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DOUGLAS MDC J4484

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ANALYSIS OF OPERATIONAL REQUIREMENTS FOR MEDIUM DENSITY AIR TRANSPORTATION

FINAL REPORT

VOLUME II

MARCH 1975

PREPARED UNDER CONTRACT NO. NAS2 8135
FOR
SYSTEMS STUDIES DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MOFFETT FIELD, CALIFORNIA 94035

DOUGLAS AIRCRAFT COMPANY

MCDONNELL DOUGLAS

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FOREWORD

This Volume II contains the detailed description and results of a contracted study performed for NASA, "Analysis of Operational Requirements for Medium Density Air Transportation", by the Douglas Aircraft Company, McDonnell Douglas Corporation.

The NASA Technical Monitors for the study were Thomas L. Galloway and Susan N. Norman, Systems Studies Division, Ames Research Center, Moffett Field, California.

The Douglas Study Team consisted of J. Seif, Technical Director, assisted by M. A. Sousa, responsible for Aircraft Analysis, and S. C. Nelson, responsible for Systems Operations and Economic Analysis. The following personnel contributed to the study effort in the disciplines as indicated:

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Aerodynamics	:	R. D. Walls, J. H. Lindley
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The subcontractor participation included the following companies and personnel:

Air California	:	F. R. Davis
American Airlines	:	J. D. Graef
Cessna Aircraft	:	O. D. Mall
North Central Airlines	:	C. B. Vesper

Appreciation for their cooperation and contribution is extended to:

Avco Lycoming Division
Avco Corporation

Detroit Diesel Allison Division
General Motors Corporation

General Electric Company
Aircraft Engine Group

Hamilton Standard Division
United Aircraft Corporation

The nine month study, initiated in March 1974, was divided into three tasks: Task I - Aircraft Requirements; Task II - Aircraft Design Study; and Task III - Evaluation.

The final report for this study is presented in three volumes as follows:

Volume I Summary	-	A summary of the significant study results
Volume II Final Report	-	A detail description of the study and results
Volume III Appendix	-	The supporting study data, methods, and analyses.

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SUMMARY

This report summarizes the main features of a nine month study program for NASA-Ames on the Analysis of Operational Requirements for Meaium Density Air Transportation.

During the Aircraft Requirements phase, fifteen different parametric aircraft were designed as candidates for economic evaluation in noncompetitive operational simulations of selected regional airline networks. The aircraft analyses included engine selection, performance, weights, and acoustics. The activity concentrated on 30 to 70 passenger aircraft with two types of turbofan engines, and a 50 passenger turboprop. A 50 passenger turbofan was selected as a baseline. After evaluating the economic characteristics of these conceptual aircraft, a 50 passenger turbofan-powered aircraft was defined as a basepoint configuration.

An operations scenario was written which delineated a representative airline network, established an operating time period for airline introduction and simulated operations of a conceptual aircraft, and projected a 15 year traffic growth from a 1972 base. All of these were reflected in terms of a specific definition of Medium Density Air Transportation. An initial passenger demand forecast was made with Civil Aeronautics Board data for 1972. This forecast was used to test the original size spectrum of the aircraft (passenger capacity) and the definition of medium density transportation with resultant compatibility of all terms and definitions. A wide range of noncompetitive operational simulations was run in a mission model which reflected actual airline operations in the base year of 1972. Results of these simulations served to isolate and define the characteristics of a medium density conceptual aircraft for the design phase of the study.

During the Aircraft Study phases, fifteen different aircraft were produced for the design studies including: three different range versions of the 50 passenger turboprop, designed for lower interior noise; three different range versions of the 50 passenger turbofan basepoint; two additional passenger versions of the turbofan basepoint at the selected range; two variations of the 50 passenger turbofan with short and long field capability; and five alternate engine versions of the basepoint, using partly or wholly available current engines, sized to the selected performance requirements, with the passenger capacity as a fallout. Alternate designs were evaluated for the fuselage cross section, baggage/cargo location, structural design and materials of construction. The design effects of considering a stretch/shrink family concept were evaluated. Design-to-cost studies were conducted which included engineering - manufacturing design and performance features and avionics and other subsystems design. Noise analysis was conducted for the final design aircraft.

Various parametric evaluations of basic aircraft concepts were conducted during the Basepoint Design Study phase. A specific mission model for an airline network was created with service and demand schedules for each airport-pair route. The basic turbofan and turboprop were evaluated in this mission model. Noncompetitive and preliminary competitive evaluations were undertaken with sizes of aircraft varying from 30 to 70 passengers in increments of ten seats or less. The initial (and total) mission model was divided into low, medium, and high traffic density classes to evaluate size (seats) versus market segments. A survey of regional air carrier airports was conducted to evaluate aircraft landing/takeoff performance at elevated ambient temperatures and high altitude airports.

In the Evaluation phase, the payload-range capability of the final design basepoint was determined. For comparative evaluation, the payload-range capability and other performance, weight and descriptive data were compiled on nine existing and near-term competitive aircraft.

Various passenger capacities of the final design basepoint aircraft were studied for competitive evaluation with existing and near-term contemporary commercial air transports. A specifically-tailored traffic network and mission model was constructed from a 1974 base. The model reflected a more precise definition of the medium density market. It also included a constant base of low-density, commuter-type operations to reflect markets appropriate for a 30 passenger aircraft. The economic characteristics of the aircraft were analyzed with respect to potential airline earnings and subsidy considerations. Parametric cost sensitivities were studied covering a wide spectrum of factors in the design and operation of an aircraft for medium density transportation. The total potential for new aircraft was evaluated in the U.S. domestic market.

To assist Douglas in conducting the study, a balanced team of subcontractors was established. Cessna Aircraft Company assisted in evaluating cost and weight data of the study aircraft and participated in the design-to-cost studies. Air California, American Airlines, and North Central Airlines provided continuous assessment throughout the study to assure commercial airline realism as well as assisting in specific tasks.

The major conclusions resulting from the analyses in this study are derived with consideration of the definition of the medium density market, the aircraft performance and economic ground rules, and the operational scenarios. These conclusions are summarized as follows:

- The U. S. domestic medium density air transportation fleet mix requirements for the 1985 time period consists of approximately 400 DC-9/B-737 type aircraft plus seventy-five 30 passenger, twenty-three 40 passenger, and five 60 passenger aircraft with new configurations and design features as developed in this study.

- U. S. domestic requirements of only 103 aircraft are insufficient for a production program to achieve the aircraft price levels used in this study. The inclusion of foreign market requirements could constitute a viable manufacturing opportunity.

- Over a 15 year period from 1980, the 30 passenger turbofan powered study aircraft with stretch capability to 40 seats satisfies travel demand in the short-range, low density segment of the market better than existing or contemporary near-term turbofan aircraft.

- Aircraft of less than 50 passenger capacity, operating in the medium density market, cannot generate satisfactory profit levels within the operational and economic ground rules including CAB Phase 9 fare levels.

- Short range, low density operations cannot be profitable with any current, near-term, or study turbofan powered aircraft at the fare levels and load factors used. An increase in the load factor from 50 to 60 percent is not sufficient for the 30 and 40 passenger study aircraft to be profitable.

- The study aircraft can be designed to achieve the noise standard of 10 EPNdB below FAR 36 without affecting environmental qualities.

- Adoption of "design-to-cost" engineering and manufacturing features can save costs of the final design aircraft by one million dollars and DOC at least eight percent when compared with contemporary transport aircraft.

- A nominal range of 850 nautical miles (1,574 km) is adequate to serve the longest scheduled routes of the medium density market as defined in this study.

- Current candidate engines are deficient in appropriate size or efficiency for the aircraft passenger sizes studied. Development programs are needed for new engines, fans and/or gas generators.

- Turboprop aircraft proved to be better in operating economy than the turbofan aircraft, but a majority of the trunk and regional airline operators prefer jet aircraft.

- If engine costs and operations of turboprop aircraft can be kept at levels indicated in the study, a new turboprop aircraft would be an economic choice for the future.

Research and technology programs were identified from an evaluation of the study results. Studies in the disciplines related to aerodynamics, propulsion, systems, economics, market, and manufacturing are indicated. Recommended study areas requiring research include:

Aerodynamics	-	Wing geometry/configuration variations
Propulsion	-	Cycle characteristics
Systems	-	Low density transportation
Economics	-	Operations cost impact analysis
Market	-	Foreign market demand
Manufacturing	-	Composite and metallics cost benefits

There are communities of medium and small size populations in the U. S. domestic market currently with poor or no air transport service. Research is needed to provide a better understanding of the needs of these communities as they relate to the specific requirements for U. S. domestic low density air transportation.

INTRODUCTION

Recent government-sponsored research and general interest in air transportation have been concentrated in certain areas. These have been: high density, such as the Northeast Corridor studies; medium to high density as in the STOL operations analysis and aircraft technology studies; and low density studies with investigation of service to small communities.

The main purpose of this study was to examine the medium density air travel market and determine the aircraft design and operational requirements for aircraft to serve this market. An additional purpose was to evaluate the impact of operational characteristics on the air travel system and to determine the economic viability of the study aircraft.

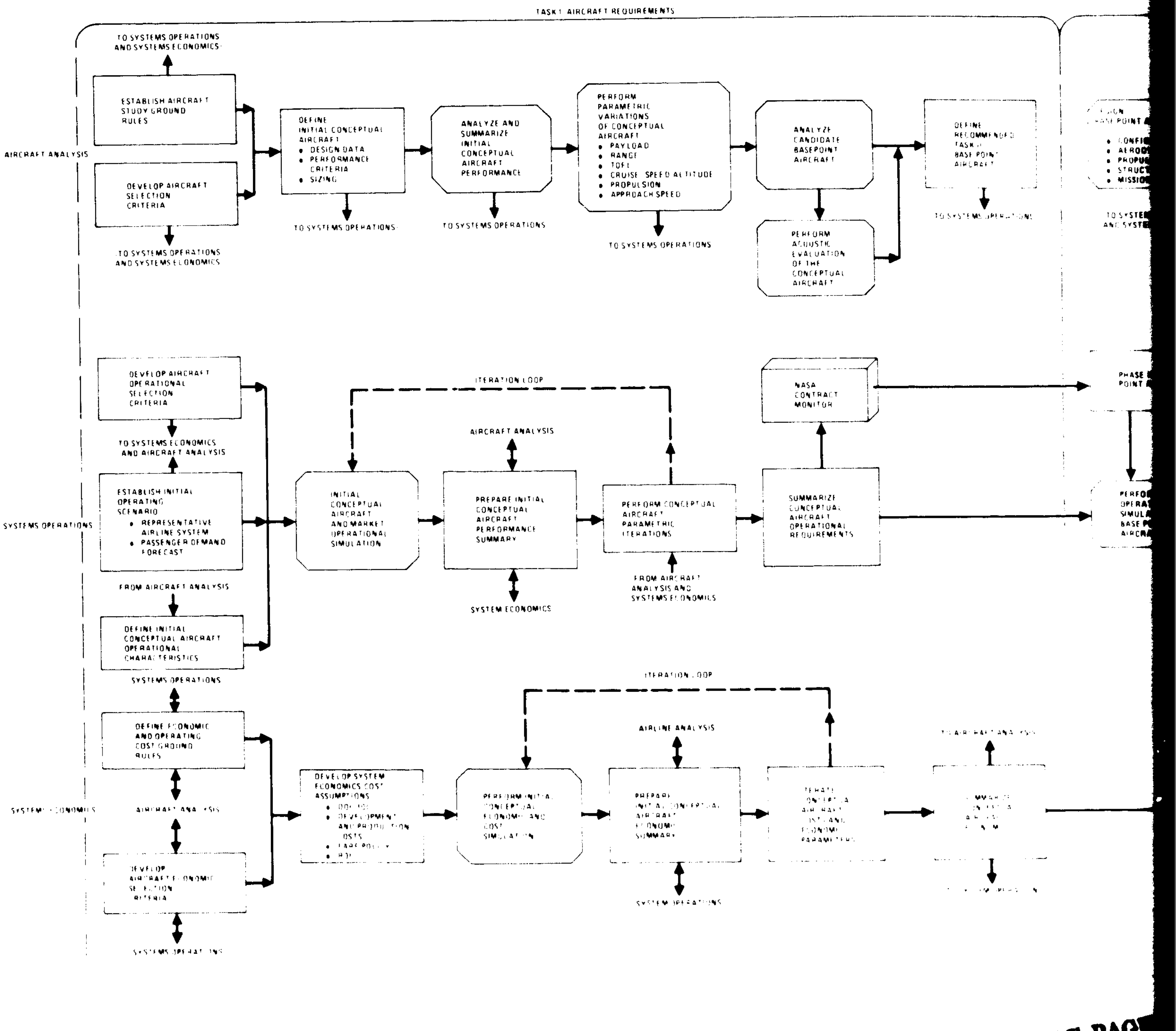
The conduct and understanding of this study is heavily dependent upon the definition of the medium density market. Medium density has been defined in terms of numbers of people transported per route per day and frequency of service. Numbers selected initially were 20 to 500 passengers per day on routes between cities. Frequency of service on each of those routes was a minimum of two round trips per day and a maximum of eight per day. Civil Aeronautics Board (CAB) data on origins and destinations (O and D) for air travelers in 1972 provided an initial base of total travelers in the medium density market. The definition was extended for operational simulation purposes to include air traffic only on ten regional carriers. Eight of these are CAB-regulated. The other two were Pacific Southwest Airlines (PSA) and Air California. These are both intrastate carriers regulated by the California Public Utilities Commission. During the middle and latter phases of the analysis, PSA and Air California were eliminated, Air New England was added and scheduled air service by 21 commuter airlines was added in the model of traffic demand for 1974.

The objectives of this study were to:

1. Determine the operational characteristics of aircraft best suited to serve the medium-density market.
2. Design a basepoint aircraft from which tradeoff studies and parametric variations can be conducted.
3. Ascertain the impact of selected aircraft on the medium-density market, economics, and operations.
4. Identify and rank research and technology objectives which can be used to guide NASA programs helpful to medium density air transportation.

The study consisted of three major tasks as shown in Figure 1, Task I, Aircraft Requirements, activity concentrated on parametric aircraft analysis of 30 to 70 passenger turbofan conceptual aircraft and a 50 passenger turboprop. A 50 passenger turbofan aircraft was designed as a baseline configuration. The aircraft analysis included weights derivation, engine selection, and acoustic evaluation. Range and field length variations were conducted as trade studies. Noncompetitive operational simulations were performed evaluating the conceptual aircraft in selected regional airline networks. Economic characteristics of the conceptual aircraft were derived and a basepoint aircraft was defined.

In Task II, Aircraft Design Study, the basepoint aircraft was sized using current engines. Noise analyses were conducted for the final design basepoint and alternate engine aircraft. Design-to-cost studies included



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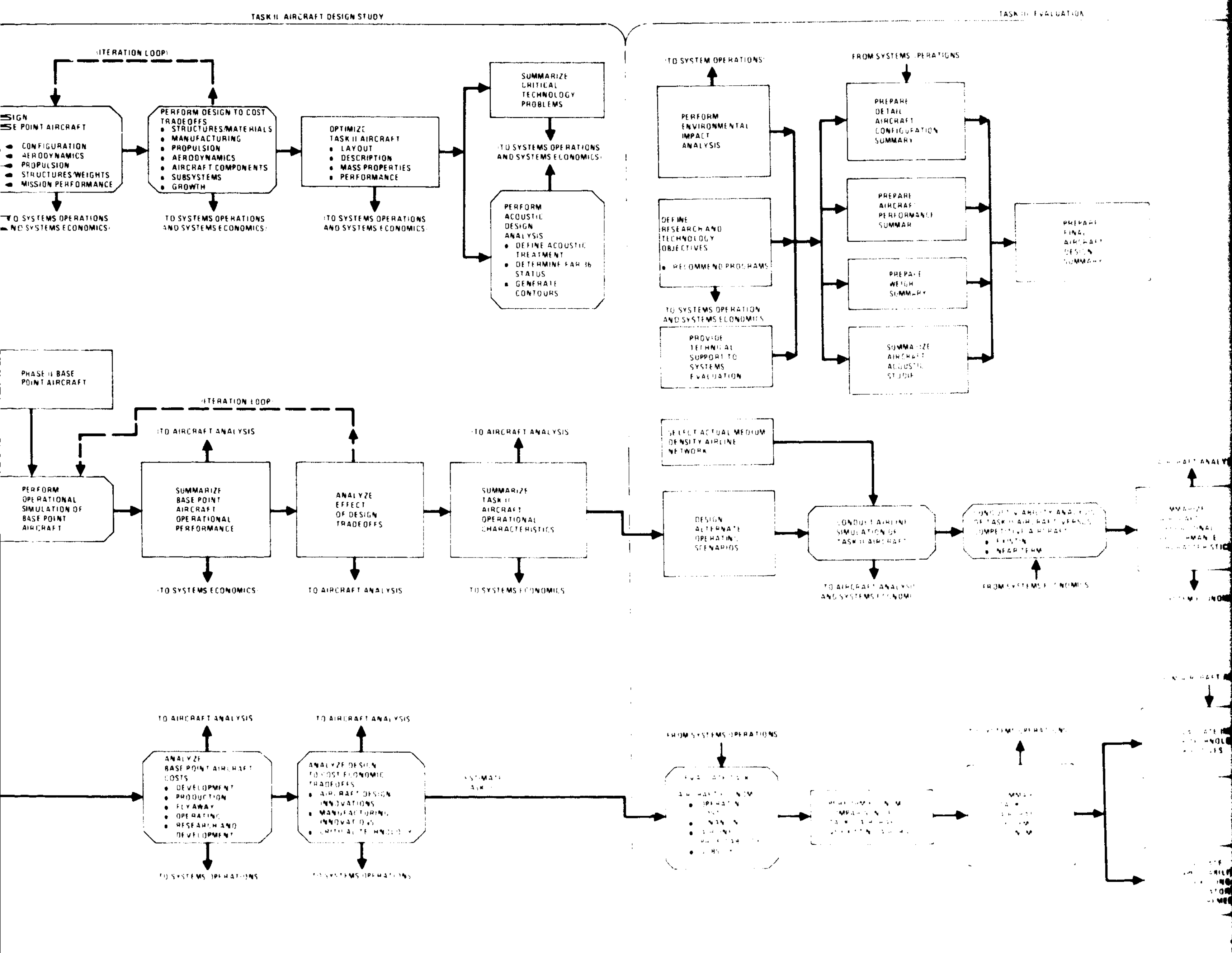

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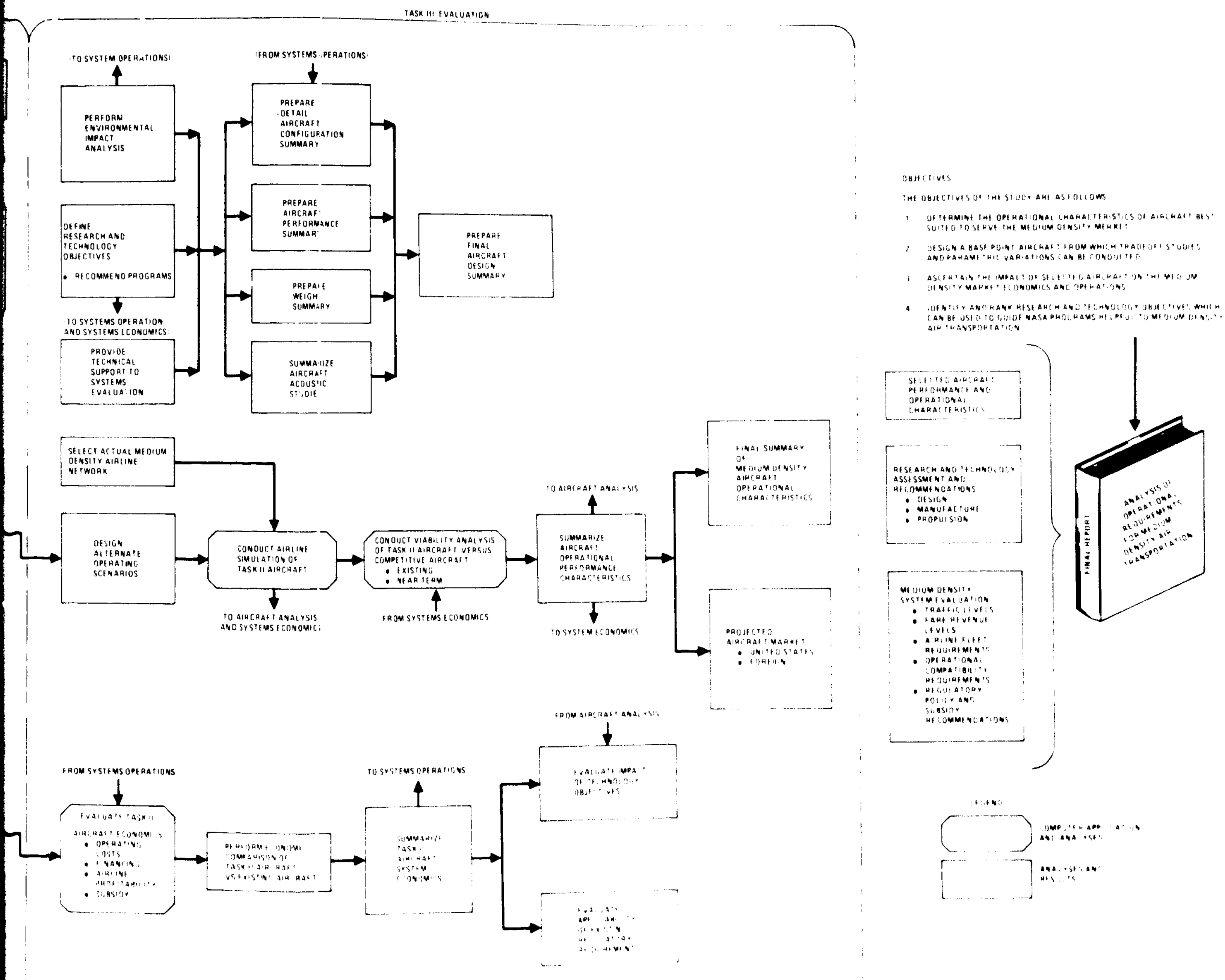

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FIGURE 1. STUDY FLOW DIAGRAM

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design and performance features, avionics, structural and subsystems design, and aircraft family concepts. An environmental impact analysis was performed at a selected airport. Economic analysis included cost comparisons of a nominal design and an advanced flap aircraft, cost estimates of the basepoint aircraft, the effect of range extension on direct operating costs, and design-to-cost and final design cost estimates. An airport survey of the regional carriers to determine runway length requirements was conducted. Trade studies included configuration arrangements and derivative engines.

Task III, Evaluation, studied the impact of the candidate aircraft on actual airline operation in terms of the economics of both the operating and initial investment costs. Competitive analyses were performed comparing the candidate aircraft with both current and near-term aircraft. Fleet operational and profitability comparisons were performed. Subsidy consideration and areas for operating cost reductions were investigated. Sensitivity analyses included studies related to load factor, fare, operating costs, and aircraft price. Payload/range curves and aircraft characteristics were prepared for the competitive and near-term aircraft.

Research and technology programs for future study consideration have been identified.

SYMBOLS & ABBREVIATIONS

ADF	Automatic Direction Finder
A_f	Fan frontal area
AR	Aspect ratio
ARP	Airport reference point
ASKM	Available seat kilometer
ASNM	Available seat nautical mile
ASSM	Available seat statute mile
ARTS	Automated radar tracking control system
ATC	Air traffic control
BED	Hanscom Field (Boston)
BPR	Bypass ratio
B-727	Boeing Model 727
C	Centrigrade; cost
CAPDEC	Commercial aircraft production and development cost
C_d	Discharge coefficient
C_D	Drag coefficient
C_{D_0}	Zero lift parasitic drag coefficient - zero lift parasitic drag/qS_W
CAB	Civil Aeronautics Board
CFM	Cubic feet per minute
C_L	Lift coefficient - lift/qS_W
C_{L_i}	Propeller integrated lift coefficient
CO	Carbon monoxide
C.S.D.	Constant speed drive
CTOL	Conventional takeoff and landing

C_μ	Gross thrust coefficient = gross thrust/qS_W
C_V	Nozzle velocity coefficient
dB	Decibel
D	Drag; diameter
DAC	Douglas Aircraft Company
DCA	Washington National Airport
Dia	Diameter
DME	Distance measuring equipment
DOC	Direct operating cost
EBF	Externally-blown-flap
EGA	Extra ground attenuation
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPNL	Effective perceived noise level
EPNdB	Effective perceived noise level in decibels
F	Thrust force; Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Air Regulations
FL	Field length
FPR	Fan pressure ratio
fps	feet per second
ft	Feet
G.A.	General aviation
H	Height of duct flow channel
HC	Hydrocarbons
h_{CRUISE}	Cruise altitude
HP	Horsepower

H.P.	High pressure
IAS	Indicated air speed
ILS	Instrument Landing System
in	Inch
IOC	Indirect operating cost
IRAD	Independent Research and Development
K	Kelvin
KE	Kinetic energy
KIAS	Indicated airspeed in knots
kg	Kilogram
km	Kilometer
kn	Knots
kW	Kilowatt
L	Length; left
LFL	Landing field length
L.P.	Low pressure
lb	Pound
LTO	Landing-Takeoff Operation
m	Meter
M	Mach number
M-150-4000	Mechanical flap, 150 passenger, 4000 ft field length
MAC	Mean aerodynamic chord
max	Maximum
MDW	Midway Airport (Chicago)
MF	Mechanical flap

min	Minimum
Mill	Million
MLS	Microwave landing system
mps	Meters per second
N	Newton
n mi (nm)	Nautical mile
NO_x	Nitrogen oxides
NPN	Non propulsive noise
OAG	Official Airline Guide
OEW	Operator's empty weight
P	Pressure
PET	Performance Evaluation Technique
PL	Payload
PLS	Propulsive lift system
PNdB	Perceived noise level in decibels
PNL	Perceived noise level
Psgr	Passengers
q	Free stream dynamic pressure
Q	Torque; quantity (no. of engines)
QCSEE	Quiet Clean STOL Experimental Engine Study
QRPLS	Quick response powered-lift system
R	Rankine; right
Rwy	Runway
s (sec)	Second
SAE	Society of Automotive Engineers

S_w	Wing area
SFC	Specific fuel consumption
SLS	Sea level static
SNA	Orange County (Calif.) Airport
SNAP	Source noise analysis procedure
sq km	Square kilometers
std	Standard
st mi	Statute miles
STOL	Short takeoff and landing
t	Time; thickness
T	Temperature
t/c	Thickness ratio
TOC	Total operating cost
TOFL	Takeoff field length
TOGW	Takeoff gross weight
T/W	Thrust-to-weight ratio
U.S.A.F.	United States Air Force
U.S.G.S.	United States Geological Survey
V	Velocity
V_{tip}	Blade tip velocity
V_R	Relative velocity (primary exhaust velocity - V_0)
V_1	Decision speed
V_2	Speed at end of gear retraction, with critical engine failed
VHF	Very high frequency
VOR	VHF omni range
W	Weight; watts
w	Mass flow

W/S	Wing loading
α	Angle of attack
γ	Flight path angle
δ	Pressure relative to sea level standard
δ_F	Flap angle
η_{fan}	Fan efficiency
θ	Aircraft pitch attitude; relative absolute temperature
$\dot{\theta}$	Aircraft pitch rate
Λ	Sweep angle
λ	Taper ratio
μ	Coefficient of friction
ν	Statuc thrust turning angle
τ	Ratio of gross thrust to takeoff gross thrust
Φ	Aircraft roll attitude

Subscripts

A	Air, airplane trimmed
CR	Cruise
DUCT	Engine fan exhaust duct
PRI	Engine core exhaust duct
T.E.	Trailing edge
T.O.	Takeoff
a	Air
am	Ambient
aver	Average
f	Fuel; fan

g	Gross
n	Net
o	Free stream, standard sea level
r	Ram
t	Total

DEFINITIONS

CONCEPTUAL AIRCRAFT = A family of aircraft sized for parametric variations in passenger capacity, field length, range capability, engine selection, and for preliminary market and economic studies.

BASELINE AIRCRAFT = An aircraft selected from the conceptual family used as a base for relative comparisons of aircraft performance and operational viability.

BASEPOINT AIRCRAFT = An aircraft designed in detail from the baseline characteristics used in the parametric analyses, tradeoffs, stretch/shrink concepts, design-to-cost, and operational and economic studies.

FINAL DESIGN AIRCRAFT = The end result of the detailed design studies.

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1.0 OPERATIONAL SIMULATION SCENARIO

A scenario was written to provide a qualified and quantified framework for evaluation of proposed conceptual configurations of aircraft for medium density transportation. Through an operational simulation technique programmed for computer analysis, various aircraft configurations were evaluated for operational and economic viability in the scenario.

1.1 Operational Assumptions

A network of airport pairs, scheduled flights, and scheduled seats was drawn from a 1972 Commercial Aircraft Operations data base. Selected data were used to simulate a network representative of medium density airline operations.

1.1.1 Time Period for Simulation

A time period of 15 years was assumed for operational simulation. The year 1980 date was chosen as representing a reasonable introduction date for a new aircraft. The 15 year period is assumed equivalent to average airline experience from introductory date, fleet build-up and full depreciation of aircraft to start of replacement with the next or follow-on generation of aircraft.

1.1.2 Definition of Medium Density Air Transportation

Studies of air transportation have generally been concentrated on STOL, Short-Haul, Long-Haul and some Low Density problems. The medium to long-haul aircraft inventory has progressed from piston and turboprop aircraft to efficient, economical jet aircraft. These aircraft are used by trunk and regional (local service) airlines in the U.S. and world wide. Typical aircraft for medium density operations include the Martin 404 (40 seats), Convair 580 turboprop (48 seats), Fairchild F-27/FH-227 (40-56 seats), BAC-111 jet (74 seats), Douglas DC-9 series (75 to 109 seats), Boeing B-737 (90 to 112 seats), and B-727 (89 to 158 seats). Currently, there is a trend within the U.S. regional carriers away from the propeller aircraft towards the larger jet aircraft. This move has been accompanied by a reduction of frequency of service to a widespread market in the United States.

This market is not well defined, except by a general term of low to medium density where passengers per day are considered. Another definition involves a geographic and service frequency concept. A geographically medium-dense market exists where towns are relatively small, such as in the Midwest or the Midsouth, but stage lengths are relatively short. Another geographic definition includes small to relatively large cities, such as Denver, Colorado, and Tucson, Arizona, and longer stage lengths up to 700 or 800 miles. Frontier Airlines and Hughes Airwest operate in such a market. A service frequency definition involves a low number of daily or weekly departures. Typical numbers would be one or two departures daily or five or six departures weekly with 20- to 50-seat aircraft.

Thus, for this study, the general dimensions from which the medium density market was defined are as follows:

Passengers per day per route	20 to 500 (2 way travel)
Stage lengths	Up to 800 miles (statute)(1,287 km)
Frequency of service/day	Minimum to be at existing 1972 levels to a maximum of 8 round trips per airport pair.

1.1.3 Domestic Medium Density Market

Data on passengers carried by selected regional (local service) airlines in 1972 was chosen to quantify the market for aircraft requirements analysis.

1.1.4 Basic Domestic Network

Airport-pair routes flown by ten regional airlines in 1972 were selected for a representative network in the Task I evaluation of conceptual aircraft.

1.2 Passenger Demand Levels and Forecast

Two approaches were used to quantify the levels of demand for the initial simulation. The first approach was to interrogate a 1972 Civil Aeronautics Bureau (CAB) online O&D tape (data Bank 4) and to compile and group the city pair data by:

- range increments of 100 mile (.161 km) up to a maximum range of 800 miles (1,287 km)
- passenger distribution in increments of 50 passengers per day to a maximum of 500 per day/per route in two-way travel.

A second approach was to interrogate a 1972 Official Airline Guide (OAG) data tape on scheduled airline service. Since flight frequencies, equipment types, and airport pairs were included in this data, a simulation network and mission model also was constructed. The application of actual load factors for each of the airlines in the network resulted in a mission model quantified with aggregated seat demand expressed as revenue passenger mile (RPM) demand.

A base year of 1972 was used for quantifying passenger demand levels in the medium density mission model. The data base for the model contained schedules of aircraft by airport pairs. For initial screening and evaluation, the number of seats available from the August 1972 schedule was grown at a rate of 6 percent per year through 1980. From 1980 through 1988, an annual rate of 5 percent was used, with 4 percent growth from 1988 through 1994. The number of seats demanded per segment in the model was equal to the number of seats scheduled times the experienced airline overall system load factors recorded for each of the airlines in the model.

1.3 Airline Simulation Networks

1.3.1 Initial Network for Derivation of Aircraft Operational Requirements

A simulation network was created by distributing all of the 1972 OAG data for the selected airlines into six regional groupings. These were Region 1, Atlantic Coast - consisting of Allegheny and Piedmont Airlines; Region 2, Mid-west - Ozark and North Central Airlines; Region 3, Rocky Mountains - Frontier Airlines; Region 4, Far West - Hughes Airwest; Region 5, South Central - Texas International and Southern; and Region 6, California - Air California and Pacific Southwest Airlines. The type of aircraft operated by each airline was distributed by the six regions. Data was organized by equipment categories and identified by an element number. Each data category included:

- Range in statute miles
- Scheduled seats per day
- Scheduled trips per day
- Scheduled seat-miles per day
- Scheduled trip miles per day
- The regional identity number
- Total number of airline scheduled route segments (airport pairs)
- Airport pair codes and actual distances between airports

A total of 172 elements included 2,694 route segments in the mission model. These were sorted into range classes by range increments of 50 miles (80 km) from 0 - 200 (321 km) and 100-mile (161 km) increments up to 900 mile (1,448 km).

These data were assembled into single sets of descriptors for each of the 172 elements. These sets were used in the operational simulation routine which was programmed for a computer. The data set for each element included the following:

- A serial number.
- The average range in statute miles.
- Seats filled per day as demand.
- Minimum flights per day.
- Total available seats per day.
- A geographic identity number denoting the region.
- Number of airport-pair routes.

1.3.2 Final Network for Evaluation of Selected Aircraft

For competitive aircraft simulation, the basepoint aircraft evaluation network differed from that used in the requirements analysis. The method of interrogation and sort of the airlines data tape was generally the same. However, as a result of experience and commentary from airline and other personnel attending interim oral presentations, some different tailoring of the mission model network was applied. Eight of the initial regional airlines plus Air New England were included. Air California and PSA networks were omitted since their route structures were served by aircraft of 100 seats or more. It was assumed inappropriate to evaluate performance of a smaller aircraft on these routes in 1980 or later years.

Another change was to eliminate those regional airline routes which would grow in seat demand to more than could be carried by a 70 passenger aircraft at a 50 percent load factor at 8 round trips per day by the year 1985. Data was drawn from published airline schedules for 1974. Demand for seat miles on each route was generated by application of a 52.5 percent load factor to the scheduled seats per week, converted to seat demand per day. Growth rates were 6 percent annually, 1974-1980; 5 percent annually, 1980-1988, and 4 percent from 1988 to 1994. These rates were applied to the nine regional airlines scheduled routes.

Also included in the final evaluation mission model is seat demand generated from published schedules for 21 commuter airlines. Routes included those on which the following aircraft were scheduled:

Aircraft Code	Name	Average Seats
BTP	Beech Turboprop	7
B99	Beech 99	15
DC-3	Douglas DC-3	26
DTO	DeHavilland Twin Otter	17/18
SWM	Swearingen Metroliner	18

The load factor used for generation of seat demand on these commuter lines and aircraft was 60 percent.

Routes and seat demand from these commuter schedules were maintained in the final mission model as a separate group. The demand in this portion of the mission model was kept constant at the 1974 level through the entire simulation period. This basic demand segment was assumed to be the equivalent of a constant influx of new traffic on low-density routes as a part of the whole medium density mission model.

1.4 Simulation Assumptions

The initial characteristics assumed for the candidate aircraft were as follows:

• Passenger Seats	30 to 70
• Range	2 x 150 n.mi. minimum (2 x 463 km), and 1 x 1,000 n.mi. maximum (1 x 1,852 km)
• Cruise Mach Number	Not specified as an input
• Operating Runway Length	3,500 feet (1,067 m) 4,500 feet (1,372 m), and 5,500 feet (1,676 m)
• Engine Type	High Bypass Ratio Turbofan and Turboprop as alternate

Operational assumptions were as follows:

- Minimum trips scheduled were the same as published by the selected airlines at the August 1972 and 1974 level. The minimum number of trips required was held constant throughout the operational simulation periods.
- The maximum number of trips was generally unconstrained for initial requirements analysis and screening of the initial conceptual aircraft. A nominal limit of eight trips per route per day was established for competitive simulation in the final evaluation of operational and economic viability.
- A system load factor target of 50 percent was assumed in generating required trips needed to satisfy demand for seats.
- All range elements were served by non-stop flights. If the range capability of any aircraft was less than the distance of the range element, the aircraft was not available to carry the traffic.
- Routes were excluded from the initial traffic model if the projected traffic level of seats demanded exceeded a medium density definition of 500 per day (both ways) by 1980.
- For the final mission model, the definition of the upper limit of

traffic was eight trips per day x 50 percent load factor x 70 seats per trip or 280 seats filled per day. This was a one-way flight limit. Any route which exceeded this limit in 1985 was excluded from the final network and mission model.

- A 52.5 percent load factor was used to generate the demand in the 1974 mission model. This reflected the average load factor experienced by the airlines included in the model.
- A 60 percent load factor applied to commuter airlines data represented the average attained for the base year of 1974.

1.5 Simulation Scenario Summary

A number of different network and mission models were used in the operational scenarios. There were five (5) general scenarios which covered these simulations. These are described as follows:

- Preliminary screening of passenger capacity and market served with use of CAB data.
- Noncompetitive simulation to determine operational requirements for baseline aircraft. This involved further differentiation as;
  - Total network and demand model based on scheduled airline operations from the 1972 OAG,
  - A single airline network drawn from the total model and used for detailed examination of conceptual aircraft, and
  - The total market divided into segments by demand level.
- Competitive simulation to evaluate the operational viability and specific requirements of one or a family of final design study aircraft.

Table 1-1 presents a matrix summarizing the scenario used for each of the five (5) simulation networks and mission models.

TABLE 1

SIMULATION SCENARIO SUMMARY

Network and Model Data	Initial Screening	Noncompetitive Simulation: Total Mission Model	Noncompetitive Simulation: Frontier Airlines Network	Noncompetitive Simulation: Segmented Market Study	Competitive Simulation Mission Model
Data Source	CAB	OAG	OAG	OAG	OAG
Base Year	1972	1972	1972	1972	1974
Routes (Two-Way Traffic)	736	1347	170	1347	1687
Airlines: Regional	--	10	1	10	9
Commuter	--	--	--	--	21
O & D Passengers	20,238,000	--	--	--	--
Scheduled Trips: Daily Round Trips	2 to 8	Up to 8	Up to 8	Up to 8	Up to 8
Annual Minimum (thousands)	--	1,716	201	1,716	1,938
Revenue Passenger Miles (Km)	--	15.568	1.889	15.568	13.307
(Billions in 1980)	--	(25.049)	(2.039)	(25.049)	(21.411)
Maximum Trip Distance (St.Mi./Km.)	800/1287	873/1404	736/1184	873/1404	873/1404
Average Stage Length (St.Mi./Km.)	--	158/25'	145/233	158/254	145/233

2.0 AIRCRAFT OPERATIONS GROUND RULES

All versions of the study aircraft were analyzed in a mission model drawn from scheduled airline operations. During the Aircraft Requirements phase each of the conceptual aircraft was tested singly against a total demand expressed in revenue passenger miles for the projected year 1980.

In the Basepoint Design phase, the same mission model was used to test different configurations of the baseline aircraft generated in the Aircraft Requirement phase of the study. A turboprop and turbofan version were tested independently in the mission model. A competitive test case also was run with the following rules:

- 30, 50, and 70 seat aircraft all available for fleet selection.
- A single airline network was drawn from the mission model for operational simulation.
- The simulation assigned an aircraft to each route by selection of the least-costly aircraft which satisfied the demand for revenue passenger miles with the minimum flight frequency equal to or greater than the published schedule in 1972.
- A total fleet summary was drawn for 1980.

Rules for aircraft operations in the Evaluation phase of the study were basically similar both to the requirements and design phases in the use of a mission model with the following exceptions:

- The aircraft consist of the 50 passenger Basepoint configuration with four parametric size variations.
- The mission model was derived from 1974 data and was created more specifically to fit a medium density market suggested by reviewers of the initial and interim review presentations.

- A basic existing and near-term contemporary fleet was used for competitive analysis with the basepoint aircraft configurations. The basic fleet consisted of four turboprop and five turbofan aircraft varying in size from 30 to 100 passenger seats.
- Three competitive operational simulations were used to select an appropriate fleet for 1985. These simulations considered a basic turboprop and turbojet fleet, a basic turbojet fleet, an all-jet basic fleet, and five basepoint and derivative aircraft.
- Variations in system load factor and ratio of indirect operating cost to revenue were studied on the all-jet competitive evaluation of the basic versus basepoint aircraft.

2.1 Environmental Compatibility

In addition to some general rules for operational simulation as specified, there were some physical ground rules applied in the study.

2.1.1 Airport - Groundside

The aircraft were designed for operational compatibility with airports and ground service equipment typically used by regional airline operators. Runway length requirements of 3,500 (1,067 m), 4,500 (1,372 m), and 5,500 feet (1,676 m) were studied both for effect on aircraft design and operational compatibility with runways used by all of the airlines included in derivation of the traffic networks.

A desired objective in design was to have the aircraft incorporate air stairs and also be compatible with powered loading bridges as used for DC-9 boarding.

2.1.2 Airport - Airside

The study aircraft were designed to be compatible with traffic pattern speeds of commercial aircraft at all airports under positive terminal control.

2.1.3 Enroute

The conceptual aircraft were configured to be operationally compatible with all airways air traffic control equipment and procedures.

2.2 Airline Operations Criteria

The aircraft configuration was chosen for minimum impact on airline operations. The assumption was made that manpower and support requirements were to be minimized in comparison with existing and competitive types of aircraft. As far as possible, operations were to be simplified for minimum airline costs.

2.2.1 Passenger and Baggage Processing

All operations involving passenger processing were assumed to be at a minimum level to maintain indirect operating costs at a level no greater than currently incurred by regional operators. For example, only hot or cold free beverages would be served. Liquor sales were considered as optional.

Streamlined, simplified passenger and baggage check-in were assumed. Baggage carry-on was assumed as standard procedure with minimized handling of mail freight and bulky baggage.

2.2.2 Aircraft Servicing and Ground Handling

The aircraft design philosophy was to keep to a minimum any needs for ground support equipment for servicing such as a cart for ground power and cabin air conditioning. Ground handling devices were assumed of conventional design and needs held to a minimum.

2.2.3 Maintenance Policy

Consistent with minimum ground handling and service, the aircraft design was assumed to be simplified and rugged to reduce maintenance to the lowest possible level. The philosophy was the same as adopted for the DC-9 and DC-10 series aircraft built by the Douglas Aircraft Company. This philosophy offers simplicity, reliability and accessibility for maintenance and service.

3.0 ECONOMIC ANALYSIS GROUND RULES

All of the cost figures in the study were assumed at constant 1974 dollar values, essentially equal to a 1974 first quarter level.

3.1 Conceptual Aircraft Cost Estimating

A survey of commercial production aircraft prices resulted in a curve of airframe price versus weight empty less engines (airframe weight), as shown in Figure 3-1. A high and low value curve is shown with a middle level. The spectrum of aircraft concepts considered in this study is blocked in the dark color. The small block at the $120 per pound level included the Cessna Citation. Data for this was supplied by the Cessna Aircraft Company. A straight line cost function was drawn through the Citation data point and the middle of the spectrum shown. This function was used as a general approximation for aircraft costing for the initial conceptual aircraft.

A similar statistical study resulted in a curve of turbofan engine price as a function of sea level static thrust, Figure 3-2 shows two curves fitting the data. In a general sense, the lower line represents a cost curve for current technology and/or available engines including the basepoint fixed pitch turbofan engine. The upper curve defines requirements for some additional costs attributable to advanced technology developments pertinent to the variable pitch turbofan engine. The dotted line is representative of average prices for the specific engines noted and referred to in Section 7.0.

3.2 Baseline Aircraft Cost Estimating

A computerized program, Commercial Aircraft Production and Development Cost (CAPDEC), was used to estimate research and development and production costs for the detailed baseline aircraft resulting from the initial selection

AIRFRAME PRICE: 1974 DOLLARS PER POUND

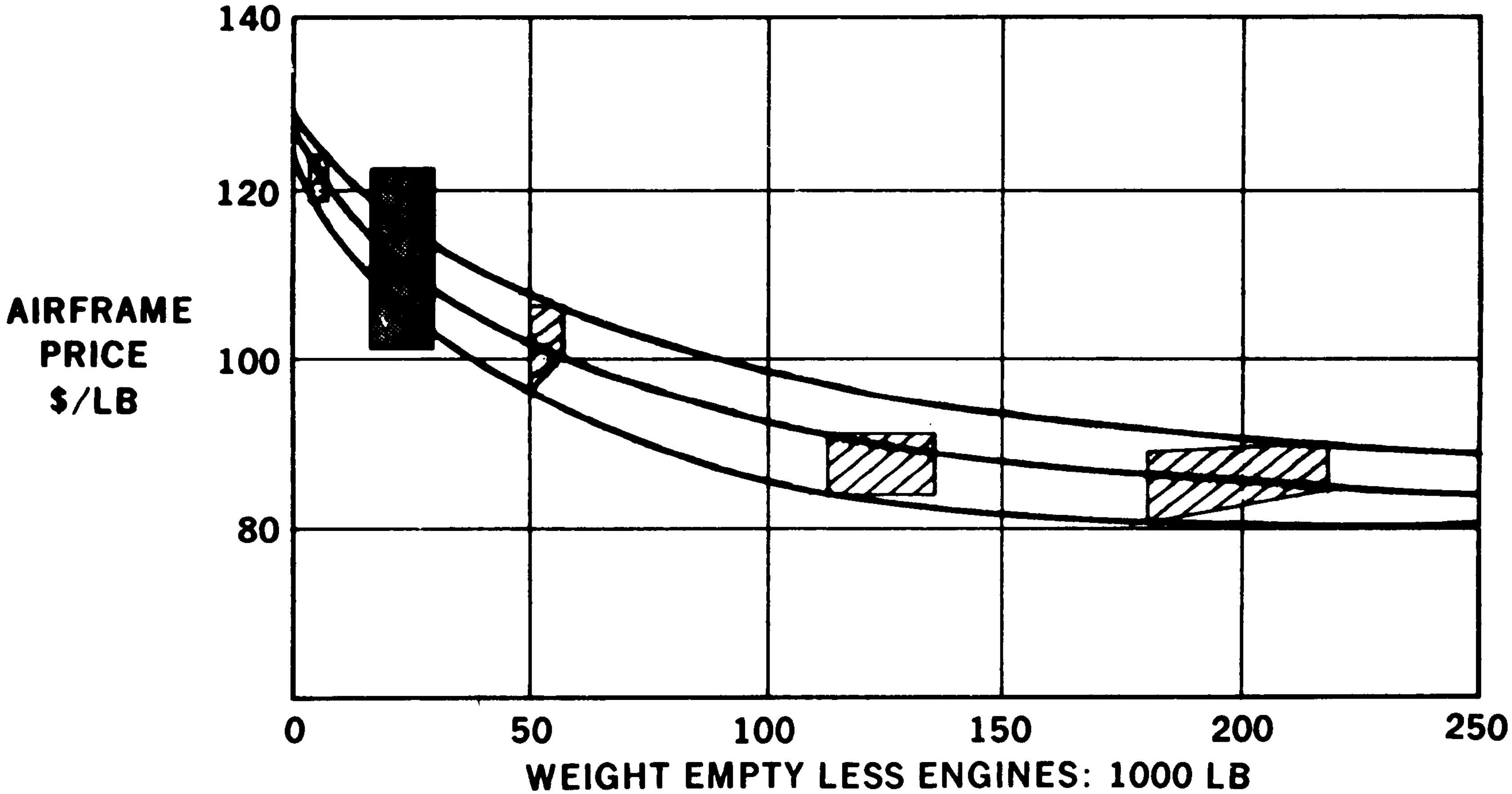


FIGURE 3-1

TURBOFAN ENGINE PRICE: 1974 DOLLARS

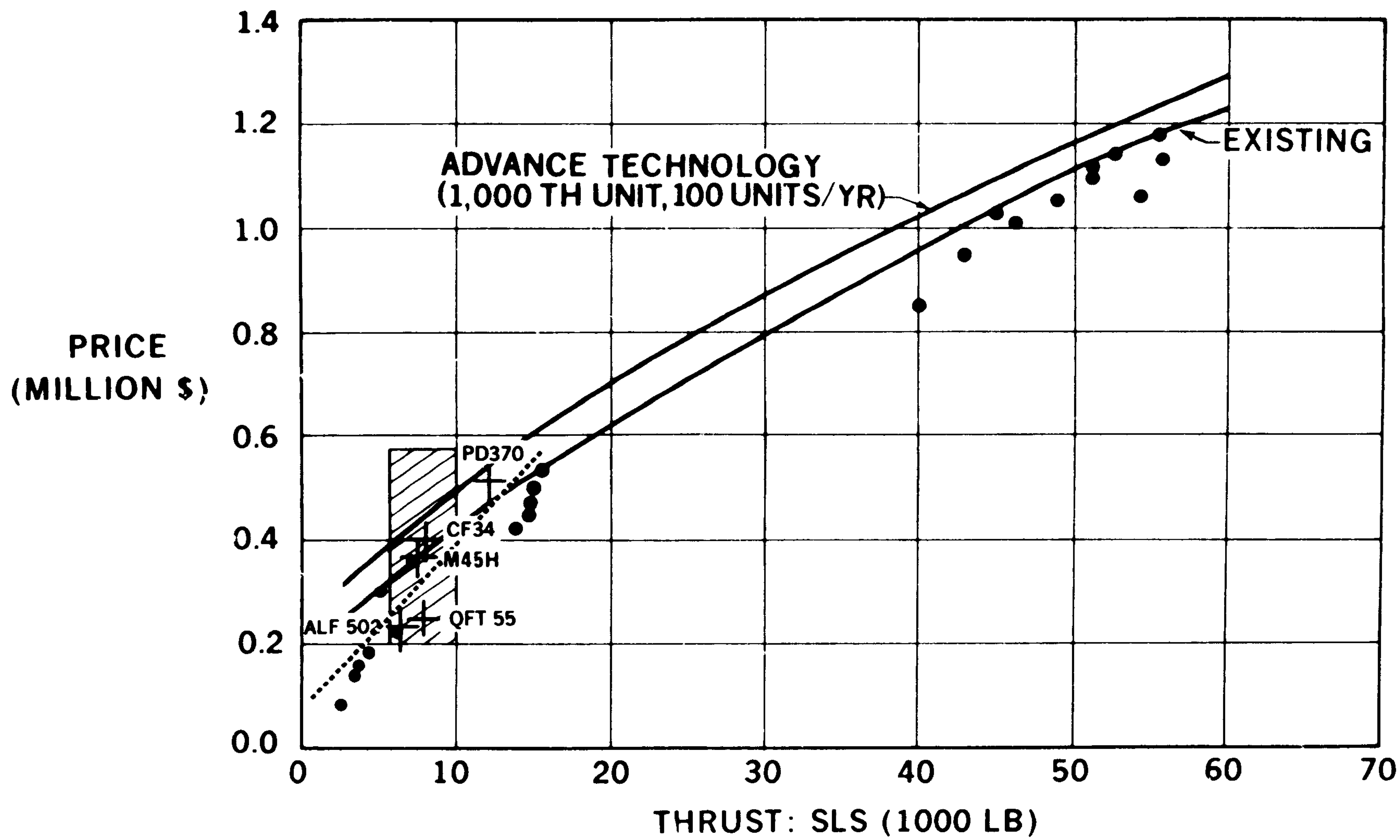


FIGURE 3-2

and evaluation processes. The method generally is based on cost estimating equations developed by the RAND Corporation (Reference 13). These were slightly modified to reflect Douglas experience in commercial aircraft production. Labor and material factors were applied to generate costs at 1974 levels.

3.3 Aircraft Operating Income Assumptions

A CAB Class 7 fare structure was assumed for aircraft passenger revenue. The formula used was a fixed fee of $12.56 plus 7.06 cents per mile for each seat occupied on each airport pair. This was applied in the initial simulations. For the final evaluation, a two step fare equation was used. For the first step to 500 miles distance, the equation was $8.85813 + .07013 x R where R was the distance flown in statute miles. The second step, 500 to 1,500 miles was $9.05385 + .03803 x R. This fare function was calibrated with June 1974 regional airline yields as reported to the CAB. It also included an allowance for freight and cargo of 5 percent. This latter amount also was was derived from reported experience.

The establishment of these revenue equations was not intended to reproduce regional airline experience with calibratable accuracy. Rather, it was to yield a representative income for the evaluation of conceptual aircraft.

3.4 Final Design Aircraft Cost Evaluation

The same cost estimating routine was applied in the developing costs for the basepoint aircraft involved in the design study phase. In addition, a detailed estimate was made of the change from a hinged to a tracked flap system. The benefit of suggested "design-to-cost" manufacturing savings were computed analytically and incorporated in the aircraft cost estimates.

These aircraft costs for the basepoint 50 passenger aircraft were used in the competitive evaluation analysis. Costs for 30, 40, 60 and 70 passenger aircraft were factored from the 50 passenger dollar value. The factors were assumed to follow the same relationships observed in detailed estimates of the 30, 50 and 70 passenger aircraft in the conceptual study analysis.

3.5 Return on Investment

The CAB considers a return on investment of 12.35 percent per year after taxes as an acceptable target for airline operations. In computing allowable subsidy on aircraft operations, this value of 12.35 percent is based on the airline purchase price of the aircraft. In this study, the value of 12.35 percent return was adopted without respect to taxes. Since results of simulation were applicable to the total domestic medium density model rather than an airline, comparisons of aircraft were simplified. In the subsidy analysis (Section 16.3.4), this assumption tends to understate subsidy needs.

3.6 Subsidy

A review was made of CAB rules for computing allowable public service revenue (subsidy) on regional airline operations. This review included application of the CAB rate formula to define subsidy need, provision for airline income, state and local taxes and offset of earnings of ineligible routes against subsidy needs on eligible routes. A detailed exposition of the CAB subsidy practices is included in Section 15.

For the final viability evaluation of aircraft performance, a simple formula was developed. This was based solely upon the type of aircraft selected in the competitive operational simulation. The formula developed for this comparison is:

Revenue - (DOC + ICO) - Return = Aircraft Subsidy Need

The allowable return in this formula was assumed to be generated by the following equation:

$$R = \frac{(C_p + C_s - RV) \times .1235}{DP}$$

where,

R	=	allowable annual return
C_p	=	aircraft price to airline
C_s	=	spares allowance (typically 10%)
RV	=	residual value of 15%
DP	=	depreciation period of 15 years

A provision for income taxes was not included to simplify the evaluation process.

4.0 AIRCRAFT SELECTION CRITERIA

A wide variety of parameters were available for consideration in the choice of selection criteria. Since the basic objective of the study pertained to a subsidized transport industry, a maximum profit choice was tempered by a consideration of service. Thus, selection criteria was divided into operational, economic, and aircraft design and performance factors.

4.1 Operational Criteria

In an operational simulation, the best aircraft is the one which most efficiently performs the assigned mission. Evaluation of conceptual aircraft initially included the following parameters: Payload (seats), Range, Operational Field Length (runway length). The mission model contained demand in terms of RPM in each statistical range class element. The ability of each aircraft to satisfy RPM demand primarily was a function of its range capability and achievement of at least the minimum flight frequency at the target system load factor. Thus, two operational performance criteria were fraction of market demand satisfied and frequency of service. Another criteria was effect of runway length requirements on number of airports used by the regional airlines. Since runways vary in length among different airports, the number of airports able to accept a new aircraft was a function of aircraft field-length design.

4.2 Economic Criteria

From a pure profit approach, the aircraft which maximized gross earnings appeared the best. Gross earnings were defined as operating income (revenue) less operating expense (direct plus indirect). In some cases, gross earnings were negative. The economic criteria for evaluation and selection of aircraft was the least cost/maximum fleet profit in all operational simulations.

4.3 Aircraft Criteria

Typical criteria for selection of the aircraft best may be applied if some performance parameter is held constant. For instance, with design range constant, a best choice of aircraft might be lowest gross weight, highest cruise speed, minimum mission fuel consumption, or smallest noise footprint on landing or takeoff. Aircraft criteria also could be measured in terms of a minimum or maximum "per passenger" value.

In the initial requirements analysis, aircraft selection criteria primarily were choice of engine cycle for propulsive efficiency and minimum noise, and straight wing fcr manufacturing simplicity. A tracked flap was chosen to minimize gross takeoff weight. An operating altitude of 25,000 feet was chosen to minimize skin gage in the fuselage and requirements for on-board oxygen systems. The engines were mounted on the aft fuselage, one on each side as on the Boeing B-727 and Douglas DC-9 configurations. This choice was made to maximize benefits as follows: added passenger safety in crash landings by major structure below the cabin floor level; minimum length of landing gear; minimum height of cabin above ground level for emergency evacuation; minimum fuselage cross-section; a clean, efficient wing; and engine noise blanking by the wing on landing approach.

4.4 Airport Criteria

A survey of the airports used by those airlines included in the initial network is summarized in Table 4-1. Only five had runway lengths of less than 4,500 feet. These were used by aircraft as large as the Convair 580 and Martin 404, both propeller type aircraft with blade pitch reversal. An altitude and temperature correction was applied to certain of these fields. A list of the airports, pertinent data, and correction results is contained in Appendix B, Section B.7. A summary of the correction effects is included herein as Table 4-2. A total of 107 runways are effectively less than 4,500 feet corrected (1,372 m). The rest are greater than 5,000 feet (1,524 m).

The 4,500 foot field length capability of the baseline aircraft was at sea level and 90°F. (32.2°C.) and at a 100 percent payload and design range. This resulted in a sufficient margin at a 50 percent load factor to justify selection of the 4,500 foot length as suitable for the great majority of fields surveyed.

At least 76 percent of regional carrier runways were suitable for maximum takeoff conditions. General airline operations are usually not at these maximum takeoff weights. Hence, the 24 percent of airports shown were not deemed sufficient to shorten the field length requirement from 4,500 feet.

TABLE 4-1

RUNWAY LENGTHS AND AIRCRAFT USED BY U.S. REGIONAL AIRLINES — 1972

RUNWAY LENGTHS (FEET)	NUMBER OF AIRPORTS		AIRCRAFT USED
	EACH CLASS	CUMULATIVE	
2500 – 2999	1	1	TWIN OTTER
3000 – 3499	0	1	NONE
3500 – 3999	2	3	CONVAIR 580, FH-227, YS-11
4000 – 4499	2	5	BEECH 99, FH-227, MARTIN 404
4500 – 4999	13	18	BEECH 99, CONVAIR 580, CONVAIR 600, F-27, FH-227, MARTIN 404, YS-11
5000 - 5499	60	78	BEECH 99, B-737, CONVAIR 500, CONVAIR 600, F-27, FH-227, MARTIN 404, TWIN OTTER' YS-11
5500 +	365	443	ALL TYPES

TABLE 4-2

REGIONAL CARRIER AIRPORTS CLASSIFIED

BY RUNWAY LENGTHS/ALTITUDE/TEMPERATURE/GRADIENT-CORRECTIONS

RUNWAY LENGTHS (FT)	NUMBER OF AIRPORTS			PERCENT
	EACH CLASS	EACH CLASS CORRECTED*	CUMULATIVE CORRECTED	
2500 - 2999	1	1	1	
3000 3499	0	6	7	7
3500 3999	2	22	29	24
4000 4499	2	78	107	26
4500 4999	13	0	107	
5000 5499	60	8	115	
5500	365	328	443	74%

* CORRECTED TO EFFECTIVE LENGTH FOR THE 85% RELIABILITY TEMPERATURE 59°F AT SEA LEVEL

5.0 OPERATIONAL SIMULATION APPROACH

Aircraft operational performance was measured in all phases of the study by means of an operational simulation technique. The approach was to quantify the aircraft in terms of physical and cost descriptors, simulate operations in a mission model, and derive annual fleet and aircraft performance statistics. This approach is diagrammed in a flow-chart, Figure 5-1. The procedure involved a traffic model which was quantified at a base year and a set of aircraft descriptors. These were input to the operational simulation routine which is computerized. The simulation was conducted either with a single aircraft in a noncompetitive mode, or to select a fleet mix solution from a basic inventory of available aircraft in a competitive mode. In the noncompetitive mode, successive iterations were used to evaluate parametric variations of aircraft descriptors.

The results from the simulation were in the form of a summary for each year of the 15 year operational period. Included in the summaries were data on fleet size, aircraft operations performance, and fleet profitability. A typical summary is presented in Table B-14, Appendix B.

Screening and preliminary selection of aircraft was accomplished manually according to any desired criteria when aircraft were parameterized and simulated noncompetitively. In a competitive simulation, a least-cost criteria was used in the fleet mix selection process.

5.1 Simulation Model

In the single aircraft, noncompetitive mode, the simulation model tested the capability of each aircraft against each element in the traffic network and demand model. The range, speed, payload, target load factor, and

SYSTEMS SIMULATION APPROACH
CONCEPTUAL AIRCRAFT EVALUATION

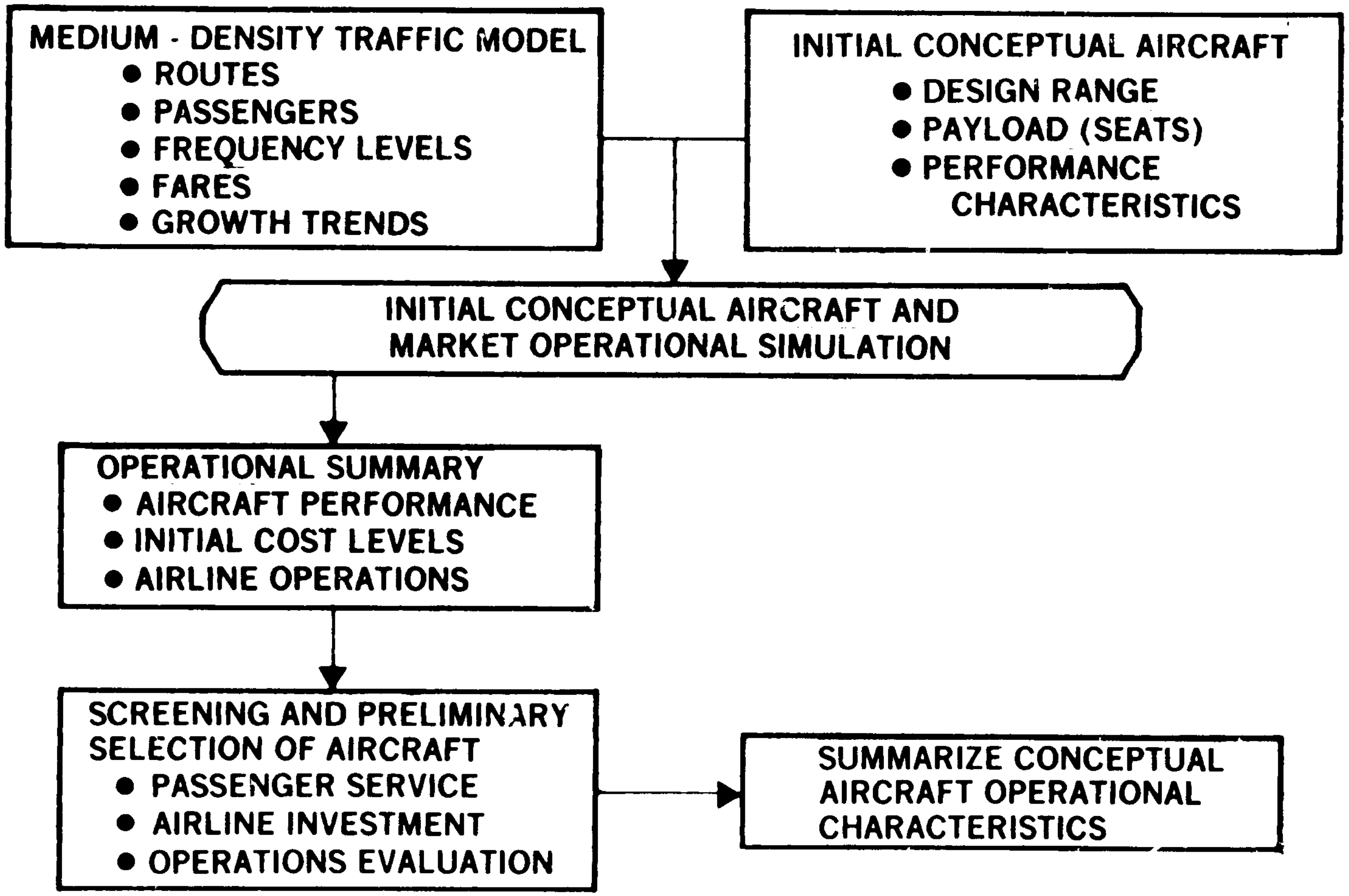


FIGURE 5-1.

annual utilization data were examined. These capabilities were applied to each element to determine number of aircraft required. This determination was based upon the total RPM demanded, the minimum number of flights required, and the average range in each element of the model. The cost of performing this service was computed and operating income determined as revenue less operations cost. Table B-13, Appendix B, contains typical results of a single aircraft evaluation.

In a competitive simulation mode, the same process applied as described above. With a least cost criterion applied for each element, the aircraft satisfying the demand, frequency, and load factor limits at the lowest cost level was assigned to that element. Summation of all elements annually resulted in a total fleet mix with all the pertinent data.

5.2 Derivation of Aircraft Characteristics

With variation of characteristics, a noncompetitive simulation was used to determine which aircraft configuration was the most desirable. In the Requirements Analysis phase, a single aircraft concept was selected for further evaluation on the basis of both operational (schedule frequency) and economic (least-cost) criteria. Typical of these characteristics were range, seating capacity, field length, and engine cycle.

During the Design Study phase, the selected aircraft was studied and evaluated parametrically. Seating capacity was fixed and a range was selected both to cover stage lengths in the model and to incorporate the suggestions made by the subcontractors. Parametric iterations were used to indicate which set of aircraft characteristics best satisfied selection criteria. These were summed as the final design aircraft.

For the Evaluation phase, the basepoint 50 passenger aircraft was analyzed competitively with a fleet of contemporary turboprop and turbofan powered aircraft. A set of factored characteristics was drawn from the 50 passenger basepoint aircraft. These described 30, 40, 60 and 70 passenger aircraft which also were used in the competitive simulation. From this evaluation were drawn the final design aircraft recommendations.

5.3 Fleet Performance Characteristics

The initial noncompetitive evaluation showed variable fleet data which were a summation of mission performance by each concept tested. Data included fleet size, revenue and revenue passenger miles generated, aircraft productivity, fleet average load factor, annual fleet fuel burned, annual trips generated, operating expenses, profit or loss, and ratio of net income of total fleet investment.

The same type of data was generated for competitive simulations. In addition, a fleet mix also was generated with different aircraft assigned to appropriate elements in the mission model.

6.0 CONCEPTUAL AIRCRAFT ANALYSIS AND DESIGN

6.1 General Ground Rules

In order to define and evaluate the medium density market, a family of conceptual aircraft was sized. A description of the basic configuration and an elaboration of the ground rules for sizing of the conceptual aircraft follows:

6.1.1 Configuration Description

The configuration used in the conceptual aircraft family (shown in Figure 6-1) has twin, aft-fuselage-mounted, fixed-pitch, turbofan engines, and a low wing with an aspect ratio of 9.0, a 5^o (0.087 radians) quarter-chord sweep, and the nominal high lift system described in Section 6.3.6. This configuration, similar to the DC-9 and B-737, was selected because of: crash landing safety; landing gear retraction; fuselage cross-sectional area; drag; wing efficiency; inlet duct ingestion; and blanketing by the wing of noise on approach. In the various parametric analyses conducted with the conceptual aircraft, DOC is used as the basis for evaluation. See Section 3.1 for airframe cost.

The basic passenger capacity is 50 passengers. The basic fuselage cross section (shown in Figure 6-2) consists of 4 abreast seating using DC-8 economy-class seats at a 32-inch (86 cm) pitch, with an 18 inch (48 cm) wide by 78 inch (198 cm) high single aisle. The cabin entrance, service, and emergency exit doors are appropriate for FAA requirements. The cabin has one lavatory per 50 seats, bare minimum galley/buffet service or operational closet space, and lower cargo bays for stowing luggage or freight. A layout for the 50 passenger cabin is shown in Figure 6-3.

GENERAL ARRANGEMENT
MEDIUM DENSITY AIRCRAFT
(PARAMETRIC BASE POINT)

PAYLOAD:	50 PASSENGERS ALL ECONOMY 4 ABREAST 32-IN. SEAT PITCH
WING AREA:	497 SQ FT
TOGW:	43,920 LB
WING LOADING:	90 LB/SQ FT
TOFL:	4500 FT
ENGINE:	2 TURBOFAN BPR-6 TSLS = 7980 LB EA

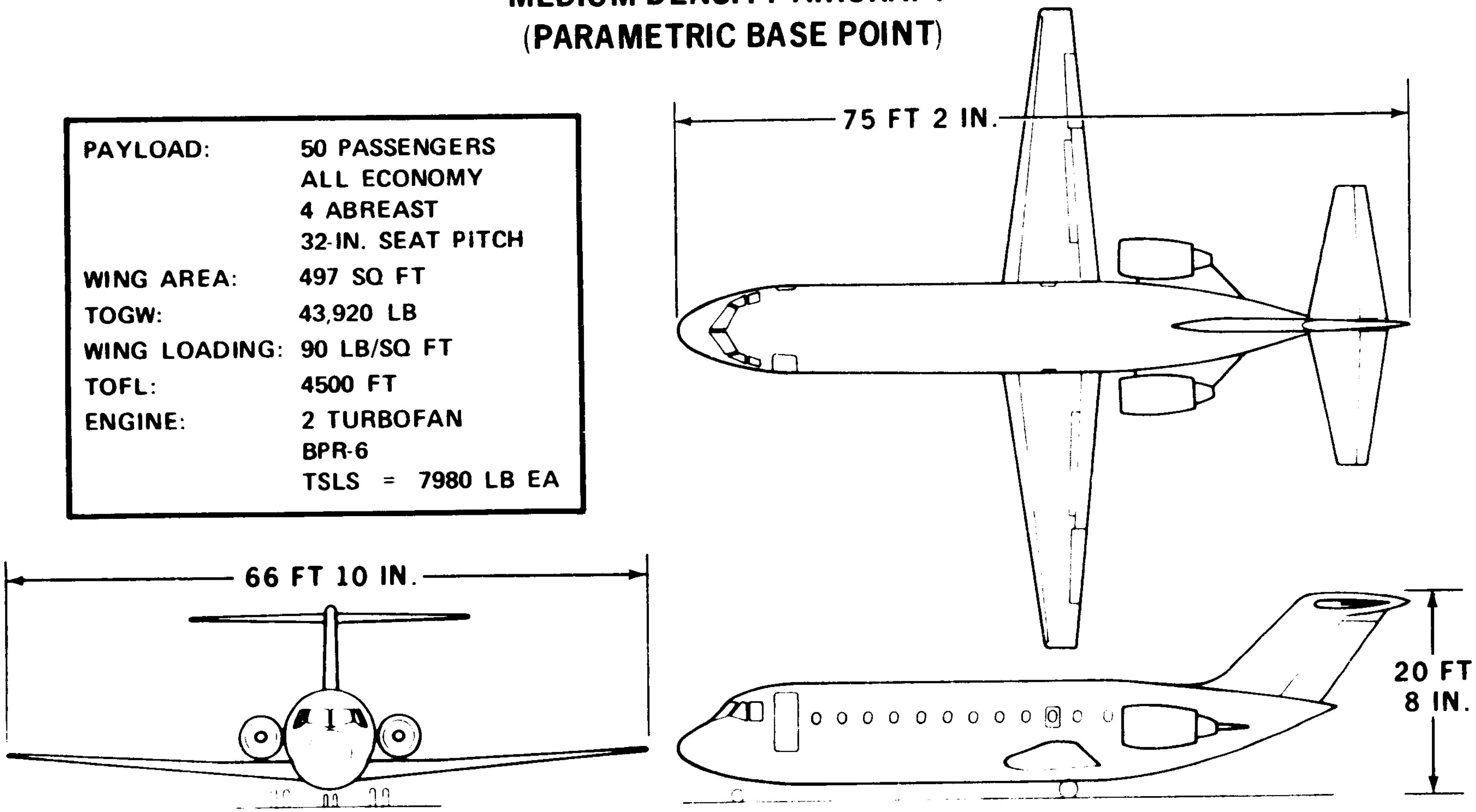


FIGURE 6-1

FUSELAGE CROSS-SECTION STUDY

CUSP FUSELAGE: LOWER BAGGAGE

MECHANICALLY
FASTENED
LONGERONS

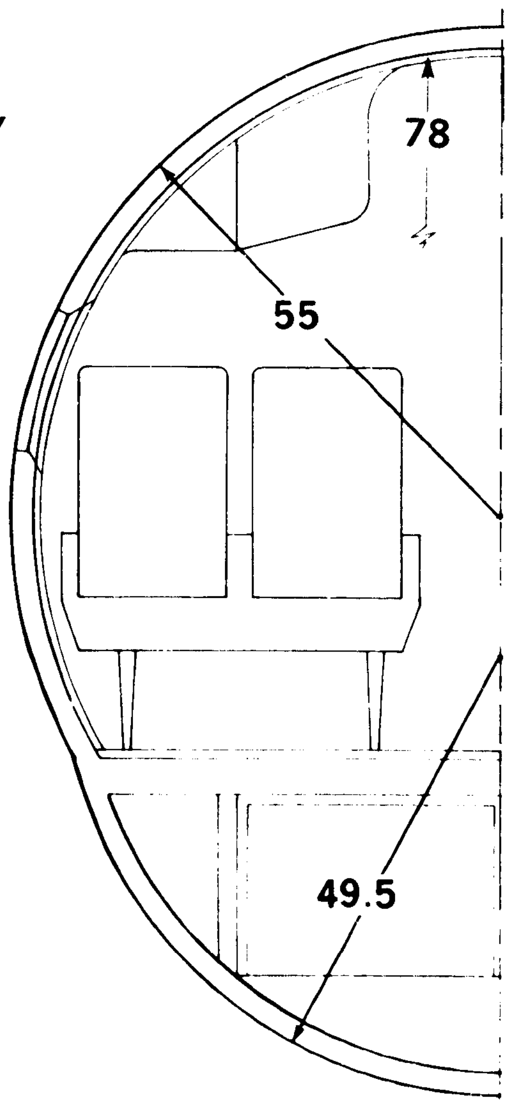


FIGURE 6-2.

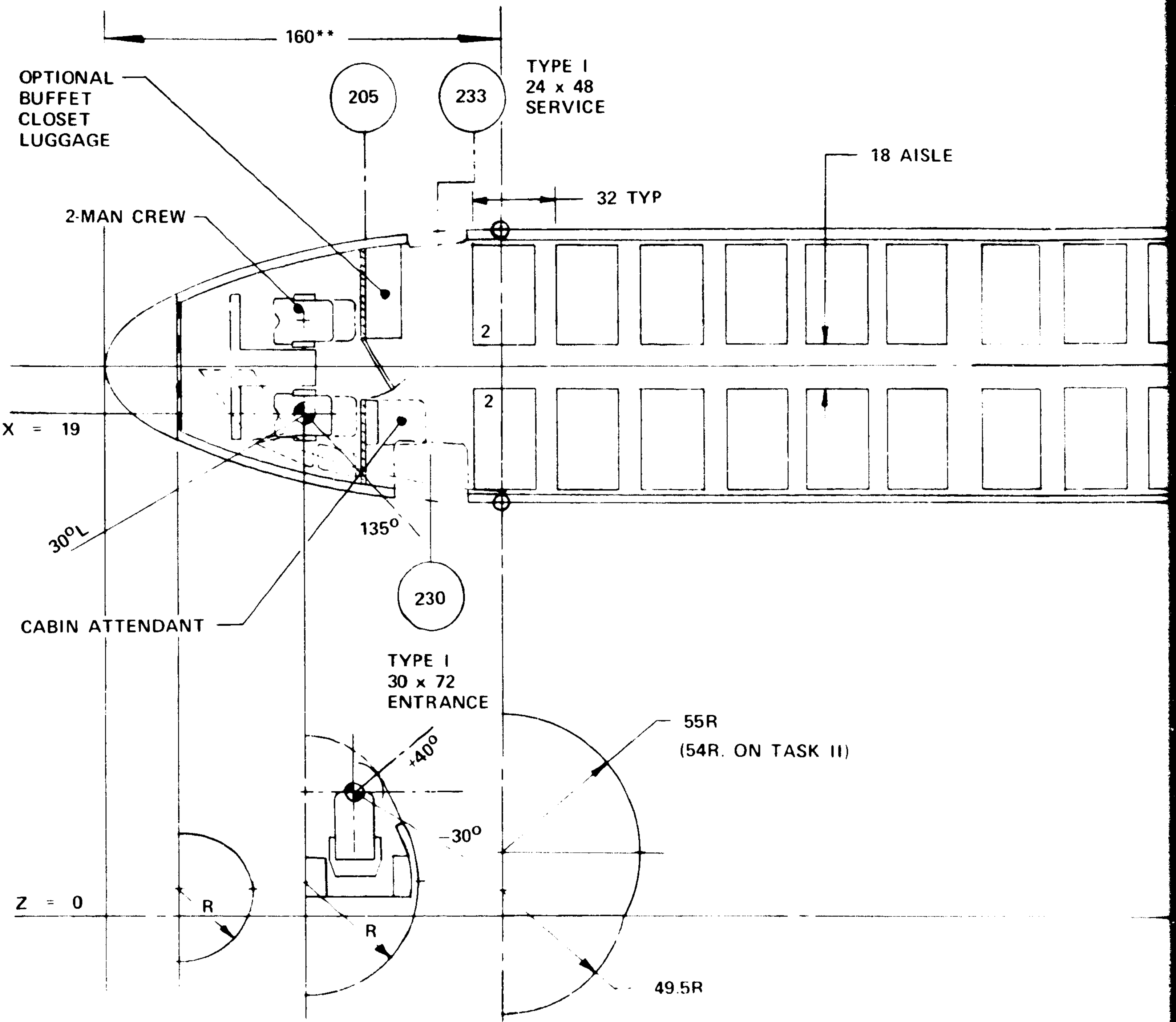
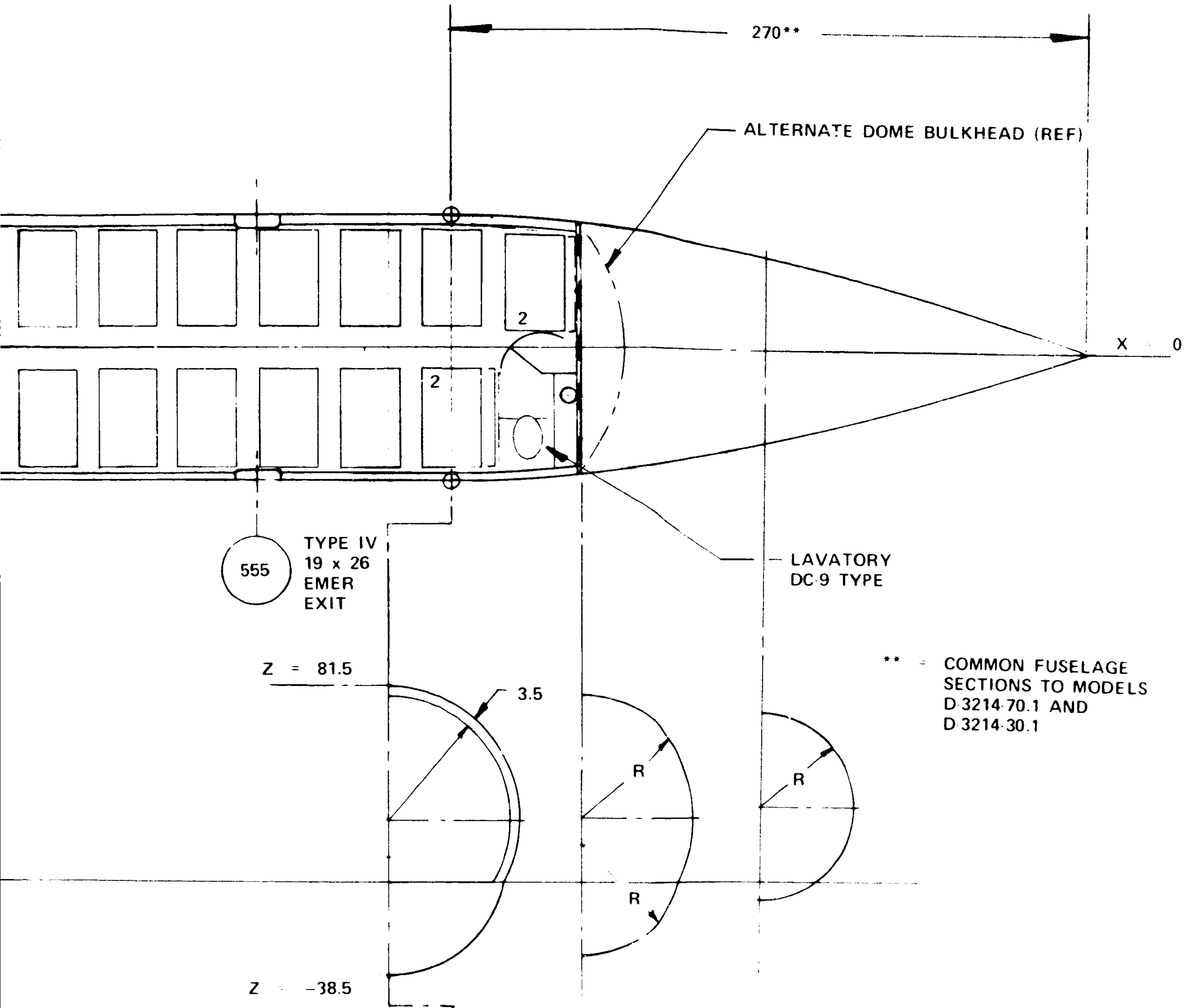


FIGURE 6-3. FUSELAGE

ORIGINAL PAGE IS
OF POOR QUALITY

FOLDOUT FRAME /



E 6-3. FUSELAGE STUDY

FOLDOUT FRAME

6.1.2 Mission Profile

The basic sizing mission profile for the conceptual aircraft (shown in Figure 6-4) has two equal stage lengths of 250 nautical miles (463 km); 563 nautical miles (1,042 km) is the single stage equivalent. Both stage lengths consist of: a takeoff time and fuel allowance; climb to cruise altitude < 25,000 feet (7,620 m); constant altitude cruise at near-maximum speed (typical minimum DOC airline operation); a 300 feet/minute (1.524 m/sec) cabin pressurization rate limited descent to the destination airport; and a landing time and fuel allowance. The reserve fuel requirement, calculated at the end of the second stage, contains sufficient fuel to climb, cruise, and descend 100 nautical miles (185 km) to an alternate airport, followed by holding at maximum endurance at cruise altitude for 45 minutes (2,700 sec). Mission performance calculations are based on standard day conditions.

