NASA CONTRACTOR REPORT

NASA CR-2355

NASA CR-2355

STUDY OF QUIET TURBOFAN STOL AIRCRAFT FOR SHORT HAUL TRANSPORTATION

by T. P. Higgins, E. G. Stout, and H. S. Sweet

Prepared by
LOCKHEED-CALIFORNIA COMPANY
LOCKHEED-GEORGIA COMPANY
LOCKHEED-AIRCRAFT CORPORATION
Burbank, Calif. 91503
for Ames Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1973

1. Report No. NASA CR-2355	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle "Study of Quiet Turbofan STOL Aircraft for Short Haul Transportation"	5. Report Date December 1973 6. Performing Organization Code
7. Author(s) T.P. Higgins, E.G. Stout, and H.S. Sweet	8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address Lockheed-California Company Lockheed-Georgia Company A Division of Lockheed Aircraft Corporation Burbank, California 91503	11. Contract or Grant No. NAS 2-6995 13. Type of Report and Period Covered Contractor Report/Summary
12. Sponsoring Agency Name and Address National Aeronautics & Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

The Douglas Aircract Company, McDonnell Douglas Corporation also did a study on quiet turbofan STOL aircraft for short-haul transportation. This study was performed under NASA Contract NAS2-6994.

16. Abstract

Conceptual designs of Quiet Turbofan STOL Short-Haul Transport Aircraft for the mid-1980 time period are developed and analyzed to determine their technical, operational, and economic feasibility. A matrix of aircraft using various high-lift systems and design parameters are considered as follows:

Lift Systems
- Externally Blown Flap
- Upper Surface Blown Jet Flap
- Augmentor Wing
- Internally Blown Jet Flap
- Upper Surface-Internally Blown Jet Flap Hybrid
- Mechanical Flap

Design Parameters
- Passenger Capacity: 50, 100, 150, 200
- Field Length (ft.): 1500, 2000, 3000, 4000 (Sea Level, 95°F)
- Range: 500 Nautical Miles
- Noise: 95 EPNdB at 500 ft. sideline

Variations in aircraft characteristics, airport geometry and location, and operational techniques are analyzed systematically to determine their effects on the market, operating economics, and community acceptance. In these studies, the total systems approach is considered to be critically important in analyzing the potential of STOL aircraft to reduce noise pollution and alleviate the increasing air corridor and airport congestion.

17. Key Words (Suggested by Author(s)) STOL Quiet Turbofan Aircraft Commercial Short-Haul Transports Design Studies	18. Distribution Statement UNCLASSIFIED - UNLIMITED

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 70	22. Price* **Domestic, $3.50** **Foreign, $6.00**

*For sale by the National Technical Information Service, Springfield, Virginia 22151

Page Intentionally Left Blank

CONTENTS

Page

FOREWORD iii

LIST OF FIGURES vi

LIST OF TABLES vii

SUMMARY 1

INTRODUCTION 5

SYMBOLS AND ABBREVIATIONS 9

DEMAND AND AIRPORT ANALYSIS 11

AIRCRAFT DESIGNS 28

AIRLINE SIMULATION AND ECONOMICS 47

COMPARATIVE EVALUATION 59

STOL BENEFITS 62

CONCLUSIONS 65

RECOMMENDATIONS 68

REFERENCES 70

Page Intentionally Left Blank

LIST OF FIGURES

Figure Page

1 SUMMARY FLOW CHART – PHASE I 8
2 SUMMARY FLOW CHART – PHASE II 8
3 LONG-HAUL ORIGIN-DESTINATION PASSENGER TRAFFIC IN MAJOR MARKETS U.S. DOMESTIC SCHEDULED SERVICE 12
4 SHORT-HAUL ORIGIN-DESTINATION PASSENGER TRAFFIC IN MAJOR MARKETS U.S. DOMESTIC SCHEDULED SERVICE 13
5 PROJECTED UNCONSTRAINED ESTIMATES OF TOTAL PASSENGERS AT 25 LEADING U.S. CITIES 14
6 J. F. KENNEDY AIRPORT ACTIVITY FORECAST 17
7 J. F. KENNEDY AIRPORT CAPACITY FORECAST CTOL 19
8 LOCAL O-D PASSENGERS FOR TWENTY LARGEST HUBS 21
9 ATLANTA – JOINT CTOL/STOL 22
10 ATLANTA AIRPORT CAPACITY FORECAST WITH STOLSTRIPS 23
11 LA GUARDIA – STOL ONLY TANDEM STOLSTRIPS 24
12 LA GUARDIA AIRPORT CAPACITY FORECAST ALL-STOL 25
13 NEW YORK METROPOLITAN HUB CAPACITY FORECAST 26
14 PHASE I DATA POINTS 29
15 PAYLOAD RANGE 32
16 AW AIRPLANE - 2000 FT. FIELD PERFORMANCE 33
17 EBF AIRPLANE - 2000 FT. FIELD PERFORMANCE 34
18 EBF AIRPLANE - 3000 FT. FIELD PERFORMANCE 35
19 OTW AIRPLANE - 3000 FT. FIELD PERFORMANCE 37
20 TWIN-ENGINE OTW/IBF AIRPLANE - 3000 FT FIELD PERFORMANCE 38
21 MECHANICAL FLAP AIRPLANE - 4000 FT. FIELD PERFORMANCE 39
22 SUMMARY OF DOC VS. FIELD LENGTH 41
23 RGW VS. 500 FT. SIDELINE NOISE LEVEL 43
24 TAKEOFF FOOTPRINT AREA RELATED TO SIDELINE NOISE 43
25 SIDELINE NOISE RELATED TO FAN PRESSURE RATIO 44
26 SUMMARY OF COST OF STOL AND QUIETING 44
27 EASTERN AIR LINE STOL O-D's. 50
28 EAL NOMINAL CASE - SIMULATION SUMMARY 53
29 EASTERN COST OF DELAY 53

LIST OF TABLES

Table		Page
I	PHASE II DESIGNS	30
II	POINT DESIGN SUMMARY	32
III	AW PRINCIPAL CHARACTERISTICS	33
IV	EBF PRINCIPAL CHARACTERISTICS	35
V	OTW PRINCIPAL CHARACTERISTICS	36
VI	OTW/IBF PRINCIPAL CHARACTERISTICS	37
VII	MF PRINCIPAL CHARACTERISTICS	39
VIII	PROGRESSIVE NOISE REDUCTION	42
IX	SUMMARY OF COSTS ASSOCIATED WITH POTENTIAL REQUIREMENTS	45
X	INDIRECT OPERATING COST FACTORS	48
XI	EAL "FLEET"	51
XII	SHORT HAUL AIRCRAFT DELIVERY SCHEDULE	56
XIII	RETURN ON INVESTMENT (CAB METHOD)	57
XIV	SYSTEM OPERATING INVESTMENT, NET INCOME, AND RATES OF RETURN TRUNK (INCLUDING PAN AMERICAN) AND LOCAL SERVICE CARRIERS, YEARS ENDED JUNE 30, 1972 AND 1971	58
XV	PUBLIC EVALUATION	60
XVI	INDUSTRY EVALUATION	60
XVII	CRITERIA FOR RATING TECHNOLOGY	68
XVIII	RESEARCH AND DEVELOPMENT RECOMMENDATIONS SUMMARY	69

SUMMARY

In May 1972, the Lockheed-California Company and Lockheed-Georgia Company initiated this two-phase twelve month study of Quiet Turbofan STOL Aircraft for Short Haul Transportation under NASA contract NAS 2-6995. To assist in obtaining the realism considered essential, subcontracts were negotiated with Eastern Air Lines and Allegheny Airlines for their active participation and consulting services. Parametric engines were defined by Detroit Diesel Allison Division of General Motors and by General Electric Company under separate contract to NASA. These contracts for studies of Quiet Clean STOL Experimental Engines (QCSEE), developed engine and noise-treated nacelle configurations which were incorporated in the aircraft concepts.

The objectives of this study were:

- Define representative aircraft configurations, characteristics, and costs associated with their development and operation.
- Identify critical technology and technology related problems to be resolved in successful introduction of representative short-haul aircraft.
- Determine relationships between quiet STOL aircraft and the economic and social viability of short-haul.
- Identify high payoff technology areas.

Not knowing the final requirements nor environment of the operating system that would utilize the new STOL vehicle concepts it was necessary to develop a broad range of aircraft designs with sufficient excursions in requirements to cover all reasonable eventualities. In Phase I, this was accomplished through employment of a comprehensive parametric computer program that allowed an evaluation and screening of concepts that narrowed the selection of designs to those most likely to produce a viable short-haul transportation system. Since the evaluation and screening of the parametric aircraft designs was accomplished with a synthesized typical short-haul scenario, the six selected

designs still encompassed the broad range of basic lift concepts and short field performance shown below:

Lift Concept		Field Length
Augmentor Wing	(AW)	2000 feet (610 m)
Externally Blown Flap	(EBF)	2000 feet (610 m)
Externally Blown Flap	(EBF)	3000 feet (914 m)
Over-the-Wing	(OTW)	3000 feet (914 m)
Internally Blown Flap	(IBF)	3000 feet (914 m)
Mechanical Flap	(MF)	4000 feet (1219 m)

and as a result of the Phase I screening, the designs were sized for 150 passengers and a Mach 0.8 cruise speed. All designs met the 95 PNdB at 500 feet (152 m) sideline noise criterion specified by NASA.

In order to properly evaluate the candidate quiet STOL aircraft designs in Phase II and determine their economic viability and community acceptance a realistic operating system and environment was developed and projected to the year 1990. This consisted of:

- Airline economic simulation - in which the candidate STOL aircraft were introduced into representative, mixed airline fleets, and airline operations using the Short Haul System Simulation computer model.
- System sensitivity analysis - in which STOL aircraft economic sensitivities were measured for variations to operational and scenario-related factors.
- ROI analysis - to provide realistic economic measures of STOL performance.

Since general agreement exists that congestion at the major hub airports is the most important factor inhibiting the growth and prosperity of the national air transportation system, both long and short-haul, the demand analysis was based upon the potential ability of improvements in terminal air traffic control (ATC) and the addition of STOL to relieve the congestion without resorting to new airports, major land acquisitions or dependence upon induced demand for a viable short-haul air transportation system.

Within the premises and scope of the study the principal conclusions are summarized as follows:

- Quiet, short field length STOL aircraft can be economically viable and benefit both long and short-haul air transportation, with community acceptability.
- Engine fan pressure ratios of 1.30 to 1.50 required.
- 148 passenger aircraft provides capacity and frequency for high density markets.
- STOL initiation should be related to airport congestion.
- Potentially congested hub airports can be relieved by improved ATC plus
    - o 3000 foot (or more) STOL-strips added to the airport, and/or
    - o One airport in each hub converted to All-STOL.
- STOL fares should be competitive with CTOL.
- Reduction of CTOL delays by 1-1/2 minutes eliminates the economic disadvantages of STOL for the nominal case.
- Secondary airport utilization should be evolutionary after congestion at the major hubs has been relieved.
- Preferred short-haul aircraft characteristics are:

	Hybrid OTW/IBF	Hybrid OTW/IBF	Mechanical Flap
EPNdB @ 500 ft. (152 m) sideline	95	107	94
80 EPNdB footprint area, sq. mi. (sq. km)	4.5 (11.6)	41.8 (108)	3.1 (8.0)
Field Length, ft. (m)	3000 (914)	3000 (914)	4000 (1219)
Passengers	148	148	148
Gross Weight, lbs (kg)	147,300 (66,900)	137,400 (62,300)	136,900 (62,000)
Engine Thrust SLS, lbs (kg)	36,800 (16,600)	31,700 (14,300)	34,000 (15,400)
Fan Pressure Ratio	1.32	1.57	1.35
Unit Cost, dollars	9.35×10^6	8.15×10^6	8.71×10^6
DOC @ 250 N.M. (462 km) cents/assm.	2.29	2.01	2.12

Detailed recommendations where additional research may result in significant improvements in STOL technology are identified in this report. The most important research subjects are summarized as follows:

- Quiet Clean STOL Experimental Engine (QCSEE) development
- Noise prediction and reduction research
- Wake vortex and separation research
- Microwave landing system development
- Airworthiness flight research
- Hybrid OTW/IBF propulsive-lift system development
- Composite structure research
- Active control technology R & D
- Alternate fuel research

INTRODUCTION

Previous studies of STOL technology and short-haul transportation systems have investigated STOL feasibility, potential demand, and a general treatment of community acceptance; but, for the most part these analyses have been restricted in scope and lack realism, especially in their treatment of advanced aircraft technology and the environmental and economic concerns of the public and industry sectors in the practical time-frame of interest.

In response to the NASA request to analyse a realistic short-haul air transportation system in the 1980-1990 time period the advanced lift concept vehicles were designed around the Quiet Clean STOL Experimental Engines of the NASA QCSEE program and a realistic competitive operational environment was postulated with the direct assistance and advice of Eastern and Allegheny Airlines.

The key to application of STOL short-haul transportation is its potential capability to economically alleviate the significant problems faced by the National Air Transportation System. These critical problems have been analyzed by many government studies in recent years such as the Department of Transportation's ad hoc Air Traffic Control Advisory Committee study, the Joint NASA/DOT CARD policy study, the Aviation Advisory Commission study, the FAA's National Aviation System Policy and Plan studies, to mention a few, and the causal factors can be summarized as follows:

- Imbedding of airports in housing and industrial developments resulting from an unprecedented national urbanization.
- Increase in air transport demand.
- Inability to expand the imbedded airport, resulting in runway saturation, terminal and approach area air congestion, saturation of ATC facilities, and airline schedule disruption and delays, and
- Sustained levels of noise impingement, air pollution and ground congestion imposed on the surrounding community.

There appears to be general agreement that congestion of the major airports and noise are the most important factors inhibiting the growth and prosperity of the national air transportation industry, both long and short-haul.

Based on this evidence, it is widely believed that many metropolitan hub airports have already reached, or soon will reach, their potential operating capacities. It seemed that this view was confirmed by the extensive air carrier delays that occurred in the summers of 1968 and 1969. Since that time, however, a slump in air travel demand, an FAA imposed quota (reservation) program at the most congested airports, more efficient scheduling by the airlines and the introduction of larger aircraft, have all contributed to a significant reduction in air delays. Nevertheless, the ever increasing trend of aircraft operations of all types guarantees the resumption of costly delays at most airports during the 1970's if the present facilities, equipment, and operating procedures are unchanged.

These opinions and the experience of this study's Phase I analysis resulted in the establishment of a broad policy premise for the guidance of the operating system development to be used in the detailed Phase II analysis. This premise envisioned that the best chance of success for an economically viable STOL short-haul system lay in solving the air-side congestion problem at the major hub airports. If, and when, based on demonstratable benefits, this becomes a feasible operation in a competitive environment, the system would then be allowed to evolve and expand to secondary airports and STOLports as the induced demand developed naturally. The induced demand results from increased convenience, improved service and added community benefits, all of which should then be observable and obvious. This policy premise was adopted as an overall guideline to this study only after extensive correlation with the many related government and industry studies and a consensus of the airline subcontractors and other experts in the field.

This approach allows the system to become an established and economically sound member of the aviation community with demonstratable benefits before it has to take on the risks of modal split and the many uncertainties associated with induced demand.

The specific technical approach to the accomplishment of this short-haul study that is summarized in this report, was to conduct an in-depth parametric aircraft design analysis of a large number of candidate aircraft concepts, sizes, and levels of performance; screen this large matrix of designs against a parametric transportation system representative of the national short-haul market; and recommend up to six point aircraft designs in Phase I of the study. In Phase II these point designs were analyzed in detail and introduced into a realistic operating environment of the 1980-1990 time period through an airline system simulation model and airport analysis that reflected the projected demands and capacities of the national air transportation system of that period.

Figures 1 and 2 are summary flow charts that outline the scope, content, sequence, and output of the Phase I and Phase II analyses.

FIGURE 1. SUMMARY FLOW CHART – PHASE I

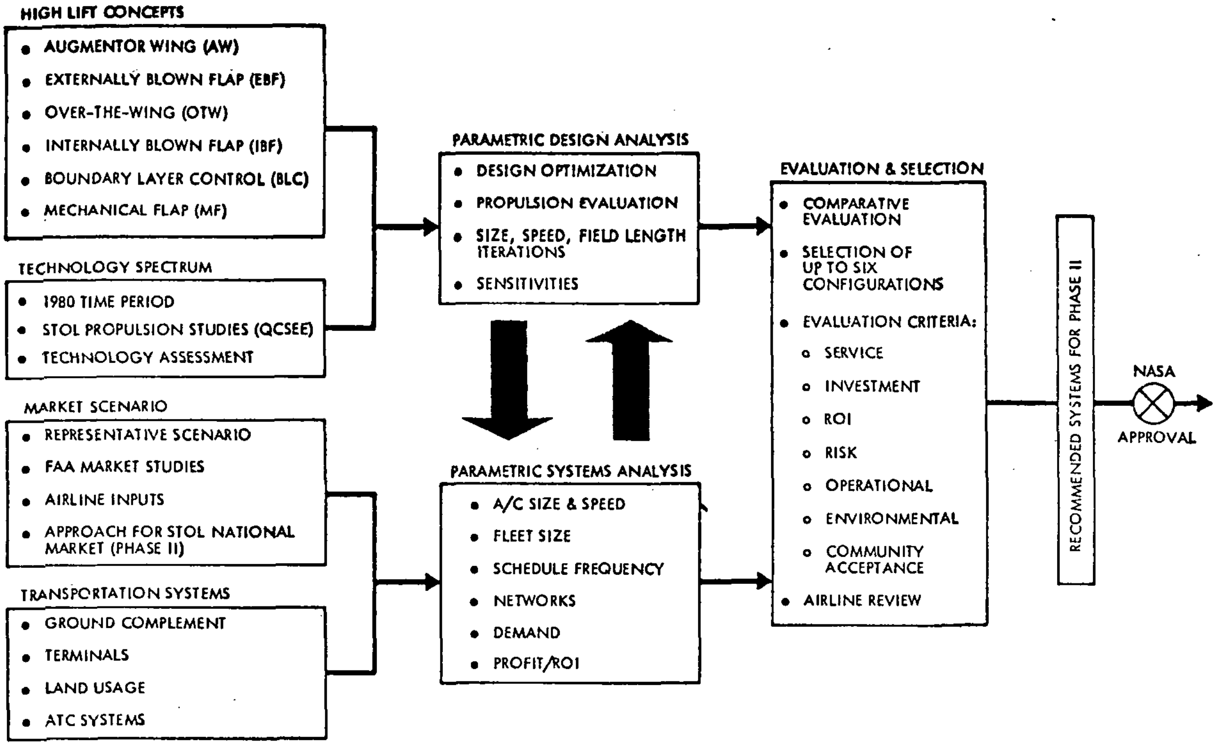
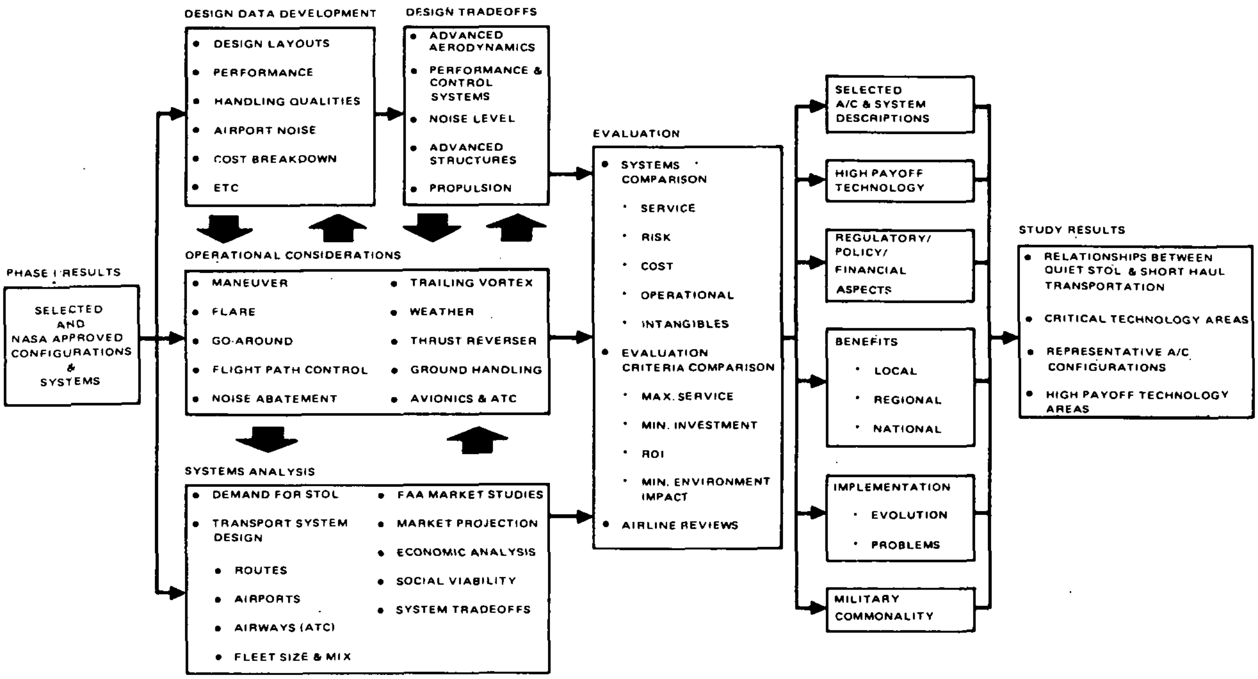


FIGURE 2. SUMMARY FLOW CHART – PHASE II



SYMBOLS AND ABBREVIATIONS

AMST = Advanced Medium STOL Transport

APFD = Autopilot Flight Director

ATC = Air Traffic Control

AW = Augmentor Wing

ATA = Air Transport Association

BLC = Boundary Layer Control

CAB = Civil Aeronautics Board

¢/ASSM = Cents per Available Seat Statute Mile

C_L = Lift Coefficient

CTOL = Conventional Takeoff and Landing

DLC = Direct Lift Control

DME = Distance Measuring Equipment

DOC = Direct Operating Cost

DOT = Department of Transportation

EBF = Externally Blown Flap

ECS = Environmental Control System

EEC = European Economic Council

EPNdB = Equivalent Perceived Noise Level

FAA = Federal Aviation Administration

FAR = Federal Air Regulation

FPR = Fan Pressure Ratio

G&A = General & Administrative (costs)

IBF = Internally Blown Flap

SYMBOLS AND ABBREVIATIONS (Continued)

IFR = Instrument Flight Rules

ILS = Instrument Landing System

IOC = Indirect Operating Cost

L/D = Lift/Drag (ratio)

M = Mach (number)

MF = Mechanical Flap

MLS = Microwave Landing System

NDI = Nondestruct Inspection

O-D = Origin - Destination

OPR = Overall Pressure Ratio

OTW = Over the Wing

PANCAP = Practical Annual Capacity (landings or takeoffs)

PAX = (number of) Passengers

PHOCAP = Practical Hourly Capacity (landings or takeoffs)

PSA = Pacific Southwest Airlines

RGW = Ramp Gross Weight

R-NAV = Area Navigation

ROI = Return on Investment

RTOL = Reduced Takeoff and Landing

STOL = Short Takeoff and Landing

TIT = Turbine Inlet Temperature

VFR = Visual Flight Rules

VOR = VHF Omni Range

V/STOL = Vertical/Short Takeoff and Landing

DEMAND AND AIRPORT ANALYSIS

One of the prime potential benefits ascribed to STOL is congestion relief at major hub airports. Since this is such an important - perhaps the most important - aspect of STOL, the demand and airport analysis was structured to:

- Determine as accurately as possible a realistic estimate of future hub airport activity between now and 1990,
- Compare this with projections of potential airport capacity based on the best government forecasts available to determine the magnitude of congestion and when it is most likely to occur, and
- Assess the potential ability of improvements in air traffic control (ATC) and the addition of STOL to relieve the congestion without inordinate cost.

