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STUDY OF AIRCRAFT IN INTRAURBAN TRANSPORTATION SYSTEMS

by E. G. Stout

Prepared by
LOCKHEED-CALIFORNIA COMPANY
Burbank, Calif.
for Ames Research Center

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16. Abstract

A systems analysis was conducted to define the technical economic and operational characteristics of an aircraft transportation system for short-range intracity commutor operations. The analysis was for 1975 and 1985 in the seven county, Detroit, Michigan area. STOL and VTOL aircraft were studied in sizes from 40 to 120 passengers. The preferred vehicle for the Detroit area was the deflected slipstream STOL. Since the study was parametric in nature, it is applicable to generalization, and it was concluded that a feasible intraurban air transportation system could be developed in many viable situations.

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FOREWORD

The Study of Aircraft in Intraurban Transportation Systems summarized in this report was accomplished by the Lockheed-California Company under NASA Ames Research Center Contract NAS 2-5989 from June 1970 through May 1971. The basic report consists of four volumes, CR 114340 through CR 114343, dated June 1971. The final oral presentation for this contract is contained in LR 24491, Volumes 1 and 2, dated June 1971.

This study was conducted 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.

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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 percent 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 attandant 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 Phase II analysis showed the conventional compound helicopter, with a gear-driven rotor, to have the highest fare, with the STOL autogyro falling roughly half-way between. If the relatively high development risk advanced compound helicopter, with the penumatically 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 (305 meters) optimum field length STOL autogyro may approach, or even improve, the low fare level of the 2000-foot (610 meters) 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, optimization, and evaluation of multiple design, 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.

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 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

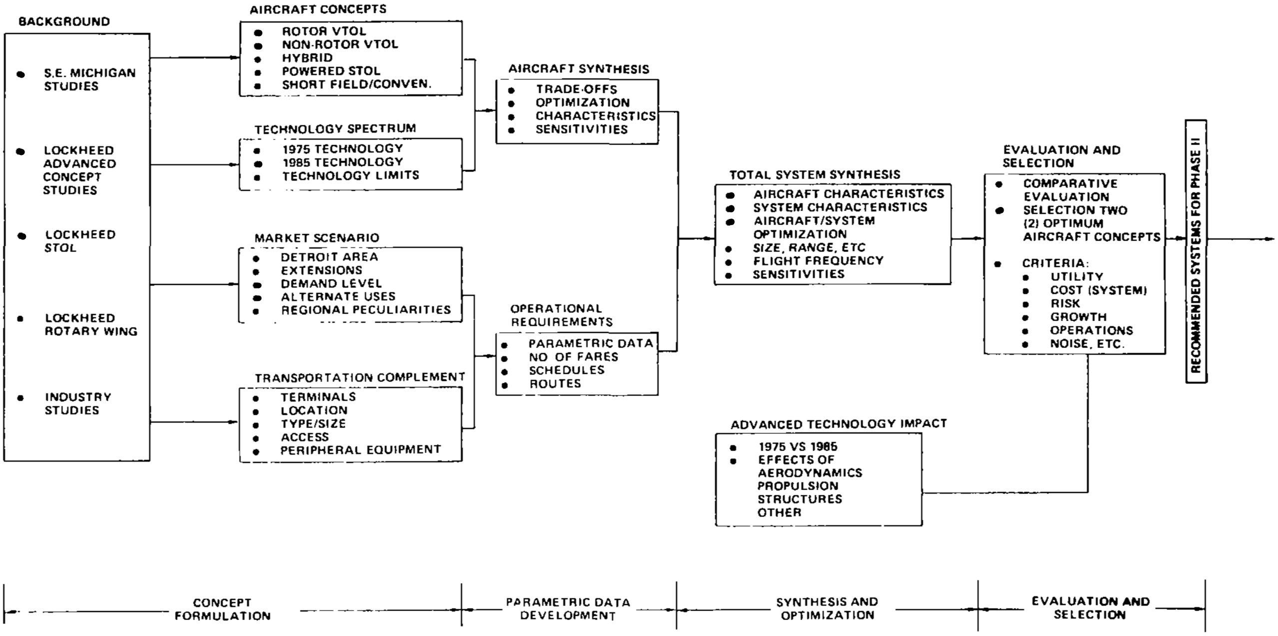
It follows then, that the basic features of aircraft; i.e., speed and flexibility, may be uniquely suited to satisfying a significant portion of the needs of the potential intraurban transportation market. Other factors relating to aircraft operation which are important considerations include:

- 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 was 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 short-haul 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 summary flow chart, this phase comprises four stages: concept formulation, parametric data development, synthesis and optimization, and evaluation and selection.

- 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
- 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., that 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, turaround time, and flight times, for each aircraft concept

- 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 following concepts.

    Passenger capacity/fleet size

    Terminal location and landing field size

    Range/endurance and trip distance

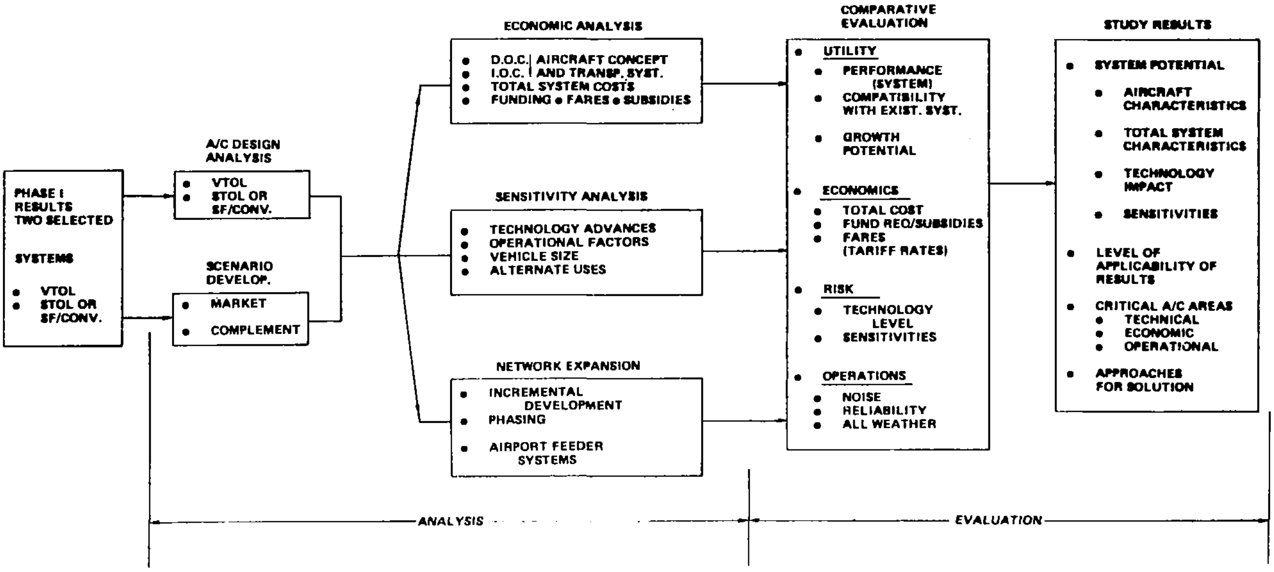
    Fares vs operating subsidies

    Frequency of service and load factors

    Speed (if applicable), turnaround time, and total trip time

- 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, hybird, 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.

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 commuter-ports, 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 studies. 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 establisn 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

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

- Each concept'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 broad study logic was defined by the previous discussion and shown in flow diagrams. Associated major subtasks, study limitations, methodologies, etc, employed after concept formulation are as follows:

Phase I

A set of performance requirements and design criteria for the intraurban transport were developed.

Aircraft concepts. - The spectrum of VTOL and STOL aircraft concepts (existing and proposed) was reviewed and several were considered appropriate for an intraurban transport for the 1975 Initial Operational Capability (IOC) and for 1985 IOC time periods were selected.

Preliminary design analysis. - The VTOL and STOL concepts were subjected to preliminary design type analysis to provide generalized vehicle definition, weight, performance, and external noise estimates. This included forecasts of the effects of advanced technology (1985 IOC).

Market scenario. - Statistical data covering metropolitan Detroit travel patterns and projections were reviewed, travel patterns and demand data forecast, and tentative commuterport locations established.

Cost basis. - A development, production, and operation cost basis was established for each aircraft concept.

Total system analysis. - The above data were employed as input to the Lockheed Total System Analysis. This program matches the aircraft performance, weight, and DOC data of the aircraft synthesis with the total trip time, market demand, and IOC data from the operational analysis. This results in the definition and optimization of the total system and its critical elements. At this point, the values of the basic aircraft design parameters of passenger capacity and Federal Aviation Regulation (FAR) field length are decided on the basis of the total system's ability to service the needs of the Detroit commuter. Critical elements in this optimization are:

- Factors affecting passenger satisfaction; such as, traffic scheduling, frequency of service, etc
- Factors affecting the economic potential of the operation; such as, investment cost, total system cost, subsidy requirements, etc

The result of this total effort is to specify, for each of the aircraft concepts, the optimum levels of the following vehicle and total transportation system characteristics:

- Passenger capacity
- Fleet size
- Terminal location and size
- Route and schedule
- Frequency of service
- Total system cost
- Commuter fare

Evaluation. - The optimum 1975, and 1985 VTOL and STOL concept payload combinations (one each per time period) were chosen for detailed study in Phase II from evaluation of total system cost, external noise, technology risk, and subjective factors.

Phase II

The Phase II work was primarily concerned with more detailed consideration of the selected intraurban transport configurations and a refinement of all data and methods.

SYMBOLS

C_D = Drag Coefficient, $\frac{D}{S\,q}$

C_L = Lift Coefficient, $\frac{L}{S\,q}$

(L/D) = Lift/Drag

q = Dynamic Pressure, Lb/Ft^2

S = Wing Area, Sq Ft

T/W = Thrust/Weight

W_f/W_g = Fuel Weight/Takeoff Gross Weight

MARKET SCENARIO

The objective of developing the scenario for the study was to identify and quantify those elements of the operational environment of the intraurban air transportation system that establish needs for, or place constraints upon, that system. Physical, social, and economic factors were considered, and their impact on travel and demand trends were determined. The primary elements of this work are discussed below.

Area Selection

To insure real-world application of the results of the study, the scenario was based on an actual U. S. metropolitan area. At NASA's request, Lockheed attempted to identify a "representative" U. S. metropolitan area. That is, a metropolitan area having a population of about five million people, experiencing significant seasonal variations in weather, and experiencing the transportation problems common to most metropolitan areas (such as congestion and unsatisfied travel demand). A further criteria for selection was the availability and accessability of a transportation data base sufficient to generate future air transportation demand projections.

The seven-county Detroit, Michigan metropolitan area was selected as the study area and the 1960-1969 Detroit Regional Transportation and Land Use Study (TALUS) was approved by NASA to serve as the base for the scenario development (Detailed in References 1 through 7).

TALUS was a nine-year, 4.5-million dollar study to produce a comprehensive plan to guide the growth and development of the seven-county, 4500-square mile (11,700 sq km) southeastern Michigan metropolitan region through 1990. These counties are Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne. A map of this area is shown in Figure 1 (Livingston county had a negligible effect on the market and was therefore not included in the analysis). A partial listing of the TALUS reports employed in the analysis is included as References 1 through 7.

Environment

Topography. - In the Detroit region, the waterways, 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 (172 to 176 meters) above sea level. Nearly flat land slopes up gently from the water's edge northwestward for about 10 miles (16.1 km) and then gives way to increasingly rolling terrain. The Irish Hills, parallel to and about 40 miles (64.4 km) northwest of the waterway, have tops 1000 to 1250 feet (305 to 382 meters) above sea level. On the Canadian side of the waterway, the land is relatively level.

In general, the topography of the Detroit region should present no obstacles to, or impose any restrictions on, the operations or construction of an intraurban air transportation system. Neither, however, has it restricted the operations of alternate transportation systems; thus, creating a potential demand for the air system.

Climate. - Detroit's climate is controlled by its location with respect to major storm tracts and 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. Artic 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.

The major factors which influence air vehicle and ground facilities design are wind, low ceiling, poor visibility, temperature, and icing. The climate in Detroit exhibits extreme variations in each of the factors and requires all-weather capability for an air transportation system.

It is significant that in Detroit, as in most northeastern and north central metropolitan areas, weather extremes in wintertime frequently disable and cripple the flow of most forms of ground transportation. These disruptions in ground transportation have significant economic and social impact on both individuals and communities. Air transportation systems with all-weather capability would serve to relieve some of these problems and would have a vital role in moving both people and goods.

Political Agencies. - The implementation of any proposed intraurban transportation system must be coordinated with at least the following agencies:

- Southeast Michigan Council of Governments - responsible for total regional planning in Southeast Michigan
- Southeastern Michigan Transportation Authority - responsible for integration and implementation of transportation plans for Southeast Michigan
- Department of Street Railways - responsible for public ground transportation systems, including rapid transit, in Detroit
- Department of Airports - responsible for airport planning and development in Detroit
- Interagency Transportation Council - responsible for statewide transportation planning and integration in Michigan
- Michigan Aeronautics Commission - responsible for statewide aviation planning and development

Community Noise. - The success of any intraurban air transportation system depends entirely on public acceptance in allowing aircraft into densely populated areas. It is patently evident from the current outcry against noise that the intraurban transport will have to be inoffensive noisewise, particularly to residential districts. This factor dominated the definition of the community noise design criteria shown in the aircraft design section.

Social Trends. - While the central business districts throughout the country have declined in recent years, Detroit has recognized this trend and has taken many steps to reverse it. Recent improvements include the following:

- A comprehensive freeway network converging upon the downtown area, thus improving accessibility
- Extensive urban renewal
- Model City Program
- Expansion of port facilities

The new effect of these improvements will be to greatly improve downtown Detroit's competitive position with respect to surburban centers. Thereby, reducing the outward flow of the population (particularly medium-to-high income) and industry to the suburbs, now being experienced, and will also increase the daily flow of commuters into and out of the central business district.

Industry/Trade. - Because of its central location within the emerging Great Lake's megalopoleis in the U. S. and Canada, the Detroit region has a large market potential for consumer goods and for semiprocessed materials, parts and finished products. It also has the characteristics of a gateway for U. S. -Canadian trade as well as for domestic transportation following the east-west route through Canada.

Detroit's location, on the Great Lakes and at the intersection of the east-west transportation axis and the two axes heading south through the Mississippi and Ohio valleys, may make the region become the gateway for international trade for the entire north central region of the U. S.

Manufacturing is concentrated in the production of durable goods; primarily, automobiles and allied products.

Detroit's industrial and market potential have a significant impact on the viability of an intraurban air transportation system, which would require a firm enonomic base to support its operations.

Income Distribution. - The distribution of families by income group is shown in Figure 2. The relatively low percentage of families in the low income categories in Detroit (as compared with U. S. averages) should be noted. This makes Detroit a more favorable location than many other metropolitan areas for a mass intraurban air transportation system.

Demand Analysis

The potential demand was forecast for two time periods, 1975 Initial Operating Capability (IOC) and 1985 IOC, per contract requirement.

In order that the study results have the broadest possible application, Lockheed elected to conduct parametric analyses of projected demand. To bound the analyses and provide a rational approach to demand projection, the potential market was defined to consist of those commuters whose average one-way trip distance is equal to or greater than 20 miles (32.2 kilometers) and whose annual income is at least $5000.

The TALUS district-to-district auto drive trip frequency data provided by the Southeast Michigan Council of Governments (SEMCOG) was employed as a basis for the demand analysis. These data present the number of daily auto driver trips (for driver's whose salaries exceed $5000 per year) between all possible permutations of district-pairs by trip purpose for the approximately 400 districts into which the TALUS region has been divided.

The TALUS population and economic distribution data was also used to identify nine major population industrial centers. These centers have an average separation of 22 miles (35.4 km). Commuterports were located within each center (see Figure 1). Each center represents a major terminus or destination for commuter travel and serves the densest travel corridors of the seven-county area.

From previous studies it was estimated that auto drive trips account for 55 percent of the total commuter trips. TALUS district-to-district auto drive trip data then provided a basis for determining the total number of commuter trips between each permutation of zone-pairs for the nine commuterport service zones by applying a factor of 1/0.55. Hence, coverting the number of auto driver trips to the number of commuter trips between the commuterport area.

Additionally, it was necessary to determine the radius around each commuterport within which commuters would be attracted to the airborne intraurban system. During Phase I, this value was estimated to be five statute miles. However, additional analysis later indicated this value could well extend to 10 miles (16 kilometers) with normal customer appeal growth and this latter value was the basis for the upper limit demand forecast examined in Phase II.

A capture range of 10 to 30 percent of the total commuter market established as outlined above was then examined parametrically.

The distribution of trip frequencies as a function of time-of-day was established by dividing the day into eight three-hour periods and employing the TALUS time distribution data to determine the percentage of trips in each period. The resulting distribution is shown below.

Time Period (hr)	Percent of Trips
0 - 0300	0
0300 - 0600	0
0600 - 0900	25
0900 - 1200	15
1200 - 1500	15
1500 - 1800	25
1800 - 2100	10
2100 - 2400	10

The results of this analysis are summarized as follows:

	1975	1985
Total population	5.25 million	6.35 million
Commuterport Inter-Zonal Auto Driver Trips per day	69,300	86,350
Commuterport Inter-Zonal Commuter Trips per day	126,000 (1.82 x 69,300)	157,000 (1.82 x 86,350)
Capture Demand Range-Trips per day (10% to 30% capture rate)	12,600 - 37,800	15,700 - 47,000

Route Structure

The regional topography and population distribution were utilized to define design operational radii and performance envelopes for the vehicle. The population distribution dictated the location of commuterports and influenced the selection routes and noise limits. The industry and income distribution influenced the estimates of demand and economic cushion for such a system.

The routes for an intraurban air transportation system are shown in Figure 1. They were selected to minimize noise impact on medium-to-high density residential communities. Where possible routes are over waterways, existing high-ambient-noise-level transportation rights-of-way and industrial parks, or, agricultural or undeveloped land. Noise is considered the major factor in community acceptance of air systems, and as a result, is a major factor controlling the design and operations of the air vehicle.

System Integration

Freeways and Proposed Rapid Transit. - Figures 3 and 4 present the proposed freeway and rapid transit systems, respectively, for the Detroit region. As can be seen from these figures, the area coverage by the airborne transportation system would serve as an excellent interim system until the ground systems are completed, and then could serve as a supplemental system carrying passengers requiring high-speed transportation not available from groundborne systems. The air system would also relieve congestion on the major routes and would provide service to those areas without adequate ground system coverage, (for example, between Pontiac and Mount Clemens).

Airports. - Current airport locations within the TALUS area are shown in Figure 5 in relation to proposed commuterports. Inspection of this figure suggests that some existing facilities might also be utilized for commuterports. However, this possibility was not considered in the economic analysis. Also, the large number of airports spread generally over the area could serve as emergency landing fields for an intraurban fleet, thus improving safety.

Analyses show that the two primary travel corridors in Detroit are the Woodward and Michigan corridors (Figure 4). It will be along these corridors that the first rapid transit lines will be located and service initiated. An intraurban air transportation system would be ideally suited to serve as an interim transportation system along these two corridors until the rapid transit becomes operational. The Michigan and Woodward corridors would also provide the demand to support the initial V/STOL system.

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

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

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

Along with the growth or expansion of the intraurban service, development of interurban service between Detroit, Toledo, Cleveland, Chicago, and Buffalo (Figure 6) could be initiated since the vehicle range will permit this. Such operations could, perhaps, utilize a part of the intraurban fleet in the low demand part of the day. Current commercial airline service has demonstrated the economic feasibility of this intercity service.

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

Because of its relatively low installation costs (especially compared with fixed-track systems) the air transportation system serves as an adequate interim system along established routes until resources become available to warrant construction of rapid transit rights-of-way.

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

AIRCRAFT DESIGN

Preliminary design type studies were carried out during Phase I to provide weight, performance, cost, and descriptive information necessary for selection of the single most appropriate VTOL and STOL concept for further study in Phase II (as required by the contract). In general, parametric type design data was developed in both studies so as to be applicable to Lockheed's "Advanced System Synthesis and Evaluation" technique which was employed in the concept evaluation during both Phase I and Phase II.

It is noted, there was no attempt to create new conceptual approaches to vehicle design problems; to the contrary, only concepts with a flight test or heavy analytical backgrounds were considered in order to provide added reality to the study.

Design Requirements and Guidelines

Aircraft design guidelines considered appropriate for the intraurban transport were developed following a review of NASA, FAA, and airline literature. To provide a consistent aircraft design basis, they are described below.

Community Noise. - The following upper limits on community noise are considered necessary for the public acceptance of an intraurban aircraft transportation system.

	Limit PNdB	
	1975	1985
Residential - suburban	85	78
Residential - metropolitan	80	73
Surburan park land and research centers	95	88
Metropolitan - high-ambient noise, industrial	95	88
V/STOL commuterport parking, administration service buildings	100	93
V/STOL commuterport load/unload area	110	103

Ride qualities. - Factors involved in the study of ride qualities include passenger normal and lateral acceleration and attitude excursions. Gust relieving devices should, therefore, be included in the configuration development.

Interior noise. - A weighted sound pressure level of approximately 85 dBA ("A" weighted noise scale) will be necessary to gain carrier and passenger acceptance of the cabin noise during cruise.

Payload. - The number of passengers was a primary study variable within the following ranges:

	Passengers
Compound helicopter VTOL	40-80
Autogyro STOL	40-100
Deflected-slipstream STOL	40-120

Airport performance. - Field length requirements was a primary study variable within the following ranges:

	Field Length (ft)
Compound helicopter	VTOL
Autogyro STOL	500-1500 (152-458m)
Deflected-slipstream STOL	1500-2500 (458-762m)

Design cruise speed. - The following design values were employed. However, it is noted that cruise speed is not a critical requirement in this scenario.

Rotory Wing	200 ktas @ 2000 ft (372 km/hr @ 610m)
Deflected-Slipstream STOL	250 ktas @ 2000 ft (464km/hr @ 610m)

Design endurance (fuel required basis). - Eight 22-mile (35.4 km) flights (stages) between refuelings with engines operating continuously with the fuel allowance pattern shown in Figure 7. This value is not necessarily optimum but is considered a representative value for this type of operation.

Communication, navigation, air traffic control. - Adequate for FAR Category 3b operation for 1975 IOC and Category 3c for 1985 IOC.

Performance, handling qualities, and structural design basis. - 1975, 1985 compound helicopter VTOL: Per applicable References 8 and 9.

- 1985 Autogyro STOL: Per applicable sections of References 8 and 9
- 1975 and 1985 Deflected Slipstream STOL: Per applicable sections of References 8 through 10
- Rotor controls and drive system to be designed for infinite lift and "fail-safe" capability between periodic inspections of approximately 300 hours
- Single runway operation in 30 kt (56 km/hr) 90-degree crosswind
- Handling qualities of STOL configurations in general accordance with the criteria of Reference 11

Flight station visibility. - Flight station visibility to conform to requirements of SAE AS 580A, "Pilot Visibility from the Flight Deck-Design Objectives for Commercial Transport Aircraft."

Airframe design. - Airframe design factors were as follows:

- Passenger accommodations - Fuselage interior arrangement per Figure 8 for all configurations at 60-passenger payload. With interior dimensions vs capacity per Figure 9. The load/unload pattern is shown in Figure 10
- Crew accommodations - Two-man crew; pilot and copilot with jump seat between and one other seat on flight deck for inspectors, etc
- Cargo alternate - Provide capability for all-cargo alternate via quick removal of passenger interior
- Fixed landing gear
- Ram-air pressurization
- No on-board auxiliary power
- Propulsion arrangement to include means for decoupling and stopping propellers and rotors to permit quick off-load/on-load without stopping engines
- Built-in loading stairs

- Passenger axial acceleration limits for performance analysis -

  Takeoff acceleration - 0.5g

  Takeoff, landing deceleration - 0.35g
- All fuel in wing outboard of fuselage, half-breadth
- Quick-release passenger seat and shoulder constraints

Technology Spectrum. - The technology spectrum was reviewed as a part of the effort to establish the weight and performance estimates for each vehicle concept in each time period (1975 and 1985 IOC). This led to the following comparative state-of-technology that was employed in the 1985 (vs 1975) aircraft design studies.

- No "breakthrough" type aerodynamics
- Structural weights reduced by 20 percent
- Propulsion specific weights reduced by 20 percent
- Propulsion specific fuel consumption reduced by 5 percent
- A quiet, hot-gas, pneumatic rotor-tip-nozzle drive system, and convertible turbofan can be developed for the 1985 compound helicopter VTOL

Maintainability and reliability. - No limitations were employed, since treatment of this element of the total design problem is beyond the scope of the present study. This element does, however, have a large effect on total costs as indicated in the "Economic Analysis," section.

Configuration Description

Phase I Configurations. - The vehicles considered in the Phase I concept selection are listed below.

Configuration	Power	IOC
Compound Helicopter VTOL	Turbofan	1975 & 1985
Tilt-Wing VTOL	Turbofan	1975 & 1985
Deflected-Slipstream STOL	Turboprop	1975 & 1985

Configuration	Power	IOC
Augmentor-Wing STOL	Turbofan	1985
Autogyro STOL	Turbofan	1985
Conventional CTOL	Turboprop	1975
Conventional CTOL	Turbofan	1985

The compound helicopter for both time periods was a high-wing arrangement employing three cross-shafted high-bypass ratio turbofans to power the rotors and to supply forward thrust. A four-blade main rotor was employed having 10.2 and 12.7 lb/ft^2 (50 and 56.8 kg/m^2) disk loading for the 1975 and 1985 IOC time periods, respectively. Rotor drive for 1975 was by a geared system from the engines, and for 1985 it was pneumatic-tip-nozzle drive using special "extra-stage" high-bypass ratio turbofans. A small wing of approximately 100 lb/ft^2 (488 kg/m^2) was used to provide fuel storage and cruise lift. The 1975 and 1985 tilt-wing concept was similar to the Fairchild-Hiller VTOL XC-142. It employed large propellers with a low tip speed for noise relief. Static thrust/weight was approximately 1.3.

The 1975 and 1985 deflected-slipstream STOL concept employed four engines and a high-lift system similar to the French Breguet 941 with a low-wing loading to achieve short takeoff and landing field lengths.

The 1985 augmentor-wing STOL concept employed a low-wing loading with four "special" turbofan engines to supply flow for wing lift augmentation to provide short takeoff and landing field lengths. Cruise thrust was also supplied by the turbofans.

The 1985 autogyro STOL employed a variable-speed, 4-blade rotor and four high-bypass ratio turbofans. Rotor spinup was by a pneumatic-tip-nozzle drive system. A small wing of approximately 100 lb/ft^2 (488 kg/m^2) was used to provide fuel storage and cruise lift.

The conventional takeoff and landing CTOL concepts utilized low wing loadings with high thrust loadings to achieve STOL performance. The 1975 concept utilized four low disk loading turboprop engines and the 1985 concept used four high-bypass ratio turbofans.

The Phase I evaluation showed that the following configuration concepts could best fulfill the intraurban transportation system vehicle requirements:

- Compound helicopter VTOL (1975 and 1985)
- Deflected-slipstream STOL (1975 and 1985)
- Autogyro STOL (1985)

Primary factors employed in the evaluation included trip fare, community noise exposure, ride qualities, passenger appeal and technical risk.

The selected concepts were exposed to more detailed design and analysis in Phase II. The resulting configurations are described below.

The interior arrangement of Figure 8 was retained, except that the rotary-wing configurations required a minor seating rearrangement necessitated by the main rotor shaft passing through the passenger cabin.

1975 Compound Helicopter VTOL. - The general arrangement is illustrated in Figure 11 and the rotor-drive system is shown in Figure 12. Primary features of this concept are as follows:

General

- Current technology
- Low technical risk
- Low-wing, under-floor gearbox arrangement for crash landing safety. Rotor shaft passes through passenger cabin to underfloor thrust bearing
- Five-blade rotor with 12.5 psf (61 Kg/m^2), 625 ft/sec (191 m/sec) tip speed
- 75 - 90 psf (366 - 440kg/m^2) wing loading
- 5 lb/SHP (2.3 Kg/SHP) power loading
- Anti-torque and directional control via fan-in-fin
- Pitch and roll control by rotor cyclic pitch
- Lift division in cruise - Wing 90 percent
  - Rotor 10 percent

Propulsion

- Power by four 7.5 bypass ratio convertible turbofans to provide rotor power (lift) and thrust for forward flight
- Power division through constant-speed variable-pitch fan
- Rotor drive through free wheeling clutch to shafting routed through wing to main gearbox
- Fan-in-fin power via shafting from main rotor gearbox

1985 Compound Helicopter VTOL. - The general arrangement is illustrated in Figure 13 and the propulsion system in Figure 14. This version is essentially the same as the 1975 configuration except for those changes associated with an advanced technology propulsion system and the general reduction is size associated with the application of 1985 IOC technology. Primary features of this concept are as follows:

General

- 1985 IOC technology
- Forecast as low technical risk for 1985 IOC
- Low-wing arrangement for crash landing safety. Rotor shaft passes through passenger cabin to underfloor thrust bearing
- Three blade 12.5 psf (61.4 Kg/M^2), 625 ft/sec (191 m/sec) rotor tip speed
- 75 to 90 psf (366-440 Kg/m^2) blade loading
- 100 psf (488 Kg/m^2) blade loading
- Torqueless-tip-nozzle rotor drive
- Directional control by air turbine motor driven fan-in-fin
- Pitch and roll control by main rotor cyclic pitch
- Lift division in cruise - Wing 90 percent
  - Rotor 10 percent

Propulsion

- Four dual-purpose gas generators provide gas power to drive rotor via rotor-tip-nozzles and/or shaft power to drive high-bypass ratio thrust fans. Currently advanced technology but forecast as low technical risk for 1985 IOC. Power division through diverter valve system (alternate concept provides rotor power through use of high-pressure inner-fan stage)
- Gas collected by insulated wing ducting system and passed through insulated rotor shaft to rotor blade ducts. Three-blade rotor to provide enlarged rotor duct cross sections
- Rotor slowed to 40 percent RPM in cruise flight

1985 Autogyro STOL. - The 1985 autogyro STOL concept is carried as a second STOL concept since in the optimum arrangement its field length was determined from the Phase I analysis to be near 1000 feet (305 meters) which places it about midway between the 500-600 foot (152-183 meters) in-ground-effect takeoff of the helicopter and the 1500-2500 foot fixed-wing STOL field length requirements. Also, the autogyro propulsion system is much simpler than that of the helicopter; i.e., it requires only a lightweight, simple engine-to-rotor power transmission system since the rotor is powered only during the 30 to 45 second pretakeoff rotor spinup period.

The general arrangement of the 1985 autogyro STOL is essentially the same as that of the 1985 compound helicopter VTOL (Figure 13). The engine-to-rotor power transmission system is shown in Figure 15.

Primary features of this concept are:

General

- Current technology - new application
- Low technical risk
- Low-wing arrangement with main rotor shaft passing through passenger cabin to underfloor thrust bearing and rotor spinup drive system.

- Five-blade, 7.8 psf (38 Kg/m^2), 625 ft/sec (190 m/sec) rotor tip speed
- 75 to 90 psf (370-440 Kg/m^2) blade loading
- 100 psf (488 Kg/m^2) wing loading
- Directional control by fan-in-fin
- Pitch and roll control by rotor cyclic pitch
- Rotor 100 percent windmilling following takeoff
- Lift division in cruise - Wing 90 percent
  - Rotor 10 percent

Propulsion

- Four high-bypass ratio turbofans with high-bleed capacity to provide rotor spinup pneumatic power
- Rotor spinup via four underfloor mounted air turbine motors supplied by engine compressor bleed through ducting system
- Fan-in-fin power by air turbine motor

1975, 1985 deflected-slipstream STOL. - The general arrangement is illustrated by Figure 16. The concept is similar to the French Breguet 941. This aircraft has been tested extensively by both NASA and the airlines and is regarded as a feasible approach for a commercial STOL aircraft. The design emphasis is on providing an effective means of vectoring the propeller slipstream during low-speed flight thereby augmenting the wing circulation lift to provide low takeoff and landing speeds for short takeoff and landing field lengths. Features of this concept include:

- Current technology
- Powered lift during takeoffs and landing through thrust vectoring with a full span multi-slotted flap system
- Sophisticated control system
- Sixty lb/ft^2 (26.7 Kg/m^2) wing loading (selected as a compromise between field length performance and ride qualities

- Four low disk loading propellers 45 psf (220 Kg/m^2) powered by four cross-shafted turboprop engines. Hamilton Standard 8-blade variable camber-type propellers with 625 ft/sec (191 m/sec) tip speed
- Conventional empennage

The 1975 and 1985 IOC concepts are the same with the latter being of reduced weight through application of advanced materials.

Weight Analysis. - The Phase II weight analysis included a re-examination of the weight bases employed in Phase I. In general, the Phase I methodology was considered satisfactory and was applied directly to the more throughly defined Phase II vehicles.

Technology factors were applied to 1975 weight estimates at approximately the same level in both fixed and rotary wing concepts to derive 1985 weights, with one exception; this was in the area of the compound helicopter power transmission from the engines to the main rotor and to the fan-in-fin rotor. The 1975 rotor mechanical drive system was replaced with a pneumatic drive system for 1985 resulting in a large weight reduction which is expected from this development.

Cursory analysis showed but a small weight penalty in all configurations due to application of the 625 ft/sec (191 m/sec.) rotor and propeller tip speed noise constraints. Therefore, tip speed effects were not investigated further.

Comparative weight breakdowns for each configuration with a 60-passenger payload are presented in Figures 17 and 18. The resulting variation of gross weight with payload, field length and technology is shown in Figure 19 to complete the weight comparisons.

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

- Gross weights for the deflected-slipstream STOL concept are the same for both 2000 (609 m) - 2500 foot - (762 m) FAR field lengths. This is because the engine size on the 2500-foot (762 m) version was established by the 250-knot (462 km/hr) cruise requirement rather than field length
- An 8-percent penalty in gross weight for the deflected-slipstream STOL types results from reducing the field length from 2000-2500 feet (609-762 m) to 1500 feet (457 m); caused by the required increase in engine size
- Application of 1985 technology to the deflected-slipstream STOL types reduces the gross weight by about 15 percent

- Application of 1985 technology to the compound helicopter VTOL can provide a gross weight reduction of as much as 35 percent, with approximately half of this reduction coming from the pneumatic rotor-tip-nozzle drive concept. All rotary-wing configurations then become competitive weightwise with the fixed-wing types, and all have shorter field lengths

The 1985 compound helicopter VTOL and the 1985 1,000-foot (305 m) autogyro STOL are estimated to have nearly the same gross weight (the latter has less complexity, however).

Characteristics Summary

Performance. - The performance bases and estimates presented below have been developed in consideration of the existing and proposed Federal Air Regulations noted under "Design Requirements and Guidelines." However, the analysis has necessarily been simplified to meet the time and budget constraints of the study.

Rotary wing configurations: The lift and drag bases employed in the performance analysis are largely existing state-of-the-art aerodynamics, and the propulsion system fuel consumption characteristics are based on engine manufacturers analyses of appropriate study engines. Comparative values of aerodynamic efficiency (L/D) along with the critical engine sizing factor are shown by the following table.

Configuration	Equivalent $(L/D)_{max}$	Thrust Req'd/Thrust Avail. at 200 kn @ 2000-ft cruise (372 km/hr @ 610 m)
1975 Compound Hel VTOL	4.0	1.00
1985 Compound Hel VTOL	4.0	1.00
1985 Autogyro STOL	4.6	0.75

Thus, the helicopter propulsion system is sized by the cruise speed requirement, while the autogyro propulsion system is sized by the one engine inoperative takeoff requirement.

The fuel required to meet the design mission varies from 12 to 19 percent of the takeoff gross weight with the highest value associated with the 1985 compound helicopter

VTOL. This is due to its rotor-tip-nozzle drive system which, though light and simple, is relatively inefficient. Stage time and fuel-required information is shown below in comparison with the deflected-slipstream STOL configuration.

The all-engine takeoff climb gradient capability of the compound helicopter is approximately 20 degrees at 70-80 knots (130-148 km). Corresponding values for the 1985 autogyro STOL are approximately 15 degrees at 70-80 knots (130-148km). Associated takeoff flight profiles are shown in Figure 20.

Normal landing approach on the compound helicopter and autogyros will be conducted near the minimum power speed of 80-90 knots (148-167 km) at low power to achieve approach angles as high as 20 degrees. The engine power is not normally increased until immediately prior to touchdown since the kinetic energy of forward flight is used to partially power the rotor in the landing flare.

Deflected-slipstream STOL configuration: The basis for the deflected-slipstream STOL configuration performance estimate is as follows:

- Clean aircraft drag - The cruise configuration drag basis was developed by making appropriate corrections to the Lockheed Electra commercial 100,000 pounds (45,400 kg) turboprop transport. The resulting drag polar is defined as follows:

  $C_D = 0.0234 + 0.0612\ C_L^2$ - which provides an $(L/D)_{max}$ of 13.2 at 170 kt (315 km/hr), and $(L/D)_{cruise} = 10.0$ for 250 kt (464 km/hr) cruise at 2000 ft (609 m)

- Installed engine power and fuel consumption characteristics per classified Pratt and Whitney study turboprop engine. Propeller thrust per Hamilton Standard Report PDB 6408 "Generalized Method for Variable Camber Propeller Performance Estimation"

- Power-on STOL type takeoff and landing lift and drag characteristics estimated from analysis of appropriate power-on wind tunnel test results and flight test results of similar configurations

- Directional control power adequate to balance any FAR required single element propulsion system failure during takeoff

Thrust requirements were established to give 1500, 2000 and 2500 feet (458, 610 and 762 m) field lengths; or the required 250-knot (464 km/hr) at 2000 feet (610 m) cruise speed, whichever was critical. Takeoff thrust requirements were based on Lockheed's judgment of the takeoff requirements of the final FAR STOL regulations and the aerodynamic capability of this concept. The resulting requirements, employing both 1975 and 1985 technologies, are as estimated below.

STOL Field Length, Ft /m	Required Static Thrust/Weight		Critical Factor
Ft./m	1975 Tech	1985 Tech	
1500/458	.52	.50	Takeoff Field Length
2000/610	.37	.36	Takeoff Field Length
2500/762	.37	.36	250 kt (464 km/hr) Cruise Speed

The comparatively large static T/W required to meet the 250-knot (464 km/hr) cruise speed requirement comes from the fact that low disk loading, high static recovery propellers are employed to provide the required takeoff thrust with low engine power. This arrangement also offers low cruise specific fuel consumption. The resulting power limits the speed accordingly. The 1975 compound helicopter, as noted, suffers likewise. This implies that power requirements for aircraft to fulfill this mission involving very low altitude cruise should probably include a margin for maneuver, etc., without loss of speed or altitude.

The fuel requirements in terms of fuel weight to gross weight ratio (W_f/W_g) are dependent on design field length (installed power).

Values requires to meet the design mission are shown below.

STOL Field Length, Ft	Required Fuel Fraction W_f/W_g	
Ft /m	1975 Tech	1985 Tech
1500/458	.0570	.0535
2000/610	.0521	.0494
2500/762	.0518	.0494

The all engine takeoff climb gradient capability for each design field length is approximately as follows:

Design Field Length Ft (m)	All Engine Takeoff Climb Gradient Deg (approx)
1500 (458)	11.0
2000 (610)	8.0
2500 (762)	4.5

The 1500-foot (458 m) takeoff profile is shown in Figure 20. The all engine climb gradient may be increased to 15 degrees by increasing the T/W to approximately 0.80. Further increases, however, would require a new directional control concept.

The stage time-distance performance for each vehicle concept is show in Figure 21. Checks of the effect of increasing the cruise altitude to 4000 feet (1219 m) showed but a slight increase in time with slight reduction in fuel required and would offer improved ride comfort in adverse weather.

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

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

The deflected-slipstream STOL employs the same powered lift principle as the French Brequet 941. This aircraft has been flown extensively by U. S. airlines and NASA flight crews. NASA pilots have judged it to be basically satisfactory for both VFR and IFR operation. However, an all-weather "hard schedule" intraurban operation acceptable to the Federal Aviation Agency may require an augmentation of the low-speed, lateral-directional control power -- especially for 1500-foot (458 m) field length operation.

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

An indication of the powerful adverse effect of low altitude operations on atmospheric turbulence -- and resultant ride comfort -- is shown in Figure 22 (taken from Reference 13). This representation is based on an extensive Air Force and NASA evaluation of atmospheric properties, and represents a statistical interpretation of available information regarding isotropic turbulence. The format utilized, defines the probability density of root-mean-square gust velocity mathematically to obtain a convenient expression for the number of load factor exceedances for any value of aircraft response function at each altitude. Basically, Figure 22 may be considered as depicting the frequency with which any given load factor will be exceeded at each altitude shown. The order of magnitude difference between 25,000 and 5000 feet (7,600 and 1520 meters) is noteworthy. Horizontal gusts are similarly relieved by altitude.

It is apparent that development of realistic design criteria for ride qualities along with practical gust load relief methods are essential for the intraurban transport.

OPERATIONAL FACTORS

Noise Considerations

External noise design goals. - Noise, or unwanted sound, is a major design problem for the intraurban transport development. The objective is to keep the aircraft sounds so low that they will be considered noises by no more than a small percentage of the population, say 10 percent. The design of the aircraft therefore, must be related to commuterport area planning. A joint design and planning study was therefore conducted to arrive at a compromise between the economics of quiet aircraft and the economics of land utilization. The first step was to select an aircraft sound characteristic with a numerical value that can be translated into both fundamental aircraft design and land use planning languages.

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

Different sounds, judged by different ratings, can be compared with the aid of Figure 23. The ordinate, PNL, applies to aircraft sounds, and the abscissa applies to either dBA or SIL equivalences of the PNLs. The noise levels of current community offenders are shown on this scale. The straightline from lower left to upper right in the figure is generally accepted for discussion purposes as an equivalence relationship. For example, municipal traffic noise laws or regulations, where they exist, usually specify that vehicle sounds must not exceed 85 dBA at a roadside measurement point. An aircraft sound with a PNL of 98 PNdB is equivalent to a traffic sound at 85 dBA.