6.1.3 Takeoff and Landing Capability

The conceptual aircraft takeoff and landing calculations were based on sea level, 90°F day performance. The methods and assumptions used for takeoff and landing calculations are presented in Appendix A. The basic field length requirement is 4,500 feet (1,372 m).

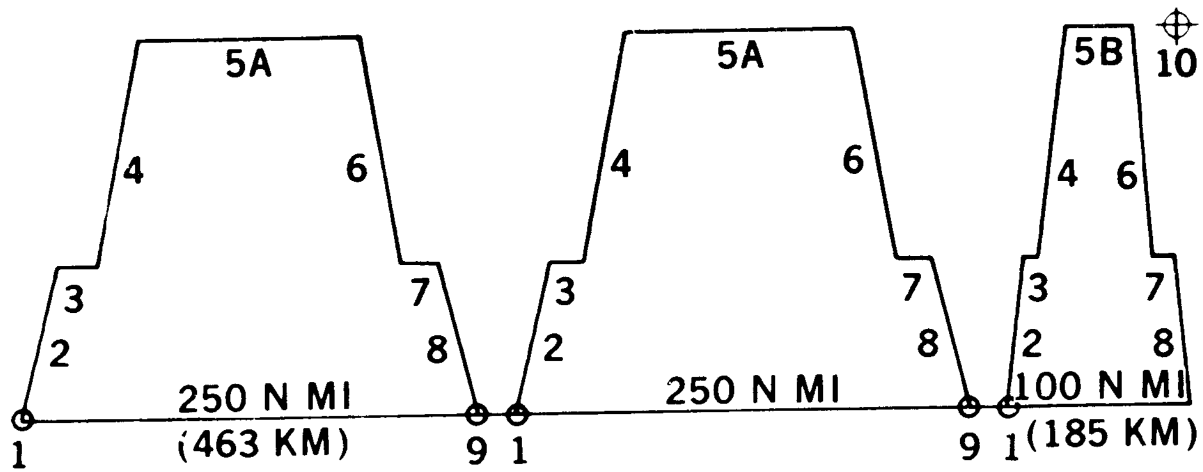
6.2 Propulsion Requirements

The fixed-pitch turbofan propulsion system is the basic system for the conceptual aircraft analysis. The variable-pitch turbofan and turboprop propulsion systems were studied and evaluated with the fixed-pitch turbofan in order to select a propulsion system for the basepoint aircraft studies.

6.2.1 Criteria

Criteria imposed on the propulsion systems studied were:

SIZING MISSION PROFILE



1. TAXI-OUT (3 MINUTES) AND TAKEOFF AND ACCELERATE TO BEST CLIMB SPEED (2 MINUTES)
2. CLIMB AT 250 KIAS (129 M/S) TO 10,000 FT (3048 M)
3. ACCELERATE TO CLIMB SPEED
4. CLIMB AT 300 KIAS (154 M/S) TO CRUISE ALTITUDE

5A. CRUISE AT MAX MACH NO. AT 25,000 FT (7620 M)

5B. CRUISE AT 99 PERCENT MAX SPECIFIC RANGE

6. DESCEND TO 10,000 FT (AT FLIGHT IDLE, INCL 300 FPM PRESSURIZATION CABIN RATE LIMITED DESCENT).
7. DECELERATE TO 250 KIAS
8. DESCEND AT 250 KIAS TO S.L.
9. APPROACH AND LAND (3 MINUTES) AND TAXI-IN (2 MINUTES)
10. HOLD (45 MINUTES) AT MAX ENDURANCE

FIGURE 6-4

- Low Noise: The engine noise signature must be low enough for the aircraft to meet a level of 10 EPNdB below the present FAR Part 36 requirements.

- Thrust reversing capability: This requirement provides a safety margin for stopping on wet or icy runways, and for reduction of brake wear and maintenance. The airline subcontractors agreed on the desirability of this feature.

- Availability: The propulsion types were limited to those for which realistic installed performance estimates could readily be made. The scope of the study did not include generation of cycle and installed performance data on new types and variations of propulsion systems.

- Low Cost: A propulsion system with low initial cost, low fuel consumption, and low maintenance is essential for aircraft for medium-density operation. The propulsion systems were compared on the basis of DOC. See Section 3.1 for engine cost.

6.2.2 Candidate Engine Cycles

Basic propulsion system characteristics for the fixed-pitch and variable-pitch turbofan engines, and the turboshaft-propeller (turboprop) propulsion system are shown in Tables 6-1 and 6-2.

Installed engine performance was estimated in all cases. Installation losses included inlet and exhaust duct pressure losses, bleed and power extraction losses, and exhaust flow scrubbing losses. Based on past experience, a value of approximately 1.5 lb/minute/passenger was used for the aircraft

TABLE 6-1

TURBOFAN CHARACTERISTICS

	Fixed-Pitch Fan	Variable-Pitch Fan
Fan Pressure Ratio	1.45	1.32
Bypass Ratio	6	12.8
(1)Specific Thrust, lb/lb/sec	28.3	22.9
uninstalled (N/kg/sec)	(277)	(224.)
(1)Fan Tip Speed, ft/sec	1400	925
(m/sec)	(427)	(282)
(2)Cruise Thrust/Rated Thrust	0.30	0.23
(2)Cruise SFC	0.63	0.60
Thrust/Weight	5.2	6.7

(1)SLS, Takeoff

(2)Uninstalled; M_o = 0.7; 25,000 ft. (7625 m)

TABLE 6-2

TURBOPROP SYSTEM CHARACTERISTICS

Engine Power/(Prop.Dia.)^2	25 hp/ft^2	(200 kw/m^2)
Engine Power/Weight	5.5 hp/lb	(9.0 kw/kg)
Static Thrust/Power	1.85 lb/hp	(11 N/kw)
Propeller Tip Speed	720 ft/sec	(220 m/sec)
Propeller Activity Factor	180	
Propeller Integrated Lift Coefficient	0.3	
Cruise Efficiency* (Propeller)	0.86	

* Mach 0.6; 25,000 ft.

bleed requirement. The propulsion systems were "rubberized", i.e., scaled to the thrust level required for the aircraft to meet the design conditions.

The fixed-pitch turbofan engine used in this study has a bypass ratio of six and a fan pressure ratio of 1.45. Previous studies indicated that an engine with these characteristics has a relatively low noise level and can meet the noise level requirement with reasonable acoustic treatment. It has a low development cost with minimum technical risk, and a low installed SFC. Based on engine company data, Figure 6-5 shows the effect of engine size (Reynolds number and tolerances) on cruise SFC. For engine cycle and performance details see Section 7.2.1.

The variable-pitch fan engine used in this study has a bypass ratio of 13 and a fan pressure ratio of 1.32; the performance was generated using a DAC cycle deck (see Reference 1). Although not optimized for the missions herein, these cycle characteristics were considered applicable based on previous short-range mission studies. The variable-pitch fan engine requires a development program of higher cost and risk than that for the fixed-pitch fan engine. The current QCSEE project is a technology development program for a variable-pitch fan engine with a 1.28 takeoff fan pressure ratio. Higher fan-pressure ratios will improve cruise performance, and although considered feasible, this will involve more technical risk and development cost. The major advantage of the variable-pitch feature is the provision of reverse thrust without the weight, complexity, cost and maintenance of nacelle-mounted thrust reversers. Other advantages are good cruise SFC, fast engine response and low noise level.

For aircraft of the size and range with which this study is concerned, propeller propulsion systems offer some advantages, because their low initial

ESTIMATED EFFECT OF ENGINE SIZE ON CRUISE SFC

BYPASS RATIO 6

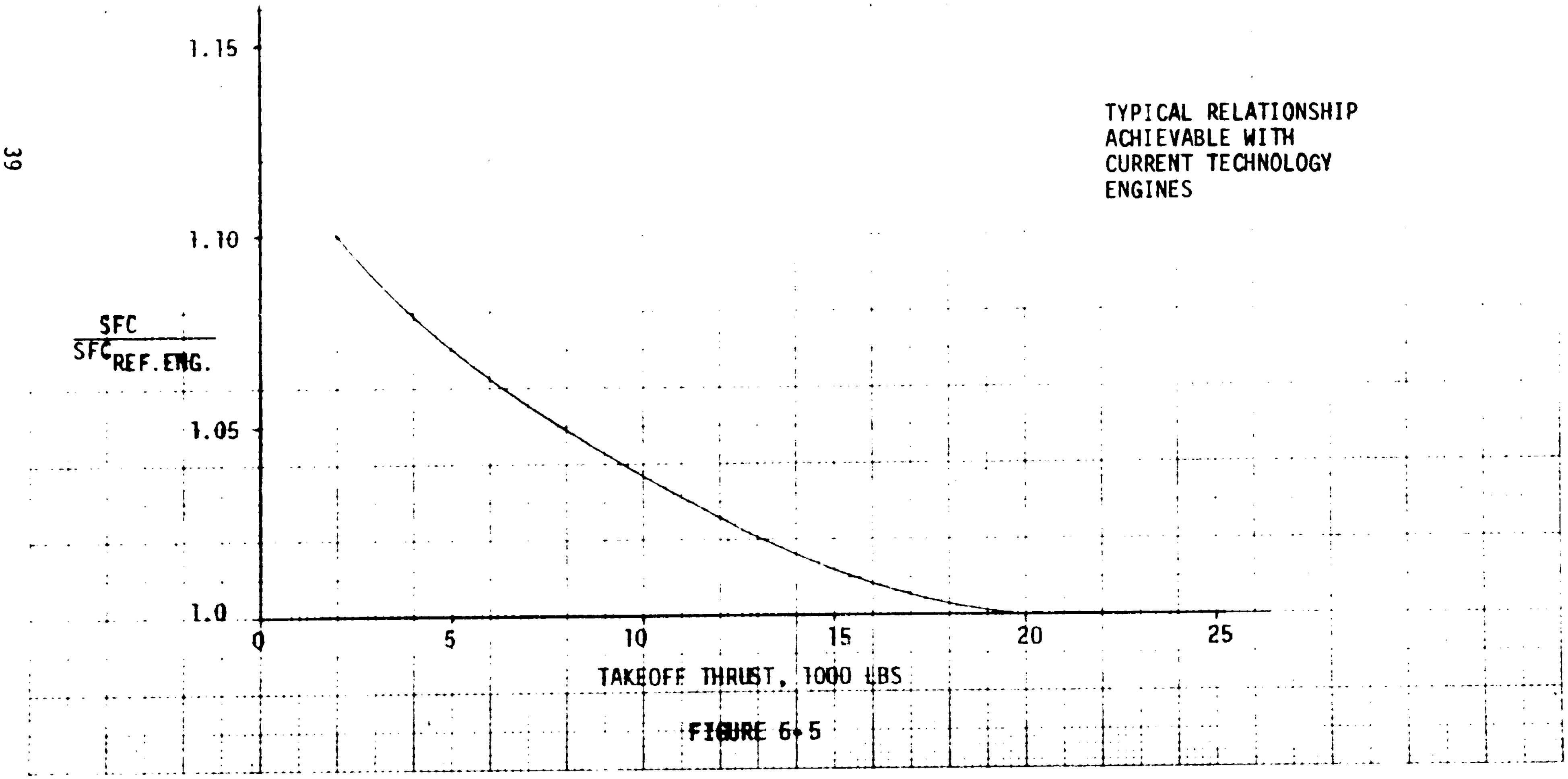


FIGURE 6-5

cost and low fuel consumption offset the low aircraft speed provided by their lower cruise thrust. The propeller/horsepower relationship was selected to give a high ratio of thrust-to-horsepower for takeoff, while maintaining a good propeller efficiency during cruise. A propeller tip speed of 720 ft/sec (220 m/sec) was selected as a compromise between noise and aircraft design considerations; the lower tip speed propellers produce less noise, but need larger diameters to provide a given thrust. The propeller integrated lift coefficient, C_{Li} of 0.3 is typical for modern propellers with a moderately high speed cruise requirement. A study was made of the effect of activity factor on the propulsion system, with the results shown in Figure 6-6. An activity factor of 180 provides the lowest weight, with a reasonable propeller diameter and cruise efficiency. The resulting four-bladed propeller is similar aerodynamically to that used in the Lockheed-Electra. Appendix A gives the details of the selection of the propeller-engine relationship, based on a technique described in Reference 2.

The scope of the study did not include the quantitative evaluation of less conventional engine cycles, because uninstalled performance data were not available in sufficient detail. Two "unconventional" cycles which have been proposed for aircraft use are a regenerative-cycle gas generator driving a fan or propeller, and a rotary engine driving a fan or propeller. Further study is required to assess the suitability of these, and other cycles, to medium-density aircraft applications. Estimates of factors such as development cost, technical risk, etc., need to be made and compared with the potential performance and other advantages that might be achieved with new types of propulsion systems.

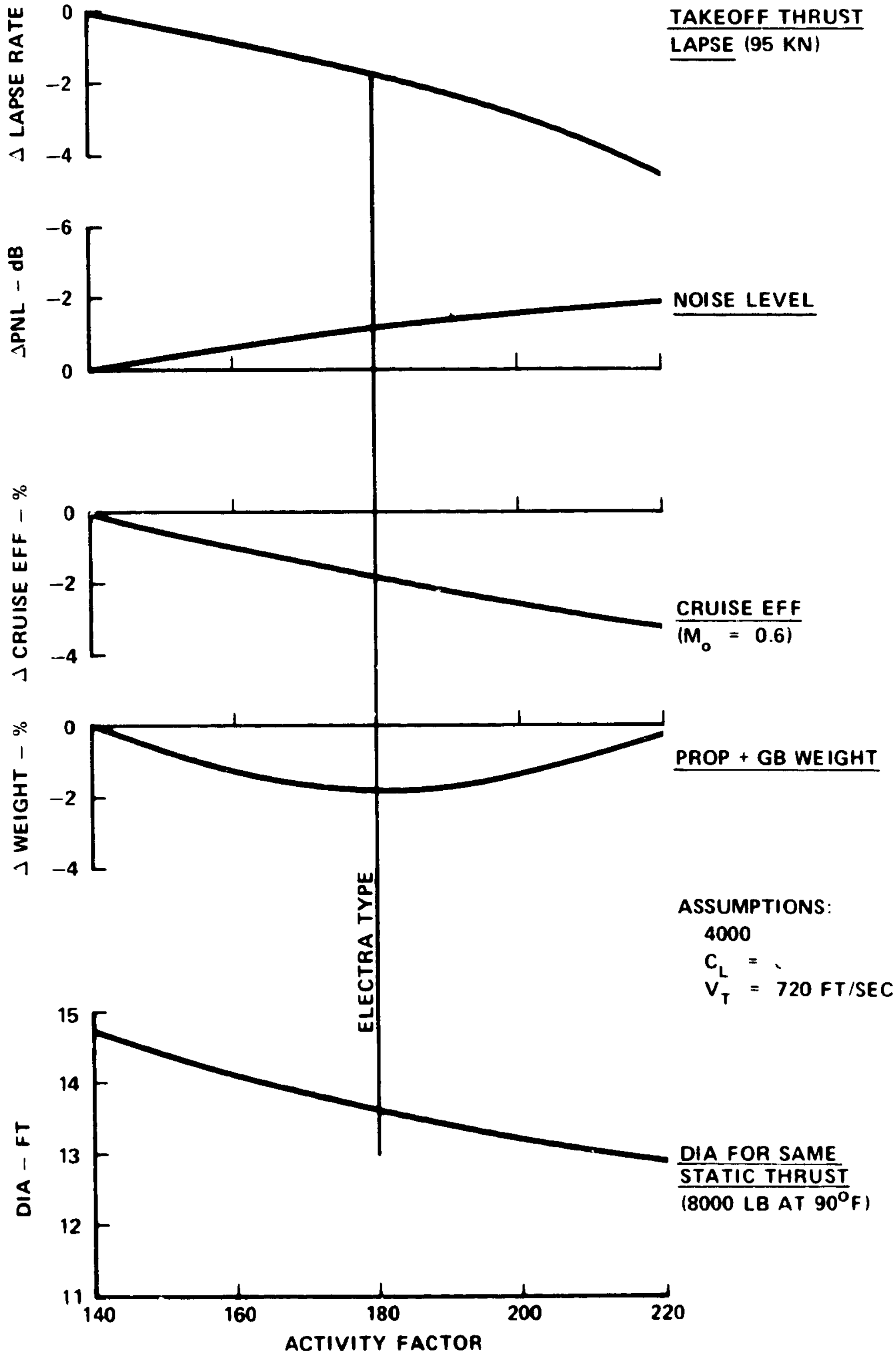


FIGURE 6-6. EFFECT OF PROPELLER ACTIVITY FACTOR

6.2.3 Initial Engine Selection: Basepoint Aircraft

The consensus of the regional and trunk airline subcontractors is that a turboprop-powered aircraft has less passenger appeal because customers have come to expect the vibration-free operation and modern appearance of turbofan aircraft. Of the two turbofan concepts, the fixed-pitch fan engine has the lower development cost and technical risk. Therefore, the fixed-pitch fan engine was selected for the basepoint aircraft propulsion system.

6.3 Parametric Aircraft Analysis: Variations and Results

Table 6-3 summarizes the variable and discrete parameters covered in this study: passenger payload, field length, range, engine cycle type and high-lift systems type. The parametric excursions were centered on a base conceptual aircraft, defined below.

6.3.1 Base Conceptual Aircraft Sizing

The base conceptual aircraft was sized for 50 passenger capacity, 4,500 foot (1,372 m) field length capability, and 2 x 250 nautical mile (2 x 463 km) stage lengths with the fixed-pitch fan engine (see Figure 6-1 above).

Sizing mission calculations were made for several of the wing loading (W/S) and uninstalled thrust-to-weight ratio (T/W) combinations which satisfy the 4,500 foot (1,372 m) field length requirement; see Figure 6-7. The selected design point for the base conceptual aircraft was chosen on the basis of minimum DOC. The W/S, T/W combination of the selected design point is at the point for balanced takeoff and landing field length. The base conceptual aircraft characteristics are summarized in Table 6-4.

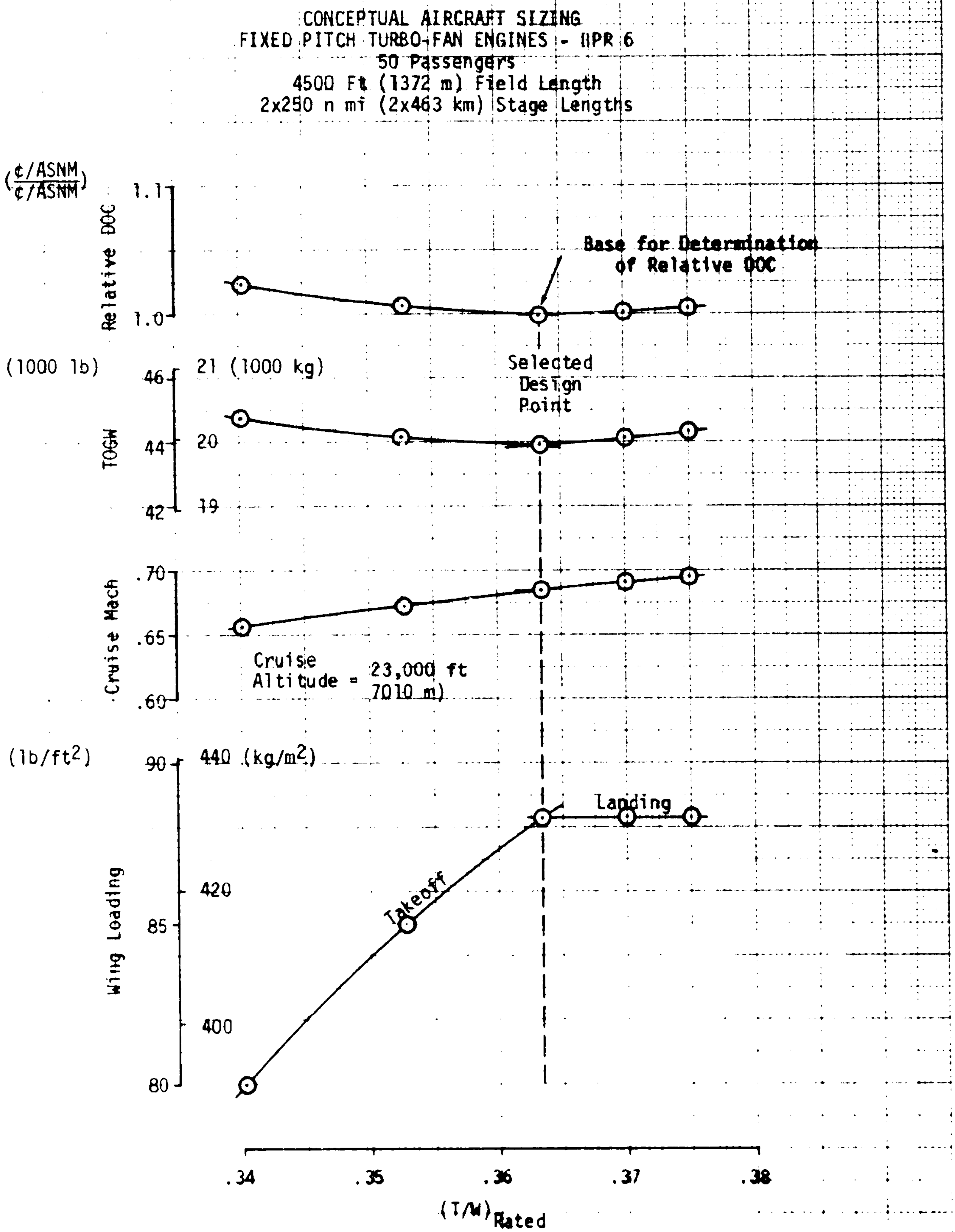
TABLE 6-3

AIRCRAFT DESIGN PARAMETERS

PSGR (NO.)	FIELD LENGTH (FT)	RANGE (N MI) SINGLE (DUAL) STAGE	ENGINE TURBO-FAN	VP FAN	TURBO-PROP
30	4,500	1 x 563 (2 x 250)	⊙		
50	3,500	1 x 563 (2 x 250)	⊙		
	4,500	1 x 337 (2 x 150)	⊙		
		1 x 563 (2 x 250)	⊕	⊙	⊙
		1 x 775 (2 x 350)	⊙		
		1 x 1,000 (2 x 460)	⊙	•	•
	5,500	1 x 563 (2 x 250)	⊙		
70	4,500	1 x 563 (2 x 250)	⊙		

○ NOISE STUDY: FAR 36 -10 EPNdB

+ HI-LIFT SYSTEMS STUDY



CONCEPTUAL AIRCRAFT SIZING
FIXED PITCH TURBO-FAN ENGINES - BPR 6
50 Passengers
4500 Ft (1372 m) Field Length
2x250 n mi (2x463 km) Stage Lengths
(¢/ASNM / ¢/ASNM)
Relative DOC
1.1
1.0
Base for Determination of Relative DOC
Selected Design Point
(1000 lb)
21 (1000 kg)
TOGW
46
44
42
20
19
Cruise Mach
.70
.65
.60
Cruise Altitude = 23,000 ft 7010 m)
(lb/ft2)
440 (kg/m2)
Wing Loading
90
85
80
420
400
Landing
Takeoff
.34
.35
.36
.37
.38
(T/W)Rated

FIGURE 6-7

TABLE 6-4. BASELINE CONCEPTUAL AIRCRAFT SUMMARY

Passenger Capacity		50
Field Length	(ft/m)	4500/1372
Stage Lengths	(n mi/km)	(2 x 250)/(2 x 463)
Engines: Fixed-Pitch Fan	(BPR/FPR)	6/1.45
Rated Thrust	No. x (lb/N)	2 x (7980/35,500)
Takeoff Gross Weight	(lb/kg)	43,920/19,920
Operator's Weight Empty	(lb/kg)	27,040/12,265
Wing Area	(ft^2/m^2	497/46.2
Wing Loading	($lb/ft^2/kg/m^2$)	88.3/431.1
Thrust-to-Weight Ratio: Rated		0.363
Cruise Altitude	(ft/m)	23,000/7010
Cruise Mach Number		0.69

6.3.2 Variation of Field Length Capability

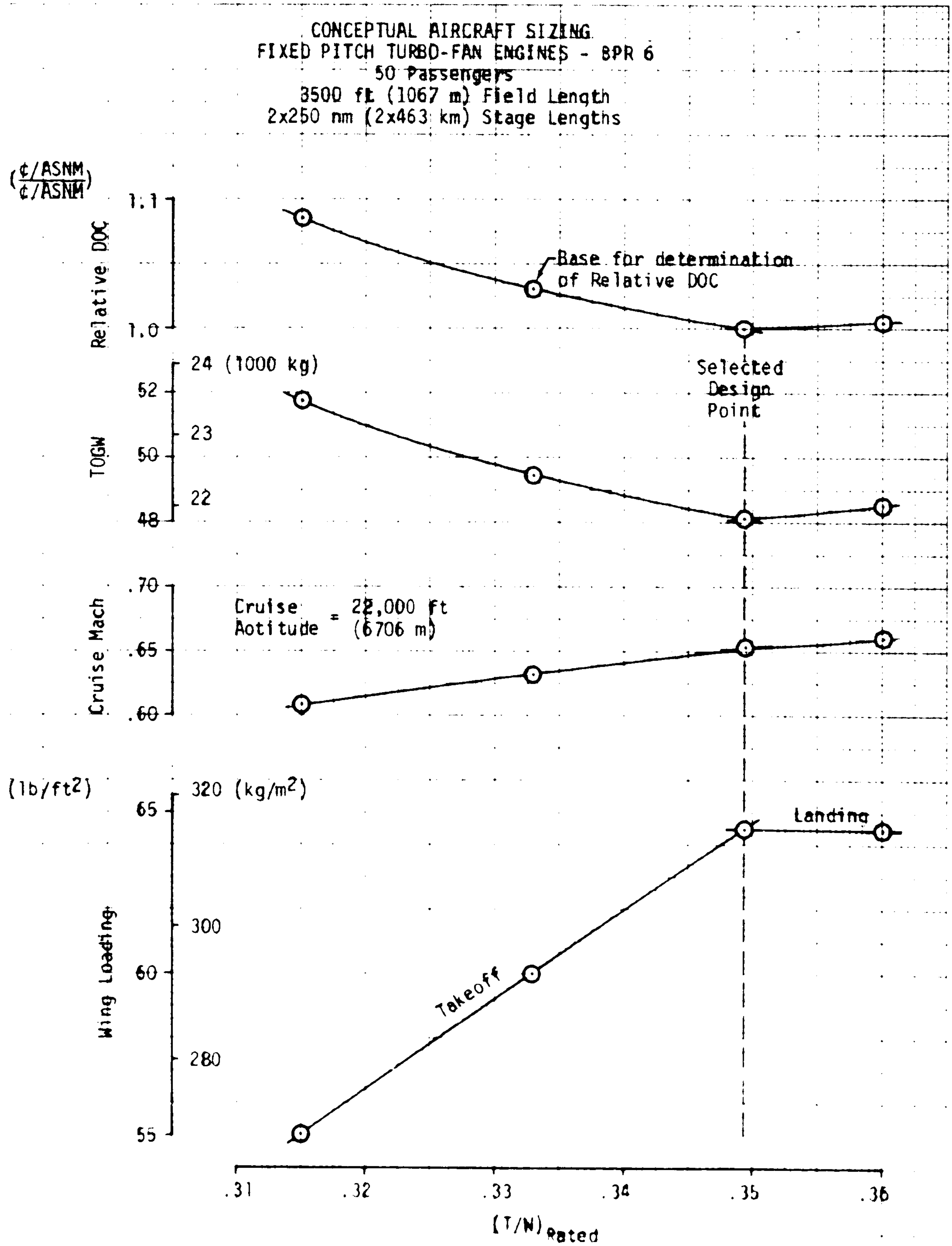
Calculations were made to determine the effect on aircraft sizing of varying the field length requirement from the base requirement of 4,500 feet (1,362 m). Takeoff and landing calculations were made to determine several W/S and T/W combinations required for 3,500 foot (1,067 m) or 5,500 foot (1,676 m) field length capabilities.

Using these W/S and T/W combinations, conceptual aircraft were sized for 50 passenger capacity, 2 x 250 nautical mile (2 x 463 km) stage lengths, and 3,500 foot (1,067 m) or 5,500 foot (1,676 m) field length capability. The selected design points for both field lengths are at the W/S and T/W combination for minimum DOC at that field length. Both selected design points occur at the W/S and T/W combination for balanced takeoff and landing field length, as depicted in Figures 6-8 and 6-9. A summary comparing aircraft characteristics of the configurations having field length capabilities of 3,500 feet (1,067 m), 4,500 feet (1,372 m), and 5,500 feet (1,676 m) is presented in Table 6-5.

Figure 6-10, showing the effect of field length on sizing, indicates that decreasing the field length requirement to less than 4,500 feet (1,372 m) causes a disproportionate increase in required takeoff gross weight and DOC.

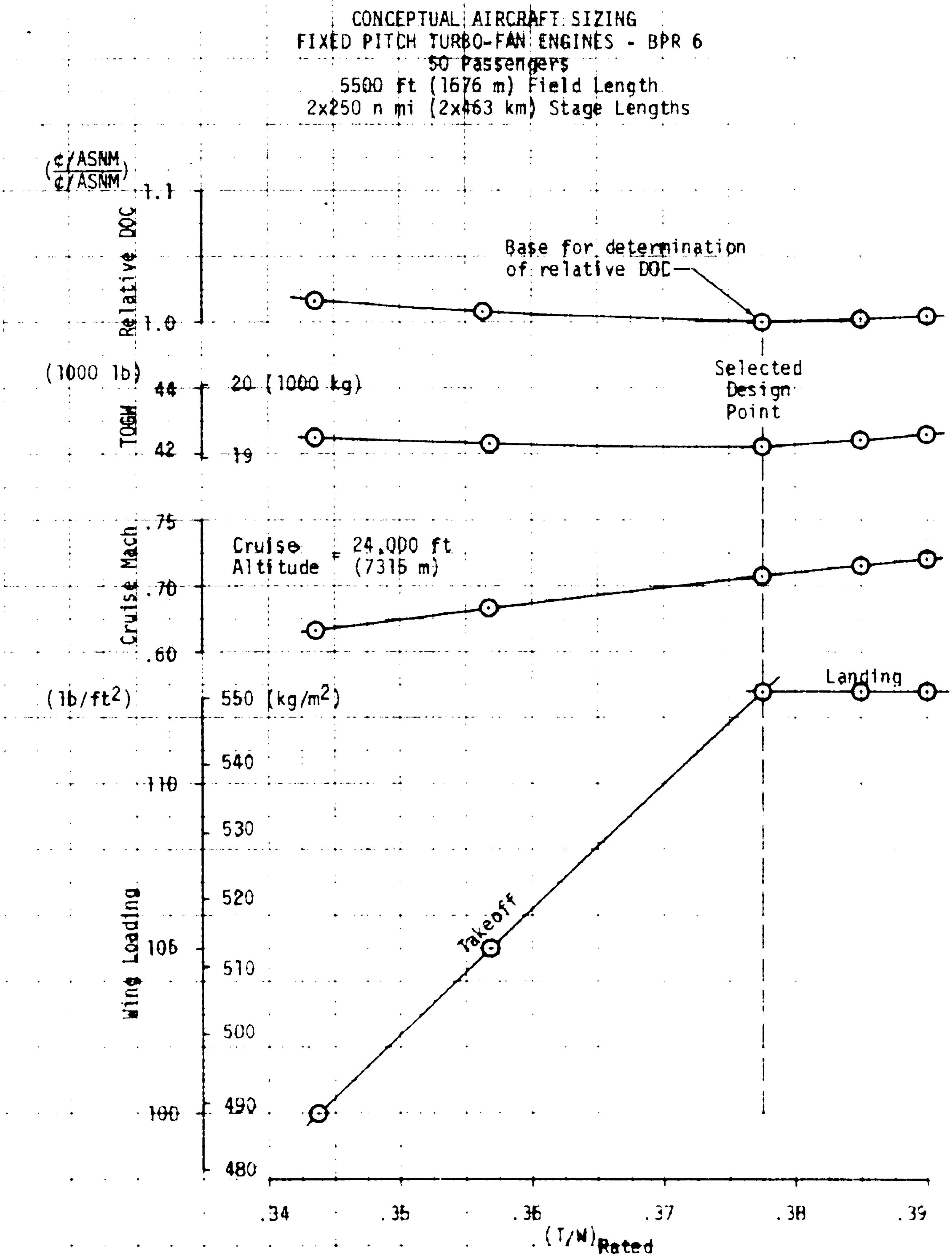
6.3.3 Variation of Passenger Capacity

Minimum and maximum passenger capacities of 30 and 70 were used to size conceptual aircraft for investigation of the effects of passenger capacity on aircraft sizing. As was the base 50 passenger capacity aircraft, these aircraft were sized for 4,500 foot (1,372 m) field length capability and a range capability of 2 x 250 nautical mile (2 x 463 km) stage lengths.



CONCEPTUAL AIRCRAFT SIZING
FIXED PITCH TURBO-FAN ENGINES - BPR 6
50 Passengers
3500 ft (1067 m) Field Length
2x250 nm (2x463 km) Stage Lengths
(¢/ASNM / ¢/ASNM)
Relative DOC
1.1
1.0
Base for determination of Relative DOC
24 (1000 kg)
23
22
52
50
48
TOGW
Selected Design Point
.70
.65
.60
Cruise Mach
Cruise Altitude = 22,000 ft (6706 m)
(lb/ft²)
320 (kg/m²)
300
280
65
60
55
Wing Loading
Takeoff
Landing
.31
.32
.33
.34
.35
.36
(T/W) Rated

FIGURE 6-8



CONCEPTUAL AIRCRAFT SIZING
FIXED PITCH TURBO-FAN ENGINES - BPR 6
50 Passengers
5500 ft (1676 m) Field Length
2x250 n mi (2x463 km) Stage Lengths
(¢/ASNM / ¢/ASNM)
Relative DOC
1.1
1.0
Base for determination of relative DOC
Selected Design Point
(1000 lb)
44
42
20 (1000 kg)
19
TOGW
Cruise Mach
.75
.70
.60
Cruise Altitude = 24,000 ft (7315 m)
(lb/ft2)
110
105
100
550 (kg/m2)
540
530
520
510
500
490
480
Wing Loading
Landing
Takeoff
.34
.35
.36
.37
.38
.39
(T/W)Rated

FIGURE 6-

TABLE 6-5. CONCEPTUAL AIRCRAFT SUMMARY, FIELD LENGTH VARIATION

50 Passengers

2 x 250 n mi (2 x 463 km) Stage Lengths

Fixed-Pitch Fan: BPR/FPR = 6/1.45

Field Length (ft/m):		3500/1067	4500/1372	5500/1676
Takeoff Gross Weight	(lb/km)	48,150/21,840	43,920/19,920	42,220/19,150
Operator's Weight Empty	(lb/kg)	30,650/13,900	27,040/12,265	25,460/11,550
Wing Area	(ft^2/m^2)	747/69.4	497/46.2	374/34.7
Rated Thrust	No.x(lb/N)	2x(8410/37,410)	2x(7980/35,500)	2x(7970/35,450)
Wing Loading	(lb/ft^2/ kg/m^2)	64.5/314.9	88.3/431.1	112.8/550.7
Thrust-to-Weight Ratio, Rated		0.349	0.363	0.378
Cruise Altitude	(ft/m)	22,000/6706	23,000/7010	24,000/7315
Cruise Mach Number		0.65	0.69	0.71
Relative Direct Operating Cost (¢/ASNM ÷ ¢/ASNM)		1.08	1.00*	0.97

*Base for determination of relative DOC

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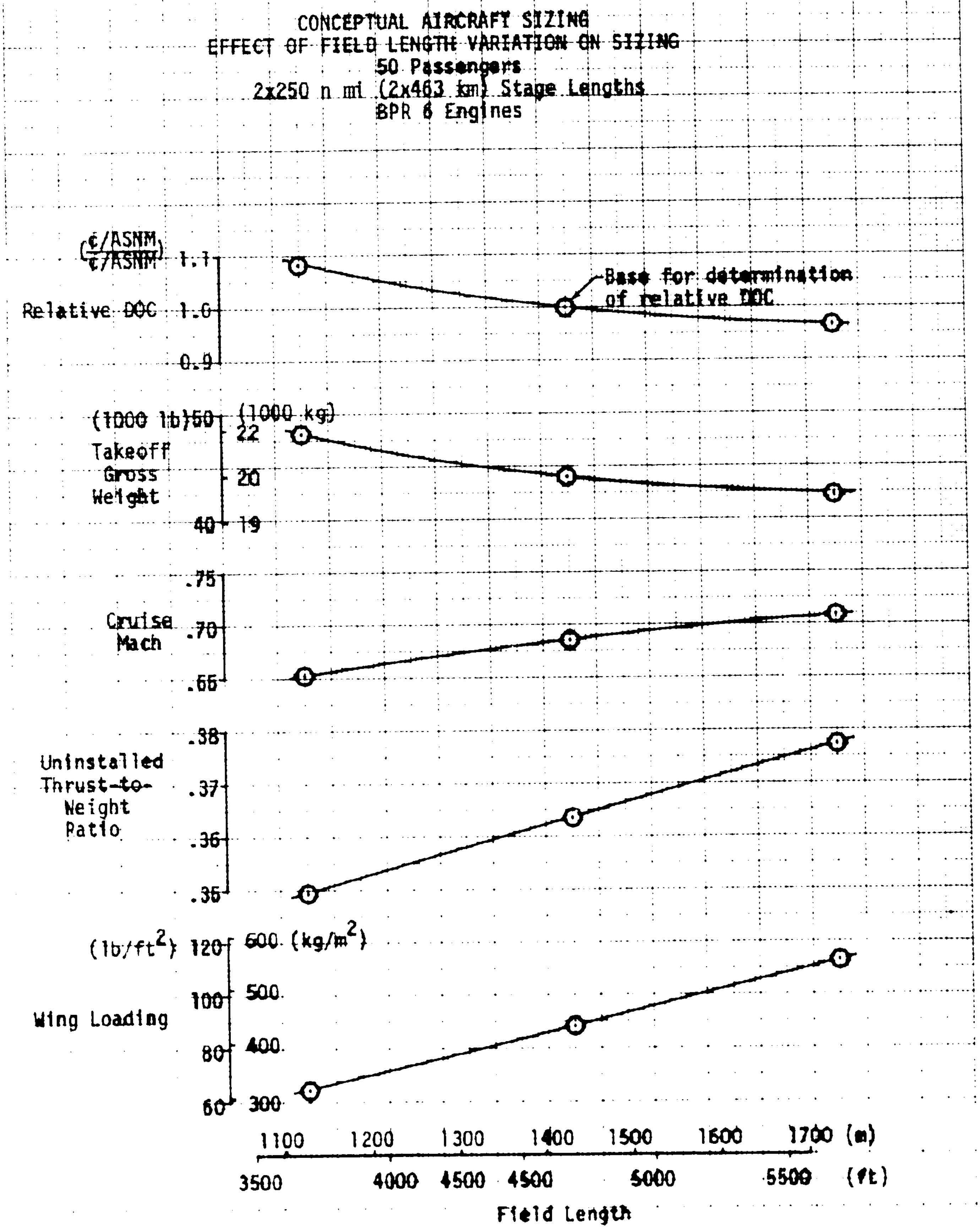

FIGURE 6-1

Sizing plots for the 30 and 70 passenger capacity aircraft, Figures 6-11 and 6-12, show that the minimum DOC points for these aircraft occur at the W/S and T/W combination for balanced takeoff and landing field length capability. This is also the case for the base 50 passenger capacity aircraft. A summary comparing characteristics of the 30, 50, and 70 passenger capacity aircraft is shown in Table 6-6.

In addition to the above comparison, passenger capacity variations of 30, 50, and 70 were used for sizing aircraft with 4,500 foot (1,372 m) field length capability and a range capability of one 775 nautical mile (1,435 km) stage length. The resultant aircraft characteristics for passenger capacity variation with 775 nautical mile (1,435 km) range capability are shown in Table 6-7. These configurations were also sized at the W/S and T/W combination for balanced takeoff and landing field length capability.

Figure 6-13 shows the variation of aircraft characteristics with passenger capacity. This figure shows a disproportionate increase in DOC as passenger capacity is decreased.

6.3.4 Variation of Range Capability

The effects of varying range capability on aircraft sizing were investigated by sizing aircraft with several range capabilities. The base 50 passenger capacity and 4,500 foot (1,372 m) field length capability requirements were used for sizing aircraft with range capabilities of 2 x 150 nautical mile (2 x 278 km) stage lengths, 2 x 350 nautical mile (2 x 648 km) stage lengths, and 1 x 1,000 nautical mile (1 x 1,852 km) stage length.

Figures 6-14, 6-15 and 6-16 show the variations of pertinent sizing parameters for these aircraft. The selected design point for each of these

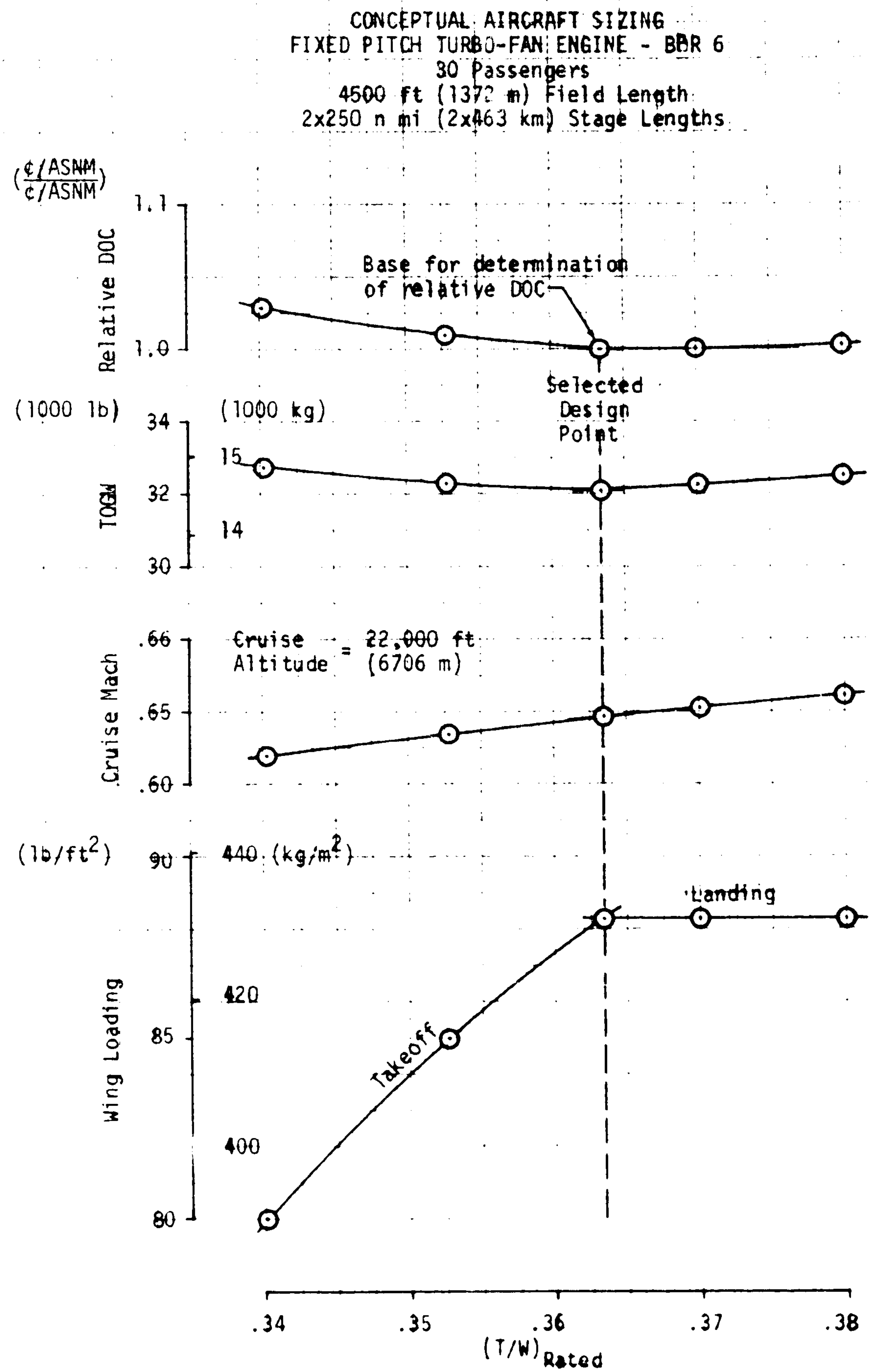
CONCEPTUAL AIRCRAFT SIZING
FIXED PITCH TURBO-FAN ENGINE - BBR 6
30 Passengers
4500 ft (1372 m) Field Length
2x250 n mi (2x463 km) Stage Lengths
(¢/ASNM / ¢/ASNM)
Relative DOC
1.1
1.0
Base for determination of relative DOC
Selected Design Point
(1000 lb)
(1000 kg)
TOGW
34
32
30
15
14
Cruise Mach
.66
.65
.60
Cruise Altitude = 22,000 ft (6706 m)
(lb/ft²)
440 (kg/m²)
Wing Loading
90
85
80
420
400
Landing
Takeoff
.34
.35
.36
.37
.38
(T/W) Rated

FIGURE 6-11

CONCEPTUAL AIRCRAFT SIZING
FIXED PITCH TURBO-FAN ENGINES - BPR 6
70 Passengers
4500 ft (1372 m) Field Length
2x250 n mi (2x463 km) Stage Lengths

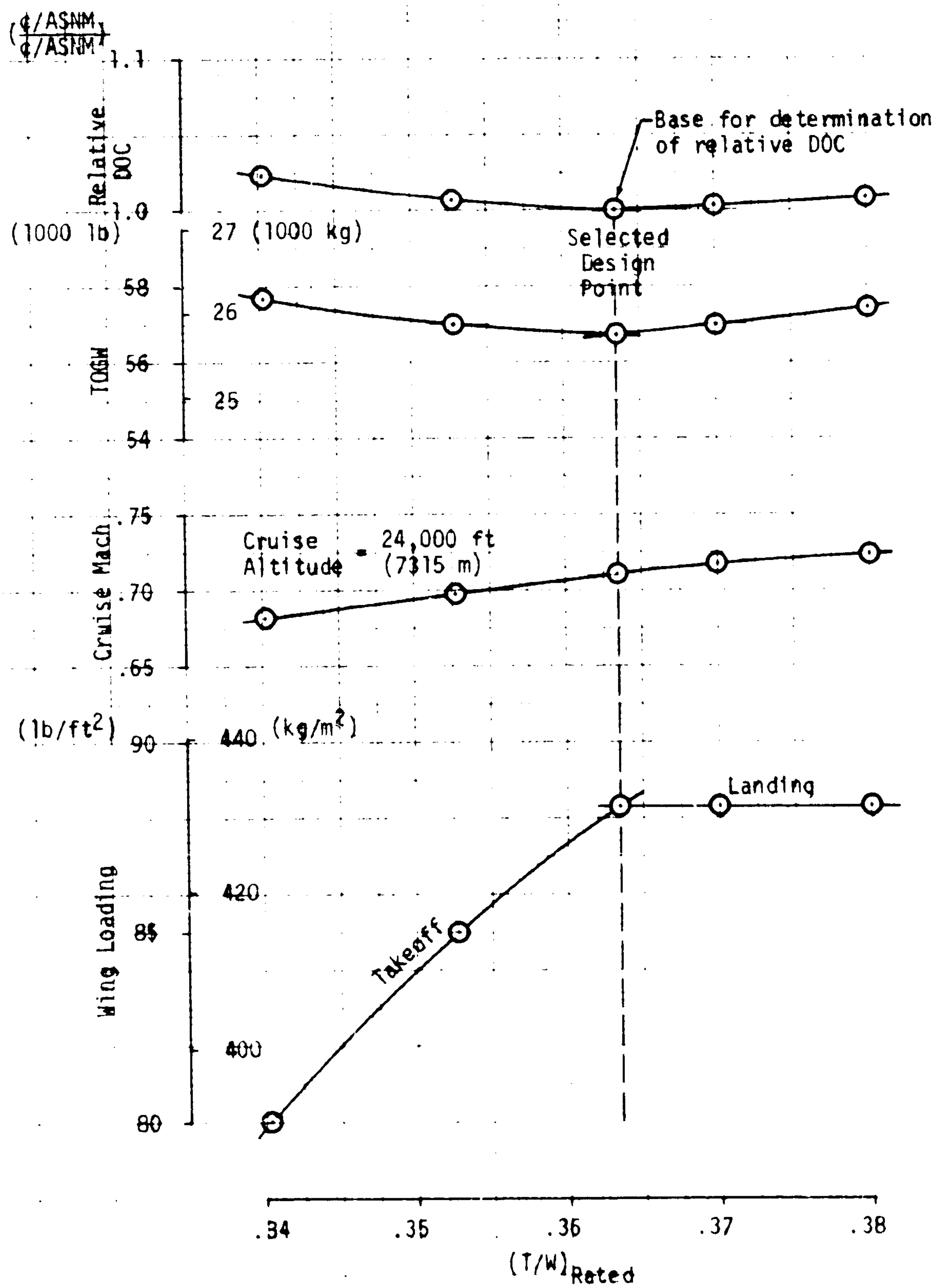

FIGURE 6-12

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TABLE 6-6. CONCEPTUAL AIRCRAFT SUMMARY, PASSENGER CAPACITY VARIATION

2 x 250 n mi (2 x 643 km) Stage Length

4500 ft (1372 m) Field Length

Fixed-Pitch Fan: BPR/FPR = 6/1.45

Passenger Capacity:		30	50	70
Takeoff Gross Weight	(lb/kg)	32,080/14,550	43,920/19,920	56,730/25,730
Operator's Weight Empty	(lb/kg)	20,590/9340	27,040/12,265	34,380/15,590
Wing Area	(ft^2/m^2)	363/110.6	497/46.2	642/195.7
Rated Thrust	No.x(lb/N)	2x(5830/25,930)	2x(7980/35,500)	2x(10,310/45,860)
Wing Loading	(lb/ft^2/ kg/m^2)	88.3/431.1	88.3/431.1	88.3/431.1
Thrust-to-Weight Ratio, Rated		0.363	0.363	0.363
Cruise Altitude	(ft/m)	22,000/6706	23,000/7010	24,000/7315
Cruise Mach Number		0.65	0.69	0.71
Relative Direct Operating Cost (¢/ASNM ÷ ¢/ASNM		1.47	1.000*	0.81

*Base for determination of relative DOC

TABLE 6-7. CONCEPTUAL AIRCRAFT SUMMARY, PASSENGER CAPACITY VARIATION

1 x 775 n mi (1 x 1435 km)
4500 ft (1372 m) Field Length
Fixed-Pitch Fan: BPR/FPR = 6/1.45

Passenger Capacity:		30	50	70
Takeoff Gross Weight	(lb/kg)	33,950/15,400	46,600/21,140	59,960/27,200
Operator's Weight Empty	(lb/kg)	21,240/9,630	27,960/12,680	35,460/16,080
Wing Area	(ft^2/m^2)	385/35.8	528/49.1	679/63.1
Rated Thrust	No.x(lb/N)	2x(6170/27,450)	2x(8470/37,680)	2x(10,890/48,440)
Wing Loading	($lb/ft^2/kg/m^2$)	88.3/431.1	88.3/431.1	88.3/431.1
Thrust-to-Weight Ratio, Rated		0.363	0.363	0.363
Cruise Altitude	(ft/m)	25,000/7620	25,000/7620	25,000/7620
Cruise Mach Number		0.67	0.70	0.72
Relative Direct Operating Cost (¢/ASNM ÷ ¢/ASNM)		1.48	1.00*	0.80

*Base for determination of relative DOC

DOC Relative to Table 6-6	1.27	0.86	0.69

CONCEPTUAL AIRCRAFT SIZING
EFFECT OF PASSENGER CAPACITY VARIATION ON SIZING
4500 Ft (1372 m) Field Length
BPR 6 Engines

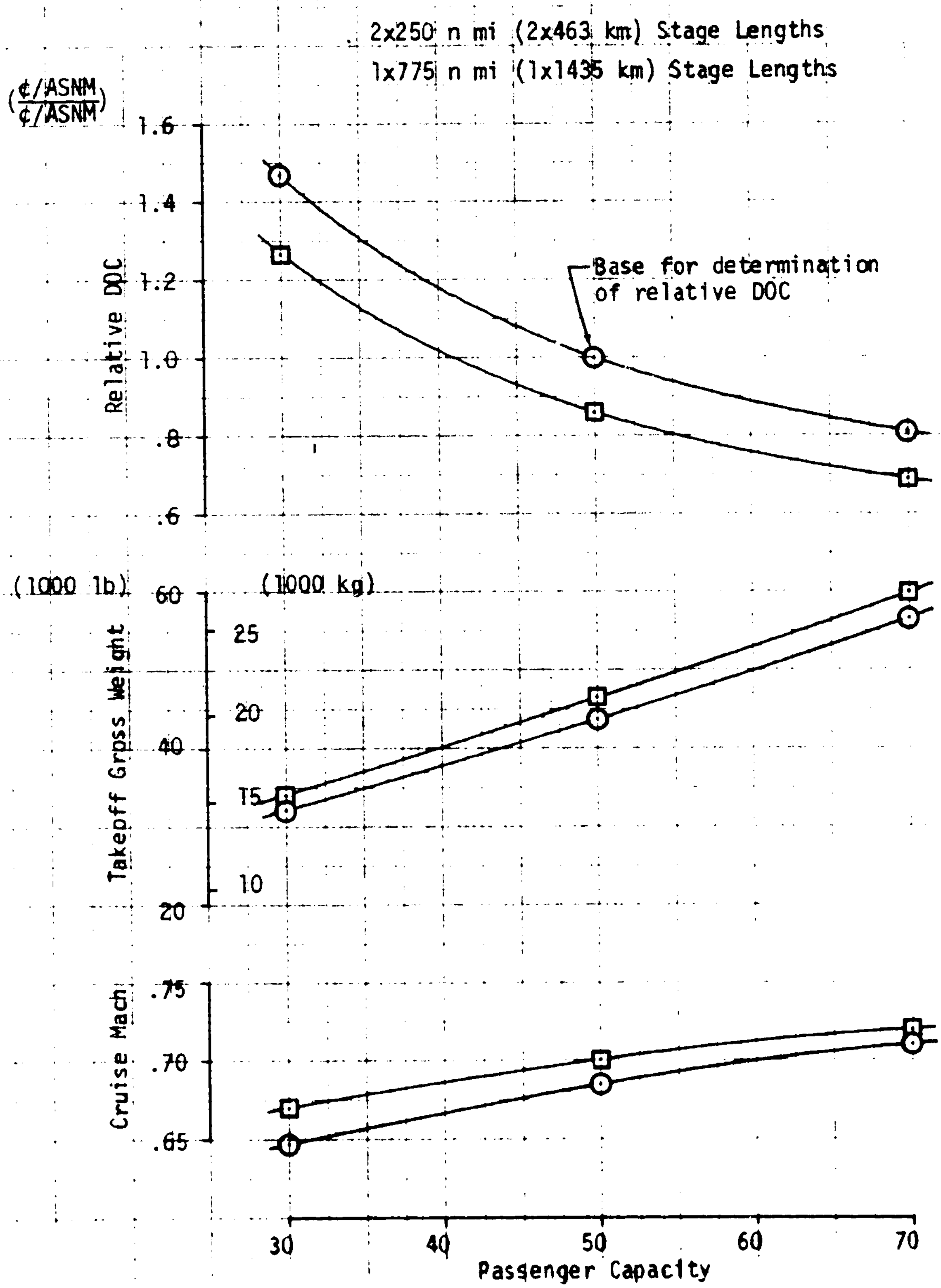

FIGURE 6-13

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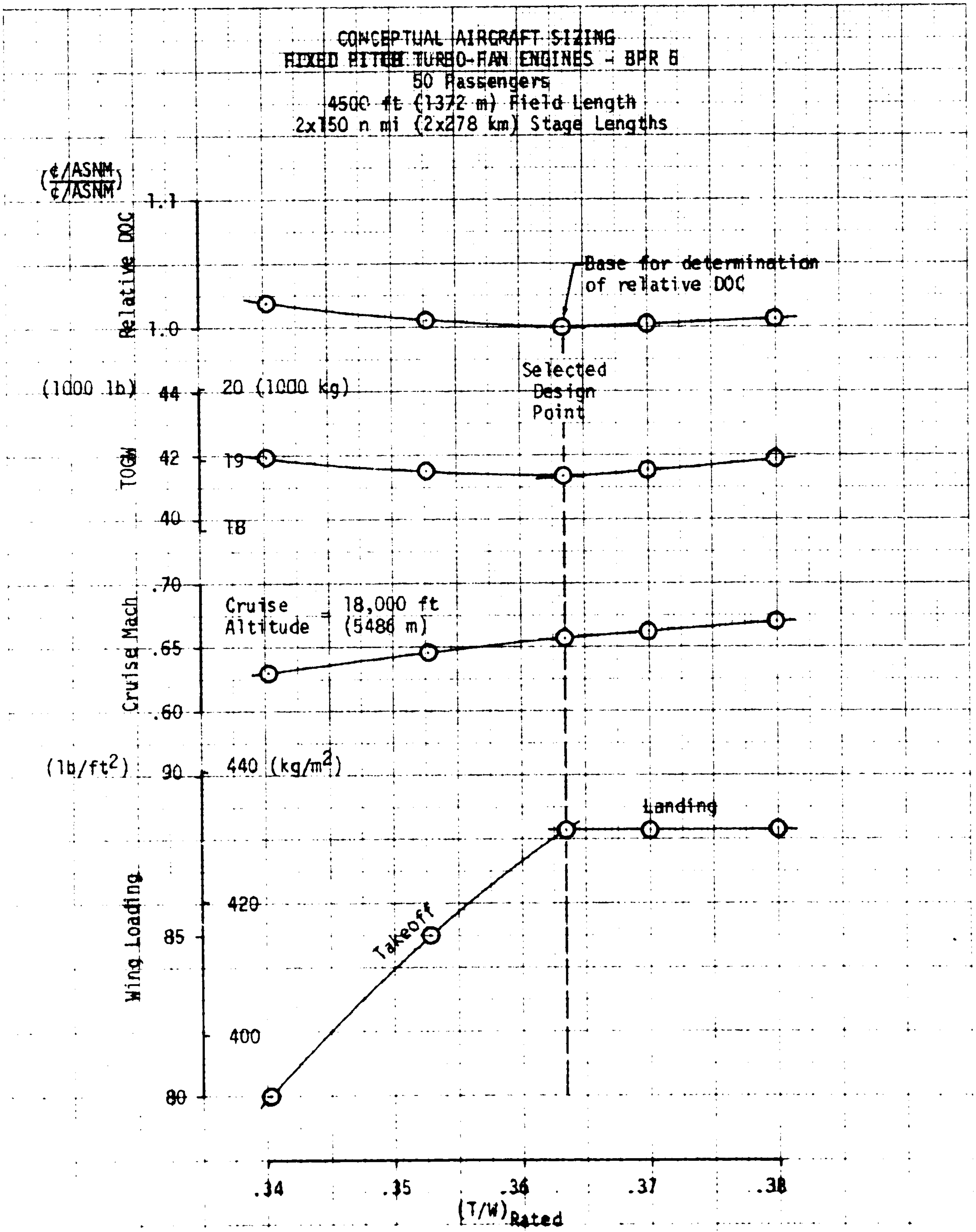
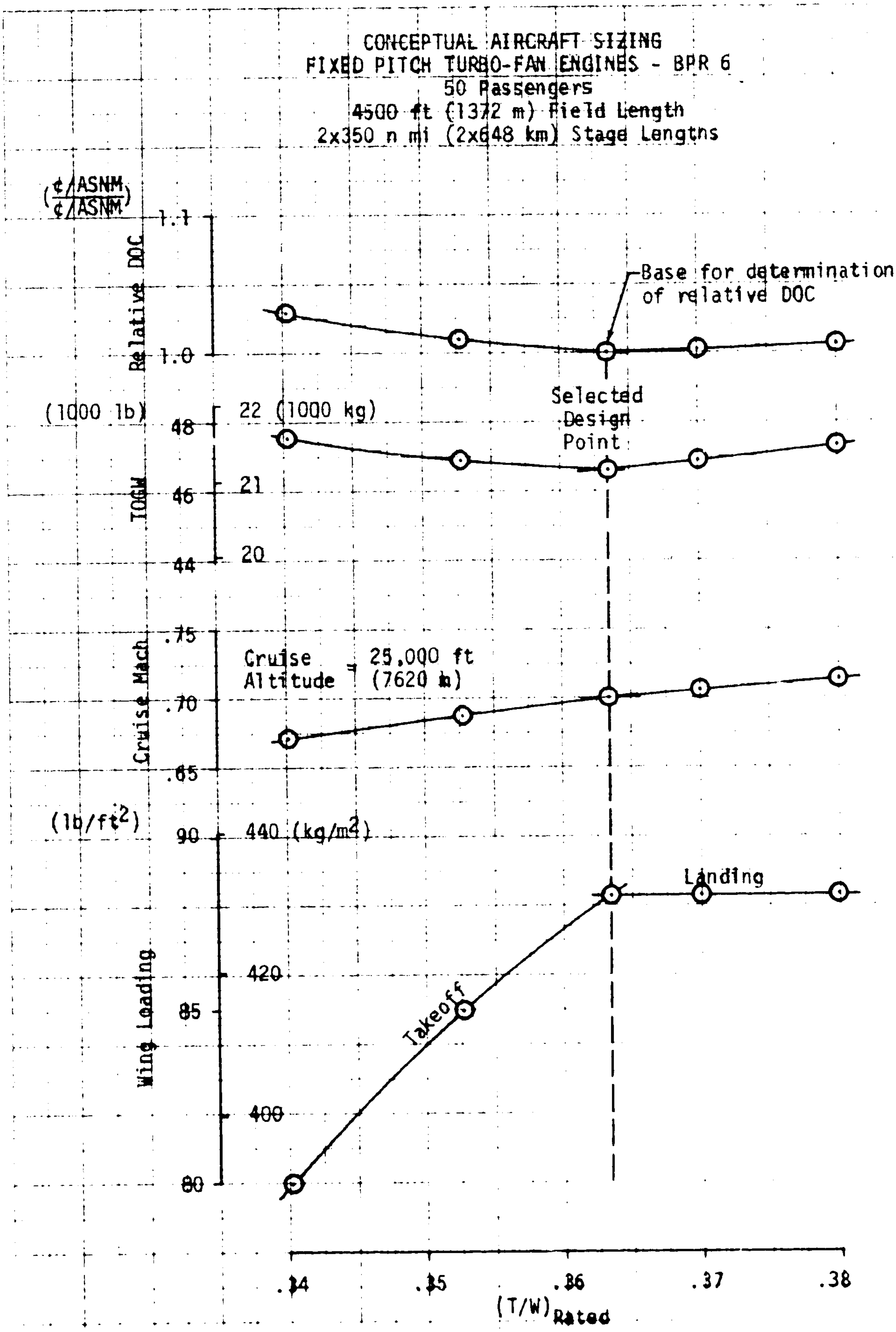


CONCEPTUAL AIRCRAFT SIZING
FIXED PITCH TURBO-FAN ENGINES - BPR 6
50 Passengers
4500 ft (1372 m) Field Length
2x150 n mi (2x278 km) Stage Lengths
(¢/ASNM / ¢/ASNM)
Relative DOC
1.1
1.0
Base for determination of relative DOC
Selected Design Point
(1000 lb)
20 (1000 kg)
TOGW
44
42
40
19
18
Cruise Mach
.70
.65
.60
Cruise Altitude = 18,000 ft (5486 m)
(lb/ft2)
440 (kg/m2)
Wing Loading
90
85
80
420
400
Landing
Takeoff
.34
.35
.36
.37
.38
(T/W)Rated

FIGURE 6-14


CONCEPTUAL AIRCRAFT SIZING
FIXED PITCH TURBO-FAN ENGINES - BPR 6
50 Passengers
4500 ft (1372 m) Field Length
2x350 n mi (2x648 km) Stage Lengths
(¢/ASNM / ¢/ASNM)
Relative DOC
1.1
1.0
Base for determination of relative DOC
Selected Design Point
(1000 lb)
22 (1000 kg)
48
46
44
21
20
TOGW
.75
.70
.65
Cruise Mach
Cruise Altitude = 25,000 ft (7620 m)
(lb/ft²)
90
85
80
440 (kg/m²)
420
400
Wing Loading
Landing
Takeoff
.34
.35
.36
.37
.38
(T/W) Rated
FIGURE 6-15

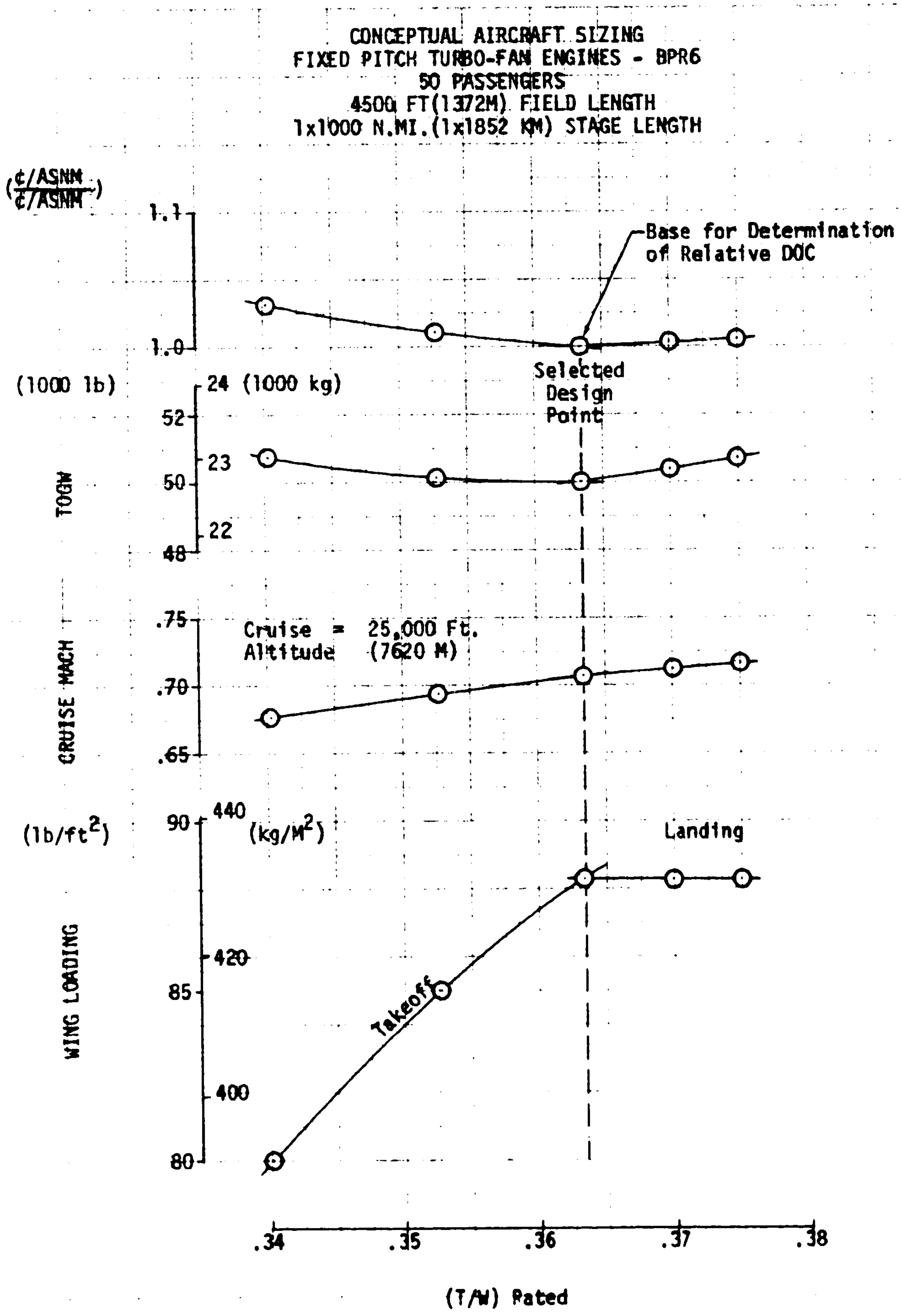

CONCEPTUAL AIRCRAFT SIZING
FIXED PITCH TURBO-FAN ENGINES - BPR6
50 PASSENGERS
4500 FT(1372M) FIELD LENGTH
1x1000 N.MI.(1x1852 KM) STAGE LENGTH
(¢/ASNM / ¢/ASNM)
1.1
1.0
Base for Determination of Relative DOC
Selected Design Point
(1000 lb)
24 (1000 kg)
52
23
50
22
48
TOGW
.75
.70
.65
Cruise Altitude = 25,000 Ft. (7620 M)
CRUISE MACH
(lb/ft²)
90
440
(kg/M²)
Landing
420
85
Takeoff
400
80
WING LOADING
.34
.35
.36
.37
.38
(T/W) Rated

FIGURE 6-16

aircraft is based on minimum relative DOC, and occurs at the W/S and T/W combination for a balanced takeoff and landing field length capability. The characteristics of the selected design point aircraft are shown in Table 6-8, along with the characteristics of the base conceptual aircraft sized at 2 x 250 nautical mile (2 x 463 km) stage lengths. Figure 6-17 depicts the variation of characteristics of these configurations with range.

6.3.5 Variation of Propulsion System

Conceptual aircraft, using variable-pitch turbofan and turboprop engines, were sized and compared with the base conceptual aircraft, sized with the fixed-pitch turbofan engines. These aircraft, used for comparison of the three propulsive systems, have a 50 passenger capacity, 4,500 foot (1,372 m) field length, and a range of 2 x 250 nautical mile (2 x 463 km) stage lengths. Characteristics of the three propulsion systems are described in Section 6.2.

Both configurations sized with turbofan engines, fixed and variable pitch fans, are twin-engine configurations with the engines mounted on the aft fuselage and with a wing aspect ratio of 9.0. The sizing description for the base conceptual aircraft is given in Section 6.3.1. This configuration's selected design point, chosen on the basis of minimum DOC occurs at the W/S and T/W combination for balanced takeoff and landing field length capability. However, for the configuration sized with the variable-pitch fan engines, the selected design point for minimum DOC occurs at a thrust-to-weight ratio higher than that for balanced field length. This is illustrated in Figure 6-18.

TABLE 6-8. CONCEPTUAL AIRCRAFT SUMMARY, RANGE CAPABILITY VARIATION

50 Passenger Capacity

4500 ft (1372 m) Field Length

Fixed-Pitch Fan: BPR/FPR = 6/1.45

Stage Lengths:	(n mi/km)	2 x 150/2 x 278	2 x 250/2 x 463	2 x 350/2 x 648	1 x 1000/1 x 1852
Takeoff Gross Weight	(lb/kg)	41,340/18750	43,920/19,920	46,600/21,140	50,010/22,680
Operator's Weight Empty	(lb/kg)	26,180/11,880	27,040/12,265	27,960/12,680	29,140/13,220
Wing Area	(ft^2/m^2	468/43.5	497/46.2	528/49.1	566/52.6
Rated Thrust	No.x(lb/N)	2x(7510/33,410)	2x(7980/35,500)	2x(8470/37,680)	2x(9090/40,430)
Wing Loading	(lb/ft^2/ kg/m^2)	88.3/431.1	88.3/431.1	88.3/431.1	88.3/431.1
Thrust-to-Weight Ratio, Rated		0.363	0.363	0.363	0.363
Cruise Altitude	(ft/m)	18,000/5486	23,000/7010	25,000/7620	25,000/7620
Cruise Mach Number		0.66	0.69	0.70	0.71
Relative DOC at 250 n. mi.		0.991	1.000	1.015	1.035

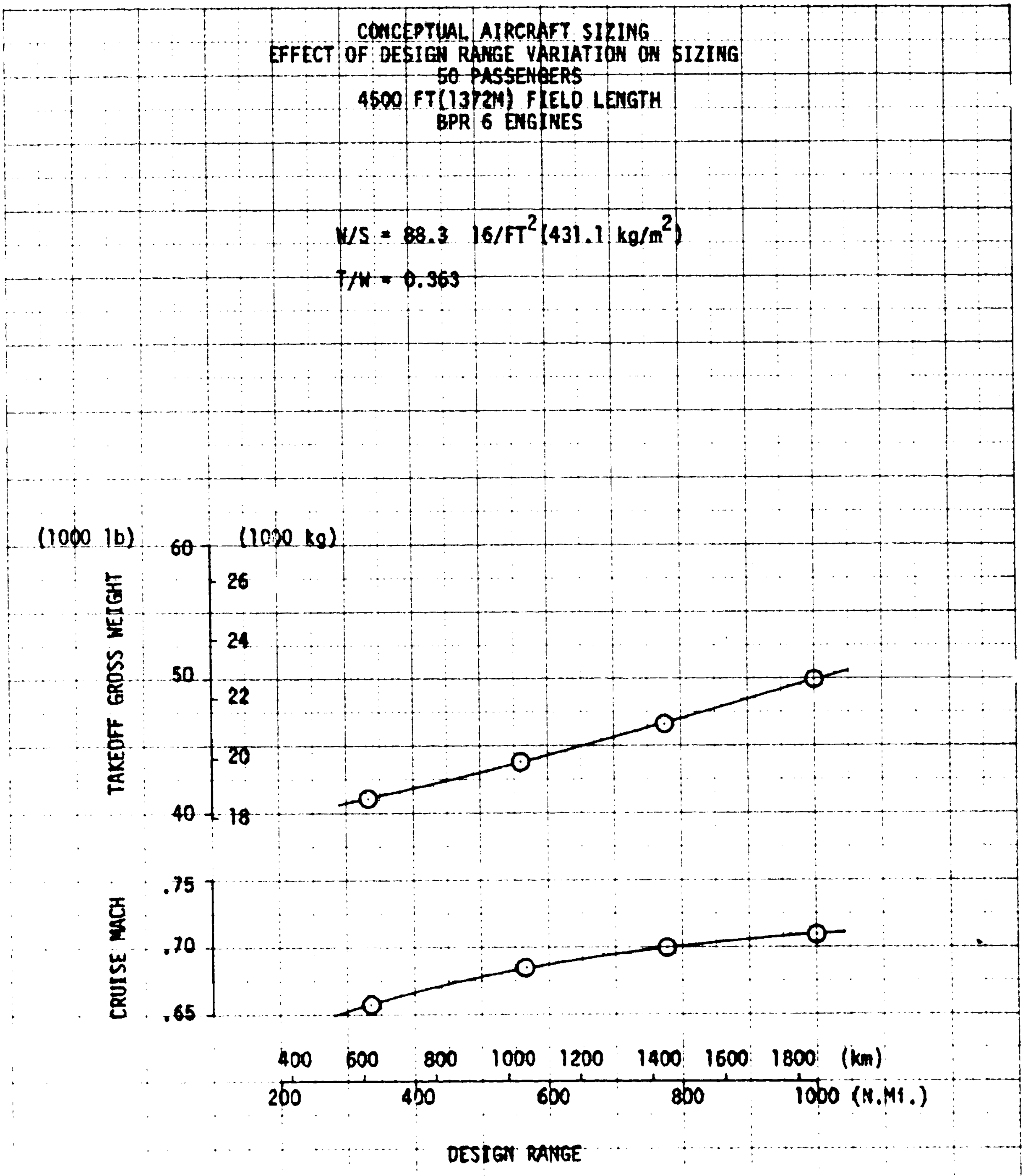
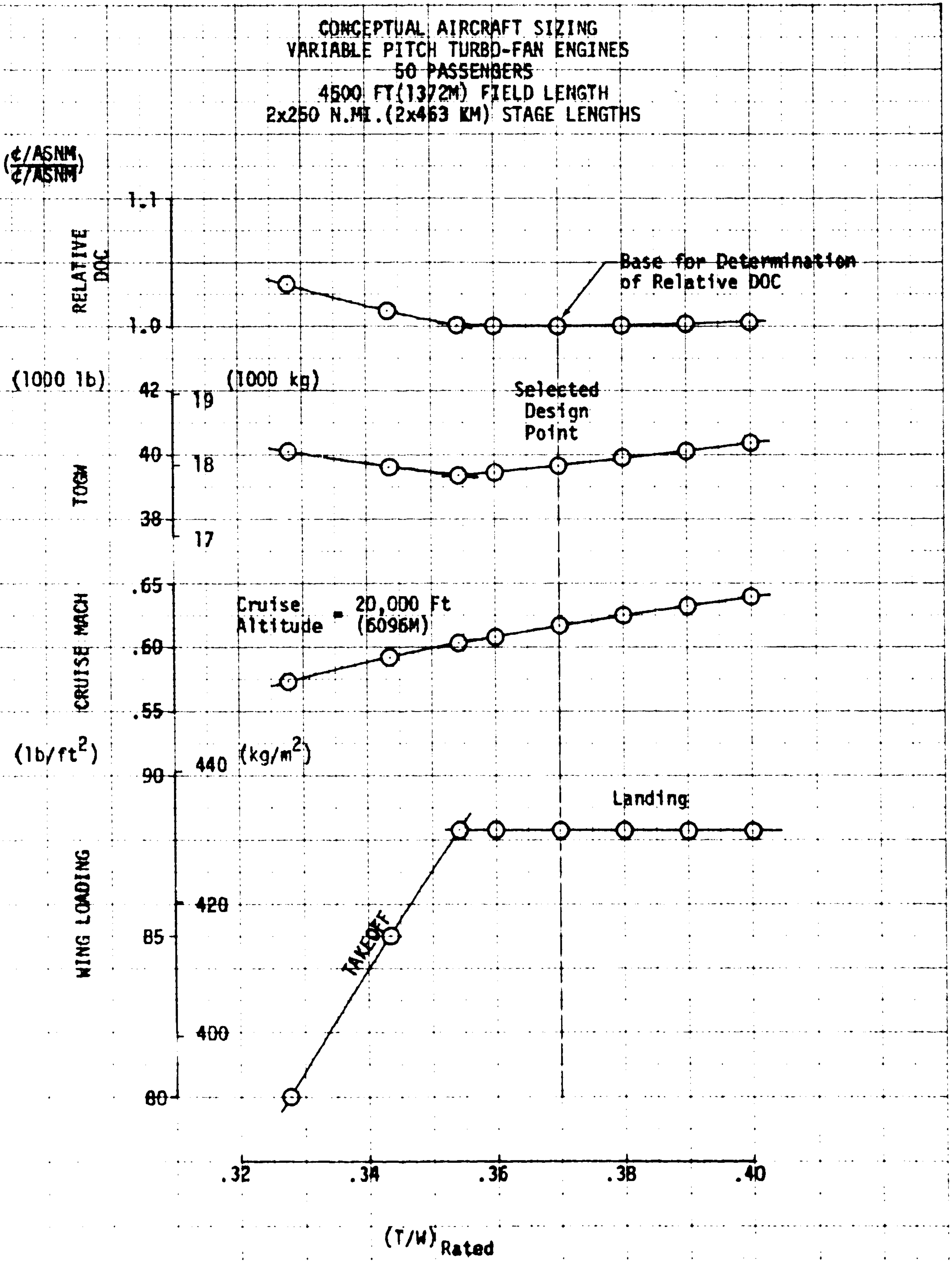

CONCEPTUAL AIRCRAFT SIZING
EFFECT OF DESIGN RANGE VARIATION ON SIZING
50 PASSENGERS
4500 FT(1372M) FIELD LENGTH
BPR 6 ENGINES
W/S = 88.3 lb/FT² (431.1 kg/m²)
T/W = 0.363
(1000 lb)
(1000 kg)
TAKEOFF GROSS WEIGHT
60
50
40
26
24
22
20
18
CRUISE MACH
.75
.70
.65
400 600 800 1000 1200 1400 1600 1800 (km)
200 400 600 800 1000 (N.Mi.)
DESIGN RANGE

FIGURE 6-17



CONCEPTUAL AIRCRAFT SIZING
VARIABLE PITCH TURBO-FAN ENGINES
50 PASSENGERS
4500 FT(1372M) FIELD LENGTH
2x250 N.MI.(2x463 KM) STAGE LENGTHS
(¢/ASNM / ¢/ASNM)
RELATIVE DOC
1.1
1.0
Base for Determination of Relative DOC
(1000 lb)
(1000 kg)
Selected Design Point
TOGW
42
40
38
19
18
17
CRUISE MACH
.65
.60
.55
Cruise Altitude = 20,000 Ft (6096M)
(lb/ft²)
(kg/m²)
WING LOADING
90
85
80
440
420
400
Landing
TAKEOFF
.32
.34
.36
.38
.40
(T/W) Rated

FIGURE 6-18

The turboprop aircraft is a wing-mounted, twin-engine, low-wing configuration (Figure 6-19). The selected design point for minimum DOC coincides with the point for a balanced takeoff and landing field (Figure 6-20). The thrust-to-weight ratio delivered by the turboshaft engine and propeller combination during takeoff is very nearly identical to that for the fixed-pitch turbofan aircraft (Appendix A-5).