The Aviation Advisory Commission's report, "The Long Range Needs of Aviation" graphically portrayed the growth in long and short-haul origin and destination passenger traffic in the major U. S. markets as illustrated in Figures 3 and 4. It is interesting to note that eight major hubs

- Boston
- New York
- Philadelphia
- Washington
- Chicago
- St. Louis
- Los Angeles
- San Francisco

are common to both figures and became candidates for the congestion analysis. Four of these hubs are in the congested N. E. Corridor, two hubs anchor the California Corridor which accounts for 22 percent of all short-haul, and the remaining two hubs are active mid-west complexing centers.

Plotting the total unconstrained estimates of passenger enplanements and deplanements at the 25 leading U. S. cities to the year 2000, from Table 2 of the Advisory Commission's report, Figure 5 indicates that the major portion of passenger traffic will be served by the eight previously listed hubs with the addition of the rapidly

FIGURE 3. LONG-HAUL ORIGIN-DESTINATION PASSENGER TRAFFIC IN MAJOR MARKETS U. S. DOMESTIC SCHEDULED SERVICE

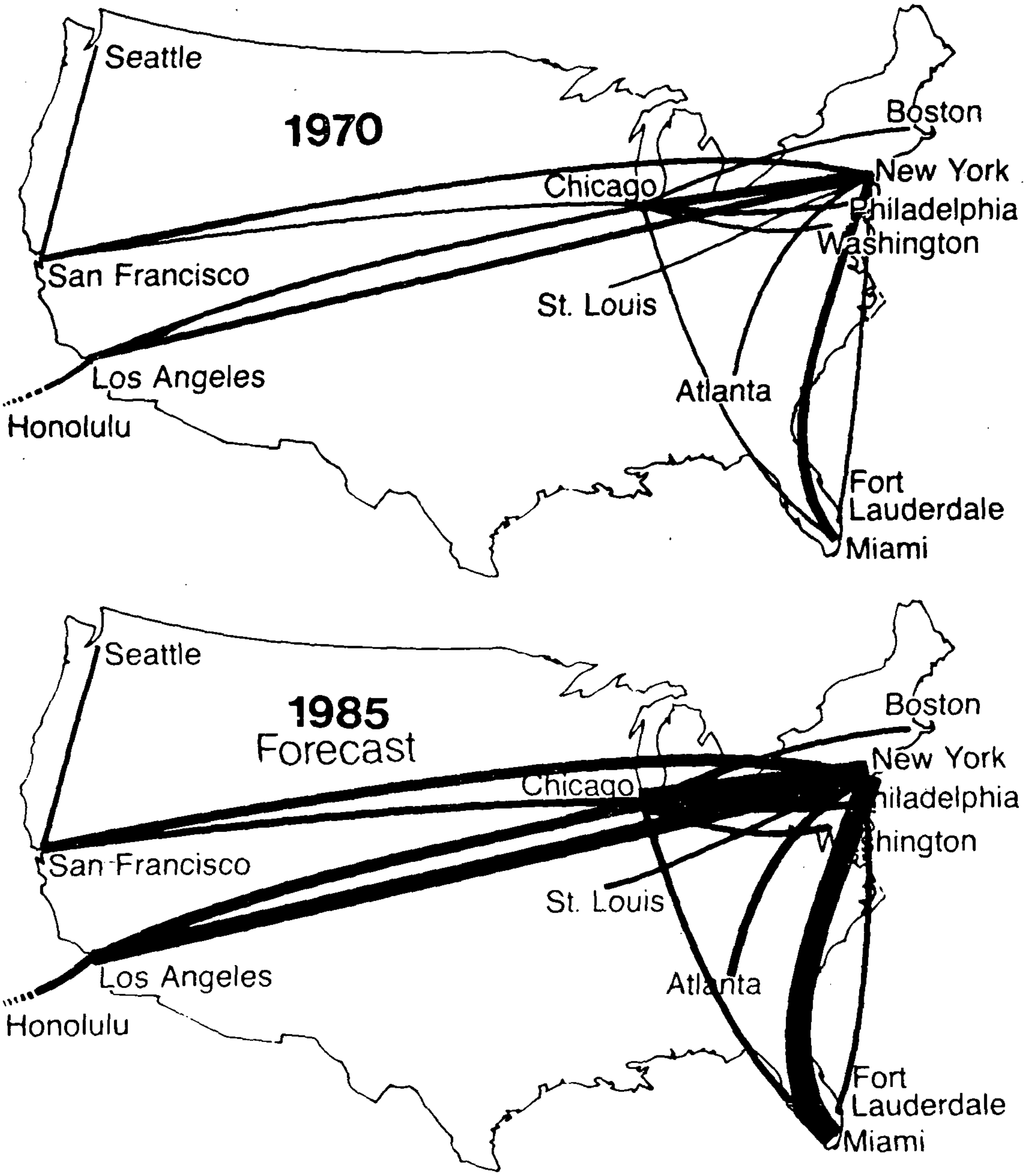


FIGURE 4. SHORT-HAUL ORIGIN-DESTINATION PASSENGER TRAFFIC IN MAJOR MARKETS U. S. DOMESTIC SCHEDULED SERVICE

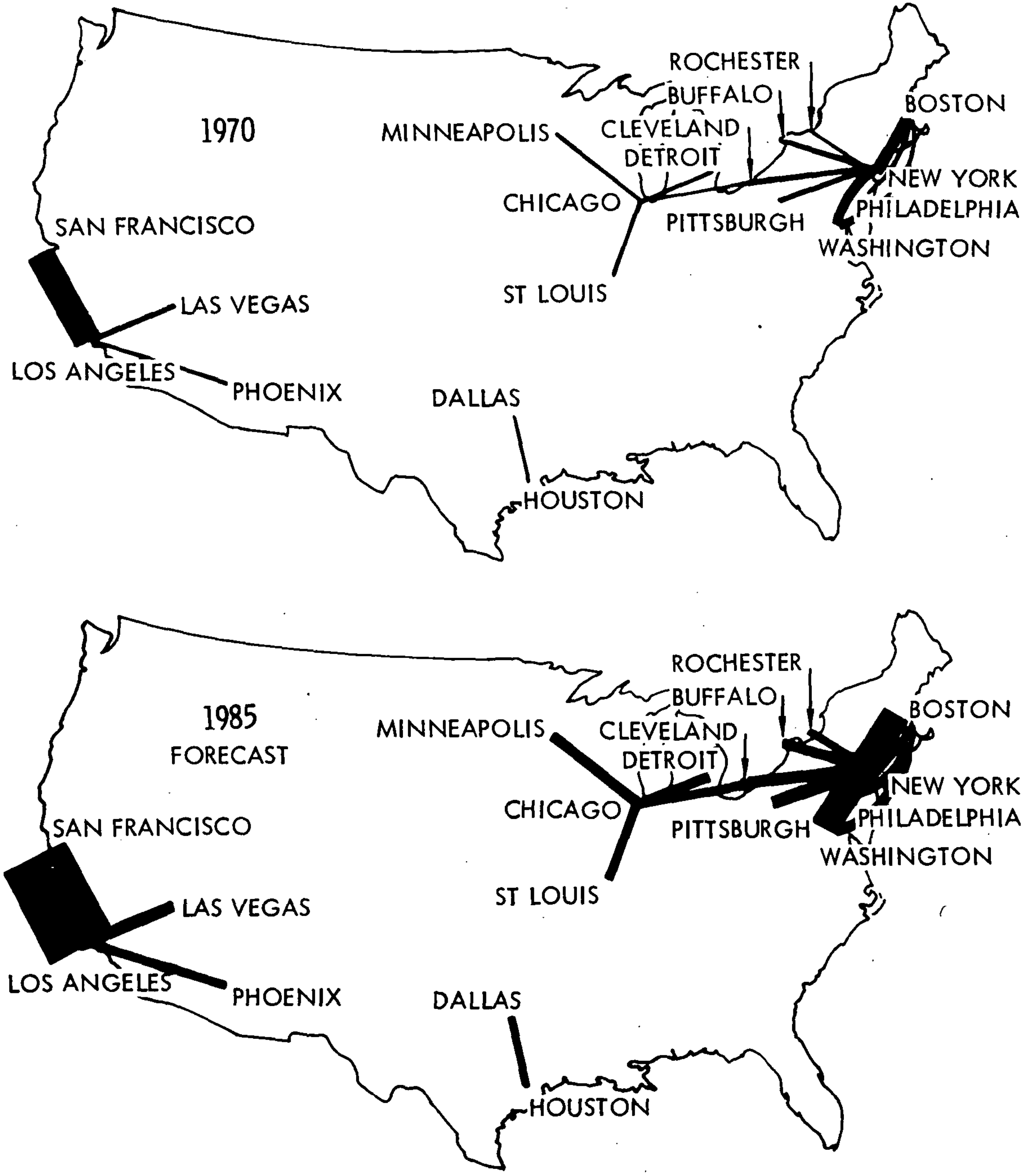
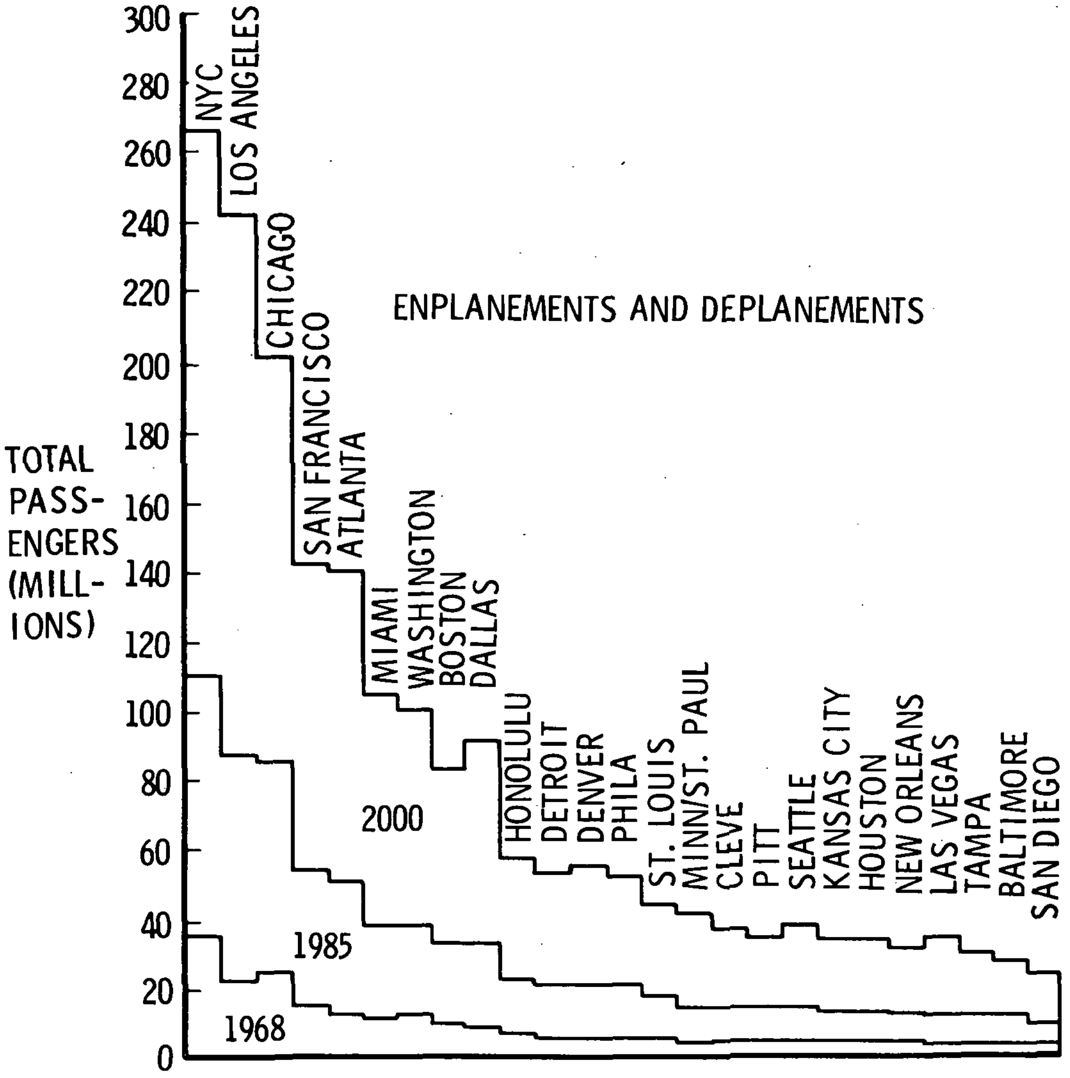


FIGURE 5. PROJECTED UNCONSTRAINED ESTIMATES OF TOTAL PASSENGERS AT 25 LEADING U. S. CITIES



growing southeastern region and Dallas. These 25 cities make up approximately 74 percent of the national total.

In 1969, the FAA published a list of the 16 most congested metropolitan hubs ranked in the order of airline delays experienced. Four of the listed hubs have more than one major airport resulting in the following list of 22 airports which were selected for the initial congestion analysis:

- New York
  - Kennedy
  - La Guardia
  - Newark
- Chicago
  - O'Hare
  - Midway
- Los Angeles
- Washington, D. C.
  - Washington National
  - Dulles
  - Friendship
- Atlanta
- Miami
- Boston
- San Francisco
  - SF International
  - Oakland
- Detroit
- Philadelphia
- Cleveland
- Minneapolis/St. Paul
- St. Louis
- Pittsburg
- Denver
- New Orleans

Dallas/Ft. Worth, Houston, and Kansas City would have been included in the list if the delays experienced in 1968 were the sole criterion; however, each of these three hubs has recently opened or soon will open a new airport with much greater capacity than the replaced facility, and should experience little or no congestion through 1990.

Each of the 22 airports of the 16 most congested hubs was analyzed. For the purpose of this summary the methodology and procedures used will be described for J. F. Kennedy Airport of the New York Hub, as an example.

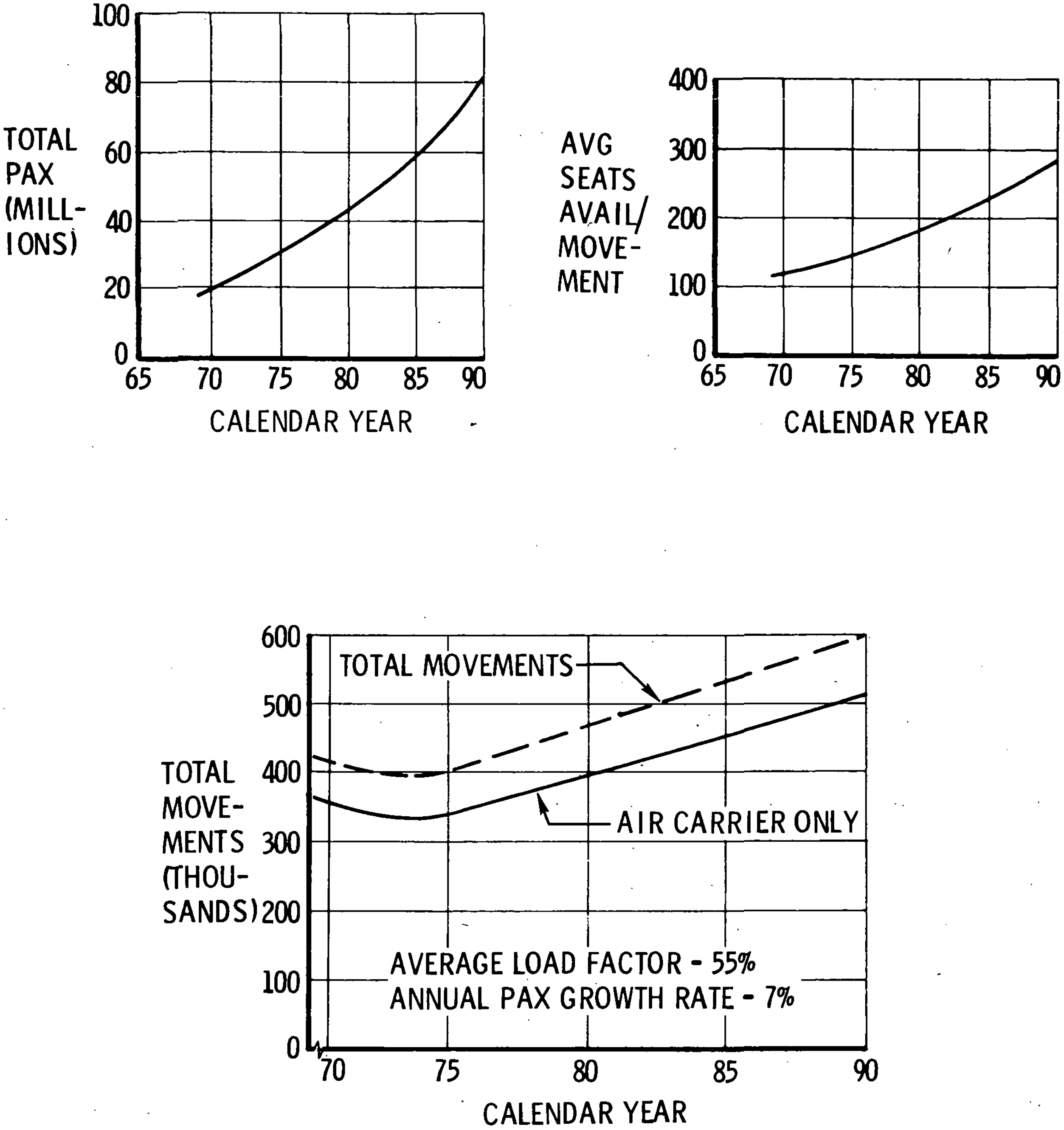
- Total passengers were projected from 1969 actuals at a conservative annual growth rate of 7 percent for the mature NE Corridor.
- Average seats available per movement were projected from 1969 actuals using the ATA airport demand forecasts which account for the introduction of larger, wide-body aircraft.
- Using these projections and an average load factor of 55 percent, the total, and carrier-only, movements were forecast to 1990. This forecast of movements was compared with the independent FAA forecast for the years 1974 and 1983 and found to agree quite well.

