NASA CR 137603
DOUGLAS MDC-J4484

ANALYSIS OF OPERATIONAL REQUIREMENTS FOR MEDIUM DENSITY AIR TRANSPORTATION

SUMMARY

VOLUME I
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
CORPORATION

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FOREWORD

This Volume I contains a summary of the significant 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.

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

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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:

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 is a summary of the significant results of a nine month study program for NASA-Ames on the "Analysis of Operational Requirements for Medium 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 aircraft with capacities of 30 to 70 passengers. Propulsion systems included two types of turbofan engines plus a 50 passenger turboprop powered aircraft. 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 formulated which delineated a representative airline network, established an operating time period for airline introduction and simulated operations of a conceptual aircraft, and projected a fifteen 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 configuration of the definition of medium density transportation. A wide range of noncompetitive operational simulations was evaluated in a mission model constructed from statistics of airline operations in the base year of 1972. Results of these simulations served to define the characteristics of a medium density conceptual aircraft for the design phase of the study.

During the Aircraft Design Study phase fifteen different aircraft were studied. These included three different range versions of the 50 passenger turboprop, designed for minimum interior noise; three different range versions of the 50 passenger turbofan basepoint; 30 and 70 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 currently available engines or components and 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 a stretch/shrink family concept were evaluated. Design-to-cost studies were conducted which included engineering-manufacturing design and performance features plus simplified 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 Aircraft Design Study phase. A specific mission model for an airline network was created with service and demand schedules for each airport-pair route. Basic turbofan and turboprop concepts 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 aircraft passenger capacity 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 aircraft 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 assessments throughout the study to assure commercial airline realism as well as assisting in specific tasks.

CONCLUSIONS

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 as established in this study. 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 of the conceptual aircraft studied in this report are insufficient for a production program to achieve the aircraft price levels used in this study. The inclusion of foreign requirements potentially could constitute a viable manufacturing opportunity if the market were 400 to 600 aircraft.
- Over a fifteen 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 which include 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 and consistent with standards for environmental qualities.
- Adoption of "design-to-cost" engineering and manufacturing features showed cost savings for the 50 passenger final design aircraft of about one million dollars and reductions in DOC of about 8 percent when compared with a transport aircraft designed to contemporary standards.
- 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 cycle 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 turbofan aircraft.
- If engine costs and operations of turboprop aircraft can be kept at levels indicated in the study, a new turboprop aircraft might be an economic choice for the future.

RECOMMENDED RESEARCH AND TECHNOLOGY PROGRAMS

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 - Optimization studies for integration of wing and engine mounting configurations and wing geometry optimization and reduction of nonpropulsive noise.

Propulsion - Minimum costs versus propulsion cycle characteristics and aircraft operational procedures to minimize cost and noise.

Systems - Extension of the study to incorporate more low-density traffic and the possibilities of economic operation of a new or revised class of carrier operations.

Economics - Creation of a new approach to quantifying acquisition, introduction, and operating costs of new aircraft for an airline operating system.

Market Analysis - Investigate the potential demand for a 30 to 70 passenger aircraft in the foreign market and features of commonality with a new military mission requirement.

Manufacturing - Perform a more detailed study of composite materials and advanced metallics cost benefits.

There are medium and small size communities in the U.S. domestic market currently with little or no air transport service. Research also 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 a total of 20 to 500 passengers per day on round trip 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 twenty-one 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 air transportation market.
2. Design a basepoint aircraft from which tradeoff studies and parametric variations could 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. In Task I, Aircraft Requirements, activity was 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.

The basepoint aircraft in Task II, Aircraft Design Study, was redesigned to generate passenger capacity as a function of current engines. Noise analyses were conducted for the final design basepoint and alternate engine aircraft. Design-to-cost studies included 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 and an advanced flap design 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, included studies of the impact of the candidate aircraft in simulated airline operations 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 derived for the competitive and near-term aircraft.

Research and technology programs for future consideration have been identified.

SYMBOLS & ABBREVIATIONS

AADA	Airport and Airway Development Act
AC	Air Conditioner
A/C	Aircraft
ADF	Automatic Direction Finder
AF	Airframe
Alt	Altitude
APU	Auxiliary Power Unit
ARINC	Aeronautical Radio, Inc.
ARP	Airport Reference Point
ARTS	Automated Radar Tracking Control System
ATC	Air Traffic Control
BFL	Balanced Field Length
BL	Blades
BPR	Bypass Ratio
C	Celsius
CAB	Civil Aeronautics Board
CAPDEC	Commercial Aircraft Production and Development Cost
COM	Communication
CM	Centimeters
Dia	Diameter
DME	Distance Measuring Equipment
DOC	Direct Operating Cost
EHSP	Equivalent Shaft Horsepower
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency

EPNL	Effective Perceived Noise Level
EPNdB	Effective Perceived Noise Level in Decibels
F	Thrust Force
FAA	Federal Aviation Administration
FAR	Federal Air Regulations
FL	Field Length
Flt Dir	Flight Director
FP	Fixed Pitch
fpm	Feet Per Minute
FPR	Fan Pressure Ratio
fps	Feet Per Second
ft	Feet
HF	High Frequency
HP	Horsepower
HR	Hour
HSI	Horizontal Situation Indicator
ILS	Instrument Landing System
in	Inch
IOC	Indirect Operating Cost
kg	Kilogram
km	Kilometer
kn	Knots
kW	Kilowatt
LE	Leading Edge
LH	Left Hand
lb	Pound
m	Meter

M-150-4000	Mechanical Flap, 150 Passenger, 4000 Ft. Field Length
MB	Multiple Band
max	Maximum
min	Minimum
Mill (Mil)	Million
MLS	Microwave Landing System
mps	Meters Per Second
N	Newton
NASA	National Aeronautics and Space Administration
Naut	Nautical
Nav	Navigation
NEPA	National Environmental Policy Act
n mi	Nautical Mile
NPN	Non Propulsive Noise
O_2	Oxygen
OAG	Official Airline Guide
O&D	Origin and Destination
OEW (OWE)	Operator's Empty Weight
OP	Operator
P	Pressure
PA	Public Address System
PNdB	Perceived Noise Level in Decibels
PNL	Perceived Noise Level or Panel
psgr	Passengers
R and D (R&D)	Research and Development
Rel	Relative
RH	Right Hand

RMI	Radio Magnetic Indicator
RPKm	Revenue Passenger Kilometers
RPM	Revenue Passenger Miles
RPT	Repeater
SAE	Society of Automotive Engineers
S_W	Wing Area
SFC	Specific Fuel Consumption
SL	Sea Level
SLS	Sea Level Static
SLT	Slant (Range)
sq ft	Square Feet
sq km	Square Kilometers
Stat (St)	Statute
std	Standard
st mi	Statute Miles
STOL	Short Takeoff and Landing
TE	Trailing Edge
TOFL	Takeoff Field Length
Tsls	Thrust Sea Level Static
T/W	Thrust-to-Weight Ratio
V_T	Blade Tip Velocity
VHF	Very High Frequency
VIR	Dual Mode Voice and Instrument Landing System
VLF	Very Low Frequency
VP	Variable Pitch
W	Weight
W/S	Wing Loading

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.

MISSION MODEL ELEMENT = A set of route and traffic data (airport pairs, flight frequencies, and seats scheduled) organized into a statistical class defined by a distance interval, such as 50 to 100 miles.

M-30 = Study aircraft identified as M (medium density) -30 (passenger capacity) through M-70 (70 passenger capacity).

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1.0 OPERATIONAL REQUIREMENTS ANALYSIS

An initial operational simulation scenario was written to describe the fremework for analysis of the operational requirements for medium density air transportation. A survey of CAB data on domestic airline operations led to selection of local service airline networks and traffic levels as best fitting a general definition of medium density air transportation. The definition of the market was adopted with the concurrence of the study subcontractors. The initial operational scenario provided for evaluation of the primary conceptual aircraft in a representative airline network and traffic model. The first aircraft evaluations were noncompetitive with each aircraft evaluated as supplying sufficient scheduled seats to meet the demand expressed as revenue passenger miles (RPM). This noncompetitive evaluation was analyzed in greater detail by segregating the market into low, medium, and high volume segments of the market.

Those aircraft characteristics which best fitted the market in the initial evaluation were then carried into the basepoint design phase of the study. Parametric excursions were made to evaluate variations in the basepoint aircraft.

A final operational scenario was written to provide an expanded definition of the medium density market. Nine regional (local service) airlines plus twenty-one selected commuter airlines were included to provide a total domestic network and traffic model. Passenger demand levels were forecasted from 1974 to 1994 on the selected network to form the mission model. Candidate aircraft operational performance characteristics were matched against scheduled demand for travel and minimum trip levels as contained in the mission model. The results were expressed in numbers and types of aircraft required to satisfy the demand. The evaluation of study aircraft was conducted by comparing their fleet performance results in a competitive airline operational simulation with current and near-term commercial transport aircraft.

The selection of either aircraft or fleet characteristics was based on operational, economic, and physical aircraft and airport criteria. These were expressed generally in terms of schedule frequency, operating profits (or minimum losses) and general compatibility of aircraft and airports.

Only selected simulation results are presented in this summary document.

1.1 Definition of the Market

The medium density air transportation market is not well defined except by a general term where frequency of service and passengers per day are considered. One possible definition involves a geographic and service frequency concept. A geographical medium-dense market exists where towns are relatively small, such as in the Midwest or the Midsouth, and 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.

A general consensus among NASA personnel, airline subcontractors, Douglas and Cessna resulted in adoption of a definition for the medium density market as follows:

Passengers per day per route	20 to 500 (2 way travel)
Stage lengths	up to 800 statute miles (1,287 km)
Frequency of service/day	Minimum to be at scheduled 1974 levels to a maximum of 8 round trips per airport pair.

Online origin and destination passenger data for 1972 were drawn from a CAB data tape (Reference 1) in compliance with this definition. Data from both trunk and local service airlines were summarized and are presented in Table 1-1.

Table 1-1

MEDIUM DENSITY AIR TRANSPORTATION MARKET

(CAB 1972)

		Passengers Carried
Local Service Airlines		20,238,000
Trunk Airlines		29,200,000
	TOTAL	49,438,000

Although the trunk airlines carried more than one-half of this traffic, it was deemed appropriate to exclude the trunk data. The basis of this decision was that the trunks carried this traffic only as a part of their routes and used equipment generally larger than 70 seats capacity. In contrast, this medium density traffic was the bulk of the local service carrier operations, and carried traffic in aircraft of less than 100 seats capacity. Hence, the local service networks and traffic levels were chosen as representative of the medium density transportation system.

The medium density traffic for 1972 was analyzed for distribution by numbers of travelers per day per route (travel-density class). Figure 1-1 shows the total number of travelers for 1972 in each of these travel-density classes.

A second distribution was made to show the distribution of city-pairs served into range-classes from zero (0) to 800 miles. This distribution is presented in Figure 1-2.

These CAB statistics served to quantify the original market definition. They also provided an initial set of data which confirmed round-trip frequency definitions achievable with aircraft of passenger capacities up to 70.

1.2 Network Characteristics and Demand Models

The initial conceptual evaluation and screening of aircraft were done in an airline simulation model constructed from data published in the Official Airlines Guide (OAG) for August 1972. Flight frequencies by equipment and airport pair data were used to establish a mission model. Application of actual load factors for selected regional airlines in the network resulted in a mission model quantified with aggregated seat demand expressed as revenue passenger mile (RPM) demand. This data was annualized to provide a base year of 1972. For initial screening and evaluation, the number of seats available from the 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 in the model was equal to the number of seats scheduled times the experienced airline overall

PASSENGERS-CARRIED DISTRIBUTED BY TRAVEL DENSITY CLASSES

MEDIUM DENSITY MARKET - 1972

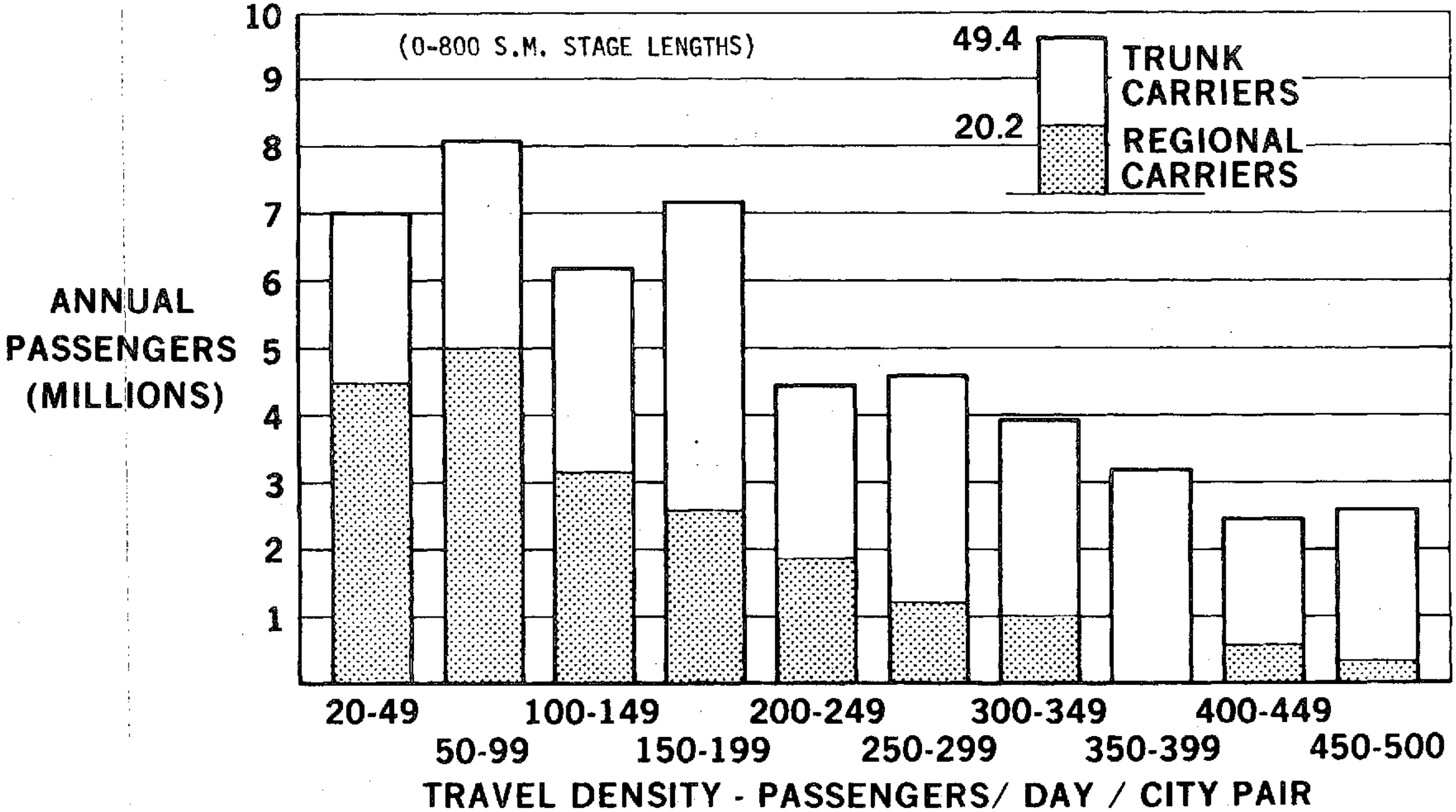

Figure 1-1

PASSENGERS-CARRIED DISTRIBUTED BY RANGE CLASS

1972 U.S. DOMESTIC MEDIUM DENSITY MARKET

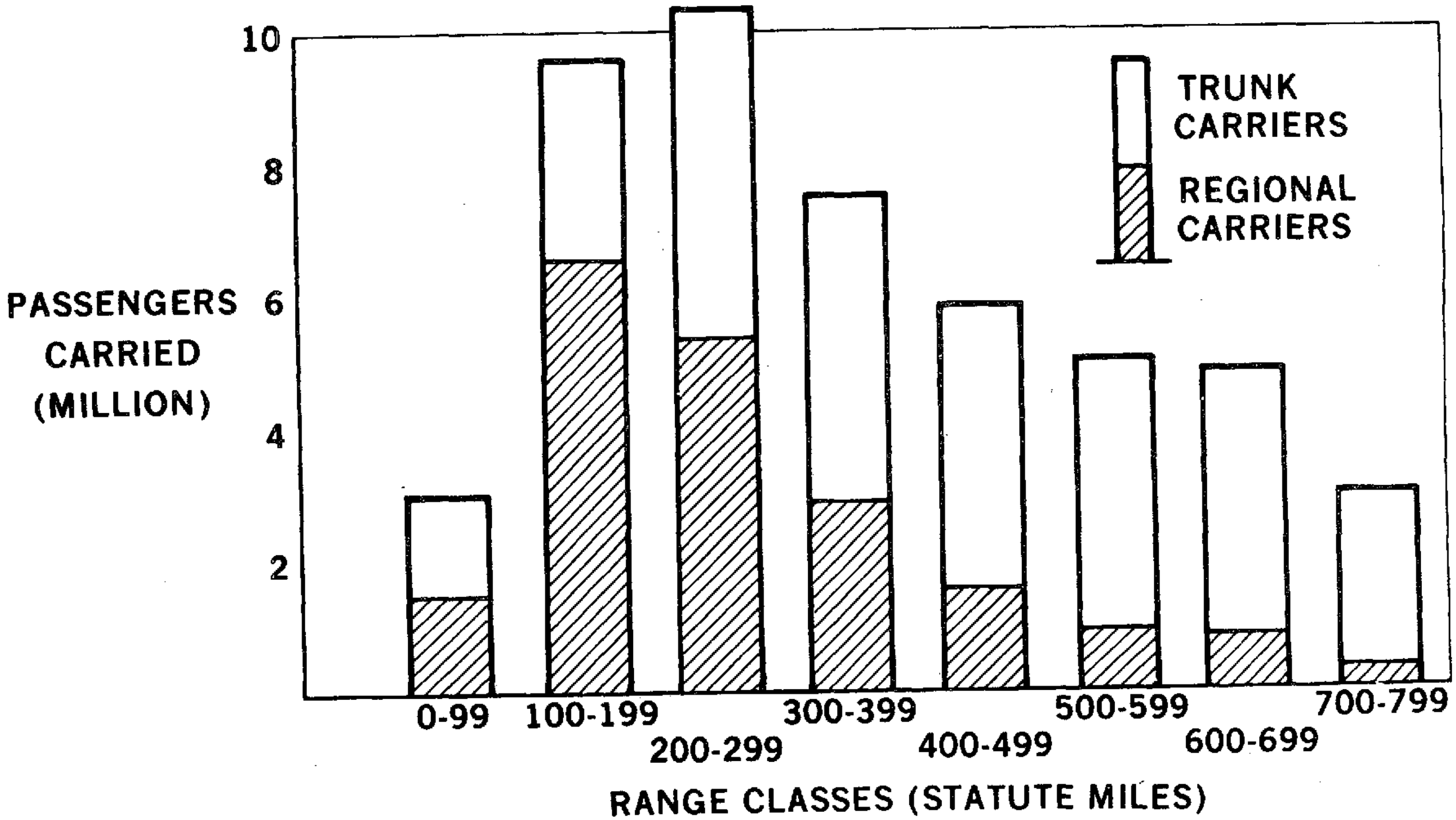

Figure 1-2

system load factors recorded for each of the airlines in the model. This model was used for all of the noncompetitive simulation and evaluation of conceptual aircraft during the aircraft requirements analysis phase of the study. A brief summary of pertinent characteristics of this initial mission model is as follows:

- o Network and mission model derived from 1972 regional airlines scheduled domestic operations as published in the August OAG.
- o 2,694 airport pairs representing 1,347 routes with nonstop two-way traffic. No new routes added in the simulated operational period.
- o Data included revenue passenger miles estimated by equipment type, actual airline system load factors and scheduled flights for 1972.
- o Model organized into statistical elements each of which contained route traffic data organized into range or distance flown intervals.
- o RPM demand forecasted to 1994 with conservative growth rates.

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 during the performance of the study, some different tailoring of the mission model network was applied. Eight regional airlines plus Air New England were included.

Those regional airlines routes were eliminated which would grow in seat demand to more than could be carried by a 70 passenger aircraft at a 50 percent load factor at eight round trips per day by the year 1985. Data was drawn from published airline schedules for August 1974. The network was drawn from routes served by the following regional airlines:

Hughes Airwest (Pacific Coastal Region)

Frontier Airlines (Rocky Mountain Region)

Texas International (South Central Region)

Southern Airways (South Central Region)

North Central Airlines (Upper Midwest)

Ozark Airlines (Great Lakes and Central Midwest Region)

Allegheny Airlines (Central and Atlantic Region)

Piedmont Airlines (Southeast Region)

Air New England (Northeast Region)

Also included in the final evaluation mission model was a network generated from published schedules for twenty-one commuter airlines. Routes included those on which aircraft listed in Table 1-2 were scheduled.

Table 1-2

AIRCRAFT USED BY 21 COMMUTER AIRLINES - AUGUST 1974

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 basic data on these airlines consisted of routes between airports, the type of equipment used with designation of passenger capacity, and numbers of trips per week. From these, total scheduled seats per week were derived. The application of load factors experienced by the airlines converted these data into seats demanded. Distances scheduled times seats demanded created a demand model in revenue passenger miles (RPM). The August 1974 data was annualized 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 statistical elements classified by range intervals and type (seat capacity) of aircraft scheduled. To preserve a low-density segment in the network, the traffic demand was constant on all elements derived from the twenty-one commuter lines. This simulated a constant traffic base at the low end of the medium density market. 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. 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 1-3, Competitive Network Mission Model. A descriptive summary of the mission model appears as follows:

Data Source		OAG
Base Year		1974
Routes (Two-Way Traffic)		1,687
Airlines:	Regional	9
	Commuter	21
O & D Passengers		--
Scheduled Trips:	Daily Round Trips	up to 8 per route
	Annual Minimum (total thousands)	1,938

TABLE 1-3

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.

Revenue Passenger Miles (km)	13.307
(Billions in 1980)	(21.411)
Maximum Trip Distance (St.Mi./Km.)	873/1404
Average Stage Length (St.Mi./Km.)	145/233

Before 1973 airline travel grew at fairly uniform and predictable rates. In 1973 a fuel shortage late in the year caused a major trauma in travel expectancies. Airline fares were raised. In 1974 the fuel shortage became of greater concern to all modes of transport. The local service airlines appeared to enjoy dramatic traffic increase as travelers chose air over auto. However, permanence of this growth was unpredictable. Thus, a conservative growth factor was adopted in this study to predict traffic growth from 1974, the base year for the study. Traffic growth rates used were 6 percent to 1980, 5 percent to 1988, and 4 percent thereafter to 1994.

1.3 Operational Simulation Techniques

A time period of fifteen years was assumed for the operational simulation. The year 1980 was chosen as representing a reasonable introduction date for a new aircraft. The fifteen year period was 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.

The general simulation approach is diagrammed in a flow-chart, Figure 1-3. 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. The simulation was conducted either with a single aircraft in a noncompetitive mode, or to select a fleet mix solution from a basic

SYSTEMS SIMULATION APPROACH

CONCEPTUAL AIRCRAFT EVALUATION

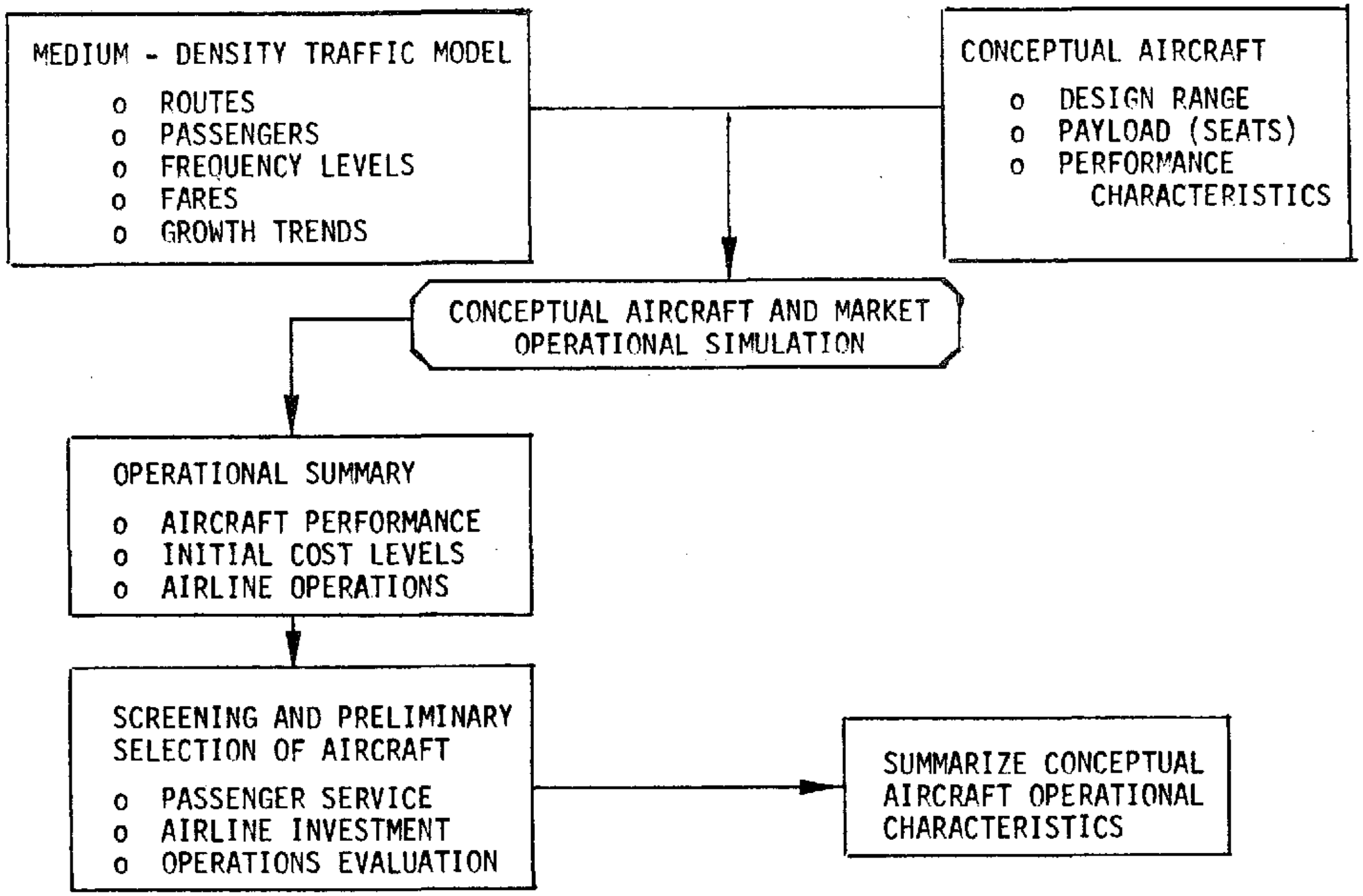

FIGURE 1-3

inventory of available aircraft in a competitive mode. In the noncompetitive mode, successive iterations were used to evaluate parametric variations of aircraft descriptors.

