NASA CONTRACTOR REPORT

NASA CR-2502

NASA CR-2502

EVALUATION OF ADVANCED LIFT CONCEPTS AND POTENTIAL FUEL CONSERVATION FOR SHORT-HAUL AIRCRAFT

H. S. Sweet, J. H. Renshaw, and M. K. Bowden

Prepared by
LOCKHEED AIRCRAFT CORPORATION
Burbank, Calif.
for Ames Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1975

1. Report No. NASA CR-2502	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Evaluation of Advanced Lift Concepts and Potential Fuel Conservation for Short-Haul Aircraft	5. Report Date February 1975
	6. Performing Organization Code
7. Author(s) H.S. Sweet, J.H. Renshaw and M.K. Bowden	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address Lockheed Aircraft Corporation Burbank, California	11. Contract or Grant No. NAS 2-6995
	13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics & Space Administration Washington, D.C.	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The effect of different field lengths, cruise requirements, noise level, and engine cycle characteristics on minimizing fuel consumption and minimizing operating cost at high fuel prices were evaluated for some advanced short-haul aircraft. The conceptual aircraft were designed for 148 passengers using the Upper Surfact-Internally Blown Jet Flap, the Augmentor Wing, and the Mechanical Flap lift systems. Advanced conceptual STOL engines were evaluated as well as a near-term turbofan and turboprop engine. Emphasis was given to designs meeting noise levels equivalent to 95-100 EPNdB at 152 m. (500 ft.) sideline.

17. Key Words (Suggested by Author(s)) STOL Design Studies Quiet Commercial Short-Haul Transports Fuel Conservative Aircraft	18. Distribution Statement UNCLASSIFIED-UNLIMITED STAR Category 07

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 78	22. Price* $4.00

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

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FOREWORD

The evaluation of Advanced Lift Concepts and Fuel-Conservation for Short Haul Aircraft was conducted under extension to NASA Ames Research Center Contract NAS 2-6995. The basic report, summarized here, is contained in NASA CR137525 and CR137526, dated June, 1974.

This study was under the direction of T. P. Higgins, Program Manager, and H. S. Sweet, Deputy Manager. The principal investigators were: J. H. Renshaw, M. K. Bowden, C. W. Narucki, J. A. Bennett, P. R. Smith, R. S. Ferrill, C. C. Randall, J. G. Tibbetts, R. W. Patterson, R. T. Meyer, and L. A. Vaughn.

The work was administered under the direction of T. L. Galloway, Technical Monitor, R. C. Savin, and M. H. Waters, Systems Studies Division, NASA Ames Research Center.

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SUMMARY

In 1972 and early 1973, Lockheed conducted for NASA Ames Research Center a "Study of Quiet Turbofan STOL Aircraft for Short Haul Transportation" (Ref. 1, 2). This study concluded that quiet, short-field aircraft can be economically viable, provide benefits to short-haul transportation, and also to long-haul transportation through relief of airport congestion. From a comprehensive array of lift concepts, cruise speeds, and field lengths, it was concluded that the most promising concepts were the 914m. (3000 ft.) field length Over-the-wing/Internally Blown Flap Hybrid (OTW/IBF) and 1220m. (4000 ft.) field length Mechanical Flap (MF) concept, both with cruise speeds of 0.8M.

More detailed analysis was needed to confirm the potential of these concepts and to evaluate the performance and economics of a twin-engine augmentor wing airplane. The present study covers two phases:

- Investigation of the critical design aspects of the OTW/IBF hybrid, augmentor wing, and mechanical flap aircraft for 914m. (3000 ft.) field length with parametric extension to other field lengths.
- Evaluation of the fuel savings achievable by the application of advanced lift concepts to short-haul aircraft and determination of the effect of different field lengths, cruise requirements, and noise levels on fuel consumption and airplane economics at higher fuel prices.

All the design comparisons were made with 148 passenger aircraft. Engines used in the designs were those defined in the pre-hardware phases of the Quiet Clean STOL Experimental Engine program, with the addition of a near-term bypass ratio 6 engine currently under development and also turboprop engines. An advanced airfoil was used in all of the configurations, providing a greater wing thickness for a given drag rise, sweep angle, and design cruise speed. Emphasis was given to designs meeting noise levels equivalent to 95-100 EPNdB at 152m. (500 ft.) sideline.

This report covers the design refinement of the hybrid OTW/IBF, augmentor wing, and mechanical flap concepts and changes associated with minimizing fuel consumption and minimizing operating cost at higher fuel prices. Other lift concepts are examined more briefly from the standpoint of fuel conservation. The concepts are then compared and noise aspects are summarized.

The analysis and evaluation led to the following major conclusions and recommendations:

- There is the potential for a 25% savings in fuel when the vehicle configuration, mission speed and altitude are optimized for minimum fuel usage instead of minimum direct operating cost at 1972 fuel prices.
- The optimization of short-haul vehicles for higher fuel prices entails a significant speed reduction of the order of 0.05 M for each doubling of fuel price.

- The preferred reduced/short takeoff and landing (R/STOL) system for the high density short haul arena has the capability of 2780 km (1500 n.mi.) with full load and CTOL takeoff distances. This flexibility permits route scheduling on the same basis as current airplanes performing this mission; increased utilization more than compensates for the weight and cost penalties of providing the extra capability. A minimum cruise speed of 0.75 M is considered necessary for passenger acceptance in stage lengths exceeding 700 – 900 Km (380 – 485 n.mi.).

- The choice of field length requirements for R/STOL vehicles in the short-haul mode must be based on further evaluation of the land-side costs and environment. Design refinements indicate that short field lengths entail only modest DOC and fuel penalties which will potentially be more than offset by savings in real estate and congestion relief. Direct operating costs for field lengths of 610 m., 914m. and 1220m. (2000, 3000, and 4000 ft.) aircraft are estimated to be 24%, 17% and 3% higher than for vehicles designed for 1830m. (6000 ft.) field length.

- Minimum DOC designs for R/STOL vehicles meet a noise goal of FAR 36 – 15 dB; lower noise goals cause rapidly escalating costs.

- The Sperry box 80 PNdB noise criterion is neither attainable nor appropriate to high density short haul vehicles operating from existing CTOL airports with supplementary STOL runways, or from secondary airports. Similarly, a 152m. (500 ft.) sideline measuring point is of no practical significance since it is contained within the airport boundaries. Practical attention should therefore be directed towards criteria which recognize the importance of the takeoff flyover point noise and the area of the "objectionable level" footprint which impacts the community.