An objective of the acoustic segment of the study was to provide a basis for establishing relationships between acoustics, aircraft performance, and systems tradeoffs for the aircraft concepts considered. The acoustic design criteria, therefore, were selected with cognizance of the currently discussed 95 PNdB/500-foot (152 meters) limit (Reference 14), but were not necessarily governed by it. Instead, the allowable noise from the intraurban aircraft transportation system was established as a function of the community segment affected, with the limiting values as shown in the "Aircraft Design" section. Corresponding 500-foot (152 m) values are approximately as follows:

1975 IOC	102 PNdB
1985 IOC	95 PNdB

These community noise limits were established as a compromise considering a wide range of factors with special emphasis on the noise imposed by the system on residential areas in the vicinity of the commuterport.

Residents will be unlikely to complain about aircraft sounds that do not disrupt such normal activities as neighborhood socializing at backyard picnics. An extraneous sound at 75 dBA, with an SIL of 65, would cause individuals conversing at normal voice levels to instinctively raise their voices to moderately higher levels and is therefore marginal in this context. A general understanding of these factors and the intrusive character of aircraft sounds in an outdoor environment was used as a basis for selecting a 1975 IOC design goal limit of 85 PNdB shown in the "Aircraft Design" section for intraurban aircraft sounds perceived in a surburban residential area. As indicated in Figure 23, a PNL of 85 PNdB is no more intrusive than the sounds of most automobiles in a 30 mph (48 km/hr) speed zone.

For aircraft design purposes, it is necessary to translate the 85 PNdB residential design requirement into a unique frequency spectrum representative of the intraurban transport to permit evaluating the noise produced by the candidate propulsion systems.

An 85 PNdB intraurban transport, one-third octave band design goal spectrum, considered appropriate to both rotary and fixed wing types, was developed for use in assessing the total noise characteristics of each concept (Spectrum 4 of Figure 24). It is based largely on analysis of flyover noise measurements of representative rotary and fixed wing aircraft and includes consideration of noise sources capable of acoustic treatment such as compressor and fan noise, as well as largely untreatable sources such as rotors, propellers and turbine exhaust sounds. Atmospheric attenuation and background noise were also considered. This spectrum was employed in estimating the noise characteristics of the aircraft.

Community Land Planning. - The 2000-foot (610 meters) aircraft to listener distance associated with the 85 PNL residential noise limit (Figure 24) was chosen as the commuterport land allocation sideline boundary following a consideration of Detroit land costs (comparatively low) and associated commuterport costs, as opposed to the cost and risk of providing aircraft having lower noise levels.

It was initially assumed that the intraurban transport vehicles would be capable of about a 15-degree all-engine climbout gradient from a 2000-foot (610 meters) field length commuterport. Assuming 85 PNL at 2000 feet (610 meters), combined with 15-degree climb performance, and impressing the PNL contours on a suburban area produces the recommended land allocation shown in Figure 25.

Residential districts would be restricted to areas outside the 85 PNL boundary. The area within the 95 PNdB contour is considered satisfactory for the area immediately adjacent to the commuterport and is approximately 330 acres. Possible uses for the allocated land not required for the commuterport are also shown in Figure 25. They are based on the logic that higher noise levels are permissible in these areas.

The suggested land allocations were made without specifying the flight frequency to and from the heliport. However, in final analysis, acceptable allocations will be a function of this factor -- which is included in the Noise Exposure Forecast (NEF) scale, and the FAR Effective Perceived Noise Level (EPNL) scale. For the NEF basis doubling or halving the frequency of operation increases or decreases the NEF by 5 PNL and will therefore change land allocation requirements. Also, local land use and the associated background noise will also effect these requirements. The land allocations shown in Figure 25 should be considered accordingly.

All engine takeoff flight profiles are shown for each concept in Figure 20. The rotary-wing concepts are both shown to have profiles greater than the 15-degree "330-acre" profile while the deflected slipstream STOL shows lower gradients.

Estimated Exterior Noise Levels. - The following summarizes the estimate of the ability of the various configurations to meet the proposed commuterport noise requirements specified in the "Aircraft Design" section with the land allocations of Figure 25.

- The 20- to 60-passenger 1975 compound helicopter VTOLs could meet the requirements with little compromise. However, at the current state-of-the-art, payloads beyond 60 passengers will require some weight or performance penalties
- Assuming a continued public insistence on less noise - with the corresponding necessity for a strong noise research program - it is judged that the acoustic and airframe design art will evolve sufficiently during the coming 10 years to permit development of the suggested 1985 rotor-tip-nozzle drive compound helicopter to 80-passenger size without significant weight or performance penalties
- The 1985 autogyro STOL concept should have no problem in meeting the requirements up to 80-passenger size
- The 1975 and 1985 deflected-slipstream STOL concepts should meet the requirements at all sizes with little compromise.

Interior Noise. - Means are believed available to provide interior noise levels within the proposed 85 dB(A) on all of the intraurban transport concepts if the problem is treated as an integral part of the design-development effort.

Air Pollution

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. To compare the amount of pollutants emitted by an automobile, an intraurban aircraft and a bus, data are 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.

	Emissions, grams/pass mile		
	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 automobile is an average warm automobile travelling at 30 mph (48 kph). 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-weekday between 7 am and 7 pm. 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 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 an improvement will probably not 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.

Communication, Navigation, and Air Traffic Control

The conceptual development of the communication, navigation, and traffic control network envisioned for intraurban transport operation during the 1975 time frame, utilized current state-of-the-art technology including application of systems currently being used in the L-1011, 747, and DC-10 type aircraft.

Major emphasis must be placed on the problem created by the high traffic densities. For safety of flight considerations, the airspace throughout the intraurban transport routes must be tightly controlled and reserved primarily for intraurban aircraft operations.

In 1975 it is expected that control of the intraurban transport during arrival and departure will be under the direct responsibility of each commuterport control tower. Enroute air traffic control for the overall intraurban route structure will be built upon central contact of all aircraft within the closed system. A central digital data processing computer complex will handle the major share of the flight planning for the total system with central air traffic controllers monitoring the overall operation. Precision navigation equipment on board each aircraft would provide the basic control and guidance of the individual aircraft and generate the necessary monitoring annunciation to the pilot to aid him in maintaining the aircraft in its "slot."

The following paragraphs further define these navigation and control concepts and how they might be integrated into the intraurban doctrine.

Operations. - The philosophical approach is that all operations must be carried out with a high degree of automation in both airborne and ground operations to insure precision and to minimize personnel requirements.

The maximum permissable frequency of operation from a single runway (takeoff plus landing) will be limited by safety criteria. However, previous studies have indicated that greater than 100 operations-per-hour can be safe with adequate guidance and control. This compares favorably with a peak rate of 36 determined for the minimum cost system.

With regard to Weather Minimum Categories current projections indicate that an automatic all weather landing capability through Category III (b) will be available by 1975. By 1985, this will almost certainly have extended through to Category III (c); Zero-Zero weather conditions.

With a Category III (b) capability in the 1975 period, the corresponding 150-foot (46m) runway visability range (RVR) requirement means that the intraurban transport pilot, after touchdown with his auto-land system, will be able to see the first rows of taxi lights which outline the runway boundaries. Taxiing can then be accomplished visually even though at a slow speed. To speed up this taxi process and thus maintain the scheduled turnaround times, the runways and taxiways will need high-intensity centerline lighting systems with appropriate identifying symbols at the taxiway exists and ramp locations.

The ground instrumentation most suitable for control and automatic landing at the 1975 intraurban commuterport would include a microwave scanning beam ILS system as recommended by the current RTCA Special Committee 117. Figure 26 illustrates two concepts that could be applicable to the intraurban transport. These systems provide for fully automatic touchdown, broad coverage in both azimuth and elevation, relative freedom from beam bending (which makes them effective even in heavily populated and built-up areas), and utilization with curved approach and variable glide paths.

For 1975 enroute Airport Surveillance Radar (ASR) information will be made available for hand-off to control tower personnel. The combination of separate curvilinear approach and departure paths and ASR further enhances collision and hazard avoidance capability. Figure 27 illustrates that capability. Wide angular coverage permites acquisition by aircraft well separated in altitude, position, and touchdown time. Obvious advantages in terms of collision and hazard avoidance are apparent in the two views shown. Acquisitiions at time t_1 have the aircraft widely separated in position and altitude. Programmed curvilinear paths result in the separation on final approach shown at time t_2.

For the purpose of maintaining high frequency of flight schedules in arrivals and departures, especially during the peak hours (corresponding to the surface "rush hour" periods), flight separation and altitude standards must be rigorously maintained. This will be the function of a central intraurban Air Traffic Control Center. Here, by use of air-to-ground data link, surveillance radar, secondary radar, and a cooperative collision avoidance system, a ground control digital data processor/computer will track all aircraft in the network and display their tracks on a traffic management display console.

Intruders would be quickly noted and warning and avoidance instructions could be fed to the affected aircraft. Figure 28 depicts a typical arrangement concept for the

1975 time frame. For the 1985 time frame, the data link system would have to be able essentially to "fly" each aircraft automatically, throughout the route structure and institute landing and takeoff procedures via satellite controls at the terminal areas.

Navigation, Collision, Avoidance and Separation Standards. - Airborne navigation equipment includes precision area navigation systems, data link, microwave ILS receiver, weather radar, collision avoidance, and other appropriate systems. The basic area navigation (R-Nav) system concept will utilize received signals from existing as well as supplemental VOR/DME stations, in conjunction with a computer and stable platform to provide position data and separation of parallel tracks.

Use of area navigation allows the most flexible routing for the fleet without constraint upon VOR radial tracking and/or high crew workload. Thus, an instant capability would be available for fast route changes, extended routing, deadhead flights, and weather and hazard avoidance. Routes may be coordinated within the intraurban transport structure as well as for flights outside the local system. Standard VHF/UHF ILS receivers/couplers will be included to allow conventional approaches whenever necessary at alternate airports. Data link exchange with ground terminal sources will allow four-dimensional guidance and monitoring to be maintained consistent with the strategic control plan.

Navigating between takeoff and landing points with the small aircraft separations associated with the busy heliports will require a mechanized on-board collision avoidance system so that other similarly equipped aircraft could never get closer than about 6000 feet (1829 meters) without an avoidance maneuver being commanded (climb or dive). Inadvertent intruders would generally be detected by the en route ground radar surveillance system, by visual observation (VRF situation), and by on-board radar if utilized. High intensity collision lights would be installed on all aircraft in the system. The on-board R-Nav system would present, not only its own aircraft track, but encompass (via its data link/collision avoidance system) those aircraft within a 10 mile (16 kilometers) radius. This would enable the pilot to adjust his spacing in cases where other aircraft might be experiencing difficulty in maintaining airspeed.

Production hardware for 1975 will require essentially current state-of-the-art and integration of the hardware, software, and human operators (ground and airborne) represents the major challenge for the near term development.

Figure 29 presents a block diagram of the aircraft avionic system for the 1975 intraurban aircraft.

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

The areas in which this enhanced and increased automation are most apparent would be in the commuterports. While the basic ILS approach as defined above will be the same, the landing and takeoff scheduled times will be remotely controlled by signals from the Main Air Traffic Control Center with takeoff time rigidly controlled.

The pilot's job will then be that of supervisor of the airborne part of the overall system. Any deviation in flightpaths and schedules would be noted by the ground computer and the pilot would get instructions from the ground control.

The operation will include automatic taxiing to and from the ramp. This could be achieved by tracking to a buried cable for induction-coil servo-guidance control of the nose-wheel steering mechanism.

The equipment needs for both the airborne and ground stations will still be quite similar to the 1975 baseline concepts described previously. Since the 1975 system already possesses the capability of automatically landing the aircraft in a hand-off operation, the major differences will be in the area of remote control of the separate terminal operations. This will also require a large increase in system reliability to avoid temporary havoc upon catastrophic failure of the central traffic control system.

Technology. - The approaches suggested to provide a communication, navigation, air traffic control system for an airborne intraurban transportation system will require no major avionics developments. Most subsystems concepts utilize existing technology while the specialized needs of the interface of computer/hardware systems can be met by current systems design practice.

The systems previously described are based on use of an Automatic Flight Control System (AFCS). General characteristics of the system are discussed below.

Many of the AFCS modes will be identical to those currently used in conventional jet airline equipment. In addition, novel, but state-of-the-art for 1975 are modes such as Autothrottle (ETA control using navigation data), Autoland (automatic capture of microwave ILS and path and letdown guidance).

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

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

To meet the stated requirements, it is necessary that those portions of the AFCS which are used for both automatic landing and automatic cruise operation be quadruplex. The redundancy configuration for 1985 must be compatible with the following: in the automatic landing mode, the system should be fail-operative for the first and second failure.

By 1985, the use of microwave ILS will be expanded to include conventional airline operations, and the need for two present day ILS receivers will no longer exist. One microwave ILS receiver will replace the conventional receivers, but the degree of reliability necessary for operation is still maintained.

Microelectronics will be employed to not only reduce size and weight of the AFCS, but allow the use of whole new avenues of design in terms of redundancy, complex adaptive control, multiplexing, digital control, etc. Additionally, increased system reliability and more effective maintainability tend to lower maintenance costs, simplify logistics, simplify inventory and ultimately improve availability and system effectiveness.

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

Commuterport Design/Operation

The Phase I analysis showed that the commuterport operation contributes a significant portion of the total system cost. The Phase II route-schedule-fleet size analysis showed that the maximum traffic flow at each commuterport could be accomodated with a single loading facility. A conceptual commuterport layout, considering these factors, was therefore developed and is shown in Figure 30. Commuters pass between the aircraft and the terminal via under ground walkways, using stairs to the surface, as shown, with painted walkways leading to and from the aircraft. This concept should permit unload-load operations within the five minutes allowed in the economic, and route and schedule analyses.

The arrangement assumes a single runway located symmetrically about the loading area. Approximately 5 acres are involved in the runway, loading area, terminal and parking facilities. It is equally applicable to both rotary and fixed wing aircraft and is commensurate with the land allocations in Figure 25.

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

Vehicle Alternate Uses

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

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

	Approx Cargo Load (lb/kg)
Minimum change - Remove seats to provide area -- no floor beefup. Suitable for light cargo; i.e., mail, light freight, etc.	15,000 (6800)
Convertible - Remove seats and add floor beefup for heavy cargo with provisions for reinstallation of seats	13,000 (5900)
Production cargo configuration	18,000 (8200)

Door sizes are considered adequate

Performance Limits. - The range payload potential of 60-passenger vehicles is shown by Figure 31. Long-range cruise speeds are approximately 150 knots (280 kph) and 190 knots (350 kph) for the rotary and fixed wing aircraft, respectively. The usable high speed capability of the rotary wing vehicles will be limited to a design value of around 200 knots (370 kph). The corresponding value for the deflected slipstream STOL is 275-300 knots (510-555 kph) as a function of field length (installed T/W).

ECONOMIC ANALYSIS

Approach

The economic analysis for the study of aircraft in intraurban transportation systems includes the determination of Direct Operating Cost (DOC), Indirect Operating Cost (IOC), and Total System Cost (TSC). The TSC model is a combination of the cost elements of the DOC and IOC models. The purpose of the various cost models is to provide cost data for the various tasks set forth for Phase I and II of the study. During Phase I the DOC model was used to provide DOC information for the parametric data development, and the IOC and TSC were used for system synthesis and the evaluation and selection of the vehicles to be carried on into the Phase II analysis. The Phase II cost analysis consisted in the refinement and modification of the cost models, and provision of cost results for the selected vehicles.

The Direct Operating Cost (DOC) model comprises a set of estimating relationships for the determination of cost for the following DOC elements:

- Flight Crew
- Fuel and Oil
- Insurance
- Depreciation (Aircraft)
- Maintenance
- Maintenance Burden

The determination of the cost for each of the above elements is accomplished by submodels that provide the proper information to be placed in the proper category. Figure 32 illustrates the submodels and how they provide the information for the DOC elements.

The Indirect Operating Cost (IOC) model is constructed to build up the indirect costs in accordance with the demands placed upon ground support facilities, equipment, and personnel. The estimating relationships for the IOC elements are based upon the operational characteristics of the system. The elements of IOC are:

- Facilities Depreciation
- System Personnel
- Other Expense
- Facilities Maintenance
- Facilities Maintenance Burden
- Ground Equipment Depreciation

The element of "Other Expense" includes publicity and general and administrative costs.

The Total System Cost (TSC) model mainpulates the cost elements of DOC and IOC to provide total cost for various elements. The elements of TSC are:

- Aircraft Purchase Cost
- Spares Purchase Cost
- Facilities Purchase Cost
- Equipment Purchase Cost
- Operating Cost of Aircraft
- Operating Cost of Facilities

The major difference between this and DOC/IOC is that TSC model shows the purchase of aircraft, equipment, and facilities in total, whereas in the DOC/IOC models these items are converted to an annual cost (through depreciation) and combined with the operating cost of the vehicle. The operating cost of the aircraft and facilities in the TSC model is calculated for the total system life (12 years) in order that is may be combined with the purchase costs. Figure 33 illustrates the interrelationship between the DOC/IOC models and the TSC model.

Cost Analysis Results

The Phase I cost analysis is based on a fixed demand, which was treated parametrically. The demand levels investigated were taken as percentages (10, 20 and 30) of the people earning over $5000 per year who travel between the zones selected for the commuterports. The system was sized to satisfy these demand levels, and the frequency of service was allowed to vary accordingly.

The Phase II analysis is based on a scheduling program, where the criterion is satisfying the frequency of service and not just the demand. The change from using demand as the primary criterion to frequency of service has a significant effect on cost. In satisfying the frequency of service, there are more aircraft, an increase in nonrevenue flights, and a change in aircraft utilization. These differences make it infeasible to compare the absolute costs between Phase I. and Phase II but reasonable to compare the cost trends and to note the minimum cost points.

One comparison that may be made is to note the difference in cost due solely to the cost factor changes that occurred because of the additional analysis. The changes are noted below:

- Increase the land area to runway area ratio from 3 to 15
- Change helicopter runway length from 150 feet (46 meters) to 600 feet (183 meters)
- Reduce number of work shifts from 3 to 2 and increase pay to include 2 hours overtime per day
- Decrease number of system personnel from 14 per gate to 9 per gate
- Change publicity cost from $.50 per passenger per year, to $.25

The costs shown in Column 2 of Figure 34 are the result of these changes for the 60-passenger deflected-shipstream aircraft as operated in the Phase I scenario and passenger demand criterion. The overall result is a slight decrease in the IOC which is reflected in the TSC and the fare.

The Plase II cost factors that result in the costs noted in Column 2 are the basis for the Phase II cost analysis. These costs are on the basis of the refined cost factors and the Phase II scheduling criteria.

The overall results of the Phase II cost analysis are shown in the Total System Evaluation section. This information is in parametric form, and does not show the breakdown of the various cost items. These costs (for each element in the IOC/DOC and TSC) are shown in the DOD/IOC/TSC summary sheets (Figure 35). This table presents the evaluation of each aircraft for one set of data. The data presented here are for the 60-passenger configurations, with the 30-percent demand (factored by 1.57), and using the nine commuterports. This is one set of data from among many that are shown in the Evaluation section and is representative of the aircraft in the area of minimum fare.

Fare Structure Basis

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

- The first method (1) is a calculation of the fare on the basis of total system cost. The fare is determined by dividing total system cost plus a 15-persent profit factor by the number of passengers served during the 12-year life of the aircraft system

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

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

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

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

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

The fares, as calculated by the above methods are shown in Figure 35.

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* PROF - Profit Factor

APASS - Annual Passenger Volume

DA - Depreciation Period of Aircraft

XNAC - Number of Aircraft in Fleet

Subsidies/Grants

There are numerous possibilities for some form of subsidy or grant that would affect fare level. The ones considered here are listed below. The effect on the fare is shown in the Subsidy/Grant Comparison Table (Figure 36).

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

B. A general subsidy of $2.00 per passenger is received.

C. A capital grant is received for two-thirds of the cost that cannot reasonably be financed from revenues (Urban Mass Transportation Act of 1964). The revenue is based on a fare of $1.73. This fare is based on the assumption that the commuter is willing to pay five cents per mile (equivalent to the operating cost of his own car, not including depreciation or insurance.

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

The subsidy/grant analysis is based on the 1975 60-passenger deflected-slipstream aircraft. This amount of subsidy required for the other aircraft would be in proportion to the fares without subsidy or grant aid. The subsidies/grants are applied against fare number (1). In the instance of subsidy "C" and "D," the grant aid would be $23.83 million and $12.6 million per year for two-thirds of the operating cost not covered by revenue. The remainder in each case ($11.94 million and $6.3 million) would have to be subsidized by another agency.

The total system cost without subsidy in each case is what the operator would be responsible for and the remainder would be covered by some form of subsidy or grant to bring the fares to the levels shown. The fares include a profit for the operator of the system.

** TRMSCT - Terminal Cost
XMPROP - Maintenance Cost on Property and Equipment

TOTAL SYSTEM ANALYSIS

General

The fixed-wing concepts were subjected to a parametric analysis to determine the effects of payload anf field length on resulting vehicle gross weight, flyaway, and operational costs. The Lockheed Advanced System Synthesis and Evaluation Technique (ASSET) was employed for this work, as indicated below.

The compound helicopter VTOL and autogyro STOL concepts were defined with respect to a single field length requirement in each case (500 feet (152 meters), for helicopter VTOL, and 1000 feet (305 meters), for autogyro STOL) using optimized configurations. The effect of payload on gross weight, flyaway, and operational costs was then established at three payload levels,and these data were employed in developing performance and costs for comparison with fixed-wing aircraft.

Parametric Data

A 60-passenger aircraft was selected as the initial baseline configuration for each approach concept. These preliminary baseline configurations provided a basis for study by each of the technology analysts: aerodynamics, weights, propulsion, and cost. The analysts were thereby enabled to provide parametric data information on the propulsion systems, performance capabilities, fuel requirements, component weight coefficients, and system cost factors.

Because a bank of design data has been accumulated over the years by Lockheed, NASA, and other agencies, the technologists need only to focus on analyzing the unique demands of each of the given approaches.

Weight Analysis

The fixed-wing aircraft weight analysis made use of the ASSET program 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. Weights are calculated for the structure components, propulsion components, furnishings, equipment systems, and payload items.

The subroutine makes estimates of aircraft weights by using parametrized weight equations having 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 design includes weight provisions for engine cross shafting, clutches, auxiliary gearboxes, tail rotor, additional support structure, and wing tilt mechanisms. The deflected-slipstream aircraft design includes provisions for engine cross shafting, clutches, auxiliary gearboxes, and heavy flaps. The augmentor-wing aircraft design allows for exhaust ducting, valves, heavy flaps, high horizontal tail, and boundary layer control on the tail. The conventional takeoff and landing aircraft design has a low horizontal tail.

Parameters such as wing thickness ratio, taper ratio, and tail volume coefficient are fixed for each basepoint 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 example, 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'input.

The following format is typical for the parametrized weight equation:

$$\begin{aligned}\text{Weight} = \Big[& (\text{Coefficient})\,(V_{\text{Parameter } 1})^{\text{Power } 1}\,(V_{\text{Parameter } 2})^{\text{Power } 2} \\ & (F_{\text{Parameter } 3})^{\text{Power } 3}\,(1 + F_{\text{Parameter } 4})^{\text{Power } 4} \big/ \cos \\ & (F_{\text{Parameter } 5}) + \text{Constant} \Big]\end{aligned}$$

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.

Aircraft Synthesis Methodology

The basic initial design task is to determine an overall aircraft configuration that will meet the performance requirements. This is accomplished by doing parametric studies of each configuration concept. A parametric study implies creating a mathematical model of the system of concern and then varying the principal variables to obtain a spectrum of results. The Advanced System Synthesis and Evaluation Technique (ASSET) program is the basic tool employed in doing the parametric study of these aircraft systems.

The ASSET program is shown schematically in Figure 37. The program consists of six basic subroutines: configuration geometry, performance, weight sizing, research and development cost, production cost, and the direct operating cost model. Basic input data to the program include weight and volume coefficients, performance characteristics, and costing coefficients.

An initial estimate of the takeoff gross weight, wing area, and fuel required is used to initiate the iteration process of the ASSET program.

The fuel consumption and flight times are computed in the performance subroutine based on the particular parametric values of thrust-to-weight ratio and wing loading being computed. These data are then fed to the weight-sizing and DOC model. Based on the assumed takeoff gross weight, each of the weight components is computed. These elements are summed to get the calculated takeoff gross weight, which is compared with the assumed weight, and if they agree, this is a solution. If they do not agree, then a convergence technique is used to select the new guess, and the program iterates until a convergence is found. The weight breakdown from the final iteration is then fed to printout and the costing models. An example of the weight-sizing printout is shown in Figure 38. In addition to showing the detailed weight breakdown of the major component elements, the percentage fraction of major components is shown in the right-hand column.

Optimization Analysis (Fixed-Wing Aircraft)

The CTOL and deflected-slipstream STOL concepts are analyzed in terms of wing loading and thrust loading for the 1975 and 1985 time periods, and the augmentor-wing STOL is analyzed in these terms only for the 1985 time period. The 1975 and 1985 tilt-wing VTOL, with their fixed thrust/weight requirements, are considered only in terms of wing loading.

The aircraft synthesized for the 1985 period utilize the benefits of technology growth specified in the "Aircraft Design" section. Some results of the parametric aircraft syntheses are illustrated in Figures 39 through 43.

These data show the effect of wing loading and thrust-to-weight ratio variation for the basic 60-passenger requirement. The effect on takeoff gross weight, flyaway cost, and DOC are shown with the takeoff and landing field length constraints superimposed on each of these plots. The intersection point of the takeoff and landing field length requirements is the optimum combination of wing loading and thrust-to-weight ratio to achieve the minimum takeoff gross weight for a given field length.

To provide a valid relative performance ranking for the selection of the candidate aircraft, a comprehensive tradeoff analysis is made to ensure that the candidate system design has the best system characteristics.

The tradeoffs conducted on each of the approach concepts study variations in the passenger capacity and field requirements for the CTOL and STOL approaches. For the tilt-wing VTOL, variations in the passenger capacity and wing loading are made. These results are presented in Figures 44 through 50.

Aircraft Concepts Selection

1975 Time Period. - The effect of variations in airport field length for 1975 IOC concepts is shown in terms of takeoff gross weight and Total System Cost (TSC) in Figure 51 for 20-percent demand, 75-percent load factor and 80-percent payload. Increasing the field length for the CTOL and deflected-slipstream STOL concepts reduces the takeoff gross weight but shows little or no change in the TSC.

The minimum TSC for the CTOL concept is shown by Figure 51 to occur at a runway length of 2500 feet (762 meters) and between 1500 to 2000 feet (457 to 609 meters) for the STOL. Using a runway length of 1500 feet (457 meters) for the deflected-slipstream STOL and 2500 feet (762 meters) for the CTOL concept, the effect of aircraft size is investigated as shown in Figure 52. The TSC goes down as the aircraft size is increased to 100 passengers due to the reduction in the total fleet size; but from a fare standpoint, as the aircraft size increases, the fare does not reduce for all vehicle concepts. This is due to the fact that as aircraft size is increased, fewer total passengers are served because of the minimum load factor criterion. The TSC is thus spread over fewer people, and this results in a higher fare per person. This effect is damped by the TSC decreasing with increased aircraft size. The tilt-wing VTOL concept shows a steady decrease in fare with increased aircraft size, whereas the deflected-slipstream STOL shows little or no advantage, from a minimum fare standpoint, in increasing the aircraft size beyond 70 passengers. The CTOL concept also has a minimum fare optimum at 70 passengers.

1985 Time Period. - Figure 53 presents the aircraft concepts in the 1985 technology time period for the effect of field length variation on the takeoff gross weight and TSC for a 20-percent passenger demand, 75-percent minimum load factor, and 80-passenger aircraft size. The deflected-slipstream STOL, augmentor-wing STOL, and CTOL concepts show a weight advantage by increasing the field length beyond 2000 feet (609 meters). From the TSC standpoint, the deflected-slipstream STOL indicates an optimum (minimum TSC) at a field length of 2000 feet (609 meters) and the CTOL concept at 2800 feet (855 meters). The augmentor-wing concept shows a steady improvement in TSC for the interval of field lengths examined; i.e., 1000 to 2500 feet (305 to 762 meters).

The minimum TSC for the autogyro occurs at 1000 feet (328 meters). Increasing the field length beyond this point only increases the TSC. Using these near-optimum field lengths for each of the concepts and the same demand conditions, the effect of aircraft size is examined in Figure 54. For all of the concepts examined, the TSC continues to decrease as aircraft size is increased due to the reduced fleet size requirements. Under these particular market demand conditions, none of the 1985 technology concepts shows an optimum fare as a function of aircraft size. All of the concepts are pushed to the largest aircraft size considered to minimize the fare.

Examining the results of both the 1975 and 1985 technology time periods, it appears that under the market demand conditions used in this investigation, the deflected-slipstream STOL concept will result in the minimum total system cost and fare. This concept is examined in greater detail for the 1975 time period. Figure 55 is a bar diagram showing the makeup of the total system cost for variations in the field length and for 10 to 30 percent variations in demand, holding the aircraft size constant at 100 passengers and the minimum load factor at 75 percent. The overriding conclusion is that runway length is not a sensitive parameter in the Detroit area due to the low cost of land there.

The operating cost of the terminal facility and the aircraft accounts for over 75 percent of the TSC. With increased runway length, the acquisition cost of the aircraft goes down, and the facility and equipment cost goes up. One just about offsets the other.

Picking a runway length of 2500 feet (762 meters) for the 1975 deflected-slipstream STOL and holding the market demand at 20 percent, the effect of aircraft size and minimum load factor is shown in Figure 56. To decrease the number of passengers per aircraft increases the aircraft acquisition cost and the aircraft operating cost due to the expanded fleet size required with smaller aircraft. The DOC starts to dominate the TSC picture when the aircraft size starts to get small. The acquisition cost and operating cost of the facilities are relatively insensitive to these small changes in fleet size.

Sensitivity Analysis

In order that the results of the subject study will have general applicability to other scenarios, Lockheed determined the sensitivities of the candidate aircraft concept systems to variations in five of the market and operational parameters: demand, minimum load factor, number of shifts, subsidy plans, and land values. The basepoint for each concept from which the parameter values were varied was 20-percent demand, 75-percent minimum load factor, three shifts, no subsidy, and the basic land values of the Detroit Metropolitan area. The results of this analysis are presented in Figure 57 which shows the percent change in total system cost and fare for various changes from the base data noted.

Some of the parameters have not been evaluated for the helicopter and the autogyro, but the percent change in these will be consistant with the change noted for the tilt-wing aircraft.

The sensitivities to variations in the market and operational parameters are consistent among the candidate concepts within each of the selected categories (1975 STOL, 1975 VTOL, 1985 STOL, and 1985 VTOL); they present no significant differences upon which to base a selection. This consistency, however, along with the insignificant variations in TSC and fares structure (per scenario), is significant because it suggests that the final selection will be based on such factors as noise, comfort, convenience, and safety.

Another method of illustrating the sensitivity of cost to variations in market and operational parameters is displayed in Figure 58. This bar chart depicts the cost sensitivity of the 1975 deflected-slipstream STOL concept to the changes noted. Since the trends for all aircraft in the fixed-wing class are the same, this example is considered representative for all aircraft except the helicopter, autogyro, and tilt wing. Although not all of the sensitivities have been conducted on the rotary-wing and tilt-wing aircraft, those that have been indicate a consistent pattern as is shown for the fixed wing, and the bar chart is used to back up the discussion of the various parameters.

Aircraft system sensitivities to major design parameters are presented in Figures 59 through 62 as a percentage variation in takeoff gross weight, flyaway cost, and DOC versus the corresponding parameter variation in percentages. These design parameters include thrust-to-weight ratio, wing loading, fuel fraction, airframe structural weight fraction, and engine weight fraction. In addition to the design parameters, the following costing parameters are investigated: number of production aircraft, research and development cost, airframe cost, block time, and maintenance cost. For each of the applicable concepts, both the 1975 and 1985 technology analyses are included in the same figure.

Frequency of Service

The frequency of service provided between any two of the commuterports is a direct function of the number of people commuting between those ports and the size of the aircraft used.

In Phase I of the study, the relationship of fare versus flight schedule is summarized in Figure 63. It is typical for all aircraft investigated; the difference between concepts could be noted by slightly shifting the carpet plot to the right or left.

This plot shows that to obtain a reasonable fare and schedule, there must be a daily passenger volume of approximately 25,000 people. This corresponds to the 30-percent demand level for the 1975 time period. If a $4.00 fare and a 20-minute schedule are desired, then a daily traffic volume of approximately 30,000 people would be required, and the aircraft would be of 80-passenger capacity. If the demand is considered as fixed at a constant volume, then an aircraft size may be chosen to minimize the time between flights and the fare. If the daily traffic volume between the Central Business Distruct (CBD) and Mount Clements (MCLE) is determined to be 20,000 people, a 60-passenger aircraft would be a compromise between fare and schedule. The schedule may be minimized to 10 minutes if daily traffic volume of 25,000 persons is transported in a 40-passenger aircraft. This could be accomplished at a fare of $5.35, but poses the question as to whether this many people would pay the $5.35 fare for this distance. If minimum time between flights is the primary objective but people would not pay the fare to support the system, then the alternative is adding a subsidy to lower the fare to the point where it would be acceptable.

During Phase II of the study, frequency of service became a primary variable and was an integral part of the route and scheduling analysis.

Figure 64 is an example of the frequency of service provided by a 100-passenger, deflected-slipstream, STOL aircraft operating in the 1985 demand time period. The commuter demand for this particular situation varies from 30 passengers, per-hour to 303 passengers-per-hour. Corresponding frequency of service varies from one flight to four flights-per-hour, depending on the number of commuters at each of the commuterports.

The 100-passenger aircraft making four flight-per-hour to carry 303 commuters between CBD and Mount Clemens would have an average land factor of 76 percent. The single flight-per-hour from Monroe to Ann Arbor, which carries 30 passengers, would have a load factor of only 30 percent. The mixing of all of these varying flight frequencies over an 18-hour work day becomes a rather complicated but necessary step of analysis to provide a real-world route and schedule for each of the aircraft and commuterports.

Total System Synthesis

Total system synthesis consists in combining the data developed for each of the candidate aircraft concepts with those data generated in the market scenario, the transportation complement and operational requirements, and the results from the DOC and IOC cost analysis.

Figure 65 is a basic summary block flow diagram of the total system synthesis. For each aircraft concept, the optimum vehicle is matched with the total transportation system characteristics to determine the best fleet size, aircraft size, terminal size, total system cost, fare, and schedule frequency. This is only an overall flow diagram and does not show all the necessary internal crossfeed links and feedbacks loops required in this type of total system synthesis.

The total system synthesis solves for the following:

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

For a given fixed commuter demand, the fleet size is inversely proportional to the design capacity of the aircraft. As the aircraft size is increased, the fleet size is reduced.

A small fleet size, in turn, reduces the frequency of service to the commuter. As a basic ground rule to this analysis, at least one flight-per-hour is provided. This means that there is some minimum number of aircraft required to satisfy this constraint. Thus, as the aircraft size is increased, a point of deminishing return is reached where increasing the aircraft size no longer reduces the total number of aircraft in the fleet.

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

By properly combining the aircraft size with a fixed market demand, it is possible to solve for the best mix of aircraft size, fleet size, load factor, frequency of service in terms of minimum fare or TSC. Each of the aircraft concepts for both market time periods is subjected to this analysis. By comparing these results, it is then possible to evaluate each concept, relative to each other concept, on a consistent basis.

TOTAL SYSTEM EVALUATION AND SELECTION

Phase I

The final task of Phase I was the comparative evaluation of the optimized transportation systems in each of the conceptual classes of VTOL rotor, VTOL non-rotor, powered STOL, and short-field conventional aircraft. This evaluation was used to determine the concepts to be carried into Phase II of the study for more detailed analysis.

The resultant "stacking" of the VTOL concepts is shown in Figure 66 , and the comparison of the STOL concepts is shown in Figure 67. Inspection of these data shows that the spread in required fare varies significantly with aircraft concept, particularly for the STOL category. For the VTOL category, the helicopter is clearly the lowest-fare concept. For the STOL category, the deflected-slipstream concept shows the lowest fare in the minimum fare analysis, while the lowest fare concept changes from CTOL in 1975 to STOL in 1985 for the 20-minute schedule analysis. From cost considerations, it is therefore judged that the preferred concepts are the compound-helicopter VTOL and the deflected-slipstream STOL.

Other factors considered in the evaluation criteria are summarized in Figure 68. The concepts recommended for more detailed study in Phase II are shown on this summary of the concept selection of Phase I.

Phase II

The results of exposing each of the Phase II aircraft concepts to the total system synthesis are shown in Figures 69 through 73. Each concept is presented in terms of aircraft size, frequency of service, fleet size, and average fleet load factor for three potential commuter demands. For each concept and given commuter demand, the optimum aircraft and fleet size are shown as a minimum fare point on the appropriate curve. The resulting average fleet load factor and frequency of service can be determined from these same plots, which are presented as follows:

Figure 69 Total Synthesis of 1975 Deflected-Slipstream STOL

Figure 70 Total synthesis of 1975 Conventional Compound Helicopter

Figure 71 Total Synthesis of 1985 Deflected-Slipstream STOL

Figure 72 Total Synthesis of 1985 Compound Helicopter

Figure 73 Total Synthesis of 1985 Autogyro

For all of the data points shown on these curves, a real-world route and schedule has been solved for and used in the analysis to determine these final total system results.

The final step in the evaluation consists in cross plotting the minimum fare points against the passengers served for each of the concepts. Figure 74 shows the final stacking of the aircraft concepts for both time periods. In both the 1975 and 1985 time periods, the deflected-slipstream STOL concept proves to be the minimum-fare system.

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

The 1000-foot (305 meter) field length STOL autogyro fares lie midway between the 1975 conventional compound helicopter and the 2000-foot (609 meter) deflected-slipstream STOL. In a city where the necessary land for a 2000-foot (609 meter) STOL runway could not be acquired in the downtown metropolitan area, the autogyro might prove to be a very attractive concept.

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

The results of the other elements of evaluation criteria, namely, community acceptance, ride qualitites, passenger appeal, utility, risk, etc. have been re-examined and found to show no change from the results of Phase I.

CONCLUSIONS

The propeller-powered, deflected-slipstream STOL is the preferred concept (nearest competitors were the compound helicopter VTOL and the autogyro STOL). This judgment is based on the following factors:

- For all of the market demands investigated, the 2000-foot (609 meters), deflected-slipstream STOL concept is the most cost effective aircraft in terms of minimizing the fare by a margin of 4 to 22 percent, depending on the demand
- The 1000-foot (305 meter) STOL autogyro shows promise where land is not available for the building of a 2000-foot (609 meter) STOL commuterport
- The optimum aircraft size for the deflected-slipstream STOL in this market is 110 passengers. It would provide a frequency of service of three to four flights-per-hour at the high demand commuterports
- A fleet of 20 aircraft would be required to satisfy this demand, and it would operate with an average load factor of 42 percent
- The deflected-slipstream STOL concept will meet the recommended community noise requirements at all sizes, whereas the compound helicopter VTOL and autogyro STOL are marginal at the larger sizes

Current technology is sufficient for the development of the intraurban transport system for 1975 time period. Advanced technology available by the 1985 time period will offer largely indirect benefits to the system, i.e., reduced noise and improved passenger comfort, but it will offer little cost benefit.

All vehicle concepts considered are believed to involve low technical risk in their respective time periods.

Air polution would be reduced in the Detroit area with the establishment of an airborne intraurban transportation system.

Research is needed in at least the following areas for continued evolution of this concept: certification standards, acoustics, ride qualities, propulsion system reliability and maintainability versus performance and cost, and passenger modal split analysis.