These data for Kennedy Airport are plotted in Figure 6 and the reduction in movements from the observed actuals of 1969 is due to the introduction of wide-body aircraft and improved load factor. By 1975 this temporary congestion relief is overtaken by the compounded 7 percent growth in passengers and the forecast shows a steady increase in aircraft movements from this point to the year 2000.

After projecting the aircraft movements for each of the 22 airports, as illustrated in Figure 6, the basic visual flight rules (VFR) and instrument flight rules (IFR) airport capacities for 1970 were estimated from FAA airport capacity criteria defined in FAA aircraft circulars AC-150/5060-1A and 3A. For the example Kennedy airport the VFR practical hourly capacity (PHOCAP) was 99 and IFR was 75. These criteria consider such factors as runway separation, point of intersection (if applicable), aircraft mix, runway exit configuration and wind rose data (percent of crosswind) all corrected to an assumed average delay standard of four minutes. Multiplying PHOCAP by 4150 gives the practical annual capacity (PANCAP) of the airport at a 7 percent "peaking factor" recommended by Eastern Air Lines. This results in a VFR PANCAP for Kennedy airport in 1970 of 410,000 movements per year and an IFR PANCAP of 311,000.

The Department of Transportation formed the ATC Advisory Committee in the summer of 1968 for the purpose of recommending an air traffic control system for the 1980's and beyond. Their study shows that it is possible to greatly increase these 1970 capacities at present airports by the development and implementation of improved air traffic control (ATC). Very briefly their findings identify five options which summarize

FIGURE 6. J. F. KENNEDY AIRPORT ACTIVITY FORECAST



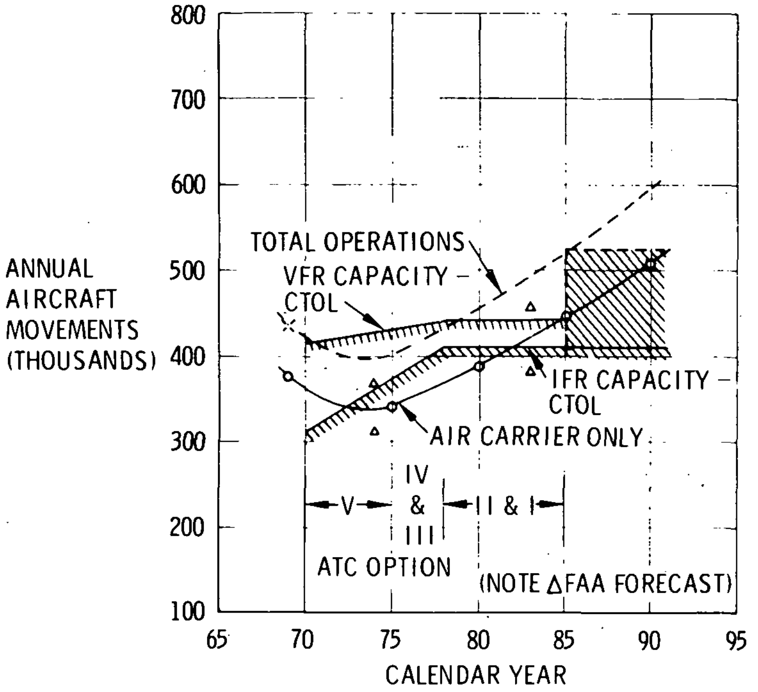
the various automation and procedural alternatives and dates for implementation. These options are coded I through V with Option I incorporating all of the projected improvements as described below:

- Option V - 1975 - Present standards with speed segregation, speed class sequencing, and computer-aided approach spacing which will reduce the delivery error to the approach gate from about 30 seconds to 11 seconds.
- Option IV - 1977 - With command control spacing there will be a further reduction in delivery error to five seconds.
- Option III - 1978 - Reduction of the spacing between successive arrivals from three miles to two miles which will probably require the installation of a scanning beam microwave instrument landing system. The two mile separation is predicated on the solution of wake turbulence problems.
- Option II - 1979 - Reducing departure/arrival spacing from two miles to a departure/arrival interval of 40-second average.
- Option I - 1980 - Reduction of the lateral separation distance between parallel runways required for arrival independence from 5000 feet to 2500 feet.

For this study a recommendation of MITRE was considered a reasonable compromise for projecting the increase in airport capacity due to implementation of the ATC options. This study increases the IFR capacity 20 percent by 1975 and another 50 percent in 1985 when all five options are assumed to be operational. For VFR a 5 percent increase in capacity is assumed for 1975 and then phased out by 1985, since IFR is the operational mode that is considered feasible in the highly automated ATC environment of options I and II. These capacity curves have been added to the J. F. Kennedy activity plot of Figure 6 as shown in Figure 7.

Figure 7 indicates that J. F. Kennedy Airport will go critical in the late 1970's based on total operations and full VFR capacity. If all general aviation, military and air taxi is eliminated the critical date is only moved to the early 1980's. It should be noted that the VFR capacity is computed on the standard four minute average delay. The slight difference in VFR capacity computed for JFK and the actual total operations counted in

FIGURE 7. J. F. KENNEDY AIRPORT CAPACITY FORECAST CTOL



1969, represents a difference of only one minute delay. Actually, American and United Airlines kept precise records of their total operations and delays experienced in 1969 and the average was 6.74 minutes delay per operation at Kennedy for the entire year. J. F. Kennedy Airport ranked third in the nation for delays in 1969 after O'Hare and Los Angeles. This seems to be an ample explanation for those few cases where VFR capacity appears to be less than actual observations.

Using this procedure the degree of potential total, and air carrier only, runway congestion was determined for all 22 of the potentially congested airports of interest - and within the framework of the ground rules and premises assumed, when the congestion is likely to occur.

By analyzing each of the 22 potentially congested airports in the manner described it was determined that nine major airports would become runway congested within the time frame of this study. Since short-haul in the California Corridor is adequately served today by CTOL, San Francisco was eliminated and a detailed analysis of the effect of STOL on congestion relief was conducted on the following eight congested airports and the metropolitan hub surrounding them, if applicable:

- J. F. Kennedy (JFK)
- La Guardia (LGA)
- Newark (EWR)
- Washington National (DCA)
- Philadelphia (PHL)
- O'Hare (ORD)
- Atlanta (ATL)
- Miami (MIA)

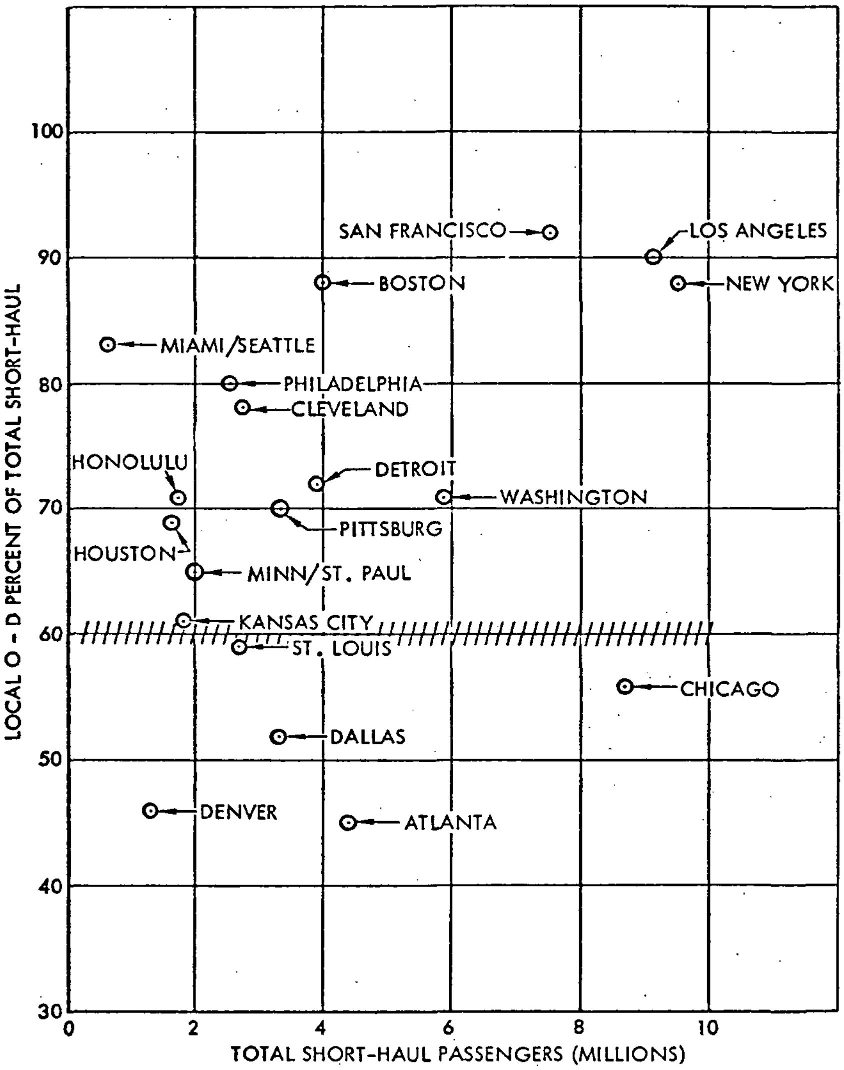
Before proceeding with the impact of STOL in relieving airport congestion a breakdown of the short-haul passenger demand into local O-D and interline connecting passengers was made. Figure 8 shows the total short-haul passengers in millions for the 20 largest U. S. hubs plotted against the percentage of these passengers that are local O-D as given in the Aviation Advisory Commission Report. It is interesting to note that for these 20 largest cities, local O-D passengers constitutes 74 percent of all short-haul.

The six hubs showing 60 percent or less local O-D in Figure 8, i.e., Denver, Kansas City, St. Louis, Dallas, Atlanta, and Chicago, are all recognized complexing centers. Of these six hubs, only Atlanta and Chicago appear in the list of candidate congested airports. The other six congested airports (there are three congested airports in the New York Hub) that show over 70 percent local O-D demand are candidates for relief through a separate reliever airport, since there is sufficient local O-D to support such an operation.

To determine the impact of STOL on congestion relief the approach taken was to analyze each airport of a hub individually and from a map study only, evaluate the possibility of laying in STOL-strips within the current airport boundary in an effort to increase local capacity with the introduction of STOL. This was followed by determining the effect of converting certain CTOL runways to STOL-strips for joint CTOL/STOL operations. And finally, in the multi-airport hub situations, the effect of converting a CTOL airport to an all-STOL reliever airport was examined.

Figure 8 indicated that the congestion at Atlanta and Chicago should be relieved by the addition of STOL-strips on the airport if at all possible due to the high percentage of interconnecting short-haul passengers. The addition of STOL-strips to all of the eight congested airports was investigated in the study. However, since Atlanta is not part of a

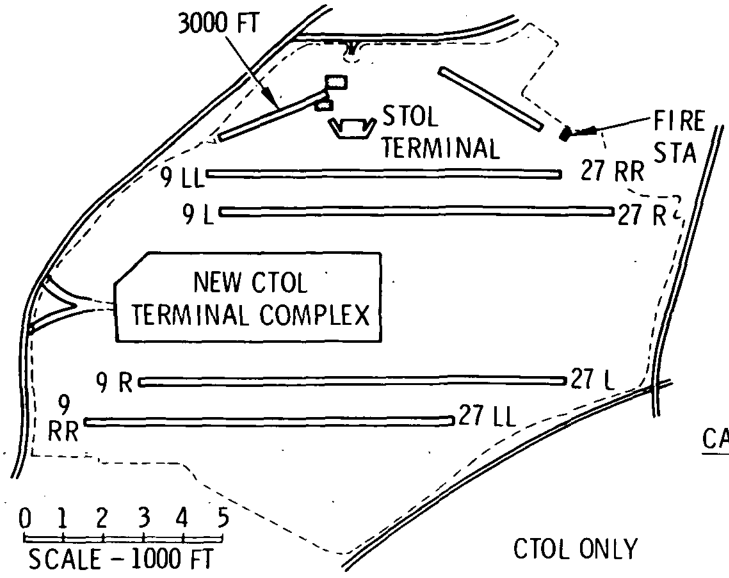
FIGURE 8. LOCAL O-D PASSENGERS FOR TWENTY LARGEST HUBS



larger hub and the addition of STOL runways is probably the best solution in this case, Atlanta will be used in this summary as an example of this procedure to increase airport capacity.

Figure 9 shows a sketch of the Atlanta airport with two 3000 foot STOL runways added. Atlanta recognized their congestion problem and in 1968 they predicted complete runway congestion by 1972 - 1973 and started a long range master plan. The airport at that time (1968) consisted of the existing terminal and two long parallel runways, with two seldom used diagonal cross runways. Construction was started on a new runway and it was scheduled for completion in 1972. There was a slippage of one year and this new runway just opened in March, 1973. The master plan called for another new runway to be completed in 1975. This too has slipped and it is estimated to be operational in 1977 - 1978. In conjunction with this fourth runway the existing terminal and the cross runways will be abandoned and a new terminal will be constructed. The existing terminal will be used for the STOL terminal and the two 3000 foot STOL runways will give a STOL PHOCAP of 60, increasing the total airport capacity from 98 to 158.

FIGURE 9. ATLANTA – JOINT CTOL/STOL



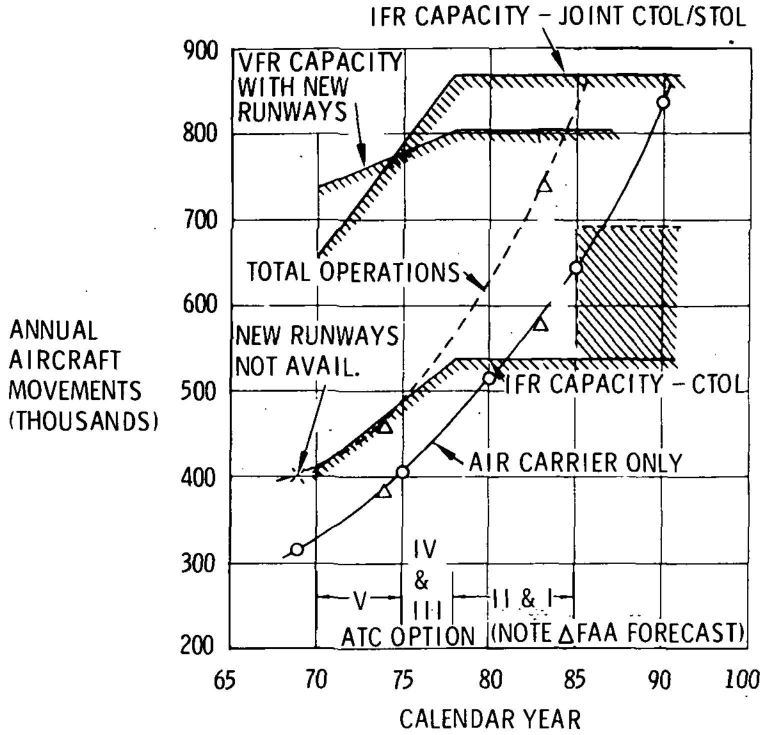
CAPACITY

	IFR PHOCAP	IFR PANCAP
CTOL ONLY	98	467,000
JOINT CTOL/STOL	98/60	407,000/ 249,000
	(158)	(656,000)

NOTE: EXISTING FACILITIES IN CONFLICT ARE SHOWN IN CROSSHATCH

Figure 10 depicts the dramatic increase in capacity through the addition of a small, compact STOL runway system at the perimeter edge of the airport utilizing what will be the abandoned present terminal and in terms of aircraft movements this will provide adequate IFR airport capacity for air carriers beyond 1990.

FIGURE 10. ATLANTA AIRPORT CAPACITY FORECAST WITH STOLSTRIPS

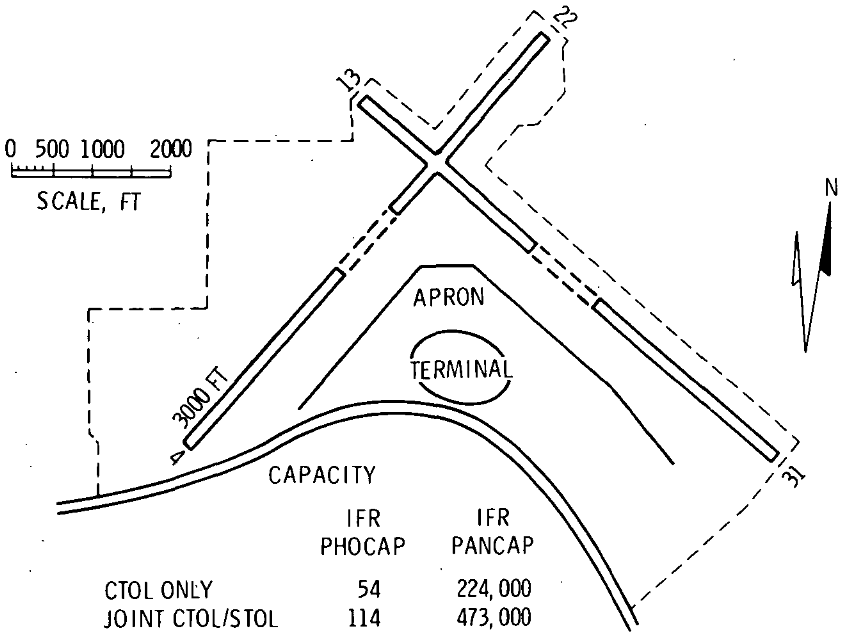


Atlanta is a large complexing center for connecting passengers (over 55 percent of all short-haul); therefore, the use of a STOL operation on the airport is preferred to a separate reliever airport in this situation.

Returning to the original J. F. Kennedy example used earlier in this summary, its congestion relief is attractive through the use of an all-STOL reliever airport since it is part of a large metropolitan hub complex and its percentage of local O-D short-haul passengers is high.

Since La Guardia airport is a close-in airport it is a logical candidate for conversion to all-STOL, as shown in Figure 11, and thereby relieve J. F. Kennedy and Newark of all local O-D and complexing passengers (connecting passengers without NYC as a destination). In this case both CTOL 7000 foot runways are divided into two 3000 foot tandem runways with landing on the downwind runway (toward the center) and takeoffs on the upwind runway (from the center), with 1000 feet of separation. The existing CTOL runways would not be disturbed, the STOL runways would be designated by paint, lights and instrumentation which allows much leeway in the conversion commitment date. Even after commitment the CTOL strips are available for emergency use or use by overloaded STOL aircraft being flown outside of peak hours on longer range RTOL type operations to improve their utilization - a feature attractive to the airline operators.

