NASA CR-151920

FEASIBILITY STUDY OF MODERN AIRSHIPS

Phase II

VOLUME II - AIRPORT FEEDER VEHICLE

GOODYEAR AEROSPACE CORPORATION
AKRON, OHIO

SEPTEMBER 1976

CONTRACT NAS2-8643

PREPARED FOR AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA

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FOREWORD

Goodyear Aerospace Corporation [GAC] under a jointly sponsored NASA/Navy Contract [NAS2-8643] has conducted a Phase II investigation into the feasibility of modern airships. The Ames Research Center and the Naval Air Development Center were the respective NASA/Navy sponsoring agencies. The Phase II investigation has involved further study of mission/vehicle combinations defined during the Phase I portion of the aforementioned contract. NASA Contractor's Report NASA CR-137692 summarizes the GAC Phase I investigation.

Volume II of the Phase II final report summarizes the work performed relative to the Airport Feeder Vehicle/System Concept. Contract funding for this portion of the effort was $60,000.

Dr. Mark Ardema, the NASA Project Monitor, provided valuable technical guidance and direction to the entire study effort. Mr. Ralph Huston was the GAC Program Manager. Jon Lancaster was the Project Engineer/Principal Investigator for the Airport Feeder [A/F] Study effort. Other principal personnel include:

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Cost/Weights	Don Block
Operational Procedures	J. Wolfersberger L. Cermak
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Subcontractors supporting the GAC study team include:

Aerodynamics/Stability & Control
Nielsen Engineering & Research

Institutional/Operational Constraints
Battelle Columbus Laboratories

Propulsion Systems
Hamilton Standard, Division of United Technology

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NOMENCLATURE

ACOE	Adjusted cash operating expense per year: Total operating expense less aircraft depreciation, ground property and equipment depreciation, amortization and general and administrative expenses.
AF	Airport Feeder
ALGW	Fleet-average maximum landing gross weight per flight
ASKM	Available Seat Kilometer
ASL	Average Stage Length ∿ km (n.mi.)
ASSM	Available Seat Statute Mile
Beta	Static Lift to Gross Weight Ratio
CB	Center of Buoyancy
C_e	Engine unit cost [U.S. dollars]
C_f	Fuel cost [U.S. dollars per U.S. gallon]
CG	Center of Gravity
C_t	Aircraft unit cost [U.S. dollars]
CTOL	Conventional Takeoff and Landing
$C_{L_{\dot{\theta}}}$	Variation of life coefficient with pitch rate, $$-\frac{1}{Q_o \forall^{2/3}} \frac{\partial F_z}{\partial q} \quad \text{(sec)}$$
$C_{M_{\dot{\theta}}}$	Variation of pitching moment with pitch rate, $$\frac{1}{Q_o \forall} \frac{\partial M_y}{\partial q} \quad \text{(sec)}$$

NOMENCLATURE [Cont'd]

C_{M_α}	Pitching-moment slope, $\frac{1}{Q \, \forall} \frac{\partial M_y}{\partial \alpha}$
C_{N_α}	Lift-curve slope, $- \frac{1}{Q_o \, \forall^{2/3}} \frac{\partial F_z}{\partial \alpha}$
C_{n_β}	Yawing-moment slope, $\frac{1}{Q_o \forall} \frac{\partial M_z}{\partial \beta}$
C_{n_r}	Variation of yawing moment with yaw rate, $\frac{1}{Q_o \forall} \frac{\partial M_z}{\partial r}$ (sec)
C_X	Axial-force coefficient, $\frac{F_x}{Q_o \, \forall^{2/3}}$
C_{Y_β}	Side-force slope, $\frac{1}{Q_o \, \forall^{2/3}} \frac{\partial F_y}{\partial \beta}$
C_{Y_r}	Variation of side force with yaw rate, $\frac{1}{Q_o \, \forall^{2/3}} \frac{\partial F_y}{\partial r}$
DFE	Flight equipment depreciation expense per year: total fleet including spares/spare parts
DOC	Direct Operating Cost
DP	Depreciation period (years)
ERP	Enplaned revenue passengers per year
ESHP	Equivalent shaft horsepower, takeoff rating
FCF	Flight crew factors: 0 for two-man crew 1 for three-man crew
FCR	Fuel consumption rate [U.S. gallons per aircraft block hour]
FS	Fleet size [number of aircraft operated]
FTPF	Flight time per flight [hours]

NOMENCLATURE [Cont'd]

F_x, F_y, F_z	Vehicle aerodynamic forces along x,y,z axes, kg (lbs)
GAC	Goodyear Aerospace Corporation
GW	Vehicle Gross Weight at Takeoff
h	Distance from vehicle center of buoyancy to rotor hub ∿ m (ft)
h_c	Cruise Altitude (ft)
IOC	Initial Operating Costs
IR	Insurance Rate [percent of initial cost]
I_{xx}, I_{yy}, I_{zz}	Vehicle moments of inertia about x,y,z axes, respectively ∿ kg - m^2 (slug - ft^2)
kg	Kilogram
km	Kilometer
K_T	Variation of rotor thrust with inflow velocity ∿ kg/m/sec (lbs/ft/sec)
ℓ	Fore or aft distance of rotor hubs from center of gravity ∿ m (ft)
Lb	Pounds
ℓ/d	Vehicle length to maximum diameter ratio
LERTA	Lake Erie Regional Transportation Authority
LTA	Lighter-Than-Air
m, mass	Vehicle mass kg (slugs)
m, meter	meter
m/s	Meters/second
m_x, $m_y = m_z$	Vehicle apparent additional masses for translation in x and y (or z) directions, respectively ∿ kg (slugs)

NOMENCLATURE [Cont'd]

M_x, M_y, M_z	Vehicle aerodynamic moments about x,y,z axes, [right-hand rule] ∿ kg-m (ft-lbs)
NASA	National Aeronautics & Space Administration
N_e	Number of engines per aircraft
n.mi.	Nautical Miles
NRP	Normal Rated Power
pNdB	Perceived Noise in Decibels
PV/E	Pounds Velocity/Weight Empty
$\tilde{p}$, $\tilde{q}$, $\tilde{r}$	Perturbation angular velocities about x,y,z axes, espectively [right-hand rule] (rad/sec)
Q_o	Dynamic pressure, $\frac{1}{2}\rho u_0^2$ kg/m^2 (lbs/ft^2)
Q*	Vehicle apparent additional moment of inertia kg - m^2 (slug-ft^2)
RABH	Revenue aircraft block hours per aircraft per year [i.e., aircraft utilization]
RAD	Fleet revenue aircraft departures per year: aircraft flights [i.e., departures] per year per aircraft [AFPY] times fleet size [FS]
RAM	Revenue aircraft [statute] miles per year
RDT&E	Research, Development, Test and Evaluation
RPM	Revenue Passenger [statute] miles per year
RTM	Revenue ton- [statute] miles per year; in this model: RTM = (0.1113) (RPM)
RV	Residual value [percent of initial cost]

NOMENCLATURE [Cont'd]

›HP	Shaft Horsepower
SFC	Specific Fuel Consumption
t	Time
·OC	Total Operating Cost
·OGW	Maximum takeoff gross weight (lb)
T/W	Thrust/Weight
u_o	Cruise speed m/sec (ft/sec)
$\tilde{u}$, $\tilde{v}$, $\tilde{w}$	Perturbation velocities along x,y,z axes, respecgively m/sec (ft/sec)
$\forall$	Hull volume m^3 (ft^3)
V_c	Cruise Speed m/s [knots or ft/sec]
VDC	Design cruise speed at design cruise alti tude m/s (mph)
V_{TIP}	Propeller Tip Speed m/s (ft/sec)
VTOL	Vertical Takeoff and Landing
W	Aircraft weight: Manufacturer's weight empty less engine weight (lb)
W_B	Weight supported by buoyant lift kg (lbs)
W_P	Weight supported by aerodynamic or rotor lift ∿ kg (lbs)
x, y, z	Right-hand axis system with origin at vehicle center of gravity
$\bar{y}$	Lateral offset of rotor hubs m (ft)
z_m	Vehicle metacentric height m (ft)

NOMENCLATURE [Cont'd]

α	Angle of attack, $\tilde{w}/u_o$
β	Angle of sideslip, $\tilde{v}/u_o$
δ	Rotor tilt angle
θ_0	Cruise pitch attitude
$\tilde{\theta}$	Perturbation pitch attitude
$\tilde{\phi}$	Perturbation roll attitude
ρ	Air density kg/m^3 ($slugs/ft^3$)
$(\dot{\ })$	Differentiation with respect to time

1.0 SUMMARY

The Airport Feeder is one of the mission/vehicle concepts specified by NASA for further study during the second phase of the Modern Airship Feasibility Study. An overview of the two phase program is shown in Figure 1.

The Airport Feeder vehicle is a VTOL, semi-buoyant ellipsoidal airship capable of transporting passengers or cargo to major CTOL hub terminals from suburban and downtown depots. One concept of operations is shown in Figure 2. The Phase II study effort was comprised of six tasks: 1) Vehicle Design Definition, 2) Operational Procedures Analysis, 3) Cost Analysis, 4) Comparison with Alternate Transportation Modes, 5) Mission/Vehicle Feasibility Assessment, and 6) Technology Assessment.

The vehicle design definition task resulted in the baseline vehicle shown in Figure 3. Principle vehicle/design characteristics are:

Pressurized metalclad construction
Volume = 12,135 M^3 [428,500 Ft^3]
Gross Weight = 30,618 kg [67,500 Lb]
β = Static Lift/Gross Weight = 0.35
80 Passenger design capacity
Modularized cargo/passenger design

Operating characteristics identified for maximum specific productivity [payload × velocity/empty weight] within the NASA study guidelines include:

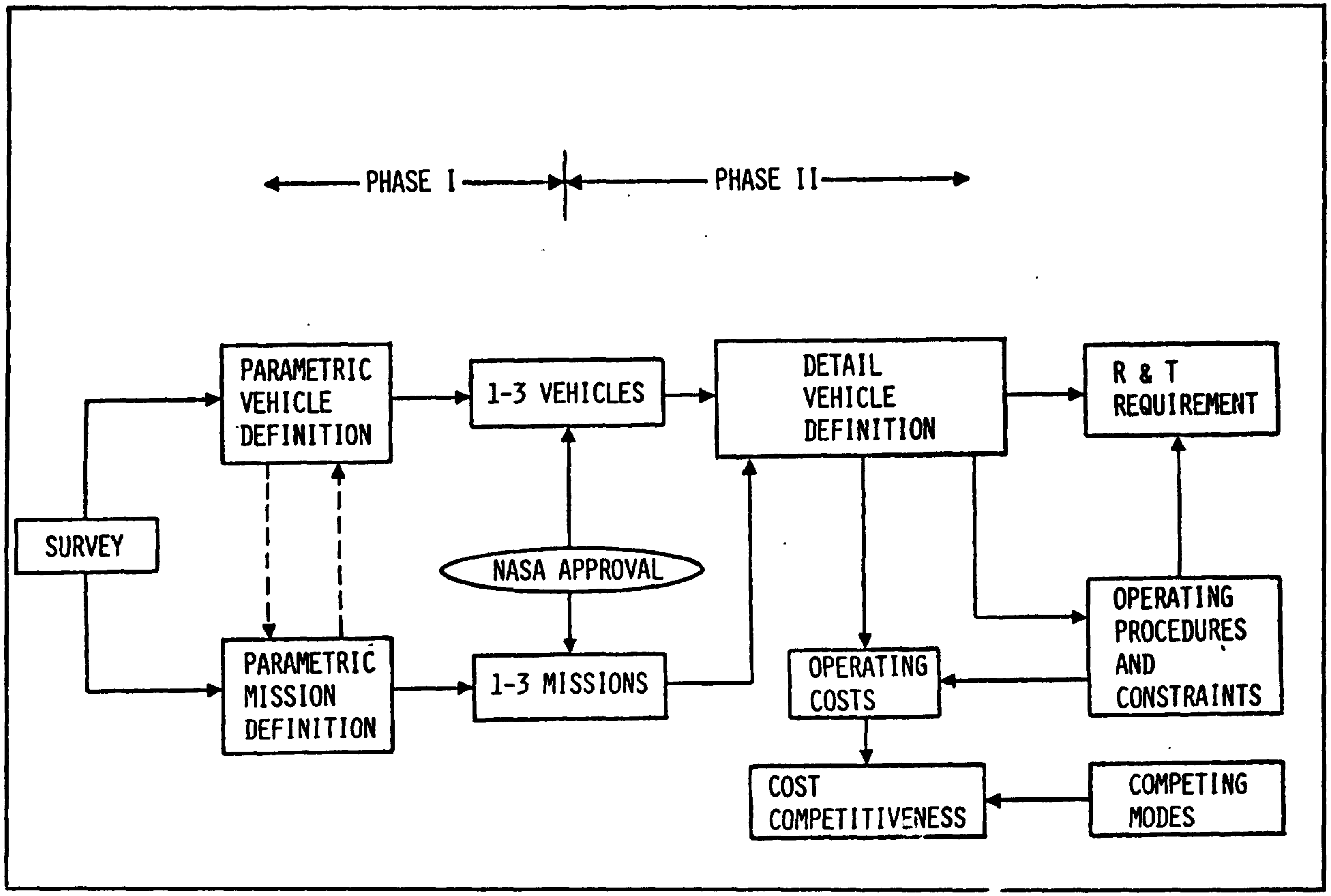


Figure 1. NASA Mod·rn Airship Feasibility Study Overview

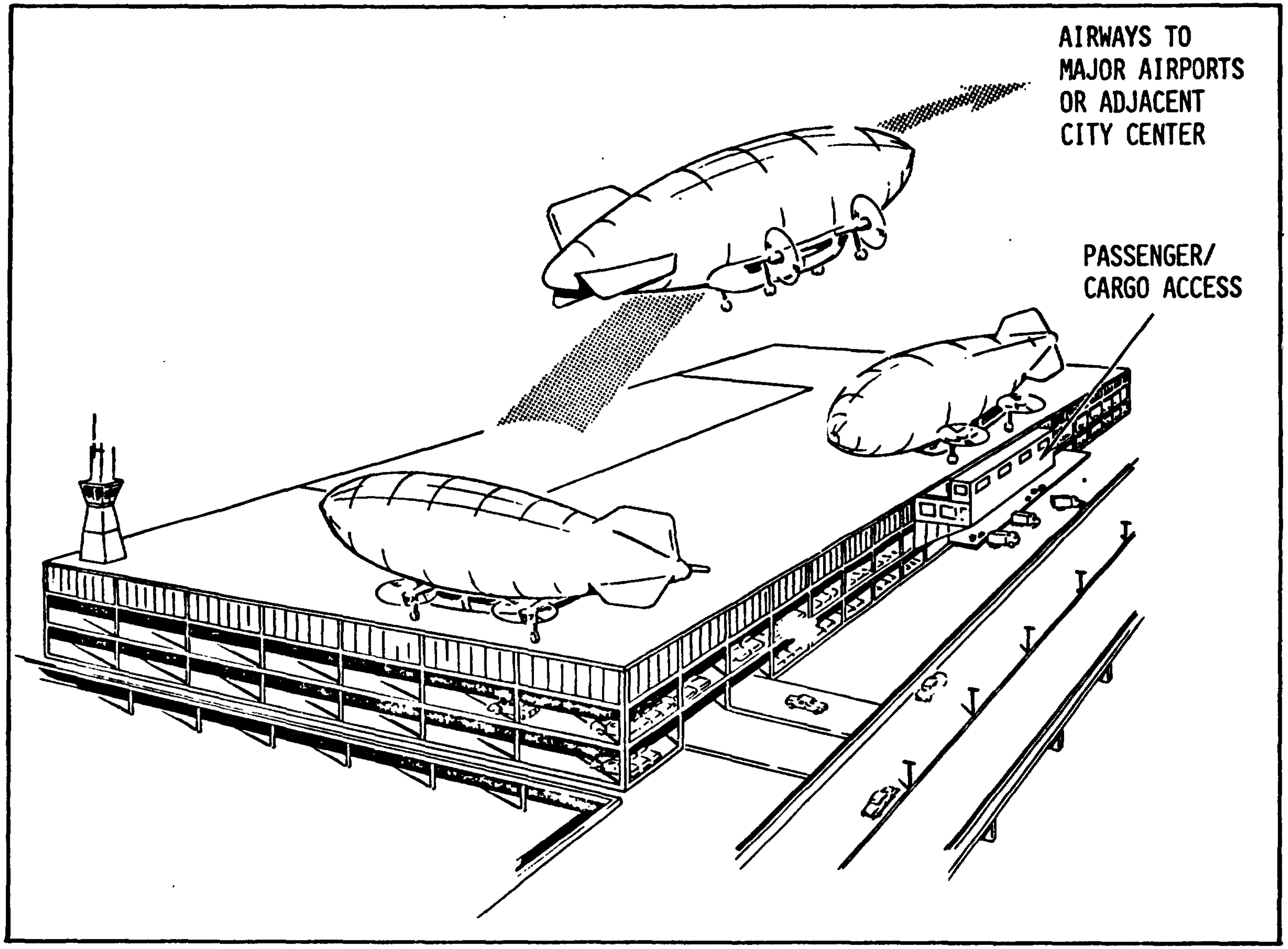


Figure 2. Airport Feeder Concept of Operations

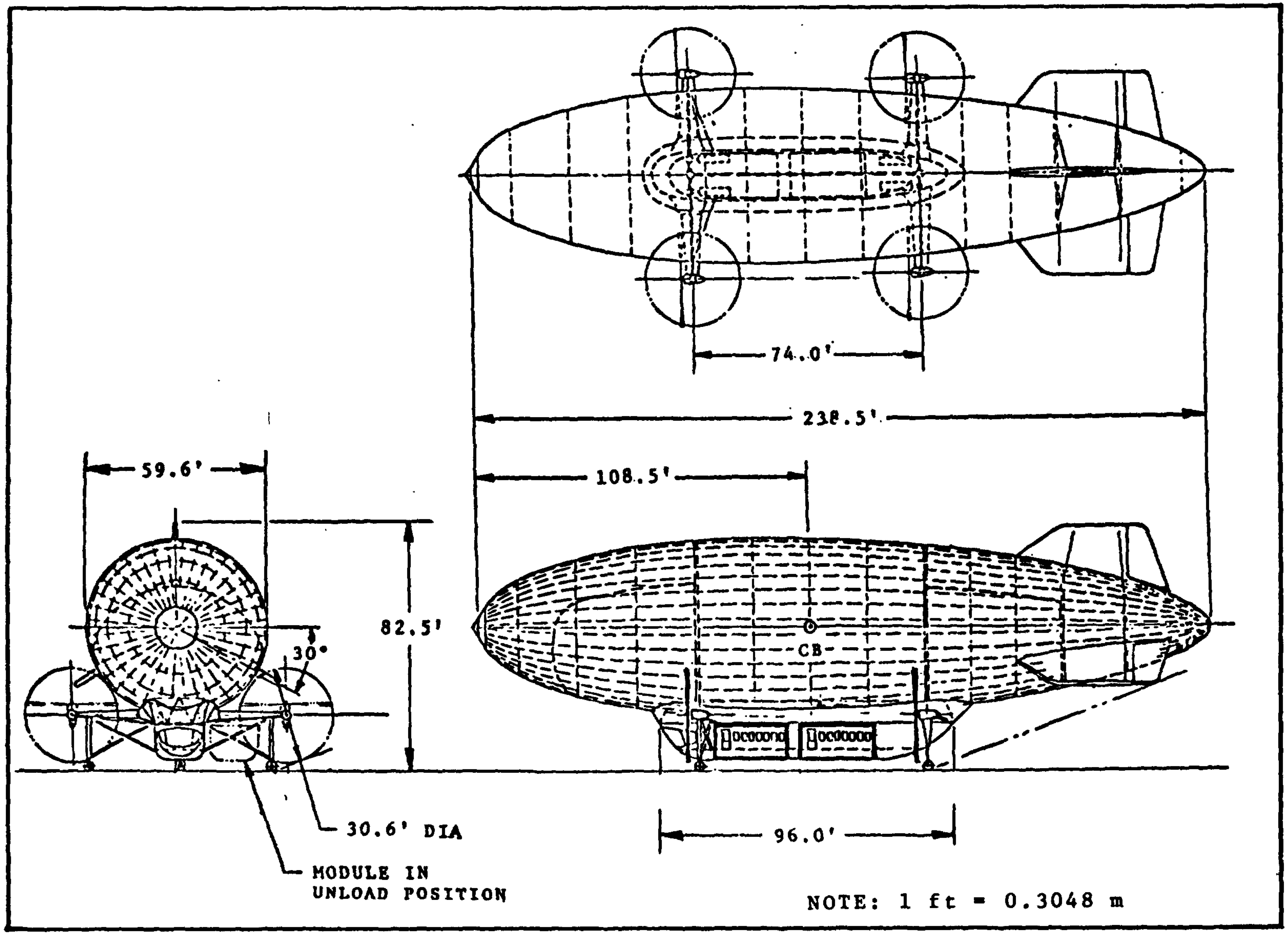


Figure 3. Final Phase II Baseline Configuration Concept

VTOL capable
Cruise speed = 67 m/s [130 kts]
Normal cruise altitude = 610 m [2,000 ft]
Maximum range = 741 km [400 n.mi.]

Operationally, the vehicle is envisioned as a "Feeder" system capable of transporting passengers and cargo from suburban or downtown terminals tc major CTOL hub airports. Normal stage lengths would range from 27.8 km [15 n.mi.] to 278 km [150 n.mi] with an average stage length of 74.1 km [40 n. mi.]. Terminals would be located on roof-tops of parking garage type facilities in suburban and city center regions.

An innovative tether/winch landing system was conceived which offers substantial improvements in ground handling operations. Both VTOL and on-ground operations appear possible with a one-man "ground crew".

Substantial analysis is required to define the passenger demand and market size for the Airport Feeder system concept. If the market is sufficient to justify 125 production units, Direct Operating Costs, DOC are estimated to be approximately 50% better than current technology rotor craft. Cargo operations in off peak and night time hours may significantly improve the overall economic viability of the Airport Feeder System concept.

Areas requiring further effort include hover, transition and cruise stability, control, and turbulence response, airframe/propulsion interference, low cost manufacturing methods and processes, and detailed market analysis.

Overall, the Airport Feeder System/operational concept is sufficiently promising to justify continued NASA support of this modern airship concept. The combination of buoyant lift with propulsive lift results in a vehicle with VTOL capability, which can satisfy stringent noise constraints in an energy efficient, economically competitive manner.

2.0 INTRODUCTION AND BACKGROUND

Today's concern for the environment and for energy conservation has generated new interest in a means of flight older than the airplane. Airships were once a significant element in world-wide transportation providing the only means of non-stop rapid travel across the world's oceans. Later, during and after World War II, they were a bulwark of this Nation's anti-submarine defense as well as a significant element of the U.S. Airborne Early Warning System. The only role of airships during the last decade has been the Goodyear advertising airship fleet. However, new requirements for military applications, transporting heavy loads over short ranges and providing economic, quiet and energy conservative intercity transportation are reviving interest in modern lighter-than-air vehicles.

As a result of the resurgent interest in lighter-than-air, the NASA Ames Research Center contracted with Goodyear Aerospace to perform a two-phase study of modern airships. As a part of the Goodyear Aerospace Phase I Study, the history, potential mission applications, and designs of modern lighter-than-air [LTA] vehicles were researched and evaluated to determine if there were combinations of transportation missions and airship concepts that were sufficiently attractive on the basis of the NASA specified figure of merit, productivity [payload ton-miles per hour], to warrant a more detailed study in Phase II. The results of the Phase I Study are documented in NASA CR 137692 entitled "Feasibility Study of Modern Airships - Phase I".

As a result of the Phase I Study, Goodyear recommended that further study during Phase II be directed toward the investigation of a short-haul, heavy-lift cargo airship, a short-haul passenger/cargo airship and a large Navy Sea Control Airship [Reference 1]. This report documents the results of the Phase II Study of the short-haul passenger/cargo feeder concept which could be used to transport passenger and cargo from outlying areas [suburbs, downtown city centers, or secondary airports] to major hub airports.

This system concept is particularly attractive today because of its potential to reduce ground congestion at major hub airports, to reduce take-off and landing noise to levels acceptable for operations in urban and suburban areas, and to reduce fuel consumption and operating costs to levels below existing helicopter systems and competitive with conceptual heavier than air VTOL aircraft systems.

2.1 Phase I Overview

The Phase I study consisted of three principal task efforts: A Historical Overview, A Mission/Applications Analysis, and A Parametric Performance Analysis.

As a part of the historical overview task, the history of lighter-than-air [LTA] vehicles was reviewed to provide a background for the mission analysis and parametric analysis tasks. In addition, data from past airships and airship operations were analyzed and documented for use during the Phase II Study.

The following areas are detailed in Reference 1 for past LTA vehicles and operations:

a. Parameterization of design characteristics

b. Overview of historical markets, missions, costs, and operating procedures

c. Definition of the 1930 state-of-the-art [SOA], both technically and economically

d. Development of indices of efficiency for comparisons with 1975 SOA performance characteristics

e. Identification of critical design and operational characteristics.

The Mission Analysis Task consisted of a comprehensive investigation and screening of potential uses for modern airship vehicles. The missions included not only conventional cargo and passenger applications but also unique applications which could capitalize on the unique performance characteristics of LTA and Modern Hybrid or Semi-Buoyant LTA vehicles. A concurrent analysis was made of potential Department of Defense Missions. A survey of current transportation systems was made and potential areas of competition were identified as well as potential missions resulting from limitations of present systems.

In addition to the three missions recommended to NASA for further study in Phase II, the Mission Analysis Task identified many additional promising potential LTA applications. Many of the promising missions were in the category of unique or unconventional applications, wherein productivity, per se is not the dominant figure of merit.

As a part of the Phase I Parametric Analysis Task, various types of lighter-than-air [LTA] vehicles from fully buoyant to semi-buoyant hybrids were examined. Geometries were optimized for gross lifting capabilities from 1360.8 kg to 2,721,600 kg [3000 lbs to 6,000,000 lbs] for ellipsoidal airships, modified delta planform lifting bodies, and a short-haul heavy-lift vehicle concept. Propulsive lift VTOL and aerodynamic lift augmented cruise flight was shown to significantly improve the productivity of low to medium gross weight ellipsoidal airships.

Furthermore, at low gross weights, the parametric analysis task results indicated that very low buoyancy ratios [static lift/gross weight] beta would maximize productivity. It was recognized, however, that several key mission related vehicle design and/or performance requirements had not been included in the generalized Phase I results and needed further analysis during the Phase II study. The three most important factors were the requirements for one engine out VTOL capability; the structural, design, and weight implications associated with the passenger accommodations and for cargo transport capability; and the requirement for low community noise.

Combining the results of the mission analysis and the parametric analysis tasks resulted in the recommendation for further study of an Airport Feeder [A/F] vehicle-system concept during the Phase II study.

In addition to specific mission related vehicle design and performance requirements, the Phase II study emphasized the operational aspects, acquisition costs and operating economics of the A/F system concept.

The Airport Feeder operational concept is schematically illustrated in Figure 2. This concept envisions a hybrid airship with VTOL capability for use as a feeder to major hub airport terminals from suburban and downtown terminals. The focus of the Phase II study has been to investigate the potential of hybrid [semi-buoyant] airship technology to improve performance, improve operational capability, reduce energy requirements, enhance operating economy, and reduce undesirable environment effects such as noise and air pollution.

2.2 Phase II Scope

The scope of the Phase II study of the Airport Feeder concept consisted of six major tasks:

I. Vehicle design definition
II. Operational procedures analysis
III. Cost analysis
IV. Alternative transportation mode comparison
V. Mission/vehicle feasibility assessment
VI. Technology assessment

The vehicle design definition, Task I, was a mixture of point design type of analysis and parametric vehicle sizing and performance optimization. The objective of this task was to define the optimum vehicle characteristics for the short-haul airport feeder vehicle with emphasis on two mission related factors not considered during the Phase I study: The design requirements associated with the 8^ passenger payload capability and the propulsion system design and performance characteristics associated with one engine out VTOL capability. In addition to these two considerations, the major parameter of interest was beta.

The objective of the operational procedures task was to define operational procedures which would result in significantly improved ground handling operations over past LTA vehicles. A concept of operations for the short haul passenger transportation system was postulated and the vehicle/system related operational requirements defined. The postulated concept of operations was used to assess the Institutional and Operational Constraints which could affect the viability or success of the Airport Feeder Concept.

The objective of the cost analysis, Task III, was to utilize the vehicle design and concept of operations defined in Tasks I and II to develop estimates of the acquisition and operating cost of the A/F system concept.

Task IV provided a comparison of the Airport Feeder vehicle concept with alternate air transportation modes. The comparison, both on the basis of economics and fuel efficiency provided one of the major inputs to the Mission/Vehicle feasibility assessment effort in Task V.

The final activity, Task VI, consisted of an overall assessment of the technology developments required for the successful development of the Airport Feeder system concept.

The NASA Ames Research Center provided the mission specifications, study guidelines, and overall study objectives for the Phase II Study Effort.

2.3 Phase II Study Guidelines and Objectives

Due to the limited scope of the Phase II study effort, a detailed market analysis was not made. The A/F mission as defined by NASA overlaps what has traditionally been defined as the Intra-urban and Inter-urban passenger and cargo market, with the major emphasis on the passenger mission application. In contrast with the short-haul heavy-lift airship study, the A/F study effort was much more or a conceptual level of analysis. The fundamental objective of this study was to answer the question "Can buoyant lift be employed to provide a VTOL capability which can meet stringent noise constraints with no major adverse operational problems and with economics and fuel consumption competitive to existing or proposed air transportation systems?" The NASA Study guidelines summarized in Table 1 include the specification that the vehicle shall have a 80-passenger capacity with a 740 kilometer [400-nautical mile] design range and an average stage length of 74 kilometers [40 nautical miles]. The criteria for the airport feeder vehicle design study was maximum specific productivity, PV/E [payload x velocity/empty weight] subject to a noise constraint at take-off of 95 perceived noise decibels at take-off power, 152 meters [500 feet] from the vehicle centerline.

As further guidance to the Phase II Study, NASA provided the following mission rationale and guidelines.

2.3.1 Stage Lengths

The vehicle cruise speed and other factors probably limit the practical stage lengths for passenger applications to a range of from 28 kilometers to 280 kilometers [15 nautical miles to 150 nautical miles]. Most of the trips would be at the low end of this spectrum and thus 74 kilometers [40 n.mi.] was selected as the average stage length at which performance and economics would be computed. The vehicle was specified to

Table 1. Feeder Mission Specification for "Feasibility Study of Modern Airships"

Passenger Capacity - 80

Unpressurized Cabin with All-Economy Seating at 34" Pitch

400 n. mi. Design Range (Maximum range at maximum payload with reserves)

Reserves - 40 n. mi. at most efficient cruise plus 20 minutes at most efficient loiter

Noise - goal is 95 EPNdB at 500 ft from centerline of airship - noise to be calculated at takeoff power on the ground and at 300 ft altitude

Missions - airport feeder and cargo

Speed, Buoyancy Ratio, and Geometry selected for best productivity-to-empty weight ratio

VTOL Power - for sea level, standard day, free air conditions the following minimum thrust-to-weight ratios are required:

1) 1.05 at takeoff power

2) 1.03 at maximum power with one engine out

Cruise altitude selected to maximize productivity-to-empty weight ratio subject to a minimum of 2000 ft (community impact limit) and a maximum of 8000 ft (cabin comfort limit). Pressure height to be 2000 ft above cruise altitude.

Performance and economic calculations to be made at a stage length of 40 n. mi.

Acquisition costs to be computed for production quantitites of 1, 25, 100. Technology levels and costs appropriate to the early 1980's shall be assumed but all costs shall be expressed in 1975 dollars. An avionics price of $250,000 per aircraft will be used.

NOTE: 1 n.mi = 1.853 km, 1 inch = .0254 m have a design range of 740 kilometers [400 n.mi.] for reasons of route and scheduling flexibility. Thus, constant refueling would not be necessary and the occasional longer trip could be accomplished. Also, cargo operations would tend to have longer stage lengths than passenger operations.

2.3.2 Markets

The market for a vehicle with stage lengths as described above is not well defined at present. The situation is complicated by the fact that the airport feeder system/ operational concept overlaps the markets traditionally called Intra-urban [stage length less than 40 n.mi.] and Inter-urban [stage lengths from 40 n.mi. to 400 n.mi.]. Thus, a definitive estimate of the market for the feeder vehicle was beyond the scope of the Phase II Study.

2.3.3 Passenger Amenities

For a stage length of 280 kilometers [150 n.mi.], lavatories and beverage service would be appropriate while for 28 kilometers [15 n.mi.] neither would be needed. In view of the relatively low penalty for extra volume on an airship, it was assumed that provisions for lavoratoires and beverage service would be allowed for in the nominal design. In any case, food service would not be needed.

2.3.4 Noise

Any vehicle proposed for the feeder mission must be quite. The noise goal as specified in Table 1, 95 pNdB must be closely met or would be improved upon if possible.

2.4 Summary of Phase II Results

The vehicle design task, Task I, was the major area of study during the Phase II program. Principle results include the selection of a pressure stabilized metalclad vehicle illustrated in Figure 3 with a beta of 0.35 and a gross weight of 30,600 kg [67,500 pounds]. The metalclad construction concept was selected on the basis of maximum specific productivity, PV/E, or payload times velocity divided by empty weight. The payload subsystems for both passenger and cargo operations will be modularized into modular payload compartments to enable either all passenger or all cargo operations or a combined passenger and cargo mode. The engines are fully cross shafted enabling one engine out VTOL and cruise capability. The propulsion systems are turboprops with conventional Hamilton Standard propellers. A noise level at take-off power of 86.5 pNdB, achieved by utilizing large diameter low tip speed propellers, is below the NASA Study objective by 8.5 pNdB.

Cruise altitude for maximum PV/E is 610 meters [2000 ft] which was the lower limit specified by NASA. Cruise speed for maximum PV/E is 67 m/s [130 knots]. In an all cargo mode of operations, the payload capability is approximately 8150 kg [18,000 pounds].

The Phase I results showed that productivity continued to increase as beta approached zero, the Phase II results indicated that productivity will be maximized at about a beta value of 0.35. Two mission-related vehicle requirements resulted in the difference between the Phase I and Phase II optimum productivity/beta trends: (1) Propulsion System Design for one engine out VTOL and cruise capability, and (2)

Incorporation of the modularized passenger module with 80 passenger seating capability.

The second task, Operation Procedures Analysis, resulted in a conceptual mode of operation in which the feeder could operate from downtown, parking garage type VTOL ports or other suburban pickup facilities with a minimum of ground support equipment and personnel. A unique tethered landing system has been conceived to improve the vehicle's operational characteristics at both outlying facilities and at major hub operations. The "one man ground crew" take-off and landing operations, made possible by the combination of the semi-buoyant, vectored thrust vehicle design and the "winch down" tether landing concept offers significant improvements in the A/F operational flexibility relative to previous fully buoyant airships.

This operational capability eliminates ballast transfer requirements for payload/cargo transfer operations and minimizes problems associated with winds during on-ground operations.

In Task III, the Cost Analysis Task, cost estimating relationships developed by the NASA Ames Research Center for conventional aircraft and short-haul, passenger air transportation systems were used as the reference point for developing both the acquisition cost and operating economics of the airport feeder system. Acquisition and operating cost estimates were calculated parametrically as a function of RDT&E costs, annual utilization, fleet size, stage length and load factor. The Direct Operating Cost, DOC element of the total operating cost was the primary parameter of interest. Results indicate a DOC per available seat statute mile of approximately six cents over a wide range of operational variables.

In Task IV, a brief comparison was made with alternative air transport modes. The results indicate that the airport feeder hybrid LTA vehicle concept is competitive both in terms of economics and fuel consumption per unit available seat statute miles with existing and proposed VTOL passenger transportation systems.

Task V, the mission vehicle feasibility assessment, several specific items were identified which will require research and technology development prior to successful development of the airport feeder vehicle. The primary area needing further work centered around the market for such an air transportation system and the stability and control and flying qualities of such a vehicle operating in downtown regions or in the turbulence environment associated with CTOL airport operations. In Task VI, a technology assessment was made of the various technologies required for a successful introduction of the hybrid LTA airport feeder vehicles and several areas for further work have been identified.

The areas requiring further effort can be loosely grouped into three general categories: (1) Aerodynamics/Stability and Control, (2) Mission/Market Operational Analysis, (3) Other General Research and Development areas. Research and Development items in each of the three areas are itemized in Tables 3, 4 and 5.

Finally, the overall conclusions resulting from the Phase I and Phase II Study of the Airport Feeder vehicle

Table 3. Aerodynamics/Stability and Control/Flight Dynamics R&D Areas

Hull/Rotor Interference Effects (Hover and Cruise)

Gust Environment/Vehicle Response in Airport and City Center Regions

Ride Quality During Cruise at Low Altitudes

Stability and Control in Transition and Hover Flight

Application of Active Controls Technology

Aerodynamic Configuration Modifications for Improved Lift/Drag

Table 4. Mission/Market Analysis R&D Areas

Market Analysis vs Vehicle Design and Performance Capability

Passenger Acceptance of Low Altitude Ride Quality

Design Optimization based on Return on Investment

Design Optimization at High Fuel Cost

Table 5. Other/General R&D Areas

Operational Development/Verification of Tether/Winch Landing System

Propeller Interference during Transition

Low Cost Materials Handling/Manufacturing Approaches

Passenger Compartment Noise Level Reduction

Environmental and Operational Limitations of Minimum Gauge Metalclad Hull Structure

Design Implications of High Ground-Air-Ground Cycle Operations

Applications of Advanced Materials

concept indicate that the A/F concept appears to be a potentially promising option for short haul passenger transportation systems of the future. Recommendations for further study are made which could ultimately result in a research vehicle similar to the tilt rotor research aircraft.

3.0 TASK I - PARAMETRIC ANALYSIS AND VEHICLE DESIGN DEFINITION

3.1 General

The Parametric Analysis and Vehicle Design Definition Task was one of the major efforts of the Phase II Study. Task efforts were conducted in three general phases in order to arrive at the final point design baseline configuration. The first phase consisted of a preliminary parametric analysis utilizing the methodology employed in the NASA Phase I Study. The primary tool employed for this study effort was the Goodyear Airship Synthesis Program, GASP. The GASP Methodology is shown in Figure 4.

It was recognized during the Phase I Study that several key mission related vehicle requirements had not been considered in the generalized Parametric Analysis: Two of the most significant factors being the passenger accommodation requirements and the capability for one engine out vertical take-off and landing. Thus, the second phase of Parametric Analysis and Vehicle Design Definition Task consisted of point design analyses of critical areas not considered during Phase I.

The results of the point design analyses were used during the third and final phase of Task I to perform the final vehicle optimization and design definition. Key study results for each phase of the Task I Analyses are described in the following sections.

3.2 Preliminary Parametric Analysis

The primary objectives of the preliminary parametric analysis study effort was to investigate further some of the

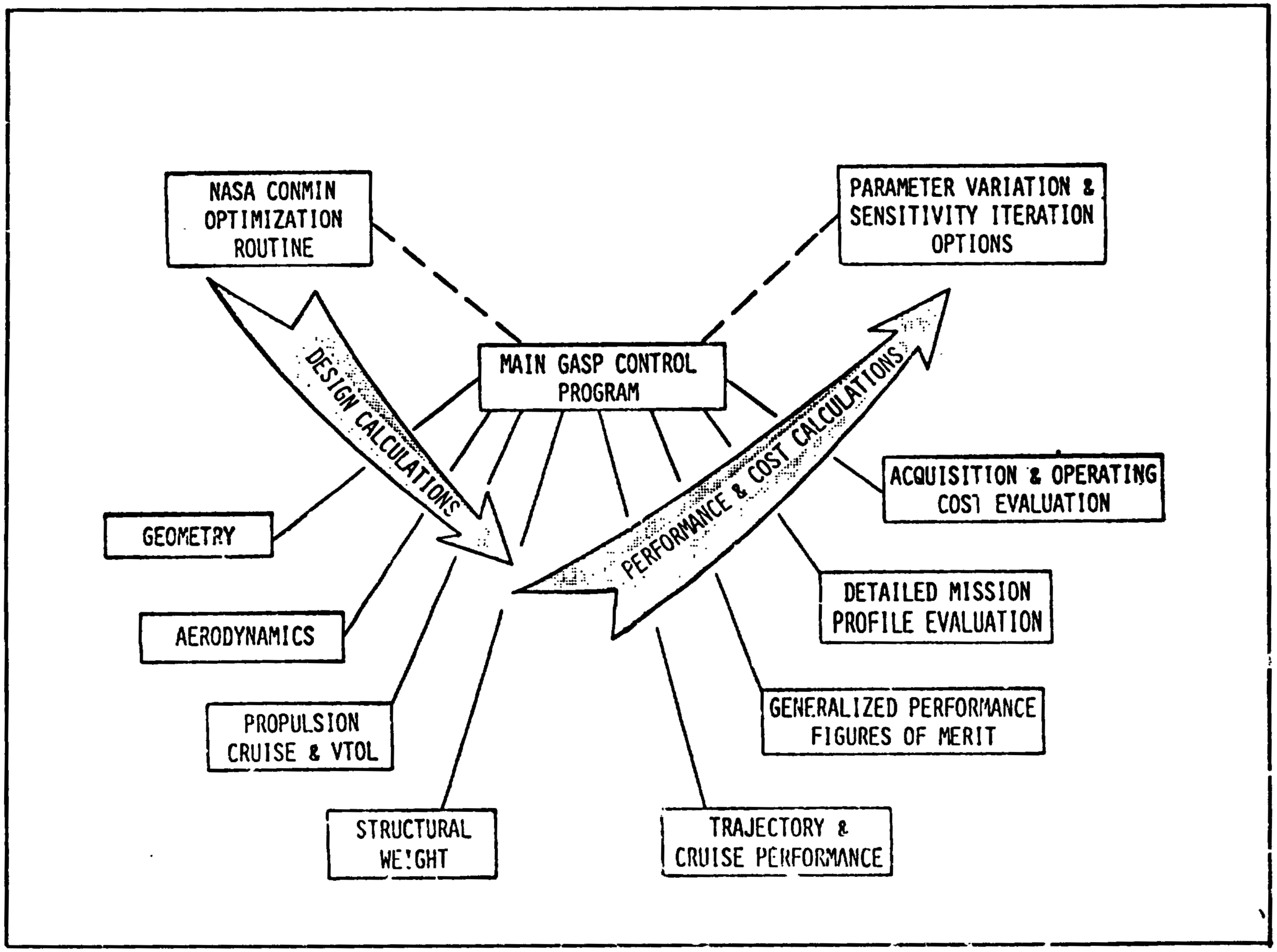


Figure 4. Configuration Optimization Tradeoff Study
Methods of Analysis

data trends identified during the Phase I study, particularly the effects of altitude and the type of construction concept. This preliminary analysis was performed at a gross weight of 21,500 kg [47,500 pounds].

Conclusions resulting from the preliminary analysis were consistent with the Phase I results. That is, the uncompartmented pressurized metalclad construction concept maximized specific productivity with the Kevlar non-rigid a close second. Although the conventional rigid also appeared competitive, the lack of minimum gauge constraints in the Weight Estimating Relationships was considered to result in an underestimate of the vehicle structural weight. Hence, it was not considered further during the Phase II Study. The Sandwich Shell Monocoque construction concept was also briefly examined for the Airport Feeder Vehicle. Weight Estimating Relationships were developed based on the Phase I Analysis [Volume IV, Reference 1] utilizing component WER's from the non-rigid and metalclad construction concepts. Results indicated that the size of the Airport Feeder Vehicle concept is much too small for structurally efficient application of the sandwich shell monocoque construction concept. These results are in agreement with the results of Reference 20, wherein it is shown that the sandwich monocoque type of construction concept will probably be limited to a very large size airships. Thus, based on the preliminary analysis, major emphasis was placed on the pressurized metalclad construction concept with a lesser level of effort on the Kevlar non-rigid.

The second major parameter of interest during the preliminary parametric analysis was the altitude for maximum PV/E and the effect of altitude on the productivity vs beta trend.

Altitude was one of the parameters which had been fixed during the Phase I study to simplify the analysis and reduce the study scope. Results for the metalclad vehicle concept are shown in Figure 5, showing the effects of both altitude, cruise velocity and beta on PV/E.