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FIGURE 1. STUDY AREA

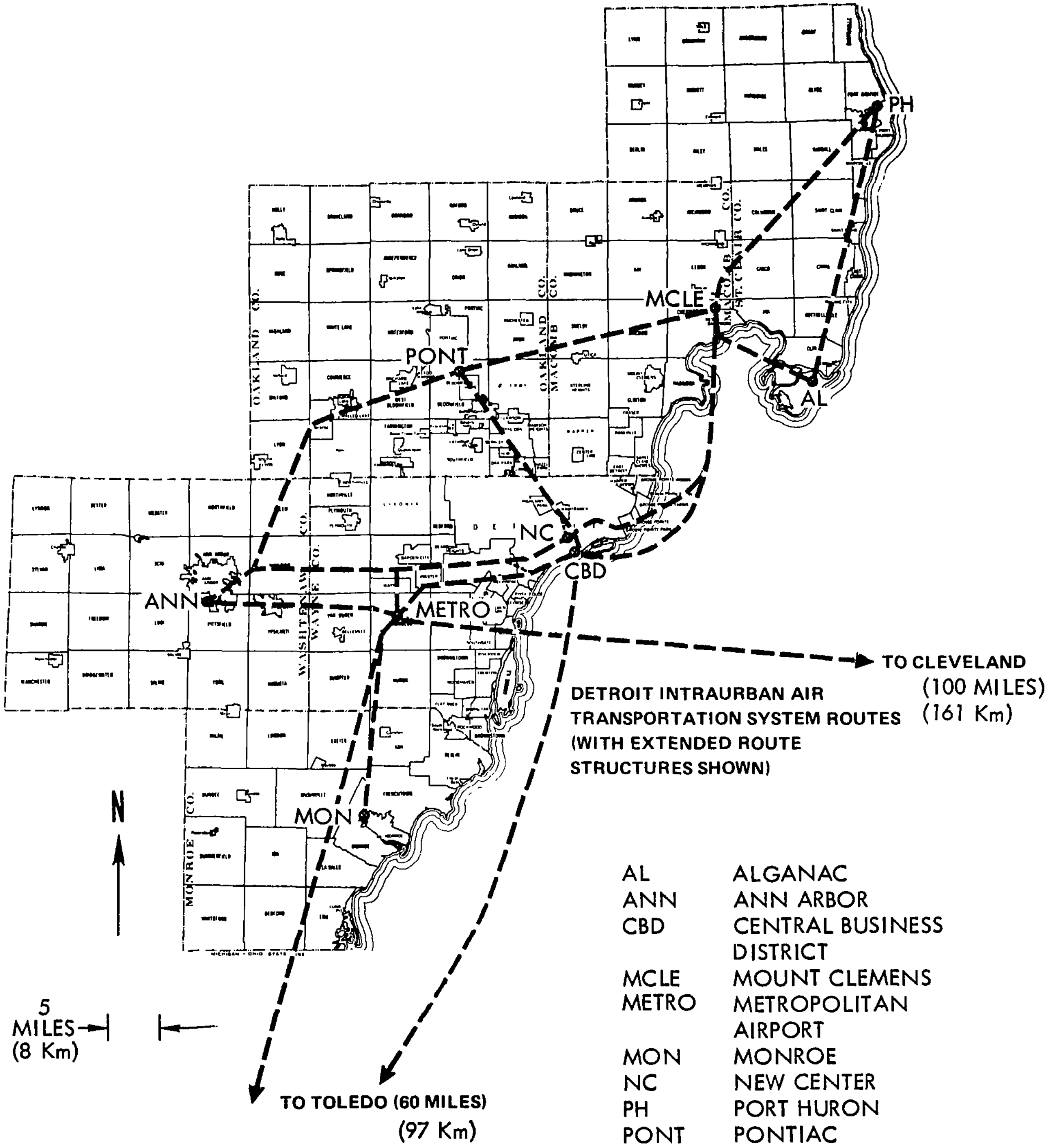


FIGURE 2. FAMILIES BY INCOME GROUP

INCOME GROUPS $/YR	PERCENTAGE OF FAMILIES		
	U. S.	MICHIGAN	DETROIT REGION
$ 1000	5.6)	3.7)	3.6)
1000 - 1999	7.5)	5.6)	5.0)
2000 - 2999	8.3) 41.9	6.3) 33.2	5.7) 30.2
3000 - 3999	9.5)	7.2)	6.4)
4000 - 4999	11.0)	10.4)	9.5)
5000 - 5999	12.3)	13.7)	13.3
6000 - 6999	10.7	12.0	12.0
7000 - 7999	8.6	9.8	10.2
8000 - 8999	6.6	7.9	8.3
9000 - 9999	4.8	6.0	6.5
10,000 - 14,999	10.5	12.7	14.1
15,000 - 24,999	3.3	3.5	4.0
25,000 and above	1.3	1.2	1.4
TOTAL	100.0	100.0	100.0

FIGURE 3. FREEWAY SYSTEM

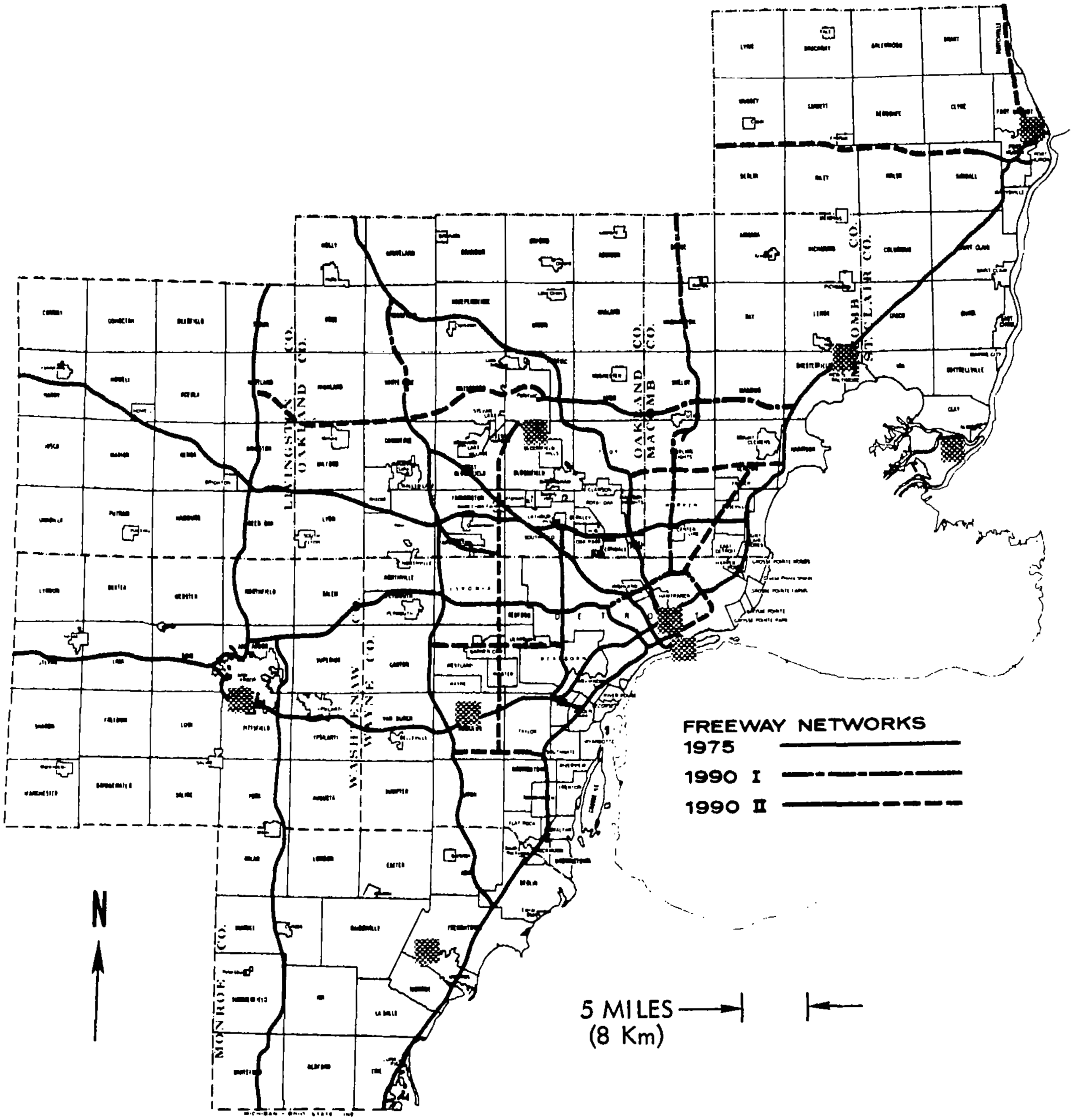


FIGURE 4. 1990 TEST RAIL RAPID TRANSIT SYSTEM

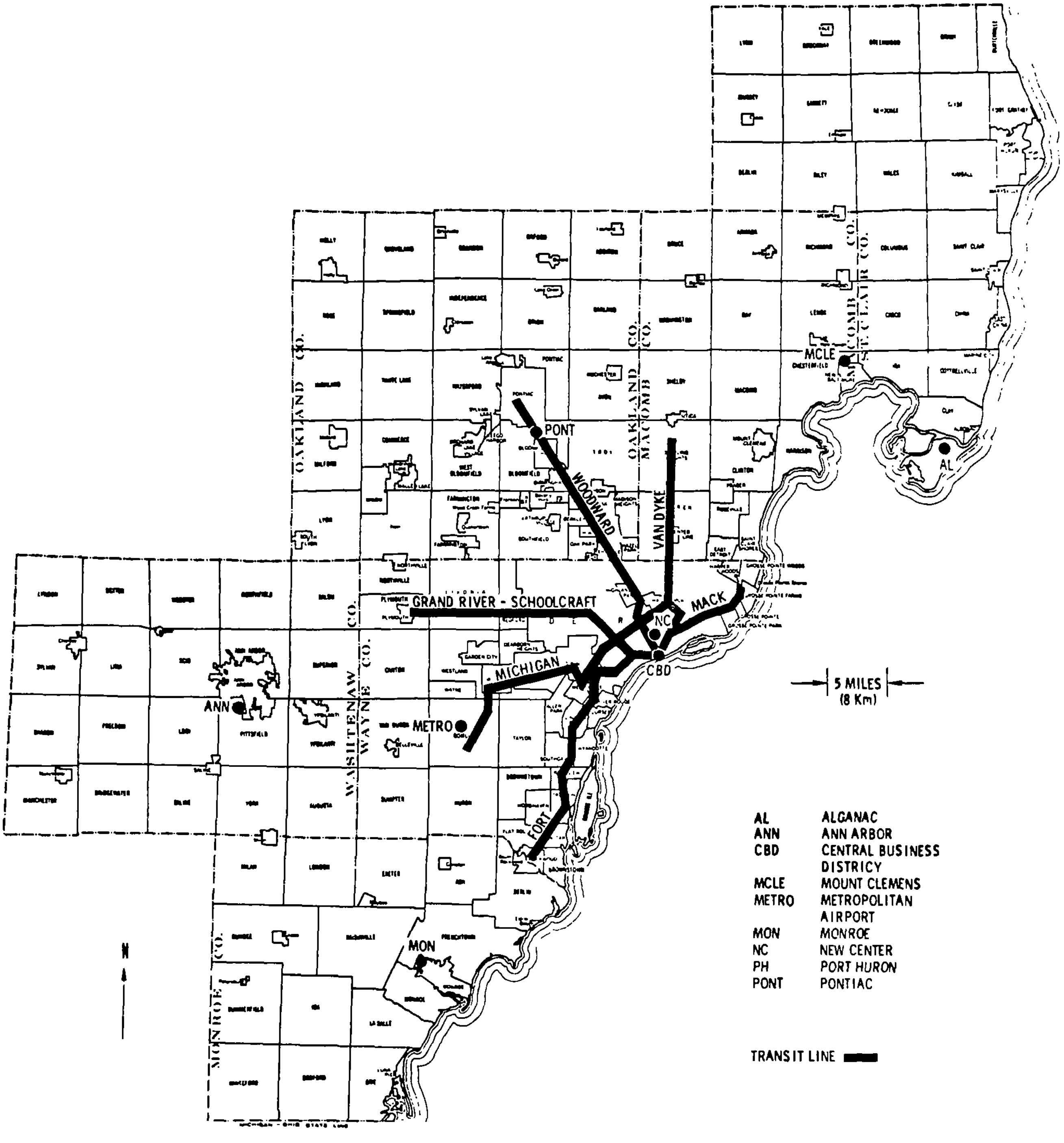


FIGURE 5. AIRPORT LOCATIONS

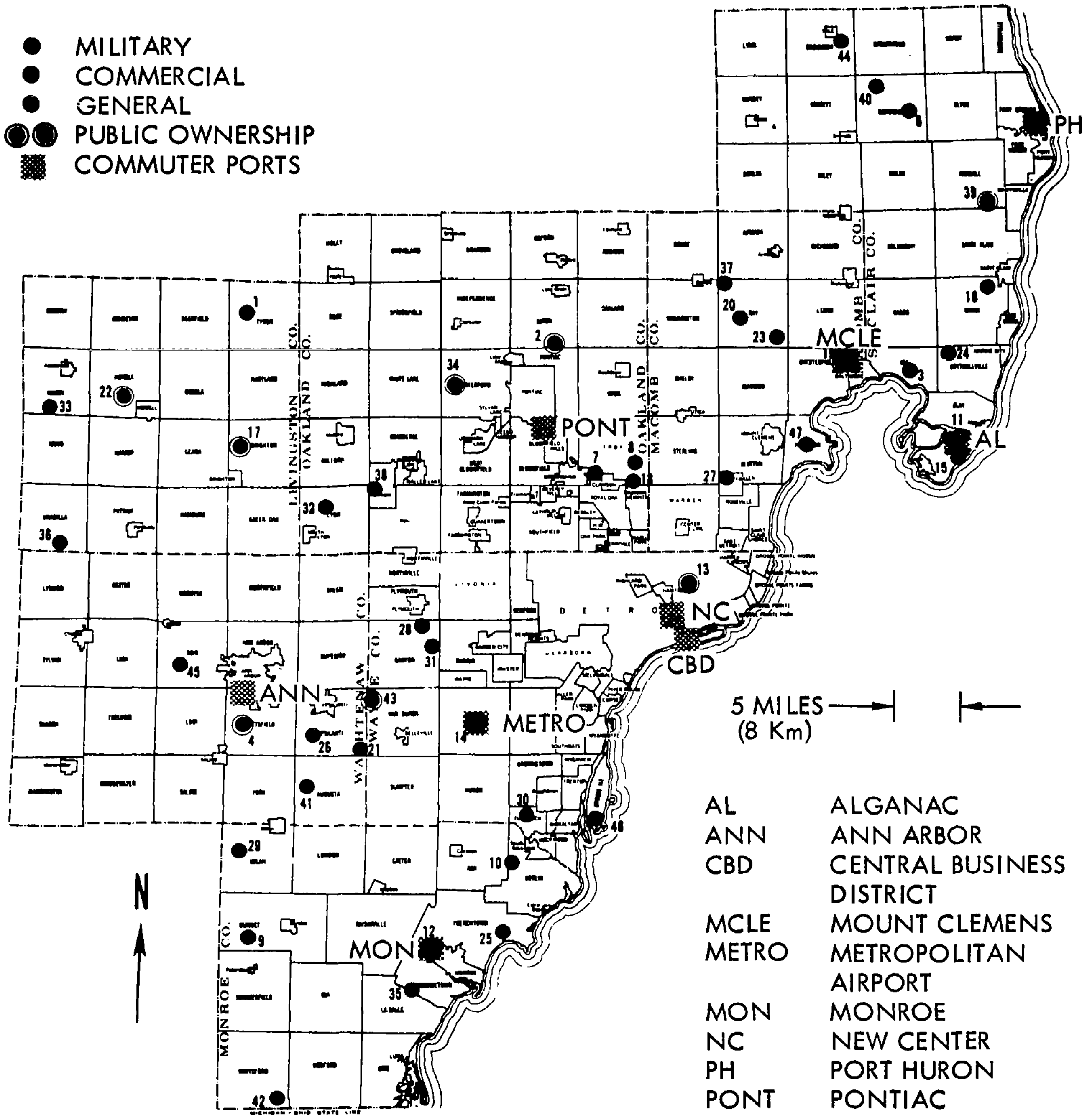


FIGURE 6. NETWORK EXPANSION

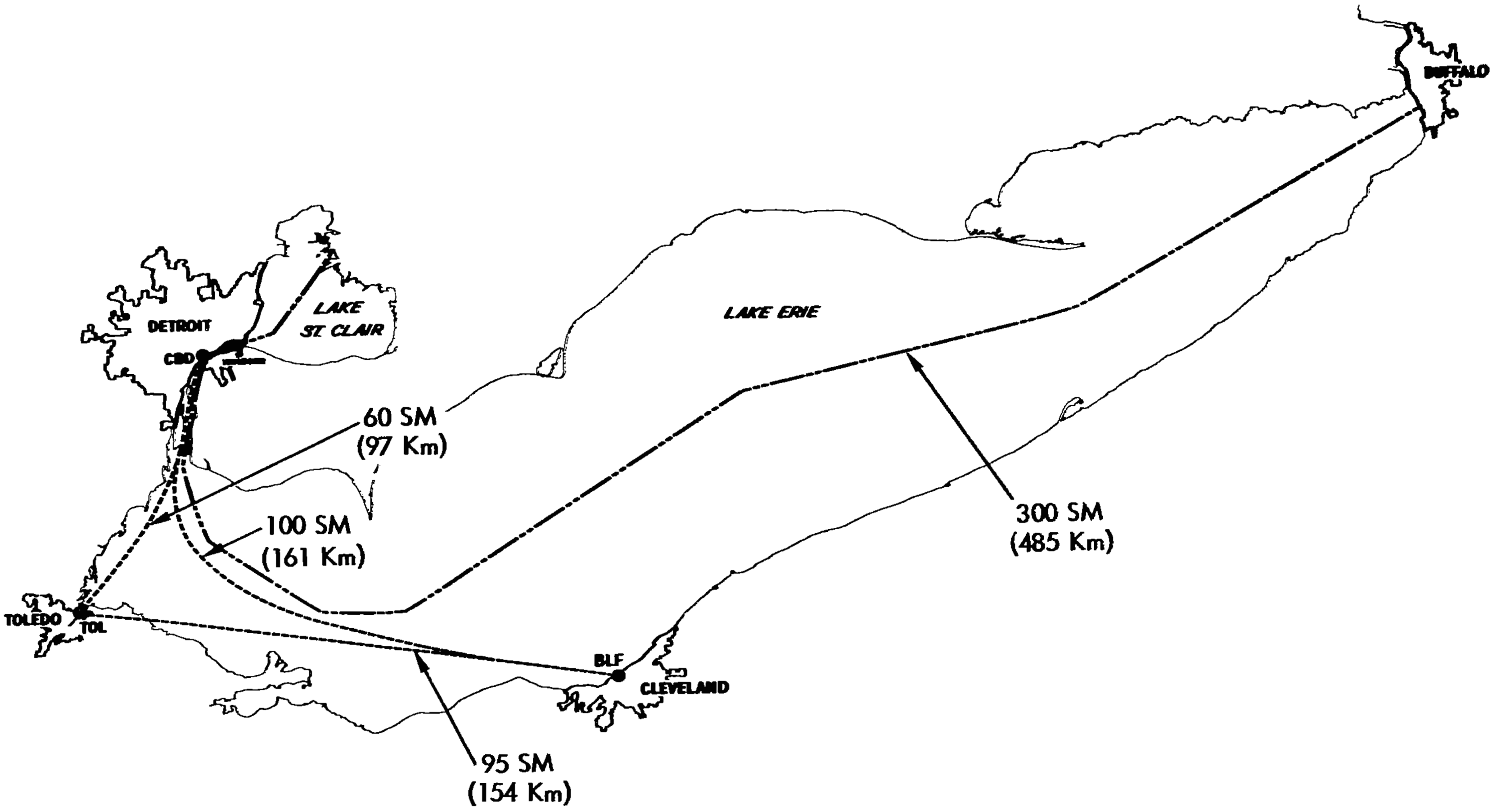


FIGURE 7. BLOCK FUEL, TIME BASE

STAGE SEGMENT	CONFIGURATION	TIME ALLOWANCE AND FUEL SEGMENT BASIS
Taxi Out at Low Power	VTOL STOLs	- 0.5 minute at 9% rated power fuel flow rate - 1.0 minutes at 9% rated power fule flow rate
Takeoff	All	- Actuals to 35 feet (10.7m) altitude, all engines
Climb	All	- MCP climb from 35 (10.7m) to (610m) 2000 feet (610m) at best R/C speed
Cruise	Hel VTOL Autogyro STOL	- 200 kt (370 Km/hr) TAS at 2000 ft (610m) altitude
	Fixed-Wing STOL	- Same as above except use 250 kt (464 Km/hr TAS cruise
Descent	All	- No fuel, time, or distance allowed
Approach Air Maneuvers	All	- 0.5 minute at 50% MCP fuel flow rate
Landing	All	- 1.0 minute at power for level flight
Taxi in at Low Power	VTOL STOLs	- 0.5 minute at 9% rated power fuel flow rate - 1.0 minute at 9% rated power fuel flow rate
Load-Unload	All	- 5 minutes at 9% rated power fuel flow rate

Reserves - 5% initial fuel

FIGURE 8. INTERIOR ARRANGEMENT, 60-PASSENGER, ALL CONFIGURATIONS

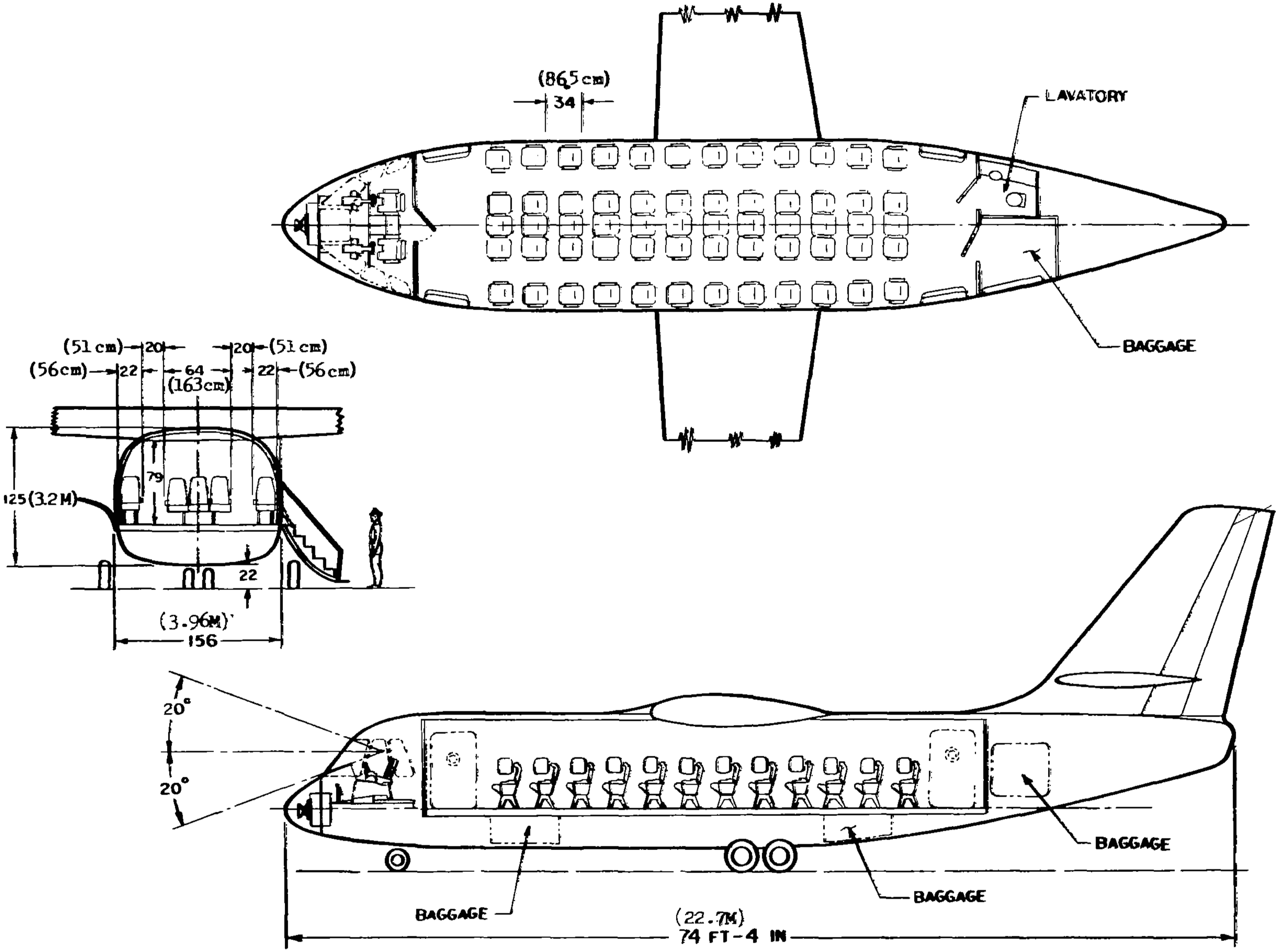


FIGURE 9. FUSELAGE INTERIOR VS CAPABILITY

Interior Arrangement Passenger Capacity ⟶	40	60	80	100
CABIN WIDTH, IN.	156	156	156	184
CABIN WIDTH, M	3.96	3.96	3.96	4.68
APPROX. CABIN LENGTH, IN.	405	530	655	710
APPROX. CABIN LENGTH, M	10.30	13.46	16.63	18.03
SEAT ROW CONFIGURATION	2-1-2	2-1-2	2-1-2	2-2-2
SEAT WIDTH, IN.	22	22	22	22
SEAT WIDTH, CM	55.9	55.9	55.9	55.9
SEAT PITCH, IN.	34	34	34	34
SEAT PITCH, CM	86.6	86.6	86.6	86.6
NUMBER OF AISLES	2	2	2	2
AISLE WIDTH, IN.	20	20	20	20
AISLE WIDTH, CM	50.8	50.8	50.8	50.8
NUMBER OF DOORS	4	4	4	4
DOOR WIDTH, IN.	42	42	42	42
DOOR WIDTH, CM.	106.5	106.5	106.5	106.5
TIME AT ENROUTE STOP WITH 100% PASSENGER TRANSFER	3:13	3:50	4:27	5:07

FIGURE 10. ONLOAD/OFFLOAD TRAFFIC PATTERN

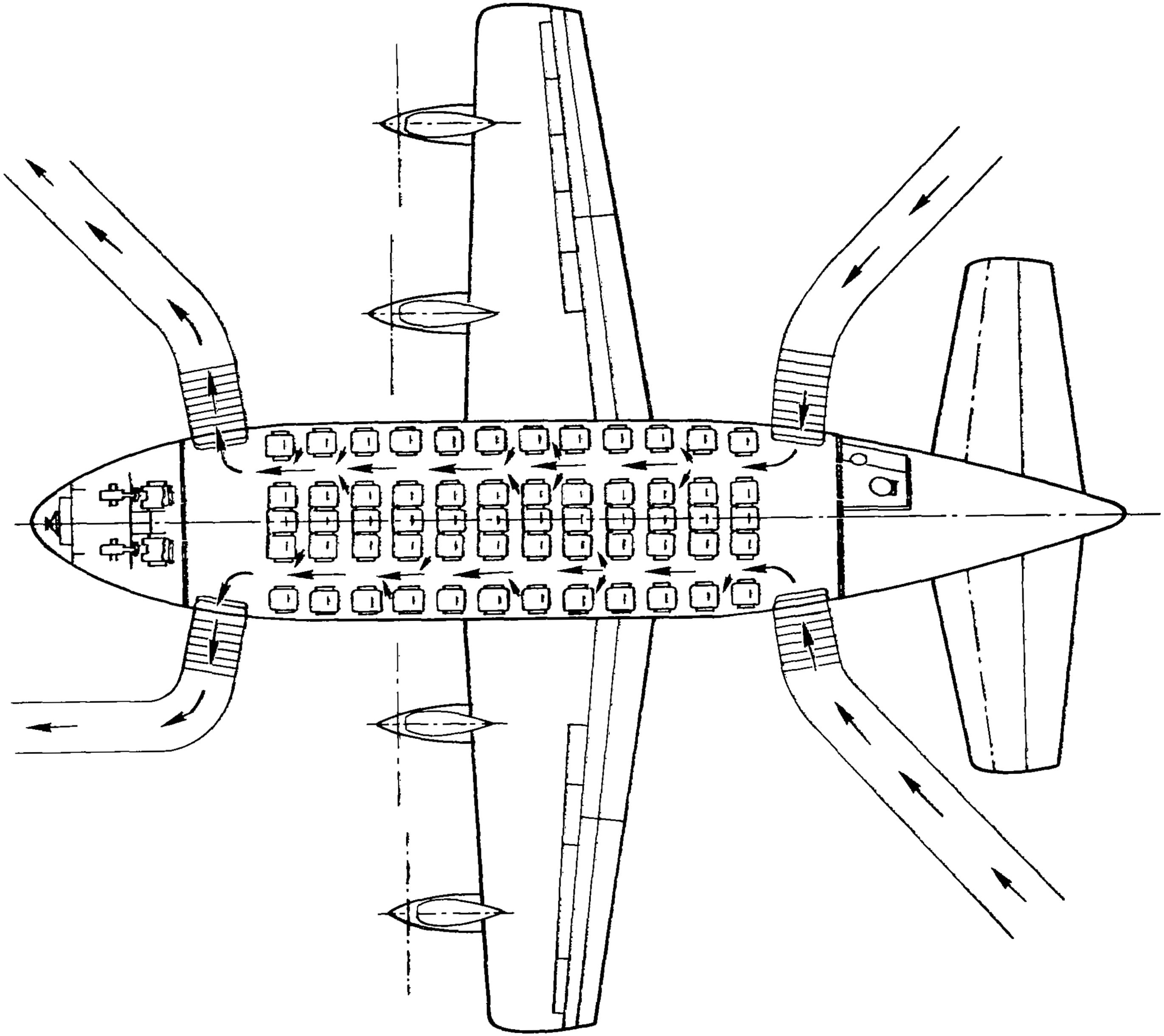
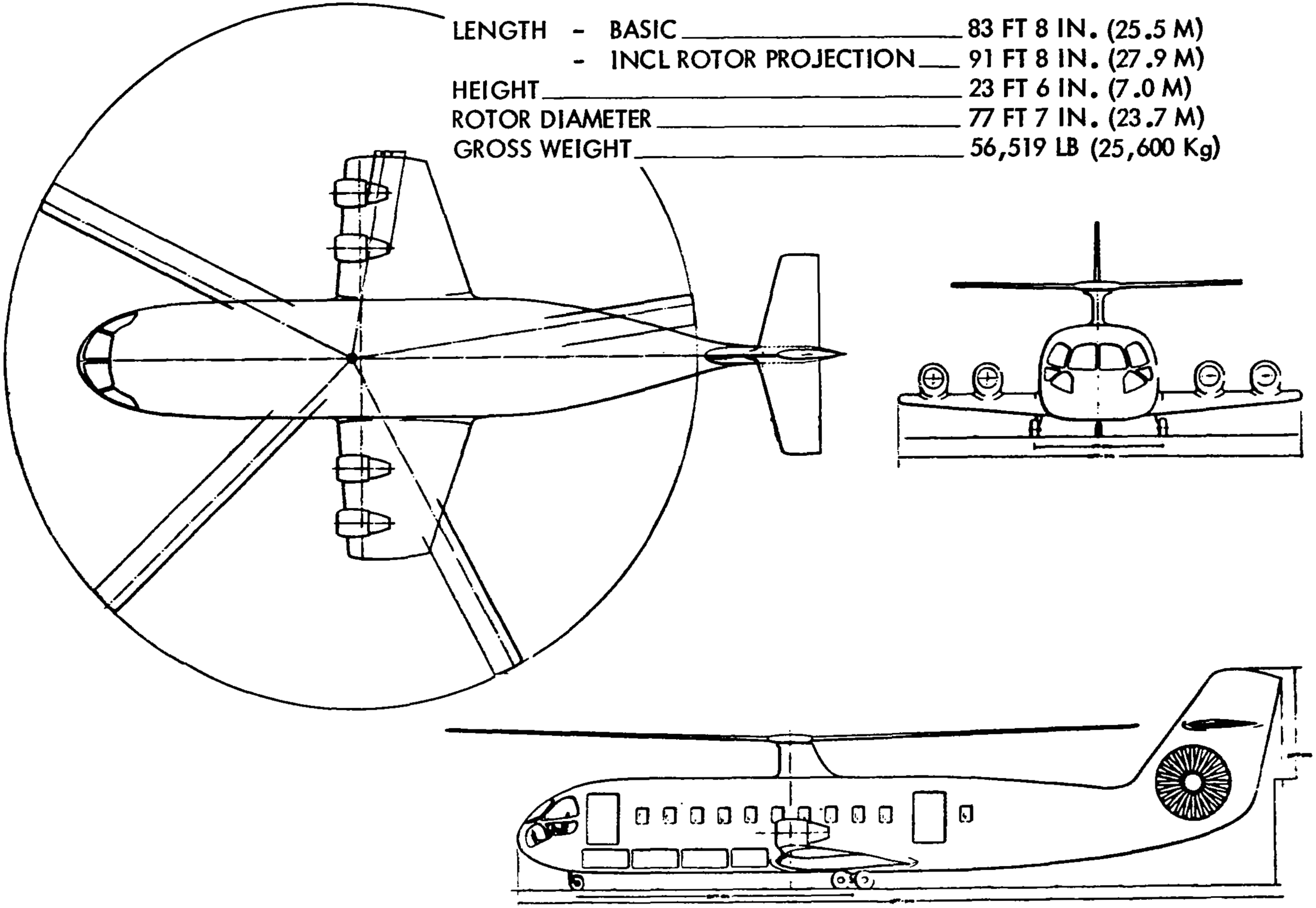


FIGURE 11. 1975 60-PASSENGER COMPOUND HELICOPTER VTOL GENERAL ARRANGEMENT



LENGTH - BASIC	83 FT 8 IN. (25.5 M)
- INCL ROTOR PROJECTION	91 FT 8 IN. (27.9 M)
HEIGHT	23 FT 6 IN. (7.0 M)
ROTOR DIAMETER	77 FT 7 IN. (23.7 M)
GROSS WEIGHT	56,519 LB (25,600 Kg)

FIGURE 12. 1975 COMPOUND HELICOPTER PROPULSION SYSTEM

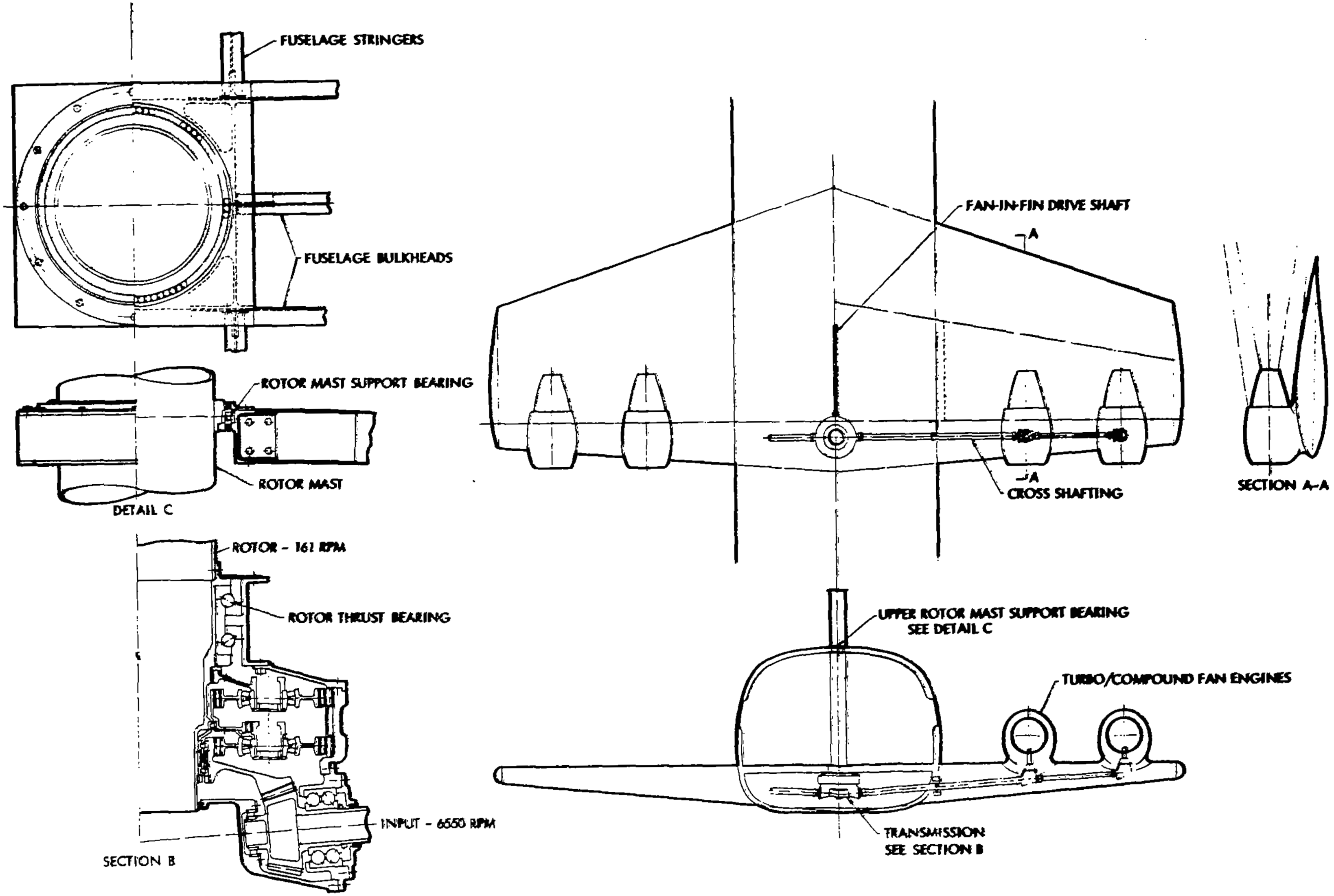
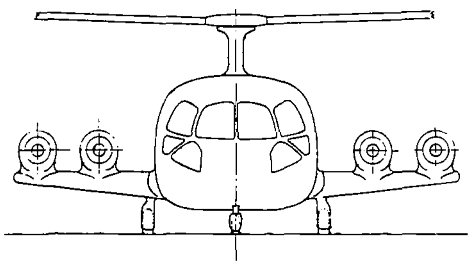


FIGURE 13. 1985 60-PASSENGER COMPOUND HELICOPTER VTOL AND AUTOGYRO STOL GENERAL ARRANGEMENT

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



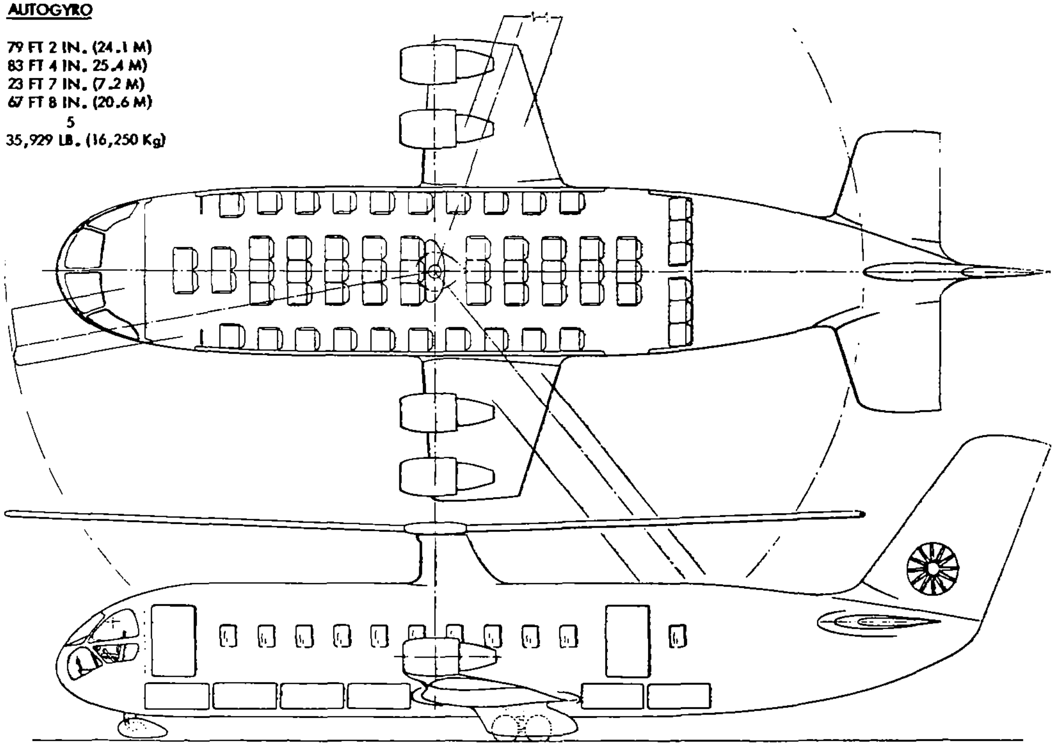


FIGURE 14. PROPULSION SYSTEM ARRANGEMENT, 1985 HELICOPTER PNEUMATIC ROTOR DRIVE

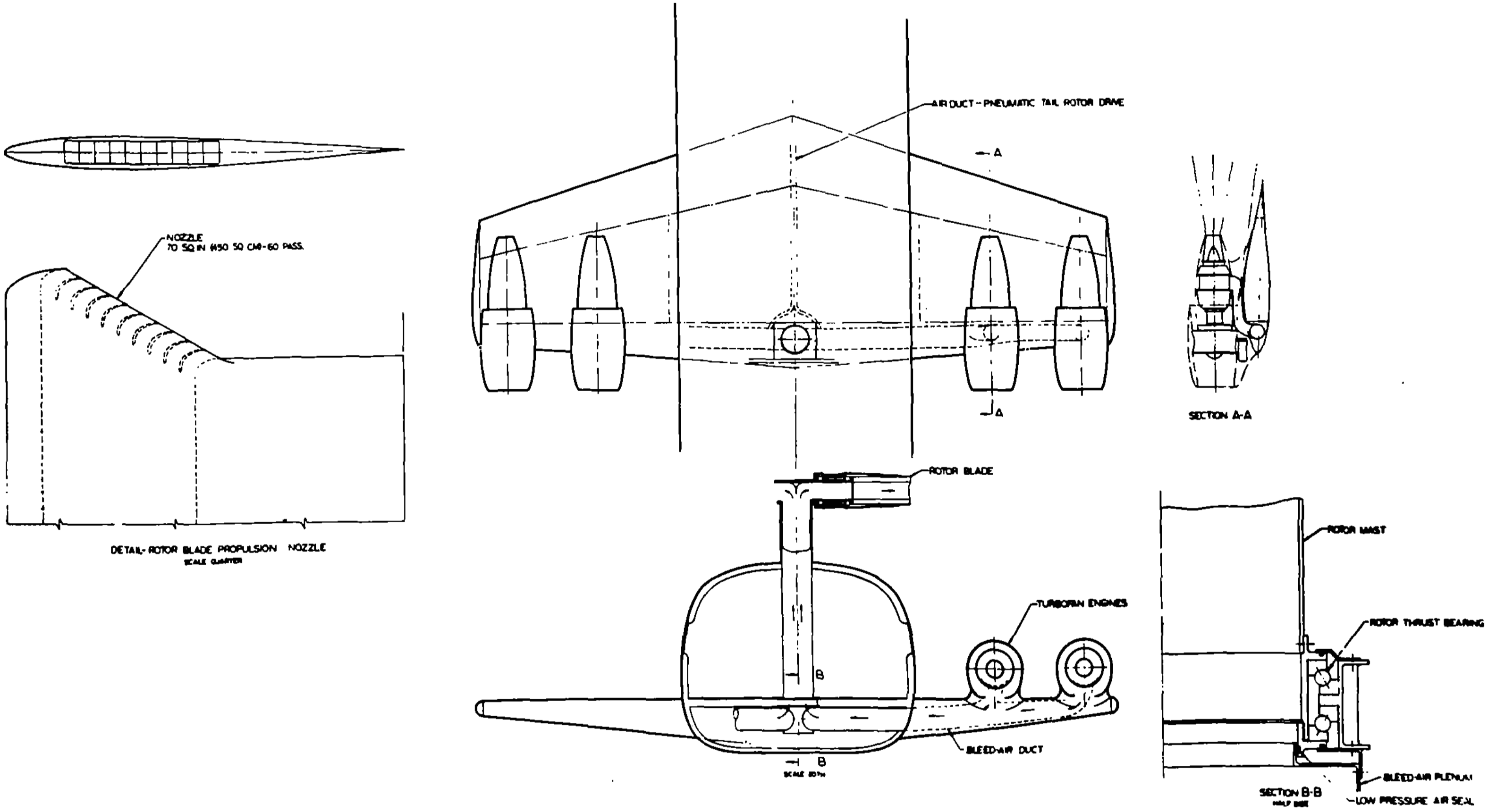


FIGURE 15. 1985 AUTOGYRO-SPINUP PNEUMATIC DRIVE SYSTEM

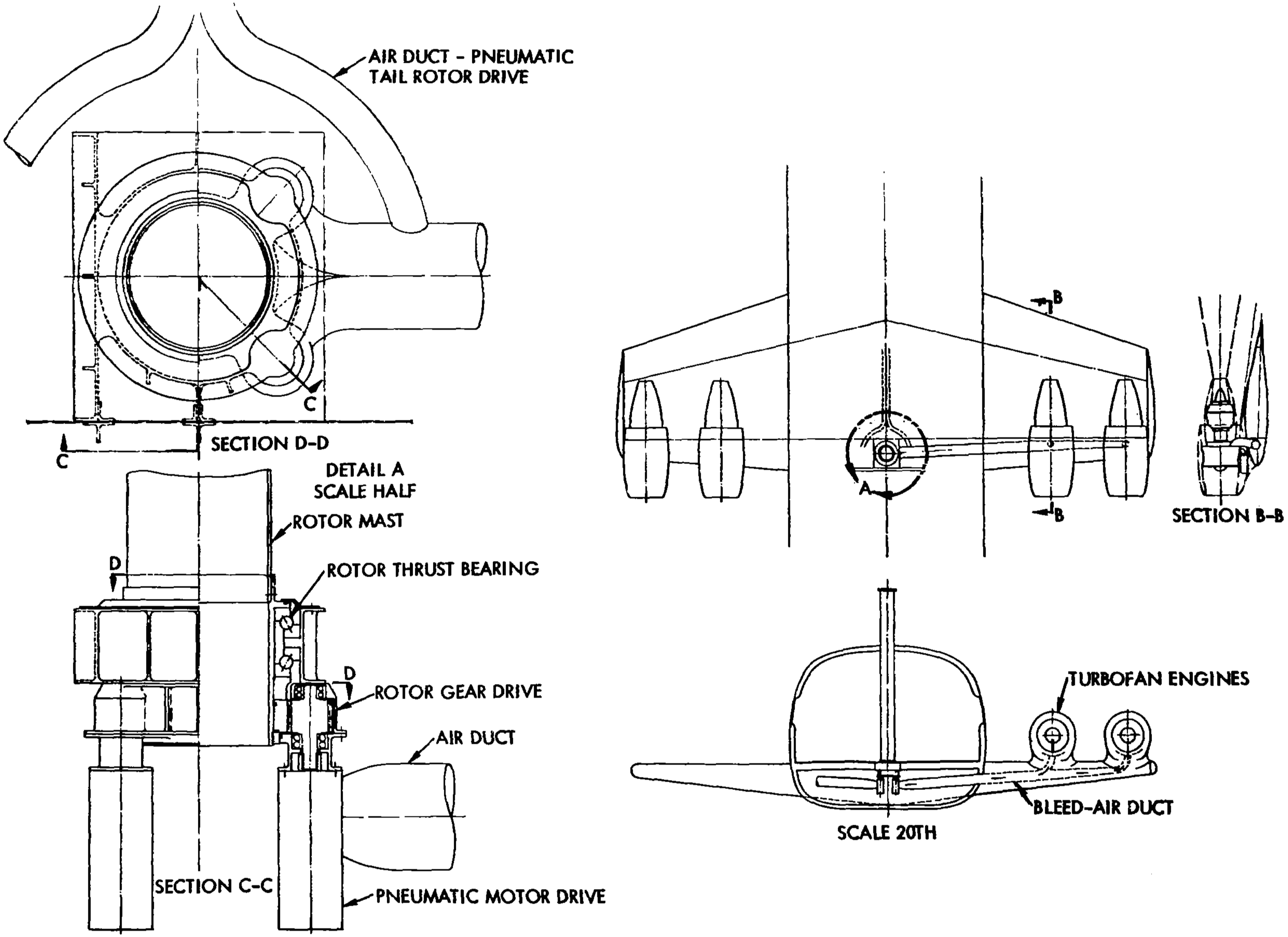
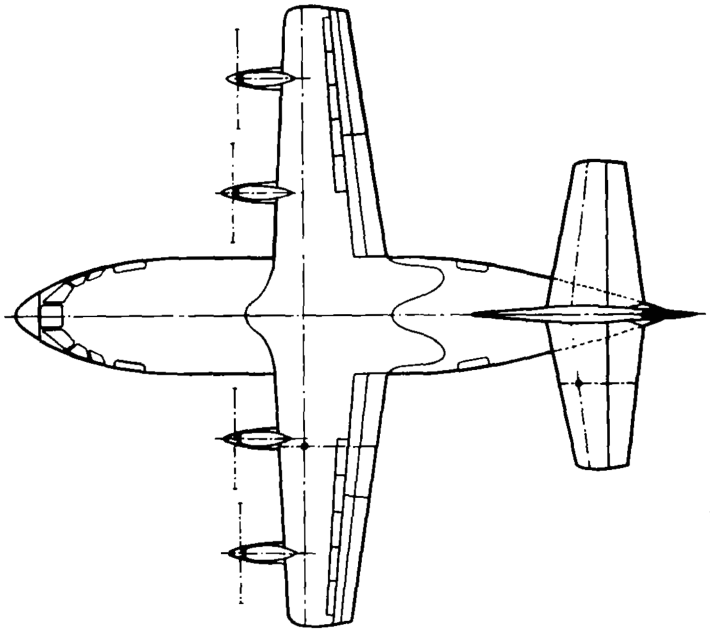