- In many areas a 1220 meters (4000 ft.) field length is appropriate and a twin-engine mechanical flap airplane is clearly superior to powered-lift concepts evaluated in this study. Using engines with fan pressure ratios of 1.35 and a design cruise speed of M 0.75, the noise footprint and fuel consumption are highly attactive. For shorter field lengths, wing loadings below 400 kg/sq. m. (80 psf) are required and both ride qualities and fuel consumption for mechanical flap aircraft become questionable. At twice 1972 fuel prices and 914m (3000 ft.) field length, the direct operating cost for the twin-engine mechanical flap and the hybrid OTW/IBF is a standoff.

- At field lengths of 914m. (3000 ft.) and under, the hybrid OTW/IBF aircraft is recommended because of lower fuel consumption, better ride qualities, speed advantage, and potential for further improvement. The 610m. (2000 ft) hybrid aircraft is now estimated to have a cost penalty which may be more economically viable -- a 24 percent increase in DOC over CTOL aircraft compared to the 50 percent penalty estimated in previous studies (Ref. 1 and 2).

- Recent experimental data have validated the performance potential of the hybrid OTW/IBF concept. However, research and development are needed to expand the data base so that the best compromise solutions can be selected considering cruise performance minimizing SFC losses, high lift performance, and noise level in terminal operations. Higher, and possibly increasing, fuel prices dictate that the expanded data base should emphasize low-sweep wings with aspect ratios of 10 to 14, cruise speeds below Mach 0.8, and 4-engine airplanes. Since fuel consumption is better with 4-engine rather than 2-engine designs, the pure OTW system requires further evaluation; additional data are needed to establish the optimum amount of flap blowing, if any, for a given set of requirements.

- The optimum engine for both MF and OTW/IBF applications for a 914m. (3000 ft.) field length and current fuel prices, has been shown to have a fan pressure ratio in the range 1.30 – 1.40. On the basis of the discrete engines (with some differences in fan configuration, etc.) which have provided the propulsion data for this study, a fixed pitch, 1-1/2 stage fan, 1.35 FPR engine is preferred.

- The use of the thicker supercritical airfoil in an 0.75 Mach number application avoids significant weight and aeroelastic penalties at the high aspect ratios and low sweep angles appropriate for fuel conservative vehicles.

SYMBOLS AND ABBREVIATIONS

AR	airplane aspect ratio or nozzle aspect ratio, b/h
AW	augmenter wing
b	span
BLC	boundary layer control
BPR	bypass ratio, engine secondary airflow/engine primary airflow
C_D	drag coefficient
C_L	lift coefficient
C_P	pressure coefficient
C_R	roll moment coefficient
C_T	thrust coefficient
C_X	axial force coefficient
C	blowing coefficient
c	chord
¢/ASSM	cents/available seat statute mile
CTOL	conventional takeoff and landing
D	diameter
dB	decibel
DOC	direct operating cost
DOC-1	DOC at 11.5c/gallon fuel
DOC-2	DOC at 23c/gallon fuel
DOC-4	DOC at 46c/gallon fuel
DOC-10	DOC at $1.15/gallon fuel
EBF	externally blown flap
EPNdB	unit of effective perceived noise level
F	engine thrust

Symbols and Abbreviations (Cont'd.)

f	frequency (Hertz)
FAR	Federal Aviation Requirements
FPR	fan pressure ratio
g	gravitational constant
H	nozzle height
Hz	Hertz, unit of frequency
IBF	internally blown flap
LE	leading edge
M	Mach number or Meter
m	airflow or meter
MF	mechanical flap
NPR	nozzle pressure ratio
OASPL	overall sound pressure level
OPR	overall pressure ratio of engine
OTW	over-the-wing
OTW/IBF	over-the-wing/internally blown flap hybrid
OWE	operating weight empty
PNdB	unit of perceived noise level
PNL	perceived noise level
q	dynamic pressure
R	coanda radius
RGW	ramp gross weight
R_N	Reynolds number
ROI	return on investment
R/STOL	reduced/short takeoff and landing

Symbols and Abbreviations (Cont'd.)

SFC	specific fuel consumption
SLS	sea level static
SPL	sound pressure level
STOL	short takeoff and landing
T	temperature or airplane net thrust
t	wing thickness
T/O	takeoff power setting
TOFL	takeoff field length
TOGW	takeoff gross weight
T/W	airplane thrust/weight ratio
T/S	airplane thrust/wing area ratio
V	velocity
W	weight or airplane weight
α	angle of attack
γ	flight path angle
Δ	increment of
η	power setting or fraction of wing span
λ	taper ratio

INTRODUCTION

Background

Studies of Quiet Turbofan STOL Aircraft for Short Haul Transportation were conducted by Lockheed and McDonnell-Douglas for NASA Ames Research Center in 1972 and early 1973. These were reported in detail in references 1, 2, and 3. Both studies concluded that quiet short field aircraft can be economically viable and benefit both long and short-haul transportation. To be economically viable, field lengths of 914 to 1220m (3000 to 4000 ft.) were strongly preferred; operating cost penalties for 610m (2000 ft.) or shorter field length appeared to be greater than could be balanced by STOL indirect benefits.

In the Lockheed study, it was determined that the various powered high-lift concepts such as the externally blown flap, the internally blown flap, and the over-the-wing blown flap (upper surface blown flap) produced configurations with approximately equal economic results. However, two particularly promising concepts appeared to be the Over-the-Wing/Internally Blown Flap (OTW/IBF) hybrid at a field length of 914m (3000 ft.) and the Mechanical Flap (MF) at a field length of 1220m (4000 ft.). Unfortunately, the data base upon which the OTW/IBF concepts is based is neither as extensive nor as well substantiated as competing concepts, such as the externally blown flap or augmentor wing.

It was also shown that more economical vehicles could be developed for both these concepts if the 152m (500 ft.) sideline noise level requirement were relaxed somewhat from 95 EPNdB. Additional benefits would accrue from such a choice of noise level since the engines suited for slightly higher noise level have fan pressure ratios (FPR's) on the order of 1.4 to 1.6 which make them suitable for advanced CTOL airplanes meeting FAR 36 minus 10dB noise levels, a level to be expected in the 1980 time period.