In the single aircraft, noncompetitive mode, the simulation routine tested the capability of each aircraft on groups of routes (range elements) in the traffic network and demand model. The range, speed, payload, target load factor, and 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 revenue passenger miles (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.

In a competitive simulation mode, the same process was applied. 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.

During the Design Study phase a 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 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.

The operational simulation resulted in data which were a summation of mission performance by each aircraft. Data included revenue and revenue passenger miles generated, aircraft productivity, average load factor, annual fuel burned, annual trips generated, operating expenses, profit or loss, and ratio of net income to total aircraft investment.

In addition, a fleet mix was generated with different aircraft assigned by least cost performance to appropriate elements in the mission model.

A number of different network and mission models were used in the operational scenarios applicable to the various noncompetitive and competitive simulations. There were five general scenarios which covered these simulations. These are described as follows:

- o Preliminary screening of passenger capacity and market served with use of CAB data.
- o 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.

TABLE 1-4

SIMULATION SCENARIO SUMMARY

Network and Model Data	Initial Screening	Noncompetitive Simulation			Competitive Simulation Mission Model
		Total Mission Model	Frontier Airlines Network	Segmented Market Study	
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.)	--	158/254	145/233	158/254	145/233

- Competitive simulation to evaluate the operational viability and specific requirements of one or a family of final design study aircraft.

Table 1-4 presents a matrix summarizing the scenario used for each of the five simulation networks and mission models.

In all of the operational simulations a series of rules and assumptions were established. These were:

- The mission model was derived from selected base year data and was created specifically to fit a medium density market as defined.
- Minimum trips scheduled were the same as published by the selected airlines at the August base year level. The minimum number of trips required was held constant throughout the operational simulation periods.
- The maximum number of trips was eight per route per day for non-competitive and competitive simulation in the evaluation of operational and economic viability.
- A system load factor target of 50 percent was assumed in generating required aircraft trips needed to satisfy demand for seats.
- The aircraft consisted of the 50 passenger basepoint turbofan configuration with four parametric size variations, plus a 50 passenger turboprop configuration.
- 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.

- o No new routes were added to the model.
- o All operations were non-stop and two-way or round trip assuming symmetrical flow.

1.4 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.

1.4.1 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.

1.4.2 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.

1.4.3 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 and 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 for 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 system. 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.

1.4.4 Airport Criteria

A survey of airport runway lengths and site altitudes was conducted on the airports included in the initial regional airline network. An altitude and temperature correction of runway lengths was applied to these fields. A list of the airports, pertinent data, and correction results is contained in Appendix B, Section B.7, Volume III. A summary of the correction effects is included herein as Table 1-5. 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 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 1-5

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

2.0 AIRCRAFT ANALYSIS

2.1 Conceptual Aircraft Analysis

2.1.1 Ground Rules

In order to evaluate the medium density market a family of conceptual aircraft was designed in conformance with the ground rules in Table 2-1, which shows the scope of the payload, field length and stage length parameters covered. Two types of turbofan engines (fixed and variable pitch, with current technology) were used, along with a turboprop power plant. The aircraft were designed for field length (wing loading and thrust/weight ratio); then, they were sized for stage length and payload, with the cruise condition being a fall-out.

The missions consisted of either a single stage or a dual (of equal lengths) stage, performed without refueling. Each stage length included: takeoff time and fuel allowance; climb to cruise; constant altitude cruise at near-maximum speed (typical minimum DOC airline operation); 300 fpm (1.53 mps) cabin pressurization rate limited descent; and landing time and fuel allowance. The reserve fuel contained 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. Performance was based on standard day conditions.

Direct operating cost was the evaluating yardstick. For this purpose, preliminary airframe prices were based upon statistical data representing modern airliners and business-jet aircraft. These prices agreed very closely with the final prices, estimated by computer program and used in the systems operations and economics studies. Also, statistical data was compiled on prices for existing large and small sized engines.

TABLE 2-1

AIRCRAFT ANALYSIS GROUND RULES

PAYLOAD:	30, 50 AND 70 PSGR
ENGINES:	CURRENT TECHNOLOGY FIXED AND VARIABLE PITCH TURBOFANS TURBOSHAFT-PROPELLER
TAKEOFF AND LANDING:	SEA LEVEL, 90°F; FAR PART 25 FIELD LENGTH: 3500, 4500 AND 5500 FT. 15 FPS DESCENT RATE: 3° FOR NOISE
NOISE:	FAR PART 36 LESS 10 EPNdB
CRUISE CONDITION:	FALLOUT (MACH NO. AND ALTITUDE) 25,000 FT. MAXIMUM
STAGE LENGTH:	ONE 337, 563, 775, 850, AND 1000 N.MI. (TWO 150, 250, 350) RESERVES: 100 N.MI. AND 45-MIN. HOLD

2.1.2 Configuration

The configuration has: twin, aft-fuselage-mounted, turbofan engines; a low wing with an aspect ratio of 9.0 and a 5 degree quarter-chord sweep; and a high-lift system consisting of a leading edge slat and a hinged flap with a fixed vane. This configuration, similar to the DC-9 and B-727, was selected because of desirable features involving: crash landing safety; alleviation of landing gear retraction problems; minimum fuselage cross-sectional area; low drag; maximum wing efficiency; reduction of inlet duct ingestion problems; and blanketing by the wing of noise on approach.

The passenger cabin has DC-8 economy-class seating, 4 abreast at a 32-inch (86 cm) pitch, and a single aisle, 18 inches (58 cm) wide and 78 inches (198 cm) high. 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 space, and lower baggage/cargo bays.

2.1.3 Propulsion

Basic criteria imposed were: low noise, 10 EPNdB below FAR 36 requirements; reverse thrust, a safety measure desired by airline subcontractors; low initial cost, fuel consumption and maintenance; and availability, limiting the engine cycles to those for which realistic performance estimates could be made. The scope of the study did not include generation of performance data or quantitative evaluation of new types and variations of propulsion systems or of less conventional engine cycles because of the unavailability of uninstalled performance data.

The fixed-pitch turbofan was selected as the basic propulsion system for the conceptual aircraft analysis because of low development cost and technical risk. The variable-pitch turbofan and turboshaft-propeller (turboprop) were evaluated in order to select the best propulsion system for the final basepoint aircraft studies. Installed performance was estimated and the engines were "rubberized," i.e., scaled to the size required for the aircraft to meet the design conditions.

The fixed-pitch turbofan has a bypass ratio of 6 and a fan pressure ratio of 1.45. Previous studies (Reference 2) showed that an engine with these cycle characteristics has a low noise level and a low installed fuel consumption (see Volume II for engine cycle details).

The variable-pitch turbofan has a bypass ratio of 13 and a fan pressure ratio of 1.32, characteristics considered applicable (although possibly not optimum) for short-range missions. Its advantages include inherent provision of reverse thrust, good cruise fuel consumption and low noise level. Its disadvantage is the requirement for a development program and thus, a potentially higher cost and risk than that for the fixed-pitch turbofan. Higher fan pressure ratios would improve cruise performance, and although feasible, this would increase development cost and risk.

For aircraft of the size studied, turboprop propulsion systems offer some advantages due to availability and low risk, cost and fuel consumption. The turboshaft engine and propeller combination was selected to provide the required takeoff thrust, while maintaining a minimum cruise speed of 0.60 Mach, using the characteristics of available turboshaft engines and conventional propellers. In order to achieve a low noise level with a minimum diameter and weight, a parametric study of propeller characteristics was conducted involving tip speed, number of blades, integrated lift coefficient and activity factor (see Section 2.1.4.5).

2.1.4 Parametric Analysis

Table 2-2 summarizes the variable and discrete parameters covered: passenger payload; field length; range, engine cycle type; and high-lift system. The parametric excursions were centered on a baseline conceptual aircraft, powered by the fixed-pitch turbofan engine, and sized for 50 passengers, a 4500 foot (1372 m) field and 2 x 250 nautical mile (2 x 463 km) dual stage lengths.

2.1.4.1 - Baseline Conceptual Aircraft Sizing - Based upon minimizing DOC, the selected design point occurs at the point of balanced takeoff and landing field length (Figure 2-1). For the effect of propulsion cycle variation see Section 2.1.4.5.

2.1.4.2 - Field Length Variation - Takeoff and landing calculations were made to determine several wing loading and thrust-to-weight ratio combinations required for 3500 foot (1067 m) and 5500 foot (1676 m) field lengths. Using these W/S and T/W ratio combinations, conceptual aircraft were sized for 50 passengers and 2 x 250 nautical mile (2 x 463 km) dual stage lengths. As with the 4500 foot field above, the minimum DOC points for these two field lengths occur at the W/S and T/W ratio combination for balanced takeoff and landing field lengths. Figure 2-2 summarizes the effect of field length variation, showing that fields shorter than 4500 feet increase DOC and gross weight rapidly. Also shown is a slight increase in T/W ratio with an increase in field length. For this class of aircraft, minimum DOC is achieved as field length becomes longer by allowing W/S to increase fast enough to require this slight increase in T/W ratio. This is not the case with large

TABLE 2-2

AIRCRAFT DESIGN PARAMETERS

PSGR (NO.)	FIELD LENGTH (FT)	RANGE (N MI) SINGLE (DUAL) STAGE	TURBO-FAN	ENGINE 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

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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

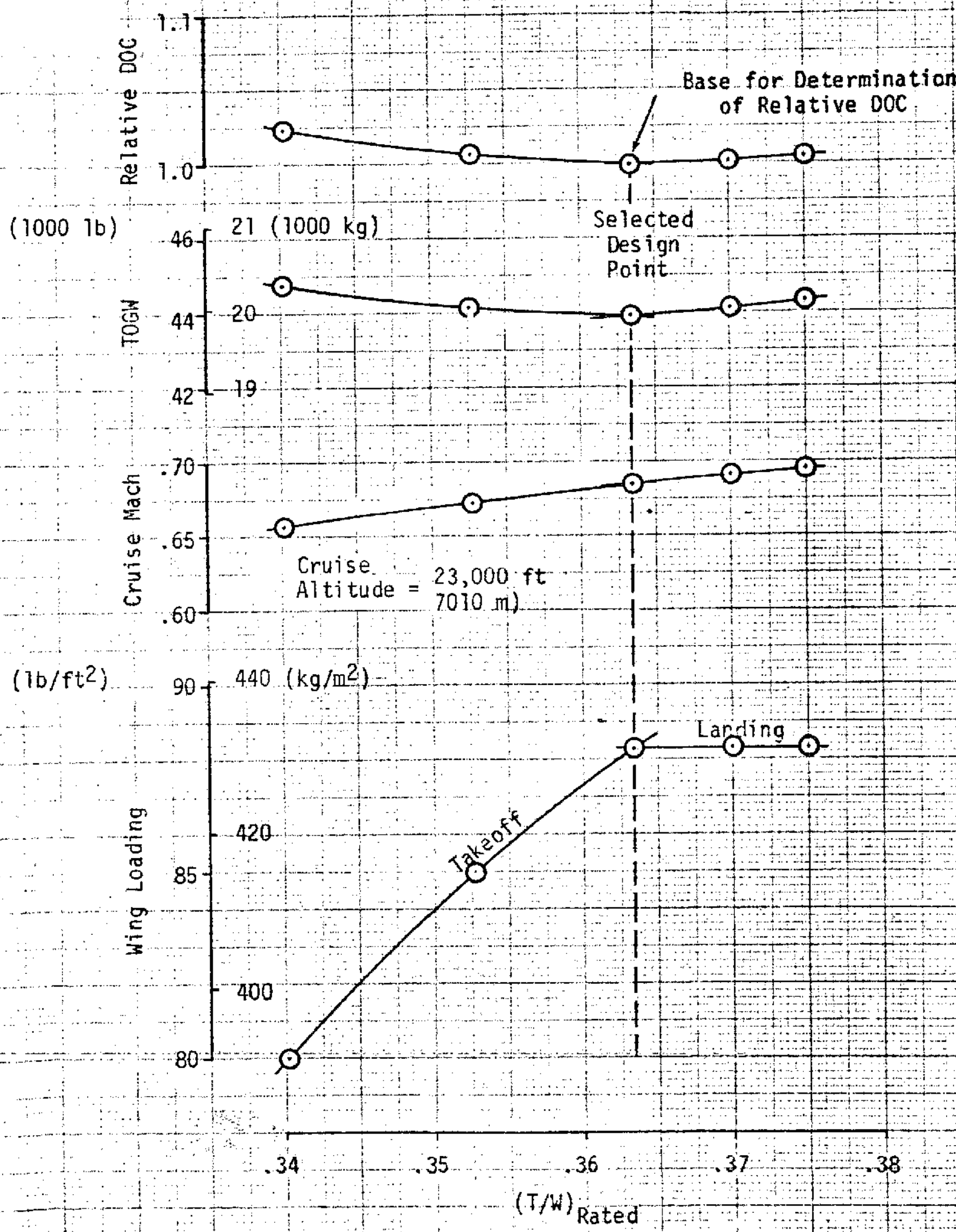

FIGURE 2-1

CONCEPTUAL AIRCRAFT SIZING
EFFECT OF FIELD LENGTH VARIATION ON SIZING
50 Passengers
2x250 n mi (2x463 km) Stage Lengths
BPR 6 Engines

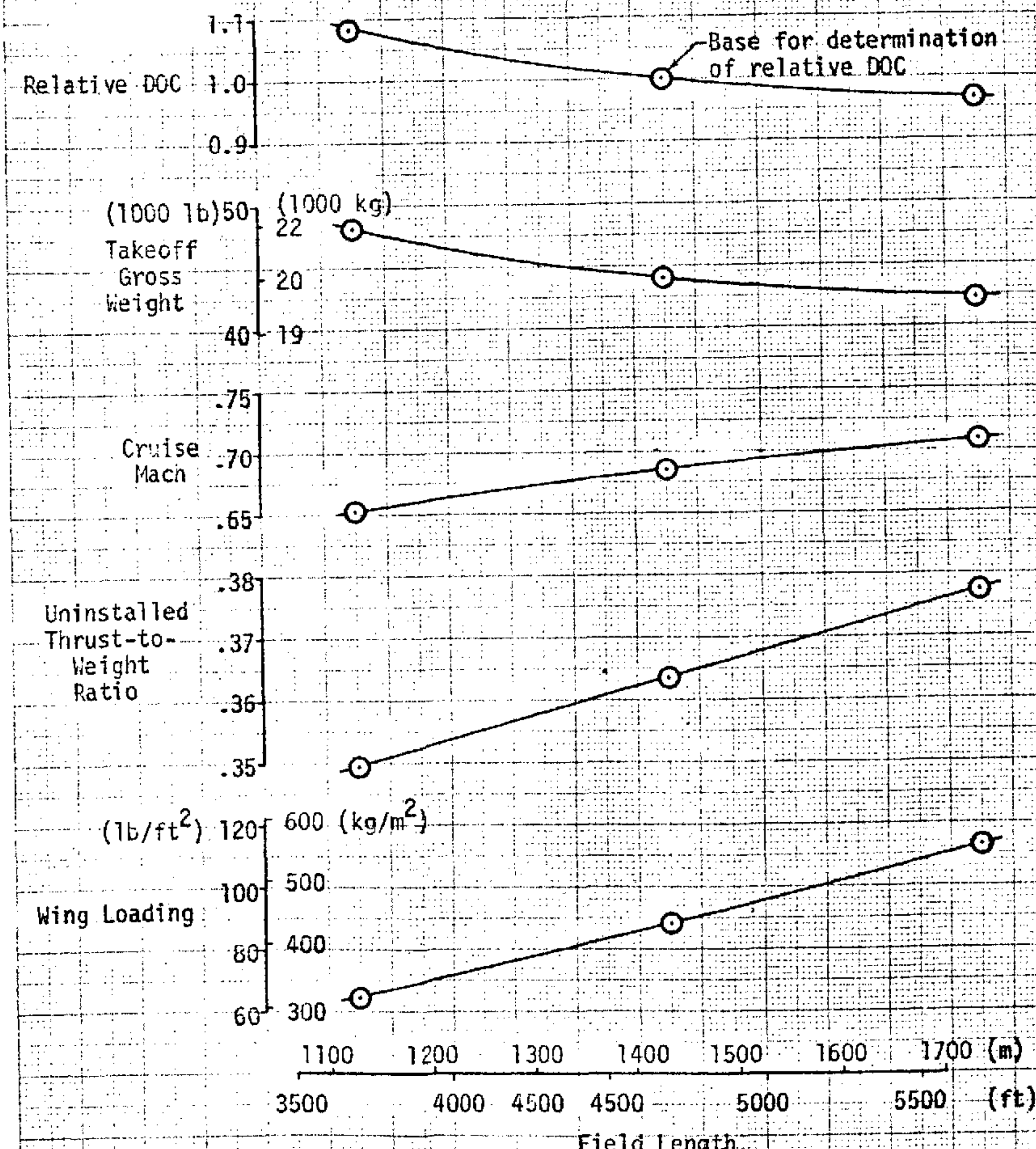

FIGURE 2-2

swept-wing aircraft, designed for higher cruise speed and longer field lengths.

2.1.4.3 - Passenger Capacity Variation - Conceptual aircraft, with passenger capacities of 30 and 70, were sized for a 4500 foot (1372 m) field and for two range capabilities, i.e., 2 x 250 nautical miles (2 x 463 km) dual stage lengths, and a 1 x 775 nautical mile (1435 km) single stage length. As with the baseline aircraft, the minimum DOC points for these aircraft occur at the W/S and T/W combination for balanced takeoff and landing field length. Figure 2-3 summarizes the effect of passenger capacity variation, showing the expected decrease in "seat-mile" DOC and increase in gross weight and cruise speed as passenger capacity is increased.

2.1.4.4 - Range Variation - Using the base 50 passenger capacity and 4500 foot field length, aircraft were sized for 2 x 150 nautical miles (2 x 278 km), and 2 x 350 nautical miles (2 x 648 km) dual stage lengths, and 1 x 1000 nautical miles (1 x 1852 km) single stage lengths. As with the baseline aircraft, the minimum DOC points for these aircraft occur at the W/S and T/W combination for balanced takeoff and landing field length. Figure 2-4 summarizes the effect of range variation, using single stage equivalents of the dual stage lengths on the abscissa.

2.1.4.5 - Propulsion System Variation - Conceptual aircraft, using variable-pitch turbofan and turboprop propulsion systems, were sized for 50 passengers, a 4500 foot field length and two ranges, i.e., 2 x 250 nautical miles (2 x 463 km) dual stage lengths and 1 x 1000 nautical miles (1 x 1852 km) single stage length. These aircraft were compared with the fixed-pitch turbofan aircraft above.

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

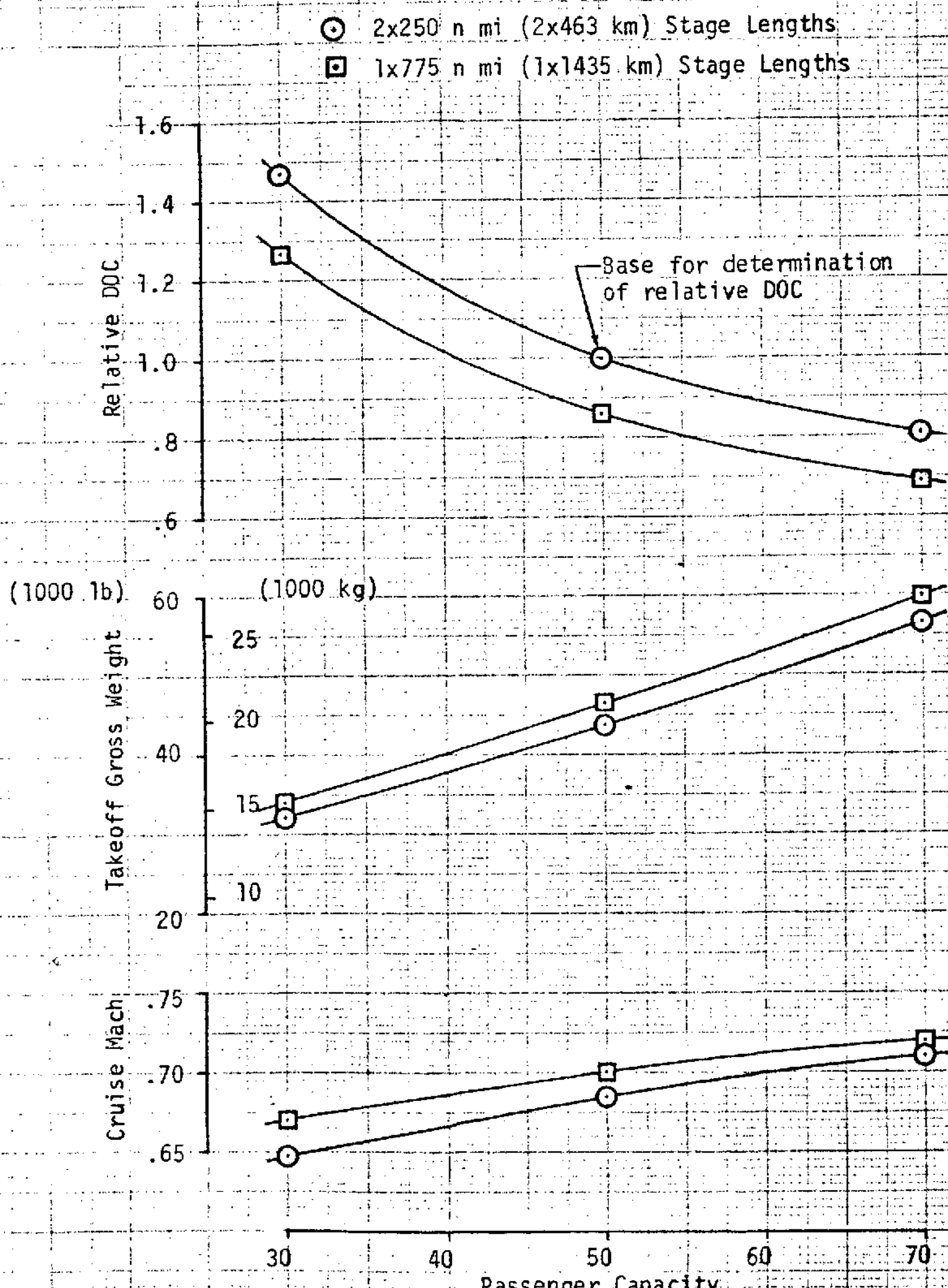

FIGURE 2-3

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CONCEPTUAL AIRCRAFT SIZING
EFFECT OF DESIGN RANGE VARIATION ON SIZING
50 PASSENGERS
4500 FT(1372M) FIELD LENGTH
BPR 6 ENGINES