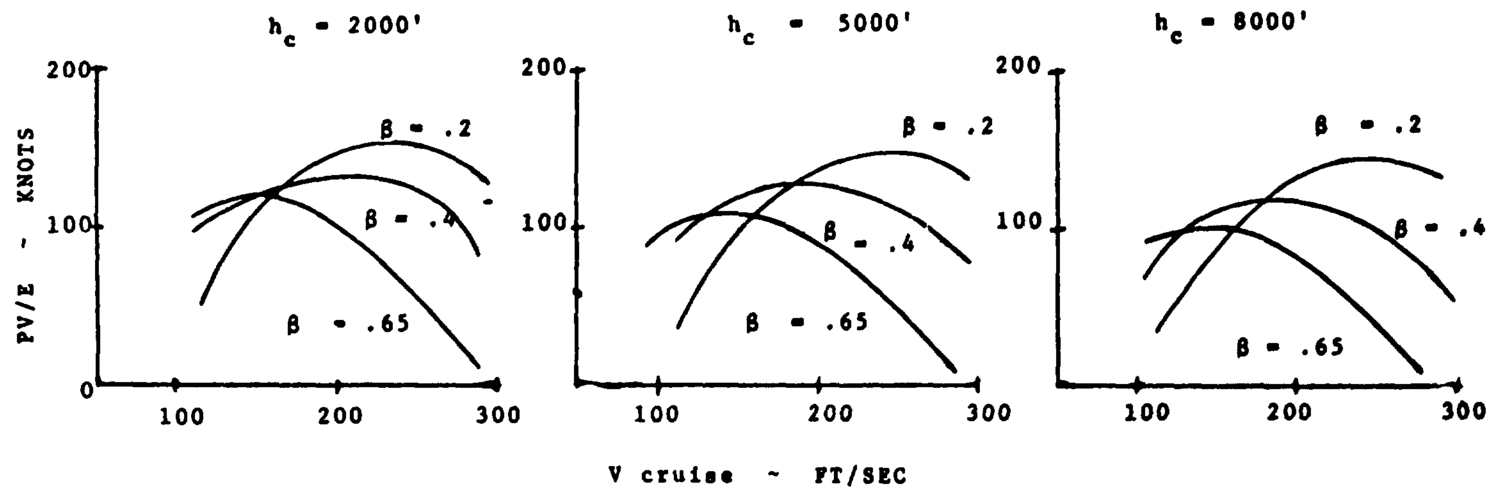
Figure 6 summarizes the effects of altitude on PV/E at the cruise velocity for maximum PV/E. As noted, the lower limit altitude maximizes PV/E for all beta's considered with the lowest beta configuration least sensitive to altitude over the ranges considered and the higher beta's slightly more sensitive. This variation can be traced to the larger volume required for a given beta at higher altitudes.

An additional parameter of interest in the preliminary parametric analysis was the length to diameter ratio [ℓ/d] for maximum PV/E. Figure 7 illustrates the sensitivity of PV/E to ℓ/d. At this short range, the lower limit value of fineness ratio maximizes PV/E which is consistent with the Useful Load X Cruise Velocity/Empty Weight figure of merit results obtained during the Phase I study. However, it should be noted that other study efforts have shown higher fineness ratios to be optimum for endurance oriented figures of merit. Thus, this low ℓ/d optimum should be recognized as peculiar to the short haul, low gross weight Airport Feeder vehicle based on a PV/E figure of merit.

Figure 8 summarizes the beta trend for maximum productivity utilizing the GASP Metodologies from the Phase I Study. This trend is of course similar to the Phase I study conclusion that low beta's maximize productivity for low gross weight vehicles.

Pressurized Metalclad Vehicle Gross Weight = 47,500# Range = 440 N.Mi.

Phase I GASP Methodology



NOTE: 1 ft = 0.3048m, 1 ft/sec = 0.3048 m/s
1 lb = 0.4536 kg, 1 n.mi = 1.853 km

Figure 5. Preliminary PV/E Optimization Results

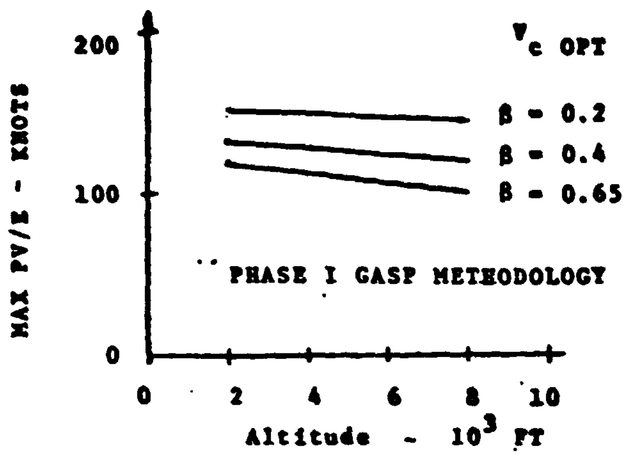


Figure 6 - Effect of Cruise Altitude on PV/E

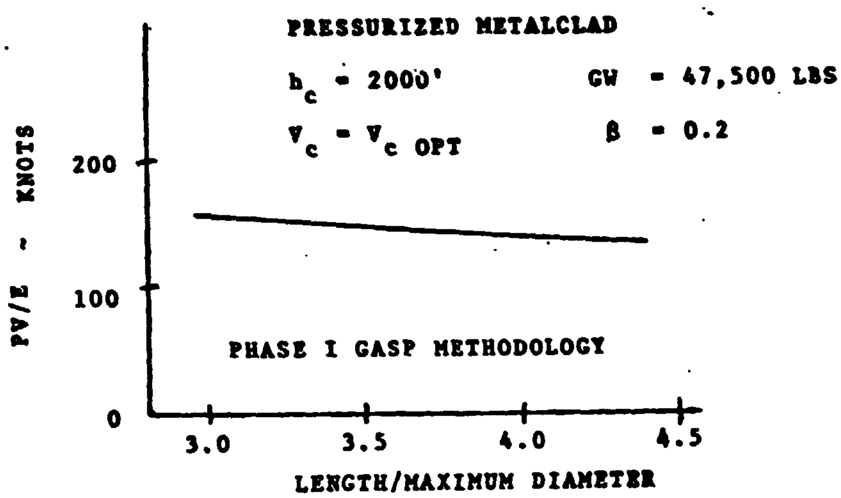


Figure 7 - Effect of Vehicle ℓ/d on PV/E

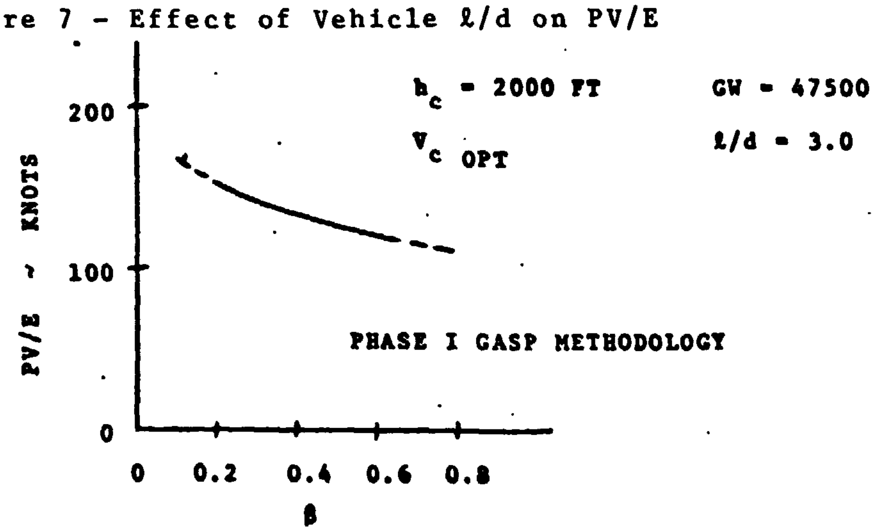


Figure 8 - Generalized Phase I PV/E vs Beta Trend

NOTE: 1 lb = 0.4536 kg, 1 ft = 0.3048m,
1 knot = 0.5148 m/s

The primary objective of the preliminary parametric analysis effort, however, was only to determine general vehicle configuration preferences and operating conditions [altitude and velocity] for use in the point design efforts.

3.3 Point Design Analysis

In order to proceed with the parametric design and optimization effort required for the Phase II Study several critical vehicle design factors were analyzed on a point design basis to assess their structural weight and performance implications. These factors included the car structure and passenger accommodations required for the 80 passenger seating capacity and the propulsion system characteristics dictated by the one engine out VTOL and cruise capability. Other investigations were also made in the areas of the aerodynamic configuration and the interaction of the vehicle construction concept and the passenger accommodations structure.

3.3.1 Car Structure/Passenger Accommodations Analysis

The payload requirements for the 80 passenger car structure were defined based on the data of References 2 and 3 and are summarized in Table 6. In the initial stages of the parametric design optimization task it was realized that there was a considerable interaction between the type of vehicle construction, [conventional rigid, pressurized metal-clad or pressurized non-rigid] the car structure and passenger accommodations requirements and the propulsion system characteristics. Several alternate car structure/passenger accommodations were investigated. The concepts evaluated included 4, 5 and 6 abreast seating in both single or modular passenger compartments with 2, 4, 6 and 8 entrance/exit door configurations. Several factors were found to be related to the

Table 6. A/F Payload/Passenger Accommodations Requirements

Passenger (PAX) Wt.:	
(160#/PAX) + Baggage Wt (20#/PAX)	14,400 Lb
Crew Wt and Gear (2 @ 190)	380
Attendants Wt and Gear (2 @ 140)	280
Seats and Belts 80 @ 16	1,280
Beverage Service and Cart	100
Crew Seats and Belts	142
Lavatory	300
TOTAL PASSENGER PROVISIONS	16,882
Flight Instruments (Incl. APU)	1,200
TOTAL A/F VEHICLE DESIGN PAYLOAD	18,082 Lb

Note: 1 Lb = 0.4536 Kg

acceptable car structure arrangement. These factors included the noise associated with the engine and propeller, the number of engines, whether or not the engines were cross shafted, propeller slipstream interference, the integration of the envelope and the car, the total car structure weight, the flexibility with cargo operations, and the potential flexibility with future system concepts such as the door to door short haul and other integrated inter-modal systems concepts.

Two basic types of payload compartment/car structure configurations were investigated; single module and double module configurations. Various seating arrangements were defined and the resulting overall car geometry evaluated. Figures 9, 10, and 11 illustrate three of the single module arrangements examined. Figures 12 and 13 illustrate two of the double module arrangements. As noted in the figures a seat pitch of 0.865 meters [34 inches] and a seat width of 0.533 meters [21 inches] was used for the seating arrangements. Double width doors 1.22 meters [48 inches] were incorporated in all designs to expedite passenger loading/ unloading operations.

The preliminary analysis of the critical design factors associated with the car structure/passenger accommodations and seating arrangement configuration indicated that the two most significant interactions would be: 1) the integration of the large car with the envelope/hull structure, and 2) the requirements imposed on the propulsion system capable of one engine out VTOL. Based on this assessment two configurations were selected for a point design analysis in conjunction with the propulsion system trade study discussed below. The two configurations were both modular concepts, one with six abreast

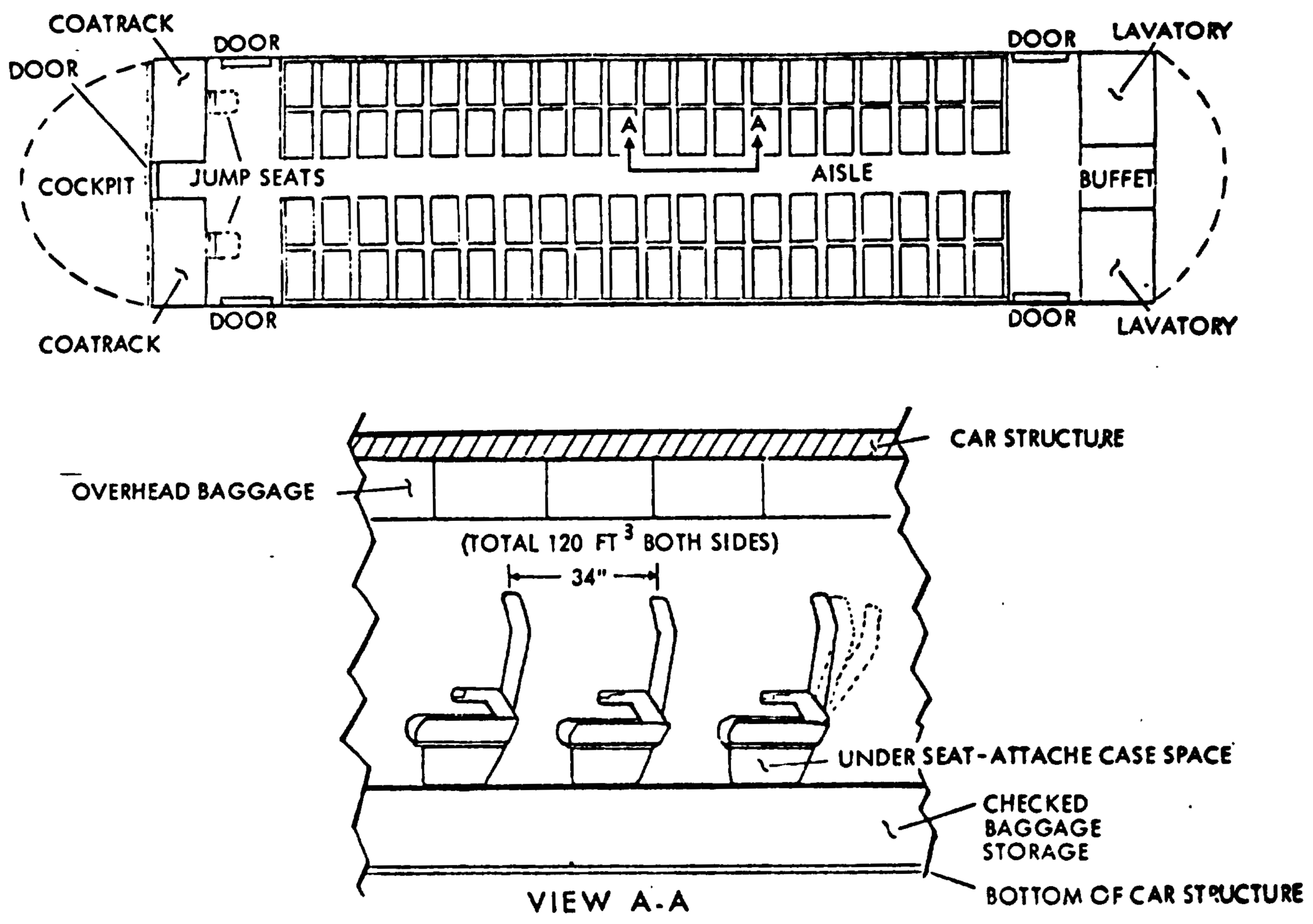


Figure 9. Basic Single Aisle - Cabin Layout

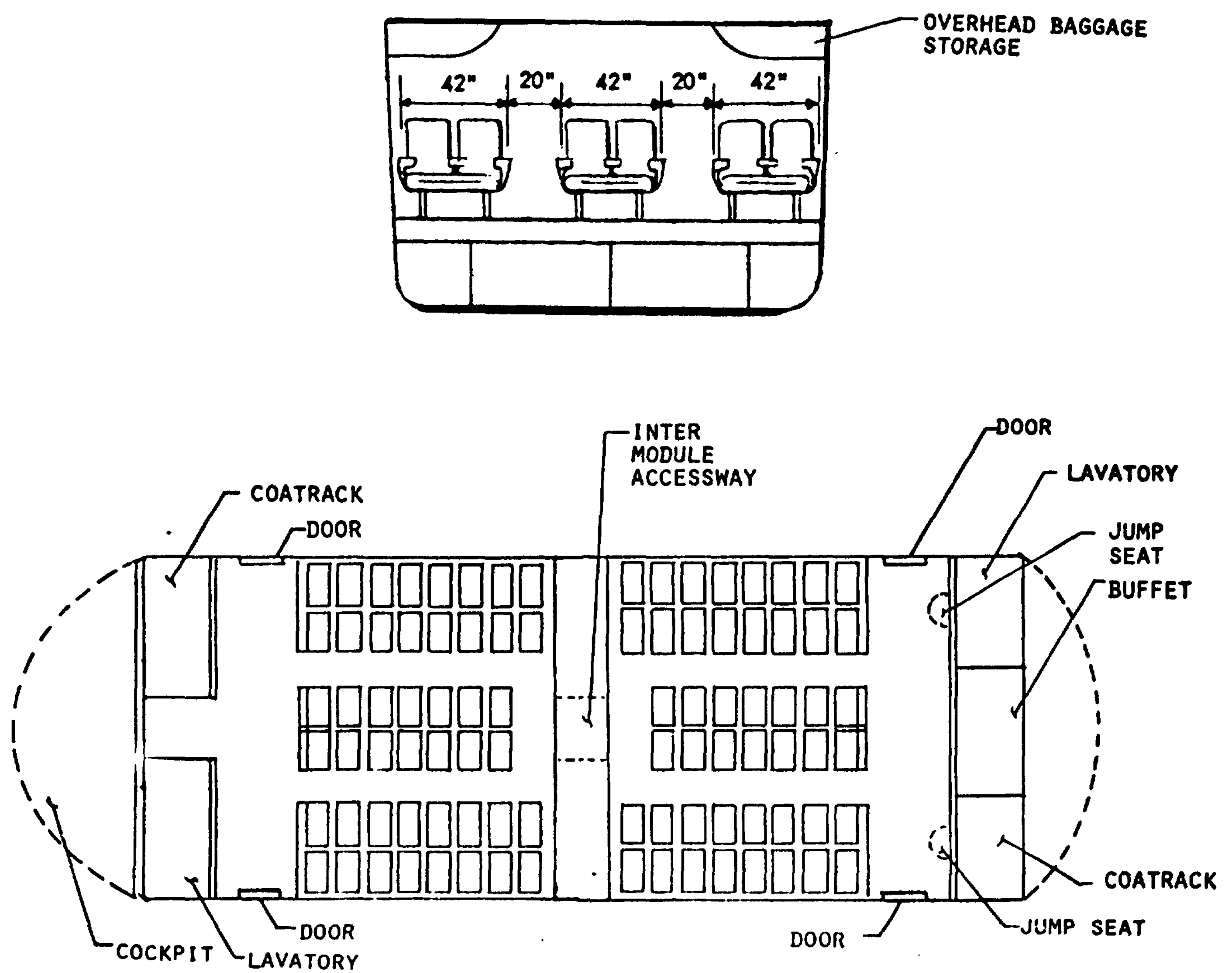


Figure 10. Conceptual Single Module (2-2-2 Seating) Double Aisle Cabin Layout

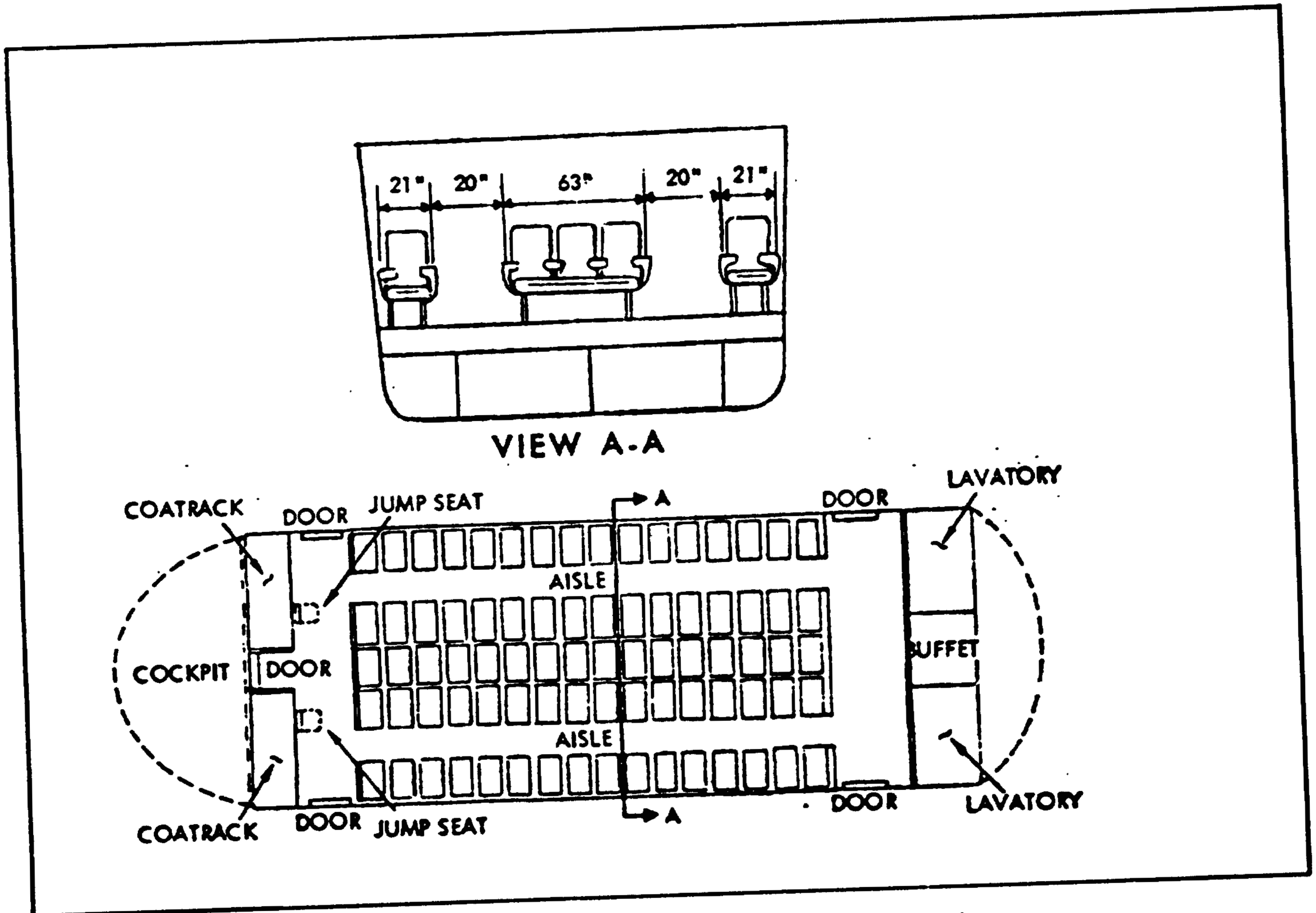


Figure 11. Conceptual Single Module (1-3-1 Seating)
Double Aisle Cabin Layout

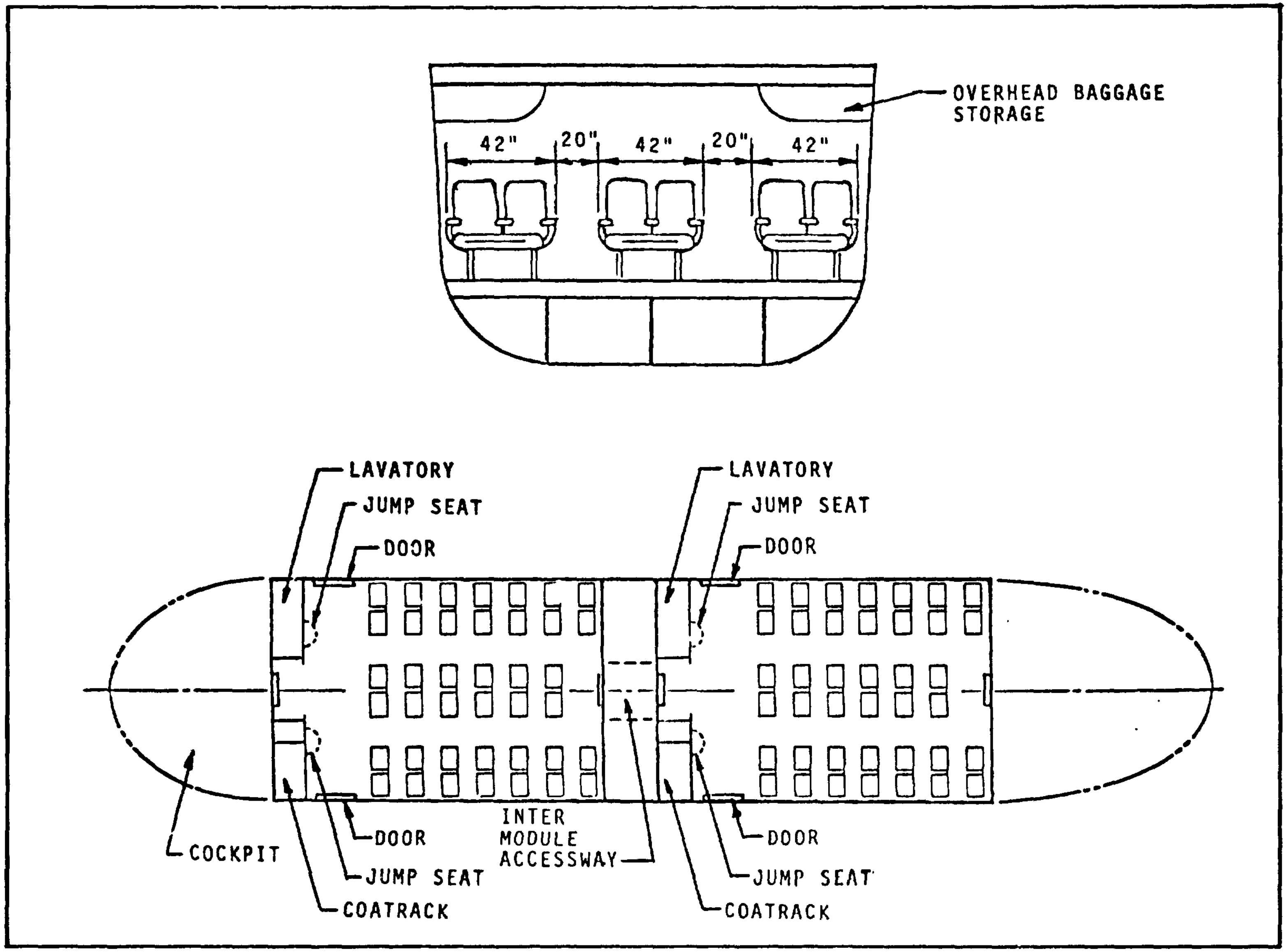


Figure 12. Two-Segment Payload Module Cabin Layout
(6 Abreast Seating)

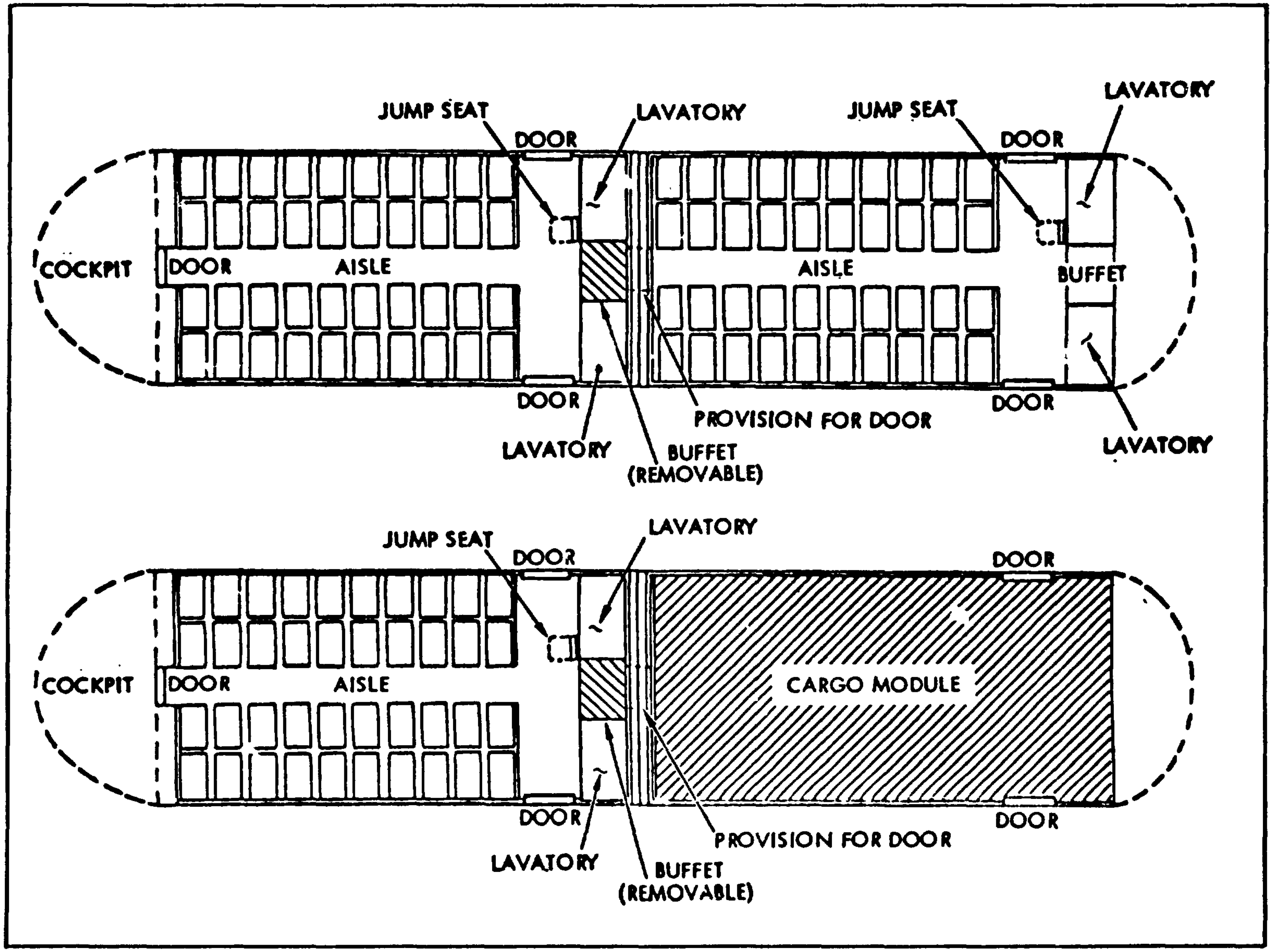


Figure 13. Two-Segment Payload Module Cabin Layout
(4 Abreast Seating)

seating and one with four abreast seating. These two configuration concepts are illustrated schematically in Figures 12 and 13, respectively. The modular concept selection was based on the rationale that the vehicle would be more flexible, hence offer potentially wider market applications if it could operate in an all passenger, all cargo, or combined mode of operation. Furthermore, these two configurations satisfied the design requirements associated with the key propulsion trade study question to be addressed: e.g., whether a six engine configuration without cross shafting was preferrable to a four engine fully cross shafted configuration.

The six engine configuration, Figure 14, satisfied the following design requirements. First, the separation between the propeller planes was approximately equal to two propeller diameters. Secondly, the internal passenger seating arrangements were clear of the "prop noise cone" for both the fore, aft and mid body engines. The six engine configuration, or "LONG CAR" configuration presented several envelope/hull integration problems and would likely require a higher length to diameter ratio hull than the "SHORT CAR" configuration.

The four engine fully cross shafted, "SHORT CAR" configuration also satisfied the preliminary design requirements for a separation between the fore and aft propeller planes of two prop diameters, Figure 15. Also, the passenger seating arrangements were clear of the "prop noise cone" while minimizing the overall total separation of the propulsors.

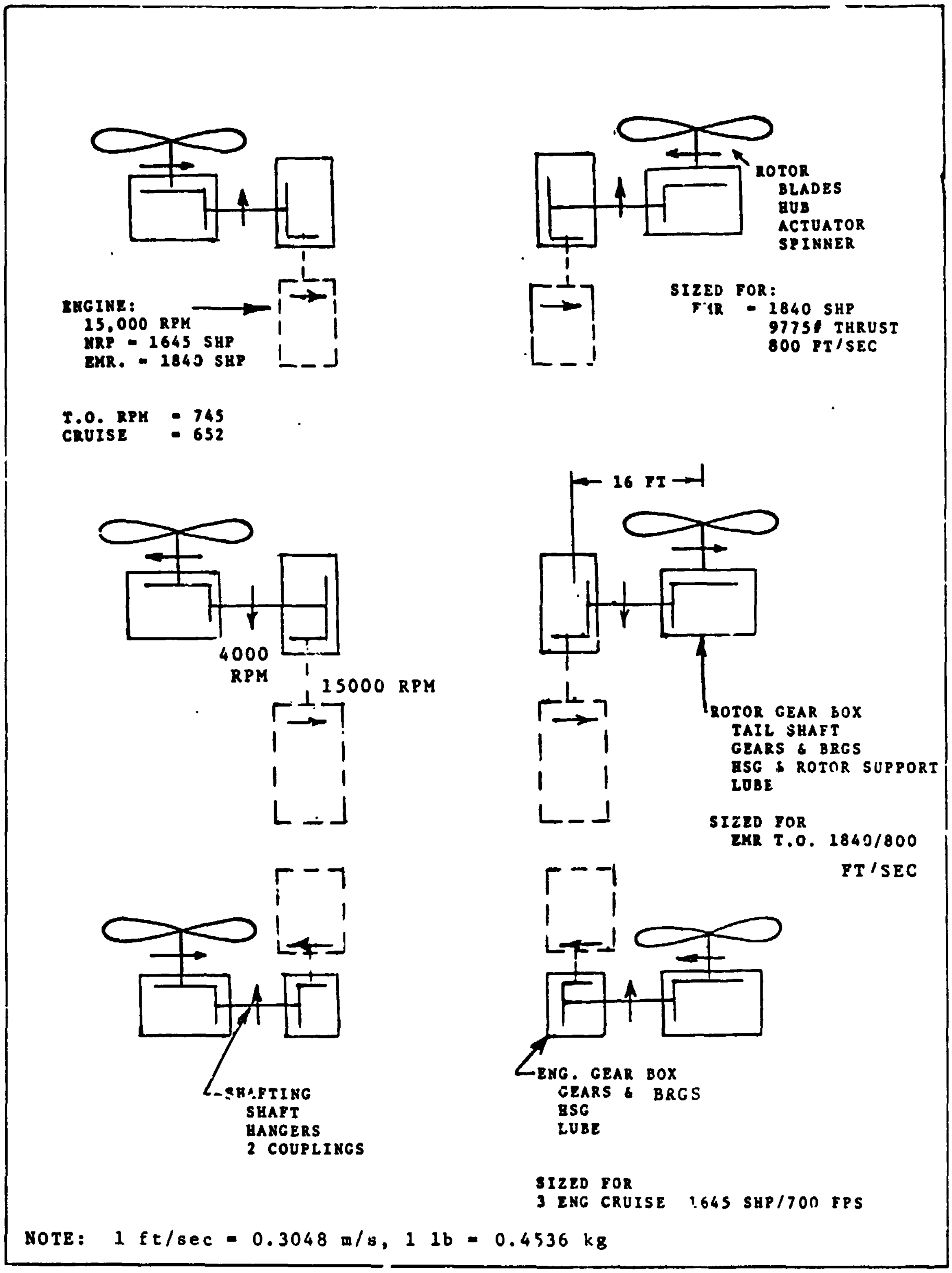
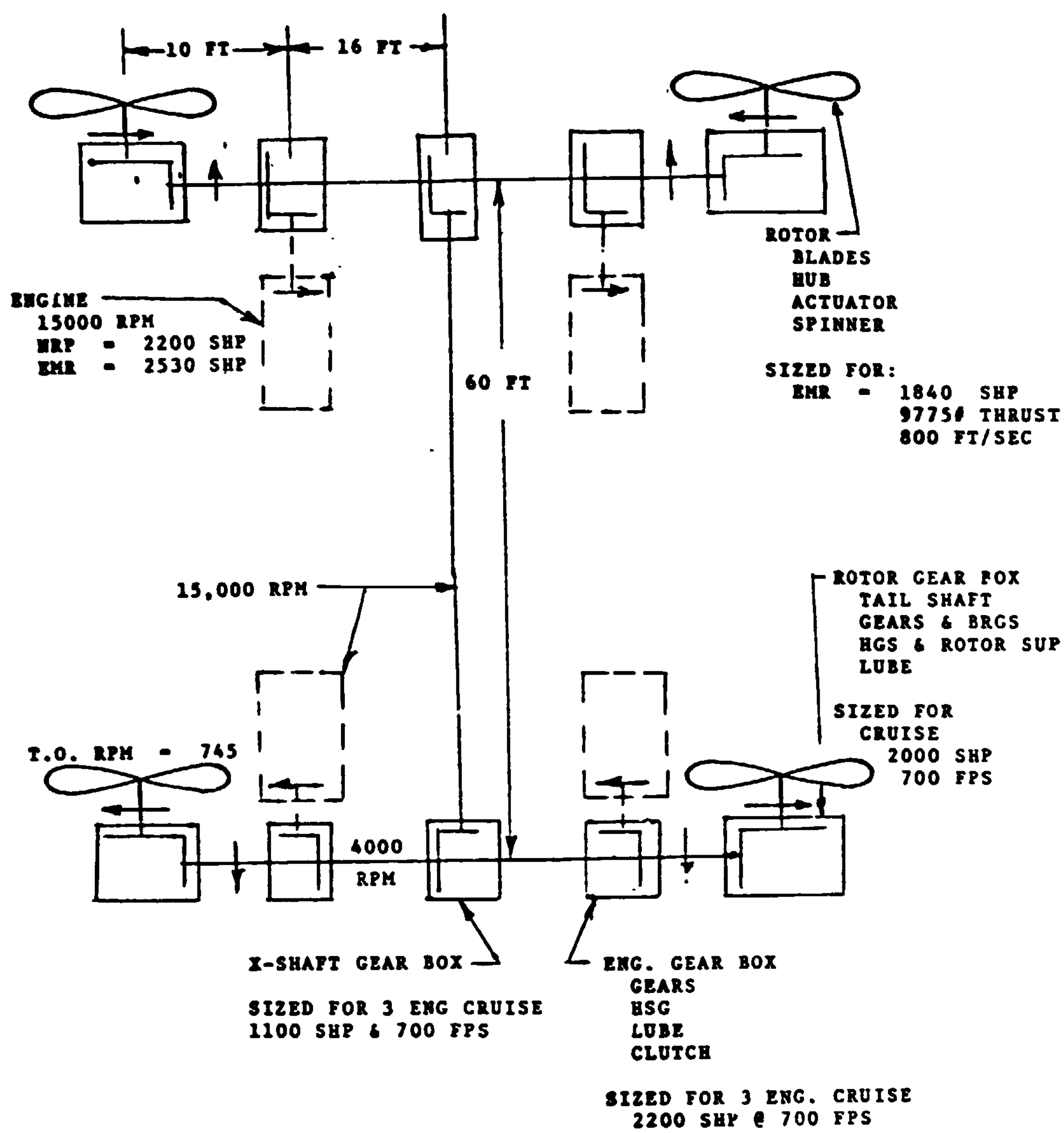


Figure 14. 6-Engine Configuration Schematic



NOTE: 1 ft/sec = 0.3048 m/s, 1 lb = 0.4536 kg

Figure 15. 4-Engine Configuration Schematic

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As noted previously, the interaction between the car/passenger arrangement and the total propulsion system characteristics was one of the primary design interactions in the airport feeder configuration selection process. Thus, the final configuration selection required a propulsion system point design type of trade study which could be integrated with the results of the car structure/passenger arrangement results. The propulsion system point design trade study results which support the final configuration selection are discussed in the following section.

The final car structure concept which was selected was a modular concept with two-forty passenger modules and six abreast seating which would enable either all passenger, all cargo, or combined operations. The rationale for the selection was that this concept resulted in the lowest total structural weight, minimized the engine cross shafting requirement, and provided adequate propeller slipstream separation for minimum propeller interference. [NOTE: The initial estimate of prop separation requirement was made at slightly higher cruise disk loadings than the final baseline configuration and should be re-examined in subsequent study phases.] The results of the weight study of two conceptual car structure concepts, a short, four engine, six abreast seating concept, and a longer, six engine, four-abreast seating concept are:

Item	Long Passenger	Long Cargo	Short Passenger	Short Cargo
Basic Structure	4,943	4,943	3,893	3,893
Modules [2]	7,640	6,700	6,850	6,000
Total Car Structure Weight ∿ Lbs.	12,583	11,643	10,743	9,893

NOTE: 1 Lb = 0.4536 Kg

3.3.2 Propulsion System Trade Study

The second major point design tradeoff study area was in the propulsion system requirements. The concept investigated consisted of three basic options: A four engine fully cross shafted configuration, a six engine totally uncross shafted configuration, and finally a four engine cross shafted incorporating ducted propellers.

The variables which were investigated included propeller tip speed, propeller diameter, number of blades per propeller the cross shafting requirements, and weight associated with each configuration option. The primary requirement was to satisfy the noise level constraint at take-off. The primary areas of concern included the total propulsion system weight, one engine out performance capability, prop wash interference and the geometric relationship between the VTOL thrust moment, the center of gravity and the center of buoyancy. The propulsion system point design performance tradeoff study was supported by Hamilton Standard, Division of the United Technology, Inc. and was performed based on a preliminary baseline vehicle sized at 47,500 pounds and a beta of

0.2. Factors considered were the emergency sizing requirements, free air versus shrouded propeller, tip speed and the weight studies of the various configurations. This point design study is briefly summarized below.

3.3.2.1 Emergency Sizing

Schematic arrangements for both four and six engine configurations were defined from the car structure/passenger arrangement analysis as shown in Figure 14 and 15. Both configurations were sized to achieve a total thrust level of 39,100 pounds based on the preliminary baseline configuration characteristics [GW = 47,500 and beta = 0.2]. Static operations with a T/W [Thrust/Weight] - 1.03 in an emergency condition with a loss of one engine was a NASA specified requirement. The six engine configuration has no cross shafting and shuts down a second engine for VTOL pitch and roll thrust moment stability requirements. The four-engine configuration is cross shafted and will operate with three engines uniformly powering four propellers. The four-engine configuration requires a larger size engine to meet this condition. The engines for both configurations utilize an estimated 15% increase in power over the normal rated power for a five (5) minute period in the engine-out condition.

The power summary for the two configurations is:

Configuration	6 Engine	4 Engine
SHP/Propulsor [5 Min]	1840	1840
Total SHP [5 Min]	7360	7360
Number of Operating Engines	4	3
SHP/Engine [5 Min]	1840	2453
SHP/Engine [NRP]	1600	2133

3.3.2.2 Free Air vs Shrouded Propeller

Weight is an important factor when comparing free air and shrouded propellers. Thus, minimum size was a prime objective. For the comparison, a three (3) bladed, 20.5 foot diameter, 120 activity factor,0.7 integrated design lift coefficient, free air propeller was compared to a three (3) bladed, 13.5 foot diameter, 133 activity factor, 0.5 integrated design lift coefficient, shrouded propeller. Both operate at 800 feet per second tip speed. The 800 feet per second was selected as a reasonable point of compromise between noise and performance. Tip speeds can be reduced with increases in diameter and/or activity factor, resulting in an increase in weight but a reduction in noise level. An increase in tip speed would reduce weight but the associated increase in noise level was assumed undesirable.

The three-bladed propeller was selected because of structural advantages. Although a four-bladed free air propeller would reduce the diameter slightly, it would be heavier. On the shrouded configuration, the three-bladed propeller offers minimum weight since increasing the number of blades at the same total activity factor is heavier and does not increase performance.

The results of the free air vs shrouded selection study comparing thrust vs blade diameter is shown in Figure 16. For this curve the diameters were rounded off to the next half foot.

An additional study comparing thrust vs shaft horsepower for the cruise condition between the free air and shrouded configuration was made. The results of this study are shown in Figure 17. For this study the configuration of each, as described above, was maintained. A 150 knots true airspeed at 2000 foot altitude was used. A tip speed of 700 feet per second was selected because it was determined that the noise level could be reduced at this speed with no noticeable degradation in performance. Note that this figure shows that there should be no problem meeting the estimated cruise thrust requirements of 2445 pounds per propulsor with partial power and one engine out.