It was therefore proposed to investigate and analyze the critical aspects of the 914m (3000 ft.) OTW/IBF design to that level which will provide a meaningful configuration for developing test configurations for future R&D programs and to compare the performance of this concept to the performance of the MF concept at 914m (3000 ft.) field length. The number of engines has a significant effect upon operating cost as illustrated by the mechanical flap configuration examined in references 1, 2, and 3. Whereas the preference for two engines for unpowered lift systems was clear-cut, more detailed analysis was required to resolve the question in a rigorous manner for powered lift systems. Accordingly, 2, 3 and 4 engine OTW/IBF vehicles were included in the present study and these were complemented with a study of a twin-engine augmentor-wing vehicle. Since the twin engine pure OTW and EBF configurations are virtually excluded by engine-out trim considerations and the other candidate configurations have already been examined, the AW study completed a comprehensive review of this aspect for all powered lift systems. (The twin-engine Boeing AMST is classified here as a hybrid OTW system since it uses leading-edge blowing.)

Work was initiated on this study extension in July 1973. Early in the program it was observed that the fuel consumption of airplanes using the hybrid propulsive-lift concept was lower than for the mechanical flap or augmentor wing concepts for aircraft designed for 914m (3000-ft.)

field performance, low noise level, and cruise at M0.8. The wing loading and aspect ratio for propulsive lift aircraft can be higher than that possible for a mechanical flap airplane at any given field length; this generally means lower fuel consumption. Increasing prices and scarcity of fuel in late 1973 highlighted the need to examine operating requirements such as cruise speed and altitudes, as well as the effect of different potential noise requirements on fuel consumption and airplane design for minimum operating costs at higher fuel prices. Accordingly, an additional task was initiated in early January 1974 to cover these aspects.

Objectives

This report describes the results of analyses integrated to accomplish the following objectives:

- Detailed definitive design and economic comparison of 914m (3000 ft.) field length MF, AW and OTW/IBF configurations. A primary objective was establishing credibility of performance estimates, including sensitivity to variations in basic data.
- Detailed determination of the economic and noise level effects of using an intermediate bypass engine suitable for an advanced CTOL, as well as use of a low-noise engine.
- Development of the preliminary design of optimized OTW/IBF airplanes to that level which could provide test configurations for future R&D programs.
- Development of additional data for OTW/IBF configurations with 610 and 1070m (2000 and 3500 ft.) field length capability and MF configurations with 1070 and 1220m (3500 and 4000 ft.) field length capability.
- Evaluation of the fuel savings achievable by application of advanced lift concepts to short-haul aircraft; determination of the effect of different field lengths, cruise requirements and noise levels on fuel consumption.

Approach

Specific configuration design points were selected for different lift concepts and field lengths, as summarized in Figure 1. Emphasis was placed on the points designated "preliminary design" in the figure: 914m (3000-ft.) field length for over the wing/internally blown flap, mechanical flap, and augmentor wing; 1220m (4000-ft.) field length for the mechanical flap. The preliminary design data were then extended to other field lengths, as shown. Initially these aircraft were optimized for M 0.8 cruise at 9140m (30,000 ft.) for minimum direct operating cost with 1972 prices for fuel, aircraft and engines, maintenance, and other DOC elements. Optimization would not be affected if these inflated uniformly; for convenience in comparing to previous studies, the 1972 price basis was maintained. However, the rapid price increase for fuel in 1973 indicated that fuel consumption would assume a more dominant position in airline economics and that airplane and engine features which conserved fuel should be evaluated from two standpoints: minimum fuel consumption and minimum direct operating cost optimizations at higher fuel prices.

A range of cruise speeds and altitudes was investigated for each lift concept and engine combination. The wing loading, thrust loading and wing aspect ratio for minimum fuel at each speed and altitude were determined. For each of these cases the direct operating cost at 1, 2, 4 and 10 times the 1972 fuel price was determined, as well as the gross weight and operating weight of the aircraft. As indicated in Figure 1, the externally blown flap and deflected slipstream (turboprop engines) were also included in the evaluation of fuel consumption. Finally, the noise characteristics and footprint areas of representative cases were determined so that the interaction of potential noise criteria with aircraft economics and fuel consumption could be defined.

In the first section, the short haul system elements are re-examined briefly to review qualitatively the effects of the fuel shortage on short haul air transportation and on the need for fuel- and real-estate-conserving quiet aircraft. Section 2 defines the evaluation criteria and design requirements. Section 3 shows the design features of the candidate aircraft. Evaluation of the aircraft configurations from the standpoint of fuel consumption, DOC at different fuel prices, and noise are presented in Section 4; the penalties in fuel and DOC for different potential noise requirements are also defined. Section 5 then discusses the compromises in the selection of potentially viable systems combining the factors of fuel economy, noise, aircraft versatility and flexibility, and airline economics. Finally, conclusions are summarized and recommendations are listed for further research and development and institutional development toward an improved short haul air transportation system.

- REFINE DESIGN OF SHORT-HAUL AIRCRAFT -- M 0.8, 9140m. (30,000 FT.) CRUISE

FIELD LENGTH	610m. (2000 FT.)	914m. (3000 FT.)	1070m. (3500 FT.)	1220m. (4000 FT.)
OVER THE WING/INTERNALLY BLOWN FLAP	○	⊙	○— PARAMETRIC DESIGN	
MECHANICAL FLAP		⊙	○	⊙
AUGMENTOR WING		⊙—PRELIMINARY DESIGN		

- REOPTIMIZE ABOVE AIRCRAFT (WING AR, CRUISE SPEED AND ALTITUDE) FOR MINIMUM FUEL AND HIGHER FUEL COSTS
  REEXAMINE EXTERNALLY BLOWN FLAP
  ADD DEFLECTED SLIPSTREAM WITH TURBOPROP ENGINES
  EXTEND MECHANICAL FLAP ANALYSES TO COVER 1830m. AND 2440m. (6000 AND 8000 FT.)
  EVALUATE ENGINES WITH FPR 1.25, 1.35, 1.47

- DETERMINE FUEL AND DOC PENALTY FOR POTENTIAL NOISE CRITERIA:
  - 95 EPNdB AT 152m. (500 FT.) SIDELINE
  - PART 36 MINUS 5, 10, 15 EPNdB
  - SPERRY BOX LEVEL* OF 80 EPNdB
  - 90 EPNdB FOOTPRINT AREA LIMITED TO 2.59, 1.39, 0.78 km^2 (1.0, 0.5, 0.3 SQ. MI.)
  - 90 EPNdB FOOTPRINT LENGTH LIMITED TO 6.5, 3.7, 1.9, 1.2 km (3.5, 2.0, 1.0 N. MI., 4000 FT.)