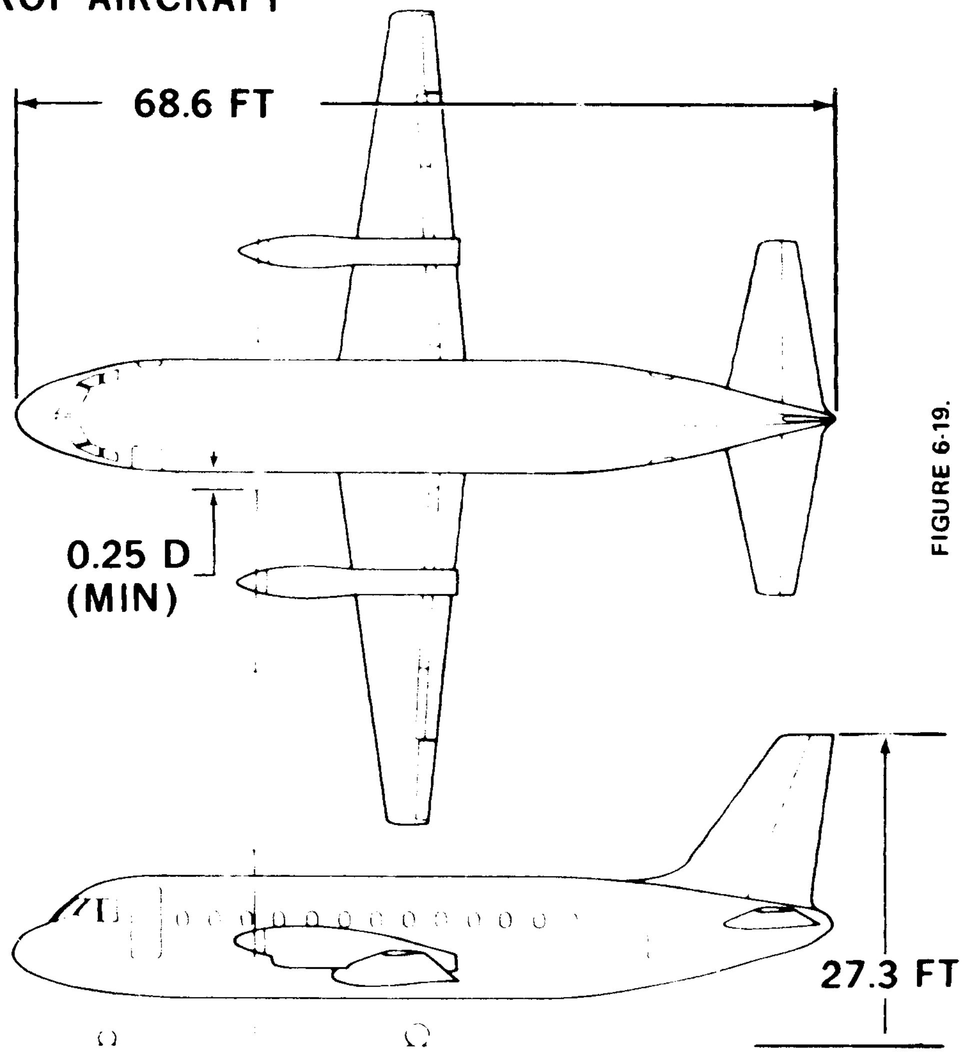
The turboprop configuration was subjected to a preliminary steady-state study to determine the basic requirements for one-engine-out control speed, a highly important consideration in the design of turboprop aircraft (Figure 6-21). The solid lines in this figure show the single-engine thrust coefficient at full throttle. The dash lines show the maximum thrust coefficient that can be controlled with full deflection of the control surface; aileron control includes yaw due to rudder, and vice-versa for rudder control. With bank angle limited to 5^{0}, the aircraft is allowed to sideslip only to the extent that a straight flight path can be maintained; largest at low speed, the sideslip is less than 10^{0}. The results show that spoilers are not needed as the lift-off speed is 120 to 125 knots.

In the one-engine-out control study, the wing aspect ratio was 9.0 and the propeller-fuselage clearance was 10 percent of the propeller diameter. Due to cabin noise, the propeller was moved outboard to obtain a 25 percent clearance, as in the Lockheed-Electra (Figure 6-22). In order to maintain the same degree of one-engine-out control, the wing aspect ratio was increased to 10.5. Figure 6-23 illustrates the insulation treatment used, which is the same as that in the Lockheed-Electra.

Figure 6-24 depicts a study conducted to determine the effect of designing the turboprop aircraft to a slower cruise speed.

GENERAL ARRANGEMENT
TURBOPROP AIRCRAFT

PAYLOAD:	50 PASSENGERS (4/32)
WING AREA:	498 SQ FT
TOGW:	43,840 LB
WING LOADING:	88.0 LB/SQ FT
TOFL:	4500 FT
ENGINE:	TURBOSHAFT 2 x 4,230 HP
PROPELLER:	4BL x 180AF 13.0 FT DIA V_T = 720 FPS



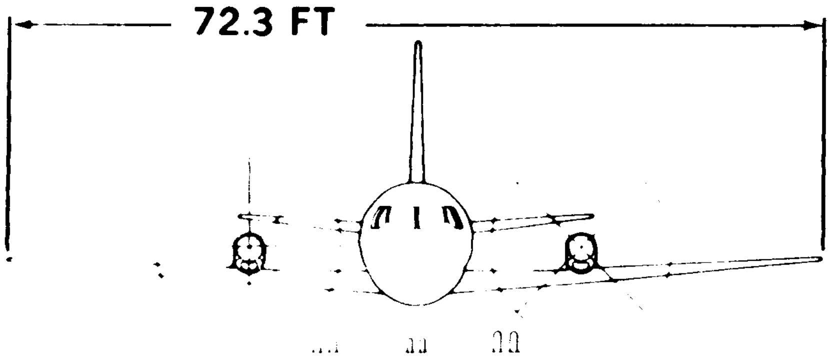
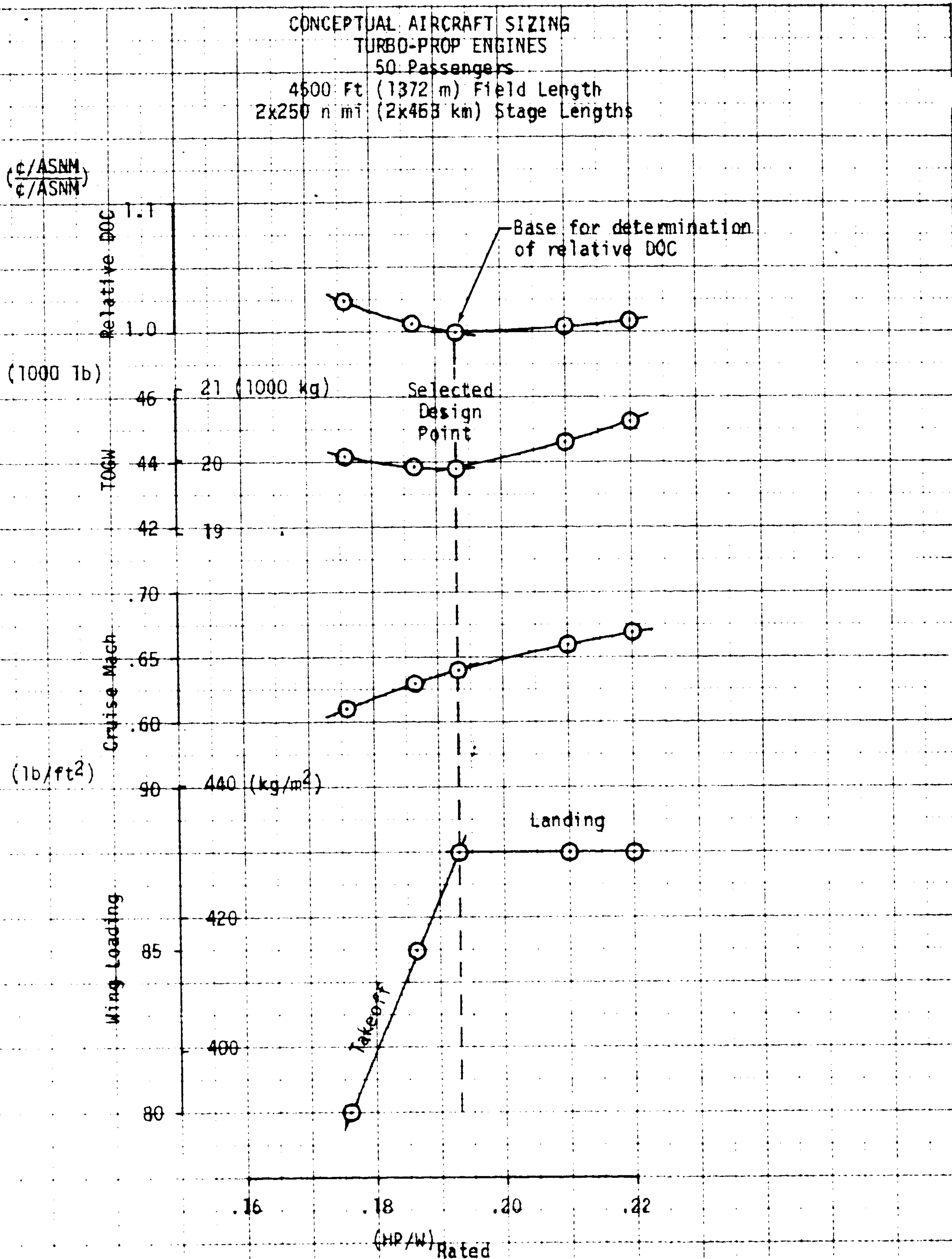


FIGURE 6-19.

FIGURE 6-19



CONCEPTUAL AIRCRAFT SIZING
TURBO-PROP ENGINES
50 Passengers
4500 Ft (1372 m) Field Length
2x250 n mi (2x463 km) Stage Lengths
(¢/ASNM / ¢/ASNM)
Relative DOC
1.1
1.0
Base for determination of relative DOC
(1000 lb)
21 (1000 kg)
46
44
42
20
19
TOGW
Selected Design Point
.70
.65
.60
Cruise Mach
(lb/ft^2)
440 (kg/m^2)
90
85
80
420
400
Wing Loading
Landing
Takeoff
.16
.18
.20
.22
$(HP/W)_{Rated}$

FIGURE 6-20

TURBOPROP AIRCRAFT CONTROL SPEED ONE ENGINE OUT

WEIGHT = 30,000 LB   BANK ANGLE = 5 DEG   INOPERATIVE PROP FEATHERED

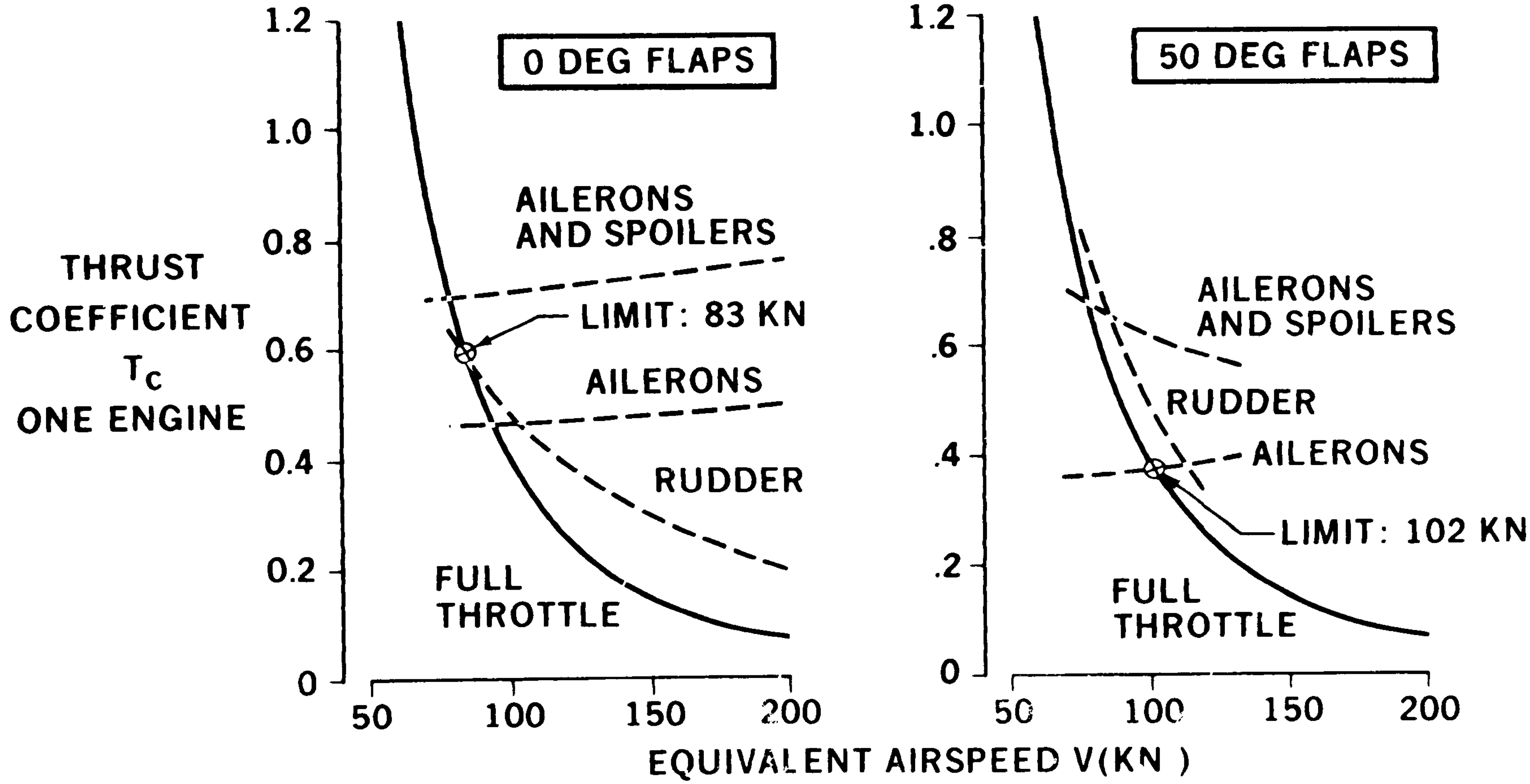


FIGURE 6-21

PROPELLER NOISE: NEAR FIELD

EFFECT OF TIP SPEED AND DISTANCE IN PLANE ROTATION

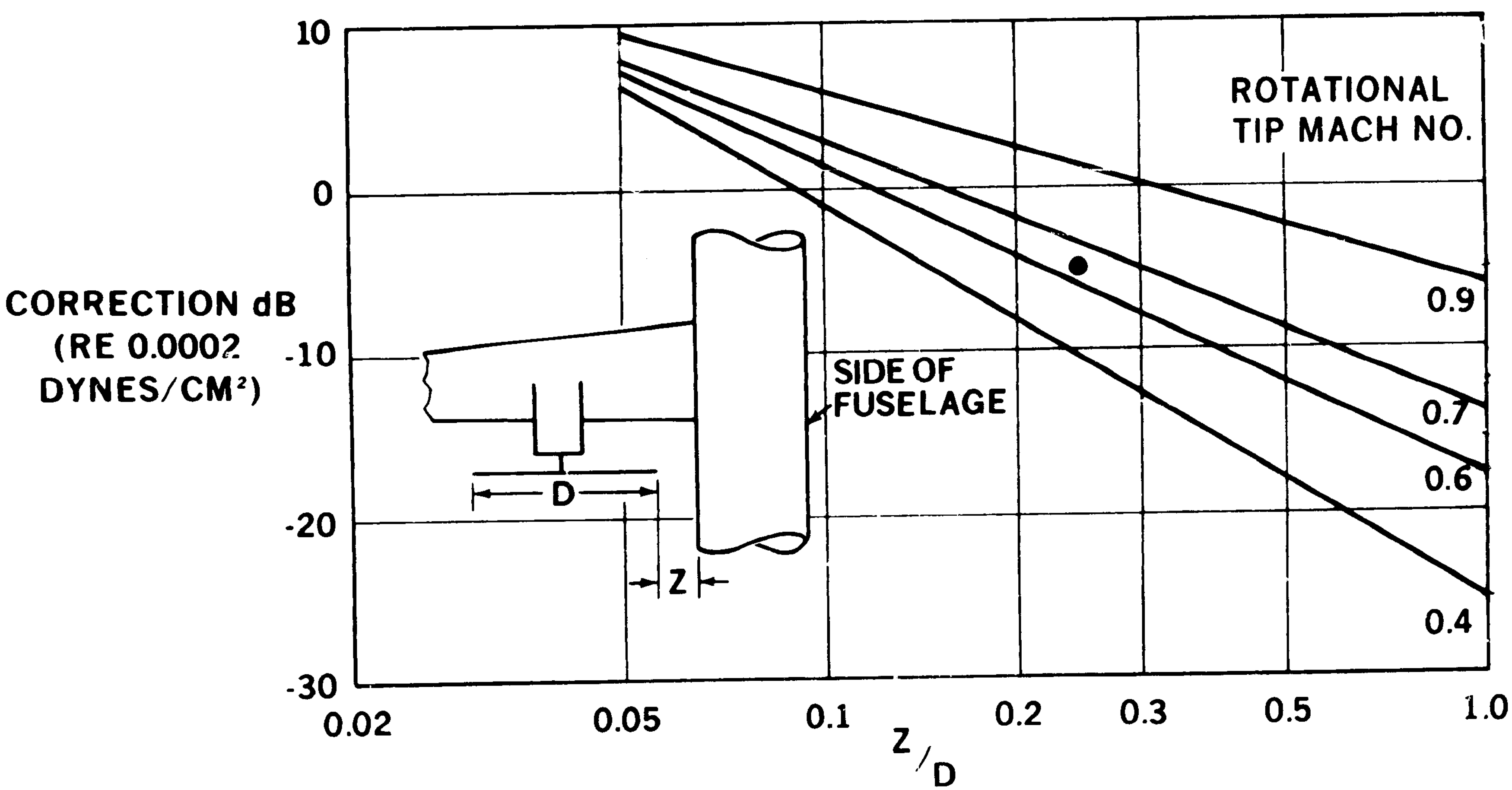


FIGURE 6-22

TURBOPROP AIRCRAFT: INTERIOR NOISE CONSIDERATIONS

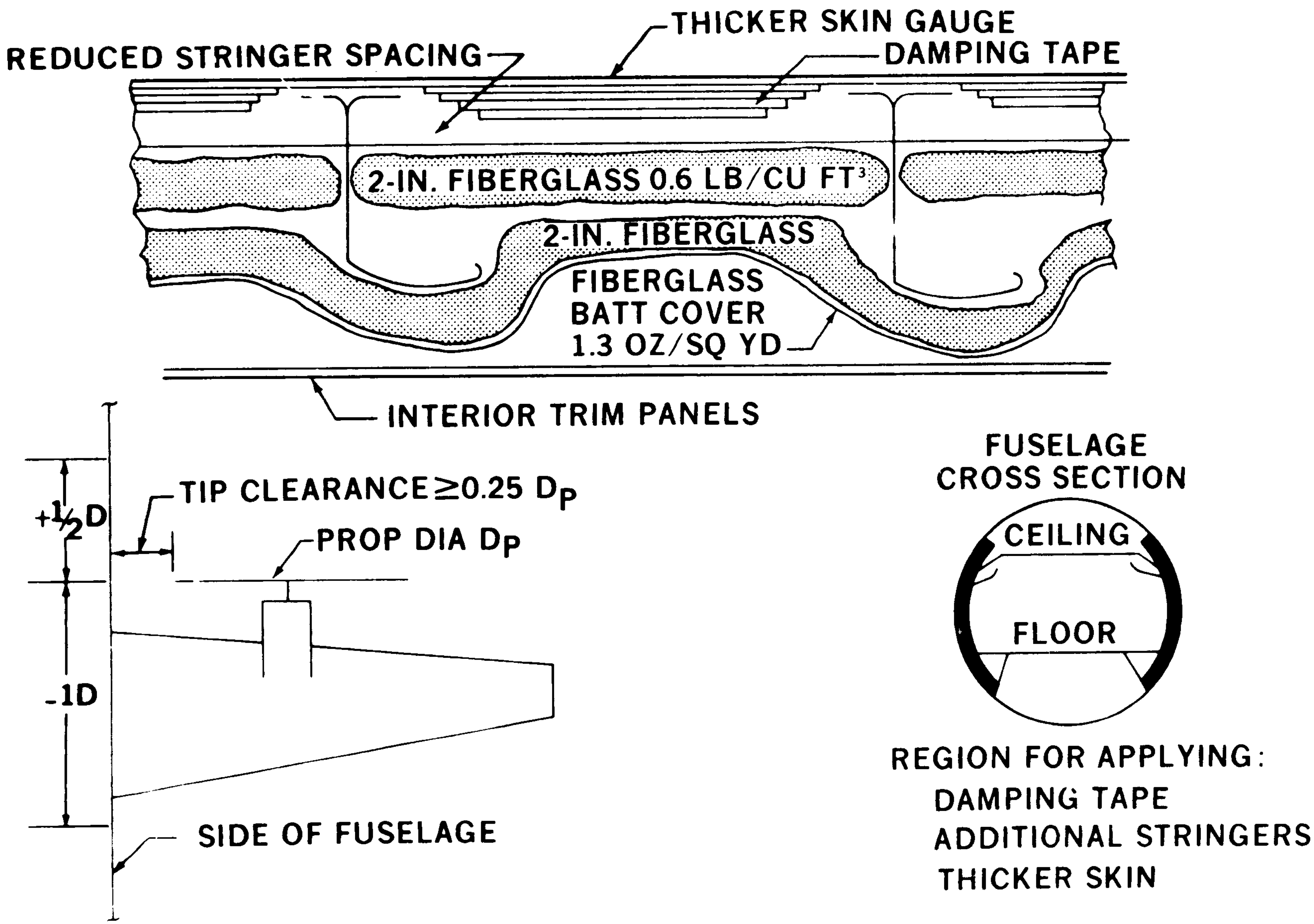


FIGURE 6-23

EFFECT OF CRUISE MACH NUMBER
TURBOPROP AIRCRAFT

50 PASSENGERS FIELD LENGTH = 4500 FT RANGE = 2 x 250 N MI

W/S = 88 PSF, HP/W = 0.196

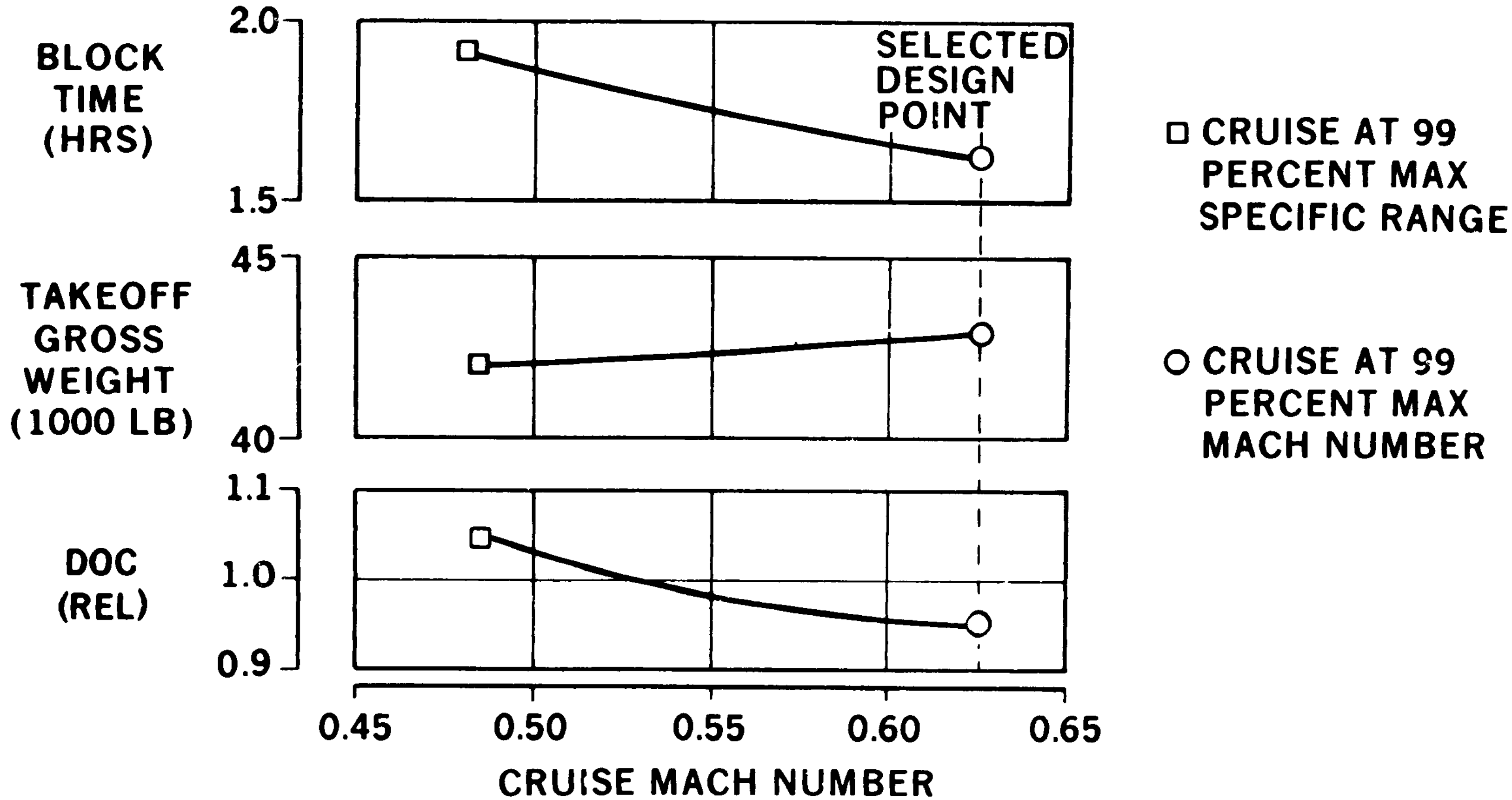


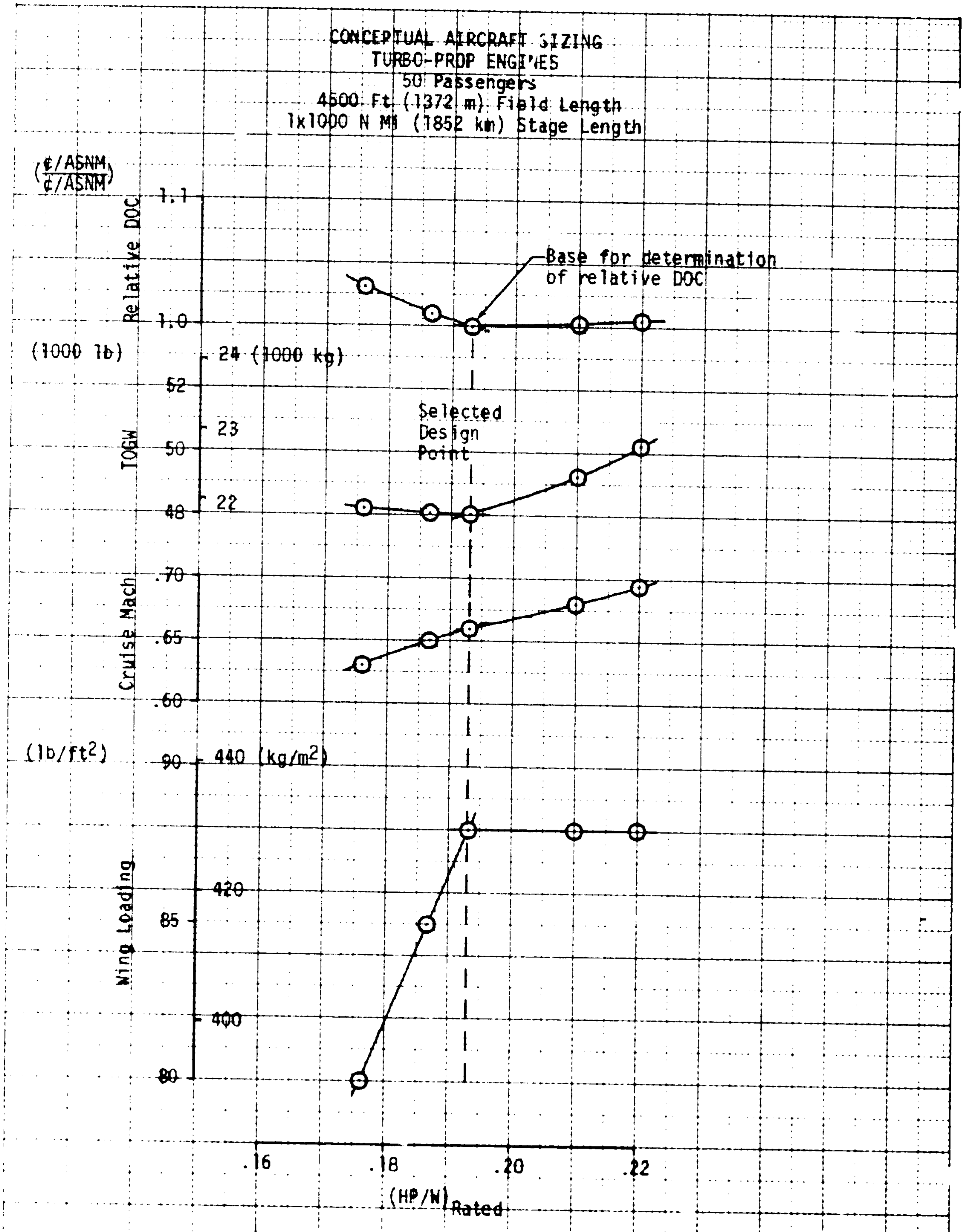
FIGURE 6-24

Keeping the airframe configuration unchanged, a reduction in cruise speed to 0.48 Mach number (point of minimum mission fuel) saved only 800 pounds of fuel. Resizing the aircraft for this low cruise speed, and maintaining the same mission and field length, resulted in reducing the engine size by only 12 percent while the propeller diameter remained constant. Including growth effects, a complete resizing of the aircraft would result in a gross weight reduction of less than 1,600 pounds. This is grossly insufficient to offset the increase in DOC shown in Figure 6-24 for the reduced cruise speed and substantiates the high cruise speed used in designing this turboprop aircraft.

In addition, these three propulsion systems were used to size similar configurations with a range capability of 1 x 1,000 nautical miles (1 x 852 km). Again the selected design points for minimum DOC occur at a balanced takeoff and landing field length for the fixed-pitch turbofan and turboprop aircraft (Figures 6-16 and 6-25).

As before, the selected design point for the variable-pitch fan aircraft occurs at a thrust-to-weight ratio higher than that for a balanced field length (Figure 6-26). A comparison of Figures 6-18 and 6-26 shows that this thrust-to-weight ratio increases with an increase in design range, because DOC decreases very slowly beyond the balanced field length point. A more practical design point, occurring at a lower thrust-to-weight ratio and with a negligible increase in DOC, could be selected for the higher range. Variable-pitch fan aircraft have slower cruise speeds than fixed-pitch fan aircraft. This will improve as design effort is applied to increase variable-pitch fan pressure ratio.

Table 6-9 summarizes the characteristics of all six configurations.



CONCEPTUAL AIRCRAFT SIZING
TURBO-PROP ENGINES
50 Passengers
4500 Ft (1372 m) Field Length
1x1000 N Mi (1852 km) Stage Length
(¢/ASNM / ¢/ASNM)
Relative DOC
1.1
1.0
Base for determination of relative DOC
(1000 lb)
24 (1000 kg)
52
23
TOGW
50
22
48
Selected Design Point
Cruise Mach
.70
.65
.60
(lb/ft²)
90
440 (kg/m²)
Wing Loading
420
85
400
80
.16
.18
.20
.22
(HP/W)Rated

FIGURE 6-23

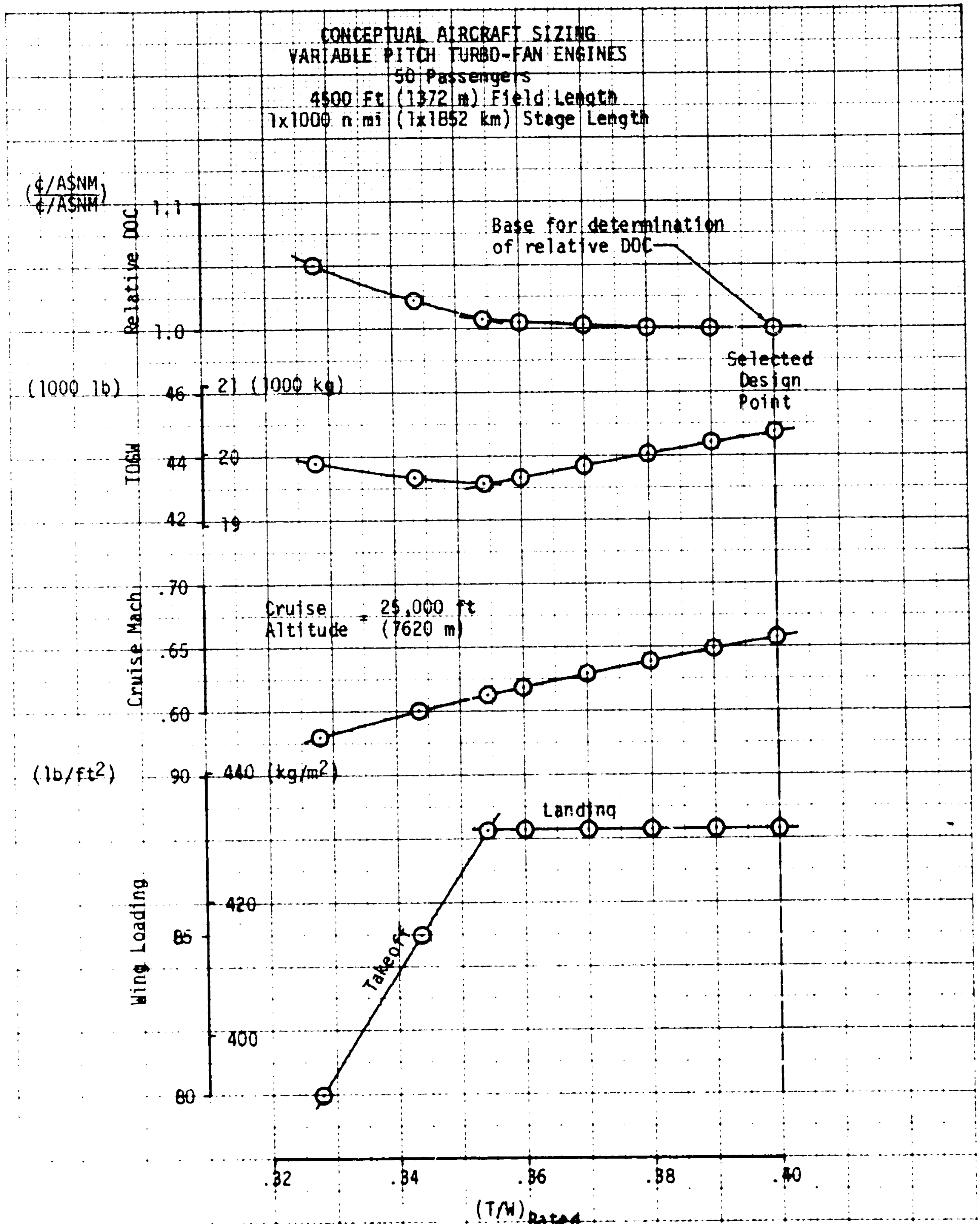

CONCEPTUAL AIRCRAFT SIZING
VARIABLE PITCH TURBO-FAN ENGINES
50 Passengers
4500 Ft (1372 m) Field Length
1x1000 n mi (1x1852 km) Stage Length
(¢/A$NM / ¢/A$NM)
Relative DOC
1.1
1.0
Base for determination of relative DOC
Selected Design Point
(1000 lb)
21 (1000 kg)
TOGW
46
44
42
20
19
Cruise Mach
.70
.65
.60
Cruise Altitude = 25,000 ft (7620 m)
(lb/ft²)
440 (kg/m²)
Wing Loading
90
85
80
420
400
Landing
Takeoff
.32
.34
.36
.38
.40
(T/W)Rated

FIGURE 6-26

TABLE 6-9. CONCEPTUAL AIRCRAFT SUMMARY, PROPULSION SYSTEM VARIATION

50 Passenger Capacity

4500 ft (1372 m) Field Length

		Range = 2 x 250 n mi (2 x 463 km) Stage Lengths			Range = 1 x 1000 n mi (1 x 1852 km) Stage Lengths		
Engines:		BPR 6	BPR 13	Turbo-Prop	BPR 6	BPR 13	Turbo-Prop
Takeoff Gross Weight	(lb/kg)	43,920/19,920	39,740/18030	43,840/19,890	50,010/22,680	44,790/20,320	48,030/21,790
Operator's Weight Empty	(lb/kg)	27,040/12,265	24,510/11,120	27,920/12,660	29,140/13,220	26,420/11,980	29,310/13,300
Wing Area	(ft^2/m^2)	497/46.2	450/41.8	498/46.3	566/52.6	507/47.1	546/50.7
Rated Thrust (HP)/ Engine	(lb/n)	7980/35,500	7350/32,690	(4230 hp)	9090/40,430	8960/39,860	(4640 hp)
Wing Loading	(lb/ft^2/ kg/m^2)	88.3/431.1	88.3/431.1	88./429.7	88.3/431.1	88.3/431.1	88./429.7
Thrust (horsepower)-to-Weight Ratio, Rated		0.363	0.370	(0.193)	0.363	0.400	(0.193)
Cruise Altitude	(ft/m)	23,000/7010	20,000/6096	20,000/6096	25,000/7620	25,000/7620	25,000/7620
Cruise Mach		0.69	0.62	0.64	0.71	0.66	0.66
Wing Aspect Ratio		9.0	9.0	10.5	9.0	9.0	10.5
Relative Direct Operating Cost (¢/ASNM/¢/ASNM)		1.00*	1.00	0.95	1.00*	1.01	0.94

*Base for determination of relative DOC

The turboprop columns in this table, along with Figures 6-20 and 6-25, include the combined effect of the higher wing aspect ratio and the heavier fuselage insulation mentioned above. Turboprop data pertaining to aspect ratio 9.0 is contained in Exhibit A of Section 6.4.4.

Turboprop and especially variable-pitch-fan aircraft are lighter in gross weight and use less fuel than fixed-pitch-fan aircraft. These advantages increase with range. As range increases, the turboprop begins to use less fuel than the variable-pitch-fan aircraft.

6.3.6 Comparison of High-Lift Systems

Three types of mechanical flap systems were investigated to determine their relative merits for use in sizing conceptual aircraft. The three systems called simple, nominal, and advanced high-lift systems are described in Appendix A.2.1.

The simple high-lift system is essentially the nominal high-lift system without a leading edge slat. The large difference in maximum lift coefficient permitted the simplified comparison of these two high-lift systems, discussed below and illustrated in Table 6-10.

As an additional comparison, Table 6-10 presents data on the Cessna Citation high-lift system. This is a simple, tracked-flap, without a leading-edge slat, that is very similar in performance to the simple DC-9-30 system at the same flap angle of 40^0.

A simplified analysis, conducted by eliminating the flare maneuver, resulted in wing loadings of 67.0/63.0 and 62.3 lb/ft^2 (327.0/307.6 and 304.1 kg/m^2) for the simple high-lift systems. At an assumed gross weight

TABLE 6-10

AIRCRAFT HI-LIFT SYSTEM COMPARISON

FIXED PITCH FAN, 50 PSGR, 4,500 FT FL, 2 x 250 N MI

HI-LIFT SYSTEM	NOMINAL DC-9-30 FLAP AND SLAT	SIMPLE DC-9-30 FLAP, NO SLAT	CITATION FLAP, NO SLAT
Max δ_F	50 Deg	50/40 Deg	40 Deg
Max C_L at V_{Min}	3.00	2.28/2.14	2.12
TOGW (lb)	43,920	48,000*	48,000*
S_W (sq ft)	497	762	770
W/S (lb/sq ft)	88.4	67.0/63.0	62.3
Relative S_W	1.00	1.53	1.55
Weights (lb):			
Wing	3,015	4,445	4,445
Flap	692	1,117	945
Slat	595	0	0
Total	4,252	5,562	5,390
Relative	1.00	1.31	1.27

* Optimistic estimate: does not account for wing, tail, engine and other weight growth effects (including the effect of higher cruise drag and lower cruise speed on mission fuel).

of 48,000 pounds (21,773 kg), the simple high-lift systems caused an increase in wing area of over 50 percent and in wing weight of 31 to 27 percent. Past experience with weight growth effects (wing, tail, engine, fuel, etc.) shows that the assumed gross weight is optimistic, i.e., too low. Obviously, the aircraft with the simple high-lift system will have a much higher DOC than the airplane with the nominal high-lift system, thus precluding the necessity for a more sophisticated analysis.

A comparison of the advanced and nominal high-lift systems demand a full-fledged in-depth analysis. The high-lift system yielding the configuration with the lower DOC is not readily discernable without an accurate definition of both configurations, sized to the same field and mission requirements. Table 6-11 presents the pertinent information; additional detailed weight data is furnished in Exhibit A of Section 6.4.4.

The slightly lower DOC displayed by the advanced flap configuration in Table 6-11 is considered inadequate for a decision. Hence, an additional comparative evaluation was conducted (see Table 6-12). This table lists weights and complexity factors for the advanced and nominal flap configurations. The complexity factors are a measure of the manufacturing labor, tooling and planning involved.

Examination of Table 6-12 shows that the advanced flap is much more complex than the nominal flap (1.75 to 1.10), resulting in a total wing that is more complex (0.96 to 0.78). Because the remainder of the airframe is identical in both cases, the advanced flap airframe is only 3 percent more complex, which results in a 1 percent increase in airframe cost. Finally, a 6 percent increase in airframe cost is required in order to equalize the

TABLE 6-11. CONCEPTUAL AIRCRAFT SUMMARY, COMPARISON OF HIGH-LIFT SYSTEMS

2 x 250 n mi (2 x 463 km) Stage Lengths

4,500 ft (1,372 m) Field Length

Fixed-Pitch Fan: BPR/FPR = 6/1.45

50 Passengers

High-Lift System:		Nominal	Advanced
Max δ_F		50 deg	50 deg
Max C_L at V_{Min}		3.00	3.42
Takeoff Gross Weight	(lb/kg)	43,920/19,920	43,360/19,670
Operator's Weight Empty	(lb/kg)	27,040/12,265	26,550/12,040
Wing Area	(ft^2/m^2	497/46.2	430/39.9
Rated Thrust/ Engine	(lb/n)	7,980/35,500	8,110/36,070
Wing Loading	(lb/ft^2/ kg/m^2)	88.3/431.1	100.9/492.6
Thrust-to-Weight Ratio, Rated		0.363	0.374
Cruise Altitude	(ft/m)	23,000/7,010	24,000/7,315
Cruise Mach Number		0.69	0.71
Relative Direct Operating Cost (¢/ASNM/¢/ASNM)		1.000*	0.986

*Base for determination of relative DOC

TABLE 6-12

HIGH-LIFT SYSTEM EVALUATION: COMPLEXITY FACTORS

50 Passengers 4,500 Ft Field Length 2 x 250 N Mi Range

	NOMINAL		ADVANCED	
	WEIGHT (Lb)	COMPLEXITY FACTOR	WEIGHT (Lb)	COMPLEXITY FACTOR
Flap	690	1.10	930	1.75
Slat	550	1.16	470	1.16
Wing (Less High Lift)	3,040	0.64	2,660	0.64
Wing (Total)	4,280	0.78	4,060	0.96
AFM Cost Wt (Less Wing)	18,750	1.05	18,440	1.05
Airframe Cost Weight	23,030	1.00	22,500	1.03
Airframe Cost (Rel)		1.00		1.01
Airframe Cost (Rel) for Equal DCC		1.00		1.06

DOC of the advanced and nominal flap aircraft. Thus, the advanced high-lift system is selected for use on the final design aircraft.

6.4 Aircraft Weights

The weight estimation methods have been developed during various commercial and military transport programs and from in-house efforts committed to improvement of existing techniques. The equations for structure and systems components utilize parametric relationships isolated during post design analyses of production transport aircraft. The weights for major structural, propulsion, avionics, and furnishings are derived by multi-station and multi-component analyses. The remaining systems weights are derived by empirical relationships considering aircraft such as the Citation, F-28, DC-9, 737 and 727.

6.4.1 Methodology

Parametric weights are generated using the Parametric Weight Estimation Program (M5BA). Weight effects were evaluated for several variations including passenger capacity, design range, stage length, field length, cruise Mach number and altitude, engine type, high-lift system, noise, and approach speed. The weight data was evolved through a multi-step process as follows:

- An initial aircraft detail weight derivation and balance check is made, based on inputs consisting of criteria, loads geometry and system descriptions.

- Factors derived from these initial weights are input into the program M5BA. The resulting matrix of weight values is integrated with the aerodynamic performance sizing program, and aircraft design weights are generated based on mission objectives.

- Detail weights developed from step 2 are examined based on the degree of deviation from those of step 1. These refined weights represent the final weight analysis.

6.4.2 Structural Definition

- Wing: This is a two spar box, with ailerons between 65 and 85 percent span, and spoilers over the trailing edge flaps. The high-lift systems consist of a full span leading edge slat, with double-slotted hinged or track-type trailing edge flaps (see Section 6.3.6 and Appendix A.2). The wing rear spar is located 90 degrees to the fuselage centerline and both front and rear spar are designed with zero built-in twist. The wing is configured with internal fuel tanks from the fuselage centerline to 85 percent span.

- Empennage: This consists of a horizontal stabilizer, a vertical stabilizer, two elevators and a rudder in a "T" tail arrangement. The horizontal stabilizer is designed with zero built-in twist and the rear spar located 90 degrees to the fuselage centerline.

- Fuselage: This has a double-bubble or cusped cross-section with an upper radius of 55 inches, a lower radius of 49.5 inches, and a height of 120 inches. The fuselage is an all-metal, semi-monocoque design with single plane cockpit windshields, cabin windows, and flat fore and aft pressure bulkheads. The fuselage is designed for a cabin altitude of 6,000 feet at 25,000 feet altitude, with a minimum skin gauge of .040 inches. All material and fabrication methods are assumed conventional except for those in the design-to-cost study (see Section 9.3).

6.4.3 Subsystem Definition

- Landing Gear System: This consists of the main and nose landing gears and includes struts, side and drag braces, axles, trunnion, attachment fittings and bulkheads, and extra load-path material in the wing for wing mounted gear, wheels, brakes, tires, operating mechanisms, controls, and systems. The main gear is wing-mounted, and all materials are conventional.

- Flight Controls and Hydraulic System: The primary flight control system is a conventional, mechanical, cable-controlled system designed for simplicity. The secondary flight control system is hydraulically powered. The hydraulic power system is a single 3,000 psi continuous system with pressure supplied by two engine-driven pumps and an electrically driven auxiliary pump. The auto flight control system is included in the flight control system.

- Power Plant, Fuel and Auxiliary Power Unit System: The base propulsion system consists of two aft-fuselage-mounted turbofan engines. The nacelle is a long-duct, mixed-flow design with a fan-exhaust cascade-type thrust reverser and acoustic treatment in the inlet and fan exhaust sections. The fuel system consists of two integral main wing fuel tanks and an integral center wing fuel tank. Each half-wing is considered wet from the fuselage centerline to 85 percent span. The auxiliary power unit provides power for air conditioning and electrical functions during ground operations and pneumatic power for main engine starting. Fuel is supplied from the aircraft main fuel system.

- Instruments: This group includes basic conventional monitoring and warning systems associated with the flight of the aircraft, electrical, hydraulic and pneumatic system operation, engine operation, and fuel quantity. It includes cockpit readout devices, warning lights, black boxes at the point of signal input and circuitry between the black box and monitoring device.

- Pneumatic System: This group includes all heat exchangers and ducting from the main engines and auxiliary power unit to the air conditioning units.

- Electrical System: This system consists of the AC and DC power systems, and all the internal and external lighting systems. The AC and DC power systems includes generators, constant speed drives, batteries, transformer-rectifiers, circuit breakers and the necessary wiring, structure and hardware. The interior and exterior lighting systems include passenger cabin and reading lights, cockpit lights, landing and signal lights, and the associated wiring, structure and hardware.

- Avionics: This system is assumed to be a minimal Category II system. It includes a single marker beacon system, a dual VOR/ILS/GS system, a dual VHF comm system, a dual ATC system, a dual DME system, a dual ADF system, an interphone and public address system, and the associated antennas, coax, wiring rack structure and hardware.

- Furnishings: This group includes the crew seats, cabin attendants seats, console panels, passenger seats and tracks, observer seat, lavatories, coffee bar, crew oxygen system, cockpit instrument panels, glareshield, consoles and pedestal cabin stowage, floor covering, acoustic and thermal insulation, movable utilities, window equipment, cockpit partition, overhead stowage, ceiling and sidewall panels, cargo compartment lining, floor and hold down equipment, fire extinguishing system, and emergency equipment.

- Air Conditioning System: This includes the basic and conventional flight compartment and passenger cabin conditioned air and pressurization system. It includes the air cycle units, water separators, flow control valves, distribution ducting and controls, pressure regulators, and cabin outflow valves controlled by cabin pressure control equipment.

- Ice Protection System: This system assumes protection for the wing leading edge, horizontal tail leading edge, and engine inlets. The windshield protection system consists of windshield anti-ice, and windshield wiper system.

- Handling Gear Group: This group consists of fittings and structural provisions for jacking, hoisting and mooring the aircraft.

- Operating Items: Table 6-13 lists the items included. A second cabin attendant is added beyond 50 passengers. The passenger service total of 3.7 lb/passenger represents a level

TABLE 6-13. OPERATING ITEMS: WEIGHT (LB)

	30 Pax	50 Pax	70 Pax
Cockpit Crew (2)	340	340	340
Cabin Attendant	130	130	260
Crew Baggage	60	60	80
Brief Case (2)	50	50	50
First Aid Kit	12	12	12
Escape Chute	28	28	28
Engine Oil	99	124	138
Lav. Fluids	16	16	32
Inert: Total	735	760	940
Food Service (Refreshment): 0.5 #/Pax			
Pax Service (Cabin & Lav Supp): 2.0 #/Pax	110	185	260
Galley Service (Refreshment): 0.2 #/Pax			
Potable H_2O: 1.0 #/Pax			
Total Pax Service: 3.7 #/Pax			
Inert + Variable: Total	845	945	1200
*Trapped Fuel = $6.026\ S_w^{0.5}$ (2 tanks)	110	130	150
Sum Total	955	1,075	1,350

*$9.04\ S_w^{0.5}$, for 4 tanks

considered suitable for medium density operations.

6.4.4 Weight Summaries of Parametric Analyses

Exhibit A presents a tabulation of the results of the parametric analyses. Shown are group weight statements, dimensional, performance and other descriptive data. The base aircraft, used as the focal point for the parametric analyses (field length, passenger capacity, stage length, propulsion type and high-lift system) is listed in column 1.

The field length parametric study, conducted by fixing all the parameters except field length, is shown in columns 2 and 3. The passenger or payload capacity parametric study, conducted by fixing all parameters except the number of passengers, is given in columns 4 and 5. The additional parametric study, done at the higher range of 2 x 350 nautical miles (2 x 648 km), was not shown because the trends are the same. The stage length or range parametric study, done by fixing all parameters except stage length, is contained in columns 6, 7, and 8. The propulsion type parametric study, shown in columns 9 through 12, consisted of making two discrete variations to the baseline aircraft, i.e., using twin variable-pitch-fan engines and then twin turboshaft-propeller engines. The high-lift system parametric study, shown in column 13, consisted of making two discrete variations to the baseline aircraft, i.e., using a simplified version of the nominal flap system and an advanced high-lift system or tracked flap (see Section 6.3). Data for the former system are not included herein because the results were obviously in favor of the nominal high-lift system.

DESCRIPTION		BASE AIRCRAFT	FIELD LENGTH		PASSENGER CAPACITY	
Flap Type		Nominal	Nominal	Nominal	Nominal	Nominal
Stage Length	(n.mi)	2 x 250	2 x 250	2 x 250	2 x 250	2 x 250
Number of Seats		50	50	50	30	70
Field Length	(ft)	4,500	3,500	5,500	4,500	4,500
Wing Area (ft^2)/Aspect Ratio		497/9.0	747/9.0	374/9.0	363/9.0	642/9.0
Engine Designation		F.P. Fan	F.P. Fan	F. P. Fan	F.P. Fan	F.P. Fa
Engine Thrust	(lb)	2 x 7,980	2 x 8,410	2 x 7,970	2 x 5,830	2 x 10,31
Horiz/Vert Tail Area	(ft^2)	167/110	222/152	139/90	133/95	211/134
Horiz/Vert Tail Arm	(in)	370/290	370/290	370/290	290/210	430/350
Horiz/Vert Tail Volume		1.27/1.08	.92/.06	1.62/.10	1.27/.08	1.27/.0
Wing Loading	(lb/ft^2)	88.3	64.5	112.8	88.3	88.3
Thrust Ratio		.3634	.3493	.3776	.3634	.3636
Fuel Fraction		.1566	.1558	.1601	.1711	.1472
Fuselage Diameter/Length	(in)	110/806	110/806	110/806	110/636	110/976
Wing	(lb)	4,252	6,364	3,261	3,046	5,598
Horizontal Tail	(lb)	598	797	502	477	766
Vertical Tail	(lb)	624	783	555	537	762
Fuselage	(lb)	5,497	5,521	5,490	4,384	6,679
Landing Gear	(lb)	1,932	2,119	1,858	1,412	2,496
Power Plant	(lb)	5,224	5,505	5,217	3,816	6,749
Fuel System	(lb)	274	336	238	234	312
Auxiliary Power Unit	(lb)	398	398	398	269	553
Flight Controls	(lb)	998	1,345	827	815	1,214
Instruments	(lb)	300	300	300	300	300
Hydraulics	(lb)	301	406	250	247	367
Pneumatics	(lb)	93	93	93	51	139
Electrical	(lb)	893	893	893	536	1,150
Avionics	(lb)	436	436	436	436	436
Furnishings	(lb)	3,370	3,370	3,370	2,481	4,536
Air Conditioning	(lb)	377	377	377	205	562
Ice Protection	(lb)	463	568	402	397	514
Handling Gear	(lb)	20	20	20	20	20
Weight Empty Manufacturer's		26,050	29,631	24,487	19,673	33,153
Operator's Items		990	1,019	973	917	1,227
Weight Empty Operator's		27,040	30,650	25,460	20,590	34,380
Payload		10,000	10,000	10,000	6,000	14,000
Mission Fuel		6,880	7,500	6.760	5,490	8,350
Maximum Takeoff Weight		43,920	48,150	42,220	32,080	56,730

AMETRIC ANALYSIS EXHIBIT A

PASSENGER CAPACITY		STAGE LENGTH			PROPULSION TYPE				HI-LIFT
Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Advanced
x 250	2 x 250	2 x 150	2 x 350	1 x 1000	2 x 250	1 x 1000	2 x 250	1 x 1000	2 x 250
30	70	50	50	50	50	50	50	50	50
4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500
63/9.0	642/9.0	468/9.0	528/9.0	566/9.0	450/9.0	507/9.0	486/9.0	533/9.0	430/9.0
.P. Fan	F.P. Fan	F.P. Fan	F.P. Fan	F.P. Fan	V.P. Fan	V.P. Fan	Turboprop	Turboprop	F.P. Fan
x 5,830	2 x 10,310	2 x 7,510	2 x 8,470	2 x 9,090	2 x 7,350	2 x 8,960	2 x 4,200 hp	2 x 4,610 hp	2 x 8,110
33/95	211/134	152/101	183/120	203/134	144/95	172/113	162/129	185/148	140/88.5
90/210	430/350	370/290	370/290	370/290	370/290	370/290	370/360	370/360	370/290
.27/.08	1.27/.08	1.28/.08	1.27/.08	1.27/.08	1.27/.08	1.27/.08	1.27/.12	1.27/.12	1.27/.08
88.3	88.3	88.3	88.3	88.3	88.3	88.3	88.0	88.0	100.8
.3634	.3636	.3634	.3634	.3634	.3700	.400	.364	.364	.3741
.1711	.1472	.1248	.854	.2174	.1316	.1869	.1327	.1797	.1569
10/636	110/976	110/806	110/806	110/806	110/806	110/806	110/812	110/812	110/806
3,046	5,598	4,031	4,464	4,755	3,888	4,326	4,189	4,497	4,010
477	766	538	663	748	505	619	645	741	506
537	762	571	682	763	520	620	502	581	515
,384	6,679	5,492	5,534	5,565	5,480	5,518	5,760	5,804	5,487
,412	2,496	1,819	2,050	2,200	1,749	1,971	1,884	2,065	1,908
3,816	6,749	4,916	5,544	5,950	3,613	4,410	4,849	5,322	5,307
234	312	266	283	293	261	277	271	284	255
269	553	398	398	398	398	398	398	398	400
815	1,214	940	1,058	1,136	907	1,016	1,006	1,101	963
300	300	300	300	300	300	300	300	300	300
247	367	285	321	344	274	308	304	334	293
51	139	93	93	93	93	93	93	93	94
536	1,150	893	893	893	893	893	893	893	893
436	436	436	436	436	436	436	436	436	436
,481	4,536	3,370	3,370	3,370	3,370	3,370	3,763	3,763	3,370
205	562	377	377	377	377	377	377	377	377
397	514	452	478	495	441	468	450	471	431
20	20	20	20	20	20	20	20	20	20
,673	33,153	25,197	26,964	28,136	23,530	25,420	26,140	27,480	25,565
917	1,227	983	996	1,004	980	1,000	990	1,010	990
,590	34,380	26,180	27,960	29,140	24,510	26,420	27,130	28,490	26,555
,000	14,000	10,-00	10,000	10,000	10,000	10,000	10,000	10,000	10,000
,490	8,350	5,160	8,640	10,870	5,230	8,370	5,680	8,430	6,805
,080	56,730	41,340	46,600	50,010	39,740	44,790	42,810	46,920	43,360

7.0 BASEPOINT AIRCRAFT ANALYSIS

7.1 Performance and Design Ground Rules

Based upon both approaches to the initial noncompetitive operational simulations (Section 12.0), conducted to select the best aircraft characteristics for medium density airline operations, the following ground rules were selected:

7.1.1 Passenger Capacity

A 50 passenger size was selected as the midpoint for a stretch/shrink design evaluation to 70 and 30 passengers, in order to fully explore the operating requirements and economic possibilities.

7.1.2 Range

Because the base case range of 563 nautical miles (1,043 km) was inadequate for the initial network, the range was increased to 850 nautical miles (1,574 km). This is compatible with airline preference for a range capability equal to that of the Convair 580 of 880 nautical miles (1,630 km). An increase in range to 1,000 nautical miles (1,852 km) to provide for charter flights, was included in order to evaluate the cost penalties involved.

7.1.3 Field Length

The regional carrier airfield studies resulted in the selection of a 4,500 foot (1,372 meters) field length on a 90°F (32.2°C), sea level day. A 3,500 foot (1,067 meter) capability was not needed and resulted in an appreciably large economic penalty.

7.1.4 Cruise Condition

Because of the short stage lengths in the route system models, the cruise speed and altitude was not a highly significant factor in the evaluations. Thus the design procedure determined the optimum combination of thrust-to-weight ratio and wing loading required for a given field length. The cruise speed was a derivative, with a maximum altitude of 25,000 feet (7,620 meters) due to pressurization system considerations. These basic requirements will be continued except for an evaluation of pressurization system effects for cruise altitudes up to 35,000 feet (10,668 meters).

7.1.5 Configuration Arrangement

The DC-9 or B-737 design will be retained because of: crash landing safety; landing gear retraction problems; minimum fuselage cross-section area; low drag; high wing efficiency; inlet duct ingestion problems; and wing blanketing of approach noise (see Section 6.1.1). The advanced high-lift system will be incorporated because of DOC improvement (see Section 6.3.6).

7.1.6 Propulsion

The fixed-pitch turbofan was continued as the preferred choice because of low DOC, development cost and technical risk. The 50 passenger turboprop was also continued for cost comparison purposes because it showed the lowest DOC and mission fuel (see Section 6.3.5). Several aircraft, powered by current engines (including core engines equipped with new or experimental fans), were designed in order to determine their suitability for medium density operations.

7.2 Propulsion Characteristics

7.2.1 Fixed-Pitch Turbofan Engine

This engine has a bypass ratio of 6 and a pressure ratio of 1.45 at takeoff (Section 6.2.2). The engine thrust/weight ratio of 5.2 represents current technology with moderate turbine inlet temperatures (2400^{o}F or 1315^{o}C, flat rated to 84°F (29°C)). Figures 7-1 and 7-2 show maximum climb and cruise thrust and fuel flow for various flight conditions, based upon a thrust rating of 8,800 pounds (31,900 N), the requirement for the 50 passenger aircraft. The installed performance includes the effects of inlet pressure recovery, customer bleed and power extraction, and scrubbing and base drag associated with the exhaust system. The nacelle drag, that is a function of the freestream dynamic pressure, is included in the airplane drag.

7.2.2 Current Engines

Engine companies were solicited for data on candidate engines, and a survey was made of available engines, below a thrust rating of 20,000 pounds. An initial screening eliminated some engines from consideration because of noise, size, or SFC. Engines with low bypass ratios have poor SFC, and high exhaust velocities with corresponding high exhaust noise levels (see Table 7-1). Potential candidates are listed in Table 7-2, along with the fixed-pitch turbofan for comparison.

The Lycoming ALF-502H is a fixed-pitch fan using the T55 turboshaft engine as its core. The T55 has been in production for many years. A military version of the ALF-502 was installed on the Northrop A-3 aircraft and flown during the A-X evaluation. The commercial ALF-502D has been flown on the Dassault Falcon 30, and was contracted for installation on the HS-146. Certification of the engine is scheduled for 1975. This engine has the lowest cost of all the engines listed in the table. Installed engine performance was based on the uninstalled performance of Reference 3.

The Rolls-Royce SNECMA M45H-01 is flying on the VFW 614 short-haul aircraft. The engine has been designed to provide a low noise signature. Reference 4 was used for performance estimates.

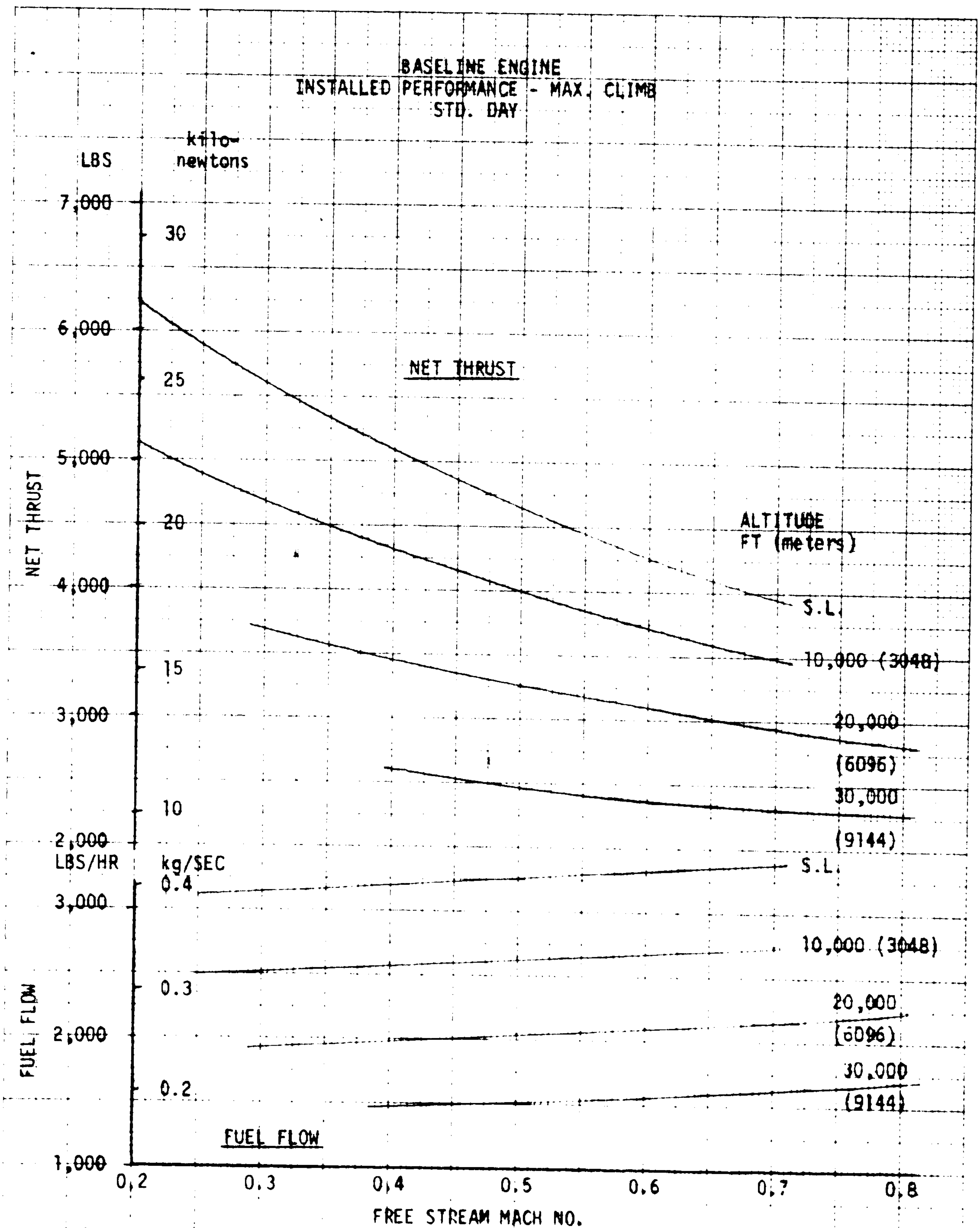

BASELINE ENGINE
INSTALLED PERFORMANCE - MAX. CLIMB
STD. DAY
LBS
kilo-newtons
NET THRUST
NET THRUST
ALTITUDE
FT (meters)
S.L.
10,000 (3048)
20,000
(6096)
30,000
(9144)
LBS/HR
kg/SEC
FUEL FLOW
FUEL FLOW
S.L.
10,000 (3048)
20,000
(6096)
30,000
(9144)
FREE STREAM MACH NO.

FIGURE 7-1

BASELINE ENGINE
INSTALLED PERFORMANCE - MAX. CRUISE
STD. DAY

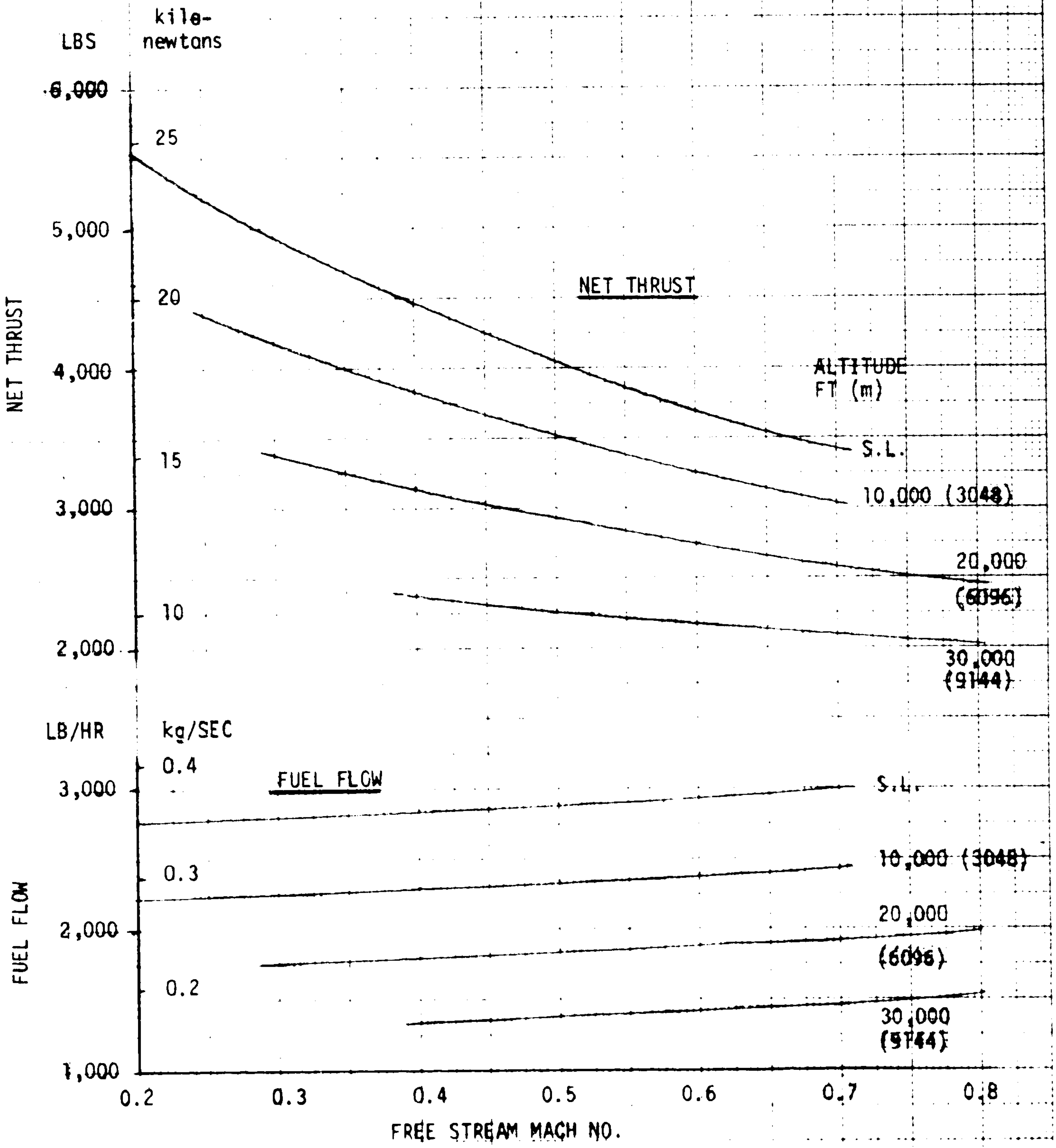


FIGURE 7-2

TABLE 7-1

CURRENT ENGINES ELIMINATED

Engine	Thrust lbs	Thrust (Newtons)	Weight lbs	Weight (kg)	Bypass Ratio	Reason Eliminated
Astafan 3B (experimental)	1,740	(7,740)	462	(1,016)	8	Size, lack of data
JT15D-4	2,500	(11,120)	557	(1,225)	2.5	Size
Larzac 04	3,000	(13,340)	584	(1,285)	1.1	Size
TFE 731-3	3,700	(16,450)	725	(1,595)	2.8	Size
RB172 Adour (military)	5,200	(23,130)	1,215	(2,673)	1	Noise
Spey MK 555	9,850	(43,810)	2,113	(4,649)	1	Noise
JT8D-9	14,500	(64,500)	3,217	(7,077)	1	Size, noise
QCSEE (experimental)	18,300	(81,400)	2,935	(6,457)	11.8	Size

TABLE 7-2

CURRENT ENGINES: POTENTIAL CANDIDATES

		Available Commercial Engines		Derivative of Military Engine	Experimental	Existing Core	New
		Lycoming ALF 502H	RR-SNECMA M45H-01	General Electric CF34	Hamilton Standard QFT-55-28	Allison[1] PD 370-1	Baseline
Takeoff Thrust, SLS, std. day	lbs (N)	6,500 (28,900)	7,600 (33,800)	8,000 (35,580)	7,800 (34,700)	12,200 (54,270)	8,770 (39,000)
Takeoff Thrust, 100 Kn, 90°F	lbs (N)	4,800 (21,300)	6,000 (26,700)	6,450 (28,700)	5,410 (24,060)	8,800 (39,100)	7,250 (32,250)
Weight	lbs (kg)	1,250 (567)	1,440 (653)	1,537 (697)	1,360 (617)	2,130 (970)	1,685 (764)
Bypass Ratio		6	3	6	10	7.6	6
Fan Pressure Ratio		1.45	1.5	1.4	1.28	1.45	1.45
Max Cruise Thrust*	lbs (N)	1,905 (8,470)	2,430 (10,810)	2,474 (11,000)	1,982 (8,815	3,650 (16,280)	2,600 (11,560)
SFC*		0.76	0.74	0.64	0.71	0.66	0.63

* Uninstalled; 25,000 feet; 0.7 Mach Number

(1) Other cycles have also been proposed for this core.

The Hamilton-Standard QFT-55-28, using an uprated Lycoming T55 as its core, is a variable-pitch fan with a takeoff fan pressure ratio of 1.28. The Hamilton-Standard demonstrator engine has a fan pressure ratio of 1.18, and has undergone extensive testing. The higher pressure ratio fan provides a better specific thrust (thrust per unit airflow) and a smaller diameter nacelle. Performance is presented in Reference 5.

The CF-34 engine is a commercial version of the TF34, which was designed for the S-3A, and completed its MQT in August 1972. A slightly modified version, the TF34-GE-100, is installed on the A-10. A model designated CF-34 with a commercial rating of 8,000 pounds (35.6 kilonewtons), flat rated to 84^{o}F (29^{o}C), was studied using performance presented in Reference 6. Acoustical treatment in the inlet and fan exhaust duct provided the desired FAR 36-10 dB noise level (Reference 7).

Suitable engines in the 12,000-14,000 pound (53,000-62,000 N) thrust class do not exist, but could be built using existing cores. One possibility is the Allison PD370-1, a fixed-pitch fan with a pressure ratio of 1.45, built on the T701 turboshaft engine being developed for a heavy lift helicopter. The PD370-1 performance was based on a concept released for a military application (Reference 8). The takeoff rating was reduced 5 percent for a commercial rating (Reference 9). Table 7-2 shows the results of the rating reductions. Other uninstalled performance levels were not changed.

7.3 Final Design Aircraft Summary

Exhibit B tabulates the detail weights, along with pertinent dimensional and descriptive data. The results are grouped by propulsion concept: Turboprops in columns 1, 2 and 3; fixed-pitch turbofans in columns 4 through 8; and current engines in columns 9 through 13. As a reference point, the turboprop and fixed-pitch turbofan groups include the base design stage length of 2 x 250 nautical miles (2 x 463 km).

7.3.1 Turboprop Aircraft

Columns 1, 2 and 3 include the effects of higher aspect ratio and heavier acoustic insulation on the fuselage. A comparison, columns 1 and 3 with columns 12 and 13 in Exhibit A of Section 6.0, shows that these effects have increased the gross weights by 1,000 to 1,100 pounds, due to wing and fuselage weight changes.

A comparison with the corresponding fixed-pitch turbofan aircraft has already been made and reported in Section 6.3.5 and Table 6-9. The turboprop uses less fuel at a given range; its weight empty is greater, but its gross weight compares favorably; in fact, at the design ranges (850 to 1,000 nautical miles, 1,574 to 1,852 km), its gross weight is lower. Despite a slower cruise speed, the turboprop DOC is lower due to lower aircraft and fuel costs. A general arrangement sketch is shown in Figure 6-19, Section 6.3.5.

Further improvement in turboprop aircraft design can be expected from recent developments in propeller blade design. The use of advanced airfoils will permit cruise speeds equivalent to those of turbofan aircraft and formerly attainable only with the variable camber propeller.

FINAL DESIGN AIRCRAFT

DESCRIPTION		TURBOPROPS			F	
Flap Type		Nominal	Nominal	Nominal	Advanced	Advanced
Stage Length	(n.mi)	2 x 250	1 x 850	1 x 1000	2 x 250	1 x 850
Number of Seats		50	50	50	50	50
Field Length	(ft)	4,500	4,500	4,500	4,500	4,500
Wing Area (ft^2)/Aspect Ratio		498/10.5	527/10.5	546/10.5	430/9.0	464/9.0
Engine Designation		Turboprop	Turboprop	Turboprop	F.P. Fan	F.P. Fan
Engine Thrust	(lb/eng)	2 x 4,230 hp	2 x 4,480 hp	2 x 4,640 hp	2 x 8,110	2 x 8,770
Horiz/Vert Tail Area	(ft^2)	155/143	182/145	192/153	123/106	138/119
Horiz/Vert Tail Arm	(in)	370/362	370/362	370/362	350/275	350/275
Horiz/Vert Tail Volume		1.27/.12	1.27/.12	1.27/.12	1.103/.091	1.103/.091
Wing Loading	(lb/ft^2)	88.0	88.0	88.0	100.9	100.9
Thrust Ratio		.357	.357	.357	.374	.374
Fuel Fraction		.1350	.1644	.1816	.1568	.194
Fuselage Dia/Length	(in)	110/812	110/812	110/812	110/806	110/806
Wing	(lb)	4,424	4,667	4,867	3,937	4,360
Horizontal Tail	(lb)	619	728	768	445	500
Vertical Tail	(lb)	559	567	598	617	693
Fuselage	(lb)	6,532	6,532	6,532	5,732	5,735
Landing Gear	(lb)	1,929	2,040	2,113	1,734	1,874
Power Plant	(lb)	4,728	5,007	5,186	5,306	5,740
Fuel System	(lb)	274	282	287	255	265
Auxiliary Power Unit	(lb)	400	409	416	400	400
Flight Controls	(lb)	1,029	1,058	1,077	823	849
Instruments	(lb)	300	300	300	300	300
Hydraulics	(lb)	309	317	323	190	200
Pneumatics	(lb)	95	98	99	100	100
Electrical	(lb)	893	893	893	825	825
Avionics	(lb)	436	436	436	436	436
Furnishings	(lb)	3,551	3,551	3,551	3,505	3,505
Air Conditioning	(lb)	377	377	377	435	435
Ice Protection	(lb)	455	468	477	430	448
Handling Gear	(lb)	20	20	20	20	20
Manufacturer's Empty Weight		26,930	27,750	28,320	25,490	26,685
Operator's Items		990	990	990	1,070	1,075
Operator's Empty Weight		27,920	28,740	29,310	26,560	27,760
Payload		10,000	10,000	10,000	10,000	10,000
Mission Fuel		5,920	7,620	8,720	6,800	9,090
Maximum Takeoff Weight		43,840	46,360	48,030	43,360	46,850

ORIGINAL PAGE IS
OF POOR QUALITY

FOLDOUT FRAME

L DESIGN AIRCRAFT EXHIBIT B

	FIXED PITCH TURBOFANS					CURRENT ENGINES				
vanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced
x 250	1 x 850	1 x 1000	1 x 850	1 x 850	1 x 850	1 x 850	1 x 850	1 x 850	1 x 850	1 x 850
50	50	50	30	70	61	42	35	31	62	
,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	
0/9.0	464/9.0	489/9.0	342/9.0	605/9.0	573/9.0	417/9.0	395/9.0	357/9.0	637/9.0	
P. Fan	F.P. Fan	F.P. Fan	F.P. Fan	F.P. Fan	PD370-1	CF34	M45H01	QFT55	ALF502	
8,110	2 x 8,770	2 x 9,240	2 x 6,450	2 x 11,420	2 x 10,800	2 x 7,960	2 x 7,090	2 x 7,030	4 x 5,830	
3/106	138/119	150/129	112/104	177/147	174/147	130/115	128/116	117/108	199/140	
0/275	350/275	350/275	274/199	407/332	382/307	316/242	297/222	278/204	391/376	
3/.091	1.103/.091	1.103/.091	1.103/.091	1.103/.091	1.103/0.091	1.103/0.091	1.103/0.091	1.103/0.091	1.103/.091	
00.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9	98.9	
.374	.374	.374	.374	.374	.3734	.3786	.3554	.3900	.3700	
.1568	.194	.2161	.2039	.1891	.2076	.1965	.2238	.2101	.2243	
0/806	110/806	110/806	110/636	110/976	110/902	110/742	110/710	110/678	110/866	
.937	4,360	4,689	3,143	5,910	5,550	3,840	3,630	3,227	6,163	
445	500	540	405	645	629	471	463	425	863	
617	693	750	605	860	851	669	675	630	567	
,732	5,735	5,732	4,310	7,170	6,488	5,120	4,653	4,362	6,471	
,734	1,874	1,975	1,379	2,440	2,314	1,682	1,596	1,441	2,680	
,306	5,740	6,050	4,221	7,473	7,816	5,530	5,165	4,856	8,948	
255	265	330	347*	305	295	251	445*	372*	523	
400	400	400	343	460	475	330	305	275	475	
823	849	868	750	955	925	775	750	685	1,085	
300	300	300	300	300	300	300	300	300	375	
190	200	210	171	230	225	175	170	160	280	
100	100	100	86	115	130	80	70	60	152	
825	825	825	617	1,040	934	736	670	628	946	
436	436	436	436	436	436	436	436	436	436	
505	3,505	3,505	2,623	4,720	3,967	3,125	2,846	2,669	4,020	
435	435	435	325	550	492	389	353	331	498	
430	448	460	384	511	498	424	413	393	525	
20	20	20	20	20	20	20	20	20	20	
490	26,685	27,625	20,465	34,140	32,345	24,353	22,960	21,270	35,025	
070	1,075	1,075	985	1,320	1,295	1,037	1,010	990	1,165	
560	27,760	28,700	21,450	35,460	33,640	25,390	23,970	22,260	36,190	
000	10,000	10,000	6,000	14,000	12,200	8,400	7,000	6,200	12,[illegible]00	
800	9,090	10,670	7,030	11,540	12,010	8,260	8,930	7,570	14,140	
360	46,850	49,370	34,480	61,000	57,850	42,050	39,900	36,030	63,030	

* INCLUDES FUSELAGE FUEL SYSTEM WEIGHT

FOLDOUT FRAME

7.3.2 Fixed-Pitch Turbofan Aircraft

Table 7-3 summarizes and supplements the data in Exhibit B, in order to facilitate comparisons. The fuel and payload fractions show the expected improvement in overall design efficiency with increase in aircraft size, i.e., from 30 to 70 passengers, the fuel fraction decreases by over 7 percent and the payload fraction increases by 32 percent. Also, as expected, aircraft (and payload) size increases trip cost and decreases seat-mile cost. Increasing the design range to provide charter flight capability increases DOC by less than 1 percent.

The airframe cost weight is a measure of airframe price, assuming a constant unit price (dollars per pound). Again, aircraft (and payload) size increases aircraft price and decreases price per seat. Provision for charter flight capability increases price or price per seat by 3 percent. These relative values are conservative in that they do not include the effect of engine unit price (dollars per pound of thrust), which increases as thrust decreases, thus making the smaller aircraft even more expensive.

Figures 7-3, 7-4 and 7-5 are the general arrangement sketches for the 30, 50 and 70 passenger aircraft, respectively.

Further improvement in the design efficiency of these aircraft can be expected from: recent developments in advanced airfoils, permitting the use of still greater thickness in the wings to increase wing fuel capacity (critical in small aircraft) and decrease weight; refining the wing geometry for the mission, propulsion system and landing gear design.