3.3.2.3 Six Engine vs Four Engine Noise Level

A brief investigation was conducted of tip speed vs power and the associated take-off noise for the 47,500 lbs, beta = 0.2 preliminary baseline vehicle. It was first determined that for normal operation, with all engines operating, both the four-engine and six-engine configuration could be operated at a reduced tip speed, meet the thrust requirements of both static and cruise conditions and operate at less than normal power. Figure 18 illustrates power as a function of tip speed for both modes of operation illustrating the power capability at reduced tip speeds. Note however, that for the four-engine cross-shafted configuration, available normal rated power limits the tip speed reduction to 650 feet per second. Figure 19 provides an estimated

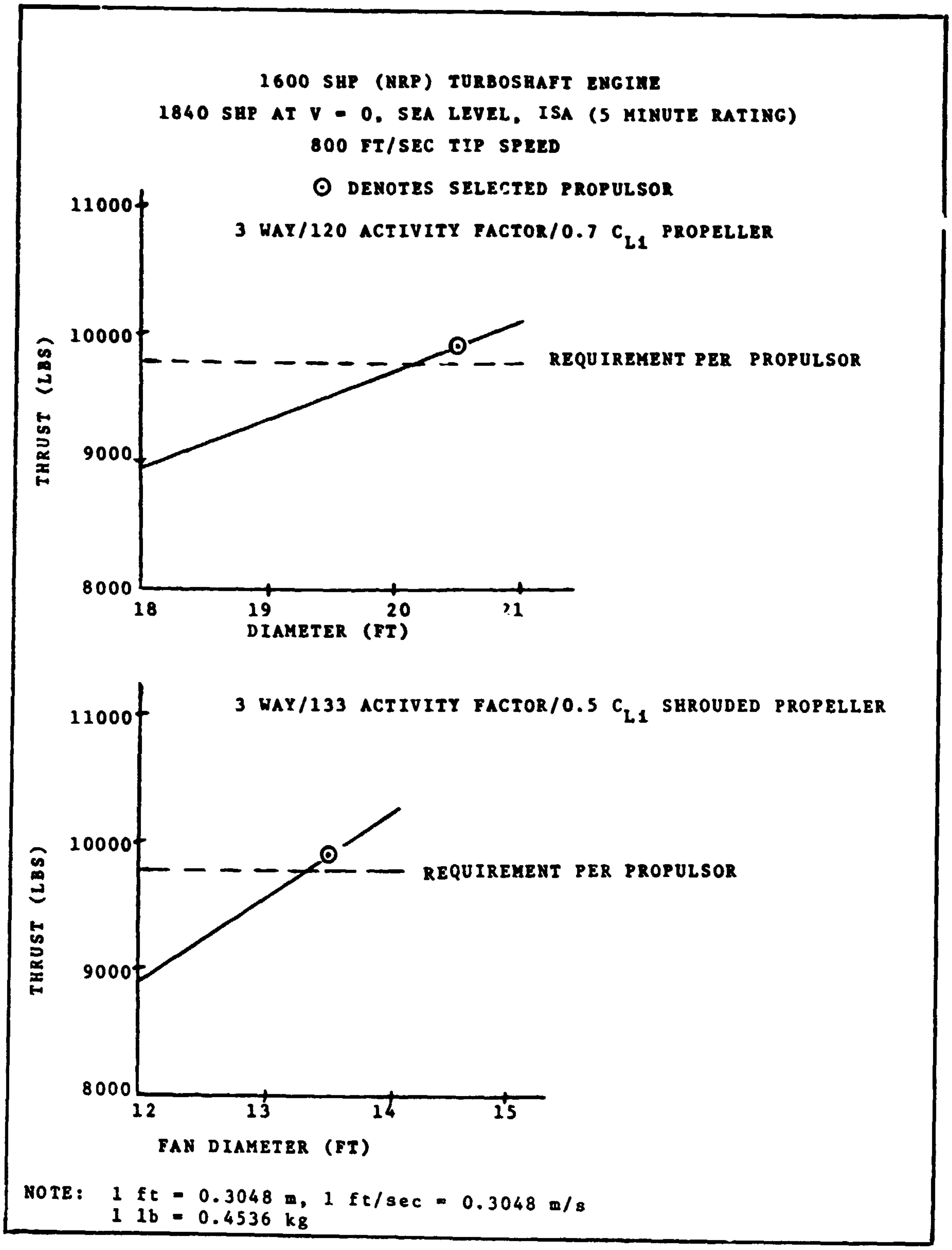


Figure 16. Free Air vs Shrouded Propulsor Trade Study Results

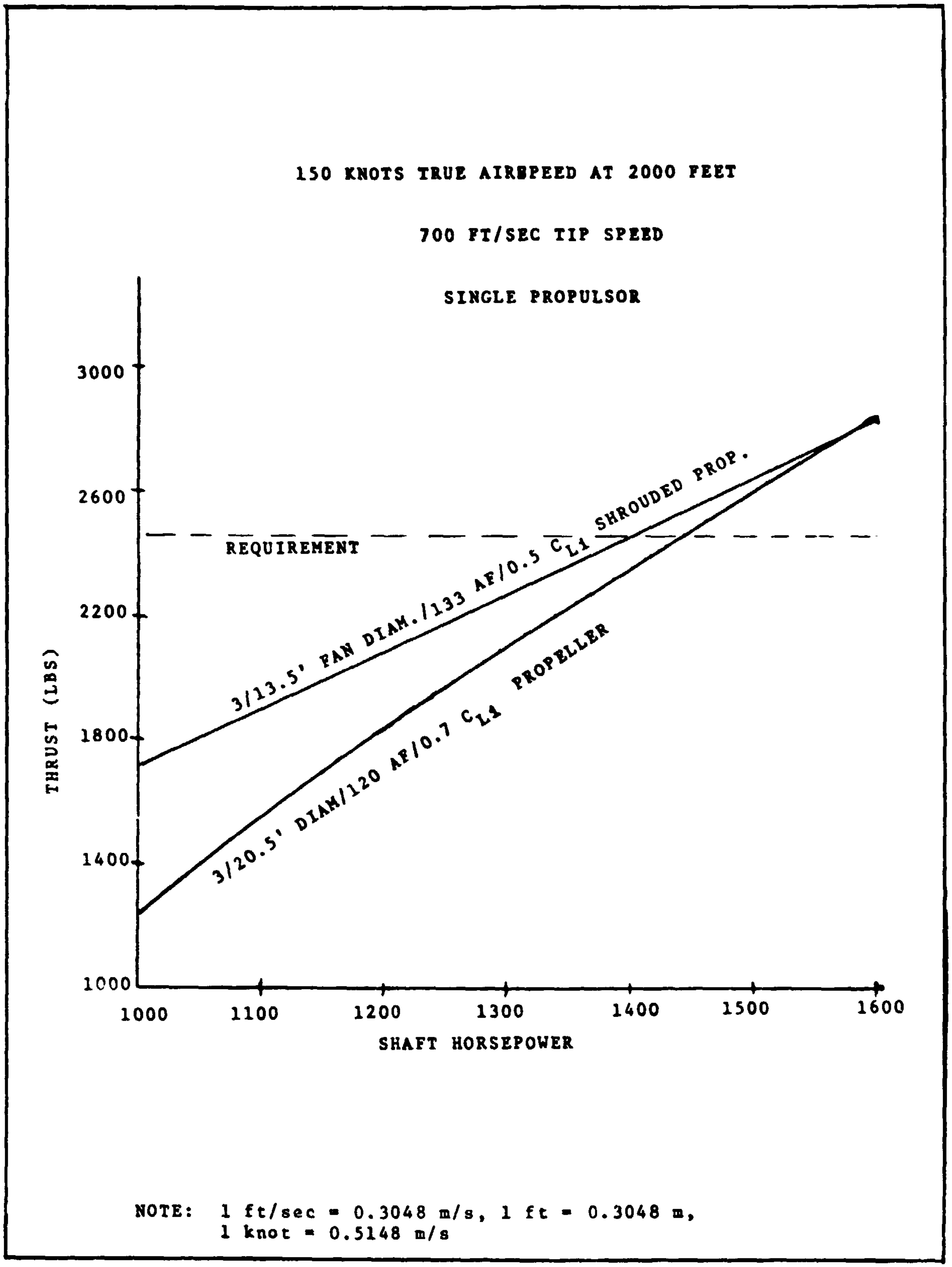


Figure 17. Propulsion Trade Study Results: Thrust vs SHP at Cruise

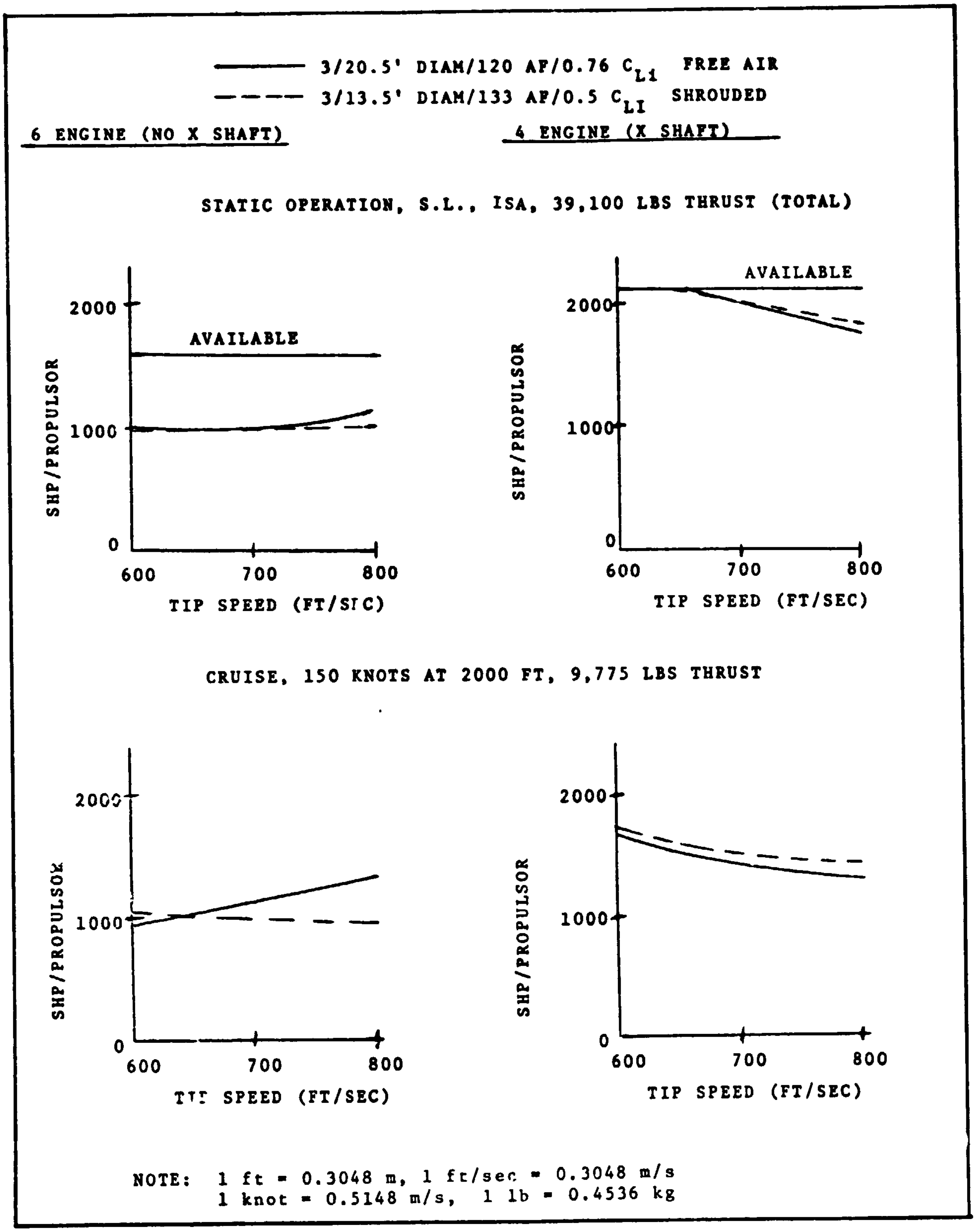


Figure 18. Power Requirements as a Function of Tip Speed With All Engines Operating

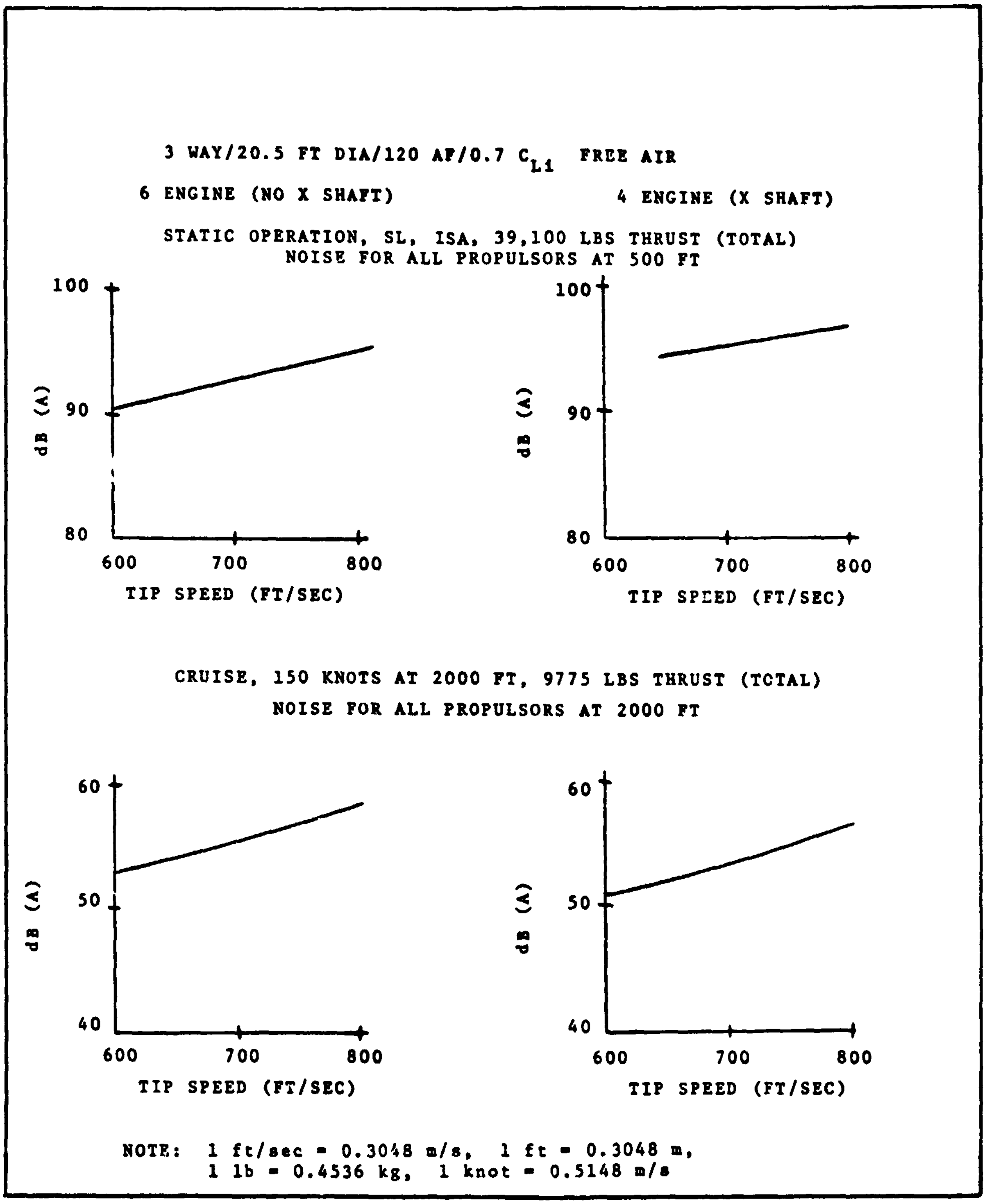


Figure 19. Estimated Noise as a Function of Tip Speed With All Engines Operating

noise level at various tip speeds for both modes of operation.

As shown in Figure 18 the power per propulsor is higher for the four-engine cross-shafted configuration. As a result, the noise level for the same configuration, as shown in Figure 19, is higher. For the final configuration, a brief design optimization analysis was made to achieve lower noise levels.

As an additional area of brief investigation in the propulsion system tradeoff study the separation requirements for negligible aft propller propwash interference was defined for the disk loadings associated with the airport feeder concept during cruise. Preliminary indications were that a separation of approximately 2 propeller diameters would be an acceptable compromise between performance, cross shafting weight and the overall length requirement for the car structure. This conclusion was based on cruise disk loadings which were higher than the final baseline design and should be re-examined in subsequent study efforts.

3.3.3 Propulsion System Weight Tradeoff Studies

Based on the propeller/propulsion system analysis and car structure/passenger arrangement study results, a weight study was conducted for the six-engine, four-engine and four-engine cross-shafted configurations. The study was made on a preliminary basis to establish first order weight trends. Individual components of each configuration were examined for weighing purposes. The components were compared to similar Hamilton Standard components that have either been produced or carefully analyzed in previous design studies. The comparison was made on the basis of power required, torque, geometry, and other related factors.

The ground rules and assumptions that were used in this study are as follows:

1) The rotor was sized to meet the emergency take-off condition of four rotors operating and a total of 7360 SHP available as defined in the emergency sizing section.

2) Opposite rotors will have opposite rotation.

3) The mission will continue after a one-engine failure and therefore the gear boxes are sized for full engine normal rated power at 700 feet/second tip speed. This is 77% of the normal cruise power for the six-engine configuration with two engines off and 82% of the normal cruise power for the four-engine configuration with one engine out.

4) The four engine cross shaft configuration will allow for ±10% power shift for control at cruise and ±35% for control at take-off.

5) The free air propeller blades are manufactured with a steel spar and fiberglass shell. The shrouded fans are manufactured with an aluminum spar and a fiberglass shell.

The weight comparison, presented in Table 7, illustrates the weight advantage of the four-engine fully cross-shafted configuration. These results were combined with the car structure/passenger seating arrangement point design study results to provide the final comparison of the six engine uncross-shafted long car configuration with the four engine, fully cross-shafted short car configuration. These

Table 7. Propulsion System Point Design Study Results

Item	6 Engine	Cross-Shafted 4 Engine	Cross-Shafted 4 Engine Ducted
Rotor	4,038	2,692	1,556
Duct	0	0	5,496
Rotor Gearbox	2,520	2,096	1,380
Engine Gearbox	732	684	452
Cross-Shaft Gearbox	0	172	113
Shafting	216	429	366
Total Weight ~ LBS	7,506	6,073	9,363

Table 8. Weight Summary of Long and Short Car Structural and Propulsion System Point Design Studies (Pounds)

Item	Long Passenger	Long Cargo	Short Passenger	Short Cargo
Basic Structure Weight	4,943	4,943	3,893	3,893
Basic Module Weight (2)	7,640	6,700	6,850	6,000
Engines (Bare)	1,920	1,920	1,710	1,710
All Engine Accessories	6,100	6,100	5,440	5,440
Props, Gear Box & Shafting	7,506	7,506	6,073	6,073
Fuel System	630	630	420	420
"Total" Car Weight Empty	28,739	27,799	24,386	23,536

NOTE: 1 lb = 0.4536 kg

results, presented in Table 8, clearly illustrate the weight benefits of the four-engine fully cross shafted configuration which was selected for the final baseline design.

The primary objective of the propulsion system point design trade study was to determine preliminary trends for "optimum" propulsion system design characteristics. The most important question was four-engine fully cross shafted vs six-engine uncross shafted designs. The decision in favor of the four-engine fully cross shafted configuration appears conclusive. However, several additional design/performance areas need to be re-examined in more depth in subsequent efforts. Among these are, the effect of lower cruise speed, 67 vs 77 m/s [130 vs 150 knots], Propeller Interference effects at the lower baseline design disk loadings and cruise speed, propeller inflow characteristics during transition and cruise, interior noise levels considering both propeller and engine noise sources, and a more rigorous investigation of propulsion system integration with the total Airport Feeder vehicle.

3.3.4 Empennage Configuration and Sizing Analysis

The inverted "Y" configuration [Figure 3] was selected based on previous GAC studies of a large family of empennage configurations [Reference 4]. These studies indicated this configuration to offer improved lateral and directional stability per unit fin area. This configuration also maximizes the tail clearance angle compared with four fin configurations. Having selected the configuration, the empennage area requirement was briefly examined.

Traditionally, neutrally buoyant airships have been statically unstable both longitudinally and laterally but have had dynamic stability characteristics which resulted in satisfactory flying qualities. At the low beta ratios initially anticipated for the maximum productivity Airport Feeder, the vehicle might be expected to more nearly satisfy heavier than air type vehicle stability criteria. For the initial parametric performance/configuration optimization study, an approximation was developed which varied the empennage area between the size estimated for dynamic stability at beta = 1.0 and the size estimated for neutral stability at beta = 0.1. This approximation acknowledges a possible requirement for some type of stability augmentation system for low beta configurations. This area will be discussed further in the stability and control section of the final baseline design.

3.4 Baseline Vehicle Design Definition

The final configuration optimization and design definition study was performed by incorporating the results of the various point design analyses into the GASP and a new version of the program called GASPOP. The GASPOP version of the program operates in conjunction with the NASA Ames CONMIN optimization routine [Reference 5]. In the GASPOP mode of operation, constrained or unconstrained optimization studies may be performed for any specified figure of merit. The criteria for the final optimization study was maximum specific productivity, PV/E, evaluated at a design range of 740 kilometers [400 n.mi.] plus a 74 kilometer diversion [40 n.mi.] plus a 20 minute hold at speed for maximum endurance.

The independent variables considered in the final optimization study included cruise altitude, cruise velocity, beta, gross weight and fineness ratio and for two types of construction: pressurized metalclad or pressurized Kevlar non-rigid.

3.4.1 Optimum Type of Construction

The Phase II results, consistent with the Phase trends, indicated that the pressurized metalclad type of construction was slightly superior to the pressurized non-rigid for maximum PV/E. The section modulus properties of the metalclad hull are also more compatible with those of the long car required for the passenger accommodations.

The pressurized metalclad airport feed baseline vehicle is basically a metal skinned "non-rigid" airship. While it has main frames to transmit loads, it is not compartmented but employs ballonets to control internal pressure in the same manner as a non-rigid airship. Thus, this construction approach combines some structural features of the non-rigid airship and some of the rigid airship. The metalclad obtains its bending and shear strength through the pressurization of a metal hull. The empennage structure has features similar to both the rigid and non-rigid.

The metalclad transfers the car structure loads into the metal hull skin through the use of wire braced main frames rather than an internal and external catenary system. Concentrated loads such as those that result from the empennage loads also are transferred to the metal hull skin through the use of frames. A brief description of the major hull components is presented below:

Main Frames - The main frames of the metalclad serve the same function as the main frames of the rigid airship. They will be of the same construction as used in the rigid airships [a wire-braced ring].

Intermediate Frames - These frames are of the same construction as that used on the rigid airship. Their function is to maintain the shape of the hull during construction and to act as vertical stiffeners.

Longitudinal - The longitudinals are essentially light weight stringers to provide local stiffness to the skin. These members also help to maintain the shape of the hull during construction.

Ballonets - The ballonets will be of coated cloth construction. Two ballonets, one fore and one aft will be used. They will be of cylindrical construction and attached to the main frames and car structure keel.

Outer Cover - The outer cover will be of 7050 aluminum alclad sheet. A minimum gage constraint of 0.0203 mm [0.008 inches] was assumed and approximately the entire skin is minimum gage constrained.

Utilization of a pressurized non-rigid construction would require a modest extension in the current seam strength technology due to the high internal pressures required for the high flight speeds and low beta's. However, the pressurized Kevlar non-rigid could potentially offer a lower cost, more operationally flexible airport feeder vehicle and should be retained as a potential candidate in future studies.

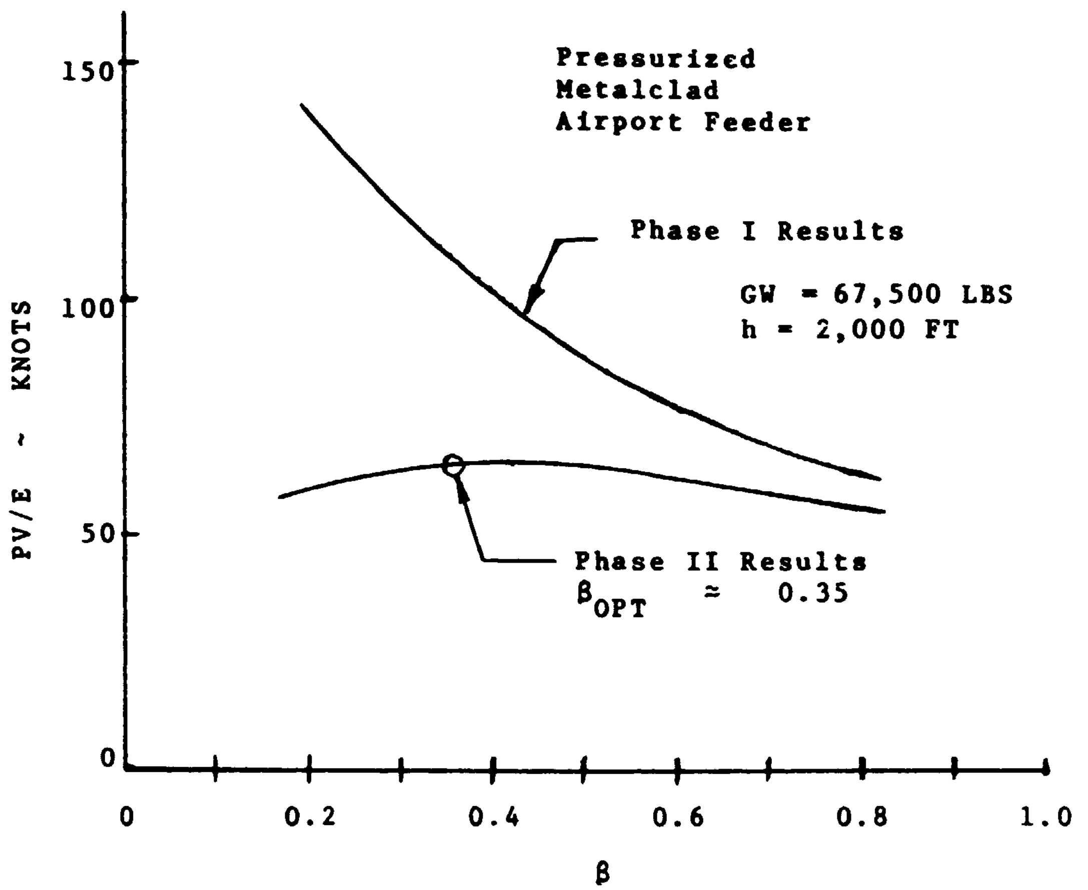
3.4.2 Optimum Buoyancy Ratio

The optimum buoyancy ratio was the major independent parameter of interest in the Phase II parametric study. The results of the Phase II study are shown in Figure 20 along with a comparison of the Phase I study trend. As noted in the figure, an optimum beta of ≈ 0.35 was found for the Phase II vehicle configuration, although the sensitivity of PV/E between beta's of ≈ 0.3 to 0.5 is very slight. The fundamental sources of the difference between the Phase I and Phase II study results can be traced to the car structure/passenger accommodations weight requirement and the propulsion system weights required for the one engine out VTOL capability.

It is noteworthy that the insensitivity of PV/E to beta suggests further optimization in terms of DOC, particularly at higher fuel prices might result in slightly higher values for beta optimum. This is due to the fact that at higher beta's, the optimum cruise velocity is reduced with some reduction in PV/E but with a corresponding reduction in fuel consumption. These trades should also consider the effects on ground operations in the Airport Feeder concept of operations.

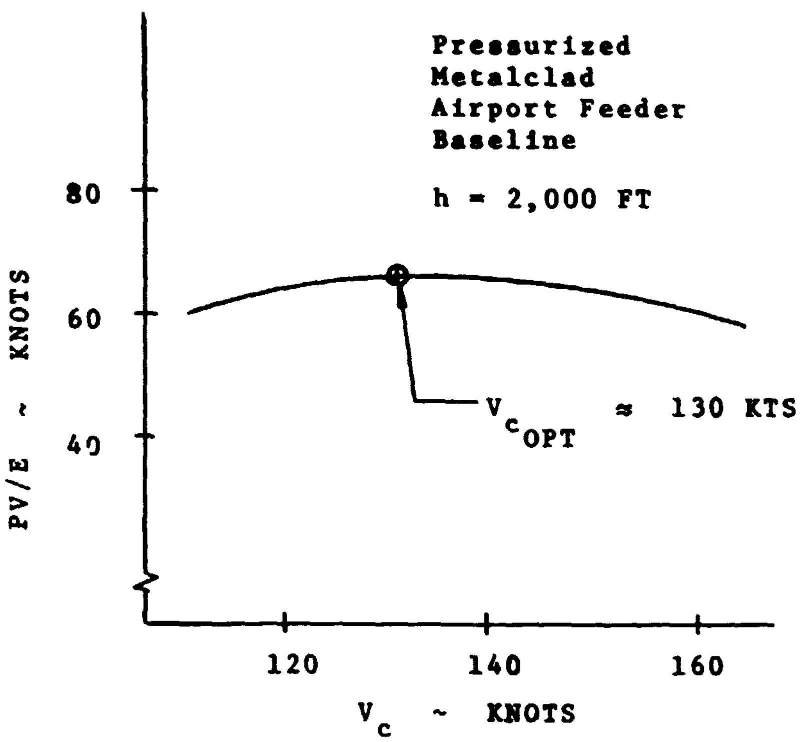
3.4.3 Optimum Cruise Velocity, Altitude and Gross Weight

The cruise velocity trend for maximum productivity is illustrated in Figure 21 for the 30,600 kg [67,500 pounds] pressurized metalclad baseline vehicle concept. The 30,600 kg [67,500 pounds] vehicle gross weight was the minimum gross weight capable of satisfying the payload requirements defined in Table 6. The cruise altitude for maximum PV/E was the NASA specified lower limit for cruise altitude of



NOTE: 1 ft = 0.3048 m, 1 lb = 0.4536 kg, 1 knot = 0.5148 m/s

Figure 20. Buoyancy Ratio Trends for Maximum Productivity: Phase I and Phase II Study



NOTE: 1 knot = 0.5148 m/s, 1 ft = 0.3048 m

Figure 21. Cruise Velocity Trend for Maximum Productivity

610 meters [2000 feet]. This lower limit is based on the noise constraint assumed for overflying populated regions.

3.4.4 Optimum Fineness Ratio

The fineness ratio for maximum PV/E converged to a value of 3.0, the lower limit allowed in the parametric study. However, in the final baseline design development two problems arose in attempting to integrate the 29.2 meter [96 foot] car structure with the $\ell/d = 3.0$ hull. The first problem [and least severe] was the requirement for a large amount of fairing required due to the large curvature of the hull structure over the car length. The second problem area encountered was locating the car in a position with respect to the center of gravity and center of buoyancy which would produce balanced thrust moments during VTOL and an acceptable metacentric moment during cruise. After several design/performance iterations the fineness ratio was finally constrained to a lower limit of 4.0 for the baseline configuration. The penalty was a nominal 5.5% reduction in PV/E at the baseline gross weight.

3.4.5 Performance Sensitivity Analysis

A brief analysis was conducted of the baseline vehicle performance sensitivity to variations in key design or performance parameters. The results are presented in Figure 22 in terms of the percent variation of the baseline vehicle specific productivity resulting from ±20% changes in the following design characteristics: (1) total propulsion system weight, (2) unit gas lift, (3) total cruise drag, and (4) non-propulsive structural weight.

The sensitivity of PV/E to changes in propulsion system weight is shown to be approximately one to minus one. That is a 1% increase in total installed propulsion system will result in approximately a 1% decrease in PV/E.

The sensitivity of PV/E to unit gas lift is approximately one to one. A 1% increase in unit gas lift will result in about 1% increase in PV/E. This same exchange ratio also applies to η_H, the hull efficiency [ratio of lifting gas volume to total hull volume] since the total static lift is proportional to the product η_Hx unit gas lift.

Sensitivity of PV/E to total cruise drag is about half that of installed propulsion system weight for the short range Airport Feeder Vehicle. A 1% increase in cruise drag will result in approximately ½% decrease in PV/E.

Non-propulsive structural weight, which includes the hull, fins, car structure, etc., has the strongest influence on specific productivity. A 1% increase in non-propulsive structure weight will result in about 2% decrease in PV/E. This sensitivity indicates that subsequent design efforts must investigate the Airport Feeder structural design concept, particularly the car-hull structural interface and the non-optimum weight components associated with the fabrication and erection of the large minimum gage hull structure in more detail than was possible during the Phase II study effort. The Kevlar non-rigid should be retained as a potential construction candidate in subsequent design efforts.

3.5 Baseline Vehicle Design Description

The baseline vehicle configuration is presented in Figure 3. The overall configuration characteristics are summarized in Table 9. Table 10 presents the weight breakdown of the baseline vehicle. Table 11 summarizes the baseline Airport Feeder Performance Characteristics. As noted in Table 6 the passenger accommodation weights were based on data contained in Reference 5 for the study guidelines of conceptual 1985 VTOL aircraft.

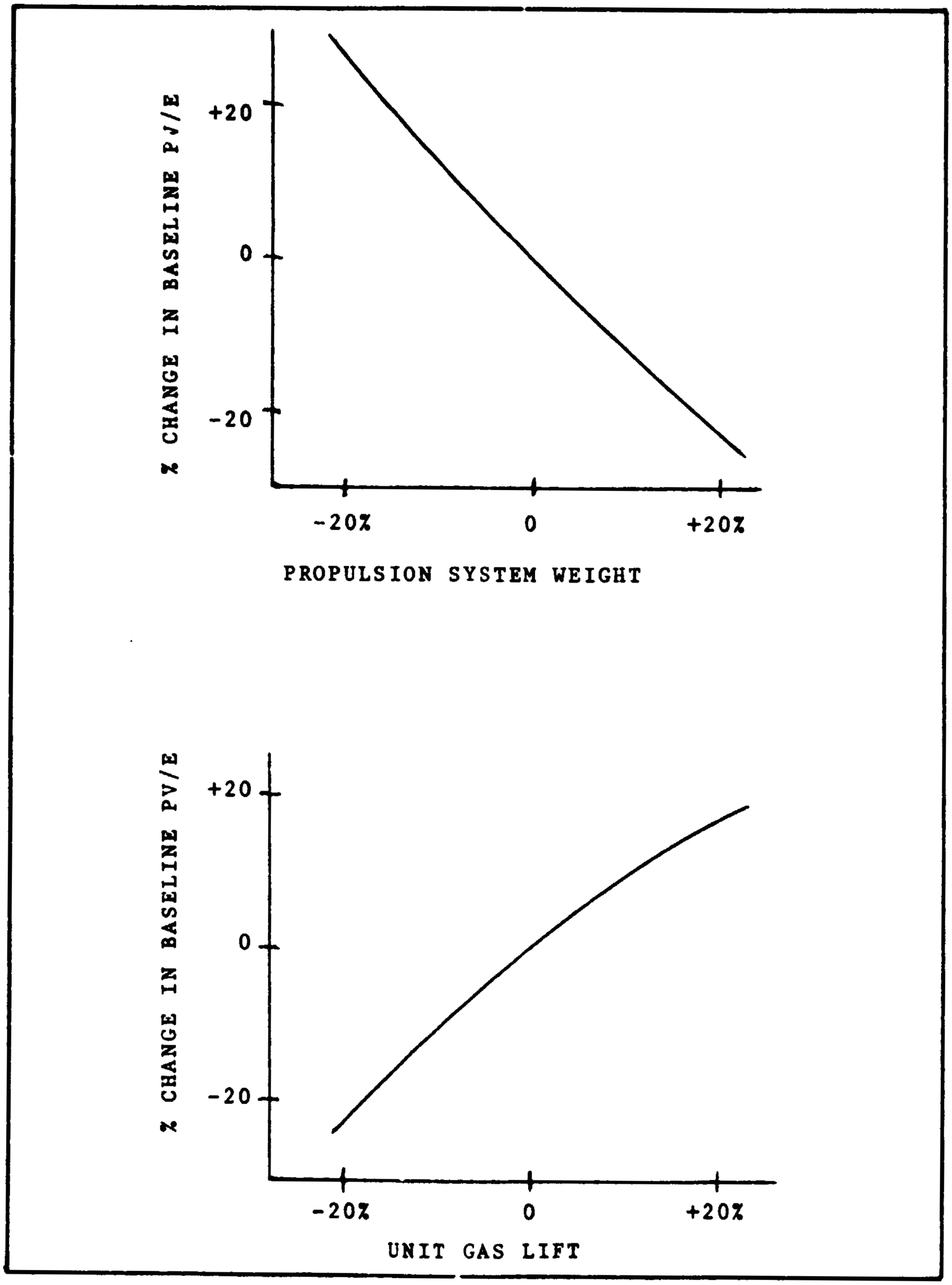


Figure 22. Baseline Vehicle Performance Sensitivity Study Results (Sheet 1 of 2)

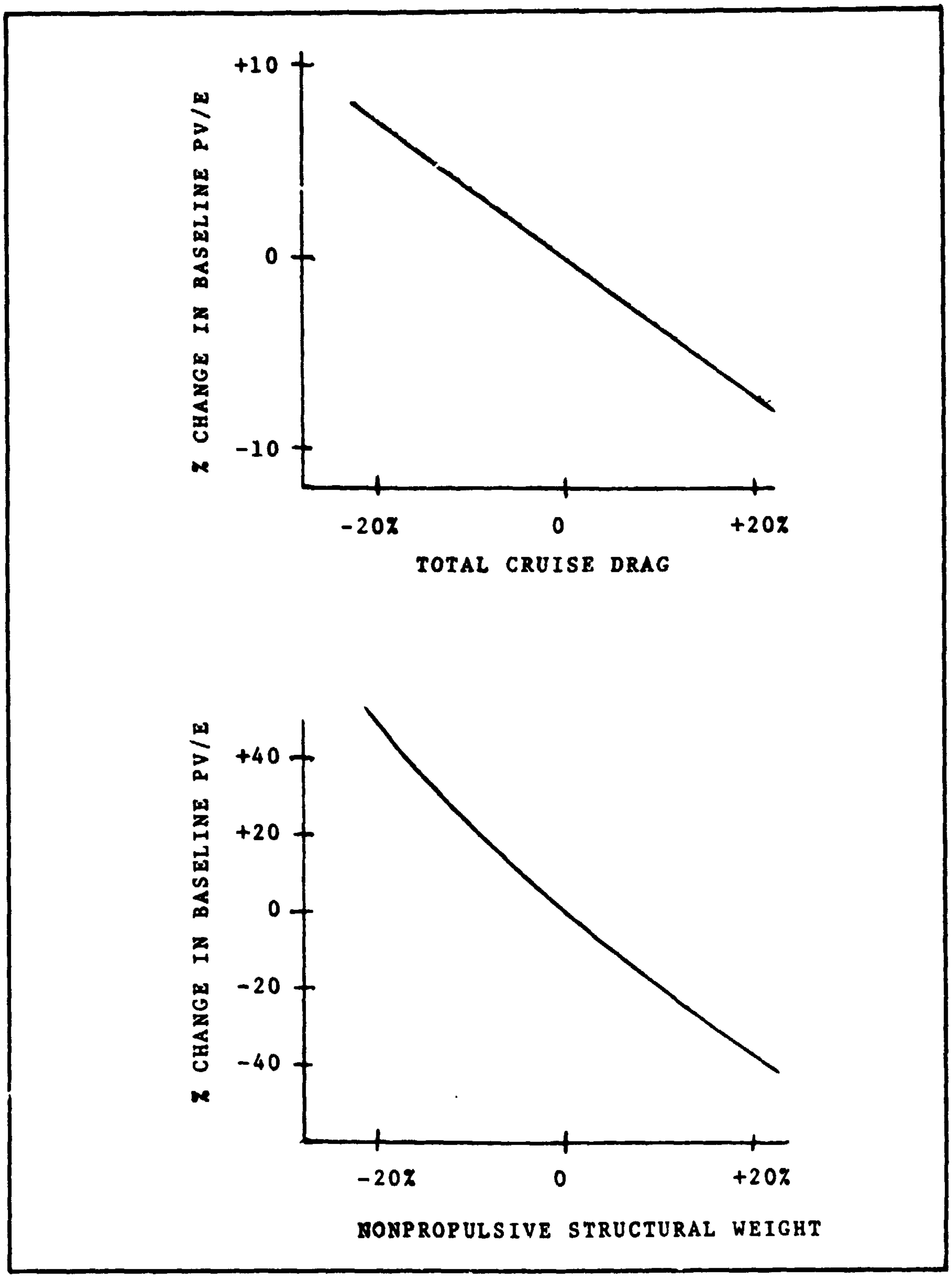


Figure 22. Baseline Vehicle Performance Sensitivity Results
(Sheet 2 of 2)

Table 9 - Baseline Concept Configuration Characteristics

Design Characteristics		
Buoyancy Ratio, β	-	0.35
Gross Weight	-	67,500 Lb.
Static Lift	-	23,600 Lb.
Empty Weight	-	43,620 Lb.
Volume	-	428,500 Cu. Ft.
Length	-	238.5 Ft.
Maximum Diameter	-	59.6 Ft.
Ballonet Volume	-	10,000 Cu. Ft. [Capacity]
Installed Horsepower [4 at 2220 HP/Engine]	-	8,880
Cruise Power Required	-	5,930

NOTE: 1 lb = 0.4536 kg, 1 cu ft = 0.02832 m^3
1 ft = 0.3048 m

Table 10 - Baseline Configuration Weight Summary

Hull Structure	11,150 Lb.
Car Structure	4,600
Modular PAX Compartment [2]	7,000
Empennage and Controls	3,100
Landing Gear	1,120
Propulsion System	15,050
Fuel and Fuel System	7,400
Flight Instruments and APU	1,200*
Furnishings/Seats and Belts	1,820*
Crew [2] STU's [2] and Gear	660*
80 PAX @ 160 Lb/PAX + 20 Lb/PAX Baggage	14,400*
TAKEOFF GROSS WEIGHT	67,500 Lb.

*Based on NASA "Study Guidelines for Conceptual 1985 V/STOL Aircraft"

NOTE: 1 lb = 0.4536 kg

Table 11 - Baseline Concept Performance

Cruise Speed	-	130 Knots
Design Range	-	400 Naut. Mi.
		+40 Naut. Mi. Diversion
		+10% Fuel Reserves
Payload Performance		
All Passenger	-	80 PAX
Combination	-	40 PAX
	-	9000 Lb. Cargo
All Cargo	-	18,000 Lb. Cargo

NOTE: 1 lb = 0.4536 kg, 1 n.mi = 1.853 km

The furnishings, seats and belts contained in Reference ^ are for very lightweight passenger accommodations. This area may require further investigation in terms of passenger acceptability for the airport feeder concept operations. Table 12 summarizes the estimated noise characteristics at takeoff, during cruise flight at 2000 feet and a near-field noise estimate at the exterior of the car surface. As shown in Table 12 the 97.5 pNdB near-field noise level at the exterior surface of the car structure may require some shielding/absorbtion material to be included in the car skin structure to achieve acceptable interior noise levels. Since the interior noise level will depend on the material and thicknesses employed, an estimate of the interior cabin noise was not performed.

The methodology of Reference 6 was utilized to estimate both the near field and far field perceived noise levels. The final analysis of the takeoff noise level/propulsion system operating conditions indicated the tip speed could be reduced to 213 m/s [700 ft/s] to achieve the 86.5 pNdB noise level at take off with acceptable performance.

3.6 Preliminary Stability and Control Assessment

Due to the limited scope available for the preliminary stability and control analysis, the Phase II study effort was directed primarily towards the linearized analysis of the vehicle's behavior at cruise. Nielsen Engineering and Research performed the following analysis, capitalizing on their background gained in the analytical and experimental analysis of the heavy lift airship configuration.