* REF. 4

Figure 1 Study Approach

1. AIRPORT CONGESTION AND ENERGY SHORTAGES

The previous systems studies (References 1-3) highlighted the primary need for STOL short-haul capability for the relief of congestion at the major hub airports. An additional major advantage was cited as the increase in convenience to the public if additional airports could be utilized which were closer to the sources of origin and destination. Current study activity has involved an examination of the effect of recent developments on this scenario. Of major importance is the recognition that a very effective short-haul and long-haul air transportation network is functioning today. It is a complex interacting system in which a major effect on profitability of the long-haul system is the short-haul collection system which brings people to a hub airport by air in sufficient quantity to achieve profitable load factors on wide-body equipment.

The effects of the energy crisis on airline operations have been discussed with representatives of Delta, Eastern, and Northeast Airlines. These discussions investigated the impact of short fuel supply on passenger travel habits, schedules, load factors, and average delay rates. Fuel allocations and increased fuel costs were also examined to determine the influence on operations and future planning. Anticipated changes in previously projected air passenger traffic growth and airport congestion were analyzed to better determine the benefits of quiet R/STOL aircraft for short haul traffic with short runways added on a noninterfering basis with CTOL operations.

Air passenger travel habits have not changed as drastically as first anticipated. The reduction in low demand flights appears to have an insignificant effect on loss of passengers to other modes of transportation. Passengers appear to reschedule their own activities to accept other available flights. The anticipated passenger traffic has been boosted somewhat by a shift to the airlines from automobile travel, caused by the gasoline shortage. Records show that the 1973 air passenger traffic exceeded expectations and 1974 is expected to exceed predictions made in the initial phases of the fuel crisis.

Schedule cuts have been made at the times of least demand so that peak hour airport operations have not been affected to any extent. Considerable improvements have been experienced in average load factor; however, this has not affected the ability to meet demand.

Fuel allocation cutbacks have led the airlines to examine further the various means of conserving fuel in addition to eliminating low-demand flights. Reduced throttle settings result in reduction in fuel consumption with only small increases in block time. Other methods exercised during peak hours as initiated by Reference 5 include holding a departing flight at the gate until clearance to takeoff is obtained, thereby conserving fuel in ground operations, or holding at the point of origination until clearance is obtained at the point of destination to reduce airborne delays.

The higher fuel prices have increased the break even load factor, even though various cost reduction practices have been implemented. This has been offset generally by the improvements in average load factor that are presently being experienced. Continued fuel cost increases and lower fuel allocations are still a major concern with all airlines. Where there is sufficient passenger traffic, this situation tends to favor the more fuel-efficient wide-body aircraft and, in some cases, airlines are attempting to accelerate the introduction of these aircraft into their route structure. In cases where load factors on 747 aircraft were low, smaller equipment better matching the demand has been reintroduced because the fuel per passenger is highly sensitive to load factor.

The consensus of all airlines is more optimistic toward a continued passenger growth rate during the coming years. However, the predicted rate of growth varies somewhat. Airport congestion is not viewed as a significant problem for the next several years. Nevertheless, congestion is being viewed as a future problem that must be recognized in present planning. Major cities are continuing to evaluate the anticipated traffic growth in terms of the need for expanding the capabilities of existing facilities and property or the need for acquiring additional property for new airports. A typical example of this type of planning exists in the Atlanta area. Recognizing the extremely long lead times in obtaining necessary land and constructing required facilities, the Atlanta Regional Commission has an active transportation planning program in progress which is studying the feasible ways of meeting the future air traffic needs of the Atlanta area. A second airport is in serious consideration at the present time to augment the capabilities of the Hartsfield Atlanta International Airport. New York is also looking at the possibility of an additional airport, and Chicago is still studying the problems of a workable system in the Midway/O'Hare combination. Of course, any steps in developing additional workable airports for congestion relief will have a tendency to postpone the need for, and benefits to be derived from, R/STOL type aircraft operations.

A recent paper by Charles L. Blake (Ref. 6) summarizes the report of the FAA Airport Study Team which highlights the groundside congestion problem assuming considerable ATC improvements in airside capacity. Recognizing the fuel shortage and the uncertainties in predicting future developments, it is noted that "the FAA Airport Study Team predicts a steadily increasing strain on airport capacity." Mr. S. B. Poritzky of the Air Transport Association has commented (Ref. 7) that "quantifiable ATC-based airport capacity improvements. . . are smaller than expected. The bigger payoff must come from optimized total airport design and enough runways, and in the long run more 'real-estate-stingy' airplanes."

Demand — Capacity Analyses

Airport capacity and demand analyses were described in Reference 2 and these have been reexamined in the light of the energy crisis to determine if the saturation of major airport hub capacities still remains a serious concern inhibiting the growth and prosperity of the national air transportation industry. The changes resulting from the fuel shortage such as the anticipated future growth of air passenger traffic, airline operations, and cost of fuel were assessed in terms of future airport demand versus capacity and cost of delay under various levels of fuel costs. The cost of delay with and without R/STOL capabilities was compared to show the economics of augmenting airport CTOL capacity with R/STOL capabilities.

The Atlanta Airport was used as an example of a major hub airport in these analyses. Figure 2, shows the presently predicted demand and capacity of the Atlanta Airport. The demand, in terms of average peak hour aircraft movements, is shown rising from 100 in 1974 to over 200 by 1995. Capacity increases by the addition of multiple paralled runways are shown by the horizontal bars; the third runway, added in 1973 has increased current capacity to satisfy the demand. A possible fourth CTOL runway and conservative estimates of the effect of ATC improvements promise to satisfy demand until approximately 1985. At this point additional capacity can be attained by installation of short haul R/STOL runways which could alleviate congestion until approximately 1995 when the demand is predicted to exceed 200 peak hour movements. Doubling of average airplane passenger size is taken into account in these projections.