7.3.3 Current Engine Aircraft

This design investigation involved the sizing of aircraft with

TABLE 7-3

FINAL DESIGN: EFFECT OF RANGE AND PAYLOAD
4,500 FT FIELD LENGTH BPR 6 F.P. FAN ADVANCED FLAP

PASSENGERS	(No.)	30	50	70	50
RANGE	(N Mi)	1 x 850	1 x 850	1 x 850	1 x 1,000
OPERATING WT EMPTY	(Lb)	21,450	27,770	35,460	28,700
FUEL	(Lb)	7,030*	9,090	11,540	10,670
PAYLOAD	(Lb)	6,000	10,000	14,000	10,000
GROSS WEIGHT	(Lb)	34,480	46,860	61,000	49,370
WING LOADING	(Lb/Sq Ft)	101	101	101	101
THRUST	(No. x Lb)	2 x 6,450	2 x 8,770	2 x 11,420	2 x 9,240
THRUST/WEIGHT RATIO		0.374	0.374	0.374	0.374
FUEL FRACTION		0.204	0.194	0.189	0.216
PAYLOAD FRACTION		0.174	0.214	0.230	0.203
CRUISE MACH	No.	0.73	0.75	0.75	0.75
CRUISE ALTITUDE	(Ft)	25,000	25,000	25,000	25,000
AIRFRAME COST WT	(Lb)	17,210	22,310	28,480	23,020
REL. DOC AT 850 N. Mi.	(Trip)	0.867	1.000	1.138	1.008
	(Seat-Mile)	1.445	1.000	0.813	1.008
REL. PRICE		0.772	1.000	1.276	1.032
REL. PRICE PER SEAT		1.285	1.000	0.912	1.032

*WING FUEL LIMITED, BELLY TANK FUEL REQUIRED (LB) 715

GENERAL ARRANGEMENT: FINAL DESIGN

TURBOFAN AIRCRAFT

PAYLOAD:	30 PASSENGER (4/32) ADVANCED HI-LIFT
WING AREA:	342 SQ FT
TOGW:	34,480 LB
WING LOADING:	101 LB/SQ FT
TOFL:	4,500 FT
RANGE:	850 N MI
ENGINE:	F.P. FAN (BPR=6) $T_{SLS} = 2 \times 6{,}450$ LB

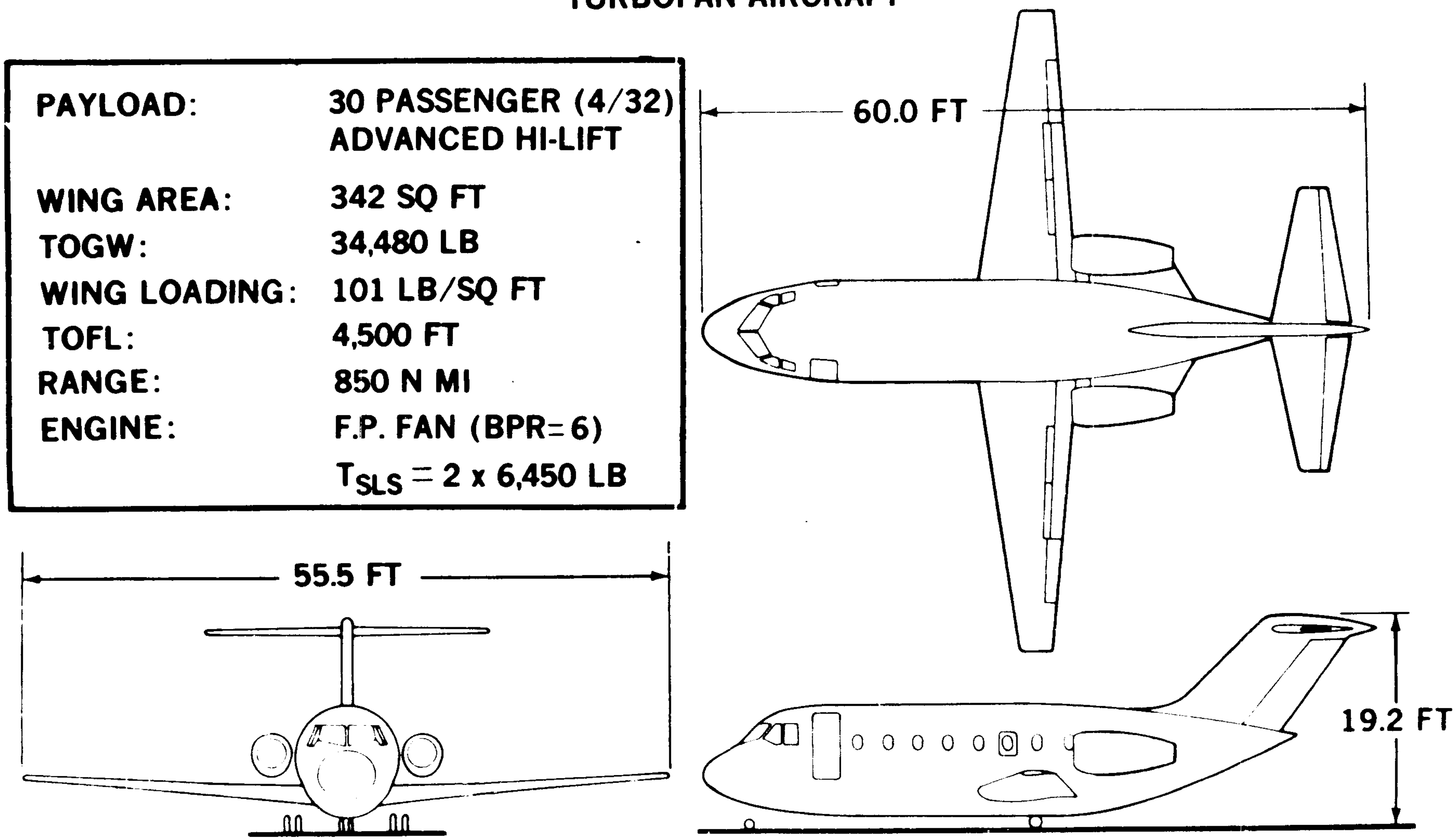


FIGURE 7-3

GENERAL ARRANGEMENT: FINAL DESIGN

TURBOFAN AIRCRAFT

PAYLOAD:	50 PASSENGERS (4/32)
	ADVANCED HI-LIFT
WING AREA:	464 SQ FT
TOGW:	46,850 LB
WING LOADING:	101 LB/SQ FT
TOFL:	4500 FT
RANGE:	850 N MI
ENGINE:	F.P. FAN (BPR = 6)
	T_{SLS} = 2 x 8,770 LB

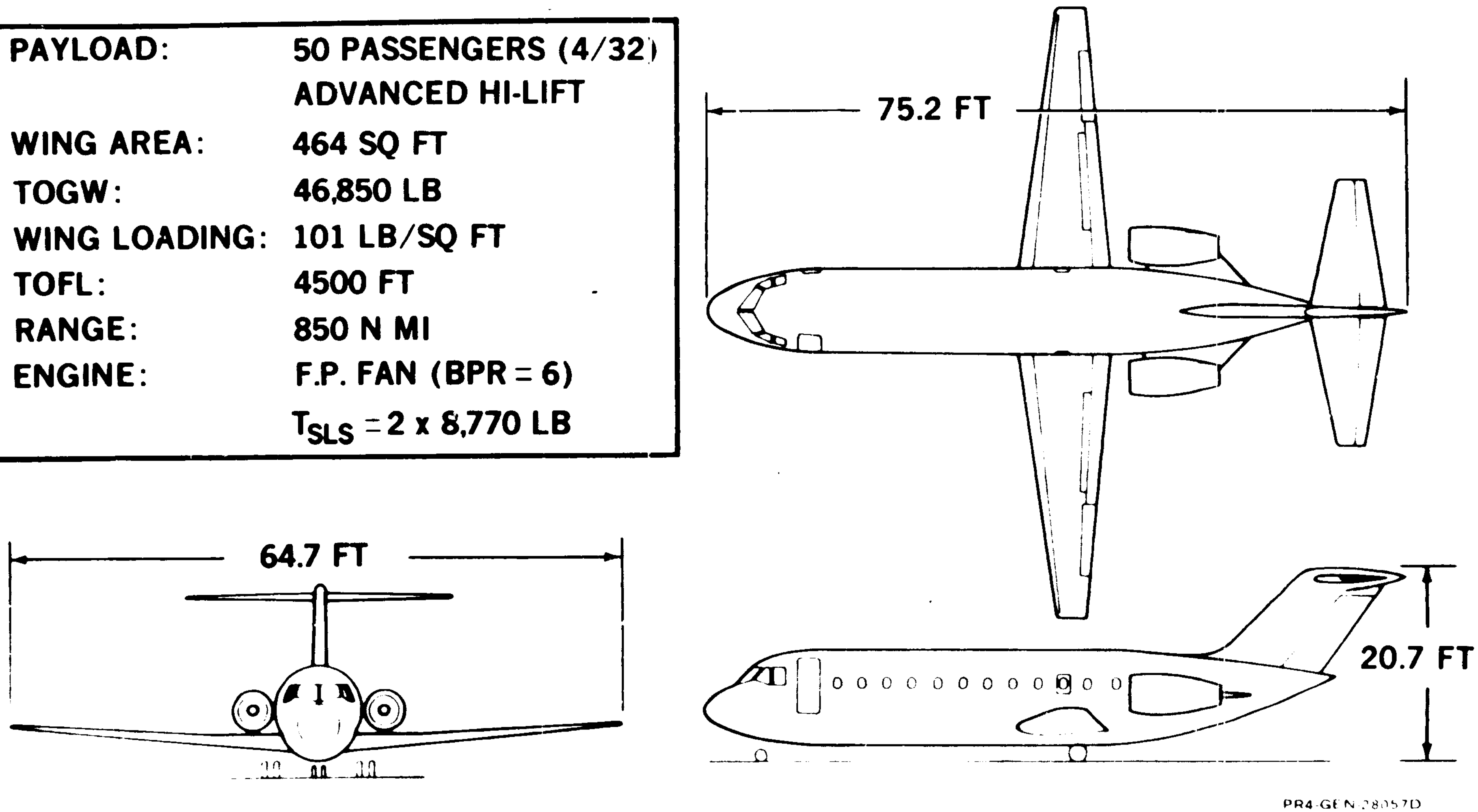
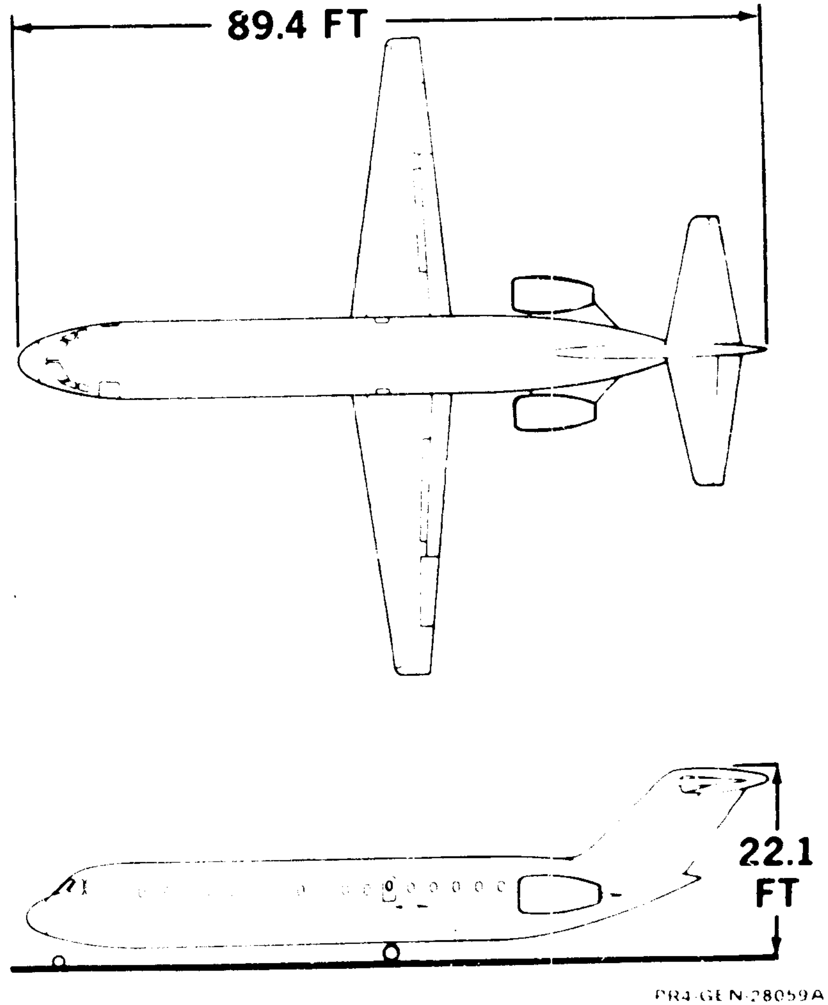


FIGURE 7-4

GENERAL ARRANGEMENT: FINAL DESIGN

TURBOFAN AIRCRAFT

PAYLOAD:	70 PASSENGERS (4/32) ADVANCED HI-LIFT
WING AREA:	605 SQ FT
TOGW:	61,000 LB
WING LOADING:	101 LB/SQ FT
TOFL:	4,500 FT
RANGE:	850 N MI
ENGINE:	F.P. FAN (BPR= 6) T_{SLS}= 2 x 11,420 LB



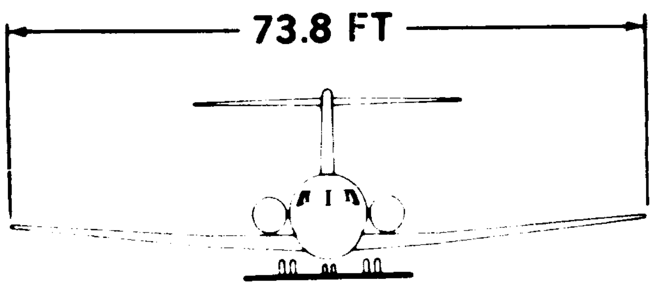


FIGURE 7-5

engines of fixed size and propulsion cycles differing from the fixed-pitch turbofan. Holding the design range and field length constant, and with the number and size of engines determining the gross weight, the passenger capacity was a fall-out. The payload capacity varies from 31 to 62 passengers. All of the aircraft are aft fuselage-mounted, twin-engine, low-wing configurations. The exception is the ALF502 configuration, which has four wing-mounted engines. Two ALF502 engines would have carried less than 30 passengers and three-engine configurations were not considered (see Figure 7-6 for general arrangement sketch).

Table 7-4 summarizes and supplements the data in Exhibit 6 for comparative purposes. In each column is an aircraft powered by the base fixed pitch turbofan and sized to the same passenger capacity as the aircraft with the current engine. Inspection of this table shows the following:

- Only two engines can be considered as "fully off-the-shelf" engines, the ALF-502 and M45H-01, and thus available
- The other three engines may be defined as "partly off-the-shelf" engines. The QFT-55 is an experimental variable pitch fan driven by a T55 core used in the ALF-502. The CF-34 is a commercial version of the military TF34, requiring commercial certification. The PD370-1 is a proposed fixed-pitch fan driven by an experimental "hardware" gas generator.
- Examination of the mission fuel, gross weight and airframe cost weight shows that the current engine aircraft are not as efficient as the fixed-pitch turbofan aircraft, because all of these values are higher. Thus, it is obvious that the DOCs of the current engine aircraft suffer in comparison with the turbofan

GENERAL ARRANGEMENT

PAYLOAD:	62 PSGRS (4/32)
WING AREA:	637 SQ FT
TOGW:	63,030 LB
WING LOADING:	98.9 LB/SQ FT
TOFL:	4,500 FT
ENGINE:	ALF502
	T_{SLS} = 4 x 5830 LB

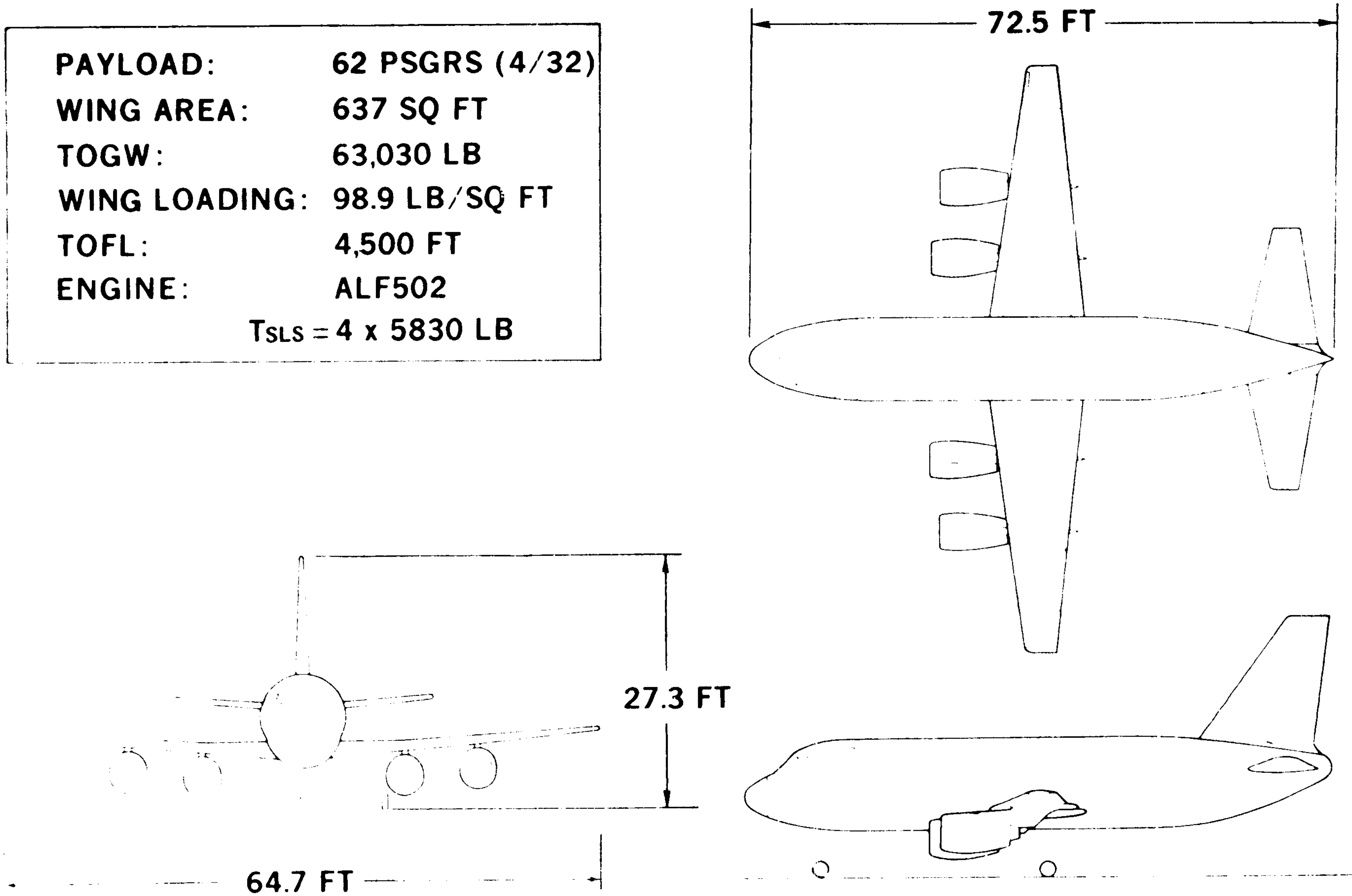


FIGURE 7-6

TABLE 7-4

AIRCRAFT CHARACTERISTICS: CURRENT ENGINES

4,500 FT FIELD LENGTH   850 N MI RANGE   ADVANCED FLAP

101 LB/SQ FT WING LOADING   CRUISE: 0.75 MACH AT 25,000 FT

ENGINE DESIGNATION		ALF502	M45H01	QFT55	CF34	PD370-1
THRUST: SL, 90°F, 100 KN		4 x 4,800	2 x 6,000	2 x 5,410	2 x 6,450	2 x 8,800
THRUST/WT: SLS, 90°F		0.370	0.355	0.390	0.379	0.373
OP WT EMPTY	(LB)	36,490	23,970	22,250	25,390	33,640
FUEL	(LB)	14,140	8,930*	7,570*	8,260	12,010
PAYLOAD	(LB)	12,400	7,000	6,200	8,400	12,200
GROSS WT	(LB)	63,030	39,900	36,030	42,050	57,850
COST WT	(LB)	28,670	18,990	17,520	20,760	26,700
FIXED PITCH TURBOFAN						
THRUST: SL, 90°F, 100 KN		2 x 8,560	2 x 5,780	2 x 5,420	2 x 6,440	2 x 8,440
THRUST/WT: SLS, 90°F		0.374	0.374	0.374	0.374	0.374
OP WT EMPTY	(LB)	32,350	22,850	21,700	25,000	31,950
FUEL	(LB)	10,550	7,480	7,120	8,200	10,400
PAYLOAD	(LB)	12,400	7,000	6,200	8,400	12,200
GROSS WT	(LB)	55,300	37,330	35,020	41,600	54,550
COST WT	(LB)	25,900	18,350	17,430	20,100	25,580

*WING FUEL LIMITED, BELLY TANK FUEL REQUIRED (LB)		1,196	835

aircraft; the ALF502 is the highest; the CF34 and the QFT55 are the lowest. In order to improve DOC, more efficient engine cycles and engines of higher thrust ratings must be developed.

8.0 ACOUSTIC ANALYSIS

8.1 Aircraft Noise Definition

Aircraft noise of mechanical flap aircraft can be broadly classified into two categories; aerodynamic noise produced by the turbulence associated with the passage of the aircraft through the ambient air, and propulsive noise produced by the aircraft engines.

8.1.1 Aerodynamic Noise

Aerodynamic or nonpropulsive noise is produced by airflow over aircraft surfaces. It is generated by turbulence or separated flows at or about the airframe surfaces. During the landing approach condition nonpropulsive noise (NPN) may become dominant when (in addition to inflow turbulence from the boundary layer) aerodynamic flows are interacting with the extended landing gear, flaps, slats, wheel well doors and cavities. Aerodynamic noise is configuration dependent.

8.1.2 Propulsive Noise

The propulsive noise sources considered in this study are turbofan and turboprop engines.

Turbofan Engine

Turbofan engine noise can be subdivided into two main categories: jet-exhaust noise generated external to the engine and turbomachinery noise generated by the rotating components of the engine. Internally generated turbomachinery noise can usually be suppressed by the installation of acoustic materials in the engine nacelle. Jet noise is not easily suppressed and generally requires forced mixing of the exhaust gases to achieve a measurable reduction.

Turboprop Engine

The noise from a turboprop engine is produced by two main sources: the propeller and the jet exhaust. Propeller noise is more dominant and disturbing. Reduction of propeller noise can be obtained by reducing the propeller tip speed and by low blade loading. Tip speed is reduced by decreasing propeller diameter and/or RPM. A reduction in blade loading is accomplished by lower horsepower, increased blade area or by increasing the number of blades. In new installations propeller noise can be minimized by designs using large diameter multiblade propellers operating at low rotative speeds consistent with engine horsepower and gearing limitations. The principal acoustical problem with propeller-powered aircraft is suppression of fuselage interior noise levels.

8.2 Noise Prediction Procedures

8.2.1 Parametric Procedure - Turbofan Aircraft

In this study phase, engine and aircraft performance data used to estimate noise consisted of takeoff gross weight, number of engines, engine thrust, engine bypass ratio, altitude at the FAR Part 36 measuring points, and the acoustic treatment level. The data provides the input to the Douglas noise computer program (B5BA).

Figure 8-1 presents a flow diagram of the noise program, which produces Effective Perceived Noise Level (EPNL) maps as a function of distance and power setting for generalized engines having bypass ratios of 3, 6, 9 and 12. These generalized engines and the engines assumed for this task are based on separate exhaust flow designs. The engines are therefore assumed to be installed in short to medium fan duct length nacelles. The analysis is performed for three levels of acoustic treatment: (1) Hardwall- no acoustic

NOISE PREDICTION PROCEDURE

(NOISE PROGRAM B5BA)

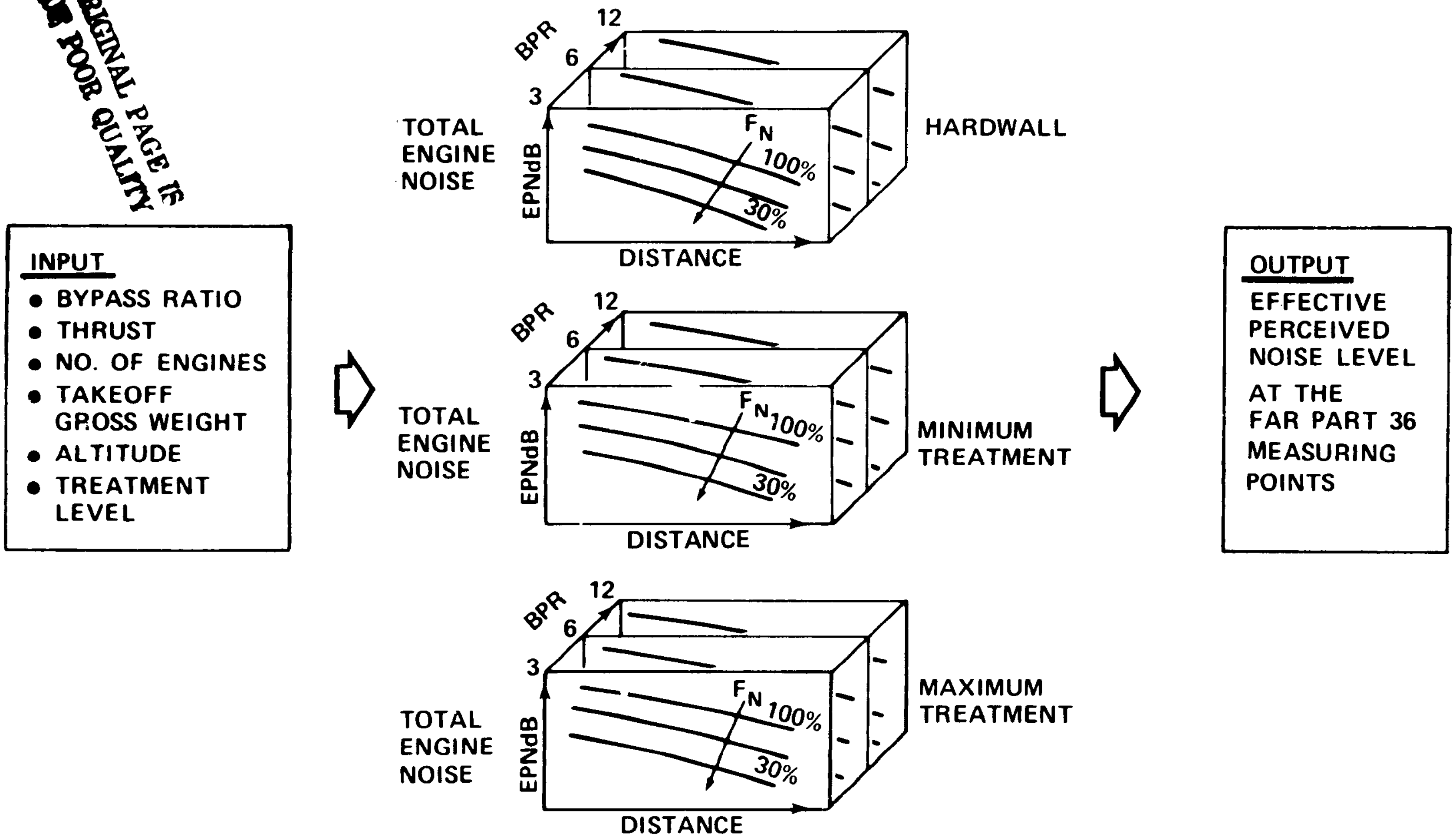


FIGURE 8-1.

treatment, (2) Minimum Treatment - cowl wall treatment only, and (3) Maximum Treatment - treatment required to lower the fan and turbine noise levels to the jet/core noise floor. The program uses multiple quadratic interpolation of the input data to determine the flyover noise level at the FAR Part 36 measuring points.

8.2.2 Parametric Procedure - Turboprop Aircraft

The Hamilton Standard generalized noise procedure was used, which estimates far field noise based on the power input and the propeller tip speed, diameter and number of blades. Corrections are made for noise directivity, distance from the propeller, number of propellers, and conversion to Perceived Noise Level (PNL) and EPNL.

8.2.3 Final Design Procedure - Turbofan Aircraft

In this study phase additional engine cycle data was used and the more comprehensive Douglas Source Noise Analysis Procedure (SNAP) computer program was employed. SNAP utilizes static noise data from engines A and C of the NASA Quiet Engine Program and from DC-8, DC-9, and DC-10 flyover noise data. Inputs include engine fan pressure ratio, fan tip velocity, bypass ratio, air flow rates, nozzle exit velocities, and nozzle exit areas. Figure 8-2 presents a summary of the source noise analysis procedure. The peak Perceived Noise Level (PNLM) is calculated for each noise source in the forward quadrant and in the aft quadrant relative to the engine inlet. The noise sources are the fan inlet, fan exhaust, turbine, core, and the jet exhaust. Adjustments for the number of engines, distance from the noise source, and turbomachinery suppression are applied to the engine component noise source levels, which are then summed logarithmically. The resulting total inlet or

NOISE PREDICTION PROCEDURE

(SOURCE NOISE ANALYSIS)

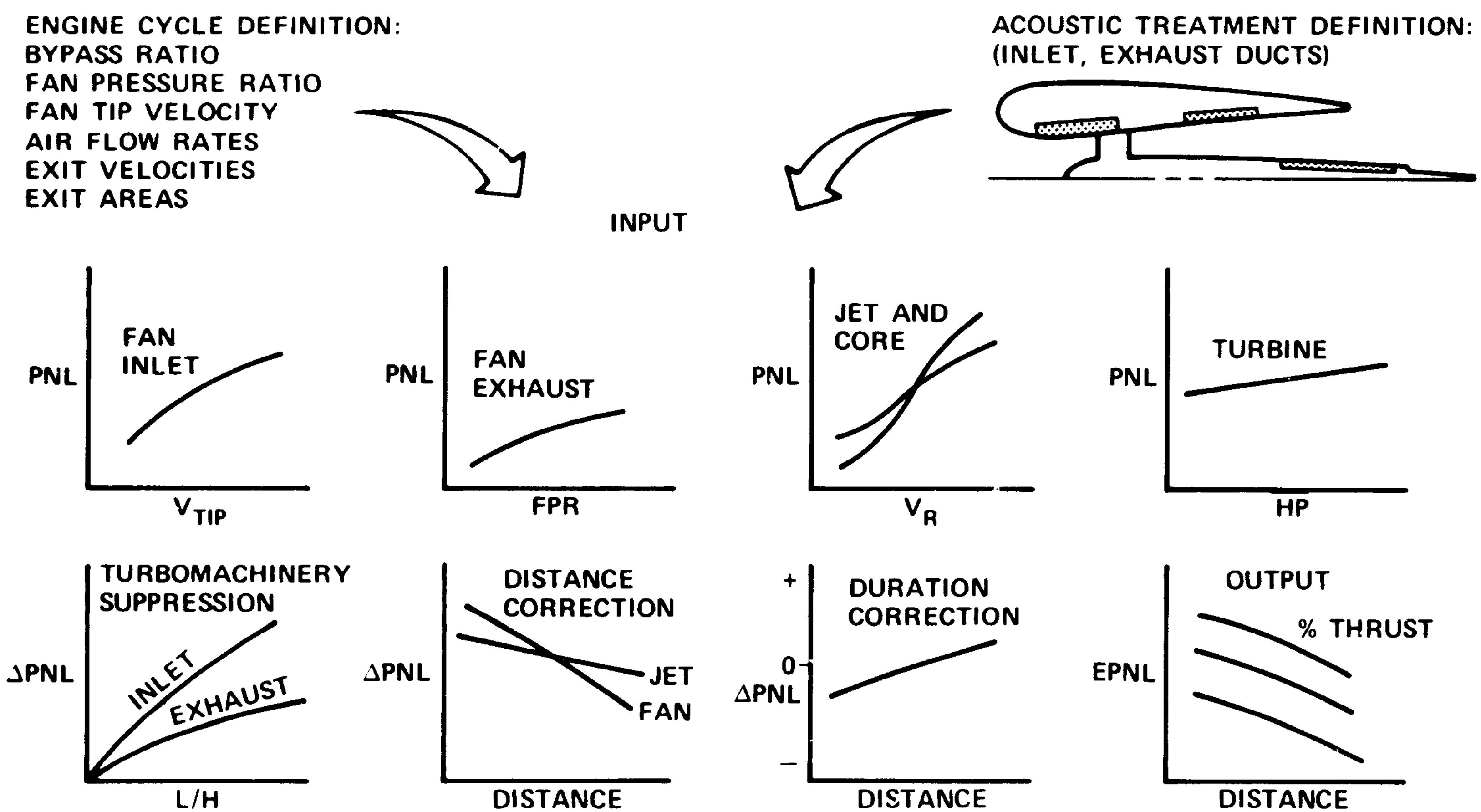


FIGURE 8-2.

exhaust PNL, whichever is maximum, is corrected for noise duration to determine the EPNL.

8.3 Noise Contour Procedure

FAR Part 36 noise contours of 80, 85, and 90 EPNdB were generated for the takeoff and 3 degree approach flight paths of the final design basepoint using a computer program developed for the Hewlett Packard 9820A system. The computer inputs consist of noise data in the form of EPNL as a furction of distance and flight path, and performance data on aircraft altitude, airspeed, flap setting, and engine thrust. Adjustments are made to EPNL for airspeed based on a 10X log airspeed relationship and for ground attenuation based on SAE document ARP 1114.

In order to conduct the community impact analysis, noise contours of 80 to 100 EPNdB were generated for a typical operational takeoff and approach flight path of the basepoint aircraft by using the Douglas developed Aircraft Noise Contour/Community Noise Impact Evaluation digital computer program (AlFA) in conjunction with a Gerber plotter. The inputs for this analysis are the same as noted above for the HP 9820A system. The noise contours generated are used to calculate the noise levels for the takeoff and approach flight path at 500 foot sideline intervals relative to the runway centerline. The result is a rectangular grid of EPNL values from which contours of equal EPNL may be obtained by interpolation. The EPNL at each grid point is then determined by finding the minimum distance to the flight path and relating the noise level to the aircraft operating conditions at that point on the flight path. Figure 8-3 depicts the basic concept of noise contour generation.

NOISE CONTOUR GENERATION

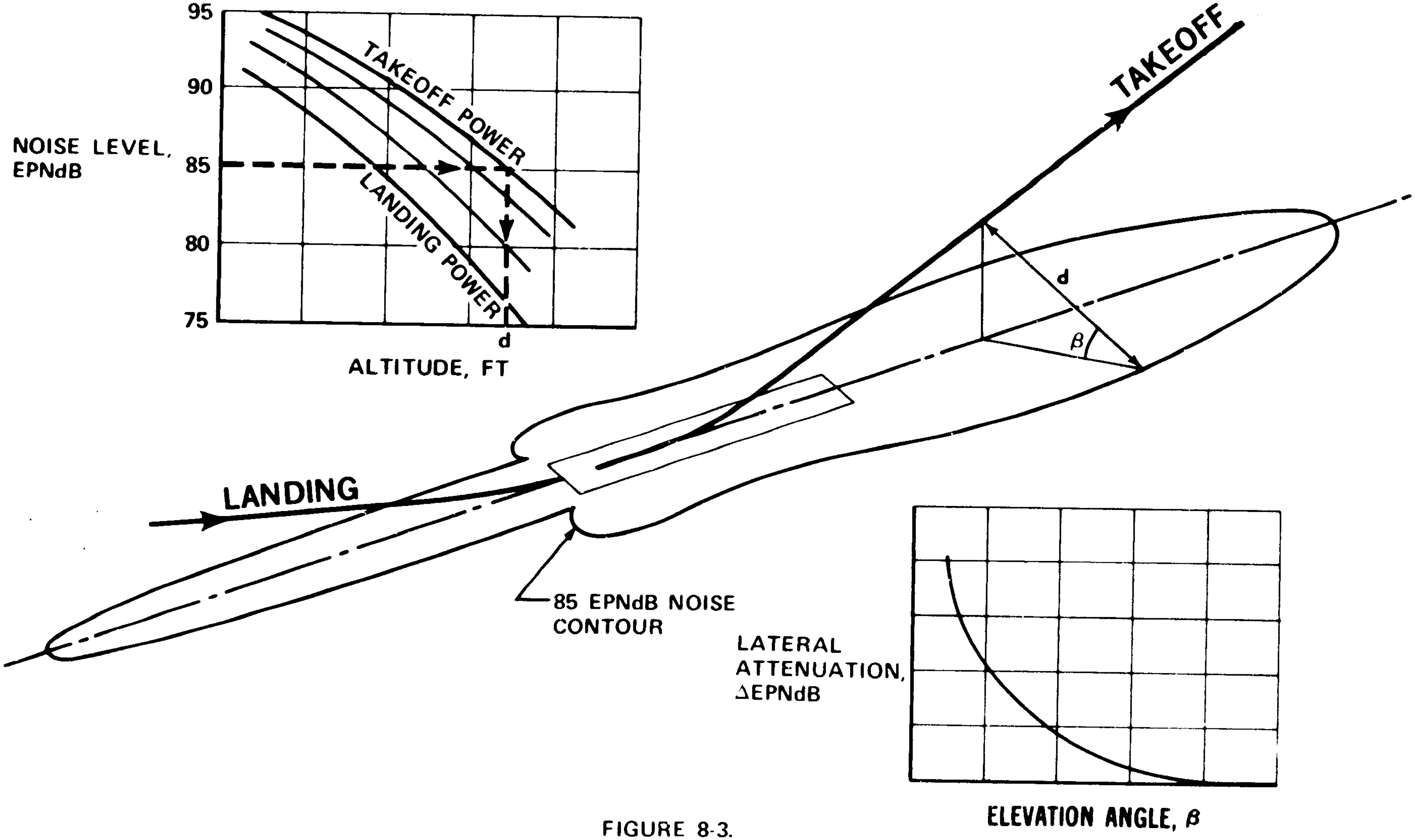


FIGURE 8-3.

8.4 Community Noise Impact Procedure

The community noise impact of the basepoint aircraft at the selected airport (Chicago Midway) is calculated using the AIFA digital computer program. The EPNL grid coordinate system described in paragraph 8.3 is transformed into a population density coordinate system, i.e., the average number of people at each 500 foot sideline interval relative to a rectangular coordinate system with its origin at the airport reference point. Interpolation is used to determine the EPNL at each population grid point. The fraction of people highly annoyed and finally the community noise impact (i.e., number of people highly annoyed) are calculated for all grid points within the 80 EPNdB contour. Details of the method used are described in paragraph 5.4.1 of the NASA STOL Community Impact Report, (Reference 1). The community noise impact results are included in the Environmental Impact Analysis, Section 10.0.

Figure 8-4 is a pictorial presentation of the community noise impact computer program used in this study.

8.5 FAR Part 36 Noise Estimated for Conceptual Aircraft

Aircraft and engine parameters for nine turbofan and one turboprop aircraft, determined from the conceptual aircraft studies, were used for estimating flyover noise levels at the FAR Part 36 measuring points. The parameters used to generate the EPNL estimates are listed in Table 8-1. The noise estimates were made for engines installed in nacelles without acoustic treatment (hardwall). Thus a direct comparison with the FAR Part 36 -10 EPNdB noise goal can be made, along with an assessment of the overall acoustic treatment required for each aircraft configuration.

The results of the analysis are presented in Table 8-2. The sideline noise estimates are 4 to 6 EPNdB below the noise goal and the takeoff noise

MCDONNELL DOUGLAS COMMUNITY NOISE IMPACT COMPUTER PROGRAM

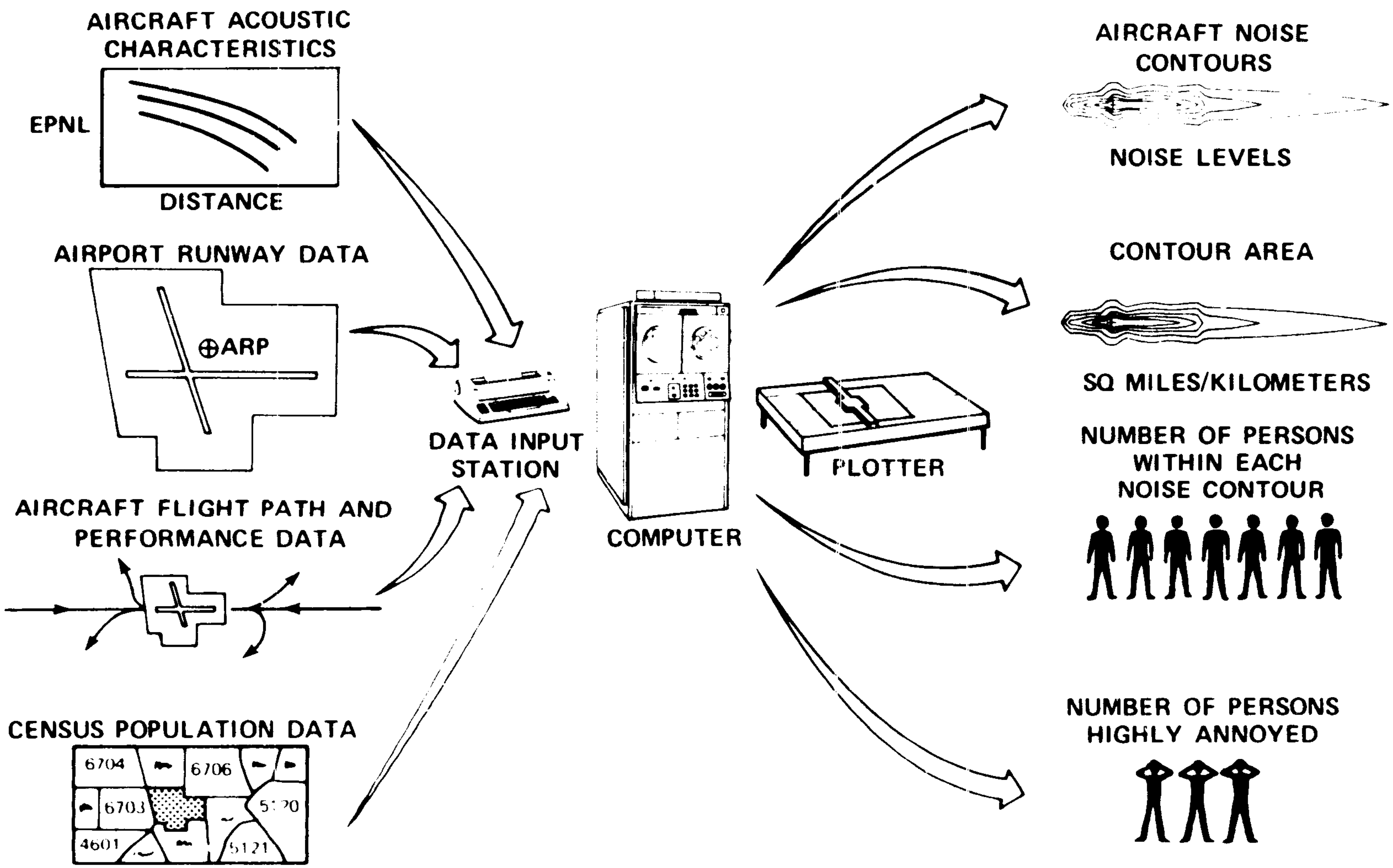


FIGURE 8-4.

TABLE 8-1

AIRCRAFT AND ENGINE PERFORMANCE PARAMETERS FOR ESTIMATING AIRCRAFT FLYOVER NOISE LEVELS

NO. OF PASSENGERS	FIELD LENGTH FT (m)	STAGE LENGTH NM (km)	TOGW LBS (kg)	THRUST/ENG SLS LBS (N)	*ENGINES	TAKEOFF ALTITUDE FT (m)	TAKEOFF VELOCITY KTAS (m/s)	APPROACH VELOCITY KTAS (m/s)
50	4500 (1371.6)	250 (463)	43920 (19922.8)	7980 (35496.8)	Turbofan	2970 (905.3)	146 (75.1)	134 (68.9)
50	3500 (1066.8)	250 (463)	48150 (21840.5)	8410 (37409.5)	"	3140 (957.1)	125 (64.3)	116 (59.7)
50	5500 (1676.4)	250 (463)	42220 (19150.7)	7970 (35452.3)	"	2850 (868.7)	163 (83.9)	150 (77.2)
30	4500 (1371.6)	250 (463)	32080 (14551.2)	5830 (25933.1)	"	2970 (905.3)	146 (75.1)	134 (68.9)
70	4500 (1371.6)	250 (463)	56730 (25732.3)	10310 (45861.2)	"	2970 (905.3)	146 (75.1)	134 (68.9)
50	4500 (1371.6)	150 (277.8)	41340 (18751.5)	7510 (33406.1)	"	2970 (905.3)	146 (75.1)	134 (68.9)
50	4500 (1371.6)	350 (648.2)	46600 (21137.4)	8470 (37676.4)	"	2970 (905.3)	146 (75.1)	134 (68.9)
50	4500 (1371.6)	1000 (1852)	50010 (22684.2)	9090 (40434.3)	"	2970 (905.3)	146 (75.1)	134 (68.9)
50	4500 (1371.6)	250 (463)	39740 (18025.8)	7350 (32694.4)	Var. Pitch Turbofan	2950 (899.2)	146 (75.1)	134 (68.9)
50	4500 (1371.6)	250 (463)	42810 (19418.3)	4200HP (3131.9 kW)	Turboprop	3600 (1097.3)	146 (75.1)	134 (68.9)

*ENGINES: 2 - BPR 6 TURBOFAN ENGINES, 2 - BPR 12.8 VARIABLE PITCH TURBOFAN ENGINES,
2 - TURBOPROP ENGINES, 13.8 FT (4.21m) DIA., 4 BLADE PROPELLER

TABLE 8-2

ACOUSTIC NOISE LEVELS: UNTREATED

PSGR/LFL/RANGE No./Ft/NM (No./m/km)	ENGINES No. x Lb (N) Thrust		NOISE LEVEL: EPNdB SIDELINE 1672 Ft SLT (509.5 m)	TAKEOFF *	APPROACH 370 Ft (112.8 m)
50/4500/2 x 250 (50/1371.6/2 x 463	2 x 7980 (2 x 35496.8)	FIXED PITCH TURBOFAN	87	80	98
50/3500/2 x 250 (50/1066.8/2 x 463)	2 x 8410 (2 x 37409.5)	"	87	80	99
50/5500/2 x 250 (50/1676.4/2 x 463)	2 x 7970 (2 x 35452.3)	"	87	81	98
30/4500/2 x 250 (30/1371.6/2 x 463)	2 x 5830 (2 x 25933.1)	"	86	79	97
70/4500/2 x 250 (70/1371.6/2 x 463)	2 x 10310 (2 x 45861.2)	"	88	81	99
50/4500/2 x 150 (50/1371.6/2 x 277.8)	2 x 7510 (2 x 33406.1)	"	87	80	98
50/4500/2 x 350 (50/1371.6/2 x 648.2)	2 x 8470 (2 x 37676.4)	"	87	81	99
50/4500/1 x 1000 (50/1371.6/1 x 1852)	2 x 9090 (2 x 40434.3)	"	88	81	99
50/4500/2 x 250 (50/1371.6/2 x 463)	2 x 7350 (2 x 32694.4)	VARIABLE PITCH TURBOFAN	86	78	94
50/4500/2 x 250 (50/1371.6/2 x 463)	2 x 4200 HP (2 x 3131.9 KW)	TURBOPROP	87	81	89
	FAR 36-10 EPNdB		92	83	92

*FP AND VP AT 3000 + 150 FT (914.4 + 45.7m), TP AT 3600 FT (1097.3m) estimates are 2 to 5 EPNdB below the noise goal. The approach estimates for the turboprop aircraft are 3 EPNdB below the noise goal. However, for the turbofan aircraft the approach estimates are higher than the noise goal by 2 to 7 EPNdB. Only cowl wall treatment would be required in the inlet and exhaust ducts to reduce the approach noise levels to the 92 EPNdB noise goal. The flyover noise levels were calculated for the propulsive system only and do not include an estimate for nonpropulsive noise.

8.6 Basepoint and Alternate Engine Aircraft: Final Design

8.6.1 Procedure

Flyover noise levels at the FAR Part 36 conditions were estimated for the basepoint aircraft with two BPR 6 fixed pitch turbofan engines, and for an aircraft with two Hamilton Standard QFT-55-28-2 variable pitch turbofan engines. The acoustic analysis was performed using the SNAP program described in paragraph 8.2.3. Input parameters are listed in Tables 8-3 and 8-4.

8.6.2 Acoustic Treatment Configuration

The nacelle selected for the BPR 6 engine was a long duct mixed flow configuration and for the QFT-55 engine a short fan duct configuration. Acoustic treatment was applied to the engine nacelle inlet and exhaust duct walls in order to reduce the noise levels to at least 10 EPNdB below the FAR Part 36 approach condition requirements. The nacelle acoustic treatment is shown in Figure 8-5 and is described by the ratio of the length of acoustic treatment to the duct passage height (L/H). The acoustic material is assumed to be perforated sheet bonded to aluminum honeycomb. The preliminary design chart shown in Figure 8-6 was used to determine the fan and turbine noise suppression required for each treatment configuration. This chart was

TABLE 8-3

ACOUSTICS ANALYSIS INPUT PARAMETERS FOR BASEPOINT AIRCRAFT WITH BPR 6 ENGINES

PARAMETER	FAR PART 36 MEASURING POINTS .25 NM (463m) Sideline	3.5 NM (6482m) Takeoff	1.0 NM (1852m) Approach
Net Thrust/Engine, lbs (N) - Installed	5541 (24648)	3865 (16392)	2283 (10155)
No. of Engines	2	2	2
Fan Pressure Ratio	1.438	1.317	1.178
Fan Tip Speed, Ft/sec (m/sec)	1405 (428.2)	1252 (381.6)	1008 (307.2)
No. Fan Rotor Blades	26	26	26
Total Flow Rate, lbs/sec (kg/sec)	315 (142.9)	255 (115.7)	217 (98.4)
Mixed Nozzle Exit Area, Ft^2 (m^2)	5.72 (.531)	5.72 (.531)	5.72 (.531)
Mixed Nozzle Exit Velocity, Ft/sec (m/sec)	947 (288.6)	814 (248.1)	610 (185.9)
Primary Flow Rate, lbs/sec (kg/sec)	45 (20.4)	34 (15.4)	27
Primary Area, Ft^2 (m^2)	1.22 (.113)	1.22 (.113)	1.22 (.113)
Primary Velocity, Ft/sec (m/sec)	1390 (423.7)	1130 (344.4)	771 (235)
Engine RPM	7523	6704	5398
Distance from Aircraft, Ft (m)	1672 (509.6)	2800 (853.4)	370 (112.8)
Takeoff Gross Weight, lbs (kg)	46850 (21251)	46850 (21251)	-
Aircraft Velocity, Knots (m/sec)	165 (84.9)	165 (84.9)	134 (68.9)

TABLE 8-4

ACOUSTICS ANALYSIS INPUT PARAMETERS FOR AIRCRAFT WITH HS QFT-55-28-2 ENGINES

PARAMETER	FAR PART 36 MEASURING POINTS		
	.25 NM (463m) Sideline	3.5 NM (6482m) Takeoff	1.0 NM (1852m) Approach
Net Thrust/Engine, lbs (N) - Installed	4912 (21850)	3178 (14136)	1935 (8607)
No. of Engines	2	2	2
Fan Pressure Ratio	1.25	1.175	1.103
Fan Tip Speed, Ft/sec (m/sec)	850 (259.1)	850 (259.1)	850 (259.1)
No. of Fan Rotor Blades	22	22	22
Fan Flow Rate, lbs/sec (kg/sec)	330 (149.7)	280 (127)	228 (103.4)
Fan Nozzle Area, Ft^2 (m^2)	6.63 (.616)	6.63 (.616)	6.63 (.616)
Fan Exit Velocity, Ft/sec (m/sec)	690 (210.3)	590 (179.8)	490 (149.4)
Primary Flow Rate, lbs/sec	34 (15.4)	28 (12.7)	20 (9.1)
Primary Nozzle Area, Ft^2 (m^2)	1.39 (.129)	1.39 (.129)	1.39 (.129)
Primary Exit Velocity, Ft/sec (m/sec)	960 (292.6)	710 (216.4)	543 (165.5)
Engine RPM	4163	4163	4163
Distance from Aircraft, Ft (m)	1672 (509.6)	3070 (935.7)	370 (112.8)
Takeoff Gross Weight, lbs (kg)	36030 (16343)	36030 (16343)	-
Aircraft Velocity, Knots (m/sec)	164 (84.4)	164 (84.4)	134 ([illegible])

ENGINE-NACELLE ACOUSTIC TREATMENT

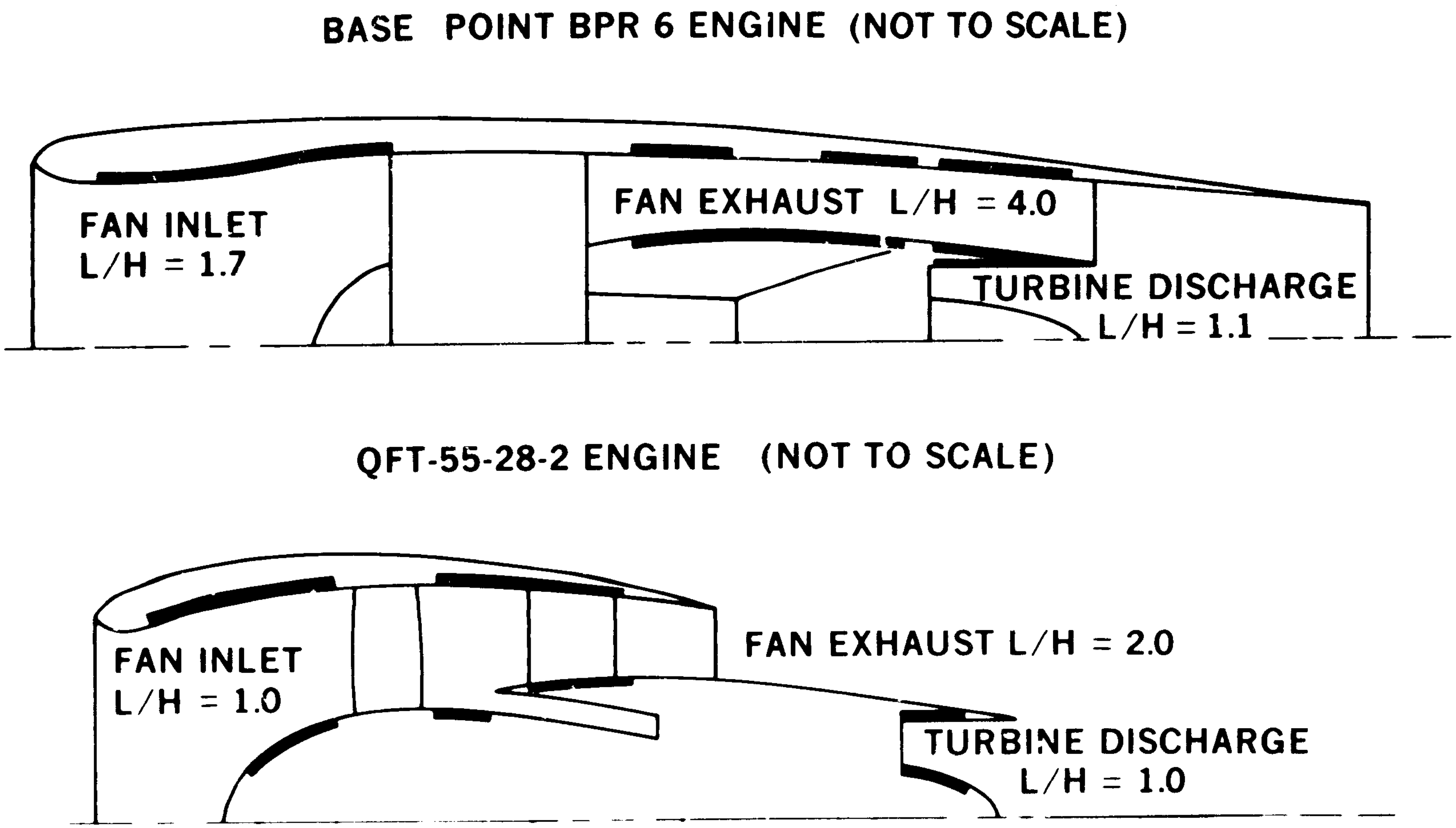


FIGURE 8-5.

PRELIMINARY DESIGN CHART FOR ACOUSTICALLY TREATED INLET AND DISCHARGE DUCTS

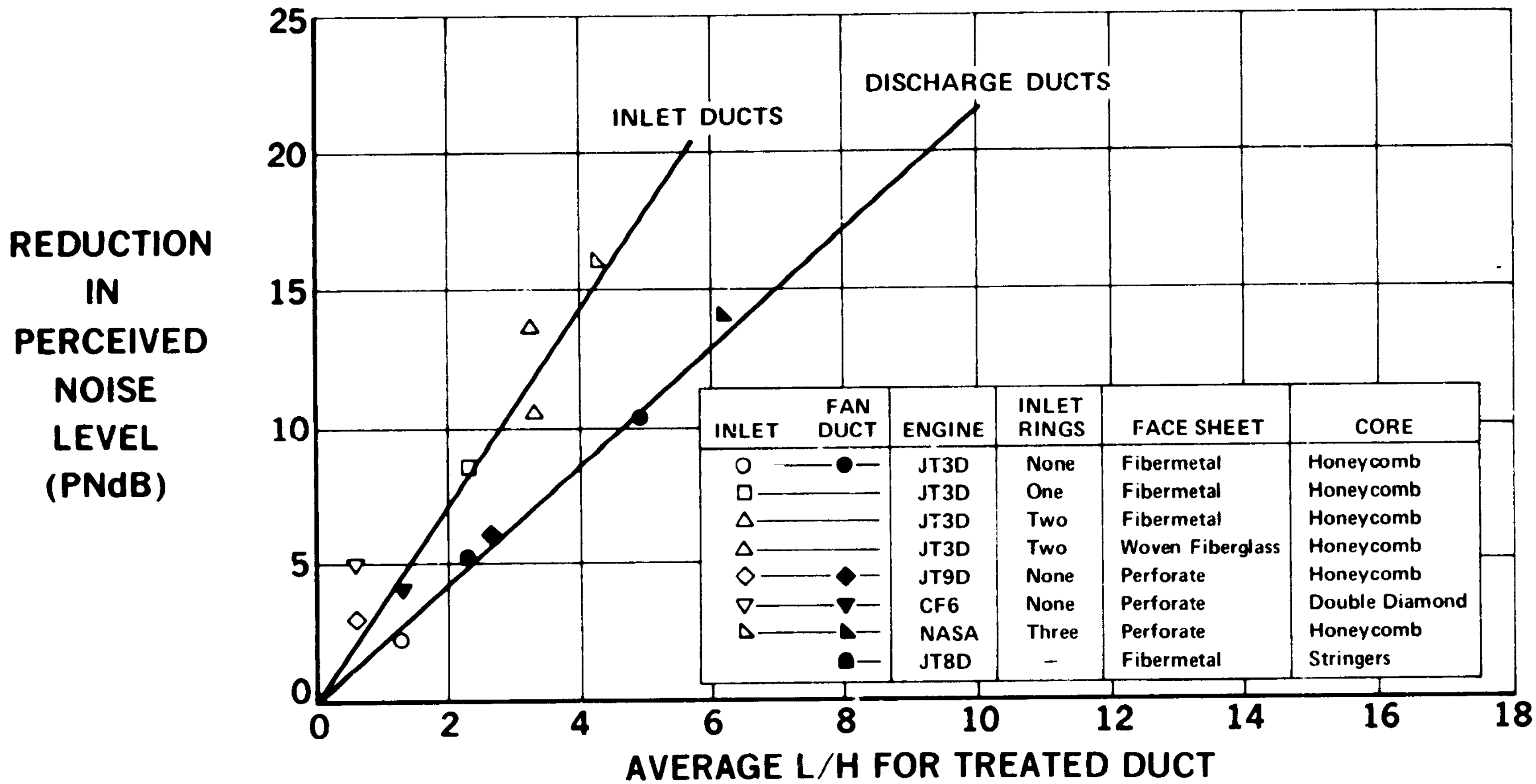


FIGURE 8-6.

developed from the results of numerous suppression tests on JT3D, JT8D, JT9D and CF6 engines.

8.6.3 FAR Part 36 Noise Estimates

The results of the analysis are presented in Table 8-5. The EPNL for both the basepoint and QFT-55 engine aircraft are equal to or less than the noise goal of 10 EPNdB below the FAR Part 36 requirements. The levels however do not include nonpropulsive noise. Figure 8-7, showing preliminary flight test measurements of nonpropulsive noise as a function of maximum takeoff gross weight, indicates that these noise sources may produce noise levels that are only 8 to 10 EPNdB below the current requirements of FAR Part 36. Extrapolation of this test data to the study aircraft results in NPN levels of 92 to 96 EPNdB. Logarithmic addition of these NPN levels with the engine noise levels of the study aircraft would result in an increase in the approach EPNL of 2 to 5 EPNdB above the noise goals. Based on current understanding, nonpropulsive noise may, therefore, be a constraint below which additional noise reduction will be difficult to achieve. Further research and development in this area will be necessary to effect a lowering of the nonpropulsive noise floor.

8.6.4 Noise Contours

Figure 8-8 presents the noise contours calculated for the FAR Part 36 takeoff and 3 degree approach flight paths of the basepoint aircraft.

Figure 8-9 presents the 80, 85, 90, 95 and 100 EPNdB noise contours calculated for the basepoint aircraft using the typical landing and takeoff flight profiles shown in Figures 8-10 and 8-11. These contours were used in the community impact analysis.

TABLE 8-5

NOISE LEVELS: TWIN ENGINE AIRCRAFT

Engines: Basepoint BPR6/QFT-55-28-2
Thrust Rating Lb(N): 8770(39010.9)/7800(34696.1)

		FAR PART 36 CONDITION AND SLANT RANGE		
		SIDELINE 1672 Ft (509.6 m)	TAKEOFF 2800/3070 Ft (853.4 m)/(935.7 m)	APPROACH 370 Ft (112.8 m)
PNdB (PEAK)	FAN INLET	80.2/76.2	69.0/66.0	97.2/91.4
	FAN EXHAUST	81.7/81.7	67.8/68.2	93.1/91.6
	TURBINE DISCHARGE	69.4/68.4	56.1/53.1	92.3/91.2
	CORE	86.4/77.5	74.9/63.0	89.0/80.3
	JET	81.6/77.2	62.1/50.7	64.9/55.6
PNdB (SUM)	AFT QUADRANT	88.8/84.3	76.0/69.7	97.2/94.8
	FWD QUADRANT	84.6/79.1	72.6/66.9	97.5/91.7
EPNdB	FAR PART 36 -10 EPNdB NOISE GOAL	92.0	83.0	92.0
	CALCULATED EPNL	84.7/81.9	76.6/72.0	92.0/89.3
	DIFFERENCE	-7.3/-10.1	-6.4/-11.0	0.0/-2.7

AIRCRAFT NONPROPULSIVE NOISE

APPROACH: 1.0 N MI FROM THRESHOLD

NONPROPULSIVE NOISE SOURCES:

- LANDING GEAR WHEELWELL AND DOOR FLOW
- TURBULENT BOUNDARY LAYER
- EXTENDED FLAP AND SLAT FLOW
- LIFT SURFACE AND FUSELAGE WAKE VORTICITY

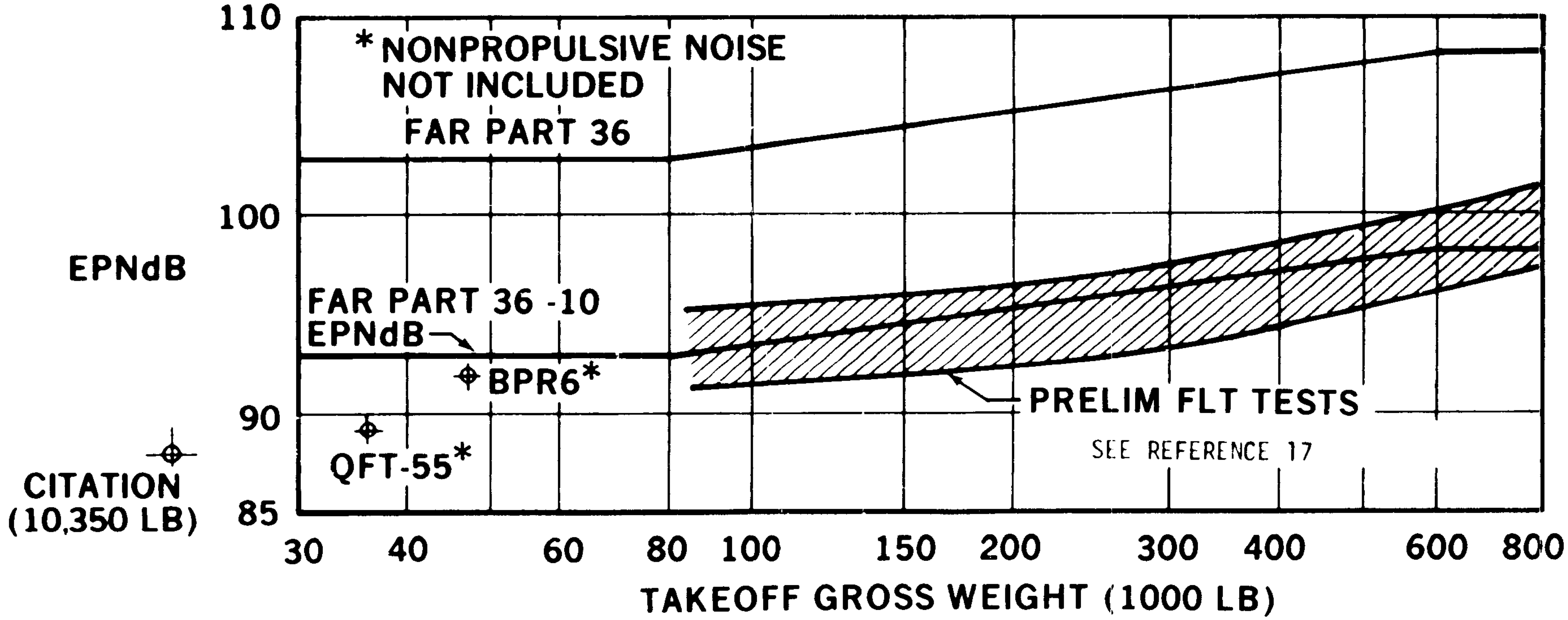


FIGURE 8-7.

ESTIMATED NOISE CONTOURS

BASE POINT MODEL 4500-FT TOFL 850-N MI RANGE

EPNL	80	85	90
AREA (SQ MI)	3.59	1.87	0.99

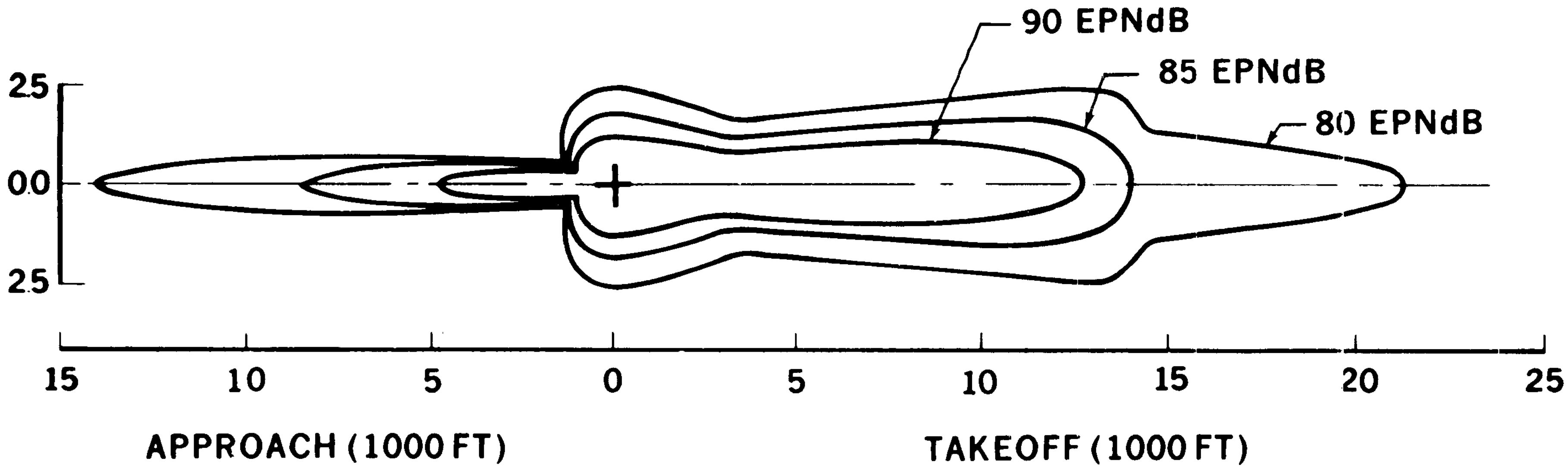


FIGURE 8-8.

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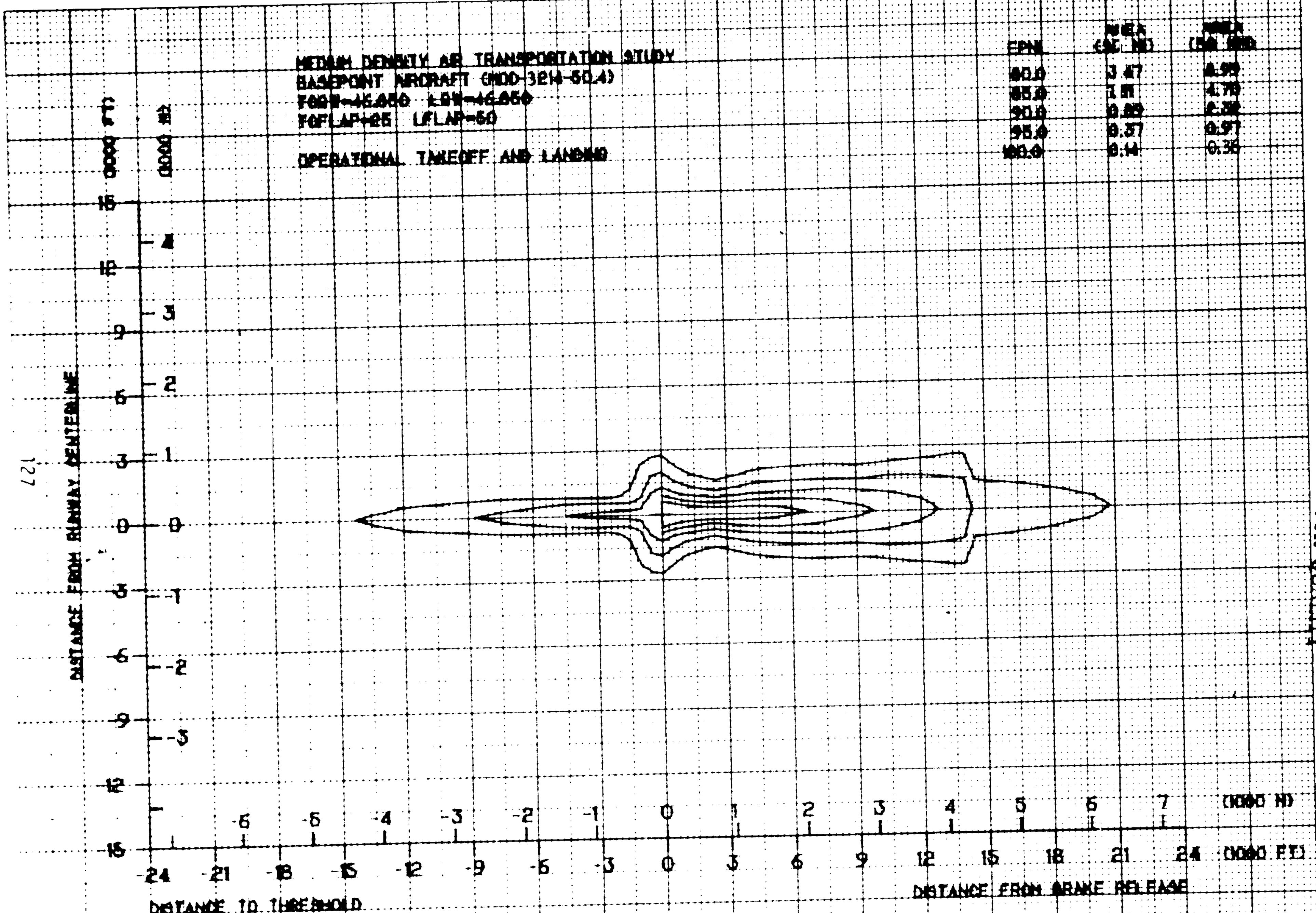

FIGURE 8-9

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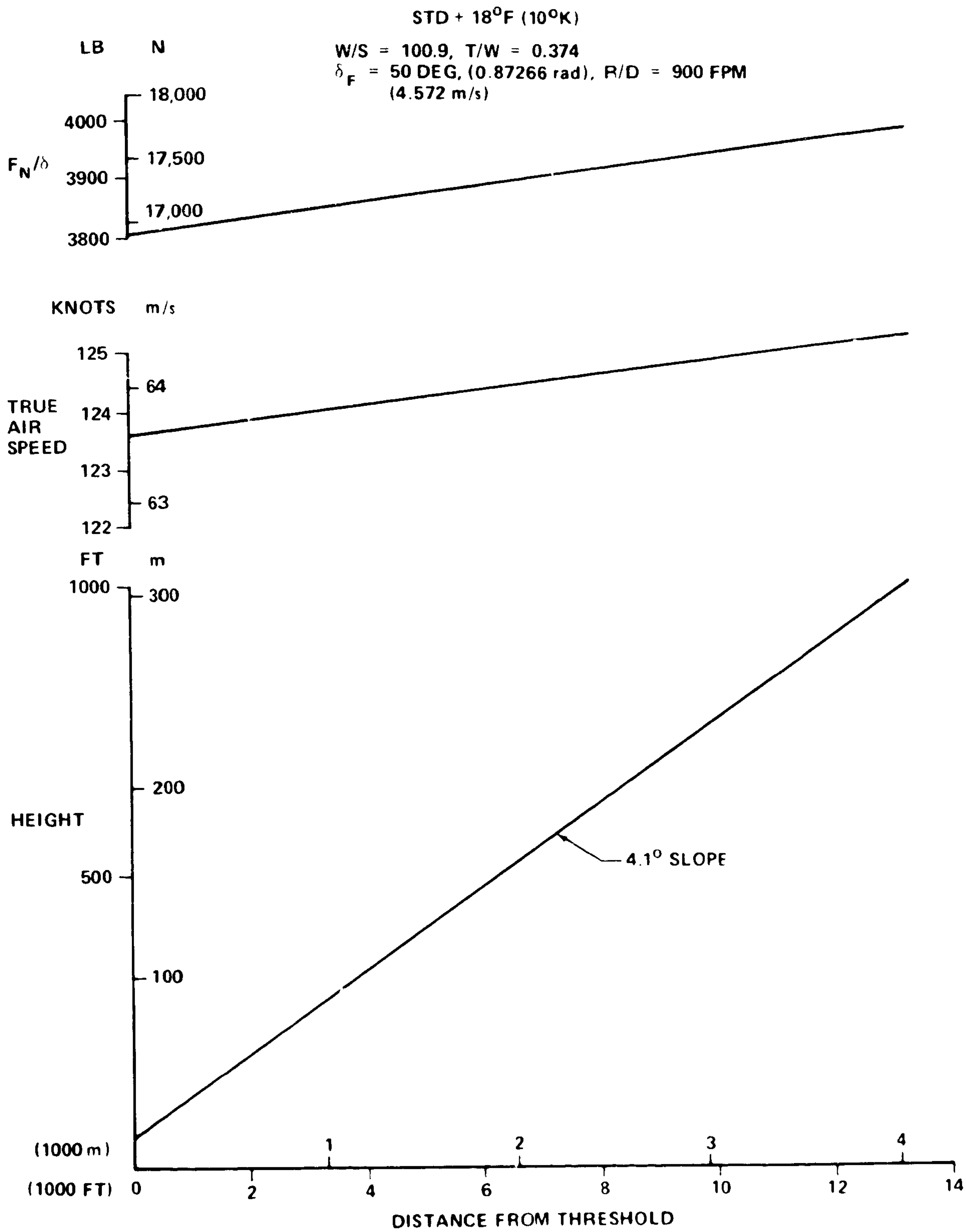


FIGURE 8-10. OPERATIONAL APPROACH PROFILE

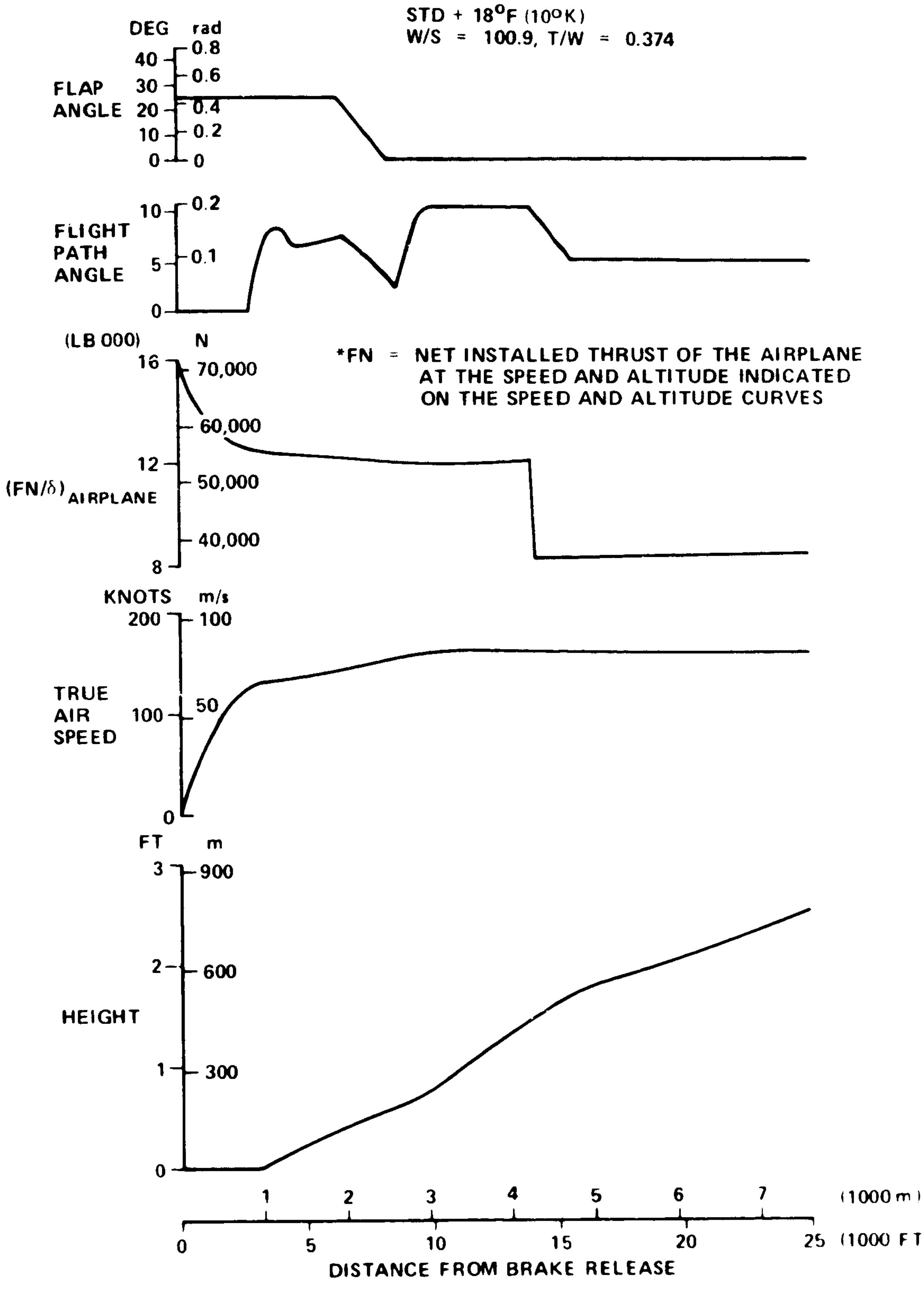


FIGURE 8-11. OPERATIONAL TAKEOFF PROFILE

Slight differences in the areas calculated for the two sets of contours is attributed to the different approach and takeoff flight paths (FAR Part 36 versus a typical operational flight profile).

8.7 Summary of Results

The turboprop aircraft provides the lowest approach flyover noise levels and meets the FAR Part 36 -10 EPNdB noise goal at the FAR Part 36 measuring points (Reference Table 8-2).

The basepoint aircraft with the fixed-pitch BPR-6 turbofans and the aircraft with Hamilton Standard QFT-55-28-2 variable-pitch turbofans meet the FAR Part 36 -10 EPNdB noise goal at all three measuring points for propulsive noise. The noise levels shown in Table 8-5 include estimates for turbo-machinery noise, core noise, and jet noise. The approach noise level for the QFT-55 engine aircraft is 89 EPNdB and for the BPR-6 aircraft this level is 92 EPNdB. Nonpropulsive noise was not included since the techniques to reliably predict the strength and directivity of the sources contributing to this noise are still under development. Based on Figure 8-7 it is estimated that aircraft nonpropulsive noise may increase the approach noise levels of these aircraft by 2 to 5 EPNdB above the 92 EPNdB approach noise goal. It therefore may be necessary to examine methods for reducing nonpropulsive noise as well as propulsion system noise if further reductions in total system noise are to be effected.

The community noise impact study results are included in the Environmental Impact Analysis, Section 10.0.

9.0 DESIGN-TO-COST STUDY

The achievement of minimum airframe cost is not only dependent upon production quantity, which in turn is dependent upon marketability, but upon a great many factors covered in the broad and overlapping categories discussed in this section.

Table 9-1 summarizes the items covered in this evaluation. Many items of equal cost importance could only be qualitatively evaluated herein, as this study did not provide for the in-depth detail design required. Table 9-2 presents a summary of the results of the cost evaluations.

9.1 Engineering-Manufacturing Studies

9.1.1 Design and Performance Requirements

These aircraft are not designed to requirements generally adopted for major trunk airlines. Thus, several design features have been incorporated which result in major weight (and thus cost) savings.

Although important on long stage lengths, very high subsonic speed and high altitudes do not provide a large payoff on the routes considered in this study. Because of the short fields and thrust-to-weight ratios required, ample cruise speed can be provided with unswept wings. Supercritical airfoils are used and the fuselage skin gauge is lower. Interior furnishings and subsystems are simplified and/or eliminated.

Table 9-3 illustrates the effect of these requirements in relation to the design level for major trunk airlines, i.e., a weight empty decrease of 15 percent. The result is a cost decrease of 15 percent on a constant $/lb basis.

TABLE 9-1

DESIGN-TO-COST: STUDY ITEMS

ITEMS COSTED	ITEMS NOT COSTED
DESIGN & PERFORMANCE REQUIREMENTS	
WING	WING
High-Lift Systems	Fuselage Attachment
Rear Spar	Ribs
Spar Caps	Taper Lock Bolts
Wing Fillets	Hole Patterns
EMPENNAGE AND CONTROL SURFACES	EMPENNAGE AND CONTROL SURFACES
Vertical Tail	Fittings
	Tabs
FUSELAGE	FUSELAGE
Pilots' Enclosure	Pressure Bulkheads
Doors and Jambs	Radome Attachment
Cusp Line	Clips and Supports
Compound Contours	
Gear Door Jamb	
STRUCTURE & SUB-SYSTEMS	STRUCTURE & SUB-SYSTEMS
Avionics	Fuselage Cross-Section & Baggage/Cargo
APU/Air Conditioner	Advanced Metallics & Composites
Cabin Windows	Cabin Interior

TABLE 9-2

DESIGN-TO-COST: SUMMARY
50 Passengers: 4500 Ft Field Length; 850 N Mi Range; Advanced Flap

ITEM	REFERENCE SECTION	INCREMENTAL COST/AIRCRAFT ($)	
Design & Performance Requirements	9.1.1		- 450,000
Wing	9.1.2		- 54,000
Hi-Lift System: Advanced less Nominal		+ 25,000	
Rear Spar and Spar Caps		- 56,000	
Wing Fillets		- 23,000	
Fuselage	9.1.4		- 25,000
Pilot Enclosure		- 3,000	
Cross-Section Shape		- 13,000	
Doors: Landing Gear and Cabin		- 7,000	
Compound Contour Panels		- 2,000	
Empennage and Control Surfaces	9.1.3		- 21,000
Sub-Systems and Interiors			- 3,000
Air Conditioning and APU Installation	9.2.4	- 1,000	
Cabin Windows	9.2.5	- 2,000	
Avionics	9.2.3		- 275,000
TOTAL			- 828,000

TABLE 9-3

DESIGN-TO-COST: DESIGN AND PERFORMANCE REQUIREMENTS

	% WEIGHT EMPTY SAVED OVER DESIGN LEVEL FOR MAJOR TRUNK AIRLINES
o Wing Geometry Lower Sweep, Higher Thickness to Chord Ratio	-5.3
o Horizontal Tail Geometry Lower Sweep	-1.6
o Fuselage Lower Minimum Gage	-2.1
o Propulsion Higher Engine T/W	-1.7
o Avionics Business Jet Type	-0.9
o Furnishings Coffee Service in lieu of full Galley Service All Tourist Light Weight Seats Reduced Paneling And Lining Weights Eliminate Drop Out Oxygen	-3.7
TOTAL EFFECT	-15.2

Again, on short routes, very high cruise altitudes do not provide a high payoff. Thus, the parametric and final design aircraft were limited to a cruise altitude of 25,000 feet in order to minimize O_2 system and pressure capsule structural weight and eliminate hydraulic system pressurization. Table 9-4 shows the effect of cruise altitude upon the O_2 pressurization system weight and cost, the pressurization stresses in the fuselage skin for the radii considered (see Section 9.2), and stress values for several other aircraft.