Table 12 - Estimated Airport Feeder Noise Characteristics

	Noise Level ∿ pNdB	
	Takeoff	Cruise
Near Field Noise Level[1]	99.5	97.5
Far Field Noise Level[2] [500 Ft. Sideline]	86.5	--
Far Field Noise Level[3] [2000 Ft.]	--	54

[1]Exterior to cabin wall [interior noise level not estimated]

[2]Tip Speed = 213 m/s [700 Ft/s]

[3]Achievable at 152 m/s [500 Ft/s] tip speed

NOTE: 1 ft = 0.3048 m

The configuration schematic and nomenclature for the stability and control analysis is shown in Figure 23. The linearized equations for motion about a trimmed cruise flight condition at speed u_o, pitch angle θ_0, for the airport feeder with the rotor axes aligned with the body centerline axis, are

$$
\begin{aligned}
&(m + m_x)\dot{\tilde{u}} - (K_T\cos^2\delta + \rho u_o \mathcal{V}^{2/3} C_X)\tilde{u} \\
&\qquad + K_T\sin\delta\,\cos\delta\,\tilde{w} - z_m m_x \dot{\tilde{q}} + W_p\,\cos\theta_0\,\tilde{\theta} = 0
\end{aligned}
$$

$$
\begin{aligned}
&K_T\sin\delta\,\cos\delta\,\tilde{u} + (m + m_y)\dot{\tilde{w}} + (\tfrac{1}{2}\,\rho u_o \mathcal{V}^{2/3}\, C_{N_\alpha} \\
&\qquad - K_T\sin^2\delta)\tilde{w} + [Q_o\mathcal{V}^{2/3}\, C_{L_{\dot{\theta}}} - u_o\,(m + m_x)\tilde{q} \\
&\qquad + W_p\sin\,\theta_0\tilde{\theta} = 0
\end{aligned}
$$

$$
\begin{aligned}
&-z_m m_x\dot{\tilde{u}} - \rho u_o \mathcal{V}^{2/3}\, C_X z_m \tilde{u} \quad \tfrac{1}{2}\,\rho u_o \mathcal{V}\, C_{m_\alpha}\tilde{w} + (I_{yy} + Q^* \\
&\qquad + m_x z_m{}^2)\dot{\tilde{q}} \quad -\{Q_o\mathcal{V}\, C_{m_{\dot{\theta}}} + 4K_T\,[\ell^2\,\sin^2\delta \\
&\qquad + (n - z_m)^2\,\cos^2\delta]\}\tilde{q} + W_B z_m\cos\,\theta_0\tilde{\theta} = 0
\end{aligned}
$$

$$\dot{\tilde{\theta}} = \tilde{q}$$

$$
\begin{aligned}
&(m + m_y)\dot{\tilde{v}} - \tfrac{1}{2}\,\rho u_o \mathcal{V}^{2/3}\, C_{Y_\beta}\,\tilde{v} + z_m m_y\dot{\tilde{p}} + [u_o\,(m + m_y) \\
&\qquad - Q_o\mathcal{V}^{2/3}\, C_{Y_r}]\tilde{r} = 0
\end{aligned}
$$

$$
\begin{aligned}
&z_m m_y\dot{\tilde{v}} + (I_{xx} + m_y z_m{}^2)\dot{\tilde{p}} - 4K_T\,\bar{y}^2\,\sin^2\delta\tilde{p} \\
&\qquad + (z_m m_x u_o - 4K_T\bar{y}^2\,\sin\delta\,\cos\delta)\tilde{r} + W_B z_m\tilde{\phi} = 0
\end{aligned}
$$

$$
\begin{aligned}
&-\tfrac{1}{2}\,\rho u_o \mathcal{V}\, C_{n_\beta}\tilde{v} - .z_m\,(m_x - m_y)u_o + 4K_T\bar{y}^2\,\sin\delta\,\cos\delta]\tilde{p} \\
&\qquad + (I_{zz} + Q^*)\dot{\tilde{r}} - (Q_o\mathcal{V}\, C_{n_r} + 4K_T\bar{y}^2\,\cos^2\delta)\tilde{r} = 0
\end{aligned}
$$

$$\dot{\tilde{\phi}} = \tilde{p} + \tilde{r}\,\tan\theta_0$$

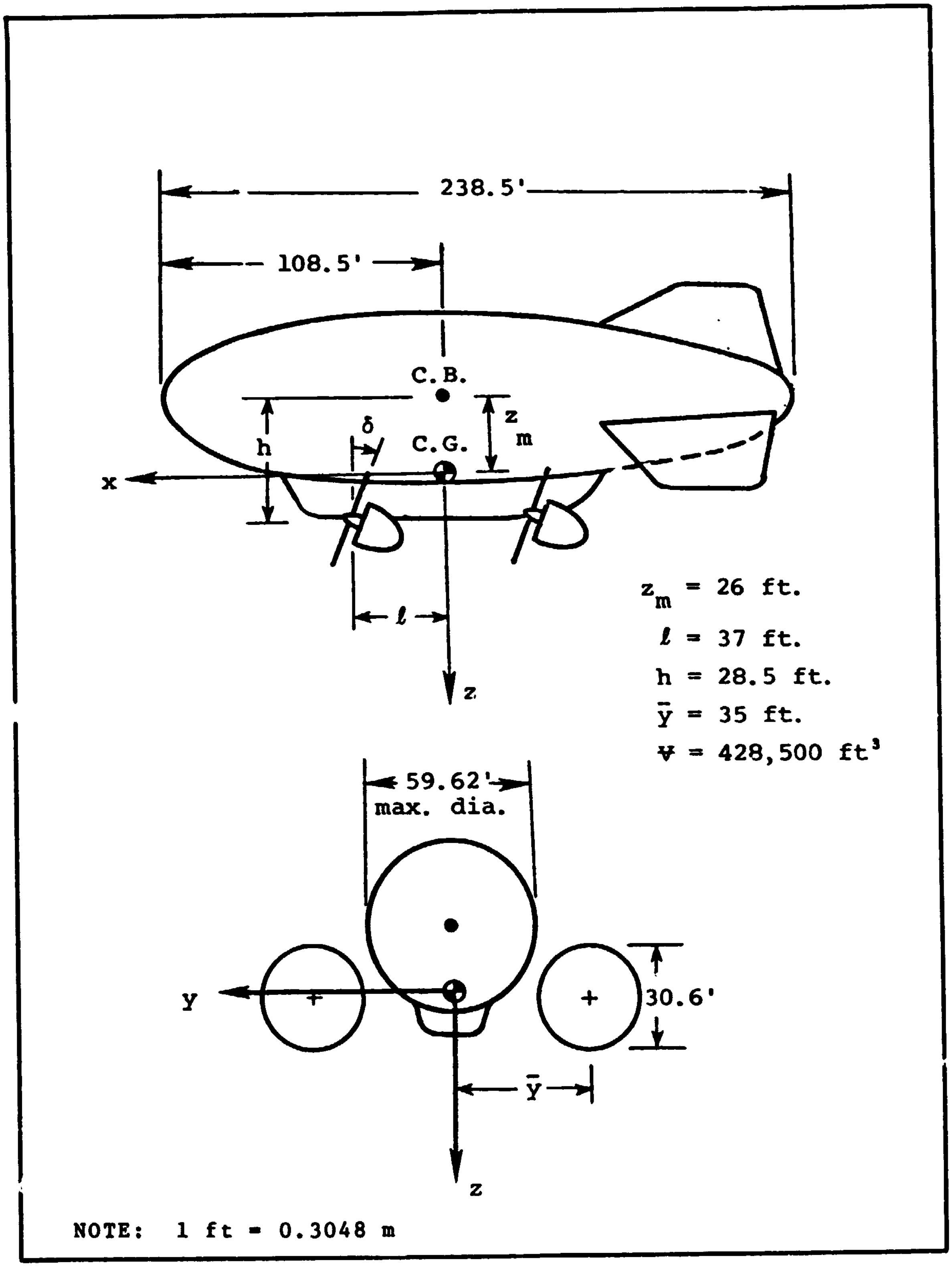


Figure 23. VTOL Airport Feeder Vehicle

As would be expected, these equations decouple into a longitudinal set and a lateral-direction set. The rotor effects are confined to a single parameter, K_T, which represents the change in rotor thrust per unit change in relative speed normal to the rotor plane. The changes in this relative speed were related to vehicle perturbation velocities and angular rates, and the thrust changes were resolved into changes in vehicle forces and moments in order to obtain proper terms for each equation. No hull-rotor interference effects were included. A nominal value of K_T was estimated from data in Reference 21.

The stability derivatives were estimated by making use of techniques and data in the GAC LTA Aerodynamics Handbood [Reference 4]. The values of these derivatives and of the system parameters are summarized in Table 13.

To obtain the characteristic roots, the characteristic determinants of the longitudinal and lateral-directional equations were set to zero. These determinants may be written as follows:

Longitudinal

$$(AFK - FD^2)s^4 + (AFL + AKG + BFK - GD^2 - JFD)s^3$$
$$+ (AMF + AGL - C^2K + BFL + CDH - DEF + BGK - AHO$$
$$+ CDO - JGD)s^2 + (AGM - C^2L + CDI + CHJ - DGE$$
$$- JEF - AIO - BHO + BMF + BGL)s + BGM + CEL$$
$$+ CIJ - C^2M - JGE - BIO = 0$$

Lateral

$$(FSY - P^2Y)s^4 + (FSZ + FYT + NSY - P^2Z)s^3$$
$$+ (-FXU + FYV + NSZ + PUW + FTZ + NTY + PXR$$
$$- WRS)s^2 + (FVZ - FXV \tan\theta_0 - NXU + NTZ + NYV$$
$$- WRT + WPV \tan\theta_0)s + NVZ - WRV - NXV \tan\theta_0 = 0$$

Here the coefficients of the differential equations have been written as

$A = m + m_x$, $B = -(K_T \cos^2\delta + \rho u_o \mathcal{V}^{2/3} C_X)$,

$C = K_T \sin\delta \cos\delta$, $D = -z_m m_x$, $E = W_p \cos\theta_0$, $F = m + m_y$,

$G = \frac{1}{2} \rho u_o \mathcal{V}^{2/3} C_{N_\alpha} - K_T \sin^2\delta$, $H = Q_o \mathcal{V}^{2/3} C_{L_{\dot\theta}} - u_o (m + m_x)$,

$I = W_p \sin\theta_0$, $J = -\rho u_o z_m \mathcal{V}^{2/3} C_X$, $K = I_{yy} + Q^* + m_x z_m^2$,

$L = -\{Q_o \mathcal{V} C_{m_{\dot\theta}} + 4K_T [\ell^2 \sin^2\delta + (h - z_m)^2 \cos^2\delta]\}$,

$M = W_B z_m \cos\theta_0$, $N = -\frac{1}{2} \rho u_o \mathcal{V}^{2/3} C_{Y_\beta}$, $O = -\frac{1}{2} \rho u_o \mathcal{V} C_{m_\alpha}$,

$P = z_m m_y$, $R = u_o (m + m_y) - Q_o \mathcal{V}^{2/3} C_{Y_r}$, $S = I_{xx} + m_y z_m^2$,

$T = -4K_Y y^{-2} \sin^2\delta$, $U = z_m m_x u_o - 4K_T y^{-2} \sin\delta \cos\delta$,

$V = W_B z_m$, $W = -\frac{1}{2} \rho u_o \mathcal{V} C_{n_\beta}$, $X = -[z_m (m_x - m_y) u_o$
$+ 4K_T y^{-2} \sin\delta \cos\delta]$, $Y = I_{zz} + Q^*$,

$Z = -Q_o \mathcal{V} C_{n_r} - 4K_T y^{-2} \cos^2\delta$.

Roots of the characteristic determinants were obtained for six cases. These roots are summarized in Table 14, which

Table 13 - Summary of Airport Feeder System Parameters and Aerodynamic Derivatives

m	=	2237.2 slugs	m_y	=	m_z = 875.9 slugs
m_x	=	83.5 slugs	$\mathcal{V}$	=	428,500 Ft^3
W_p	=	43,875 Lbs	C_{n_β}	=	-0.99
W_B	=	23,625 Lbs	C_{n_r}	=	-1.15 Sec
I_{xx}	=	1,243,500 slug-Ft^2	$C_{m_{\dot\theta}}$	=	-0.65 Sec
I_{yy}	=	5,088,900 slug-Ft^2	C_{m_α}	=	0.81
I_{zz}	=	4,671,600 slug-Ft^2	ρ	=	0.002377 slugs/Ft^3 [Sea Level]
Q^*	=	1,529,800 slug-Ft^2	u_o	=	220 Ft/Sec
K_T	=	-104.2 Lbs/Ft/Sec	θ_0	=	6°
C_X	=	-0.03	δ	=	0°
C_{N_α}	=	0.79	z_m	=	26 Ft
$C_{L_{\dot\theta}}$	=	0.49 Sec	ℓ	=	37 Ft
C_{Y_β}	=	-0.83	h	=	28.5 Ft
C_Y	=	1.15 Sec	$\bar{y}$	=	35 Ft

NOTE: 1 slug = 14.606 kg, 1 Lb = 0.4536 kg, 1 Ft^3 = 0.02832 m^3, 1 slug Ft^2 = 1.357 kg m^2, 1 Lb/Ft = 1.488 kg/m, 1 Ft/Sec = 0.3048 m/Sec.

Table 14 - Summary of Longitudinal and Lateral Characteristic Roots

LONGITUDINAL

K_T	C_{m_α}	f, Hz	ξ	t_2 or $t_{1/2}$ Sec	t_2 or $t_{1/2}$ Sec	$t_{1/2}$, Sec	$t_{1/2}$, Sec
- 50	0.81	0.0106	0.747	9.21	-	25.8	0.234
-104.2*	0.81	0.0113	0.750	9.74	-	11.4	0.234
-200	0.81	0.0122	0.745	8.13	-	6.21	0.234
-104.2	1.6	-	-	1.22 (t_2)	26.8 (t_2)	9.30	0.205
-104.2	0.4	0.0184	-0.150	8.19	-	3.08	0.148
-104.2	-0.4	-	-	289 (t_2)	6.97 ($t_{1/2}$)	0.731	0.382

*[Nominal]

LATERAL

K_T	C_{n_β}	f, Hz	ξ	t_2 or $t_{1/2}$ Sec	t_2 or $t_{1/2}$ Sec	$t_{1/2}$, Sec	$t_{1/2}$, Sec
- 50	-0.99	0.0939	-0.149	7.80	-	151	0.142
-104.2*	-0.99	0.0938	-0.148	7.86	-	85.1	0.141
-200	-0.99	0.0937	-0.146	7.96	-	48.4	0.139
-104.2	-2.0	0.0993	-0.0928	11.9	2.20(t_2)	-	0.131
-104.2	-0.5	0.0889	-0.143	8.19	-	3.08	0.148
-104.2	0.5	0.0856	-0.0783	16.4	-	0.846	0.166

*[Nominal]

gives the time to half amplitude [$t_{\frac{1}{2}}$] or times to double [t_2] for all roots, plus the frequency f and damping ratio ζ for the oscillatory roots.

The first three cases are for different values of K_T. It is seen that the vehicle is slightly unstable longitudinally but stable laterally for values of K_T ranging from -50 to -200. In either case, the times to double or half amplitude are rather large - on the order of 8 to 9 seconds. In part, this is caused by the unstable values of C_{m_α} [positive] and C_{n_β} [negative]. To better illustrate this, root loci for both C_{m_α} and C_{n_β} were sketched. To obtain root loci, the terms in the characteristic determinants factoring C_{m_α} and C_{n_β} were grouped together, and the determinants were rewritten in the root-locus form

$$\frac{N_1(s)}{D_1(s)} = K_1 C_{m_\alpha}, \quad \frac{N_2(s)}{D_2(s)} = K_2 C_{n_\beta}.$$

With the nominal values of the stability derivatives, these can be written as

$$\frac{(s - p_1)(s - p_2)(s - p_3)(s - p_4)}{(s - z_1)(s - z_2)} = 1.88952\ C_{m_\alpha}$$

and

$$\frac{(s - p_1)(s - p_2)(s - p_3)(s - p_4)}{(S - z_1)(s - z_2)} = -1.93378\ C_{n_\beta}.$$

The values of the poles p_i and zeros z_i are given in Table 15. Standard root-locus techniques were used to sketch the loci of Figures 24 through 27 for both positive and

Table 15. Poles and Zeros for the C_{m_α} and C_{n_β} Root Loci

ROOTS OF $N(s) = 0$ FOR C_{m_α} LOCUS

SOLUTION OF THE LONGITUDINAL QUARTIC EQUATION

COEFFICIENTS

I	A(I)	
1	0.1000000E 01	s^4
2	0.2862123E 01	s^3
3	0.1234908E 01	s^2
4	0.1133842E 00	s
5	0.4131296E-03	s^0

ROOT	REAL PART	IMAGINARY	D(s) = 0:
1	-0.3300463E-02	0.0000000	
2	-0.1222218E 00	-0.0000000	z_1 = 0.01309028
3	-0.3771284E 00	0.0000000	
4	-0.2358971E 01	-0.0000000	z_2 = -0.08332292

ROOTS OF $N(s) = 0$ FOR C_{n_β} LOCUS

SOLUTION OF THE LATERAL QUARTIC EQUATION

COEFFICIENTS

I	A(I)
1	0.1000000E 01
2	0.5089016E 01
3	0.3176174E 01
4	0.1747221E 01
5	0.6673486E 00

ROOT	REAL PART	IMAGINARY	D(s) = 0:
1	-0.6241226E-01	0.5396358E 00	z_1 = 0.001321868 + 0.5841006i
2	-0.6241226E-01	-0.5396358E 00	
3	-0.5074100E 00	0.0000000	z_2 = 0.001321868 - 0.5841006i
4	-0.4456781E 01	-0.0000000	

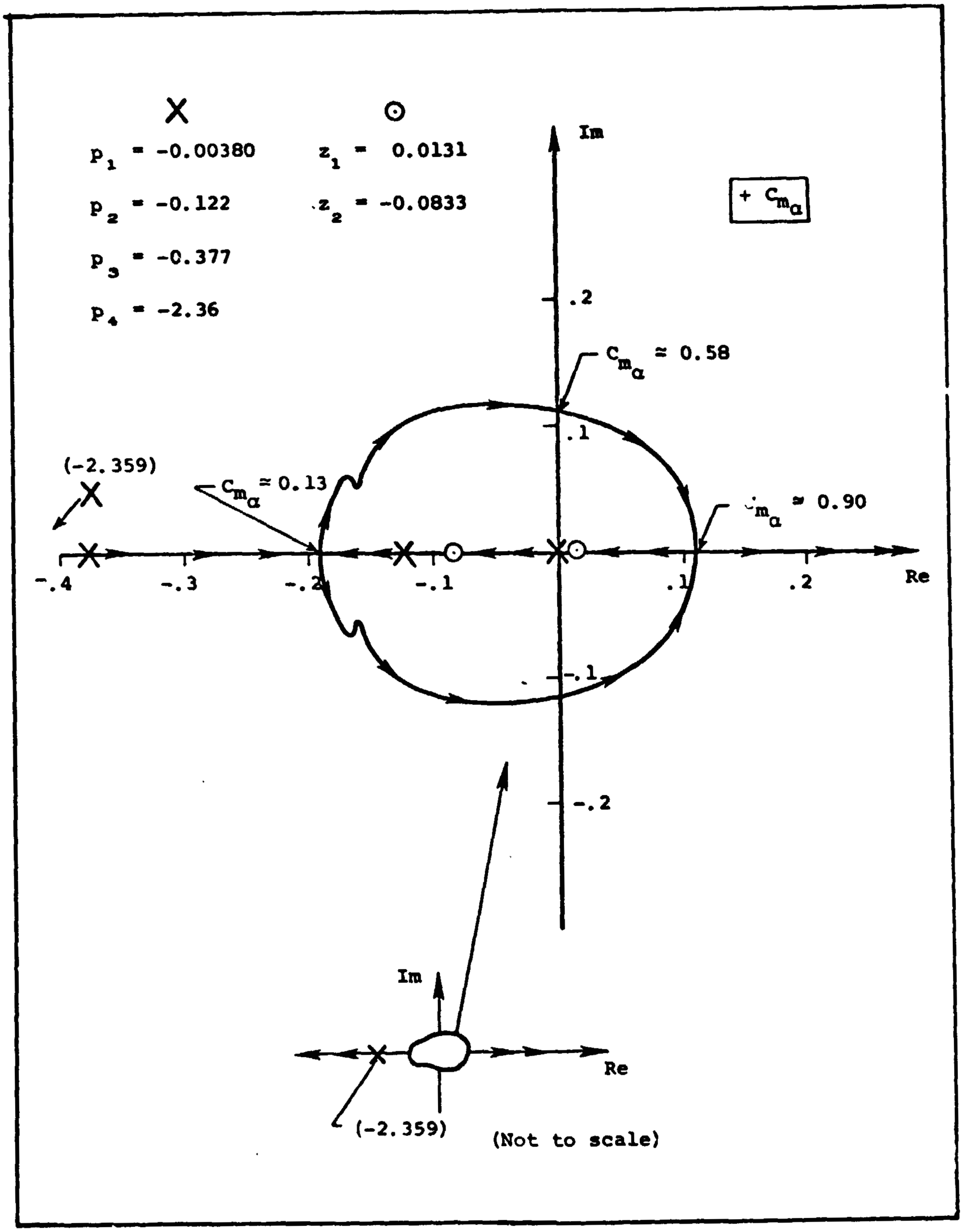


Figure 24. Positive C_{m_α} Root Locus

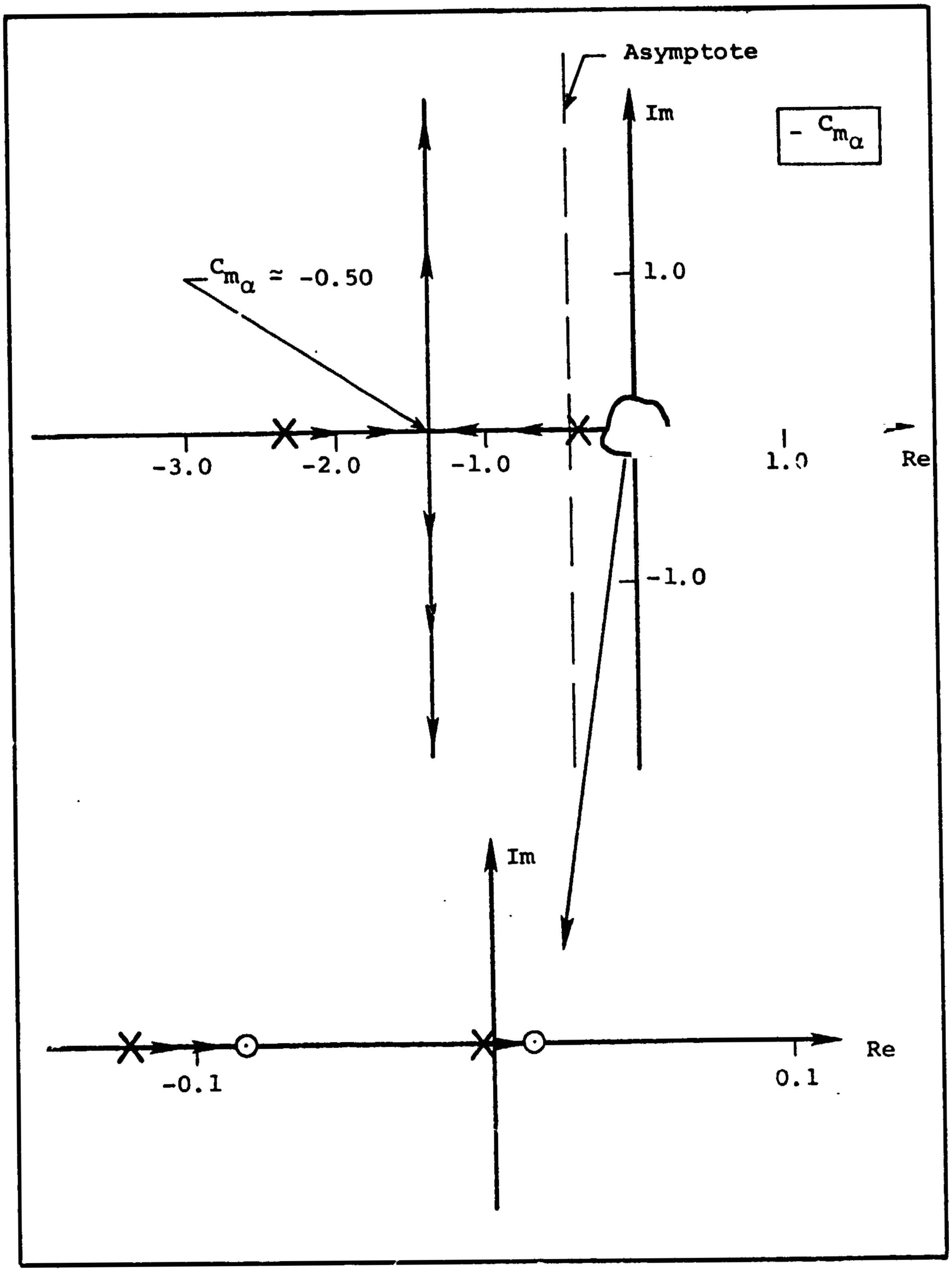


Figure 25. Negative C_{m_α} Root Locus

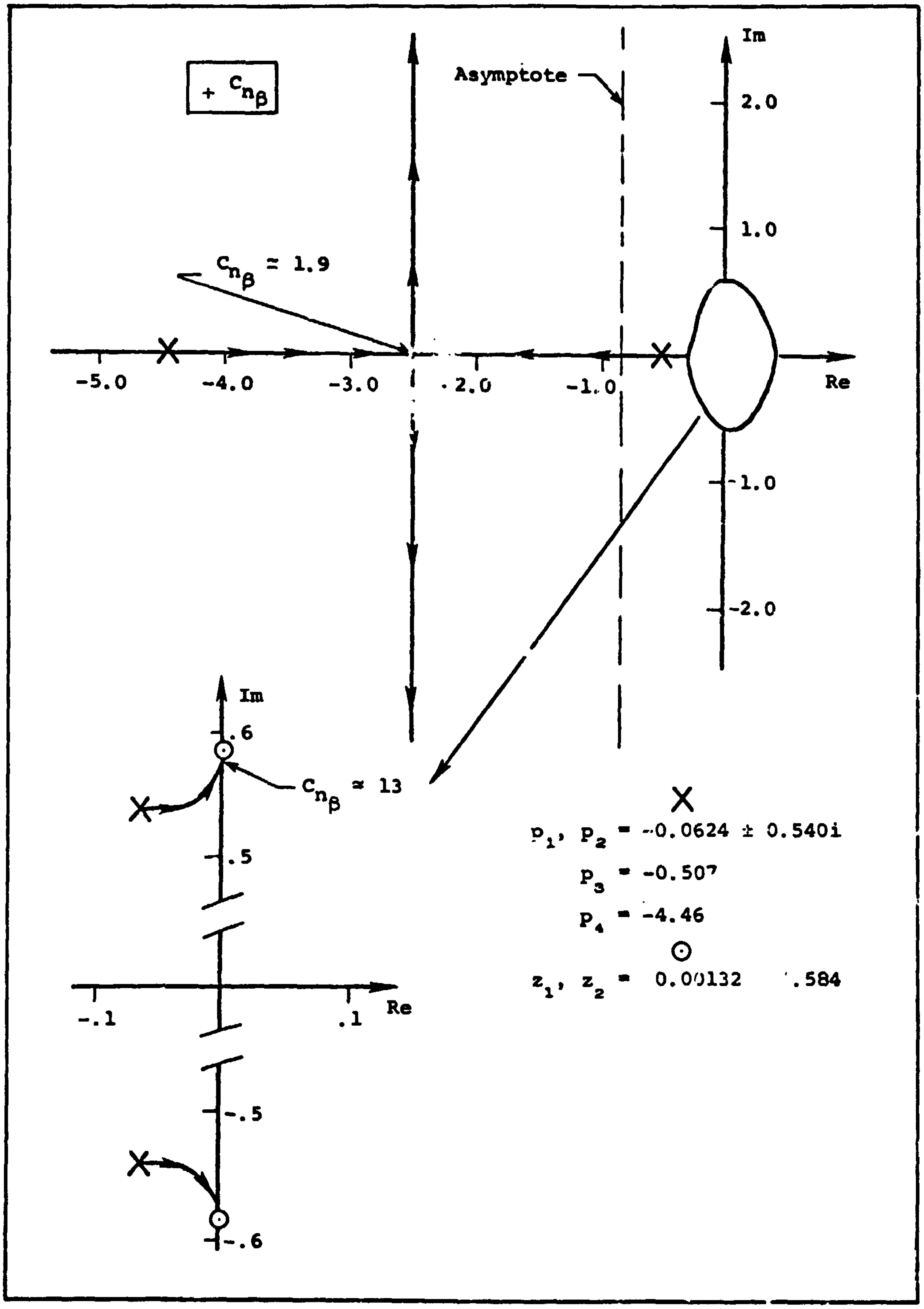


Figure 26. Positive C_{n_β} Root Locus

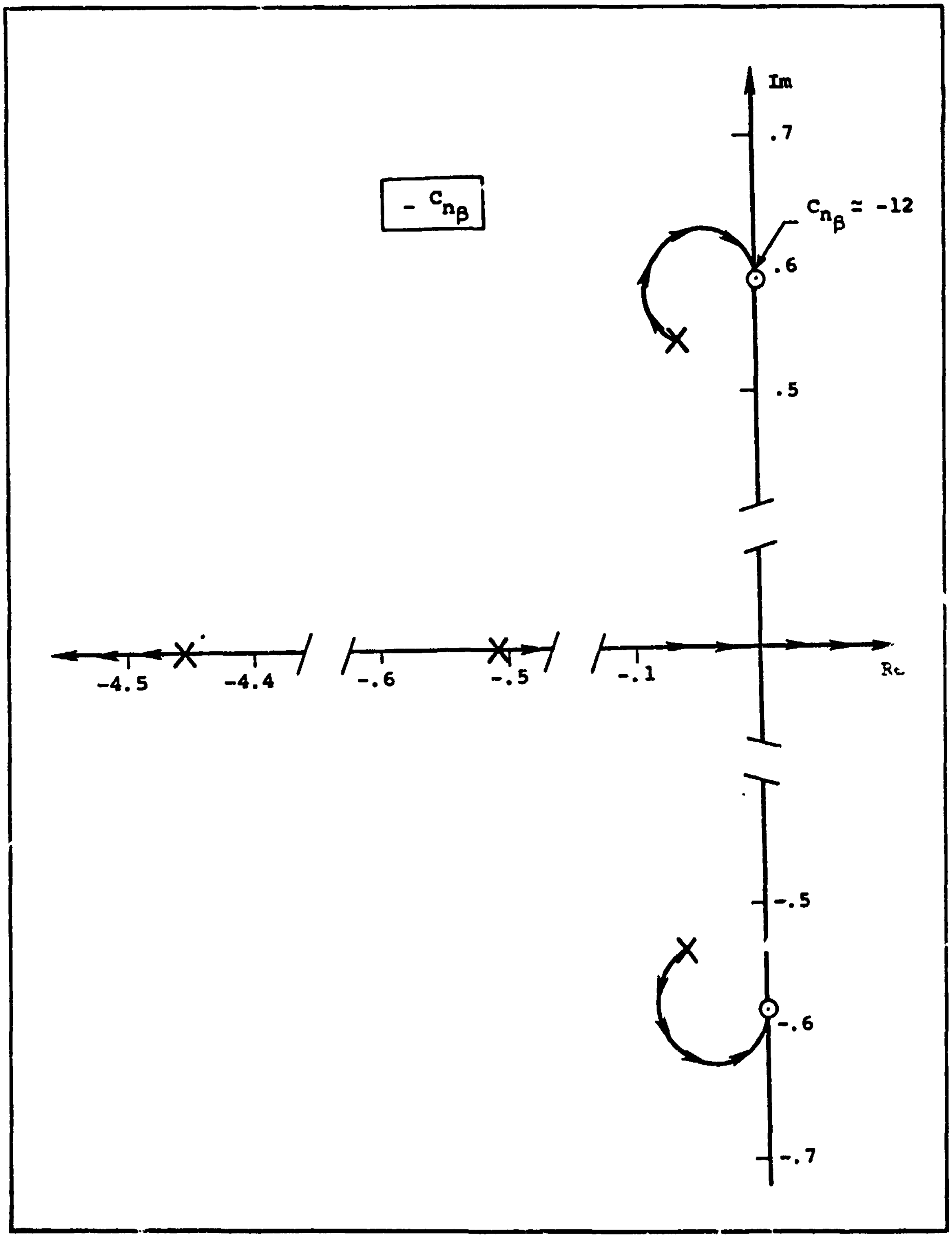


Figure 27. Negative C_{n_β} Root Locus

negative values of C_{m_α} and C_{n_β}.

In Figure 24, it can be seen that it is not necessary to have a stable value of C_{m_α} in order for the vehicle to be dynamically stable. It is also apparent from the migration of the unstable root pair that C_{m_α} exerts a major influence on longitudinal stability. Figure 25 shows that even with a stable value of C_{m_α} it is possible to have a slightly unstable or a slightly stable root near the origin. Futhermore, it is clear that some other parameter would have to be changed in order to move this root very much, as long as C_{m_α} remains negative. Figures 26 and 27 demonstrate that there is an oscillatory pair of roots that may be slightly stable or slightly unstable as C_{n_β} is varied. However, this is not affected greatly by $C_{n_{\dot\beta}}$. In Figure 26, the roots that are influenced by C_{n_β} remain very stable, while there is one potentially strong real-axis instability influenced by C_{n_β} in Figure 27. Unfortunately, there was insufficient time to find the parameter or parameters that would affect more the root pair near the imaginary axis in Figures 26 and 27.

In view of the uncertainties in estimating the stability derivatives and the effects of the rotors, the results discussed above must be considered as only suggestive of possible stability problems. However, there is not reason to believe that simple stability augmentation systems cannot be designed to provide adequate stability, at least for cruise.

It is anticipated that the inability of the current rotor configuration to produce side forces will provide the principal control problem. At cruise or CTOL approach speeds, adequate side forces can probably be achieved by yawing the vehicle. However, for lower speeds or for hover, this strategy may not be adequate. Definitive answers to these questions can only be found with a detailed vehicle simulation that includes nonlinear and interference effects. Work with the heavy lifter could provide valuable guidance in this area.

3.7 Task I Summary and Conclusions

The vehicle design definition task results indicate that a VTOL capable pressurized metalclad vehicle concept with a gross weight of 30,600 kg [67,500 Lbs] and a beta = 0.35 will maximize the specific productivity for the 80 passenger short haul mission. All NASA specified design and performance criteria defined in Table 1 can be met or exceeded. Of paramount importance, the noise constraint at takeoff can be improved by 8.5 pNdB.

The baseline vehicle design concept employs two payload modules to allow all passenger, all cargo or combined operations at stage lengths from 38 km [15 n.mi.] to 740 km [400 n.mi.]. Nominal cruise conditions are 630 m [2000 Ft] altitude at a speed of 67 m/s [130 knots].

The major area of technical uncertainty is the hover and transition phase stability and control characteristics and flying/ride qualities in turbulent air. Several important areas for further R&D have been identified and will be discussed in the technology assessment task discussion.

r. 5

4.0 TASK II OPERATIONAL PROCEDURES ANALYSIS

4.1 General

The Operational Procedures Analysis task was comprised of three major subtask activities: Institutional Constraints Analysis, Scenario Development and Operational Procedures Analysis. The Institutional Constraints Analysis, performed by Battelle Columbus Laboratories, was based on a generalized analysis of operational characteristics of a "most probable" airport feeder system operating within the existing transportation infra-structure. This effort was non-locale oriented effort performed to identify the operational attributes and potential constraints associated with a typical A/F system. These were then examined to define the operational, vehicle related, performance and design requirements.

The Scenario Development effort was a site-specific analysis of a potential A/F system operation in the Lake Erie Regional Transportation Authority [LERTA] service region. The objective was to investigate potential design, performance, and/or operational limitations and requirements of the A/F system concept operating in a service region wherein airport access was known to be a major problem area.

The results of the above efforts were utilized to develop a generalized concept of operations and operational procedures for this conceptual A/F system.

4.2 Institutional Constraints Analysis

A thorough definition of institutional constraints is normally derived from a detailed market study of the new vehicle being considered for introduction into service. However, a detailed market study was beyond the scope of the resources available for this Phase II effort. Therefore, a less rigorous scenario definition approach was adapted as the means to identify significant institutional considerations.

The scenario approach consists of a series of qualitative and/or quantitative assumptions about the most likely institutional setting of the new service being considered. In the discussion which follows, institutional attributes are derived by implication from the operational attributes of an assumed mission/service. The resulting scenario, therefore, presents a set of operational requirements to be satisfied and, by implication, a set of institutional constraints to be overcome in order to achieve acceptable operational results.

The Airport Feeder short haul passenger mission/service in many ways would resemble the scheduled intraurban helicopter service subsidized by the Federal Government in New York City, Chicago, and Los Angeles between 1963 and 1967.

The first objective of the Institutional Constraints Analysis was to define the general institutional attributes of a combination intraurban-interurban air transportation system. These attributes are itemized in Table 16 for each of the following category areas:

1) Potential Travelers
2) Community Residents
3) Air Carriers
4) Aircraft/Equipment Manufacturers
5) Investors
6) Airport Operators
7) Local Government
8) Federal Government Regulation
9) Air Traffic Control System
10) Federal Research and Development
11) Federal Appropriations

Table 16. Institutional Attributes of an Intraurban Air Transportation System

1.0 Potential Travelers

1.1 Trip Purpose

1.1.1 Business
1.1.2 Pleasure
1.1.3 Other Personal

1.2 Segment of Trip

1.2.1 Point-to-Point (O-D)
1.2.2 Connecting

1.3 Travel Time Preference

1.3.1 Peak Commuter Hours
1.3.2 Other Daytime
1.3.3 Other Nighttime

1.4 Competing Travel Modes

1.4.1 Auto (Private, Taxi, Rental)
1.4.2 Bus/Limo
1.4.3 Rail
1.4.4 Air (Scheduled, Unscheduled)

1.5 Segment O-D

1.5.1 Central Business District
1.5.2 Suburb
1.5.3 CTOL Airport

1.6 Acceptability Criteria

1.6.1 Maintain Present Safety Levels (Air ahd Ground)
1.6.2 Reduce Total Trip Time (Air and Ground)
1.6.3 Reduce Total Trip Cost (Air and Ground)
1.6.4 Schedule Adequate Frequency of Service
1.6.5 Schedule Preferred Departure/Arrival Times
1.6.6 Maintain Present Schedule Dependability
1.6.7 Maintain Comfortable Ride Quality
1.6.8 Easy Intermodal Transfer
1.6.9 Convenient Ground Access to Airport

Table 16. (Continued)

2.0 Community Residents

2.1 Proximity to Terminals

2.1.1 Immediate
2.1.2 Nearby Political Jurisdictions

2.2 Resident Type

2.2.1 Private Homeowner
2.2.2 Industrial Firms
2.2.3 Public Institutions
2.2.4 Real Estate Interests
2.2.5 Citizen Action Groups
2.2.6 Politicians
2.2.7 News Media

2.3 Acceptability Criteria

2.3.1 Acceptable Noise Levels
2.3.2 Acceptable Air Pollution
2.3.3 Minimum Hazard (Ground and Air)
2.3.4 Relieve Ground Congestion and Delay
2.3.5 Favorable Impact on Property Values
2.3.6 Relieve Local Tax Burden
2.3.7 Acceptable Industrial Expansion
2.3.8 Minimum Emotional Impact

3.0 Air Carriers

3.1 Carrier Type

3.1.1 Trunks
3.1.2 Regionals
3.1.3 Locals
3.1.4 Commuters

3.2 Corporate Entity

3.2.1 Integral to Existing Corporate Structure
3.2.2 Subsidiary

3.3 Acceptability Criteria

3.3.1 Sufficient Demand for Service
3.3.2 Acceptable Profit Potential
3.3.3 Pricing Flexibility
3.3.4 Reasonable Capital Requirements
3.3.5 Compatible with Prevailing Market Image

Table 16. (Continued)

4.0 Aircraft/Equipment Manufacturers

4.1 Systems/Subsystems/Components/Parts

4.1.1 Aircraft
4.1.2 Engines
4.1.3 Avionics
4.1.4 Ground Facilities

4.2 Acceptability Criteria

4.2.1 Acceptable Development Risk for State of the Art Required
4.2.2 Profitable Sales Volume
4.2.3 Acceptable Capitalization
4.2.4 Extensive Military Commonality
4.2.5 Minimum Competition with Foreign Technology
4.2.6 Adequate Labor Intensiveness

5.0 Investors

5.1 Investment Sources

5.1.1 Debt
5.1.2 Equity
5.1.3 Air Carrier Retained Earnings

5.2 Acceptability Criteria

5.2.1 Reasonable Investment Risk
5.2.2 Adequate Stability and Level of Earnings
5.2.3 Continual Long-Term Growth

6.0 Airport Operators

6.1 Availability Category

6.1.1 Existing
6.1.2 Improved
6.1.3 New

6.2 Acceptability Criteria

6.2.1 Reasonable Real Estate Requirements
6.2.2 Reasonable Terminal Building Requirements
6.2.3 Adequate Auto Parking Facilities
6.2.4 Adequate Income Generating Potential
6.2.5 Compatible Surrounding Land Use

Table 16. (Continued)

7.0 Local Government

7.1 Pertinent Agencies

7.1.1 Executive
7.1.2 Legislative
7.1.3 Administrative
7.1.4 Judicial
7.1.5 Planning
7.1.6 Regulatory

7.2 Acceptability Criteria

7.2.1 Compatible with Other Intra and Inter-Regional Goals
7.2.2 Satisfactory Industrial Development Potential
7.2.3 Tax Generating Potential Compatible with Value of Service to the Community
7.2.4 Benefits to the Nonuser Offset Costs to the Nonuser

8.0 Federal Government Regulation

8.1 Scope

8.1.1 Economic
8.1.2 Equipment Certification
8.1.3 Operational Certification
8.1.4 Airmen Certification
8.1.5 Aeronautical Publications
8.1.6 Environment (Noise and Air Quality)
8.1.7 Energy

8.2 Agencies

8.2.1 Civil Aeronautics Board (CAB)
8.2.2 Federal Aviation Administration (FAA)
8.2.3 Environmental Protection Agency (EPA)
8.2.4 Federal Energy Administration (FEA)

8.3 Acceptability Criteria

8.3.1 Maintain Consistency with Regulatory Precedents
8.3.2 Tailor Evolutionary Changes to Take Maximum Advantage of Technological Improvements
8.3.3 Compliance with Evolving Environmental Standards
8.3.4 Compatible with Evolving Energy Conservation Measures
8.3.5 Retain Present Level of Flight Safety.

Table 16. (Continued)

9.0 Air Traffic Control System

9.1 Elements

9.1.1 Personnel
9.1.2 Facilities
9.1.3 Procedures

9.2 Flight Phase

9.2.1 En Route
9.2.2 Terminal Area
9.2.3 Final Approach
9.2.4 Airport Surface

9.3 Acceptability Criteria

9.3.1 Relieve Aircraft Congestion and Delay in Large Hub Airport Terminal Areas
9.3.2 Maintain Present Safety Standards
9.3.3 Accommodate a Wide Range of Aircraft Types
9.3.4 Retain "First Come First Served" Policy to the Maximum Extent Possible
9.3.5 Balanced Use of Airport and Airway Development Funds (ADAP)

10.0 Federal Research and Development

10.1 Elements

10.1.1 Aircraft
10.1.2 Engines (Performance, Noise, Air Pollution)
10.1.3 Avionics
10.1.4 Air Traffic Control System

10.2 Agencies

10.2.1 FAA
10.2.2 NASA
10.2.3 DOD

10.3 Acceptability Criteria

10.3.1 Maximize the Application of "Conventional" Technology
10.3.2 Fill the Technology Gaps Not Suited to Private Sector Risk Taking
10.3.3 Maximize Civil/Military Commonality
10.3.4 Balance the Emphasis on Air Versus Ground Transportation System Improvements
10.3.5 Identify the Need (If Any) for Service Demonstration Programs

Table 16. (Concluded)

11.0 Federal Appropriations

11.1 Sources

11.1.1 Congressional (House and Senate)
11.1.2 Executive (White House, OMB)

11.2 Acceptability Criteria

11.2.1 Encourage Urban Decentralization
11.2.2 Provide Incentives for Private Sector Risk Taking
11.2.3 Disperse the Application of Federal Tax Revenue Over a Broad Geographic Base
11.2.4 Fund Air Transportation Improvements in Keeping with Other Competing Domestic Priorities
11.2.5 Retain Favorable Balance of Payments with Foreign Aviation Technology Competitors
11.2.6 Minimize Environmental Impact

The major items or areas of concern in each of the 11 institutional areas were then examined to identify the areas most critical to the successful introduction of the A/F system and to define the institutional/operational constraints. Results of these examinations are discussed in the following subsections.

4.2.1 Airport Feeder Passenger Service

The basic purpose of the anticipated Airport Feeder service would be to provide high income business travelers with a means to travel by air between the vicinity of his urban origin or destination [Central Business District, suburb or other CTOL airport] and a major CTOL airport, where scheduled cnnections would be made with a longer-haul interurban flights. This type of air traveler is expected to value his time at a high level [e.g., $15 per hour]. Therefore, he would be willing to pay a premium for either the convenience or time advantage of the Airport Feeder Service.

In order for the service to be perceived as convenient, there would be a strong preference for adequate trip frequencies and scheduled departure arrival times in terms of scheduled CTOL flight departure/arrival times. Given the known patterns of high density business commuter travel habits, this means high trip frequencies in the early morning and late afternoon hours of the typical week-day. This time-of-day preference is also reinforced by the desire to avoid CTOL airport ground access congestion and delay which are typically most severe during intraurban ground commuter travel hours.

Other traveler perceptions which might enter into a decision to use an Airport Feeder service include:

Flight safety comparable to CTOL service
All-weather schedule dependability

Reasonably comfortable ride quality during flight

In each case, acceptable airship service should be configured to satisfy these highly subjective travel criterion.

4.2.2 Impact on Surrounding Airport Community

The second major group of people concerned with, and impacted by, an Airport Feeder service would be the local community residents living and/or working in the immediate vicinity of the airports [or airship ports] where Airport Feeder service could be provided. In most cases these people would be neither frequent nor infrequent users of the Airport Feeder service. Such nonusers in a site-specific airport situation might include

Private homeowners
Airport renters
Industrial firm employees
Public institution employees
Local real-estate firms
Citizen action groups
Local news media

In each case, to one degree or another, these nonuser groups within the general public could perceive Airship Feeder service as an intrusion or threat to their routine life style in one or more of the following ways:

Adverse impact on property values
A local tax burden
Reinforce local industrial expansion
Safety hazard due to accidents
Environmental hazard due to noise & air pollution

These potential impacts are difficult to quantify before the actual start of service so the important element here is the prior perception of what these impacts might be. There is a natural human tendency to assume the worst and excessive negative reaction is often the result.

As a consequence there will be a continuing public relations need to differentiate in a pursuasive way between how an airship service will impact the surrounding airport community in relation to an equivalent CTOL service which is more familiar to most aviation nonusers.