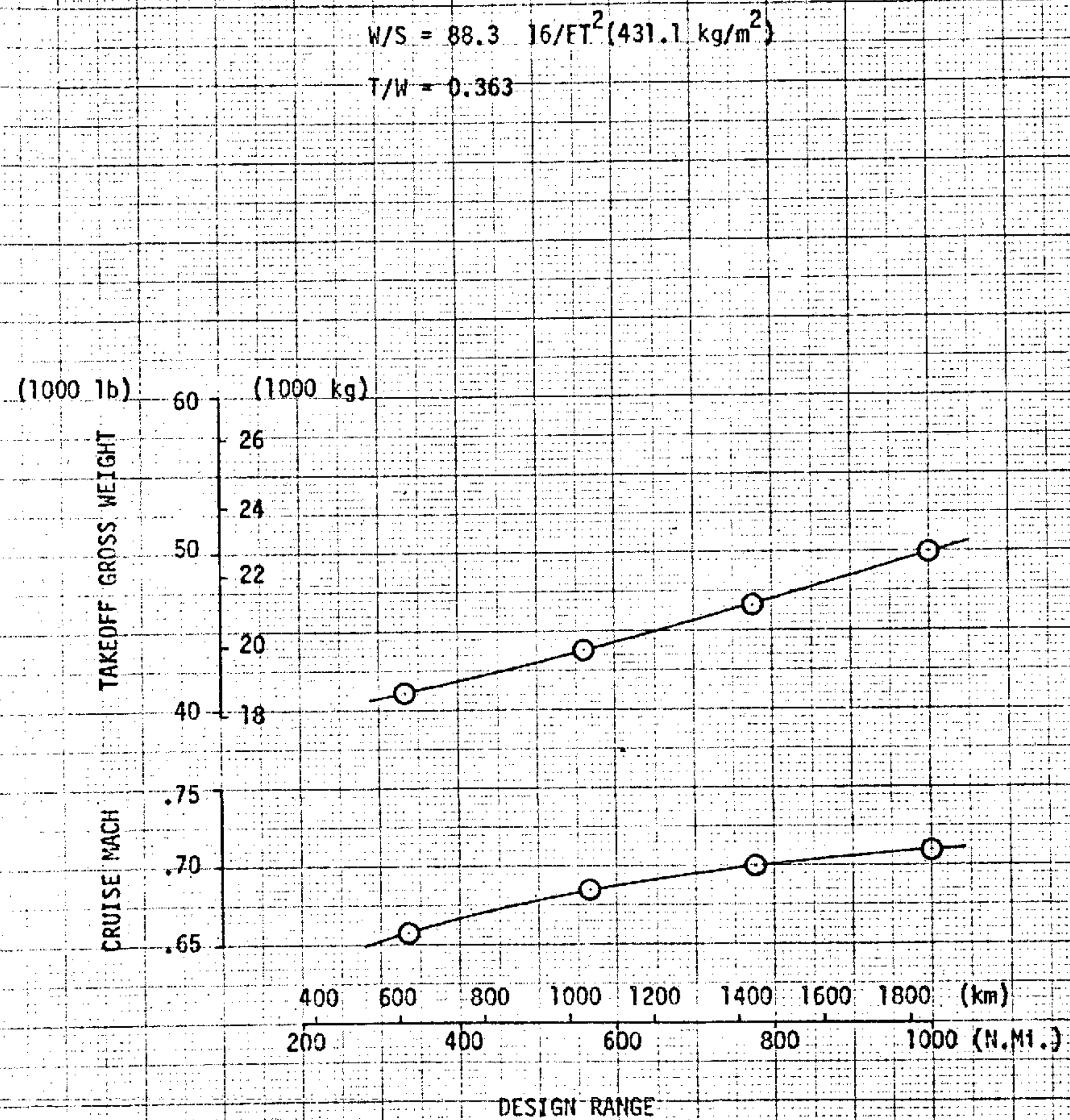

FIGURE 2-4

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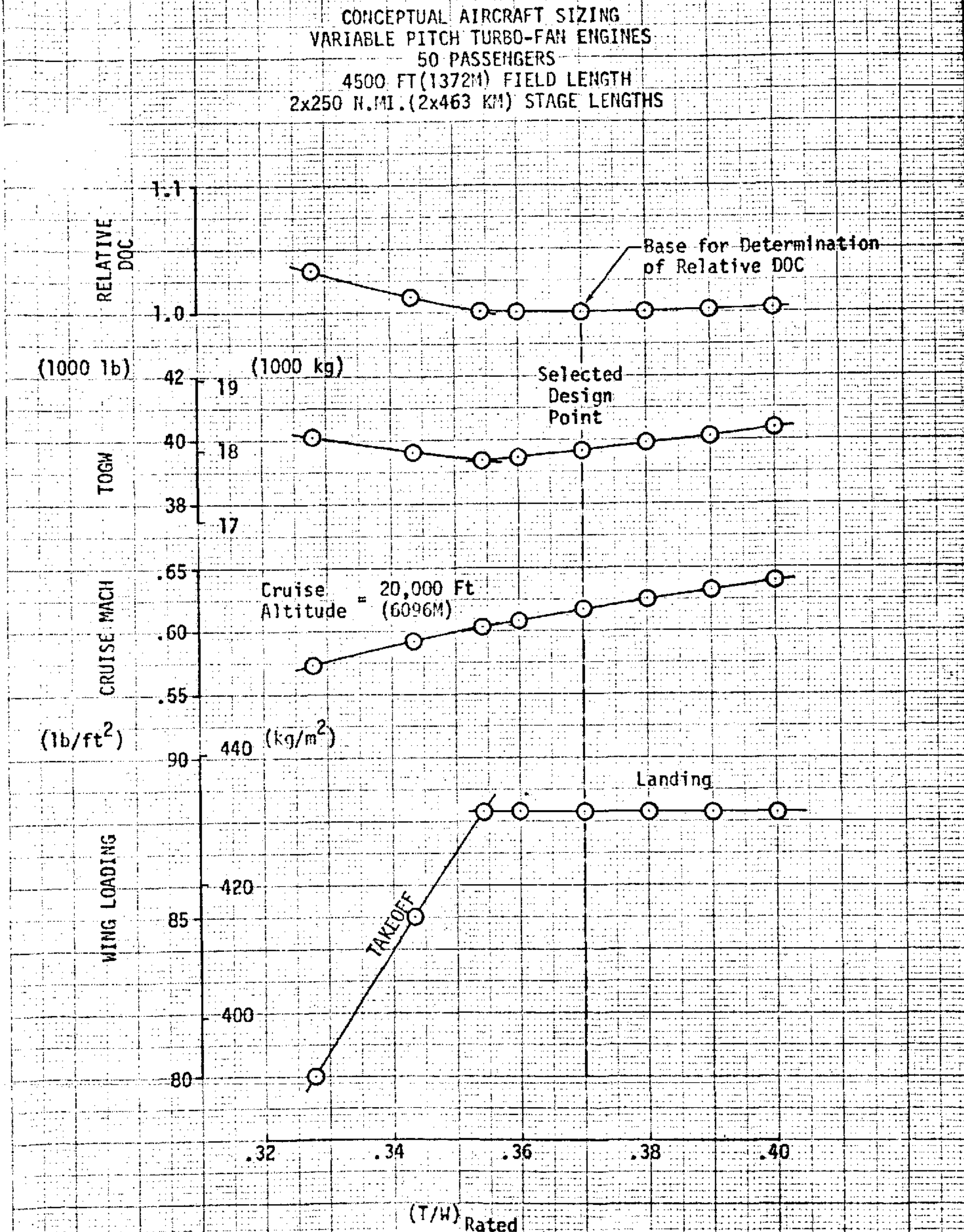
FORM 20-88-4 (REV. 6-71)

Figures 2-5 and 2-6 summarize the results of the variable-pitch turbofan aircraft, showing that the minimum DOC points occur at T/W ratios higher than that for a balanced field length, i.e., the takeoff field is shorter than the landing field. A comparison of these two figures shows that the optimum T/W ratio increases as design range increases. At the higher ranges, an off-optimum but more practical design point could be picked at a lower gross weight and T/W ratio that would result in a negligibly higher DOC (see Figure 2-6). Variable-pitch turbofan aircraft have slower cruise speeds than the fixed-pitch turbofan aircraft (compare Figures 2-5 and 2-6 with 2-4). However, this will improve as design effort is applied to increase the fan pressure ratio of the variable-pitch turbofan.

The turboprop aircraft is a wing-mounted, twin-engine, low-wing configuration. The parametric study of propeller characteristics resulted in selection of a 720 fps (220 mps) static tip speed and four blades with a 180 activity factor per blade. This propeller, aerodynamically similar to the Lockheed-Electra propeller, provided minimum weight (engine, gear box and propeller) with a small diameter and a low noise level. It achieved the desired performance goals, i.e., a high cruise efficiency at a cruise speed of Mach 0.60, with a T/W ratio sufficient for a 4500 foot takeoff field length. The thrust lapse during the takeoff run was similar to that of the fixed-pitch turbofan, resulting in the same static T/W ratio.

A preliminary steady-state study was conducted to determine basic one-engine-out control requirements, a highly important design consideration for turboprop aircraft. With bank angle limited to 5°, the aircraft was allowed to sideslip (less than 10°) only to the extent that a straight flight path could be maintained. The results showed that spoilers were not needed,



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

FIGURE 2-5

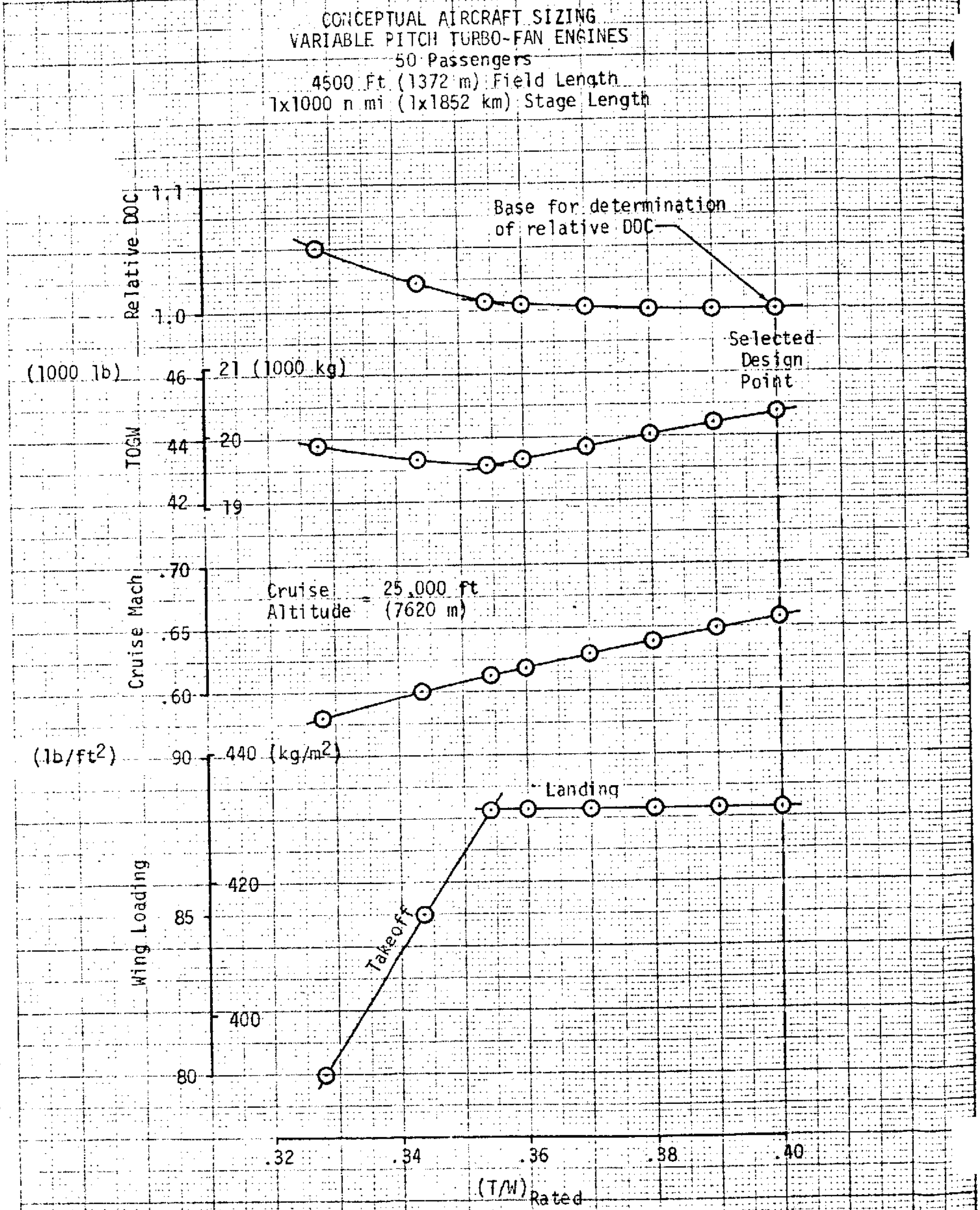

CONCEPTUAL AIRCRAFT SIZING
VARIABLE PITCH TURBO-FAN ENGINES
50 Passengers
4500 Ft (1372 m) Field Length
1x1000 n mi (1x1852 km) Stage Length
Relative DOC
1.1
1.0
Base for determination of relative DOC
Selected Design Point
(1000 lb)
46
44
42
TOGW
21 (1000 kg)
20
19
Cruise Mach
.70
.65
.60
Cruise Altitude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

FIGURE 2-6

as the aircraft could be controlled well below lift-off speed with either full aileron deflection (including yaw due to rudder) or full rudder deflection (including roll due to aileron).

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. In order to maintain the same one-engine-out control, the wing aspect ratio was increased to 10.5.

A study was conducted to determine the effect of designing the turboprop aircraft to a slower cruise speed. 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 for the reduced cruise speed and substantiates the high cruise speed used.

Figures 2-7 and 2-8 summarize the results of the turboprop aircraft, showing that the minimum DOC points occur at T/W (or horsepower-to-weight) ratios for balanced takeoff and landing field length. The turboprop cruise speeds (Mach 0.64 to 0.66) exceeded the desired goal and are approximately the same as those of the variable-pitch turbofan (Mach 0.62 to 0.66).

Table 2-3 summarizes the variable-pitch turbofan and turboprop aircraft and compares them with the fixed-pitch turbofan aircraft. Turboprop,

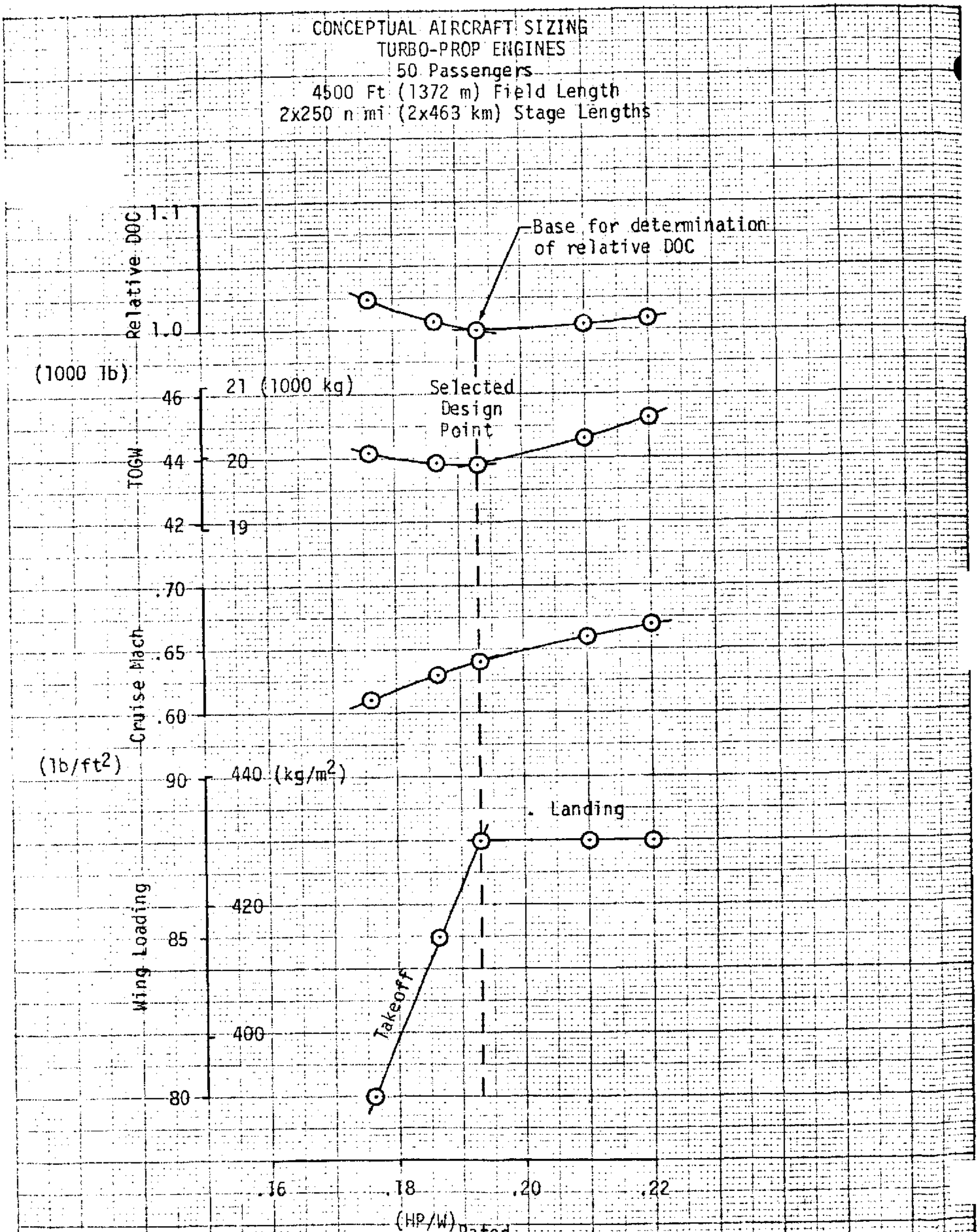

CONCEPTUAL AIRCRAFT SIZING
TURBO-PROP ENGINES
50 Passengers
4500 Ft (1372 m) Field Length
2x250 n mi (2x463 km) Stage Lengths
Relative DOC
1.1
1.0
Base for determination of relative DOC
(1000 lb)
21 (1000 kg)
Selected Design Point
TOGW
46
44
42
20
19
Cruise Mach
.70
.65
.60
(lb/ft²)
440 (kg/m²)
90
Landing
Wing Loading
420
85
Takeoff
400
80
.16
.18
.20
.22
(HP/W) Rated

FIGURE 2-7

DOUGLAS

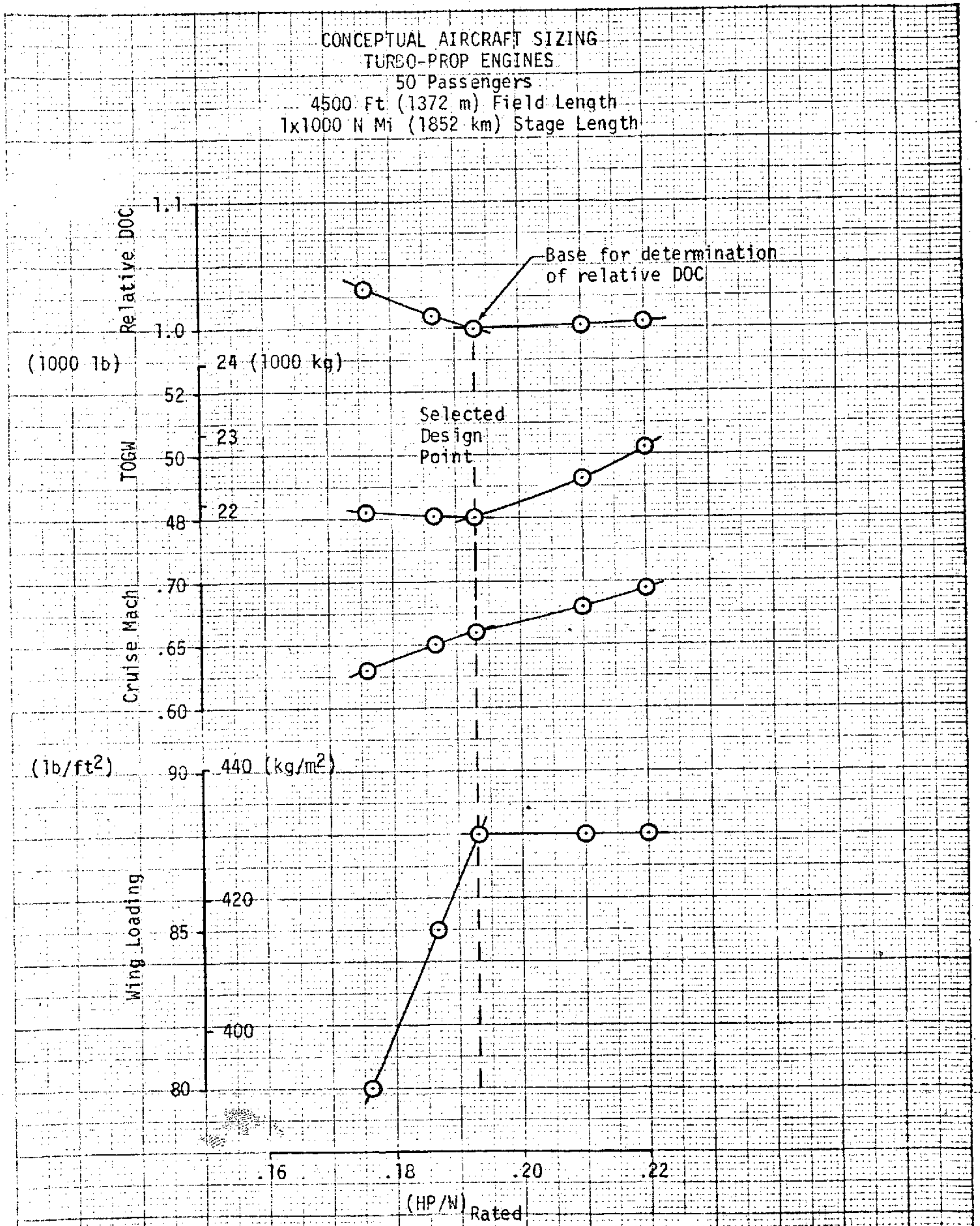


FIGURE 2-8

TABLE 2-3 CONCEPTUAL AIRCRAFT SUMMARY, PROPULSION SYSTEM VARIATION

50 Passenger Capacity
4,500 ft (1,372 m) Field Length

		Range = 2 x 250 n mi (2 x 463 km) Stage Lengths			Range = 1 x 1,000 n mi (1 x 1,852 km) Stage Lengths		
Engines:		Fixed Pitch BPR 6	Variable Pitch BPR 13	Turbo-Prop	Fixed Pitch BPR 6	Variable Pitch BPR 13	Turbo-Prop
Takeoff Gross Weight	(lb/kg)	43,920/19,920	39,740/18,030	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)	7,980/35,500	7,350/32,690	(4,230 hp)	9,090/40,430	8,960/39,860	(4,640 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)	23,000/7,010	20,000/6,096	20,000/6,096	25,000/7,620	25,000/7,620	25,000/7,620
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		1.00*	1.00	0.95	1.00*	1.01	0.94

*Base for determination of relative DOC

and especially variable-pitch turbofan aircraft, are lighter in gross weight and use less fuel than fixed-pitch turbofan aircraft. These advantages increase as range increase; also, as range becomes greater, the turboprop begins to use less fuel than the variable-pitch turbofan aircraft. The turboprop columns in this table include the combined weight effect of the higher wing aspect ratio and heavier fuselage acoustic insulation treatment, required to maintain interior noise at a level comparable to the Lockheed-Electra.

2.1.4.6 - High-Lift Systems Comparison - Three types of mechanical flap systems were investigated to determine their relative merits. The three systems are called simple, nominal and advanced high-lift systems. The nominal high-lift system, used in the parametric analysis, is the DC-9-30 system (a hinged flap with a fixed vane and a leading edge slat). The simple high-lift system is the nominal system without a leading edge slat. As an additional comparison, the Cessna Citation high-lift system is included. 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 degrees. The advanced high-lift system is a tracked flap with a moving vane and a leading edge slat.

The nominal system lift coefficient is 3.00 at 50 degrees deflection as compared with 2.28 for the simple system or 2.12 for the Cessna system at 40 degrees. The large difference between the two simple high-lift systems and the nominal system facilitated the following comparison.

A simplified analysis, which eliminated the landing flare maneuver, resulted in wing loadings of 67.0 and 62.3 lb/ft^2 (327.0 and 304.1 kg/m^2) for both simple high-lift systems. At an assumed gross weight 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 demanded an in-depth analysis, requiring an accurate definition of both configurations, sized to the same field and mission requirements. The slightly lower DOC displayed by the advanced flap configuration (Table 2-4) was inadequate for a decision and an additional evaluation was conducted (Table 2-5). This table lists complexity factors, which are a measure of the manufacturing labor, tooling and planning involved. 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, resulting in a one percent increase in airframe cost. Finally, a 6 percent increase in airframe cost is required in order to equalize the DOC of the advanced and nominal flap aircraft. Thus, the advanced high-lift system was selected for use on the final design aircraft.