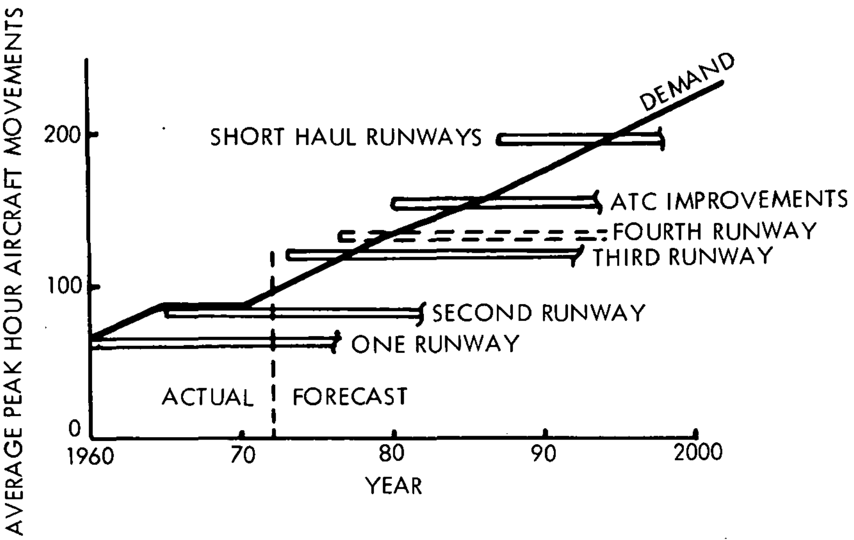


Figure 2 Atlanta Airport Traffic Projection

Fuel savings on the order of 147.42 million kg (50 million gal.) per year by 1995 are indicated to be achievable at this one airport by adding R/STOL to expand capacity and cut average delay time. Corresponding annual savings in airplane direct operating cost are on the order of 50 million dollars. It appears that analysis of O'Hara Airport would give similar results at an earlier time period.

Savings in fuel through relief of congestion would be achieved, also, by construction or use of additional airports. The California corridor represents a significant example of the successful dispersion of air traffic from the hubs to secondary airports; the volume of passengers not interconnecting with long-haul is high enough to support this system with sufficient frequency of flights at the secondary airports. However, the importance of the interconnection problem in other areas must be recognized. Chicago and Atlanta are primary examples of the cases where a short-haul collection system brings passengers to an interchange which offers a tremendous choice of destinations with high frequency of service. Some quotations from a working paper of the Atlanta Regional Commission, Reference 14, serve to illustrate the magnitude of this valuable service to the public:

> "Atlanta now serves 92 cities with nonstop flights... some 597 nonstop flight departures daily... A large number of the Atlanta nonstop flights are on-line continuation flights which provide service to other cities involving one or more stops... (including off-line connections)' these scheduled routes provide service to 171 other cities... (providing) convenient access to all domestic airports when the connection potential of the served cities is considered... for every 100 inbound plus outbound passengers at Atlanta only 27 are Atlanta originations or destinations. Only one in 10 of the inbound plus outbound passengers is a resident of the Atlanta region."

> "During the morning busy hour from 10:00 o'clock to noon there are over 200 scheduled flights at the Atlanta airport. Flight connections are those flights departing one-half hour to two hours after a flight arrival. There are 97 flight arrivals from 68 different cities during the time interval from 10:00 o'clock to 11:30 daily each morning. There are 89 flight departures to 72 different cities during the time interval from 10:30 o'clock to noon... a total of 4,093 directional flight connections can be made during the peak involving service between the 116 different cities. Each day Atlanta provides over 14,000 directional flight connections."
>
> "When all considerations are taken into account, it would not be until the year 2000 that Atlanta as a two aircarrier airport hub could provide the present level of scheduled service at both airports."
>
> "In addition to the relationship of Hartsfield to a second aircarrier airport for Atlanta, the expansion potential at Hartsfield should be determined for future development of a centrally managed air traffic control system to provide increased runway aircraft acceptance rates. Development of an independent short-haul air system at Hartsfield airport using quiet, reduced take-off and landing aircraft should be studied to determine the probability of such a future technical improvement in operating capacity."

Assessment of the Aircraft Fuel Shortage

Certain premises are advanced for planning in the areas of short haul transportation and aircraft design, in spite of the numerous uncertainties and hazards in projecting the petroleum fuel situation. Aircraft fuel is such a small fraction of the petroleum used in transportation that its destiny will be determined as a by-product of the situation (or solution) worked out for the major users.

In very approximate terms, air transport revenue passenger miles grew 10 percent annually from 1967 to 1972 while fuel use grew about 5 percent annually. It is projected that air passenger growth may be maturing such that growth rates of 6 to 8 percent are projected for the future along with fuel demand growth rates of 2 to 4 percent. (The fuel requirements grow at a lower rate because of the phasing-in of larger, more 'fuel-efficient' aircraft.) It is concluded that requirements for aircraft fuel are likely to grow more slowly than the most modest estimates of total energy growth rates. Therefore, extreme penalties in airplane design and economics for absolute minimum fuel consumption are unwarranted.

Studies at NASA Ames Research Center have indicated that implementation of coal and shale conversion processes may stabilize aircraft fuel prices at two to three times the 1972 levels. No projections have been observed for fuel prices returning to less than twice 1972 prices. It is concluded that future aircraft design and operational procedures should be predicated on at least double the 1972 fuel price -- and escalated or inflated from that point along with the rest of the economy.

The aircraft design implications of fuel shortages include a slight lowering of design speeds to those which give minimum operating costs at the higher fuel prices. Fuel savings offset the penalty of increased block times. Moderate weight and cost increases for wings with higher aspect ratios are more than balanced by the savings in fuel costs. The lowering in speed also permits an increase in wing aspect ratio with minimum weight penalty. Of particular significance is the increase in aspect ratio without weight penalty which can be afforded by the greater thickness of advanced supercritical airfoils.

2. EVALUATION OF REQUIREMENTS

Requirements and criteria for mission performance, airworthiness and operations originated in the NASA request for proposal on the original systems study. During the course of that study, NASA requested that these be reexamined and that changes be recommended. The following discussion summarizes the bases for performance analysis and economic evaluation that have been applied.

