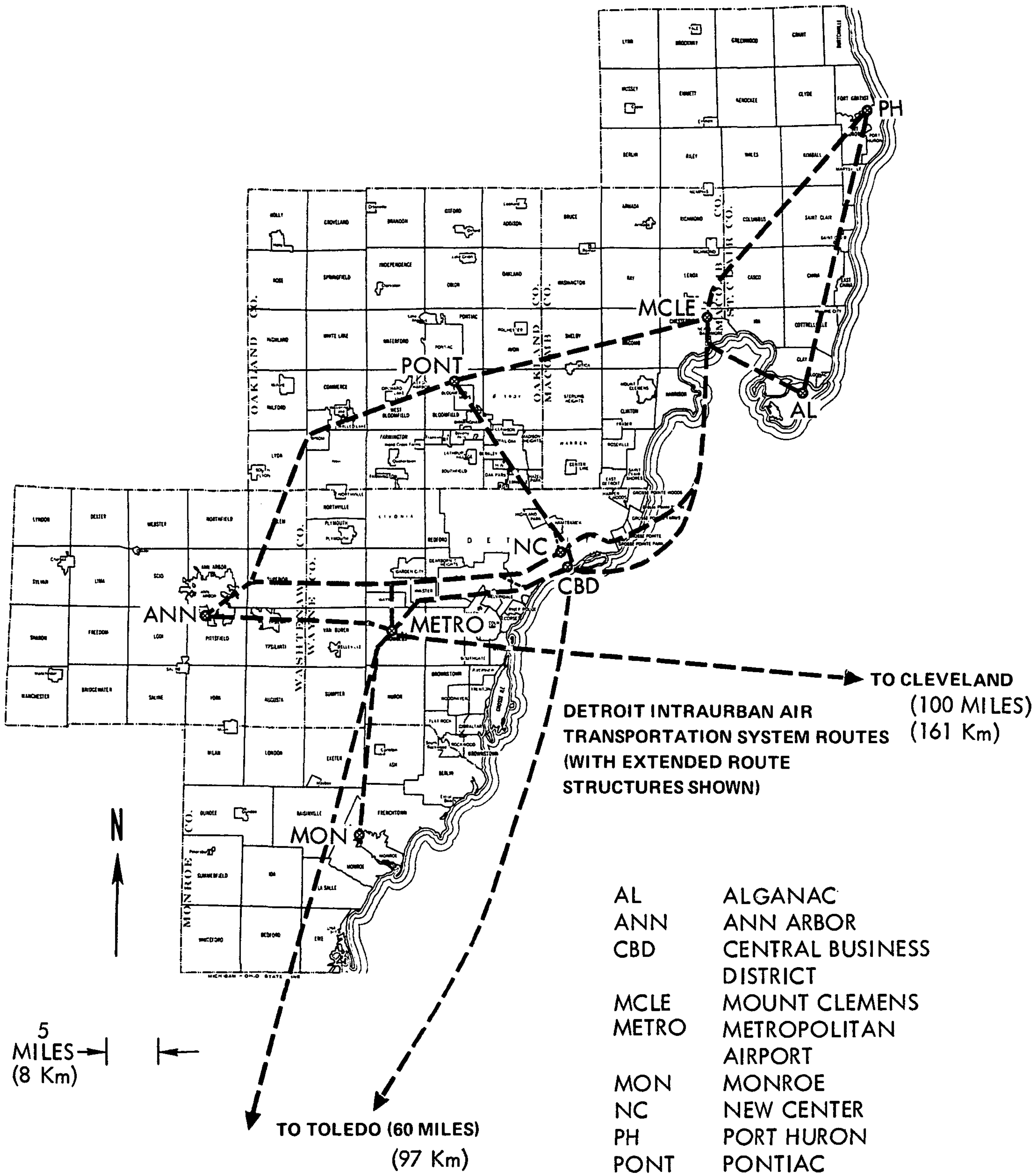

Figure 1.1-31. Commuterport Locations

- Each terminal would have Category III landing ground equipment
- Primary maintenance, service, and fueling facilities would be located at a single, centrally located terminal separate from the nine passenger terminals -- with some reserve or emergency equipment at all terminals
- Passenger ticketing would be automated

1.1.4.1.3 Land Values per Terminal

The average land values within each of the nine terminal service zones are presented in following Table 1.1-31. These land values were obtained from SEMCOG.

1.1.4.1.4 Passenger Capacity Requirements

Passenger capacity requirements at each terminal were determined by calculating the total number of passengers arriving and departing the terminal during a peak traffic period (Tables 1.1-32 through 1.1-37.) This information was used as input to the cost model to determine the size of the passenger termins. The detailed data are included in Appendix A in Tables A1.1-7 through A1.1-12.

TABLE 1.1-31 AVERAGE LAND VALUES

Zone	$/Acre	$/ft^2
CBD	110,254	2.53
NC	110,254	2.53
MON	37,941	0.87
PONT	73,476	1.69
ANN	62,412	1.43
METRO	1,359	0.03
PH	55,846	1.28
AL	23,392	0.54
MCLE	61,118	1.40

TABLE 1.1-32 PASSENGER ALLOCATION

PERCDE = 10% 1975

PASS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	653	578	440	600	512	260	532	420	240	484	270	200
NC	2	436	361	280	391	324	180	326	202	160	326	194	100
MCLE	3	949	930	920	949	880	630	949	706	560	810	664	500
MON	4	236	177	120	183	60	60	148	62	0	62	0	0
PONT	5	522	450	360	480	456	300	480	344	160	480	200	200
METRO	6	440	407	280	440	282	180	375	222	160	284	168	0
ANN	7	389	233	200	244	120	120	211	160	160	168	168	0
PH	8	90	80	80	90	47	0	90	0	0	0	0	0
AL	9	103	94	80	103	103	30	103	0	0	54	0	0
	10												