FIGURE 11. LA GUARDIA – STOL ONLY TANDEM STOLSTRIPS

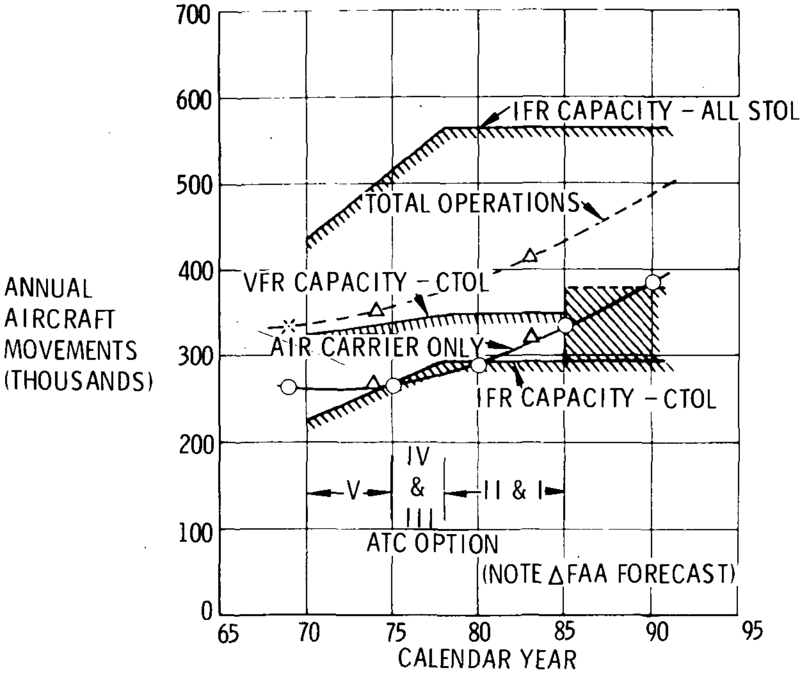


CAPACITY

	IFR PHOCAP	IFR PANCAP
CTOL ONLY	54	224,000
JOINT CTOL/STOL	114	473,000
STOL ONLY	104	432,000

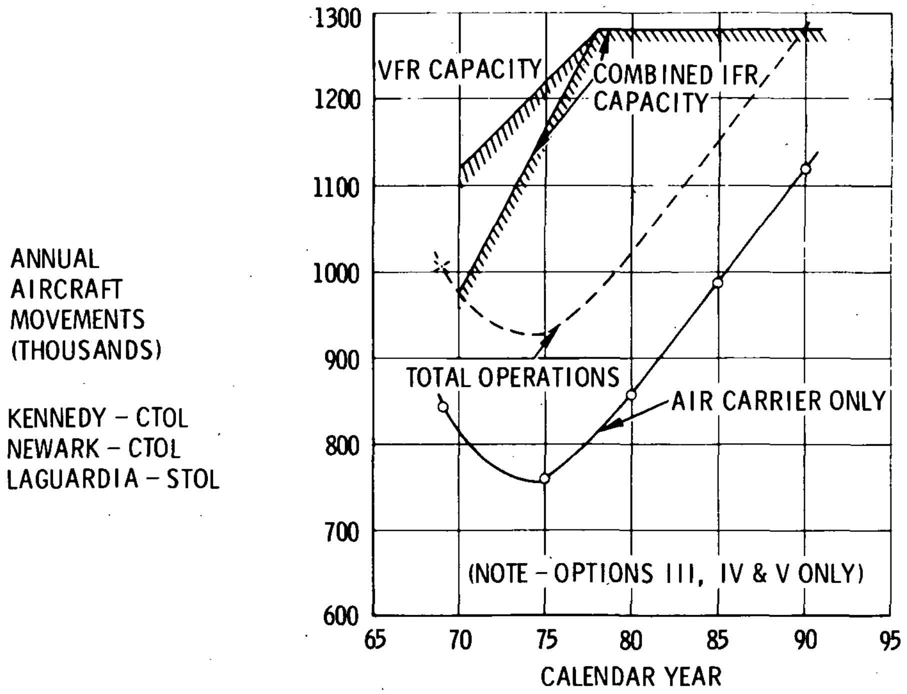
Figure 12 shows the all-STOL capacity forecast that results when La Guardia airport is converted to a STOL short-haul reliever airport. This figure indicates that La Guardia airport is critical today with respect to total operations and continues to degrade to 1990. This is borne out by the fact that operations are now strictly controlled by the FAA and the introduction of all the ATC improvement options will not overcome this situation. VFR delays exceed the four minute standard slightly until approximately 1975 then the divergence becomes increasingly intolerable. This airport is one of the prime candidates for the dramatic increase in capacity inherent in converting to STOL operation. ATA and FAA forecasts agree precisely for La Guardia providing a high level of confidence for these projections.

FIGURE 12. LA GUARDIA AIRPORT CAPACITY FORECAST ALL-STOL



For the purpose of this summary it is assumed that the total air carrier hub demand will be satisfied with J. F. Kennedy and Newark as CTOL-only airports and La Guardia is converted to STOL-only. Simply combining the total capacities and operations on this basis the New York Hub capacity forecast of Figure 13 is obtained. A cursory examination shows that by converting La Guardia to a STOL-only airport and leaving Kennedy and Newark for CTOL-only there is sufficient capacity in the New York Hub for all forecast operations to 1990. Any STOLstrips added at Kennedy or Newark for added convenience for connecting passengers would simply add to this capacity.

FIGURE 13. NEW YORK METROPOLITAN HUB CAPACITY FORECAST



One disadvantage of any Hub complex, of course, is the problem of connecting passengers. Obviously, this is simplified when the STOL and CTOL terminals are on the same airport. However, evidence seems to bear out the fact that in the time frame when congestion becomes critical there will be sufficient short-haul passengers to support a separate airport with local O and D passengers only. A high percentage of connecting short-haul passengers do not have a hub as an origin or a destination. These passengers are now complexed at a hub thus adding considerably to its congestion. These passengers as well, can be moved and complexed at the reliever short-haul airport.

This alternative appears to be an ideal solution for the complex New York Hub for a minimal cost.

The airport and demand analysis summarized here confirmed the basic premise that there will be serious runway congestion at several of the key metropolitan hubs in the time frame of this study and that the projected local O and D demand will support the implementation of STOL and provide the congestion relief required for a viable national short-haul transportation system. This general conclusion is based on the following evidence generated in the analyses of this section:

- Major metropolitan hub runway congestion by 1985 appears certain at;
  - New York
  - Chicago
  - Washington National
  - Atlanta
- All-STOL reliever airports at La Guardia, Midway and Washington National will solve congestion at the first three hubs.
- Joint CTOL/STOL will relieve congestion at Atlanta
- Local O and D demand represents a significant portion of the total short-haul air demand.
- Joint CTOL/STOL will completely relieve all potentially congested individual airports except O'Hare.
- 3000 foot STOL strips at all critical airports appear feasible - good possibility of 4000 foot STOLstrips with 10 percent saving in DOC.
- Best implementation for STOL is at congested hubs - followed by induced growth to secondary airports and STOLports.
- Increased facility cost is minimal by converting key reliever airports at the critical hubs to all-STOL.

The next section defines the quiet turbofan STOL aircraft developed in this study.

AIRCRAFT DESIGNS

The ground rules which were agreed to with NASA for the initial Phase I parametric aircraft design analysis were as follows:

- Aircraft Noise Level: 95 PNdB at 500-Foot (152 m) Sideline
- Design Range: 500 Nautical Miles (930 km)
- Cruise Altitude: 20-30,000 Feet (6,100-9,200 m)
- Reserves: 200 N Mi. (370 km) at cruise altitude and 15 min at 10,000 feet (3,050 m)
- Field Altitude and Temp: Sea Level, 95°F (35°C)
- Approach: 800 Ft/Min (243 m/m)
- Touchdown: 3 Ft/Sec (0.92 m/Sec.)
- Federal Air Regulations: Parts XX, 25, and 121
- Deceleration During Rollout: 0.35 g
- Production Quantity: 300 Aircraft

and the following parameters were studied:

- Six lift concepts
  Augmentor Wing (AW) with 2 stream and 3 stream engines
  Externally Blown Flap (EBF)
  Over-the-Wing (OTW)
  Internally Blown Flap (IBF)
  Boundary Layer Control (BLC)
  Mechanical Flap (MF)
- Field Lengths from 1500 feet (457 m) through 4000 feet (1219 m)
- Cruise Mach numbers from 0.70 through 0.80
- Passenger capacities of 50, 100 and 200
- Ranges of parametric engines from Detroit Diesel Allison and General Electric Company.

The Phase I parametric aircraft which were generated for each of the lift concepts are shown in Figure 14.

FIGURE 14. PHASE I DATA POINTS

FIELD	1500' (457 m)									2000' (610 m)									2500'			3000' (914 m)									4000' (1219 m)								
MACH	0.70			0.75			0.80			0.70			0.75			0.80			0.80			0.70			0.75			0.80			0.70			0.75			0.80		
PAX	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
AW2S	●	●	●	●	●	●	●	●	●	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲	● ▲				●	●	●	●	●	●	●	●	●									
AW3S																● ▲	● ▲	● ▲																					
EBF		●			●			●		●	●		●	●	●	● ▲	● ▲	▲				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
OTW	●	●	●	●	●	●	●	●	●	●	● ▲	●	●	● ▲	●	●	● ▲	●				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
IBF																● ▲	● ▲	● ▲																					
BLC																	●						●			●		●	●	●									
MF																			●	●	●		●					●	●	●		●					●	●	●

PAX, A = 50, B = 100, C = 200   ▲ GE   ● DDAD

Not knowing the final requirements nor environment of the operating system that would utilize the new STOL vehicle concepts it was necessary to develop a broad range of aircraft designs with sufficient excursions in requirements to cover all reasonable eventualities. In Phase I, this was accomplished through employment of a comprehensive parametric computer program that allowed an evaluation and screening of concepts that narrowed the selection of designs to those most likely to produce a viable short-haul transportation system. Since the evaluation and screening of the parametric aircraft designs was accomplished with a synthesized typical short-haul scenario, the six selected designs for detailed point design in Phase II still encompassed a broad range of basic lift concepts and short field performance as indicated in Table I.

TABLE I. PHASE II DESIGNS

500 NM; MACH 0.8; 95, 100, & 105 EPndB @ 500 FT. SIDELINE

FIELD LENGTH	2000			3000			4000		
PAX	100	150	200	100	150	200	100	150	200
AW		◉			○				
EBF		◉			◉				
OTW		○		○	◉	○		○	
IBF					◉				
MF					○		○	◉	○

◉	POINT DESIGNS
○	PARAMETRIC VARIATION

The Phase II point designs were made for a 148 passenger all-coach configuration. The more detailed point designs included:

- Initial sizing and design layouts
- Weight routines examined and modified. For example the hydraulic system was sized, including plumbing run lengths, pipe diameters and fluid weight. Titanium tubing was used for high pressure lines and with welded or brazed fittings for the 1980 time period. The system weight was slightly higher than Phase I data. All other weight routines were similarly examined.
- Drag routines updated to include a number of small increases such as fuselage and roughness drag, trim and general interference drag.
- Phase II engine data from the QCSEE program used in lieu of Phase I data.
- Costing data modified to reflect value engineering cost estimates.

- More consideration given to geometric constraints such as the limitations on engine size to wing area or limitations on wing loading in order to install ducts.
- Detailed equipment and subsystem analysis.
- Loads, stiffness and flutter analyses.
- Structural weights by station analysis.
- Detailed performance, stability and control.
- Noise level variations including noise footprints.

A fan pressure ratio (FPR) of 3.0 was used for the Augmentor Wing and fan pressure ratios (FPR) of 1.25 to 1.98 were used in the other lift concepts.

In addition to four-engine configurations, two and three-engine candidates were also considered. For field lengths of 3000 ft (914 m) and greater, the two-engined aircraft has an economic advantage. The three-engine configurations have the advantage of increased operational flexibility but with approximately two percent penalty in DOC.

Table I indicates a point design for both Over-the-Wing (OTW) and Internally Blown Flap (IBF) at the 3000 foot (914 m) field length. As the study developed it appeared desireable to substitute a hybrid, twin-engine Over-the-Wing/Internally Blown Flap aircraft for the intended four-engine IBF configuration.

These six point designed aircraft are summarized in Table II.

Figure 15 shows the payload range curve for the 3000 foot (914 m) field length EBF airplane as typical of this class of aircraft. All airplanes are sized to have fuel in excess of 500 N.M. (930 Km), plus reserves, equal to half payload. With 50 percent load factor these aircraft are then capable of nearly 1500 N.M. (2,780 Km) without increase in gross weight. For this example if the wing is filled with fuel 36 passengers could be carried 2000 N. M. (3,700 Km).

The 2000 foot field performance Augmentor Wing (AW) aircraft is shown in Figure 16 and the principal characteristics of the point design is shown in Table III along with a supplementary design point at 3000 foot field length.

TABLE II. POINT DESIGN SUMMARY

148 PASSENGERS: M 0.8; 30,000 FT (9100 m); 500 N.Mi. (930 km) DESIGN RANGE; 95 EPNdB AT 500 FT (150m)

LIFT CONCEPT/ FIELD LENGTH	RAMP GROSS WT. LBS (kg)	MISSION FUEL LBS (kg)	W/S	T/W	ENGINE F.P.R.
AW/2000 FT	195,710 (88,772)	23,300 (10,570)	81.1	0.383	3.0
EBF/2000 FT	182,990 (83,002)	18,160 (8,240)	73.2	0.59	1.25
EBF/3000 FT	146,670 (66,528)	13,930 (6,320)	93.3	0.512	1.25
OTW/3000 FT	136,370 (61,856)	13,290 (6,030)	98.6	0.456	1.32
OTW/IBF/3000 FT (TWIN-ENGINE)	147,350 (66,837)	13,960 (6,330)	93.2	0.453	1.32
MF/4000 FT (TWIN-ENGINE)	136,950 (62,119)	12,930 (5,860)	93.1	0.445	1.35

FIGURE 15. PAYLOAD RANGE

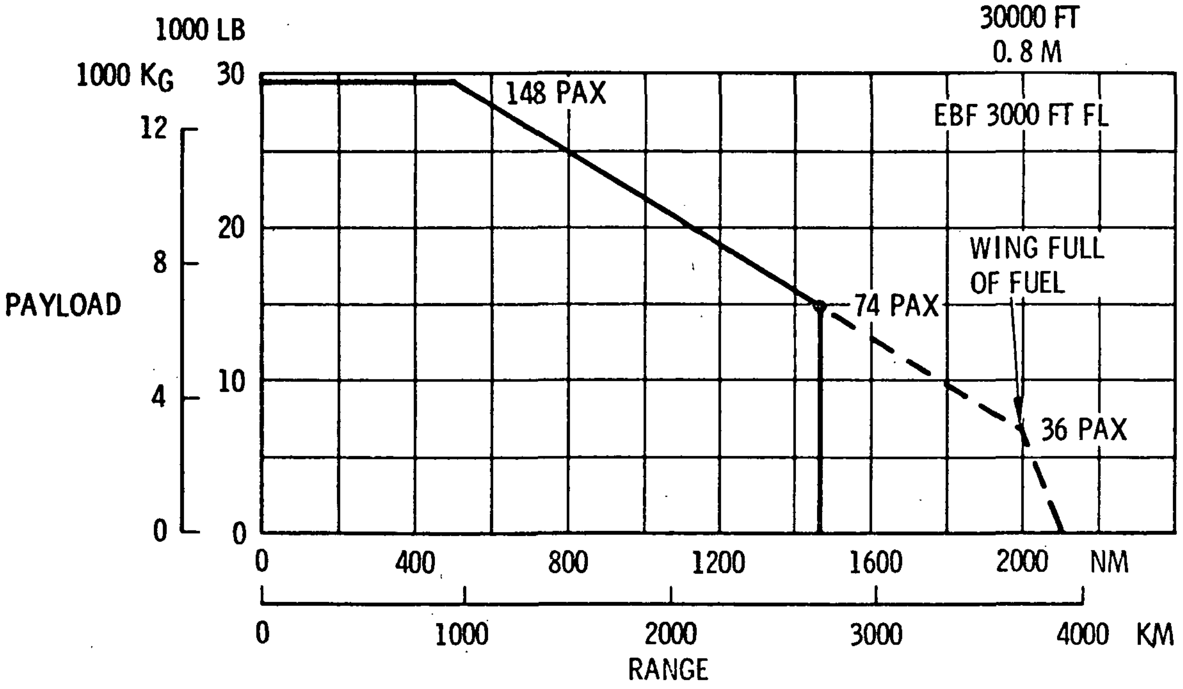
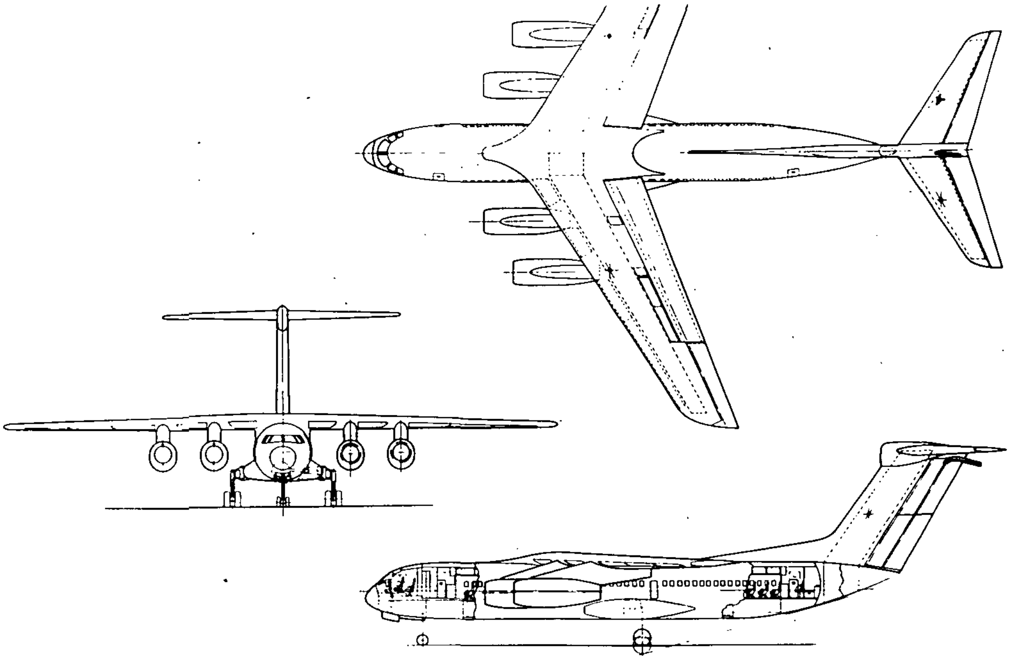


TABLE III. AW PRINCIPAL CHARACTERISTICS

	POINT DESIGN	SUPPLEMENTARY POINT
FIELD LENGTH,~FT	2,000	3,000
PAX SIZE	148	148
OWE, LB	136,620	94,620
RGW, LB	195,710	147,540
W/S, LB/SQ FT	81	106.9
RATED THRUST/ENG, LB	20,400	11,640
INSTALLED T/W	0.383	0.289
FPR	3.0	3.0
AIRFRAME COST, $M	7.658	6.213
4-ENGINE COST, $M	3.351	2.753
DOC, CENTS/ASSM	2.182	1.817
FUEL (500 NM), LB	23,300	17,320

FIGURE 16. AW AIRPLANE - 2000 FT. FIELD PERFORMANCE



Items of interest for the Augmentor Wing design are:

- Four FPR 3.0 two-stream engines; 85 percent fan flow to trailing edge flap, 10 percent to leading edge and 5 percent to aileron.
- Span is 125 ft (38 m), wing area 2400 sq ft (223 sq m).
- Flying stabilizer plus geared elevators; blown ailerons; double hinged slotted rudder; augmentor chokes for low speed roll, DLC and dumping lift on ground
- High speed requires spoilers for roll.
- Note the wide pylons to accommodate augmentor ducting.

The Externally Blown Flap 2000 foot field performance airplane is shown in Figure 17 and the 3000 foot in Figure 18. The principal characteristics of the two point designs are shown in Table IV.

FIGURE 17. EBF AIRPLANE - 2000 FT. FIELD PERFORMANCE

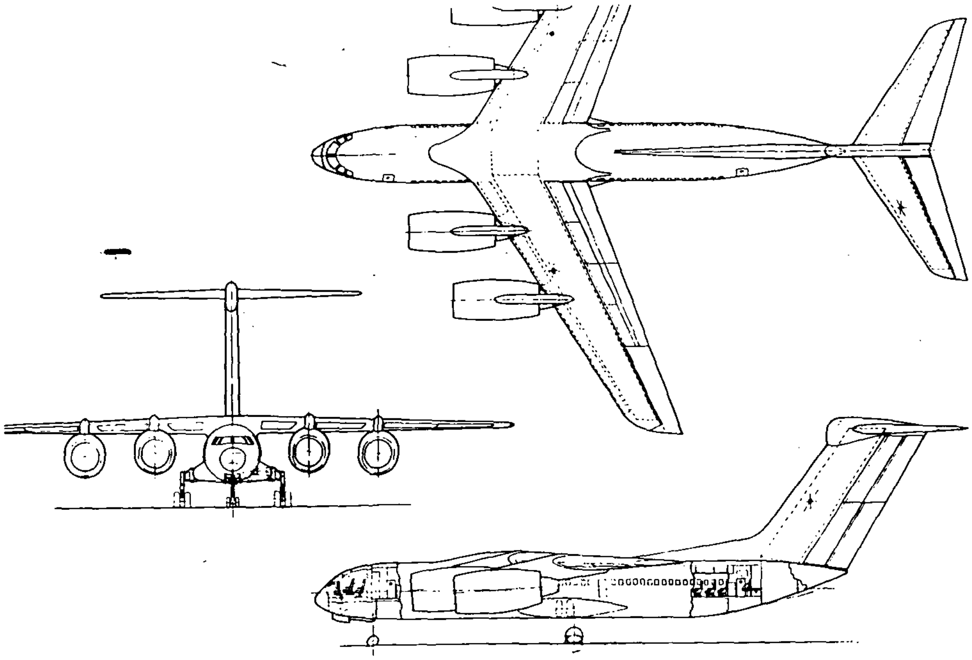
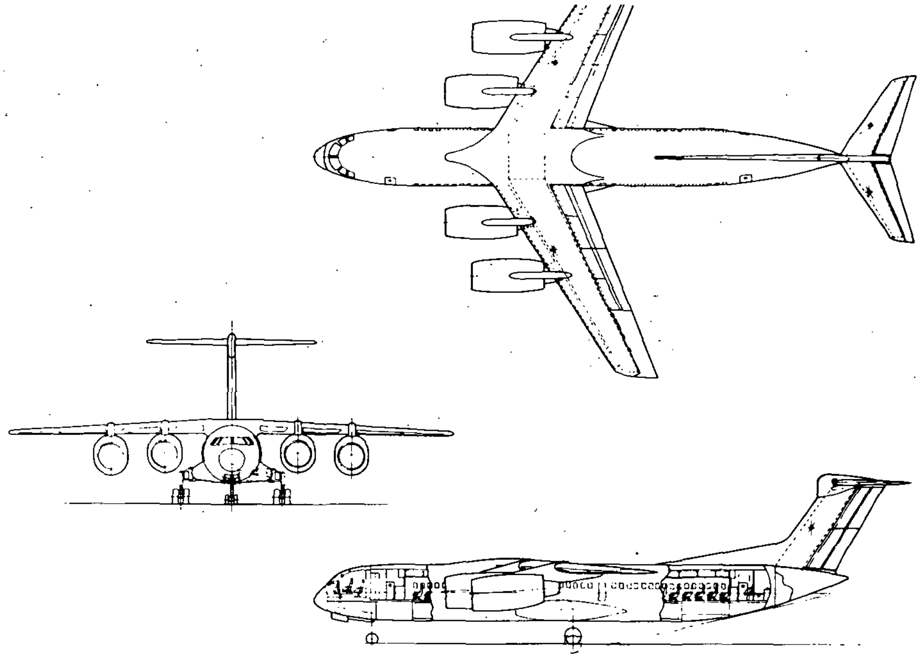


FIGURE 18. EBF AIRPLANE - 3000 FT. FIELD PERFORMANCE



These two designs are quite similar in appearance except for the marked difference in vertical and horizontal tail size for the two field lengths.