2.1.4.7 - Acoustic Analysis - Aircraft noise is produced by nonpropulsive noise due to aerodynamic turbulence and propulsive noise due to the engines. During the landing approach, nonpropulsive noise increases when normal turbulence is augmented by the extended landing gear and doors and high-lift systems. Turbofan engine noise is caused by the jet exhaust and turbo-

TABLE 2-4. 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		1.000*	0.986

*Base for determination of relative DOC

TABLE 2-5

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 DOC		1.00		1.06

machinery. Jet noise suppression required forced mixing of exhaust gases. Turbomachinery noise suppression requires acoustic insulation. Turboprop noise is produced by the propeller and jet exhaust. Propeller noise is dominant and can be reduced by using large diameter, multi-blade, slowly rotating propellers. The principal problem is suppression of noise in the cabin interior.

A computerized noise analysis was used to determine turbofan flyover noise at the FAR Part 36 measuring points. It uses data representing typical turbofan engines, installed in short-to-medium fan duct nacelles with separate exhaust flow. Three levels of acoustic treatment are used: hardwall (none); minimum (cowl wall only); and maximum (reduce fan and turbine noise to jet core floor). The Hamilton-Standard procedure was used for propellers. It estimates far field noise based on power, tip speed, diameter and number of blades. Corrections are made for noise directivity, distance and number of propellers.

Table 2-6 shows the results, assuming that the engines are installed in nacelles without acoustic treatment (hardwall), enabling a direct comparison with the FAR Part 36 -10 EPNdB noise goal, and an assessment of the acoustic treatment required. The sideline noise estimates are 4 to 6 EPNdB below the noise goal and the takeoff noise 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

TABLE 2-6

ACOUSTIC NOISE LEVELS: UNTREATED

PSGR/LFL/RANGE	ENGINES		NOISE LEVEL: EPNdB SIDELINE	NOISE LEVEL: EPNdB TAKEOFF	NOISE LEVEL: EPNdB APPROACH
No./Ft/NM (No./m/km)	No. x Lb (N) Thrust		1,672 Ft SLT (509.5 m)	*	370 Ft (112.8 m)
50/4,500/2 x 250 (50/1,372/2 x 463)	2 x 7,980 (2 x 35,497)	FIXED PITCH TURBOFAN	87	80	98
50/3,500/2 x 250 (50/1,067/2 x 463)	2 x 8,410 (2 x 37,410)	"	87	80	99
50/5,500/2 x 250 (50/1,676/2 x 463)	2 x 7,970 (2 x 35,452	"	87	81	98
30/4,500/2 x 250 (30/1,372/2 x 463)	2 x 5,830 (2 x 25,933)	"	86	79	97
70/4,500/2 x 250 (70/1,372/2 x 463)	2 x 10,310 (2 x 45,861)	"	88	81	99
50/4,500/2 x 150 (50/1,372/2 x 278)	2 x 7,510 (2 x 33,406)	"	87	80	98
50/4,500/2 x 350 (50/1,372/2 x 648)	2 x 8,470 (2 x 37,676)	"	87	81	99
50/4,500/1 x 1,000 (50/1,372/1 x 1,852)	2 x 9,090 (2 x 40,434)	"	88	81	99
50/4,500/2 x 250 (50/1,372/2 x 463)	2 x 7,350 (2 x 32,694)	VARIABLE PITCH TURBOFAN	86	78	94
50/4,500/2 x 250 (50/1,372/2 x 463)	2 x 4,200 HP (2 x 3,132 kW)	TURBOPROP	87	81	89
	FAR 36-10 EPNdB		92	83	92

*FP AND VP AT 3,000 ± 150 FT (914 ± 45.7m), TP AT 3,600 FT (1,097.3m) were calculated for the propulsive system only and do not include an estimate for nonpropulsive noise.

2.1.4.8 - Weight Summary of Parametric Analysis - The weight estimation methods were developed during various commercial and military transport programs and from Douglas efforts to improve existing techniques. The equations for structure and systems components utilize parametric relationships derived during post design analyses of production transport aircraft. The weights for major structure, 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. 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.

Exhibit A tabulates the results of the parametric analyses, showing group weight statements, dimensional, performance and other descriptive data.

- o 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.

- o The field length parametric study, conducted by fixing all the parameters except field length, is shown in Columns 2 and 3.

- o 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

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PARAMETRIC ANALYSIS EXHIBIT A

DESCRIPTION		BASE AIRCRAFT	FIELD LENGTH		PASSENGER CAPACITY		STAGE LENGTH			PROPULSION TYPE				HI-LIFT
Flap Type		Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Advanced
Stage Length	(n.mi)	2 x 250	2 x 250	2 x 250	2 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
Number of Seats		50	50	50	30	70	50	50	50	50	50	50	50	50
Field Length	(ft)	4,500	3,500	5,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	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	468/9.0	528/9.0	566/9.0	450/9.0	507/9.0	486/9.0	533/9.0	430/9.0
Engine Designation		F.P. Fan	F.P. Fan	F. P. Fan	F.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
Engine Thrust	(lb)	2 x 7,980	2 x 8,410	2 x 7,970	2 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
Horiz/Vert Tail Area	(ft^2)	167/110	222/152	139/90	133/95	211/134	152/101	183/120	203/134	144/95	172/113	162/129	185/148	140/88.5
Horiz/Vert Tail Arm	(in)	370/290	370/290	370/290	290/210	430/350	370/290	370/290	370/290	370/290	370/290	370/360	370/360	370/290
Horiz/Vert Tail Volume		1.27/1.08	.92/.06	1.62/.10	1.27/.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
Wing Loading	(lb/ft^2)	88.3	64.5	112.8	88.3	88.3	88.3	88.3	88.3	88.3	88.3	88.0	88.0	100.8
Thrust Ratio		.3634	.3493	.3776	.3634	.3636	.3634	.3634	.3634	.3700	.400	.364	.364	.3741
Fuel Fraction		.1566	.1558	.1601	.1711	.1472	.1248	.854	.2174	.1316	.1869	.1327	.1797	.1569
Fuselage Diameter/Length	(in)	110/806	110/806	110/806	110/636	110/976	110/806	110/806	110/806	110/806	110/806	110/812	110/812	110/806
Wing	(lb)	4,252	6,364	3,261	3,046	5,598	4,031	4,464	4,755	3,888	4,326	4,189	4,497	4,010
Horizontal Tail	(lb)	598	797	502	477	766	538	663	748	505	619	645	741	506
Vertical Tail	(lb)	624	783	555	537	762	571	682	763	520	620	502	581	515
Fuselage	(lb)	5,497	5,521	5,490	4,384	6,679	5,492	5,534	5,565	5,480	5,518	5,760	5,804	5,487
Landing Gear	(lb)	1,932	2,119	1,858	1,412	2,496	1,819	2,050	2,200	1,749	1,971	1,884	2,065	1,908
Power Plant	(lb)	5,224	5,505	5,217	3,816	6,749	4,916	5,544	5,950	3,613	4,410	4,849	5,322	5,307
Fuel System	(lb)	274	336	238	234	312	266	283	293	261	277	271	284	255
Auxiliary Power Unit	(lb)	398	398	398	269	553	398	398	398	398	398	398	398	400
Flight Controls	(lb)	998	1,345	827	815	1,214	940	1,058	1,136	907	1,016	1,006	1,101	963
Instruments	(lb)	300	300	300	300	300	300	300	300	300	300	300	300	300
Hydraulics	(lb)	301	406	250	247	367	285	321	344	274	308	304	334	293
Pneumatics	(lb)	93	93	93	51	139	93	93	93	93	93	93	93	94
Electrical	(lb)	893	893	893	536	1,150	893	893	893	893	893	893	893	893
Avionics	(lb)	436	436	436	436	436	436	436	436	436	436	436	436	436
Furnishings	(lb)	3,370	3,370	3,370	2,481	4,536	3,370	3,370	3,370	3,370	3,370	3,763	3,763	3,370
Air Conditioning	(lb)	377	377	377	205	562	377	377	377	377	377	377	377	377
Ice Protection	(lb)	463	568	402	397	514	452	478	495	441	468	450	471	431
Handling Gear	(lb)	20	20	20	20	20	20	20	20	20	20	20	20	20
Weight Empty Manufacturer's		26,050	29,631	24,487	19,673	33,153	25,197	26,964	28,136	23,530	25,420	26,140	27,480	25,565
Operator's Items		990	1,019	973	917	1,227	983	996	1,004	980	1,000	990	1,010	990
Weight Empty Operator's		27,040	30,650	25,460	20,590	34,380	26,180	27,960	29,140	24,510	26,420	27,130	28,490	26,555
Payload		10,000	10,000	10,000	6,000	14,000	10,-00	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Mission Fuel		6,880	7,500	6.760	5,490	8,350	5,160	8,640	10,870	5,230	8,370	5,680	8,430	6,805
Maximum Takeoff Weight		43,920	48,150	42,220	32,080	56,730	41,340	46,600	50,010	39,740	44,790	42,810	46,920	43,360

of payload capacity, 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 turbofan engines and then twin turboshaft-propeller engines. The turboprop data in Columns 11 and 12 do not include the combined weight effect of the higher wing aspect ratio and the heavier acoustic insulation in the fuselage, mentioned above (Section 2.1.4.5 and Table 2-3). These weight effects are shown later in Section 5.0.

- The high-lift system parametric study, shown in Column 13, consisted of making two discrete variations to the baseline aircraft, i.e., using a simple version of the nominal flap system and an advanced tracked flap high-lift system. Data for the simple high-lift system are not included herein because the results were in favor of the nominal high-lift system, see Section 2.1.4.6, High-Lift Systems Comparison.

General arrangement sketches are shown in Section 2.4, Final Design Aircraft Summary.

2.2 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 many design features discussed below. Section 2.5.1 summarizes the features, quantitatively covered. Many others of equal cost importance could only be qualitatively evaluated because of the in-depth detail design required; these are discussed in Section 2.5.2, future considerations are in Section 2.5.3.

2.2.1 Design Features Quantitatively Evaluated

The quantitative evaluation results in a total cost savings of \$828,000 per basepoint airframe (see Table 2-7). The disposition of these savings is illustrated below. The left-hand column depicts the basepoint airframe designed in a manner similar to that for the B-737/DC-9 class aircraft for the major trunk air carriers. The right-hand column describes the same airframe as designed herein for the regional airline operators. The result is a cost decrease of 26%.

ITEM: $\$(10)^{-6}$	DESIGN PHILOSOPHY DC-9 Class	Study Aircraft
Airframe: Basic	2.823	---
Design & Performance Rqm'ts: Savings	0.0	0.450
Airframe: Basic	---	2.373
Design-To-Cost: Savings	0.0	0.103
Avionics	0.400	0.125
Airframe: Equipped	3.223	2.395

2.2.1.1 - Design and Performance Requirements - Because these aircraft are not designed to major trunk airline requirements, several design features produce major weight reductions and thus, the highest cost savings (\$450,000 on the baseline aircraft).

TABLE 2-7

DESIGN-TO-COST: SUMMARY
50 Passengers: 4,500 Ft Field Length; 850 N Mi Range; Advanced Flap

ITEM	% WEIGHT EMPTY SAVED OVER DESIGN LEVEL FOR MAJOR TRUNK AIRLINES	INCREMENTAL COST/AIRCRAFT ($)	
<u>Design & Performance Requirements</u>			- 450,000
Wing Geometry: Lower Sweep, Higher Thickness	- 5.3		
Horizontal Tail Geometry: Lower Sweep	- 1.6		
Fuselage: Lower Gage	- 2.1		
Furnishings: Austere, Galley, Seats, Paneling, etc.	- 3.7		
Propulsion: Higher T/W	- 1.7		
Avionics: Business Jet Type	- 0.9		
	-15.2%		
<u>Wing</u>			- 54,000
Hi-Lift System: Advanced Less Nominal		+ 25,000	
Rear Spar and Spar Caps		- 56,000	
Wing Fillets		- 23,000	
<u>Fuselage</u>			- 25,000
Pilot Enclosure, Doors, Compound Contours		- 12,000	
Cross-Section Shape		- 13,000	
<u>Empennage: Vertical Tail</u>			- 21,000
<u>Sub-Systems and Interiors</u>			- 278,000
Avionics: Non-ARINC less ARINC		- 275,000	
A/C, APU and Windows		- 3,000	
<u>TOTAL</u>			- 828,000

Very high subsonic cruise speed and altitude do not provide a large payoff on these short routes. Due to the field length requirements which demand high thrust-to-weight ratios, ample cruise speed is provided with unswept wings having supercritical airfoils. The pressurization stress in the fuselage skin is lower than conventional; interior furnishings and subsystems are simplified and/or eliminated. The parametric and final design aircraft were limited to a cruise altitude of 25,00 feet in order to minimize O_2 system and pressure capsule weight and eliminate hydraulic system pressurization. A study of the effect of cruise altitude upon O_2 system weight and cost disclosed that a 30,000 foot cruise altitude caused only a small increase in weight, cost and complexity (130 pounds, $10,000 and immediately available plug-in O_2), as compared to the simplified system with portable O_2. Considering this and the magnitude of the pressure capsule stresses, a study of a 30,000 foot design altitude is recommended as it will provide higher performance capability and greater marketability.

2.2.1.2 - Wing - Although the advanced high-lift system is more costly to build, it is preferred due to decreased DOC. Considering the wing sizes of these aircraft, it appears that a detailed design study could simplfy the advanced flap system and bring it much closer to the "double-slotted roller" type used in business-jet aircraft and reduce the costs shown.

Because high cruise speed is not a design criterion, the wing sweep (about 5 degrees) is determined by manufacturing considerations so that the rear spar is perpendicular to the plane of symmetry. Simple, right and left-hand flap and aileron fittings 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 (constant bevel). Wing-to-fuselage fillets are made of laminated fiberglass, are minimized in size and avoid overlapping or interference with doors, flaps, antennas, etc.

In summation, despite the cost increase due to the advanced high-lift system, these features result in a manufacturing cost savings of $54,000 on the baseline aircraft (see Table 2-7).

2.2.1.3 - Fuselage - Pilot enclosure costs are reduced by means of flat plane windows and frames (to simplify machining of frames, i.e., no compound contours). The window track rigging is simple - boxes are added to the frame to fix 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.

All doors and jambs are the same size. 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 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 and left-hand, forward and aft), as well as straight line elements.

Changing the fuselage cross-section from the double-bubble or cusp type, by fairing the cusp or by using a fully circular cross-section, results in cost savings.

These features save a total of $25,000 on the baseline aircraft (see Table 2-7).

2.2.1.4 - Empennage - The vertical tail was designed as an untapered surface. Because of the many common parts such as ribs, fittings, etc., the cost savings were $21,000 on the baseline aircraft (see Table 2-7).

2.2.1.5 - Subsystems and Interiors - Table 2-8 contains a list of required and optional avionics equipment, with adequate performance and reliability for the study aircraft. The equipment cost is of major importance; it is only 30 percent of typical DC-9 or B-737 equipment, used by a major trunk airline. The reason is that this equipment does not conform to the ARINC regulations which were 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 typical list; there is a multiplicity of choice in price and/or performance for most items. The result is a major cost savings of $275,000 (see Table 2-7).

The APU and AC 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, these units may be mounted low enough so that work stands or ladders may be avoided, or minimized in size.

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

TABLE 2-8

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)

These cost savings are small ($3,000, see Table 2-7).

2.2.2 Design Features Qualitatively Evaluated

These features were not costed.

2.2.2.1 - Aircraft Family Concept - Historically, new aircraft have been conceived as single-point designs developed for a specific segment of the market and not as an aircraft family for a broad market. Later, the market life of the single-point design is extended by adopting the "stretch" concept, usually a fuselage stretch at first. Still later, 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 because cost savings due to learning and commonality can no longer be achieved.

A "stretch/shrink" family concept was investigated in an attempt to initially and efficiently encompass the 30 to 70 passenger payload variation and thus maximize the cost savings. Figure 2-9 shows that four fuselage barrels are common and only two new plug barrels are required for the three fuselages.

The stretch/shrink family was based on the 50 passenger aircraft, using its wing and engines. As expected, it is shrink limited, in that it can be shrunk only from 50 to 42 passengers. Obviously, a wing-mounted-engine configuration will provide greater stretch/shrink capability; its disadvantages (wing efficiency, ground height, etc.) will not offset the cost savings achieved by the stretch/shrink concept.

STRETCH/SHRINK FAMILY DESIGN

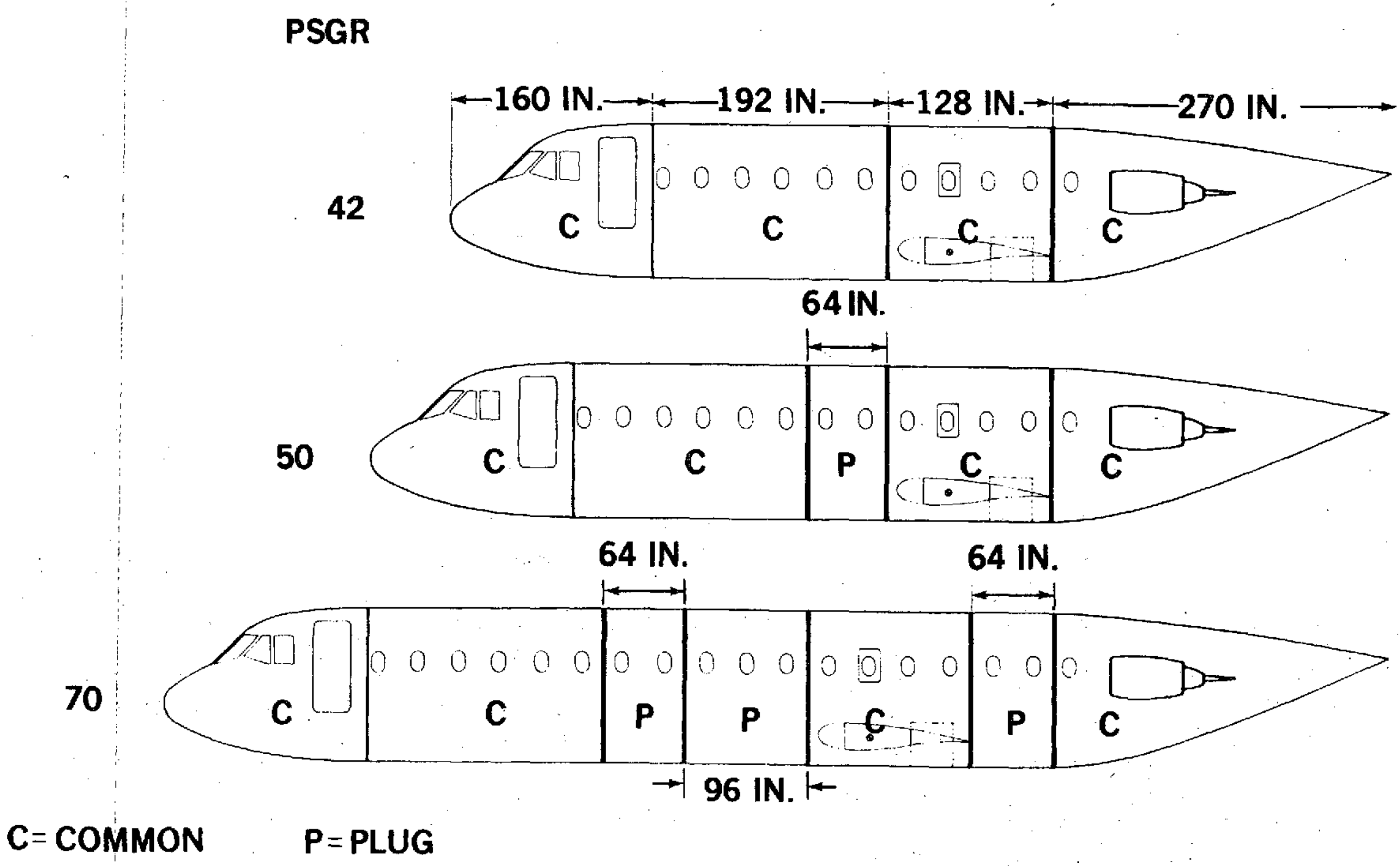


FIGURE 2-9

Additional in-depth study of this concept is merited. It appears that design modifications can be made to the center and tail barrels to provide for wings and engines of different sizes. This would increase stretch/shrink capability. Possibilities for substantial cost savings are anticipated.

2.2.2.2 - Fuselage Cross-Section and Baggage/Cargo Design - This study involved a comparison of four different fuselage types: the unfaired cusped fuselage, with riveted longerons and below-floor baggage/cargo compartment, used on all baseline aircraft; the baseline fuselage, modified by fairing the cusp and bonding the longerons; "large" diameter circular fuselage with a below-floor baggage/cargo compartment and bonded longerons; and the "small" diameter circular fuselage with an above-floor baggage/cargo compartment and bonded longerons.

Compared with the baseline fuselage, the following results were obtained: due to bonding, both below-floor baggage fuselages are much lighter and negligibly different in wetted area; the above-floor baggage fuselage is a little lighter, but has 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 B-737. Study scope limitations precluded in-depth design required for further analysis of operational aspects of above-floor versus below-floor baggage.

2.2.2.3 - Advanced Materials of Construction - Table 2-9 depicts the type and application of advanced materials of construction. Advanced metallics

TABLE 2-9

DESIGN-TO-COST: ADVANCED METALLICS AND COMPOSITES

50 Passengers; 4,500 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

were considered for initial application. Because of development time, composites were applied after the advanced metallics. The longer, above-floor baggage fuselage was used because of its favorable operational aspects.

Because of the time period (1980-1985) for operational introduction of these aircraft, composite materials were used only in 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, i.e., integrally stiffened plate for the wing box; honeycomb for the tail boxes; and bonded skin and longerons (with the longerons flattened-out through the frames) for the fuselage shell.

Table 2-9 shows that the use of advanced metallics saved 5 percent of the wing, tail and fuselage weight; when composites were added to the advanced metallics, 10 percent of the weight was saved. A comparison of the basepoint aircraft with aircraft using these above-floor baggage fuselages, shows that the unresized weight savings increase payload capacity by 4 percent and 10 percent, respectively. The conservative assumptions adopted for use of advanced materials shows that this area merits further exploration that should result in lucrative cost and weight savings.

2.2.3 Design Features: Future Considerations

Additional concepts, requiring in-depth detail design to determine weight and cost effects and/or feasibility, are listed below.

- Wing: Minimize the number of bolts and eliminate rigging in the wing-to-fuselage attachment. Reduce the number of cant ribs and taper lock bolts and locate the latter in the same material. Standardize hole patterns.

- Horizontal Tail: Use constant chord planform geometry. Design fittings and tabs for right and left-hand use and machine before location on jig.

- Fuselage: Avoid contours and attachments and eliminate doors on pressure bulkheads. Standardize clips and supports and avoid picking up existing fasteners. Minimize the brazing of wire terminals and use silver for hydraulic lines. Simplify the radome attachment.

- Cabin Interior: Minimize handwork and use di-electric tools for patterns on lining panels. Use standard mill-run lining panels with nonmatching patterns. Use soft, textured and covered vinyl for floor covering. Use automotive suppliers for ash trays, nameplates, handles and knobs, including the use of decals and nylon. Simplify baggage racks (see FAR 25.787).

- Miscellaneous: Minimize margins of safety and design to facilitate changes for the stretch/shrink concept. Reduce landing gear and flap limit speeds, consistent with safety. Consider a slab tail. Use the landing actuator as a side brace. Use lightweight, closed-cell foam to reduce unusable fuel. Combine jacking and mooring functions. Design forgings and castings with the formed draft included and/or use precision forgings to avoid machining. Where possible, use tapered stringers, stepped extrusions, stiffening beads, lap joints, spot-welding, nylon tubing, lightweight wiring, roll stock, and plastic tools.

2.3 Basepoint Aircraft Analysis

2.3.1 Performance and Design Ground Rules

Based upon the initial operational simulations, the following ground rules were selected:

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

- Range: Because the 563 nautical mile (1043 km) range of the conceptual design aircraft was inadequate, the range was increased to 850 nautical miles (1574 km). This is compatible with airline preference for capability equal to that of the Convair 580 (880 nautical miles, or 1630 km). An increase to 1000 nautical miles (1852 km) to provide for charter flights, was included in order to evaluate the cost penalties involved.

- Field Length: The regional carrier airfield studies resulted in the selection of a 4500 foot (1372 meters) field length on a 90°F (32.2"C), sea level day.

- Cruise Condition: Because of the short stage lengths, high cruise speed and altitude were not highly significant factors. The design procedure determined the optimum T/W ratio and W/S for a given field length. The cruise speed was a fall-out, resulting from the thrust available to cruise at a maximum altitude of 25,000 feet (7620 meters) at normal power setting. These requirements were a continuation of the conceptual design phase except for the evaluation of pressurization system effects for altitudes up to 35,000 feet (10,668 meters).

- Configuration Arrangement: The DC-9 or B-727 configuration was retained because of: crash landing safety; alleviation of landing gear design and retraction problems; minimum fuselage cross-section area; low drag; high wing efficiency; reduction of inlet duct ingestion problems; and wing blanketing of approach noise. The advanced high-lift system was incorporated because of DOC improvement.