4.2.3 Airport Operator Requirements

Airport operators are most often the focus of the preceding nonuser public concerns in the first instance. They represent the first level contact between community residents and the aviation system in general. For this reason local airport authorities are often made up of local residents and various political appointees. Their concerns range from the general public impact of their enterprise to hard economic questions of revenue and funding for satisfactory airport service to the traveling public.

The introduction of a radically new airship service will require a somewhat unique airport criterion, most likely patterned after the valuation of scheduled helicopter service. Some of the more obvious areas of concern to a typical airport operator would include:

Adequate income-generating potential
Compatible surrounding land use
Adequate terminal building provisions
Efficient and convenient ground access/egress

It is also likely that the existing airport authorities in any given metropolitan area would assume the responsibility for owning and operating any new or modified airports for analysis. Therefore, they are the ones whose cooperation would have to be obtained to satisfy all airport terminal requirements.

4.2.4 Interaction with Local Government

Airport operators are in turn generally responsible to some local government body or agency. Other local government units are also involved in aviation activities to one extent or another. The scope of involvement and/or surveillance might include the following local and state governmental functions:

Executive
Legislative
Administrative
Judicial
Planning
Regulatory

Their concerns might range over the full scope of public sector attributes already mentioned.

Other private and federal sector attributes of possible concern are noted in the remaining parts of this section.

4.2.5 Air Carrier Market Potential

Attention now shifts to the air carrier segment of private industry. The first major question of concern here is the matter of market areas and volumes sufficient to sustain a profitable level of Airship-Airport Feeder service.

Based on experience with scheduled intraurban helicopter services provided since the 1950s, it would appear that only the largest metropolitan hub areas can generate even marginally adequate airport feeder passenger volumes. Rank-ordered CTOL airport passenger enplanements for the top 30 hub airports in fiscal year 1973, are shown in Table 17 to illustrate the rapid drop off in passenger enplanements beyond the top seven major hub airports [i.e., 34 percent of all U.S. domenstic passenger enplanements in 1973 occurred at the top seven hub airports].

Given this concentration of potential airport feeder markets in a few cities and CTOL airports it is possible to identify the existing U.S. domenstic air carriers providing interurban air travel to/from these airports. In the first instance these carriers would likely have a vested interest in the success of a potential airship Airport Feeder service because such service could add to their interurban travel market shares.

For example, the mix of scheduled carriers serving the top seven hub airports in early 1974 are shown in Table 18, including the distribution of schedules departing seats providing and the respective market shares in terms of those departing seats. It can be seen from Table 18 that different carriers dominate each respective hub airport market. It would appear that most of the trunkline carriers would have a strong vested interest in the success of an Airport Feeder service according to the following mix of carriers and hub airports.

Hub Airport	Dominant Carriers
Chicago O'Hare (ORD)	United, American & Trans World
Los Angeles (LAX)	Local Service Carriers and United

Table 17. Airport Ranking of Air Carrier Passenger Enplanements, Top 30 Airports, FY 1973[a]

Rank	City-Airport/State	Airport	Passengers (000)	Percent of Total	Cummulative Percent
1	Chicago-O'Hare, Ill.	ORD	15,245	7.60	7.60
2	Los Angeles-Int'l, Calif.	LAX	11,197	5.58	13.18
3	Atlanta, Georgia	ATL	11,079	5.52	18.70
4	New York-Kennedy, N.Y.	JFK	10,034	5.00	23.70
5	San Francisco, Calif.	SFO	7,458	3.71	27.41
6	New York-La Guardia, N.Y.	LGA	7,315	3.64	31.05
7	Dallas-Love Fld. Texas	DAL	6,113	3.04	34.09
8	Washington-National, D.C.	DCA	5,380	2.68	36.77
9	Miami, Fla.	MIA	5,236	2.61	39.38
10	Boston, Mass.	BOS	5,175	2.58	41.96
11	Denver, Colorado	DEN	4,867	2.42	44.38
12	Honolulu, Hawaii	HNL	4,177	2.08	46.46
13	Detroit, Mich.	DTW	3,906	1.94	48.40
14	Philadephia, Pa.	PHL	3,598	1.79	50.19
15	Pittsburgh, Pa.	PIT	3,547	1.76	51.95
16	Newark-Newark, N.J.	EWR	3,446	1.71	53.66
17	St. Louis, Mo.	STL	3,320	1.65	55.31
18	Minneapolis, Minn.	MSP	2,873	1.43	56.74
19	Cleveland, Ohio	CLE	2,818	1.40	58.14
20	Houston, Texas	IAH	2,521	1.25	59.39
21	Las Vegas, Nev.	LAS	2,424	1.20	60.59
22	Seattle, Washington	SEA	2,419	1.20	61.79
23	Tampa, Fla.	TPA	2,218	1.10	62.89
24	New Orleans, La.	MSY	2,186	1.09	63.98
25	Kansas City, Mo.	MCI	2,092	1.04	65.02
26	San Juan, P.R.	SJU	1,964	0.97	65.99
27	Phoenix, Ariz.	PHX	1,868	0.93	66.92
28	Memphis, Tenn.	MEM	1,717	0.85	67.77
29	Baltimore Int'l, Md.	BAL	1,528	0.76	68.53
30	Ft. Lauderdale, Fla.	FLL	1,473	0.73	69.26

(a) Source: DOT/FAA, "Terminal Area Forecasts: 1976-1986", September, 1974, p xi.

Table 18. Comparison of Carriers and Departing Seat Market Shares, Top Seven Enplaning Hub Airports, February, 1974 (a)

Carrier/Type	Hub Airport: ORD Departing Seats, thousands	ORD Market Share, percent	LAX Departing Seats, thousands	LAX Market Share, percent	ATL Departing Seats, thousands	ATL Market Share, percent	JFK Departing Seats, thousands	JFK Market Share, percent	SFO Departing Seats, thousands	SFO Market Share, percent	LGA Departing Seats, thousands	LGA Market Share, percent	DFW Departing Seats, thousands	DFW Market Share, percent
• Trunkline														
American (AA)	338	$\boxed{16}$	164	12	-0-	-0-	93	$\boxed{14}$	82	9	215	$\boxed{28}$	300	$\boxed{29}$
Braniff (BN)	60	3	2	≈ 0	-0-	-0-	27	4	2	≈ 0	9	1	390	$\boxed{37}$
Continental (CO)	63	3	116	9	-0-	-0-	-0-	-0-	11	1	0-	-0-	39	4
Delta (DL)	220	10	74	6	759	$\boxed{50}$	96	$\boxed{15}$	38	4	69	9	180	17
Eastern (EA)	66	3	5	≈ 0	502	$\boxed{33}$	95	$\boxed{12}$	-0-	-0-	192	$\boxed{25}$	18	2
National (NA)	-0-	-0-	64	5	-0-	-0-	108	$\boxed{16}$	27	3	48	6	-0-	-0-
Northwest (NW)	220	10	14	1	34	2	34	5	7	1	14	2	-0-	-0-
TransWorld (TW)	291	$\boxed{14}$	162	12	5	≈ 0	85	$\boxed{13}$	120	13	91	12	-0-	-0-
United (UA)	643	$\boxed{30}$ (b)	276	$\boxed{21}$	105	7	69	10	288	$\boxed{31}$	52	7	-0-	-0-
Western (WA)	-0-	-0-	167	12	-0-	-0-	-0-	-0-	101	11	-0-	-0-	-0-	-0-
• Local Service (c)	224	11	295	$\boxed{22}$	482	$\boxed{32}$	54	8	242	$\boxed{26}$	68	9	125	12
Totals	2,125	100	1,339	100	1,527	100	661	100	918	100	750	100	1,052	100

(a) Source: DOT/FAA, "Selected Statistics of Published Domestic Air Carrier Schedules", Volume II, February, 1974, pp 31-139.
(b) Box denotes carriers with the largest market shares at the given hub airport.
(c) Allegheny, Frontier, Ozark, Piedmont, etc.

Hub Airport	Dominant Carriers
Atlanta (ATL)	Delta, Eastern, and Local Service Carriers
New York-Kennedy (JFK)	National, Delta, American, Eastern, and TWA
San Francisco (SFO)	United and Local Service Carriers
New York, LaGuardia (LGA)	American and Eastern
Dallas Ft. Worth Regional (DWF)	Braniff and American

4.2.6 Air Carrier Investment Requirements

Given this potential market structure for Airport Feeder service a second major question concerns the willingness of at least the dominant hub airport carriers to acquire and operate airships themselves. A related question concerns whether they might be integrated into the existing CTOL aircraft operation and management structure or whether a separate corporate entity within the existing airlines would be more suitable in terms of the unique operating features of an airship.

If past helicopter experience [1952-1976] is any indication, it would appear that none of the above options are likely. Possible reasons include (1) the localized nature of an Airport Feeder service, (2) the unique operating requirements of airships, (3) the substantial financial risks of implementing a profitable Airship/Airport Feeder service, and (4) incompatibility with prevailing jet aircraft market image. As a result it must be assumed that an all together new corporate class of carriers will have to come into existance, similar to the scheduled helicopter companies now operating in the largest metropolitan areas.

The interest of existing helicopter companies in adding airships to their fleets may be very unlikely since they have been struggling to remain financially viable since Federal subsidies were completely removed in 1967.

There is the possibility that certain existing CTOL carriers would help finance a new but separate airship venture, but recent airline industry financial trends have prevented these carriers from even re-equipping their own CTOL fleets. To the extent that this trend is substantially reversed in the future, there is the possibility, that certain carriers would find it in their best interests to subsidize a fledgeling airship service in selected metropolitan areas.

4.2.7 Air Carrier Operating Cost Requirements

Assuming sufficient financing for initial acquisition of airships can be arranged, operating cost requirements become the second major economic concern to potential operators. A detailed operating cost analysis for the 80 passenger airport feeder airship selected for this Phase II study is discussed in Task III below. It is presumed that airships must at least equal, [if not be lower than] helicopter operating cost levels to be competitive.

4.2.8 Federal Government Regulation Requirements

The prospect of a new corporate class of airship carriers places an especially unique burden on the Federal government agencies which are responsible for regulating the interstate portion of the air transportation system.

An initial legal judgement must be made as to whether an essentially intrastate airship operation can be legitimately regulated from the Federal level on the grounds that it supports interstate, interurban passenger travel. For purposes of the following discussion it is assumed that Federal jurisdiction still applies in much the same way that Federal jurisdiction is applied to intraurban helicopter operations.

Given this assumption, there is a whole family of Federal regulatory issues and agencies which come into play. The more obvious of these are:

Economics (CAB)
Equipment Certification (FAA)
Operational Certification (FAA)
Airmen Certification (FAA)
Aeronautical Publications (FAA)
Environmental Impact (FAA & EPA)
Energy Conservation (FEA)

In the first instance, it can be reasonably assumed that the CAB would have to initiate a subsidized airships service in selected metropolitan areas, much like the pattern of subsidized economic regulation imposed on scheduled helicopter operators from their inception in the late 1940s through 1967.

The FAA will play a major role in establishing the usefulness of the Airport Feeder airship. This agency is responsible for establishing the airworthiness of the vehicle and, in turn, establishing the traveling public's initial perceived notion of the safety of flying in such a vehicle. The certification process will be a lengthy one because it will be an educational process and there are no recent precedents to draw upon.

The environmental impact is a serious question within the FAA and Environmental Protection Agency (EPA) for any new concept. In addition to the obvious impacts such as noice inside and outside of the passenger compartment, the pollution from engine exhaust, and the possible rezoning and developing of land to serve as passenger pick-up points, the problem of creating a public nuisance must be addressed. After the initial aura of curiosity about the new airship system has worn off, the problems associated with the invasion of the privacy of nonusers to satisfy the wishes of a few travelers may become an issue. The thought of large, low-flying vehicles, droning over residential areas may detract from the attributes of the vehicle because people on the ground may object to the noise and the possible sensed invasion of privacy of people peering at them from above.

Energy conservation has become a vital concern in the Federal Energy Agency (FEA) for the development of a new transportation system. Even though it can be shown that buoyant vehicles are more efficient users of energy in their direct operations when compared to other modes of air transportation, particularly at short ranges, the impact of energy conservation will be applied to the complete development and manufacturing cycle of the new system.

The primary issue in the area of government regulation is that of retaining the present level of flight safety and, therefore, perceived flight emergency problems must be anticipated and solutions addressed as part of the design and development of the vehicle.

4.2.9 Air Traffic Control System

The operating altitude range 610m to 2440m [2000 to 8000 ft] for the Airport Feeder airship places it outside the controlled airspace for commercial transport for most of its flying. Therefore, flight planning becomes a concern for controlling the vehicle at major hub airports from where most of the feeder airship activity will originate or terminate. Since the vehicle is designed for scheduled passenger use it must have an all-weather capability at least equal to that of its predecessor, the helicopter. Also the vehicle must help relieve congestion and delay at the airport so that it must be able to integrate into the normal operating pattern of the airport and, therefore, it cannot be overly sensitive to atmospheric disturbances such as gusts, and wind shears, or to the wake turbulence from other aircraft.

4.2.10 Federal Appropriations

Federal appropriations may be obtained for programs that meet a perceived national need as identified by either the legislative or executive branches of the government. The funding may take on many forms from direct subsidy to the providing of incentives for private risk taking.

The development of a specialized vehicle such as the Airport Feeder airship may cost on the order of $100 million to $200 million based on projections of past air transport development costs. Also, based on current prices of transport aircraft, the price of the vehicle may range from approximately $4 million to $6 million. These costs imply that a fleet of several hundred vehicles may have to be produced to recover the investment costs, or that the development has to be underwritten by private or federal funds. Federal funds would be justified only if the program had a significant impact on a broad segment of the national transportation system.

4.2.11 Summary of Institutional Constraints Analysis Results

The most important institutional considerations and constraints and the resulting or implied operational requirements for the A/F system concept are summarized below:

User Acceptance Factors

System will serve high income (business) travelers
User must perceive convenience and/or time advantage

Implied Operational Requirements

Adequate trip frequencies
Scheduled departures
CTOL flight safety
All weather
Reasonable [≈ CTOL] ride quality

Non-User/Community Acceptance Factors

Noise/air pollution/ground congestion
Adverse impact on property values
Safety hazard due to accidents
Local tax burden

Implied Operational Requirements

Quiet operation
Adequate land access consideration
High safety level
Public relations program defining benefits

Airport Operations

First level of contact with user/non-user group
Major areas of concern

Income potential

Compatibility with existing operations

Potential for reduced congestion

Potential for reduced terminal delays

Implied Operational Requirements

Feeder must be integrated into or be compatible with existing airport operations

Insensitive to gust environment in airport areas

Market Size

Finally, the market size for A/F system operations may limit passenger operations to only the largest 7 to 10 metropolitan areas unless some non-market type of constraint - such as an off-shore airport requires a short haul air transportation type of system. The uncertainty of the market potential for an Airport Feeder type of service is possibly the single most important area of uncertainty.

4.3 Scenario Development and Analysis

The purpose of the scenario development and analysis effort was to define alternate operational modes for A/F systems and identify major system elements and requirements of the most promising operational mode. In contrast with the institutional constraints analysis approach described in the preceding section, the scenario development approach was based on the analysis of a specific major hub airport service region.

The Lake Erie Regional Transportation Authority [LERTA] service region was selected for the scenario development for the following reasons:

1) Opportunity to capitalize on the extensive planning and analysis efforts performed in support of the LERTA site study and planning efforts and to obtain suggestions and comments from the LERTA staff in Cleveland.

2) The unique physical restrictions assocated with airport access to the potential lakeport site may result in a unique requirement for and benefit from a short haul airport feeder transportation system.

The LERTA service region is shown in Figure 28 including the potential lakeport site, major interstate highway systems and secondary airports.

As noted in the figure, ground access to the lakeport site will either require construction of several overwater access roads, tunneling, boats, or air modes of access. Most of the nonair mode options will potentially require a considerable increase in traffic through downtown Cleveland which is most undesirable. An air transportation system may be the most desirable regardless of the competitiveness of the operation on a purely economic basis.

The general objectives and potential benefits of an Airport Feeder Air Transportation System operating in the LERTA service region or perhaps in any Airport Feeder capacity might include the following:

1) Significantly reduce ground traffic congestion near airports.

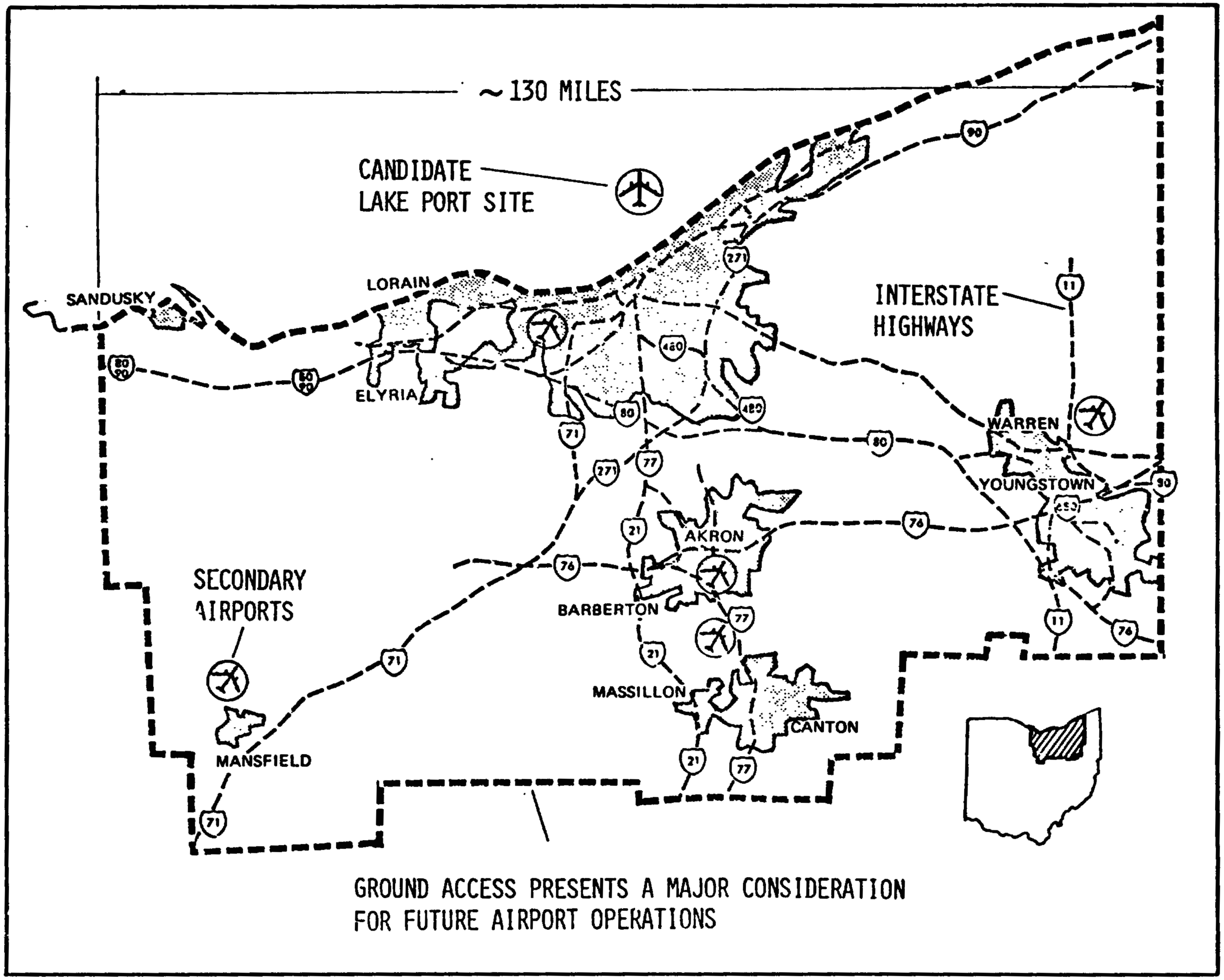


Figure 28. LERTA Area: Major Airports and Highways

2) Eliminate need for major new freeway construction.

3) Reduce noise produced by numerous low overflights of large, conventional aircraft.

4) Significantly reduce home to airport and airport to home travel time for large fraction of passengers using a [Lake Erie] jetport.

5) Provide a rapid, efficient mode for air cargo delivery from prime "jetport" service area and beyond.

6) Provide selective air service to jetport from major cities outside primary [LERTA] service area [e.g., Columbus, Erie, Toledo].

4.3.1 Candidate A/F Operational/Service Concepts

Two A/F operational concepts were conceived. First, an air limousine type of service offering express or multi-pickup type of service with no direct interface with major trunk airlines. This concept is somewhat analogous to the small commuter lines operating in the Northeast corridor. One such operation has been unsuccessful in the Cleveland-Akron-Erie, Pa. area.

A second concept of operations would be one fully integrated with the major trunk airlines and would provide one-stop baggage and ticket service. This type of concept would be similar to many of the door-to-door transportation system concepts proposed for future intermodal transportation systems.

Three potential Airport Feeder operational/service approaches were examined; Downtown to Hub Airport, Secondary Airport(s) to Hub Airports, and Suburbs to Hub Airports.

Each approach could operate in one or more of the following modes: Non-stop service, i.e., a commuter liner type of operation; limited passenger pickup between origin and destination, i.e., an air limousine type of operation; and multiple passenger/cargo pickups between terminal facilities throughout its operational area, i.e., an air bus type of operation . The type of operational mode [commuter, air limo or air bus] will depend on the passenger density and specific nature of the region served. All thr-e modes could be feasible depending on the region of operation.

The Operational Approach, however, [downtown, suburb, or secondary airport] appears to be a more major concern to the design/operational requirements of the A/F vehicle system. Several factors relevant to each type of operation were defined and qualitative evaluation of the three approaches was performed. These results are presented in Table 19.

As shown in the table, operations from secondary airports would appear to be most desirable based on consideration of adequate auto parking, acceptance of [heavy] air operations, minimum ground facilities cost associated with introduction of the "new" A/F system and compatibility with air cargo operations. However, operational capability from downtown/city centers or suburban facilities would potentially offer the most promising market potential, provide the most flexible system capability, and impose the most severe design requirements on the A/F vehicle/system concept. Therefore, this mode of operation was assumed for specific investi gation of operational procedures.

The final A/F operational concept and system requirements/guidelines can be summarized as follows: A/F system

Table 19. Qualitative Evaluation Results of A/F Operational Alternatives

Desired Characteristic	Downtown to Hub	Sec. Airport to Hub	Suburbs to Hub
Minimize Ground Travel	Acc.	Poor to Acc.	Best
Adequate, Secure Auto Park	Acc. to Good	Good to Acc.	Poor to Acc.
Acceptance of Heavy Air Operations	? to Acc.	Best	?
Minimize Ground Facilities Cost	Acc.	Best	Acc.
Compatibility with Air Cargo Service	Acc.	Best	Acc.
Minimize Local Traffic Congestion	Acc. to ?	Acc.	Acc.

NOTE: Acc = Acceptable

objective - transport large numbers of passengers from suburbs, downtown city centers and secondary airports to major hub airports.

4.3.2 System/Operational Requirements [Guidelines]

Integrated or compatible with CTOL operations

Scheduled departures - high frequency operations

Outlying facilities [suburbs or downtown] are required

Airport access times less than auto travel times [optimally less than ½ the average auto travel time]

Minimal ground access congestion and parking problems at outlying points

Acceptable socially and technically to non-user groups in outlying operation region

Minimum on-ground time for passenger loading and off-loading

These preliminary system requirements results, combined with the generalized institutional constraints analysis results were utilized as the general guidelines to develope the operational procedures and further define the system requirements for the Airport Feeder System Concept.

4.4 Operational Procedures Analysis

The operational requirements and procedures of any Modern LTA system performing an Airport Feeder function will require significant improvements over prior airship operations. Among the major operational problems of past airship operations have been the takeoff, landing, and on-the-ground handling procedures. This area of operations will be critical to the economic and operational success of the A/F system and a reasonable requirement would be the capability for operation with an absolute minimum ground crew at all facilities.

Although the A/F vehicle operates as an HTA vehicle, it will retain LTA characteristics due to the large helium filled envelope. This will be particularly true during ground handling operations. Therefore, the need for some ground handling equipment, personnel and mooring facilities will still exist.

The off-loading, on-loading time and weight factors will become critical to high vehicle utilization and low transit times. Passenger control and safety considerations must allow failsafe operations both at the main terminal and at the outlying facilities. Due to the importance of the on-ground operations to the success of the Airport Feeder system concept, this was a major area of analysis in the Operational Procedures Subtask.

4.4.1 Candidate Passenger Transfer Systems

Several solutions to the loading and unloading passengers were examined. The vehicle could be on the mast, as in conventional LTA operations, and passengers and cargo could be off-loaded or on-loaded conventionally through a staircase and/or door arrangement. This could be rather time consuming. Also since a moored LTA vehicle may change position if the wind shifts, caution must be taken in interest of passenger safety.

A second concept would utilize a passenger/cargo module which could be pre-loaded and driven out to the mooring site. When one module is detached from the vehicle, a new module could be attached. The modules could be self propelled or transported by auxiliary vehicles. At the low beta's of the A/F vehicle, the aircraft would be statically heavy even with no modules attached.

The selected concept was based on a modular passenger payload module which could be transferred from the basic Airport Feeder with all passengers aboard or could employ CTOL type ramp facilities for passenger access. These two conceptual modes of operation are shown in Figures 29 and 30, respectively.

4.4.2 Ground Handling Operations Analysis

The primary objective of the ground handling operations analysis was to identify ground handling procedures, systems or equipment which would minimize the ground personnel required for or ground operations.

A promising concept was conceived which is similar to the tether/winch retrieval systems utilized by the Navy to land helicopters on ships at seas up to sea state 5. In the A/F system, a tether cable would be deployed from the vehicle while in a hover mode a few hundred feet above the landing surface as shown in Figure 31. A ground attendant would attach the tether cable to mooring cup/winch mechanism mounted flush on the landing surface. The winch system [which might be adapted from those used in prior "mobile mule" ground handling tractors] would then pull the A/F down to the landing surface while the propulsion system maintained hover attitude. When the vehicle is finally on the landing surface the winch

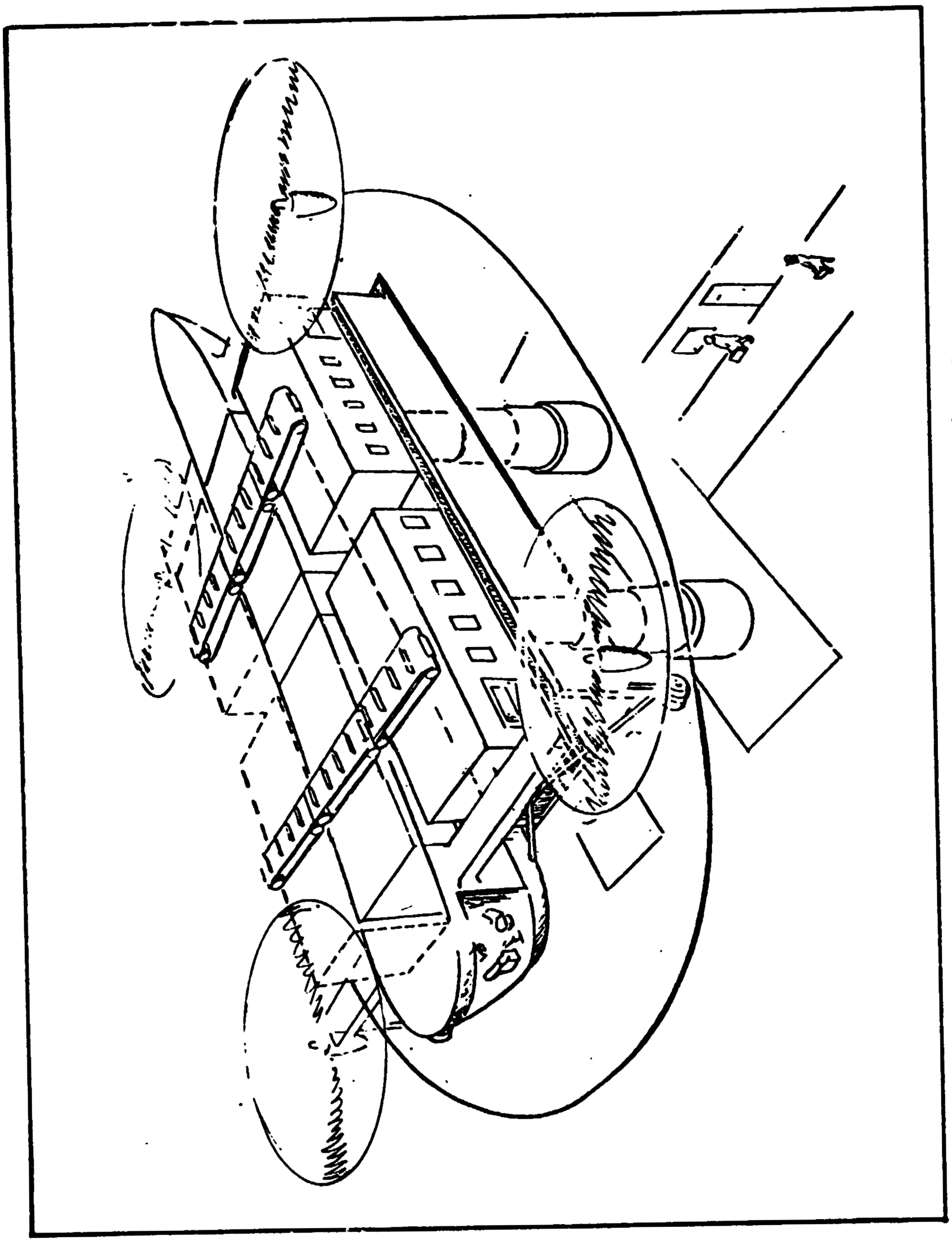


Figure 29. Central Operations Module Transfer Concept

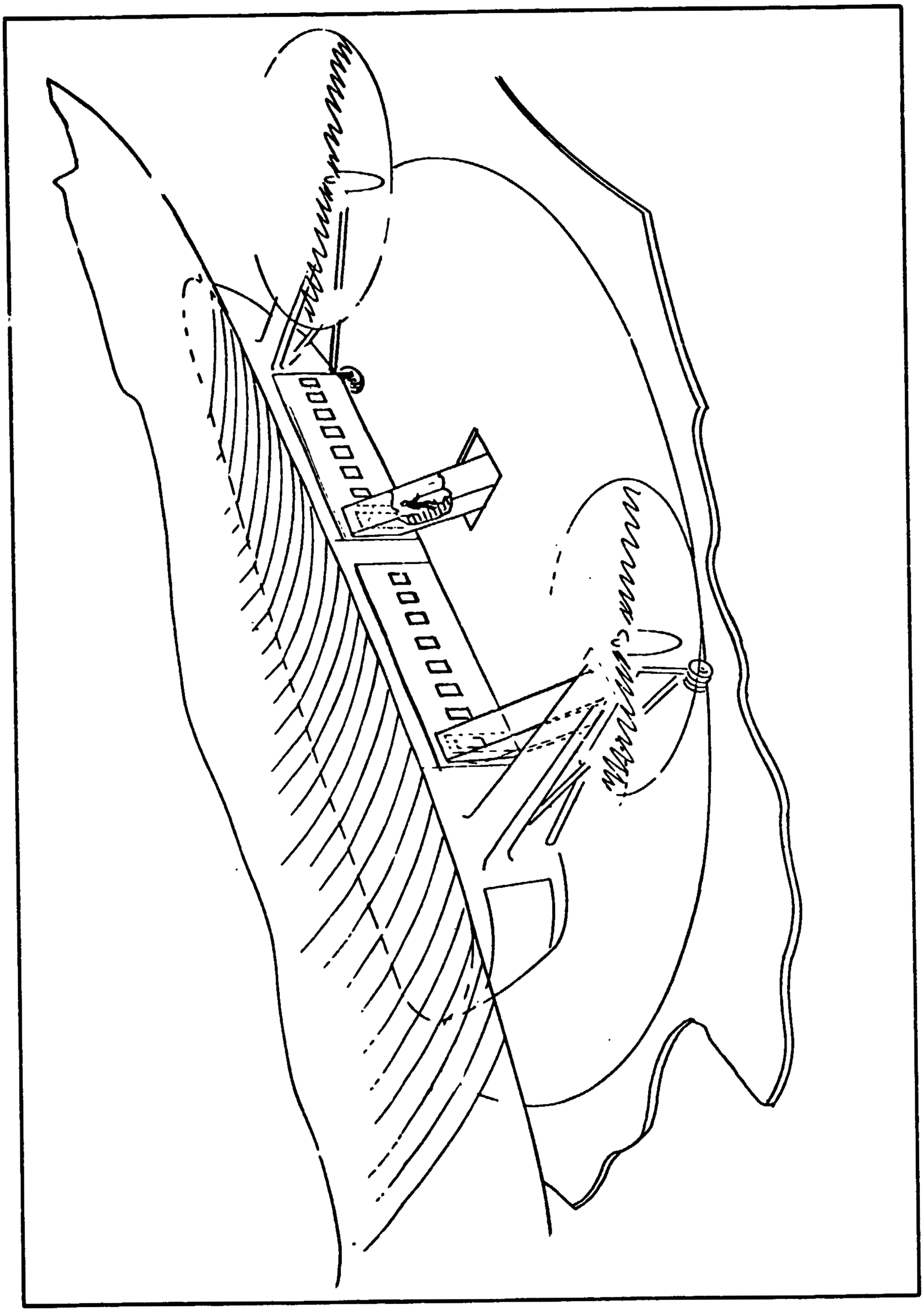


Figure 30. Ramp Enplaning/Deplaning Operations Concept

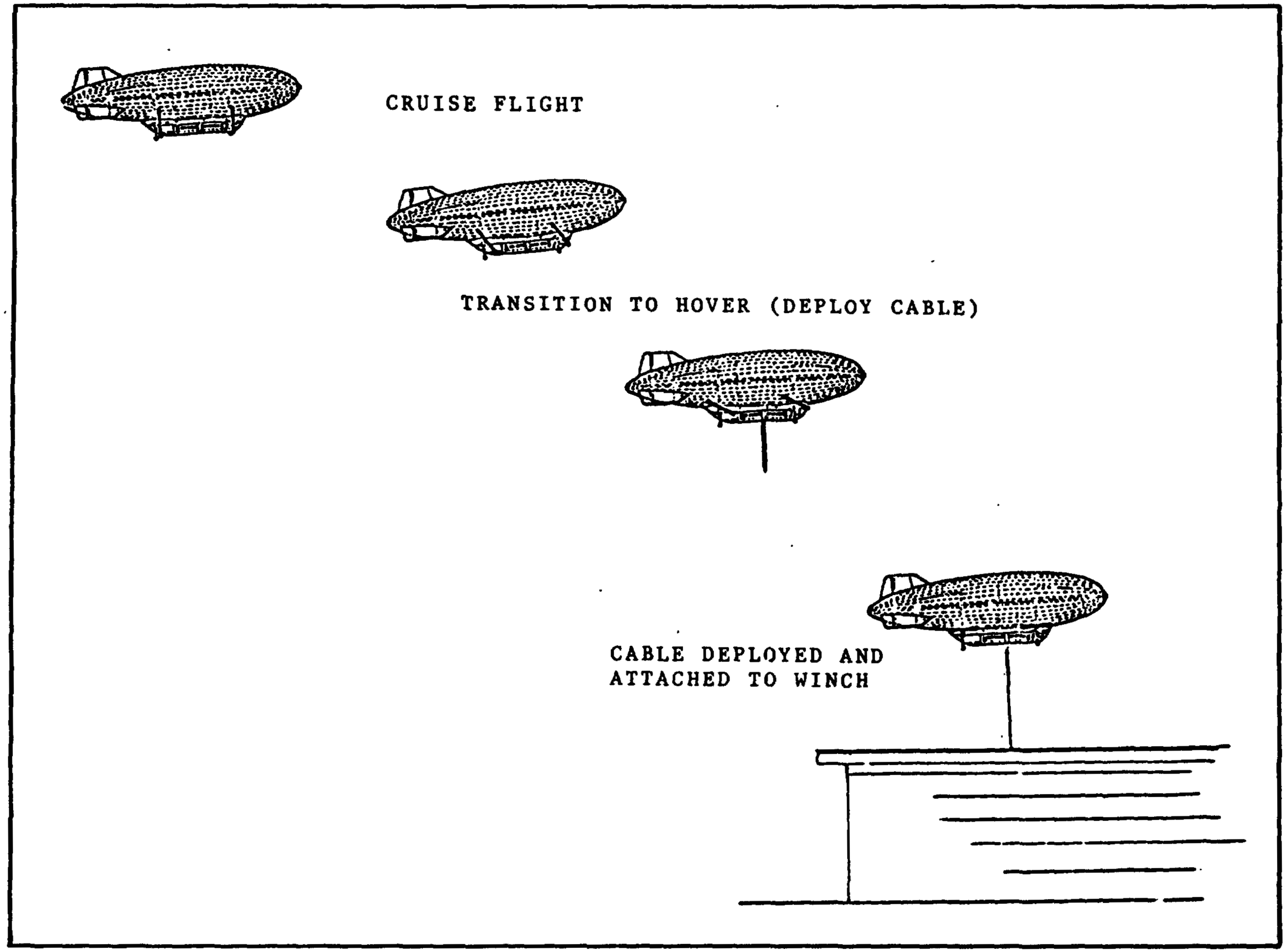


Figure 31. Tether/Winch Landing Sequence

would maintain tension on the tether cable to keep the vehicle "moored" while on the ground. The tether attach point is approximately at the vehicle CG and CB and the vehicle is free to weathercock similar to the stub mast/center point mooring approach investigated for the short-haul heavy lift vehicle. A further innovation would have the mooring cup platform on a rotatable base which could be aligned into the prevailing wind for landing/ground operations. This capability appears most compatible with the modular and ramp passenger enplaning/deplaning operations. Alternately, the vehicle could simply be firmly tied down by four or more additional tiedown cables and designed for any sidewind loads during on-the-ground operations. Passenger enplaning/deplaning facilities could then be permanently positioned at each terminal facility.

The proposed concept of operations at a "downtown" VTOL terminal is shown in Figure 32. A conceptual outlying facility concept is illustrated in Figure 33 and the conceptual rooftop access platform in Figure 34.

The advantages of this operational concept include the following:

1) Positive vehicle attitude and position control during landing and on ground operations.

2) Minimum ground crew required [one man for normal operations].

3) No ground handling equipment is required.

4) No mooring mast is required.

5) The only noticeable airship related items at a terminal would be the flush mounted mooring cup,

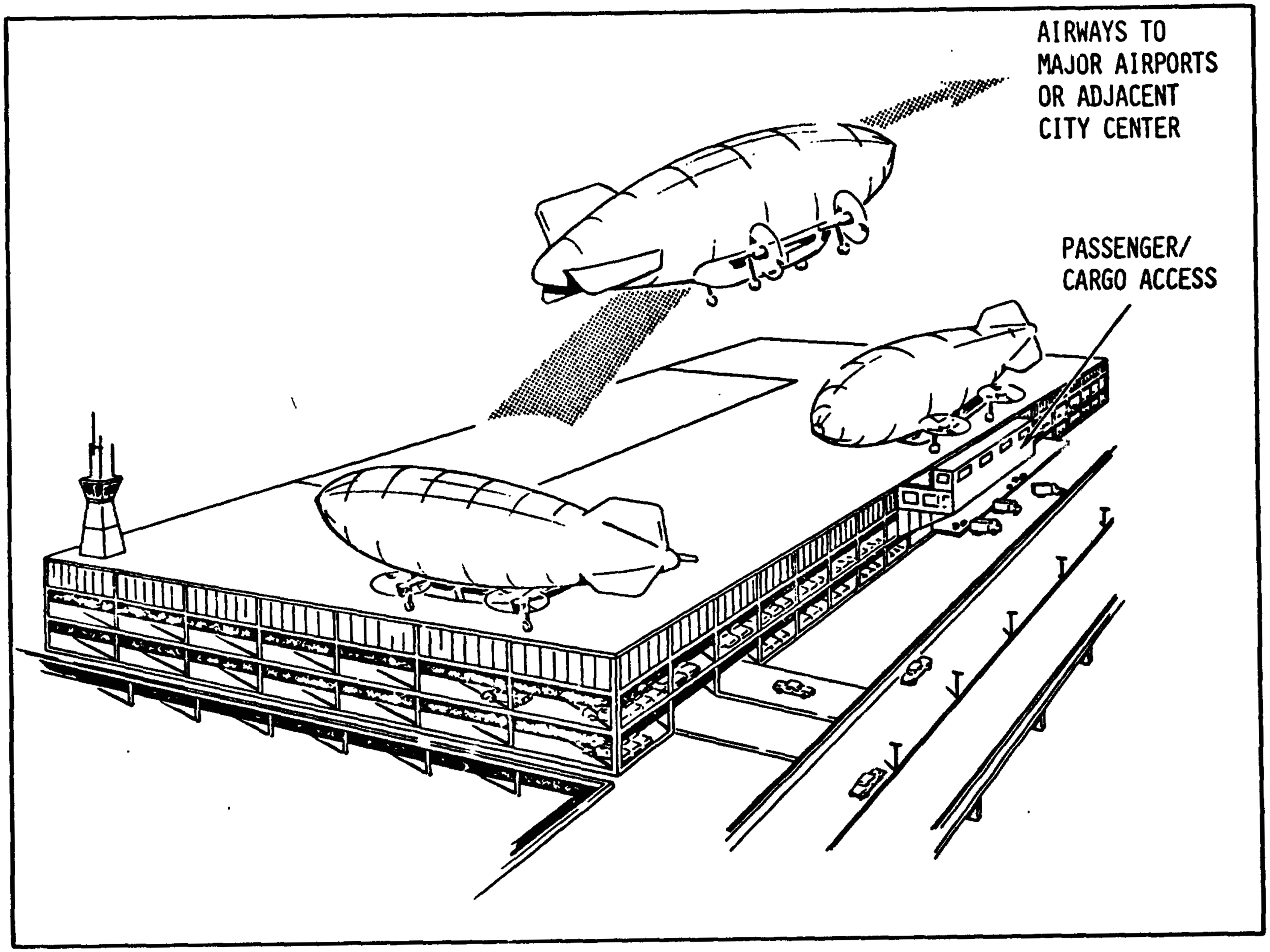


Figure 32. Conceptual Downtown VTOL Terminal Operations

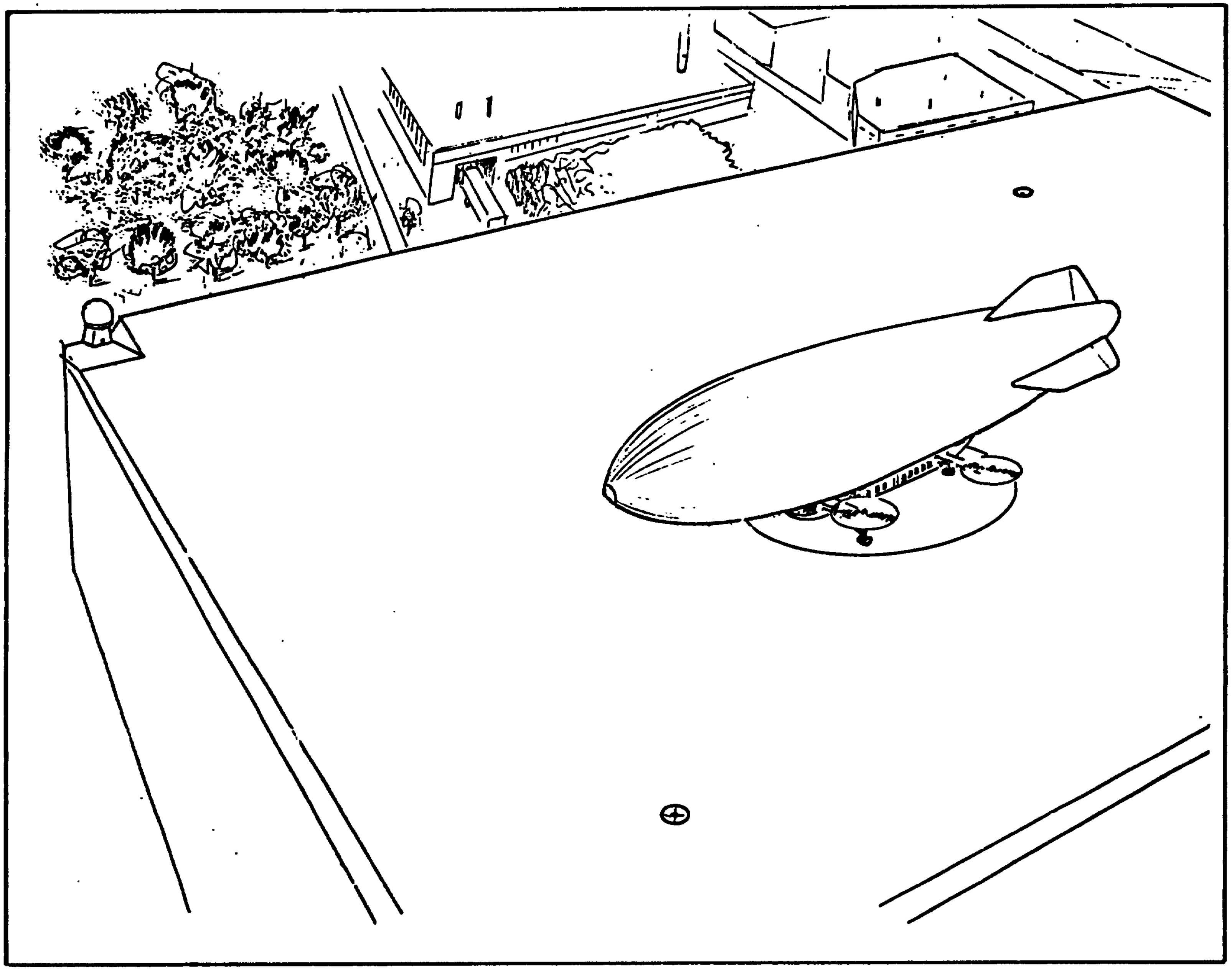


Figure 33. Candidate Outlying Terminal Operations Concept

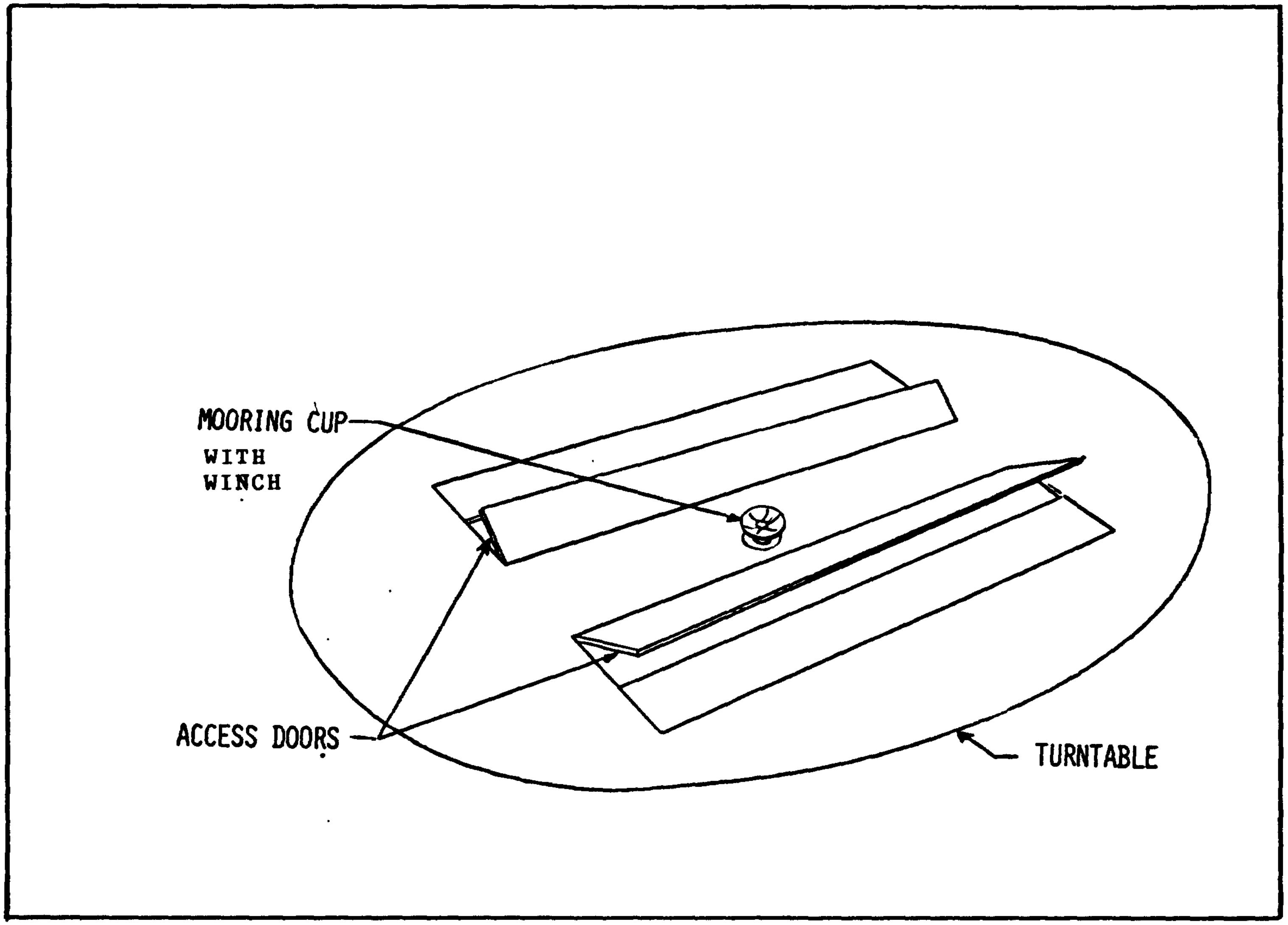


Figure 34. Conceptual Rooftop Access Mooring Platform

flush mounted circle of deadmen [tiedown positions], and the disc shaped mooring area.