TABLE IV. EBF PRINCIPAL CHARACTERISTICS

	POINT DESIGNS	
FIELD LENGTH,~FT	2,000	3,000
PAX SIZE	148	148
OWE, LB	127,950	97,530
RGW, LB	182,990	146,450
W/S, LB/SQ FT	73.2	93.3
RATED THRUST/ENG, LB	29,190	20,300
INSTALLED T/W	0.59	0.512
FPR	1.25	1.25
AIRFRAME COST, $M	7.485	6.373
4-ENGINE COST, $M	4.386	3.870
DOC, CENTS/ASSM	2.238	1.943
FUEL (500 NM), LB	18,160	13,930

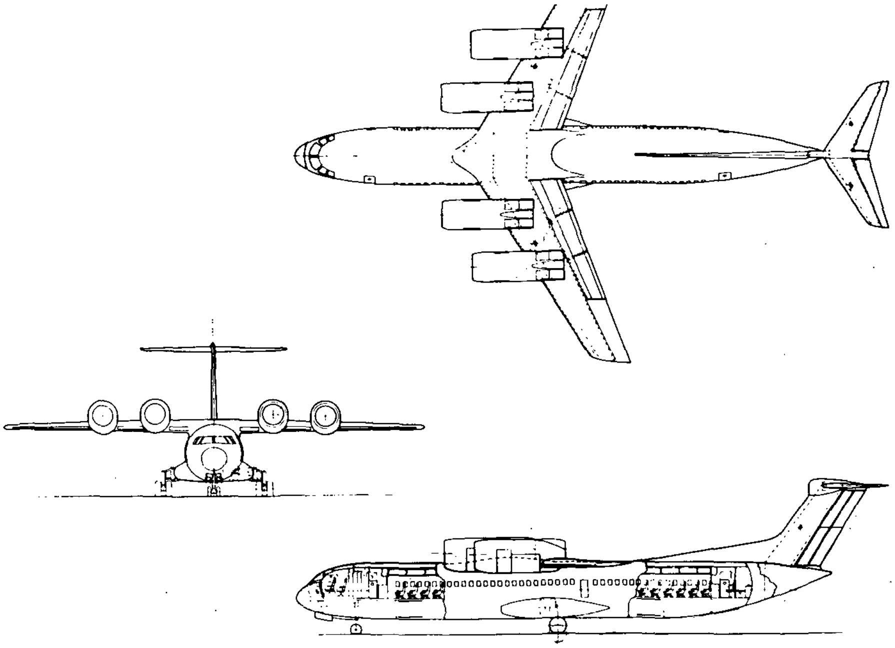
The four-engine Over-The-Wing (OTW) point design for 3000 foot field performance is shown in Figure 19 and the principal characteristics for the 3000 foot point design and four supplementary design points are shown in Table V.

TABLE V. OTW PRINCIPAL CHARACTERISTICS

	POINT DESIGN	SUPPLEMENTARY POINTS			
FIELD LENGTH, FT	3,000	2,000	3,000	3,000	4,000
PAX SIZE	148	148	100	200	148
OWE, LB	88,180	114,400	63,440	116,010	85,390
RGW, LB	136,370	167,800	96,960	179,820	133,080
W/S, LB/SQ FT	98	73.2	98	98.5	109
RATED THRUST/ENG, LB	17,150	25.040	12,680	22,630	16,630
INSTALLED T/W	0.456	0.543	0.474	0.457	0.453
FPR	1.325	1.325	1.325	1.325	1.325
AIRFRAME COST, $M	6.241	7.283	4.985	7.540	6.137
4-ENGINE COST, $M	3.651	4.163	3.289	4.017	3.612
DOC, CENTS/ASSM	1.873	2.143	2.347	1.598	1.846
FUEL (500 NM), LB	13,290	17,070	9,680	17,050	13,030

The high wing in this configuration is primarily required to maintain nacelle/fuselage clearance and an acceptable location of the outboard engine.

FIGURE 19. OTW AIRPLANE - 3000 FT. FIELD PERFORMANCE



The twin-engine hybrid Over-the-Wing/Internally Blown Flap (OTW/IBF) airplane for a 3000 foot field performance is shown in Figure 20 and its principal characteristics are listed in Table VI.

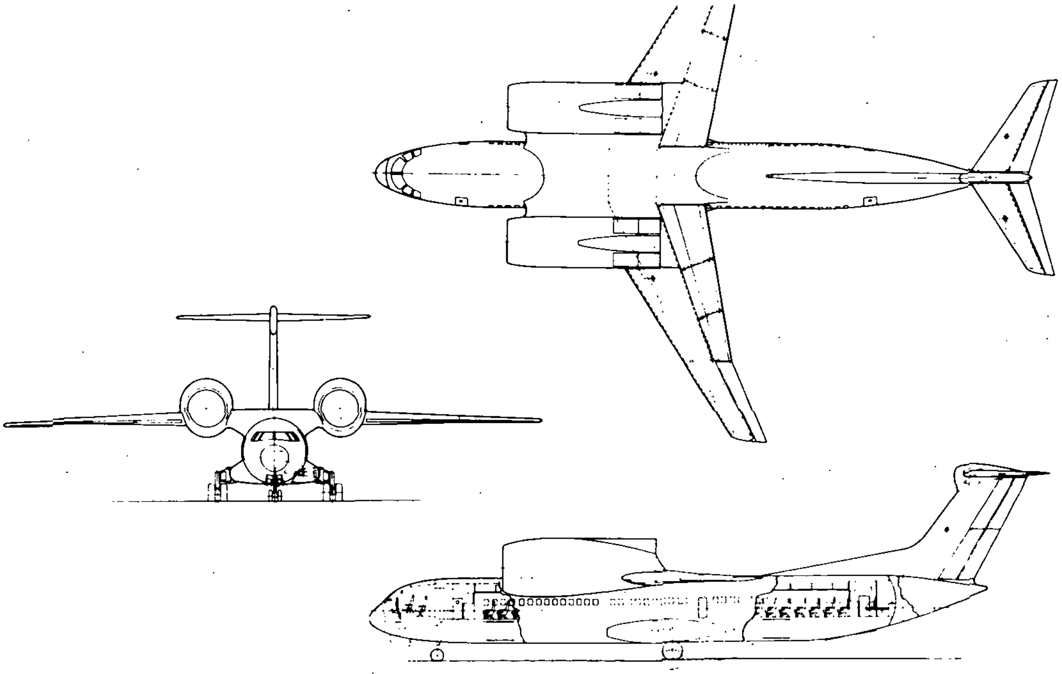
TABLE VI. OTW/IBF PRINCIPAL CHARACTERISTICS

	POINT DESIGN
FIELD LENGTH, FT	3,000
PAX SIZE	148
OWE, LB	98,250
RGW, LB	147,350
W/S, LB/SQ FT	93.2
RATED THRUST/ENG, LB	36,810
INSTALLED T/W	0.453
FPR	1.325
AIRFRAME COST, $M	6.380
2-ENGINE COST, $M	2.970
DOC, CENTS/ASSM	1.797
FUEL (500 NM), LB	13,960

The items of particular interest for this hybrid design are as follows:

- Configurations embodying internally blown flap strongly influenced by duct space.
- The FPR's required to meet 95 EPNdB are such that only a portion of the fan air can be ducted to the flap (10-15%).
- In Phase I the remaining fan air was exhausted through vectoring nozzles. In this concept the remaining fan air is vectored through the OTW arrangement of the engine and flap.
- The point design vehicle is shown and is a twin-engine arrangement with a RGW of 147,000 lb, OWE of 98000 lb, W/S = 93, and 37000 lbs of thrust per engine. To improve the L/D for the one engine out second segment climb the aspect ratio has been increased to 7.0. The span is 105 ft (32 m) and wing area is 1571 sq. ft. (146 sq. m).
- The planform is arranged to provide maximum chord at the engine and to preserve continuity for the expanding duct flap.
- The engines are located as far inboard as possible to minimize the effects of an engine failure and to minimize the amount of ducting.

FIGURE 20. TWIN-ENGINE OTW/IBF AIRPLANE - 3000 FT FIELD PERFORMANCE

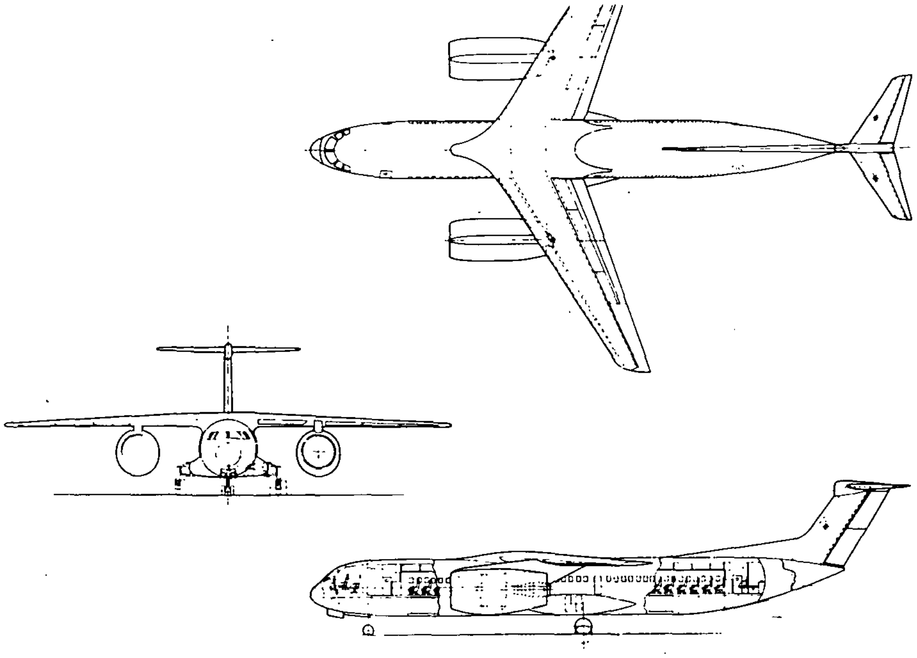


The last of the point design airplanes, the Mechanical Flap (MF) for a 4000 foot field performance, is shown in Figure 21. The principal characteristics for the point design and three additional supplementary points are listed in Table VII.

TABLE VII. MF PRINCIPAL CHARACTERISTICS

	POINT DESIGN	SUPPLEMENTARY POINTS		
FIELD LENGTH, FT	4,000	3,000	4,000	4,000
PAX SIZE	148	148	100	200
OWE, LB	89,300	115,940	62,430	118,090
RGW, LB	136,950	168,890	95,280	181,360
W/S, LB/SQ FT	93.1	61	93.3	88
RATED THRUST/ENG, LB	33,800	43,950	23,130	42,610
INSTALLED T/W	0.445	0.470	0.438	0.424
FPR	1.350	1.350	1.350	1.350
AIRFRAME COST, $M	6.215	7.250	4.822	7.548
2-ENGINE COST, $M	2.499	2.739	2.188	2.710
DOC, CENTS/ASSM	1.681	1.931	2.056	1.451
FUEL (500 NM), LB	12,930	16,640	9,190	16,610

FIGURE 21. MECHANICAL FLAP AIRPLANE - 4000 FT. FIELD PERFORMANCE



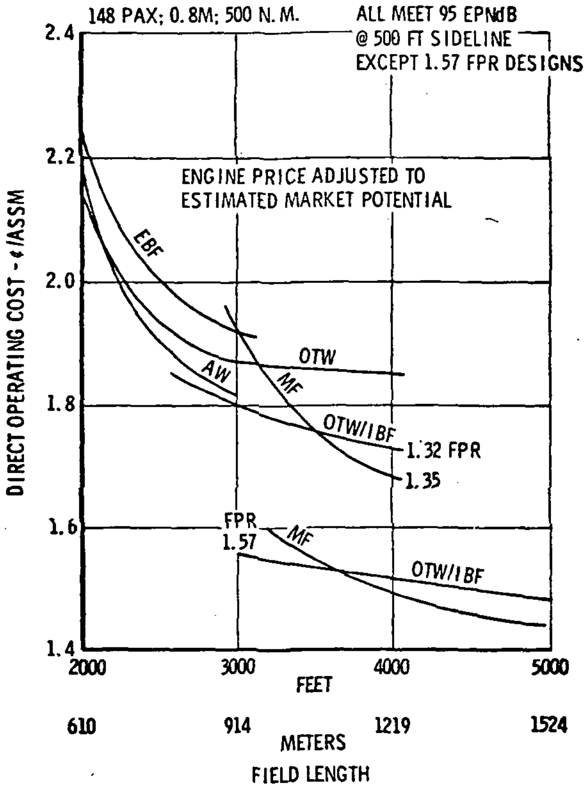
Additional items of interest for the 4000 foot Mechanical Flap airplane are listed as follows:

- Because of engine out second segment gradient, AR increased to 7.0.
- The large diameter 1.35 FPR fixed pitch engines determine the high wing arrangement and T-tail.
- The DOC is lower than any other point design airplane presented but at 3000 ft it is higher than the other concepts but approximately equal to the EBF airplane.
- Airplane second segment climb critical; double slotted flap selected (flap chord = .35 wing chord).
- Unblown ailerons and spoilers for roll; flying tail and geared elevator for pitch, and double hinged and slotted rudder for yaw; spoilers also provide DLC and lift dumping on ground.

The summary of Direct Operating Cost (DOC) versus Field Length for these aircraft is given in Figure 22. All meet 95 EPNdB at a 500-foot sideline except for those with 1.57 fan pressure ratios. For FAR balanced field lengths below 3000 feet no clear preference for lift concept is shown as a function of economics, although there is an indication of superiority in the twin-engine OTW/IBF concept down to 2500 foot field length and it appears superior to other propulsive-lift concepts at 3000 feet. The mechanical flap aircraft at 3000-foot field length appear slightly inferior in economics; at this field length the wing loading of 65 psf makes it difficult to achieve ride qualities equal to the propulsive lift aircraft at a wing loading of 90 psf. At 4000-foot field length, the mechanical flap aircraft ride qualities are excellent (wing loading of 90 psf) and it is indicated to be clearly superior in economics. Additional analysis and experimental data are warranted for evaluation of the 3000 to 3500-foot field length cases.

The economic superiority of the airplanes with 1.57 fan-pressure-ratio engines is affected by two factors -- better cruise performance and lower lapse rates compared to the lower fan pressure ratio and lower-noise engines; and assumption of commonality with CTOL applications so that the production base for pricing the engine was taken as 1500 engines.

FIGURE 22. SUMMARY OF DOC VS. FIELD LENGTH



One of the prime requirements of the aircraft design analysis was to achieve a low noise level. To put aircraft noise areas into a quick perspective, the area in square miles of ≥90 EPNdB on takeoff and landing are shown in Table VIII for long range transports of the 60's, the quiet wide-bodied jets of the 70's, and two levels (≈ FAR 36 -10 EPNdB and FAR 36 -19 EPNdB) of quieted STOL candidate aircraft. The latter case (FAR 36 -19 EPNdB) being roughly equivalent to the study requirement of 95 EPNdB at 500 feet sideline.

It may be noted that the L-1011/DC-10 wide-bodied jets will reduce the area to about 1/10th of that experienced in the 1960's. The FAR 36 -10 EPNdB STOL's will reduce the current wide-bodied tri-jets noise area by ≈ 75% and the FAR 36 -19 EPNdB STOL's will reduce that area by ≈ 75% more.

The relationship of noise to other basic design parameters and cost is summarized in Figure 23 through Figure 26. Figure 23 is a summary of airplane gross weights plotted as a function of the 500-foot sideline noise level. The scatter reflects the variation due to different lift concept and small differences in balanced noise treatment of the different engines.

TABLE VIII. PROGRESSIVE NOISE REDUCTION

CURRENT UNMODIFIED TRANSPORT AIRCRAFT AND PROJECTED STOL'S	NOISE AREA IN SQUARE MILES ≥ 90 EPNdB TAKEOFF AND LANDING
B707-300C DC-8-61	≈100 SQ MI (259 SQ Km)
DC 10 L1011	≈8 SQ MI (20.7 SQ Km)
(STOL CANDIDATES)	
MF 4000 FT FPR 1.57	≈2 SQ MI (5.2 SQ Km)
OTW/IBF 3000 FT FPR (1.4-1.57)	≈1.5-6 SQ MI
EBF 3000 FT FPR 1.25	≈0.5 SQ MI (1.3 SQ Km)
OTW/IBF 3000 FT FPR 1.32	≈0.5 SQ MI (1.3 SQ Km)
MF 4000 FT FPR 1.35	≈0.5 SQ MI (1.3 SQ Km)

Figure 24 relates the 500-foot sideline noise to the takeoff foot print area in square miles for a number of airplanes with different climb gradients, shielding and noise signature, and Figure 25 relates the sideline noise to the fan pressure ratio.

The summary of costs associated with noise and field length is given in Table IX and Figure 26.

In Table IX the effect on economics of potential requirements that include restriction of the area within an 80 EPNdB contour is summarized. A reference base for comparison of requirements costs to CTOL was taken as the 6000-foot (1830 m) mechanical flap aircraft with fan pressure ratio of 1.57; this airplane could meet Part 36 minus 10 and its DOC was 1.42 cents per available seat statute mile for 148 passengers at 500 nautical miles (930 Km).