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

2.3.2 Propulsion Characteristics

2.3.2.1 - Fixed-Pitch Turbofan Engine - This engine has a bypass ratio of 6 and a fan pressure ratio of 1.45. Its thrust-to-engine-weight ratio of 5.2 represents current technology with moderate turbine inlet temperatures of 2400°F or 1315°C, flat rated to 84°F or 29°C. The twin-engined 50 passenger aircraft required each engine to have a thrust rating of 8770 pounds (31,900 N). Installed performance includes inlet pressure recovery, bleed and power extraction, and scrubbing and base drag associated with the exhaust system. The nacelle drag due to freestream dynamic pressure is included in the airplane drag.

2.3.2.2 - Current Engines - Engine companies were solicited for data, and a survey was made of available engines, below a thrust rating of 20,000 pounds. An initial screening eliminated some engines because of noise, size or SFC. Potential candidates are listed in Table 2-10, along with the fixed-pitch turbofan for comparison.

The Lycoming ALF-502H is a fixed-pitch turbofan using as its core the T55 turboshaft engine (in production for many years). A military ALF-502 was flown on the Northrop A-9 aircraft during the A-X evaluation. A commercial ALF-502D was flown on the Dassault Falcon 30, and was contracted for the HS-146. Certification is scheduled for 1975. It has the lowest cost of all engines in Table 2-10; installed performance is given in Reference 3.

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

TABLE 2-10

CURRENT ENGINES: POTENTIAL CANDIDATES

		Available Commercial Engines		Derivative of Military Engine	Experimental	Existing Core	New
		Lycoming ALF 502H	RR-SNECMA M45H-01	General Electric CF-34	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 (7,64)
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)	3,660 (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

‡ Geared

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

The Hamilton-Standard QFT-55-28 is a variable-pitch turbofan with a fan pressure ratio of 1.28, using an uprated Lycoming T55 as its core. The demonstrator engine has a fan pressure ratio of 1.18 and has been extensively tested. The higher pressure ratio fan provides better specific thrust and a smaller diameter. Performance is presented in Reference 5.

The TF34, designed for the S-3A aircraft, completed its MQT* in August 1972. A slightly modified version, the TF34-GE-100, is installed on the A-10 aircraft. A commercial version of the CF-34 is rated at 8,000 pounds (35.6 kilonewtons) and flat rated to 84°F (29°C). Performance is 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 on existing cores. One possibility is the Allison PD370-1, a fixed-pitch turbofan with a fan 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 military concept; the takeoff rating was reduced 5 percent for a commercial rating (Reference 8).

2.4 Final Design Aircraft Summary

Exhibit B tabulates detail weights, 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), used in the conceptual aircraft analysis phase.

* Military Qualification Test

FINAL DESIGN AIRCRAFT EXHIBIT B

DESCRIPTION		TURBOPROPS			FIXED PITCH TURBOFANS				
Flap Type		Nominal	Nominal	Nominal	Advanced	Advanced	Advanced	Advanced	Advanced
Stage Length	(n.mi)	2 x 250	1 x 850	1 x 1000	2 x 250	1 x 850	1 x 1000	1 x 850	1 x 850
Number of Seats		50	50	50	50	50	50	30	70
Field Length	(ft)	4,500	4,500	4,500	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	489/9.0	342/9.0	605/9.0
Engine Designation		Turboprop	Turboprop	Turboprop	F.P. Fan	F.P. Fan	F.P. Fan	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	2 x 9,240	2 x 6,450	2 x 11,420
Horiz/Vert Tail Area	(ft^2)	155/143	182/145	192/153	123/106	138/115	150/129	112/104	177/147
Horiz/Vert Tail Arm	(in)	370/362	370/362	370/362	350/275	350/275	350/275	274/199	407/332
Horiz/Vert Tail Volume		1.27/.12	1.27/.12	1.27/.12	1.103/.091	1.103/.091	1.103/.091	1.103/.091	1.103/.091
Wing Loading	(lb/ft^2)	88.0	88.0	88.0	100.9	100.9	100.9	100.9	100.9
Thrust Ratio		.357	.357	.357	.374	.374	.374	.374	.374
Fuel Fraction		.1350	.1644	.1816	.1568	.194	.2161	.2039	.1697
Fuselage Dia/Length	(in)	110/812	110/812	110/812	110/806	110/806	110/806	110/636	110/976
Wing	(lb)	4,424	4,667	4,867	3,937	4,360	4,689	3,143	5,910
Horizontal Tail	(lb)	619	728	768	445	500	540	405	645
Vertical Tail	(lb)	559	567	598	617	693	750	605	860
Fuselage	(lb)	6,532	6,532	6,532	5,732	5,735	5,732	4,310	7,170
Landing Gear	(lb)	1,929	2,040	2,113	1,734	1,874	1,975	1,379	2,440
Power Plant	(lb)	4,728	5,007	5,186	5,306	5,740	6,050	4,221	7,473
Fuel System	(lb)	274	282	287	255	265	330	347*	305
Auxiliary Power Unit	(lb)	400	409	416	400	400	400	343	460
Flight Controls	(lb)	1,029	1,058	1,077	823	849	868	750	955
Instruments	(lb)	300	300	300	300	300	300	300	300
Hydraulics	(lb)	309	317	323	190	200	210	171	230
Pneumatics	(lb)	95	98	99	100	100	100	86	115
Electrical	(lb)	893	893	893	825	825	825	617	1,040
Avionics	(lb)	436	436	436	436	436	436	436	436
Furnishings	(lb)	3,551	3,551	3,551	3,505	3,505	3,505	2,623	4,720
Air Conditioning	(lb)	377	377	377	435	435	435	325	550
Ice Protection	(lb)	455	468	477	430	448	460	384	511
Handling Gear	(lb)	20	20	20	20	20	20	20	20
Manufacturer's Empty Weight		26,930	27,750	28,320	25,490	26,685	27,625	20,465	34,140
Operator's Items		990	990	990	1,070	1,075	1,075	985	1,320
Operator's Empty Weight		27,920	28,740	29,310	26,560	27,760	28,700	21,450	35,460
Payload		10,000	10,000	10,000	10,000	10,000	10,000	6,000	14,000
Mission Fuel		5,920	7,620	8,720	6,800	9,090	10,670	7,030	11,540
Maximum Takeoff Weight		43,840	46,360	48,030	43,360	46,850	49,370	34,480	61,000

DESCRIPTION		CURRENT ENGINES				
Flap Type		Advanced	Advanced	Advanced	Advanced	Advanced
Stage Length	(n.mi)	1 x 850	1 x 850	1 x 850	1 x 850	1 x 850
Number of Seats		61	42	35	31	67
Field Length	(ft)	4,500	4,500	4,500	4,500	4,500
Wing Area (ft^2)/Aspect Ratio		573/9.0	417/9.0	395/9.0	357/9.0	637/9.0
Engine Designation		PD370-1	CF34	M45H01	DFT55	ALF502
Engine Thrust	(lb/eng)	2 x 10,800	2 x 7,960	2 x 7,090	2 x 7,030	4 x 5,830
Horiz/Vert Tail Area	(ft^2)	174/147	130/115	128/116	117/108	199/140
Horiz/Vert Tail Arm	(in)	382/307	316/242	297/227	276/204	391/376
Horiz/Vert Tail Volume		1.103/0.091	1.103/0.091	1.103/0.091	1.103/0.091	1.103/.093
Wing Loading	(lb/ft^2)	100.9	100.9	100.9	100.9	98.9
Thrust Ratio		.3734	.3786	.3554	.3900	.3700
Fuel Fraction		.2076	.1965	.2238	.2101	.2243
Fuselage Dia/Length	(in)	110/902	110/742	110/710	110/678	110/866
Wing	(lb)	5,550	3,840	3,630	3,227	6,163
Horizontal Tail	(lb)	629	471	463	425	863
Vertical Tail	(lb)	851	669	675	630	567
Fuselage	(lb)	6,488	5,120	4,653	4,362	6,471
Landing Gear	(lb)	2,314	1,682	1,596	1,441	2,680
Power Plant	(lb)	7,816	5,530	5,165	4,856	8,948
Fuel System	(lb)	295	251	445*	372*	523
Auxiliary Power Unit	(lb)	475	330	305	275	475
Flight Controls	(lb)	925	775	750	685	1,085
Instruments	(lb)	300	300	300	300	375
Hydraulics	(lb)	225	175	170	160	280
Pneumatics	(lb)	130	80	70	60	152
Electrical	(lb)	934	736	670	628	946
Avionics	(lb)	436	436	436	436	436
Furnishings	(lb)	3,967	3,125	2,846	2,669	4,020
Air Conditioning	(lb)	492	389	353	331	498
Ice Protection	(lb)	498	424	413	393	525
Handling Gear	(lb)	20	20	20	20	20
Manufacturer's Empty Weight		32,345	24,353	22,960	21,270	35,025
Operator's Items		1,295	1,037	1,010	990	1,165
Operator's Empty Weight		33,640	25,390	23,970	22,260	36,190
Payload		12,200	8,400	7,000	6,200	12,400
Mission Fuel		12,010	8,260	8,930	7,570	14,140
Maximum Takeoff Weight		57,850	42,050	39,900	36,030	63,030

* INCLUDES FUSELAGE FUEL SYSTEM WEIGHT

2.4.1 Turboprop Aircraft

Columns 1, 2 and 3 include the effects of higher aspect ratio and heavier acoustic insulation in the fuselage. A comparison, of Columns 1 and 3 with Columns 11 and 12 in Exhibit A of Section 2.1.4.8, shows that these effects have increased the gross weights by 1000 to 1100 pounds, due to wing and fuselage weight changes. A general arrangement sketch is shown in Figure 2-10.

In comparison with the fixed-pitch turbofan aircraft, the turboprop uses less fuel at a given range; its weight empty is greater, but its gross weight compares favorably; in fact, at the longer ranges (850 to 1000 nautical miles, 1574 to 1852 km), its gross weight is lower. Despite a slower cruise speed, the turboprop DOC is lower due to lower aircraft costs and fuel consumption. Further improvement can be expected from recent developments in propeller blade design, where advanced airfoils will permit cruise speeds equivalent to those of turbofan aircraft and formerly attainable only with the variable camber propeller.

2.4.2 Fixed-Pitch Turbofan Aircraft

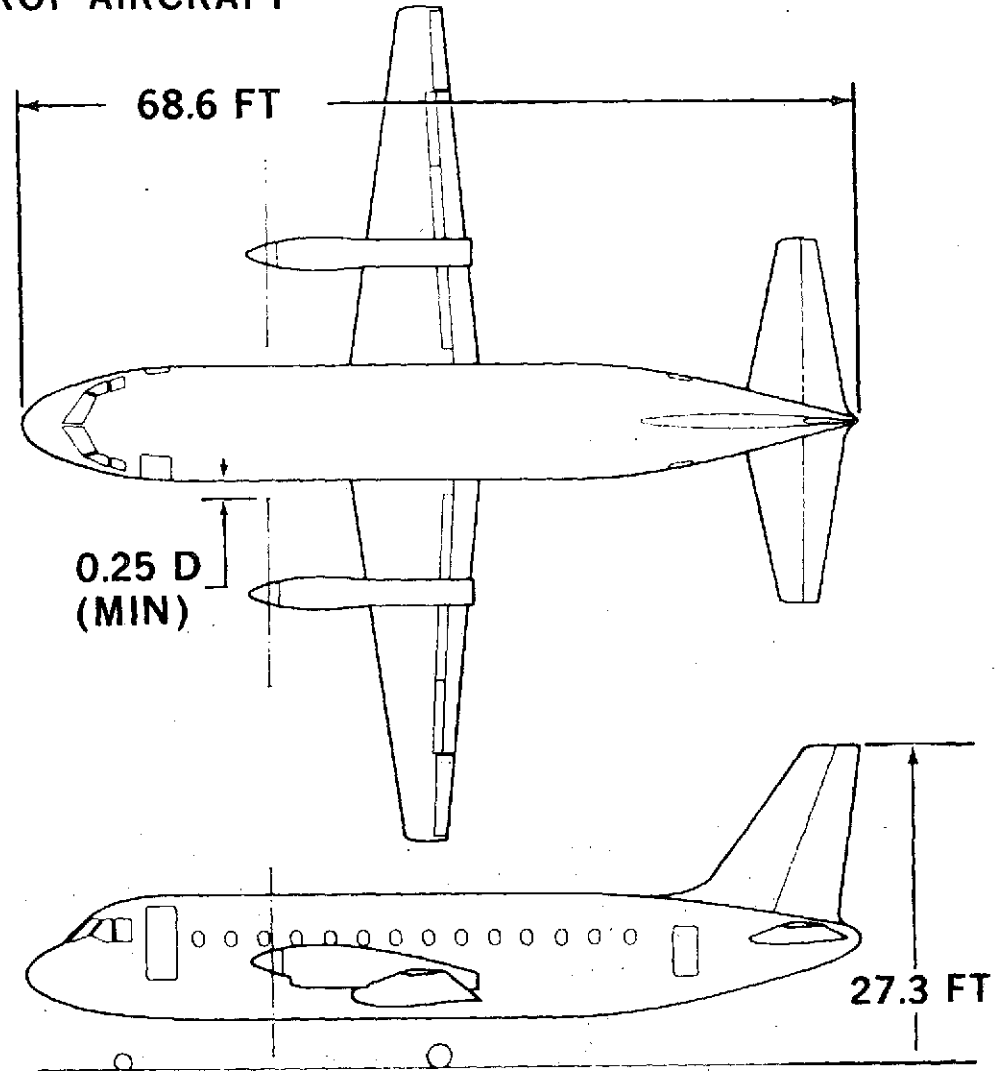
Table 2-11 supplements Exhibit B, Columns 5 through 8, to facilitate comparisons. Figures 2-11, 2-12 and 2-13 are the general arrangement sketches for the three passenger capacities.

The fuel and payload fractions show the expected improvement in design efficiency with increase in aircraft size. Also, as expected, an increase in aircraft size resulted in higher trip cost and decreased seat-mile cost. Increasing the design range to provide longer flight capability increased DOC by less than one percent.

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



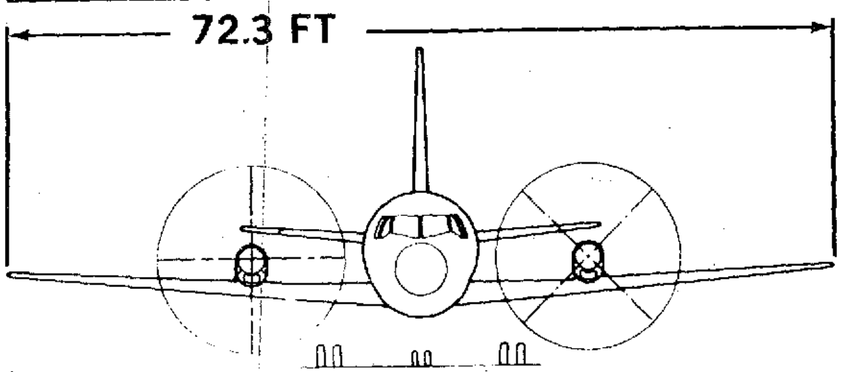


FIGURE 2-10

TABLE 2-11

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

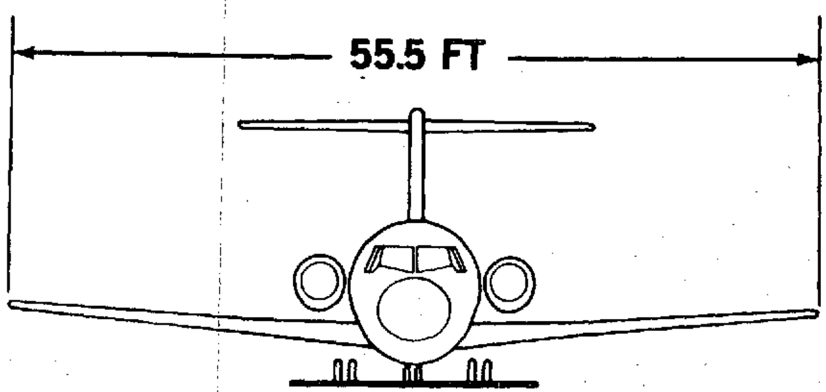
PASSENGERS	(No.)	30	50	70	50
RANGE	(N Mi)	1 x 850	1 x 850	1 x 850	1 x 1,000
OPERATING WT EMPTY	(Lb)	21,450	27,770	35,460	28,700
FUEL	(Lb)	7,030*	9,090	11,540	10,670
PAYLOAD	(Lb)	6,000	10,000	14,000	10,000
GROSS WEIGHT	(Lb)	34,480	46,860	61,000	49,970
AIRFRAME COST WT	(Lb)	17,210	22,310	28,480	23,020
FUEL FRACTION		0.204	0.194	0.189	0.216
PAYLOAD FRACTION		0.174	0.214	0.230	0.203
CRUISE SPEED (25,000 FT)	(Mach No.)	0.73	0.75	0.75	0.75
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

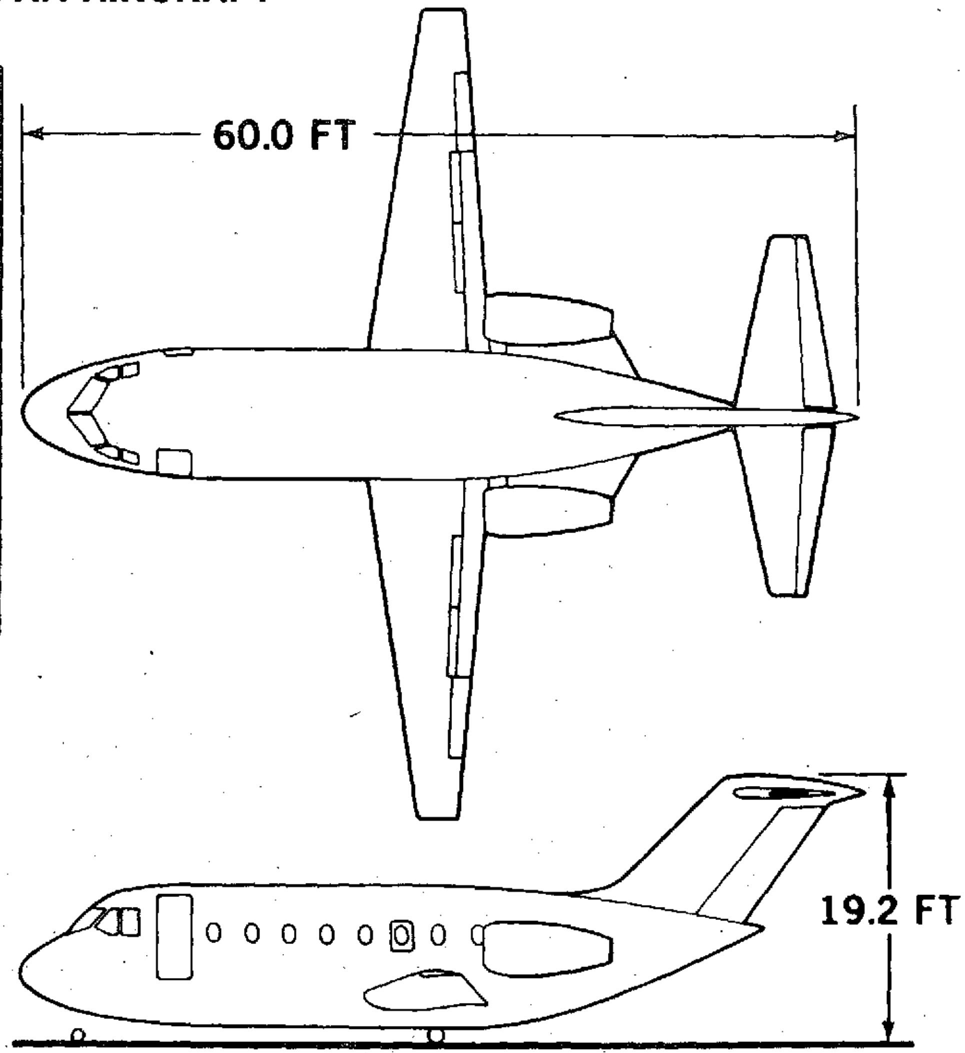
*WING FUEL LIMITED, BELLY TANK FUEL REQUIRED (LB) 715

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 x 6,450 LB





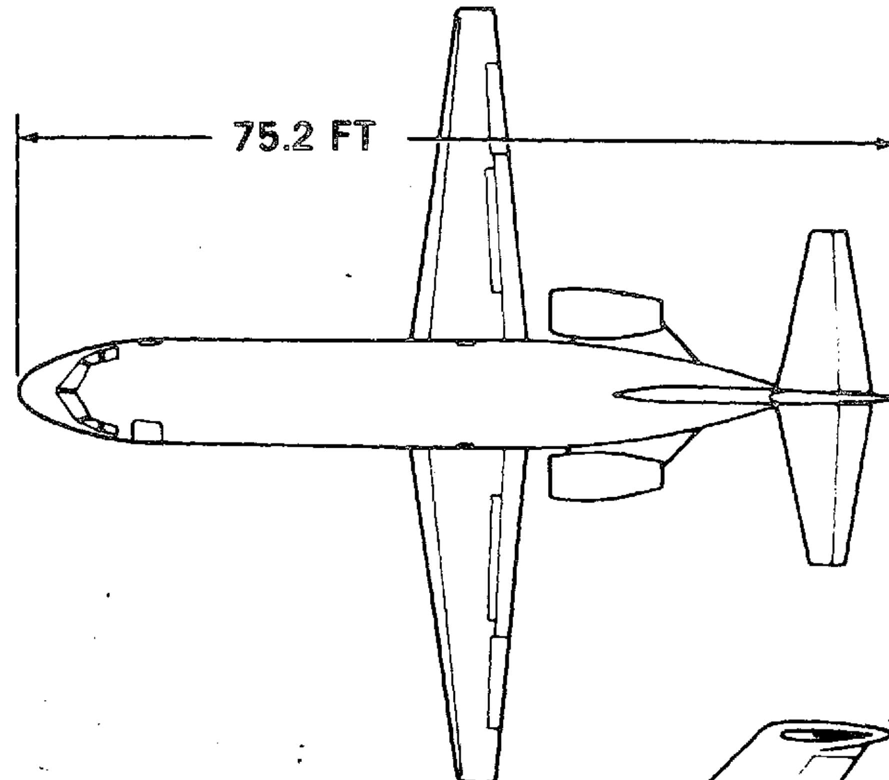
PR4-GEN-28058D

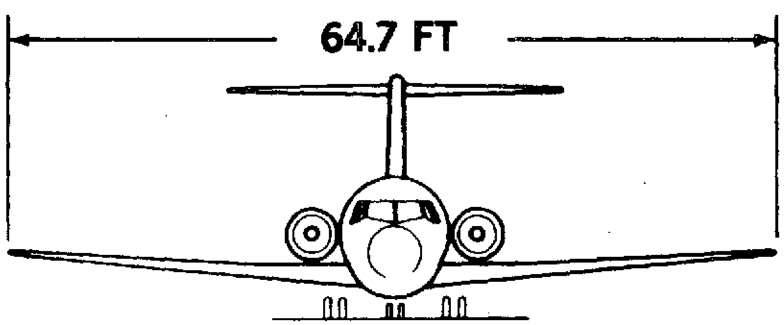
FIGURE 2-11

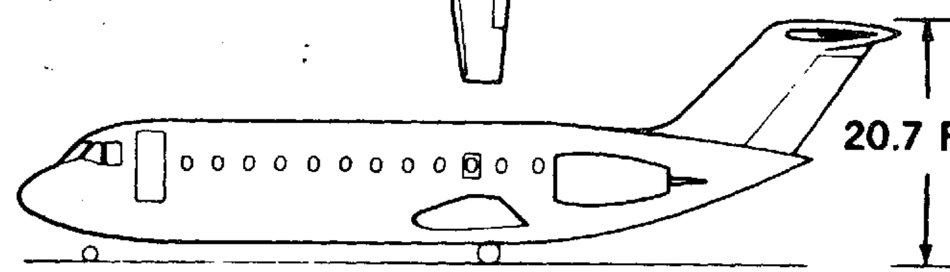
GENERAL ARRANGEMENT: FINAL DESIGN

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







PR4-GEN-28057D

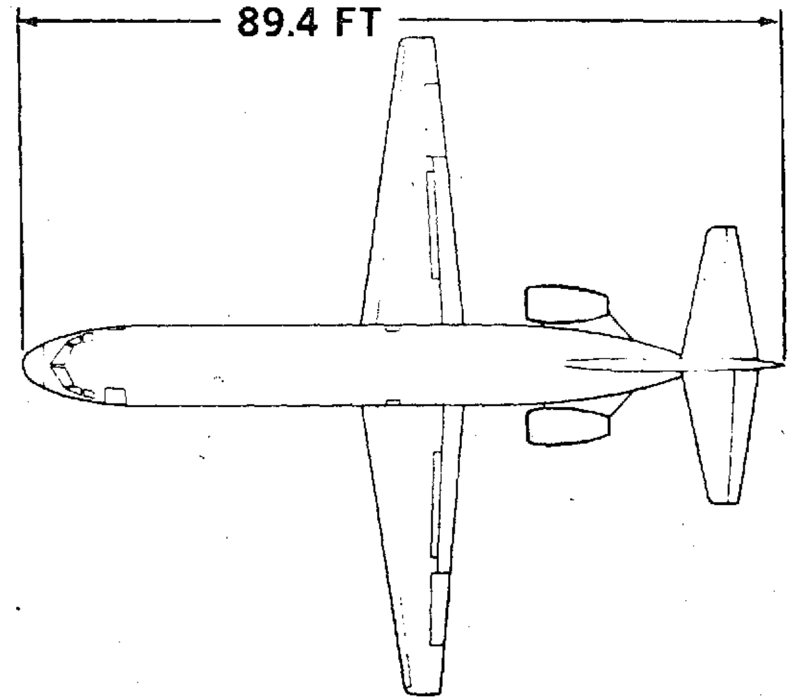
FIGURE 2-12

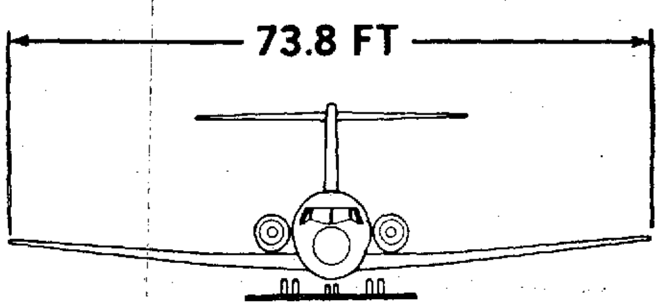
C-2

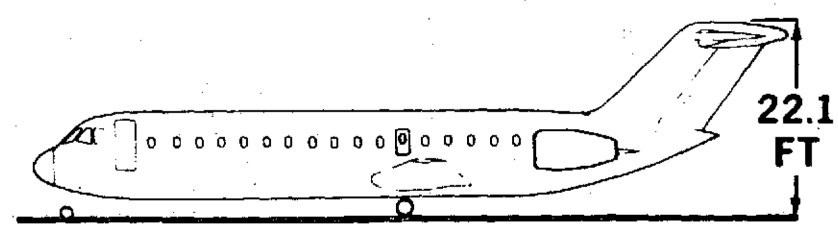
GENERAL ARRANGEMENT: FINAL DESIGN

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







PR4-GEN-28059A

FIGURE 2-13

The airframe cost weight is a measure of airframe price, assuming a constant unit price (dollars per pound). Aircraft size increased aircraft price and decreased price per seat. Provision for longer flights increased the price and price per seat by 3 percent. These relative values are conservative as they omit engine unit price (dollars per pound of thrust) which increases as thrust decreases, thus making the smaller aircraft even more expensive.