6) The mooring area would only be slightly larger than the aircraft total length.

7) Since the aircraft remains stationary when moored, vehicles can drive right under the aircraft for cargo loading and unloading, maintenance and repair.

8) Maintenance working conditions are safer because of the stationary mooring.

9) Passenger and personnel safety is increased by use of the prepositioned enplaning/deplaning facilities.

In summary, the proposed operational concept offers substantial improvements in the landing/on ground operations of the A/F vehicle compared with previous airship operations. Much of this improvement is possible of course because the vehicle is substantially heavy as opposed to neutrally buoyant, has vectorable thrust, and is mechanically "pulled" onto the landing surface at predetermined vertical descent rate. The payoff is of course greatly improved cost, safety and handling operations.

4.4.3 Overview of Conceptual Airport Feeder Operation

The major facility would be located at a major hub airport. Outlying pickup points would consist of either high-rise parking facilities or cleared areas with remote passenger processing facilities. Operations could be conducted in either downtown or suburban areas.

The parking garage type of facility would be located in multi-level garages with flat, flight deck roofs. Existing facilities might be adaptable to the A/F system requirements. The lower floors of each building would provide protected auto parking space. The top floor of each building would house services for the operation; ticketing, waiting rooms, loading, administration, and cargo handling facilities. In addition, the main distribution point at the jetport would interface with the major airlines. Clear approaches and minimum land usage area are some of the advantages to this type of building.

An additional storage and major maintenance facility would have to be available. The size of this facility would depend on the number of vehicles in the fleet. Since the size of one vehicle is relatively large, obviously the storage and maintenance buildings would have to be large. This may, due to limited land area available at most jetports, require an outlying maintenance facility which could be located at a region remote from either the major hub airport or any outlying facility.

The personnel required for this operation would fit into three basic categories of administration, operational, and service.

The administrative personnel would be located at the main distribution point at the jetport. Their responsibilities would be with management, finance, accounting, advertising, public relations, etc.

The operational personnel would consist of the flight crews and flight deck attendants. The flight crew for one vehicle would be made up of a pilot, co-pilot and two stewardesses. The flight deck attendant would assist in the ground operations of the vehicle. In addition, he could be qualified mechanic capable of handling on-the-spot emergency maintenance.

The service personnel would take care of passenger and cargo handling. The ticketing at each station could be automatic. The service personnel would thereby devote their efforts to directing passengers for ramp or modular loading as well as handling luggage and cargo. Two such attendants would be required at each outlying station. Four such attendants would be required at the central station. The major maintenance personnel would also be considered in the service category and would be located at the annex facility for maintenance and storage.

A modular loading/unloading system is utilized at the central distribution point because this is the only point where all passengers will enplane or deplane. A ramp loading system is used to facilitate the partial passenger loading/unloading at outlying points.

The modular system consists of a module that is designed to fit a cavity in the main car structure of the aircraft. The module is located below the flight deck on a hydraulic lift platform. This is its initial loading position. The loading of the module is accomplished prior to the arrival of the aircraft. The aircraft lands and is secured to a mooring cup. Its position when secured is such that it is centered between two doors in the flight deck. Once the flight deck doors are opened, two arms which secure the module to the car structure during flight allow the module to be extended laterally from the car structure for removal or replacement of the module.

Once the on-load module is in position, a hydraulic lift raises the loaded module through the opened flight deck door to a point even with the floor of the car cavity. Simultaneously, a lift is raised to the opposite side of the car cavity in a position ready to receive the off-loading module. The off-loading module is extended outward onto the off-load shift platform and lowered. When the on-loading module is in position, catches on the arms engage latches in the top of the loading module and position the module securely in the car structure. Once the transfer is complete the off-loading module is lowered below the flight deck. The flight deck doors are then closed. The aircraft is released from its mooring for flight, and the passengers, baggage, and cargo on board the just off-loaded module are removed. The now empty module is then prepared for the next loading.

Since only partial load transfers occur at the outlying stations, enplaning/deplaning access ramps will be utilized instead of total modular changes. The operation of the outlying stations are the same up to the opening of the flight deck door and the securing of the aircraft car. At this point covered ramps extend through the flight deck doors on both sides of the car. They are so positioned as to contact the side of the car at the module doors previously described. Once the ramps are locked into position the modular doors are opened. Off-loading passengers descend the ramps on one side of the car while on-loading passengers ascend the ramps on the other. Cargo and baggage is simultaneously handled by attendants. Once the loading/unloading opeation is complete the module doors are closed and secured and the ramps retracted. The flight deck doors are then closed and the aircraft released for take-off.

When approaching the central distribution point or jetport, an incoming aircraft will call the jetport approach control for landing instructions. Upon receiving clearance the co-pilot will contact the passenger service personnel and the flight deck attendant on a company frequency giving the aircraft ETA. The aircraft proceeds inbound switching to tower frequency for final landing instructions. Once cleared for landing the pilot decelerates to a hover over the flight deck and drops the pull-in line. The flight deck attendant secures the line to the mooring cup. The aircraft is then winched in to a landing utilizing vertical thrust to control the vertical descent and landing. The pull-in line continues to be winched in until the aircraft car is centered between the flight deck loading doors. At this point the engines are idled and the doors opened engaging the aircraft car, as previously described, completing the mooring.

A preliminary investigation of the minimum times required for flight deck operations was performed utilizing the results of Reference 22 as a guideline. Timeline estimates [ramp operations] are as follows:

Hover over landing spot	15 Sec.
Pull in line hook up	15 Sec.
Descent to touch down	10 Sec.
Final aircraft positioning	10 Sec.
Aircraft securing for load/off load	5 Sec.
Ascent of load ramps	10 Sec.
Opening of module doors	5 Sec.
Off/on loading of passengers	60 Sec.
Closing of module doors	5 Sec.
Retraction of load ramps	10 Sec.
Preparation for take-off	120 Sec.
Disengagement from mooring cup	5 Sec.
Take-off and climb to cruise	5 Sec.
TOTAL	275 Sec.

Timeline estimates for operations at the central hub terminals [module operations] are as follows:

Hover over landing spot	15 Sec.
Pull in line hook up	15 Sec.
Descent to touch down	10 Sec.
Final aircraft positioning	10 Sec.
Aircraft securing for load/off load	5 Sec.
On load module ascent	10 Sec.
On load module hook up	5 Sec.
Module exchange	10 Sec.
Off load module/module detachment	5 Sec.
Off load module retraction	10 Sec.
On load module securing	5 Sec.
Preparation for take-off	120 Sec.
Disengagement from mooring cup	5 Sec.
Take-off and climb to cruise	5 Sec.
TOTAL	230 Sec.

After the on-loading/off-loading is completed the flight deck doors are closed. The pilot and co-pilot complete their pre-flight cockpit check. Once satisfied the aircraft is ready for flight, the pilot calls the jetport tower for take-off and course clearance. When clearance is received the pilot checks with the flight deck attendant that all is clear externally for take-off. After receiving the clear signal from the flight deck attendant the pull-in line is released from the mooring cup and the pilot executes a vertical take-off and transition to cruise flight. The pilot and co-pilot complete their post take-off cockpit check, climb to altitude and course as directed by the jetport control tower establishing cruise to the first outlying point. When instructed, the pilot switches to departure control for enroute traffic. The co-pilot switches to the company frequency to inform the flight deck attendant and passenger service personnel at the outlying station of the aircraft ETA. The rest of the flight to the outlying terminal facilities proceeds as previously described. The only difference is that the pilot handles his own traffic control visually and via company frequency at the outlying terminal.

4.5 Task II Summary

Significant results of the operational procedures and institutional constraints analyses can be summarized as follows:

From the Institutional Constraints Analysis, the A/F system should have the following operational characteristics:

1) Scheduled high frequency service coordinated with CTOL service characteristics
2) Safe all-weather operations with at least close to CTOL ride qualities
3) Operations which are integrated with CTOL airport operations and processing
4) A tether/winch landing system which can enable a one-man ground crew landing operation and provide positive vehicle positioning while on the ground.
5) The passenger compartment designed for both modular and conventional ramp type operations which can minimize the vehicle on-ground time.

Although a detailed market analysis was beyond the scope of the current study, preliminary indications are that only the 7 to 10 largest metropolitan areas might be able to support the A/F system unless some physical/institutional constraints dictate a short-haul air system, such as the potential Lake Erie Jetport.

5.0 TASK III - COST ANALYSIS

5.1 General

The objective of Task III was to estimate the operating cost of the Airport Feeder final baseline vehicle defined in Task I, operating in the short haul operating mode defined in Task II. Due to the limited funding available for this task, extensive use was made of several NASA sponsored/developed cost estimating relationships [CER's]. The cost analysis task was comprised of three major subtask efforts which addressed the RDT&E cost, Acquisition Cost and Operating Cost of the Baseline Airport Feeder System. All cost data is in the 1975 dollars unless otherwise noted.

5.2 RDT&E Cost

Estimating the RDT&E costs of the A/F vehicle/system concept is complicated by several major areas of uncertainty. These include:

Government support of RDT&E
FAA Certification Requirements
RDT&E required for the "Second Ever" Metalclad
RDT&E required for developing the terminal facilities

The approach used for Phase I was to investigate the RDT&E costs parametrically and to determine the variations of the operating costs as a function of the RDT&E costs. Estimates of the RDT&E costs of the Airport Feeder vehicle were based on a combination of past GAC airship development, past VTOL aircraft programs such as the XC22 and XC142 aircraft as well as prior CTOL aircraft programs. Much of the data used in the past RDT&E cost estimates for the latter two categories of aircraft were based on the data contained in Reference 8. A minimum RDT&E cost program breakdown would result from a RDT&E program similar to that used on prior Goodyear airship development for the U.S. Navy. This bottom level or minimum cost breakdown results in a lowest estimate RDT&E program of $40,900,000. The components of this RDT&E cost program are shown in Table 20. The engineering hours were based upon the ZPG-1 airship development program [escalated to 1975 dollars] to obtain the total engineering costs associated with the first production unit which is assumed to be utilized as a flight research test vehicle. The fabrication, assembly and erection costs similarly were also based on the ZPG-1 history escalated to 1975 dollars. The cost escalation factor utilized to escalate the prior cost results to 1975 dollars was the consumer price index shown in Table 21. As shown in Table 20 this minimum RDT&E cost program has very low cost allowances for the market survey, operations analysis, as well as the engineering, fabrication and erection of the first flight vehicle. In order to develop an upper limit estimate on the RDT&E cost, the XC142 tilt wing VTOL vehicle program was used as a reference concept. This vehicle development RDT&E cost approached $200,000,000 for the XC142 [Reference 8]. Assuming that the wealth of VSTOL R&D programs conducted by NASA and the various DOD Agencies during the last ten years would substantially reduce the costs associated with the similar programs today, an upper limit estimate of $160,000,000 was defined for the Airport Feeder vehicle, parametric upper bound. The baseline RDT&E cost breakdown is shown in Table 22.

A substantial allowance for the market survey and operational analysis is allotted in the Baseline RDT&E cost. The

FAA certification, which is a major area of uncertainty, is estimated to be $5,000,000 based on assumed two-year flight test program. The certification flight test program cost was based on an assumed 50 man engineering/flight test personnel level of effort during the two year program. Extensive use of Government test facilities, data reduction, and flight test support would be expected.

The airframe development costs are again based on prior GAC airship development experience but with a substantial allowance for the RDT&E associated with developing manufacturing, assembly and erection procedures associated with the metalclad vehicle. The propulsion system cost estimate is based on an assumption that no major engine development would be required for the airport feeder vehicle. That is, an existing engine or derivative thereof would be utilized for the Airport Feeder vehicle. The major development costs associated with the propulsion system would be the RDT&E associated with integrating the engine cross shafting and thrust vectoring capability with an off-the-shelf core engine.

The flight control system development cost is also based on capitalizing on the R&D performed by NASA and the various VSTOL study programs that assumes that modest additional development would be required to develop the flight control system associated with the semi-buoyant Airport Feeder vehicle. The first unit production cost is based on a composite of prior GAC airship programs as well as the first unit acquisition cost estimates to be described below. The final baseline RDT&E cost shown in Table 22 was $80,000,000.

The sensitivity of the average vehicle acquisition cost as well as operating cost sensitivity to the RDT&E program

Table 20. Minimum Estimate: Airport Feeder Prototype RDT&E Cost

Market Survey Cost			$ 500,000
Operational Analysis			$ 500,000
GFE Analysis			0
Specification Dev.			$ 600,000
Initial Flight Research Vehicle			
A. Engineering (850,000 Hrs based on ZPG-1 Development Program)		$27,000,000	
B. Fabrication, Assembly, Erection (ZPG-1 Cost Analogy) = 11,300,000 + $1,000,000 (Engines)		$12,300,000	
			$39,300,000
	Total		$40,900,000

Table 21 - Consumer Price Index Cost Escalation Factors[1]

Year	$ Value[2]
1940	2.381
1950	1.387
1955	1.247
1960	1.145
1965	1.058
1970	0.86
1973	0.751
1975	0.629

[1]Cost escalation factor to 1975 $ = $ Value in year x ÷ $ value in 1975

[2]Based on CPI for all items

Table 22 - Baseline RDT&E Cost Breakdown

Market Survey and Analysis	$ 1,000,000
Operational Analysis	$ 1,000,000
FAA Certification	$ 5,000,000
Airframe and Integration	$40,000,000
Propulsion Systen	$10,000,000
Flight Control Syste	$ 5,000,000
First Unit Production	$12,000,000
Tooling	$ 6,000,000
TOTAL	$80,000,000

cost will be described in subsequent sections. It should be pointed out that the baseline RDT&E cost does not include the cost associated with the R&D and construction of any outlying terminal facilities. The rationale for excluding this element of the RDT&E cost is that until the operational concept and market associated with the conceptual airport feeder operation can be more fully defined, the precise cost associated with the terminal facilities would be highly conjectural.

The $80,000,000 RDT&E program may appear to be somewhat low based on comparison with other VTOL systems concepts such as the XC22 and XC142 aircraft. However, the complexity of the Airport Feeder vehicle concept itself would appear to justify this level of RDT&E cost. The vehicle, propulsion systems, and associated control system requirements should be simpler than some of the more exotic, powered lift VTOL concepts investigated during the last several years due to the semi-buoyant vehicle characteristics. The vehicle itself is a rather simple concept and the propulsion system requirements are considered to be low-risk items which could be implemented in the near-term. As discussed in Task I the incorporation of either prop rotor technology, tilt rotor technology or cyclic pitch control capability will likely be required. However, this too is judged to be a low-risk technology application. In conclusion, the RDT&E cost associated with the Airport Feeder concept should indeed be significantly lower than those associated with conventional heavier-than-air/non buoyant powered lift VTOL vehicles. This is another of the potential benefits of the semi-buoyant hybrid LTA concept: By reducing the power requirements associated with VTOL capability via incorporation of buoyant lift, the system complexity, hence cost is significantly reduced.

5.3 Acquisition Cost

The second major analysis effort of Task III was the development of the acquisition cost estimates for the Airport Feeder vehicle concept. The NASA study guidelines dictated that the ultimate operating costs shall be based on production quantities of 1, 25 and 125 vehicle production runs. Several different approaches were reviewed and analyzed to develop the final acquisition cost models.

Joseph Anderson of the NASA Ames Research Center has conducted extensive analysis and development of cost estimating relationships, CER's, for aircraft systems [Reference 9 and 10]. In addition, the data contained in Reference 8 and also the cost estimating relationships used in-house by NASA in their aircraft system studies were all reviewed to develop the final acquisition cost model.

The final methodology used in the acquisition cost analysis effort can be summarized as follows: The NASA Ames aircraft cost estimating relationships were used as the basic reference for the following items: 1) learning factors, 2) aircraft systems, 3) passenger provisions and furnishings, 4) propulsion group, and 5) the car structure and passenger accommodations. GAC reference data was used to develop modifications to the basic NASA CER's for the car structure, the hull structure and the empennage. The final summary of acquisition cost estimating relationships are presented in Table 23 for the various Airport Feeder vehicle subsystems. As shown in Table 23 most of the cost estimating equations are of the form

Table 23 - Baseline Airport Feeder Cost Estimating Relationships

Item	Cost Equation
<u>Hull Group</u>	$C = 2640\ W^{.70}\ Q^{-.218}$
Main Frames	
Intermediate Frame	
Longitudinals	
Outer Cover	
Pressure System and Valves	
Mooring and Handling	
Ballonets	
Miscellaneous	$C = 2640\ W^{.70}\ Q^{-.218}$
<u>Car Structure</u>	$C = 2890\ W^{.70}\ Q^{-.218}$
Basic Structure	
Module Structure	
<u>Landing Gear</u>	$C = 1220\ W^{.678}\ Q^{-.218}$
<u>Tail</u>	$C = 2640\ W^{.678}\ Q^{-.218}$
<u>Propulsion Group</u>	
Engines	$C = 173.075(HP)^{.9283}\ Q^{-.218}$
Gear Goxes	$C = 3510$ [illegible]$^{.678}\ Q^{-.218}$
Propellers	$C = 3.4(3 \times 4^{.75} + 3.5)W\ Q^{-.218}$
Outriggers	$C = 2640\ W^{.678}\ Q^{-.218}$
Nacelle & Eng. Acces.	$C = 2640\ W^{.678}\ Q^{-.218}$
<u>Surface Controls</u>	$C = 1440\ W^{.8}\ Q^{-.218}$
<u>Flight Instrumentation</u>	$C = 230\ W\ Q^{-.184}$
<u>Fuel System</u>	$C = 3510\ W^{.678}\ Q^{-.218}$
<u>Furnishings</u>	$C = 2070\ W^{.75}\ Q^{-218}$
<u>Avionics</u>	\$250,000 NASA Guideline
<u>Electrical</u>	$C = 270\ W\ Q^{-.218}$
<u>Air Conditioning</u>	$C = 2670\ W^{.71}\ Q^{-.218}$
<u>Anti-Icing</u>	$C = 2670\ W_{32}^{-.29}\ W_{33}\ Q^{-.218}$
<u>Hydro & Pneumatic</u>	$C = 2650\ W^{.73}\ Q^{-.218}$
<u>Aux. Power Unit</u>	$C = 1560\ W^{.77}\ Q^{-.218}$

$$\text{Cost} = A \cdot W^B Q^C$$

where A, B and C are constants based on a statistical analysis of previous aircraft cost data. W is the weight of the specific category in question, and Q is the production quantity.

The final set of acquisition cost estimating relationships were incorporated in the Goodyear Airship Synthesis Program to check out the various acquisition costs sensitivities. The sensitivity of production or acquisition costs to the number of units produced with and without the baseline RDT&E costs are shown in Figure 35. Table 24 contains a summary level breakdown on the average unit production cost for a 125-unit production run for the 6 major weight groups of a baseline Airport Feeder concept. The production cost senitivity to RDT&E costs for 125 production units is shown in Table 25. As shown, the average unit cost for 125 total production unit is not extremely sensitive to the RDT&E costs over the range of $40,000,000 to $160,000,000, varying only approximately 13% as the RDT&E cost is doubled from $80,000,000 to $160,000,000.

5.4 Operating Cost Analysis

The third major area of analysis in the cost analysis task effort was to investigate the operating cost for the Airport Feeder vehicle/system concept. The ultimate nature of the operational characteristics of A/F system concept were rather uncertain. As an approximation, the operating cost estimating relationships developed for short haul passenger operations [Reference 11] were utilized to estimate the operating cost of the Airport Feeder vehicle concept. This cost

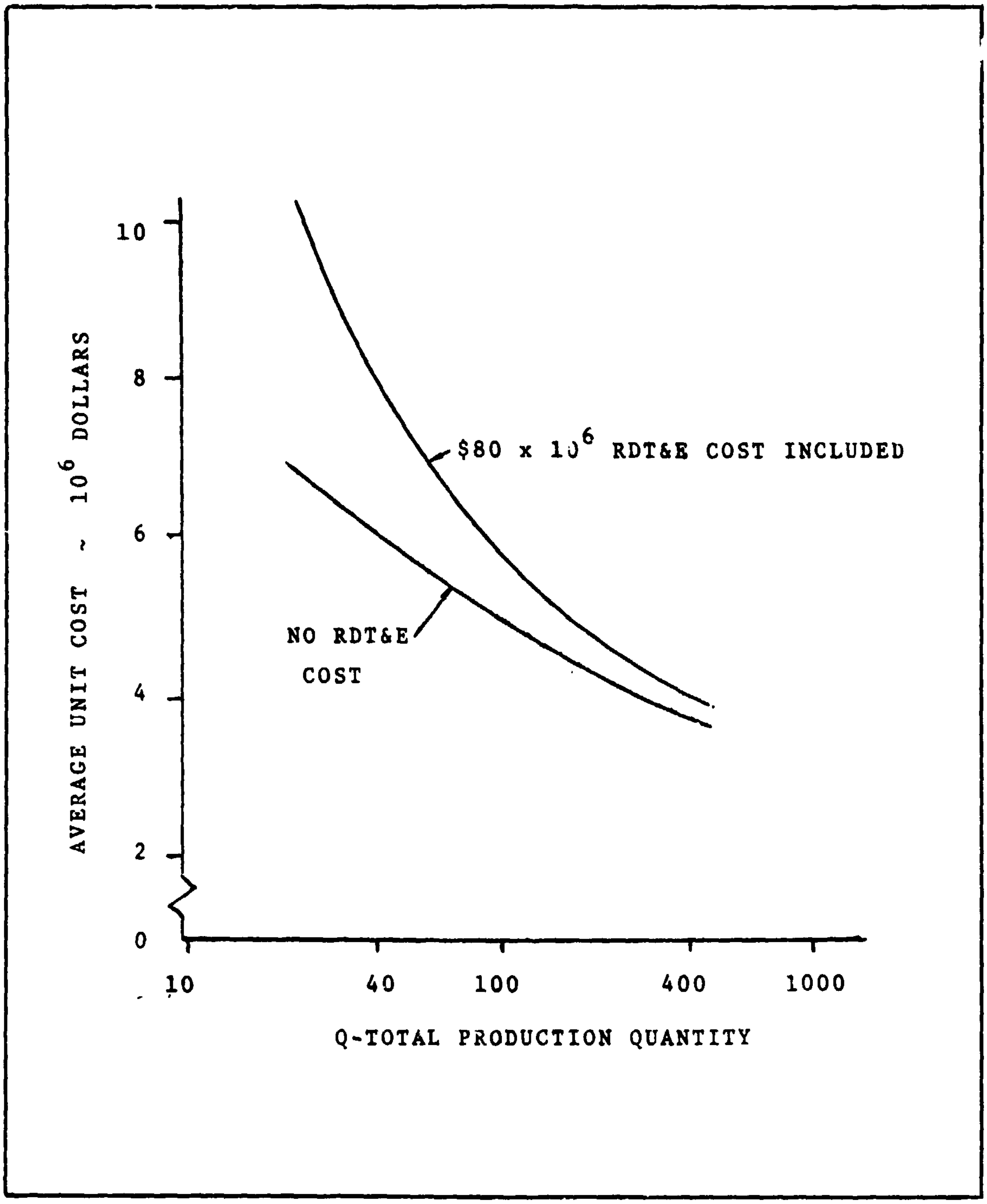


Figure 35. Average Unit Acquisition Cost vs Production Quantity - With and Without RDT&E Cost

Table 24 - Baseline Airport Feeder Production Cost Breakdown

Hull Structure	$ 763,150
Car [Structure/Module/Furnishings]	$1,272,350
Empennage and Controls	$ 482,000
Landing Gear	$ 59,800
Propulsion and Fuel System	$1,609,200
Flight Instruments and Systems	$ 677,300
Average Unit Production Cost [125 Total Production Units]	$4,863,800

Table 25 - Baseline* Airport Feeder Average Unit Acquisition Cost Sensitivity to RDT&E Cost, 125 Total Production Units

RDT&E Costs [$ 10^6]	Average Unit Cost [$ 10^6]	% of Avg. Unit Cost Due to RDT&E
40	5.184	6.1
80	5.503	13.0
120	5.823	19.6
160	6.144	26.0

*Q = 125 Production Units

model contains cost estimating relationships for both the direct operating cost, DOC, and the indirect operating cost elements, IOC, associated with short haul passenger operations. The elements contained in the reference methodology for both the DOC and IOC cost elements are shown in Table 26.

The complete equations utilized for each of the DOC, IOC cost elements are summarized in Table 27. The operating cost assumptions utilized for the baseline operating cost results are shown in Table 28. The 74 km [40 n.mi.] average stage length was specified in the NASA study guidelines. The average block speed is a very important quantity in the operating cost of any aircraft system. The average block speed for the Airport Feeder vehicle was based on the analysis of Reference 12 as well as an analysis of the takeoff and transition times associated with the vertical take-off and climb to 2000 feet altitude. This analysis indicated that the vertical take-off, transition and climbout to cruise flight at 610 m [2000 feet] could be accomplished in 90 seconds or less for various wind conditions. During this time interval, no distance credit is allowed. The block time is based on an assumption of 50% headwind and 50% tailwind with a mean wind speed of 13 m/s [25 knots]. The block time can thus be calculated from the following equation [Reference 12]:

$$t_B = \frac{R}{S\left(1 - \frac{V_W^2}{S^2}\right)} + 0.05$$

t_B = block time ∿ hrs

V_W = wind speed = 13 m/s [25 knots]

S = cruise speed = 68 m/s [130 knots]

R = range ∿ km [n. miles]

Table 26 - Operating Cost Model Elements

DOC	IOC ELEMENTS
Flight Crew	Cabin Attendants
Fuel Oil and Taxes	Beverage Expense
Insurance	Other PAX Service
Maintenance	A/C Control & Line Servicing
Depreciation	A/C Landing Fees
Helium	Traffic Servicing
	Promotion and Sales
	Ground Property & Equipment
	GP&E Depreciation
	General & Administrative

Table 27. Operating Cost Model Equations (Ref. 11)

DOC MODEL SUMMARY

(MILLIONS OF 1973 DOLLARS)

- FLYING OPERATIONS
  - FLIGHT CREW EXPENSE:

$$FCE = \left[27.97 + 33.53\left(\text{FLIGHT CREW FACTOR}\right) + 0.18\left(\frac{\text{TOGW}}{10^3} + \text{DESIGN CRUISE SPEED}\right)\right]\left(\text{ANNUAL BLOCK HOURS PER AIRCRAFT}\right)\left(\text{FLEET SIZE}\right)\left(10^{-6}\right)$$

  - FUEL, OIL AND TAXES:

$$FOT = \left[\left(\text{FUEL CONSUMPTION RATE}\right)\left(\text{FUEL COST}\right)\left(1.045\right)\right]\left(\text{ANNUAL BLOCK HOURS PER AIRCRAFT}\right)\left(\text{FLEET SIZE}\right)\left(10^{-6}\right)$$

  - INSURANCE:

$$INS = \left[\left(\text{AIRCRAFT UNIT COST}\right)\left(\text{INSURANCE RATE}\right)\right]\left(\text{FLEET SIZE}\right)\left(10^{-6}\right)$$

- COMPOSITE FLYING OPERATIONS COST-ESTIMATING RELATIONSHIP:

$$FO = FCE + FOT + INS$$

Table 27. (Continued)

DOC MODEL SUMMARY

(MILLIONS OF 1973 DOLLARS)

- DIRECT MAINTENANCE - TURBOPROP AIRCRAFT:
  - AIRFRAME DIRECT MAINTENANCE:

$$ADMTP = \left[1.2\left(\text{Airframe Weight}\right)^{0.358}\right]\left(\text{Annual Block Hours Per Aircraft}\right)\left(\text{Fleet Size}\right)\left(10^{-6}\right)$$

  - AIRFRAME LABOR CONTENT:

$$ALCTP = \left[0.66\left(\text{Airframe Weight}\right)^{0.371}\right]\left(\text{Annual Block Hours Per Aircraft}\right)\left(\text{Fleet Size}\right)\left(10^{-6}\right)$$

Table 27. (Continued)

DOC MODEL SUMMARY

(MILLIONS OF 1973 DOLLARS)

- DIRECT MAINTENANCE - TURBOPROP AIRCRAFT:
  - ENGINE DIRECT MAINTENANCE:

$$\text{EDMTP} = \left[2.863 + \frac{3.037}{10^3}\begin{pmatrix}\text{Equiv.}\\ \text{Shaft HP}\\ \text{Per}\\ \text{Engine}\end{pmatrix}\right]\begin{pmatrix}\text{Engines}\\ \text{Per}\\ \text{Aircraft}\end{pmatrix}\begin{pmatrix}\text{Annual}\\ \text{Block}\\ \text{Hours Per}\\ \text{Aircraft}\end{pmatrix}\begin{pmatrix}\text{Fleet}\\ \text{Size}\end{pmatrix}\left(10^{-6}\right)$$

  - ENGINE LABOR CONTENT:

$$\text{ELCTP} = \left[2.037 + \frac{1.357}{10^3}\begin{pmatrix}\text{Equiv.}\\ \text{Shaft HP}\\ \text{Per}\\ \text{Engine}\end{pmatrix}\right]\begin{pmatrix}\text{Engines}\\ \text{Per}\\ \text{Aircraft}\end{pmatrix}\begin{pmatrix}\text{Annual}\\ \text{Block}\\ \text{Hours Per}\\ \text{Aircraft}\end{pmatrix}\begin{pmatrix}\text{Fleet}\\ \text{Size}\end{pmatrix}\left(10^{-6}\right)$$

Table 27. (Continued)

DOC MODEL SUMMARY

(MILLIONS OF 1973 DOLLARS)

- APPLIED MAINTENANCE BURDEN:

$$\text{AMB} = 1.88 \left[\text{AIRFRAME LABOR} + \text{ENGINE LABOR} \right]$$

- DEPRECIATION - FLIGHT EQUIPMENT:

$$\text{DFE} = \underset{(1.12^{*})}{\left(\begin{matrix} \text{AIRCRAFT} \\ \text{UNIT} \\ \text{COST} \end{matrix} \right) \left(\begin{matrix} \text{AIRCRAFT} \\ \text{SPARES} \\ \text{FACTOR} \end{matrix} \right)} \underset{(1 - .15^{*})}{\left(1 - \begin{matrix} \text{RESIDUAL} \\ \text{VALUE} \end{matrix} \right)} \left(\begin{matrix} \text{FLEET} \\ \text{SIZE} \end{matrix} \right) \left(10^{-6} \right) \underset{\left(\frac{1}{12 \text{ YEARS}}^{*} \right)}{\left(\frac{1}{\text{DEPREC. PERIOD}} \right)}$$

* COST MODEL AVERAGE VALUES

Table 27. (Continued)

IOC MODEL SUMMARY

(MILLIONS OF 1973 DOLLARS)

- PASSENGER SERVICE EXPENSE
  - CABIN ATTENDANT EXPENSE:

    $$CAE = -0.023 + 3.466 \left[\underset{\text{(BILLIONS)}}{\text{REVENUE PASSENGER MILES}} \right]$$

  - FOOD AND BEVERAGE EXPENSE:

    $$FBE = 0.831 + 0.35 \left[\underset{\text{(MILLIONS)}}{\text{ENPLANED REVENUE PASSENGERS}} \right]$$

  OR

  - BEVERAGE-ONLY EXPENSE:

    $$BOE = -0.026 + 0.03 \left[\underset{\text{(MILLIONS)}}{\text{ENPLANED REVENUE PASSENGERS}} \right]$$

  - OTHER PASSENGER SERVICE EXPENSE:

    $$OPSE = 0.232 + 1.564 \left[\underset{\text{(MILLIONS)}}{\text{REVENUE PASSENGER MILES}} \right]$$

- COMPOSITE COST-ESTIMATING RELATIONSHIP:

$$PSE = CAE + \begin{matrix} FBE \\ \text{OR} \\ BOE \end{matrix} + OPSE$$

Table 27. (Continued)

IOC MODEL SUMMARY

(MILLIONS OF 1973 DOLLARS)

- AIRCRAFT AND TRAFFIC SERVICING EXPENSE
  - AIRCRAFT CONTROL AND LINE SERVICING EXPENSE:

$$\text{ACLSE} = 0.86 + 0.199 \left[\underset{\text{(MILLIONS)}}{\text{REVENUE AIRCRAFT MILES}} \right]$$

  - AIRCRAFT LANDING FEES EXPENSE:

$$\text{ALFE} = \left(\frac{0.688}{10^6} \right) \left[\left(\begin{array}{c} \text{LANDING} \\ \text{GROSS} \\ \text{WEIGHT} \end{array} \right)_{\text{(1000 LB)}} \left(\begin{array}{c} \text{AIRCRAFT} \\ \text{DEPARTURES} \\ \text{PER YEAR} \end{array} \right)_{\text{(THOUSANDS)}} \left(\begin{array}{c} \text{FLEET} \\ \text{SIZE} \end{array} \right) \right]^{1.6015}$$

  - TRAFFIC SERVICING EXPENSE:

$$\text{TSE} = 1.31 + 0.082 \left[\underset{\text{(MILLIONS)}}{\text{REVENUE TON-MILES}} \right] + 0.041 \left[\begin{array}{c} \text{REVENUE} \\ \text{AIRCRAFT} \\ \text{DEPARTURES} \end{array} \right]_{\text{(THOUSANDS)}}$$

- COMPOSITE COST-ESTIMATING RELATIONSHIP:

$$\text{ATSE} = \text{ACLSE} + \text{ALFE} + \text{TSE}$$

Table 27. (Continued)

IOC MODEL SUMMARY

(MILLIONS OF 1973 DOLLARS)

- PROMOTION AND SALES EXPENSE:

$$\text{PASE} = 1.785 + 1.201 \underbrace{\begin{bmatrix} \text{ENPLANED} \\ \text{REVENUE} \\ \text{PASSENGERS} \end{bmatrix}}_{\text{(MILLIONS)}} + 4.716 \underbrace{\begin{bmatrix} \text{REVENUE} \\ \text{PASSENGER} \\ \text{MILES} \end{bmatrix}}_{\text{(BILLIONS)}}$$

- GROUND PROPERTY AND EQUIPMENT EXPENSE:

$$\text{GPEE} = -0.369 + 0.227 \begin{bmatrix} \text{FLIGHT EQUIPMENT} \\ \text{DEPRECIATION EXPENSE} \\ \text{(\$MILLIONS)} \end{bmatrix}$$

- GPEE DEPRECIATION CONTENT:

$$\text{GPDC} = -0.244 + 0.099 \begin{bmatrix} \text{FLIGHT EQUIPMENT} \\ \text{DEPRECIATION EXPENSE} \\ \text{(\$MILLIONS)} \end{bmatrix}$$

Table 27. (Concluded)

IOC MODEL SUMMARY

(MILLIONS OF 1973 DOLLARS)

- AMORTIZATION (OF DEVELOPMENTAL AND PREOPERATING EXPENSE):

$$\text{ADPE} = -0.094 + 0.019 \left[\begin{array}{c} \text{REVENUE AIRCRAFT MILES} \\ \text{(MILLIONS)} \end{array} \right]$$

- GENERAL AND ADMINISTRATIVE EXPENSE:

$$\text{GAE} = 0.916 + 0.054 \left[\begin{array}{c} \text{TOTAL OPERATING COST} \\ \text{LESS} \\ \text{FLIGHT EQUIPMENT DEPR. EXPENSE} \\ \text{LESS} \\ \text{GROUND PROP. DEPRECIATION EXPENSE} \\ \text{LESS} \\ \text{AMORTIZATION EXPENSE} \\ \text{LESS} \\ \text{GENERAL AND ADMIN. EXPENSE} \\ \text{(\$ MILLIONS)} \end{array} \right]$$

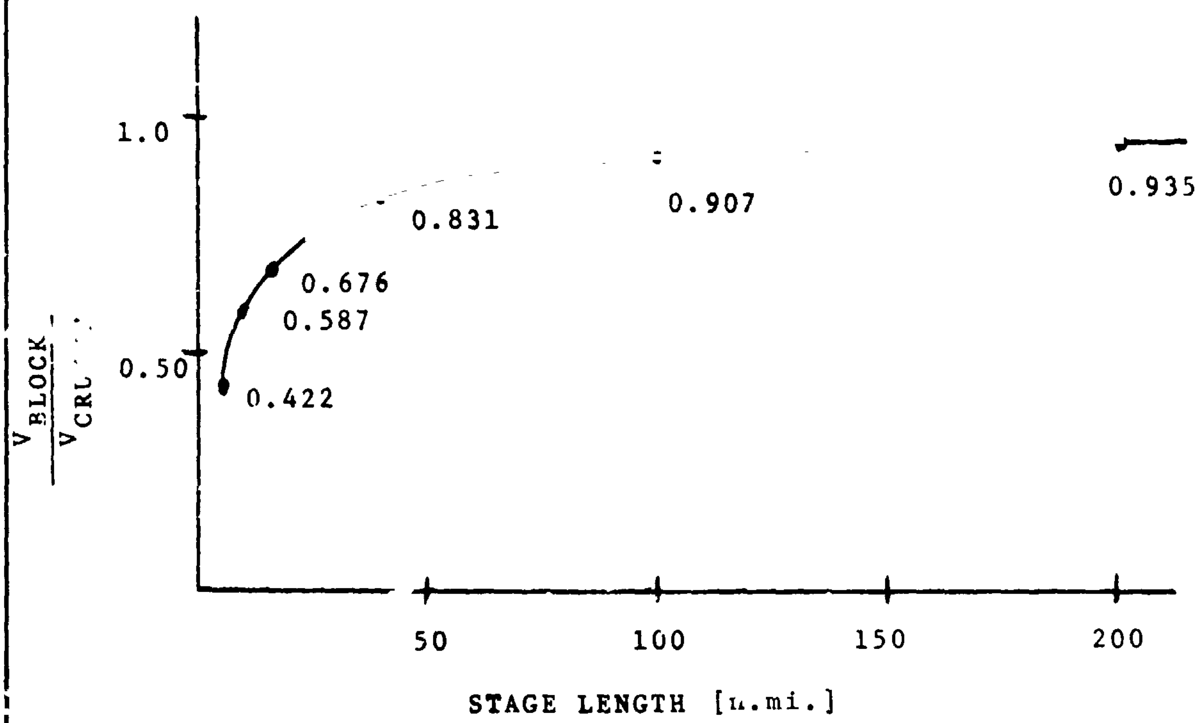
Table 28. Baseline Operating Cost Assumptions

- 40 NAUT MI AVERAGE STAGE LENGTH
- 125 FEEDER FLEET SIZE
- 3000 HOURS PER YEAR UTILIZATION
- BLOCK SPEED BASED ON
  - TAKEOFF TRANSITION TIME (= 90 SEC)
  - 50% HEAD WIND/50% TAIL WIND
  - WIND SPEED = 25 KNOTS
- RDT&E = $\$80 \times 10^6$
- FUEL COST = \$0.30 PER GALLON
- HELIUM COST OF \$40 PER 1000 CU FT

The 0.05 is the time allocated for take-off, transition to cruise flight, climb to a cruise altitude, accelerate to the cruise speed and the reverse maneuver for landings. As stated before, no time or distance credit is allowed for this maneuver. The block time is of course very sensitive to the design range. Although the reference or baseline point for the calculations was 74 km [40 n.mi.], the operating cost sensitivity to design stage length was of interest. Figure 36 shows the block speed sensitivity to design range.

Utilizing the baseline acquisition cost estimate for 125 units, an $80,000,000 RDT&E cost, and the baseline operating cost assumptions of Table 28, results in the estimated operating cost breakdown for direct and indirect cost shown in Table 29. The indirect operating cost is approximately 35% higher than the direct operating cost. The source of this high indirect operating cost element can be traced to the cost estimates associated with promotion and sales, traffic servicing and the aircraft landing fees cost elements. The cost estimating relationships for these items are based on the revenue aircraft departures for the complete Airport Feeder system. The low stage lengths results in high revenue aircraft departures for the short-haul airport feeder system concept.