The data indicate that technology improvements represented by SFC, performance, and weight of the modern FPR 1.57 engine give improved economy so that aircraft capable

FIGURE 23. RGW VS. 500 FT. SIDELINE NOISE LEVEL

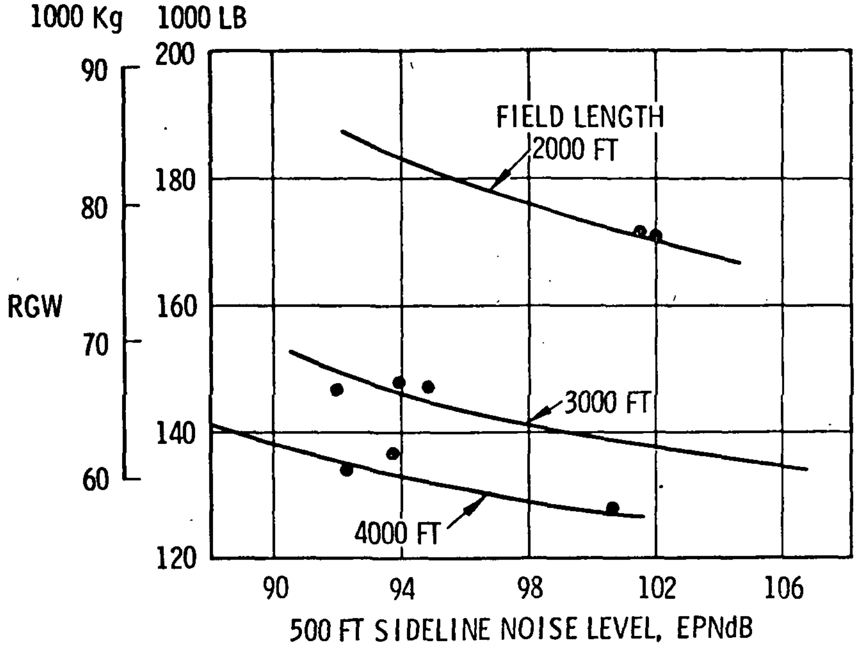


FIGURE 24. TAKEOFF FOOTPRINT AREA RELATED TO SIDELINE NOISE

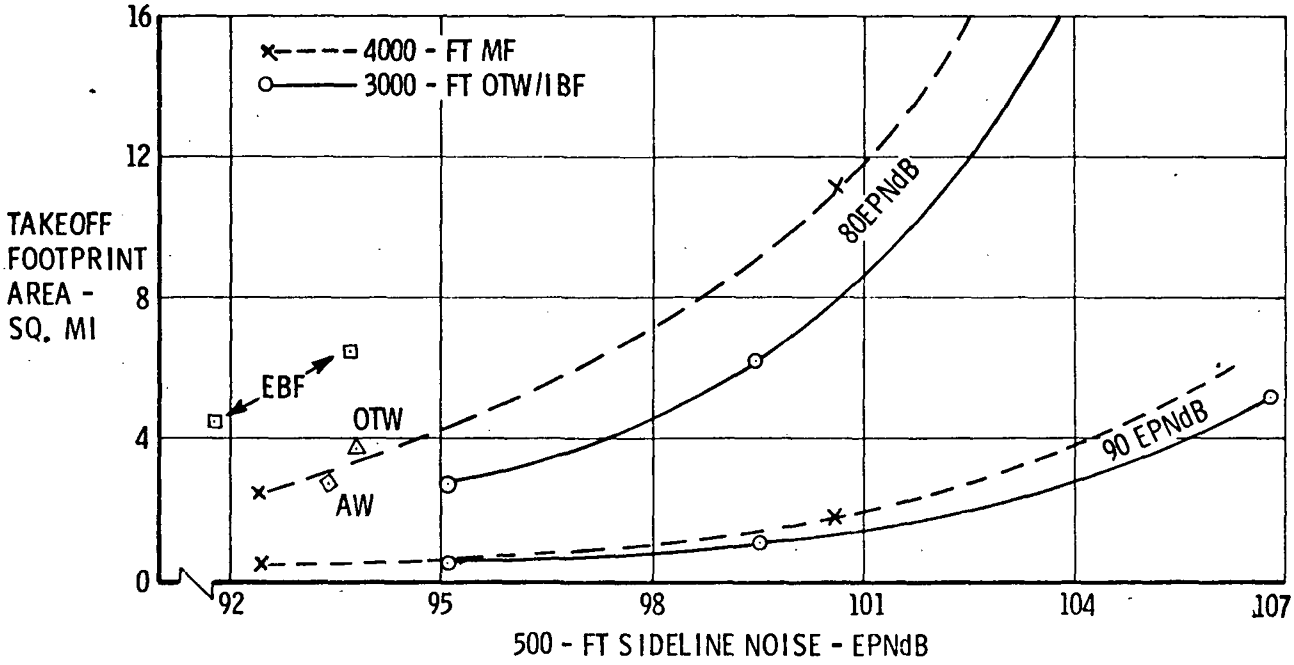


FIGURE 25. SIDELINE NOISE RELATED TO FAN PRESSURE RATIO

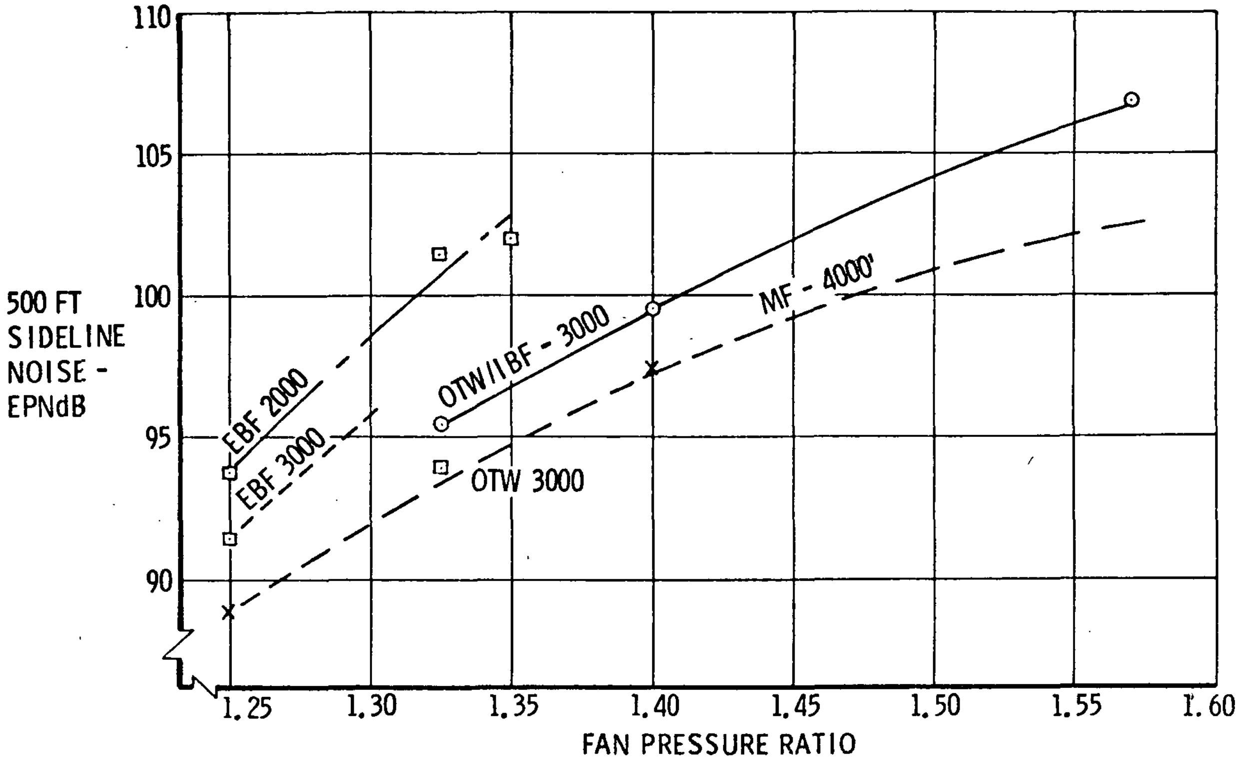


FIGURE 26. SUMMARY OF COST OF STOL AND QUIETING

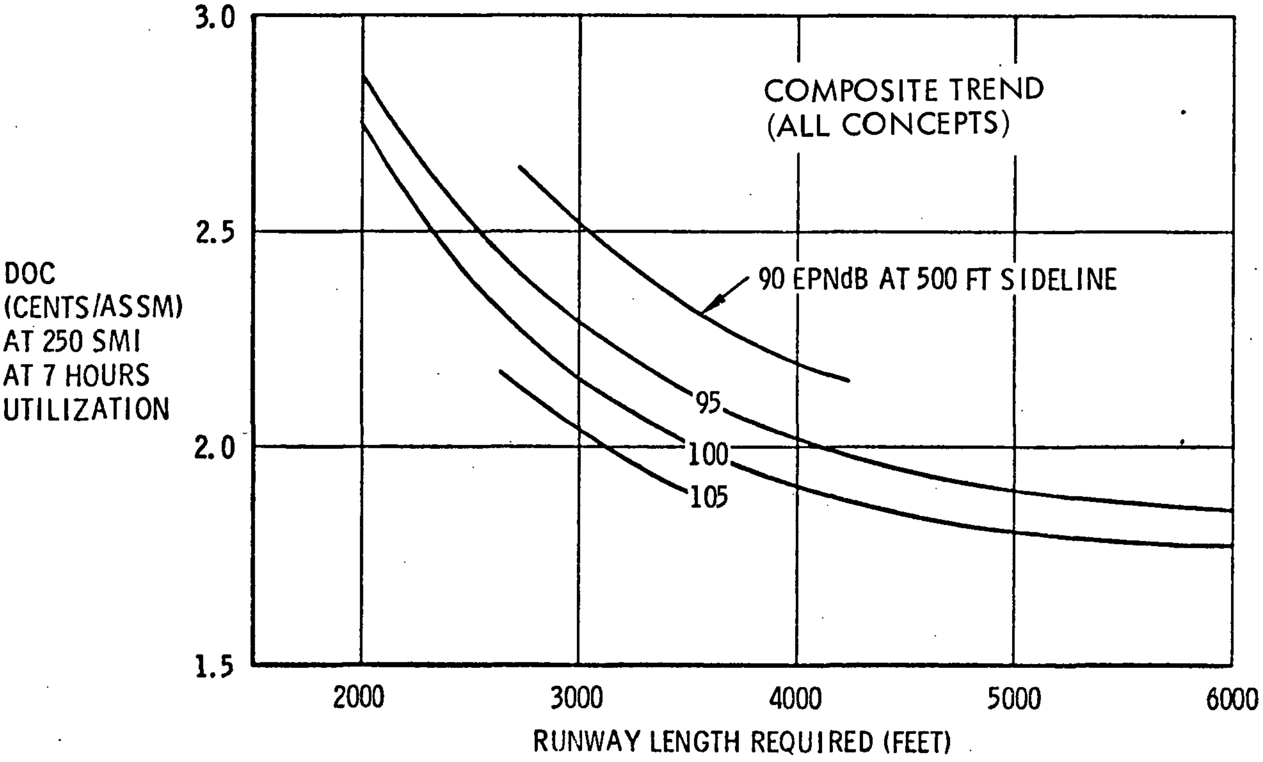


TABLE IX. SUMMARY OF COSTS ASSOCIATED WITH POTENTIAL REQUIREMENTS

FIELD LENGTH (FT)	NOISE RELATIVE TO PART 36	SQ MI WITHIN 80 EPNdB T.O. CONTOUR	LIFT CONCEPT	ENGINE FPR	RELATIVE DOC
6000	PART 36-10	10-20	2-ENG MF	1.57+	100
4000	PART 36-10	10	2-ENG MF	1.57	105
	PART 36-19	2	2-ENG MF	1.35	112
3000	PART 36-10	10	2-ENG OTW/IBF	1.50	111
	PART 36-19	2	2-ENG OTW/IBF	1.32	121
2000	PART 36-10	10	4-ENG EBF	1.35	147
	PART 36-19	2	4-ENG AW	3.0	147

of meeting Part 36 -10 are equal to aircraft with 1960 technology engines at much higher noise levels. If it were sensible to optimize a 1980 engine for meeting Part 36, it should reflect slightly lower costs. This is not considered a realistic noise level for 1980 and was not considered in the study.

Going to 4000-foot balanced field length is indicated as a 5 percent penalty in DOC compared to the CTOL base; area within the 80-EPNdB takeoff contour can be 10 square miles, slightly better than the CTOL airplane. Further restriction of noise to a 2-square-mile area (approximately Part 36 minus 19, and 95 EPNdB at the 500-foot sideline) causes a significant increase in the DOC penalty -- to 12 percent.

To progress to a 3000-foot field length involves a 6 to 8 percent additional penalty -- approximately the same increment as is involved in decreasing the 80 EPNdB takeoff footprint from 10 to 2 square miles. This cost penalty may well be justified when total system aspects are fully assessed. The penalty for 2000-foot field performance is 47 percent compared to the reference CTOL.

Figure 26 is a summary of the average direct operating cost of the study aircraft as a function of field length and 500 foot sideline noise. This figure shows significant trends that illustrate the conflicting interests of the community, airport and industry when financial viability is the question.

The rapidly diverging penalties of very short field length (less than 3000 feet) and very low noise (less than 95 EPNdB at 500 feet sideline) is apparent.

AIRLINE SIMULATION AND ECONOMICS

The economic analysis of potential STOL short-haul air transportation systems consisted of three basic analyses:

- Airline economic simulation - in which the candidate STOL aircraft were introduced into representative, mixed airline fleets, and airline operations simulated using the Short Haul System Simulation computer model.
- System sensitivity analysis - in which STOL aircraft economic sensitivities were measured for variations to operational and scenario-related factors.
- ROI analysis - provided realistic economic measures of STOL performance.

Changes to the DOC factors used in Phase I and approved by NASA were incorporated into the economic evaluation of the systems for Phase II to provide information for a more realistic evaluation of the return on investment (ROI). The changes to the DOC factors were made because it appeared that the ATA method with the Phase I factors produced results that were high when compared to the DOC's as reported by the airlines to CAB for the B-707, B-727, DC-9 and L-1011.

The indirect operating expenses were estimated by a method used by Lockheed over the past few years. This method is an updating of the past effort by Boeing, Lockheed, and the Airlines and is reported in "Revision to 1964 Lockheed/Boeing Indirect Operating Expense Method" Report COA 2061, December, 1969.

The table of K factors shown in Table X represents several points of view concerning the operational concepts for the STOL aircraft. These views are expressed as follows:

(1) The STOL system has no advantage over CTOL with respect to the operational factors influencing the indirect operating cost (CTOL).

(2) The STOL system has advantages which slightly reduce the IOC (STOL(a)).

  - o System expense is reduced
  - o Aircraft control is less
  - o No food cost
  - o Passenger service is reduced

(3) In addition to the reduction specified above, it is possible that in the future the STOL may have two other advantages (STOL(b))

- The landing fees are reduced for STOL because it is assumed that the fee will eventually be based on noise and pollution as well as size
- The baggage and cargo handling system for the separate STOL facilities requires less personnel. (System has less need for baggage and cargo handling than CTOL.)

(4) The STOL system has no constraints in terms of rules and regulations and the system is designed in such a manner to eliminate or reduce the IOC activities that are associated with the CTOL operation (STOL(c)).

TABLE X. INDIRECT OPERATING COST FACTORS

	CTOL	STOL(a)	STOL(b)	STOL(c)	PSA
K-1 SYSTEM EXPENSE	0.54	0.41	0.41	0.41	0.37
K-2 LOCAL EXPENSE	1.43	1.43	1.12	1.00	0.25
K-3 AIRCRAFT CONTROL	19.00	16.53	16.53	16.53	
K-4 HOSTESS EXPENSE	20.00	20.00	20.	20.	18.00
K-5 FOOD AND BEVERAGE	0.79	0.20	0.20	0.20	
K-6 PASSENGER SERVICE	5.15	3.65	3.65	3.65	1.35
K-7 CARGO HANDLING	70.43	70.43	35.00	8.00	
K-8 OTHER PASSENGER EXPENSE	0.0044	0.0044	0.0044	0.0044	
K-9 OTHER CARGO EXPENSE	0.0086	0.0086	0.0043	0.0025	
K-10 GENERAL AND ADMINISTRATIVE	0.06	0.06	0.06	0.04	0.09

The PSA factors were calculated from the indirect expenses as reported to the Public Utilities Commission and were included for comparative purposes. The base case for this study was the very conservative STOL(a) factors.

The return on investment (ROI) was determined by several methods. The methods included a simple relationship, and other more detailed analyses derived from information pertaining to the cash flow analysis.

The simplified ROI measure was used for screening purposes during Phase I and II, where the screening process involved a large number of aircraft types and systems.

A detailed cash flow analysis was performed for selected systems. The results of this analysis are shown in the evaluation section that follows. The cash flow analysis provided the necessary information to calculate the ROI as outlined by the CAB and specified in the "Air Carrier Financial Statistics" by CAB where the ROI is determined by the annual net income plus interest divided by the average long term debt and equity.

The selection of Eastern Air Lines (EAL) as one of the test airlines for the simulated introduction of STOL aircraft was based on the following factors:

- Eastern is representative of major trunk airlines with respect to its wide variation of route lengths and traffic densities, and the aircraft mix which comprises its fleet.
- Eastern has extensive service in the Northeast Corridor and to the major congested airports.
- Eastern provides extensive service to the Southeast (with its high rate of growth) and has a major complex through Atlanta.

Figure 27 shows the portion of the Eastern total network over which the introduction of STOL was simulated. Note that lines connect city-pairs and do not necessarily represent routes. They may be served by one or two-stop flights. This short-haul subnetwork consists primarily of medium to high density O-D's. The O-D's were chosen on the basis of potential congestion relief and on the basis of the economic performance of the STOL aircraft serving these O-D's.

Presented in Table XI are the design and performance characteristics of the wide-bodied Twin, the B-727-200, and the EBF STOL aircraft which comprise the EAL short-haul fleet used in the simulation. Engine costs of the Twin were increased by 50% and the B-727

FIGURE 27. EASTERN AIR LINE STOL O-D's

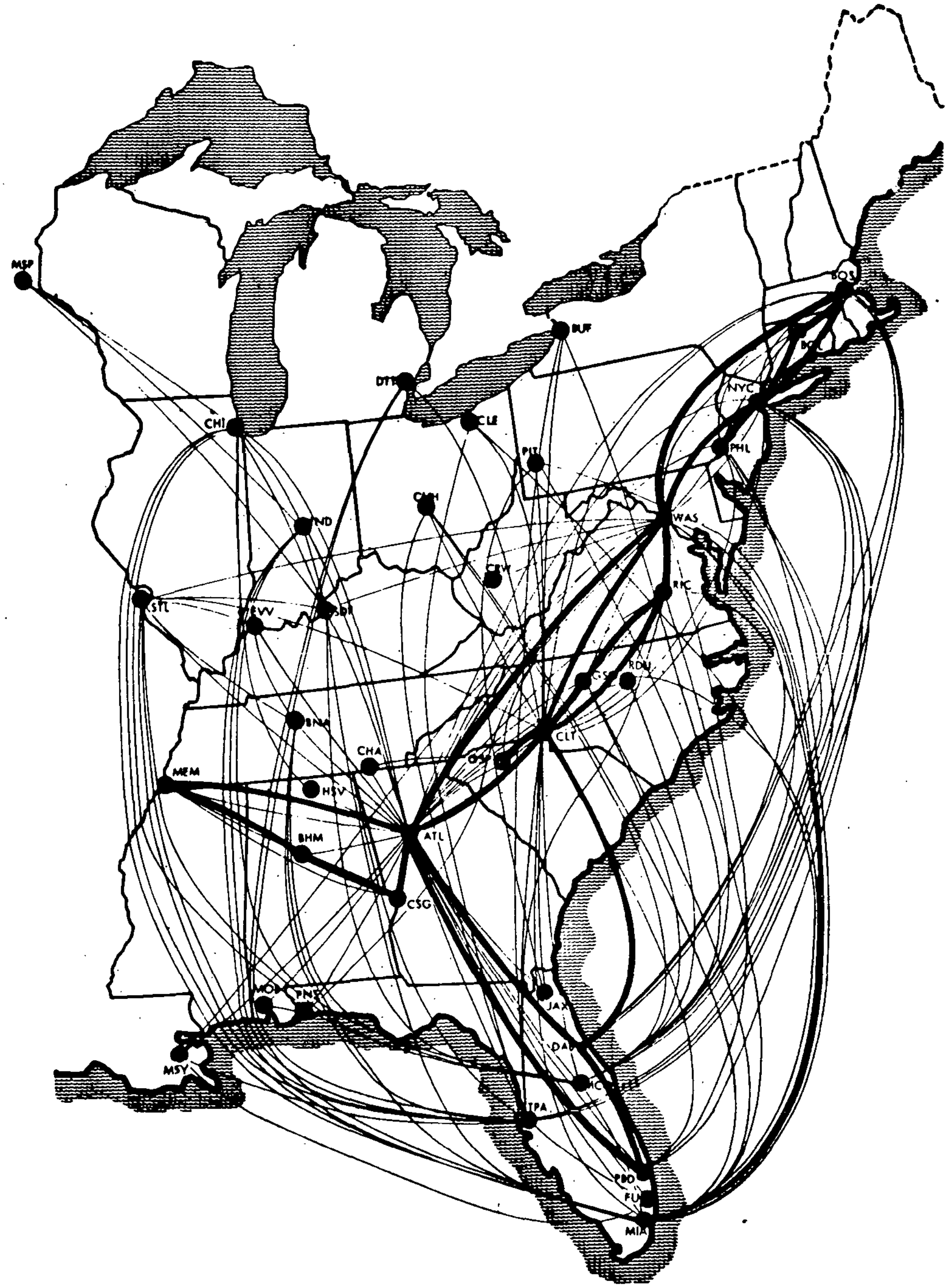


TABLE XI. EAL "FLEET"

AIRCRAFT	STOL*	TWIN	727
PASSENGER CAPACITY	148	205	127
OPERATING WEIGHT EMPTY (LB)	97,531	168,000	99,000
GROSS WEIGHT (LB)	146,669	276,000	190,000
FLYAWAY COST ($)	10,243,432	14,700,000	8,840,000
AIRFRAME COST ($)	6,373,406	11,400,000	5,960,000
ENGINE COST ($)	3,870,026	3,300,000	2,880,000
AIRFRAME WEIGHT (LB)	82,327	141,000	87,000
THRUST/ENGINE (LB)	20,306	45,000	18,000
NO. OF ENGINES	4	2	3
BLOCK TIME AT 250 SMI (HRS)	0.755	0.797	0.796
BLOCK FUEL AT 250 SMI (LB)	9,095	11,285	7,717
DOC AT 250 SMI (¢/ASSM)	2.489	2.150	2.396

*Note that the Externally Blown Flap (EBF) airplane with a fan pressure ratio of 1.25 and a 3000 foot field performance is used as the nominal case.

by 100% to account for the cost of quieting to FAR Part 26 -10 EPNdB; appropriate increases in engine performance (thrust) also were postulated.