Range

A baseline mission range of 926 km. (500 n.m.) has been applied widely as a criterion for short-haul transportation. It is based on analyses which show that approximately 50 percent of revenue passengers travel this distance or less. It was also the range suggested by Eastern Air Lines and American Airlines in their past requests for proposal of STOL aircraft. However, it is slightly inadequate for some significant high density segments between Chicago, New York, Atlanta and Miami. Both Eastern and Delta Air Lines have indicated a preference for additional range, suggesting that the flexibility for scheduling would increase utilization sufficiently to more than compensate for the penalties of flying a heavier airplane on short legs. Their experience in scheduling DC-9 and 727 aircraft leads to this conclusion. It has been suggested that the airplane should be capable of R/STOL performance for stage lengths up to 926 km. (500 n.m.) and able to perform CTOL takeoffs with a full passenger load and fuel for 2780 km. (1500 n.m). On the other hand, strong cases have been made for uncompromised austere short haul aircraft which would be most economical for the short segments (300 to 800 km.) that form the majority of legs. Passenger amenities that are required for stage lengths of more than 900 km. contribute to increased aircraft size and cost, as well as the structure required for heavier fuel loads.

The issue will be resolved in the long run by negotiation with airline customers when the environment permits implementation of advanced short-haul aircraft. This is most likely to be deferred to the 1980's in the case of high-density short-haul. The current task of evaluation of advanced lift concepts and fuel conservation is not significantly affected by this variable, although somewhat higher design cruise speeds would be appropriate for the longer ranges. Aircraft designs described in this report are based on 926 km (500 mi.) range with extensions in some cases to 2780 km (1500 n.mi) full-load capability with CTOL takeoff.

Passenger Capacity

Both Lockheed and McDonnell-Douglas have concluded that a passenger capacity of approximately 150 is well-suited for the high-density scenarios which were being examined in systems studies. The Lockheed analysis showed that return on investment for a representative case was essentially the same with aircraft of 100 and 200-passenger capacities. A passenger size of 148 was chosen for the purposes of further evaluation of lift concepts and fuel consumption.

As with the question of range, the size of the operational airplane will be resolved considering customer needs and the conditions prevailing in the 1980's; the comparative evaluations in the current study are essentially unaffected by this issue. It is anticipated that R/STOL evolution will progress from the current Twin Otter service through larger propeller-driven aircraft serving the shorter low-density segments; the next step may be fan-powered aircraft in the 60 to 100 passenger size, also with stage lengths limited to less than 900 km. Evolution to the high-density arena with extended range capability and larger aircraft is likely to follow these other steps. In each step, the availability and size of a suitable engine will be a strong factor in determining the matching airplane size.

Field Length

The rapid increase in cost as design field length was reduced below 914m. (3000 ft.) has led both Lockheed and McDonnell-Douglas to conclude that the best chance for a viable economical R/STOL short-haul system would involve 914m. (3000 ft.) or longer in available runway lengths. McDonnell-Douglas emphasized the use of secondary airports for city-pairs with significant local origination and destination traffic. They concluded that 914m. (3000 ft.) field performance would be desirable and that this capability was available at almost every site examined. Lockheed emphasized the importance of interconnection with other airline flights and suggested that congestion and noise relief would occur if CTOL short haul traffic was offloaded to non-interfering short haul runways 914m. (3000 ft.) or more at existing hub airports. The need for expanding the airport boundaries would be zero or minimal if the runway lengths were 914m. (3000 ft.) and would increase at some of the major airports if runway lengths of 1220m. (4000 ft.) were required. The Aviation Advisory Committee concluded that 1220m. (4000 ft.) runways were appropriate, and needed for short haul transport. No definitive cost tradeoff has been made that includes the airport expansion cost increment as a function of runway length. It is concluded that the requirement for 914m. (3000 ft.) airplane capability is sufficiently probable that it should continue to be pursued. Conditions in the late 1980's and beyond are most likely to lend considerable value to a 'real-estate stingy' airplane.

The design requirement that the airplane be capable of a given field performance on a 35°C (95°F) day has been associated with a sea level field elevation. It seems reasonable that higher-elevation airports can be assumed to compensate with additional runway length for the elevation effect. Other field requirements have also been included in the current study: 610m., 1070m., 1220m., and 1830m. (2000, 3500, 4000 and 6000 ft.). The consequent airplane designs and economics give perspective to the effect of this variable.

Cruise Speed and Altitude

Cruise speed of M 0.8 and 9140m. (30,000 ft.) altitude were selected as design requirements for 926 km (500 n.mi.) aircraft in the basic system study, based on the following considerations:

- Initial screening of quiet propulsive lift aircraft indicated that performance at this cruise condition gave the lowest direct operating cost in most cases – at 1972 cost and fuel price levels.
- Air-traffic compatibility with aircraft currently employed in short-haul air transport indicated the desirability for cruise in the neighborhood of M 0.8.
- For stage lengths up to 926 km. (500 n.mi.), flexibility in routing and ATC assignments indicated the desirability of 9140m. (30,000 ft.) altitude capability.

- For 926 km. (500 n.mi.) flights it was felt that block times should be approximately equivalent to those available from CTOL aircraft now performing the mission so that this factor would not be detrimental from the standpoint of passenger preference.

With the advent of an aircraft fuel shortage, and increased fuel prices, the aircraft in current use were slowed slightly to conserve fuel. This was beneficial with current aircraft designs such as the DC-9, down to approximately M 0.75. The influence on block time was negligible from the standpoint of the passenger for short-haul segments. Direct operating costs, in real terms, were either unaffected or slightly reduced from the fuel saving, compared with what they would be at faster speeds and lower block times. This amount of slow down did not require rescheduling of the airplane so that it flew as many revenue-miles per year as previously; the annual utilization increased in terms of block hours and the annual productivity was essentially unchanged.

In considering new short-haul aircraft designs it was considered appropriate to reexamine design cruise speed and altitude as they affected fuel consumption and direct operating cost at higher fuel prices. Design cruise speed of M 0.75, and perhaps lower would be competitive with current generation aircraft in the short-haul mission and would be compatible with air traffic in this environment. An evaluation of the effect of cruise speed and altitude, as a function of fuel price, is presented in the following sections of this report. It is suggested that aircraft flying a spectrum of stage lengths up to 926 km (500 n.mi.) in high density markets should have the capability of flying M 0.75 at 9140m. (30,000 ft.). In the following analyses, the DOC calculations are conservatively high for the slower aircraft because annual utilization has been assumed to be 2500 hr. per year; in practice the slower aircraft would probably have a higher annual utilization in terms of hours. The annual productivity in short-haul missions would probably be as high as faster aircraft.

Flight Profile, Performance Criteria, and Reserves

The flight profile and definition of fuel reserves were presented in Reference 2. No changes from the conditions selected initially have been deemed necessary or desirable. The following summarizes the criteria used:

1. Takeoff and initial climb according to the performance criteria of FAR XX (Ref. 8) for propulsive lift aircraft and FAR Part 25 for mechanical flap designs; sea level field at 35°C (95°F).