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.

2.4.3 Current Engine Aircraft

This investigation involved the sizing of aircraft with engines fixed in size and composed of propulsion cycles different from the fixed-pitch turbofan. Holding range and field length constant, and with the number and size of engines determining the gross weight, the passenger capacity was a fall-out. All of the aircraft are aft-fuselage-mounted, twin-engine, low wing configurations, except the ALF502 configuration which has four wing-mounted engines. An aircraft powered by two ALF502 engines would not carry 30 passengers and three-engine configurations were not considered (see Figure 2-14).

Table 2-12 supplements Exhibit B, Columns 9 through 13, for comparative purposes. In each column (below the aircraft with the current engine) is an aircraft powered by the fixed-pitch turbofan and sized to the

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
	$T_{SLS} = 4 \times 5830$ LB

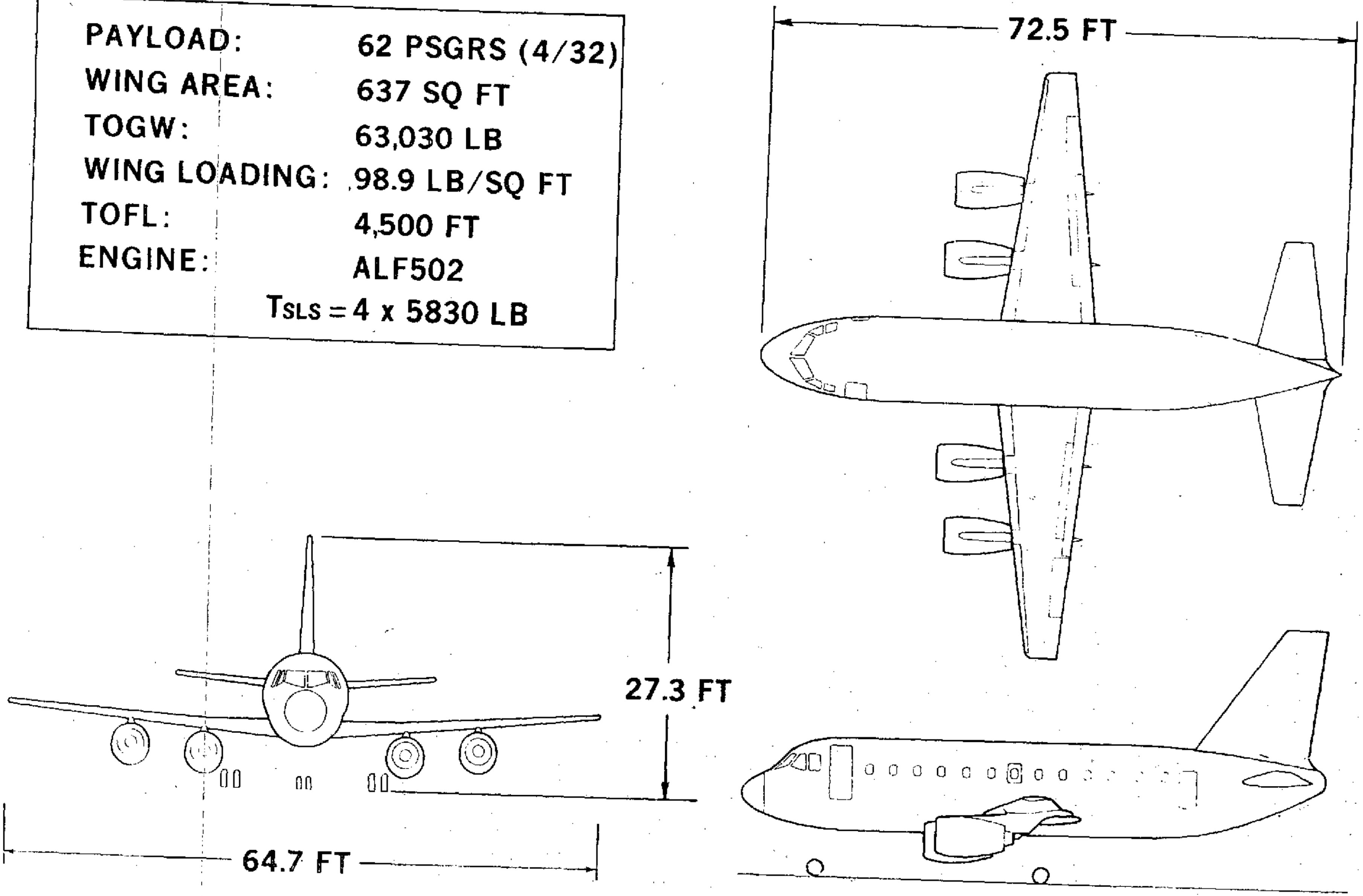


FIGURE 2-14

TABLE 2-12

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

PAYLOAD (LB) (PASSENGERS) (NO)	12,400 (62)	7,000 (35)	6,200 (31)	8,400 (42)	12,200 (61)
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	22,260	25,390	33,640
FUEL (LB)	14,140	8,930*	7,570*	8,260	12,010
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: BPR6/FPR 1.45					
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
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		

same passenger capacity. Inspection shows the following:

- Only two engines are "fully off-the-shelf" available engines, the ALF-502 and M45H-01.

- The other three engines are "partly off-the-shelf" engines. The QFT-55 is an experimental variable-pitch turbofan driven by a T55 core. The CF-34 is a commercial version of the military TF34 and requires commercial certification. The PD370-1 is a proposed fixed-pitch turbofan driven by an experimental "hardware" gas generator.

- Examination of 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. Obviously, the DOCs of the current-engine aircraft suffer in comparison with the turbofan aircraft; the ALF-502 is the highest; the CF34 and QFT55 are the lowest or best. In order to improve DOC, more efficient engine cycles and engines of higher thrust ratings must be developed.

2.4.4 Acoustic Analysis

For the turbofan engines, a computer program was employed which uses static noise data from the NASA Quiet Engine Program and DC-8, DC-9 and DC-10 flyover noise data. Inputs include: fan pressure ratio and tip velocity; bypass ratio; air flow rates; and nozzle exit velocities and nozzle exit areas. Peak perceived noise levels (PNL) are calculated in the forward and aft quadrants relative to the engine inlet. The noise sources are: fan inlet and fan exhaust; turbine; core; and jet exhaust. Adjustments for number of engines, distance from noise source, and turbomachinery suppression are applied and summed logarithmically. The total inlet or exhaust PNL, whichever is maximum, is corrected for noise duration to determine the EPNL.

FAR Part 36 noise contours of 80, 85 and 90 EPNdB were generated by a computer program. Inputs consist of noise data as a function of distance and flight path, and aircraft performance data. Airspeed adjustments are made on a logarithmic basis; for ground attenuation, SAE document ARP 1114 is used. For the community impact analysis, noise contours of 80 to 100 EPNdB were generated for a typical operational takeoff and approach using a computer program. The noise levels are used to establish an EPNL grid system which is transformed into a population density grid system. The number and fraction of people highly annoyed is calculated for all grid points within a given EPNdB contour (see Reference 2 and Section 2.4.5).

Flyover noise under FAR Part 36 conditions was estimated for the final design, 50 passenger aircraft with two fixed-pitch turbofans, and for the aircraft with two Hamilton-Standard QFT-55-28-2 variable-pitch turbofan engines. The fixed-pitch turbofan engine has a long-duct mixed-flow nacelle and the QFT-55 engine has a short duct, separated-flow nacelle. Acoustic treament, applied to the nacelle inlet and exhaust duct walls, is perforated sheet bonded to aluminum honeycomb.

Table 2-13 shows the results of the FAR Part 36 analysis and Figure 2-15 shows the noise contours. The EPNL for 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. However, the levels do not include nonpropulsive (NPN) noise. Extrapolation of NPN test data to the study aircraft results in NPN levels of 92 to 96 EPNdB. Logarithmic addition of these NPN and

TABLE 2-13

NOISE LEVELS: TWIN ENGINE AIRCRAFT

Engines: Final Design BPR 6/QFT-55-28-2

Thrust Rating LB: 2(8770/7800)

	Noise Source	FAR Part 36 Condition and Slant Range		
		0.25 - N.Mi. Sideline 1672 Ft.	3.5 - N.Mi. Takeoff 2800/3070 Ft.	1.0 - N.Mi. Approach 370 Ft.
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

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

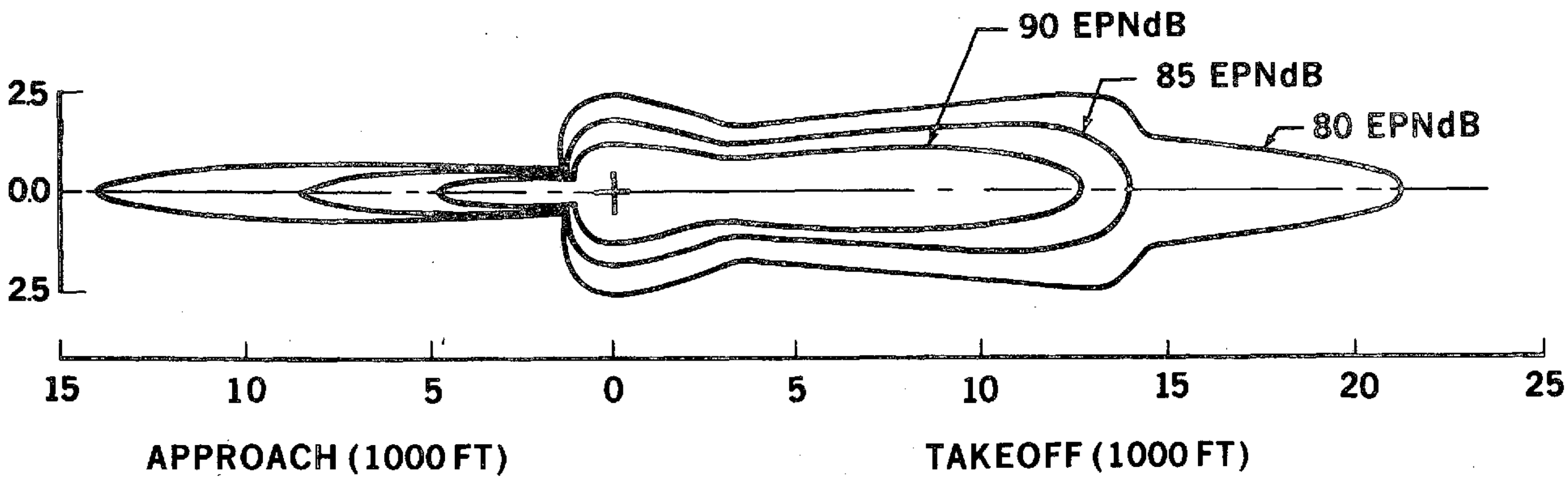


FIGURE 2-15

engine noise levels would result in increasing the approach EPNL by 2 to 5 EPNdB. Therefore, nonpropulsive noise may be a constraint below which additional noise reduction will be difficult to achieve. It may by necessary to study methods for reducing nonpropulsion and propulsive noise, if lower noise levels are desired.

2.4.5 Environmental Impact Analysis

Emphasis on environmental protection has resulted in design criteria and operational standards for transportation, e.g., the National Environmental Policy Act (NEPA) of 1969; the Clean Air Act of 1970; Noise Control Act of 1972; and the Airport and Airway Development ACT (AADA) of 1970. Specific aircraft regulations are the FAR Part 36 Noise Standards and the EPA Emissions Standards. The NEPA and AADA also established requirements for the Environmental Impact Statement (EIS) for federal funded projects.

This analysis defines environmental characteristics and impact of the study aircraft. Computer graphic display techniques were utilized in the noise impact analysis. Methodology and data developed in two previous NASA studies (References 2 and 9) were used.

2.4.5.1 - Selected Airport: Chicago Midway - Midway was selected as a typical hub in a medium density transportation system, because of its potential as a key airport in the nation's feeder-line route network, as a reliever for O'Hare short-haul traffic. This has been advocated by the FAA, the CAB and the City of Chicago, and opposed by the trunk airlines and some regional carriers with high transfer traffic, due to the cost of dual facilities. As traffic grows and O'Hare becomes saturated, Midway must absorb more short-haul and feeder operations. Midway was included in previous NASA short-haul and FAA studies (References 2, 9 and 10).

Scheduled aircraft operations in the Chicago hub have remained constant for five years at 300,000 departures per year, 9 percent of which are by small aircraft with 30 to 75 passenger capacity. Because there is no reason for this to change by 1985, a daily level of 150 movements (75 departures and 75 arrivals) was assumed as a conservatively high value for this analysis.

2.4.5.2 - Airside and Groundside Compatibility - No airfield or ATC compatibility problems are anticipated with the final design 50 passenger aircraft or its larger or smaller derivatives. A level of 150 daily movements is low compared to those experienced before 1960 (over 800 daily in 1958). The final design aircraft is comparable to the aircraft operating during that time and should cause no ground problems. The advanced air traffic control systems (ARTS III and MLS), planned for 1980, should provide improved ATC capability for the entire Chicago area.

The final design aircraft and its derivatives are fully compatible with Midway's terminal facilities. A potential maximum terminal "throughput" of 1000 peak hour passengers (500 arriving and 500 departures) is well below its total throughput capacity. The terminal was enlarged in 1967; it now has 29 gate positions (all suitable for the Boeing 727) and, a more expansive lobby, concourses, ticketing and baggage areas, and parking lot.

2.4.5.3 - Community Noise Impact - Straight-in-and-out approach and departure paths were used because there was no need to develop minimum impact flight procedures. A comparison of the noise impact of the final design aircraft and a potential STOL aircraft is presented in Table 2-14. For operations from a given runway, Table 2-14 shows the area and population within a given noise contour, along with the percentage of the population annoyed. This noise impact could be reduced further by applying operational

TABLE 2-14

NOISE IMPACT SUMMARY - CHICAGO MIDWAY AIRPORT
BASELINE MEDIUM DENSITY AIRPLANE

RUNWAY	EPNL CONTOUR	AREA SQ. MI.	AREA (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: POTENTIAL STOL AIRCRAFT, REFERENCE 1

RUNWAY	EPNL CONTOUR	AREA SQ. MI.	AREA (SQ.KM)	POPULATION AFFECTED	PERCENTAGE ANNOYED
22L	80	3.29	(8.52)	11352	14.9
31L	80	3.29	(8.52)	14413	15.6

techniques listed in Reference 2.

Three types of three-dimensional computer graphic displays were also used to illustrate the noise impact. A noise intensity map, of single-event and composite approaches and departures, was generated for noise levels of 80 EPNdB and above to evaluate operations from a given runway. A community noise impact map was developed to illustrate community annoyance resulting from operations from a given runway, considering noise intensity and population density. Useful for noise abatement flight paths, a population density map was developed for the 130 square mile (337 sq. km.) area surrounding Midway(see Figure 2-16). Density values range from 0 to 54,000 persons per square mile (20,850 per sq. km.).

2.4.5.4 - Engine Emission Levels - Emission levels for the baseline aircraft engines were assumed to meet the EPA 1979 standards. The quantity of aircraft emissions is a function of the emission rates and the landing and takeoff cycle, including all ground flight operations up to 3000 feet, using a straight-in-and-out approach and departure path.

For 75 operations per day, the emissions from the twin-engine final design aircraft would be 60 pounds HC, 300 pounds CO and 225 pounds NO_x.* Assuming conformity to 1979 standards, these emissions are approximately 50 to 75 percent lower than those of a current JT8D twin-engine transport.

2.4.5.5 - Overall Environmental Impact - Public Law 91-190 (NEPA 1969) requires preparation of an EIS for any federal action (funding or policy support) affecting the quality of the human environment. FAA Directive 1050.1A, Reference 11, establishes procedures for the environmental impact of proposed FAA actions, including certification of new aircraft.

* HC (Hydrocarbons), CO (Carbon Monoxide), NO_x (Nitrogen Oxide)

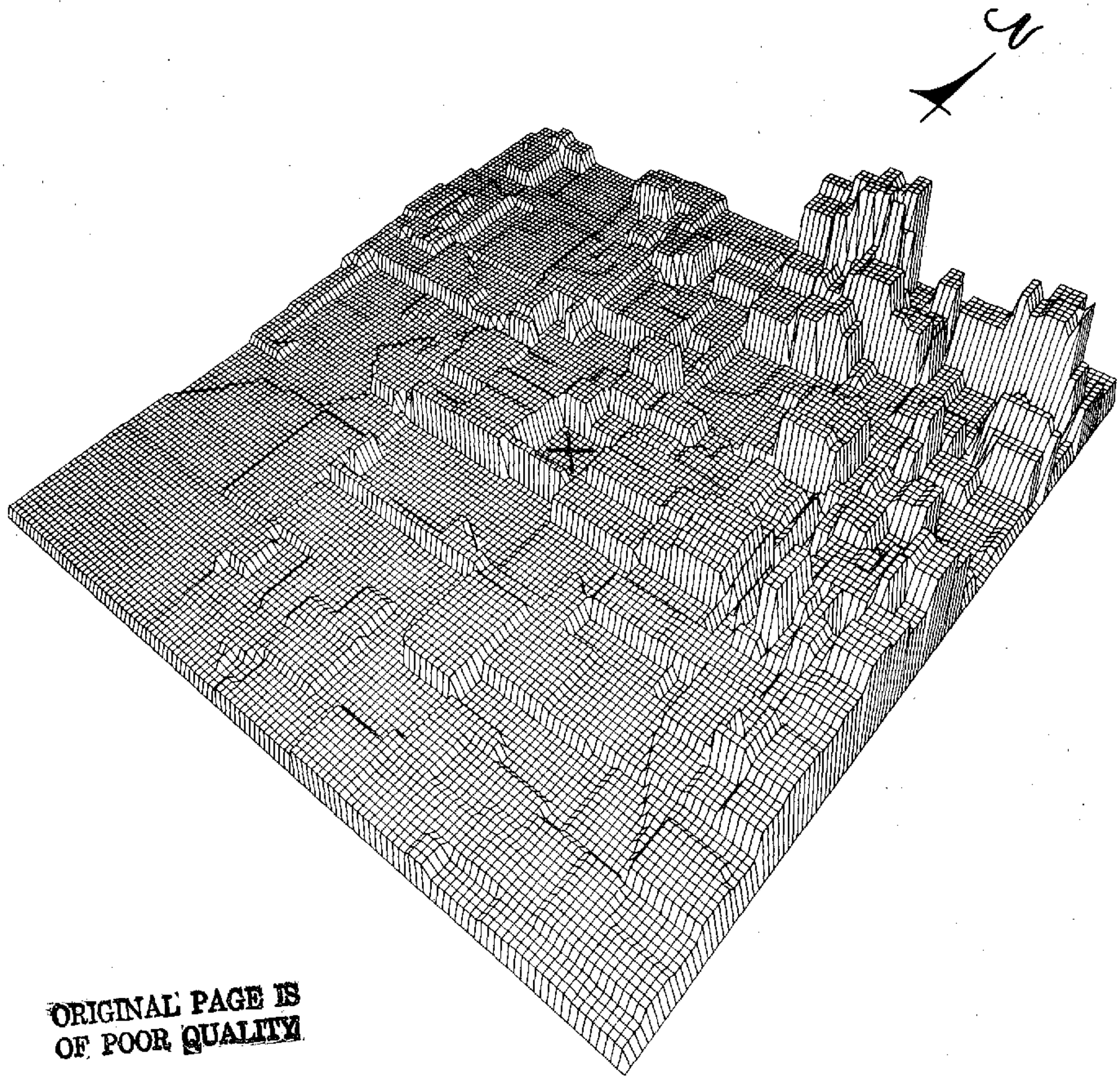


FIGURE 2-16 - COMPUTER GENERATED
POPULATION DENSITY MAP, 130 SQ. MI. AREA
CHICAGO MIDWAY AIRPORT

The baseline aircraft will comply with all airworthiness requirements. It is designed to 10 EPNdB below current FAA Part 36 noise requirements. Thus, its community noise impact will be lower than aircraft designed to meet Part 36 noise levels and especially aircraft designed prior to Part 36. It will comply with all 1979 emission standards of EPA Part 87 for Class T2 engined aircraft. Accordingly, the exhaust and the venting emissions will be lower than those of earlier aircraft designed to less rigid emission requirements.

Based on the above factors, particularly the lower noise and emission characteristics, and the replacement of earlier aircraft, it is concluded that production 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 NEPA 1969.

3.0 AIRCRAFT COST ESTIMATING

A method generally based on cost estimating equations developed by the RAND Corporation of Santa Monica, California, (Reference 12) was used to estimate research and development and production costs for the final design aircraft.

The benefit of suggested "design-to-cost" manufacturing savings were computed analytically and incorporated separately in the final aircraft cost estimates.

Engine prices were chosen to be consistent with a series of existing aircraft engines. A statistical survey resulted in a curve of engine prices versus thrust ratings at sea level static values. This curve is included as Figure 3-1. A price for turboprop engine also was based on a survey of current turboprop engines in use or currently available. The curve of turbofan engine price as a function of sea level static thrust, Figure 3-1, 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 currently available engines such as the ALF 502 and others.