FIGURE 16. GENERAL ARRANGEMENT, 60-PASSENGER DEFLECTED-SLIPSTREAM STOL CONFIGURATION

CHARACTERISTICS	WING	HORIZ.	VERT.
AREA (SQ FT)	726	291	182
ASPECT RATIO	6.5	4.0	14
SPAN (FT)	68.7	342	16
ROOT CHORD (IN)	169	136	195
TIP CHORD (IN)	84.5	68	78
TAPER RATIO	.50	.50	.40
MAC (IN)	133	105	145
SWEEP (DEG)	0	7.5	35
T/C ROOT (%)	18	10	12
T/C TIP (%)	12	10	10

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



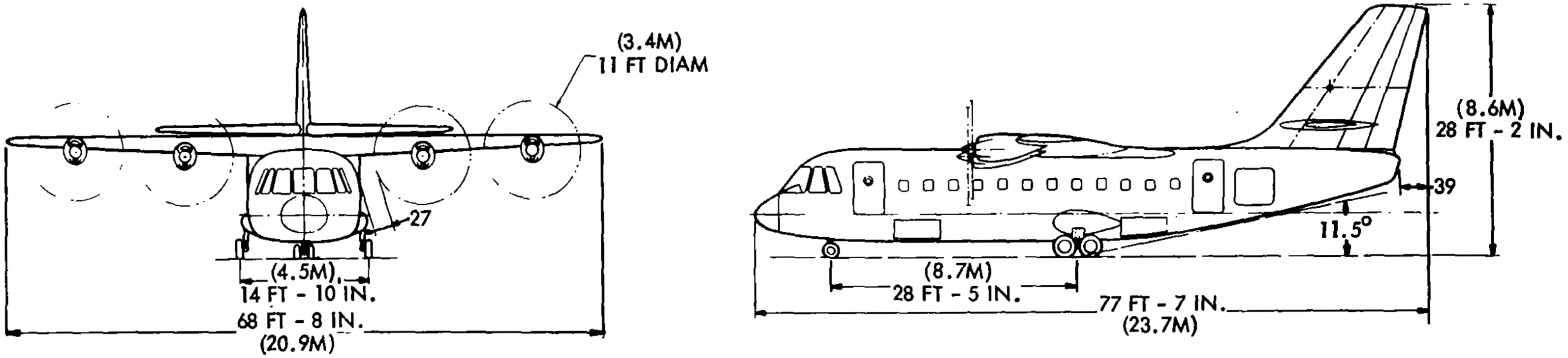


FIGURE 17. WEIGHT BREAKDOWN, 60-PASSENGER ROTARY-WING CONFIGURATION

TECHNOLOGY	1975	1985	1985
FAR FIELD LENGTH FT/METERS	500/152	500/152	1000/305
	Weight, Lb/Kg		
ITEM	Compound Helicopter VTOL		Autogyro STOL
Main Rotor	5729/2600	2998/1361	2801/1272
Wing	1387/630	788/358	728/330
Tail Fan	455/206	65/30	60/27
Empennage	625/283	325/145	300/136
Fuselage	4839/2197	3188/1447	3169/1439
Landing Gear	1854/842	1144/519	1058/480
Flight Controls	2174/987	1250/567	1250/567
Nacelles	967/439	575/261	676/307
Engines	3200/1453	1810/822	2170/985
Propulsion Systems	871/395	665/301	719/326
Drive System	6799/3087	1000/454	270/123
Instruments	454/206	321/146	310/141
Hydraulics	280/127	182/83	181/82
Electrical	1012/459	733/333	733/333
Electronics	1178/535	875/397	875/397
Furnishings	3190/1448	2552/1158	2550/1158
Air Cond & Anti-Ice	1497/680	1140/576	1128/526
EMPTY WEIGHT	36,511/16,576	19,611/8903	18,978/8616
Operation Items	45/20	45/20	45/20
Standard Items	380/172	380/172	380/172
Oil, Etc.	133/61	152/69	84/38
OPERATING WEIGHT EMPTY	37,069/16,829	20,188/9165	19,487/8847
Payload	11,400/5176	11,400/5176	11,400/5176
ZERO FUEL WEIGHT	48,469/22,005	31,588/14,341	30,887/14,023
Fuel	8050/3655	4690/2129	5042/2259
TAKEOFF GROSS WEIGHT	56,519/25,630	36,278/16,470	35,929/16,312

FIGURE 18. WEIGHT BREAKDOWN, 60-PASSENGER DEFLECTED-SLIPSTREAM STOL CONFIGURATIONS

TECHNOLOGY	1975	1975	1975	1985	1985	1985
FAR FIELD LENGTH Ft/Meters	1500/457	2000/610	2500/761	1500/457	2000/610	2500/761
ITEM	WEIGHT, LB/KG					
WING	4230/1920	3940/1789	3917/1778	2785/1264	2641/1199	2629/1194
TAIL	1633/741	1474/669	1462/664	1043/473	963/437	956/434
FUSELAGE	4923/2235	4826/2191	4818/2187	3693/1677	3638/1652	3633/1649
LANDING GEAR	1932/871	1813/823	1803/819	1455/661	1385/629	1379/626
SURFACE CONTROLS	911/413	888/403	887/403	864/392	848/385	847/385
NACELLES	1968/893	1051/477	1022/464	1147/521	821/373	799/363
ENGINES	1619/735	1245/565	1221/554	1258/571	1012/459	996/452
PROPELLERS	1697/770	1128/512	1092/496	1143/519	771/350	747/339
FIRE EXTINGUISHER	162/74	125/67	122/55	126/57	101/459	100/454
EXHAUST	89/40	68/31	67/30	69/31	56/25	55/25
CROSS SHAFTING	1431/650	1107/503	1085/493	1291/586	1014/460	994/451
COOLING	81/37	62/28	61/28	63/29	51/23	50/23
OIL SYSTEM	81/37	62/28	61/28	63/29	51/23	50/23
ENGINE CONTROLS	76/34	59/27	57/27	59/27	48/22	47/21
STARTING	113/51	87/39	85/39	88/40	71/32	70/32
FUEL SYSTEM	436/198	436/198	436/198	436/198	436/198	436/198
INSTRUMENTS	421/191	410/186	409/186	398/181	390/177	390/177
HYDRAULICS	304/138	303/138	303/138	302/137	302/137	302/137
ELECTRICAL	1379/626	1360/617	1359/617	1339/608	1326/602	1324/601
ELECTRONICS	1178/535	1178/535	1178/535	875/397	875/397	875/397
FURNISHINGS	4186/1900	4186/1900	4186/1900	4186/1900	4186/1900	4186/1900
AIR-CONDITIONING	1553/696	1553/705	1553/705	1553/705	1553/705	1553/705
ANTI-ICING	259/118	238/108	236/107	216/98	202/92	201/91
WEIGHT EMPTY	30,181/13,702	27,602/12,531	27,421/12,449	24,450/11,100	22,738/10,323	22,617/10,268
OPERATION ITEMS	493/223	485/220	485/220	477/217	472/214	472/214
STANDARD ITEMS	196/89	170/77	168/76	171/78	153/69	152/69
OPERATING WEIGHT EMPTY	30,870/14,015	28,257/12,829	28,074/12,747	25,098/11,394	23,364/10,607	23,241/10,551
PAYLOAD	11,400/5176	11,400/5176	11,400/5176	11,400/5176	11,400/5176	11,400/5176
ZERO FUEL WEIGHT	42,270/19,191	39,657/18,004	39,474/17,921	36,498/12,030	34,764/15,783	34,641/15,727
FUEL	2574/1968	2198/998	2139/971	2221/1008	1925/874	1875/851
TAKEOFF GROSS WEIGHT	44,843/20,359	41,855/19,002	41,613/18,892	38,719/17,578	36,689/16,657	36,516/16,578

FIGURE 19. PHASE II WEIGHT SUMMARY

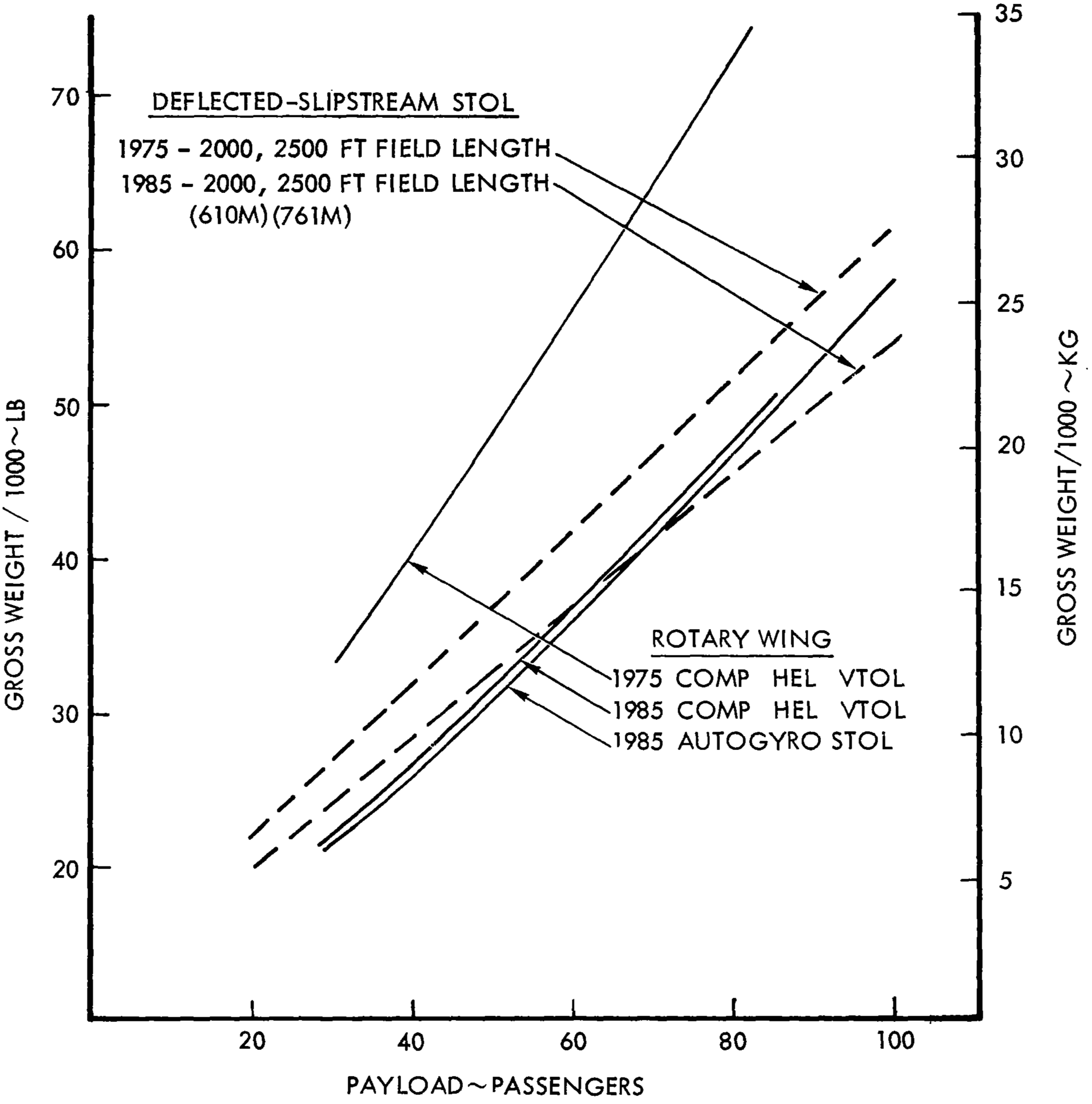


FIGURE 20. COMPARATIVE ALL-ENGINE TAKEOFF FLIGHT PROFILES

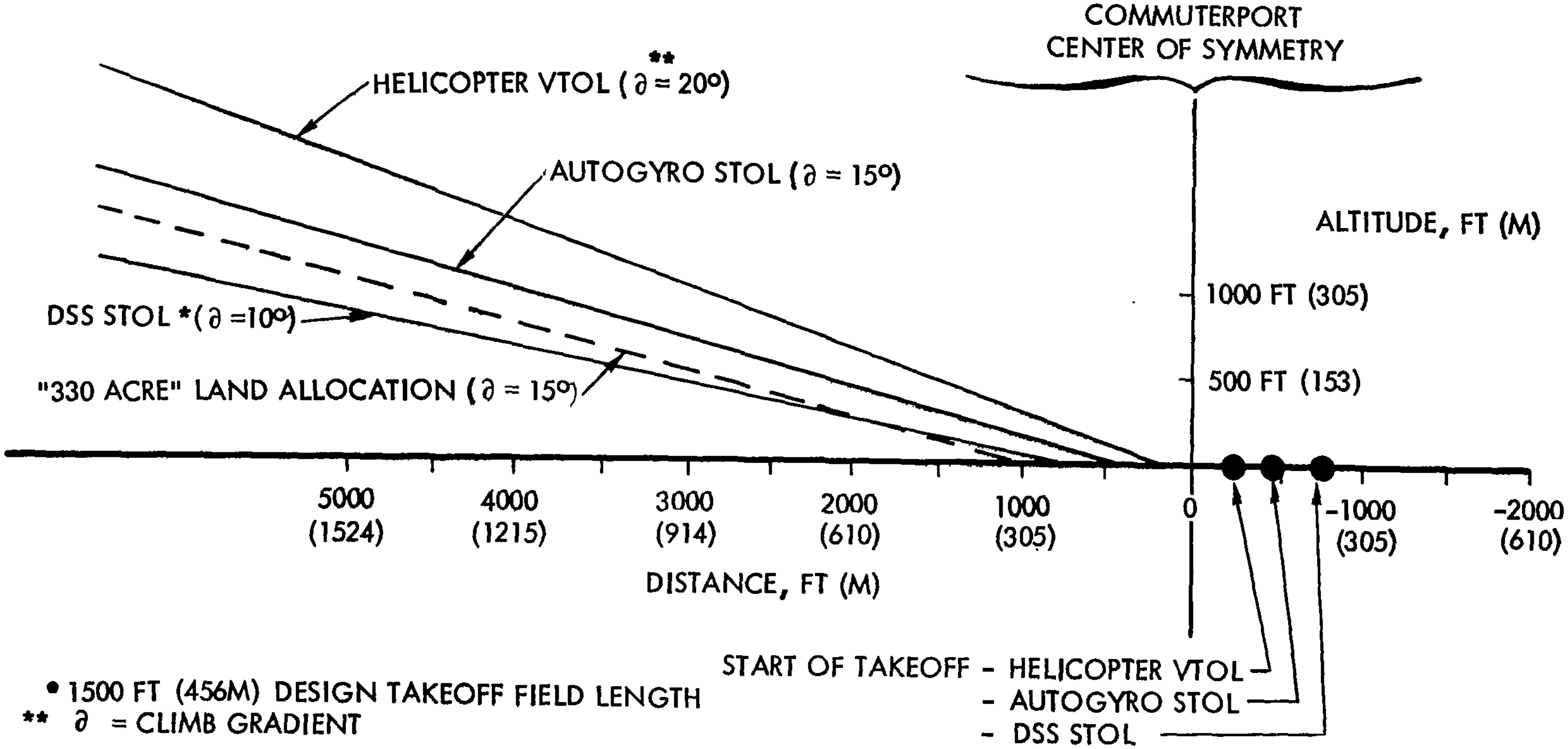


FIGURE 21. STAGE TIME VS DISTANCE

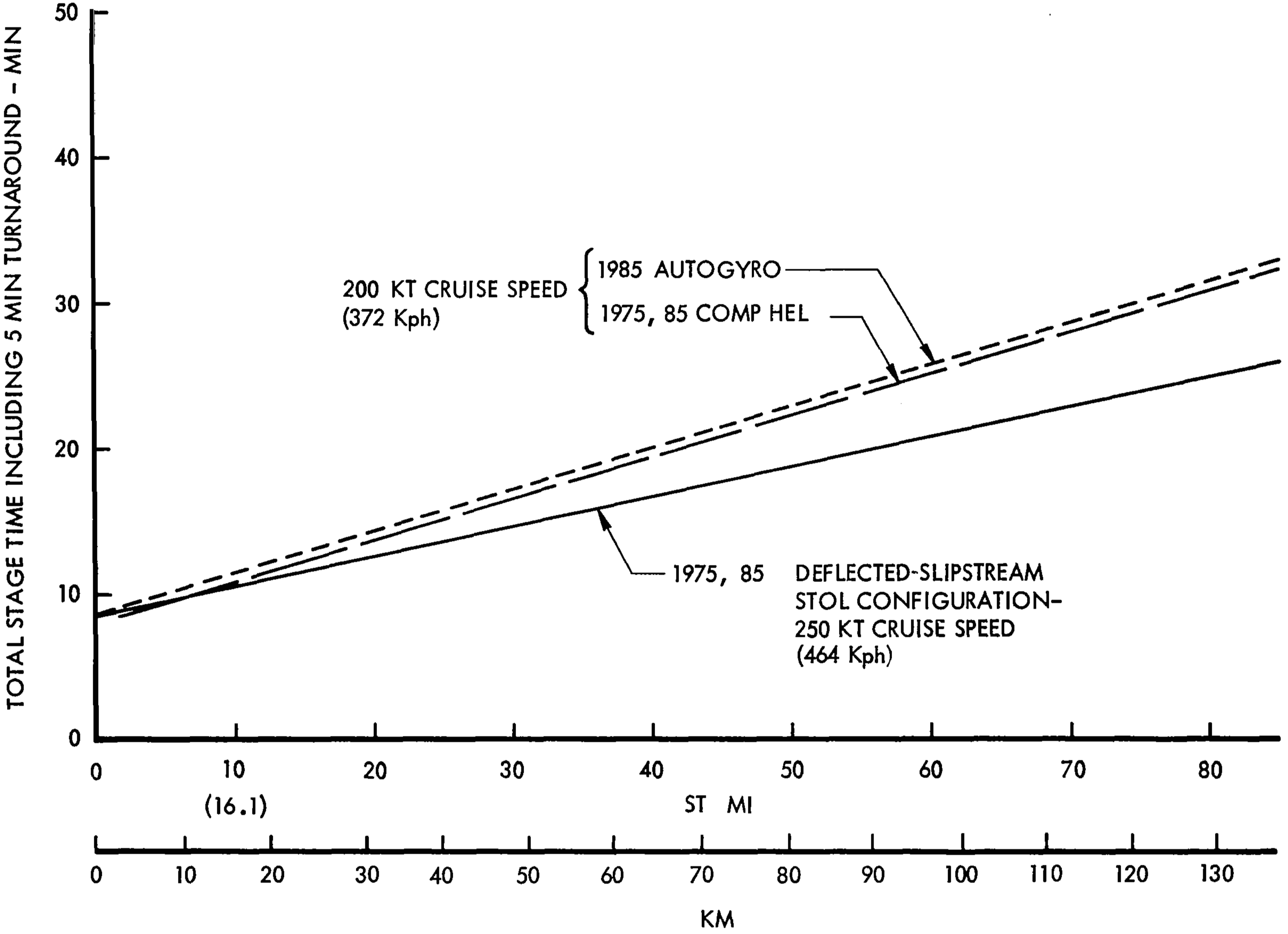
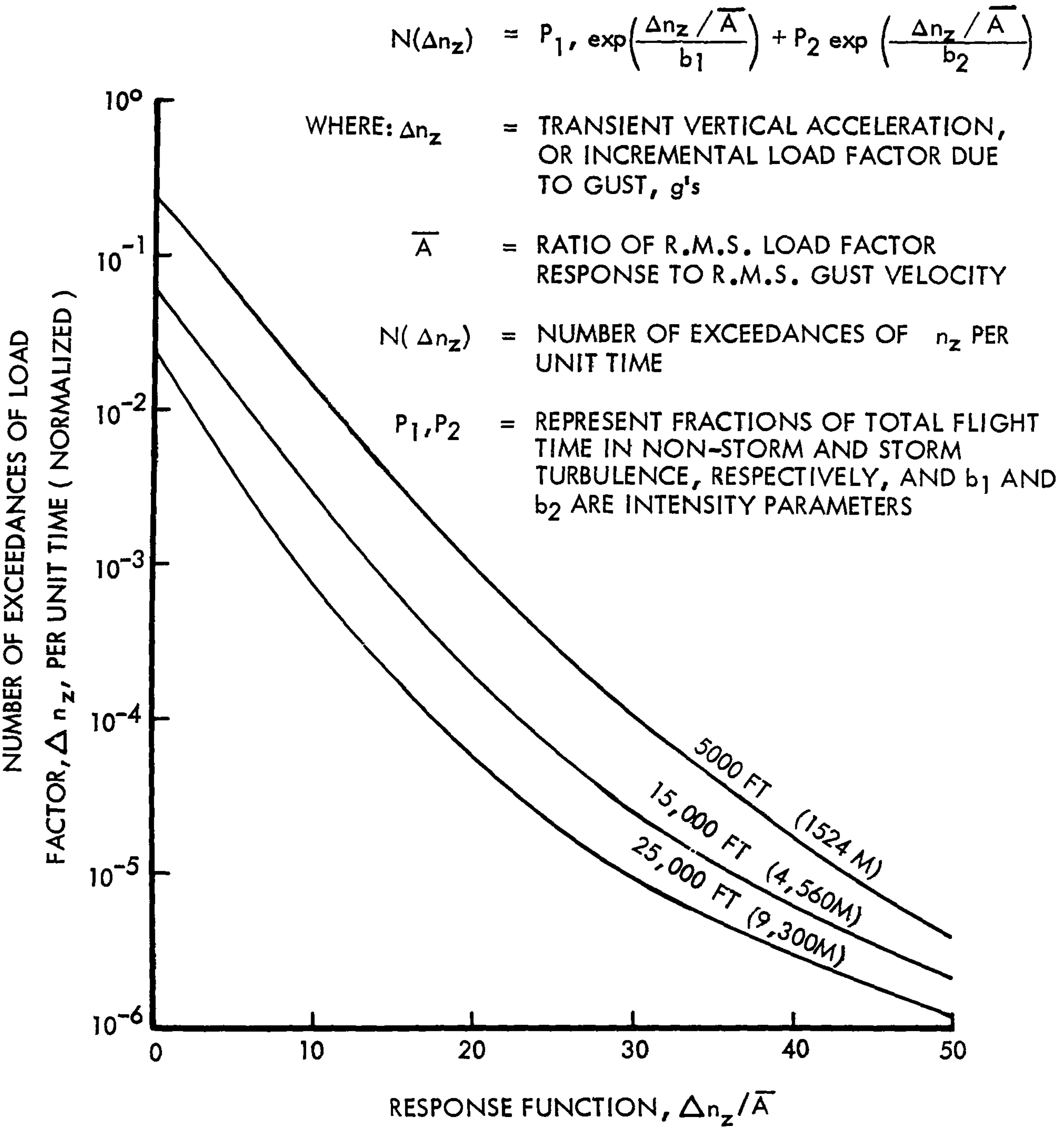


FIGURE 22. GENERALIZED LOAD FACTOR EXCEEDANCE CURVE



$$N(\Delta n_z) = P_1,\ \exp\left(\frac{\Delta n_z / \overline{A}}{b_1}\right) + P_2 \exp\left(-\frac{\Delta n_z / \overline{A}}{b_2}\right)$$

WHERE: Δn_z = TRANSIENT VERTICAL ACCELERATION, OR INCREMENTAL LOAD FACTOR DUE TO GUST, g's

$\overline{A}$ = RATIO OF R.M.S. LOAD FACTOR RESPONSE TO R.M.S. GUST VELOCITY

$N(\Delta n_z)$ = NUMBER OF EXCEEDANCES OF n_z PER UNIT TIME

P_1, P_2 = REPRESENT FRACTIONS OF TOTAL FLIGHT TIME IN NON-STORM AND STORM TURBULENCE, RESPECTIVELY, AND b_1 AND b_2 ARE INTENSITY PARAMETERS

FIGURE 23. COMPARISON OF DIFFERENT COMMUNITY NOISE RATING SCALES

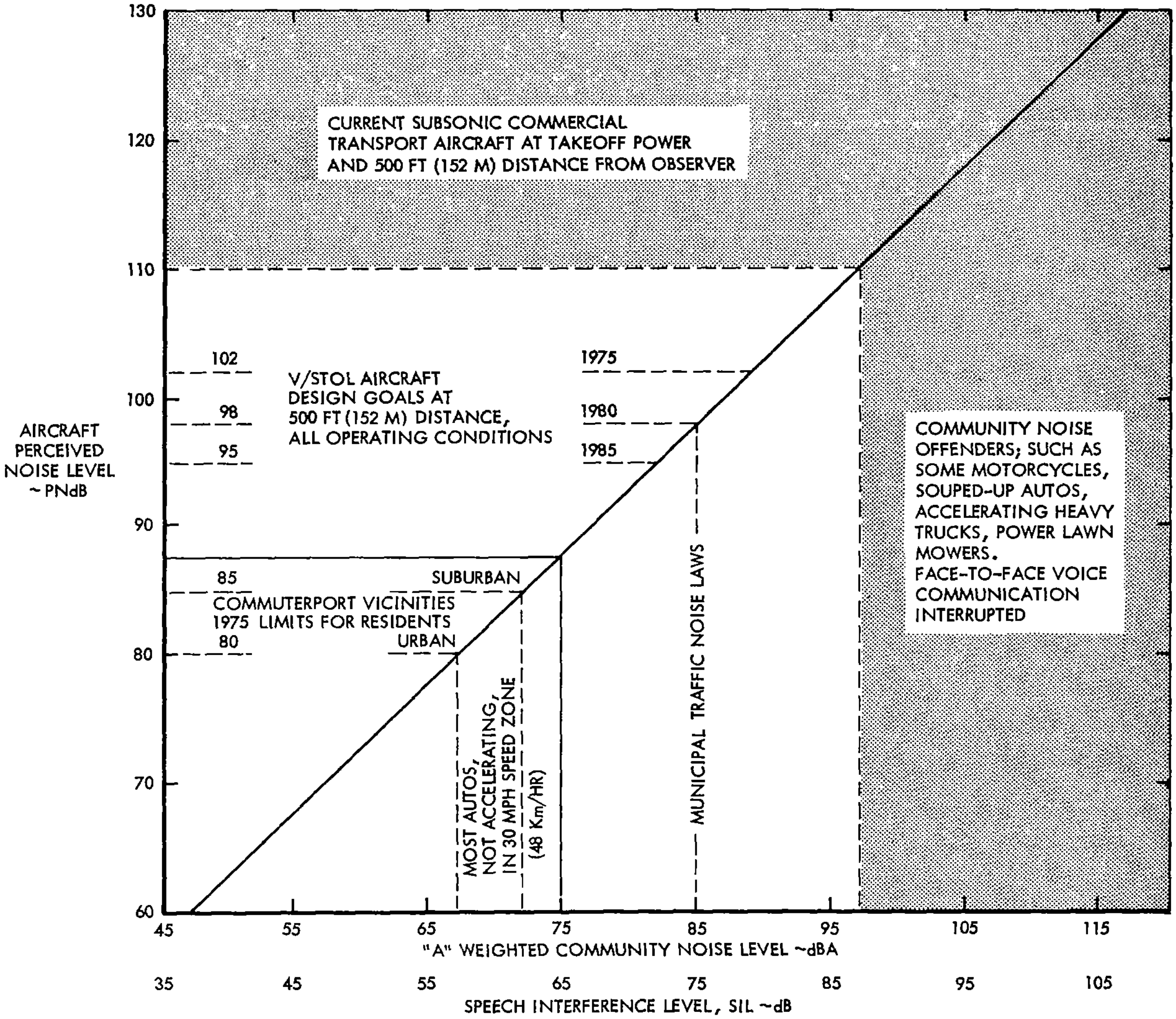


FIGURE 24. DERIVATION OF 250 FT (76M) DESIGN GOAL SPECTRUM TO PROVIDE PNL=85 PNdB AT 2000 FT (610M)