2. Power cutback at 213m. (700 ft.) for 4-engine aircraft or 305m. (1000 ft.) for 2-engine aircraft to that throttle setting which will maintain a positive climb gradient if an engine fails (Ref. FAR Part 36).

3. Acceleration to 460 km./hr. (250 knots) EAS and maximum climb at this speed after reaching a point where ground noise level is below 80 PNdB.

4. Climb to 3050m. (10,000 ft.) at 460 km./hr. (250 knots) EAS with allowance of 2 minutes for air maneuver.

5. Climb to cruise altitude at best climb speed for minimum block time.

6. Cruise at design cruise speed.

7. Descend at best descent speed for minimum block time, decelerating to 460km./hr. (250 knots) EAS at 3050m. (10,000 ft.). Cabin pressurization of 61 kN/sq.m. (8.8 psi) was established to permit maximum climb and descent rates while restricting change of pressure in the cabin to 91m. (300 ft.) per minute change in cabin altitude.

8. Descent at 460 km./hr. (250 knots) EAS to 305m. (1000 ft.) decelerating to approach speed defined in Section 3. Allowance in block time of 2 minutes is made for air maneuvers.

9. Descent at 4.6m./sec. (900 ft. per minute); flare to touchdown at 3m./sec. (10 fps).

10. 1 Second delay; rollout deceleration 0.35g.

Reserves are provided for 370 km at cruise altitude plus 15 minutes at 3030m. (10,000 ft.) altitude, maximum endurance speed.

Noise Criteria

The premise is advanced that the proposed rules for fleet noise levels will be in effect or that modifications will achieve the same effect by 1980 -- all aircraft at or below FAR Part 36. Although the L1011 and DC-10 are quieter than the levels permitted by FAR Part 36, the EPNdB levels of smaller aircraft just meeting FAR 36 are roughly the same as the noise level of the heavier wide-body aircraft. Frequency at the major airports is unlikely to increase significantly since passenger growth can be satisfied by substitution of larger aircraft. Thus, frequency and level of noise exposure will not change significantly by 1980.

Airplanes being delivered now or on order will be in service through the 1980's and it seems clear that it would be disastrous to both the airlines and the national economy to force more stringent standards on this fleet. Nevertheless, a gradual lowering of average fleet noise levels (and average airport community exposure levels) seems to be in the best interest of all concerned. Design requirements for new aircraft of 10 dB below existing FAR 36 levels are highly probable by the 1980's. It would be logical that a fleet noise averaging process be incorporated in the regulations so that the community noise benefit of the gradual introduction of quieter aircraft could be passed on as an incentive to airline operators.

Further quieting to 90 EPNdB at the airport boundary (18 EPNdB below the FAR 36 level 6.5 km (3.5 n.mi.) from brake release) for large aircraft was called for as a research goal by the CARD study (Ref. 11). Aircraft below 34,000 kg (75,000 lb.) gross weight would have a level of 80 EPNdB at the airport boundary (22 dB below the FAR 36 level for approach noise at 1.85 km

(1 n.mi.) from threshold). These goals are indeed ambitious, as the CARD report recognized in stating . ". . . establishment of such ambitious research goals at this time is a controversial issue but the failure to establish a low-level noise goal now could result in the application of scarce resources to R and D activities that may fail to provide the desired solution to the noise problem on a long-term basis."

It is concluded that designers of new aircraft to be operational by 1985 should recognize the high probability of a FAR 36 minus 10 noise requirement (as others have concluded, Ref. 12 and 13). Further lowering of levels for large long-range CTOL aircraft is likely to be much slower in coming, as the economic penalties are high for this class of aircraft. Aerodynamic noise calculations and measurements on 272,000 kg (600,000 lb.) aircraft show that FAR 36 minus 8 to 10 EPNdB would be the lowest noise level on approach that a large CTOL aircraft could achieve, regardless of how quiet the engines are. Additional quieting of aerodynamic noise would require a technological breakthrough or a decrease in approach speed (toward R/STOL characteristics). For long-range aircraft the penalties for this performance have not been assessed. For shorter-range aircraft the penalties may not be prohibitive for further lowering of noise level by 1990.

If aircraft capacity is increased by provision of non-interfacing runways for short-haul aircraft, new areas of the community are subject to impingement by aircraft noise. The appropriate compromise for establishing an allowable level at the airport boundary has not been established. The CARD research goal shows noise level varying from 80 EPNdB for 34,000 kg (75,000 lb.) aircraft to 90 EPNdB for 272,000 kg (600,000 lb.) aircraft. The data needed for a rational answer would be the tradeoff of aircraft operating cost against the cost to move the airport boundary. Data on the aircraft cost portion of this balance are given in subsequent sections of this report. It seems clear that the noise level on the takeoff or approach path will be more pertinent than the sideline noise level.

Short-haul runways on hub airports or use of secondary airports will require different criteria such as minimum footprint area and length. Downtown STOLports, now regarded as unlikely to be accepted or be operational in the 1980's, might well require 80 to 90 EPNdB noise levels at the airport boundaries; the Sperry box dimensions would represent a rectangular area 1830m. (6000 ft.) long by 610m. (2000 ft.) wide.

The approach used in the current analyses was based on the previous work which indicated that selection of an engine fan pressure ratio capable of meeting a given noise level without extensive nacelle treatment provided the lowest cost aircraft system. Consequently, the nacelles for all the systems (except augmentor wing) were designed for aerodynamic performance and acoustic treatment was applied to the walls only. In the case of the augmentor wing, the high fan pressure ratio required inlet treatment and acoustic lining of the augmentor flap. Airplanes covering a range of noise levels were designed by the use of different engines, each with acoustic wall treatment in fan inlet and exhaust. The footprint areas and contour shapes were determined for a wide range of aircraft designs and from these the economic and fuel penalties were determined for meeting any chosen level of community noise.

Economic Evaluation Criteria

The primary basis for evaluating airplane designs and for selecting optimum airplane characteristics was the direct operating cost based on updating the 1967 ATA "Standard Method of Estimating Direct Operating Costs of Turbine Powered Transport Aircraft." In the initial system studies the factors were updated to be representative of 1972 costs and prices.