Considering these small increments in cost it appears that a study of an increase to a 30,000 ft. design altitude is in order as it could provide higher performance capability and thus greater marketability for the aircraft herein.

9.1.2 Wing and High-Lift System

Because of the cruise speed requirement, the wings are swept only about 5 degrees at the quarter-chord, so that the rear spar is perpendicular to the plane of symmetry. This provides the following advantages: flap and aileron fittings are simple in design and can be used on both left and right wing panels; wing ribs and bulkheads are assembled perpendicular to the rear spar; rigging for tooling and assembly is simplified. Location of spar planes on constant-percent chord lines simplifies machining of spar caps, i.e., constant level (see Figure 9-1).

Wing-to-fuselage fillets are made of laminated fiberglass, are minimized in size and avoid overlapping or interference with doors, flaps, antennas, etc. (see Figure 9-2).

Figures 9-3 and 9-4 illustrate the flap hinge and operating mechanism for the nominal (DC-9) and an advanced (tracked DC-9) high-lift system. As explained in Section 6.4.6, the latter is preferred because, although more costly, it decreases direct operating costs.

TABLE 9-4

DESIGN-TO-COST: PRESSURIZATION

	O_2 SYSTEM REQUIREMENTS FOR FAR CERTIFICATION	RELATIVE COST	ΔWT (LB)
25,000 Ft and Under:	Portable	Base	Base
Under 30,000 Ft:	Immediately available Plug-in	+ $10,000	+ 130
30,000 Ft and over:	Immediately available Automated	+ $15,000 + Δ skin gage	+ 130 + Δ skin gage

ALTITUDE DIFFERENTIAL	6,000 Ft to 25,000 Ft			6,000 Ft to 30,000 Ft		
FUSELAGE TYPE	Baseline Cusp Riveted	Large Circle Bonded	Small Circle Bonded	Baseline Cusp Riveted	Large Circle Bonded	Small Circle Bonded
Radius: inches	55	58.25	54	55	58.25	54
Skin Gauge: inches	0.040	0.032	0.032	0.040	0.032	0.032
Skin Stress: psi	8,700	11,500	10,700	10,200	13,500	12,500

FUSELAGE SKIN STRESSES:

AIRLINERS		MILITARY TRANSPORTS	
DC-8:	12,600 psi	C-133:	16,400 psi
DC-[illegible]:	9,800 psi	C-5A:	14,500 psi
DC-10:	14,500 psi		

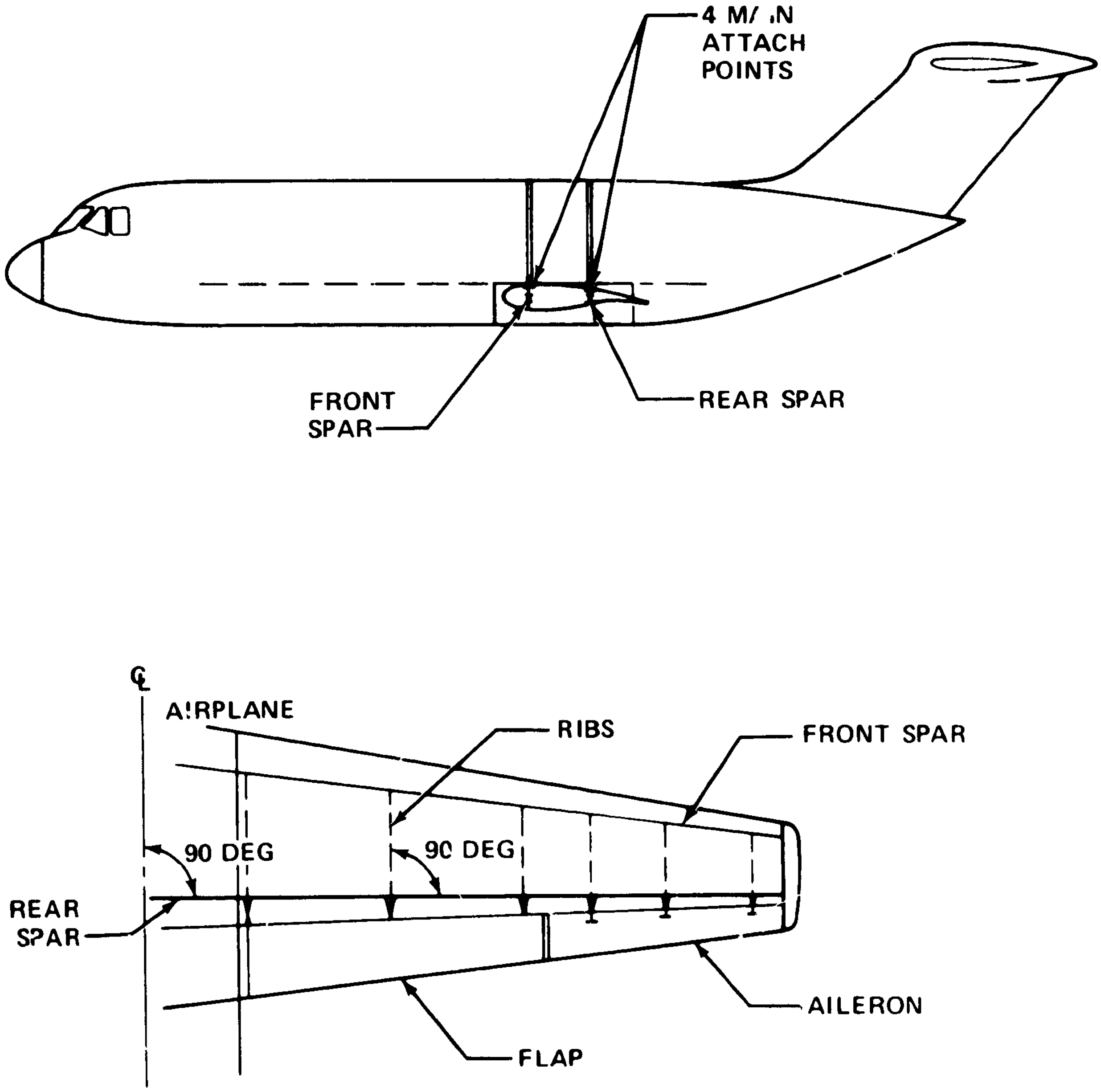


FIGURE 9-1. REAR SPAR AND WING/FUSELAGE ATTACHMENT

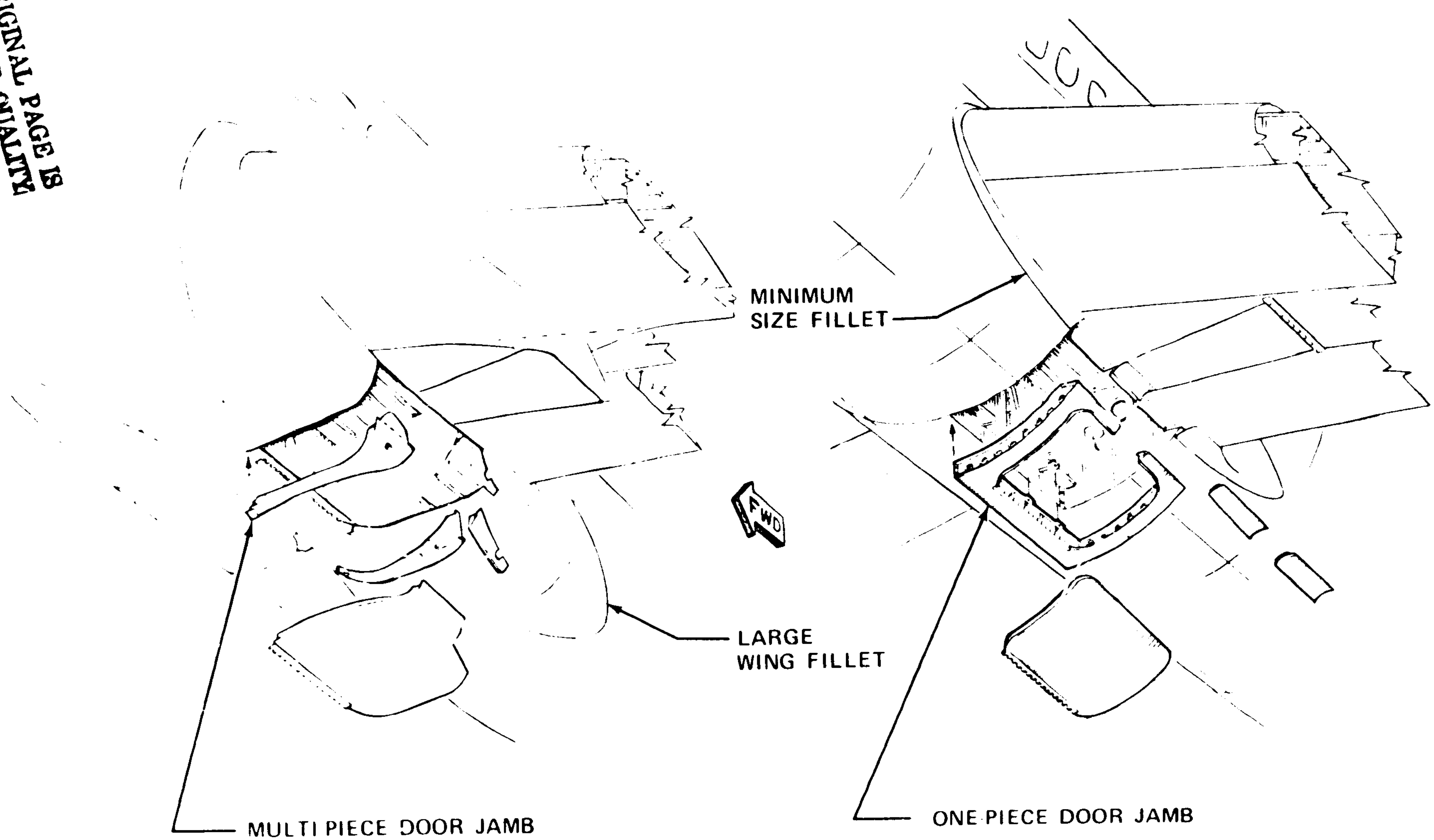


FIGURE 92. LANDING GEAR DOOR AND FILLET MODIFICATION

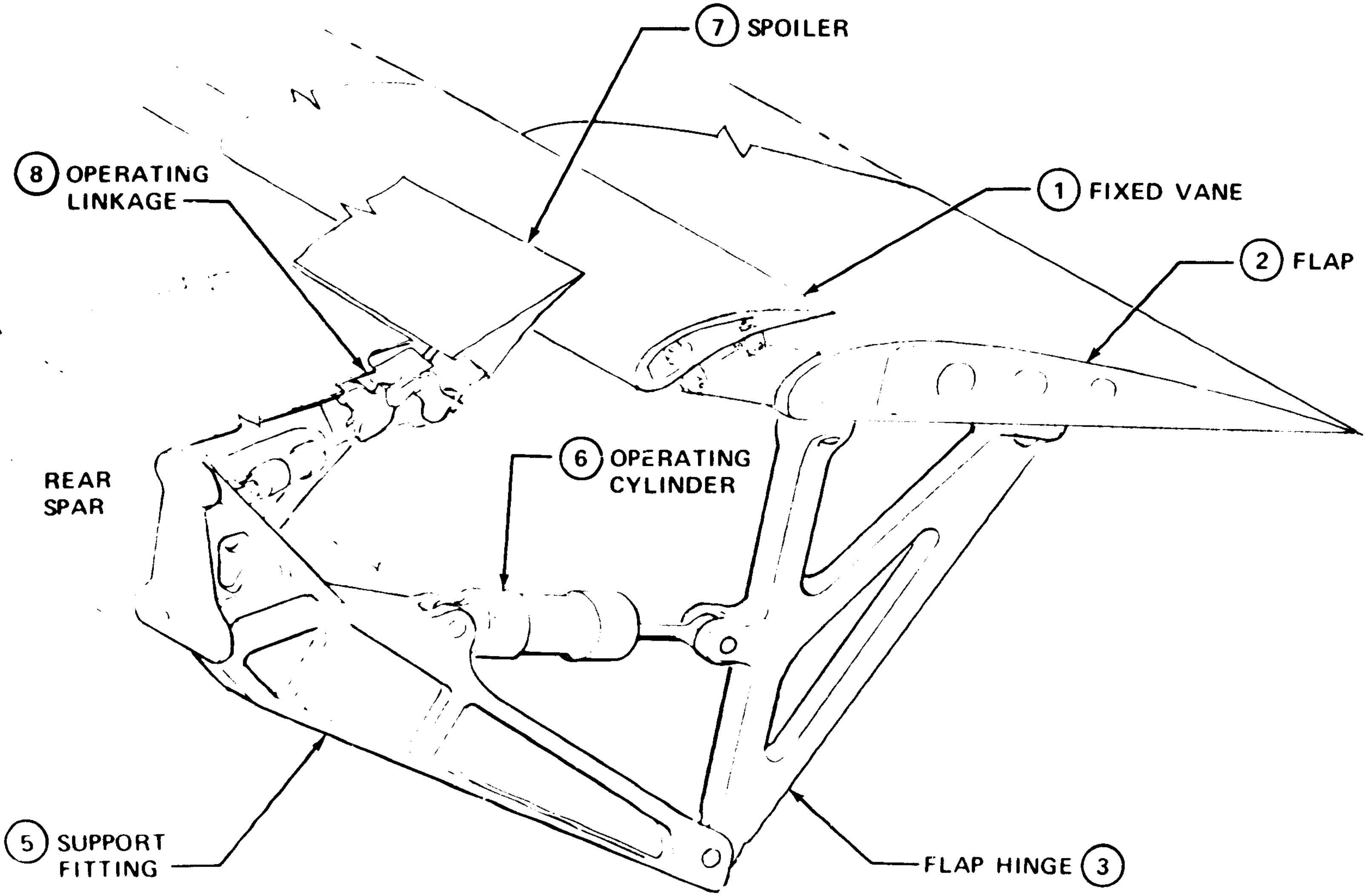


FIGURE 9.3. NOMINAL FLAP SYSTEM

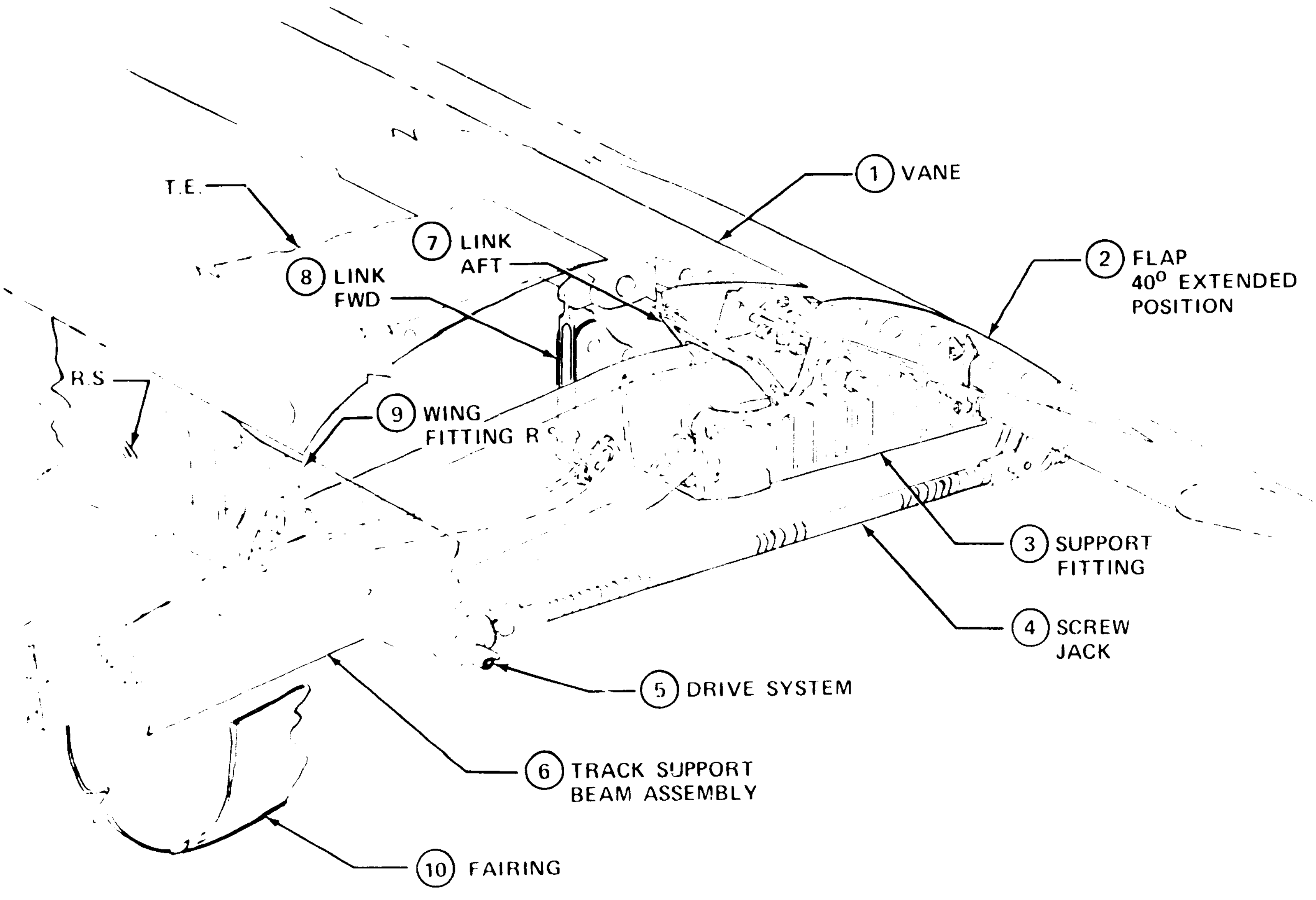


FIGURE 9.4. ADVANCED FLAP SYSTEM

The nominal high-lift system has the following advantages: the vane is fixed to the flap surface; the flap hinge and wing support fittings are simplified; the operating cylinder is hydraulic and is attached to the wing support fitting. However, the hinge and support fairings are in two pieces, presenting complex matching problems. Although the spoiler is simple, its linkage has many parts with close rigging requirements.

The advanced high-lift system has some advantages: the screw jack is a purchased assembly; the aft and forward vanes and the wing support fittings are simple machined parts; the fairing is a contoured, simple-to-assemble, part. Its many disadvantages are: a moving vane rigged to the flap surface; many support and operating points which must be held closely; titanium flap support fittings and track support beam assemblies with complex machining and close tolerances; a hydraulic motor and special gear drive system; titanium aft and forward vanes. Considering the wing sizes of the aircraft in this study it appears that a detailed design study would simplify the flap system above and bring it much closer to the "double-slotted roller" type used in business-jet aircraft.

The following items could not be costed because this study did not permit the in-depth analysis required:

- The wing-to-fuselage attachment (Figure 9-1) should be designed with a minimum number of attachment bolts; fixed attachment points to eliminate rigging; and parting surfaces in the Z plane, if possible.
- Cant ribs and taper lock bolts should be minimized; the latter should be located in the same material (not steel and aluminum alloy), normal to the head end surface.

- Hole patterns should consist of a minimum number of standard patterns, with the same size fasteners.

9.1.3 Empennage and Control Surfaces

The vertical tail was designed as an untapered surface because of the cost savings due to the many common parts such as ribs, fittings, etc.

The following items were not costed because of the detailed analysis required:

- Although the horizontal tail remained tapered because of the in-depth analysis (involving aerodynamic characteristics, planform geometry and thickness-to-chord ratio) required to assess the weight and cost tradeoffs, it appears that such an analysis is merited.
- Fittings on movable surfaces should be designed for right and left-hand installations, and should be machined completely before being located on the jig.
- Self-aligning bearings should be used, as well as forgings to reduce machining.
- Tabs should also be right and left-hand, with access provided for adjustment on assembly without removal of fillets.

9.1.4 Fuselage

Figure 9-5 illustrates the features incorporated to reduce the pilot enclosure cost. Flat plane windows and frames are used to simplify machining of frames, i.e., no compound contours. The window track rigging is simple, boxes are added to the frame for fixed location of the track. Contour transition, from window frames to enclosure loft line, is provided in the formed-skin and doublers and not in the machined frame flanges.

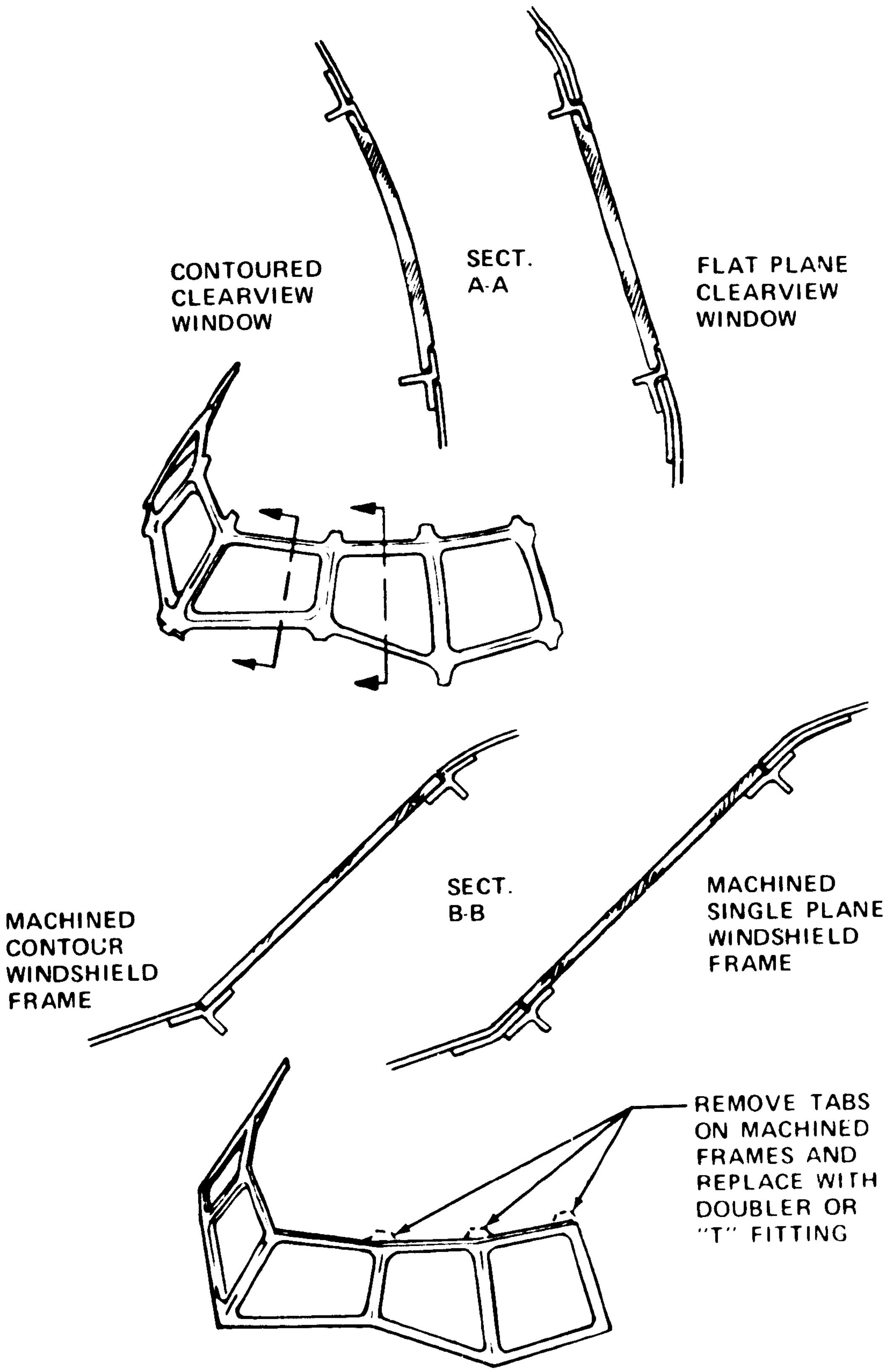


FIGURE 9-5. PILOT'S ENCLOSURE MODIFICATION

Figure 9-6 shows the doors, door jambs and contoured skin panels. All doors and jambs are the same size and the cargo doors are located in the constant section. The operating mechanism is either in the door or jamb, but not in both. The fuselage is lofted so that the left forward door and jamb is the same as the right rear (also the right forward and left rear). The main landing gear door jamb (Figure 9-2) is in one panel and not in the wing, fillet or fuselage.

Contoured skin panels are minimized. The same loft line is used for as many panels as possible (right-hand and left-hand, forward and aft), as well as straight line elements.

Figure 9-7 shows four types of cross-sections considered for the fuselage (see Section 9.2.1 for additional explanation).

The following items, requiring more detailed analysis, were not costed:

- o Pressure bulkheads should be designed to avoid spherical contours and broken "Y" attach angles and to eliminate doors.
- o Standard parts already in the system should be used for clips and supports and new designs should be standardized.
- o Existing fasteners should not be "picked up" for use in location of clips and supports.
- o The radome attachment should be made in a flat parting plane.

9.2 Structural and Subsystems Design

9.2.1 Fuselage Cross-Section and Baggage/Cargo Design

Figure 9-7 shows the unfaired cusped fuselage, with riveted longerons and below-floor baggage/cargo compartment, used on all baseline aircraft

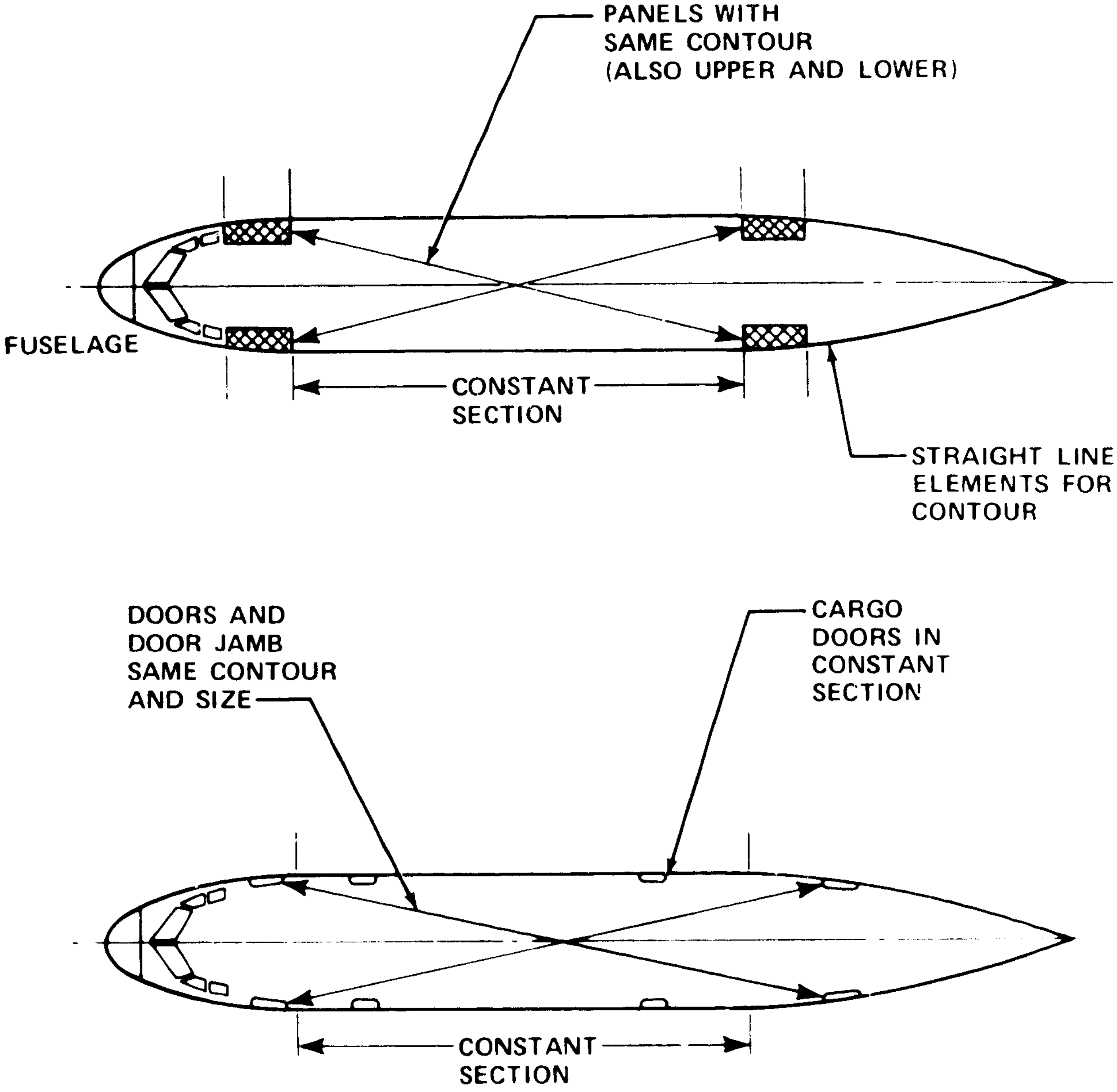


FIGURE 96 CONTOUR MODIFICATION

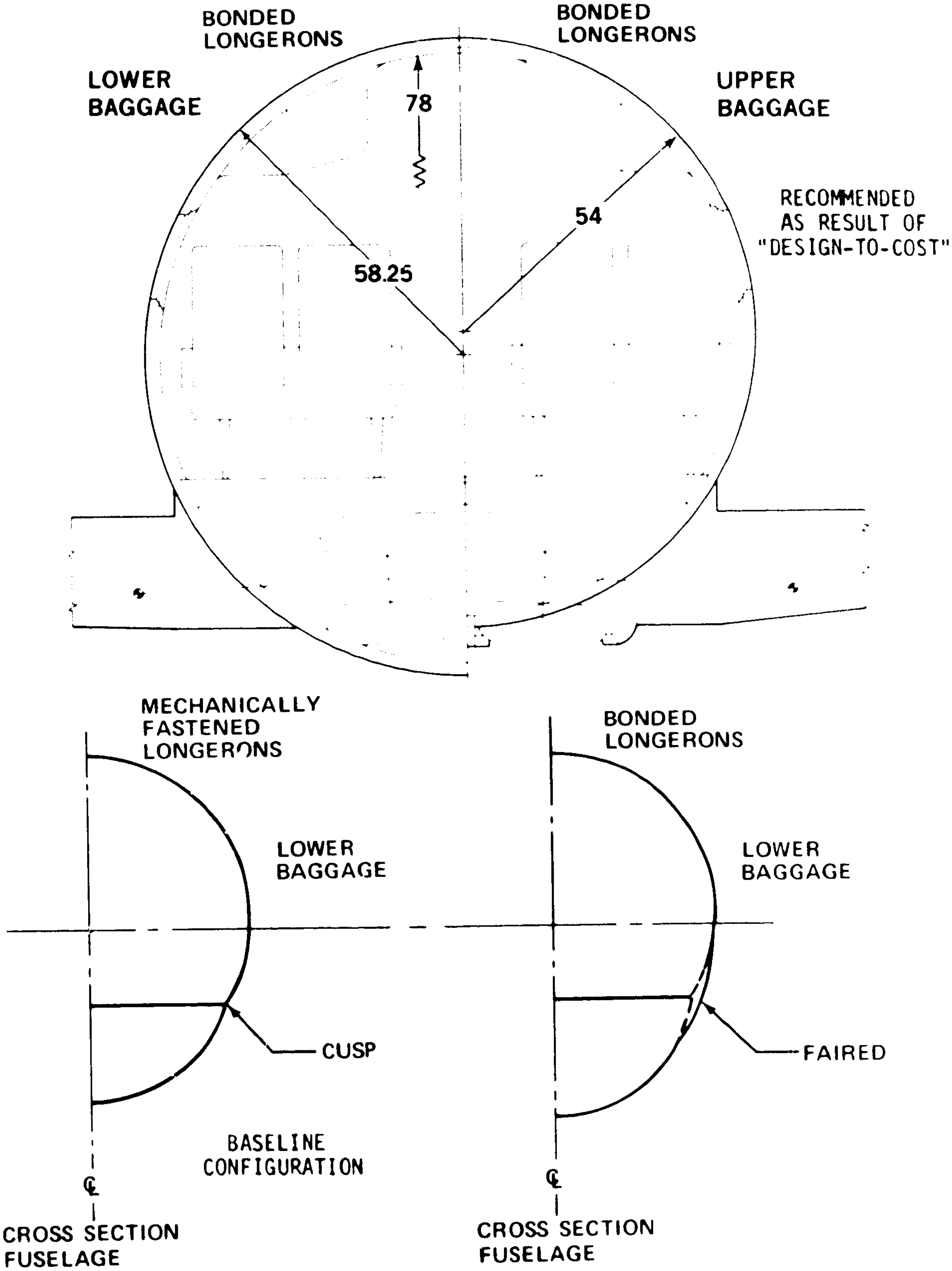


FIGURE 9-7. FUSELAGE CROSS SECTION

(parametric and final design). Also shown are the modifications made for fairing the cusp and bonding the longerons.

Figure 9-7 shows a large circular fuselage with a below-floor baggage/cargo compartment and also a smaller circular fuselage with an above-floor baggage/cargo compartment.

Weight and dimensional data describing these four fuselage types are listed in Table 9-5. Compared with the baseline fuselage, the following observations can be made: both below-floor baggage fuselages are much lighter with a neglibible difference in wetted area (or drag); the above-floor baggage fuselage is also lighter with a 6.5 percent increase in wetted area (less than 2 percent in total drag). The latter fuselage appears very promising due to favorable operational aspects of carry-on baggage; in addition, another feature is elimination of the landing gear doors, as on the B737. Time-manpower limitations precluded in-depth design required for further analysis of operational aspects of above-floor versus below-floor baggage and of manufacturing costs.

9.2.2 Advanced Metallics and Composites

Table 9-6 depicts the type and application of advanced materials of construction. Advanced metallics were considered for initial application. Because of the development time and effort required, composites were assumed to be applied after and together with advanced metallics. The advanced metallics and composites were applied to the longer above-floor-baggage fuselage because of its favorable operational aspects (see Section 9.2.1).

Because of the time period (1980-1985) considered for operational introduction of these aircraft, composite materials were used only in

TABLE 9-5
FUSELAGE CROSS SECTION & BAGGAGE/CARGO DESIGN
50 Psgr 4500 Ft Field Length 850 N Mi Range Advanced Flap

		BASELINE	MODIFIED BASELINE		
Longerons Baggage/Cargo (Rel. Floor) Cross Section Type		Riveted Below Cusp (Unfaired)	Bonded Below Cusp (Faired)	Bonded Below Circular (Large)	Bonded Above Circular (Small)
Upper Radius	(in)	55.0	54.0	58.25	54.0
Lower Radius	(in)	49.5	48.5	58.25	54.0
Height	(in)	120.0	118.0	116.50	108.0
Periphery	(in)	361.	355.	366.	339.
Length	(in)	806.	806.	806.	878.
Wetted Area	(ft^2)	(1,724)	(1,694)	(1,746)	(1,835)
Radome		24	24	25	22
Pressurized		1,356	1,332	1,373	1,490
Unpressurized		344	338	348	323
Floor Width	(in)	89	89	102	89
Minimum Skin Gage		.040	.032	.032	.032
Fuselage, Weights	(lb)				
Press Resistant Material		1,172	1,035	1,068	1,141
Unpress Resistant Material		297	234	241	223
Splices & Attach		254	220	227	236
Frames & Shear Clips		425	368	379	395
Bond vs Shear Clips		0	-59	-61	-64
Cusp		128	128	0	0
Cabin Floor (Conventional)		603	603	694	603
Aft Pressure Bulkhead		208	208	246	208
Major Joints		210	210	212	197
Landing Gear Fairings		0	0	0	40
Remaining Items		2,435	2,435	2,458	2,449
Total		(5,732)	(5,382)	(5,464)	(5,428)
Delta Weight (Relative to Baseline)		0	-350	-268	-304
Furnishings, Weight	(lb)				
Cargo Compartment Lining		109	109	109	0
Cargo Compartment Floor		65	65	65	0
Luggage Rack & Floor		0	0	0	279
Floor Covering		100	100	115	100
Sidewall & Ceiling Panels		510	510	540	510
Remaining Items		2,721	2,721	2,741	2,711
Total		(3,505)	(3,505)	(3,570)	(3,600)
Delta Weight (Relative to Baseline)		0	0	+65	+95
Systems: Delta Weight	(lb)	0	0	0	+94
TOTAL UNRESIZED DELTA WEIGHT	(lb)	0	-350	-133	-115

TABLE 9-6

DESIGN-TO-COST: ADVANCED METALLICS AND COMPOSITES

50 Passengers; 4500 Ft. Field Length; 850 N.Mi. Range

Advanced Flap

			Small Radius Fuselage	
		Basepoint	Advanced Metallics	Adv. Met. & Composites
Wing: Total	(lb)	(4,359)	(4,137)	(3,927)
Primary Structure		2,005	1,783 P	1,783 P
LE, tips, fairing, slats		998	998	998
TE, move surfaces		1,356	1,356	1,146 C
Tail Surfaces: Total	(lb)	(1,204)	(1,140)	(1,039)
Primary Structure		541	477 H	477 H
LE, tips, misc.		256	256	256
TE, move surfaces		407	407	306 C
Fuselage: Total	(lb)	(5,732)	(5,428)	(5,149)
Shell Structure		2,358	2,128 B	2,128 B
Supports, windows, misc.		1,435	1,354	1,354
Floors, doors, press. bkhds.		1,939	1,946	1,946 C
Sum Total	(lb)	(11,295)	(10,705)	(10,115)
Δ Weight		0	-590	-1,180

P: Integrally stiffened plate
H: Honeycomb
B: Bonded skin/longerons
C: Composites

secondary structural areas, i.e., wing and tail trailing edges and movable surfaces; fuselage floors, doors and pressure bulkheads.

Only advanced metallics were used in the primary structural areas, as follows: integrally stiffened plate was chosen for the wing box and honeycomb for the tail boxes; the fuselage shell was constructed of bonded skin and longerons, with the longerons flattened out through the frames.

Table 9-6 shows that the use of advanced metallics saved 5 percent of the wing, tail and fuselage weight; together with composites, 10 percent of the weight was saved. Table 9-7 compares the basepoint aircraft with a pair of aircraft equipped with above-floor-baggage fuselages constructed of advanced materials. Unresized, the weight savings increase the payload capacity by 4 percent and 10 percent.

9.2.3 Avionics

Table 9-8 contains a list of required and optional avionics equipment, with adequate performance and reliability for the study aircraft. Although lighter than the weight allowance in the analysis, the cost of this equipment is of major importance. Its cost is only about 30 percent of the cost of the typical or average DC-9 equipment, used by a major trunk airline (see Section 14.2). The reason for the low cost is that this equipment does not conform to the ARINC regulations drawn up by the avionics contractors to specify performance and interchangeability but not reliability. The major trunk airlines are becoming aware of this and are using some non-ARINC equipment. This is a list of typical equipment with multiple choice of price and/or performance for most items.

TABLE 9-7

ADVANCED METALLICS & COMPOSITES
DESIGN-TO-COST WEIGHT SUMMARY
50 Psgr 4500 Ft Field Length 850 N Mi Range Advanced Flap

Description		Basepoint	Advanced Metallics (UNRESIZED)	Advanced Metallics & Composites (UNRESIZED)
Flap Type		Advanced	Advanced	Advanced
Stage Length	(n.mi.)	1 x 850	1 x 850	1 x 850
Number of Seats		50	50	50
Field Length	(ft)	4,500	4,500	4,500
Wing Area (ft^2)/Aspect Ratio		464/9.0	464/9.0	464/9.0
Engine Designation		F.P. Fan	F.P. Fan	F.P. Fan
Engine Thrust	(lb)	2 x 8,770	2 x 8,770	2 x 8,770
Horiz/Vert Tail Area	(ft^2)	138/119.2	138/119.2	138/119.2
Horiz/Vert Tail Arm	(in)	350/275	350/275	350/275
Horiz/Vert Tail Volume		1.103/.091	1.103/.091	1.103/.091
Wing Loading	(lb/ft^2)	100.9	100.9	100.9
Thrust Ratio		0.374	0.374	0.374
Fuel Fraction		0.194	0.194	0.194
Fuselage Max. Diameter/Length	(in)	110/806	108/878	108/878
Wing	(lb)	4,359	4,137	3,927
Horizontal Tail	(lb)	518	495	430
Vertical Tail	(lb)	686	645	609
Fuselage	(lb)	5,732	5,428	5,149
Landing Gear	(lb)	1,874	1,874	1,874
Power Plant	(lb)	5,733	5,733	5,733
Fuel System	(lb)	265	275	275
Aux. Power Unit	(lb)	400	400	400
Flight Controls	(lb)	849	859	859
Instruments	(lb)	300	300	300
Hydraulic System	(lb)	200	207	207
Pneumatic System	(lb)	100	114	114
Electrical System	(lb)	825	854	854
Avionics	(lb)	436	436	436
Furnishings	(lb)	3,505	3,600	3,600
Air Conditioning	(lb)	435	450	450
Ice Protection	(lb)	448	468	468
Handling Gear	(lb)	20	20	20
Weight Empty: Manufacturer's		26,685	26,295	25,705
Operational Items		1,075	1,075	1,075
Weight Empty: Operational		27,760	27,370	26,780
Payload		10,000	10,000	10,000
Fuel		9,090	9,090	9,090
Δ Weight		0	390	980
Takeoff Gross Weight		**46,850**	**46,850**	**46,850**

TABLE 9-8

DESIGN-TO-COST: AVIONICS

REQUIRED	TYPICAL SYSTEM		LB	1974 $
Dual VHF Com	2 Collins VHF-20A		13	4,800
Dual VHF Nav/ILS/MB	2 Collins VIR-30A		13	7,000
Dual Transponder	2 Collins TDR-90		11	3,500
Dual Audio, incl cabin PA	2 Collins 387C		5	2,500
ADF	Collins DF-206		14	4,700
DME	Collins DME-40		12	3,200
Radar	Bendix RDR-1200		35	12,000
RMI	Collins 332C		3	1,000
Autopilot/Flt Dir., incl Compass and Alt Alert/Rpt	Collins FCS-106/Sperry SPZ-200		95	40,000
HSI W/Compass RH PNL	Collins PN101/Sperry RN-200		13	3,500
Cockpit Voice Rcdr	Collins AVR-101		22	3,400
Radio Alt	--		11	3,000
Flight Recorder	--		40	5,000
Access and Inst Hdwe			100	6,400
		(SUM)	(376)	(100,000)
Optional				
Dual Flt Dir			-	20,000
Dual DME			12	3,200
Area Nav			9	3,800

Inertial Nav and VLF/Omega (overwater)   Dual ADF (Canadian)   HF Com (So. American)

9.2.4 Auxiliary Power Unit and Air Conditioner

Figure 9-8 is a sketch showing the APU and AC installations. These units are mounted on a slide support or drawer, with interface attachment for lines and ducts providing accessibility for removal or service. On these aircraft, it appears that these units may be mounted low enough in the fuselage so that work stands or ladders may be avoided, or at least minimized in size.

9.2.5 Cabin Interior

Cabin windowpanes are flat and tinted to eliminate the need for sunshades. The cabin is laid out so that all windows are in the constant diameter section.

Because of detail design required, the following items were not costed:

- o Edge lighted panels should be made of stretched and not cast plexiglass as they are subject to last minute customer changes.
- o The number of wire terminals should be minimized.
- o Silver, and not gold, brazing should be used for hydraulic lines.

Also, in spite of customer changes, considerable cost savings can be made in the cabin interior:

- o Cabin lining panels can be installed with a minimum of handwork by using standard cap extensions with "snap-ins" to attach two material edges and avoid wrap around of the materials.
- o Standard mill runs and nonmatching patterns should be used for these materials.
- o Labor can be minimized by using simple dielectric tools to put patterns in the panels.
- o Vinyl floor covering (with a soft, flexible, textured and colored surface is available at half the price of carpeting and is much more durable.

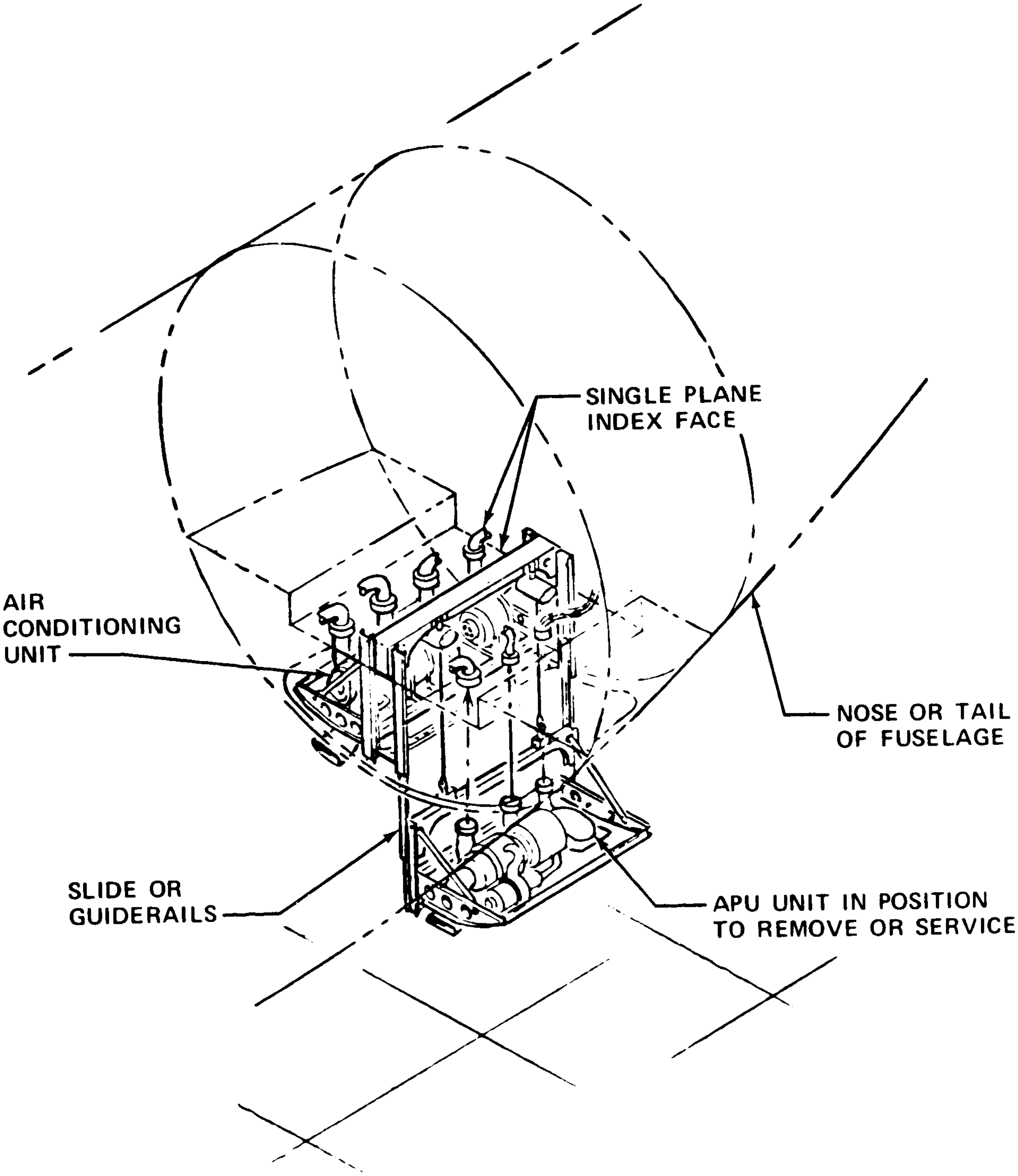


FIGURE 9-8. APU AND AIR CONDITIONING UNIT INSTALLATION

- Ash trays are available from automotive suppliers for about 10 percent of the cost of those designed for aircraft.
- Decal nameplates should be used in place of expensive etched or engraved metal nameplates.
- Nylon can be used in place of metal for clamps, knobs, handles and nonstructural fasteners.
- Expensive galley and hot food equipment can be eliminated, i.e., liquid refreshment and sandwiches or cold buffet only.
- Although FAR 25.787 regulations must be observed, overhead baggage racks may be simplified.

9.3 Aircraft Family Concept

Historically, new aircraft have been conceived as single-point designs developed for a specific segment of the market. Later, the market life is extended by adopting the "stretch" concept, i.e., principally and/or initially, a fuselage stretch. Still later, in efforts to extend market life still further, other forms of stretching are considered, i.e., wing, tail and engine modifications. Eventually this is limited by degradation in design efficiency and performance and also because cost savings due to learning and commonality can no longer be achieved.

A "stretch/shrink" family concept was investigated in an attempt to encompass the 30 to 70 passenger-payload variation considered in this study. Figure 9-9 shows the results obtained with the model configuration (aft-fuselage mounted, twin-engines). Four fuselage barrels are common to all three aircraft, i.e., the 160 inch nose, 192 inch forward, 128 inch center and 270 inch tail barrels. Two plug barrels are required, a 64 and a 96 inch section.

STRETCH/SHRINK FAMILY DESIGN

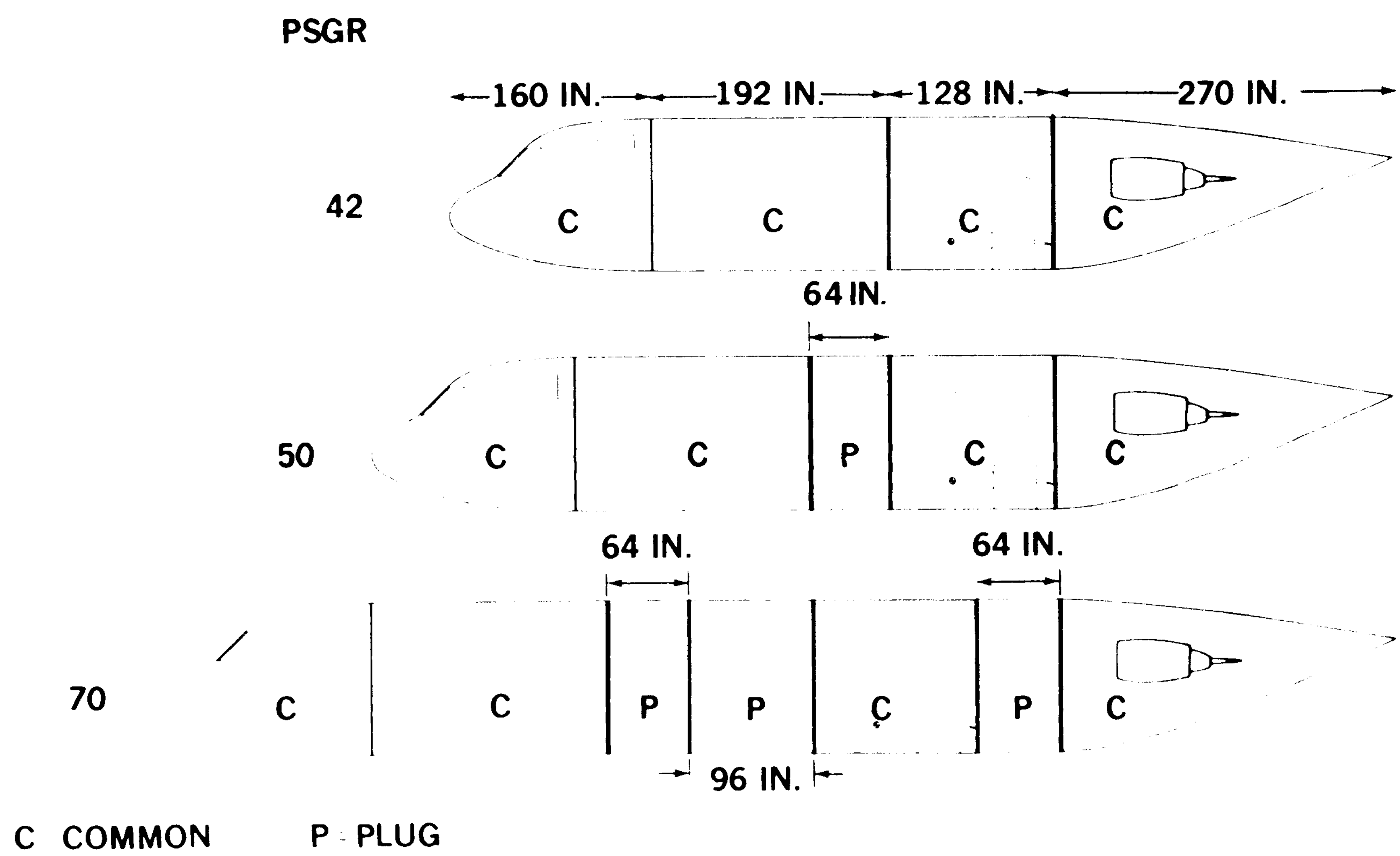


FIGURE 9-8

The stretch/shrink design was based on the 50 passenger aircraft, using its wing and engines. As expected, the model configuration is shrink limited, in that it can be shrunk only from 50 to 42 passengers. Limitations of this study precluded an investigation of a wing-mounted engine configuration. Obviously, it will provide greater stretch/shrink capability and should probably be selected as its disadvantages (wing efficiency, ground height, etc.) will certainly not offset the cost savings achieved by the stretch/shrink concept.

Additional in-depth study of the stretch/shrink concept is merited. During the course of this study it appeared that design modifications could be made to the center barrel to provide for installation of wings of different sizes and the tail barrel for different sizes of engines. This would increase stretch/shrink capability.

9.4 Engineering-Manufacturing Concepts: Future Considerations

Additional concepts for future consideration in detail design in-depth studies are listed below:

- Excessive margins of safety represent dead weight Extra strength to handle future growth should not be built into the structure. Instead, the structure should be designed to facilitate changes required for the stretch/shrink family concept.
- Flap and landing gear limit speeds should be reduced consistent with operational safety, to save weight.
- A slab tail should be considered (versus stabilizer and elevator).
- The landing gear actuator should be considered for use as a side brace.

- Unuseable fuel could be minimized by using lightweight, closed-cell foam in appropriate places in fuel tanks.
- Functions should be combined, i.e., jacking and mooring fittings.
- Forgings and castings should be designed so that the formed draft carries load and edges should be scalloped. Precision forgings should be used to eliminate excess material and avoid machining.
- Stringer ends should be tapered and stepped extrusions used.
- The use of beads as stiffening elements in skin should be considered, along with lap joints in lieu of butt joints and spot-welding in lieu of riveting, where feasible.
- Nylon tubing and lightweight electrical wiring should be used where feasible.
- Roll stock rather than flat sheet, should be used where possible (20 percent cheaper).
- Low cost plastic tools should be used where possible.

10.0 ENVIROMENTAL IMPACT ANALYSIS

Recent emphasis on protection of the enviroment, a worldwide trend, has resulted in the establishment of environmental design criteria and operational standards for all types of transportation vehicles. The framework for U.S. environmental policies and plans was provided by the National Environmental Policy Act of 1969. The Clean Air Act of 1970 and the Noise Control Act of 1972 supplemented the initial environmental legislation and provided more definitive policies and guidelines, as did the Airport and Airway Development Act of 1970. In the field of air transportation various federal agencies subsequently promulgated specific design and operational regulation for new and existing aircraft to reduce and control their environmental impact. Examples of specific U.S. aircraft regulatory measures are the FAA FAR Part 36 Noise Standards for Aircraft Type Certification and the EPA Emission Standards and Test Procedures for Aircraft. The National Environmental Policy Act and the Airport and Airway Development Act also established requirements and guidelines for preparation of an Environmental Impact Statement (EIS) for all projects involving federal funding.

The objective of the following environmental impact analysis was to define the specific environmental requirements applicable to the baseline study aircraft to determine the aircraft's environmental characteristics and to present its environmental impact in the form of a preliminary Environmental Impact Statement (EIS) which might be required of a new aircraft type if it were produced.

Advanced computer graphic display techniques developed by Douglas under the company's Independent Research and Development (IRAD) Program were utilized in the noise impact analysis. The environmental analysis also draws heavily on methodology and data developed in two prior NASA studies, References 1 and 10. Short-haul aircraft developed in the two prior studies form the basis for environmental comparison with the baseline study aircraft.

10.1 Selected Airport - Chicago Midway

Midway Airport was selected as being representative of a typical hub airport for airline operation of an aircraft in a medium density transportation system. Midway has the potential of becoming a key airport in the nation's feeder line route network. The use of Midway as a reliever for O'Hare short-haul traffic has long been advocated by the FAA, the CAB and the City of Chicago, the airport owner. The trunk airlines and some of the regionals carriers with high levels of interline transfer traffic, however, have opposed the use of Midway due to the cost of maintaining dual facilities at both O'Hare and Midway. As traffic grows and O'Hare becomes even more saturated, it is apparent Midway must absorb a greater portion of short-haul and feeder operations. Midway was one of the airports studied in the prior NASA short-haul studies of References 1 and 10, and also was the subject of a recent major FAA sponsored study, Reference 11.

Total scheduled aircraft operational levels in the Chicago hub have remained relatively constant over the past five years at approximately 300,000 departures per year. Approximately 9 percent of the departures are by small transport category aircraft of from 30 to 75 passenger capacity. There does not appear to be any valid reason why these operational levels and aircraft mix percentages will change by 1985, the assumed airline operational date for the study aircraft. Accordingly, an operational level of 150 movements (75 departures and 75 arrivals) per day was assumed for purposes of the environmental analysis. Also for purposes of this analysis, it was assumed all aircraft of this type class would operate from Midway. While this assumption may be considered somewhat unrealistic due to interline transfer requirements, it does provide a conservatively high value for environmental impact estimates.

10.1.1 Airside Compatibility

No airfield or ATC compatibility problems are anticipated with either the baseline 50 passenger aircraft or its larger or smaller derivatives. The assumed operational level of 150 movements per day is relatively low compared to total operational levels previously experienced at Midway which maintained a reputation as "World's Busiest Airport" up to 1960. Annual movements at Midway reached 293,685 in 1958, or over 800 per day. The existing runway/taxiway system therefore should be adequate. The baseline aircraft is roughly comparable in size to the aircraft types operating from Midway during that time period and should cause no ground maneuverability problem. The advanced air traffic control systems (e.g., ARTS III and Microwave Landing System - MLS) planned for the 1980 time period should provide improved ATC operational capability for the entire Chicago area.

10.1.2 Groundside Compatibility

Both the baseline aircraft and its larger and smaller derivatives are considered to be fully compatible with Midway's terminal facilities. A potential maximum terminal throughput of approximately 1,000 peak hour passengers (500 arriving and 500 departing) for this airplane is well below the total throughput capacity of the existing terminal. The terminal was redesigned and enlarged in 1967 when a number of airlines relocated a portion of their flights from O'Hare to Midway. The Midway terminal now has a total of 29 gate positions, all capable of handling an aircraft the size of the Boeing 727. The remodeling included a new lobby and lengthened and widened concourses. The larger ticketing areas, each with a baggage claim area, provide ample passenger handling facilities. The automobile parking area can accommodate 1,750 cars. Ground access also is considered adequate for the operational levels simulated in this study.

10.1.3 Community Noise Impact

Noise contours and areas for the baseline and conceptual aircraft were presented earlier in Section 8.6 of this report. The noise impact methodology was discussed in Section 8.4. The following discussion presents the results of the noise impact evaluation. Straight-in and straight-out approach and departure paths were used in the evaluation since there was no need to develop minimum impact flight procedures. Figure 10-1 shows the noise contour overlay for the two primary use runways 22L and 31L. The footprints are generally comparable in size to the "Standard" flight procedure footprints of the M-150-4500 airplane of Reference 1. A comparison of the noise impact of the baseline aircraft and the M-150-4000 STOL is presented in Table 10-1. Noise impact of the baseline study aircraft could be further reduced through application of operational techniques discussed in Reference 1, however, this refinement is beyond the scope of the subject study.

Advanced three-dimensional computer generated graphic display techniques developed under the contractor's IRAD program were used to illustrate the noise impact of the baseline airplane at Chicago Midway Airport. Three basic types of displays were generated.

- o <u>A population density map</u> showing relative density of the census tracts in the airport vicinity. The display is most useful in developing noise abatement flight paths and procedures.

NOISE FOOTPRINTS - BASELINE MEDIUM DENSITY AIRCRAFT
MIDWAY AIRPORT RUNWAYS 22L AND 31L

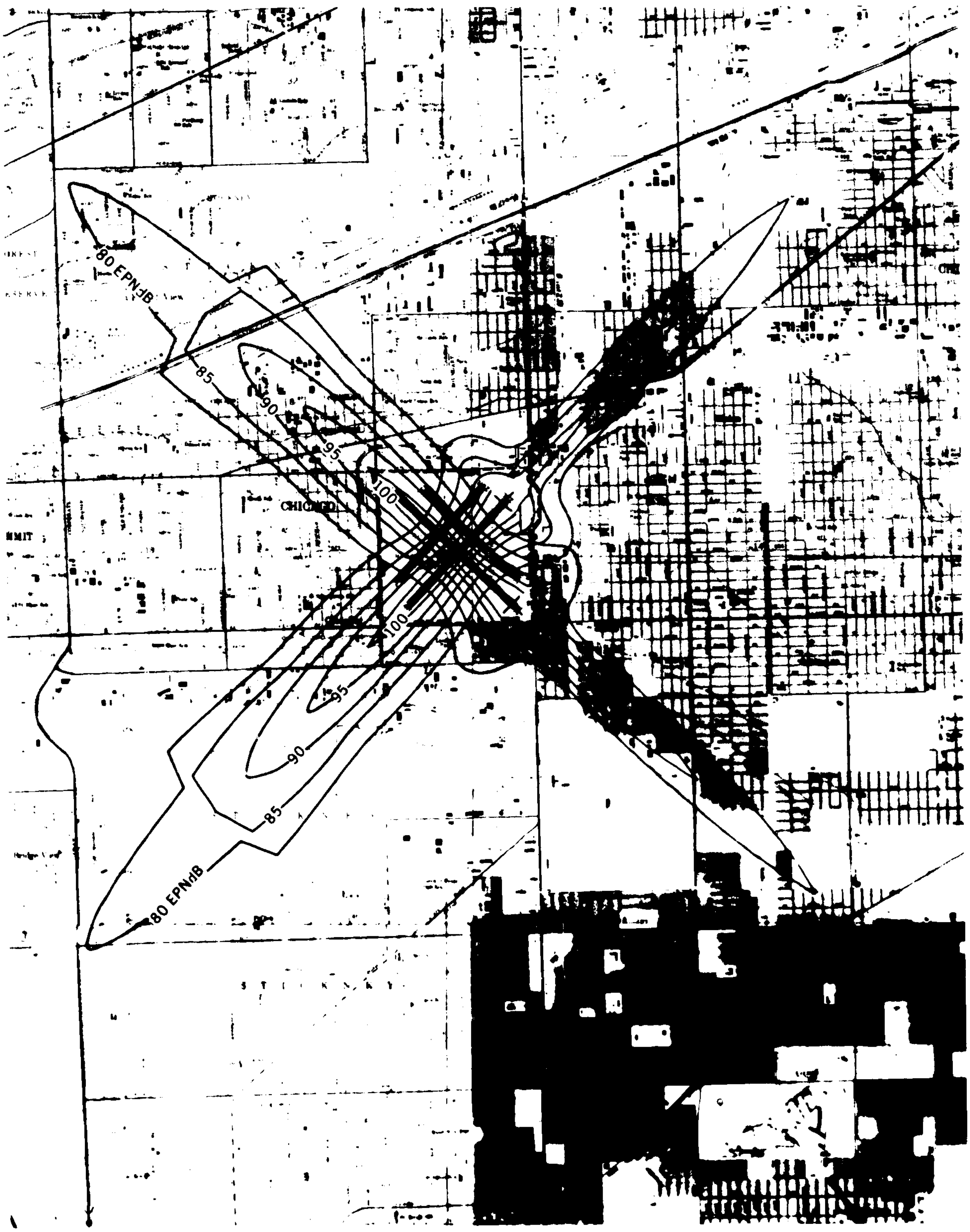


FIGURE 10-1

TABLE 10-1

NOISE IMPACT SUMMARY - CHICAGO MIDWAY AIRPORT

BASELINE MEDIUM DENSITY AIRPLANE

RUNWAY	EPNL CONTOUR	AREA SQ. MI.	(SQ. KM)	POPULATION AFFECTED	PERCENTAGE ANNOYED
22L	80	3.47	(8.99)	11613	12.8
	85	1.81	(4.70)	5809	21.3
	90	0.89	(2.32)	2901	28.7
	95	0.37	(0.97)	1471	33.9
	100	0.14	(0.36)	0	0
31L	80	3.47	(8.99)	15331	12.6
	85	1.81	(4.70)	8009	21.0
	90	0.89	(2.32)	3815	27.9
	95	0.37	(0.97)	1350	33.9
	100	0.14	(0.36)	0	0
COMPARATIVE DATA - M·150·4000 AIRPLANE (NASA CR. 114759, JUNE 1974)					
22L	80	3.29	(8.52)	11352	14.9
31L	80	3.29	(8.52)	14413	15.6

A population density map of 130 square mile (337 sq.km) area surrounding Midway is presented in Figure 10-2. The airport is located at the center of the map. Population density of the various census tracts was developed from 1970 U.S. census data. Density values range from 0 to 54,000 persons per square mile (20,850 per sq.km).

- A noise intensity map which shows the relative noise intensity of single-event approach and departure operations. Relative noise levels are displayed in the vertical dimension. This display technique is helpful in visualizing relative noise levels generated by operations from a given runway. Both single-event and composite levels can be shown with this technique.

  Figure 10-3 shows the noise levels of 80 EPNdB and higher created by a single-event operation of the baseline transport aircraft using runway 22L at Midway. The dot in the center of the display indicates the geographical Airport Reference Point (ARP) and provides a means of indexing the various displays. Figure 10-4 shows similar noise levels for Runway 31L.

- A community noise impact map showing relative community annoyance resulting from operations from a given runway. The relative noise impact, or annoyance index displayed in the vertical dimension, considers both noise intensity and population density. The method used in determining the annoyance levels was described earlier in Section 8.4 of this report. This display technique is useful in showing both the area impacted by noise from a given runway operation as well as the relative degree of annoyance experienced

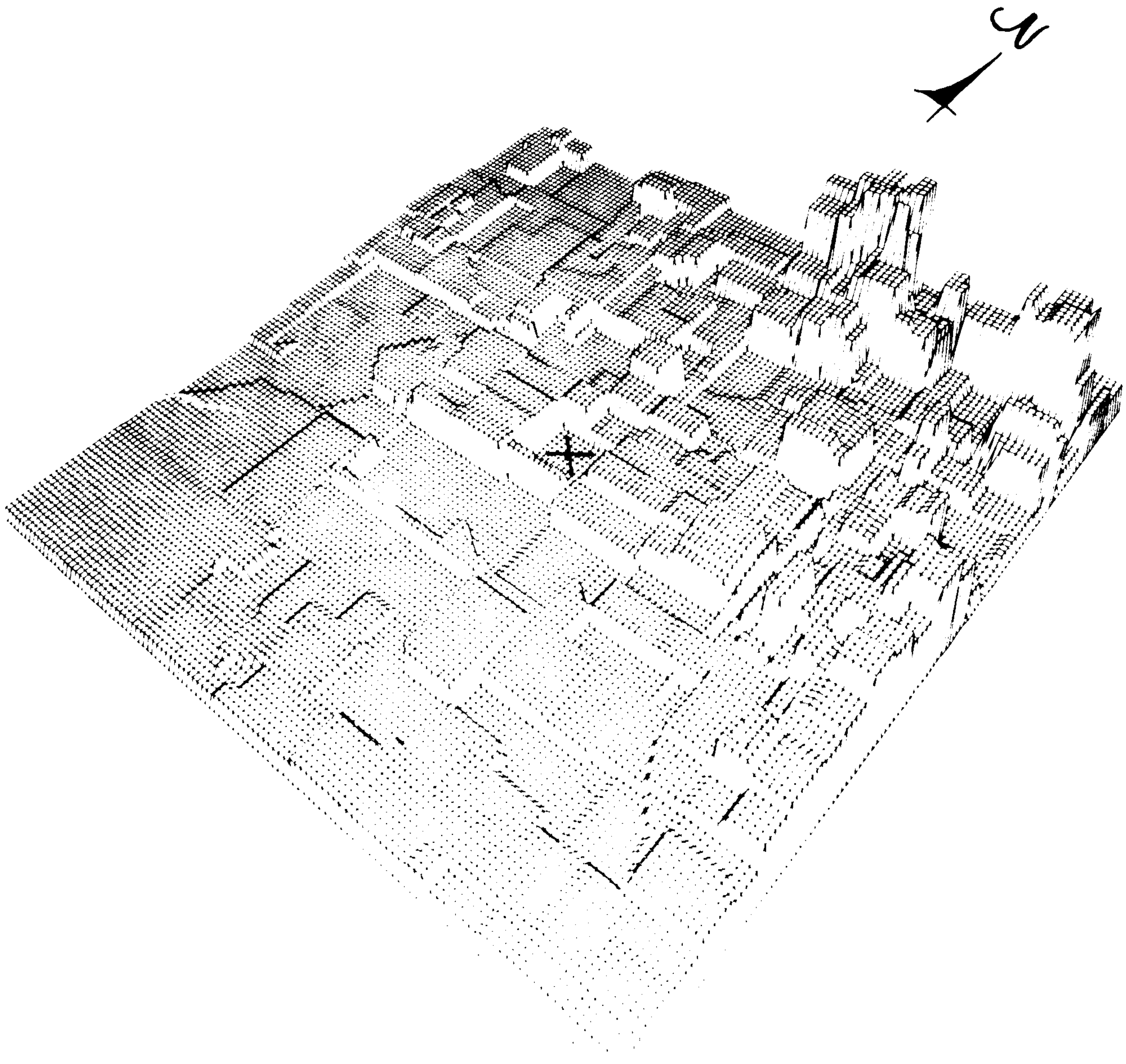


FIGURE 10-2 - COMPUTER GENERATED
POPULATION DENSITY MAP, 130 SQ. MI. AREA
CHICAGO MIDWAY AIRPORT

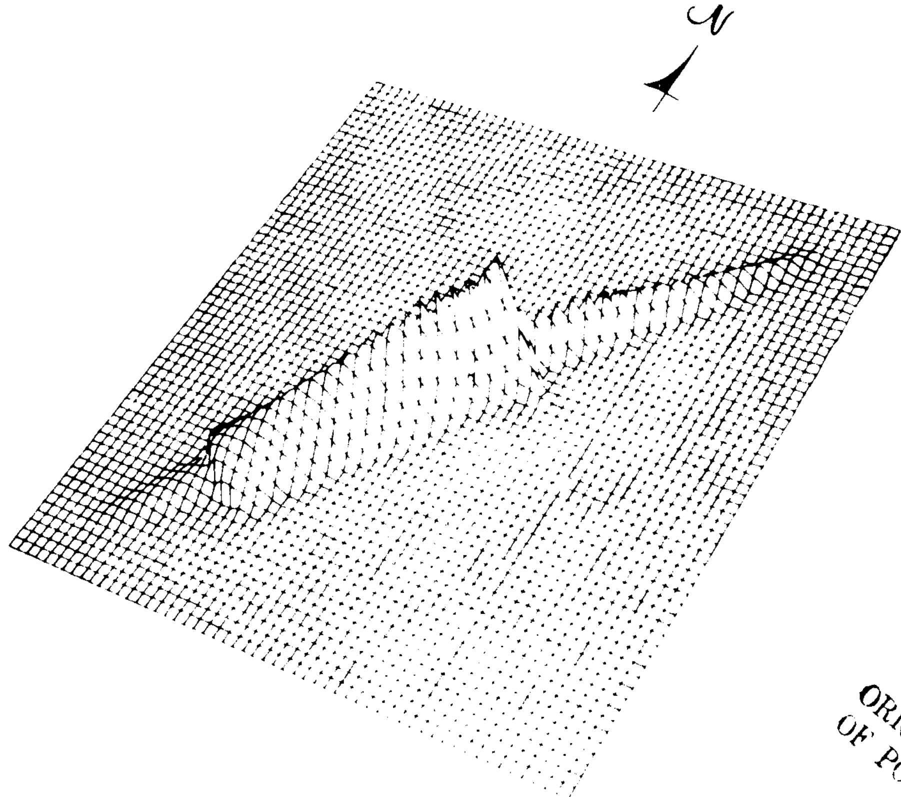


FIGURE 10-3 NOISE INTENSITY MAP - CHICAGO MIDWAY AIRPORT - RUNWAY 22L

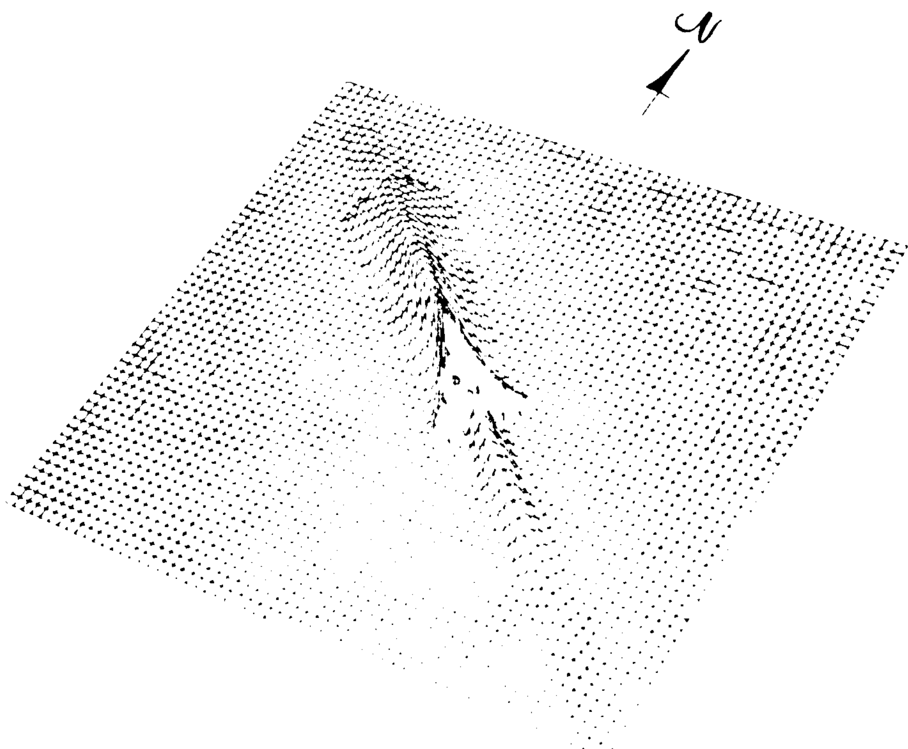


FIGURE 10-4 NOISE INTENSITY MAP - CHICAGO MIDWAY AIRPORT - RUNWAY 31L

by the community. By relating the impacted grids to the base map, the exact locations of the annoyed areas can be determined. The noise intensity variations are relative and do not lend themselves to exact numerical interpretation. Intensity values, however, can be obtained from the computer printout.

Figure 10-5 shows the relative community annoyance generated by the study aircraft using runway 22L at Midway. As shown, the annoyance generated by takeoff operations is dominant. Similar information for a single-event operation from runway 31L is shown in Figure 10-6. The computer program is capable of displaying data from any viewpoint elevation or azimuth angle.

10.1.4 Engine Emission Levels

Emission levels for the engines of the baseline study aircraft were assumed to meet the EPA 1979 standards. The standards for an engine to be manufactured after 1979 producing greater than 8,000 pounds (3,628 kg) thrust are as follows: 0.8 HC, 4.3 CO, 3.0 NO_x in EPA units and a smoke number of 20 (SAE Index).

The quantity of aircraft emissions is a function of the emission rates and the landing and takeoff cycle. Curves of emissions per 1,000 pounds (454 kg) of fuel plotted against percent takeoff thrust were generated. These curves were adjusted at the high endpoints by correlation curves.

The LTO cycle includes all ground operations and aircraft flight operations up to 3,000 feet. A straight-in approach and a straight-out departure was used to determine the flight path for the LTO cycle.

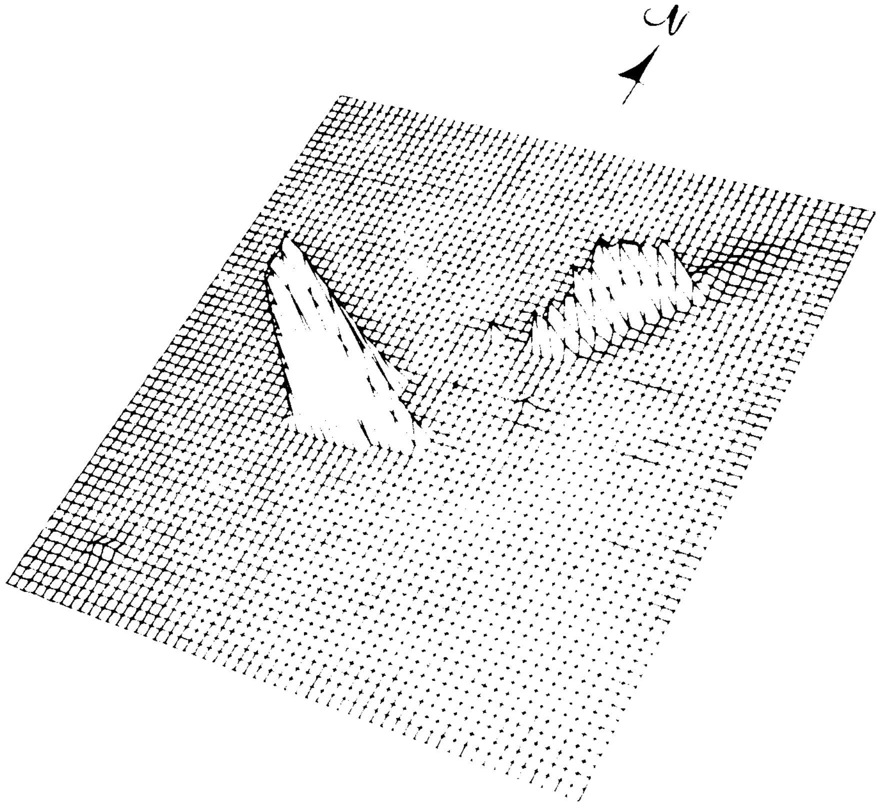


FIGURE 10-5 COMMUNITY NOISE IMPACT MAP -
CHICAGO MIDWAY AIRPORT - RUNWAY 22L

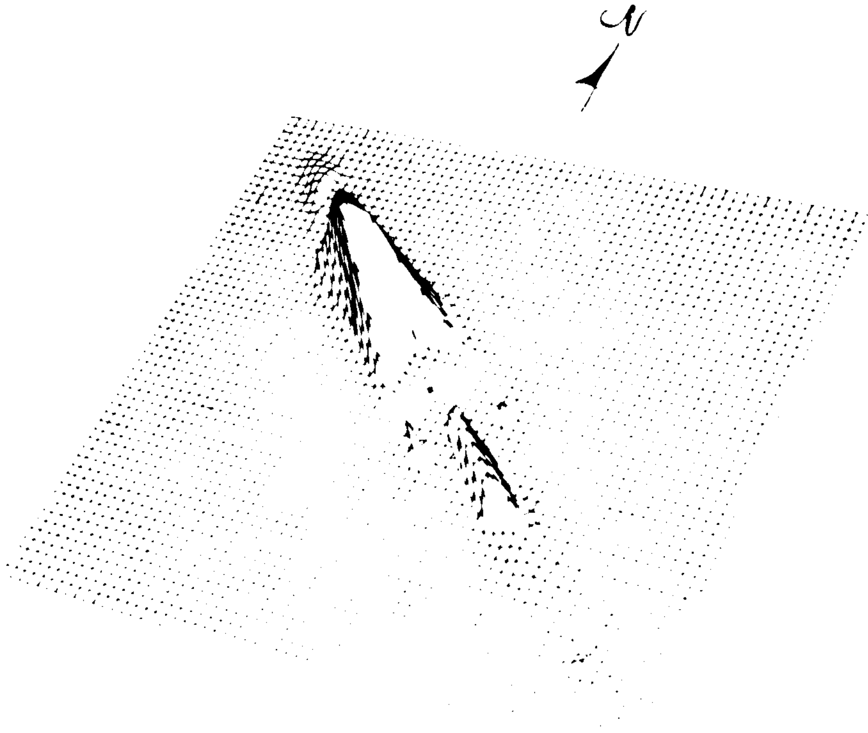


FIGURE 10-6 COMMUNITY NOISE IMPACT MAP -
CHICAGO MIDWAY AIRPORT - RUNWAY 31L

The calculated emission levels in EPA units for the selected aircraft engine are 0.76 HC, 4.1 CO, 2.9 NO_x, and smoke number of 20. These numbers convert to 1.6 pounds HC, 8.0 pounds CO, and 6.0 pounds NO_x per operation for the two engine configuration. For an estimated 75 operations per day at Midway, the daily amount of aircraft emissions from the twin engine medium density aircraft would be 60 pounds HC, 300 pounds CO, and 225 pounds NO_x.

Emissions for the baseline 50 passenger aircraft were compared to those of a typical JT8D powered twin engine jet transport. The bar chart in Figure 10-7 compares the emission levels of the two aircraft for a similar landing-takeoff cycle. Emissions for the study aircraft are approximated 50 to 75 percent below the emission levels for the current twin engine jet transport, assuming it meets 1979 standards.

10.1.5 Overall Environmental Impact

Public Law 91-190, the National Environmental Policy Act of 1969, requires preparation of an Environmental Impact Statement (EIS) for any federal action significantly affecting the quality of the human environment. This act has been broadly interpreted to require an EIS on any project involving federal funding or policy support. FAA directive 1050.1A, Reference 12, establishes procedures for considering the environmental impact of proposed FAA actions, including certification of new aircraft.

The following EIS summary statement has been prepared as a guide for the formal statement which ultimately would be required if a production program for the aircraft were to be initiated. The summary statement is in the form of a Negative Declaration as defined by Reference 12 since no adverse environmental impact is anticipated.