The simulation cases used in the system model were as follows:

- 5 Cases Per Set
  - 1980 No STOL
  - 1985 No STOL
  - 1985 With STOL
  - 1990 No STOL } No 727
  - 1990 With STOL } No 727
- 17 Sets
  - 1.) Nominal
  - 2.-14) Other STOL concepts
  - 15.) Variable Utilization
  - 16.) All Coach 727
  - 17.) All Coach Twin and 727

and the nominal case was defined as:

- Aircraft:
  - Twin, 727, STOL (EBF, 1.25, 3,000)

- Utilization:
  Twin (8.75-9.00), 727 (8.75-9.00), STOL (7.00)
- Fare:
  \$12 Plus 0.0628/S.MI (x 1.3 = First Class)
- Fare Realization:
  85%
- IOC K-Factor:
  Twin (CTOL), 727 (CTOL), STOL (STOLa)
- System Load Factor:
  55%
- $$\text{Screening ROI} = \frac{(\text{Revenue} - \text{Expenses})\ (1 - \text{Tax Rate})}{\text{Investment}}$$

For all three years (1980, 85, and 90) and for all fleet compositions, the flight assignments and routing and scheduling were based on achieving approximately a 55% system load factor (based on available seat statute miles). Utilization rates were based on actual airline experience and were recommended by the consultant airlines. The fare structure was based on the CAB Phase 9 recommendation -- the airlines however, are expected to realize only 85% of this fare due to fare discounting.

Figure 28 summarizes the simplified screening ROI and fleet size results for the nominal case in the Eastern short-haul system simulation. As can be seen from these histograms, the impact of the introduction of the STOL aircraft (EBF, 1.25 FPR, 3000 ft.) is minor in terms of economics and total fleet size when serving the same basic market. This is a significant result, since it has long been felt that the direct operating cost penalty of STOL operations would result in large penalties for the system in terms of return on investment (ROI). It should be noted that the "no-STOL" ROI (using only CTOL aircraft) assumes no congestion in the 1980 to 1990 time frame which is highly problematical. As seen in Figure 29, as little as 1-1/2 minutes average CTOL delay completely eliminates the economic advantage of CTOL for the nominal case. An average CTOL delay of 4-1/2 minutes makes STOL economically competitive even without the slight IOC advantage given STOL in the nominal case. This is extremely significant since the FAA reported an average delay for J. F. Kennedy airport in 1969 of 6.7 minutes for every operation and O'Hare airport is even more congested.

FIGURE 28. EAL NOMINAL CASE - SIMULATION SUMMARY

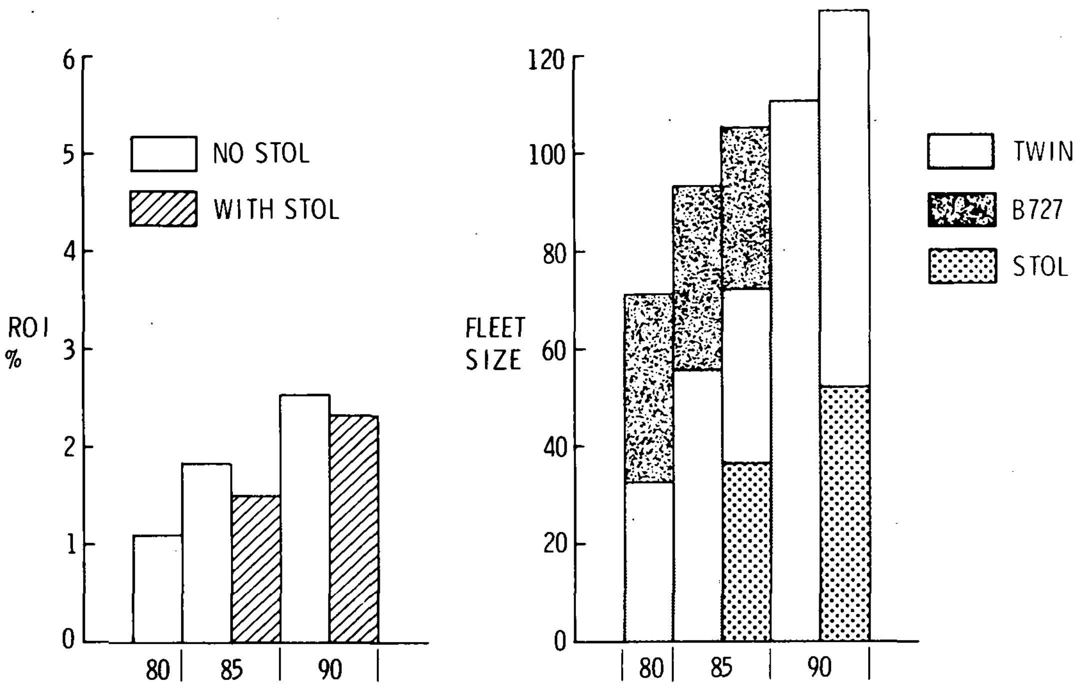
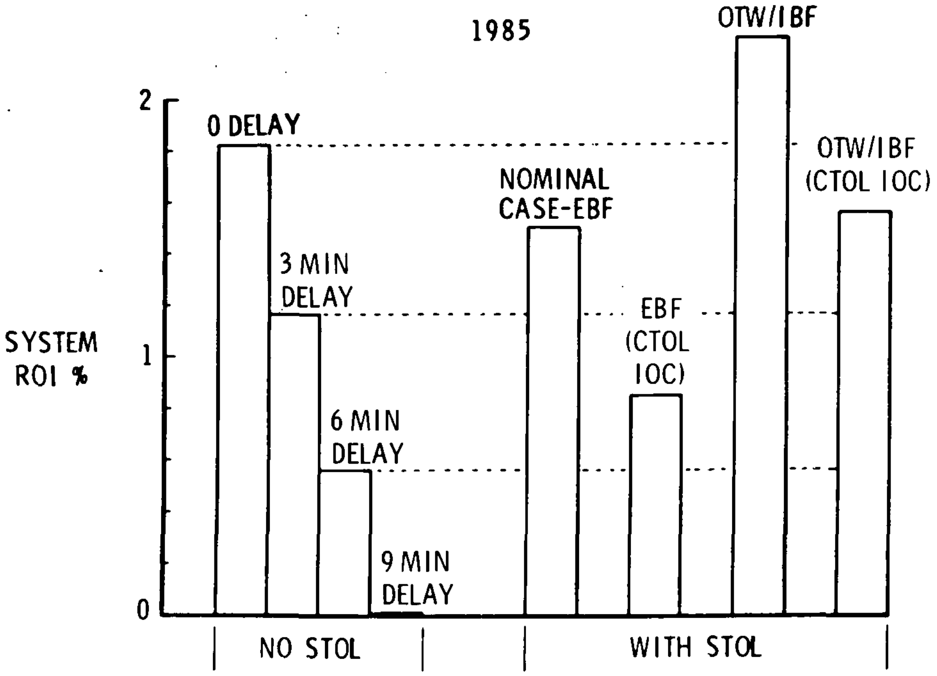


FIGURE 29. EASTERN COST OF DELAY



Although the technical development risk of the hybrid Over-The-Wing/Internally Blown Flap (OTW/IBF) airplane is somewhat greater than for the nominal EBF design, greater economical potential is indicated for this STOL concept as noted in Figure 29.

The ROI's used for the screening of the STOL aircraft concepts as shown in Figure 29 are calculated by the method shown on page 52. The more detailed economic analyses of ROI is accomplished for the following selected systems by the information obtained from a 10 year cash flow analysis. The ROI calculated from the information contained in the cash flow analysis is computed on the basis of the CAB method as described in the CAB report "Air Carrier Financial Statistics" (page 58) this method is described by the formula:

$$\text{ROI} = \frac{(\text{Revenue} - \text{Expense} - \text{Interest})\ (1 - \text{Tax Rate}) + \text{Interest}}{\text{Average Long Term Debt} + \text{Average Equity}}$$

The net income as reported in Table XIII is the term (Revenue - Expense - Interest) (1 - Tax Rate). The four typical short haul systems postulated for the Eastern Air Line short-haul network were defined as follows:

● System I	EBF/3000 (FAR Part 36 - 19 EPNdB); B-727; Twin
● System II	OTW/IBF/3000 (FAR Part 36 - 19 EPNdB); B-727; Twin
● System III	OTW/IBF/3000 (FAR Part 36 - 10 EPNdB); B-727; Twin
● System IV	OTW/IBF/3000 (FAR Part 36 - 10 EPNdB); OTW/IBF/3000 (FAR Part 36 - 19 EPNdB); B-727; Twin

In System I the quiet EBF (FAR Part 36 - 19 EPNdB) STOL is used with the CTOL aircraft.

The quiet OTW/IBF STOL (FAR Part 36 - 19 EPNdB) is used with the CTOL aircraft in System II.

The noisier OTW/IBF designed to FAR Part 36 - 10 EPNdB is used in the STOL/CTOL mix for System III. In System IV the mix includes the less quiet OTW/IBF (Part 36 - 10 EPNdB) in the 1980 to the 1985 time period and the quiet OTW/IBF in the 1985 to 1990 time period. In all four systems the B-727 is assumed to be phased out by 1990.

The following premises were assumed in determining the interest, long term debt, and the average equity for computing the CAB Return on Investment (ROI):

- Sign up date for aircraft two years prior to delivery
- Deposit payments are 30 percent of aircraft price
- Spares and GSE purchased one year prior to aircraft
- Gain/Loss on sale of aircraft is zero
- Initial debt is 60 percent of equipment requirement - Debt is repaid over 10 years at 7 percent interest.
- Aircraft notes are 70 percent of delivered equipment costs - Notes are repaid over 10 years at 7.5 percent.
- Changes in working capital is based on historical relationships as follows:
  - Other current assets 18 percent of fixed assets
  - Other current liabilities 19 percent of long term liabilities.

Revenue and expenses are determined from the airline simulation. The short-haul aircraft delivery schedule is shown in Table XII.

In the premised delivery schedule of Table XII the numbers of aircraft of each type were determined by the airline simulation model and the aircraft were scheduled accordingly. The aircraft were purchased in blocks as shown in the schedule.

The Boeing 727 schedule differed from the Twin and STOL aircraft since there were B-727's available from previous purchases. Only seven were purchased to fill out the required number in 1980 (38). All 38 727's are modified to the Part 36-10 EPNdB requirement and the modification cost plus the purchase of the additional seven determined the total investment cost for the 727.

The depreciation for the 727 aircraft included the remaining depreciation on the available aircraft and the seven new aircraft. This figure also included the cost for the engine modification. The 727's were retired in accordance with the buildup of the Twin and STOL purchases.

TABLE XII. SHORT HAUL AIRCRAFT DELIVERY SCHEDULE

YEAR	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
AIRCRAFT																	
TWIN																	
DELIVERIES PER YEAR				6	8	9	9	1	0	1	1	1	9	8	8	8	8
CUMULATIVE TOTALS				6	14	23	32	33	33	34	35	36	45	53	61	69	77
STOL (EBF/3000 OR OTW/IBF)																	
DELIVERIES PER YEAR								7	7	7	7	8	3	4	3	3	3
CUMULATIVE TOTALS								7	14	21	28	36	39	43	46	49	52
BOEING 727-200																	
DELIVERIES PER YEAR	4	0	2	1	2	1	1										
RETIRED								1	1	1	1	1	8	8	8	8	1
CUMULATIVE TOTAL	31	31	33	34	36	37	38	37	36	35	34	33	25	17	9	1	0
MODIFICATIONS		5	5	7	7	7	7										

Table XIII indicates the stream of costs used in calculating the average ROI as defined by the CAB in the Air Carrier Financial Statistics Report. Since the STOL short-haul systems do not include any activities other than air carrier transportation, such as hotels, this method is also identical to the method indicated by press releases and these ROI's may be compared to the ROI's as calculated by CAB from the carriers reported costs and revenues as shown in Table XIV where the actual published system operating investment, net income, and rates of return for trunk and local service carriers for 1971 and 1972, are reproduced for direct comparison. It will be noted that these integrated, complementary STOL systems relistically introduced into a competitive real-world environment all show economic viability.

Summarizing briefly two significant conclusions emerge:

- STOL concepts offer significant potential as viable, complementary aircraft in airline fleets serving medium to high density short-haul markets.
- OTW/IBF and MF concepts show slight economic advantage over other STOL concepts.

TABLE XIII. RETURN ON INVESTMENT (CAB METHOD)

SYSTEM I	81	82	83	84	85	86	87	88	89	90
NET INCOME	7.30	4.68	4.09	1.67	4.13	(.46)	.62	1.82	7.26	15.50
INTEREST	33.47	35.61	37.73	39.97	41.72	48.77	55.06	60.27	63.37	64.18
	40.77	40.29	41.82	41.64	45.85	48.31	55.68	62.09	70.63	79.68
AVG. LONG TERM DEBT	433.16	440.41	453.28	463.24	491.00	550.83	619.90	667.09	683.68	683.29
AVG. EQUITY	292.52	298.51	302.90	305.78	308.68	310.51	310.59	311.81	316.35	327.73
	725.68	738.92	756.18	769.02	799.68	861.34	930.49	978.90	1000.03	1011.02
R.O.I.	5.62%	5.45%	5.53%	5.41%	5.73%	5.61%	5.98%	6.34%	7.06%	7.88%
WEIGHTED R.O.I.							5.96%			
SYSTEM II										
NET INCOME	9.36	9.07	11.08	11.38	17.05	17.39	17.75	21.11	28.38	40.75
INTEREST	32.80	33.93	34.86	35.26	35.12	40.18	44.24	47.17	48.41	48.09
	42.16	43.00	45.94	46.64	52.17	57.57	61.99	68.28	76.79	88.84
AVG. LONG TERM DEBT	421.92	413.12	409.50	397.59	396.22	425.39	464.95	481.68	472.95	456.37
AVG. EQUITY	291.17	300.39	310.46	321.69	335.91	353.13	370.70	390.13	414.87	449.44
	713.09	713.51	719.96	719.28	732.13	778.52	835.65	871.81	887.82	905.81
R.O.I.	5.91%	6.03%	6.38%	6.48%	7.13%	7.39%	7.42%	7.83%	8.65%	9.81%
WEIGHTED R.O.I.							7.30%			
SYSTEM III										
NET INCOME	10.86	12.46	16.70	18.98	27.07	25.54	29.50	33.47	41.46	54.82
INTEREST	32.12	32.21	31.75	30.91	29.22	33.40	37.25	40.17	41.17	40.09
	42.98	44.67	48.45	49.89	56.29	58.94	66.75	73.64	82.63	94.91
AVG. LONG TERM DEBT	414.98	395.06	372.96	348.47	329.74	345.00	385.16	401.95	390.24	362.90
AVG. EQUITY	289.78	301.44	316.02	333.86	356.89	383.19	410.71	442.20	476.66	527.80
	704.76	696.50	688.98	682.33	686.63	728.19	795.87	844.15	866.90	890.70
R.O.I.	6.10%	6.42%	7.03%	7.31%	8.20%	8.09%	8.39%	8.72%	9.53%	10.66%
WEIGHTED R.O.I.							8.05%			
SYSTEM IV										
NET INCOME	10.92	12.51	16.72	19.05	26.29	21.59	21.66	24.68	31.72	44.08
INTEREST	32.00	32.12	31.72	30.79	30.41	35.57	40.20	43.80	45.46	45.13
	42.92	44.63	48.44	49.84	56.70	57.16	61.86	68.48	77.18	89.21
AVG. LONG TERM DEBT	411.90	390.16	368.68	343.20	335.69	366.14	413.50	439.52	436.56	419.26
AVG. EQUITY	289.01	300.73	315.34	333.23	355.90	379.84	401.46	424.23	452.83	490.73
	700.91	690.89	684.02	676.43	691.59	745.98	814.96	863.75	889.39	909.99
R.O.I.	6.12%	6.46%	7.08%	7.36%	8.20%	7.66%	7.59%	7.93%	8.68%	9.80%
WEIGHTED R.O.I.							7.69%			

TABLE XIV. SYSTEM OPERATING INVESTMENT, NET INCOME, AND RATES OF RETURN TRUNK (INCLUDING PAN AMERICAN) AND LOCAL SERVICE CARRIERS, YEARS ENDED JUNE 30, 1972 AND 1971 (MILLIONS)

	OPERATING INVESTMENT		OPERATING NET INCOME		RATE OF RETURN ON OPERATING INVESTMENT	
	6/30/72	6/30/71	6/30/72	6/30/71	6/30/72	6/30/71
TRUNKS INCLUDING PAA						
AMERICAN	$ 961.7	$ 881.9	$ 34.4	$ 8.6	3.57%	-0.97%
BRANIFF	262.8	275.1	21.2	12.4	8.08	4.51
CONTINENTAL	385.0	360.7	27.4	16.6	7.12	4.61
DELTA	530.6	464.1	60.1	34.8	11.32	7.50
EASTERN	744.5	817.8	54.6	24.4	7.34	2.99
NATIONAL	304.7	260.0	28.3	7.5	9.29	2.87
NORTHEAST	22.4	6.8	-4.0	-11.9	-18.01	-176.33
NORTHWEST	712.9	655.0	39.2	12.4	5.50	1.89
PAN AMERICAN	1,264.3	1,266.2	12.6	1.7	1.00	0.14
TRANS WORLD	952.9	908.6	52.0	-11.8	5.46	-1.30
UNITED	1,355.1	1,339.3	72.2	0.5	5.33	0.04
WESTERN	271.4	279.1	19.0	14.9	6.99	5.33
TOTAL	$7,768.3	$7,514.5	$417.0	$93.0	5.37%	1.24%
LOCAL SERVICE						
ALLEGHENY	$ 128.3[1/]	$ 120.1	$ 8.8	$ 5.3	6.85%	4.45%
FRONTIER	53.5	59.3	8.0	-1.0	14.98	-1.76
HUGHES	23.5	32.0	-0.9	-5.3	-3.65	-16.66
MOHAWK	55.4[1/]	75.2	-2.4[1/]	-2.9	1	-3.87
NORTH CENTRAL	71.0	78.1	5.9	7.4	8.31	9.45
OZARK	62.6	60.9	6.3	5.4	10.14	8.87
PIEDMONT	91.3	99.6	8.9	1.9	9.70	1.89
SOUTHERN	24.8	24.1	1.1	0.4	4.50	1.53
TEXAS INTERNATIONAL	31.3	39.6	-1.6	-1.2	-5.16	-3.13
TOTAL	$ 541.6	$ 588.8	$ 34.1	$ 9.8	6.29%	1.67%

5.37%

6.29%

COMPARATIVE EVALUATION

The overall implementation of a new STOL short-haul air transportation system must consider the traveling public, the community, and industry. The following acceptance criteria for these groups was developed and the various STOL concepts were evaluated, as shown in Tables XV and XVI to assist in arriving at a selection of preferred designs.

Public	Industry
● Fear (Crash in Community)	● Economic Viability
● Noise	● Aircraft Market Size
● Pollution	● Passenger Market Risk
● Misfeasance	● Implementation Risk
● Service (Frequency and Cost)	● Aircraft Development Risk

- Fuel Consumption (Energy Conservation)

In the public sector shown in Table XV the following observations can be made:

- Noise area reduction favors low FPR and MF 4000 foot aircraft.
    - o Introduction of aircraft with a foot print area of ≥ 80 EPNdB of 10-15 square miles (2 square miles at ≥ 90 EPNdB) may be acceptable.
    - o Noise areas of less than 4 square miles ≥ 80 EPNdB (1/2 square mile ≥ 90 EPNdB) are desirable if fares do not have to be raised to be economically viable.
- Pollution control is satisfactory on all candidate systems
- Fear area is reduced by steep descent (shorter runway requirements)
- Energy conservation favors FPR's of about 1.5-1.57

TABLE XV. PUBLIC EVALUATION

CANDIDATE IDENTIFICATION			EVALUATION CRITERIA							
				NOISE ≥ 80 EPNdB IN SQ MILES		POLLUTION IN TERMINAL AREA IN POUNDS				
CANDIDATE LIFT SYSTEM	FIELD LENGTH	FAN PRESSURE RATIO	EPNdB AT 500 FT SIDELINE	TAKEOFF	LANDING	NO_2	CO	CH_X	FEAR AREA - SQ MILES	FUEL COST CENTS/ASSM AT 250 SM RANGE
EBF	3000	1.25	91.8	4.4	0.1	6.9	4.7	0.29	9.4	0.25
OTW/IBF	3000	1.32	95.1	2.8	1.7	9.1	2.6	0.12	9.4	0.23
OTW/IBF	3000	1.57	106.8	32.7	9.1	NA	NA	NA	9.4	0.19
MF	4000	1.35	92.4	2.3	0.8	8.1	2.7	0.16	11.5	0.22
MF	4000	1.57	100.6	10.9	2.8	NA	NA	NA	11.5	0.18

TABLE XVI. INDUSTRY EVALUATION

CANDIDATE IDENTIFICATION		EVALUATION CRITERIA									
					"EAL" TYPE SHORT-HAUL						
					SENSITIVITY				RISK		
CANDIDATE LIFT SYSTEM	FIELD LENGTH	FAN PRESSURE RATIO	UNIT COST $M	DOC AT 250 SM ¢/ASSM	ROI STOL	ROI SYSTEM	ROI CAB PERCENT	DEBT TO EQUITY RATIO	DEVELOPMENT	IMPLEMENTATION	MARKET
EBF	3000	1.25	10.2	2.49	-0.6	+1.5	6.1	2.4	L	L-	L
OTW/IBF	3000	1.32	9.4	2.29	+1.6	+2.2	7.3	1.4	M*	L-	L
OTW/IBF	3000	1.57	8.2	2.01	+4.0	+2.9	8.1	1.0	M*	L	L-
MF	4000	1.35	8.7	2.12	+3.1	+2.6	NA	NA	L-	L	L+
MF	4000	1.57	7.8	1.90	+5.2	+3.2	NA	NA	L-	L	L

*REDUCED TO LOW(+) WITH R&D FUNDING

In the Industry oriented group the following comments are pertinent:

- Engine FPR's of 1.57 have an advantage in all economic indicators
- Runway length reduction has an adverse effect on all economic indicators.
- EBF - 3000 foot STOL has less favorable economics than OTW/IBF concept.
- OTW/IBF aircraft need further R&D to reduce development risk.