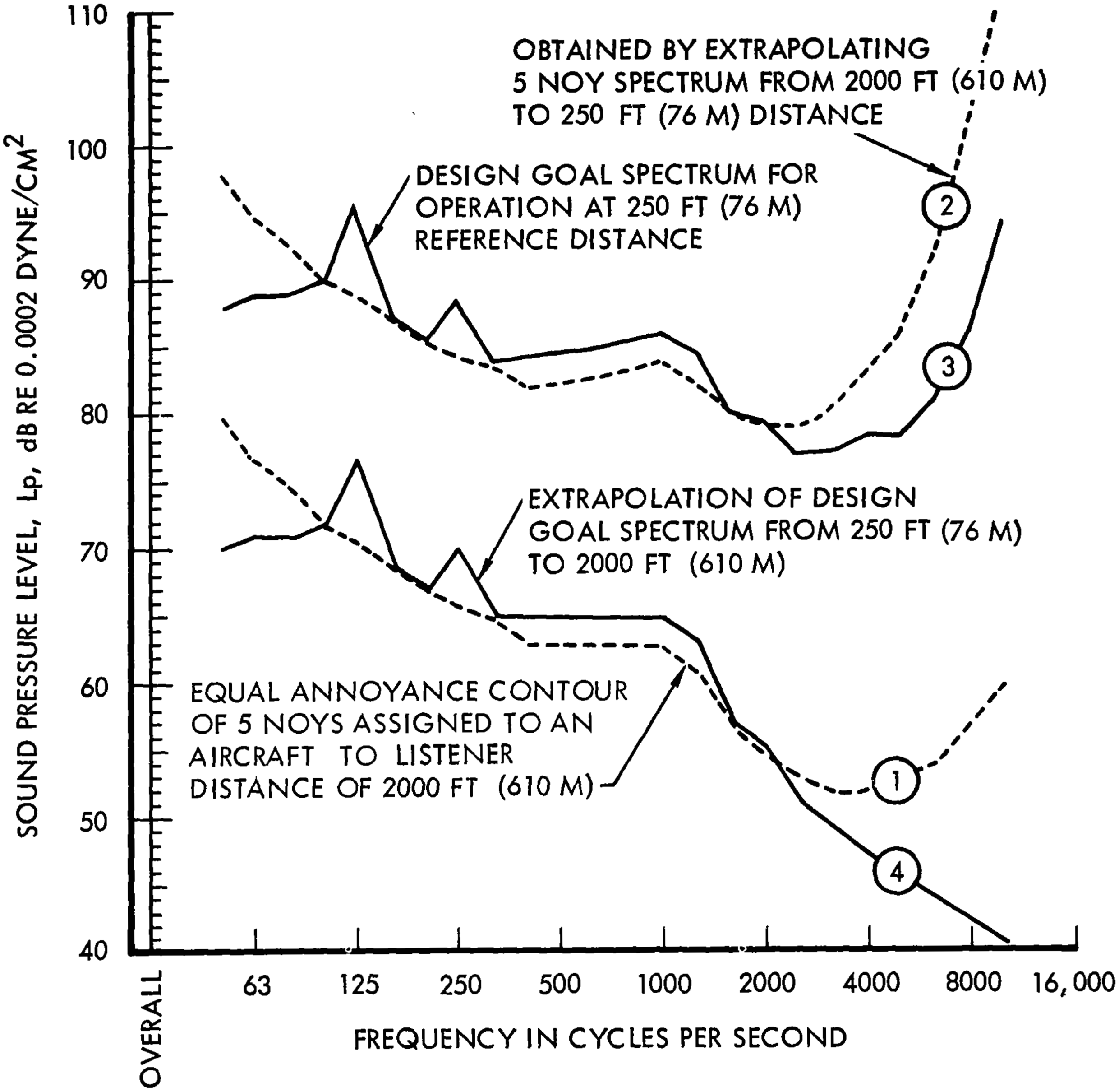


FIGURE 25. 1975 IOC COMMUTERPORT LAND ALLOCATION

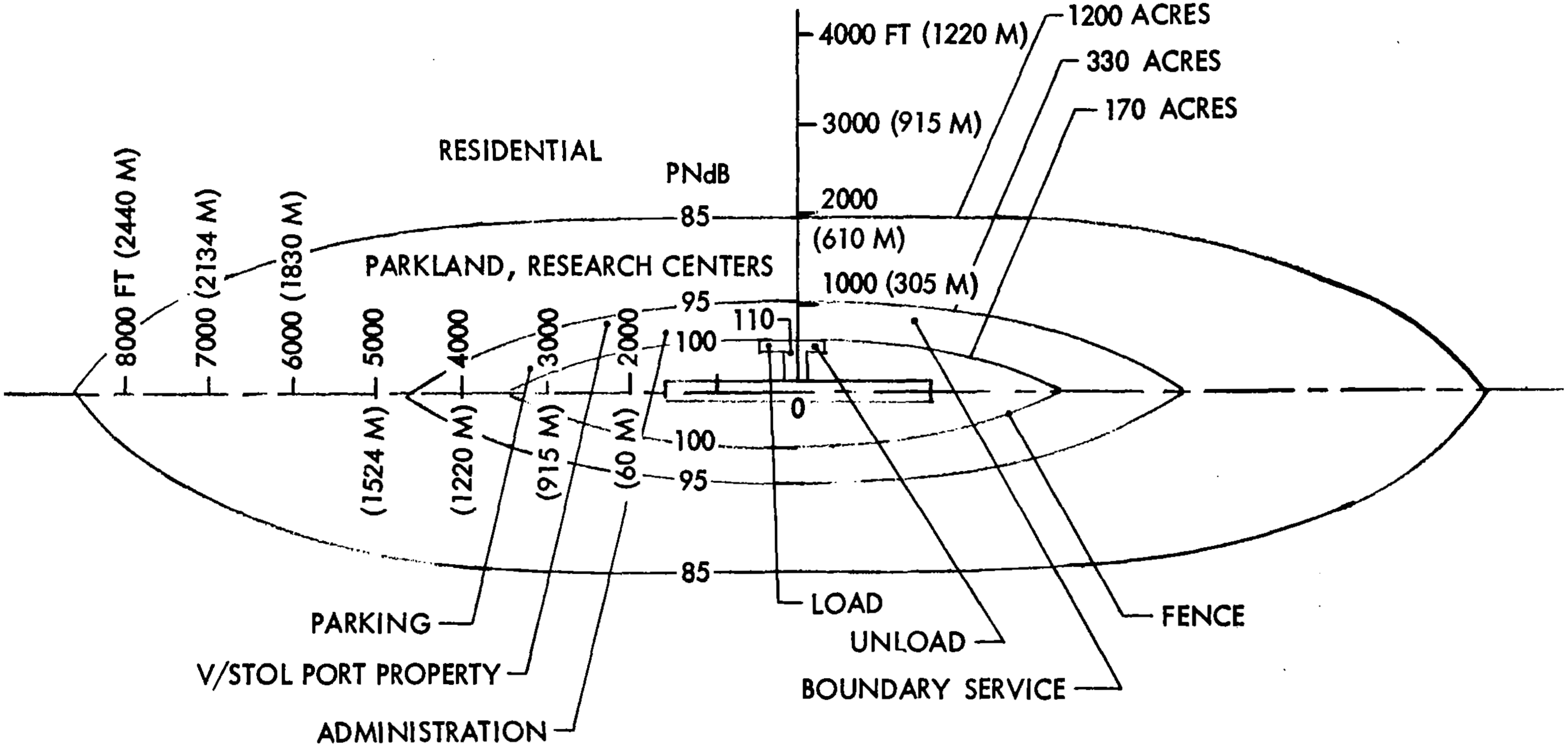


FIGURE 26. TYPICAL ARRANGEMENTS FOR MICROWAVE ILS SYSTEM

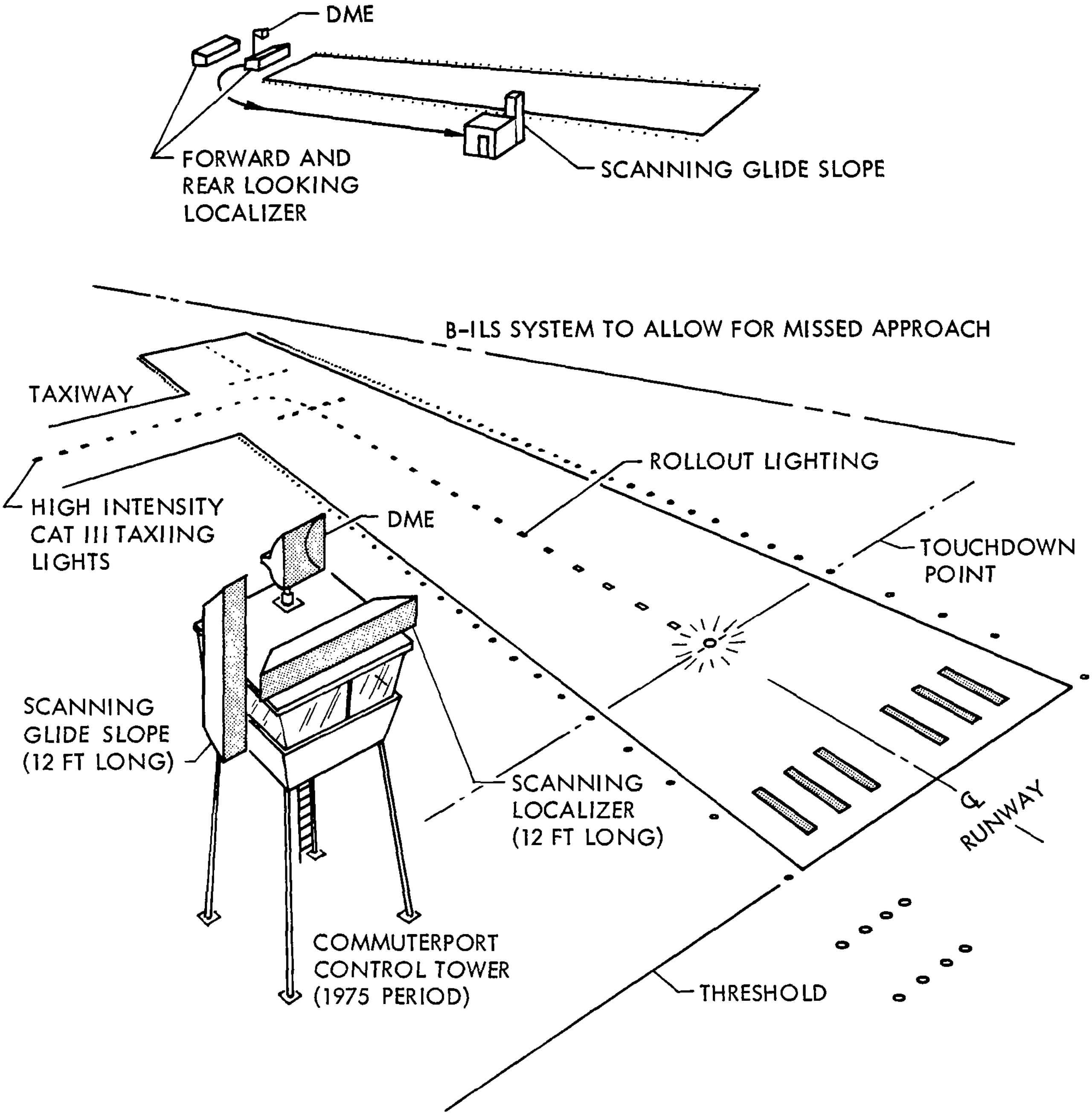


FIGURE 27. CURVED APPROACH PATHS AND EQUIPMENT LOCATION FOR MICROWAVE ILS

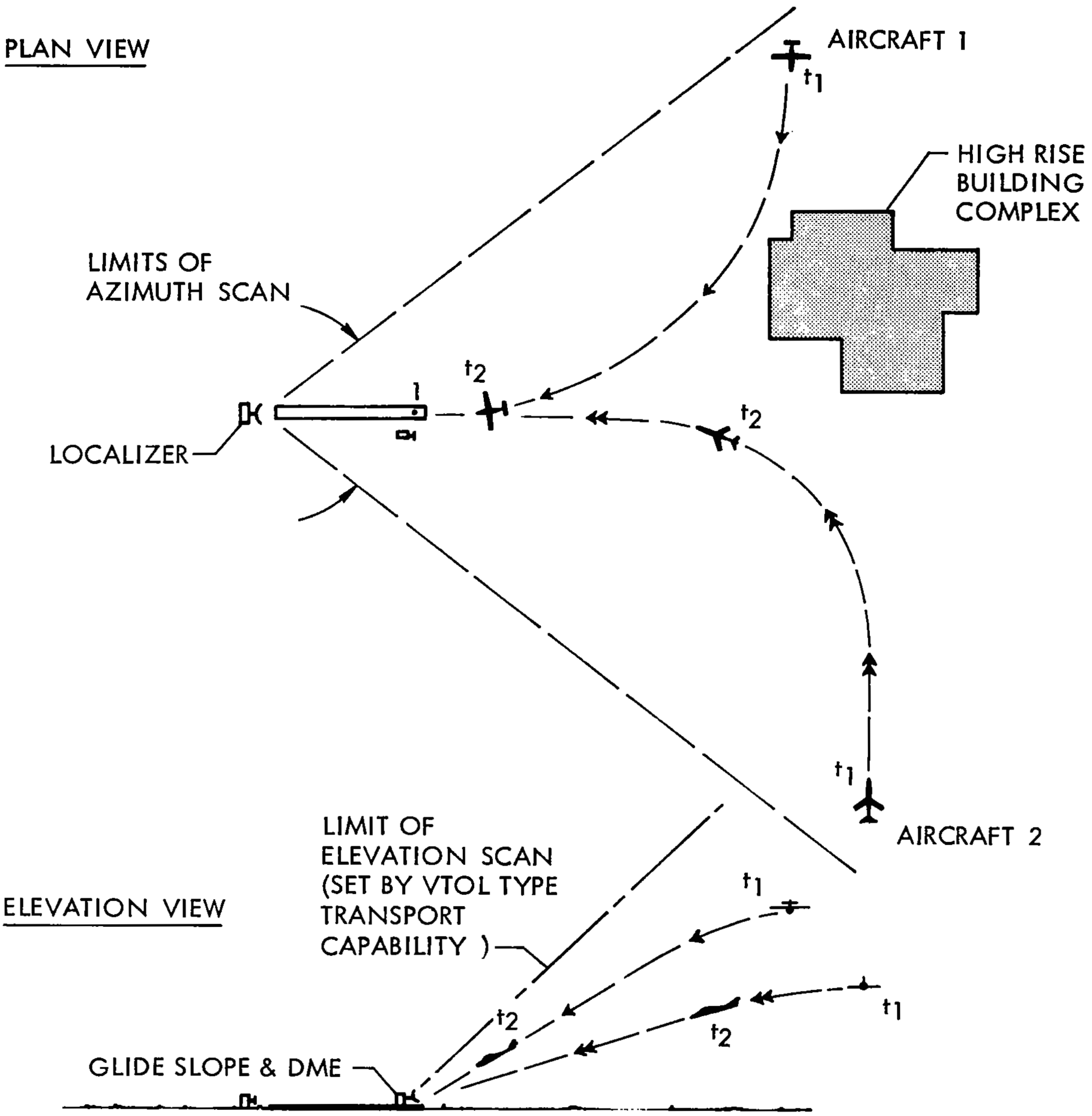


FIGURE 28. INTRAURBAN TRANSPORT TRAFFIC CONTROL SYSTEM

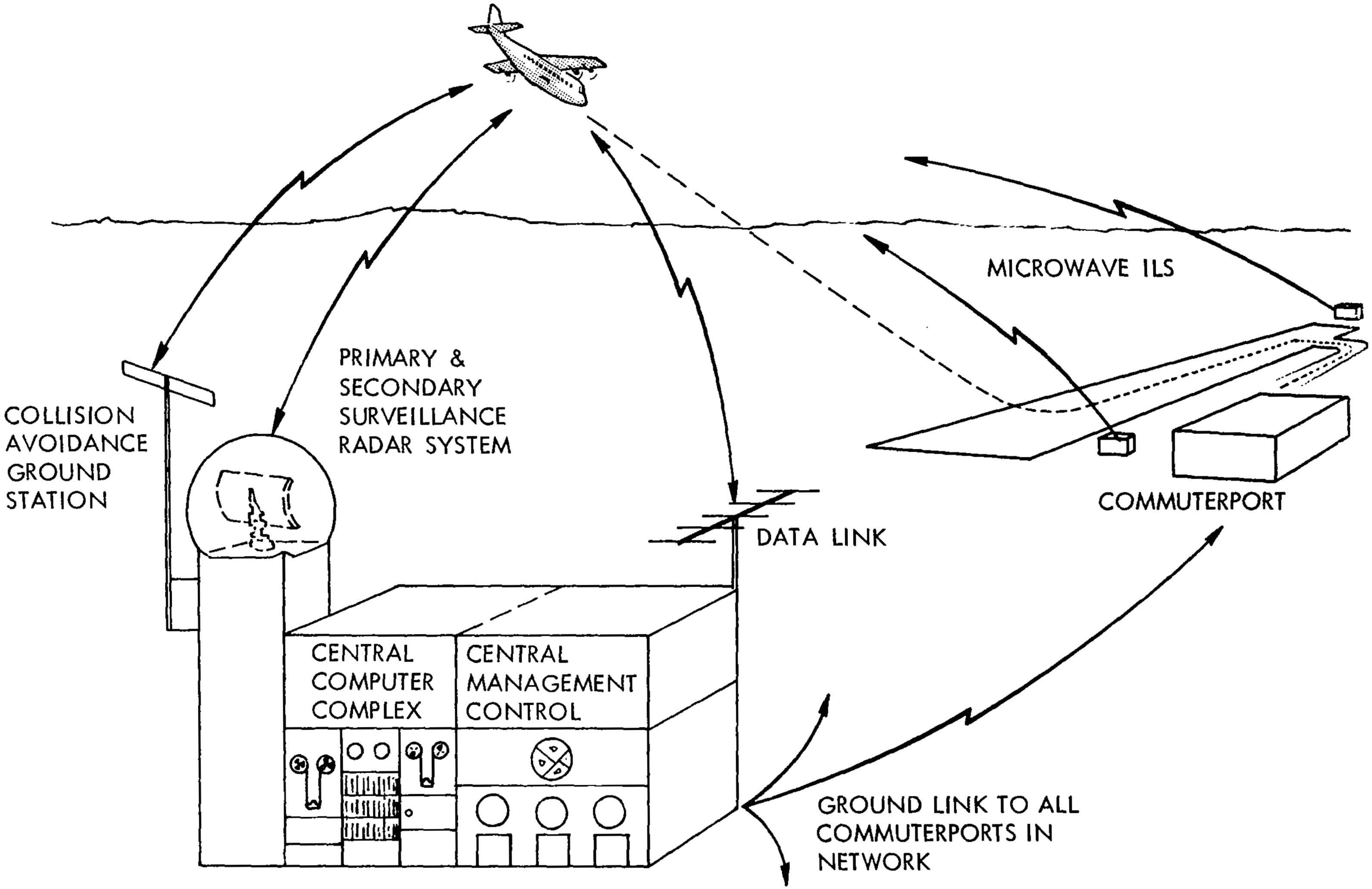


FIGURE 29. CENTRAL COMPUTER COMPLEX

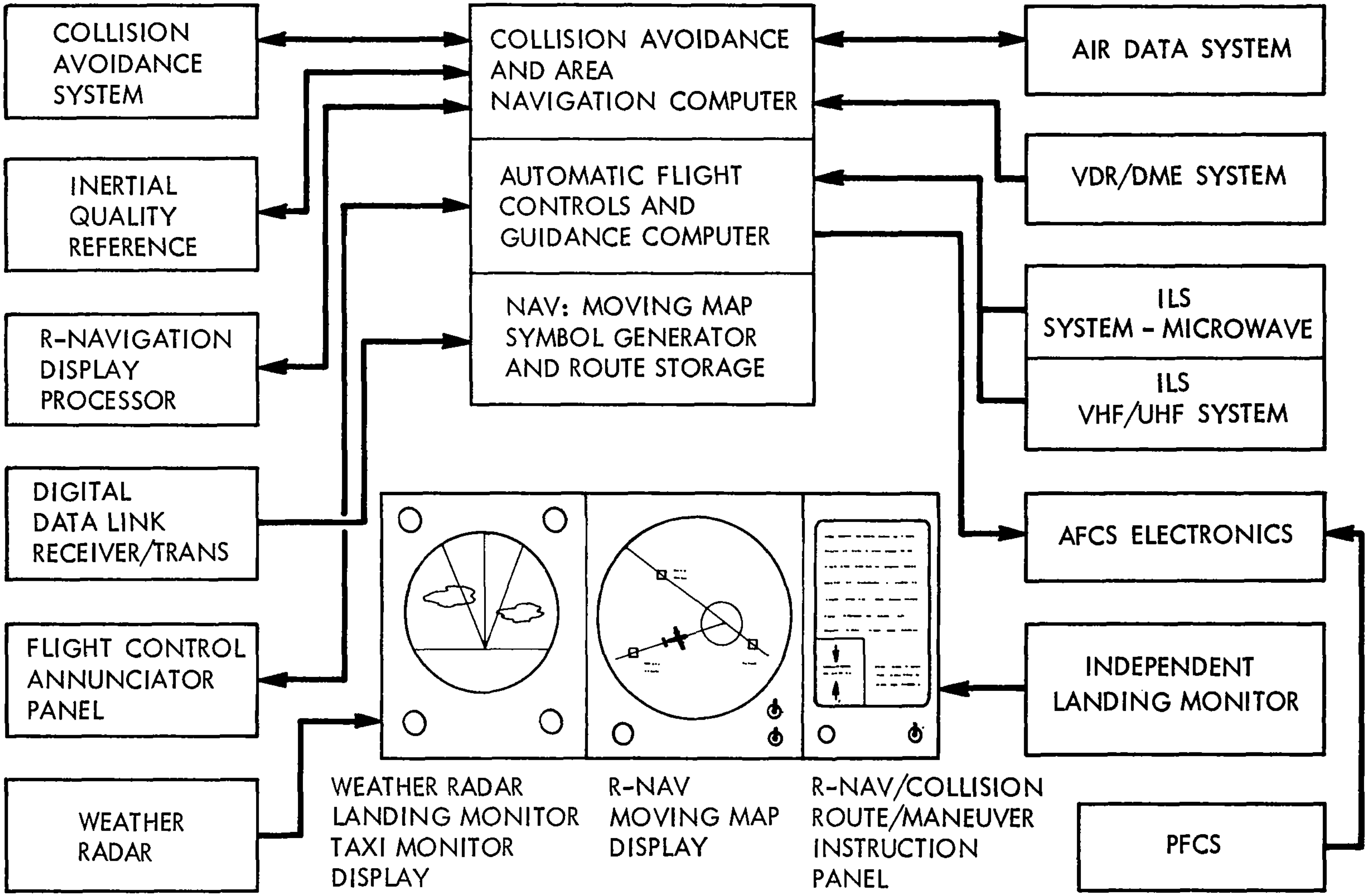


FIGURE 30. INTRAURBAN COMMUTERPORT TERMINAL AND LOADING AREA

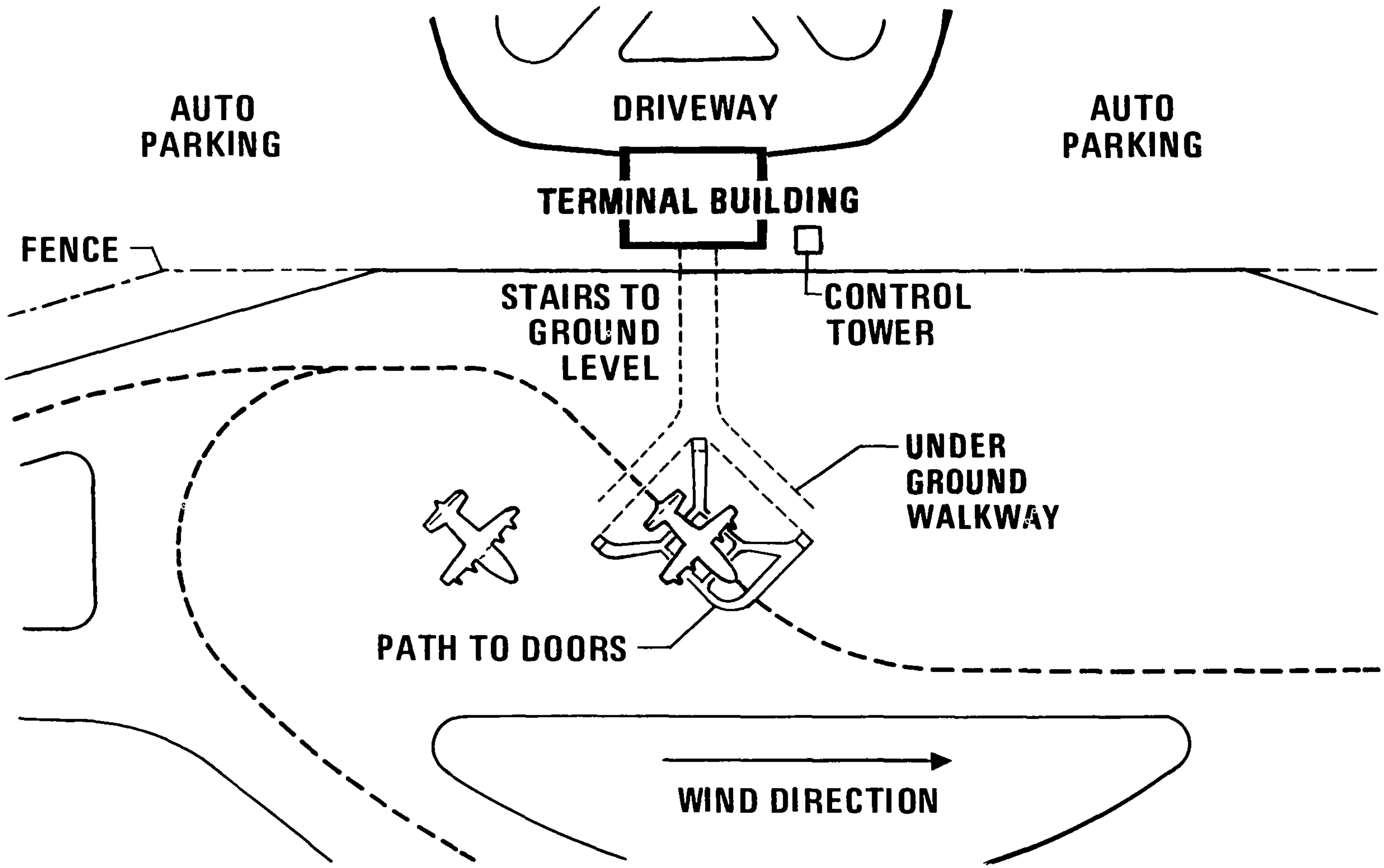


FIGURE 31. POTENTIAL RANGE/PAYLOAD, 60-PASSENGER 1975 AIRCRAFT

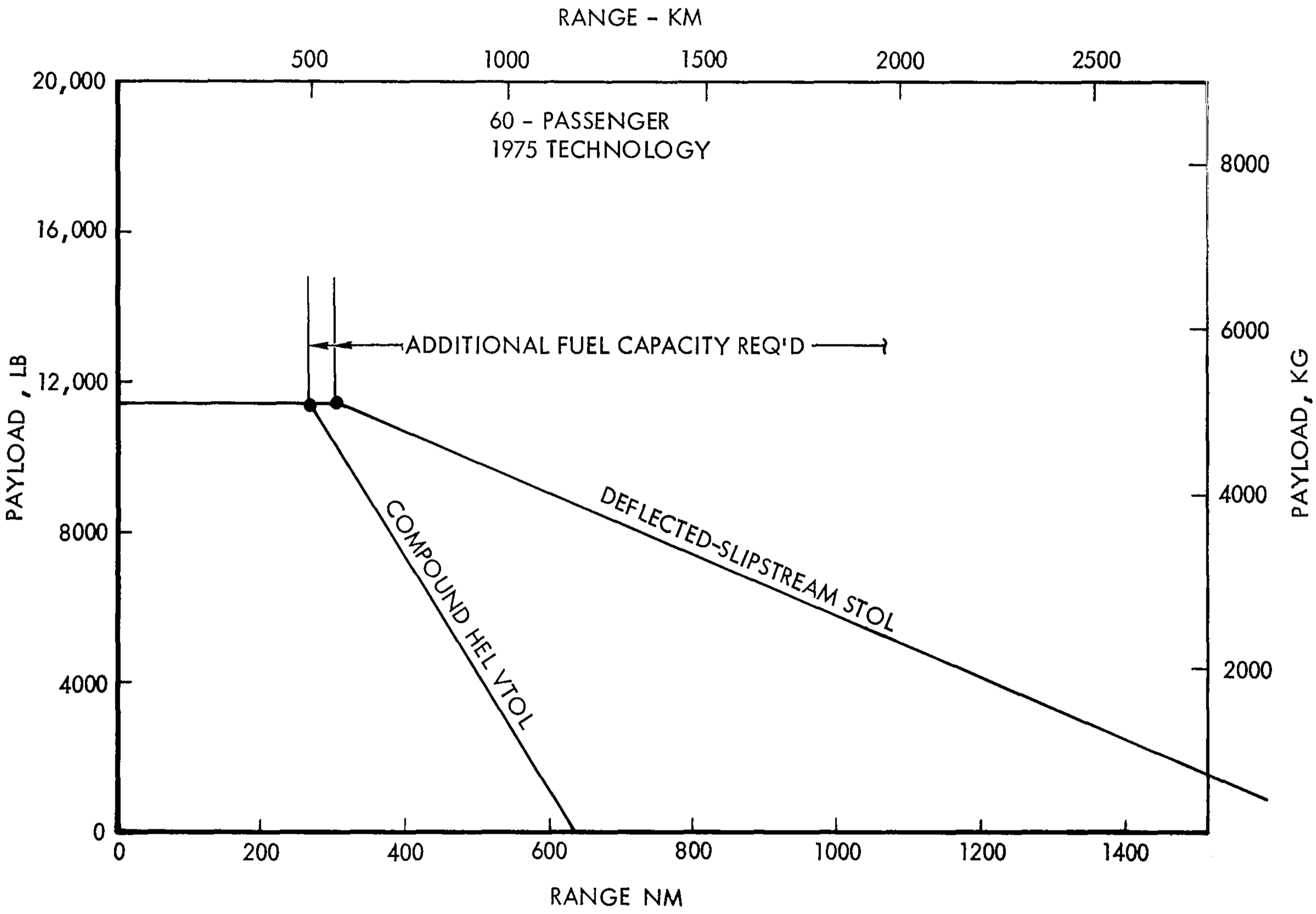


FIGURE 32. DOC FLOW DIAGRAM

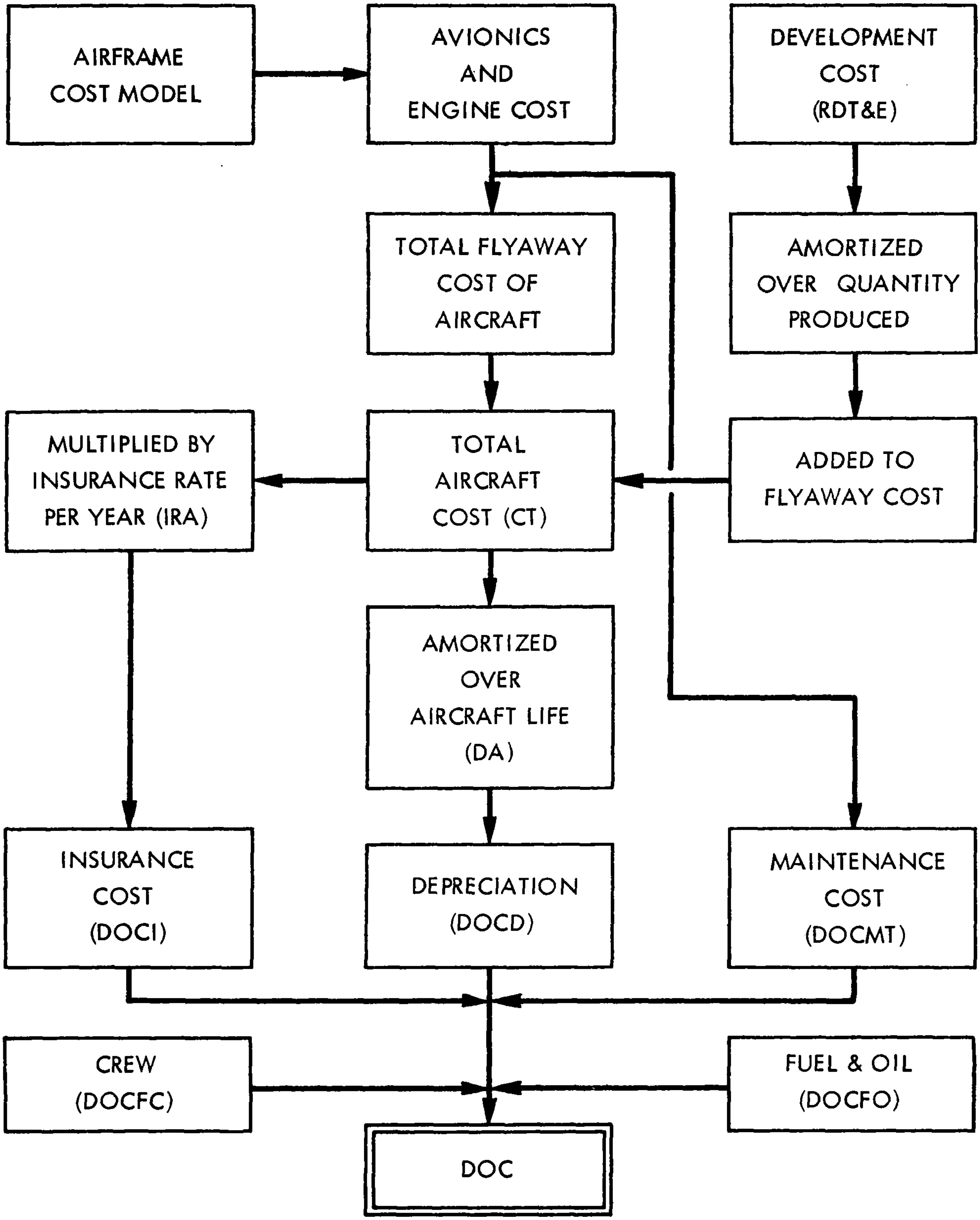


FIGURE 33. TOTAL SYSTEM COST

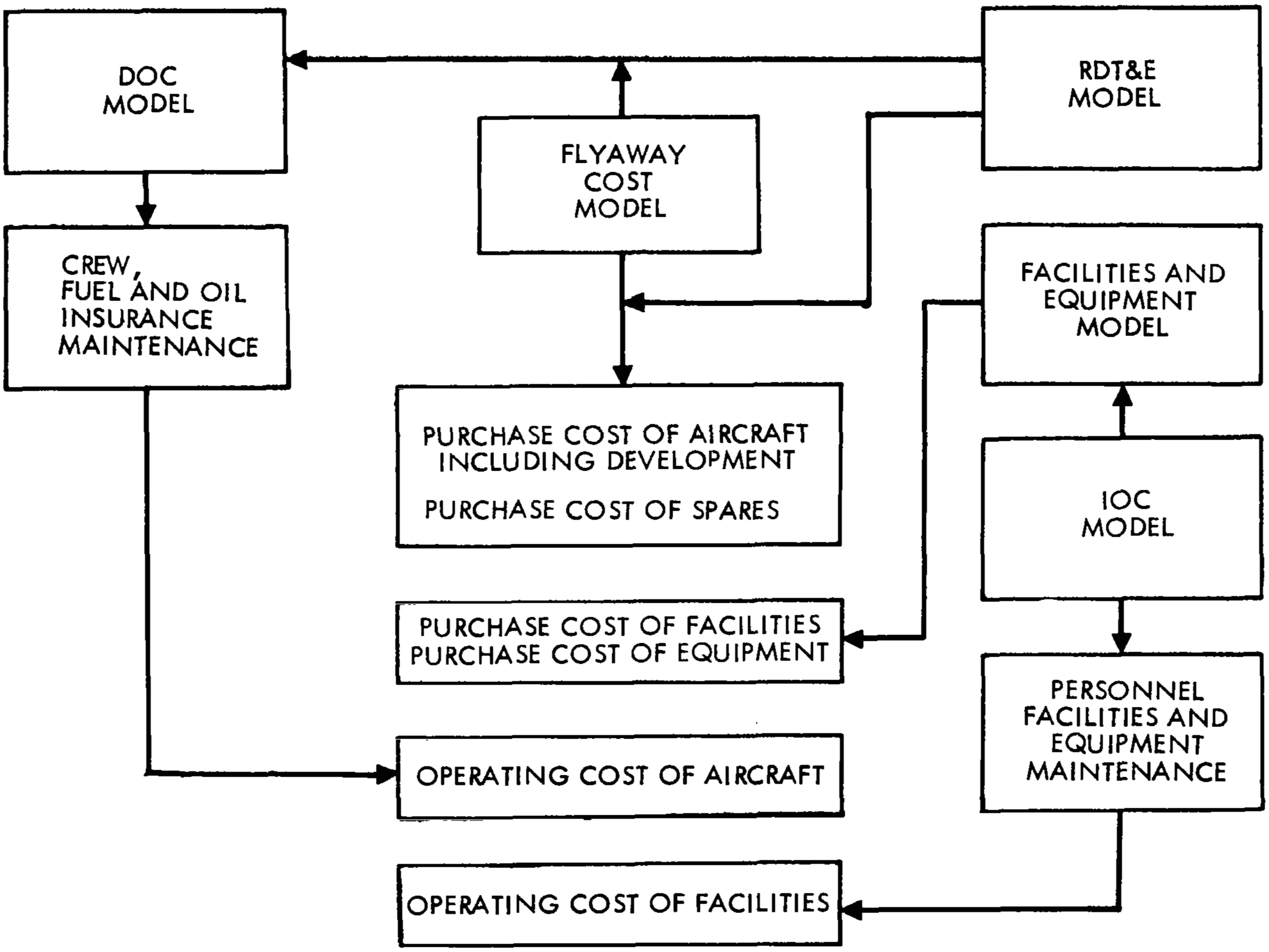


FIGURE 34. COST FACTORS, PHASE I VS PHASE II

60-Passenger DS Aircraft - 1975 20% Demand; 75% Min LF 1500 ft Runway	(1) Phase I	(2) Phase II
DOC		
Flight Crew	49.96	49.96
Fuel and Oil	54.73	54.73
Insurance	78.76	78.90
Depreciation	271.31	271.72
Maintenance	636.26	636.26
Total ($/yr/AC)($-1000)	1091.02	1091.57
IOC		
Facilities Depreciation	102.82	99.55
Personnel	385.56	201.75
Other Expense	298.39	150.52
Facilities Maint	119.10	292.00
Maintenance Burden	35.73	88.23
Ground Equip. Depreciation	5.62	5.62
Total ($/yr/AC)($-1000)	947.22	837.67
Total System Cost		
Aircraft	25.13	25.60
Spares	5.23	5.25
Facilities	18.99	47.70
Ground Equipment	0.65	0.65
Aircraft Operating Cost	94.15	94.15
Facilities Operating Cost	96.34	57.90
Total ($-millions)	240.49	231.25
(1) Fare ($/Passenger)	5.00	4.81
(2) Fare ($/Passenger)	4.97	4.71

FIGURE 35. COST ELEMENTS

60-Passenger Configuration 30% Demand (Factored by 1.57) 2000 Ft Runway	Deflected Slipstream		Compound Helicopter		Autogyro
	1975	1985	1975	1985	1985
DOC					
Flight Crew	97.118	93.182	138.072	125.443	146.506
Fuel and Oil	44.202	37.760	184.509	99.265	117.317
Insurance	79.253	95.891	112.431	93.406	94.139
Depreciation	249.075	301.097	353.640	294.706	298.346
Maintenance	770.758	728.227	979.544	821.791	848.326
Total ($/yr/AC)	1240.406	1256.157	1768.197	1434.611	1504.633
Total (Cents/Seat Mile)	5.6	5.8	8.6	7.2	7.4
IOC					
Facilities Depreciation	33.570	28.650	26.551	22.486	24.411
Personnel	88.186	74.921	87.871	82.811	85.140
Other Expense	107.503	109.904	98.151	102.552	105.597
Facilities Maintenance	121.054	102.638	49.277	41.831	58.442
Maintenance Burden	36.316	30.791	14.783	12.549	17.533
Ground Equipment Depreciation	6.376	6.397	7.350	5.889	6.014
Total ($/yr/AC)	393.005	353.300	283.984	268.117	297.136
Total (Cents/Seat Mile)	1.8	1.6	1.3	1.3	1.4

FIGURE 35. COST ELEMENTS (CONTINUED)

60-Passenger Configuration 30% Demand (Factored by 1.57) 2000 Ft Runway	Deflected Slipstream		Compound Helicopter		Autogyro
	1975	1985	1975	1985	1985
TOTAL SYSTEM COST					
Aircraft	68.686	99.087	108.684	105.860	103.553
Aircraft Spares	7.733	11.212	12.836	12.875	12.920
Facilities	52.250	52.502	22.305	22.322	31.020
Equipment	1.989	2.380	2.558	2.403	2.382
Aircraft Operating Cost	209.239	355.282	492.266	465.081	477.689
Facilities Operating Cost	110.154	118.390	87.029	97.815	105.618
Total	550.052	638.856	725.678	706.355	733.182
FARE (1) ($/Passenger)	5.38	5.00	7.06	5.52	5.73
FARE (2) ($/Passenger)	4.98	4.69	6.94	5.43	5.58
FARE (3) ($/Passenger)	4.51	4.30	6.69	5.23	5.32
Aircraft Flyaway Cost	2.642	3.196	3.748	3.113	3.138
Fleet Size (No. of AC)	26	31	29	34	33
Aircraft Utilization	1981	1931	1987	1894	2123
Load Factor (Average)	.51	.56	.50	.55	.55

FIGURE 36. SUBSIDY/GRANT COMPARISON

Subsidy	Total System Cost ($-Millions)		Fare $ Per Passenger		Cost Per Year For Subsidy ($-Millions/Year)
	Without Subsidy	With Subsidy	Without Subsidy	With Subsidy	
A	550	496	5.38	4.51	4.48
B	550	315	5.38	3.38	19.61
C	550	121	5.38	1.73	23.83 11.94 35.77
D	550	323	5.38	3.45	12.6 6.3 18.9

FIGURE 37. ASSET MODEL

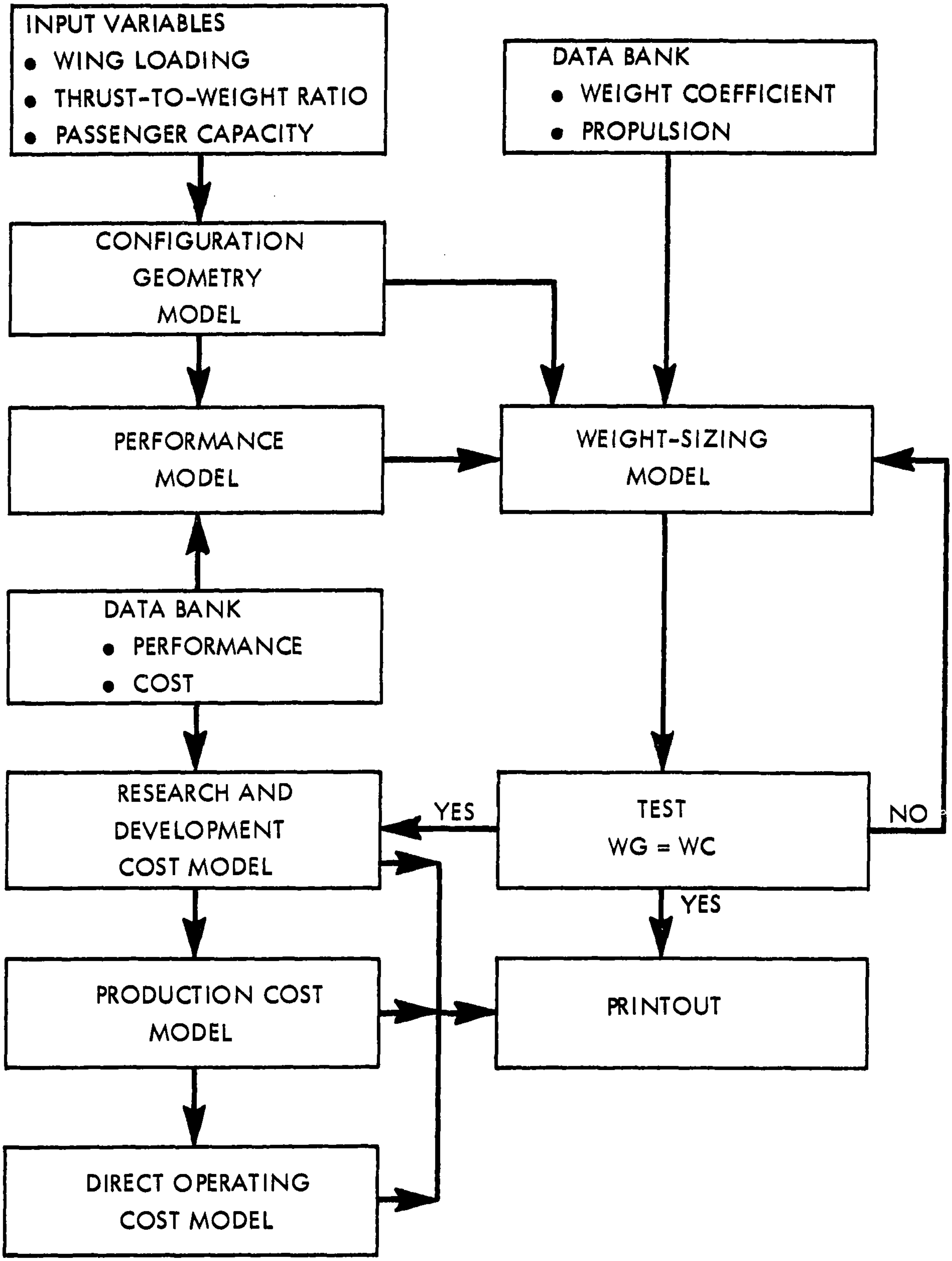


FIGURE 38. WEIGHT-SIZING PRINTOUT

DEFLECTED-SLIPSTREAM STOL - 75					CASE NO. 226
	LB	LB	%	Kg	Kg
DESIGN GROSS WEIGHT		42204.			19,143.
FUEL		2198.	5.21		997.
ZERO FUEL WEIGHT		40007.			18,147.
PAYLOAD		11400.	27.01		5170.
OPERATING WEIGHT EMPTY		28607.			12,976.
OPERATIONAL ITEMS	485.		1.15	220.	
STANDARD ITEMS	170.		0.40	77.	
EMPTY WEIGHT-MFG		27951.			12,678.
WING	3940.		9.33	1787.	
TAIL	1474.		3.49	669.	
BODY	4826.		11.44	2189.	
LANDING GEAR	1813.		4.30	822.	
SURFACE CONTROLS	888.		2.10	403.	
NACELLES	1051.		2.49	477.	
PROPULSION SYSTEM		4380.	10.38		1987.
ENGINE	1245.			565.	
PROPELLERS	1128.			512.	
FIRE EXTING	125.			57.	
EXHAUST	68.			31.	
CROSS SHAFTING	1107.			502.	
COOLING	62.			28.	
OIL SYSTEM (LESS OIL)	62.			28.	
ENGINE CONTROLS	59.			27.	
ENGINE STARTING	87.			39.	
FUEL	436.			198.	
INSTRUMENTS		410.	0.97		186.
HYDRAULICS		303.	0.72		137.
ELECTRICAL		1360.	3.22		617.
ELECTRONICS		1178.	2.79		534.
FURNISHINGS		4186.	9.92		1899.
AIR CONDITIONING		1553.	3.68		704.
ANTI-ICING		238.	0.56		108.
AUXILIARY POWER UNIT		350.	0.83		158.
SYSTEM INTEGRATION			100.00		
NO. OF PASSENGERS		60.			
SEAT PITCH, IN (CM)		34.(86.5)			
FUSELAGE LENGTH FT (METER)		74.(23.)			
FUSELAGE DIAMETER FT (METER)		13.(4.)			
WING AREA FT SQ (METER SQ)		703.(65.)			
ASPECT RATIO		7.			
WING SWEEP		0.			
NO. OF CREW		2.			
THRUST PER ENGINE LB. (KG)		3902.(1770)			1770.
HORIZ TAIL AREA FT SQ (METER SQ)		274.(25.3)			
VERT TAIL AREA FT SQ (METER SQ)		173.(16.0)			
WING T PEC C		17.			
LANDING FIELD LENGTH FT (METER)		2000.(610.)			
TAKEOFF FIELD LENGTH FT (METER)		2000.(610)			
THRUST TO WEIGHT RATIO		0.37			
WING LOADING LB/FT SQ (K/M SQ)		60.(293.)			
FUEL FRACTION		0.0521			