EMISSIONS COMPARISON

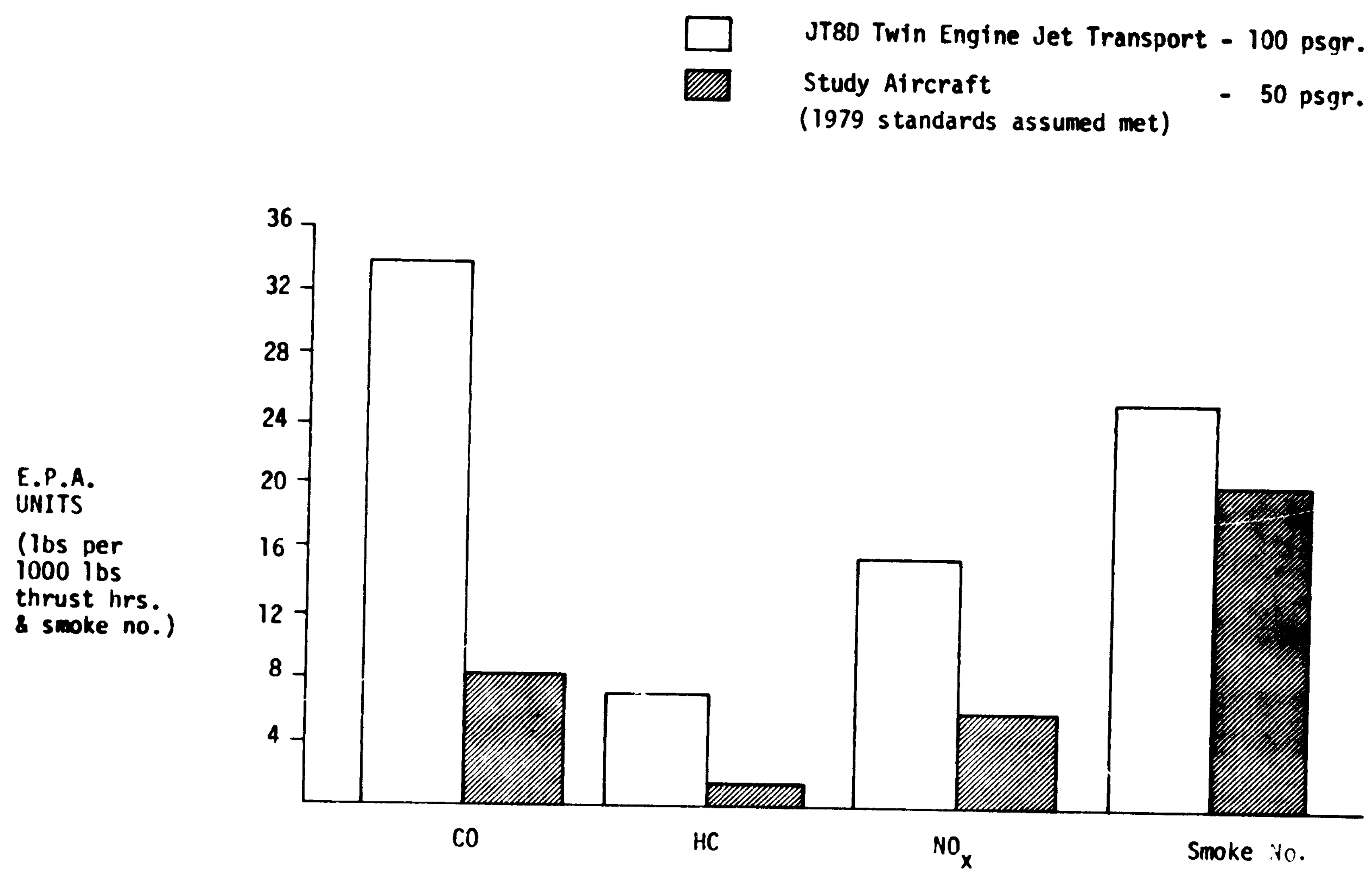


FIGURE 10-7

NEGATIVE DECLARATION

1. DESCRIPTION AND PURPOSE OF ACTION

A. Description

In accordance with Section 603 of the Federal Aviation Act of 1958, 49 U.S.C. 1423(a) and Part 21 of the Federal Aviation Regulations, it is proposed to design, develop and manufacture a medium density transportation aircraft. The aircraft would be designed to comply with the existing transport category airworthiness requirements of Part 25, the noise standards of Part 36 (-10 EPNdB), and the Environmental Protection Agency emission standards of Title 40, Chapter 1 - Part 87 - Control of Air Pollution from Aircraft and Aircraft Engines. The baseline aircraft is designed to carry 50 passengers, although different versions of from 30 to 70 passenger capacity may be produced.

B. Purpose

The purpose of the action is to develop an advanced environmentally superior aircraft with improved performance to replace older aircraft of similar size and type. It is intended that a production type certificate would be issued authorizing manufacture of duplicate aircraft conforming to the type design. Thereafter, the individual products may be certified as airworthy, if found to conform.

2. THE PROBABLE IMPACT

It is anticipated a quantity of at least 400 aircraft would be manufactured for domestic use in the transportation of passengers, cargo and mail in intrastate and interstate air transportation. The airplanes would be operated throughout the United States to and from both existing and planned new airports in the national air transportation system.

The aircraft will comply with all applicable airworthiness requirements existing at the time of design. Accordingly, the aircraft should provide greater safety of operations than prior aircraft types designed to less rigid specifications.

The aircraft is designed to better current (1974) FAA Part 36 noise requirements by at least 10 EPNdB at all three measurement points; approach, sideline and takeoff. Accordingly, the community noise impact will be noticeably lower than aircraft designed to meet the basic Part 36 noise levels and will be significantly less than aircraft designed prior to the Part 36 effectivity date.

The aircraft is designed to comply with all 1979 emission standards of EPA Part 87 for Class T2 engined aircraft. Accordingly, the exhaust and the venting emissions will be significantly less than those of earlier aircraft designed to less rigid emission requirements.

3. CONCLUSION

Based on the above factors, particularly the lower noise and emission characteristics, and the ultimate replacement of earlier less environmentally satisfactory aircraft with the environmentally improved aircraft, it is concluded that production of this aircraft will not adversely affect the quality of human environment, and is consistent with existing environmental policies and objectives as set forth in Section 101(a) of the National Environmental Policy Act of 1969.

11.0 OPERATIONAL SIMULATION

The operational simulation approach was the core of evaluation and selection of aircraft to serve the medium density market defined herein. With the process programmed for computer operations, the evaluation of an aircraft concept was conducted in the simulation process with a mathematical solution to operation of a typical airline with a traffic model, available aircraft, and a revenue schedule for potential income. The analysis was performed with summary fleet results generated independently for each of the years in the simulation period.

11.1 Airline Operations

The simulation of airline operations involved a number of different scenarios as the study progressed. Each variation involved a network, a level of demand and revenue potential and one or more aircraft concepts for assignment to the mission task.

11.1.1 Traffic Models and Networks - Initial and Final

A number of special networks and mission models were derived in addition to the total medium density model and the initial network used in the aircraft requirements analysis. The initial network, described in Section 1.3.1, was used in all of the conceptual and parametric analyses. A summary of the data describing this network is included as Table 11-1, "Initial Mission Model Characteristic Annual Statistics."

This initial traffic model was constructed by application of average system load factors to aircraft schedules for August of 1972. Annual data was assumed at 12 times the August levels.

TABLE 11-1

INITIAL MISSION MODEL CHARACTERISTIC ANNUAL STATISTICS

Year	Airport Pairs	Scheduled Trips (Million)	Scheduled Seats (Million)	Revenue Passenger Mile Demand (Million)(RP Km)	Potential Revenue ($ Million)	Maximum Stage (St.Mi.)(Km)	Average Stage (St.Mi.)(Km)
1972	2,732	1.843	121.016	12.107 (19.480)	N.A.(3)	973 (1566)	163 (262)
1980(1)	2,694	1,716	169.201	15.568 (25.049)	2086.625	873(2) (1404)	158 (254)

NOTE: (1) Elimination of potential high-density routes reduced airport-pair routes, scheduled annual trips, and average stage length (1972 to 1980)

(2) Elimination of Phoenix-Puerto Vallarte Route reduced the longest stage to 873 (Philadelphia to Memphis).

(3) Revenue for 1972 not applicable.

With application of reported system load factors for each of the airlines and scheduled seats by equipment, each trip segment (airport pair) was assigned a daily scheduled segment seat occupied. This number for each segment yielded a total demand for segment seats occupied. For the 1972 base year, this total demand was 62.546 million segment seats. Translated into revenue passenger miles, some 12.107 billion RPM's constituted total demand at the 1972 base year level. At the growth rate of 6 percent per year, the data was grown to 99.689 million segment seats and 19.297 billion RPM's as the demand for 1980. See Tables B-1 through B-5, Section B.2 of Appendix B for data on this mission model.

This initial traffic model included all of the regional routes and scheduled service (seats). A few of these routes exceeded the medium density definition of daily route demand either in the 1972 base year or projected to 1980 levels. These routes were classified high density and subsequently were excluded from the 1980 data base. There were 19 airport-pair segments excluded and removed from the 1972 base as follows:

1. High density was defined as over 500 people/day/route. At an average load factor of 50 percent, this was 1000 seats/day or 7,000 seats per week. Deflating this from 1980 to 1972 by 6 percent per year resulted in 4,392 seats per week on a round-trip basis.

2. Detailed examination of the 2,732 airport-pairs in the unadjusted initial mission model showed a total of 19 routes which were considered high density in 1972 or by 1980. These are tabulated as follows:

	Airport	Airline Code	Distance (Miles) (Km)	1972* Seats/Week	Equipment Type	Aircraft Seats
1.	Buffalo Toronto	AL	69 (111)	5,180	BAC-111	74
2.	Milwaukee Chicago	NC	66 (106)	5,202	CV-580	48
3.	Dallas Houston	TT	219 (352)	4,500	DC-9	75
4.	Pittsburg Philadelphia	AL	267 (430)	8,900	Super DC-9	100
5.	Philadelphia Boston	AL	279 (449)	8,900	Super DC-9	100
6.	Pittsburg LaGuardia	AL	334 (537)	4,900	Super DC-9	100
7.	Pittsburg Chicago	AL	411 (661)	6,300	Super DC-9	100
8.	Oakland San Jose	PS	30 (48)	6,085	727-200	158
9.	Los Angeles San Diego	PS	110 (177)	11,850	727-200	158
10.	Burbank San Diego	PS	123 (198)	5,925	727-200	158
11.	Burbank San Jose	PS	296 (476)	7,900	727-200	158
12.	Los Angeles San Jose	PS	308 (495)	11,376	727-200	158
13.	Los Angeles Oakland	PS	337 (542)	9,638	727-200	158

	Airport	Airline Code	Distance (Miles) (Km)	1972* Seats/Week	Equipment Type	Aircraft Seats
14.	Los Angeles San Francisco	PS	338 (544)	16,116	727-200	158
15.	Los Angeles Sacramento	PS	374 (602)	7,505	727-200	158
16.	Oakland San Jose	XK	30 (48)	5,798	737	92
17.	Burbank San Francisco	PS	326 (524)	4,536	737	101
18.	San Jose Santa Ana	XK	342 (550)	4,922	737	92
19.	San Francisco Santa Ana	XK	372 (598)	4,232	737	92

*Seats per week is the total number of flights times the seat capacity of the aircraft scheduled for a period of one week for the year 1972.

Since an airport pair is a one-way route, the correction on total scheduled airport pairs is twice the number listed above. Thus, airport pairs in the adjusted model are 38 less than the 2,732 or 2,694 as indicated in Section 1.3.1.

The effect of excluding these routes was to reduce the 1980 traffic demand to 85,036,000 segment seats demanded and 15,568,000,000 revenue passenger miles. These data plus scheduled seats, trips, and trip miles constituted the demand traffic statistics for the first year (1980) of the simulation period.

A calibrating analysis was applied in terms of CAB reported departures per day for August of 1972 against the scheduled departures per day in the traffic model. CAB data was obtained from CAB Form 41 Schedule T-3B, "Scheduled and Extra Section Departures Performed by Aircraft Type", Quarter Ended September 30, 1972, Reference 14 . Comparative data are shown in Table 11-2,"Calibration Statistics." Note that the reported departures are in close agreement with the model data. Since the CAB daily departures result from quarterly data, the numbers are considered as consistent for this study.

A sub-section of the initial network was drawn from the August 1972 schedules for Frontier Airlines. These routes were served by Beech 99, DeHavilland Twin Otter, Convair 580, and Boeing 737 aircraft. A total of 343 airport pair routes plus a minimum frequency of flights and a 1980 level of demand for RPMs comprised this airline mission model. The network was further divided into three sections. These routes were served by the Beech 99 and Twin Otter, the Convair 580, and the Boeing 737, respectively. In a sense these routes simulated a low, medium, and high density spectrum of routes as drawn from the Frontier data.

Another set of routes was organized from the total traffic model and used in more detailed analysis of demand and aircraft operations. The mission model was segmented into three components, these were low, medium and high densities. The definition of each of these segments was according to the size of aircraft serving the market in 1972. With August 1972 data, these segments were as follows:

Segment by Density	Served by Aircraft of Capacity:	RPM Demand 1980
- Low	15 to 26 seats	130 million
- Medium	40 to 60 seats	3,868 million
- High	74 to 112 seats	11,563 million

TABLE 11-2

CALIBRATION STATISTICS

for

MEDIUM DENSITY TRAFFIC MODEL

DAILY DEPARTURES

Airline	CAB Departures 3rd Quarter 1972	Equivalent Daily	Medium Density Model Daily Departures
Allegheny	98,689*	1073	1398
Piedmont	44,031	479	492
North Central	57,157	621	637
Ozark	40,626	442	452
Frontier	47,765	519	550
Hughes Air West	41,195	448	459
Southern	33,945	369	374
Texas International	31,725	345	358
Pacific Southwest	- (Not Reported)	-	251
Air California	- (Not Reported)	-	72

* Excludes 41 Airport Pairs with 295 OAG Departures Served with Small Aircraft

Another dimenstion of this segmented medium density model was the number of airport pairs in each segment. These were as follows:

Segment	Airport Pairs
Low	114
Medium	1,336
High	1,144
	2,594

For the competitive simulation, a new mission model and traffic network was derived from August 1974 airline data. A general discussion of this network appeared in Section 1.3.2. Pertinent data from the model are listed in Table 11-3, "Final Mission Model Characteristic Annual Statistics".

TABLE 11-3

FINAL MISSION MODEL CHARACTERISTIC ANNUAL STATISTICS

Year	Scheduled Seats (Million)	Revenue Passenger-Mile Demand (Billion)(RP Km)	Potential Revenue ($ Million)
1974	100.526	9.381 (15.094)	N.A.(1)
1980	140.130	13.307 (21.411	1,532.901
1985	177.216	16.897 (27.187)	1,941.747
1990	220.404	21.079 (33.916)	2,417.855

(1) Revenue estimated only from 1980 as first year of simulation period.

11.1.2 Preliminary Aircraft Input Data

There were two basic analytic programs in this study which computed operational and economic characteristics of aircraft. In addition, the simulation program for airline operations accepted aircraft data input.

The CAPDEC program was used to develop aircraft research and development and production costs. Basic data requirements consisted of the aircraft manufacturer's weight empty less engines and avionics weights (cost weight). Also included were the costs of engines and avionics. Appendix C, Section C.1, contains a tabulation of typical CAPDEC data and results.

The operational simulation program used in this study, Performance Evaluation Technique (PET), has a variety of sub-routines and evaluation options. Included in these are a Design/Cost/DOC module pertaining to basic characteristics of the aircraft. A special routine permits evaluation of DOC versus range in ten (10) increments of range. Another portion of PET involves simulation of airline operations with basic aircraft data and a mission model with demand and operational data. The aircraft data for this is either generated in the Design/Cost/DOC module, or directly from equivalent descriptors. Details on the aircraft data are included in Appendix B, Section B.4, Table B-9.

The basic data required for evaluation of the DOC versus range function are as follows:

- Aircraft identity numbers
- Cruise Mach number
- Design range in nautical miles
- Design payload - passengers x 200 pounds (90 kg)

- Takeoff gross weight in pounds
- Mission range fuel burned in pounds
- Landing weight
- Zero fuel weight
- Operators' weight empty
- Operator items weight
- Manufacturing weight empty
- Engines weight - uninstalled
- Airframe weight
- Number of flight crew in cockpit
- Domestic or Overwater/International service code
- Number of engines
- Type of engines
- Cost of engines
- Takeoff thrust rating in pounds
- Annual utilization factor (to correct standard ATA formula)
- Unit cost of aircraft including engines
- An operating load factor

If aircraft data are generated in the process above, all of the needed data is available for the next phase of airline operational simulation. Aircraft data also may be used in the operational simulation program in the following form:

- Aircraft identity number
- Design range in nautical miles
- Payload in seats
- A DOC function of range in the form of a slope/intercept equation

- A Block Time function of range in the slope/intercept equation form
- Fuel consumption in pounds per hour (an average rate per block hour)
- Introduction year or year of availability if a future aircraft
- Aircraft operating load factor
- Aircraft price or purchase cost to airline
- Annual utilization factor

11.1.3 Analytic Technique

The airline operational simulation technique accepted aircraft data as outlined above. The mission model consisted of a network of routes and these routes were organized into classes incremented by range intervals. Each element also included minimum flight schedules and revenue passenger miles as demand for travel. The simulation tested the productivity of an aircraft against the demand in each element. Revenue earned and total operating costs were computed for each test. Summation of test results yielded total fleet statistics on an annual basis. If more than one aircraft type was involved in the simulation test, that aircraft type which met the schedule at the least cost or maximum profit was selected. Summation of all elements and aircraft led to a definition of a fleet which included one or more aircraft configurations.

11.2 Selection of Aircraft Screening Criteria

The primary aircraft parameters investigated in the study of conceptual aircraft requirements were range and payload. Other parameters were operating field length and engine selection - turbofan and turboprop. The initial combination of range, payload and frequency of service was selected to yield the greatest fleet profit. Operating field length and engine selection were investigated as parametric excursions.

The traffic model contained elements where small aircraft were used and daily flight frequencies (trips per day) were less than the equivalent of seven per week. There were some elements where a minimum trip level per day resulted in low load factors with the proposed aircraft concept. Such load factors contributed to the generation of net losses (cost higher than revenue). If this were a result in the operational simulation, total system profit was reduced. Thus, the first screening criterion of system profitability was either maximum profits or minimum losses as appropriate with the cost estimates for the conceptual aircraft.

A second screening criterion was level of service. No specific level was assigned as a value. In general, any aircraft was acceptable if it provided at least the minimum schedule contained in the mission model at the desired load factor. Although a nominal limit of eight trips per day per route was part of the definition, none of the aircraft selected in the simulation exceeded this figure. Thus, no passengers were "left behind" in any of the model elements because of frequency limits. Various other economic and operational screening criteria were suggested. A tabulation of these is as follows:

Suggested Operational Screening Criteria

Economic	Operational	Combinations
System Profits - Annual - Cumulative	Trips - Annual - Cumulative	Profits Per Passenger - Annual - Cumulative
Direct Operating Cost - Per Trip - Per Aircraft Mile - Per Seat Mile	Fleet Size - Annual - Cumulative	Market Fraction Served - Annual - Cumulative
Total Operating Cost - Per Trip - Per Aircraft Mile - Per Seat Mile	Passenger - Annual - Cumulative	Fuel Burned Per Passenger - Annual - Cumulative
	Fuel Burned - Annual - Cumulative	

Of all of these criteria, system profits was the most precise and served as the primary criterion.

11.3 Derivation of Aircraft and Fleet Operating Characteristics

The initial set of design characteristics was established for a 50 passenger, 2 x 250 nautical mile design range, 4,500 foot field-length aircraft. A bypass ratio 6.0 turbofan engine was chosen for propulsion. These physical descriptors were used for the cost estimating and performance evaluation routines. Results from these routines along with selected initial design descriptors constituted the aircraft characteristics. Simulated airline operations with individual aircraft characteristics resulted in fleet descriptors as a summation of the numbers of aircraft required to satisfy the travel demand.

Variations of range, payload, and engines (turboprop) in a noncompettitive operational simulation produced a set of fleet characteristics for each aircraft version evaluated. Typical of fleet characteristics were number of aircraft in the fleet, total fleet price, revenue generated from passengers carried, operating costs, profit or loss, revenue passenger miles flown, number of aircraft trips (flights on airport pairs), total fuel burned, a fleet profitability index, and the average range or stage length flown. Aircraft performance characteristics were average block speed, hours of annual utilization, system operating load factor, and productivity in RPM per year per aircraft. All fleet and aircraft data were generated on an annual basis for each of the years in the simulation period.

11.4 Aircraft Parametric Variations Analysis and Evaluation

Initial variations in the conceptual aircraft were range, passenger capacity, operating field length, and engine cycle. Initial variations studied in the Aircraft Requirements phase included:

Passenger capacity (no.)	-	30, 50, 70
Range (n.mi./Km)	-	2 x 150 stages (2 x 278 Km)
	-	2 x 250 stages (2 x 463 Km)
	-	2 x 350 stages (2 x 648 Km)
	-	1 x 1000 stages(1 x 1852 Km)
Operating field length (ft.m)	-	3500,4500,5500/1067,1372,1676
Engine types	-	Turbofan with bypass ratio of 6:1
	-	Turboprop and variable pitch fan

To this list was added a comparison between the nominal hinged high-lift flap system and a tracked flap system.

In the Aircraft Design phase of the study, the tracked flap system was adopted. A basic seating capacity of 50 also was chosen. Throughout this phase of the study, the operating characteristics were constant. However, some physical characteristics were investigated for effect on price of the aircraft. These were increase in range capability from 850 to 1000 nautical miles and tooling and mnaufacturing "design-to-cost" simplifications.

In the Evaluation phase of the study, the basepoint aircraft at 50 seats was selected for competitive simulation and fleet performance evaluation. A range of 850 nautical miles and a field length of 4,500 feet were used. For fleet evaluation, aircraft of 30, 40, 60 and 70 seats were derived from the 50 passenger basepoint configuration.

12.0 NONCOMPETITIVE OPERATIONAL RESULTS

For the initial study of conceptual aircraft and parametric variations, each aircraft version was operationally simulated in a noncompetitive mode. Two approaches were used in deriving requirements for operational characteristics. The first was to conduct a preliminary sizing study with CAB statistics for the year 1972. The second was to use a representative mission model for mathematical operational simulation. This simulation was performed with a Douglas computer program.

12.1 Conceptual Aircraft - Preliminary Size Screening

A gross demand model for screening of the aircraft by number of seats was established with travel data from an Online Origin and Destination Tape (Reference 18) for the year 1972. The data were grouped by city-pairs as follows:

- range increments of 100 miles up to a maximum of 800 statute miles,
- traveler distribution in increments of 50 passengers per day per route up to a maximum of 500 passengers per day,
- separation of data into domestic trunk carrier and regional (local service) carrier listings.

Data presented in Table 12-1 shows the sorted distribution of passengers in the medium density market carried by all domestic air carriers. The data are sorted into range classes and daily passengers per city pair. Note that domestic air travelers within the medium density definition totaled about 49.4 million in 1972. In the density class of 20 to 49 passengers per route per day (two-way flow), some 500,000 travelers traveled up to 100 miles

TABLE 12-1

PASSENGERS CARRIED

MEDIUM DENSITY MARKET
DOMESTIC CARRIERS — 1972
THOUSANDS/YEAR

RANGE (ST MI)	DAILY PASSENGERS PER CITY-PAIR										TOTAL
	20-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-500	
0-99	500	448	471	312	0	94	354	132	157	344	2,812
100-199	1,287	1,608	1,143	1,387	1,385	709	463	819	158	696	9,655
200-299	1,306	1,576	932	1,530	1,172	1,371	1,055	689	323	343	10,297
300-399	1,002	1,166	1,234	816	661	1,083	828	261	319	172	7,542
400-499	810	926	821	1,109	541	473	238	417	454	179	5,968
500-599	852	829	280	755	485	505	359	142	632	339	5,178
600-699	645	890	787	942	86	201	357	564	307	167	4,946
700-799	608	603	495	317	81	201	242	137	0	340	3,024
TOTAL	7,010	8,046	6,163	7,168	4,410	4,637	3,897	3,161	2,350	2,580	49,422

SOURCE — CAB ONLINE O&D STATISTICS
EXCLUDES PSA, AIR CALIFORNIA

in distance. The 20 passengers per day was the low cut-off level for definition of medium density.

This same data is divided into regional and trunk carriers. Table 12-2 contains air passenger data on the regional carriers. Table 12-3 presents similar data for the domestic trunk carriers. Within the definition of medium density travel, note that the regional airlines carried about 20.2 million travelers and the trunks about 29.2 million travelers in 1972.

These origin and destination passengers travel between 1354 city-pairs as displayed in Table 12-4. Note the relative concentration of medium-density city pairs at ranges and daily density levels in the upper left corner of the table. This concentration is even more noticeable in Table 12-5, distribution of medium density city pairs served only by the regional air carriers. Although the regionals carried fewer passengers than the trunks, the number of city pairs served is slightly greater, 736 of a total of 1,354 or almost 55 percent of city pairs classified as being in the medium density market.

A bar chart of this city-pair data appears as Figure 12-1 in which the distribution of city-pairs is shown as a function of travel density classes. Especially apparent is the large number of city-pairs in the low density portion of the distribution. Figure 12-2 presents the same data divided into city-pairs served by trunk and regional carriers. Again, to illustrate a difference in the medium density markets served by trunk and and regional carriers, Figure 12-3 is presented. This data indicates the concentration of the regional carriers in the shorter range segments of the market.

TABLE 12-2

PASSENGERS CARRIED

MEDIUM DENSITY MARKET
REGIONAL CARRIERS — 1972
THOUSANDS/YEAR

RANGE (ST MI)	DAILY PASSENGERS PER CITY-PAIR										TOTAL
	20-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-500	
0-99	424	302	364	246	0	202	0	0	0	0	1,538
100-199	1,095	1,564	828	696	664	509	608	0	310	349	6,623
200-299	1,083	1,407	848	1,040	581	188	358	0	0	0	5,505
300-399	617	803	489	193	245	306	0	0	316	0	2,969
400-499	494	464	232	242	158	0	0	0	0	0	1,590
500-599	328	269	137	120	0	0	0	0	0	0	854
600-699	246	202	214	73	78	0	0	0	0	0	813
700-799	180	26	54	0	86	0	0	0	0	0	346
TOTAL	4,467	5,037	3,166	2,610	1,812	1,205	966	0	626	349	20,238

SOURCE: – CAB ONLINE O&D STATISTICS
– EXCLUDES PSA, AIR CALIFORNIA

TABLE 12-3

PASSENGERS CARRIED MEDIUM DENSITY MARKET

TRUNK CARRIERS — 1972

THOUSANDS/YEAR

RANGE (ST MI)	DAILY PASSENGERS PER CITY-PAIR 20-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-500	TOTAL
(0-99)	76	146	107	66	0	0	318	132	157	344	1,346
(100-199)	192	44	315	691	721	200	0	819	0	347	3,329
(200-299)	223	169	84	490	591	1,075	697	689	323	343	4,684
(300-399)	385	363	745	623	416	777	756	261	3	172	4,501
(400-499)	316	462	589	867	383	473	202	417	454	179	4,342
(500-599)	524	560	143	635	485	505	359	142	480	339	4,172
(600-699)	399	688	573	869	2	201	357	564	307	167	4,127
(700-799)	428	577	441	317	0	201	242	137	0	340	2,683
TOTAL	2,543	3,009	2,997	4,558	2,598	3,432	2,931	3,161	1,724	2,231	29,184

SOURCE: CAB ONLINE (&D STATISTICS

TABLE 12-4

DISTRIBUTION OF CITY-PAIRS

MEDIUM DENSITY MARKET
DOMESTIC CARRIERS — 1972

RANGE (ST MI)	DAILY PASSENGERS PER CITY-PAIR										TOTAL
	20-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-500	
0-99	42	17	11	5	0	1	3	1	1	2	83
100-199	111	64	25	22	17	7	4	6	1	4	261
200-299	109	61	21	25	14	14	9	4	2	2	262
300-399	90	45	27	13	8	11	7	2	2	1	206
400-499	69	36	17	17	7	5	2	3	3	1	160
500-599	72	34	6	12	6	5	3	1	4	2	145
600-699	57	34	17	15	1	2	3	4	2	1	135
700-799	53	24	11	5	1	2	2	1	0	2	101
TOTAL	603	315	135	114	54	47	33	23	15	15	1354

SOURCE: – CAB ONLINE O&D STATISTICS
– EXCLUDES PSA, AIR CALIFORNIA

TABLE 12-5

DISTRIBUTION OF CITY-PAIRS
MEDIUM DENSITY MARKET
REGIONAL CARRIERS — 1972

RANGE (ST MI)	DAILY PASSENGERS PER CITY-PAIR										TOTAL
	20-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-500	
0-99	36	12	8	4	0	2	0	0	0	0	62
100-199	94	61	19	11	8	5	5	0	2	2	207
200-299	87	55	19	17	7	2	3	0	0	0	190
300-399	55	32	11	3	3	3	0	0	2	0	109
400-499	42	19	5	4	2	0	0	0	0	0	72
500-599	28	9	3	2	0	0	0	0	0	0	42
600-699	21	8	5	1	1	0	0	0	0	0	36
700-799	15	1	1	0	1	0	0	0	0	0	18
TOTAL	378	197	71	42	22	12	8	0	4	2	736

SOURCE: – CAB ON-LINE O&D STATISTICS
– EXCLUDES PSA, AIR CALIFORNIA

MEDIUM DENSITY CITY-PAIRS DISTRIBUTED BY TRAVEL - DENSITY CLASSES

CAB DATA - 1972

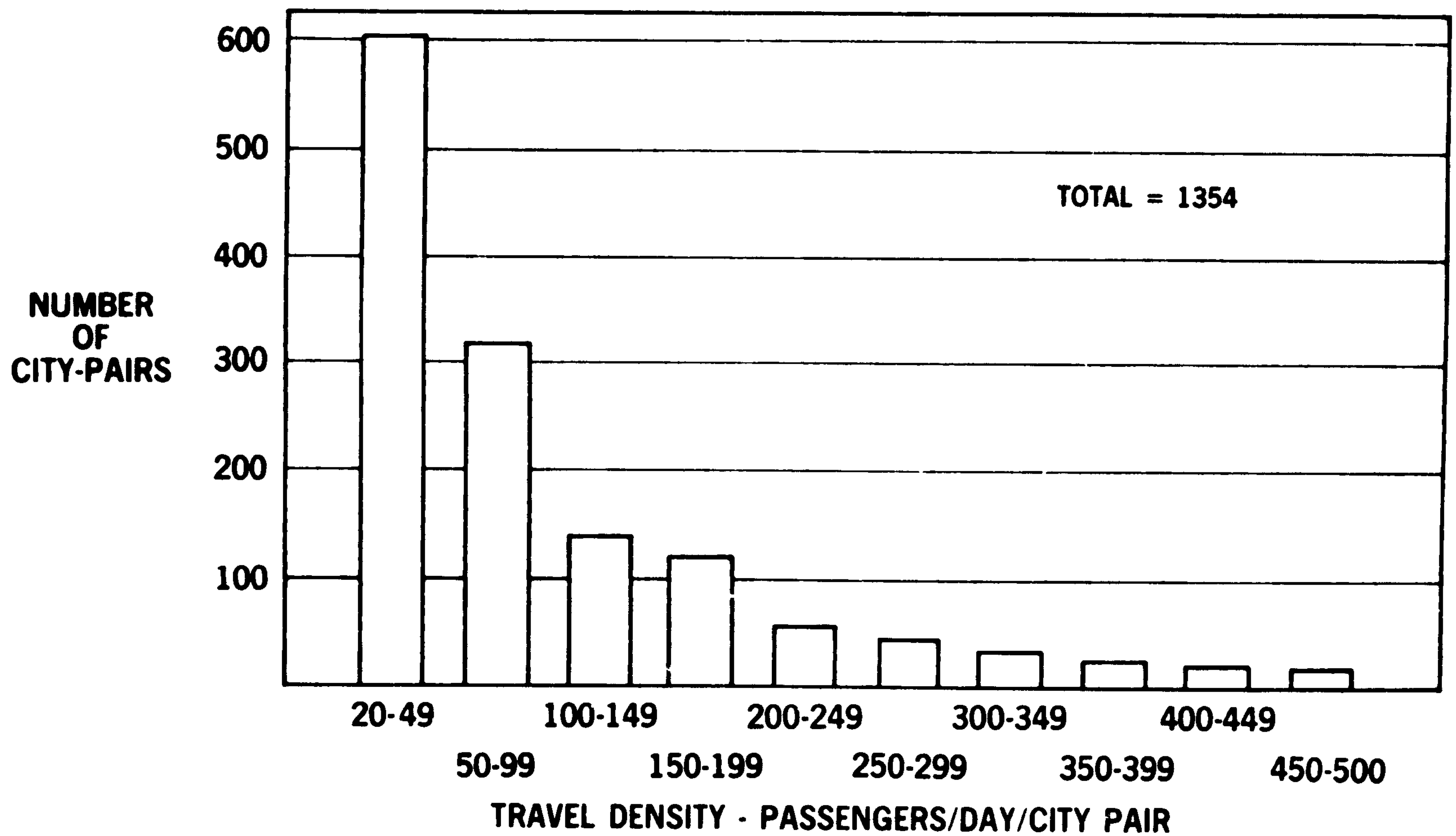


FIGURE 12-1

MEDIUM DENSITY CITY PAIRS SERVED BY TRUNK AND REGIONAL CARRIERS

- DISTRIBUTED BY TRAVEL-DENSITY CLASS -
CAB DATA — 1972

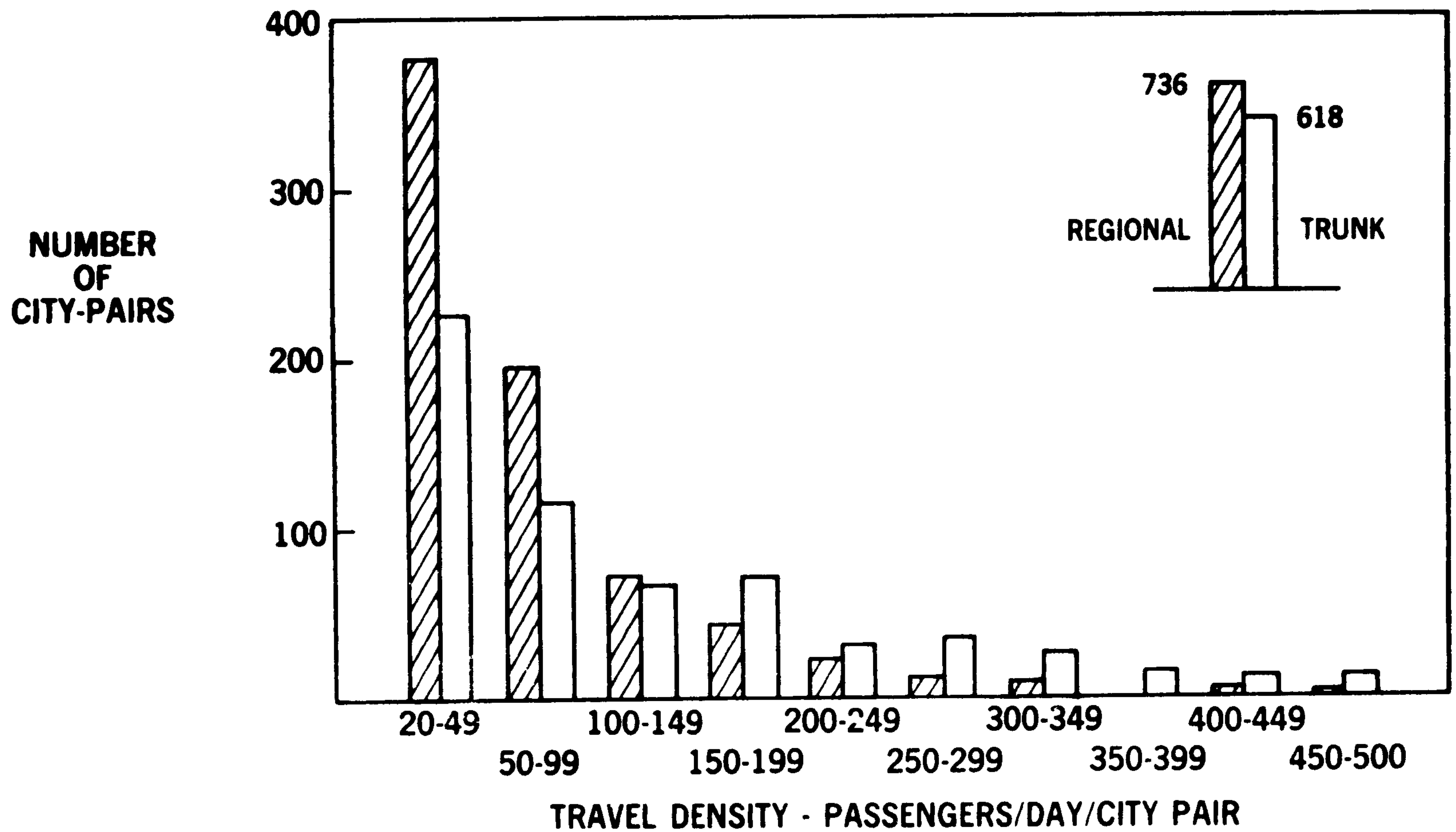


FIGURE 12-2

MEDIUM DENSITY CITY-PAIRS DISTRIBUTED BY RANGE-CLASS

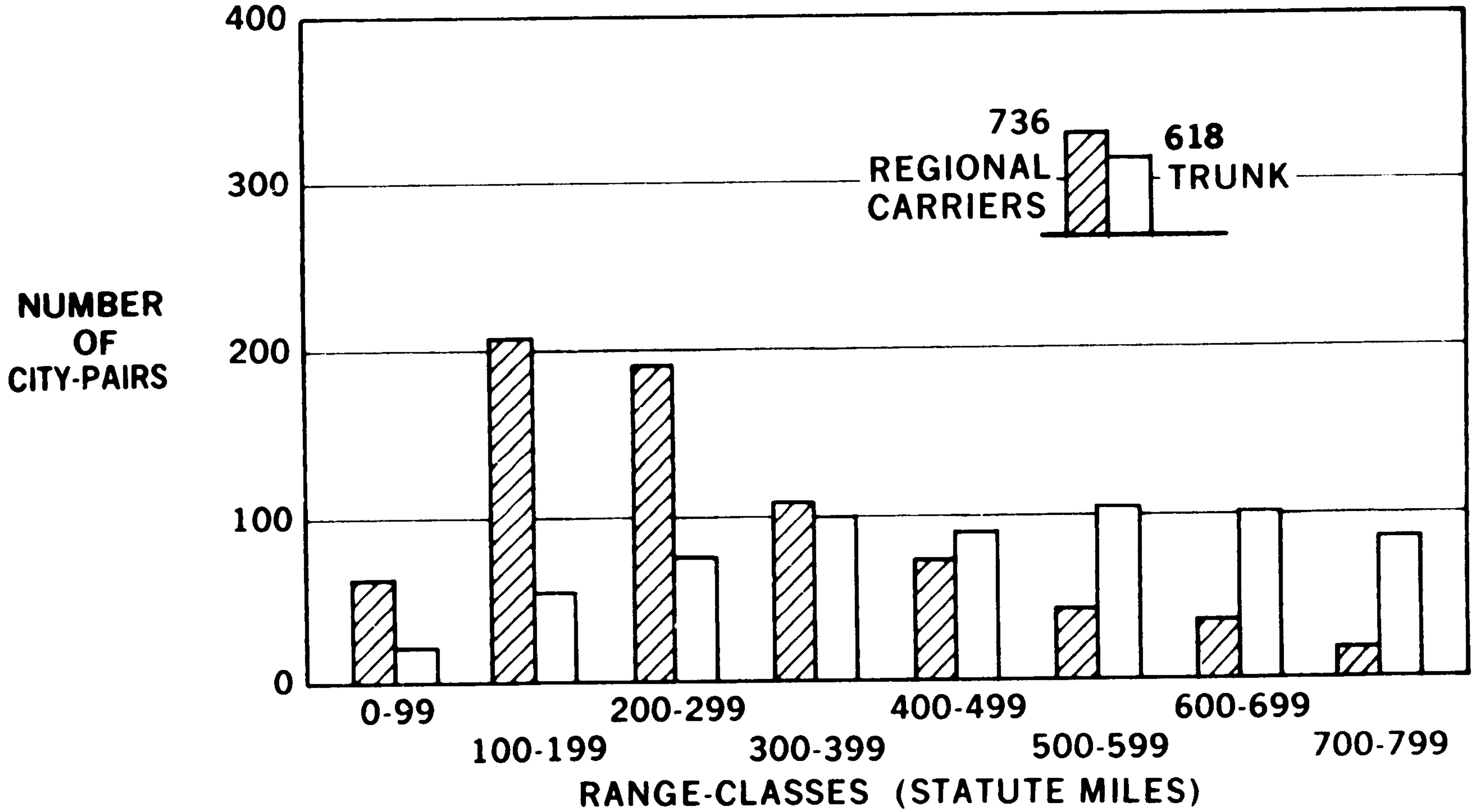


FIGURE 12-3

Additional bar charts are presented in a similar fashion to show distribution of passengers. Figure 12-4 shows a distribution of passengers-carried in each of the range classes. To illustrate, slightly over 8 million travelers in the medium density market traveled on routes over which 50 to 99 passengers per day per city-pair were carried by domestic carriers. As indicated in the lower, shaded part of the bar, about 5 million of them flew on regional airlines. This chart illustrates further the skewed distribution of travelers with route density noted with reference to Table 12-5. Another chart which illustrates the medium density market is Figure 12-5, in which the numbers of travelers carried in 1972 is distributed by range classes.

In each of these charts, the characteristics of the medium density market in 1972 show the bulk of regional carrier customers travel less than 500 miles (0 and D). The scattered nature of routes is illustrated by the fact that the major portion of route travel densities is less than 350 per day.

These data were used in a preliminary screening exercise conducted within the medium density market definition and ground rules in the operations scenario. On any route the minimum traffic per day is the product of two round trips/day x seat capacity x the system planning or target load factor. This results in a minimum of 2 x 2 x 30 x 0.5 = 60 passengers per day per route for the 30 passenger aircraft. At eight round trips per day, the 30 seat vehicle carries 2 x 8 x 30 x 0.5 or 240 passengers per day per route at the maximum limit. Similar minimum/maximum travel limits are tabulated for aircraft as follows:

PASSENGERS-CARRIED DISTRIBUTED BY TRAVEL DENSITY CLASSES

MEDIUM DENSITY MARKET - 1972

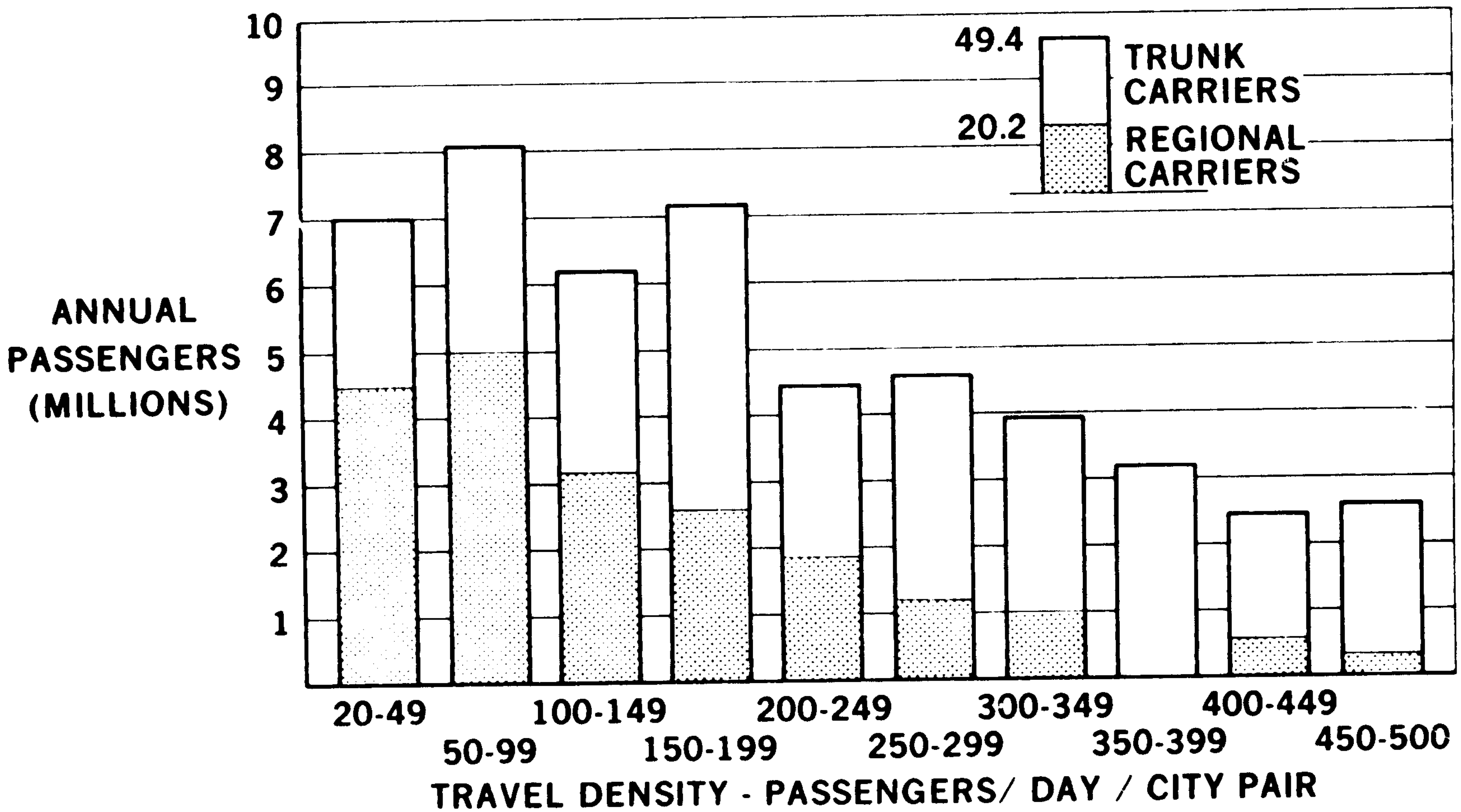


FIGURE 12-4

PASSENGERS-CARRIED DISTRIBUTED BY RANGE CLASS

1972 U.S. DOMESTIC MEDIUM DENSITY MARKET

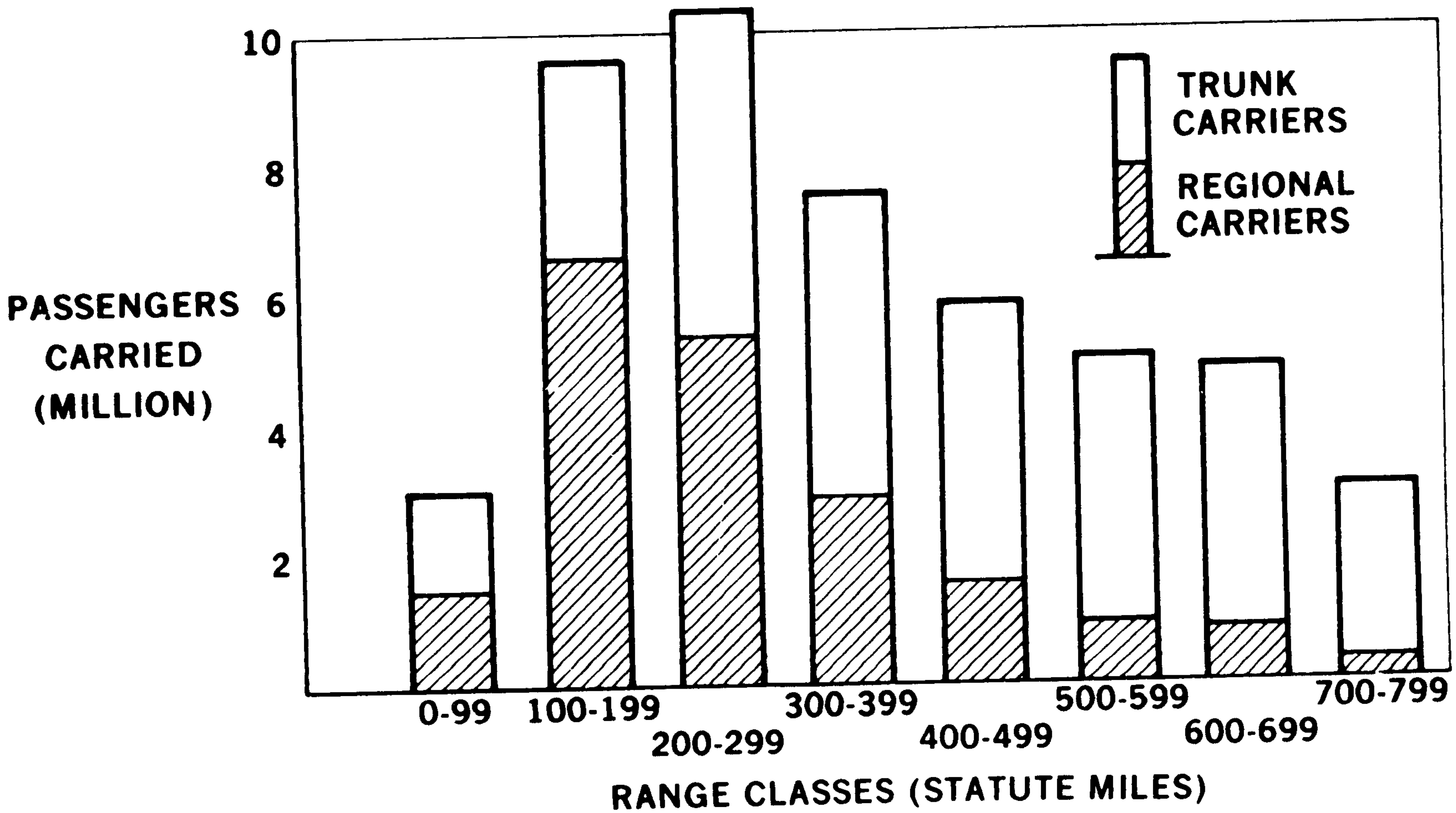


FIGURE 12-5

Seat Capacity	Travelers/Route/Day Minimum	Maximum
30	60	240
40	80	320
50	100	400
60	120	480
70	140	560

These numbers refer to two-way traffic flow equivalent to round-trip levels.

These aircraft capacity classes (travelers/route/per day) referred to in the preceding paragraph were applied to the CAB data to determine numbers of people potentially served by each size of aircraft. In the series of charts which follow, a block is shown on the data which is defined by the minimum and maximum capacity per day exhibited by each size of aircraft. For example, Table 12-6 shows that part of the 1972 market served by a 30 passenger aircraft. The lower limit of 60 passengers/route/day is in the 50-99 density class. The 240 upper limit is in the 200-249 density class. The range limit of 500 miles (804 km) was applied arbitrarily as including the bulk of regional carrier travelers. For convenience, all of the travelers were included in the limit classes, even though the class boundary may have been below or above the minimum or maximum defined capacity of the aircraft. A similar Table 12-7 indicates the market served by a 70 passenger aircraft. Although tables are not shown herein, the same procedure was used to delineate the market served by 40, 50, and 60 passenger aircraft.

These data were totaled for each of the aircraft sizes. A bar chart, Figure 12-6, reveals the potential market share each aircraft would serve if it were the exclusive carrier. The data are separated into both trunk and regional carriers.

Results of this preliminary screening process indicated that an upper

TABLE 12-6

1972 MEDIUM DENSITY MARKET SERVED BY 30-PASSENGER AIRCRAFT

THOUSANDS/YEAR

RANGE (ST MI)	DAILY PASSENGERS PER CITY-PAIR										TOTAL
	20-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	
(0-99)	500	448	471	312	0	94	354	132	157	344	2,812
(100-199)	1,287	1,608	1,143	1,387	1,385	709	463	819	158	696	9,655
(200-299)	1,306	1,576	932	1,530	1,172	1,371	1,055	689	323	343	10,297
(300-399)	1,002	1,166	1,234	816	661	1,083	828	261	319	172	7,542
(400-499)	810	926	821	1,109	541	473	238	417	454	179	5,968
(500-599)	852	829	280	755	485	505	359	142	632	339	5,178
(600-699)	645	890	787	942	86	201	357	564	307	167	4,946
(700-799)	608	603	495	317	81	201	242	137	0	340	3,024
TOTAL	7,010	8,046	6,163	7,168	4,410	4,637	3,897	3,161	2,350	2,580	49,422

NOTE: – 2 TO 8 DAILY ROUND TRIPS PER ROUTE
– 50 PERCENT LOAD FACTOR

TABLE 12-7

1972 MEDIUM DENSITY MARKET SERVED BY 70-PASSENGER AIRCRAFT

THOUSANDS/YEAR

RANGE (ST MI)	DAILY PASSENGERS PER CITY-PAIR										TOTAL
	20-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	
(0-99)	500	448	471	312	0	94	354	132	157	344	2,812
(100-199)	1,287	1,608	1,143	1,387	1,385	709	463	819	158	696	9,655
(200-299)	1,306	1,576	932	1,530	1,172	1,371	1,055	689	323	343	10,297
(300-399)	1,002	1,166	1,234	816	661	1,083	828	261	319	172	7,542
(400-499)	810	926	821	1,109	541	473	238	417	454	179	5,968
(500-599)	852	829	280	755	485	505	359	142	632	339	5,178
(600-699)	645	890	787	942	86	201	357	564	307	167	4,946
(700-799)	608	603	495	317	81	201	242	137	0	340	3,024
TOTAL	7,010	8,046	6,163	7,168	4,410	4,637	3,897	3,161	2,350	2,580	49,422

NOTE: – 2 TO 8 DAILY ROUND TRIPS PER ROUTE
- 50 PERCENT LOAD FACTOR

POTENTIAL MARKET SHARE SERVED BY CANDIDATE MEDIUM DENSITY AIRCRAFT

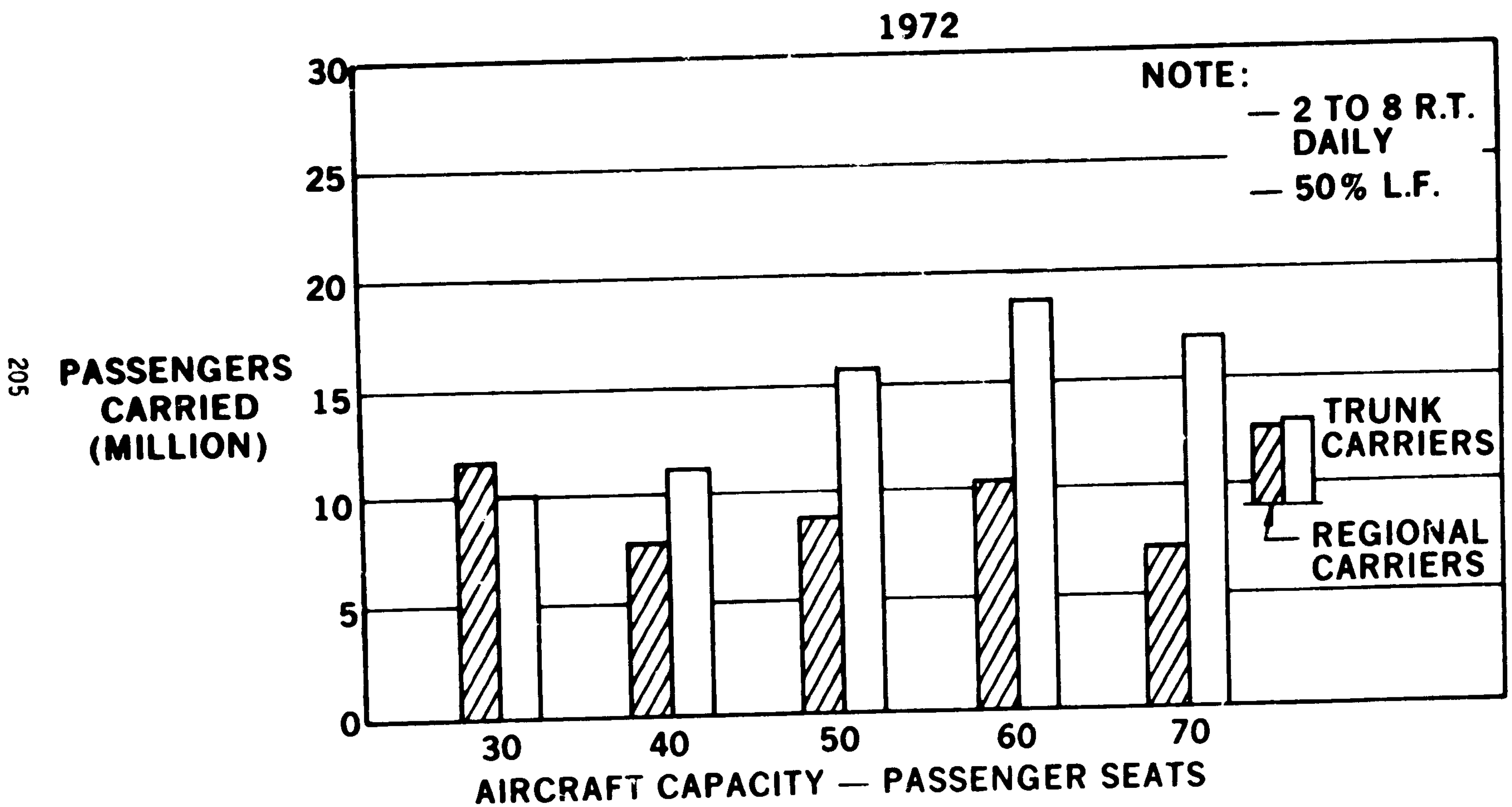


FIGURE 12-6

size limit of 70 passengers was appropriate for this medium density study. It also showed that within the medium density definition and operations scenario, no single size of aircraft appeared clearly superior.

12.1.1 Exclusion of CAB Data

The regional carrier statistics for 1972 were restricted in use by the application of medium density definitional limits. For example, regional carrier routes with greater than 500 round-trip passengers per day were excluded. Also, city-pair distances of more than 800 miles (1287 km) were omitted. Compared with 20,238,000 passengers included, a total of about 3,135,000 were excluded as being carried on higher density routes in the regional networks. There also were some 710,000 air travelers carried by regionals on routes over 800 miles in length. Table 12-8 shows those range classes and travel density classes which are in the regional CAB statistics but outside the bounds of the medium density definition.

12.2 Conceptual Aircraft - Operation Simulation Evaluation

The second approach to evaluation of the initial parametric conceptual aircraft involved the noncompetitive simulation described in Section 11.0. Some definitions are listed which apply to a series of tables following in which summary results of simulation are listed. These definitions are:

Field Length	-	Short	3,500 feet	(1,067 m)
	-	Medium	4,500 feet	(1,372 m)
	-	Long	5,500 feet	(1,676 m)
Design Range	-	Short	2 x 150 n. mi.	(2 x 278 km)
	-	Medium	2 x 250 n. mi.	(2 x 463 km)
	-	Long	2 x 350 n. mi.	(2 x 648 km)
	-	Extended	2 x 460 n. mi.	(2 x 852 km)

12.2.1 Evaluation in Initial Network

In the operational simulation each conceptual aircraft was tested in

TABLE 12-8

PASSENGERS CARRIED BY REGIONAL CARRIERS BUT EXCLUDED FROM MEDIUM DENSITY MARKET — 1972

THOUSANDS/YEAR

RANGE (ST MI)	DAILY PASSENGERS PER CITY-PAIR						TOTAL
	20 – 49	50 – 59	100 – 149	150 – 199	200 – 500	500 +	
0 – 99	20,238 IN MEDIUM DENSITY MARKET					312(1)	312 (1)
100 – 199						1602(4)	1602 (4)
200 – 299						1004(3)	1004 (3)
300 – 399						217(1)	217 (1)
800 +	257 (21)	175(7)	134(3)	144(2)	0	0	710(33)
TOTAL	257	175	134	144	0	3135	3845

SOURCE: – CAB ONLINE O&D STATISTICS
– EXCLUDES PSA, AIRCALIFORNIA AND TRANS TEXAS

NOTE: (CITY-PAIRS)

the initial network and mission model against the total traffic demand. Eight variations of the bypass ratio 6:1 turbofan powered aircraft were evaluated in the first set of simulations. Results were generated for each aircraft as performing in a fleet. Figure 12-7 presents the first of the evaluation results in terms of fleet revenue passenger miles generated for each of the eight conceptual aircraft. The total RPM demand in the mission model (15.568 billion) is shown as a horizontal line across the top of the chart. The height of each bar indicates the performance of each aircraft fleet. Only the extended range aircraft meets the total demand because its range is greater than the longest route in the model. For example, all aircraft with Medium Range capability were precluded from those routes of over 563 nautical miles (1043 kilometers). In the simulation, all aircraft trips were non-stop. No stops for refueling were permitted.

A baseline configuration was selected and shown by the shaded data bar in the center of Figure 12-7. Data on aircraft trips and miles flown in 1980 are shown in Figure 12-8. These data bars indicate that both trips and fleet miles flown are inversely proportional to range.

Another set of fleet performance data is shown in Figure 12-9. Fleet size is inversely proportional to size for the 30, 50 and 70 passenger aircraft with the same range capabilities. Annual fuel burned also is inversely proportional with passenger capacity, reflecting a smaller fleet with aircraft of increasing fuel efficiency.

A primary consideration in the evaluation of conceptual aircraft is the profitability of operations. Such profitability has been measured for each of the eight conceptual configurations. Profit is measured as the simple excess of operating income over operating cost. In Figure 12-10, this

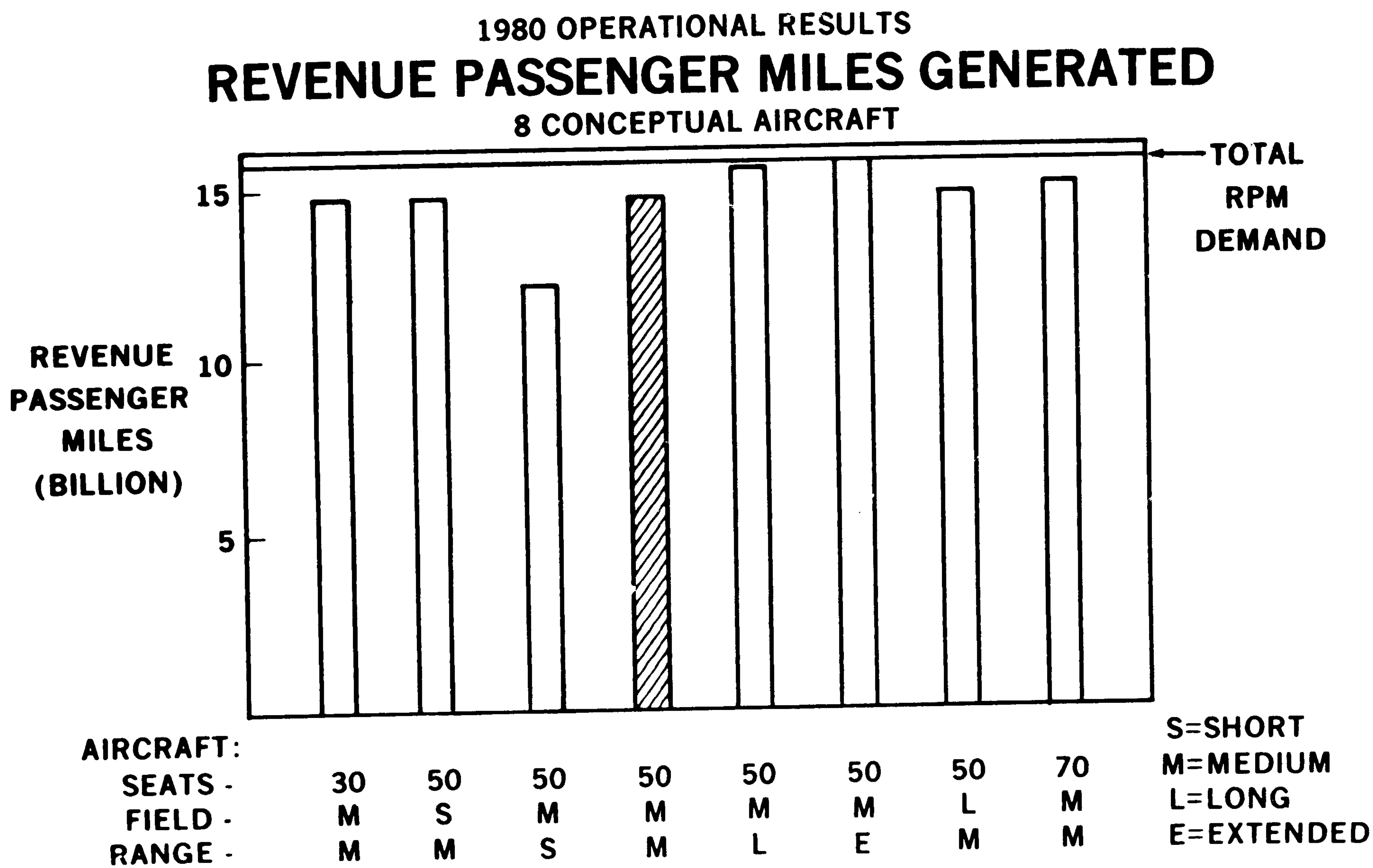

1980 OPERATIONAL RESULTS
REVENUE PASSENGER MILES GENERATED
8 CONCEPTUAL AIRCRAFT
TOTAL RPM DEMAND
REVENUE PASSENGER MILES (BILLION)
15
10
5
AIRCRAFT:
SEATS - 30 50 50 50 50 50 50 70
FIELD - M S M M M M L M
RANGE - M M S M L E M M
S=SHORT
M=MEDIUM
L=LONG
E=EXTENDED

FIGURE 12-7

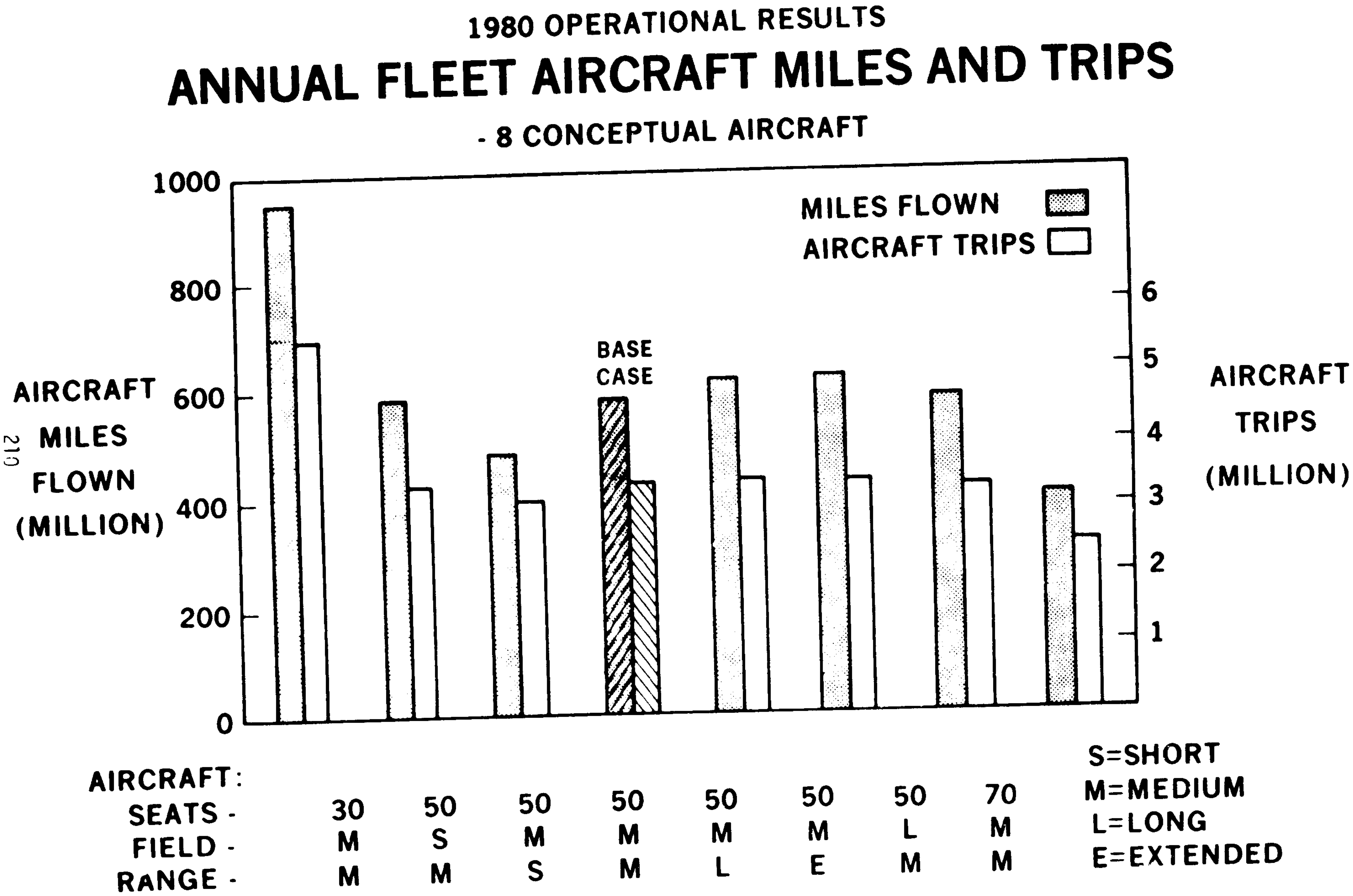

1980 OPERATIONAL RESULTS
ANNUAL FLEET AIRCRAFT MILES AND TRIPS
- 8 CONCEPTUAL AIRCRAFT
MILES FLOWN
AIRCRAFT TRIPS
BASE CASE
AIRCRAFT MILES FLOWN (MILLION)
AIRCRAFT TRIPS (MILLION)
1000
800
600
400
200
0
6
5
4
3
2
1
AIRCRAFT:
SEATS - 30 50 50 50 50 50 50 70
FIELD - M S M M M M L M
RANGE - M M S M L E M M
S=SHORT
M=MEDIUM
L=LONG
E=EXTENDED

FIGURE 12-8

1980 OPERATIONAL RESULTS

FLEET SIZE AND ANNUAL FUEL BURNED

8 CONCEPTUAL AIRCRAFT

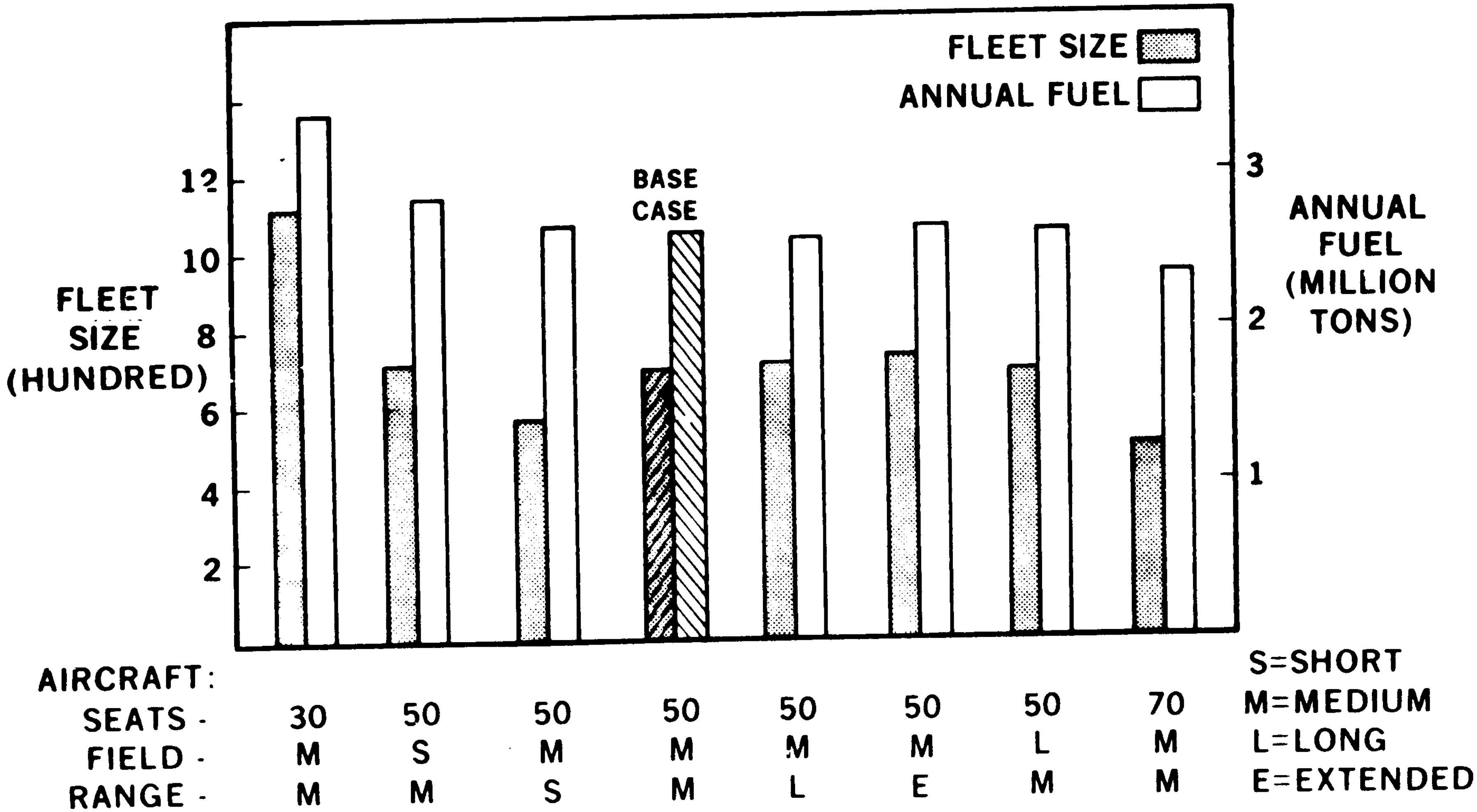


FIGURE 12-9

1980 OPERATIONAL RESULTS

RELATIVE FLEET INVESTMENT AND PROFITABILITY INDEX

-8 CONCEPTUAL FIXED PITCH FAN AIRCRAFT

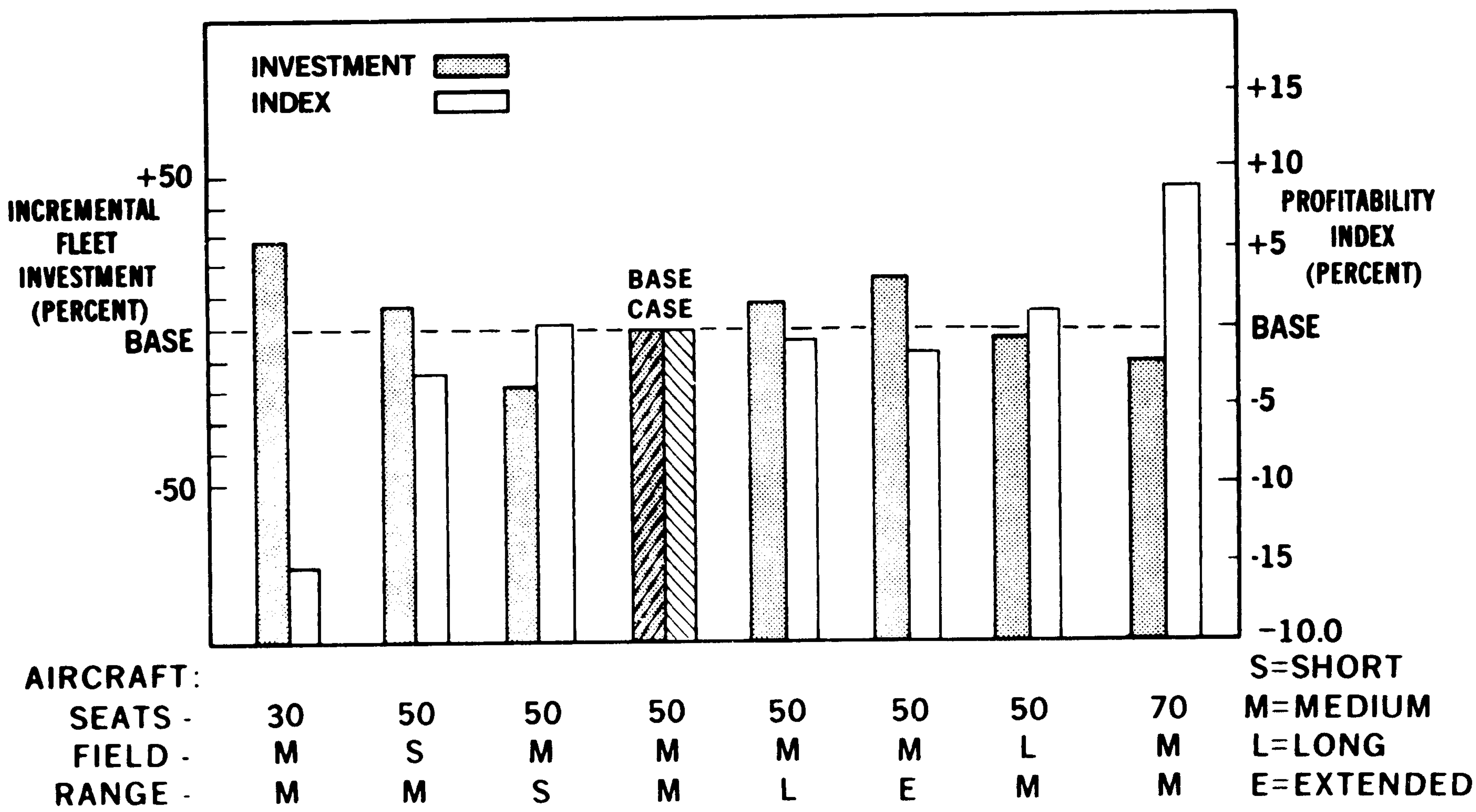


Figure 12-10

profit figure has been converted into an index of profitability (profit divided by fleet acquisition cost). The 50 passenger baseline aircraft generated a positive index. This value was chosen as a base for normalizing results of the other conceptual aircraft. Results of this are presented in the bar chart. Each case is separately discussed.

30 Passenger, Medium Range

Diseconomy of scale (high costs per seat) forced the fleet costs to be about 30 percent higher than the 50 passenger baseline aircraft. Higher operating costs resulted in negative profits. This the profitability index was about 15 percentage points below the base.

50 Passenger, Short Field, Medium Range

The cost of achieving short-field capability resulted in a higher gross weight, higher powered aircraft. The resultant higher operating costs caused the profitability index to be about three (3) percentage points below the baseline. Fleet cost was also about five (5) percent greater than the base.

50 Passenger, Medium Field, Short Range

Profitability versus investment results appeared to favor this configuration compared with the base case aircraft. However, Figure 12-7 shows this aircraft to supply only about 12 of the 15.6 billion RPM in the mission model. This represented only about 77.6 percent of the demand. The data on profitability were, therefore, biased and not considered as truly attractive.

50 Passenger, Medium Field, Long Range

Although this configuration was slightly better in terms of RPM generated, the greater cost of the aircraft and higher operating costs reduced the relative profitability to about 0.5 percentage points lower than the base.

50 Passenger, Medium Field, Extended Range

This version generated the most RPMs and satisfied the entire demand. However, the increased passenger revenue was offset by the cost of achieving the extended range. The profitability was actually slightly negative and was about two (2) percentage points below the base case.

50 Passenger, Long Field, Medium Range

Reduced requirements for takeoff and landing resulted in a lower gross weight, less expensive aircraft. Thus, the fleet cost is below base and profitability is higher as shown.

70 Passenger, Medium Field, Medium Range

At the opposite end of the size/economy scale from the 30 passenger aircraft, the 70 passenger version appeared the most attractive from the criteria of cost and profit.

Supporting data for aircraft characteristics and fleet simulation results appear in Appendix B. Data for all of the above aircraft are tabulated therein. See Section B.4, Tables B-9 through B-12, Appendix B (Volume III).

12.2.2 Evaluation in Selected Regional Airline Networks

A selective approach was made to evaluate the 30, 50, 60 and 70 passenger aircraft in an actual airline network. A 1972 Frontier Airlines network was used. This special mission model permitted detailed examination of aircraft performance on each route. The network consisted of 343 routes or airport pair linkages. These routes were served by Beech 99 and Twin Otter, Convair 580, and Boeing 737 aircraft. Demand was expressed as a function of statistical system load factor, equipment capacity, and frequency of flight service. Each route is described in the following terminology: Route between two named airports; Range distance in statute miles; RPM demanded each day; Minimum trips equivalent to actual schedule for route in August 1972; Seats scheduled and demanded; Fare charged for the route; Total potential revenue for all the RPM's demanded; and IOC as a function of revenue (58 percent).

Each aircraft had the following data input or computed for each route: Seats provided per flight; Load factor (desired and actual); Block time in hours; Cost per trip in dollars (DOC); Number of trips required to satisfy demand for RPM; and Daily utilization times. The simulation load factor was input at 0.50.

Operational economics output includes the following: Actual revenue generated; Total operating cost (IOC + DOC); and Operating Income, positive or negative (Revenue less cost).

Results of the operational simulation in this special mission model are summarized in Table 12-9, "Conceptual Fleet Data 1980 Actual Airline Network". Note that the 50 passenger aircraft is chosen as a base case for Fleet Price and Relative Return on Fleet Price. As in all other cases in this report, the return is a simple ratio (Revenue less Operating Costs divided by Fleet Price). The relative price and return percentages are differences between each case and the base case. In the Frontier network, there were two sets of airport pairs in which the distance exceeded the range capability of the conceptual aircraft. This reduced the route segments to 33[illegible] as noted in Table 12-9. Note that each fleet size results from a non-competitive simulation. For example, if the 30 passenger aircraft were the only aircraft used, the fleet size was 118.

TABLE 12-9

CONCEPTUAL FLEET DATA
1980 ACTUAL AIRLINE NETWORK

(339 ROUTE SEGMENTS)

NONCOMPETITIVE ANALYSIS

AIRCRAFT CAPACITY (SEATS)	REVENUE PASSENGER MILES (BILLION)	AIRCRAFT MILES FLOWN (MILLION)	FLEET SIZE	ANNUAL FUEL (MILLION TONS)	RELATIVE FLEET PRICE	RELATIVE RETURN ON FLEET PRICE
30	1.576	105.2	118	0.366	+30%	-15.0%
50	1.576	63.7	70	0.284	BASE	BASE
60	1.576	53.3	59	0.283	-3%	+3.2%
70	1.576	45.8	50	0.251	-12%	+8.8%

NOTE: ~ BASE CASE IS 50 SEAT/4500' FL/2x250 N.MI. RANGE

Table 12-10, "1980 Conceptual Aircraft Evaluation", contains details on sets of routes as flown by the different sizes of aircraft from the 1972 schedule. For this analysis, the performance of the 50 passenger medium density baseline aircraft on the Convair 580 routes was used as a base for comparison. The 30 passenger aircraft was unprofitable in all of the route classes. The 60 and 70 seat aircraft were relatively profitable on the Convair and B737 routes All aircraft were unprofitable on the low density routes served by the B99 and Twin Otter. The reason for this is found in the requirement to provide as a minimum the same flight frequency provided in the 1972 schedule. The 1980 demand level was not sufficient on these specific low density routes to generate either a 50 percent load factor or operating profits for any of the conceptual aircraft.