These cost categories appear to be higher than might be expected. Indeed, the major area of uncertainty in the IOC equations are the passenger servicing expense an the aircraft servicing expense. An additional area of uncertainty in the indirect operating cost associated with the Airport Feeder system is the amortization of the facilities required for the system. Since the specific nature and quantity of these facilities are not definitely known, these costs were not included



NOTE: n.mi = 1.853 km

Figure 36. Effects of Stage Length on Block Speed to Cruise Speed Ratio

Table 29 - Baseline* Airport Feeder Operating Cost Breakdown: Annual Cost

Cost Element		Millions of U.S. Dollars
Direct Operating Cost		
Flight Crew	FCE[a]	30.22
Fuel, Oil, Taxes	FOT	42.20
Insurance	INS	10.32
Aircraft Direct Maint., Turboprop	ADMTP	18.87
Aircraft Labor Content, Turboprop	ALCTP	11.81[b]
Engine Direct Maint., Turboprop	EDMTP	16.84
Engine Labor Content	ELCTP	8.88[b]
Applied Maintenance Burden	AMB	38.90
Depreciation Flight Equipment	DFE	54.58
	DOC	211.93
Indirect Operating Cost		
Cabin Attendants	CAE	10.25
Beverage Only	BOE	1.90
Other Passenger Service	OPSE	4.93
Aircraft Control & Line Service	ALCSE	13.34
Aircraft Landing Fees	ALFE	44.60
Traffic Servicing	TSE	84.10
Promotion and Sales	PASE	9[illegible].55
Ground Property & Equipment	GFEE	10.50
GPEE Depreciation Content	GPDC	4.50[c]
Amortization	ADPE	1.06
General and Administrative	GAE	23.70
	IOC	287.93
Total Operating Cost*: Baseline Assumptions from Table 28	TOC	499.56

[a]Nomenclature in Table 27

[b]Non Additive for DOC

[c]Non Additive for IOC

in the baseline IOC equations. This will be one area deserving considerable further investigation in subsequent study efforts once the definitive specification of the mission/market concept is made. Based on the history of the short haul helicopter operational experience, [Reference 13] it would appear that an IOC to DOC cost ratio in the range of 0.6 to 1 would be more representative of a short haul passenger transportation service. Several alternate cost estimating relationships were investigated for the aircraft landing fees, traffic servicing and promotion and sales cost equations. The results of these various modifications would indicate that the IOC to DOC ratio could be reduced to the area of 0.7 to 1.0.

The purpose of the total operating cost estimate including the indirect cost category was basically for reference purposes. The major area of interest in the operating cost analysis was the direct operating cost and the sensitivity to various assumptions regarding the character and utilization of the Airport Feeder system. Because IOC's would be about the same for any vehicle, it is usually sufficient to compare DOC's when comparatively evaluating vehicle concepts - a fortunate situation because, as just noted, IOC's are not well-defined for new systems and market areas.

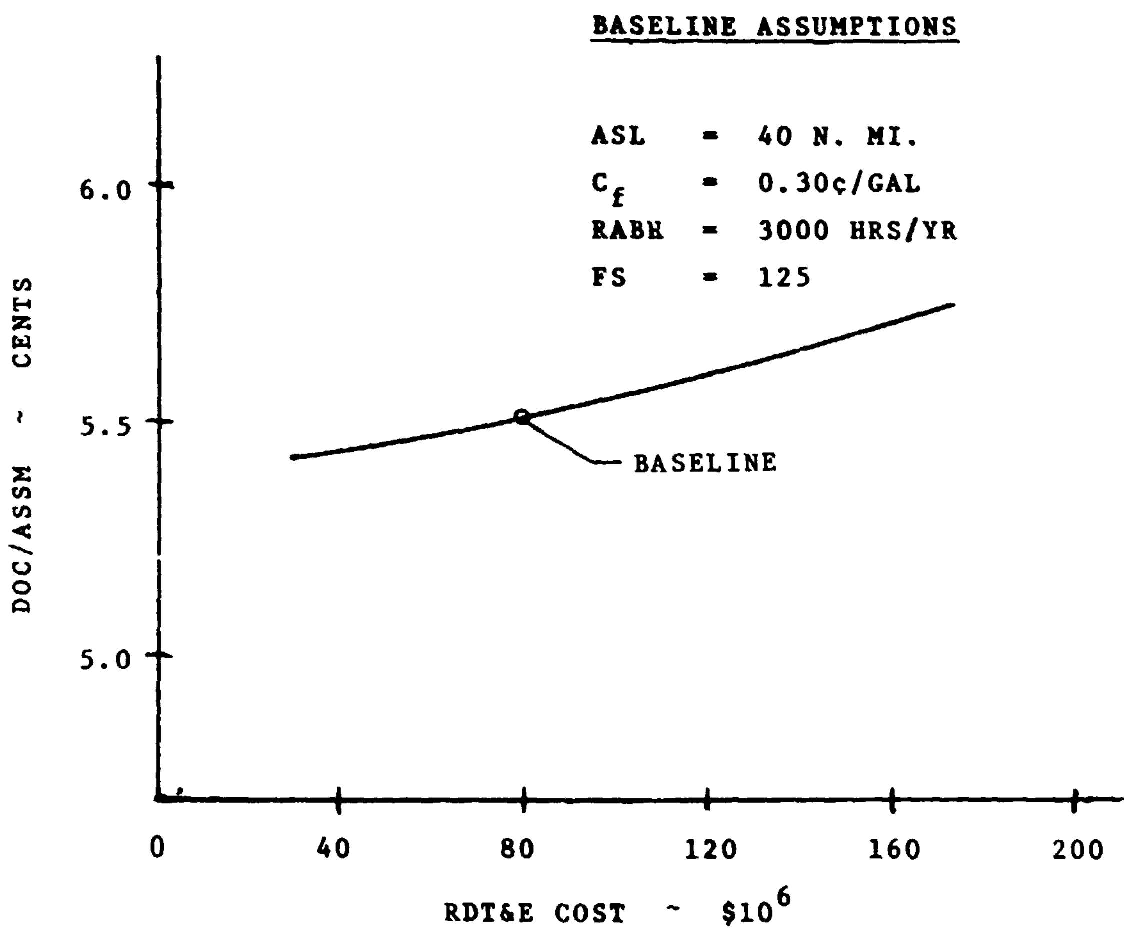
5.4.1 DOC Sensitivity Studies

Table 30 contains a breakdown of the direct operating cost for the baseline Airport Feeder and associated operating assumptions. As shown, the helium replenishment costs are an insignificant element of the total system DOC. Figures 37 through 40 illustrate the sensitivity of DOC to various operational and acquisition cost assumption. Figure 37 shows the DOC sensitivity to RDT&E costs in terms of the direct operating

Table 30 - Baseline DOC/ASSM Cost Breakdown

Item	DOC [Cents/ASSM]	% of DOC
Depreciation	1.37	25
Flight Crew Expense	0.75	13.7
Fuel Oil and Taxes	1.25	22.8
Insurance	0.26	4.7
Maintenance		
Airframe	0.41	8.5
Engine	0.42	7.6
Maintenance Burden	0.95	17.3
Helium Replenishment	0.11	0.3
DOC [Cents/Available Seat Stat Mi] =	5.52 Cents/ASSM	99.9%

NOTE: 1 Statute Mile = 1.609 km



NOTE: 1 n.mi. = 1.853 km, 1 statute mi = 1.609 km

Figure 37. DOC/ASSM Sensitivity to RDT&E Costs

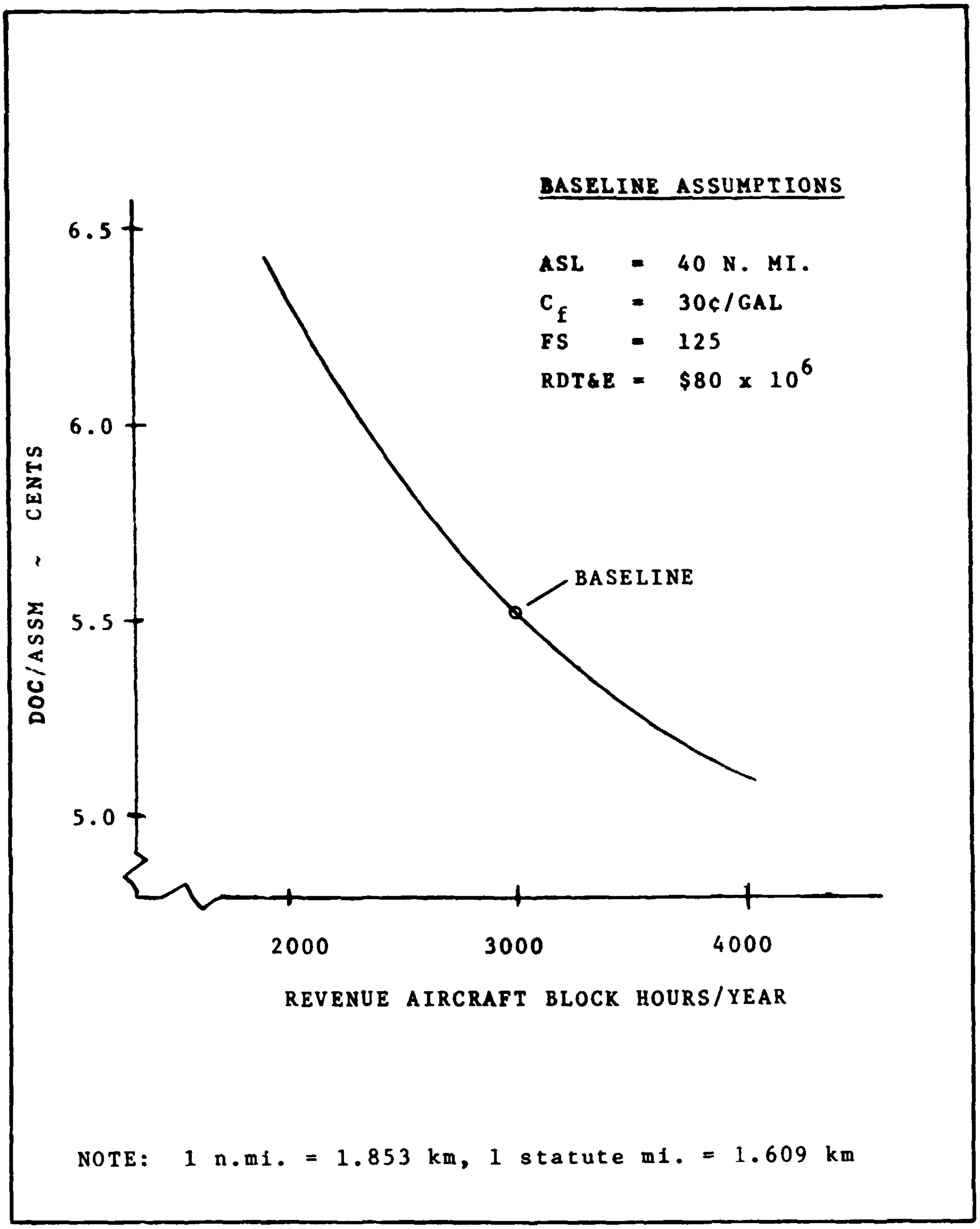


Figure 38. DOC/ASSM Sensitivity to Yearly Utilization

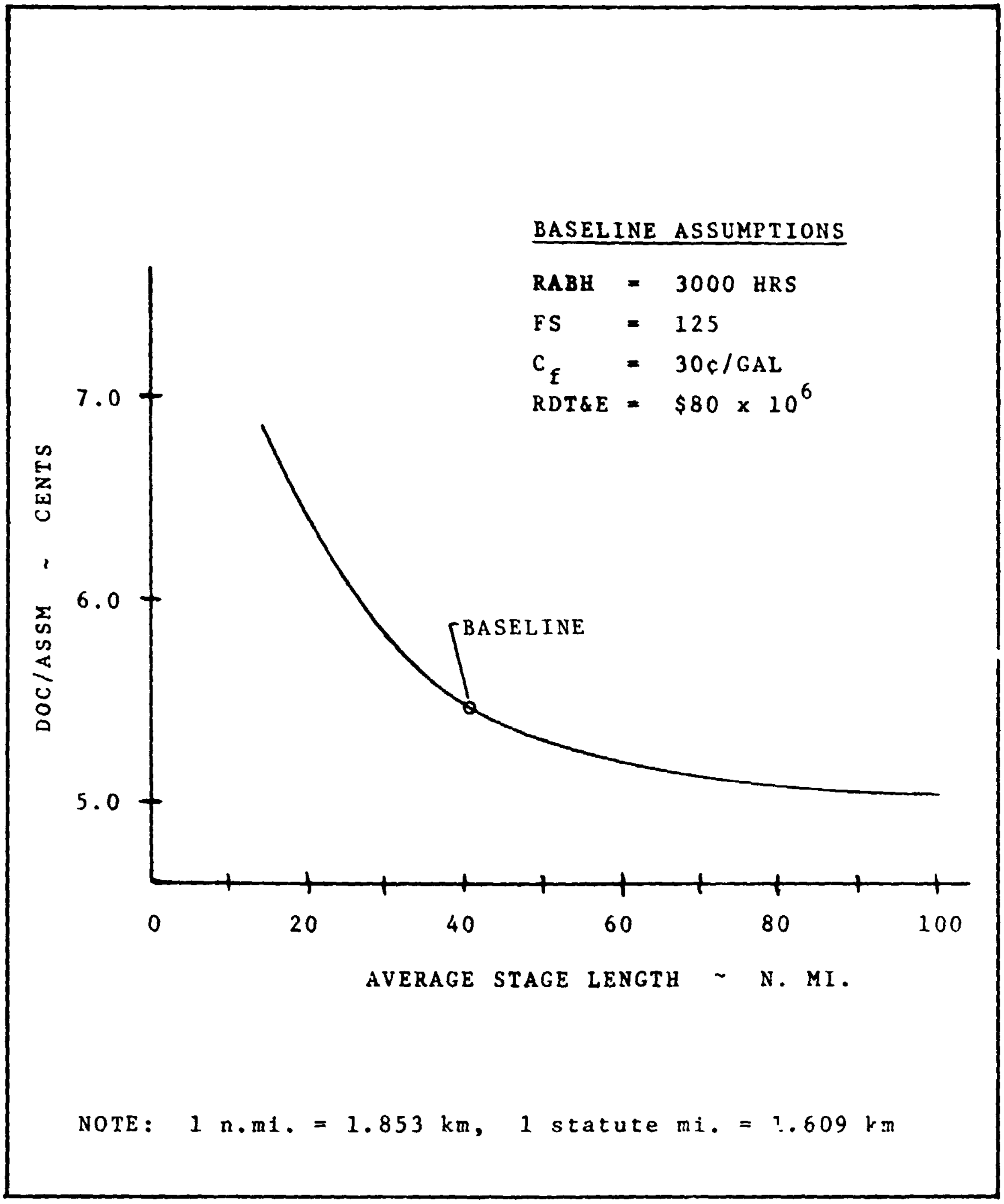


Figure 39. DOC/ASSM Sensitivity to Average Stage Length

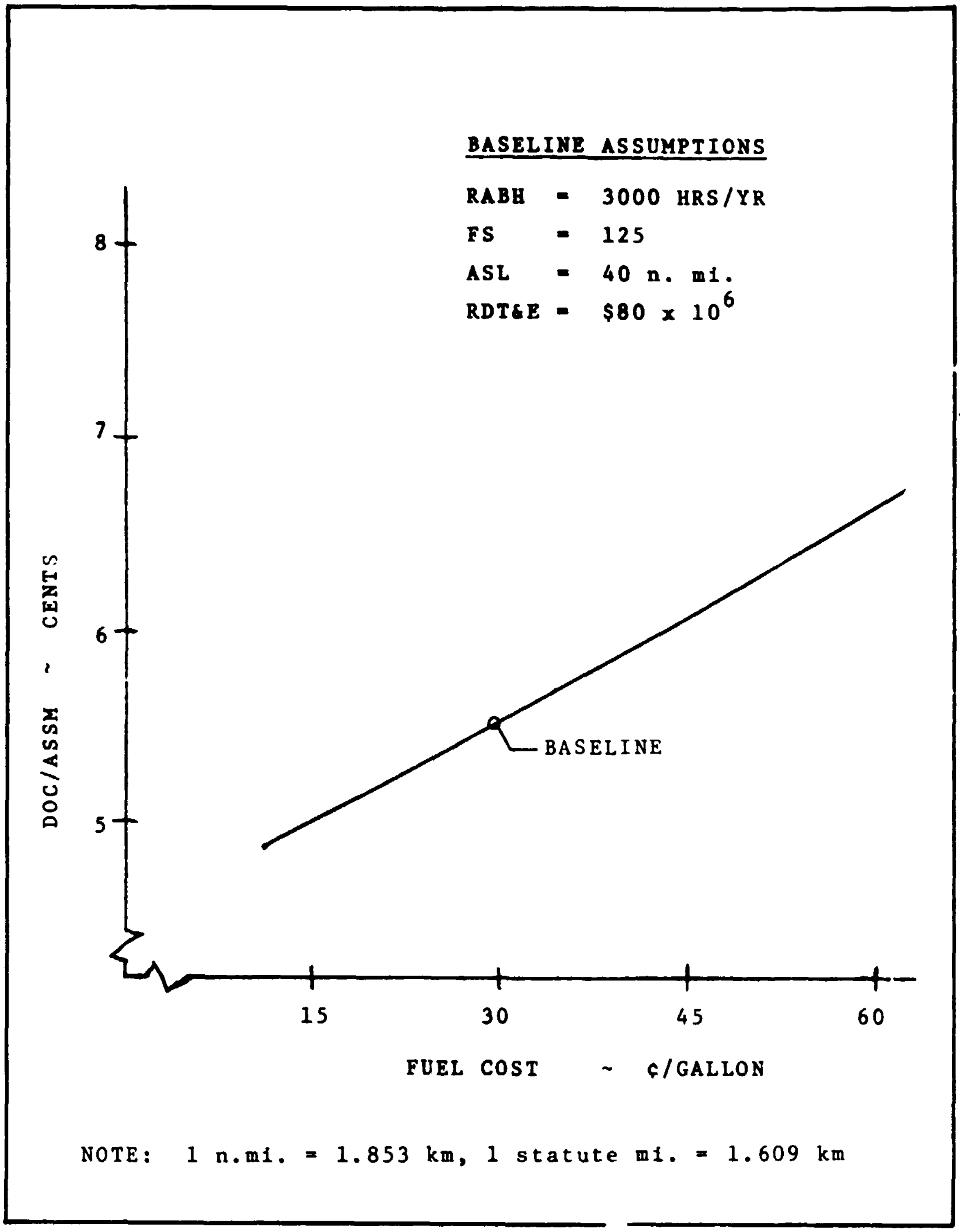


Figure 40. DOC/ASSM Sensitivity to Fuel Cost

cost in cents per available seat statute mile, DOC/ASSM. Figure 38 shows the sensitivity of DOC per available seat statute mile to the revenue aircraft block hours per year over a range of 2000 to 4000 hours of utilization per aircraft per year. Figure 39 shows the sensitivity of DOC to the average stage length over an average stage length of 15 to 100 nautical miles. Finally, Figure 40 shows the sensitivity of DOC to fuel costs. Table 31 summarizes these DOC sensitivity results for comparative purposes. As shown in Table 31 the direct operating costs are in the range of approximately 5 to 7 cents per available seat statute mile over a considerable range of alternate assumptions on the acquisition cost and operational characteristics. The greatest areas of sensitivity are, as would be expected, in the areas of low stage lengths and higher fuel costs. Figure 41 illustrates the DOC sensitivity to load factor in terms of direct operating cost in cents per revenue passenger miles over a load factor range from 1 to 0.4. As indicated in the figure the operational experience of the short haul helicopter operations has been load factors in the range of 0.4 to 0.6 [Reference 13].

For the final baseline configuration and reference set of operating and cost assumptions the DOC per revenue passenger mile is seen to vary between approximately 9 cents per revenue passenger mile at a load factor of 0.6 and approximately 14 cents per revenue passenger mile at a load factor of 0.4. These costs would translate into total operating costs of approximately 18 cents per revenue passenger mile at a load factor of 0.6 or 28 cents per revenue passenger mile at a load factor of 0.4 if the IOC to DOC ratio can be maintained at approximately 1.0. These calculations are based on the baseline assumptions: 74 km (40 n.mi.) average stage length,

Table 31 - Summary of DOC Sensitivity Analysis Results

Parameter	Parameter Values			DOC/ASSM ∿ CENTS/ASSM		
	$-\Delta$	Baseline	$+\Delta$	$-\Delta$	Baseline	$+\Delta$
RDT&E ∿ $\$10^6$	40	80	160	5.45	5.52	5.71
RABH ∿ HRS	2000	3000	4000	6.37	5.52	5.10
ASL ∿ N.MI.	15	40	100	6.80	5.52	5.07
Fuel ∿ ¢/GAL	15	30	60	4.92	5.52	6.62

NOTE: 1 n.mi = 1.853 km

Table 32 - Baseline Configuration Cost Summary

DOC/ASSM ≈ 5 to 7 cents [for various RABH, C_f, ASL, & FS]

If [IOC/DOC] ≈ 1.0

TOC per available seat mile ≈ 13 cents/ASSM @ 40 nautical mi. ASL

TOC per revenue passenger mile:

Load Factor	TOC/RPM [Cents]
0.6	18
0.4	27

Cargo operations should improve passenger economics

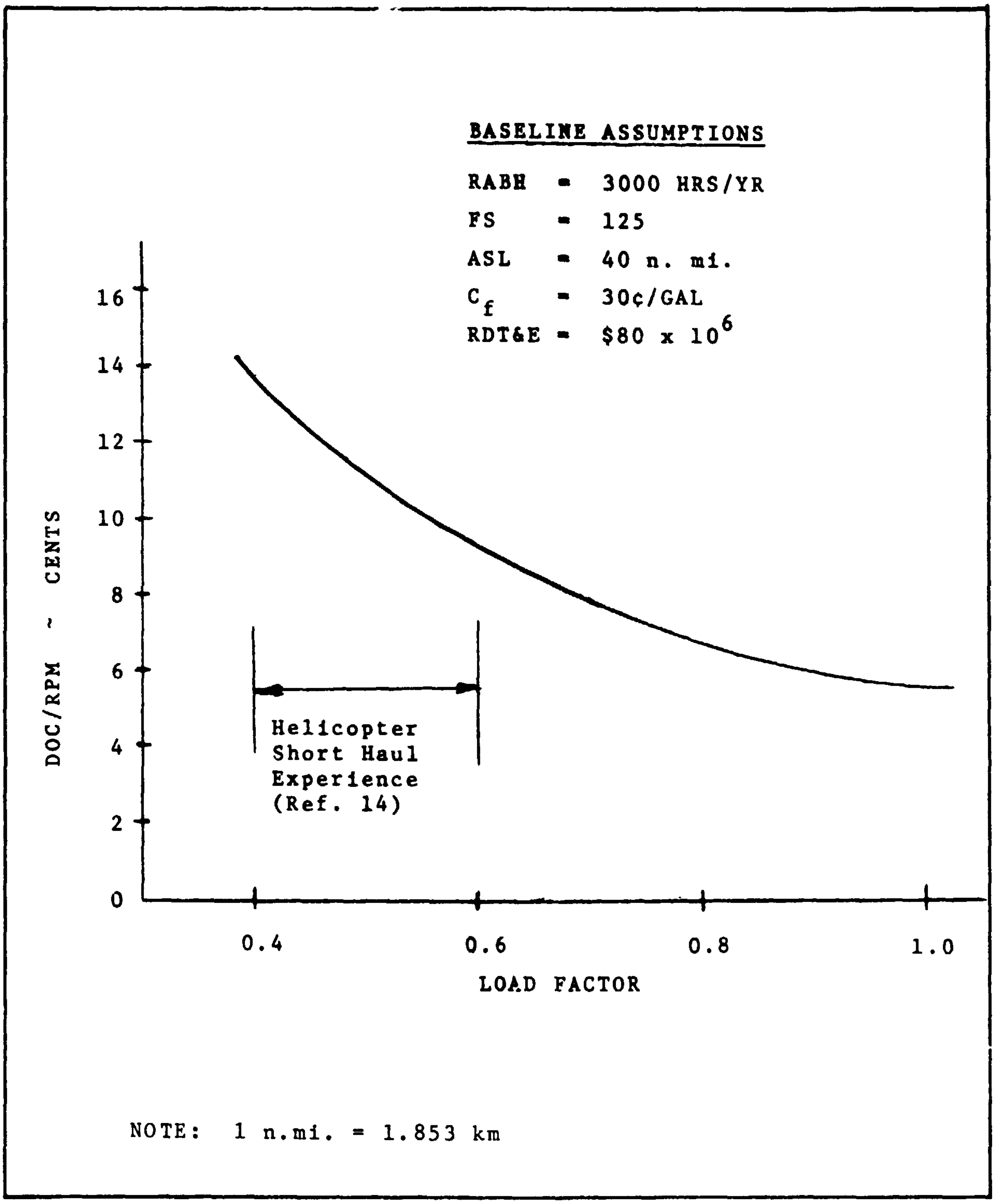


Figure 41. DOC/RPM Sensitivity to Load Factor

3000 hours per year utilization, a fleet size of 125 units and an RDT&E cost of $80,000,000. These results are summarized in Table 32.

It should be recalled that, as stated in the introductory remarks, the cargo operations in the off-peak or off-use hours could significantly improve the passenger economics by amortizing the vehicle acquisition cost over a larger average annual utilization. This area should be more fully explored in subsequent study efforts.

5.5 Task III - Cost Analysis Summary

The IOC cost elements need a more detailed analysis for the specific market and operational concept ultimately defined for the Airport Feeder vehicle. IOC/DOC ratios of 1.0 appear reasonable based on helicopter operations similar to the Airport Feeder Concept of operations. Although considerable uncertainty exists in the RDT&E cost elements, the direct operating cost is rather insensitive to RDT&E for production quantities of 125 units or more. Furthermore, there is considerable reason to expect that the RDT&E costs associated with the Airport Feeder vehicle concept may be substantially lower than those associated with non-buoyant, powered lift VTOL vehicles.

From the analysis of DOC, depreciation represents approximately 25% of the direct operating cost for the baseline operating and cost assumptions. The DOC is very sensitive to fuel costs and would suggest that additional study is warranted of the optimum operating and design characteristics of the Airport Feeder vehicle in terms of direct operating costs.

An additional area of uncertainty in the operating cost CER's is the engine maintenance cost element. The CER of Reference 11 is for a conventional fixed turbo prop propulsion system. The tilt propeller/prop rotor system envisioned for the baseline Airport Feeder may likely require considerably higher maintenance man hours per flight hour. Thus, the engine maintenance cost element and the direct operating cost may be slightly higher than the calculated baseline data.

The DOC per available seat statute mile ranges from ≈ 5¢/ASSM to ≈ 7¢/ASSM over a wide range of average stage lengths, yearly utilization, fleet size and fuel costs. However, load factors will be critical to the economic viability of the Airport Feeder system concept. Based on short haul passenger operations in San Francisco, Chicago, and New York, load factors may be on the order of 0.6 to 0.4. If IOC/DOC ratio is ≈ 1.0, total operating costs per revenue passenger mile will be ≈ 18 cents to 28 cents, respectively, for the baseline economic/operating assumptions.

6.0 TASK IV - ALTERNATE AIR TRANSPORTATION MODE COMPARISON

6.1 General

The primary objective of this task was to make a brief economic comparison of alternate air transportation modes with the baseline Airport Feeder system concept. The first comparison was based on actual operating cost experience of short haul helicopter services operated in the Chicago, Los Angeles, New York and San Francisco areas. In addition, a review and comparative evaluation was made between the projected operating economics of large turbine powered helicopters and the baseline Airport Feeder. In addition to the economic comparisons, a brief comparison of fuel consumption of the Airport Feeder and helicopter systems was made.

6.2 Comparison with Actual Helicopter Operations

A literature survey and review was performed of prior operating experience of helicopter short haul passenger operations. Figure 42 illustrates the economic performance of three Federally subsidized helicopter operators during the period of 1954 through 1970. As shown in the figure, Federal subsidies were removed in 1967. Each of the three operations in the Chicago, Los Angeles, and New York areas all operated at a total operating loss following the cessation of the Federal subsidy. Operations in the Chicago area were terminated in 1970. An additional study performed by the United Research, Inc. [Reference 15] provides an excellent overview of representative helicopter operating cost patterns and selected statistics for the actual operations.

Two passenger service expense parameters characterize the major cost determining attributes of scheduled passenger service: Total Operating Cost, TOC, per available seat mile, and TOC per revenue passenger mile. Early helicopter TOC per available passenger mile and per revenue passenger mile are summarized in Tables 33 and 34, respectively.

The time period, 1957 through 1963 in Tables 33 and 34 is representative of "mature" piston-powered helicopter service operation. Other operating costs for the newer, larger turbine-powered helicopters is presented in the next section. The period 1957 through 1963, was also the time when a relatively constant, maximum level of Federal subsidy was being provided to the three helicopter operators in Chicago, Los Angeles, and New York City, as shown in Figure 42.

It can be seen from Tables 33 and 34 that there was considerable cost variation between piston helicopter operators and a generally steady decline in average operating cost over time. Much of this variation can be explained by the major differences in operating characteristics shown in Table 35. Perhaps most significantly, the average revenue hours per day, per aircraft was only about 2 hours and 30 minutes in 1963.

Larger, turbine-powered helicopters began to be introduced in Los Angles in 1963, and a new all-turbine, nonsubsidized helicopter service [26 passenger aircraft] was introduced in San Francisco in 1968. Operating cost statistics for these two carriers from 1964 to 1970 are shown in Table 36. These data reflect the inherent operating cost economics associated with turbine powered-helicopters as compared to the piston-powered aircraft experience reflected in Table 33.

The data of Table 36 for calendar year 1970 in terms of

TABLE 33. TOTAL OPERATING EXPENSE FOR THE THREE SUBSIDIZED HELICOPTER OPERATORS, 1957 to 1963[a]
(Cents per Available Seat Mile)

Year	Chicago	Los Angeles	New York	Average
1957	55	54	76	63
1958	36	55	72	52
1959	34	51	68	48
1960	31	59	64	44
1961	31	56	74	48
1962	42	33	54	43
1963	52	28	42	31

TABLE 34 TOTAL OPERATING EXPENSE FOR THE THREE SUBSIDIZED HELICOPTER OPERATORS, 1957 to 1963[a]
(Cents per Passenger Mile)

Year	Chicago	Los Angeles	New York	Average
1957	160	105	203	158
1958	98	104	162	122
1959	68	91	140	95
1960	65	106	122	88
1961	77	104	140	102
1962	120	84	121	108
1963	129	50	90	75

Source: Reference 14.

(a) Mostly piston-powered aircraft and some small, turbine-powered aircraft.

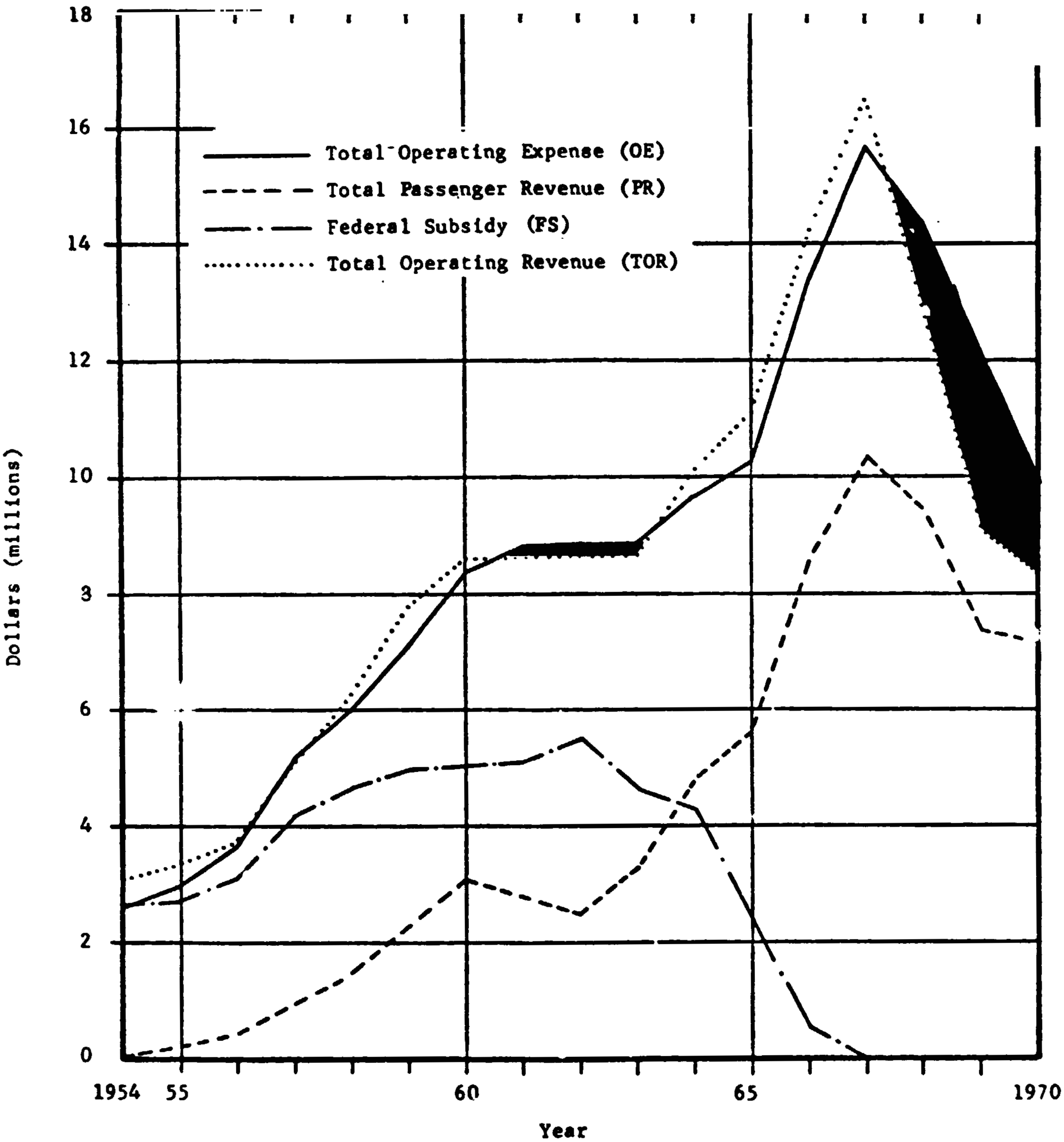


FIGURE 42 ECONOMIC PERFORMANCE OF THREE FEDERALLY-SUBSIDIZED HELICOPTER OPERATORS (CHICAGO, LOS ANGELES, AND NEW YORK)

Source: Reference 14

TABLE 35. COMPARISON OF MAJOR OPERATING CHARACTERISTICS FOR THE THREE SUBSIDIZED HELICOPTER OPERATORS, 1957-1963

Attribute	Chicago	Los Angeles	New York
• Block speed, mph	89	105	107
• Length of hop, miles	15	18	13
• Annual aircraft utilization, block hours - 1963	1,100	1,100	1,100
• Ratio of indirect to direct operating expense	1:1	1:1	1:1
• Passenger load factor, percent			
1959	51	57	49
1960	48	56	53
1961	42	55	54
1962	35	40	45
1963	36	43	43
• Daily aircraft utilization, block hours[a]			
1959	3:27	3:41	3:23
1960	3:22	3:29	4:13
1961	3:29	4:26	4:05
1962	2:38	2:40	3:02
1963	2:30	2:46	2:07

Source: Reference 15.

(a) Average revenue hours of use per day per aircraft.

NOTE: 1 mph = 1.609 km/hr

TABLE 36. TOTAL OPERATING COST FOR TURBINE-POWERED HELICOPTER OPERATORS, 1964-1970 (Cents per Available Seat Mile)

Year	Los Angeles	San Francisco
1964	19	12
1965	17	12
1966	16	11
1967	15	11
1968	18	10
1969	24[a]	12
1970	32[a,b]	13

Source: Reference 14

(a) Pilot strike

(b) Filed for bankruptcy in October, 1970.

TABLE 37. PROJECTED DIRECT OPERATING EXPENSE FOR LARGE TURBINE-POWERED HELICOPTERS[a]

Annual Aircraft Utilization, Hours	Per Hour, Dollars[c]	Per Available Seat Mile, Cents		
		Stage Length, Miles		
		10	15[b]	20
1,100[b]	313	13	12	11
1,600	280	12	10	10
2,000	265	11	10	9
2,400	255	11	10	9

Source: Reference 15.

(a) Does not include indirect operating expense projections.

(b) Approximate industry average for 1963.

(c) 1963 dollars.

1970 dollars comparing the last year of operations 1970 with the conceptual Airport Feeder baseline in 1975 dollars indicates that the Los Angeles operation total operating costs for available seat statute miles would be 44 cents, the San Francisco total operating cost per available seat statute miles would be 18 cents compared with the estimated baseline Airport Feeder system cost on the order of 10 to 14 cents TOC per available seat statute mile. Thus, in comparison with the actual cost experience of 25 to 30 seat turbine powered helicopter operations servicing the short haul, intra city passenger market, the Airport Feeder baseline appears to be reasonably competitive.

6.3 Economic Comparison with Projected Helicopter Operations

In addition to this actual turbine helicopter operating cost experience it is useful to consider a recognized authoritative projection of desirable turbine helicopter cost levels which was made in 1963, about the time more economical sized turbine helicopters were being introduced into service [Reference 15]. For purposes of this projection the following operating assumptions were made:

- Twin-engine turbine helicopter
- Twenty-six passenger seat capacity
- 110 mph average block speed on a 20-mile stage length
- 103 mph average block speed on a 15-mile stage length

Given the preceding assumptions parametric operating expense calculations were made as a function of four major operating expense determinants.

- Annual Aircraft Utilization [Block Hours]
- Average Stage Length [Miles]
- Passenger Load Factor [Percent]
- Indirect to Direct Expense Rate

The results in terms of direct operating expense per available seat mile and total operating expense per passenger mile are shown in Tables 37 and 38.

Comparing the data of Table 37 for an annual aircraft utilization of 3000 hours per year at a stage length of 15 miles for the turbine powered helicopter results in a direct operating cost per available seat statute mile of 17.4 cents [10 cents in 1963 dollars] compared with the Airport Feeder direct operating cost at the same stage length and same annual aircraft utilization of approximately 8 cents direct operating cost per available seat statute mile.

The total operating costs of the projected helicopter operation in terms of the ratio of IOC to DOC are presented in Table 38 for the 15 nautical mile stage length. Comparing the Airport Feeder total operating cost at equivalent load factors, equivalent utilization, and equivalent [assumed] indirect to direct operating cost ratio results in a TOC of 87 cents for the turbine powered helicopter as compared with approximately 40 cents for the Airport Feeder. Thus in comparison with turbine powered helicopter, operating economics, historical and projected, the Airport Feeder baseline concept appears very promising from an economic cost comparison basis. It should be noted, however, that the current helicopter operation are not considered economically viable. Thus, the question of the economic viability of the Airport Feeder system

Table 38. Projected Total Operating Expense for Large Turbine-Powered Helicopters - 15-Mile Stage Length Only (Cents per Passenger Miles)

Indirect to Direct Expense Ratio	Passenger Load Factor, Percent	Annual Aircraft Utilization, Hours			
		1100[a]	1600	2000	2400
1:1[a]	40[a]	59[b]	52	50	48
	50	47	42	40	38
	60	39	35	33	32
0.75:1	40[a]	51	46	43	42
	50	41	37	35	33
	60	34	31	29	28

Source: Reference 15

[a] Approximate industry av·rage for 1963

[b] 1963 Dollars

NOTE: [15 n.mi = 28 km]

concept remains and can only be solved by more extensive market analyses, combined with further design studies of minimum operating cost Airport Feeder system concepts.

6.4 Economic Comparison with Conceptual V/STOL Systems

The final evaluation of the Airport Feeder economics was made in comparison with a variety of V/STOL system concepts investigated by NASA during the recent years. One of the problems which arises in making comparisons of this type results from the significantly different assumptions utilized in the various studies. In many of the early NASA V/STOL studies, significant technological and performance improvements were assumed in the calculations of vehicle performance. Table 39 summarizes a typical list of performance and technological improvements which were assumed for one such study [Reference 16]. Since many of these technology and performance improvement assumptions, considerably improve the operating economics of V/STOL study concepts, it is difficult to make reliable comparisons.

A comparison between the A/F and several advanced V/STOL study concepts is shown in Table 40 [Reference 17]. The comparisons made in this figure are in terms of a simplified economic measure of effectiveness, operating cost per seat mile per hour. As shown, in the table, the A/F operating cost per seat mph ranges from about 35% to 60% lower than the alternate concepts. It should be noted that the VTOL concepts shown in the table were in many cases designed for higher cruise speeds, lower seating capacities, and longer ranges than the baseline Airport Feeder vehicle. Thus, the validity of this comparison is open to question. If one of the concepts of Table 40 were designed/optimized for the same mission/

Table 39. Representative Technology Improvement Assumptions from Prior V/STOL Concept Studies (Ref. 16)

V/STOL Technology Improvement Assumptions (1967-1985)
• Profile drag reduced by 10%
• Drag divergence Mach number increased by 10%
• Allowable placard speed increased by 20% for same comfort level
• Usable lift coefficient for STOL approach increased more than 100%
• Rotor aircraft lift-to-drag ratio increased approximately 100%
• Powerplant weights reduced by 30% to 50%
• Structure weights reduced by 30% to 36%
• Equipment weights reduced by approximately 15% to 30%
• Reduction in level of perceived noise from rotors of 10 PNdB and reduction from lift and cruise engines as much as 15 PNdB.
• Increase in avionic equipment reliability approximately 2000-fold
• Reduction in volume of avionic equipment to approximately 1/100th
• The possibility of substantially reduced air maneuver times occasioned by advanced displays and use of computer techniques in air traffic control procedures
• Increase in reliability, usable life, and time between overhaul of lift system components.

Table 40. Airport Feeder/Advanced VTOL Concept Cost Comparison (Ref. 16)

	LIFT/CRUISE FAN (MCDONNELL)	TILT ROTOR (VERTOL)	COMPOUND HELICOPTER (VERTOL)	ADVANCED HELICOPTER (VERTOL)	AIRPORT FEEDER
GROSS WEIGHT (LB)	34,500	31,789	30,814	29,944	67,500
OPERATING EMPTY WEIGHT	21,156	17,822	16,504	15,042	43,620
MAX FUEL (LB)	7,744	8,367	8,710	9,302	7,400
MAX SEATS	23	23	23	23	80
DESIGN CRUISE SPEED (KT)	490	300	225	180	130
RANGE WITH 23 PASS. (NAUT MI)	700	2,000	-	750	440
ESTIMATED PRICE ($M)	3.67	2.83	2.95	2.51	4.4
OP. COST ($/FT HR)	950	700	715	590	495
OP. COST/SEATS·V_C(¢/SEAT MPH)	8.5	10.1	13.8	14.25	4.5

NOTE: 1 lb = 0.4536 kg, 1 knot = .5148 m/s
1 n.mi = 1.853 km

performance criteria as the Airport Feeder vehicle, the economic comparison might be substantially different than the results of Table 40.

The only conclusion which seems justified regarding the economic comparison of the Airport Feeder with other conceptual V/STOL concepts is that considerable caution must be used in making such comparisons. Depending on the design and performance assumptions employed, the Airport Feeder may appear to be uncompetitive to marginally competitive or very economically competitive. Definitive comparisons should be made in subsequent study efforts wherein all design, performance and economic assumptions are uniformly made between the A/F and other advanced system concepts.

6.5 Other System Comparisons

An additional area of interest in the comparative assessment of the A/F and other VTOL systems is fuel efficiency. When comparing fuel consumption per available seat statute mile, many of the same problems discussed in the previous section arise due to assumptions related to propulsion system efficiency, SFC, lift to drag ratio improvements, etc. [see Table 39].

One previous NASA study contained performance results for a 98 passenger, 1975 technology tandem rotor helicopter [Reference 18]. This study indicated a fuel consumption of approximately 0.085 kg/A.S. km [0.3 pounds/ASSM] at a 74 km [40 n.mi.] stage length. This is approximately the same value estimated for the 44 passenger S-65 helicopter [Reference 19]. The baseline Airport Feeder fuel consumption is estimated to be approximately 0.06 kg/A.S. km [0.21 lb/ASSM] or approximately 30% better than helicopter systems.

A final factor in the comparative evaluation of the baseline Airport Feeder system was the noise level in the terminal operations area and in cruise flight. Helicopter noise is a generally recognized undesirable characteristic associated with rotor lift devices. However, no definitive calculations were available for comparison with the Airport Feeder vehicle. Summarizing again the results reported under Task I, the Airport Feeder vehicle take-off noise level was well below the NASA objective. The noise level at 500-foot sideline distance was 86.2 perceived noise decibels at take-off. Noise reductions to as low as 72 perceived decibels may be achievable by utilizing lower tip speeds with some sacrifice in cruise and VTOL performance.