FIGURE 39. 1975 CONVENTIONAL TAKEOFF AND LANDING (CTOL) - PARAMETRIC AIRCRAFT SYNTHESIS

- CONVENTIONAL TAKEOFF AND LANDING (CTOL)
- PROP POWERED - 1975 IOC
- SIXTY PASSENGERS

WING LOADING	40	60	80	100	LBS/FT^2
	195	293	391	488	Kg/m^2

FIELD LENGTH	2000	2500	3000	3500	FEET
	610	762	914	1067	METER

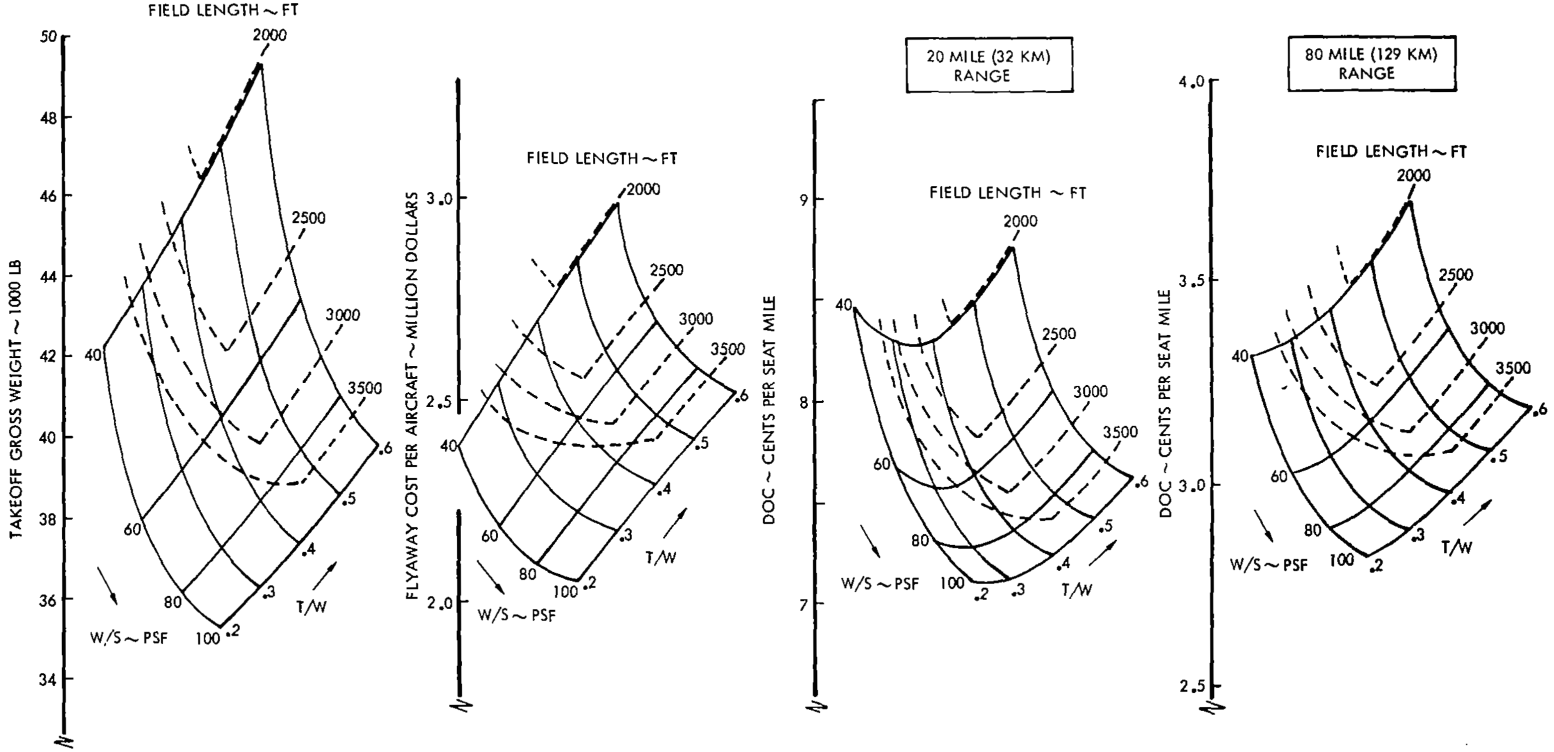
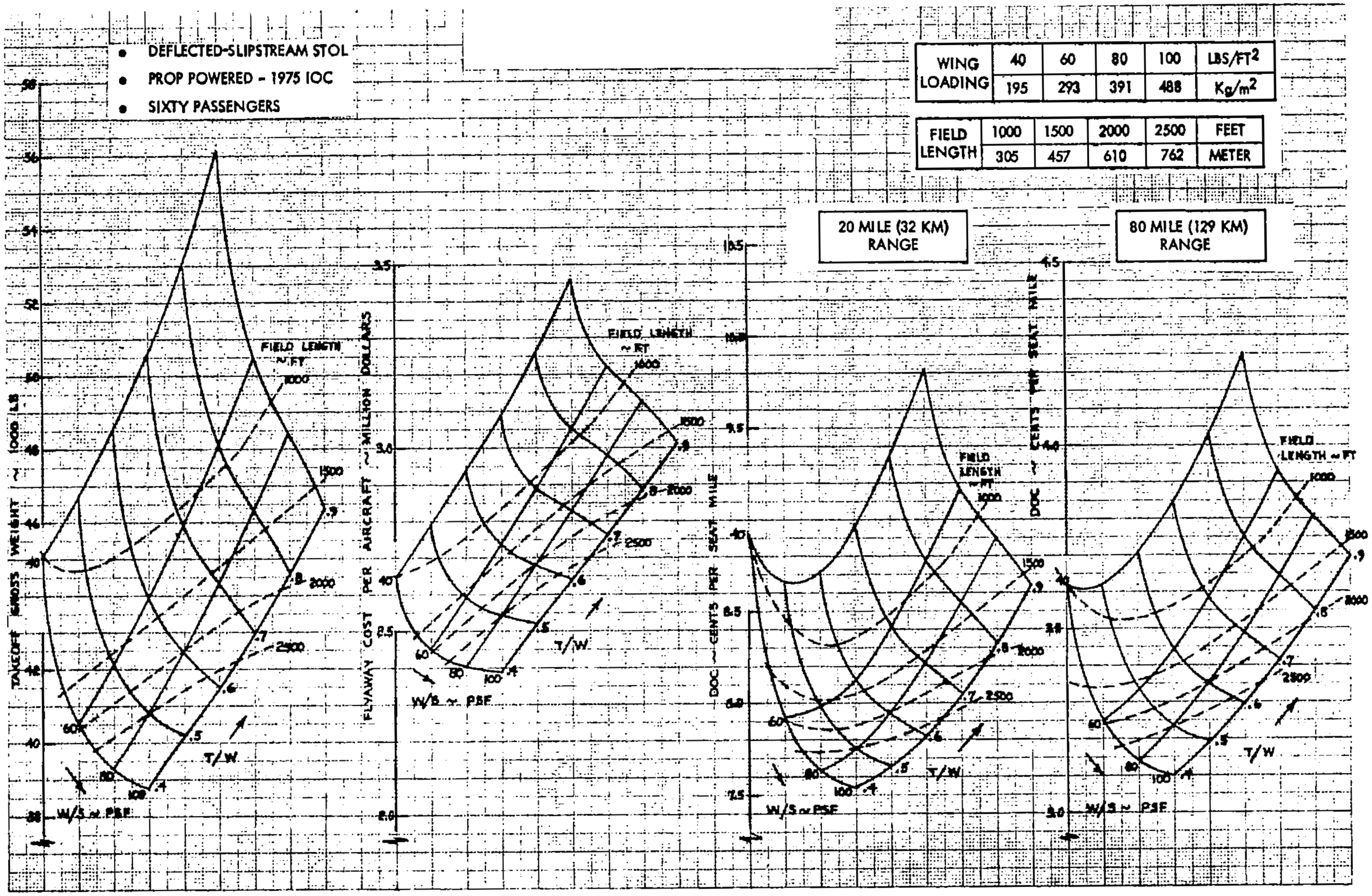


FIGURE 40. 1975 DEFLECTED-SLIPSTREAM STOL - PARAMETRIC AIRCRAFT SYNTHESIS


- DEFLECTED-SLIPSTREAM STOL
- PROP POWERED - 1975 IOC
- SIXTY PASSENGERS

WING LOADING	40	60	80	100	LBS/FT^2
	195	293	391	488	Kg/m^2

FIELD LENGTH	1000	1500	2000	2500	FEET
	305	457	610	762	METER

FIGURE 41. 1985 CONVENTIONAL TAKEOFF AND LANDING (CTOL) - PARAMETRIC AIRCRAFT SYNTHESIS

- CONVENTIONAL TAKEOFF AND LANDING (CTOL)
- FAN POWERED - 1985 IOC
- SIXTY PASSENGERS

WING LOADING	40	60	80	100	LBS/FT^2
	195	293	391	488	Kg/m^2

FIELD LENGTH	2000	2500	3000	3500	FEET
	610	762	914	1067	METER

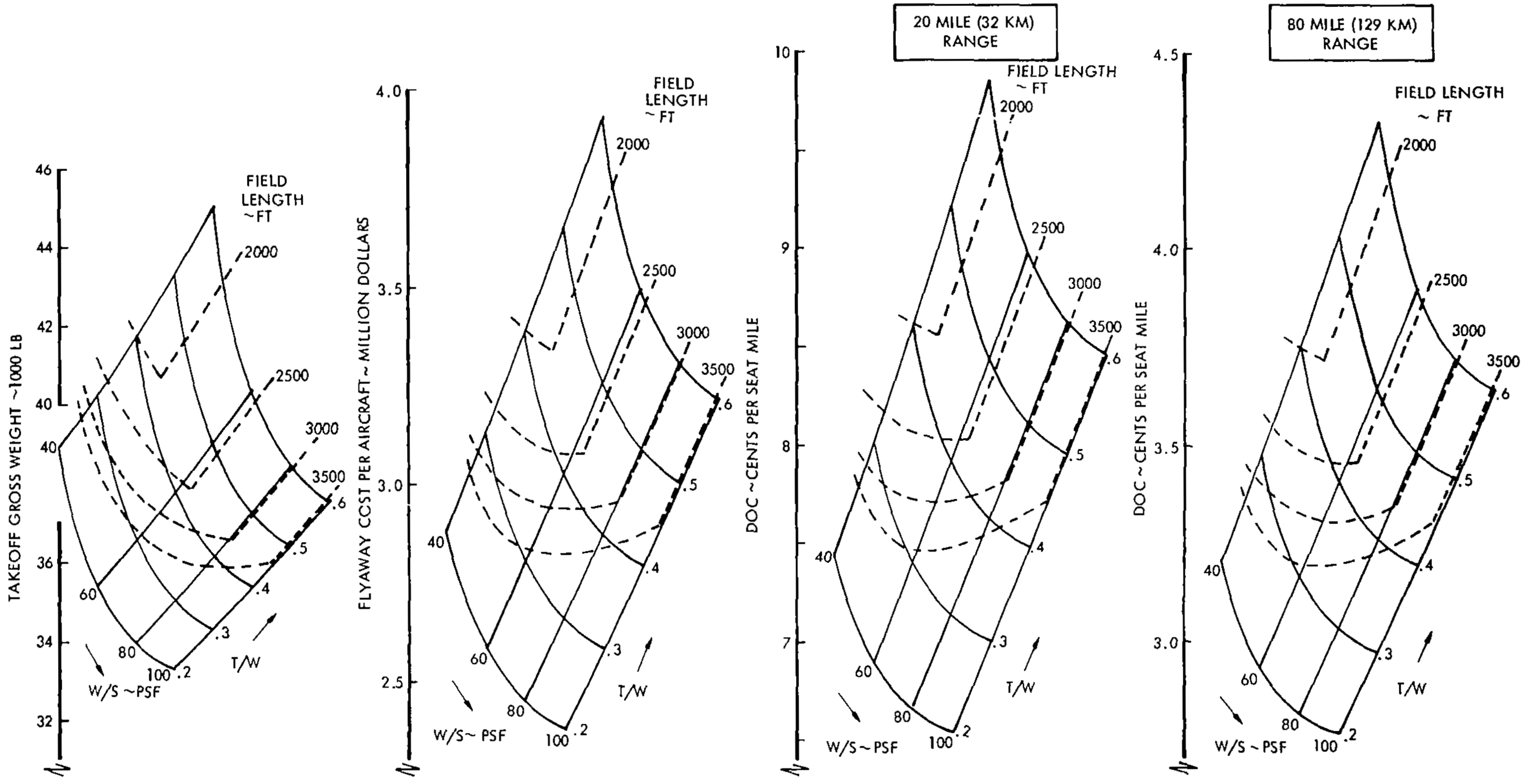
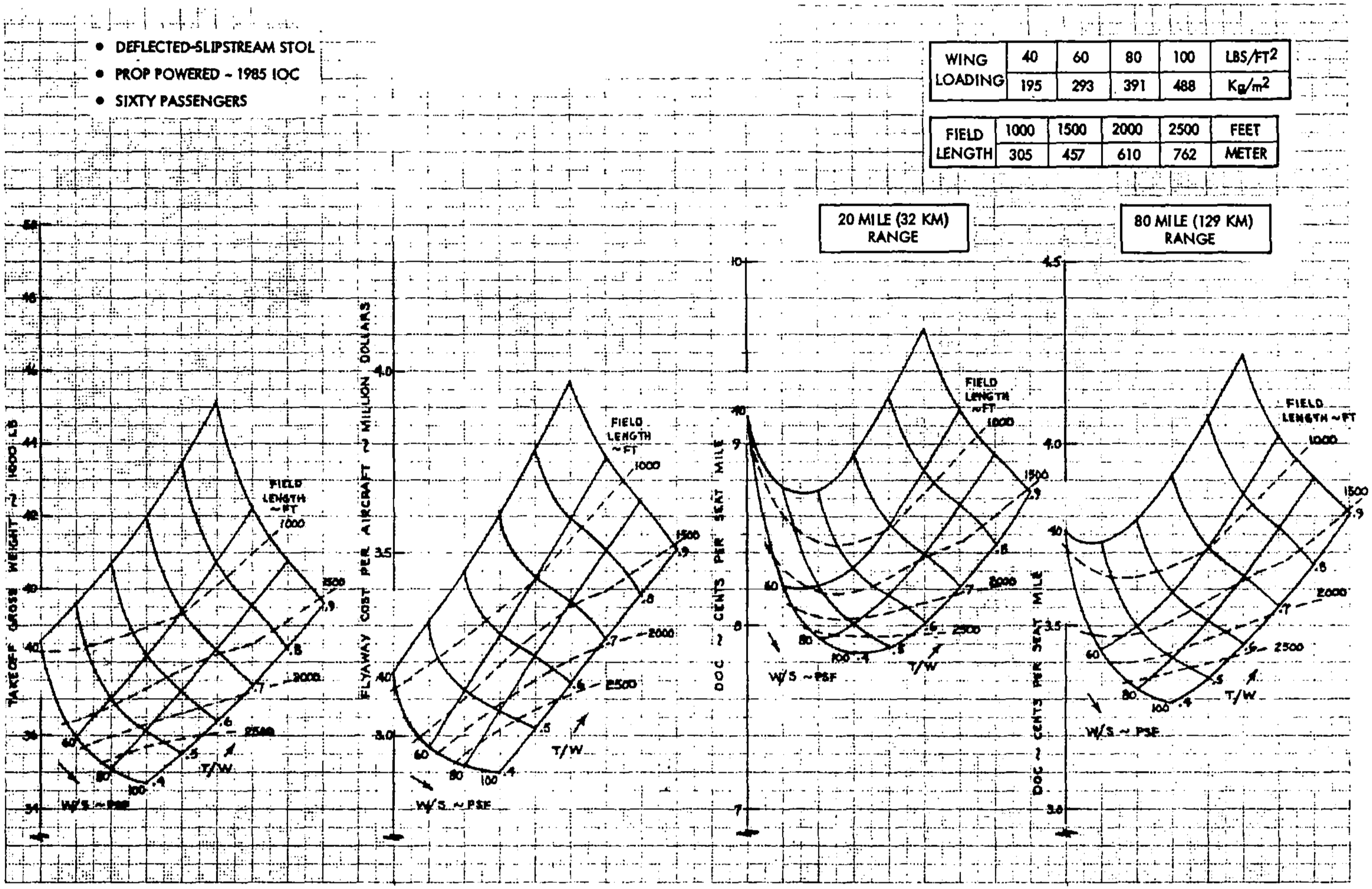


FIGURE 42. 1985 DEFLECTED-SLIPSTREAM STOL - PARAMETRIC AIRCRAFT SYNTHESIS



- DEFLECTED-SLIPSTREAM STOL
- PROP POWERED - 1985 IOC
- SIXTY PASSENGERS

WING LOADING	40	60	80	100	LBS/FT²
	195	293	391	488	Kg/m²

FIELD LENGTH	1000	1500	2000	2500	FEET
	305	457	610	762	METER

FIGURE 43. 1985 AUGMENTOR-WING STOL - PARAMETRIC AIRCRAFT SYNTHESIS

- AUGMENTOR-WING STOL
- FAN POWERED - 1985 IOC
- SIXTY PASSENGERS

WING LOADING	40	60	80	100	LBS/FT²
	195	293	391	488	Kg/m²

FIELD LENGTH	1000	1200	1400	1600	FEET
	305	366	427	488	METER

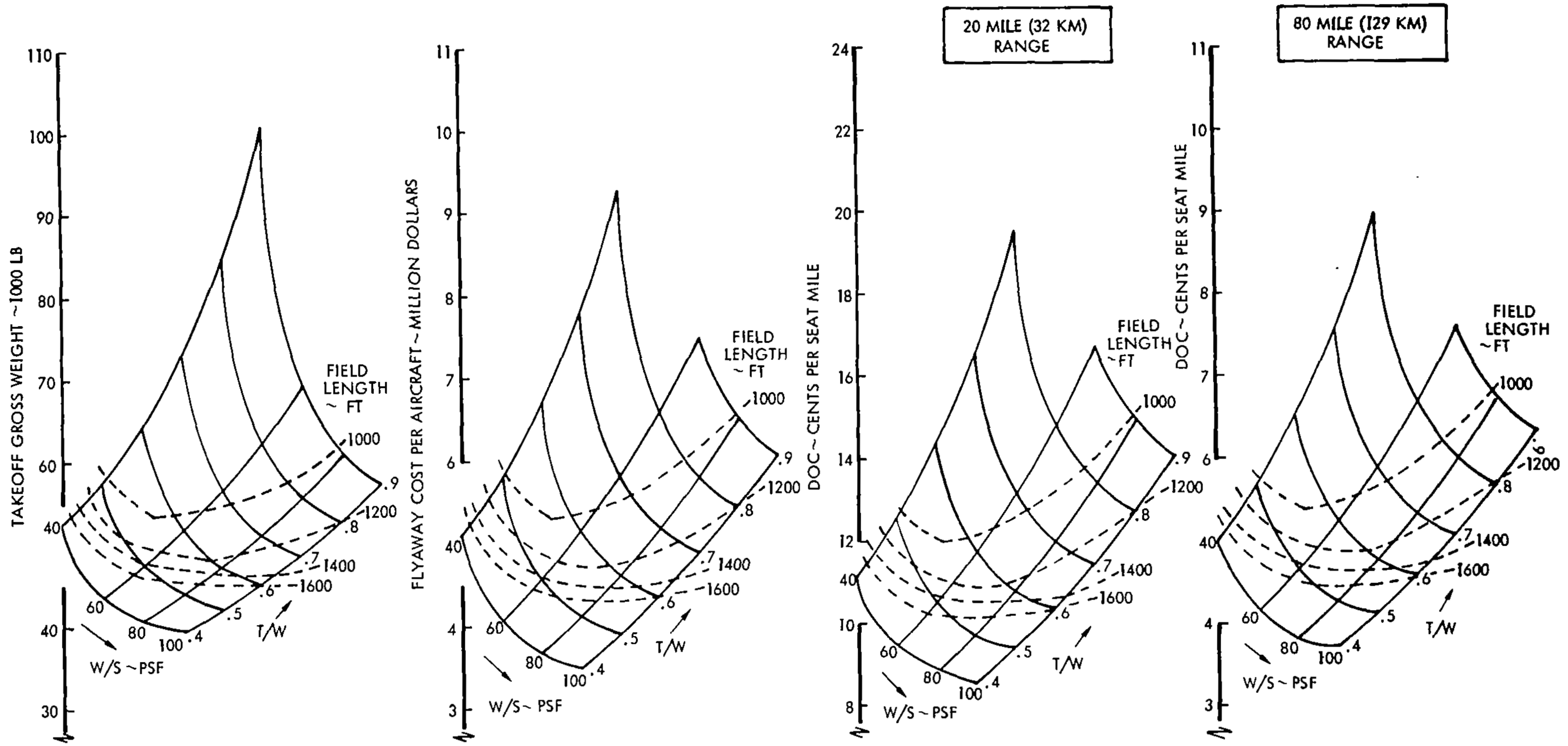


FIGURE 44. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1975 CTOL AIRCRAFT CONCEPT

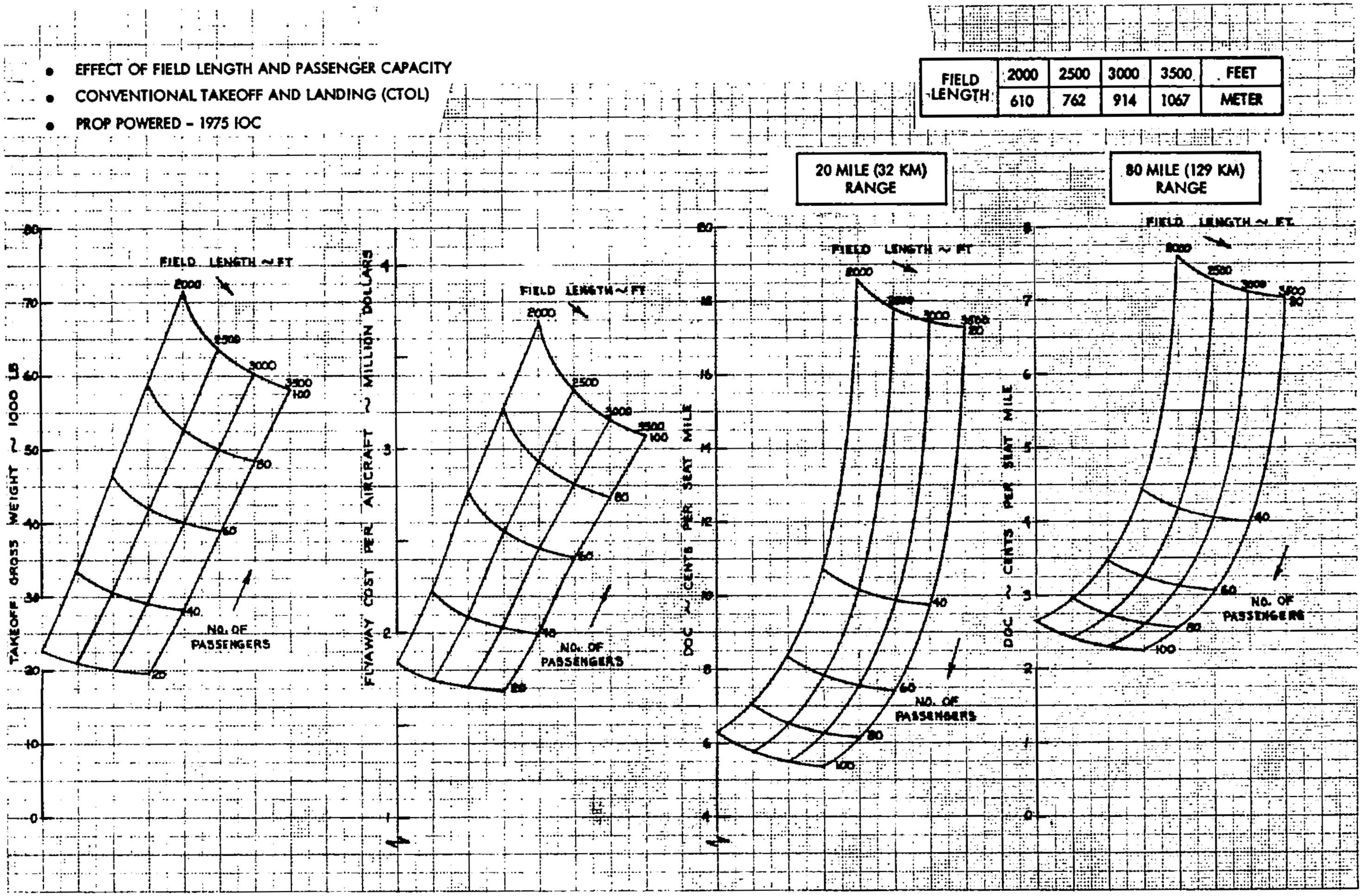


FIGURE 45. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1975 DEFLECTED-SLIPSTREAM STOL AIRCRAFT CONCEPT

- EFFECT OF FIELD AND PASSENGER CAPACITY
- DEFLECTED-SLIPSTREAM STOL
- PROP POWERED - 1975 IOC

FIELD LENGTH	1000	1500	2000	2500	FEET
	305	457	610	762	METER

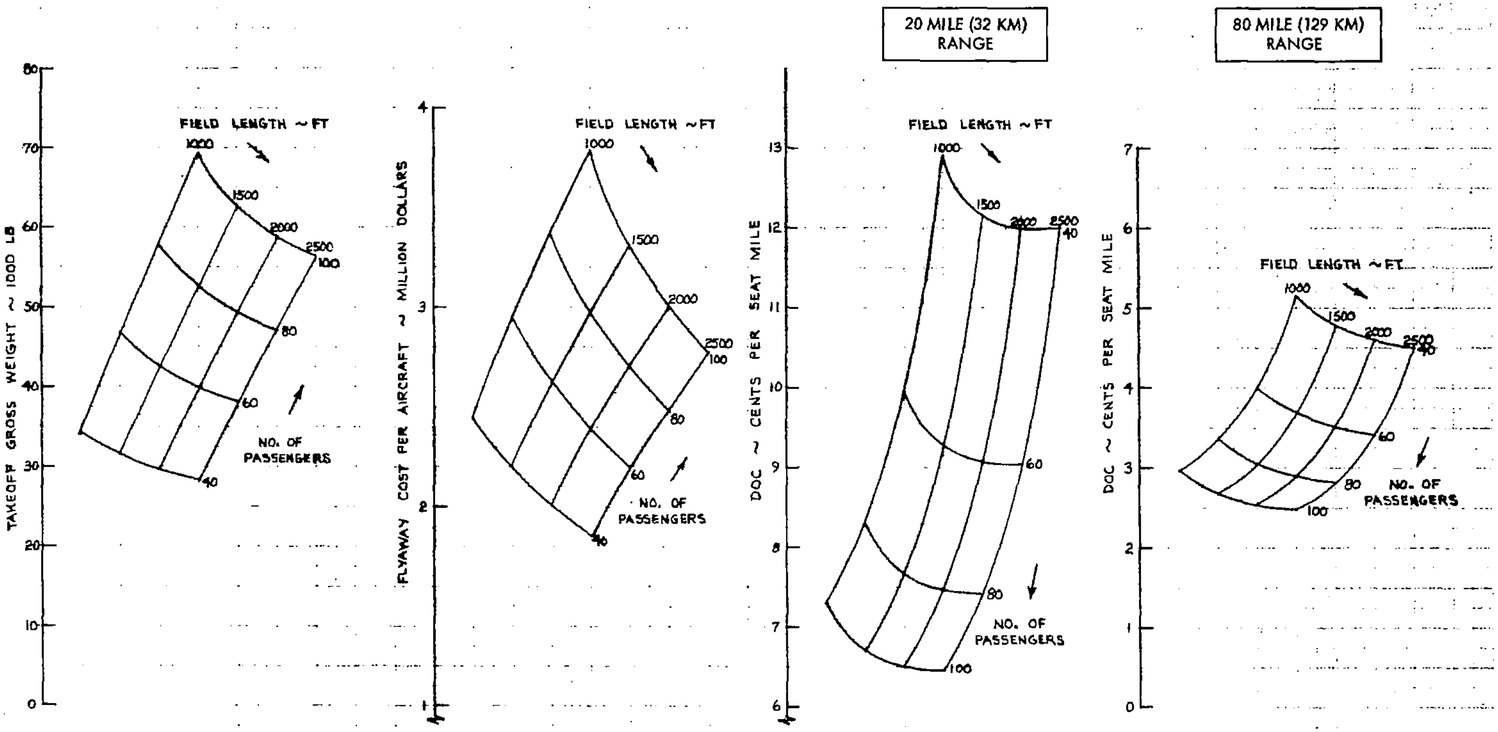


FIGURE 46. EFFECT OF WING LOADING AND PASSENGER CAPACITY ON THE 1975 TILT-WING V/STOL AIRCRAFT CONCEPT

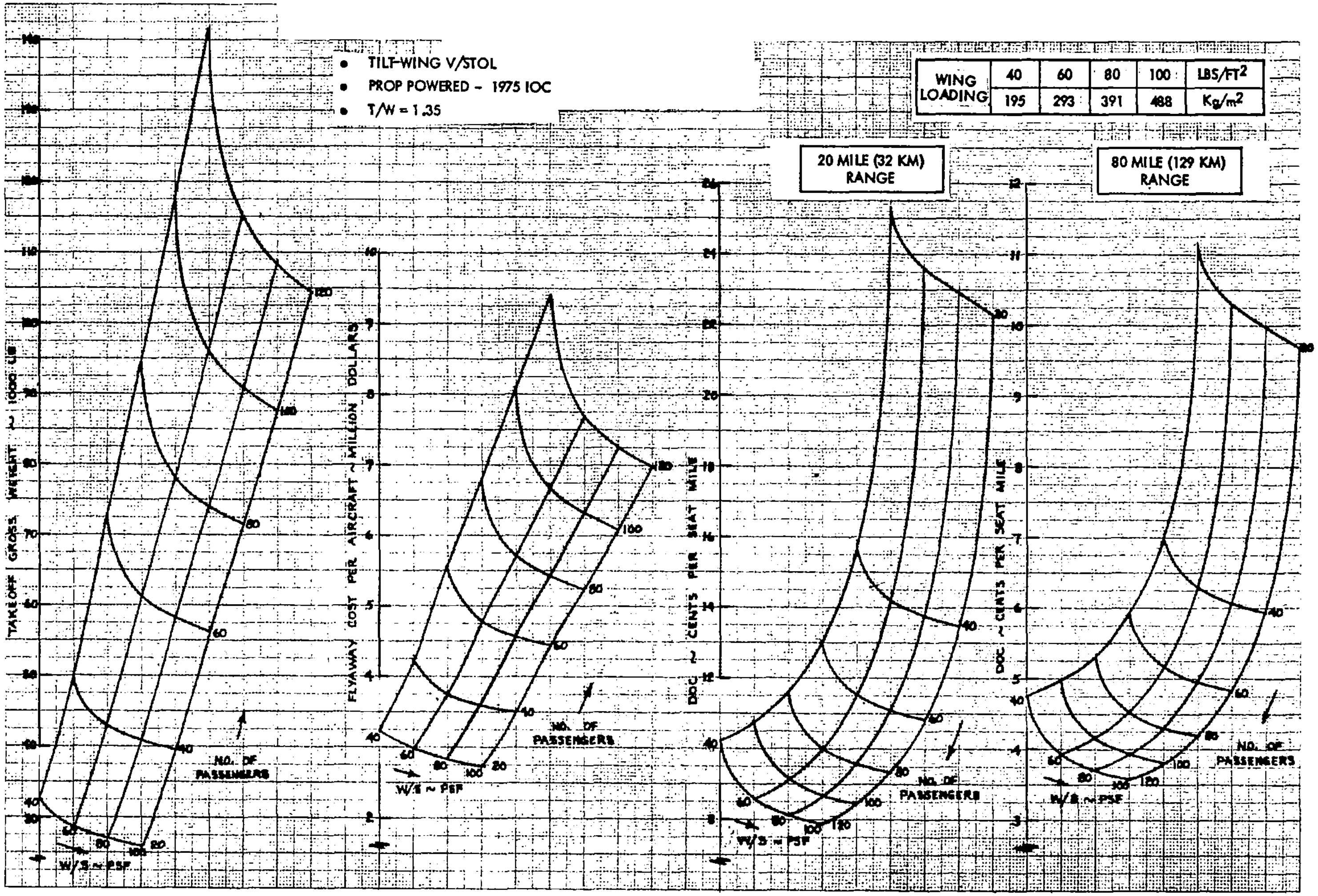


FIGURE 47. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1985 CTOL AIRCRAFT CONCEPT

- EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY
- CONVENTIONAL TAKEOFF AND LANDING (CTOL)
- FAN POWERED - 1985 IOC

FIELD LENGTH	2000	2500	3000	3500	FEET
	610	762	914	1067	METER

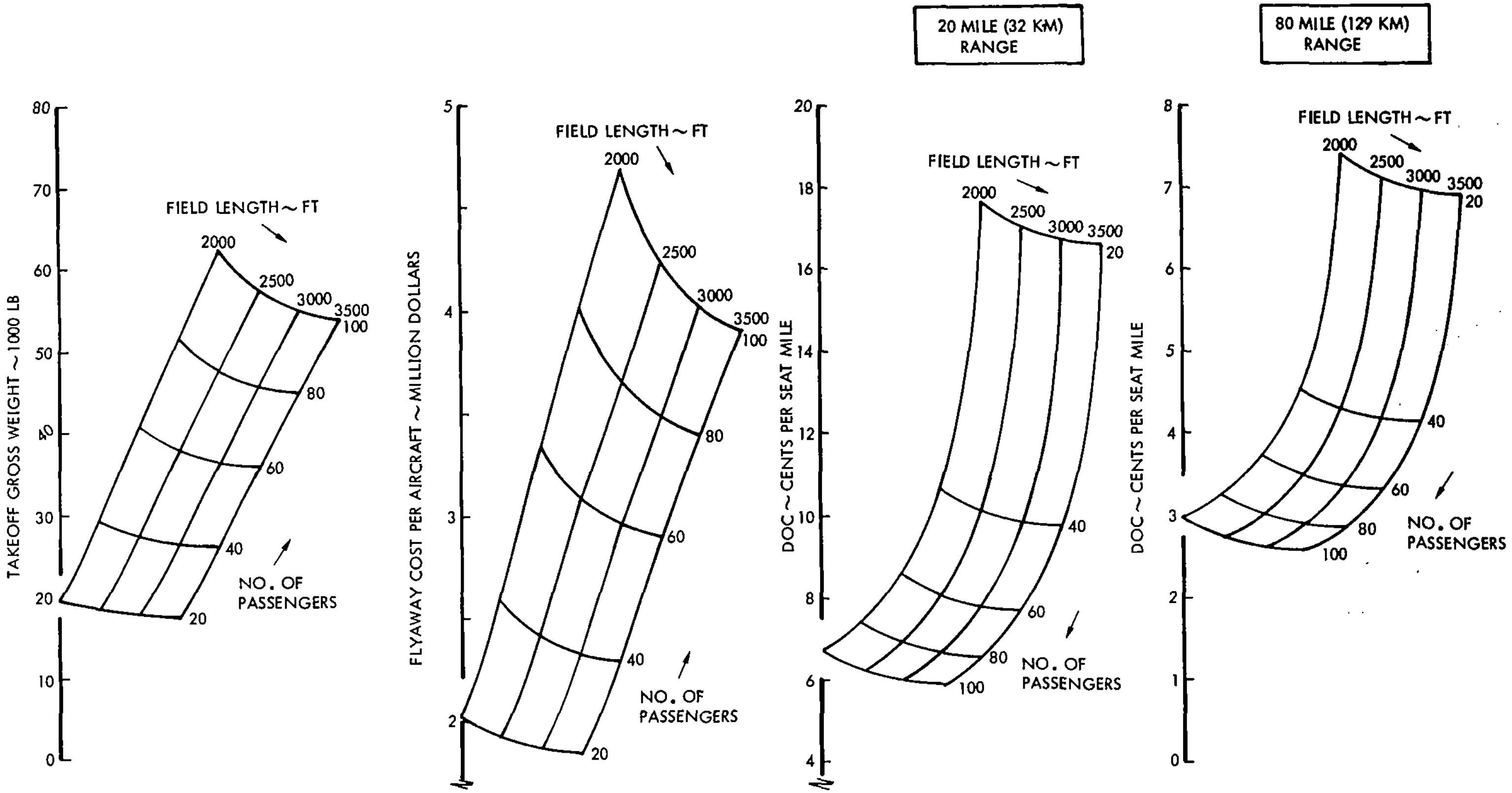


FIGURE 48. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1985 DEFLECTED-SLIPSTREAM STOL AIRCRAFT CONCEPT

- EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY
- DEFLECTED-SLIPSTREAM STOL
- PROP POWERED - 1985 IOC

FIELD LENGTH	1000	1500	2000	2500	FEET
	305	457	610	762	METER

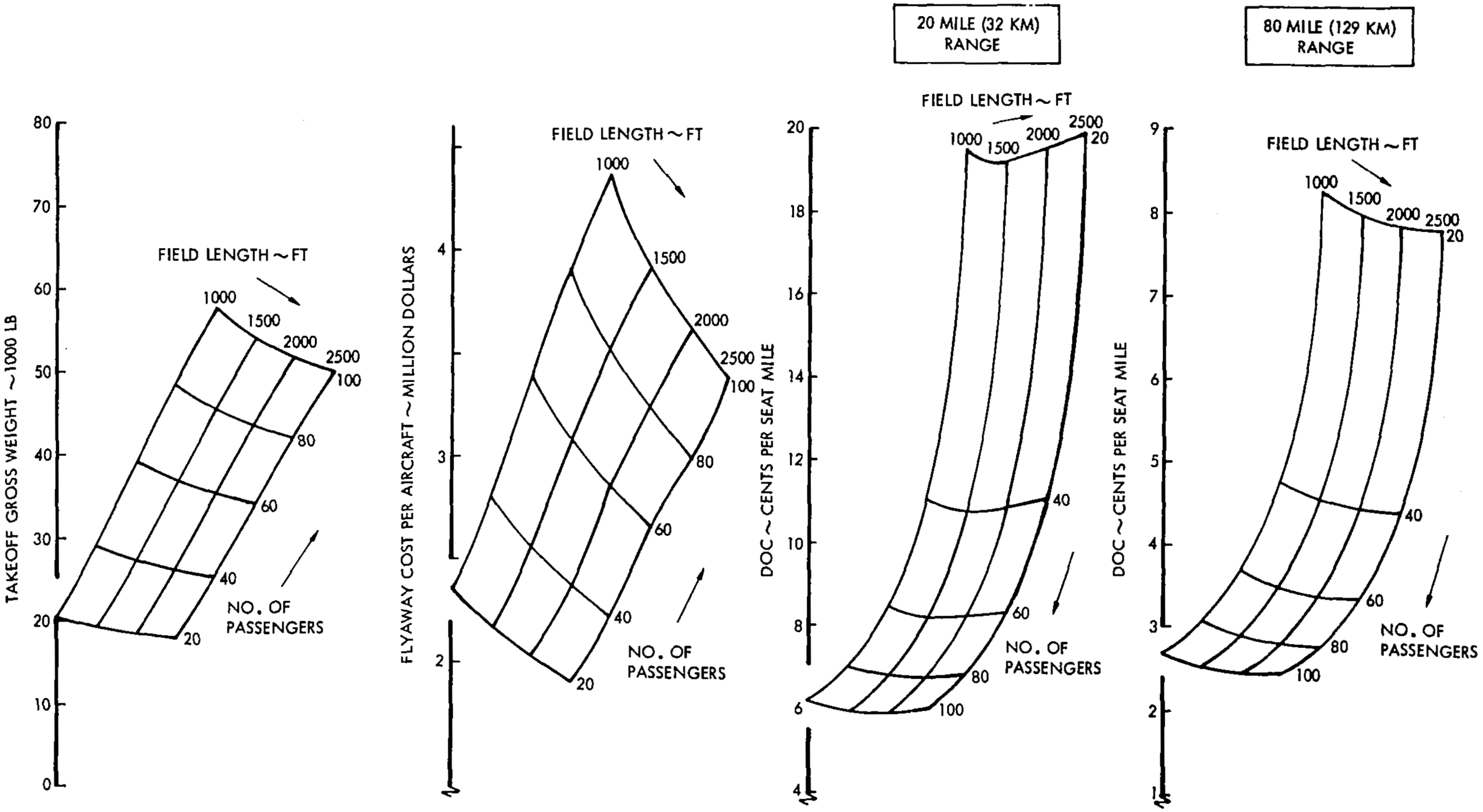


FIGURE 49. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1985 AUGMENTOR-WING STOL AIRCRAFT CONCEPT

- EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY
- AUGMENTOR-WING STOL
- FAN POWERED - 1985 IOC