12.3 Conceptual Aircraft - Preliminary Competitive Evaluation

A special simulation exercise was conducted on the Frontier network. An inventory of conceptual aircraft was input. This consisted of aircraft with 30, 50, 55, 60, 65 and 70 seats. Each had the same design range and field length capability. Hence, the competitive simulation was to evaluate the requirements for a mixed fleet of size variation only.

The simulation was conducted for a period 1980 through 1990. A 1972 schedule of 200,700 trips on 343 routes was held as the minimum service. Because of a range limitation, as in the preceding section, the routes actually served were 339. Demand in RPM per year was as follows for three selected years, also shown as revenue passenger kilometers (RPKM)

Year	RPM in Millions	(RPKM)
1980	1,899	(3,055)
1985	2,423	(3,899)
1990	3,034	(4,882)

TABLE 12-10

1980 CONCEPTUAL AIRCRAFT EVALUATION

AVERAGE DAILY ROUTE OPERATIONS ON AN ACTUAL AIRLINE NETWORK

CURRENT EQUIPMENT TYPE	NUMBER OF ROUTE SEGMENTS SERVED	CONCEPTUAL AIRCRAFT											
		30 SEATS			50 SEATS *			60 SEATS			70 SEATS		
		TRIPS PER DAY	LOAD FACTOR	REL. PROF	TRIPS PER DAY	LOAD FACTOR	REL. PROF	TRIPS PER DAY	LOAD FACTOR	REL. PROF	TRIPS PER DAY	LOAD FACTOR	REL. PROF
BEECH 99 TWIN OTTER	34	1.18	0.42	-0.11	1.18	0.25	-0.18	1.18	0.21	-0.22	1.18	0.18	-0.24
CONVAIR 580	253	4.39	0.50	-3.16	2.63	0.50	BASE	2.20	0.50	1.67	1.88	0.50	2.65
BOEING 737	52	9.0	0.50	-3.78	5.40	0.50	-0.27	4.50	0.50	0.31	3.86	0.50	1.13
TOTAL FLEET	339	4.78	0.49	-13.20	2.91	0.49	BASE	2.45	0.49	3.30	2.11	0.49	6.64

NOTE:

* 4500' FL 2 - 250 N MI STAGES RANGE CAPABILITY
BASE CASE PRODUCED A PROFIT

In the simulation process, an aircraft was selected from the available inventory. It was chosen on each route to satisfy the minimum number of trips at the input load factor of 50 percent and at the least cost of serving the demand expressed in revenue passenger miles (RPM) per day. Total fleet size was determined by annual RPM divided by aircraft capability per year. In some cases, the minimum frequency restraint resulted in payload factors of less than the desired level of 50 percent. Also, the operating cost exceeded the passenger revenue, and losses were generated by the selected aircraft on some routes.

Results of fleet selection are shown in Table 12-11. Although six aircraft were available to be selected, only three were chosen. The 30, 50 and 70 seat aircraft were selected in the simulation. Results for each are presented in Tables 12-12, 12-13 and 12-14. Note that only two of the 30 seat aircraft were appropriate in the first half of the period. In mid-period (1986), a 50 seat aircraft replaced the 30 passenger version. It lost money even with only two aircraft serving the few routes on which it was the least-cost solution. The 70 passenger aircraft, however, was indicated on the bulk of the routes as a profitable aircraft. It satisfied all of the available market in terms of RPM data from 1980 through 1990 on those routes within the range capability of the aircraft.

The 1972 service level was a minimum of 207,000 trips per year. The mixed fleet from 1980 to 1990 generated 262,000 trips in 1980 and 410,000 trips in 1990. In general, this was indicative of good service provided on all routes in the network.

The Profitability Index is the percent ratio of operating income to the cost of the fleet of aircraft (unit price x number of aircraft). The

Table 12-11

COMPETITIVE SIMULATION RESULTS

SELECTED REGIONAL AIRLINE

	AIRCRAFT REQUIRED		
	30-SEAT	50-SEAT	70-SEAT
o FLEET MIX			
1980	2	--	48
1985	2	--	61
1990	--	2	77
o RATIO OF OPERATING INCOME TO COST OF FLEET*			
1980	-14%	--	11%
1985	-9%	--	11%
1990	--	-1%	11%

*EXCLUSIVE OF SPARES AND SUPPORT EQUIPMENT

TABLE 12-12

SELECTED DATA 1980 - 1990

FRONTIER AIRLINES COMPETITIVE SIMULATION

30 PASSENGER AIRCRAFT

YEAR	RPM ACTUAL (BILLION)	ANNUAL TRIPS (MILLION)	FLEET SIZE	ANNUAL FUEL (MILLION)	RETURN ON FLEET INVEST. %
1980	.016	.015	2	.005	- 14.18
1	.017	.015	2	.005	- 12.56
2	.018	.015	2	.005	- 10.86
3	.019	.015	2	.005	- 9.53
4	.020	.015	2	.006	- 8.84
1985	.021	.016	2	.006	- 8.84
6	.009	.007	1	.003	- 8.55
7	.001	.001	1	.001	- 4.48
8	-	-	-	-	-
9					
1990					

TABLE 12-13

SELECTED DATA 1980 - 1994

FRONTIER AIRLINES COMPETITIVE SIMULATION

50 PASSENGER AIRCRAFT

YEAR	RPM ACTUAL (BILLION)	ANNUAL TRIPS (MILLION)	FLEET SIZE	ANNUAL FUEL (MILLION)	RETURN ON FLEET INVEST. %
1980					
1					
2					
3					
4					
1985	-	-	-	-	-
6	.013	.008	1	.004	- 7.03
7	.022	.014	2	.007	- 6.24
8	.024	.015	2	.007	- 4.34
9	.025	.015	2	.007	- 2.85
1990	.026	.015	2	.007	- 1.29

TABLE 12-14

SELECTED DATA 1980 - 1990

FRONTIER AIRLINES COMPETITIVE SIMULATION

70 PASSENGER AIRCRAFT

YEAR	RPM ACTUAL (BILLION)	ANNUAL TRIPS (MILLION)	FLEET SIZE	ANNUAL FUEL (MILLION)	RETURN ON FLEET INVEST. %
1980	1.560	.247	48	.242	11.25
1	1.638	.259	51	.254	11.25
2	1.720	.272	53	.267	11.25
3	1.806	.286	56	.280	11.25
4	1.896	.300	58	.294	11.25
1985	1.991	.315	61	.309	11.25
6	2.090	.331	64	.324	11.25
7	2.195	.347	68	.341	11.25
8	2.305	.365	71	.358	11.25
9	2.347	.379	74	.372	11.25
1990	2.493	.395	77	.387	11.25

fleet size is computed with a 50 percent aircraft system load factor. Number of trips per day on each route varied from an average of 2.1 in 1980 to a system average of 3.3 in 1990. The spread of trips per day per airport-pair route (one-way) was one per day to an average of nine per day on the most heavily traveled route. Since the total of 339 airport-pairs is bi-directional, round trips per link are the same. These data are considered to be representative of the limits for the medium density market.

12.4 Turbofan versus Turboprop

A turboprop version of the 50 seat aircraft was designed with a wing aspect ratio of 10.5. This aircraft was evaluated in the operational simulation model to compare it with the 50 seat turbofan configuration. Pertinent data for each aircraft are listed in Table 12-15.

Each of these aircraft was designed for 4,500 foot (1,372 m) field and 2 x 250 nautical mile (2 x 463 km) stage lengths for design range. The price of each was computed at 400 units of production. Results of the operational simulation for the year 1980 are shown in Table 12-16.

General comparison of results shows the turboprop to be a superior aircraft with respect to costs. This is dependent upon turboprop engine costs being lower than turbofan. Some comments have been expressed by airline representatives that turboprop costs on existing engines are higher than the levels used in this study. If this were true, then a different comparison would be in order.

From the operational view, airline consultants and observers of the study have expressed a preference for all-jet operations. Turboprops are stated to be lacking in desirability in terms of customer appeal an [illegible]

Table 12-15

SIMULATION CHARACTERISTICS OF
TURBOFAN AND TURBOPROP AIRCRAFT

	Turbofan	Turboprop
Takeoff Weight (lb) (kg)	43,920 (19,922)	43,840 (19,886)
Airframe Weight (lb) (kg)	22,980 (10,424)	25,390 (11,517)
Takeoff Power/Engine	7,980 (lb T) (35,500 n)	4,230 (eshp)
Total Cost/Unit ($ Millions)	3.1	2.7
Engine Cost (2) ($ Millions)	0.631	0.374
Trip Cost at Full Range ($)	692.10	671.71
DOC at Full Range (Cents/Seat N.Mi)	2.46	2.40
Block Time at Full Range (hr)	1.71	1.81
Cruise Mach Number	0.685	0.64
Target Load Factor	0.50	0.50

Table 12-16

TURBOFAN VERSUS TURBOPROP
IN 1980 OPERATIONAL SIMULATION

	Turbofan	Turboprop
Fleet Size (noncompetitive)	656	686
Fleet Cost ($ Million)	2050.6	1850.[illegible]
RPM (Billion) (RPKm)	14.7 (23.65)	14.7 (23.65)
Net Operating Income (NOI)* ($ Million)	31.8	64.7
Trips (Million)	3.414	3.414
Fuel Burned (Million Tons) (Metric)	2.66 (2.41)	2.28 (2.07)
NOI/Fleet Cost	1.6	3.5
DOC ($ Million)	846.4	813.4
IOC ($ Million)	1212.7	121[illegible].7

* Revenue less DOC and IOC

quality and in slower speed than the turbofan aircraft.

12.5 Segmented Market Simulation

The initial mission model was divided into four discrete segments according to density of travel - passengers per day per route. These segments were defined by the type or seat capacity of equipment scheduled in the 1972 network. The division was:

Low	15 to 26 Seats
Low and Medium	15 to 60 seats
Medium and High	40 to 112 seats
High	74 to 112 seats

Conceptual aircraft evaluated and the demand in each division of the market are tabulated for 1980 in the following:

30 Passenger	Minimum Trips (Millions)	RPM Demand (Billions)	(RPKm)
Low	.127	.130	(.209)
Low and Medium	1.032	3.998	(6.438)
Medium and High	1.589	15.431	(24.828)
50 and 70 Passenger			
Low and Medium	1.032	3.998	(6.438)
Medium and High	1.589	15.431	(24.828)
High	.684	11.563	(18.604)

The aircraft simulation in each of these market segments generated results which are presented in a series of charts which follow. Figure 12-11 shows the relative scale of the demand in each of the market segments. The very low demand level in the low density segment is especially evident. The

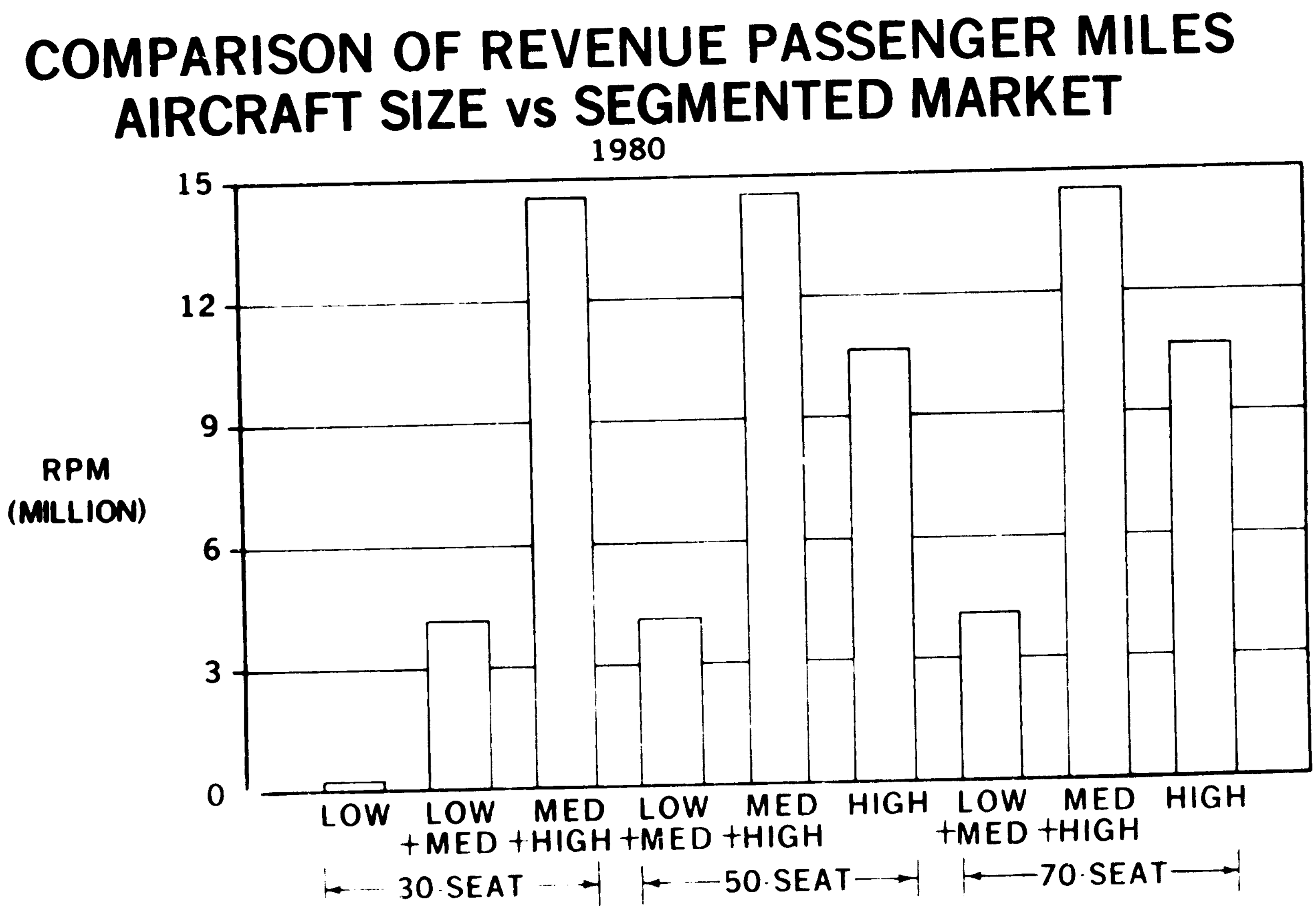

COMPARISON OF REVENUE PASSENGER MILES
AIRCRAFT SIZE vs SEGMENTED MARKET
1980
RPM
(MILLION)
15
12
9
6
3
0
LOW
LOW +MED
MED +HIGH
LOW +MED
MED +HIGH
HIGH
LOW +MED
MED +HIGH
HIGH
30-SEAT
50-SEAT
70-SEAT

Figure 12-11

bulk of demand exists on those routes served by the 40 to 60 seat aircraft in 1972.

Figure 12-12 presents a comparison of the minimum trips required, according to the assumption of service frequencies not less than in 1972, and the trips generated in 1980 by each of the three conceptual aircraft.

Another evidence of the distribution of traffic in this segmented market is shown in Figure 12-13, "Distribution of Airport Pairs - Market Segments". Note again the small portion of the market classified as low density traffic.

Fleet sizes generated for each segment of the market are listed in Table 12-17. Each of these numbers is the resultant of one size of aircraft meeting all of the demand. In the low density segment, only 16 aircraft of 30 passenger capacity are required.

The suitability of each of these aircraft is measured by relative profitability of fleet operations. This is illustrated in Figure 12-14. The relatively high operational cost of the 30 passenger aircraft is graphically illustrated by the negative profitability. These data are absolute and not normalized or compared to a 50 passenger base, as in previous analyses of conceptual aircraft. Thus, the negative relative profitability of about 13 percent on the low end of the density spectrum is based on cost and revenue estimates pertinent to the aircraft and fare structure used.

A slightly more detailed view of the segmented market is presented in Table 12-18. Each of the market segment combinations is shown as well as the medium which has not been isolated in prior tables or figures. Average trips per day per route reflect service levels which are within the medium

1980 FORECASTED vs 1972 SCHEDULED TRIPS
(30-, 50-, AND 70-PASSENGER AIRCRAFT)

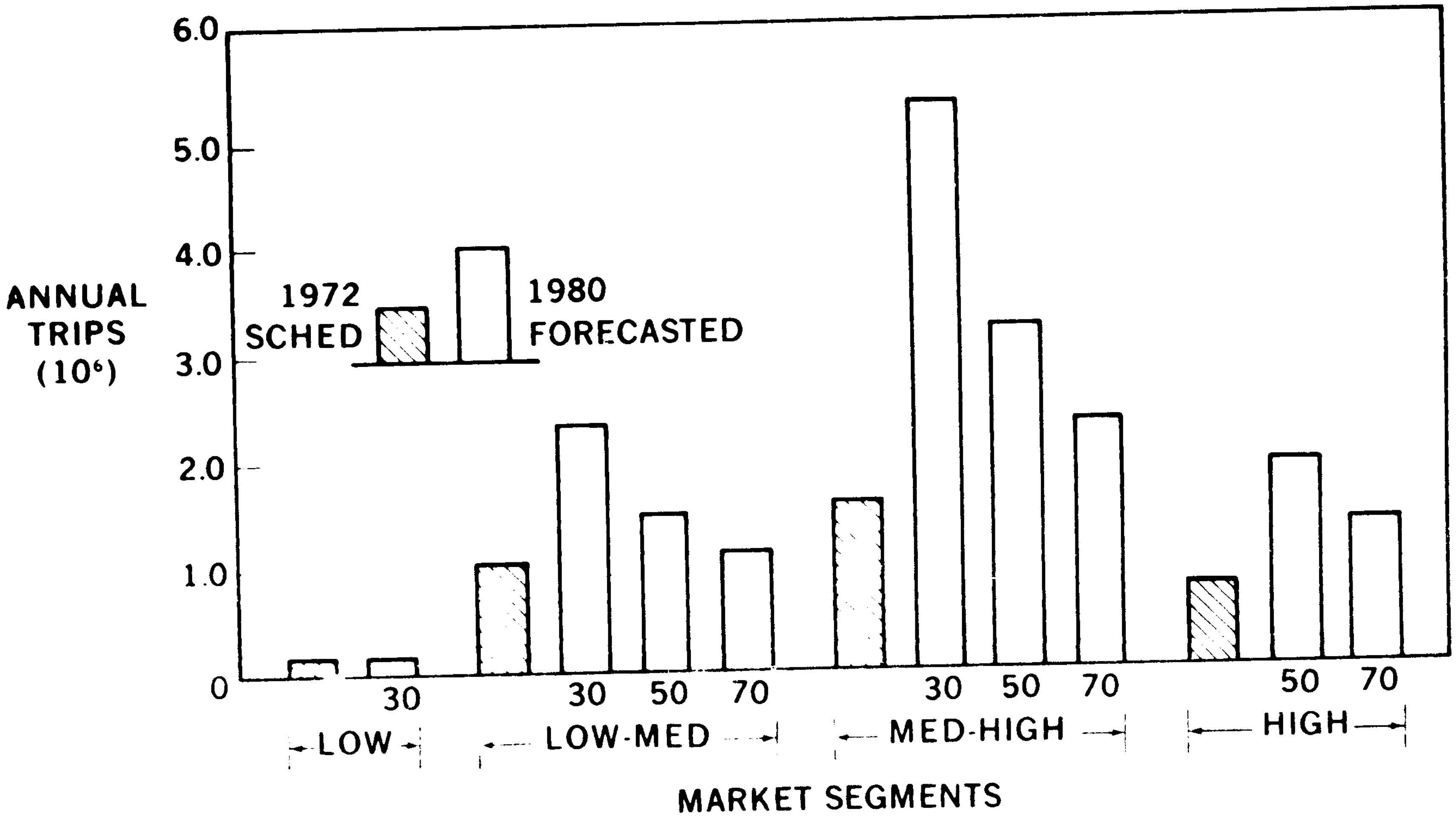


Figure 12-12

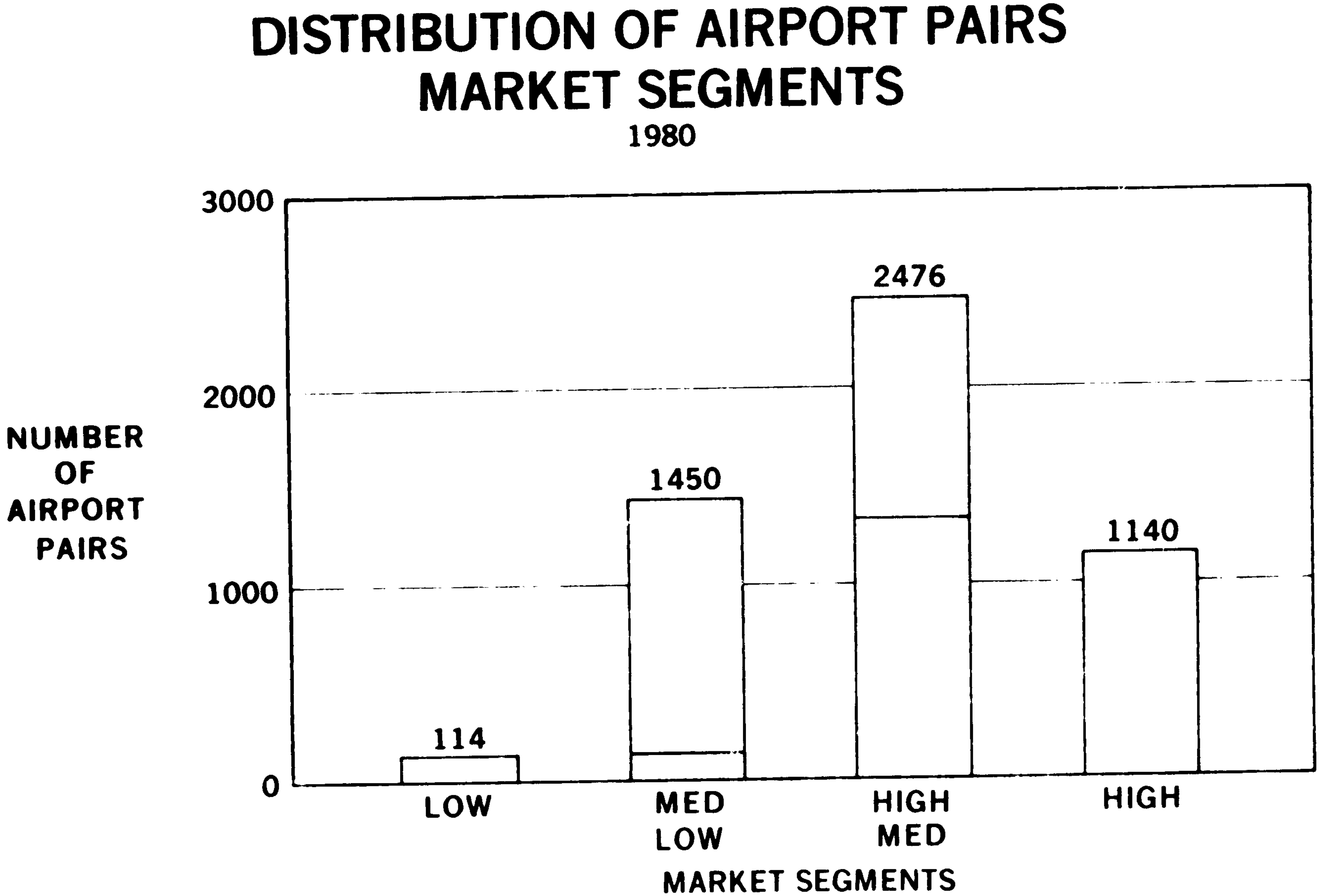

DISTRIBUTION OF AIRPORT PAIRS
MARKET SEGMENTS
1980
NUMBER OF AIRPORT PAIRS
3000
2000
1000
0
114
1450
2476
1140
LOW
MED LOW
HIGH MED
HIGH
MARKET SEGMENTS

Figure 12-13

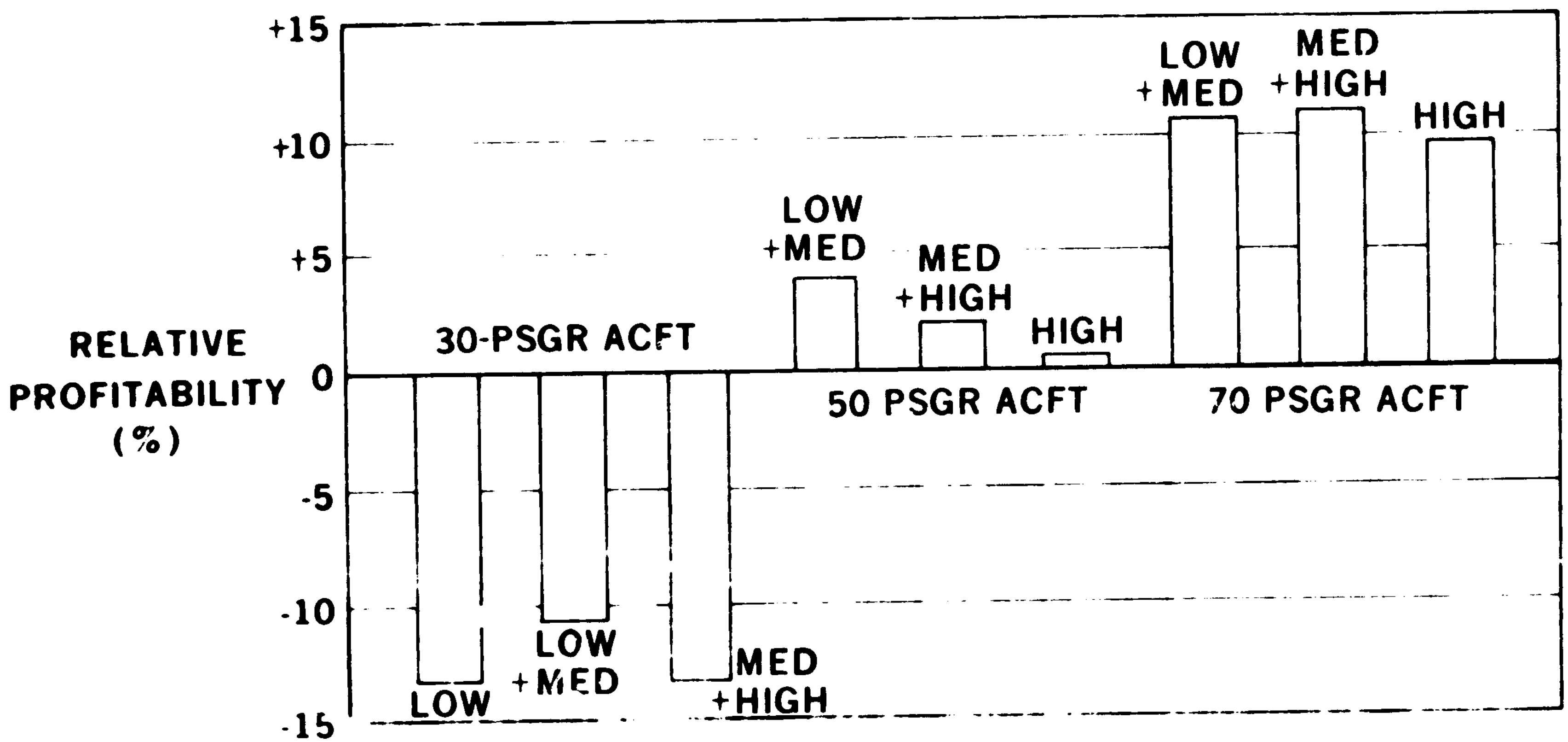
Table 12-17

FLEET SIZES REQUIRED 1980
SEGMENTED MARKET

SEATING CAPACITY	30	50	70
MARKET SEGMENT	(FLEET SIZE)		
LOW	16	-	-
LOW MEDIUM	360	218	176
MEDIUM HIGH	1090	641	459
HIGH	-	438	311

NOTE: 1. NON-COMPETITIVE ANALYSIS
2. LOAD FACTOR 50%

COMPARISON OF RELATIVE PROFITABILITY*
AIRCRAFT SIZE vs SEGMENTED MARKET
1980



*EXCLUDES AIRCRAFT SPARES

Figure 12-14

Table 12-18

TRIPS/DAY AND NET INCOME

SEGMENTED MARKET 1980

	MARKET SEGMENTS					TOTAL SYSTEM MARKET
	LOW	MED	LOW & MED	HIGH	MED & HIGH	
AVERAGE TRIPS/DAY PER ROUTE						
30-SEAT	3.15	4.66	4.54	7.68	6.05	5.92
50-SEAT	3.05	2.80	2.82	4.62	3.64	3.61
70 SEAT	3.05	2.05	2.13	3.30	2.62	2.64
NET $ INCOME TRIP						
30-SEAT	-39.00	-38.80	-38.82	-83.50	-64.90	-64.20
50-SEAT	-56.60	24.20	17.33	3.12	11.85	9.34
70-SEAT	-79.50	76.45	59.00	84.50	81.80	73.00

density definition. In the low and medium density segments, the 50 and 70 seat aircraft results were extrapolated beyond the original simulation. The results illustrate the ground rule of assuming service frequencies at least equal to the 1972 base. They also illustrate the economic penalties associated with use of larger aircraft on low demand routes. If aircraft were to be assigned in this market to provide both service and best profit overall, the 30 seat vehicle would be assigned to the low and the 70 seat aircraft to the medium and high density segments.

Some specific data were assembled from the low-density segment analysis with the 30 passenger aircraft. Simulation characteristics were as follows:

- 30 passenger aircraft at a price of $2,409,000.
- 114 airport-pair routes.
- 130 million RPM demand in 1980.
- 127,400 aircraft trips required as a minimum.
- Class 7 (CAB) fare of $12.56 plus $ .0706 x passenger miles flown.
- Overall system load factor of 50 percent.

Simulation results were as follows:

- Fleet size was 16.
- All of the 130 million RPM were achieved.
- 1980 aircraft trips were 131,000.
- Each aircraft averaged 2,600 hours per year utilization.
- A system load factor of .432 or 43.2 percent was achieved.
- The aircraft fleet burned about 44,000 tons of jet fuel.
- The average stage length of 77 statute miles was flown at a block speed of 244 mph.

These data were supplementary to the negative profitability shown in Figure 12-14 and Table 12-18.

12.6 Summary of Fleet Operational Characteristics

A series of conceptual aircraft were evaluated with the initial airline network and mission model parametric excursions. With the exception of one special simulation on a specific airline network, all of the operational simulation exercises were conducted with the full initial network and mission model. The general characteristics of the conceptual aircraft have been derived in detail for the 30, 50 and 70 seat configurations. A range of about 563 miles or 2 x 250 nautical miles stage length capability (1043 kilometers) was the basic design range for these aircraft. Fleet statistics for three aircraft with this design range are reproduced in Table 12-19, "Summary of Conceptual Aircraft Characteristics", and Table 12-20, "Conceptual Fleet Characteristics - 1980".

There are some interesting data to be extracted from this table, for example, annual trips generated by a fleet of 30 seat aircraft would be more than three times as large in 1980 as in 1972. From the passenger point of view, this represents much better service. However, for the airline/airport operators, this kind of traffic increase would create many enroute and terminal air traffic control problems. The 50 seat aircraft would double in frequency of service and the 70 seat aircraft would increase by about one-half. In terms of fuel efficiency, the larger aircraft had a decided advantage. It also generated the best profitability. Judgment on fleet size is not possible except in a relative sense, since this analysis was conducted only to evaluate characteristics of several conceptual configurations. Such judgment is reserved for an analysis based on competition with existing and near-term candidate aircraft.

Table 12-19

SUMMARY OF CONCEPTUAL AIRCRAFT CHARACTERISTICS
(4500 Ft. Field/2 x 250 N.Mi. Stages)

	Aircraft Seating Capacity		
	30	50	70
Takeoff Gross Weight (lb) (kg)	32,080 (14,550)	43,920 (19,920)	56,730 (25,730)
Single Stage Range (N.Mi) (km)	566 (1048)	563 (1043)	562 (1041)
Cruise Mach Number	0.650	0.685	0.700
Number of Engines	2	2	2
Takeoff Thrust (lb/eng) (Newtons)	5,830 (25,930)	7,980 (35,500)	10,310 (45,860)
Block Time at Design Range (hr)	1.8	1.7	1.7
Unit Price ($ Million)*	2,409	3,125	3,847
Direct Operating Costs:			
Dollars/Flight	628.83	692.10	770.93
Dollars/N.Mi.	1.11	1.23	1.37
Dollars/Seat N.Mi.	0.037	0.025	0.020

* Preliminary cost estimates used for initial operational simulation in 1974 dollars.

Table 12-20

CONCEPTUAL FLEET CHARACTERISTICS

(4500 Ft. F.L./2 x 250 N.Mi. Range)

1980

Fleet Characteristics	Aircraft Seats 30	50	70
Fleet Size	1,109	656	475
Annual Trips (Millions)	5.600	3.414	2.5[illegible]
Ratio to 1972 Schedule	3.26	1.99	1.4[illegible]
Revenue Passenger Miles Flown (Billions)	14.658	14.697	14.6[illegible]7
Revenue ($ Millions)	2,087	2,090	[illegible]
Fleet Operating Costs: ($ Millions)	2,446	2,059	[illegible]
Direct	1,236	846	[illegible]
Indirect	1,210	1,213	1,213
Net Operating Income ($ Millions)	- 359	31	[illegible]
Fleet Investment Cost ($ Millions)	2,672	2,050	[illegible]
Return on Fleet Investment (%)	-13.5	1.6	[illegible]
Annual Fuel Consumption (Million Tons)	3.414	2.656	[illegible]
Fleet Size Projected to 1990	1,730	[illegible]	744

13.0 DERIVATION OF AIRCRAFT ECONOMIC CHARACTERISTICS

The operational viability of any aircraft is strongly influenced by economic characteristics such as the acquisition cost (price) to the airline and the operating costs in airline service. All aircraft costs in this study have been estimated with techniques developed by the Douglas Aircraft Company. These techniques are mathematical and programmed for computer operations. The initial costing for the first conceptual aircraft has been described in Section 3.1. These cost estimates were used in all of the initial operational simulation and parametric variations for the conceptual aircraft. For all subsequent economic evaluations and simulation on the basepoint aircraft the CAPDEC program was used. The direct operating costs (DOC) computations were accomplished with a Douglas developed routine and used throughout all phases of the study.

Indirect operating costs (IOC) are not dependent upon aircraft characteristics. These costs were estimated as a fraction of passenger revenue. The appropriate number was suggested by North Central Airlines at 58 percent of revenue. This number was supported with statistics from the airline. A sensitivity study is reported in Section 16.3.6.

13.1 Airline Direct Operating Cost Estimates

The basic format for computing direct operating costs for the candidate aircraft is patterned after a method originally developed by the Air Transport Association. The formulae were derived empirically and updated periodically to reflect a growing body of data as more aircraft were introduced into the commercial fleet. The latest version reflects a 1967 level of aircraft technology and inflated dollar levels. Since 1967, various aircraft manufacturers have amassed detailed information on their own, as well as competitive aircraft. Each airline reports certain cost categories and expenses to the Civil Aeronautics Board. These are collected and published as CAB Form 41 reports. Pertinent of these are Schedule P-5.1, Aircraft Operating Expenses - Group I Carriers and Schedule P-5.2, Aircraft Operating Expenses - Group II, and Group III Air Carriers. Since January 1973 the Trunk and Regional Carriers are Group III. Data from these schedules are collected and published annually in the CAB "Red Book, Aircraft Operating Cost and Performance Report". The July 1973 edition contains data on turbine-powered aircraft for the years ending December 31, 1971 and 1972 (Reference 15).

While the "Red Book" is a good source of general data, the CAB cautions the reader against drawing conclusions of comparative aircraft performance. The figures are average, general, and do not include all of the variations in operating conditions among the reporting carriers.

In utilization of various data on commercial aircraft operations, DOC computed by the 1967 ATA method will not agree with data in the "Red Book". Various reasons prevail. Among these are labor and material cost inflation factors which are not uniform among carriers. Some variations in reporting procedures are allowed by the CAB which influence aggregate statistics. Operating conditions vary among carriers as well as financial management practices. These differences also influence the level of DOC for specific type aircraft.

A section of Page VII of the July CAB "Red Book" is quoted to illustrate the various points above.

"The expense data presented in the report are limited solely to aircraft operating expenses or what are frequently referred to as direct aircraft operating costs (DOCs) and indirect operating costs (IOCs). Indirect operating expenses because of their very nature are not reported to the CAB by aircraft type and thus are not considered in this report."

"Users are cautioned against drawing conclusions without qualification regarding the merits of a particular aircraft based on the unit costs data presented in this report. Different carriers may use the same type of equipment under quite different operating conditions. In other instances, the data presented is based on limited fleet size and operating experience. Performance and operating data such as average fleet size, average stage length, average speed, daily utilization, average seating configuration, etc., have been included in the report as an aid in evaluating the unit cost data. Nevertheless, all pertinent information regarding the operations of an aircraft could not be included and thus users should exercise care before making comparisons."

"In a few instances, certain of the cost elements making up total aircraft operating expense appear as negative figures in the report. Generally these negative figures result from out-of-period adjustments. Also, in some instances the component cost elements may not add exactly to the total due to rounding."

"On occasion, the aircraft cost and performance data for an equipment group and carrier group may show a pronounced variation between each of the two years presented in the report. Generally when such a pronounced variation occurs, it is due to the fact that the group total for each of the years includes a different mix of individual equipment types and different mix of individual carriers."

With this in mind, Douglas has kept operating data on its own product lines. These data are provided from field operations by the air carriers flying DC-8, DC-9 and DC-10 advanced jet aircraft. Specific data accounts for maintenance are kept for 25 structural and operating elements of aircraft such as wing, landing gear, hydraulic system, etc.. Two other accounts cover engine labor and material for maintenance. Data for these are provided by engine manufacturers.

The Douglas 1974 DOC equations used in the Medium Density Study are presented in a format generally the same as that of the ATA. The Douglas and ATA DOC differences exist primarily in the areas of spares ratios and in airframe maintenance labor, materials, and engine manufacturers' data.

The Douglas Product Support Department has maintained an extensive record of airline experience on airframe and engine spares on both Douglas and competitive aircraft. Thus, the treatment of spares in the Depreciation account is different from the ATA.

In addition, with many years of accumulated experience on Douglas DC-8, DC-9, and (more recently) DC-10 aircraft in airline use, maintenance labor and materials factors are different from the ATA. These factors have been found to be superior for evaluation of conceptual aircraft in Douglas studies.

DOUGLAS DOC FORMAT

Subsonic Jet Aircraft

Crew Costs in $ Per Trip

$$\$/\text{Trip} = K_e \left(0.05 \frac{TOGW}{1000} + 100\right) T_B$$

where

K_e = $(1 + \text{Inflation Rate})^{(1974-1967)}$

TOGW = maximum takeoff weight at the design range (lb)

T_B = block time per trip (hr)

Inflation Factor = 6% per year

Insurance in $ per Trip

$$\$/\text{Trip} = \frac{I_r C_T}{U} \times T_B$$

where

I_r = insurance premium rate = 1%

C_T = total aircraft cost (1974 $)

U = annual utilization

= 4600 (1 - e to exponent (-.69387 - .40683 T_B))

Depreciation in $ per Trip

$$\$/\text{Trip} = \frac{C_T\,(1-R + 0.1)}{U \times \text{Aircraft Life}} \times T_B$$

where

R = residual value at end of aircraft life

= 15%

Aircraft Life = 15 years

Spares = 0.1 (data from the Douglas Product Support Department indicates airframe and engine spares at 10% of the aircraft cost.)

Fuel and Oil in $ per Trip

$$\$/\text{Trip} = \frac{C_F}{6.7} \times W_{FB}$$

where

W_{FB} = fuel burned (oil is insignificant and omitted)

C_F = \$.22 per gallon

Maintenance Airframe in \$ per Trip

$$\text{Labor \$/Trip} = 0.18 \frac{W_A}{1000} \times LR \ (T_F + 0.21)$$

and

$$\text{Materials \$/Trip} = 1.75 \frac{C_A}{1,000,000} (T_F + 2.75)$$

where

W_A = airframe weight

LR = \$6.40 per hour

C_A = airframe cost

$T_F = T_B - T_M$

$T_M = .10 + .25 \ (1.0 - e^{(-.000002 \times TOGW)})$

Maintenance Turbofan Engines in \$ per Trip

The equations used herein are provided by the engine companies and reflect their operating guarantees to aircraft manufacturers and operators. The equations include flight operations, cyclic, direct and burden on labor. The equations are

$$\text{Labor \$/Trip} = 1.68 \ N_E \ LR \ [(1 + 0.0167 \ \frac{T}{1000}) \ T_F + 0.5]$$

$$\text{Materials \$/Trip} = 23.6 \ N_E \frac{C_E}{1,000,000} (T_F + 0.33)$$

where

N_E = number of engines

T = engine thrust in pounds

C_E = cost of each engine

This routine has been incorporated into a module within the operations simulation program. It was used to estimate the DOC's for all conceptual, baseline and basepoint aircraft in this study. A tabulation of typical DOC data is included in Appendix B, Section B.4.

13.2 Indirect Operating Cost Estimates

An industry working group has suggested a method for computing the IOC for large jet aircraft, such as the DC-8, DC-10, B-737 and others. Table 13-1 is a worksheet developed by the Douglas Aircraft Company to facilitate this computation. The basic material and method was taken from a report (Reference 16) by Robert Stoessel, Logistic Disto-Data, Inc., for the Lockheed-Georgia Company. The total cost per trip for IOC has been modified from the worksheet form to reflect both the distance flown in nautical miles and the trip time in block hours. This method of computation has been incorporated into the Douglas operational simulation program in a slightly modified algebraic form to yield cost per trip.

The algebraic formulation of this method is

$$\text{IOC Cost/Trip} = \left(\frac{1.44 \times \frac{TOGW}{1000} + 227}{\text{Range} \times \text{Seats} \times LF}\right) + \left(\frac{7.47}{R} + \frac{1.3}{V_B} + .0051\right)$$

The costs are computed as dollars per passenger nautical mile. The symbols are:

TOGW = takeoff weight in pounds

R = range in nautical miles

V_B = block speed in knots

LF = load factor

TABLE 13-1

INDIRECT OPERATING COST
PASSENGER CONFIGURATION

ORIGINAL PAGE IS OF POOR QUALITY

		Recommended A[illegible]	
		Domestic	International
Aircraft Type		–	–
Engine Type		–	–
$TOGW_{MAX}$ (Max Certified Takeoff Gross Weight)	LB	–	–
S_F First Class Seats		–	–
S_C Coach or Tourist Seats		–	–
B Total Weight of Passenger Baggage	Tons	–	–
N Total Number of Passengers		–	–
L Passenger Load Factor		0.55	0.55
R_P Passengers Enplaned To On Board Ratio		0.90	[illegible]
R_C Cargo Enplaned To On Board Ratio		[illegible]75	0.6[illegible]
C_B Average Cargo Handling Cost-Bulk	\$/Ton	[illegible]	[illegible]
C_P Average Cargo Handling Cost-Unitized	\$/Ton	21.[illegible]	[illegible]
F_B Average Freight Allocation Costs-Bulk	\$/Ton N.Mi	[illegible]	[illegible]
F_P Average Freight Allocation Costs-Unitized	\$/Ton N.Mi	[illegible]	[illegible]
C Weighted Average of C_B & C_P	\$/Ton		
F Weighted Average of F_B & F_P	\$/Ton N.Mi		

I (A) Ground Property & Equipment Maintenance, Burden & Depreciation + Aircraft Servicing + Administration — $K_A \cdot \frac{TOGW_{MAX}}{1000} \cdot K_{JB}$

(C) Passenger Service, Food & Beverage — [illegible] K [illegible] $S_C + G\ S_F$) K_{JB}

(E) Aircraft Servicing, Aircraft Control — $K_E \cdot K_{JB}$

(F) Passenger Handling, Traffic Servicing & Administration, Reservations & Sales — $L \cdot K_F\ (S_C + S_F)\ R_P \cdot K_{JB}$

TOTAL \$ Departure

II (B) Passenger Service, Cabin Crew Salary + Related Expenses — K_B [illegible] K_{JB}

(C) Passenger Service, Food & Beverage — [illegible] $L \cdot K$ (S [illegible] $+ G\ S_F$) K_{JB}

TOTAL \$ Block Hour

III (D) Passenger Service Support, Reservations, Sales [illegible] (Commission, Advertising, [illegible]) — [illegible] K_{JB}

TOTAL \$ Nautical Mile

IV (C) Traffic Servicing & Administration for Baggage — [illegible] $\frac{B}{N}$ [illegible] K_{JB}

TOTAL \$ Passenger

[illegible] (G) Traffic Servicing & Administration for Cargo — [illegible] K_{JB}

TOTAL \$ [illegible]

VI (H) Freight Reservations, Sales, Advertising, [illegible] — $K_H \cdot F \cdot K_{JB}$

TOTAL \$ [illegible]

	197[illegible] Domestic	197[illegible] International	197[illegible] Domestic	197[illegible] International	[illegible]
K_A	1.32	2.[illegible]	1.42	2.89	1.54
K_B	15.[illegible]	[illegible]	18.42	22.[illegible]	[illegible]
K_C	0.68	[illegible]	0.8[illegible]	1.24	[illegible].89
K_D	0.0047	[illegible]063	0.0052	0.0075	0.005[illegible]
K_E	17.00	[illegible]	20.00	43.00	23.00
K_F	5.37	[illegible]	[illegible].24	[illegible]	4.[illegible]
K_{JB}	[illegible]6.00	[illegible]	[illegible]	[illegible]	[illegible]
K_{CC}	1.75	[illegible].40	1.00	[illegible]	1.0[illegible]
K_G	[illegible].46	[illegible]	[illegible]	[illegible]	[illegible]
K_H	1.091	[illegible]	1.091	[illegible]	1.091
D	40	[illegible]	40	[illegible]	40
E	20	[illegible]	20	[illegible]	[illegible]
G	2.25	[illegible]	2.2[illegible]	[illegible]	2.[illegible]
H	1.00	[illegible]	[illegible]	[illegible]	[illegible]

A second approach used in this study was an empirical method of estimating IOC for an aircraft. With the aircraft operated in a market of characteristics for which historical data exists, the assumption was made that actual IOC experienced by an airline are functionally related to the passenger revenue generated on a type of aircraft. A ratio of IOC to revenue is used to express this by many airlines. The simulation model will accept a ratio value, in which case, the worksheet computation is bypassed in the simulation.

Indirect operating costs for the North Central system were 58 percent of passenger revenue over the 12 month period ending March 31, 1975. The CAB Form 41 data for this period was interrogated to compare the airline's actual figure with the reported data. The CAB IOC accounts for North Central over this period are shown in the following tabulation:

NORTH CENTRAL AIRLINES

IOC Accounts	Year Ending 3-31-74 (000)
Passenger Service	$ 8,528
Aircraft and Traffic Servicing	33,212
Promotion and Sales	12,423
General and Administrative	8,541
Depreciation	1,790
Maintenance	8,425
Total IOC	$ 61,609
Passenger Revenue (000) (excludes subsidy and charter revenue)	$ 106,584
IOC/Passenger Revenue	58%

C - 1

The use of IOC as a function of passenger revenue to estimate indirect operating costs has been substantiated by Air California. It is a realistic approach used by the airlines in estimating IOC and evaluating year-end results.

Air California's IOC/passenger revenue was 45.5 percent for the first six months in 1974. The variation between 45 and 58 percent illustrates the difference in service provided by North Central Airlines versus the commuter-like service provided by Air California.

A comparison has been made between the 0.58 ratio of IOC to Passenger Revenue and a formula suggested for ATA/Industry use. For a fleet of 16 aircraft of 30 seat capacity, the following data are pertinent for a 1980 operation.

Aircraft Price	$2,409,000
Airport Pairs	114
Demand RPM	130,000,000
Fare Structure	$12.56 + $0.0706 x Passenger Miles Flown
Average Load Factor	0.432
Aircraft Utilization (hours per year)	2,600
Average Stage Length (statute miles, kilometers)	77 (124)
Average Block Speed (MPH, KPH)	244 (392)

The data abcve were taken from the analysis of low density routes reported in Section 12.5 Segmented Market Simulation. The effect of the formula approach to IOC is shown in the following tabulation:

ORIGINAL.

	Fleet Economic Data ($)	
	58% of Revenue	Suggested Formula
Fleet Investment	37,963,000	same
Passenger Revenue	30,455,000	same
DOC	17,889,000	same
IOC	17,644,000	30,455,000
Total Costs	35,533,000	48,344,000
Operating Loss	5,048,000	17,889,000
Ratio of Loss to Fleet Investment	- 13.43%	- 47.12%

The use of IOC as a function of revenue generated a much more acceptable result than the suggested formula. Hence, the general simulation exercises in this study have used the ratio approach. The proposed industry IOC formula was developed primarily with major trunk carriers and large commercial aircraft data. It was apparent in this medium density study that operating conditions for regional carriers are different from those for trunk airlines.

13.3 Conceptual Aircraft Development and Production Cost Summaries

The general costing approach used in screening conceptual aircraft has been introduced in Section 3.1. More specifically, the approach involved a Design/Cost/DOC routine contained in the operational simulation program. This routine generated development and production prices for any breakeven quantity selected. The routine incorporated the DOC routine discussed in Section 13.1. These development and production costs were established with equations originally developed by the RAND Corporation in 1965. The equations have been modified any current year. They also have been calibrated to reflect the general cost/weight expression introduced in Section 3.1. Cost estimates with this approach were used in all of the noncompetitive evaluations conducted in the initial mission model. A summary of the pertinent data is included as Table 13-2.

Engine prices for all turbofan engines were estimated as footnoted. The turboprop engine price was based on an industry average computed at the thrust rating used.

13.4 Basepoint Design Aircraft Cost Estimates

For this phase of the study, a Commercial Aircraft and Development Cost (CAPDEC) estimating technique was used. This technique was derived from the same RAND Source as the cost estimating program used in the conceptual studies. There are some differences in the input format. Results, however, are in very close agreement for both methods.

CAPDEC was developed from the 1970 RAND cost equations and modified to reflect actual Douglas costs and experience in the pricing of commercial aircraft. The basic airplane inputs to the model are cost weight, engine and avionics costs, and production rate. The most significant input is the airplane cost weight defined in CAPDEC as manufacturer's weight empty minus bare engine and avionics weight. The engine and avionics costs were input to the program for this study.

The aircraft price calculated by the model was based upon total program costs including profit at a particular production quantity (pricing unit). Profit was handled as a cost element affecting the total cost of an aircraft program. A three percent interest rate was input to compute the cost of negative cash flows, inventory costs, and the value of airline prepayments.

TABLE 13-2

COMPARISON OF CONCEPTUAL AIRCRAFT ECONOMIC CHARACTERISTICS

AIRCRAFT			Program Development Cost ($ Millions)	Unit Aircraft Price ($ Millions)	Engines Price ($ Millions)	DOC AT MAX RANGE	
Seats	Field Length	Range (N.Mi.)				$/Trip	$/Seat N. Mi.
30	4500	2 x 250	82.756	2.409	0.493	628.83	0.037
50	3500	2 x 250	114.104	3.256	0.658	748.57	0.027
50	4500	2 x 150	105.765	2.982	0.601	463.88	0.028
50	4500	2 x 250	111.261	3.125	0.631	692.10	0.025
50	4500	2 x 350	118.589	3.299	0.662	898.52	0.023
50	4500	1 x 1000	126.978	3.504	0.702	1123.69	0.023
50	5500	2 x 250	112.089	3.105	0.630	670.87	0.024
70	4500	2 x 250	139.808	3.847	0.780	770.93	0.020
50	4500	2 x 250	104.016	2.700	0.374	671.71	0.024

NOTE: - Program costs at 400 units for break even point, 8 units per month production rate.

- Engines priced at $(\frac{60000}{T} + 32.00)$ = $/eng., where T = takeoff thrust lb. for turbofan engines.

The costs during an indicated year are in constant dollars for the entire year.

CAPDEC is calibrated for a typical new passenger aircraft involving no major advances in technology. The learning curves in CAPDEC, unlike the RAND method, have been broken into several segments at different production quantities reflecting more closely Douglas learning experience on the DC-9 airplane program.

COST EQUATIONS

The cost equations in the model are grouped into development and production costs reflecting current experience and costing methods for Douglas commercial airplane programs. Each equation is expressed in dollars.

The cost calibration year in CAPDEC is mid-1973. The equations include an escalation rate, which, for the medium density study, escalated hourly costs at 6 percent and material costs at 5 percent per year to mid-1974. For this study all costs were constant at that level.

DEVELOPMENT COSTS

Development costs were computed by log linear equations and distributed over time by a sine exponent equation. These costs relate to the first aircraft only, and include:

- initial engineering,
- initial tooling,
- development support,
- flight and lab tests, and
- any extraordinary costs.

Initial engineering and tooling costs are dependent upon the cost weight and speed of the aircraft. Initial tooling cost is also a function of the production rate. Both costs are based upon historical Douglas experience and have been calibrated to reflect actual Douglas costs.

Initial Engineering

$$\$ \, EI = CE \; (W^{WEE} \times TE \times EL \times EV)$$

where

CD = 787.9 (engineering calibration constant)

W = cost weight

WEE = .785 (weight exponent)

TE = .605 complexity factor (1972 RAND speed factor)

EL = 23.33 (hourly labor rate including overhead)

EV = escalation rate = 6% per year; (1.06)

Initial Tooling

$$\$ \, TI = CT \; (W^{WET} \times TT \times TL \times RT^{.4} \times EV)$$

where

CT = 74.11 (tooling calibration constant)

W = cost weight

WET = .95 (weight exponent)

TT = .745 complexity factor (1972 RAND speed factor)

TL = 19.88 (hourly labor rate including overhead)

RT = tooling rate = 6% per month

EV = escalation rate = 6% per year; (1.06)

CAPDEC development support costs include manufacturing support and product support (designed maintainability into the aircraft). Materials are procured on a fixed price basis and are included with the materials cost equation.

Development Support

$$\$ DS = DL \times TS\ (EI + FTB)/(EL \times TE)$$

where

DL = 10.00 ($/engineering hour)

TS = .536 complexity factor (1972 RAND speed factor)

EI = initial engineering cost

FTB = lab test cost

EL = 23.33 (engineering hourly labor rate)

TE = .605 engineering complexity factor

Flight and lab test costs are directly related to initial engineering and are based upon Douglas commercial experience.

Flight Test

$$\$ FTC = FC \times TF\ (1.903\ FL \times EV \times 10^6 + .058\ EI/TE)$$

where

FC = 1.0 (flight test calibration constant)

TF = .636 complexity factor (1972 RAND speed factor)

FL = 19.23 (hourly labor rate including overhead)

EV = escalation rate = 6% per year; (1.06)

EI = initial engineering cost

TE = .605 engineering complexity factor

Lab Test

$$\$ FTB = .23\ EI$$

where EI = initial engineering cost

ORIGINAL

TOTAL DEVELOPMENT COSTS

$$\$\ TDC = EI + TI + DS + FTC + FTB + DJL$$

where

DJL = extraordinary costs

Facilities and training programs necessary for the specific development program are examples of extraordinary development costs. In this candidate aircraft program, there should be no extraordinary development costs and DJL = 0.

PRODUCTION COSTS

Production costs are a function of the cost of Unit 1 and the learning curve appropriate for the additional units produced. Engineering and tooling costs are exceptions to this relationship as these costs for Unit 1 are considered development costs rather than production costs.

Production costs for a commercial aircraft program include:

sustained engineering,

sustained tooling,

manufacturing labor, and

materials

Sustained engineering cost is based upon the initial engineering cost of Unit 1 with a 62.4 percent cumulative average learning curve applied. RAND applies t e learning curve to the total initial engineering cost. Douglas experience dicates a different approach, and therefore, in CAPDEC the learning curve is applied only to 32 percent of the initial engineering costs, as indicated in the following expressions.

Unit Sustained Engineering

$$\$ ES = SEC \times SG \times EI \; (AI^{SGE} - (AI-1)^{SGE})$$

where

SEC = 1.0 (sustained engineering constant)

SG = .32 (initial engineering adjustment factor)

EI = initial engineering cost

AI = quantity produced = 400 aircraft

SGE = cum average learning slope (62.4%)

The cost of sustained tooling is based upon the initial tooling cost of Unit 1 with a 53.7 percent cumulative average learning curve.

Unit Sustained Tooling

$$\$ TS = STC \times SH \times TI \; (AI^{STE} - (AI-1^{STE})$$

where

STC = 1.0 (sustained tooling constant)

SH = 1.0 (initial tooling adjustment factor)

TI = initial tooling cost

AI = quantity produced = 400 aircraft

STE = cum average learning slope (53.7%)

Labor and material costs are determined by calculating Unit 1 costs and then applying a learning curve to the Unit 1 costs. Both learning curve slopes are a function of the number of units produced. Material costs include any non-recurring costs that were not considered in the Development Support Costs. Both costs include the cost of the first unit (aircraft) produced and are calibrated to reflect actual Douglas costs.

Unit Manufacturing Labor Cost

$$\$ UL = AI^{AV} \times PAL/AY$$

where

AI = quantity produced = 400 units

AV = learning curve slope (80% through Unit 250, 90% through Unit 500, and 100% thereafter)

PAL = Unit 1 manufacturing labor cost

AY = adjustment factor (necessary when the slope of the learning curve is changed)

Unit 1 Manufacturing Labor Cost

$$\$ PAL = CK \times W^{WEL} \times AL \times QL \times EC \times EV \times TMP$$

where

CK = 64.00 (manufacturing labor calibration constant)

W = cost weight

WEL = .83 (weight exponent)

AL = 16.89 (hourly labor rate including overhead)

QL = 1.14 (quality control factors)

EC = 1.11 (engineering change factor)

EV = escalation rate = 6% per year; (1.06)

TMP = .836 complexity factor (1972 RAND speed factor)

Unit Material Cost

$$\$ UM = AI^{AT} \times PAM$$

where

AI = quantity produced = 400 units

AT = learning curve slope (89% through Unit 500, 100% thereafter)

PAM = Unit 1 material cost

Unit 1 Material Cost

$$\$ \, PAM = CN \times W^{WEM} \times TA \times FV$$

where

CN = 240.0 (material calibration constant)

W = cost weight

WEM = .83 (weight exponent)

TA = .814 complexity factor (1972 RAND speed factor)

FV = escalation rate = 5% per year; (1.05)

TOTAL PRODUCTION COSTS

$$\$ \, TPC = ES + TS + UL + UM + EAC$$

where

EAC = engine, avionics cost (thruput costs)

OUTPUT OF CAPDEC

CAPDEC determines the cash flow to the manufacturer for an aircraft program over time. Costs, revenue and cash flow are presented as they are incurred on a quarterly basis. After costs are distributed over time, a price is determined, and the resulting revenues are also distributed over the life of the aircraft program. The cash flow generated includes interest costs.

AIRCRAFT PRICE

$$\$ \, PR = (1 + P) \times \frac{(RDA + TPC + IC)}{AI}$$

where

P	=	percent profit expressed as a decimal
RDA	=	development costs
TPC	=	airframe production costs
IC	=	interest costs
AI	=	quantity produced (pricing unit) = 400 units

13.4.1 Application of CAPDEC to the Nominal and Advanced flap aircraft

The first application of CAPDEC was to estimate the differences in cost of two conceptual aircraft. These were the baseline 50 passenger aircraft which had the nominal (hinged) flap and a 50 passenger aircraft designed with an advanced high-lift (tracked) flap. Each aircraft was designed for 2 x 250 nautical mile stages. Pricing assumptions were

1974 dollars

Interest rate - 8% per year

Profit - 10%

Engine Prices: Nominal flap aircraft - $315,000/engine

Advanced flap aircraft - $320,000/engine

Avionics cost - $125,000

The development and production costs for each aircraft are broken down in Table 13-3. The 50 passenger nominal flap aircraft was priced at $3.11 million while the 50 passenger advanced flap aircraft was priced at $3.16 million. The advanced flap aircraft price includes the additional complexity of the flap.

13.4.2 Basepoint Aircraft Costs

The following values were used with CAPDEC to estimate the cost of the 850 nautical mile, 50 seat final design basepoint aircraft:

TABLE 13-3

NOMINAL VS ADVANCED FLAP
COMPARATIVE AIRCRAFT COST ESTIMATES
($ MILLIONS)

	NOMINAL FLAP AIRCRAFT	ADVANCED FLAP AIRCRAFT
	50 PSGR	50 PSGR
Development Program (400 units)		
Initial Engineering	30.1	30.4
Initial Tooling	31.6	31.9
Development Support	13.7	13.9
Flight and Test Lab	32.5	33.4
Subtotal	107.9	109.6
Production Costs:		
Sustained Engineering	56.0	57.9
Sustained Tooling	28.0	28.9
Manufacturing Labor	416.0	421.5
Materials	144.0	144.6
Subtotal	644.0	652.9
Interest and Profit	190.0	193.5
Total	941.9	956.0
Average Mfg Cost	2.35	2.39
Engines and Avionics	.76	.77
Total Unit Cost	3.11	3.16

NOTE: Conceptual Baseline Aircraft at 2 x 250 N. Mi. Design Range.

Production Quantity	400 units
Interest Rate	8% per year
Profit	10%
Engine Price	\$ .341 million
Avionics Price	\$ .125 million

The final design basepoint was priced at \$3.18 million. Total development costs were \$109 million while total production costs were \$648 million. The aircraft price is the sum of the following cost components.

Development Costs

Initial Engineering	\$30.34 million	
Initial Tooling	31.95	
Development Support	13.83	
Flight Test	26.52	
Flight Lab	6.07	
Total Development Costs		\$ 108.7 million

Production Costs

Sustained Engineering	\$56.0 million	
Sustained Tooling	28.0	
Manufacturing Labor	420.0	
Materials	144.0	
Total Production Costs		\$ 648.0 million

Engine Cost (@ 800 units)	$ 272.8 million
Avionics Cost (@ 400 units)	50.0
Interest Expense	78.0
Total Aircraft Costs	$1157.5 million
Profit (@10%)	116.0
TOTAL AIRCRAFT PRICE (@ 400 units)	$1273.5 million
PRICE PER AIRCRAFT	$ 3.18 million

The final design basepoint aircraft is slightly higher in price than the advanced flap aircraft discussed in the previous section. The essential difference of these two configurations is the range capability of 850 versus 560 nautical miles (1574 vs 1037 km) and 2,000 pounds (610 kilograms) in airframe weight. Appendix C, Section C.1 contains a typical cost development tabulation to illustrate the use of CAPDEC in generating the cost of the final design aircraft.

13.5 Comparison of Basepoint and Current Aircraft Prices

A survey of published data on a wide range of aircraft is summarized in Figure 13-1. The aircraft vary in size from the Cessna Citation to the Boeing B-747. Prices vary from about $800,000 to $30,000,000, as shown on the logarithmic curve. Note that three turboprop versions are shown at a lower cost than comparable turbofan aircraft of the same weights. The Basepoint 50 passenger aircraft with "design-to-cost" benefits shows on the low side of the cost trend curve. In contrast, the same aircraft estimated with contemporary factors is some $800,000 more expensive.

COMMERCIAL TURBINE AIRCRAFT
NEW, EQUIPPED PRICE
VS
EQUIPPED O.W.E.

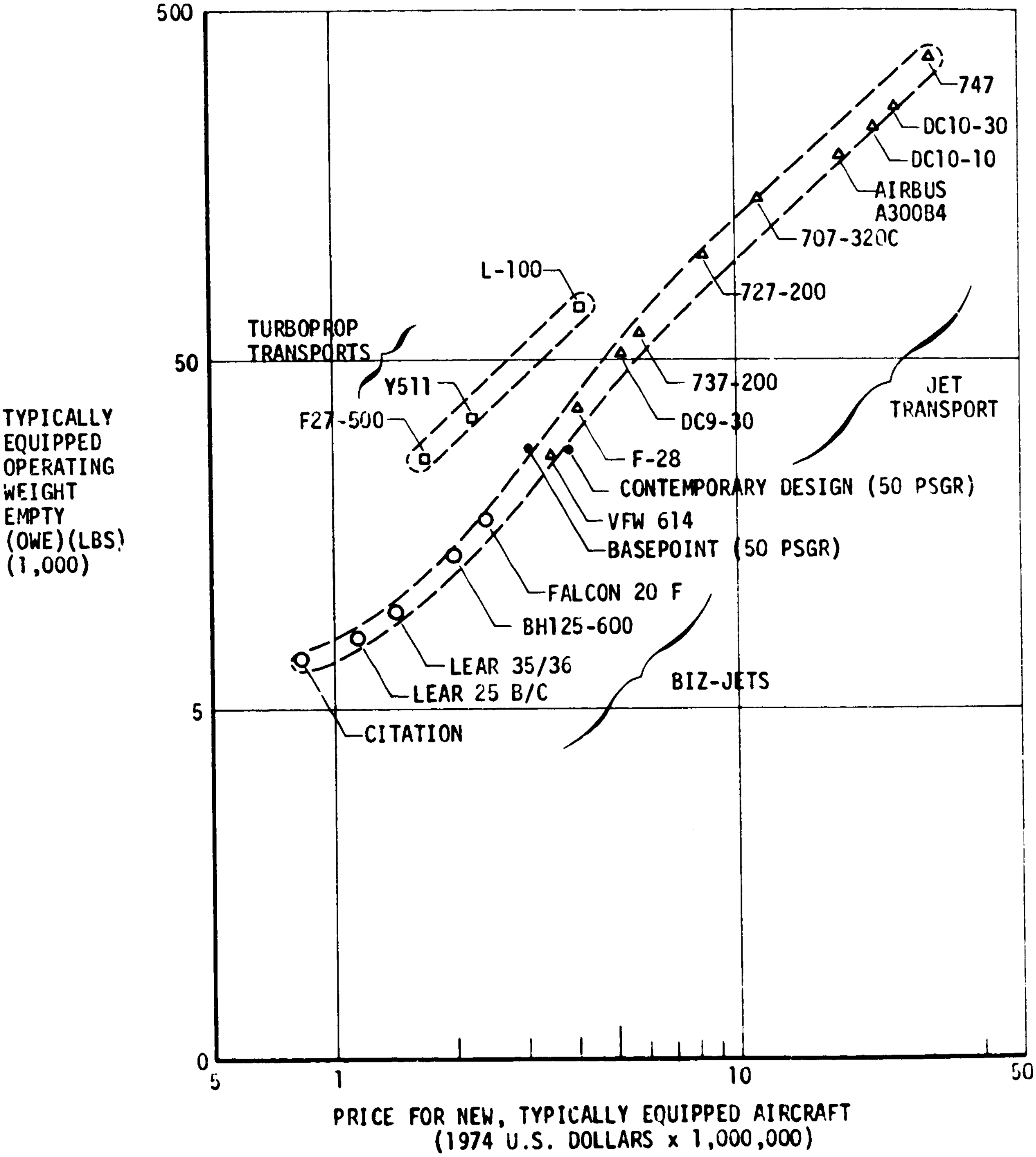


FIGURE 13-1

The basepoint cost estimates are at 400 production units, thus the curve shows a relative position on the trend at that number. The dotted band indicates a spread in the possible cost variations.

14.0 AIRCRAFT COST SENSITIVITY ANALYSES

The effects of various program assumptions and aircraft design excursions were investigated in terms of the effect on aircraft production and operating costs. All of these effects were applied to the final design basepoint aircraft. This was the 50 passenger, 850 nautical mile (1,574 km) range, 4,500 foot (1,372 m) field length aircraft powered by the bypass ratio 6:1 turbofan engine.

14.1 Production Cost

The unit costs of the 50 passenger aircraft vary with the assumption of the breakeven unit used for pricing. All aircraft unit costs included in prior sections have been based on a pricing quantity of 400. The effect on price for lower quantities is tabulated as follows:

Pricing Unit	Price Per Unit
100	$5,290,000
200	$3,990,000
300	$3,480,000
400	$3,180,000

14.2 Design-to-Cost Tradeoffs

A very extensive list of manufacturing simplifications was suggested in the design study of the basepoint aircraft (50 seats, 850 nautical mile range). Of these, a few major features were believed significant in reducing the production costs of the aircraft. Primary areas suggested for cost reduction were wing, empennage, fuselage and interiors. A cost summary is included as Table 14-1, "Design-to-Cost" Savings Summary. Note that the wing cost is increased by addition of a tracked flap compared to a hinged

TABLE 14-1

DESIGN-TO-COST SAVINGS SUMMARY

	ESTIMATED COST EFFECTS PER AIRCRAFT
WING:	
ADVANCED FLAP SYSTEM	+ $25,000
REAR SPAR, CAPS, FILLETS	- 79,000
SUBTOTAL	- 54,000
VERTICAL AND HORIZONTAL STABILIZER	- 21,000
FUSELAGE	- 25,000
SYSTEMS AND INTERIORS	- 3,000
TOTAL SAVINGS PER AIRCRAFT	-$103,000

flap. The net effect of this, however, was beneficial on the total aircraft. The wing was smaller and performance better than an equivalent design with a hinged flap as incorporated in the initial conceptual studies.

An estimate was made of the difference in the basepoint aircraft as designed with an equivalent configuration designed to contemporary high-performance jet aircraft. A comparison of aircraft reveals about a 15 percent savings in airframe weight in favor of the basepoint simplified design. The savings in avionics is due to less expensive equipment being specified. This is the type of equipment used on corporate and business jet aircraft. It is completely certified for service.

If the basepoint aircraft were designed to the same complexity level as the B-737/DC-9 class of aircraft, the unit cost would be considerably higher, as shown in Table 14-2. Note the total cost excess is estimated to be $828,000 per aircraft, or about 27 percent above the basepoint aircraft. The difference in airframe costs is attributable to the 15 percent weight savings mentioned above.

14.3 Operating Costs Sensitivity

A number of sensitivity analyses were made to determine where changes in factors might affect the cost of operations of the basepoint aircraft. To set a framework for understanding factors affecting direct operating costs (DOC), a recap of relative parts of DOC is presented for three sizes of basepoint aircraft. This is included as Table 14-3.

14.3.1 Changes in DOC Resulting from Increases in Research and Development Costs

Research and development (R & D) costs may be spread over any number

TABLE 14-2

COMPARISON OF SIMPLIFIED AND

CONTEMPORARY DESIGN COST EFFECTS

ITEM	SIMPLIFIED (BASEPOINT)	CONTEMPORARY
Airframe	2.373	2.823
Engines	.682	.682
Avionics	.125	.400
Design-to-Cost Savings	-.103	
Total	3.077	3.905

In 1974 $ Millions at 400 Production Units for Pricing.

TABLE 14-3

DIRECT OPERATING COST/AIRPLANE MILE

	AIRCRAFT CAPACITY (PASSENGERS)		
	30	50	70
CREW	45%	39%	35%
FUEL	20%	24%	26%
DEPRECIATION AND INSURANCE	15%	17%	19%
ENGINE MAINTENANCE	11%	10%	10%
AIRFRAME MAINTENANCE	9%	10%	10%

of production units. A curve is presented in Figure 14-1 which shows the portion of R & D in the unit price of the basepoint 50 passenger,(850 n.mi/ 1574 km), aircraft. At a price of $3.077 million, the fraction of R & D is about nine percent (9%).

The effect of higher development costs for 400 units was evaluated for both price of the aircraft and its DOC at the 850 nautical mile design range. Results are summarized in Table 14-4.

Some of these data are plotted in Figure 14-2. Both DOC and increased aircraft price are shown as functions of the percent increase in development (non-recurring) program costs. Note that a three-fold increase in non-recurring costs represents a price increase from $3,077,000 to $3,645,000 or 18.5 percent above the basic cost at 400 units production.

Operating costs as a function of trip distance are shown in Figure 14-3. The DOC and trip cost curves for the basepoint aircraft are the lowest of the curves. The upper set of curves represents costs for the aircraft with the price resulting from a 200 percent increase in development costs.

14.3.2 Effect of Increased Fuel Costs on DOC

The nominal fuel cost for the conceptual aircraft is 22¢ per gallon or 3.284¢ per pound. Variations are evaluated at 4¢ per gallon increments to 38¢ per gallon. The effect is measured in terms of DOC and trip costs as shown in Table 14-5.

The effect of higher fuel prices on DOC at the design range is shown in Figure 14-4. An increase of 16 cents/gallon (about 73 percent) in fuel costs results in a 17.5 percent increase in the design range DOC.

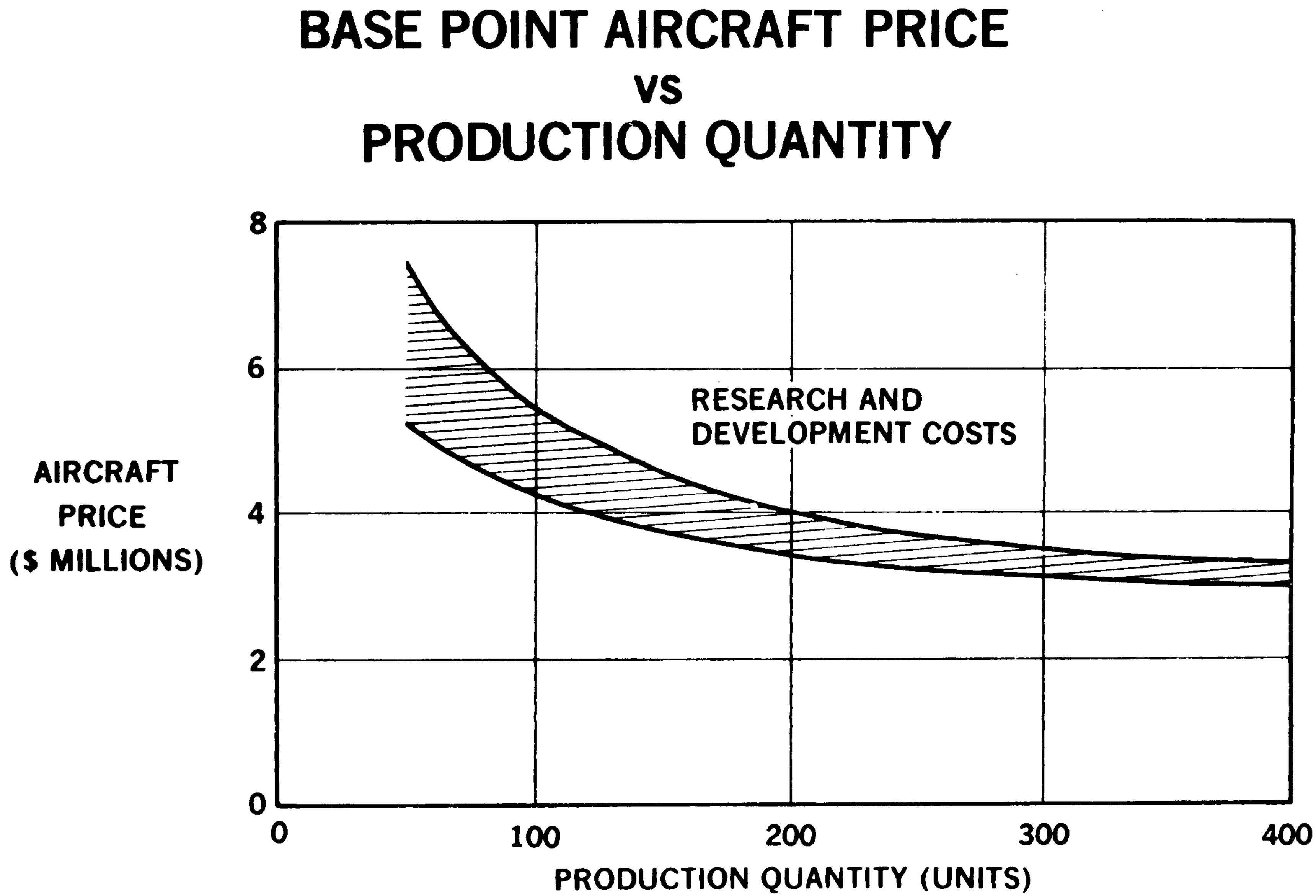

BASE POINT AIRCRAFT PRICE
VS
PRODUCTION QUANTITY
AIRCRAFT
PRICE
($ MILLIONS)
8
6
4
2
0
0
100
200
300
400
PRODUCTION QUANTITY (UNITS)
RESEARCH AND
DEVELOPMENT COSTS

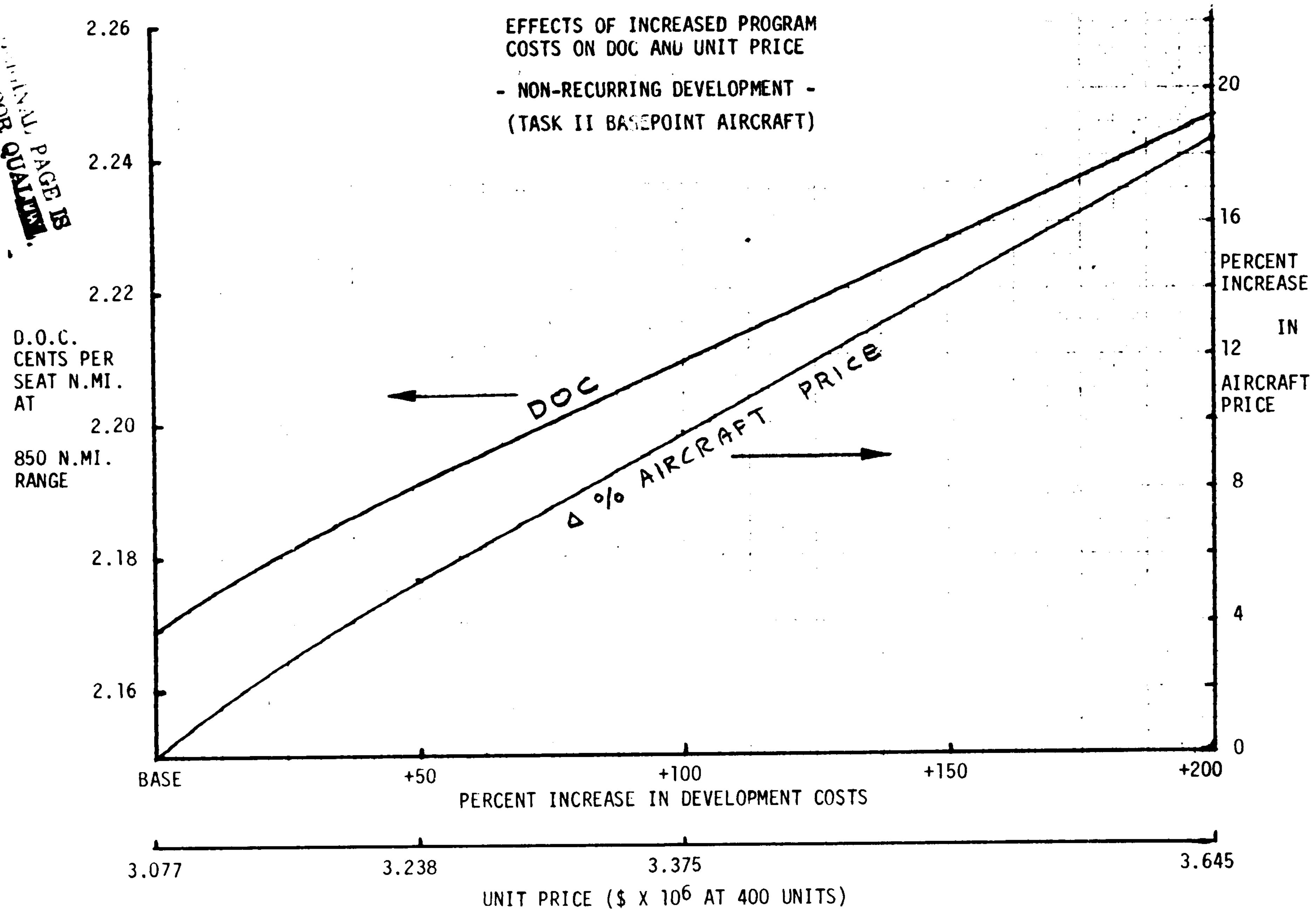
FIGURE 14-1

TABLE 14-4

EFFECT OF VARIATIONS IN RESEARCH AND DEVELOPMENT COSTS ON AIRCRAFT DIRECT OPERATING COSTS

COST ITEMS (400 Units)	BASE POINT AIRCRAFT	R AND D VARIATIONS		
		+50%	+100%	+200%
Total R&D ($ Millions)	108.700	163.050	217.400	326.100
Unit Aircraft Costs ($ Millions)				
- Recurring	2.933	2.933	2.933	2.933
- Non Recurring R&D	.247	.408	.545	.815
- Total	3.180	3.341	3.478	3.748
Design-To-Cost Savings ($ Millions)	-.103	-.103	-.103	-.103
Net Aircraft Costs	3.077	3.238	3.375	3.645
Direct Operating Costs				
- $ per Trip	921.89	931.13	938.99	945.12
- $ per N. Mile	1.08	1.095	1.105	1.12
- ¢ per Seat N. Mi.*	2.17	2.19	2.21	2.25

* Rounded to two decimal places.