In the overflight condition, the noise level will also be very important since the Airport Feeder will be operating in many cases in highly populated regions. The noise level on the ground for the Airport Feeder at 2000 foot altitude cruise flight conditions is estimated to be 54 perceived decibels.

6.6 Task IV Summary

Comparisons with conceptual V/STOL systems are very difficult to interpret due to the significantly different design, performance and economic assumptions employed in other studies. In comparison with some conceptual study results, the A/F appears economically superior while for others it is marginal to non-competitive.

The most valid comparison would seem to be with actual helicopter experience. In this comparison, the Airport

Feeder is superior by a factor of two based on direct operating cost per available seat statute mile.

Fuel consumption per available seat statute mile is estimated to be approximately 30% better than current technology helicopters. Further design optimization efforts could result in even further improvements in fuel efficiency.

In the important area of noise levels associated with the Airport Feeder concept, the take-off noise level was below the NASA study objective by 8.8 pNdB. Additional noise reductions may also be possible by further design optimizations.

7.0 TASK V - MISSION/VEHICLE FEASIBILITY ASSESSMENT

7.1 General

One of the more important tasks of the Phase II Study was to provide an overall assessment of the feasibility of the semi-buoyant modern airship operating in the short haul passenger transportation market. The feasibility assessment results are discussed in two major categories: Mission/Market Feasibility and Vehicle Feasibility.

7.1.1 Mission/Market Feasibility

Perhaps the greatest single area of uncertainty associated with the Airport Feeder concept is the market for the service provided. Several key questions have been identified which should be investigated in more detail. These include market size, vehicle performance/design requirements for maximum economic viability, user acceptance, nonuser reaction, and a more detailed investigation of cargo operations.

Detailed market studies need to be performed to further define the demand and potential utilization for the Airport Feeder system concept. The preliminary results of Task II indicate that perhaps only the 7 to 10 largest metropolitan regions may provide sufficient passenger demand for an economically viable Airport Feeder system. This may be insufficient to justify production quantities required for economical introduction of the new vehicle concept.

The market analysis effort should be integrated with further vehicle design, performance and operational trade studies in order to further determine the economic viability of the vehicle concept. Promising study areas would include further vehicle optimization in terms of direct operating cost as a function of design passenger capacity, fuel costs, and buoyancy ratio. Smaller size vehicles [perhaps 40, 50 or 60 passenger capacity] may provide a larger market application and be more compatible with high frequency operations.

User acceptance of the semi-buoyant Airport Feeder service may depend on several factors: ticket price, ride quality, perceived convenience of the service offered, safety, etc. The ride quality at the low altitude cruise is one area for further technology related investigations. The internal noise environment may also affect user acceptance and must be fully analyzed.

The entire area of user acceptance and nonuser rejection has been one of the critical areas of uncertainty in many of the short haul V/STOL systems studied during the last decade. In this respect, the novelty of the Airport Feeder vehicle may enhance both user and nonuser acceptance. The quiet operational characteristic both in the terminal areas and during cruise may be one of the most attractive characteristics of the entire concept.

Application of the vehicle in a cargo operations mode may substantially improve the economic performance and viability of the entire system concept. Several cargo operational approaches may be feasible. The first would utilize the modular characteristics of the vehicle to operate in a combined 40 passenger/9000 pound cargo mode of service. The second mode of operation would be to utilize the vehicle in the off peak or night time hours in a dedicated cargo mode and during the daytime peak passenger demand hours in an all passenger role. The third potential mode of cargo operations would be to have two basically dedicated vehicle concepts, one which would be totally designed or configured for a cargo mode of operations and one for all passenger operations. The low beta ratio of the optimized vehicle will allow for considerably improved cargo/payload transfer operations when on the ground without the necessity for ballast transfer.

7.1.2 Vehicle Feasibility Assessment

The Airport Feeder vehicle concept appears to be technically feasible. No technical unknowns have been discovered which present technological barriers to the successful development of the vehicle concept. However, many areas have been identified which require additional research and development; primary among these are hover performance/stability and control, aerodynamics, and vehicle response to turbulence associated with CTOL airport and surburban/downtown operations, flying/ride qualities, and development and integration of cyclic propellor/prop-rotor technology low hover control. Overall, the specified design and performance requirements appear to be achievable based on the results to date.

In summary, the results indicate that in terms of operating economics, fuel consumption, and noise performance, the Airport Feeder vehicle concept is promising. The operating cost characteristics are significantly improved over existing and proposed helicopter or rotary VTOL systems. This can be largely traced to the utilization of buoyant lift to offset the power requirement for a VTOL capable vehicle. In terms of fuel consumption per available seat statute mile, the Airport Feeder potentially offers about a 30% improvement compared with similar generation helicopter systems. Finally in terms of the noise characteristics, the Airport Feeder concept has the potential of being a very good neighbor to both user and nonusers in terminal operations area and during cruise flight.

8.0 TASK VI - TECHNOLOGY ASSESSMENT

8.1 General

One of the specific tasks identified in the NASA Statement of Work was the Technology Assessment Task. The objectives of this task were threefold: 1) Identify any critical technology areas or areas of uncertainty, 2) Identify important technology areas where research and development can substantially improve the performance, economics, and safety of modern airships, and 3) Identify the need for a serial development program and/or flight research vehicles.

The results of this task include the identification of several technology items/areas which are judged to be critical to the successful development of the Airport Feeder vehicle concept. These items should be addressed in detail in subsequent design/study phases or pursued as separate technology development programs.

In addition to these "critical" problem areas, several areas have been defined where substantial improvements to the performance, economics, and general technology base supporting modern airship developments can be achieved by successful technology development programs. These "Research and Technology Base" programs constitute a portion of the first stages of a serial development program which could lead to a "proof of concept" flight research vehicle. A preliminary schedule for such a program is given.

8.2 Summary of Critical Problem Areas

Problem areas judged to be critical to the successful development and introduction of the Airport Feeder vehicle/

system concept fall in four general categories: (1) mission/market definition, (2) stability, control and hover performance, (3) operational concept development, and (4) manufacturing.

8.2.1 Mission/Market Definition

The market potential for the Airport Feeder service is the most critical area of uncertainty for the Airport Feeder system concept. Market size will dictate vehicle production quantities and thus have a substantial influence on the economic viability of the concept. Although the results of the current study indicate the Airport Feeder may be economically superior to existing short haul helicopter operations, these operations are not currently economically successful.

Detailed Mission/Market Analyses are required to further define the potential market size for the concept as well as provide further refinements of design and performance requirements [e.g., passenger capacity, average stage length, and user acceptance criteria] for the vehicle/system concept. Factors to be considered from the user acceptance viewpoint should include ride quality, internal noise levels, frequency of operations, and fare structure.

The Mission/Market Analysis should include a thorough investigation of the cargo application of the Airport Feeder Vehicle. The Phase I study results [Reference 1] indicated a significant potential for a VTOL air transportation system with performance characteristics similar to the Airport Feeder. Briefly, these missions were envisioned as cargo operations between City Centers and between shipper and customer.

Between City Centers. This mission consists of regularly scheduled service between city centers 32.18 to 80.45 km [20 to 50 mi] apart. A VTOL capability, with moderate flight speeds are required with cargo payloads of 4536 to 9072 kg [5 to 10 tons] [Reference 1].

Between Shipper/Customer. This mission consists of transporting cargo from collection points near major shippers to collection points near or directly to their destination at ranges from 80.45 to 644 km [50 to 400 n.mi.]. The cargo is primarily high-value, break-bulk [manufactured products]. A VTOL capability and CTOL competitive door-to-door times with a payload capacity of 9072 to 13,608 kg [10 to 15 tons] is required.

Another application of the A/F cargo vehicle would be as the short haul element of a dedicated All Cargo air transportation system. These future systems would probably use air terminals far removed from city center regions. The VTOL capability, range and payload of the A/F may be ideal for the terminal to city center phase of this type of system.

8.2.2 Stability, Control and Hover Performance

The second problem area is the hover performance, stability, and control of the Airport Feeder vehicle during hover, transition, and cruise flight. This problem area encompasses a variety of interrelated problems including hull/rotor interference phenomena, stability and control during hover and transition, aerodynamics and flight dynamics at large angles of [combined] attack and sideslip prop wash interference, and the gust environment and vehicle response in the proposed areas of operations.

In the Goodyear sponsored wind tunnel tests of the heavy lift airship configuration, significant interference effects between the rotor and the airship hull were measured.

The Airport Feeder configuration is similar in many respects to the heavy lift vehicle; particularly during hover. These interference phenomena [HULL-ROTOR and ROTOR-ROTOR] must be quantified in order to define the propulsion and the stability and control system requirements in all flight regimes: hover, transition, and cruise. Prop wash interference limits need further definition both for transition and normal cruise flight. Applications of the tilt rotor technology developments should be explored.

The results of the hull-rotor interference investigations, large angle aerodynamic characteristics investigations, and the propulsion system analysis can be combined into a flight dynamics simulation model to fully investigate the flying qualities, stability and control characteristics, and control system requirements. The stability and control/flight dynamics simulation must also address the gust/turbulence environment in CTOL airport operations areas as well as in city centers and suburban operating areas.

8.2.3 Operational Concept Development

The operational concept proposed for the landing and ground handling operations of the Airport Feeder vehicle offers significant potential for improvement over previous fully buoyant airship operations. However, a more detailed design and analysis is required to develop and verify the operational feasibility of the concept. This effort should be included in the flight dynamics/control system simulation analysis, and may ultimately require a flight research vehicle verification [possibly subscale].

8.2.4 Structures, Materials, and Manufacturing Methods

The selection of the pressure stabilized metalclad construction concept was based on maximum specific productivity, payload velocity/empty weight, PV/E. The pressurized metalclad approach offers a slight improvement in empty weight over the nonrigid construction at the gross weight, heaviness and flight speed of the Airport Feeder Baseline Vehicle. However, successful development and operation of a metalclad Airport Feeder may introduce many unique manufacturing and operational problems.

In the manufacturing area, specialized equipment, manufacturing techniques and materials handling procedures must be developed to fabricate the large, minimum gage hull structure economically. Specialized erection techniques must also be developed which of necessity will be considerably different than those employed for either rigid or nonrigid vehicles. Detailed design efforts must also include the integration/interface of the hull and the car structures, seam design, gas retention, ground impact loads, and fatigue effects resulting from the high ground-air-ground cycles characteristic of an Airport Feeder system.

Operational aspects of the metalclad vehicle operating in the short haul cargo/passenger application also need in depth examination. Factors of concern include natural phenomena [hail damage, lightning strikes, and superheat effects] as well as man made phenomena [bullet damage, accidental operational abuse during ground operations, maintenance and repair]. Airworthiness, crash safety and commercial certification requirements must also be defined.

In summary, more detailed investigations are needed to make the final choice of hull material and construction approach. Investigations should continue into the development and application of advanced aramid fibers such as Dupont's Kevlar 49. As discussed in Reference 23, this new polymeric fiber appears to be ideal for airship applications. In addition to its high tensile strength, it has a tensile modulus of about double that of aluminum, and a linear stress-strain curve. As a textile replacement for present airship fabrics it appears to be a promising candidate. Much research and development work must be performed to realize the full potential of Kevlar and other advanced technology fabrics. These areas are briefly discussed in Appendix A.

8.3 General Technology Development Programs

The technology assessment task results also identified several areas where technology development programs could make substantial improvements to the performance and/or economics of modern airships and improve the overall technology base, not only for the Airport Feeder concept but also for modern airship programs in general. Program areas include:

1) Aerodynamics and Flight Dynamics
2) System Level Technology Programs
3) Avionics and Controls Systems
4) Propulsion
5) Human Factors Analysis
6) Operational Procedures
7) Computer Aided Design
8) Structures and Materials

A brief discussion of these technology development programs are included in Appendix A.

8.4 Serial Development Program Requirements

A serial development program appears to be a reasonable approach to development and implementation of the Airport Feeder system concept. A preliminary development program has been defined which consists of the following major elements:

1) Mission/Market Analysis
2) Technology Base Development Programs
3) Hover Performance Analysis
4) Vehicle Preliminary Design
5) Flight Research Vehicle Programs

Figures 43 illustrates the interactions of the serial development program elements in a general fashion.

8.4.1 Priorities, Funding and Schedule

Insufficient information exists at this point in the Airport Feeder concept development program to project the entire funding and schedule requirements associated with intorudction of the short haul air transport service.

Priorities, schedules and funding estimates for the initial portion of the serial development program are shown in Table 41. Brief descriptions of the initial program elements follow.

8.4.2 Mission/Market Analysis

A detailed mission/market analysis effort is the

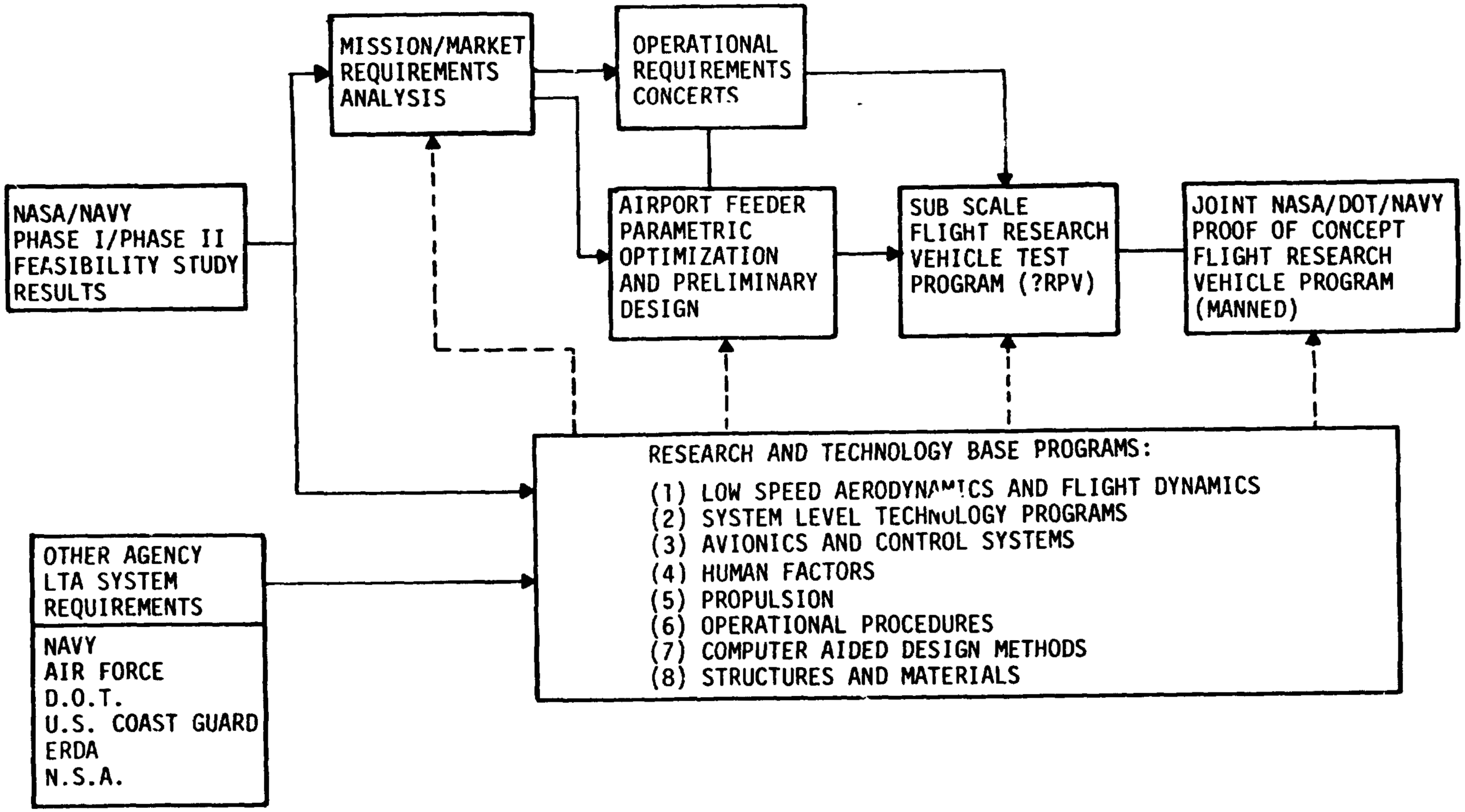


Figure 43 Preliminary Serial Development Program Supporting Airport Feeder and Other Modern Airship Technology Development.

Table 41 - Priority, Schedule and Funding for Initial Elements of Airport Feeder Serial Development Program

ITEM	PRIORITY	START DATE	DURATION	ESTIMATED FUNDING
Market Analysis	1	FY 77	1 Year	$100,000
Technology Base Programs Low Speed/Hover Analysis	1	FY 78	Continuing	Absorb into existing NASA R&T Programs
Preliminary Design Development	2	FY 78	1 Year	$100,000
Wind Tunnel Testing	2	FY 78	1 Year	$100,000
Final Design Definition	3	FY 79	?	?
Wind Tunnel Testing				
Flight Research Programs Sub Scale Full Scale	4	?	?	?

logical first step in the serial development of the Airport Feeder system concept. This effort should explore the market potential of an Airport Feeder type of service and define the most economically promising design and operational requirements for the vehicle/system concept. Alternate concepts of operations should be defined including analysis of high value break bulk cargo operations.

8.4.3 Technology Base Development Programs

As shown in Figure 43, the supporting technology base programs provide a continuous input to the Airport Feeder development program. These programs will provide the fundamental data base of technology which will be required to support the development of a technically and economically viable modern semi-buoyant airship which can satisfy the short haul air transportation needs of the future in an environmentally acceptable energy efficient manner.

One of the high priority elements of the Airport Feeder development plan is a detailed analysis of the stability and control characteristics during the low speed, hover, and transition phases of the flight profile. Both fundamental and applied research programs [analytical and experimental] are required to develop a more complete understanding of potential aerodynamic and flight dynamics problems. Key elements of this technology area include the following:

1) Aerodynamic - Propulsion Interface phenomena [Hull-Rotor and Rotor-Rotor]

2) Aerodynamics at large [combined] angles of attack and sideslip

3) Gust Environment and vehicle response

A second important technology base area is structures and materials technology. In particular, the development/adaptation of recent fiber and fabrics technology to modern LTA transporters offers considerable potential.

Additional discussion of the recommended Technology Base programs is contained in the Appendix.

8.4.4 Preliminary Design Development

The second phase of the program should include design "optimization" in terms of direct operating cost and/or return on investment for the mission/market/operational concept defined in the preceding phase. This effort would be very similar to the design study of the heavy lift airship conducted during the NASA Phase II Study. Key program elements would include wind tunnel testing of alternate configurations based on the results of the Aerodynamics and Flight Dynamics Technology Base Program results. Detailed stability and control system analyses, supported by a hover/flight dynamics simulation would also be performed during this program.

Key areas requiring larger scale/flight testing would be identified in order to assess the viability of a subscale flight research vehicle. This vehicle could conceivably utilize recent developments in RPV test technology. Subscale flight research vehicle flight testing could be conducted simultaneously with the final Airport Feeder design definition phase. The subscale flight research vehicle could be utilized to develop the tether/winch ground handling system and to define operational procedures for the Airport Feeder system.

8.4.5 Full Scale Flight Research Vehicle

The results of both the Final Design Development and the subscale flight research vehicle testing would provide the data required for the first full scale, manned prototype flight research vehicle. This vehicle could constitute a "proof of concept" demonstrator similar to the XV-15 Tilt Rotor Research Aircraft Program which could provide full scale data on the handling and flying qualities of the Airport Feeder vehicle concept, was well as all aspects of the operational system.

9.0 CONCLUSIONS AND RECOMMENDATIONS

The Airport Feeder system concept is a promising candidate for the short haul air transportation requirements of the future. Significant results of the Phase II Study can be summarized in three areas:

1) Vehicle Related
2) Operations Related
3) Market Related

9.1 Vehicle Related Conclusions

Results of the Phase II Study indicate a pressure stabilized metalclad airship concept to be the preferred concept due to the desired combination of cruise speed and heaviness. A vehicle gross weight of 67,500 pounds and a beta [buoyant lift to gross lift ratio] of 0.35 resulted in the maximum specific productivity and also satisfied the design and performance requirements defined by NASA for the short haul passenger feeder line concept of operations. Noise levels at takeoff were substantially below the NASA specified limit. Additional investigations are required of cabin noise levels and potential noise shielding requirements.

For the specified operating conditions, fuel consumption is estimated to be about 30% lower than helicopter systems. Direct operating costs are estimated to be approximately 50% lower than the current technology rotorcraft and probably competitive with other advanced V/STOL systems.

Major problem areas requiring further effort include hover, stability and control performance and the development of low cost manufacturing methods and processes for the ultra-light-weight, minimum gauge hull structure.

9.2 Operational Related Conclusions

An innovative tether/winch landing system was conceived which in combination with the low beta, vectored thrust baseline vehicle concept, offers substantial improvements in VTOL and ground handling operations as compared with past airships. The concept of operations for the Airport Feeder would employ parking garage type facilities in suburban and city center regions at ranges from 27.8 to 278 km [15 to 150 nautical miles] from major hub airports. Further analysis is required of the turbulence environment, particularly in downtown regions, and the resulting airport feeder ride quality characteristics.

9.3 Market Related Conclusions

Substantial additional mission/market analysis is required to substantiate the passenger demand and market size for an airport feeder type of service. Preliminary results indicate user acceptance may require high frequency operations, integrated with CTOL operations at major hub airports. Perhaps only the largest 7 to 10 metropolitan regions may be able to support an Airport Feeder type system. Exceptions might arise from unique situations such as the offshore airport currently in the planning stages in the Cleveland, Ohio area.

Cargo operations in off-peak and night time hours may significantly improve the overall Airport Feeder economic viability.

9 4 Recommendations

A preliminary serial development program is defined which will support the development and implementation of an economically viable Airport Feeder system. The Airport Feeder system/operational concept is sufficiently promising to justify continued NASA support. The combination of buoyant lift with both propulsive and aerodynamic life results in a vehicle with VTOL capability, which can satisfy stringent noise constraints in an environmentally acceptable energy efficient, economically competitive manner with no major operational limitations.

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APPENDIX A

RESEARCH AND TECHNOLOGY BASE

PROGRAM REQUIREMENTS

A-1 INTRODUCTION

A serial development program appears to be a promising approach to development and implementation of the Airport Feeder system concept. A preliminary development program has been defined which consists of the following major elements:

1) Mission/Market Analysis
2) Technology Base Development Programs
3) Hover Performance Analysis
4) Vehicle Preliminary Design
5) Flight Research Vehicle Programs

Figure A-1 illustrates the interactions of these major program elements discussed in Section 8.4 of the main report.

A-2 TECHNOLOGY BASE PROGRAMS

The technology assessment task identified several areas where successful technology development program could make substantial improvements to the performance and/or economics of modern airships and improve the overall technology base, not only for the Airport Feeder concept but also for modern airship programs in general. Several of the more promising technology development program areas are similar to on-going NASA research and development programs. Program areas include:

1) Aerodynamics and Flight Dynamics
2) System Level Technology Programs
3) Avionics and Controls Systems
4) Propulsion
5) Human Factors Analysis
6) Operational Procedures

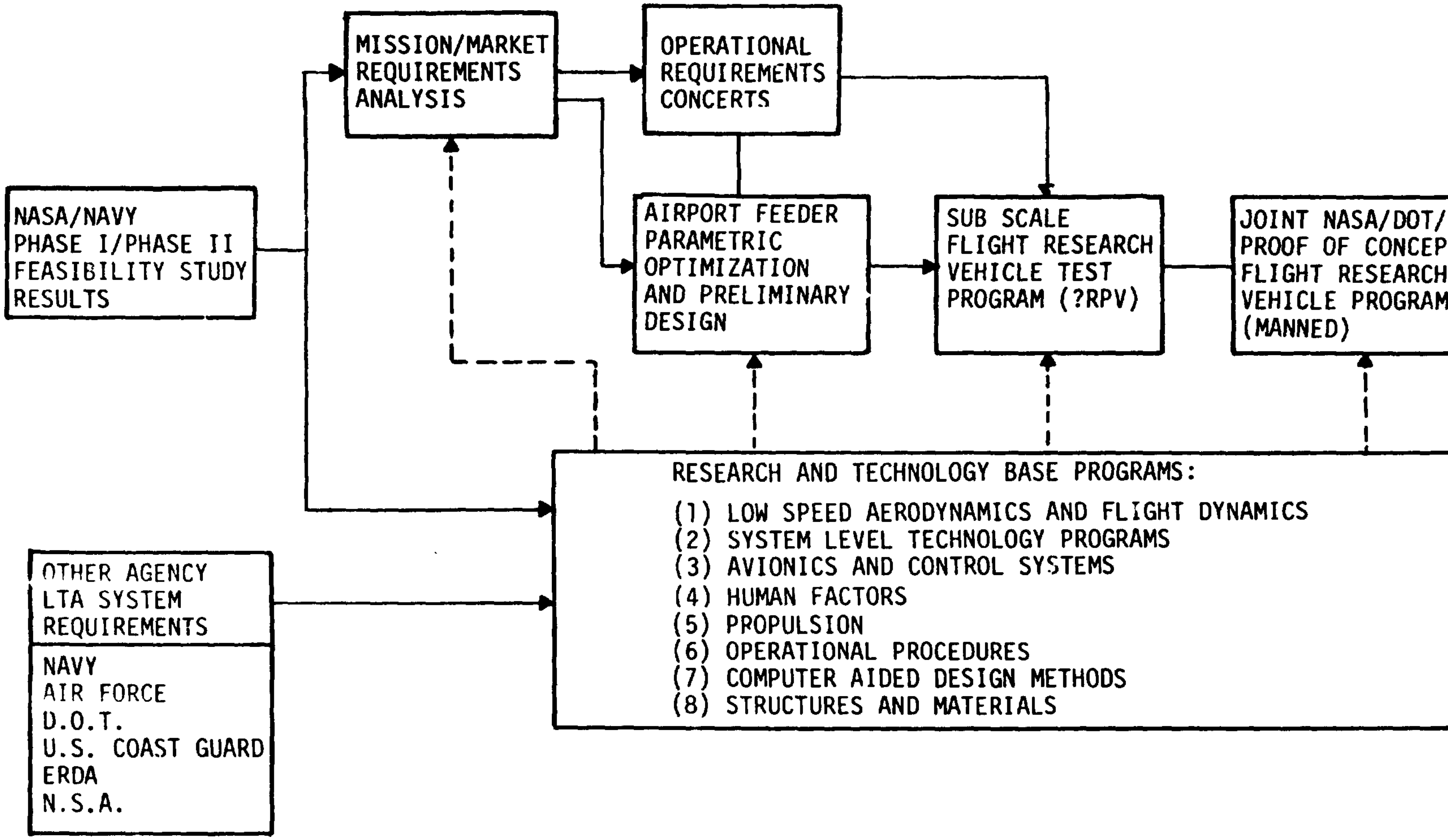

Figure A-1 Preliminary Serial Development Program Supporting Airport Feeder and Other Modern Airship Technology Development.

7) Computer Aided Design
8) Structures and Materials

As shown in Figure A-1, the supporting technology base programs discussed in this Appendix provide a continuous input to the Airport Feeder development program. These programs will provide the fundamental data base of technology which will be required to support the development of a technically and economically viable modern semi-buoyant airship which can satisfy the short haul air transportation needs of the future in an environmentally acceptable, energy efficient manner.

Some of the more promising Research and Technology Base Program Areas are briefly discussed. The suggested programs are not intended to be all inclusive of all technology program requirements but merely to provide a repliminary description of representative programs.

A-3 LOW SPEED AERODYNAMICS AND FLIGHT DYNAMICS

A-3.1 Airship Handling Qualities - Turbulence/Flexibility

Aircraft and pilot responses during atmospheric turbulence encounters are prime factors in the design and operation of all airships. To develop the basis for improved methods for specifying acceptable behavior under these circumstances work is needed to (1) refine ride qualities criteria for application to future large military or civil airships, and (2) develop improved displays, autopilot modes and pilot procedures for severe turbulence encounters with advanced airships. This work should include analytical and piloted simulator studies.

A-3.2 LTA V/STOL Flight Dynamics

Generalized analytical studies, ground based simulations and flight research are required to provide data for establishment, revision and extension of existing handling qualities and certifications criteria for V/STOL LTA aircraft.

The data will apply to the following critical areas: flight path, airspeed, and attitude control, ground effect roll and yaw control for cross wind hover/landing, and the control of a powered lift V/STOL following loss of an engine. Tentative airworthiness criteria based on studies of representative powered lift airship concepts, together with techniques for determining compliance should be developed in cooperative FAA/NASA piloted simulation studies. These results will contribute to generalized criteria for all concepts. Flight research in both handling qualities and certification areas will ultimately be required.

A-3.3 Three Dimensional Airship Computation Aerodynamics

The objective is to develop the capability to analytically predict complete aerodynamic characteristics of complex three dimensional airship configurations, now obtainable only by extensive wind tunnel tests, to a degree that preliminary airship design concepts can be evaluated and screened with reduced wind tunnel test time and cost. Analytical and numerical procedures are required for the prediction of pressure distributions, aerodynamic characteristics, flow fields, and skin friction for viscous flows with attached and separated boundary layers, detached lee side flows with vortex formation and other interactions. Both linear and nonlinear, exact and approximately flow equations should be developed.

This activity must address the flight regimes of interest to the hover capable VTOL semi-buoyant Airport Feeder; high angles of attack, sideslip and combined angles. The analytical modeling effort should also include aero/propulsive interference analysis supported by wind tunnel correlation experiments.

A-4 SYSTEMS TECHNOLOGY PROGRAMS

A-4.1 Technology Studies of LTA Systems

The objectives of this program area are to help develop a sound technological base for future decisions relating to the design, development, and operation of commercial transportation systems utilizing LTA concepts. This objective will be achieved through studies that examine the relationships between LTA technology, airline economics and markets, and environmental constraints. These studies will be done in sufficient detail to provide a realistic assessment of technical problems regarding LTA Transporter design, development and operations and their development and operational costs. Study results will be used to help define the future direction of productive technical [and system related] activity for air transportation systems based on LTA concepts.

A-4.2 Traveler Acceptance Low Density Short-Haul Systems

The objective of this project is to identify, study in detail, and model those factors influencing acceptance and use of LTA Transporters as the preferred mode of travel by the public in the low- to medium-density short-haul market. Appropriate information should be compiled through literature search, traveler questionnaires, and measurements aboard low- to medium-density, short-haul airline systems. Information should also be obtained concerning competing modes of transportation which could influence choice of travel mode. The data should be analyzed, mathematically modeled, and existing types of aircraft used in low-density, short-haul service evaluated with the mode.

A-5 AVIONICS AND CONTROLS

A-5.1 Advanced LTA Transporter Avionics System

The overall objective of this program is to provide the critical information required for the design of a reliable state-of-the-art avionics system applicable to LTA Transporter systems which would enhance their safety and utility. The technology will include the total avionics functional capability - navigation, guidance, control, power-plant management, displays, Digital Fly-By-Wire [DFBW], etc. The program will include analysis, system concept studies, piloted simulations, and component R&D.

A-5.2 Active Control Technology Applications

The objective of this program is to apply Active Control Technology [ACT] to the semi-buoyant Airport Feeder Vehicle concept. This program should include development of a data base which will allow assessments to be made of potential performance, economic, fuel savings, and passenger acceptance benefits resulting from ACT. The data base will also be used to determine the technical feasibility of ride control and gust load alleviation systems and to predict Airport Feeder flying qualities.

One approach would be to integrate the relevant computer programs used in aerodynamics, structure, propulsion, control and economics into a single interdisciplinary active control system design program that is applicable at any state in the aircraft design cycle. The design program should be evaluated by simulation and flight tests. In addition, design methodology for total active control systems for powered lift airships should be developed and evaluated by simulations.

A-5.3 Digital Fly-By-Wire [DFBW] Experiment

DFBW will likely be required for the Airport Feeder Vehicle concept. The objective of this project is to provide the technology necessary for the implementation of DFBW in the Airport Feeder design. Of particular interest is the adaptability of the state-of-the-art emanating from the space shuttle project including control system software, hardware and redundancy management concepts and the F8C multichannel digital system currently in flight test. Systems utilizing redundancy management concepts being developed by Langley Research Center should be investigated.

A-5.4 Development of Theoretics in Digital Control Applied to Modern Airships

The development of low cost flight computers of ever increasing speed, capacity, and reliability in recent years has provided a potential for more effective and easier implementation of flight control law mathematics than has been the case for the continuous time or analog systems of the past. Early applications of digital flight computers to control systems have in many cases employed rudimentary and intuitive concepts for control law development and implementation. The purpose of this research is to provide needed design techniques and operational concepts for discrete time systems to insure more efficient and effective use of digital computing systems for flight control for modern airships. Experience and studies in the more applied programs such as ASA, TCV and the F8 DFBW program will serve to highlight problems of significance to which attention will be given. In turn the theoretical treatments will serve to advance concepts for possible proof of concept exploration when an LTA flight research platform becomes available.

A-6 PROPULSION SYSTEMS TECHNOLOGY

A-6.1 Advanced Tilt Rotor Aerodynamics

The objective of this project is to provide technical data to enable rotor and control system design optimization for advanced tilt rotor airship configurations. Design information for control systems that will maximize maneuver capability, reduce rotor loads, and reduce tilt rotor sensitivity to gust and turbulence will be developed. Variable geometry rotors will be investigated to determine potential improvements in rotor and aircraft cruise performance. A dynamically scaled wind tunnel model of a tilt rotor system coupled to a large buoyant structure will be constructed. The parametric variation in rotor and aircraft loads during transition will be investigated and the current tilt rotor mathematical model updated. The performance gains and blade load reduction achievable by putting cyclic control under pilot command will be assessed. The existing data base for hingeless rotor performance will be extended to a simulated cruise speed of 150 knots. The effect of tilt angle and flight speed on the transition flight boundaries, rotor performance and stability characteristics will be determined.

A-6.2 Rotor Aerodynamics

Definition of wake geometries and characteristics of rotors is vitally important to the current conceptual designs of the various classes of modern airships. Of particular importance are the LTA requirements for multiple rotors staged fore and aft and the effect upon rotors of proximity to large buoyant structures in varying flight and wind conditions.

Analytical and experimental studies will be made to identify factors contributing to the aerodynamic and structural characteristics of rotors suitable for use in modern airship designs. Studies will be made to define wake geometry and analytical procedures which include wake characteristics in predicting airloads, structural response and aerodynamic performance in the various LTA configurations. Experimental studies will be continued to better define unsteady local-flow parameters significant in the prediction of rotor blade section lift and drag. Analytical, wind-tunnel, whirl tower, and flight investigations will be made to determine performance, dynamic loads, vibrations, and wake flow characteristics of advanced rotor concepts, rotorcraft configurations, and tail rotor arrangements. These studies will be coordinated with the airfoil development research, with the rotor aeroelastic and acoustic studies and with rotor systems development.

A-6.3 Rotorcraft Maintenance Costs Methodology Development

Use of multiple propulsors in modern airship concepts such as the Airport Feeder introduces the critical problems of availability, reliability and maintainability of these systems in combined operation. It may emerge as the most dominant cost element in cost/benefit tradeoffs. This project covers evaluation of current rotorcraft maintenance cost experience of both civil and military operations and the establishment of techniques for projecting maintenance cost of advanced rotorcraft in particular the tilt rotor concept. Commercial and military operations will be surveyed to provide a basis of current experience enabling projections of likely technological developments in subsystem design to be made. An analysis of rotor craft maintenance costs will be made. Multiple regression techniques will be used to develop the importance of parameters such as vibration level, mission cycle vs flight hours, etc. as well as the effects of major technical design differences, if pertinent, in determining good maintenance cost estimating relationships.

A-7 HUMAN FACTORS

A-7.1 Airships Interior Noise Reduction

The potential of reducing power plant noise in LTA transports by burying the engines within the lifting gas enclosure system or location in areas where the hull has shielding effects should be investigated. The object of this project is to develop the technology needed to reduce airships interior noise levels to achieve increased operating safety, hearing protection, and comfort of crew and passengers with minimum weight and cost penalties. The noise sources for airships will be determined from this as well as other ongoing programs. In addition, the transmission of the noise through the structure and the transmission paths will be determined. Structural designs will be investigated which have more acceptable transmission characteristics with minimum weight penalties. A parallel effort will determine acceptable levels of interior noise for safety and comfort of crew and passengers.

A-7.2 Airship Ride Quality

The objective is to define and quantify those ride-environment properties, particularly motion, cabin noise, and vibration, that determine ride quality and associated passenger acceptance pertaining to LTA transports. To achieve these objectives research studies will be doncuted to develop data appropriate for establishing criteria for ride-environment requirements and for airship operational limits relevant to attitude, accelerations, interior noise level, and angular motion. This program should include field studies to obtain data aboard the Goodyear Advertising Airships as well as other vehicles, studies under controlled conditions aboard research aircraft, laboratory studies using ride-motion simulators under closely controlled conditions, and analytical studies of experimental data to model the phenomena and to develop criteria. Supporting efforts will be carried out to develop appropriate study methodology, subjective response opinion questionnaires, portable ride-measuring instruments, laboratory simulators, and analytical procedures.

A-7.3 Aircraft Performance and Aviation Safety

The introduction of a new class of air transports such as the Airport Feeder vehicle permits initiation of an optimized flight crew training and operational procedures system concurrent with the advent of the flight equipment. The objectives of this program are to investigate current problems in pilot training, performance measurement and evaluation, and communications between flight crew members and other components of the aviation system. General aviation and civil air transport operations will be considered together with the unique characteristics of the LTA transport. Specific objectives are to: (1) develop objective, precise, and stable measures of airship performance for use in research and operational training programs; (2) develop new technology and methodology for training necessary flight crew skills, and (3) explore fundamertal problems in the transfer of information to pilots from other components of the aviation system, e.g., navigation charts and cockpit warning systems. To achieve these objectives, the GAC-1 simulator will be modified to permit full-mission simulation capability and automated performance monitoring. This facility will be used to examine pilot behavior, especially cognitive or decision-making behavior, and to evaluate alternative methods of human performance measurement. The effectiveness of various candidate solutions for identified training problems will be evaluated using both formal experimental evaluations, and more informal feasibility demonstrations [pilot projects]. Specific problems in the transfer of information between pilots and other components of the present aviation system will be used to identify fundamental problem areas, and to develop and evaluate potential solutions.

A-8 OPERATIONAL CONSIDERATIONS

A-8.1 Air Traffic Control Integration Study

This research is concerned with the problems of integrating LTA Transport and their air traffic control system into the total air traffic control environment of the terminal area. The objectives are to determine: (1) airship design and equipment requirements, (2) operating procedures and airspace volumes, (3) ATC equipment and handling procedures and airspace volumes, (3) ATC equipment and handling procedures, and (4) requirements for compatibility and integration of the airship systems with the total ATC complex.

A-8.2 VLF Wide Area Navigation for Low-Density Short-Haul Transportation by LTA Transports

The objective of this project is to investigate VLF navigation techniques and to develop promising approaches for en-route and terminal area navigation. Systems such as Omega can provide large geographic coverage with a limited number of ground stations, and are relatively unaffected by altitude or terrain. Characteristics such as these are highly desirable for short-haul, low-density transportation systems, where direct terminal-to-terminal routes at relatively low altitudes are required. Work will be conducted in two areas. The first area consists of the measurement and analysis of error due to propagation anomalies and atmospheric noise. The second area consists of the development and evaluation of Omega avionics, including both idfferential and composite Omega configurations.

A-8.3 LTA Operating Systems Experiments

The objective is to develop a data base for use in establishing system concepts, design criteria, and operational procedures for VTOL LTA Transport. The technology base will aid the development of efficient, economical VTOL short-haul operations with minimum adverse environmental impact. The objective also includes a research and technology program to support military requirements for assuring a VTOL operational capability into a wide variety of landing sites, under reduced visibility conditions. The approach will utilize, analytical studies, piloted closed-loop simulations, and flight experiments. The systems should be installed in a fixed-base simulator at Ames for development of computer software programming and piloted simulation studies. The system can then be checked out in a subscale flight research vehicle prior to implementation in the full-scale manned prototype. These systems can be used to investigate alternative avionics functional configurations, flight paths, operational procedures, levels of automation, and landing aids. Time constrained flight paths, steep curved, decelerating, and omnidirectional approaches, and the effects of winds will be investigated.

A-9 COMPUTER AIDED DESIGN

A-9.1 Computer-Aided Design Methods

Advanced computer-aided analysis and design methods are required for design of modern LTA structures. Analysis techniques are required with the generality and efficiency for the iterative calculations involved in sizing structural members. Developments should include algorithms to accomplish LTA structural sizing to meet constraints including strength, stiffness, aeroelasticity, thermal stresses, and minimum gage. Considerations should address the best system architecture for structural analysis and design and evolve specifications for the component computational modules in such systems.

A-10 STRUCTURES AND MATERIALS

A-10.1 Design Technology for Composite Structures for LTA

The objective is to advance the technology of filamentary composite structures which will provide the potential of a large weight reduction by conducting analytical and experimental laboratory investigations of selected airship structural components. Advanced methods of predicting the strength and stability of laminates, panels and stiffened components will be applied to new test data. Analysis will be applied to define the limitations of conventional test methods, and to develop more satisfactory test methods. A large series of graphite panels with either open or closed sections will be designed, fabricated and tested in the appropriate NASA Structures Laboratory. Effort will include industry-developed as well as NASA-developed designs. Data will be generated over a large range of loading to provide a substantial NACA type data bank upon which to base LTA sturctural design. Designs to be investigated include sandwich and stiffened shear web approaches using graphite materials, Kevlar and hybrid laminates.

A-10.2 Fatigue and Fracture

Specific goals of this research program of advanced LTA structures are to improve fatigue life prediction techniques, to devise ways to predict the residual strength of reinforced sheet structures, and to assess the feasibility of compressing test time during the measurements of fatigue life. Reliability methods will be devised and applied to LTA structures for use where the number of structures tested is limited by cost and where measured parameters must be revised according to new data acquired during fleet operation.

A-10.3 Loads, Aeroelasticity, and Structural Dynamics

In order to predict aeroelastic phenomena more accurately, research must be conducted to improve aeroelastic analysis methods including rotor dynamic analysis as applied to advanced LTA propulsion systems. Various load prediction techniques [including FLEXSTAB] should be evaluated and improved for integration into computer systems such as LTA versions of ATLAS and IPAD. In order to develop methods for predicting acoustic loads, structural response, and noise transmission through airship structures, methods for anlayzing panel response with a thick boundary layer should be developed and compared with experiment.

The objective of these efforts is to provide the technology necessary to increase airship performance and service life and to improve safety and ride quality through improvements in methods for predicting loads, aeroelastic efrects, and structural response of LTA designs.

A-10.4 Advanced Fabrics Technology Development

Research and Development work is required to apply the recent developments in light weight, high strength man made fibers and fabrics to advanced LTA transports. Potential benefits to be derived from the successful development of advanced [non-rigid] airship envelope and ballonet fabrics include lower manufacturing cost, improved operational flexibility, lower annual maintenance costs, and greater flexibility in errection operations.

The objectives of this program are to investigate the applications of films, film fabrics, triaxial weaves, Kevlar, rip stop designs, elastomers permitting heat sealed seams, and high strength seam design to advanced LTA Transport vehicles. This program will include analytical efforts in support of a specimen test program.

The fabrics technology program would begin with a compilation of possible candidates for evaluation and development of a methodology by which each combination would be screened. The screening would conceivably involve both test and analysis with the analysis including a compilation and review of all applicable background data. Those candidates judged successful in the initial screening would be considered against a more comprehensive series of tests similar to those used for qualification testing of current airship fabrics. Representative specimen tests may include:

Weight	- Small Specimens
Strength	- Strip Tensile
Strength	- Cylinder Burst [Tensile]
Strength	- Hot Cylinder Burst [Seam]
Strength	- After Crease
Strength	- After Rotoflex
Strength	- Seam
Adhesion	- Ply
Adhesion	- Bias Ply Seam
Adhesion	- Coat
Diffusion	- Original
Diffusion	- After Rotoflex
Diffusion	- After Hot Cyclic Load
Elongation	- Cylinder Stretch
Tear Test	- Center Slit
Shear Modulus	- Torsion Cylinder
Aging Test	- Oven - 60 days - 158° F [70° C]
Aging Test	- Oven - 24 hrs - 250° F
Aging Test	- Cold Fold

It should be emphasized, however, that new fibers, new fabrics, etc. may have unique characteristics requiring other tests before their suitability to all aspects of airship application is assured. A control specimen of current technology will be included in the advanced fabrics test program for comparative purposes.

The potential of Kevlar should be thoroughly investigated in the fabrics technology program. Investigations must include: (1) basic yarn design; (2) yarn finish; (3) type of Kevlar (49 or 29); (4) yarn treatment for proper adhesion to the elastomer or film and proper self-abrasion protection; (5) weave design to permit proper seam strength development and to minimize self-abrasion; (6) and ultraviolet radiation effects and protection. Extensive efforts should be devoted to development of high strength seam designs. In the case of heat sealed seams, the problems of quality control must also be defined.