FIELD LENGTH	1000	1200	1400	1600	FEET
	305	366	427	488	METER

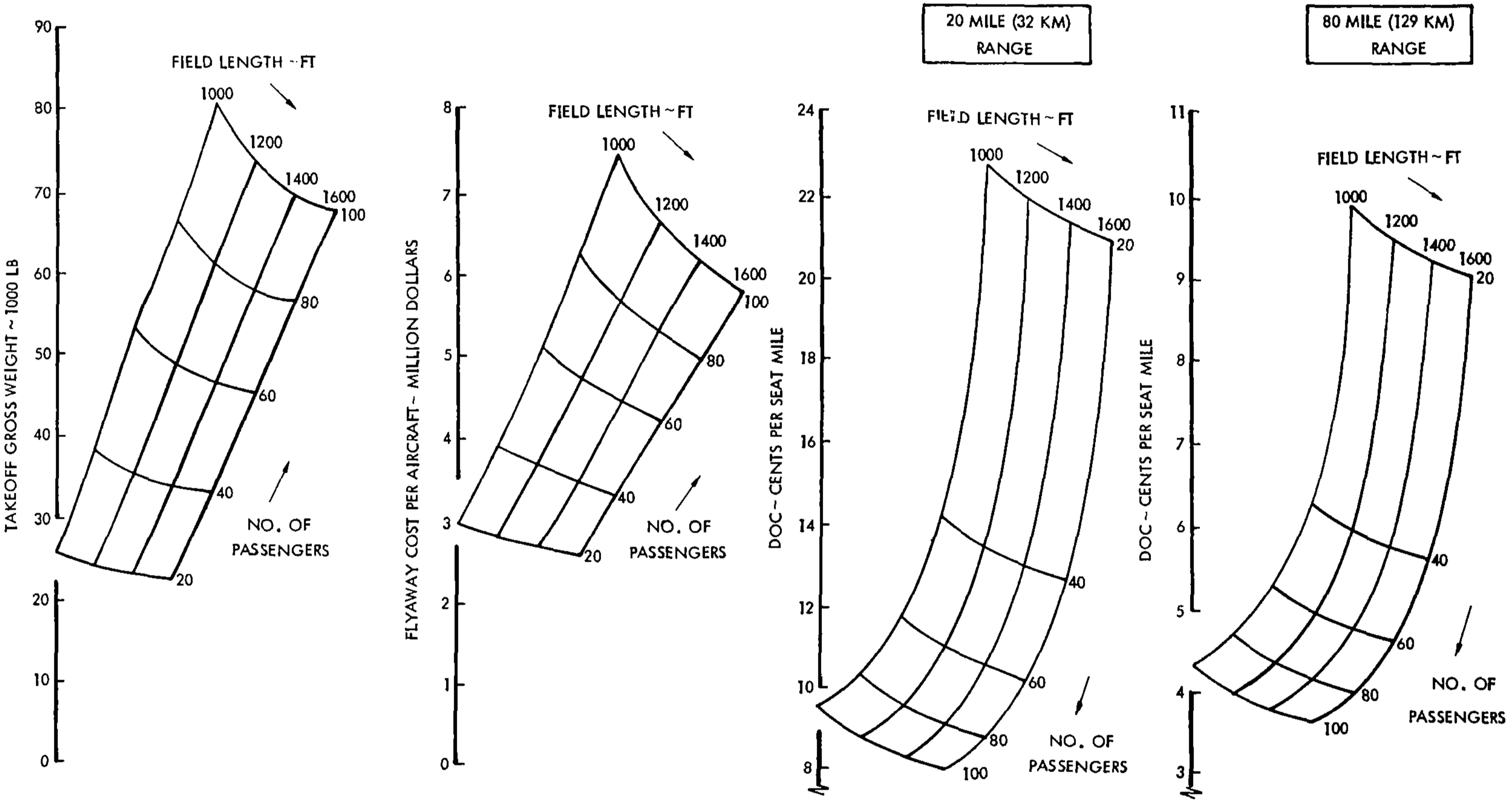


FIGURE 50. EFFECT OF WING LOADING AND PASSENGER CAPACITY ON THE 1985 TILT-WING V/STOL AIRCRAFT CONCEPT

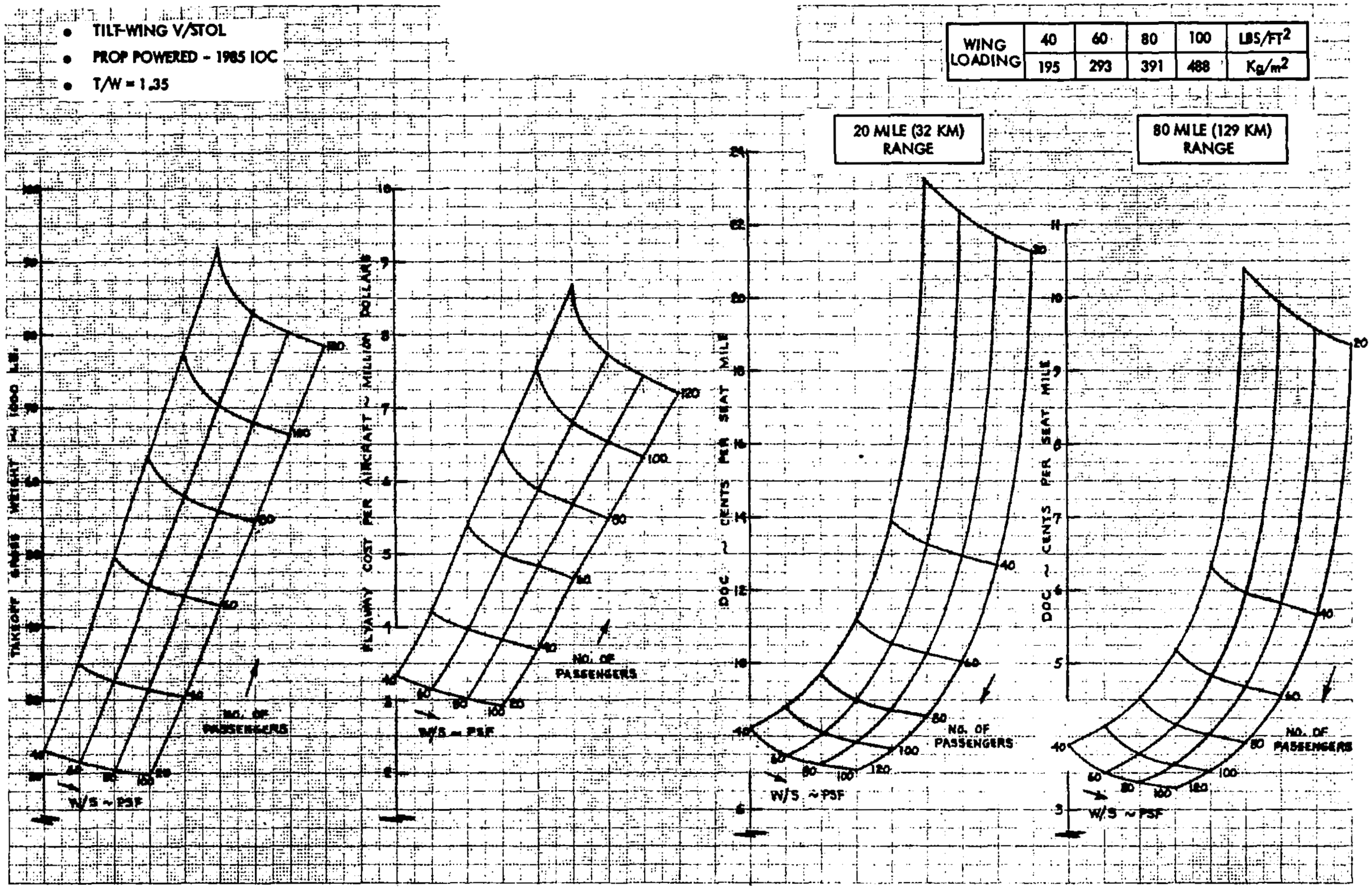


FIGURE 51. 1975 CONCEPT COMPARISON - TAKEOFF GROSS WEIGHT AND TSC VS FIELD LENGTH

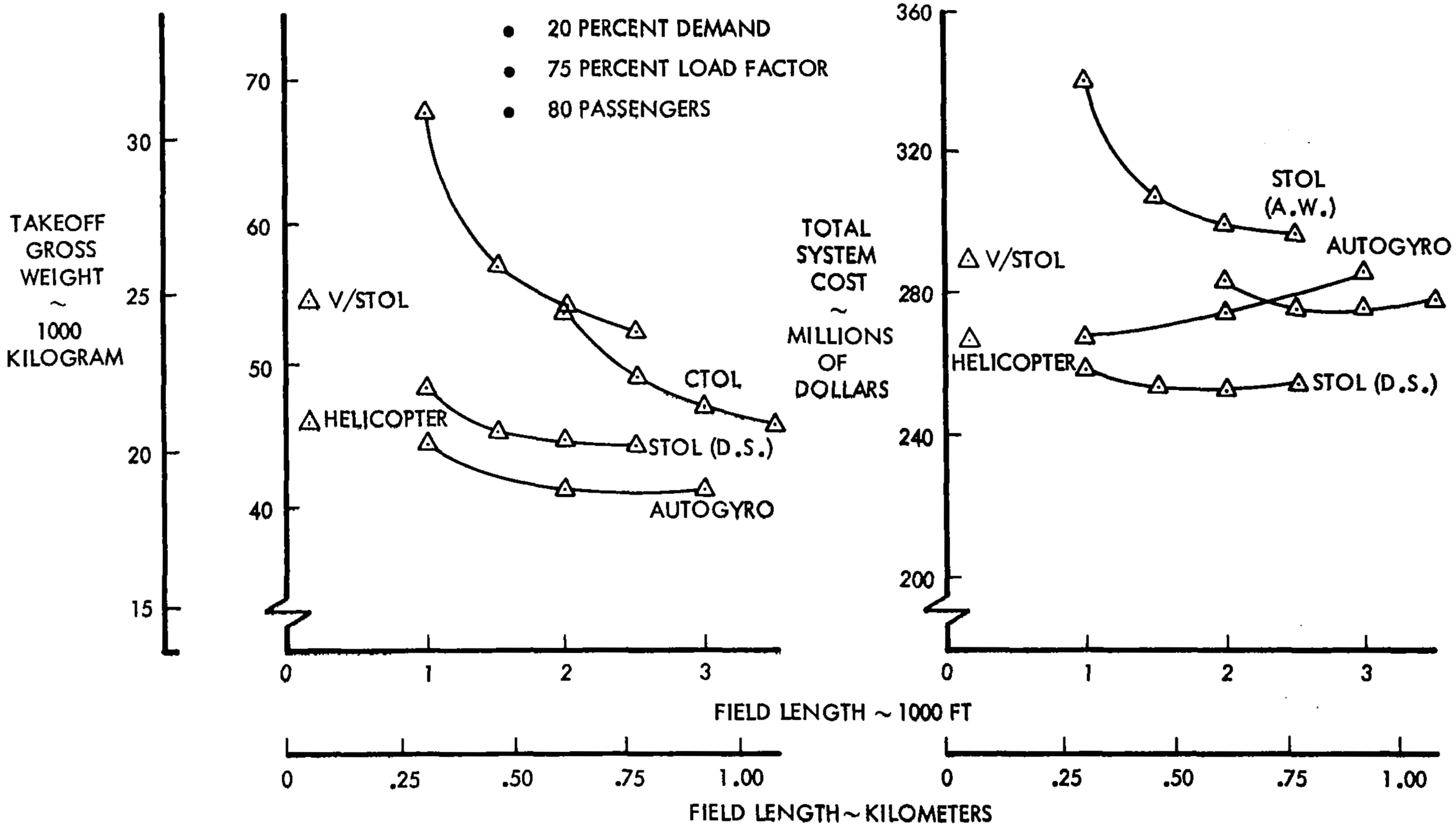


FIGURE 52. 1975 CONCEPT COMPARISON - TSC AND FARE VS SIZE

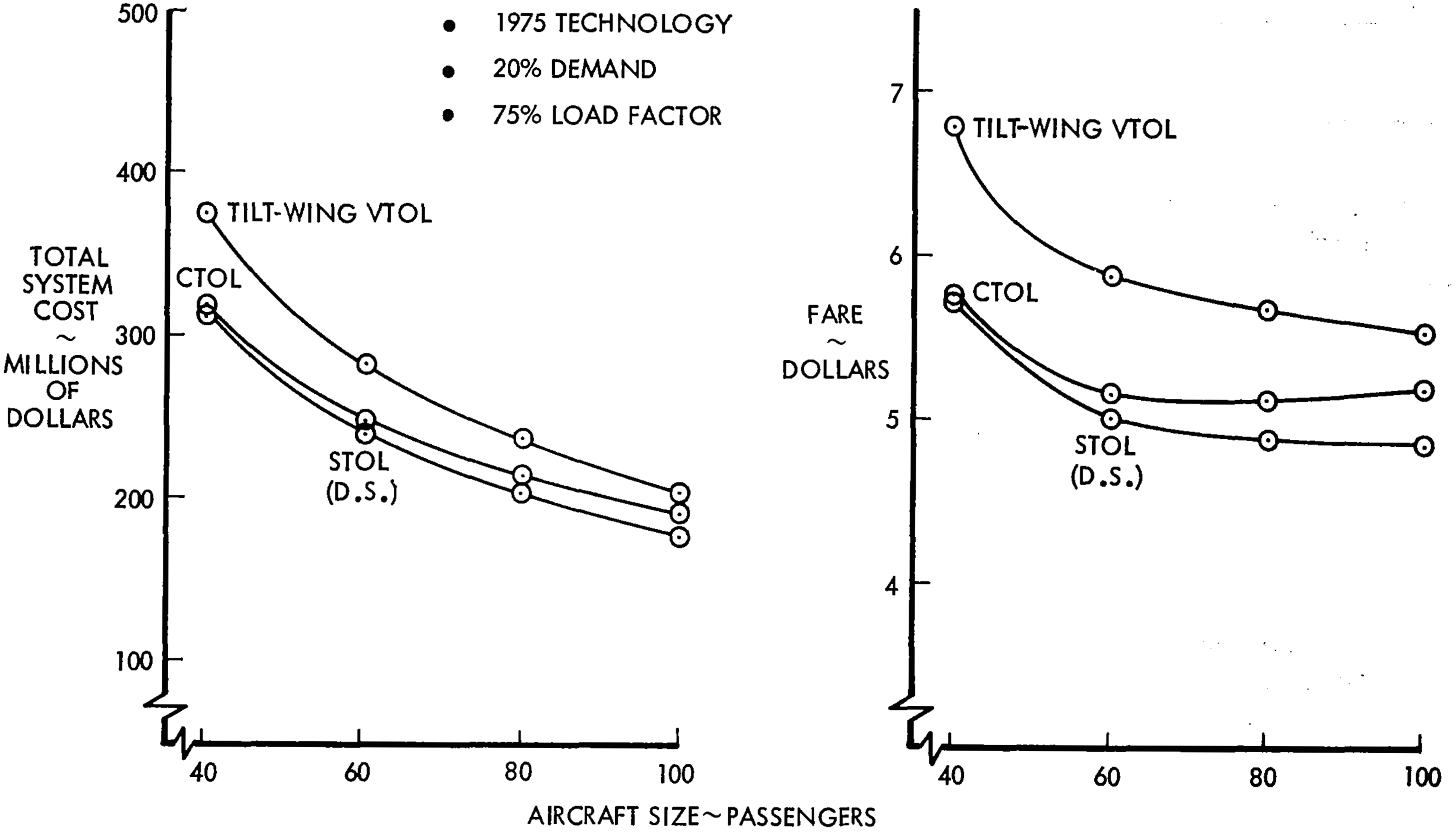


FIGURE 53. 1985 CONCEPT COMPARISON - TAKEOFF GROSS WEIGHT AND TSC VS FIELD LENGTH

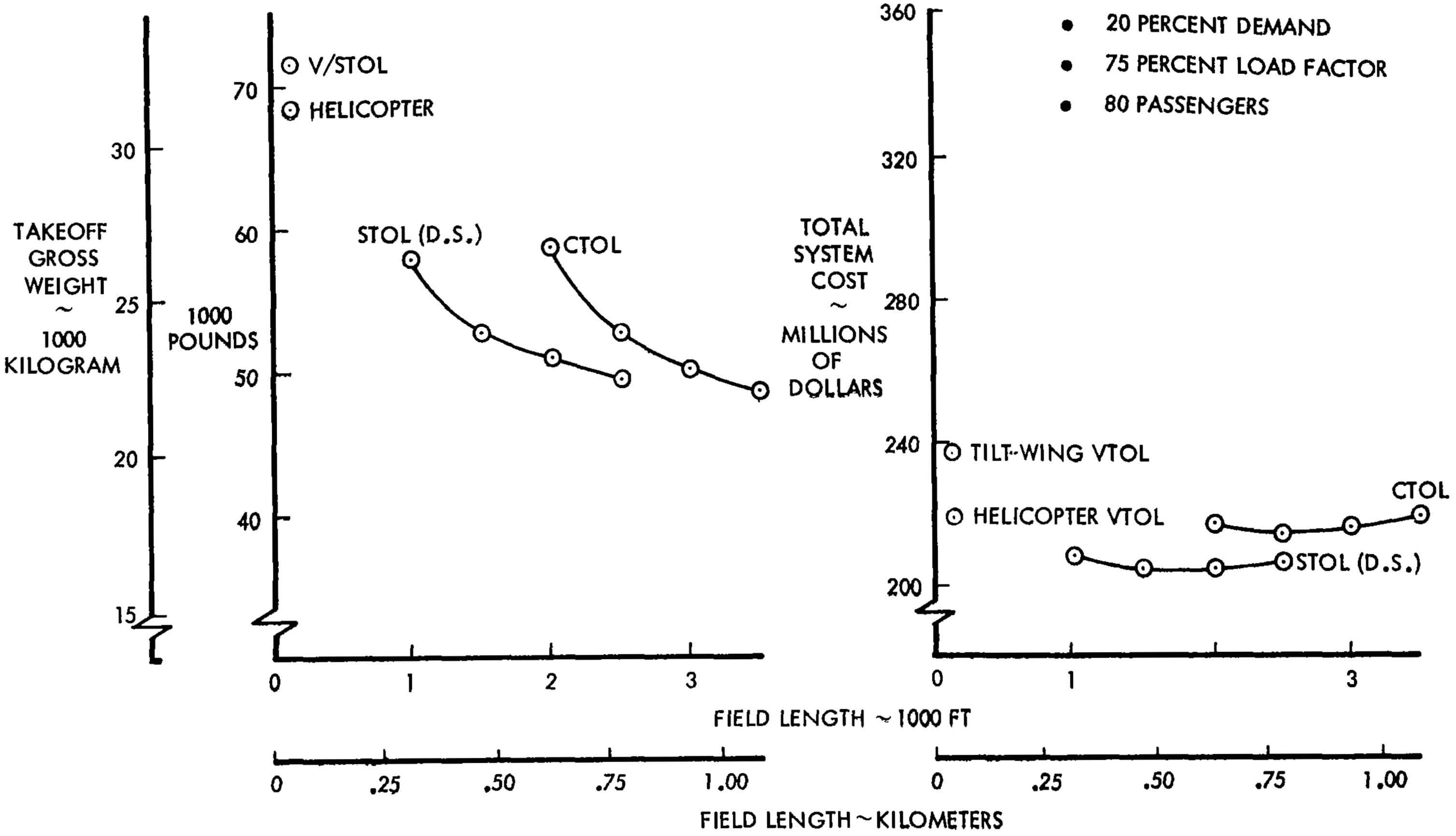


FIGURE 54. 1985 CONCEPT COMPARISON - TSC AND FARE VS AIRCRAFT SIZE

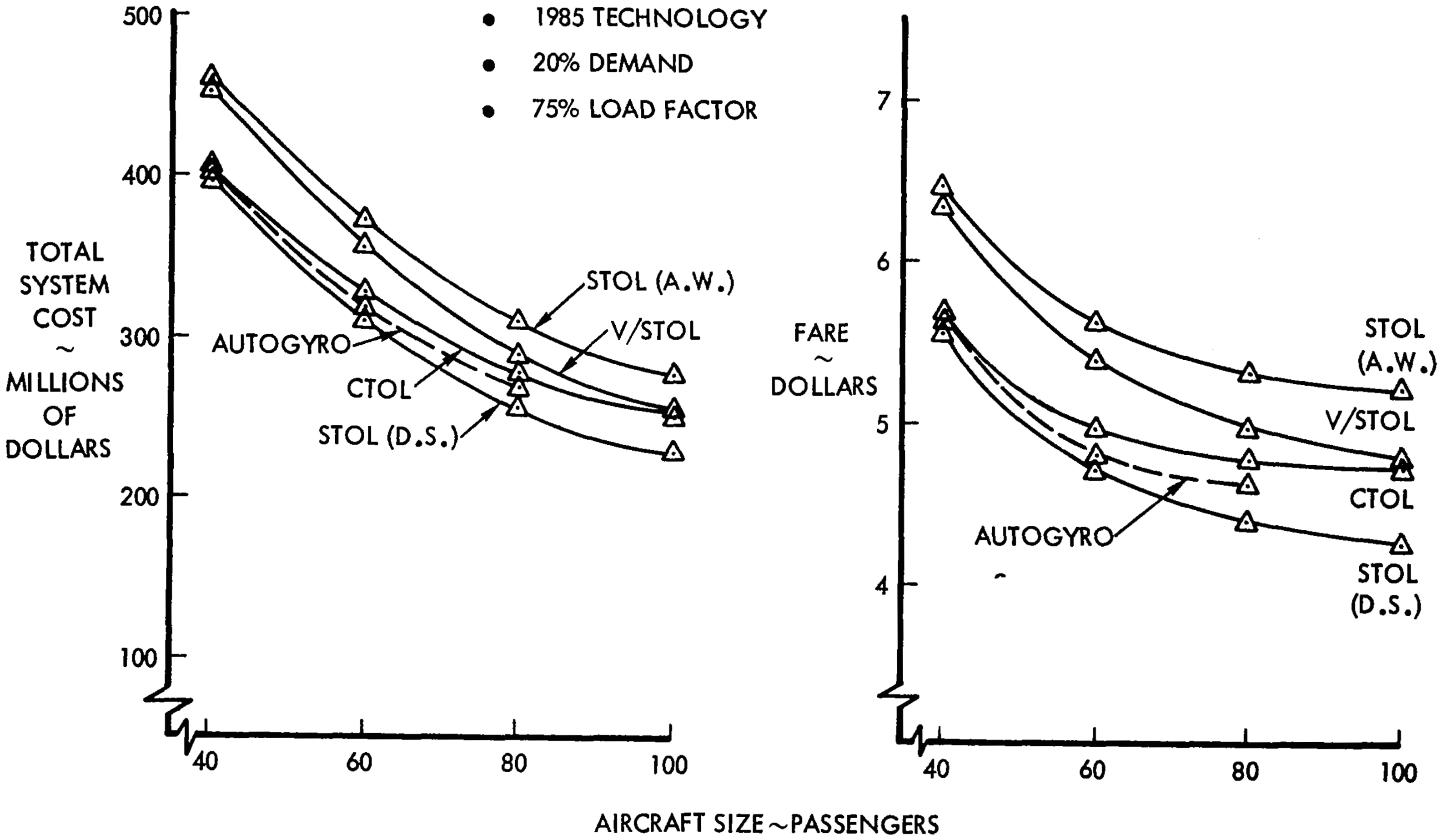
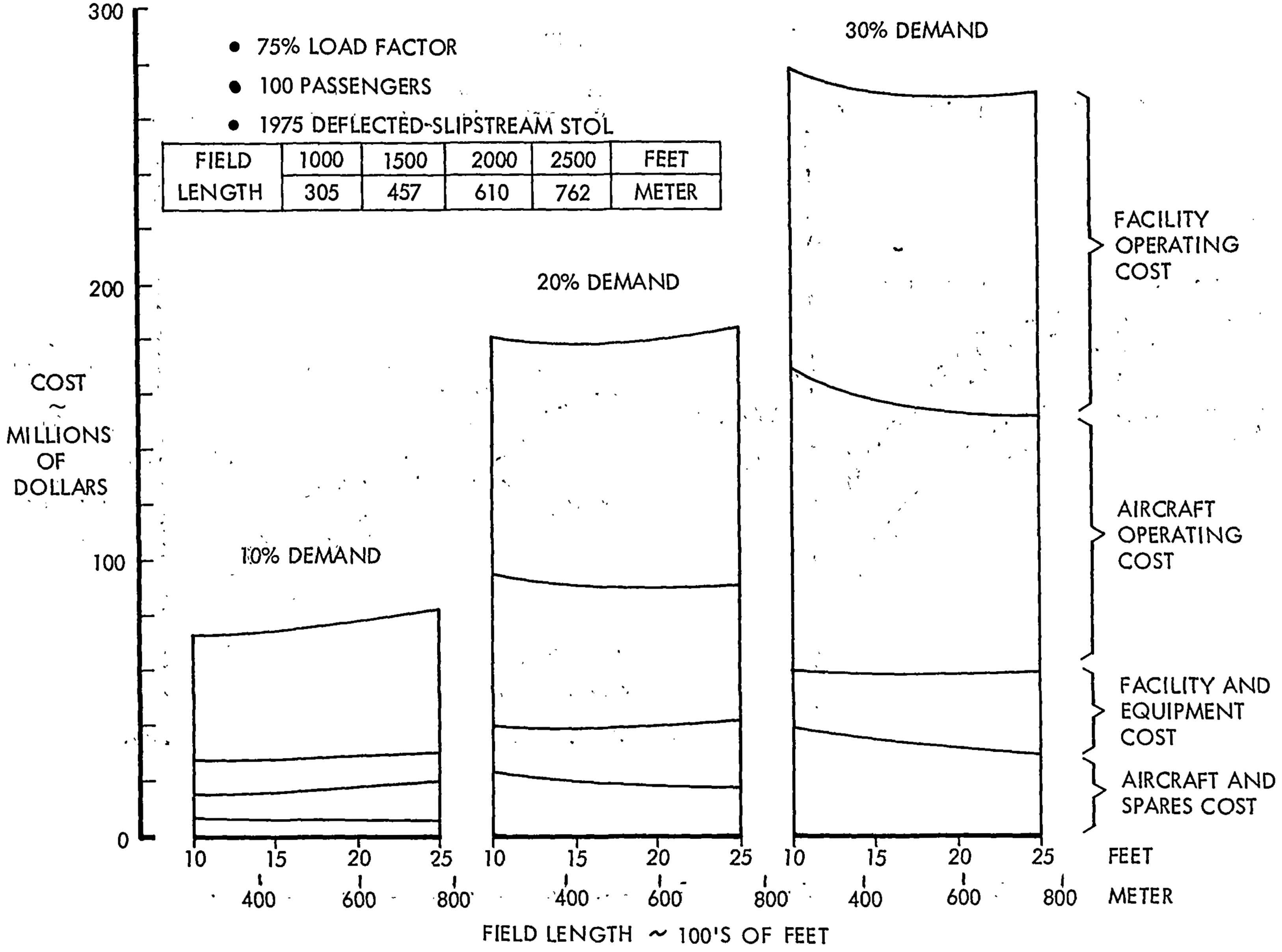


FIGURE 55. TOTAL SYSTEM COST MAKEUP VS RUNWAY LENGTH



FIELD LENGTH	1000	1500	2000	2500	FEET
	305	457	610	762	METER

FIGURE 56. TOTAL SYSTEM COST MAKEUP VS AIRCRAFT SIZE

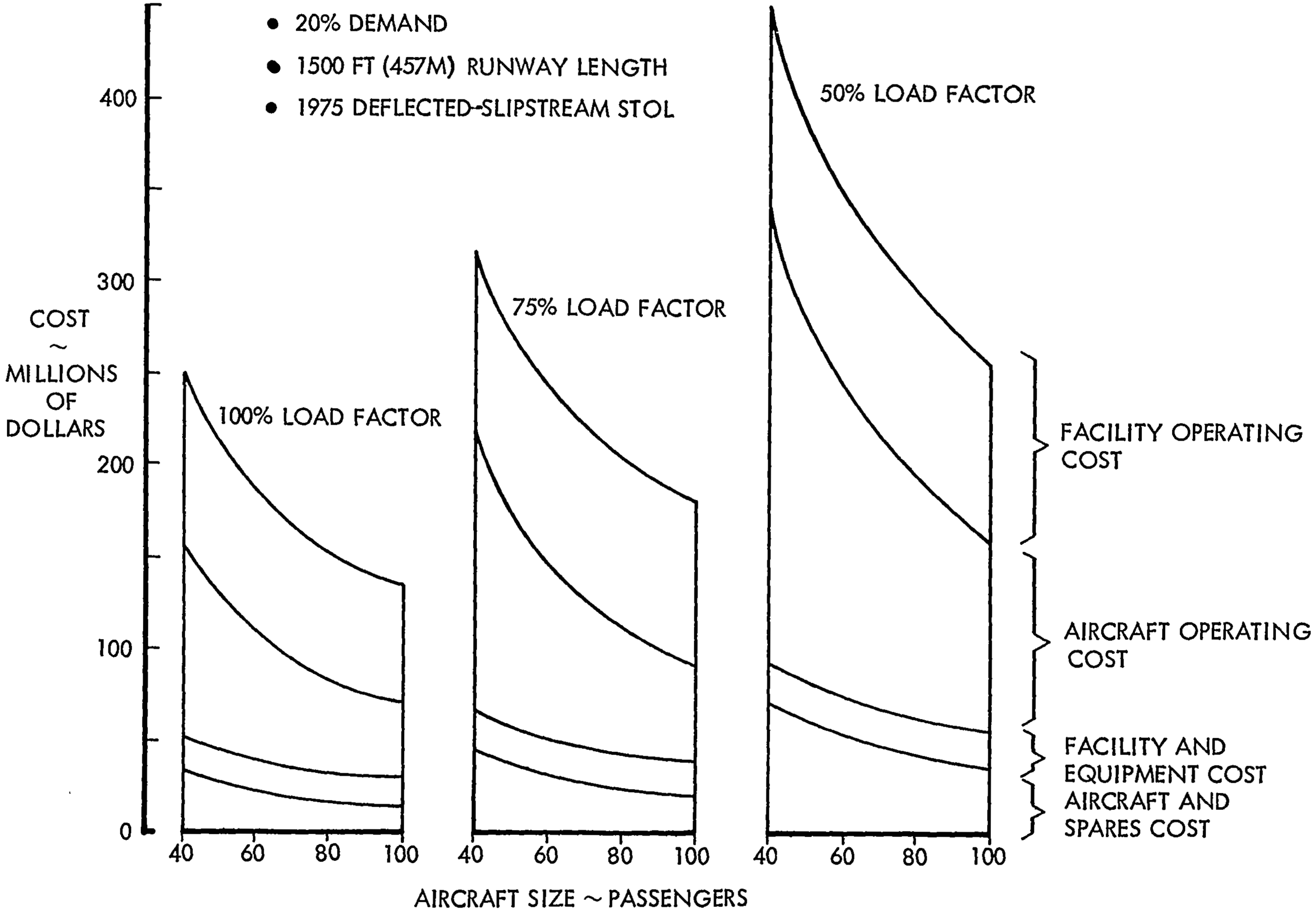
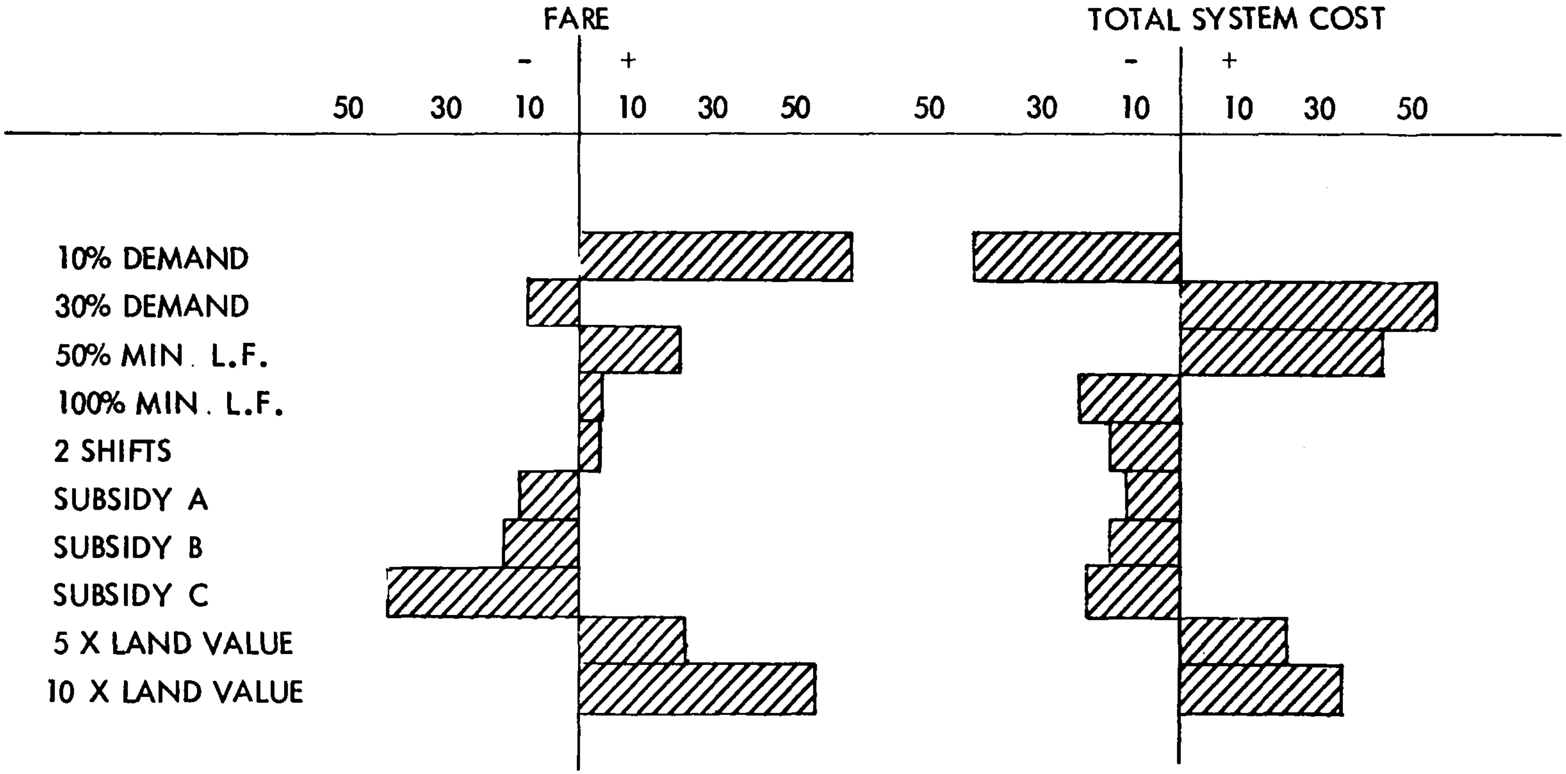


FIGURE 57. SENSITIVITY ANALYSIS RESULTS

	1975 COMPOUND HELICOPTER	1985 COMPOUND HELICOPTER	1975 TILT WING	1985 TILT WING	1975 DEFLECTED SLIPSTREAM	1985 DEFLECTED SLIPSTREAM	1985 AUGMENTOR WING	1975 CTOL	1985 CTOL	1985 AUTOGYRO
BASE DATA:										
DEMAND	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
PASS CAPACITY	60	60	60	60	60	60	60	60	60	60
MIN LOAD FACTOR	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%
FIELD LENGTH, Ft/M	150/46	150/46	150/46	150/46	1500/457	1500/457	1500/457	2500/762	2500/762	2000/610
TSC, $\$ \times 10^{6}$	242	319	282	355	240	310	371	247	327	323
FARE, \$/TRIP	5.04	4.83	5.90	5.40	5.01	4.70	5.60	5.15	4.95	4.88
TSC SENSITIVITY DATA (% CHANGE)										
10% DEMAND	- 50.4	- 55.0	- 52.9	- 54.9	- 46.7	- 52.3	- 53.9	- 44.2	- 51.1	- 50.5
30% DEMAND	+ 58.3	+ 53.0	+ 61.3	+ 54.1	+ 54.2	+ 50.0	+ 51.9	+ 51.4	+ 48.6	+ 47.8
50% MIN L.F.	+ 49.2	+ 40.4	+ 53.5	+ 42.5	+ 44.6	+ 36.8	+ 40.8	+ 42.1	+ 36.1	+ 35.4
100% MIN L.F.	- 24.0	- 26.6	- 25.2	- 27.0	- 22.1	- 24.8	- 26.2	- 21.0	- 24.2	- 24.0
2 SHIFTS			- 15.9	- 14.9	- 16.3	- 14.5	- 14.6	- 15.4	- 16.2	
SUBSIDY A			- 5.7	- 5.6	- 12.5	- 10.3	- 9.2	- 16.2	- 15.0	
SUBSIDY B			- 7.5	- 7.3	- 14.2	- 12.6	- 10.8	- 17.8	- 16.8	
SUBSIDY C			- 3.5	- 3.9	- 20.8	- 2.3	- 3.0	- 2.0	- 3.7	
5X LAND VALUE			+ 4.6	+ 4.2	+ 22.9	+ 19.4	+ 15.4	+ 35.2	+ 25.4	
10X LAND VALUE			+ 6.4	+ 9.6	+ 35.8	+ 42.2	+ 34.8	+ 78.6	+ 59.4	
FARE SENSITIVITY DATA (% CHANGE)										
10% DEMAND	+ 48.6	+ 30.0	+ 40.7	+ 27.8	+ 59.9	+ 37.5	+ 31.1	+ 67.0	+ 40.9	+ 38.2
30% DEMAND	- 7.9	- 5.8	- 6.4	- 5.6	- 10.6	- 7.5	- 7.1	- 12.2	- 8.5	- 8.0
50% MIN L.F.	+ 26.4	+ 27.4	+ 28.8	+ 29.7	+ 22.4	+ 24.1	+ 28.6	+ 20.2	+ 23.4	+ 24.4
100% MIN L.F.	+ 3.8	+ 1.2	+ 1.7	0	+ 6.2	+ 3.4	+ 1.8	+ 7.8	+ 4.5	+ 3.7
2 SHIFTS			+ 5.1	+ 5.6	+ 4.4	+ 6.6	+ 7.1	+ 5.4	+ 4.9	
SUBSIDY A			- 6.8	- 5.6	- 12.2	- 10.6	- 8.9	- 16.3	- 14.9	
SUBSIDY B			- 8.5	- 7.4	- 14.4	- 12.6	- 10.7	- 17.9	- 16.8	
SUBSIDY C			- 37.3	- 40.8	- 42.4	- 45.1	- 37.6	- 40.8	- 44.0	
5X LAND VALUE			+ 3.4	+ 3.7	+ 22.8	+ 19.2	+ 16.1	+ 34.8	+ 25.5	
10X LAND VALUE			+ 10.2	+ 9.3	+ 51.1	+ 42.1	+ 35.7	+ 78.3	+ 59.5	

FIGURE 58. SENSITIVITY ANALYSIS



BASE POINT:

20% DEMAND

60 PASSENGER AIRCRAFT

75% MINIMUM L.F.