TABLE 1.1-33 PASSENGER ALLOCATION

PERCDE = 20% 1975

PASS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	1316	1280	1120	1306	1270	850	1306	1156	880	1258	996	800
NC	2	928	896	720	906	818	660	872	722	560	782	632	500
MCLE	3	1898	1892	1720	1898	1872	1620	1898	1832	1680	1898	1884	1300
MON	4	528	468	400	506	406	300	472	354	240	424	272	100
PONT	5	1112	1108	920	1112	940	780	1044	900	720	960	868	800
METRO	6	1470	942	760	948	840	660	880	814	640	880	718	400
ANN	7	778	722	680	778	618	360	778	466	400	604	422	200
PH	8	256	250	160	256	154	120	180	160	160	180	180	0
AL	9	282	282	160	282	206	60	206	160	160	206	198	100
	10												

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TABLE 1.1-34 PASSENGER ALLOCATION

PERCDE = 30% 1975

PASS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	1959	1952	1760	1959	1920	1780	1959	1906	1600	1959	1837	1400
NC	2	1392	1381	1240	1392	1344	1080	1359	1263	1040	1359	1171	800
MCLE	3	2847	2847	2680	2847	2838	2580	2847	2845	2400	2847	2730	2400
MON	4	792	774	640	792	702	600	759	676	480	759	573	600
PONT	5	1668	1646	1440	1668	1662	1380	1668	1556	1280	1668	1439	1200
METRO	6	1422	1400	1200	1322	1263	1140	1422	1283	1120	1422	1245	1100
ANN	7	1167	1153	1000	1167	1083	780	1167	1134	800	1104	877	500
PH	8	384	350	280	384	375	240	327	270	160	384	200	200
AL	9	423	389	320	423	423	240	366	307	240	423	262	200
	10												

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TABLE 1.1-35 PASSENGER ALLOCATION

PERCDE = 10% 1985

PASS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	772	734	520	748	606	480	672	559	320	632	372	200
NC	2	520	465	320	465	379	360	390	390	160	390	200	200
MCLE	3	1253	1246	1040	1253	1213	1020	1253	1210	800	1253	956	600
MON	4	264	191	160	211	117	60	211	71	0	128	0	0
PONT	5	606	557	400	557	531	480	557	557	160	557	200	200
METRO	6	513	496	320	513	382	240	438	293	160	395	195	100
ANN	7	474	324	200	341	265	120	265	160	160	265	195	100
PH	8	227	220	120	227	120	120	151	144	80	151	0	0
AL	9	247	247	120	247	171	120	171	154	80	171	0	0
	10												

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TABLE 1.1-36 PASSENGER ALLOCATION

PERCDE = 20% 1985

PASS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	1544	1536	1320	1544	1492	1260	1544	1468	1360	1496	1302	1000
NC	2	1100	1048	880	1100	1006	840	1040	930	640	1100	814	600
MCLE	3	2506	2506	2280	2506	2498	2160	2506	2492	1760	2516	2478	1800
MON	4	588	534	440	588	482	300	528	382	320	482	366	200
PONT	5	1288	1270	1120	1288	1164	960	1212	1114	800	1168	982	800
METRO	6	1102	1096	840	1102	970	840	1026	992	640	1026	880	600
ANN	7	948	882	680	948	900	540	948	648	400	948	594	400
PH	8	454	454	360	454	414	360	454	440	240	454	426	200
AL	9	494	494	360	494	494	420	494	494	240	494	494	200
	10												

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TABLE 1.1-37 PASSENGER ALLOCATION

PERCDE = 30% 1985

PASS i		XNPASS = 40			XNPASS = 60			XNPASS = 80			XNPASS = 100		
		SF			SF			SF			SF		
Terminal	i	50	75	100	50	75	100	50	75	100	50	75	100
CBD	1	2316	2316	2120	2316	2304	1500	2316	2246	1920	2316	2164	1900
NC	2	1650	1626	1400	1650	1572	1320	1617	1488	1280	1617	1535	1100
MCLE	3	3759	3759	3520	3759	3759	3900	3759	3759	3360	3759	3759	3200
MON	4	882	858	760	882	588	660	849	774	560	849	671	500
PONT	5	1932	1897	1720	1932	2118	1680	1932	1817	1520	1932	1720	1400
METRO	6	1653	1619	1480	1653	1644	1260	1653	1472	1280	1653	1485	1200
ANN	7	1422	1407	1240	1422	1323	1080	1422	1328	1120	1422	1328	800
PH	8	681	681	560	681	681	540	681	613	560	681	653	500
AL	9	741	741	640	741	741	540	741	673	560	741	713	600
	10												

1.1.4.1.5 Gate Requirements

The number of gates required at each terminal is calculated by the following equation:

$$XNGT_i = FLTS_i \times GT/180 \text{ min.},$$

where

$XNGT_i$ = number of gates at terminal i

$FLTS_i$ = number of flight arrivals or departures, whichever is larger, at terminal i during a peak-period

GT = average gate time per aircraft

1.1.4.2 Terminal Access Requirements

For the purpose of the Phase I analyses, it is assumed that the requirements of terminal access are not differentiated by aircraft concept, rather they are more a function of demand. Furthermore, the current emphasis on integrated planning and development of ground transportation systems at all levels of government suggests that the financing and design of terminal access will not be controlled entirely by the air transportation system owners and operators. For these reasons, Lockheed did not consider terminal access as a cost factor in the Phase I analysis.