EFFECTS OF INCREASED PROGRAM COSTS ON DOC AND UNIT PRICE
- NON-RECURRING DEVELOPMENT -
(TASK II BASEPOINT AIRCRAFT)
D.O.C. CENTS PER SEAT N.MI. AT 850 N.MI. RANGE
2.26
2.24
2.22
2.20
2.18
2.16
DOC
Δ % AIRCRAFT PRICE
PERCENT INCREASE IN AIRCRAFT PRICE
20
16
12
8
4
0
BASE
+50
+100
+150
+200
PERCENT INCREASE IN DEVELOPMENT COSTS
3.077
3.238
3.375
3.645
UNIT PRICE ($ X 10^6 AT 400 UNITS)

FIGURE 14-2

AIRCRAFT PRICE VARIATIONS AFFECT DOC
AND COST PER TRIP AT VARIOUS TRIP DISTANCES

(BASEPOINT AIRCRAFT - 1974 DOLLARS)

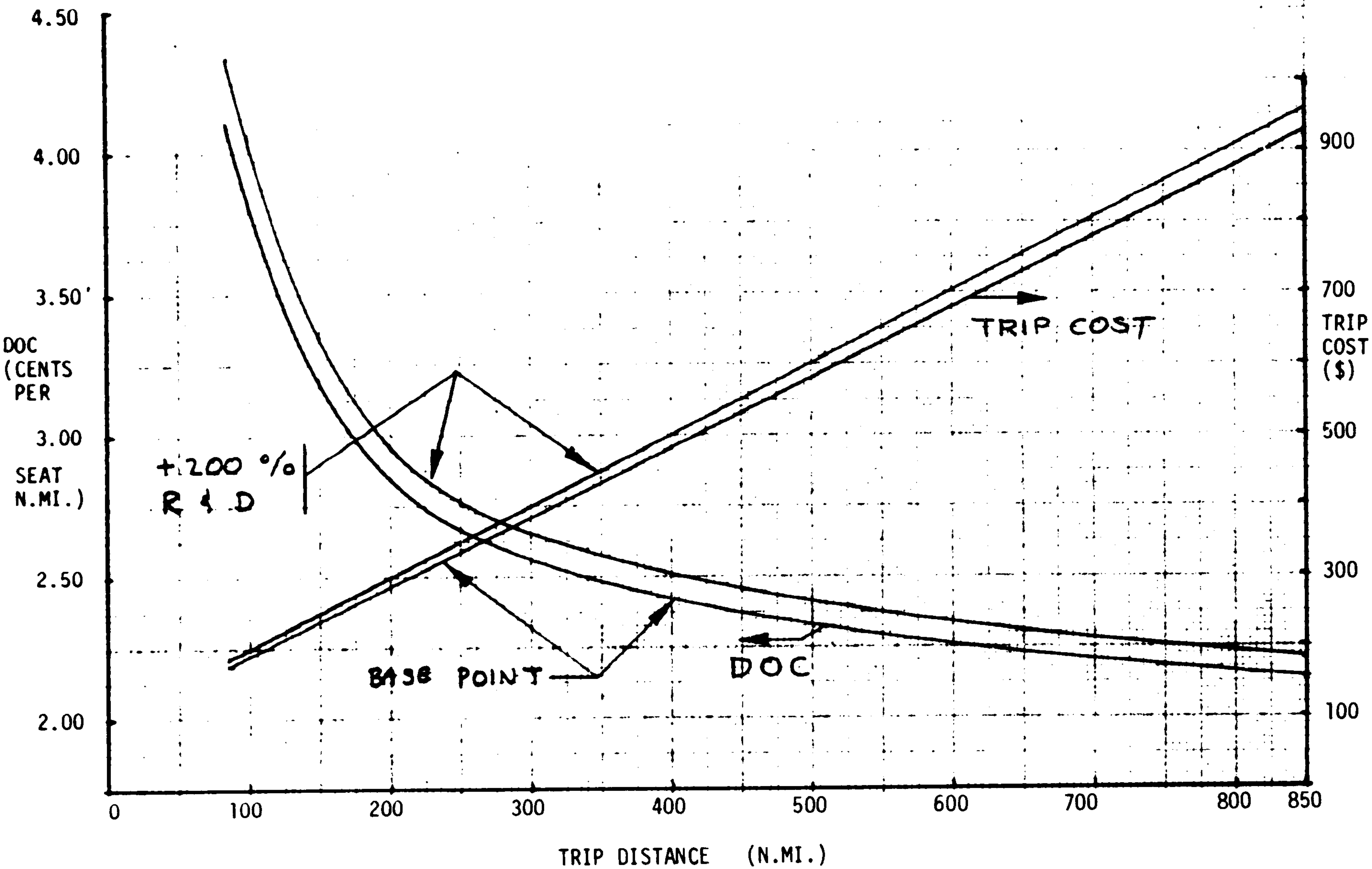


FIGURE 14-3

TABLE 14-5

VARIATION OF TRIP COST AND DOC
WITH INCREASES IN COST OF FUEL

Costs at 850 n mi	FUEL COST - CENTS/GALLON				
	22	26	30	34	38
Trip Total	921.89	962.18	1002.61	1042.97	1083.32
$/n mi	1.08	1.13	1.18	1.23	1.27
$/stat mi	.93	.98	1.02	1.07	1.10
¢/seat mi (stat)	1.86	1.96	2.05	2.14	2.20
¢/seat mi (naut)	2.17	2.26	2.36	2.45	2.55
% Increase in DOC	(Base)	4.15	8.75	12.90	17.50

Note: Basepoint 50 passenger aircraft

EFFECT OF INCREASES IN FUEL PRICES
ON DIRECT OPERATING COSTS AT DESIGN RANGE
(BASE POINT AIRCRAFT - 1974 DOLLARS)

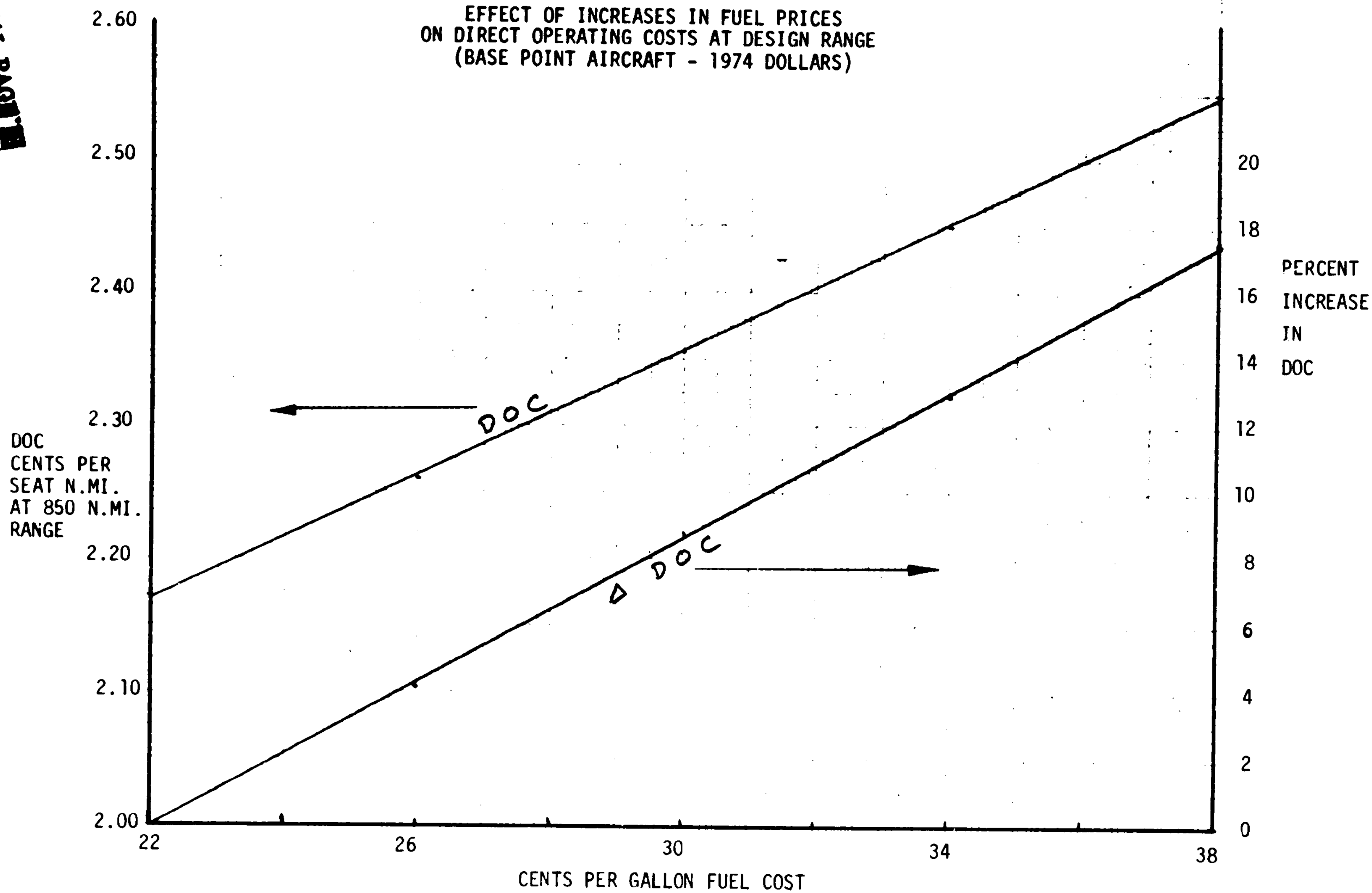


FIGURE 14-4

The variations in DOC above the nominal fuel cost are shown in Figure 14-5. Two extremes are shown, with the lower curve resulting from fuel costs at 22 cents per gallon. This reflects the base fuel costs recommended for the medium density regional carriers. Only the highest DOC figures corresponding to fuel at 38 cents per gallon are plotted in Figure 14-5.

14.3.3 Variation of DOC with Engine Price

An assumption of engine prices was made in Section 13.0 which was based on characteristics of production engine programs. To determine the effect on DOC of increased engine prices, engine prices were increased by 25 and 50 percent. Table 14-6 presents the engine price effects on aircraft unit costs and DOC. The trip costs and DOC's at the design range are normalized at 1.00 for the nominal basepoint configurations. Both absolute and relative effects are shown for increased engine prices. Note the effect on trip costs and DOC's of about 2 percent on a 30 seat aircraft to a maximum of 5 percent on a 60 seat aircraft.

14.4 Effect of Extended Range Capability on Fleet Economics

The basepoint aircraft was designed to a nominal 850 n.mi/1574 km range. The effect of increasing the range to 1000 n.mi/1852 km was evaluated in the simulation mission model. The aircraft price was increased by $108,000 at the pricing unit of 400.

Examination of the mission model showed no routes in the range class over 781 n.mi/1446 km. Thus, a 1,000 mile range capability was not needed. No additional traffic existed. If the cost penalty of $108,000 per aircraft were applied to the noncompetitive fleet sizes shown in Section 12.0, a fleet of about 650 aircraft would cost about $70,800,000 more with the extended

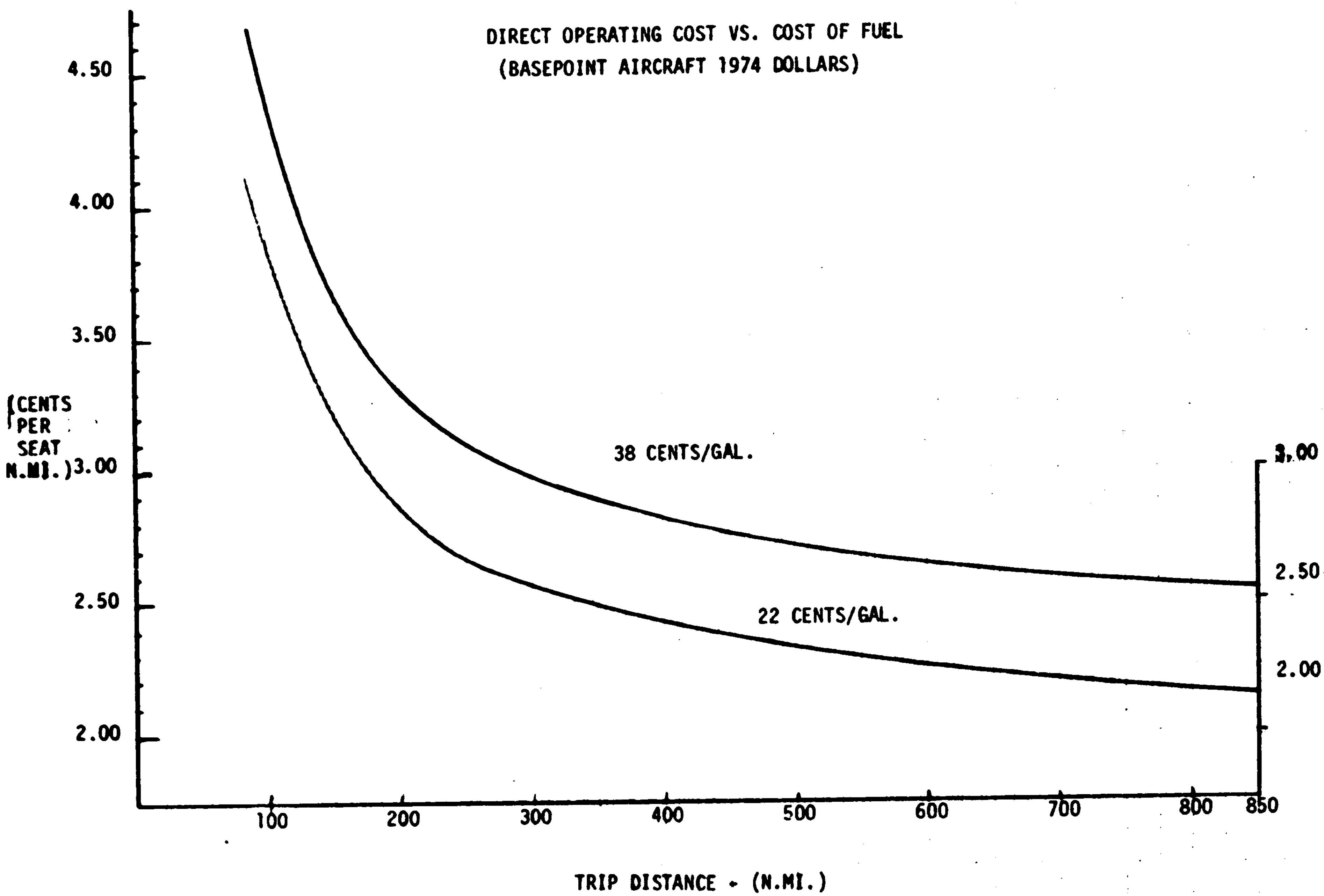

DIRECT OPERATING COST VS. COST OF FUEL
(BASEPOINT AIRCRAFT 1974 DOLLARS)
4.50
4.00
3.50
(CENTS PER SEAT N.MI.) 3.00
2.50
2.00
38 CENTS/GAL.
22 CENTS/GAL.
3.00
2.50
2.00
100
200
300
400
500
600
700
800
850
TRIP DISTANCE - (N.MI.)

FIGURE 14-5

TABLE 14-6

EFFECT OF ENGINE PRICE INCREASES ON UNIT COST AND DOC

AIRCRAFT SEATING	30	40	50	60	70
Basepoint Aircraft Price ($ x 10^6)	2.372	2.726	3.077	3.585	3.788
Engines (2) Cost ($ x 10^6)	.532	.606	.682	.762	.842
Trip Cost at 850 N. Mi. ($)	834.72	896.74	958.60	959.94	1086.01
Seat Cost (¢/N. Mi.)	3.273	2.637	2.256	1.882	1.825
Trip and Seat Costs Normalized	1.00	1.00	1.00	1.00	1.00
+ 25% Engine Costs:					
Aircraft Price	2.505	2.877	3.247	3.775	3.998
Engines Cost	.665	.757	.852	.952	1.052
Trip Cost - Relative	1.020	1.021	1.022	1.025	1.025
Seat Cost - Relative	1.020	1.022	1.022	1.025	1.025
+ 50% Engine Costs:					
Aircraft Price	2.638	3.029	3.418	3.966	4.209
Engines Cost	.799	.909	1.023	1.143	1.263
Trip Cost - Relative	1.040	1.043	1.045	1.050	1.049
Seat Cost - Relative	1.041	1.043	1.045	1.050	1.049

range capability. Thus, with no additional passenger revenue and added fleet costs, extended range capability is unprofitable within the market as defined in this study.

14.5 Cost Impact of Engine Technology Changes

The effect of improved engine efficiency was evaluated on a known aircraft and engine. For this purpose the DOC distribution on a DC-9-10, 75 passenger aircraft was used. It was assumed that improvements in engine technology would reduce both engine maintenance and fuel consumption. Table 14-7 presents reductions in DOC assuming 5, 10, and 15 percent reductions in these two areas. Note that a 5 percent improvement in engine characteristics results in a reduction in DOC of about 2.1 percent.

TABLE 14-7

DIRECT OPERATING COST DISTRIBUTION
AND EFFECT OF ENGINE IMPROVEMENTS

DC-9-10, 75 PASSENGER AIRCRAFT	DOC BASIC (%)	ENGINE IMPROVEMENT FACTORS		
		-5%	-10%	-15%
Crew	28.5			
Insurance & Depreciation	19.1		SAME	
Airframe Maintenance	11.0			
Engine Maintenance	8.5	8.1	7.6	7.2
Fuel Costs (22¢/gal)	32.9	31.2	29.6	28.0
	100.0	97.9	95.8	93.8
Reductions in DOC Due to Engine Maintenance & Improved Fuel Efficiency		-2.1	-4.2	-6.2

15.0 AIRLINE OPERATING ECONOMICS

In this conceptual study, airline economics have been simplified. Net operating income is passenger revenue less the total of DOC and IOC. IOC was calculated as 58 percent of revenue. A profitability index has been expressed as the ratio of net operating income to total fleet investment cost. Fleet investment cost equals the price per aircraft multiplied by the fleet size. The validity of this simplified approach to determine relative return was tested using a computerized model of return on investment discussed in the next section. Since many of the results in the study show negative profitability, analysis of subsidy considerations also was conducted and is reported in Section 16.0, Aircraft Operations and Economic Viability.

15.1 Nominal Return on Investment

A basic computerized return on investment method was used to evaluate conceptual aircraft. This method was developed by Douglas as an airline financial planning and evaluation tool.

The program used in the analyses to evaluate the economic viability of the aircraft is based upon the discounted cash flow technique. This method considers the time-value of cash flows with the average annual rate-of-return derived from a specific investment. The delivery date of the aircraft represents "time-zero", which is the focal point in developing ROI. Detailed aspects of the program are presented in the following text.

REVENUE

Total revenue is the sum of passenger, cargo, and other revenue. The program uses average block speed, number of seats, utilization, and load factor per aircraft to compute the revenue. Also included are the number of aircraft and the value of the first year's average RPM yield. An appropriate annual growth rate can be applied to this yield for each subsequent year if desired.

TOTAL CASH COSTS

The total cash costs were the sum of direct (excluding depreciation) and indirect operating expenses. The first year's DOC and IOC per aircraft mile and the number of aircraft were the initial starting data for the analysis.

GROSS INCOME

Total Revenue

Less: Total cash costs, depreciation, and interest expense, equals

Gross Income

NET INCOME

Gross Income

Plus: Investment tax credit

Less: Income tax, equals

Net Income

Income tax is handled as a function of the tax rate and the taxable income.

CASH FLOWS

1. Operating Cash Flow:

   Net income

   Plus: Total depreciation

   Less: Principal repayment on debt, equals

   Operating Cash Flow

2. Total Cash Flow:

Operating Cash Flow

Plus: Cash flow from sale of equipment, equals

Total Cash Flow

DEPRECIATION

Four methods were available to be applied individually to determine the aircraft, spares or ground support equipment depreciation. The residual percentages and depreciable years were determined for each type of equipment.

The four methods were:

(a) variable declining with switchover

(b) variable declining

(c) straight line

(d) sum of the years-digits

For methods (a) and (b), an accelerated rate was determined for each of the types of equipment mentioned above.

Straight line depreciation was used for the medium density study. This is expressed as

$$\text{Annual Depreciation (\$)} = \frac{\text{Price-Residual}}{\text{Life (Yrs)}}$$

AVERAGE ROI ON CASH INVESTMENT

The rate of return on investment in this method was calculated by converging on a rate which, when applied in determination of the present value of a series of annual cash flows, equated the total present value to the amount invested. The program assumed cash flows to occur at year end, and the present value for each flow was computed as:

$$\text{Present Value (PV)} = \frac{\text{Flow}_I}{(1 + R)^I}$$

where I is the year of the flow. Hence the program iterated to find R such that

$$\text{Investment} = \sum_{I=1}^{\text{Life (Yrs)}} \frac{\text{Flow}_I}{(1 + R)^I}$$

where life = the economic life of the investment.

The basic investment was the sum of the purchases of the aircraft and/or spares and ground support equipment plus start-up costs and capitalized interest less the amount financed. Capitalized interest was that amount of interest which could have been earned by the airline had it not been required to make progress payments on the purchased aircraft. This interest was computed from the time of each payment and compounded monthly until the equipment's delivery.

The average return on investment was determined for the conceptual aircraft at 30, 50 and 70 seat configurations. As expected, ROI for the 70 passenger airplane was the highest at almost 10 percent by 1994. ROI's for the 30 and 50 seat aircraft by 1994 were -13.1 percent and 1.95 percent, respectively. The proposed 30 passenger airplane could not be operated without subsidy in the simulated medium density market of the study.

The assumptions used in determining the average return on investment for each airplane are given in Table 15-1. The results of the ROI analyses are presented graphically in Figure 15-1. The value of the return at any calendar year as shown in Figure 15-1 represents the cumulative earnings (or losses) of the aircraft plus its market value at that year all measured with respect to the original value of the aircraft. Each of the 50 and 70 passenger aircraft generated positive ROI values. The 30 passenger aircraft, however, generated a cumulative loss, as shown by the downward slope with time. A typical ROI exercise is shown in Section C.2 of Appendix C.

TABLE 15-1

ROI ASSUMPTIONS

	SEATS/AIRCRAFT		
	30	50	70
Number of Aircraft	1	1	1
Price ($M)	2.41	2.99	3.61
Delivery Date	1980	1980	1980
Economic and Depreciable Life	15	15	15
Start-up Costs ($000)	22.5	37.5	52.5
Residual (%)	15	15	15
Income Tax Rate (%)	48	48	48
Annual Passenger Utilization (Hrs)	2,860	2,845	2,835
Block Speed (mph)	308	319	319
Passenger Load Factor (%)	50	50	50
Yield (¢/rpm)	14.2	14.2	14.2
DOC Excl. Depreciation ($/mi)	1.11	1.23	1.38
IOC ($/mi)	1.24	2.05	2.83

15.2 Basic Subsidy Analysis and Considerations

The federal airline subsidy practices are summarized as follows: The Civil Aeronautics Board established the Class Rate VII as the fair and

FORM 25-BP-4 (REV 6-71)

PREPARED BY: JCV MODEL REPORT NO. REVISED

REFERENCE PAGE NO. DATE: 8-12-74

NASA MEDIUM DENSITY STUDY

COMPARATIVE RETURN ON INVESTMENT

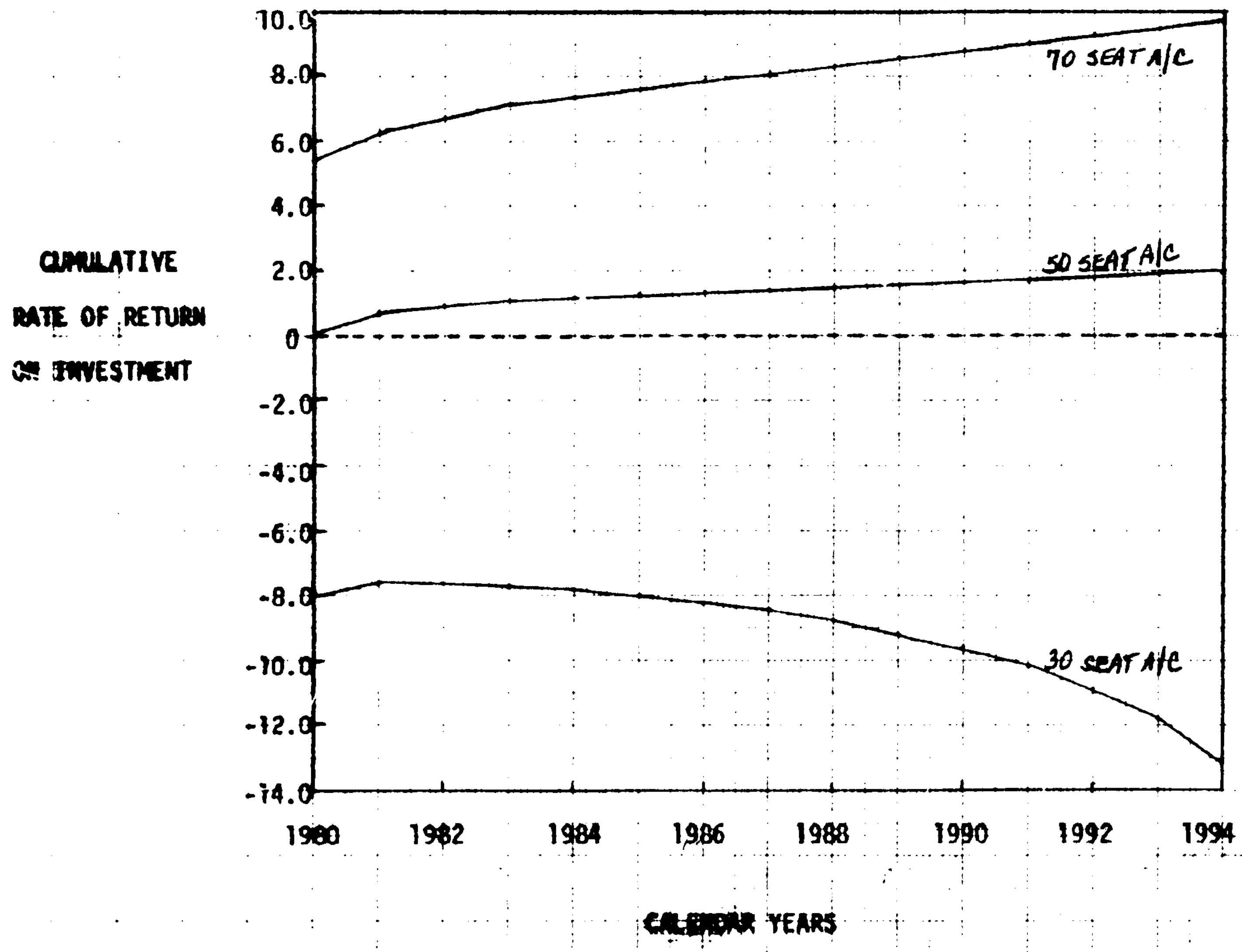


Figure 15-1

reasonable subsidy rate for the local service carriers on and after July 1, 1973. This formula provides for an equitable distribution of the subsidy payments among the eight local service airlines under subsidy at that time. The subsidy level provided for these carriers as of July 1, 1973 was $69.5 million under the Class VII rate. Calculation of this subsidy level determined a breakeven need of $36.9 million, a return provision of $29.9 million, federal income taxes of $8.2 million, excess profits offset of $5.3 million and ad hoc adjustments totaling $.2 million.

The Class rate VII formula used by the CAB in computing subsidy need is broken down into three parts:

- The basic formula which distributes the need of the subsidy eligible services (before federal income taxes) to the individual carriers,
- an allowance for federal income taxes for subsidy-eligible services, and
- a provision to offset excess earnings from the ineligible services against the gross need of the eligible services.

The formula also provides for a review and updating of the eligible services federal income tax allowance and the ineligible services excess earnings offset on a recurrent six-month basis during the life of the rate. These six-month reviews will allow for adjustments in the net subsidy payable to fluctuate as changes in the federal tax and profit offset amounts occur.

In the event of a fuel crisis, the formula is designed to automatically compensate for a reduction in predetermined services by reducing the subsidy payable. The CAB believes that the relationship established between revenues, expenses and investment will not materially change during periods of energy crisis operations.

The subsidy rate applicable to each carrier is based upon the subsidy-eligible services performed. Ineligible services are those operations performed with certification or exemption authorities under which the CAB has specifically excluded such operations from subsidy eligibility. This includes all charter operations and scheduled all-cargo services.

The formula identifies those services for which subsidy will be paid and relates the subsidy rate for operations between pairs of points to the traffic density. Subsidy eligible services are limited to a maximum daily average of two round trips in scheduled revenue passenger service between stations classified as: A-D, A-E, B-D, B-E, C-C, C-D, C-E, D-D, D-E, E-E. A station is classified upon the basis of its annual enplaned passengers as shown in the following tabulation:

STATION CLASSIFICATION

Class Rate VII Classification	Annual Enplaned Passengers	Hub Classification
A	1,600,632 or more	Large
B	400,158 to 1,600,631	Medium
C	80,032 to 400,157	Small
D	16,000 to 80,031	Nonhub
E	Less than 16,000	Nonhub

The maximum subsidy payable to a carrier limited to the gross formula payments plus the maximum federal tax allowance for subsidy-eligible services. The maximum subsidy payable is in lieu of, and not in addition to, the mail compensation received by the operators for mail transported over their entire systems on and after July 1, 1973.

SUBSIDY NEED DISTRIBUTION

The distribution of subsidy to the local service industry and the individual carriers is based upon the following formula as a function of traffic density. In applying the formula, only stations with service on five or more days per week are included. Stations in this category are handled as stations with a daily average of one departure.

A. Subsidy Need Recognized for Subsidy Eligible Services as of July 1, 1973:

- $40,000 annually X number of stations served with a daily average of one departure.
- $60,000 annually X number of stations served with daily average departures greater than one.
- $95.00 X number of departures flown.
- $1.89 X revenue plane miles (airport to airport mileage)

A = the sum of 1, 2, 3 and 4.

B. Passenger Revenue Anticipated from Subsidy Eligible Services as of July 1, 1973:

- $5.70 X revenue passengers flown (standard passenger load X number of departures per pair of stations).
- $ .06 X revenue passenger miles (standard passenger load X revenue plane miles).

B = the sum of 5 and 6.

A carrier's computed need from this formula is based on its relative position in the industry. This position is determined from the number of eligible services performed, its traffic density and its revenue/cost relationship. The revenue and costs used in the formula reflect reported industry averages keyed to service with an average aircraft with 44 seats.

Actual Subsidy Need

Therefore, the subsidy need computed on the operational factors is reduced by the revenues related to passengers carried and passenger miles flown. This net result is adjusted to compensate for variations between the formula rate based on industry averages and actual individual carrier needs as substantiated by financial and traffic data provided to the CAB.

Reported actual carrier results are presented to the CAB for scheduled subsidy eligible and ineligible services as well as nonscheduled operations. All data is also submitted by city pair and aircraft type allocated to each type of service.

The actual subsidy need determined by applying the Class VII rate against reported actuals is further adjusted by federal income tax allowances, excess profits offset, ad hoc provisions, and maximum subsidy payable limitations.

FEDERAL INCOME TAX PROVISION

An individual carrier's subsidy need will be increased where applicable by an allowance for taxes. Federal income taxes will be paid to carriers determined to be in a tax position in subsidy eligible services. Carriers actually incurring a Federal income tax liability for eligible operations exclusive of allowable investment tax credits will be in a tax position.

The determination of the taxes allowable is based upon an evaluation of the carrier's filed actual federal income tax return, and/or on the basis of a pro forma tax return filed with the Board demonstrating the exhaustion of available tax carry-forward credits. The Board will accept tax credits as they appear on the carriers' tax returns. It will not provide in subsidy rates for the payments of direct taxes to:

- revenues not related or considered to be generated by air carrier activities (not considered "other revenue"),
- income from non-transport ventures and subsidy ineligible certificated services not otherwise considered in the determination of the carrier's subsidy needs, nor
- capital gains on the disposition of flight equipment.

EXCESS PROFITS OFFSET

The subsidy payable to the carrier was reduced by the amount of excess profits from the carrier's services ineligible for subsidy. Commencing on and after January 1, 1974, the amount of reduction was based on the governments' share of profits in excess of 12.35 percent after federal taxes.

The recognized return before offset is based on 12.35 percent times the carrier's recognized investment. The recognized system investment is determined from the weighted average of the five quarterly system balance sheets reported for the period under review. The average system investment is allocated to subsidy ineligible services by the proportion of revenue hours flown in ineligible services by aircraft type. Recognized profit is based upon the reported operating profit in ineligible services for the review period.

Subsidy payments including federal tax allowances are reduced by the government's share in excess profits. The government share is 50 percent of the recognized profit from ineligible services less the sum of the recognized return and any applicable federal taxes.

AD HOC PROVISIONS

When a carrier's operating authority in its subsidy eligible service is changed with a projected impact of $100,000 or more on the subsidy payments due and payable, the Board may make an appropriate ad hoc amendment to the ceiling provisions of this rate. It will make adjustments downward on its initiative, and upward only on request from the carrier.

MAXIMUM SUBSIDY PAYABLE

The subsidy payments made to the local service industry is limited by the sum of the gross formula payments and maximum Federal income tax allowance determined for subsidy-eligible services.

APPLICATION OF CLASS VII SUBSIDY RATE TO MEDIUM DENSITY STUDY

Due to the complexity of the Class VII subsidy rate as demonstrated above, an alternative formula is presented for use in determining the relative subsidy needs of competitive aircraft in comparison with the final basepoint airplane. The operational simulation model used in the final evaluation to simulate the local service industry through 1994 was not subject to the classification of services by city pair into subsidy eligible and ineligible operations. It was impossible to predict which city pairs were subsidy eligible because the traffic data was aggregated into elements classified by range.

Data for use in determining the recognized system investment in ineligible subsidy services and the excess profits recognized for offset are obviously not available for each local service carrier in the base year 1980. It would be unrealistic to attempt to forecast the fleet decisions each airline management will make between 1974-1980. Alternative aircraft choices, unlimited financing techniques including the rental or lease of equipment, as well as unknown airline strategies would preclude any realistic assessment of the industry's investment base by 1980.

Since the purpose of determining subsidy requirements was critical to the relative economic viability of the final design basepoint aircraft against competitive airplanes, a formula was adopted to estimate a gross subsidy need. The subsidy need is based strictly upon the aircraft and its characteristics. The formula developed for this is:

$$\text{Revenue} - (\text{DOC} + \text{IOC}) - \text{Return} = \text{Aircraft Subsidy Need}$$

A fair annual return of 12.35 percent of the investment in an aircraft was considered for each aircraft type. This investment in an aircraft included the estimated selling price plus the cost of spares less a residual value of 15 percent. The airplanes had an estimated service life of 15 years equal to the depreciation period used in calculating DOC's. Therefore, the annual return was determined as follows:

$$\text{Return} = \frac{(\text{A/C Cost} + \text{Spares} - \text{Residual Value}) \times 12.35\%}{\text{Depreciation Period}}$$

The results of the application of this method are included in the competitive fleet evaluations in Section 16.0, Aircraft Operations and [illegible] Viability.

16.0 AIRCRAFT OPERATIONS AND ECONOMIC VIABILITY

The final simulation analyses were conducted with the network and mission model created for the evaluation of the selected aircraft. Various combinations of contemporary existing and near-term and the basepoint aircraft were included in the simulation program. Cost sensitivity studies were conducted to evaluate the effect of fleet load factors targeted at 60 percent, potential savings in maintenance, variations in the IOC to revenue ratio, and the effect of reductions in crew costs for the final design 30 passenger aircraft. A 50 passenger basepoint turboprop aircraft also was simulated in competition with the all-jet contemporary and study aircraft.

The composition of three simulation schedules is contained in Table 16-1. Nine existing and near-term aircraft comprised the mixed fleet inventory. Exclusion of turboprop aircraft yielded the all-jet fleet. The addition of the study aircraft to the all-jet fleet inventory formed the third schedule. In the operational simulation, a fleet solution was chosen from available inventory to satisfy the following criteria:

- o Aircraft must fly at least the number of flights scheduled in 1974.
- o The achieved load factor must not exceed a target of 50 percent.
- o The aircraft must have a design range greater than or equal to each range element to be flown in the mission model.

Each aircraft was simulated operationally on each of the elements to meet the criteria above. The aircraft chosen was the one which accomplished the task (schedule, RPM and load factor) at the lowest possible cost.

16.1 Final Network and Mission Model

The airline network mission model was drawn from published schedules

TABLE 16-1

1980 - 1990 OPERATIONAL SIMULATION
COMPETITIVE SCENARIO

AVAILABLE AIRCRAFT	SIMULATION SCHEDULES		
	MIXED FLEET	ALL-JET FLEET	ALL-JET + Mσ FLEET
SD-3-30 (TP)	X		
DHC-7 (TP)	X		
CONVAIR 580 (TP)	X		
F-27 MK 500 (TP)	X		
FALCON 30	X	X	X
VFW - 614	X	X	X
F-28 MK 1000	X	X	X
HS-146	X	X	X
DC-9-30	X	X	X
MEDIUM DENSITY SYSTEM STUDY AIRCRAFT:			
M-30			X
M-40			X
M-50			X
M-60			X
M-70			X

NOTE: M-30 refers to 30 passenger aircraft, etc., to M-70.

M σ is symbol for the medium density transportation study aircraft.

for nine regional U.S. airlines and 21 scheduled commuter airlines. The base year was 1974 with demand expressed as revenue passenger mile demand on 1,687 airport-pairs. For convenience in the simulation program, the data were assembled into 122 elements classified by range intervals and type (seat capacity) of aircraft scheduled in August 1974. To preserve a low-density segment in the network, the traffic demand was constant on all elements derived from the 21 commuter lines. This simulated a constant traffic base at the low end of the medium density market. All of the traffic on the rest of the network was expanded to represent an annual growth rate through the simulation period. Pertinent data for 1980 and 1985 are shown in Table 16-2. "Competitive Network Mission Model". Typical mission model data are shown in Tables B-6 to B-8, Appendix B, Section B.3.

16.2 Competitive Fleet Simulation Characteristics

Economic charateristics for all aircraft used in the competitive analysis have been expressed in terms of 1974 dollars. Four existing or near-term turboprop aircraft plus five jet aircraft were used as available aircraft for competitive simulation. Competing against these were five medium density study aircraft. These latter were the basepoint 50 seat aircraft plus four size derivatives. Data on the existing and near-term aircraft were derived from published sources such as Flight International magazine and related manufacturer's brochures. All of the cost functions were expressed with 1974 fuel costs of 22 cents per gallon. Both DOC and block time functions were expressed by a slope/intercept equation for the distances in the airline network mission model. Table B-11, Section B.4 of Appendix B contains details of the operating costs of the five final design basepoint and derivative aircraft.

TABLE 16-2

COMPETITIVE NETWORK MISSION MODEL

	1980			1985		
	REGIONAL CARRIERS	COMMUTER CARRIERS	TOTAL NETWORK	REGIONAL CARRIERS	COMMUTER CARRIERS	TOTAL NETWORK
MINIMUM AIRCRAFT TRIPS SCHEDULED - (MILLIONS)	1.594	0.344	1.938	1.594	0.344	1.938
SEAT MILES SCHEDULED (BILLIONS)	24.755	.517	25.272	31.595	0.517	32.112
AVERAGE LOAD FACTOR (PERCENT)	52.5	60.0	52.65	52.5	60.0	52.62
REVENUE PASSENGER MILES (BILLIONS)	12.997	0.310	13.307	16.587	0.310	16.897

DATA PROJECTED FROM 1974 BASE

1637 AIRPORT PAIRS WITH TWO-WAY SERVICE

16.2.1 Contemporary Fleet

Data developed for the existing and near-term aircraft are included as Table 16-3, "Economic Data for Existing and Near-Term Contemporary Aircraft". The estimates are the best approximations to 1974 cost levels which were attainable from the data sources previously mentioned. The Convair 580 data was drawn essentially from 1973 CAB sources, and represents a composite experience of several airlines. Detailed performance data and aircraft characteristics for the contemporary turboprop and turbofan aircraft are presented as graphs and tables in Section A.4 of Appendix A.

16.2.2 Medium Density Derivative Fleet

Pertinent economic data on each of the study aircraft are listed in Table 16-4. The 50 passenger aircraft was the final result of the aircraft basepoint design study. The price of the aircraft was generated for a pricing unit of 400 in the CAPDEC program. The block time function resulted from a flight performance analysis at the mission design range. Data on each of the other configurations was derived from the 50 passenger version.

16.3 Results of Operational Simulation

All of the simulations conducted in the final phase of this study were in the competitive mode with the final network and mission model. In each of the competitive fleet evaluations, the approach was to match each aircraft in an available inventory against the traffic demand in each mission model element. The aircraft was selected which provided the service at the least cost. Fleet statistics resulted from the summation of results for each year in the operational period. Various combinations of contemporary and basepoint aircraft are reported in sections which follow.

TABLE 16-3

ECONOMIC DATA FOR EXISTING AND NEAR-TERM

CONTEMPORARY AIRCRAFT

AIRCRAFT	RANGE (N Mi/Km)	SEATS	UNIT PRICE ($ Mil)	BLOCK TIME FUNCTION (Hr)	DOC FUNCTION ($ Per Trip)
F-27 (TP)	810/1498	56	2.1	0.2 + .0043 x R	41.32 + 0.888 x R
CV-580 (TP)	880/1628	52	0.7	0.2 + .0036 x R	89.88 + 1.618 x R
DHC-7 (TP)	768/1421	48	2.83	0.2 + .0044 x R	55.02 + 1.210 x R
SD-3-30 (TP)	320/592	30	1.3	0.2 + .00467 x R	29.93 + 0.699 x R
FALCON 30	780/1443	30	2.8	0.2 + .00246 x R	82.63 + 1.016 x R
VFW-614	650/1202	40	3.6	0.2 + .00262 x R	96.05 + 1.169 x R
F-28 MK 1000	1125/2081	60	4.6	0.2 + .00244 x R	109.25 + 1.424 x R
HS-146	1200/2220	71	5.5	0.2 + .00247 x R	145.39 + 1.796 x R
737/DC-9 Type	1600/2960	100	5.4	0.2 + .00244 x R	100.53 + 1.226 x R

TABLE 16-4

ECONOMIC DATA FOR MEDIUM DENSITY AIRCRAFT

AIRCRAFT	RANGE (N Mi)	SEATS	UNIT PRICE ($ Mil)	BLOCK TIME FUNCTION (Hr)	DOC FUNCTION ** ($ Per Trip)
M.D. 30	850*	30	2.37	0.2 + .00256 x R	77.80 + 0.930 x R
M.D. 40	850	40	2.73	0.2 + .00256 x R	85.84 + 0.999 x R
M.D. 50	850	50	3.08	0.2 + .00256 x R	93.98 + 1.068 x R
M.D. 60	850	60	3.59	0.2 + .00256 x R	97.90 + 1.071 x R
M.D. 70	850	70	3.79	0.2 + .00256 x R	111.13 + 1.210 x R

* 850 N. Mi. = 1,572 Km.

** DOC functions based on aircraft prices at 400 units of production.

16.3.1 Contemporary Fleet

Simulation results are presented in Table 16-5 for the mixed turboprop/turbojet fleet for the year 1985. Out of all aircraft made available, three aircraft were picked. These were the Short SD-3-30 Turboprop, the Fokker F-27 MK500 turboprop, and the 737/DC-9-30 type turbofan aircraft. A total fleet of 757 was projected for 1985. The SD-3-30 generated a loss for the year. At a 50 percent load factor and the fare levels used, the DOC and IOC exceeded the passenger revenue generated. In contrast, the F-27 and the 100 passenger jet generated profitability indexes of 11.61 and 9.29 percent respectively. These results were based on fleet costs as shown in the table. The turboprop aircraft were chosen to fly the shorter routes. Examination of the RPM reveals a dominant role for the 100 passenger jet. Assignment of the shorter range turboprop aircraft reflected matching of performance characteristics to the mission model requirements.

16.3.2 All-Jet Contemporary Fleet

The all-jet contemporary fleet was tested as a base case to reflect airline consultant recommendations. During the course of the study, mention was made several times that the regionals generally desired an all-jet fleet. Simulation results for 1985 continued to show the dominance of the 100 passenger jet aircraft as shown in Table 16-6. The Falcon 30 and VFW-614 shared the short-range elements in the model. However, each of these operated at a relative loss as shown by the ratio of profit to fleet investment in percent. Note that the 737/DC-9-30 aircraft in all-jet competition was assigned a share of the market flown by turboprops in the previous analysis. This resulted in a larger fleet of 100 passenger aircraft, larger total profits, but a lower profitability index. This reflects assignment to shorter

TABLE 16-5

COMPETITIVE OPERATIONAL SIMULATION
MIXED FLEET - 1985

	SELECTED AIRCRAFT			
	SD-3-30	F-27 MK 500	DC-9-30	TOTAL
NUMBER AIRCRAFT REQUIRED	103	326	328	757
REVENUE PASSENGER MILES GENERATED (BILLIONS) (RPKM)	0.535 (0.861)	3.026 (4.869)	13.336 (21.458)	16.897 (27.187)
REVENUE GENERATED ($ MILLIONS)	97.666	525.811	1318.271	1941.747
ANNUAL PROFIT ($ MILLIONS)	-1.512	79.369	164.579	242.435
FLEET INVESTMENT ($ MILLIONS)	133.900	683.902	1771.200	2589.001
PROFIT/FLEET INVEST. (%)	-1.13	11.61	9.29	9.36
AIRCRAFT UTILIZATION (HOURS/YEAR)	2759	2103	2360	2304
AVERAGE STAGE LENGTH (STAT. MILES) (KM)	79 (127)	85 (137)	260 (418)	181 (291)

SYSTEM LOAD FACTOR TARGET = 50%

1687 TWO-WAY ROUTES

TABLE 16-6

COMPETITIVE OPERATIONAL SIMULATION
ALL-JET FLEET - 1985

	SELECTED AIRCRAFT			
	FALCON 30	VFW - 614	DC-9-30	TOTAL
NUMBER AIRCRAFT REQUIRED	95	16	493	604
REVENUE PASSENGER MILES GENERATED (BILLIONS) (RPKM)	0.486 (0.782)	0.122 (0.196)	16.289 (26.209)	16.897 (27.187)
REVENUE GENERATED ($ MILLIONS)	84.886	21.855	1835.005	1941.746
ANNUAL PROFIT ($ MILLIONS)	-43.269	-6.130	232.537	183.139
FLEET INVESTMENT ($ MILLIONS)	265.021	59.222	2660.834	2985.077
PROFIT/FLEET INVEST. (%)	-16.33	-10.35	8.74	6.14
AIRCRAFT UTILIZATION (HOURS/YEAR)	2019	2006	2173	2144
AVERAGE STAGE LENGTH (STAT. MILES) (KM)	85 (137)	81 (130)	189 (304)	181 (291)

SYSTEM LOAD FACTOR TARGET = 50%

1687 TWO-WAY ROUTES

routes on which its DOC was relatively higher than on the longer average route in the prior analysis.

16.3.3 All-Jet Contemporary and Derivative Fleet

Simulation results for the contemporary and medium density all-jet fleet are presented in Table 16-7. Again, the 100 passenger jet was selected for the bulk of the market. The basepoint and derivative aircraft supplanted the Falcon 30 and VFW-614. This would be indicative of these derivatives being designed more specifically for this market. In 1980, the 30 passenger (M 30) candidate jet was selected in the largest number of all the conceptual aircraft available. A few 40 seat aircraft plus some 40 of the 60 seat vehicle completed the fleet selection. Note that the relative return was very negative for the smaller aircraft. The 60 passenger aircraft operated at a slight profit.

The appropriate fleet mix in 1985 shows a lower number of 30 passenger aircraft, a slightly larger requirement for the 40 seat aircraft, with the 50 seat aircraft required also. In 1990, all four of the aircraft are required for the least-cost fleet mix. Only the 60 seat aircraft is profitable to complement the profitability of the 100 passenger 737/DC-9 class. The relative share of traffic generated by these fleets is shown in Tables 16-8, 16-9, and 16-10 for the respective years 1980, 1985, and 1990. The results for each year are an independent solution with respect to prior years.

The generation of load factors of less than 0.5 or 50 percent was a result of aircraft assignment to routes with a requirement to provide at least the same number of trips as flown in 1974. Since there were commuter type, low density routes included in the mission model at zero growth rates, trips needed to serve routes had the overall effect of maintaining low load factors through the entire simulation period.

TABLE 16-7

COMPETITIVE OPERATIONAL SIMULATION
ALL-JET PLUS MEDIUM DENSITY FLEET

AIRCRAFT	1980		1985		1990	
	FLEET SIZE	PROFITABILITY INDEX	FLEET SIZE	PROFITABILITY INDEX	FLEET SIZE	PROFITABILITY INDEX
DC-9-30	299	9.41	404	10.71	521	11.02
M - 30	91	-19.13	75	-18.77	55	-20.57
M - 40	5	- 7.37	16	-9.94	23	-8.87
M - 50	-	-	5	- 2.12	13	-5.56
M - 60	42	2.98	-	-	5	3.54
FLEET TOTAL	437	5.72	500	8.09	618	9.00

SYSTEM LOAD FACTOR TARGET = 50%

1687 TWO-WAY ROUTES

TABLE 16-8

ALL-JET COMPETITIVE FLEET

TRAFFIC STATISTICS

1980

Aircraft	Trips (Million)	RPM (Billion) (RPKm)	Profit ($ Million)	Load Factor	Average Stage (St. Miles) (Km)
M 30	0.579	0.544 (0.875)	-41.339	0.365	85 (137)
M 40	0.030	0.049 (0.079)	- 0.940	0.484	84 (136)
M 60	0.233	0.738 (1.187)	4.515	0.498	106 (171)
DC-9-30	1.310	11.976 (19.269)	151.855	0.474	200 (322)
TOTAL	2.152	13.307 (21.411)	114.091	0.470	180 (290)

TABLE 16-9

ALL-JET COMPETITIVE FLEET

TRAFFIC STATISTICS

1985

Aircraft	Trips (Million)	RPM (Billion) (RPKm)	Profit ($ Million)	Load Factor	Average Stage (St. Miles) (Km)
M 30	0.463	0.471 (0.758)	-33.365	0.375	90 (145)
M 40	0.115	0.138 (0.222)	- 4.436	0.436	69 (111)
M 50	0.030	0.063 (0.101)	- 0.308	0.494	84 (136)
DC-9-30	1.779	16.226 (26.108)	233.649	0.489	190 (307)
TOTAL	2.388	16.897 (27.187)	195.540	0.484	181 (291)

TABLE 16-10

ALL-JET COMPETITIVE FLEET

TRAFFIC STATISTICS

1990

Aircraft	Trips (Million)	RPM (Billion) (RPKm)	Profit ($ Million)	Load Factor	Average Stage (St. Miles) (Km)
M 30	0.345	0.310 (0.499)	-26.938	0.338	88 (141)
M 40	0.150	0.221 (0.355)	- 5.582	0.453	80 (129)
M 50	0.086	0.153 (0.246)	- 2.298	0.438	81 (130)
M 60	0.031	0.078 (0.125)	0.624	0.500	84 (136)
DC-9-30	2.147	20.317 (32.609)	310.041	0.499	190 (307)
TOTAL	2.758	21.079 (33.916)	275.846	0.495	181 (291)

Of the four sizes of conceptual aircraft chosen, only the 60 passenger aircraft was profitable in the simulations.

The apparent shift in kinds of aircraft required was a result of the mechanics of the simulation model. The solution for each year is an independent, least-cost solution. Thus, the introduction of a new size has the apparent effect of displacing other aircraft from a previous year.

Another simulation was made with a target load factor of 60 percent. Fleet statistics resulting from this exercise are reproduced in Tables 16-11 16-12, and 16-13.

In the 1980 fleet mix, the larger load factor permitted the 70 passenger aircraft to be selected - in contrast to the 50 percent load factor solution. This size, however, was only marginally attractive compared with the 60 seat vehicle in terms of importance in the fleet solution. The 60 seat aircraft generated almost one-fourth of the trips, about one-sixth of the RPM, and about 13 percent of all positive profits. The 30 passenger aircraft was still nominally unprofitable, as in previous analyses.

A 1985 solution showed the 40 seat aircraft called in to serve some routes, although at a loss. The 60 and 70 seat aircraft shared their portions of the market with almost equal profitability.

The 1990 solution shifted to a mostly B-737/DC-9 type solution, with the 60 seat aircraft providing an insignificant share of the 70 seat losing its share of the market completely. A summary of these results is presented in Table 16-14.

TABLE 16-11

ALL-JET COMPETITIVE FLEET

TRAFFIC STATISTICS

60% LF - 1980

Aircraft	Trips (Million)	RPM (Billion) (RPKm)	Profit ($ Million)	Load Factor	Average Stage (St. Miles) (Km)
M 30	0.610	0.593 (0.954)	-42.076	0.377	85 (137)
M 50	0.114	0.355 (0.571)	2.399	0.596	105 (169)
M 60	0.481	2.016 (3.244)	27.840	0.589	119 (191)
M 70	0.011	0.121 (0.195)	1.251	0.600	260 (418)
DC-9-30	0.806	10.222 (16.447)	181.709	0.583	221 (355)
TOTAL	2.021	13.307 (21.411)	171.123	0.570	180 (290)

TABLE 16-12

ALL-JET COMPETITIVE FLEET

TRAFFIC STATISTICS

60% LF - 1985

Aircraft	Trips (Million)	RPM (Billion) (RPKm)	Profit ($ Million)	Load Factor	Average Stage (St. Miles) (Km)
M 30	0.578	0.608 (0.978)	-36.306	0.409	84 (136)
M 40	0.031	0.063 (0.101)	- 0.078	0.60	84 (136)
M 60	0.120	0.453 (0.729)	7.333	0.60	105 (169)
M 70	0.101	0.475 (0.764)	7.739	0.597	113 (182)
DC-9-30	1.373	15.299 (24.616)	286.136	0.576	199 (320)
TOTAL	2.202	16.897 (27.187)	264.823	0.569	181 (291)

TABLE 16-13

ALL-JET COMPETITIVE FLEET

TRAFFIC STATISTICS

60% LF - 1990

Aircraft	Trips (Million)	RPM (Billion) (RPKm)	Profit ($ Million)	Load Factor	Average Stage (St. Miles) (Km)
M 30	0.460	0.505 (0.812)	-30.372	0.406	90 (145)
M 40	0.118	0.179 (0.288)	- 1.617	0.544	70 (113)
M 60	0.030	0.078 (0.125)	0.780	0.516	84 (136)
DC-9-30	1.830	20.317 (32.609)	409.367	0.591	190 (307)
TOTAL	2.438	21.079 (33.916)	378.158	0.584	181 (291)

TABLE 16-14

COMPETITIVE OPERATIONAL SIMULATION WITH 60 PERCENT LOAD FACTOR

CONTEMPORARY ALL-JET PLUS FINAL DESIGN BASEPOINT AND DERIVATIVE AIRCRAFT

	1980		1985		1990	
Aircraft	Fleet Size	Profitability Index	Fleet Size	Profitability Index	Fleet Size	Profitability Index
DC-9/B-737 Type	236	14.26	303	17.49	406	18.67
M 30	96	-18.5	91	-16.83	74	-17.23
M 40	--	--	5	- 0.60	--	--
M 50	20	3.82	--	--	--	--
M 60	93	8.37	22	9.42	5	4.57
M 70	3	11.01	19	10.70	--	--
FLEET TOTAL	448	8.96	440	13.14	502	15.55

16.3.4 Evaluation of Subsidy Needs - 1980 Fleet

The simplified subsidy analysis approach discussed in Section 15.2 was applied to the 1980 competitive fleet. Details of the economic results are shown in Table 16-15.

TABLE 16-15

FLEET ECONOMIC DATA - 1980

ALL-JET COMPETITION

Aircraft	Fleet Cost ($ Millions)	Net Operating Income ($ Millions)
B-737/DC-9 Type	1,614.000	151.000
M-30	216.143	- 41.339
M-40	12.750	- 0.940
M-60	151.755	+ 4.515

The subsidy formulae applied are:

$$\text{Subsidy Need} = \text{Revenue} - \text{DOC} - \text{IOC} - \text{Return}$$

$$\text{Return} = \frac{\text{Fleet Cost} + \text{Spares} - \text{Residual} \times 0.1235}{15}$$

With 10 percent spares and a 15 percent residual value, the computations of return and subsidy for the M-30 are:

$$\text{Return} = \frac{(216.143 + 21.614 - 33.421) \times 0.1235}{15}$$

$$= \$\ 1.684 \text{ (million)}$$

$$\text{Subsidy Need} = 95.122 - 136.461 - 1.684$$

$$= -43.023 \text{ (million)}$$

Subsidy needs for the M-40 and M-60 were computed in the same manner. The subsidy needs for all three aircraft are summarized in Table 16-16.

TABLE 16-16

SUBSIDY NEEDS - 1980 FLEET

Aircraft (Fleet)	Fleet Profit ($ Millions)	Return ($ Millions)	Subsidy Need ($ Millions)
M-30 (91)	- 41.339	- 1.684	- 43.023
M-40 (5)	- 0.940	- 0.100	- 1.040
M-60 (42)	+ 4.515	- 1.187	+ 3.328
		TOTAL	- 40.735

A gross subsidy need for this fleet was $40.735 million. Since the calculations above resulted in a negative number, a positive number would have indicated no need for subsidy. The data for the B-737/DC-9 type aircraft have been excluded from these computations.

16.3.5 Potential Maintenance Savings

The maintenance concept for the 50 passenger medium density transportation aircraft was based upon the same design philosophy used for the DC-9 and DC-10. This design philosophy incorporated maintainability characteristics that feature system simplicity, reliability and accessibility.

The DC-10 maintenance program was formulated under the guidelines of the airline/manufacturers Maintenance Program Planning Document No. MSG-2, approved by the FAA and employed by the airline operators. On the DC-10 program, the three primary maintenance processes were broken down into the following percentages:

"Hard Time" or Scheduled Overhaul	-	less than 1% (7 items)
Condition Monitor	-	68%
On-Condition	-	32%

A similar program was developed for the medium density transportation aircraft, it closely approximated the DC-10 percentages above. The maintenance program for the baseline 50 passenger aircraft consisted of both scheduled and unshceduled tasks. Table 16-17 reflects the scheduled program and consists of a service check, an "A" check, and a "C" check with the structural inspection program.

The service check is performed prior to each flight and is for the purpose of refueling the aircraft, routine replacement of expendable fluid and gases, servicing of potable water, lavatory and galley systems and walk around inspection for obvious damage or discrepancy.

The "A" check (walk around) is performed each 100 flight hours. This check is a general visual inspection for conditon of the entire exterior/interior of the aircraft with spoilers, flap, and slats and main landing gear door open to check for obvious fluid leaks, structural damage and other items affecting aircraft serviceability. The interior aspect includes a visual inspection of the cockpit, cabin, galley, and cargo area for obvious items affecting aircraft serviceability.

The "C" check (area check) is performed each 1,000 hours and consists of a visual inspection of the entire aircraft by specific area and is made to locate discrepancies such as damage, leaks, hose connections, corrosion and abrasion which are visible without removal of equipment or access doors except those listed on the work cards. This inspection includes the interior of all

TABLE 16-17

SCHEDULED INSPECTIONS

Inspection Period	Inspection Frequency	Engines*	Elapsed Time: Hours Out of Service	Elapsed Time: Man Hours	Est. Maint.-Man Hours/Flight-Hr.
Line Maintenance and Service	Prior to first flight or as necessary		--	--	0.30
A	100 hours	OC	4	50	0.50***
C	1,000 hours	OC	36**	1,116	1.12***
SSI***	4,000 hours				
	8,000				
	12,000				
	16,000				
				TOTAL	1.92

* Engine maintenance programs have progressed from the arbitrary setting of TBO limits for engine overhaul to a systematic maintenance reliability program which subjects engines to an On Condition (OC) checking process (threshold sampling, on condition test/inspection, and condition monitoring processes).

** The hours out of service can be broken down into smaller segments if desired by the operator.

*** Structural significant inspection items are included in appropriate intervals of the "A" and "C" check periods. The time for these items is included in each of the time estimates.

equipment compartments and the engines with cowling doors opened in addition to the flight controls, hydraulic systems and service panels. Control cables are inspected at multiples of this inspection. Radiographic engine inspection and engine heavy maintenance will be accomplished on the engines as required by the engine manufacturer.

The structural inspection is performed at the intervals indicated in Table 16-16 in conjunction with the "C" check and consists of an "internal" and "external" inspection to assure the structural integrity of the airframe. One hundred percent of the fleet will receive an external inspection of those items of structure which are designated by the manufacturer to be significant. The external inspection also supports the internal sampling by providing some probability of the adjacent internal items condition.

The "internal" inspection of the structure provides structural integrity at an economical cost through fleet sampling. Only those items of internal structure designated by the manufacturer will be inspected. The size of the sampling is also established by the manufacturer and is determined by the significance of the item to be inspected, i.e., the more significant the item, based on fatigue, corrosion, crack propagation, redundancy, the larger the sample size.

The unscheduled maintenance will consist primarily of removing, replacing or repairing those discrepancies discovered during flight or the above scheduled maintenance periods. The man-hours required for unscheduled maintenance will be kept to a minimum by the use of Built-In-Test Equipment (BITE), and Flight Environment Fault Indication/Turnaround Fault Identification (FEFI/TAFI) which is a concept for fault identification and isolation that will isolate the problems to a Line Replaceable Unit (LRU) and then verify the repair after the failed LRU is removed and replaced by a known good spare. This concept of removal and replacement of LRU's will allow maximum aircraft availability and permit the shops to accomplish repair of the faulty LRU at a more convenient time.

The maintenance tasks for the aircraft were planned to be consistent with the airlines' present organizational structure. The service check and "A" check plus removal and replacement of LRU's which cannot be deferred can be accomplished at any airport that has turnaround capabilities. These maintenance functions generally may be accomplished by maintenance personnel with ordinary skill levels. The "C" checks, structural inspection program, engine heavy maintenance, and replacement of deferred LRU's may be accomplished at a maintenance base which has shop level capability and skilled mechanics. The DC-9-10 maintenance plan, developed from detailed reliability, maintainability and maintenance planning analysis plus actual airline performance data, was used to derive the direct maintenance cost estimates for the baseline medium density aircraft.

In the DOC routine adopted for the medium density study, a slightly more conservative assumption was used for maintenance costing. The savings resulting from the more detailed examination are shown in Table 16-18.

16.3.6 Indirect Operating Cost Sensitivity

All of the analyses on aircraft profitability were conducted with a ratio of IOC to passenger revenue at a 58 percent level. In order to evaluate the effects of lower and higher IOC ratios, a simulation was conducted on the all-jet contemporary plus the basepoint 30, 40, and 50 seat aircraft. Fleet sizes were unaffected, with the only effect being on the profitability indexes.

Ratios of 45 percent and 65 percent were used. Results showed that with lower IOC, profits were greater or losses of lower magnitude. Increased IOC reduced profits and increased the loss indexes. These results are tabulated in Table 16-19, "IOC Versus Fleet Profitability".

TABLE 16-18

MAINTENANCE IMPROVEMENT VERSUS DOC

FOR 50 PASSENGER AIRCRAFT

	Costs Per Flight Hour
Airframe and Engine Maintenance	
Medium Density DOC Method	$ 89
Revised Maintenance Estimate	71
Reduction	$ 18

This represents a four (4) percent savings in DOC

TABLE 16-19

IOC VERSUS FLEET PROFITABILITY

	Profitability Index (%)		
Percent IOC to Revenue:	45%	58%	65%
Fleet Aircraft			
B-737/DC-9	21.6	10.7	4.9
M-30	-13.0	-18.8	-21.9
M-40	- 2.0	- 9.9	-14.2
M-50	7.7	- 2.1	- 7.4

16.3.7 Crew Cost Reduction Potential

A survey was made to compare crew costs of the commuter airlines with the regional and trunk carriers. In the DOC routine used for this study, an assumption was made to estimate crew costs on the same base as pertinent to local service and trunk airlines. The flight crew cost was estimated for a 30 to 70 passenger aircraft with the same formula as for a DC-9 or larger class of aircraft. By contrast, crew salaries for the commuter lines used in the final evaluation mission model were generally about $1,350 to $1,400 per month. This level was between one-third to one-half lower than the regional pay scales. Table 16-20, "Crew Cost Versus Fleet Profitability", reveals the effect of assuming a 50 percent reduction in crew costs for a fleet of 91 of the 30 passenger study aircraft. The profit level is from the competitive fleet evaluation for 1980, Table 16-8. The fraction of DOC attributable to crew costs was shown to be 45 percent as listed in Table 14-3, "Direct Operating Cost/Airplane Mile" (Section 14.3). The effect of reducing crew costs by one-half was to reduce the annual loss from $41.3 million to $23.4 million, a net reduction in DOC of $17.9 million.

TABLE 16-20

CREW COST VERSUS FLEET PROFITABILITY

30 Passenger Aircraft

1980

	Study DOC Crew Cost Method ($ Millions)	Reduction of 50% in Crew Cost ($ Millions)
Revenue	95.1	95.1
DOC	81.2	63.3
IOC	55.2	55.2
GROSS PROFIT	-41.3	-23.4

16.3.8 All-Jet Fleet versus Study Turboprop Aircraft

The 50 passenger, 2 x 250 nautical mile range turboprop aircraft was evaluated in competition with the all-jet contemporary and final design study aircraft. Detailed characteristics of the turboprop configuration were listed in Table 12-15, Section 12.0. The block time and DOC functions are:

$$T_B = 0.12 + 0.00309 \times R$$

$$\$/Trip = 77.30 + 1.056 \times R$$

with R in nautical miles.

Competitive simulation results are shown in Table 16-21 for the separate years 1980, 1985, and 1990. The dominance of the DC-9 type aircraft is noted by the large fleet requirements. The turboprop 50 passenger was selected over the study turbofan, even though the range of the turbofan is 850 as against 563 nautical miles for the turboprop versions. In contrast with the all-jet results shown in Table 16-7, the turboprop configuration reduced requirements for the 40 passenger aircraft by one (1) in 1980, three (3) in 1985, and five (5) in 1990. The 60 passenger fleet size was not changed. Thus, with better operating costs, a turboprop configuration should be expected to displace the same or slightly smaller turbofan aircraft with higher seat-mile DOC.

TABLE 16-21

CONTEMPORARY ALL-JET VS STUDY TURBOFAN AND TURBOPROP AIRCRAFT

AIRCRAFT	COMPETITIVE RESULTS					
	1980		1985		1990	
	FLEET SIZE	PERCENT RETURN	FLEET SIZE	PERCENT RETURN	FLEET SIZE	PERCENT RETURN
DC-9-30	299	9.41	405	10.68	524	10.96
M-30	91	-19.13	75	-18.77	55	-20.57
M-40	4	-7.57	13	-9.88	18	-9.56
M-50	—	—	—	—	—	—
M-60	42	2.98	—	—	5	3.54
M-50TP	1	-5.40	8	-3.87	20	-4.16
FLEET TOTAL	437	5.72	502	8.08	622	8.99

SYSTEM LOAD FACTOR TARGET- 50 PERCENT

17.0 SUMMARY OF OPERATIONAL AND ECONOMIC CHARACTERISTICS

All of the conceptual baseline, basepoint design and final design aircraft were evaluated with the operational simulation program and mission model. Choice of appropriate aircraft design characteristics resulted from these simulations. Various physical characteristics were selected at each stage to serve as data to the next. Operating costs were key screening criteria in all stages of both noncompetitive and competitive evaluations. The final evaluation phase resulted in assessment of the appropriate physical characteristics such as passenger capacity, fleet sizes for the U.S. domestic medium density market, and the economic viability of selected aircraft.

17.1 Operational Characteristics

A basepoint design range of 850 n.mi. (1574 K_m) was selected for the final design aircraft. This range was sufficient to cover all of the domestic routes in the traffic network used in the mission model. An airline preference was expressed for a range of about 1,000 nautical miles (1852 km). However, this was for charter purposes with less refueling stops, and actually was not as profitable in the simulated operations as the aircraft with range of 850 nautical miles. Therefore, it was concluded that the 850 nautical mile range satisfied the market requirements.

The basepoint aircraft was configured to carry 50 passengers. In the final, all-jet competitive competition, the 50 passenger aircraft was not selected at all in 1980. Only five (5) were required in the 1985 fleet, and 13 in the 1990 fleet mix with the 50 percent target system load factor. The 30 seat aircraft was selected in the largest number of all the basepoint derivative configurations. In the 1980 fleet mix, the 60 passenger aircraft was the second to the 30 passenger aircraft in numbers required. It also generated a positive, though small, profitability index. Section 16.3.4, All Jet Contemporary and Derivative Fleet, Table 16-7 contains specific data which illustrates these statements and those which follow.

With projected traffic growth to 1985, the fleet composition changed in total with the B-737/DC-9 type still dominant. Subject to the ground rule of minimum frequency, the basepoint fleet composition showed a need for more of the 40 seat version, fewer of the 30 seat, and five (5) of the 50 seat aircraft. This is in contrast to the independent fleet solution in 1980. The 60 seat aircraft was not selected at all in 1985.

In the 1990 solution, the B-737/DC-9 class of aircraft is still dominant, but of a slightly lower percentage of the total fleet than in 1980 and 1985. Note, however, that the profitability index of the 100 passenger jet is improved over the 1985 solution shown in Table 16-7. The basepoint configuration also was shown with four (4) sizes as appropriate in the least-cost solution. Although the 30, 40, and 50 seat aircraft are negative in profitability, they still were the best choice to serve the routes. The contemporary Falcon 30 and VFW-614 were more costly in operating in the market, hence not selected. The 60 seat aircraft generated a positive profitability index.

Of all sizes studied, 30 to 70 seats, the 30 passenger aircraft was selected within the constraints of least cost, minimum frequency of service, and desired load factor. The relative profitability of the 60 seat aircraft indicated it also was a desired candidate to meet market requirements.

These two results, service by the 30 seat configuration and relative profitability of the 60 seat compared with the 50 seat, led to selection of these two sizes as the best fit to market requirements of service frequencies and cost. Growth capability could expand the smaller aircraft to 40 seats as demand warrants. Shrink/stretch capability in the 60 seat version could match needs for a 55 or 70 to 75 seat aircraft in the same manner.

Consideration of the total number of aircraft required, however, led to a pessimistic view of the U.S. domestic market. If the trunk carriers were to show interest in this size of aircraft, total fleet requirements could be doubled. However, this would still result in total new aircraft requirements of only about 200 in 1985 and no increase in number in 1990. This was not considered to be a viable prospect for one or more potential manufacturers.

The field length study indicated that a 4,500 foot (1372 M) length was generally satisfactory. The economic penalty of achievement of 3,500 foot (1067M) capability was shown in the noncompetitive conceptual aircraft evaluation. The short field capability is achieved only by a larger, heavier aircraft with attendant higher costs than the 4,500 foot field length version. An aircraft with 5,500 foot (1676 M) field length capability was less costly than the 4,500 foot version. However, the airport survey showed about 115 of 443 regional airports to have runways of effective hot-day, high-altitude runway lengths of less than 5,500 feet. See Section 4.4, Field Length versus Existing Regional Carrier Airports, for survey data.

This evaluation of the three different field length capabilities led to the selection of the 4,500 foot length as the best compromise considering both availability of airports with varying runway lengths and operational cost of the candidate aircraft.

The economics of propulsion systems weighed favorably toward the turboprop compared with the turbofan. Airline preference, however, indicated desire to replace turboprop with turbofan for passenger appeal and fleet standardization. The variable pitch-fan would be competitive with the fixed pitch-fan if development were more advanced. The data available revealed a slight economic advantage to the BPR 6 turbofan engine from among all those considered in this study.

17.2 Economic Characteristics

The estimated cost (price) of $2,372,000 for the 30 seat and $3,585,000 per unit for the 60 seat study aircraft made them better choices in the operational simulation. This was with respect to the Falcon 30 and VFW-614 chosen from the all-jet current and near-term contemporary fleet. Refer to Section 16.0, Aircraft Operations and Economic Viability, Tables 16-6 and 16-7. The price of the candidate study aircraft was based on 400 units of production. These numbers cannot be achieved in the U.S. domestic regional market as simulated in this study. Thus, if the prices used in the economic evaluation were to be based on less than 400 units for pricing, they would be higher, as shown in Section 14.1, Production Costs.

It was noted in Section 12.1, Conceptual Aircraft - Preliminary Size Screening that regional carriers in 1972 served about 20 of 49 million passengers which were within the medium density travel definition. The initial mission simulation model contained only the regional carrier networks and forecasted demand. Trunk carriers which served the remainder of the 49 million 1972 travelers were not considered as potential candidates for a new aircraft of 30 to 70 seat capabity.

No study was made of the suitability of the study aircraft to trunk carriers for short haul or feeder service. Hence, use by trunk airlines of these aircraft is purely speculative. However, if the major domestic carriers were proper candidates, the domestic fleet conceivably could include some of the larger size aircraft of 60 or 70 passengers capacity. The trunks would not be in the market for any smaller aircraft which required subsidy.

Studies by Hawker Siddeley Aviation, Ltd. of Great Britain in the 1960's led to the HS-136 concept. Originally, this was a 40 to 50 seat aircraft. This study was based on a total world market with predictions for Free World sales of 600 to 1000 aircraft. Hawker Siddeley eventually planned the HS-146 as a 70 seat aircraft. This was the smallest aircraft which could be built to produce reasonable operating costs under the general conditions they assumed.

If this market were to be exploited with a new aircraft, such as the candidates studied herein, the foreign potential might be double or triple that of U.S. domestic carriers. This possibility, plus the simplified "Design-to-Cost" approach used in this study should be pursued with the object of total production quantities which could lead to an aircraft with the desired performance and cost characteristics.

The military potential also was excluded, but it is entirely possible that this size of aircraft (30 to 70 seats) would satisfy requirements for a specific military personnel transport mission.

18.0 SUBCONTRACTOR PARTICIPATION

To assure realism in the study, the subcontractors were given specific tasks to perform and their key contributions are delineated as follows:

Cessna Aircraft Company

During the Aircraft Requirements phase of the study, Cessna performed the following tasks:

- Assisted in developing cost estimating data for existing Douglas programs directed toward accuracy for the smaller size aircraft being studied and supplied operating cost data to aid in estimating operating costs for study aircraft configurations.
- Provided Group and Detail Weight Statements for smaller existing aircraft and verified applicability of Douglas weight estimation formulae for the smaller size aircraft. Evaluated Douglas empty weight estimates for 30, 50, and 70 passenger aircraft configurations. Cessna's analysis was within 3 percent of the Douglas empty weight.
- Assisted in the evaluation of various types of wing high-lift devices and furnished aerodynamic and geometric data.
- Specific performance data were provided to verify the accuracy of Douglas noise estimation methods when applied to the smaller aircraft.
- Reviewed and commented on aircraft design and operational analysis data of the candidate aircraft.

The prime area of Cessna support during the Aircraft Design phase of the study included the following:

- Provided structural and system concepts for potential cost and/or weight savings.
- Cessna analyzed FAR 121 requirements and evaluated a variety of available components to fulfill function requirements. The avionics equipment list furnished provided high quality reliable equipment at a lower weight and cost than the avionics packages currently in use on larger transports. This data provided the basis for the avionics weight and cost used on the aircraft configurations analyzed in the study.
- Evaluated the Douglas weight estimate on the Furnishings Group and verified the furnishings weight to be within $\pm$ 2 percent of Cessna's estimate.
- Reviewed the Douglas analytical pricing methods as applied to the smaller aircraft and verified that the Douglas costing routine was suitable for the aircraft being studied.
- Furnished performance and characteristic data related to competitive aircraft.

North Central Airlines

During the Aircraft Requirements phase of the study, North Central's contribution included the following tasks:

- Reviewed and commented on the Operations Scenario and assisted in defining the Medium-Density market.
- Identified key operational criteria for selection and screening of candidate aircraft and reviewed and commented on the conceptual aircraft performance ground rules.
- Provided predictive trends in future fare levels for the period of the study.

North Central's participation during the Aircraft Design Study phase involved the following tasks:

- Reviewed the aircraft interior layouts and overall configuration three-view drawings for airline acceptability.
- Assessed federal policy towards subsidy of Medium-Density operations through 1985.
- Evaluated candidate aircraft operational compatibility with ground support and maintenance systems, terminal facilities, and air/ground control environment.

During the Evaluation phase North Central's contributions included the following:

- Reviewed the proposed network system and routes for suitability for Medium-Density air transportation and commented on the final Operations Scenario.
- Reviewed the physical and economic descriptions of the selected competitive aircraft.

- Reviewed and commented on the final aircraft operational characteristics for airline acceptability.

Air California

The following tasks were performed by Air California during the various phases of the study:

- Reviewed and commented on the Operations Scenario and commented on the conceptual aircraft performance ground rules.
- Reviewed the aircraft interior layouts and overall configuration three-view drawings for airline acceptability.
- Generated basic assumptions of IOC with respect to cost per passenger processed versus aircraft DOC and passenger revenue.
- Reviewed final aircraft operational characteristics for airline acceptability.

American Airlines

The contribution to the study by American Airlines included the following:

- Assessment of the trunk carrier's view of the Medium Density market in terms of the compatibility of a fleet of smaller size aircraft integrated into the transportation system.
- Interface problems related to the Medium-Density market integrating trunk carriers, regional, and commuters.
- Impact of various levels of passenger amenities upon indirect costs.

The study results reflect the contributions made by the subcontractors. The significant comments influencing the study are outlined below.

Basic Design

- o A turboprop is not acceptable.
- o The range should not be less than the Convair 580 (880 n.mi.)
- o Power/weight ratio should provide climb performance equal to DC-9/B-737.
- o Runway requirement 4,500 minimum, prefer longer length.
- o Thrust reversers and onboard APU required.
- o Eliminate leading edge devices to minimize cost, weight, and complexity.
- o Flying at 30,000 feet for stage lengths over 300 miles produces more efficiency in terms of fuel consumption compared with 25,000 feet.

Passenger Service

- o A thirty-two inch pitch seat is acceptable.
- o Closed overhead racks are required.
- o Space and connections should be proved for a galley to be inserted.
- o Beverage service is required.
- o Provision must be made for thirty gallons of water minimum.
- o Seats should have drop-down trays.
- o Interior materials must be removable units and capable of being wiped down from ceiling to floor.

Operations

- Air stair door should be compatible with jet-way loading.
- The cruise Mach number should be 0.74.
- Anti-skid provisions are required.
- Escape chutes are not required as aircraft is low enough to the ground.

Economics

- Fuel cost for 1974 should be approximately $0.22/gallon.
- Depreciation period should be 15 years.
- IOC should be 58 percent of passenger revenue.
- Six percent surcharge should be applied to passenger fares.
- Maintenance labor rate should be approximately $7.45 per hour.
- Crew cost inflation should be between 7.5 percent and 10 percent per year.
- Indirect operating costs will grow faster in the next 5-10 years than direct costs. The ratio of IOC to DOC will be over 100 percent.

19.0 CONCLUSIONS AND RECOMMENDATIONS

A comprehensive aircraft and systems evaluation approach was used throughout the study integrating the interaction of markets, aircraft, airports, economics and operations to analyze the operational requirement for Medium Density Air Transportation. A review of the results of the study indicate the following major conclusions and research and technology recommendations:

CONCLUSIONS

Aircraft Design

- Using current technology, turbofan and turboprop powered aircraft can be designed to perform efficiently in the medium density air transportation market.
- A balanced field length of 4,500 feet (1,372 m) and a single stage range of 850 nautical miles (1,574 Km) are acceptable design criteria for medium density transportation aircraft.
- The simplification of engineering and manufacturing design utilization of low-cost avionics are promising areas in the "Design-to-Cost" philosophy.
- The turboprop aircraft provided the lowest approach flyover noise level and achieved the FAR Part 36 -10 EPNdB noise goal at the FAR Part 36 measuring points.
- The basepoint aircraft with the fixed-pitch BPR 6 turbofans and the aircraft with the Hamilton Standard QFT-55-28-2 variable pitch turbofans also met the FAR Part 36 -10 EPNdB noise goals.

- Turboprop aircraft are second-best considering design efficiency and are best in terms of operating cost, but lack passenger appeal because of interior cabin noise and vibration.
- Aircraft with fixed-pitch turbofan engines of moderately high bypass ratio are the most suitable fan powered aircraft because of lower operating cost, although they are poorest in design efficiency (i.e., weight and fuel).
- Aircraft with variable-pitch turbofan engines are the best fan powered aircraft considering design efficiency (low weight and fuel), but suffer in terms of cruise speed and operating cost, due to the assumed higher engine price, resulting from the fan development.
- The introduction of the final design aircraft will not adversely affect the quality of human environment and is consistent with existing environmental policies and objectives as set forth in Section 101(a) of the National Environmental Policy Act of 1969.

Propulsion

- Current candidate engines are deficient in appropriate size or efficiency for the aircraft passenger sizes studied. Development programs are needed for new engines, fans and/or gas generators.
- Existing engines in the required thrust class (from 6,000 to 12,000 pounds each for 30 to 70 passenger twin-engine aircraft) are
  - very few in number (only two engine designs are available),
  - too low in thrust capacity for aircraft above 50 passengers,
  - somewhat lacking in propulsion cycle efficiency, as compared with the engines in use on the modern major trunk airliners.

- Very few (only two) efficient gas generators are available for integration with newly developed fixed or variable pitch fans to produce new turbofan engines.
- Use of current available engines increases weight, fuel, price, and operating cost.
- Development programs for new engines, fans and/or gas generators are required to produce suitable and efficient aircraft for medium density transportation aircraft.

Operations and Economics

- The U.S. domestic medium density air transportation fleet mix requirements for the 1985 time period consists of approximately 400 DC-9/B-737 type aircraft plus 75 30-passenger, 23 40-passenger and 5 60-passenger aircraft with new configurations and design features as developed in this study.
- Over a 15 year period from 1980, the 30 passenger turbofan powered study aircraft with stretch capability to 40 seats satisfies travel demand in the short-range, low density segment of the market better than existing or contemporary near-term turbofan aircraft.
- A nominal range of 850 nautical miles (1,574 km) is adequate to serve the longest scheduled routes of the medium density market as defined in this study.
- U.S. domestic requirements of only 103 aircraft are insufficient for a production program to achieve the aircraft price level used in this study. The inclusion of foreign and military market requirements could constitute a viable manufacturing opportunity.

- Short range, low density operations cannot be profitable with any current, near-term, or study turbofan powered aircraft of 30 and 40 passengers at the fare levels and the load factors used. An increase in the load factor from 50 to 60 percent is not sufficient for the 30 and 40 passenger study aircraft to be profitable.
- The inclusion of relatively low-density routes in the analysis did not improve significantly the unprofitable characteristics of this market if served under 1974 CAB fare and regulatory structure.
- Adoption of "design-to-cost" engineering and manufacturing features can reduce costs of the final design aircraft by about one million dollars and DOC at least eight percent when compared with contemporary transport aircraft.
- Aircraft of less than 50 passenger capacity, operating in the medium density market, cannot generate satisfactory profit levels within the operational and economic ground rules of this study, including CAB Phase 9 fare levels.
- Turboprop aircraft proved to be better in operating economy than the turbofan aircraft, but a majority of the trunk and regional airline operators prefer jet aircraft.
- If engine costs and operations of turboprop aircraft can be kept at levels indicated in the study, a new turboprop aircraft would be an economic choice for the future.

RECOMMENDATIONS

(1) Identify propulsion cycle characteristics and operational techniques (enroute and terminal area) which will minimize operating costs and noise impact of the aircraft for low and medium density markets.

(2) Determine aircraft aero-structural and operating sensitivity to wing geometry variations.

(3) Define the optimum combination of wing geometry and propulsion cycle characteristics which result in the "best" aircraft and operating system for the low and medium density market requirements.

(4) Conduct layout design evaluation of various discrete configuration parameters in terms of weight, drag, cost and operational compatibility.

(5) Continue and expand the design-to-cost investigations to include advanced metallics and composites and the in-depth detail design required for a thorough evaluation of cost reduction.

(6) Define in depth the structural and subsystem design detail required for a stretch/shrink aircraft family to satisfy the performance requirements compatible with low and medium density markets.

(7) Continue turboprop studies to include advanced propeller technology to determine methods for improving efficiencies and decreasing noise levels.

(8) Conduct studies to improve non-propulsive noise prediction techniques and evaluate the importance of non-propulsive noise for aircraft designs in the current and future programs.

(9) Conduct a study of the foreign market demand and aircraft requirements for the class of aircraft in this study.

(10) Perform an aircraft design and systems study defining the requirements for a low density transportation system integrating commuter markets, local service low density markets, and trunk low-density feeder system into a new integrated network system.

(11) Define and develop a new system cost analysis approach and technique for quantifying the initial acquisition, introduction, and operating impact of a new aircraft on a total airline operating system.

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