TSC $240 MILLION

FARE $5.0 PER PASSENGER

FIGURE 59. CTOL AIRCRAFT SENSITIVITIES

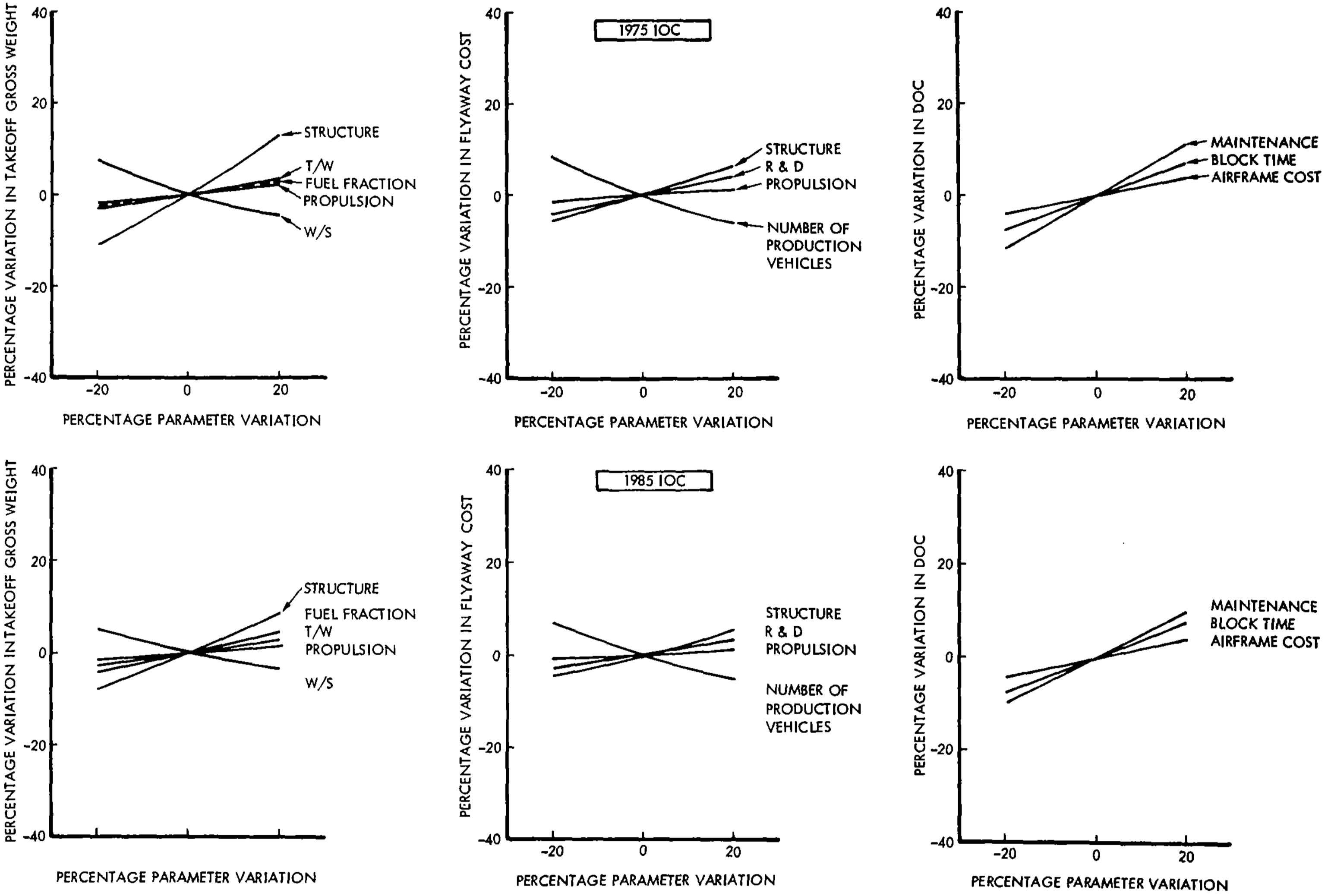


FIGURE 60. STOL DEFLECTED-SLIPSTREAM AIRCRAFT SENSITIVITIES

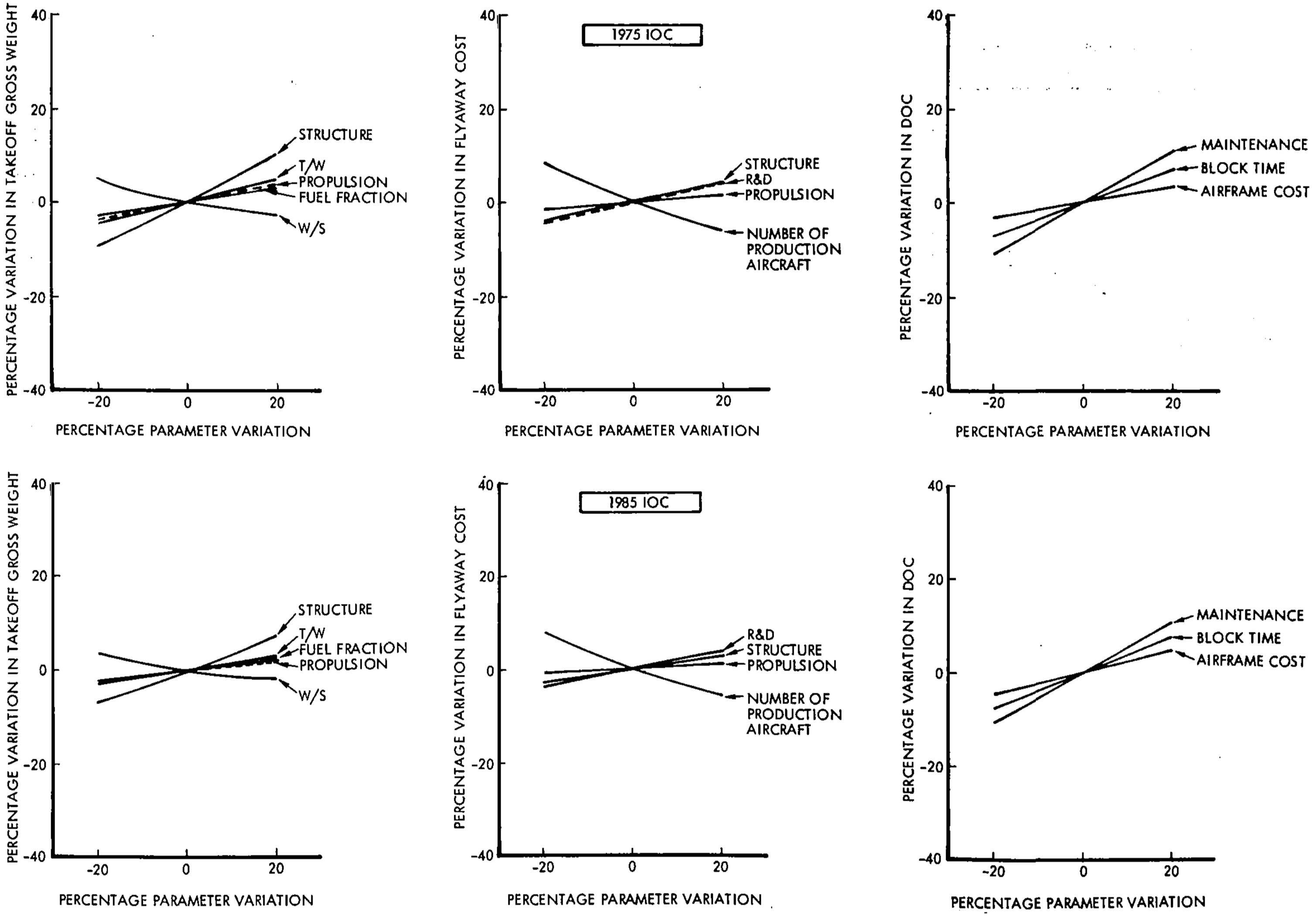


FIGURE 61. STOL (AUGMENTOR-WING) AIRCRAFT SENSITIVITIES

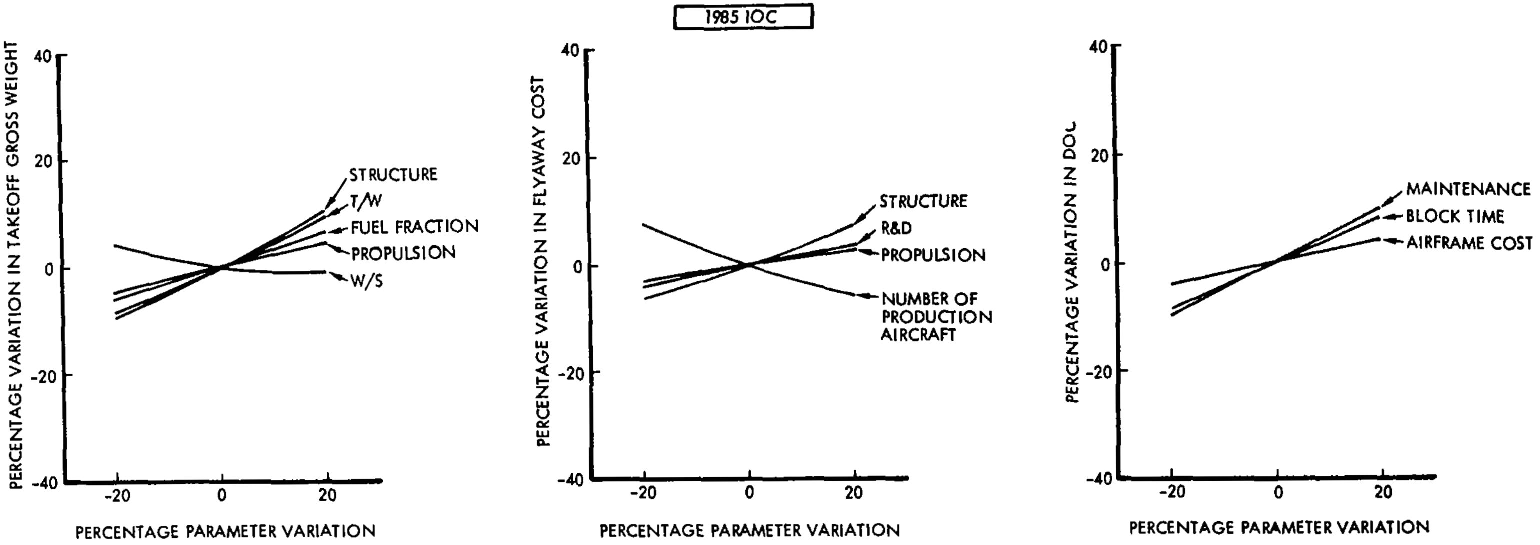


FIGURE 62. VTOL (TILT-WING) AIRCRAFT SENSITIVITIES

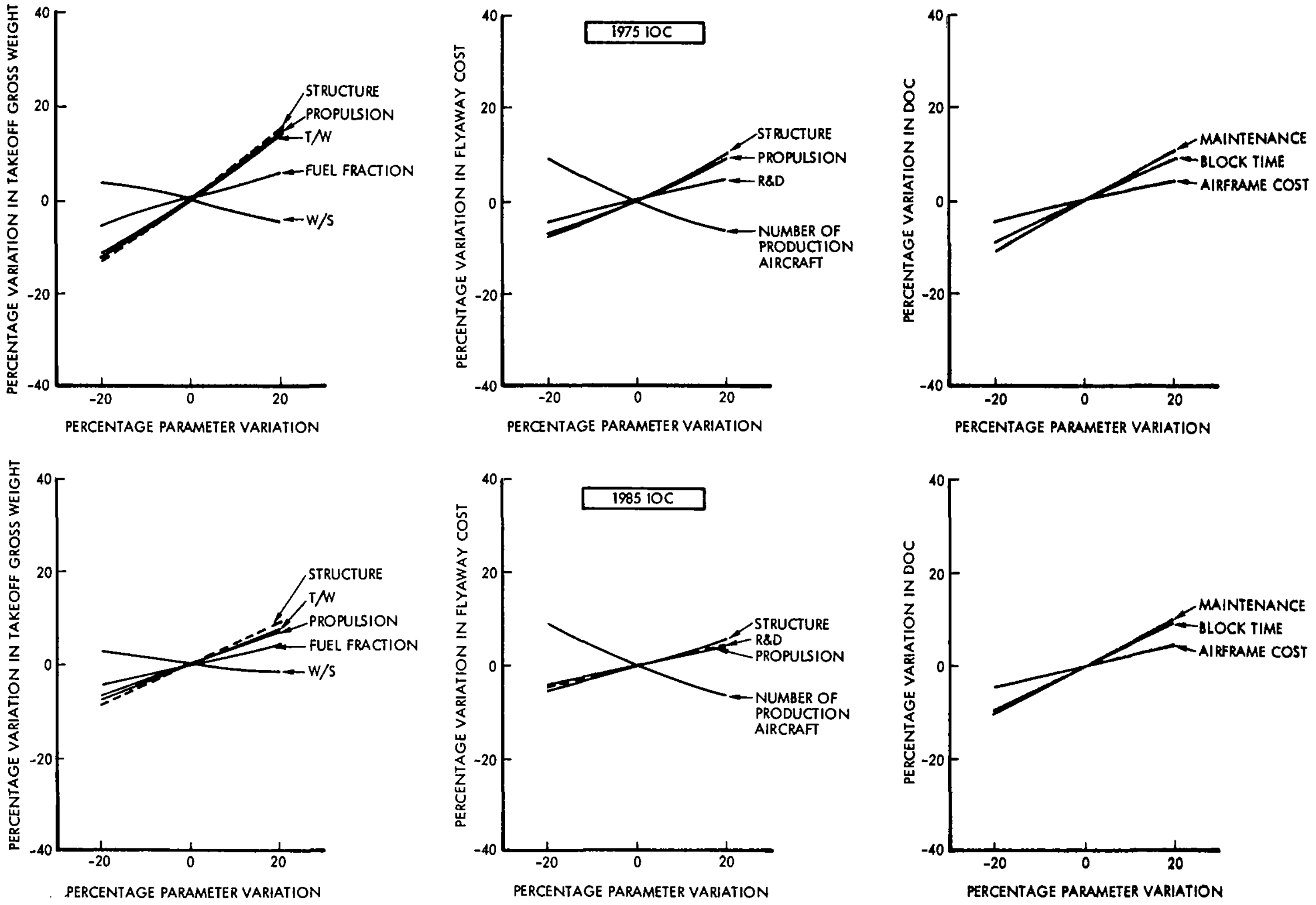


FIGURE 63. PHASE I - FARE $/TRIP VS AIRCRAFT SIZE AND PAYLOAD

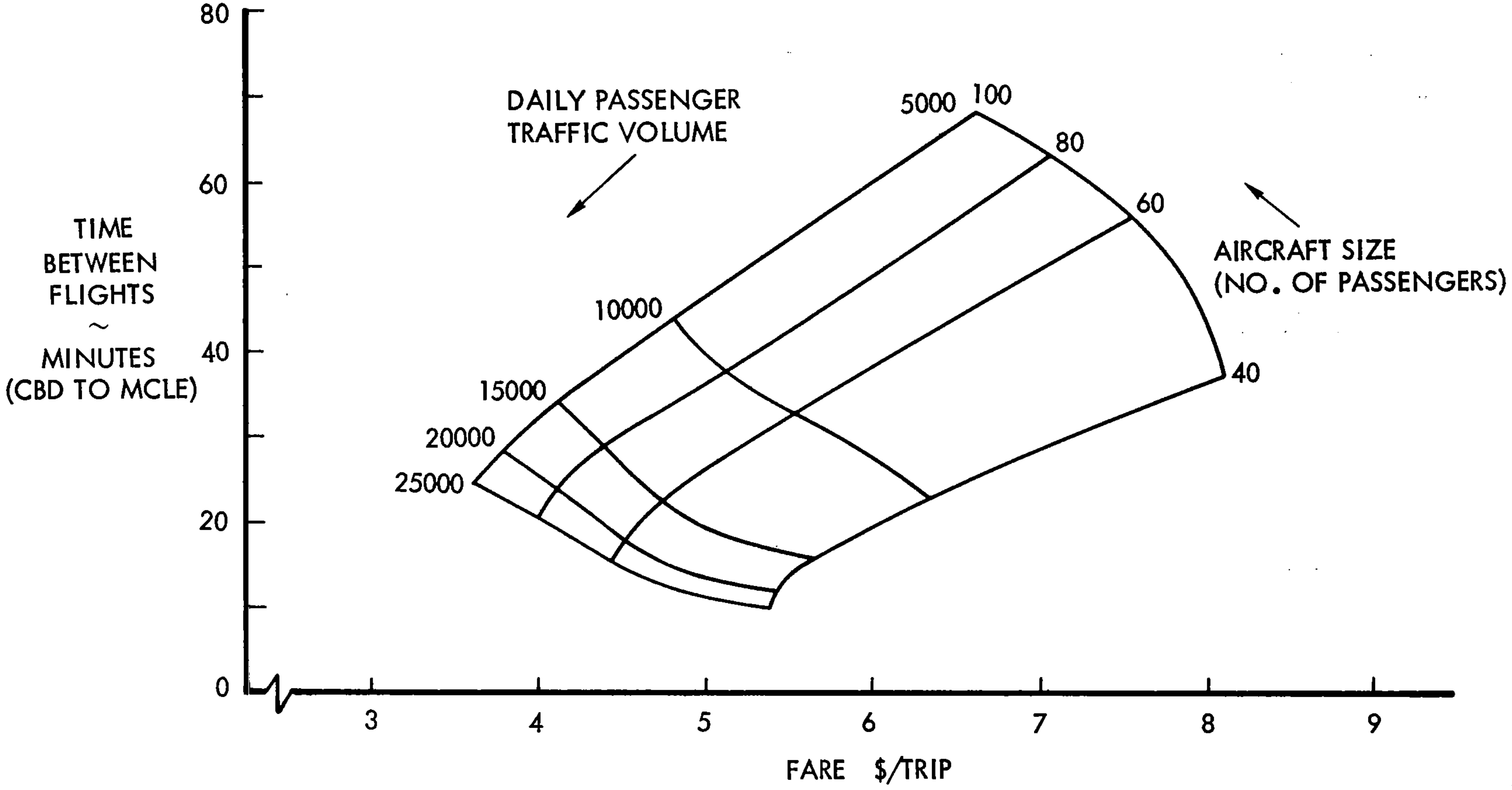


FIGURE 64. FLIGHTS-PER-HOUR DURING PEAK DEMAND TIME PERIOD

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

FIGURE 65. TOTAL SYSTEM SYNTHESIS-FLOW DIAGRAM

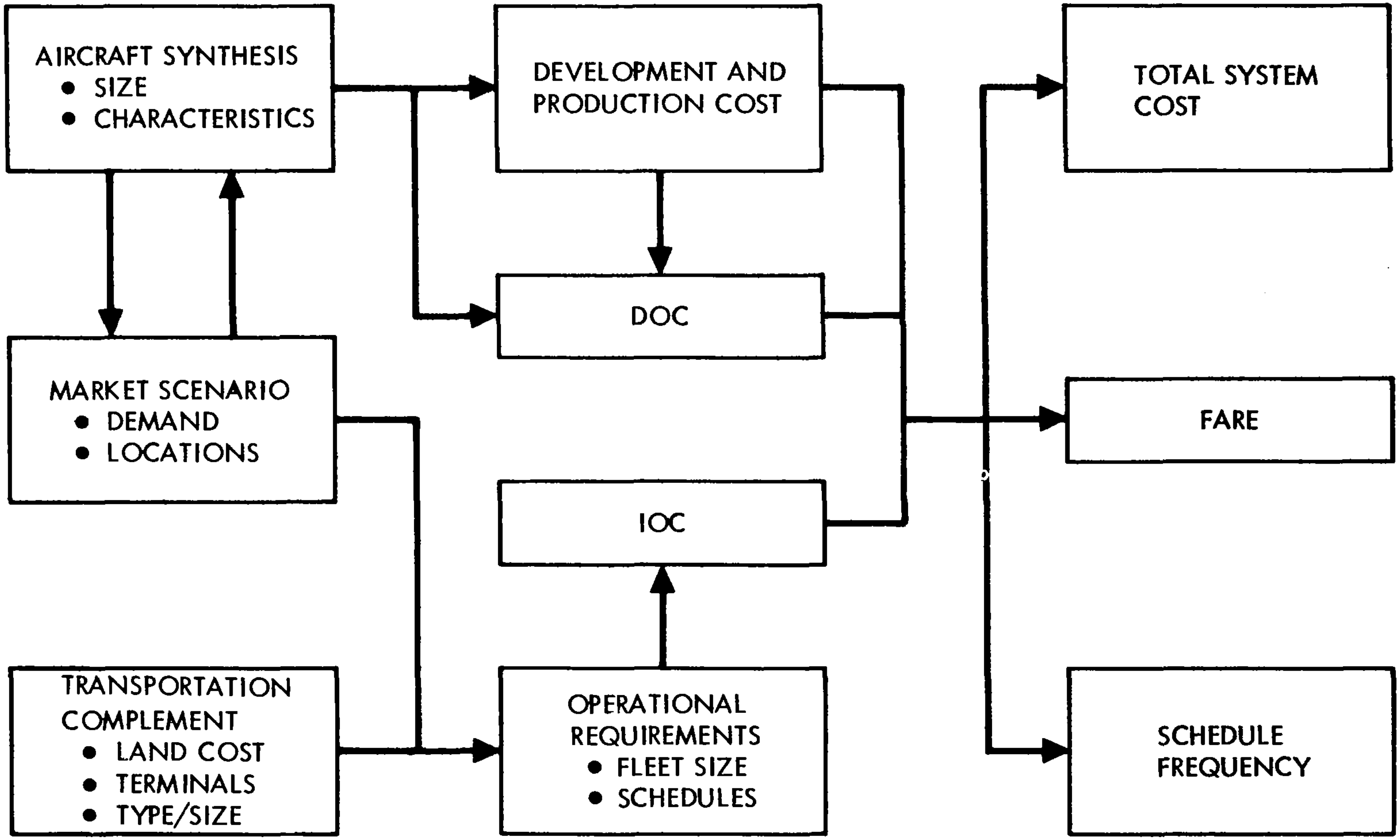
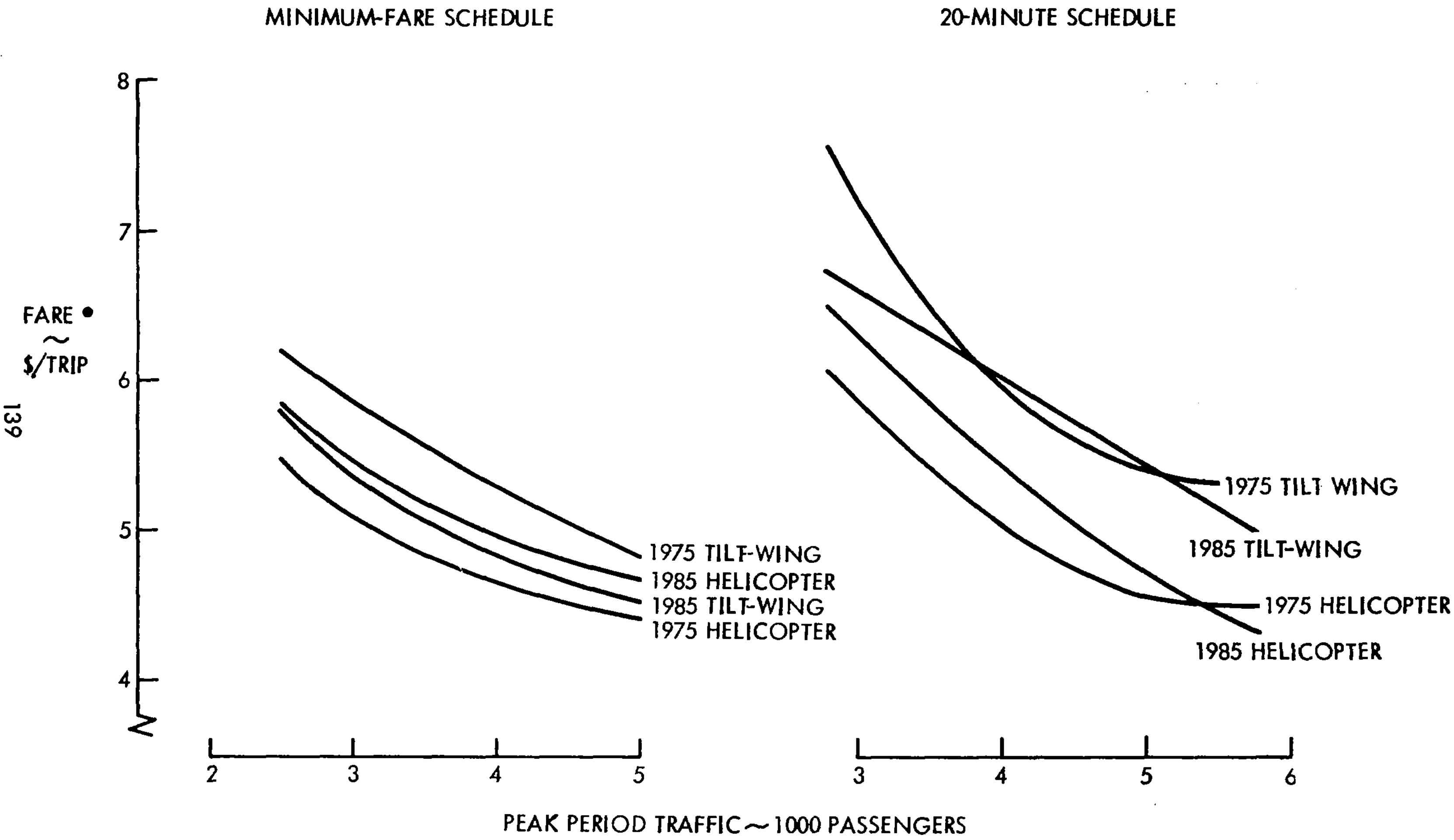
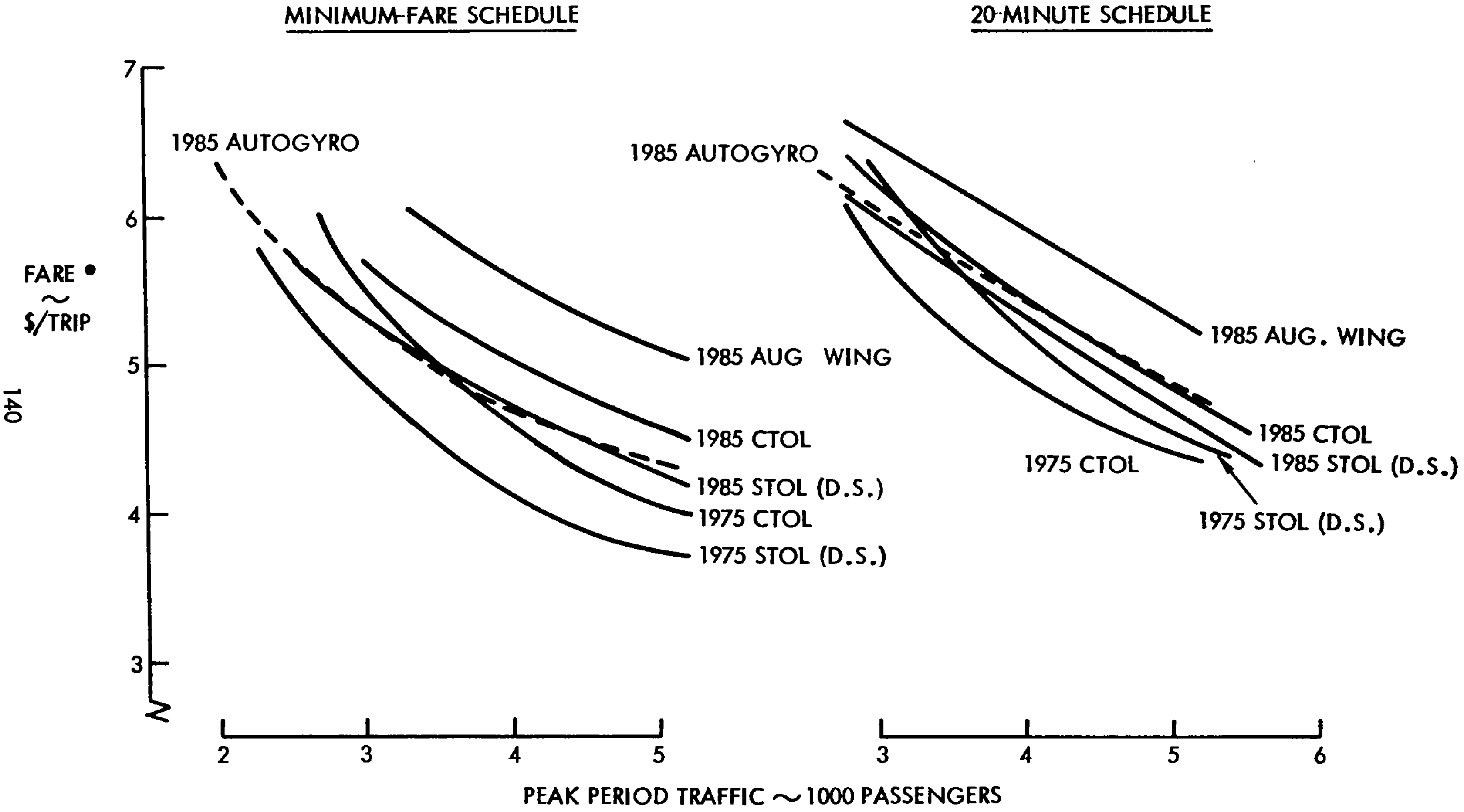


FIGURE 66. COMPARISON OF VTOL CONCEPTS



• NO SUBSIDY; 15% RETURN ON INVESTMENT

FIGURE 67. COMPARISON OF STOL CONCEPTS



• NO SUBSIDY; 15% RETURN ON INVESTMENT

FIGURE 68. CONCEPT DELECTION SUMMARY-PHASE I

Concept	Fare ~ $/Trip				Takeoff Noise Level PNL ~ PNdB 1000 FT (305 Meter) Sideline		Community Acceptance	Ride Qualities	Passenger Appeal	Tech Risk	Selection	
	20 Mile Service		Min Fare Schedule									
	1975	1985	1975	1985	1975	1985					1975	1985
Comp Helicopter VTOL	5.40	5.30	5.20	5.00	90.2	87.7	Good	Good	Fair	Low	✓	✓
Tilt-Wing VTOL	6.50	5.90	5.70	5.15	100.0	96.0	Poor	Good	Fair	Low		
Defl Slipstream STOL	5.40	4.90	5.30	4.46	86.0	83.0	Fair/Good	Fair/Good	Good	Low	✓	✓
Augmentor-Wing STOL	-	5.80	-	5.35	-	91.7	Fair	Fair	Good	Medium	-	
Autogyro STOL	-	5.00	-	4.87	-	(1)	Fair/Good	Good	Fair	Medium	-	(2) ✓
Short Field Conventional	5.70	5.35	5.55	5.15	88.7	90.0	Fair/Good	Fair/Poor	Good	Low		

(1) Autogyro noise analysis still underway

(2) To be carried as non-contract parallel study

FIGURE 69. TOTAL SYNTHESIS OF 1975 DEFLECTED-SLIPSTREAM STOL

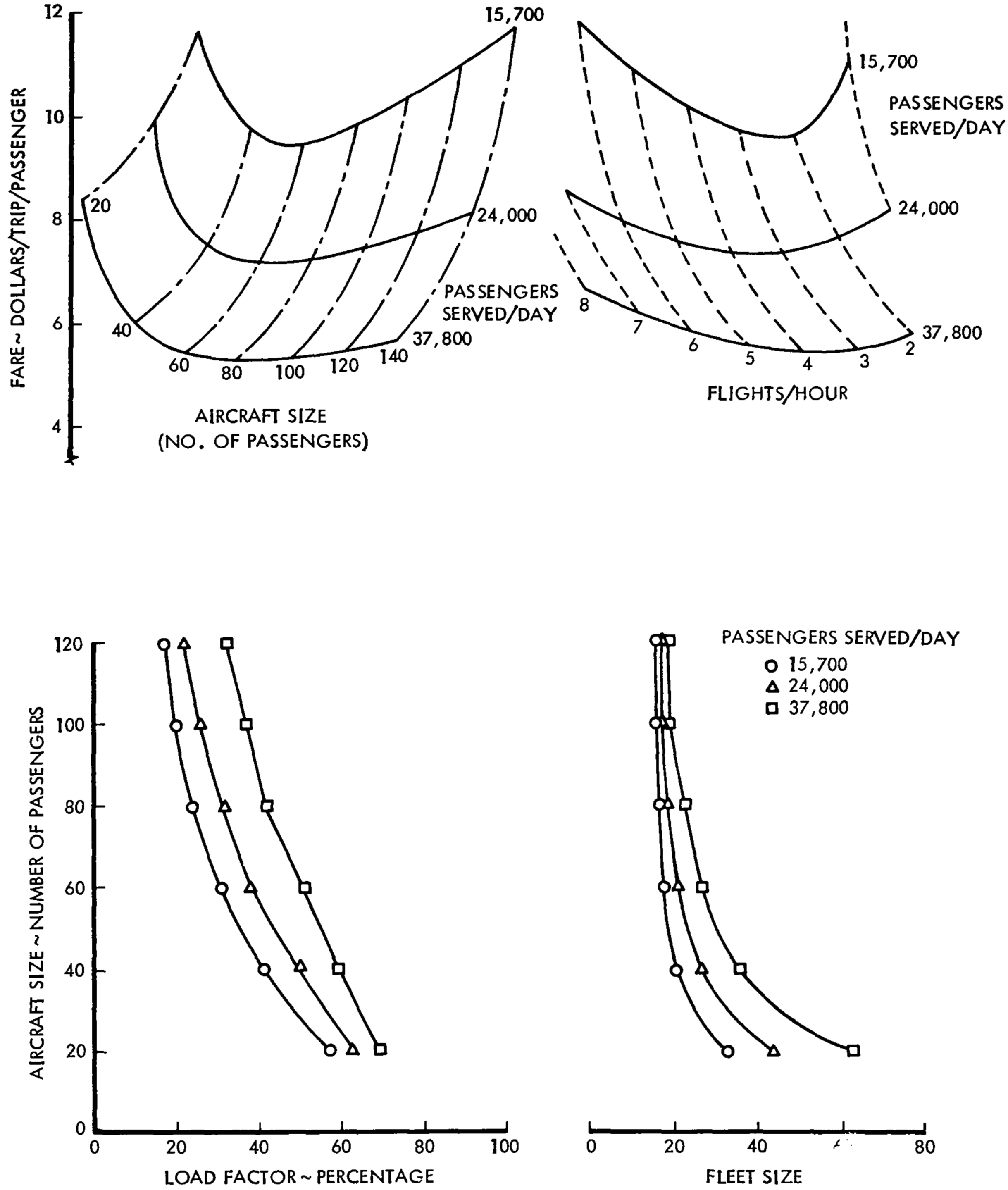


FIGURE 70. TOTAL SYNTHESIS OF 1975 COMPOUND HELICOPTER

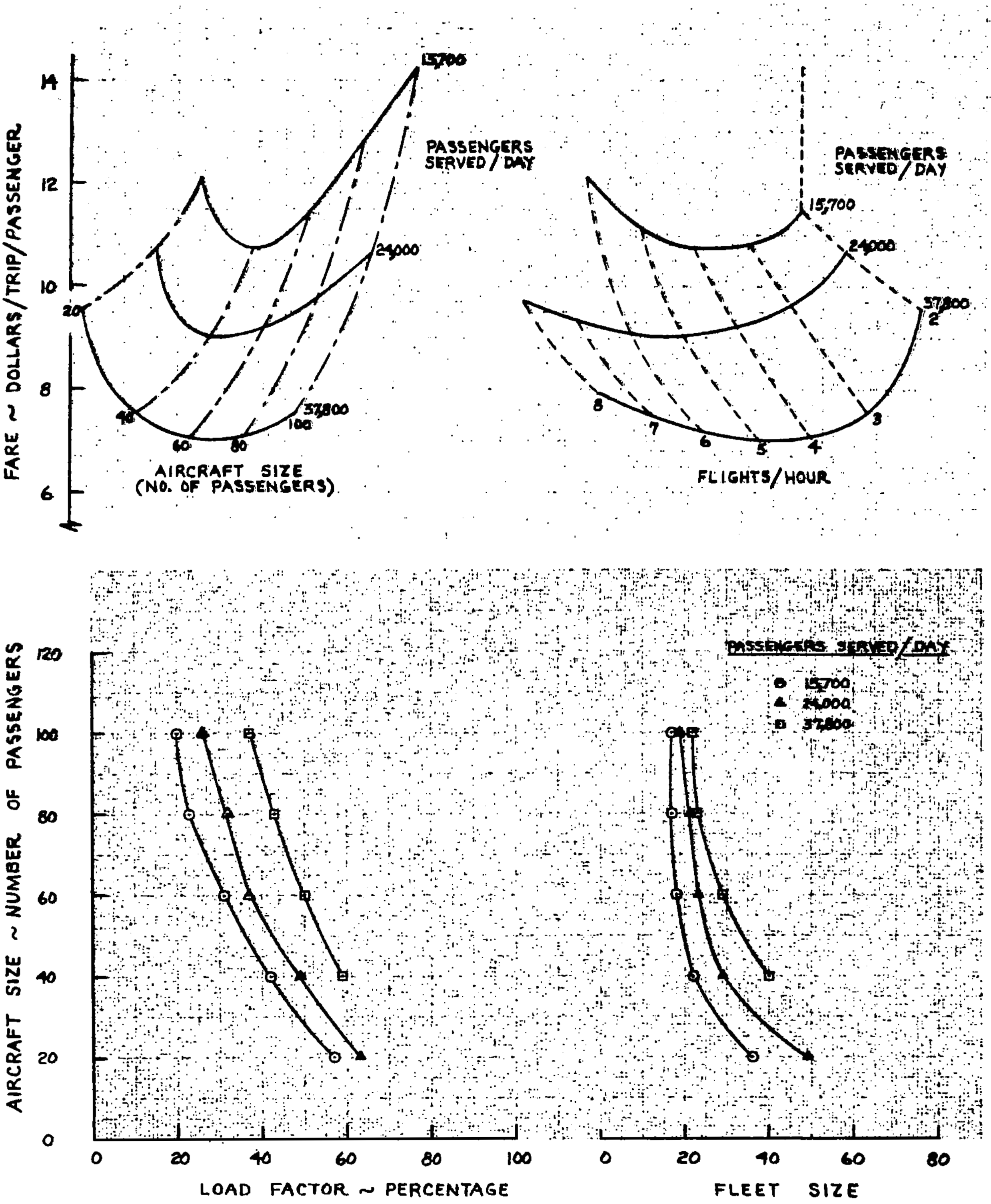


FIGURE 71. TOTAL SYNTHESIS OF 1985 DEFLECTED-SLIPSTREAM STOL

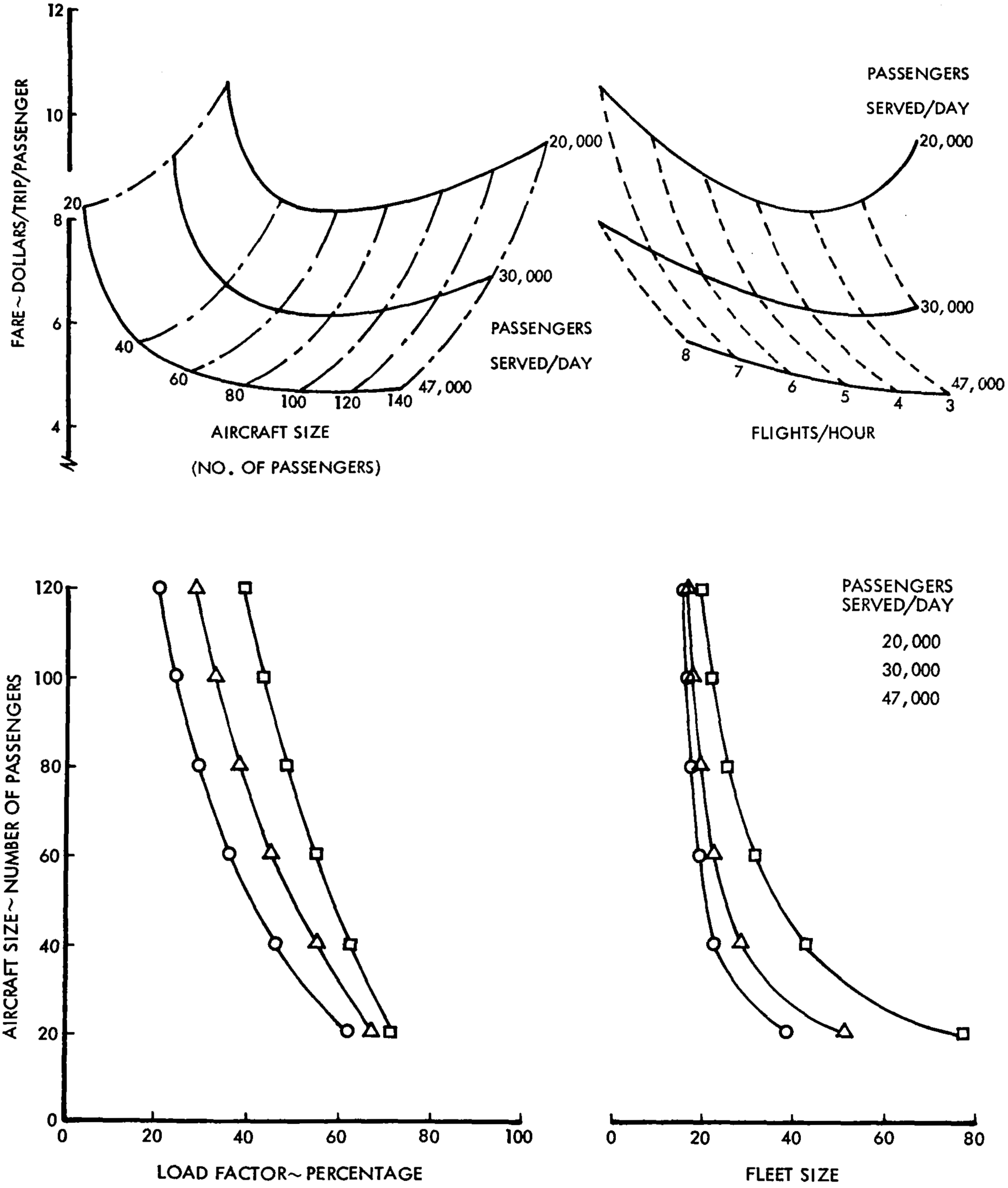


FIGURE 72. TOTAL SYNTHESIS OF 1985 COMPOUND HELICOPTER

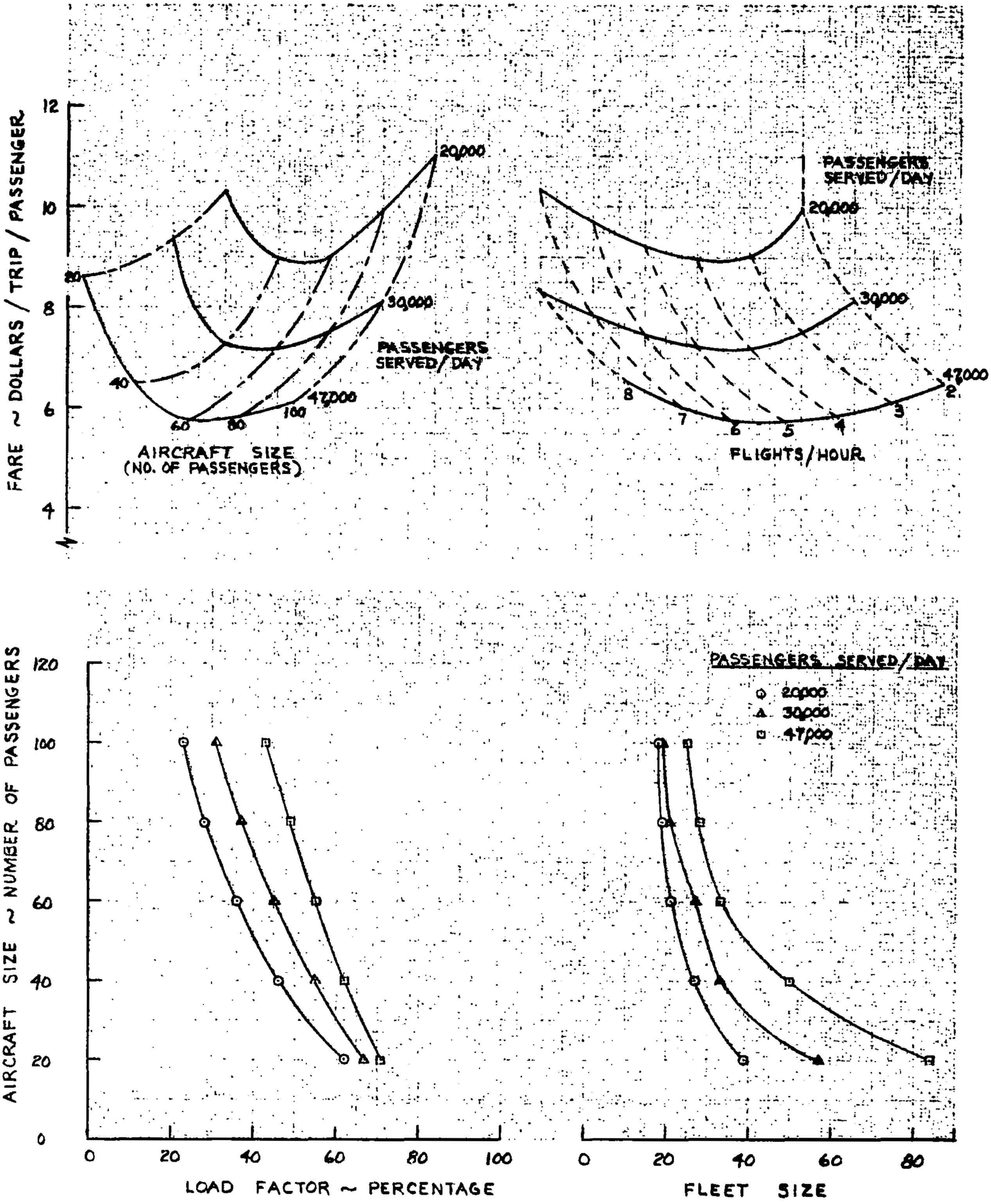


FIGURE 73. TOTAL SYNTHESIS OF 1985 AUTOGYRO

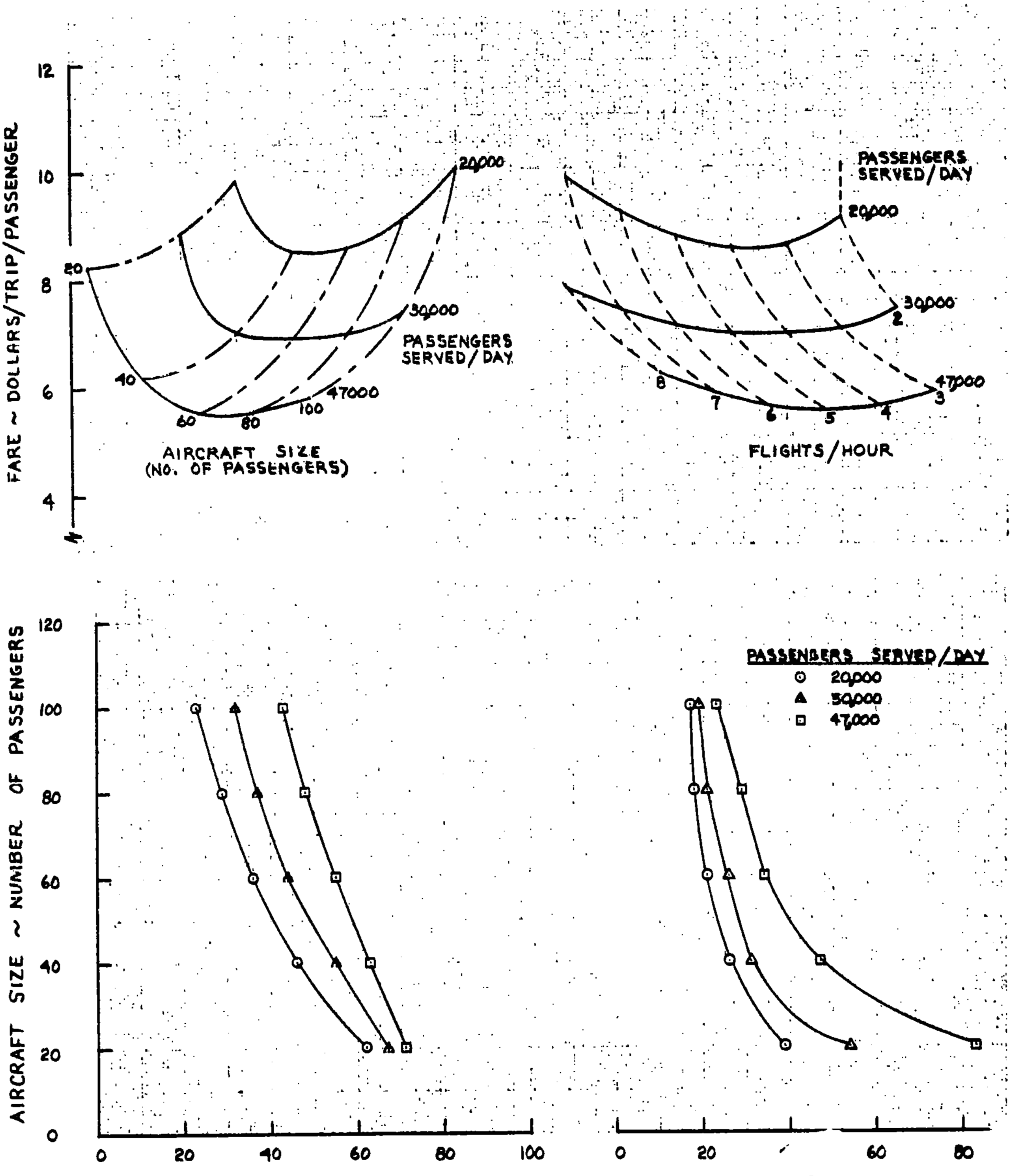


FIGURE 74. FARE VS DEMAND