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

Production Quantity	400 units
Interest Rate	8% per year

TURBOFAN ENGINE PRICE: 1974 DOLLARS

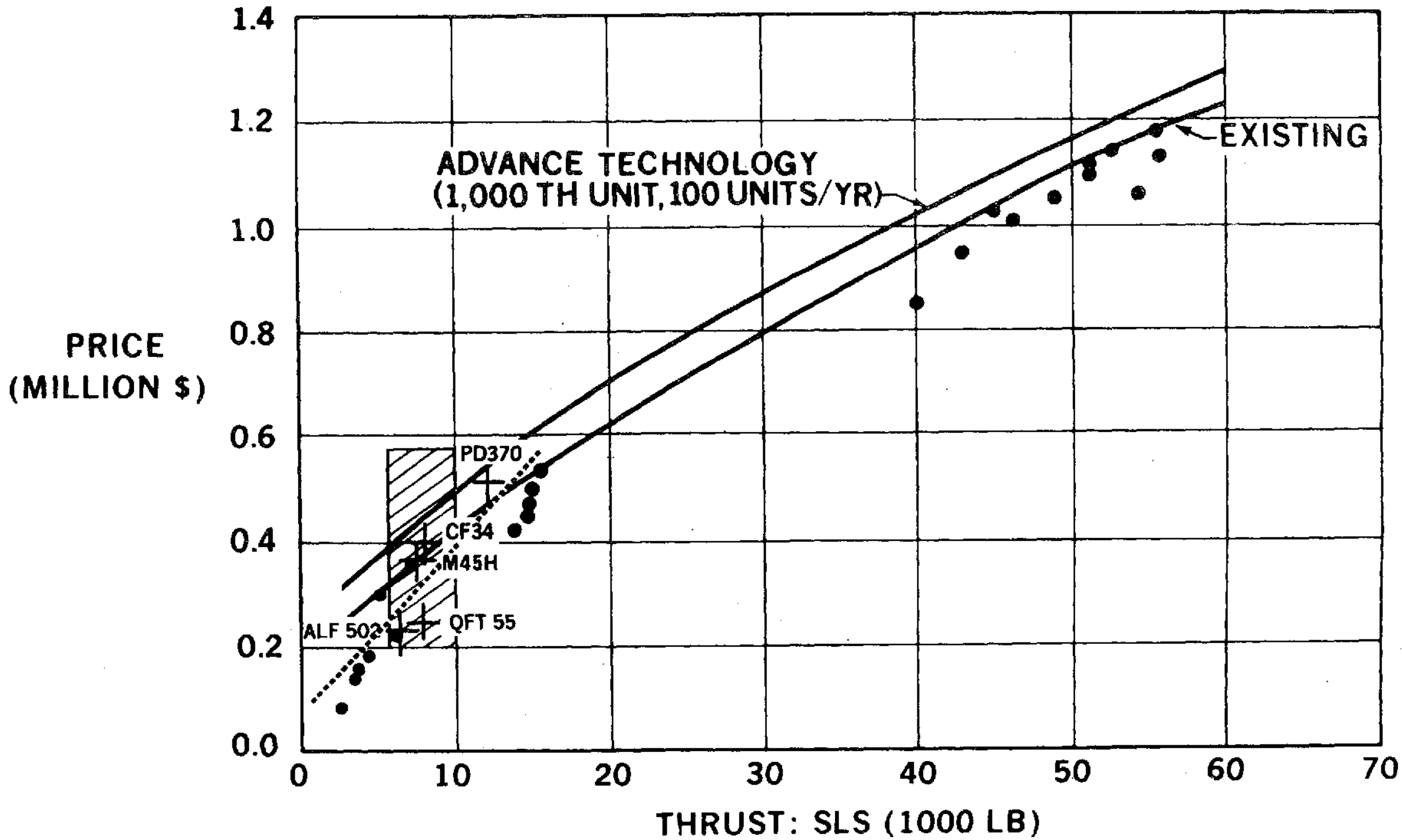


FIGURE 3-1

Profit	10%
Engine Price	$ .341 million
Avionics Price	$ .125 million

The final design basepoint initially was priced at $3.18 million, excluding the design-to-cost savings presented in Section 2.2.1. 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

A survey of published data on a wide range of aircraft is summarized in Figure 3-2. 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 base-point 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.

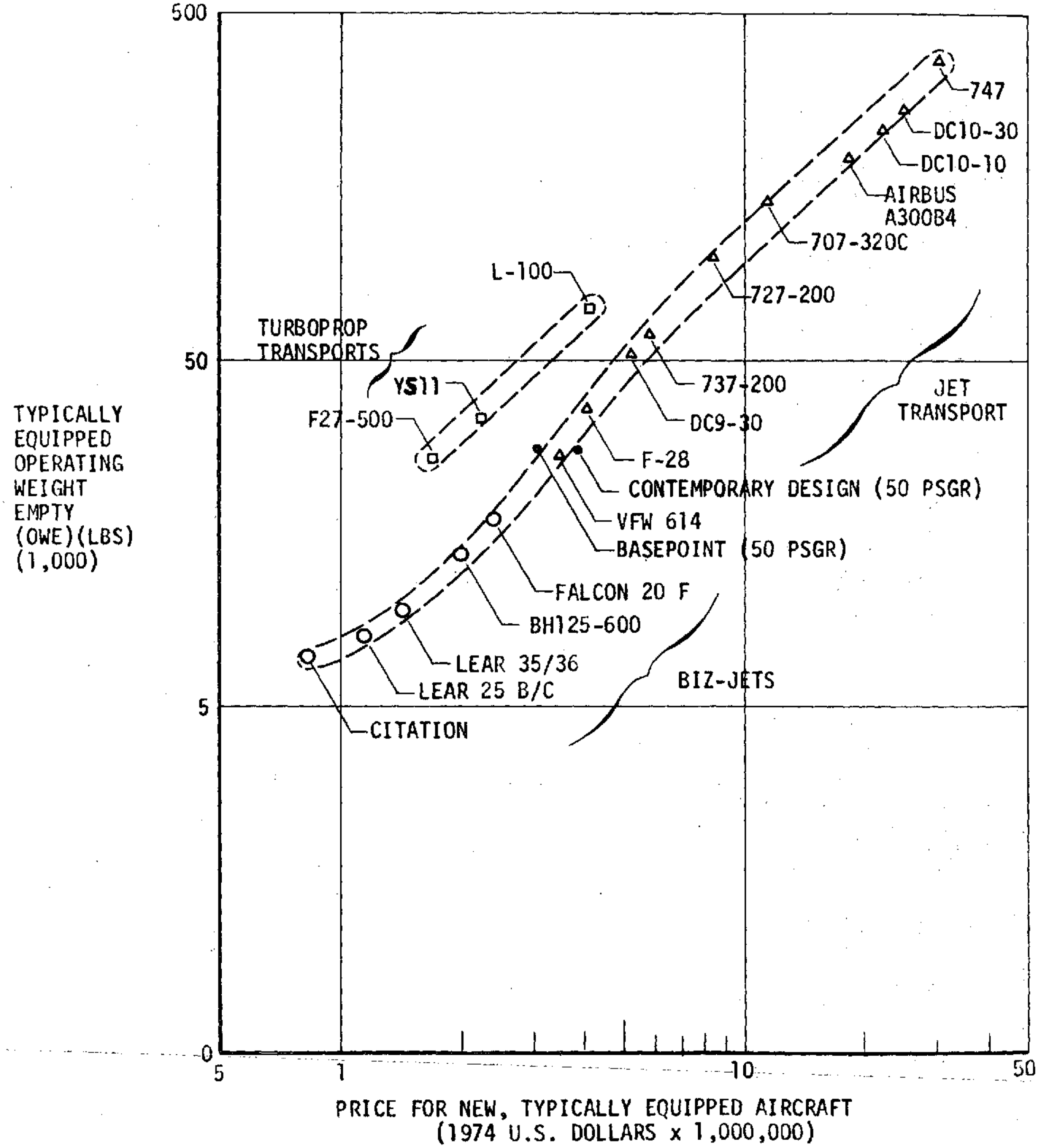


FIGURE 3-2

4.0 SIMULATION ANALYSES

The airline operational 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 for either noncompetitive or competitive simulations. In each operational simulation, a fleet solution was chosen to satisfy the following criteria:

- o Aircraft must fly at least the number of flights scheduled in the base year.
- 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 which it is assigned in the mission model.

The computer simulation program method of assigning an aircraft to an element in the model was a least-cost computation. Each aircraft was tested against the data on minimum number of flights, revenue passenger miles demanded, and a load factor maximum limit of 50 percent. Of all available aircraft which could perform the required task, the one with the lowest total trip costs was selected. Each element also contained the total revenue potential as a function of the RPM. A CAB Class 7 fare structure was assumed for aircraft passenger revenue.

With this revenue function, a dollar income was computed for all RPM values generated in each part of the model. An IOC value of 58 percent of the revenue was then computed. Computation of DOC values completed the cost of each aircraft satisfying the demand for RPM. With all of these values determined, profitability of the fleet was then calculated as revenue less indirect and direct operations costs. In some portions of the mission model, this profitability figure was a negative value. Summary of all data on all aircraft in the selected fleet results in a fleet profitability statement.

4.1 Noncompetitive Aircraft Evaluation

In the aircraft operational requirements phase, eight variations of the conceptual aircraft were evaluated. These were 30, 50, and 70 passenger configurations with field length and design range variations as follows:

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)

Results of the operational simulation were measured for each aircraft tested in the initial (1972 base year) traffic model. Fleet profitability results were measured for each aircraft concept. A profitability index was defined as the ratio of net operating income to the total fleet investment. Figure 3-1 presents a bar graph of profitability indexes. The 50 passenger medium range turbofan aircraft was selected as the base case with which all other aircraft were compared. Each aircraft was tested against the entire RPM demand. Each aircraft is discussed in the following paragraphs.

30 Passenger, Medium Range

Diseconomy of scale (high costs per seat) forced the fleet costs to be about

1980 OPERATIONAL RESULTS

RELATIVE FLEET INVESTMENT AND PROFITABILITY INDEX

-8 CONCEPTUAL FIXED PITCH FAN AIRCRAFT

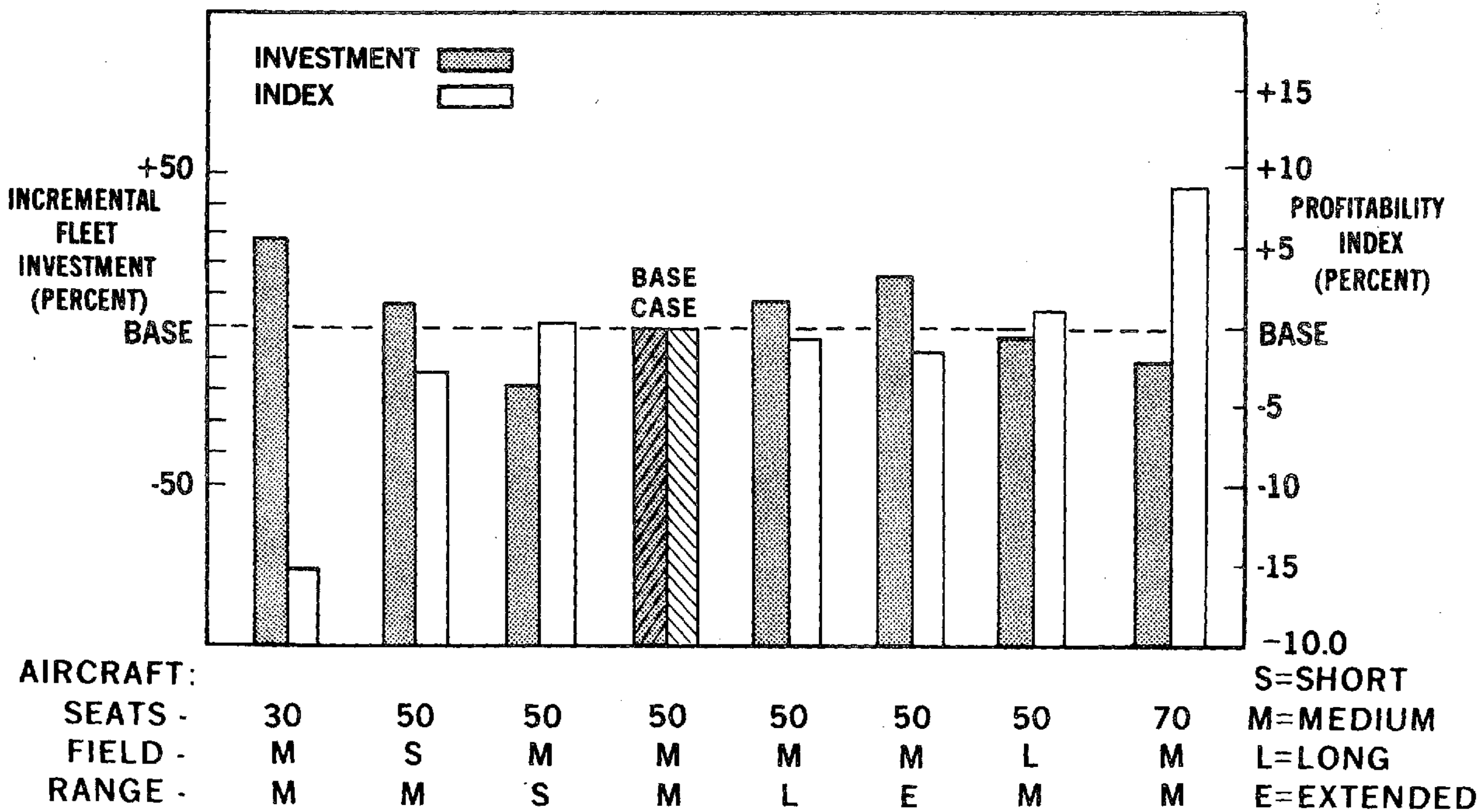


FIGURE 4-1

30 percent higher than the 50 passenger baseline aircraft. Higher operating costs resulted in negative profits. Thus 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, this aircraft satisfied only about 12 of the 15.6 billion RPM in the mission model. This represented only 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.

Three aircraft configurations were chosen for derivation of fleet data from the operational simulation model (noncompetitive mode). Table 4-1 presents a summary of the aircraft characteristics and Table 4-2 contains fleet results for the year 1980. The fleet sizes generated show only the total fleet sizes needed to satisfy the RPM demand exclusively with only one type of aircraft.

4.1.1 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. 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. Each route was 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).

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

Table 4-1

SUMMARY OF CONCEPTUAL AIRCRAFT CHARACTERISTICS

(4500 Ft. Field/2 x 250 N.Mi. Stages)

	Aircraft Seating Capacity		
	30	50	70
Takeoff Gross Weight (lb)	32,080	43,920	56,730
(kg)	(14,550)	(19,920)	(25,730)
Single Stage Range (N.Mi)	566	563	562
(km)	(1048)	(1043)	(1041)
Cruise Mach Number	0.650	0.685	0.700
Number of Engines	2	2	2
Takeoff Thrust (lb/eng)	5,830	7,980	10,310
(Newtons)	(25,930)	(35,500)	(45,860)
Block Time at Design Range (hr)	1.8	1.7	1.7
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 4-2

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	2.500
Ratio to 1972 Schedule	3.26	1.99	1.46
Revenue Passenger Miles Flown (Billions)	14.658	14.697	14.697
Revenue ($ Millions)	2,087	2,090	2,090
Fleet Operating Costs: ($ Millions)	2,446	2,059	1,909
Direct	1,236	846	696
Indirect	1,210	1,213	1,213
Net Operating Income ($ Millions)	- 359	31	181
Fleet Investment Cost ($ Millions)	2,672	2,050	1,826
Return on Fleet Investment (%)	-13.5	1.6	10.0
Annual Fuel Consumption (Million Tons)	3.414	2.656	2.356
Fleet Size Projected to 1990	1,730	1,038	744

TABLE 4-3

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

Results of the operational simulation in this special mission model are summarized in Table 4-3, "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 339 as noted in Table 4-3. 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.

4.1.2 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)

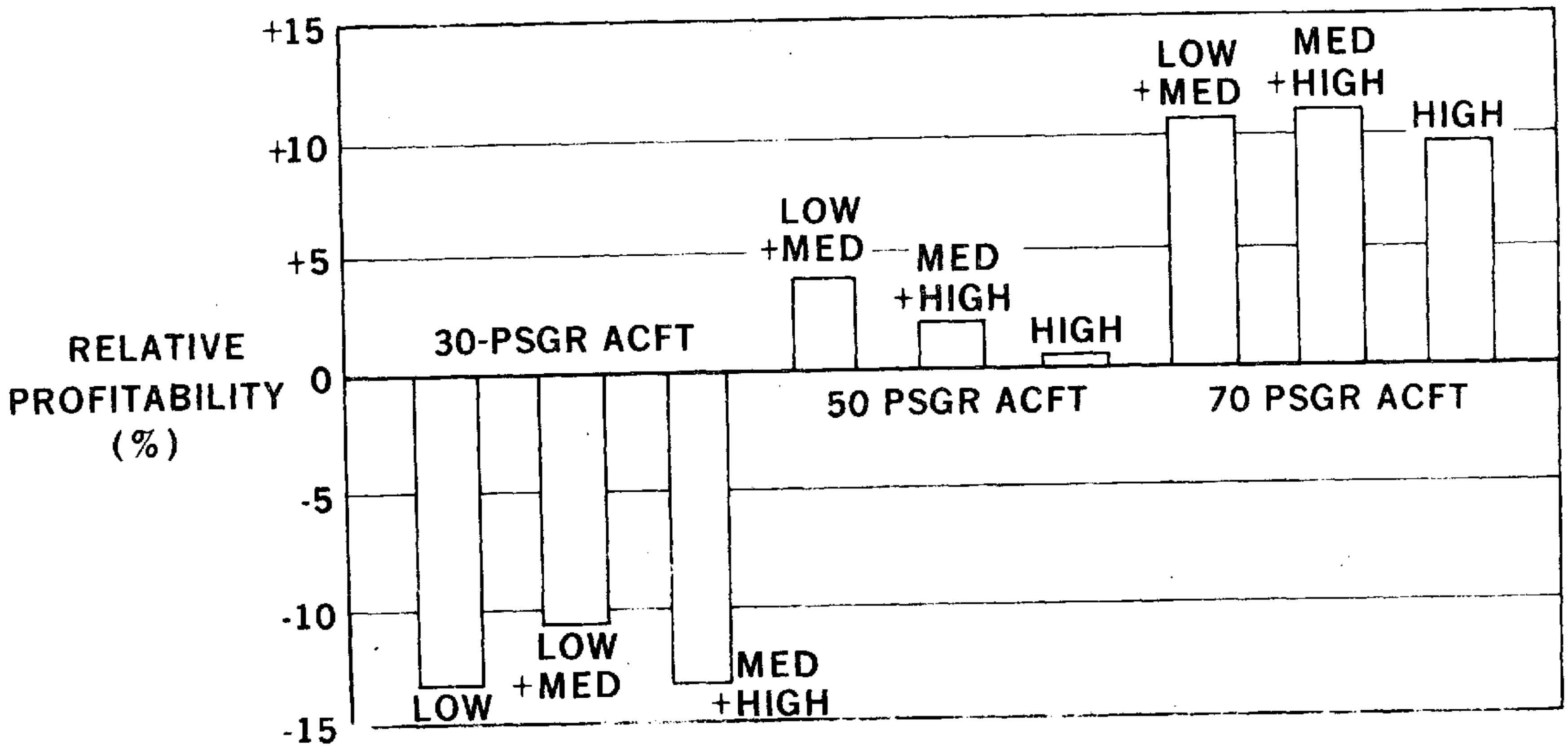
The very low demand level in the low density segment is especially evident. The bulk of demand exists on those routes served by the 40 to 60 seat aircraft in 1972.

The suitability of each of these aircraft is measured by relative profitability of fleet operations. This is illustrated in Figure 4-2. 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.

4.2 Competitive Simulation Results

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

COMPARISON OF RELATIVE PROFITABILITY*
AIRCRAFT SIZE vs SEGMENTED MARKET
1980



* EXCLUDES AIRCRAFT SPARES

FIGURE 4-2

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.

4.2.1 Fleet Simulation Characteristics

Economic characteristics 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 the jet aircraft were five medium density study aircraft. These latter were the basepoint M - 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 of the form y + bx for the distances in the airline network mission model. Pertinent Summary data on these aircraft are listed in Table 4-4, Economic Data for Medium Density Basepoint Aircraft and Table 4-5, Economic Data for Existing and Near-Term Contemporary Aircraft.

The DOC estimates are the best approximations to 1974 cost levels which were attainable from the data sources mentioned. The Convair 580 data was drawn essentially from 1973 CAB sources, and respresents a composite experience of several airlines.

4.2.2 Contemporary Mixed Fleet

Simulation results are presented in Table 4-6 for the mixed turboprop/ turbojet fleet for the year 1985. Out of all aircraft made available, three aircraft were selected. Short SD-3-30 Turboprop, Fokker F-27 MK500 Turboprop,

TABLE 4-4

ECONOMIC DATA FOR MEDIUM DENSITY BASEPOINT AIRCRAFT

BASEPOINT AIRCRAFT (SEATS)	RANGE (N Mi)	UNIT PRICE ($ Mil)	BLOCK TIME FUNCTION (Hr)	DOC FUNCTION ($ Per Trip)
Turbofan:				
M-30	850	2.37	0.2 + .00256 x R	77.80 + 0.930 x R
M-40	850	2.73	0.2 + .00256 x R	85.84 + 0.999 x R
M-50	850	3.08	0.2 + .00256 x R	93.98 + 1.068 x R
M-60	850	3.59	0.2 + .00256 x R	97.90 + 1.071 x R
M-70	850	3.79	0.2 + .00256 x R	111.13 + 1.210 x R
Turboprop:				
M-50	560	2.70	0.2 + .00309 x R	77.30 + 1.056 x R

*Study aircraft identified as M-30 (30 passenger capacity) through M-70 (70 passenger capacity)

TABLE 4-5

ECONOMIC DATA FOR EXISTING AND NEAR-TERM

CONTEMPORARY AIRCRAFT

AIRCRAFT	RANGE (N Mi)	SEATS	UNIT PRICE ($ Mil)	BLOCK TIME FUNCTION (Hr)	DOC FUNCTION ($ Per Trip)
F-27 (TP)	810	56	2.1	0.2 + .0043 x R	41.32 + 0.888 x R
CV-580 (TP)	880	52	0.7	0.2 + .0036 x R	89.88 + 1.618 x R
DHC-7 (TP)	768	48	2.83	0.2 + .0044 x R	55.02 + 1.210 x R
SD-3-30 (TP)	320	30	1.3	0.2 + .00467 x R	29.93 + 0.699 x R
FALCON 30	780	30	2.8	0.2 + .00246 x R	82.63 + 1.016 x R
VFW-614	650	40	3.6	0.2 + .00262 x R	96.05 + 1.169 x R
F-28 MK 1000	1125	60	4.6	0.2 + .00244 x R	109.25 + 1.424 x R
HS-146	1200	71	5.5	0.2 + .00247 x R	145.39 + 1.796 x R
737/DC-9 Type	1600	100	5.4	0.2 + .00244 x R	100.53 + 1.226 x R

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.

4.2.3 Contemporary Turbofan Fleet

The contemporary turbofan fleet was tested as a base case. (During the course of the study, mention was made several times that the regionals generally desired an all-jet fleet.) Simulation results for 1985 shown in Table 4-7 continued to show the dominance of the 100 passenger jet aircraft as shown in Table 4-6. 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 routes on which its DOC was higher than on the longer routes in the prior analysis.

4.2.4 Contemporary and Final Design Study Aircraft Fleet

The fleet composition resulting from simulation with a turbofan contemporary fleet and the final design study and derivative aircraft fleet

TABLE 4-6

COMPETITIVE OPERATIONAL SIMULATION

Contemporary 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 4-7

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

is presented in Table 4-8. 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 derivative jet was selected in the largest number of all the conceptual aircraft available. A few 40 seat aircraft plus about 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 excess of revenue over operating costs.

The appropriate fleet mix of 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 4-9, 4-10, and 4-11 for the respective years 1980, 1985, and 1990. The results for each year are an independent solution with respect to prior years.

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. Since the solution for each year is an independent, least-cost solution, the introduction of a new size has the effect of displacing other aircraft from a previous year.

The generation of load factors of less than 50 percent was a result of aircraft assignment to routes with a requirement to provide at least the

TABLE 4-8

COMPETITIVE OPERATIONAL SIMULATION

ALL-JET PLUS MEDIUM DENSITY FLEET

	1980		1985		1990	
AIRCRAFT	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 4-9

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 (0.979)	- 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 4-10

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 4-11

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)

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 these routes had the overall effect of maintaining low load factors through the entire simulation period.

4.2.5 Competitive Aspects of Study Turboprop Aircraft

The final competitive evaluation was conducted with the 50 passenger, 2 x 250 nautical mile range turboprop aircraft in competition with the all-jet contemporary and final design turbofan aircraft. Detailed characteristics of the turboprop configuration are listed in Table 4-12. The 2 x 250 mile range was used in this competition because results of contemporary fleet mix showed smaller aircraft operated on routes of less than 100 miles. Competitive simulation results are shown in Table 4-13 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 4-8, 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.

4.3 Subsidy Analysis

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.

TABLE 4-12

SIMULATION CHARACTERISTICS OF TURBOPROP AIRCRAFT

Characteristics	Values
Takeoff Weight (lb) (kg)	43,840 (19,886)
Airframe Weight (lb) (kg)	25,390 (11,517)
Takeoff Power/Engine (ehsp)	4,230
Total Cost/Unit ($ Millions)	2.7
Engine Cost (2) ($ Millions)	0.374
Trip Cost at Full Range ($)	671.71
DOC at Full Range (Cents/Seat N.Mi)	2.40
Block Time at Full Range (Hr)	1.81
Cruise Mach Number	0.64
Target Load Factor	0.50
Design Range (n.mi)	2 x 250 (Stages)

TABLE 4-13

CONTEMPORARY ALL-JET
VS
STUDY TURBOFAN AND TURBOPROP AIRCRAFT

AIRCRAFT	1980 FLEET SIZE	1980 PERCENT RETURN	1985 FLEET SIZE	1985 PERCENT RETURN	1990 FLEET SIZE	1990 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

Since the purpose of determining subsidy requirements was pertinent 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:

Revenue - (DOC + IOC) - Return = 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:

$$\text{Return} = \frac{(\text{A/C Cost} + \text{Spares} - \text{Residual Value}) \times 12.35\%}{\text{Depreciation Period}}$$

Subsidy Need = Revenue - DOC - IOC - Return

This simplified subsidy analysis approach was applied to the 1980 competitive fleet. Details of the economic results are shown in the table below.