From an industry viewpoint, the OTW/IBF 3000 foot aircraft are preferred if the development risk can be reduced by R&D. If 4000 foot runways are available, then the MF 4000 foot aircraft would be preferred, but this loses flexibility and is an increased implementation risk. The EBF 3000 foot aircraft would be a third level choice because of the considerably less favorable economic indicators. Attempts should be made to first introduce aircraft at the FAR 36 - 10 EPNdB noise level at the major airports. Then if necessary go to FAR 36 - 19 EPNdB at a later time.

The selection of a preferred system where many of the criteria are intangible and even contradictory from the point of view taken, has been summarized as follows:

- OTW/IBF 3000 ft, FPR 1.57 (Quieted to FAR 36 -10 EPNdB) modified to FAR 36 -19 EPNdB (FPR 1.32) after 1985 if necessary is the recommended system to implement.
  - o Economically viable
  - o Good public acceptance
  - o 3000 ft field capability allows great flexibility
  - o Low risk by introduction at congested hub
  - o Medium risk of development can be reduced to acceptable level by R&D program
- MF 4000 ft FPR 1.57 (FAR 36 -10 EPNdB) modified to FAR 36 -19 EPNdB (FPR 1.35) after 1985 if necessary is second choice. Lack of flexibility (4000 foot runways) introduces increased implementation risk unless key airports can provide 4000 ft STOL runways.
- Other propulsive lift concepts are about equal to each other, but are less preferable than the OTW/IBF and MF.

STOL BENEFITS

The principal benefits of STOL to the national air transportation system are best illustrated in three important categories: public service, airport environment, and airline economics.

Improved Public Service. - The advent of a 3000 foot (914 m) takeoff and landing quiet short-haul aircraft can economically provide congestion relief at major airports. Various projections of delays, without relief, range from 15 minutes to 3 hours.[1] It appears obvious that airlines will alter their operations when the delays become too great as they did in 1968 in several areas. Flight quotas were placed on airlines by assigning slots and the public then received less service (frequency).

Recent experience has shown that expansion to secondary airports is received with great disfavor by the public. With noise takeoff footprints exceeding 100 square miles (259 sq km) and landing patterns exceeding 30 or 40 square miles (78 or 104 square km) at the ≥ 80 EPNdB noise level, the public refuses to accept such environmental degradation to their community.

With the new quiet STOL transports reducing the ≥ 80 EPNdB noise area ≥ 98 percent over today's nosiy jets, a community is much more likely to allow a 3000 foot (914 m) runway at an airport in their community and may consider it a desirable light industry and an asset because of the transportation convenience. The change in public attitude could be dramatic.

A plan was outlined to relieve congestion and hence reduce delays, as well as to provide more frequent service by starting with STOL-strips on existing major airports for which future congestion is projected. It appeared to be the least risk and most positive approach to introducing STOL aircraft to a market (congestion induced) sufficient to cause a demand for 250 to 350 aircraft, the minimum amount required for a manufacturer to start production. As the congestion oriented system proves itself, further demand (service induced) should allow enough flights to be transferred to secondary fields to provide better local O-D service. STOL-strips on existing major airports also maximize the use of available land in areas where land is extremely expensive, providing additional return from land that is increasing in value with time.

The technology advances in efficient propulsive-lift coupled with quiet engines can make this possible.

Improved Airport Environment. - The study showed that a dramatic decrease in noise can be given to the community around an airport. In addition the steep descent and climb-out will relieve many in the community of fear due to both the increase in distance and reduction in noise of the aircraft. The clean engines will reduce the many objections to the pollution of the 1960's.

All these events can produce a cumulative effect on the population around the airport. As shown in several recent studies many people felt the airport abused them. If the public sees less aircraft close to them, dramatically less noise and greatly reduced pollution, their attitude may well become more tolerant since they see signs that their personal complaints are receiving attention by the air transportation industry.

Very large decreases in the pollution characteristics have been projected in the Quiet Clean STOL Engine studies. Further improvement in chemical emissions would have no significance unless automobiles, trucks, and busses are improved drastically below levels that can now be foreseen for petroleum fuel internal combustion engines. If new propulsion concepts for surface transportation should become a reality, then further reduction in chemical emissions by aircraft could be achieved by use of alternate fuels, such as hydrogen.

Improved Airline Economics. - It is very difficult to compare 1985 and 1990 airline operations with and without STOL. In the classic approaches of the past the viability of STOL was compared to CTOL as though they were two independent uncongested systems and STOL always suffered by comparison due to its inherently higher DOC's, more sophisticated technology, need for higher fares, lack of a well defined market, etc. At best STOL's contribution to the total system consisted of siphoning off an indefinite percentage of the congestion at the major hubs to outlying secondary airports without ever being an integral part of the critical problem - congestion relief at the major hubs. By not attacking this pressing problem directly and contributing to its solution the operators had no real incentive to adopt STOL with a further dilution of a declining return on investment.

By conservative estimates this study has shown that introduction of STOL at the congested hub airports does increase the capacity of the total system. For the eight most critical airports this increase in capacity due to STOL alone (disregarding ATC improvements) averaged over 60 percent above today's actual VFR capacity based on the standard four minute average delay. For added conservatism the capacities with STOL-added were based on full IFR capability. With this approach total system capacity is greatly increased with the addition of STOL directly at the source of the problem and it follows that congestion delays will be correspondingly reduced to the advantage of the total system - CTOL and STOL alike.

By all measures the cost of congestion delay is considerable and if by introducing STOL into the system these delays are reduced, or eliminated, the viability of STOL should be measured by a comparison of the system ROI without STOL (congestion) and with STOL (congestion reduced or eliminated). As summarized in Figure 29, this study has shown that an average delay reduction of as little as 1 1/2 minutes completely offsets the economic penalty of introducing the relatively risk free 3000 foot (914 m) externally blown flap STOL aircraft into a realistic short-haul system. Other STOL concepts, involving slightly more technical risk, are even more effective in increasing system ROI. A large part of this improvement is increased productivity of the CTOL elements of the system.

The FAA, the Aviation Advisory Commission and others have concluded that alternate solutions to the congestion problem such as: vast new major airport building and/or expansion programs, expanded imposed quota program with its drastic curtailment of service, use of jumbo-jumbo jets, and other approaches are not cost-effective even if the militancy of the communities could somehow be overcome.

If the introduction of STOL can in fact bring about this congestion relief, and all evidence indicates it can in conjunction with the planned ATC improvements, the integrated STOL system is in a favorable position to provide a realistic and viable solution to the congestion/delay problem. Alternatively, a congestion free air transportation system based upon CTOL only is remote, if not impossible.

When the intangible benefits of this congestion relief such as improved service, improved land usage, improved community acceptance due to noise reduction, to name a few, are considered - the overall viability of STOL becomes exciting indeed.

CONCLUSIONS

Within the premises and scope of the study the conclusions are as follows:

1. Expected growth in air travel will cause airport congestion in the 1980-1990 time frame which will be especially critical in the major East Coast hubs, Chicago, and Atlanta.

2. Recent actions in the public sector are threatening further expansion of the air transportation system. Aircraft movements and development of new airports have been and will continue to be subject to restrictions.

3. Quiet STOL aircraft, with 3000 to 4000 ft (914 to 1219 m) field lengths, can greatly reduce the current noise annoyance area around major airports. The quiet STOL designed to FAR 36-10 EPNdB has an 80 EPNdB contour area which is only seven percent of the same contour area for current high fan pressure ratio jets. Further design reductions to FAR 36-19 EPNdB reduce the 80 EPNdB contour area to two percent of the noisy jet.

4. Quiet STOL aircraft, with 3000 to 4000 ft (914 to 1219 m) field lengths, are technically feasible in the 80's.

5. Favorable public reaction to quiet STOL aircraft is predicted. Carefully planned introduction of quiet aircraft can help foster a positive attitude toward air travel growth.

6. Utilization of STOL to provide airport congestion relief in the major Eastern hubs, Chicago, and Atlanta, will generate a market for over 300 STOL aircraft.

    a. Short-haul systems will probably be implemented initially to help relieve congestion at large hubs.

    b. As economic feasibility and community acceptance of short-haul is proven, it is expected that the system will expand to secondary airports. The induced market response can be expected to further stimulate the system growth.

    c. Major hubs can be relieved of runway congestion until about 1990.

    d. Congestion relief provided by STOL will also benefit CTOL by reducing future delays.

7. Individual airports, which are expected to experience congestion, can increase total capacity and relieve the forecasted congestion by adding STOL strips within existing boundaries.

    a. For the airports where STOL strips are added in this study, runway lengths of at least 3000 ft (914 m) are obtainable.

   b. "Canted" runways or a small amount of land acquisition or conversion may allow runways as long as 4000 ft (1219 m); detailed studies of each critical airport and in-depth discussions with their planners would be required before establishing a 4000 ft (1219 m) field length as a design criterion.

8. The three prime congested areas - NYC, Chicago, and Washington, - can eliminate runway congestion of the metropolitan hub by a planned conversion of one existing commercial airport to an "all-STOL" reliever airport in each metropolitan area.

   a. The CTOL runways are retained for mixed operations during a gradual transition from CTOL to STOL, and for STOL emergency or overload operations after conversion to an all-STOL airport.

9. Secondary airports in the metropolitan hubs are available which have 5000 ft (1520 m) runways, but a low noise level is necessary to facilitate the acceptance of commercial service.

10. The preferred short-haul configuration depends on the maximum available field length at critical airports.

    a. If only 3000 ft (914 m) is available, propulsive lift aircraft configurations are required. Further analytical and experimental data are needed to refine choice of lift system although the OTW/IBF appears most promising.

    b. If 4000 ft (1219 m) is available, a mechanical flap configuration is preferable due to better economics.

11. Designing for reduced noise and reduced field length are compatible objectives.

12. Point design data are as follows for two outstanding candidates:

	Mechanical Flap	OTW/IBF
No. of passengers	148	148
Field Length, ft (m)	4000 (1219)	3000 (914)
Gross Weight, lbs (kg)	136,900 (62,000)	147,300 (66,900)
No. of Engines	2	2
Engine Thrust, SLS lbs (kg)	34,000 (15,400)	36,800 (16,600)
Unit Cost, dollars	8.71×10^6	9.35×10^6
DOC @ 250 n.mi., cents/assm	2.12	2.29
80 EPNdB Footprint Area sq. mi. (sq. km)	3.1 (8.0)	4.5 (11.6)

13. The evolution and operation of a short-haul system using the Quiet STOL aircraft should consider the following factors:

    a. 148 passenger aircraft provide capacity for high density markets and maintain adequate frequency of schedules as well as allow operations on future less dense markets.

b. Utilization of short-haul STOL airplanes should be initiated on potentially congested hub airports.

c. Goals of 12 sq mi (41 km^2) (80 EPNdB contour area) per landing and departure should be a goal for STOL introduction reducing to 4 sq miles (14 km^2) by the late 1980's.

d. High STOL DOC's can be partially offset by a short-haul system which achieves low IOC's through a spartan operation.

e. Short-haul STOL fares should be competitive with CTOL fares to attract required demand at the major airports.

f. Development of semi-segregated short-haul system should be an evolutionary process.

g. Effects of adding all-coach STOL aircraft to airline fleet operations are as follows:

   - Adding all-coach STOL with 2000 ft (610 m) field length capability, to first class/coach CTOL fleet or to all-coach CTOL fleet, lowers ROI.
   - Adding all-coach STOL, with 3000 to 4000 ft (914 to 1219 m) capability to first class/coach CTOL fleet, raises ROI.
   - Adding all-coach STOL, with 3000 to 4000 ft (914 to 1219 m) field length capability, to all-coach CTOL fleet, lowers ROI.

h. Secondary airport utilization should be initiated only after service at the major airports is established and the induced demand is apparent.

14. Phasing in of lower noise level requirements in the 1980's may well be accomplished in a manner analogous to the current fleet noise level approach which has been announced as an advanced notice of proposed rule making. If this occurs the airline operator will find it advantageous to introduce quiet STOL aircraft to his fleet to lower the average fleet noise so he can realize a longer useful life from his inventory of noisier aircraft.

RECOMMENDATIONS

Detailed recommendations where additional research and development may result in significant improvements in STOL technology are identified in Tables XVII and XVIII. Each item in Table XVIII is referenced to the paragraph in the final report (Volume II, CR 114613) where an in-depth discussion may be found.

TABLE XVII. CRITERIA FOR RATING TECHNOLOGY

READINESS RATING	PRIORITY RATING	JOINT BENEFIT RATING
1. TECHNOLOGY-PERMITS PRODUCTION COMMITMENT	1. TASK CRITICAL (1980-85) MAJOR EFFECT REQUIRED	1. TASK HAS SIGNIFICANT BENEFITS TO ● GENERAL PUBLIC ● SHORT HAUL TRAVELER ● AIRLINE OPERATOR ● ADVANCED CTOL, RTOL AND STOL ● MILITARY TRANSPORT
2. TECHNOLOGY-ADDITIONAL DEVELOPMENT FOR HIGH PROBABILITY OF NEAR TERM SUCCESS	2. HIGH PAYOFF TASK. INADEQUATELY COVERED BY EXISTING PROGRAMS.	2. TASK BENEFIT RESTRICTED TO SHORT HAUL ● STOL ● RTOL
3. TECHNOLOGY NOT WELL DEFINED. ADDITIONAL DEVELOPMENT REQUIRED.	3. TASK FUNDAMENTAL FOR LONGER-TERM TECHNOLOGY BENEFITS (1990)	3. TASK BENEFIT RESTRICTED TO FIELD LENGTHS OF 1500 - 2500 FEET CATEGORY.
	4. TASK FUNDAMENTAL-CURRENT PROGRAMS WILL PROVIDE BASIS.	
	5. TASK WILL CONTRIBUTE SIGNIFICANTLY BUT IS NOT FUNDAMENTAL TO ACHIEVEMENT OF TECHNOLOGY BENEFITS IN SECTION 4.0.	

TABLE XVIII. RESEARCH AND DEVELOPMENT RECOMMENDATIONS SUMMARY

SYSTEM AND AIRCRAFT REQUIREMENTS	READINESS RATING	PRIORITY RATING	JOINT BENEFIT
5.2.1 FIELD LENGTH AND NOISE LEVEL	3	1	2
5.2.2 AIRWORTHINESS REQUIREMENTS FOR PROPULSIVE-LIFT AIRCRAFT	2	1	2
5.2.3 WAKE VORTEX AND SEPARATION REQUIREMENTS			
● ANALYTICAL STUDY OF WAKE VORTICES	3	2	1
● WAKE VORTEX AVOIDANCE SYSTEM	3	1	1
● EXPERIMENTAL EVALUATION OF PROPULSIVE-LIFT WAKE VORTEX	3	2	1
5.2.4 MICROWAVE LANDING SYSTEM	2	3	1
5.2.5 AREA NAVIGATION	2	3	1
5.2.6 LANDING APPROACH SIMULATION STUDY-PROGRAM DEFINITION	2	1	2
5.2.7 MARKET DEMONSTRATION PROGRAMS	2	1	2
AIRCRAFT DESIGN-NEAR TERM			
5.3.1 PROPULSIVE-LIFT SYSTEM DEVELOPMENT VS. MECHANICAL FLAP	3	1	2
5.3.2 HYBRID OTW/IBF RESEARCH AIRCRAFT	3	1	1
5.3.3 ADAPTIVE LANDING GEAR	2	2	2
5.4.1 QUIET CLEAN STOL EXPERIMENTAL ENGINE	2	1	1 OR 3
5.4.2 ENGINE OPTIMIZATION FOR IBF	3	2	1
5.4.3 ENGINE CYCLE/AIRCRAFT INTEGRATION FOR MIN. FUEL CONSUMPTION	2	1	1
5.4.4 NOISE ESTIMATION FOR OTW/IBF CONCEPTS	3	1	1
5.4.5 IMPROVE ENGINE-BLEED PERFORMANCE BY OPTIMIZATION OF ENGINE CYCLE	2	2	1
5.4.6 FAN AND PRIMARY JET NOISE SUPPRESSION	2	2	1
AERODYNAMICS-NEAR TERM			
5.5.1 OTW AERODYNAMICS	3	1	2
5.5.2 HYBRID OTW/IBF AERODYNAMICS	3	1	1
STRUCTURES AND MATERIALS-NEAR TERM			
5.6.1 FILAMENT REINFORCED ALUMINUM-ROOM TEMP. CURING	2	2	1
FLIGHT CONTROL			
5.7.1 APPLICATION OF ACTIVE CONTROL TECHNOLOGY	3	2	1
ECONOMICS			
5.8.1 EFFECTS OF INFLATION ON BENEFIT OF ADV. TECHNOLOGY	2	2	1
AIRCRAFT TECHNOLOGY-LONG TERM			
5.9.1 HYDROGEN-FUELED SHORT HAUL AIRCRAFT	3	3	1
5.9.2 COMPOSITE STRUCTURES	3	3	1
5.9.3 AUGMENTOR WING	3	5	3

REFERENCES

1. *Report of Department of Transportation Air Traffic Control Advisory Committee, Volumes 1 and 2*, FAA, Department of Transportation, December, 1969.

2. *The National Aviation System Policy Summary*, FAA, Department of Transportation, March, 1972.

3. *The National Aviation System Plan, Ten Year Plan 1973 - 1982*, FAA, Department of Transportation, March 1972.

4. *Large and Medium Hub Aviation Activity Forecast*, FAA, Office of Aviation Economics, Department of Transportation, July, 1971.

5. *A Suggested Action Program for the Relief of Airfield Congestion at Selected Airports*, FAA, Department of Transportation, April, 1969. (Also Supplement to above dated February 19, 1970.)

6. *Airport Capacity Criteria Used in Long-Range Planning*, FAA, Department of Transportation, December, 1969. (AC-150/5060-3A)

7. *Airport Capacity Criteria Used in Preparing the National Airport Plan*, FAA, Department of Transportation, July 1968 (AC-150/5060-1A)

8. *Terminal Area Airline Delay Data, 1964-1969*, Working Paper, FAA Air Traffic Service, September 1970.

9. *The Long Range Needs of Aviation*, Aviation Advisory Commission, January 1, 1973.

10. *Design Integration and Noise Studies for Jet STOL Aircraft*, NASA CR 114283, Vol. I - Program Summary, May 1972.

11. *Preliminary Noise Tests of the Engine-Over-The-Wing Concept II. 10°-20° Flap Position* NASA TMX-68104, June 1972.

12. *Preliminary Noise Tests of the Engine-Over-The-Wing Concept I. 30°-60° Flap Position* NASA TMX-68032, March 1972.

13. *Key Features of the Upgraded Third Generation Air Traffic Control System of the Federal Aviation Administration*, by D. R. Israel, Director, Office of Systems Engineering Management, FAA, at International Air Transport Association 19th Technical Conference, Dublin, Oct. 23-28, 1972.

14. *National Plan for Development of the Microwave Landing System*, AD-733 268, FAA, Department of Transportation, July 1971.

NASA-Langley, 1973 —— 2

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

SPECIAL FOURTH-CLASS RATE
BOOK

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
451

U.S.MAIL

DEPT OF THE NAVY
NAVAL TRAINING EQUIPMENT CENTER
ATTN: TECHNICAL LIBRARY
ORLANDO FL 32813

157 001 C1 U 02 731130 S00703HU

POSTMASTER : If Undeliverable (Section 158 Postal Manual) Do Not Return

---

> *"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."*
>
> —NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546