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

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 the following tabulation.

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

This gross subsidy need estimate was based upon a total fleet evaluation in the total domestic medium density market as defined. It was not applied to a specific airline. A detailed subsidy analysis can be done only on a station by station basis on subsidy-eligible operations. This procedure is described generally in Section 15.2 of Volume II, Final Report of the study. The reader is referred to this section, "Basic Subsidy Analysis and Considerations". The gross subsidy needs quoted in the paragraphs above are only indicators of the difference between revenue income and

---

* 95.122 = Revenue in $ Million

136.461 = Total Operating Cost in $ Million operating expenses for small (30 to 50 seats) turbofan-powered aircraft. They do indicate that the CAB allowable rate of return could be achieved only with subsidy for the study aircraft under the market conditions described. The data for the B-737/DC-9 type aircraft have been excluded from these computations. Again, the reader is cautioned not to extend this generalized subsidy review to the U.S. domestic subsidy in a real sense.

5.0 ECONOMIC SENSITIVITY ANALYSES

In addition to the cost savings suggested in the manufacturing design-to-cost review, other sensitivity analyses were conducted. These involved aircraft unit price effects for variations in production quantity and increased development costs. Additional studies considered factors affecting direct operating costs.

5.1 Production Quantity Variations

The cost estimating program generates costs based on the unit used for pricing. In this study, the 400th unit was the pricing unit. If 400 units were sold, the estimated profit to the manufacturer would be about 10 percent. Sales less than or greater than 400 units decrease or increase the profit commensurately. For pricing units less than 400, the unit price increases inversely, as shown in the following tabulation.

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

Note that the price at 400 units does not include the manufacturing design-to-cost savings summarized in Table 2-7 of the Aircraft Analysis Section 2.0.

5.2 Cost Sensitivity Studies

A number of sensitivity studies were conducted which affected either or both initial price (cost) of the aircraft or operating costs. System variations which affected fleet profitability were increased load factors and the level of indirect operating costs.

BASE POINT AIRCRAFT PRICE
vs
PRODUCTION QUANTITY

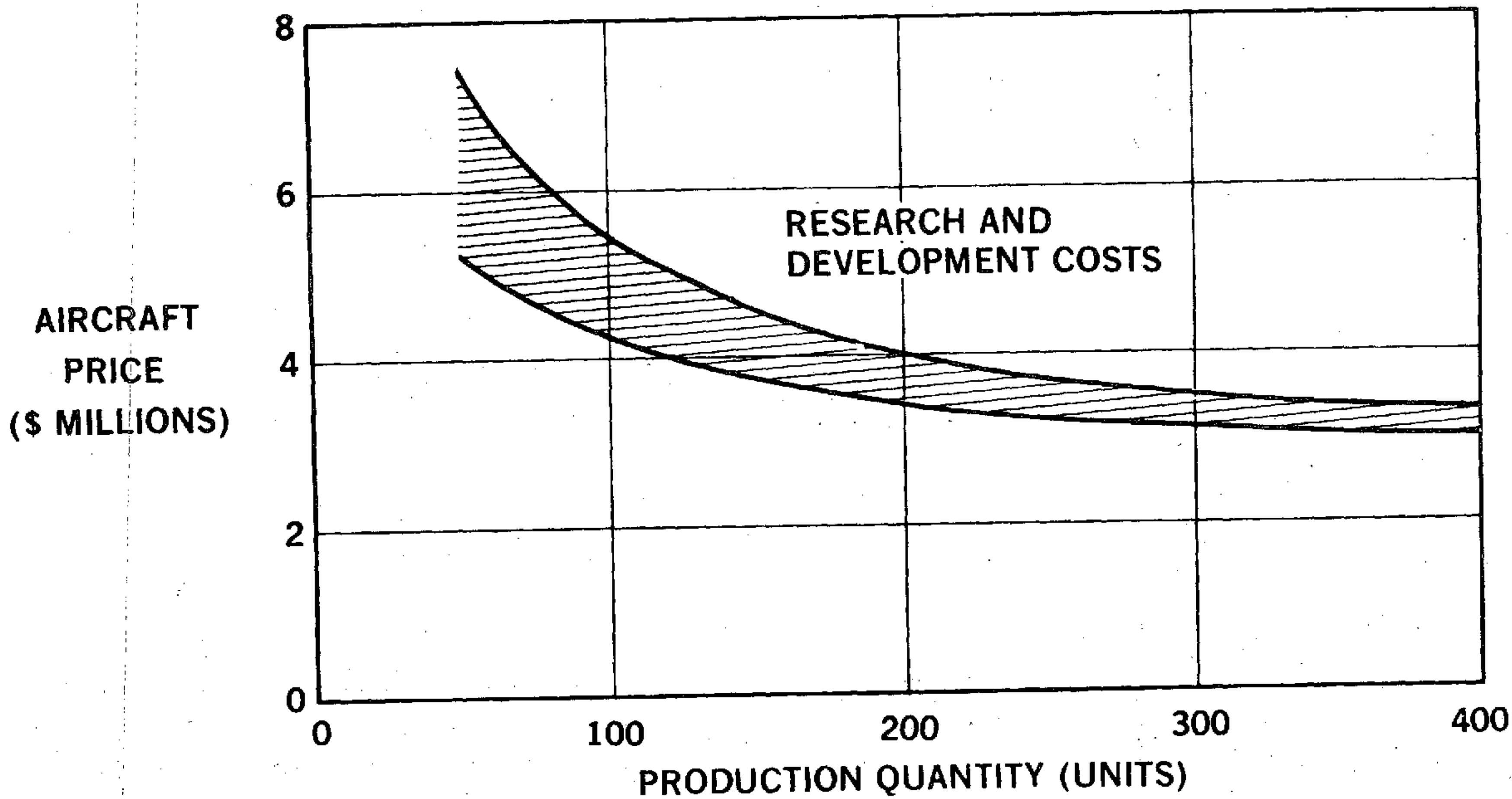


FIGURE 5-1

TABLE 5-1

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.

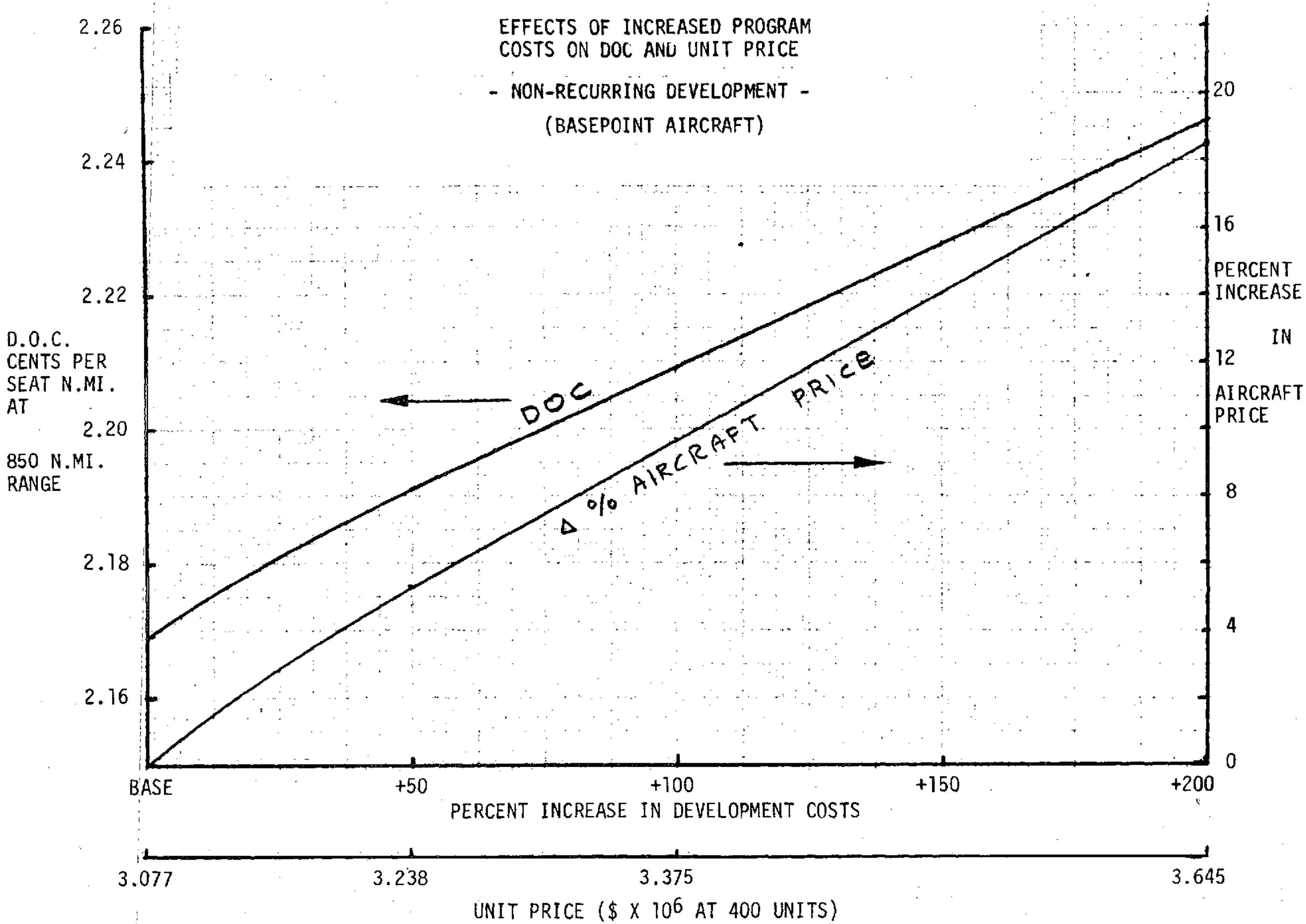

EFFECTS OF INCREASED PROGRAM COSTS ON DOC AND UNIT PRICE
- NON-RECURRING DEVELOPMENT -
(BASEPOINT AIRCRAFT)
D.O.C. CENTS PER SEAT N.MI. AT 850 N.MI. RANGE
2.26
2.24
2.22
2.20
2.18
2.16
PERCENT INCREASE IN AIRCRAFT PRICE
20
16
12
8
4
0
DOC
Δ % AIRCRAFT PRICE
BASE
+50
+100
+150
+200
PERCENT INCREASE IN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

FIGURE 5-2

5.2.1 Research and Development Variations

Research and development (R&D) costs may be spread over any number of production units. A curve is presented in Figure 5-1 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 5-1.

Some of these data are plotted in Figure 5-2. Both DOC and percent increase in 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. This increase in the unit price of the aircraft of $568,000 resulted in an increase of about 3 percent in the design range DOC (850 nautical miles).

5.2.2 Variable Fleet Load Factor

All of the operational simulation evaluations were conducted with a target system load factor of 50 percent. In general, the aircraft under 50 seats operated at negative profitability. The effect on fleet profitability of higher load factors was evaluated for a target of 60 percent. Fleet statistics resulting from this exercise are listed in Table 5-2.

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 and the 70 seat losing its share of the market completely. These results are compared with the results of fleet mixes with the 50 percent load factor shown in Table 5-2. For example, the 1980 solution at 50 and 60 percent load factors shows a larger number of DC-9/B-737 class of jet aircraft at 50 percent, e.g. 299 versus 236. In contrast, with higher load factors and the same minimum frequency requirements, more of the smaller turbofan aircraft were required. There was an increase of five aircraft at 30 passenger capacity, a shift from five of the 40 to 20 of the 50 passenger, an increase from 42 to 93 of the 60 passenger, and the addition of three of the 70 passenger aircraft. As the traffic expands to 1985 and 1990 levels the fleet mix shifts back toward the larger aircraft as total fleet size drops from 500 at 50 percent to 440 at 60 percent load factor or 618 to 502 respectively in 1990.

5.2.3 Indirect Operating Costs

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.

TABLE 5-2

COMPETITIVE OPERATIONAL SIMULATION WITH 60 PERCENT LOAD FACTOR
CONTEMPORARY ALL-JET AND FINAL DESIGN BASEPOINT AIRCRAFT

Aircraft	1980 Fleet Size	1980 Profitability Index	1985 Fleet Size	1985 Profitability Index	1990 Fleet Size	1990 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

Ratios of 45 percent and 65 percent were used. Fleet sizes were unaffected, with the only effect being on the profitability indexes. These results are tabulated in Table 5-3, IOC Versus Fleet Profitability.

TABLE 5-3

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

The column under the 58 percent IOC represents results from Table 4-8 for the 1985 all-jet competitive evaluation. Note that all of the study jets suffer losses at the IOC levels examined, except the 50 passenger aircraft at the lower IOC value of 45 percent of passenger revenue.

5.2.4 Direct Operating Costs

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 5-4.

TABLE 5-4

DIRECT OPERATING COST PERCENTAGE DISTRIBUTION

	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%

Effect of Increased Fuel Costs on DOC

The nominal fuel cost for the basepoint 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 5-5.

The effect of higher fuel prices on DOC at the design range is shown in Figure 5-3. An increase of 16 cents/gallon (about 73 percent) in fuel costs results in a 17.5 percent increase in the design range DOC.

The variations in DOC for two fuel costs are shown in Figure 5-4. Two extremes are shown, the lower curve using a fuel cost of 22 cents per gallon recommended by the airline subcontractors and a higher DOC corresponding to fuel at 38 cents per gallon.

TABLE 5-5

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

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

(BASEPOINT AIRCRAFT - 1974 DOLLARS)

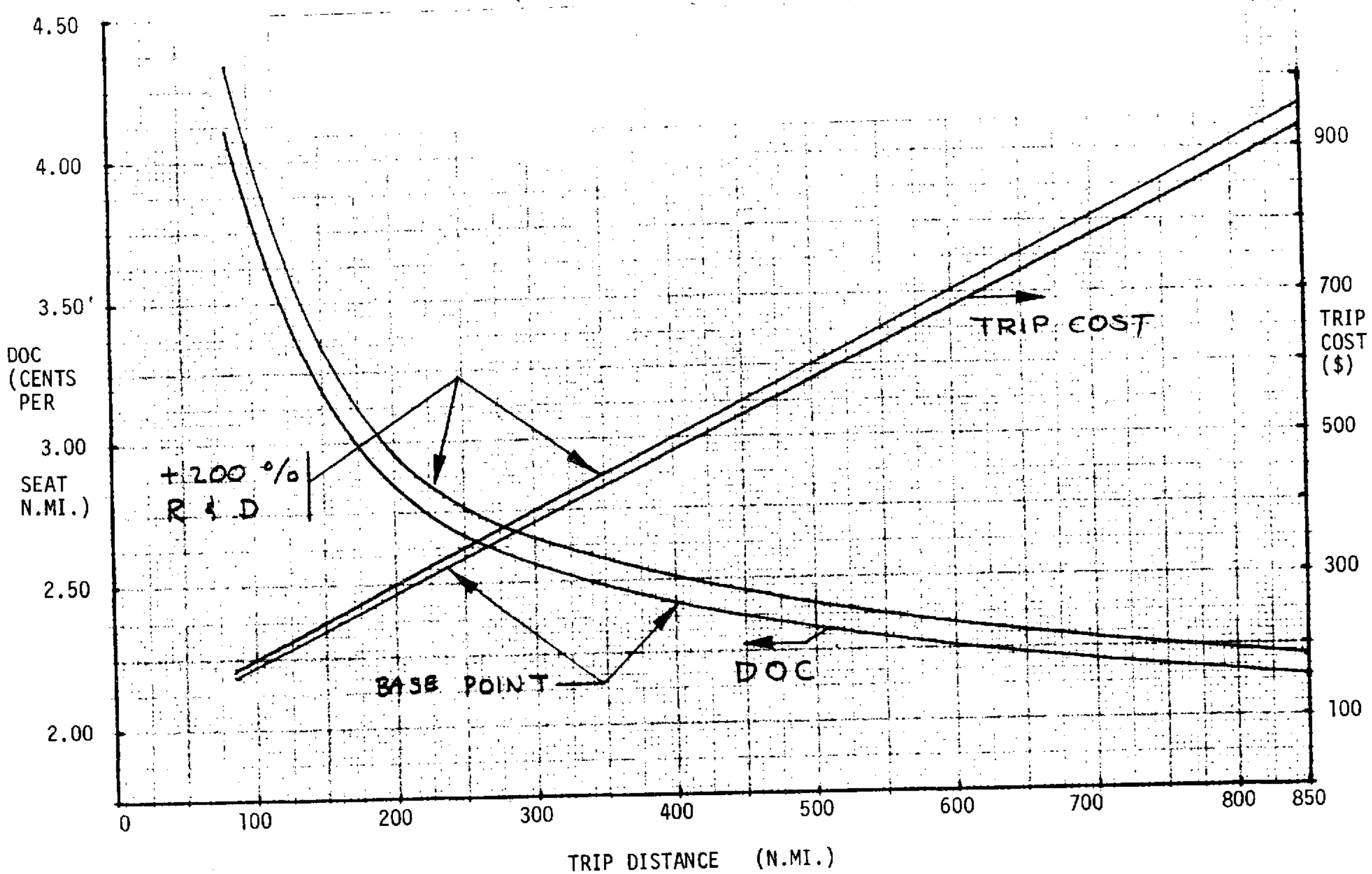


FIGURE 5-3

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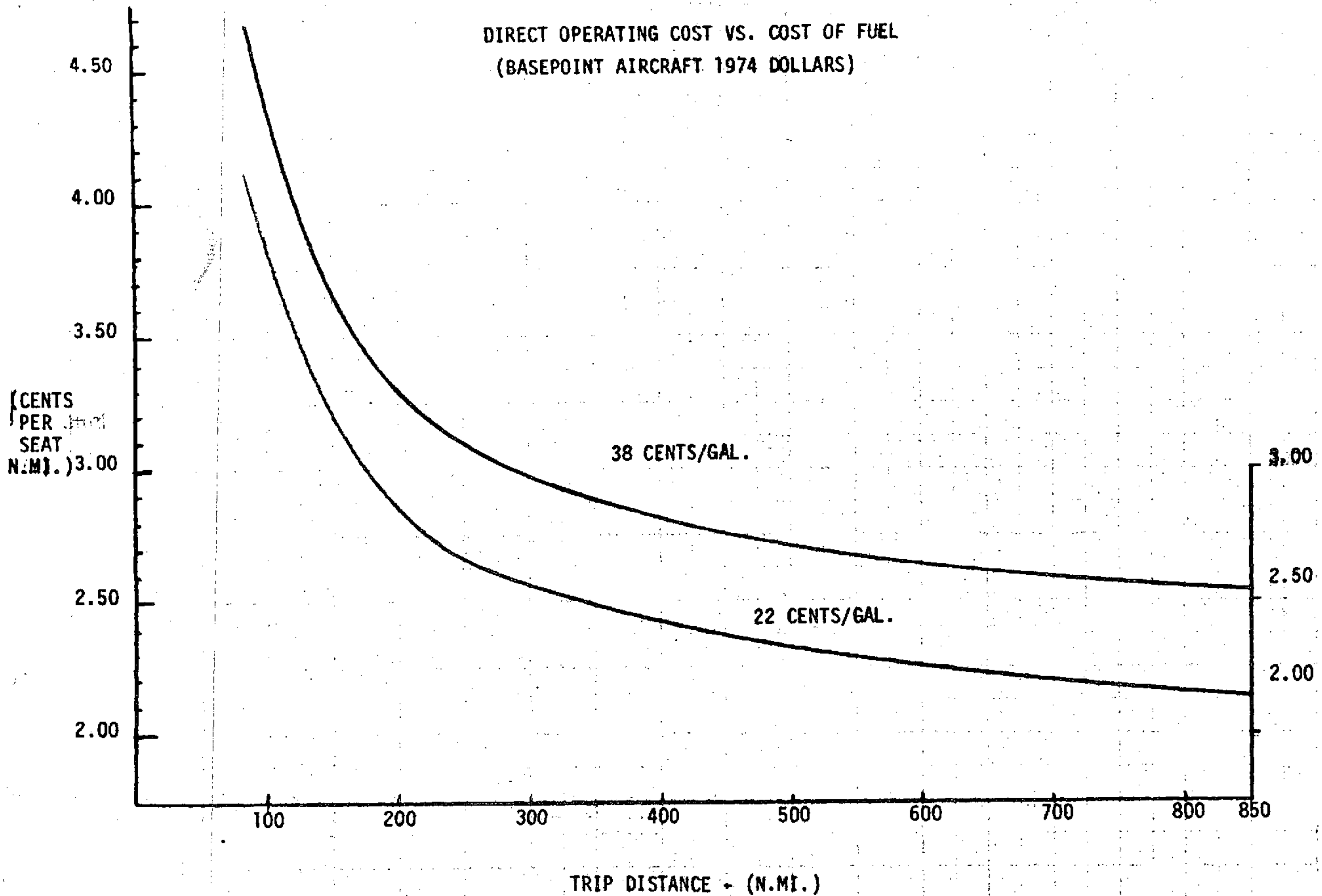
DIRECT OPERATING COST VS. COST OF FUEL
(BASEPOINT AIRCRAFT 1974 DOLLARS)
4.50
4.00
3.50
(CENTS PER SEAT N.MI.)
3.00
2.50
2.00
38 CENTS/GAL.
22 CENTS/GAL.
3.00
2.50
2.00
100
200
300
400
500
600
700
800
850
TRIP DISTANCE - (N.MI.)

FIGURE 5-4

Potential Maintenance Savings

All of the DOC estimates for the study aircraft, initial conceptual through final design, were made with equations devleoped by Douglas for evaluation of conceptual aircraft for future use. These equations included elements of maintenance expense derived from airline data reported on aircraft of the DC-9/B-737 to the DC-10/L-1011 classes. For a series of aircraft smaller than the 100 passenger turbofan aircraft, a detailed examination of the 50 passenger basepoint study aircraft revealed some potential savings in maintenance. From a review of the inspection routine and manhour requirements for maintenance, some improvement was indicated. This is tabulated in Table 5-6 as follows:

TABLE 5-6

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

For this basepoint aircraft, an $18 reduction in the aircraft operating cost per flight hour represents about a four (4) percent reduction.

5.3 Economic Sensitivities Summary

The adoption of simplified design and manufacturing technology resulted in unit aircraft price savings of about 27 percent compared with the levels used on high-speed, swept-wing transport aircraft. This represented about a six percent reduction in direct seat mile costs for a 50 passenger aircraft at the design range of 850 nautical miles.

Aircraft price variation with the production unit used as a pricing base revealed that if 200 units were used as a base, the unit price would increase by $810,000 for a 50 seat aircraft. This represents an increase of about 25 percent over the price at the 400th unit base, but only a four (4) percent increase in the design range DOC.

A change in IOC directly affected fleet profitability. An increase in IOC to 65 percent of passenger revenue increased the losses for the 30, 40, and 50 passenger aircraft. Conversely, a decrease to 45 percent from the nominal 53 percent reduced the losses on the 30 and 40 passenger aircraft and enabled the 50 passenger version to show a positive profitability.

A fuel price increase of 16 cents per gallon (22¢ to 38¢) increased DOC almost 18 percent for the 50 passenger study aircraft.

Potential reductions in aircraft maintenance resulting from the simplified design of the 50 passenger final design study aircraft showed a savings of about 4 percent below the level used in the study.

Tripling of research and development costs, from $108.7 to $326.1 million, resulted in an aircraft price increase of $568,000 at the 400th unit of the 50 passenger aircraft. At the design range of 850 nautical miles this price increase generated a DOC increase of about four percent.

With the simulation target load factor increased from 50 to 60 percent, for a total fleet in 1980, fleet profits increased from $114.091 to $171.123 million or about $57.032 million. This represented an increase of about

33 percent. Coincidentally, the fleet composition shifted with a reduction in numbers of the 100 passenger aircraft from 299 to 236. The number of 30 to 60 seat aircraft increased from 138 to 208 plus 3 aircraft of 70 passenger capacity. The net effect was to increase the total fleet from 437 to 448 aircraft for the 1980 mission model.

6.0 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 plus 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.

- o Turboprop aircraft with current propeller technology 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.

- o 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).

- o 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.

- o 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

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

- o 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.

o Very few (only two) efficient gas generators are available for integration with newly developed fixed or variable pitch fans to produce new turbofan engines.

o Use of current available engines increases weight, fuel, price, and operating cost.

o 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

o 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 of the 30 passenger, 23 of the 40 passenger, and 5 of the 60 passenger aircraft with new configurations and design features as developed in this study.

o 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 with greater frequency of service or at lower cost than existing or contemporary near-term turbofan aircraft.

o 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 for the 1985 time period of only 103 aircraft of 30 and 60 seat capacities are insufficient for a production program to achieve the aircraft price levels used in this study. However, 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 commuter routes in the analysis increased 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.

- o Turboprop aircraft proved to be better in operating economy than the turbofan aircraft, but a majority of airline operators expressed a preference for turbofan equipped aircraft.

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

RECOMMENDATIONS FOR FUTURE STUDY

(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 internal cabin noise and vibration 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 aircraft used 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 systems 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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