These same factors were retained for convenience of comparison with the initial studies, assuming that price escalation would apply uniformly to all factors except for fuel. In the current studies, additional fuel price cases were considered and defined as follows:

DOC-1 – 11.5¢/gal.
DOC-2 – 23¢/gal.
DOC-4 – 46¢/gal.
DOC-10 – $1.15/gal.

As in the initial studies, an annual utilization of 2500 hours was assumed for those aircraft with a maximum design range of 926 Km (500 n.mi.). Aircraft with a design range of 2778 Km (1500 n.mi.) were assumed to have a utilization of 3000 hours.

Airframe and engine costing was on the same basis as described in Section 2.9 of Reference 2. Cost factors were derived from detailed value engineering analysis of component cost in the Electra and C-141 programs with adjustments for complexity factors. Production quantities of 300 aircraft and 1500 engines formed the basis for pricing, with an allowance of 13 percent profit. These quantities, in general terms, are considered to represent approximately the minimum size program which would be viable and, at the same time, the maximum number of units which would be projected for the purpose of setting a price considering normal practice with respect to risk assessment.

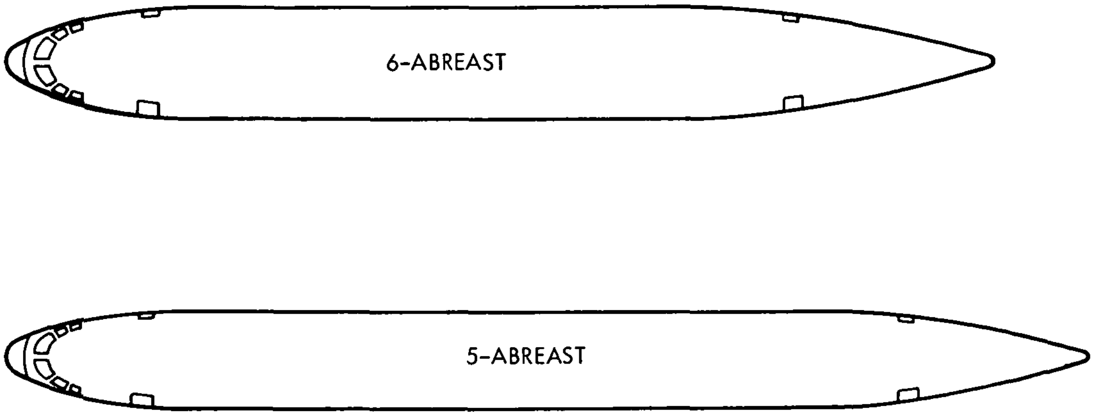
In the case of 2-engine aircraft, the number of engines including spares was 750, associated with a 300-aircraft program. Pricing data from the QCSEE studies showed that the unit price for this quantity would be 25 percent higher than the price for a 1500-unit production. The effect of this is approximately 4 percent increase in aircraft DOC and this effect is shown in the subsequent analyses. However, it was concluded that engines with fan pressure ratios of 1.35 to 1.6 would have sufficient value for CTOL applications that the larger production quantity should be used as the baseline condition for the evaluation of twin-engine aircraft for this category of engines.

3. CANDIDATE AIRCRAFT DESIGNS

For the baseline size of aircraft, 148 passengers, the fuselage was a 6-abreast configuration with a single aisle 69 cm (27 inches) wide. This arrangement, shown in Figure 3, permits passengers to pass beside a serving cart in the aisle, and provides one percent lower DOC and 2.6 percent lower fuel consumption than a twin-aisle arrangement. A 5-abreast configuration is slightly lower in weight and wetted area; it was used in the fuel conservative configurations.

Both high-wing and low-wing configurations are represented in the aircraft designs summarized in the following sections. A low wing is advantageous for the 5-abreast fuselage because the landing gear pods for a high-wing airplane become large to provide adequate main-gear tread.

Engines used in the designs were those defined in the pre-hardware phases of the QCSEE (Quiet Clean STOL Experimental Engine) program, with the addition of a near-term bypass 6 engine currently under development.



		6-ABREAST	
	5-ABREAST	SINGLE-AISLE	TWIN-AISLE
RELATIVE FUEL	0.99	1.00	1.026
RELATIVE DOC	0.997	1.00	1.01

Figure 3 Fuselage Configurations

In all cases, emphasis was given to designs meeting noise levels equivalent to 95-100 EPNdB at 152m (500 ft.) sideline. The range of fan pressure ratios for engines used in the designs was chosen to cover a range of noise levels from slightly below 95 to considerably higher than 100 EPNdB at this sideline location. Effects of this variation are summarized later. The concepts were compared at approximately the same low noise level by utilizing the engine fan pressure ratios and noise treatment listed in Table I.

Lift Concept	Engine FPR	Acoustic Treatment
Hybrid OTW/IBF	1.35	Nacelle Wall only
Augmentor Wing	3.0 - 3.2	High Mach Inlet; Exhaust Duct Wall; Flap Cavity
Mechanical Flap	1.35	Nacelle Wall only
Externally Blown Flap	1.25	Nacelle Wall only
Over-the-Wing	1.35	Nacelle Wall only
Boundary Layer Control/ Vectored Thrust	1.3	Nacelle Wall only
Internally Blown Flap/ Vectored Thrust	1.3	Nacelle Wall only
Deflected Slipstream	(Turboprop)	Nacelle Wall and Low Tip-Speed Prop

Table I **Engine Selection for Concept Comparison of Equivalent Noise Levels**

An advanced airfoil was used in all of the configurations, providing a greater wing thickness for a given drag rise, sweep angle, and design cruise speed. Figure 4 shows examples of the thickness/chord ratios for 1960, 1965, and 1974 technology levels. The reference level, defined as 0 increment of drag divergence Mach No., is the C-141 airfoil which had a t/c of 11 percent with 25 degrees sweep and a compressibility drag rise of 7 counts at M 0.75. The "peaky" airfoil of the C-5 is slightly thicker and has a compressibility drag rise of 10 counts at M 0.77; the increment of drag divergence Mach No. for the same thickness as the C-141 would have been on the order of 0.03. The right-hand bar shows the technology level which has been demonstrated in wind tunnel tests in 1974 and used in the current designs, equivalent to an increment in drag divergence Mach No. of 0.080.

The following discussion is organized to cover first the design refinement of the hybrid OTW/IBF concept and changes associated with minimizing fuel consumption or minimizing operating cost at higher fuel prices. Next the augmentor wing and mechanical flap concepts are covered. The other lift concepts are examined more briefly from the standpoint of fuel conservation.

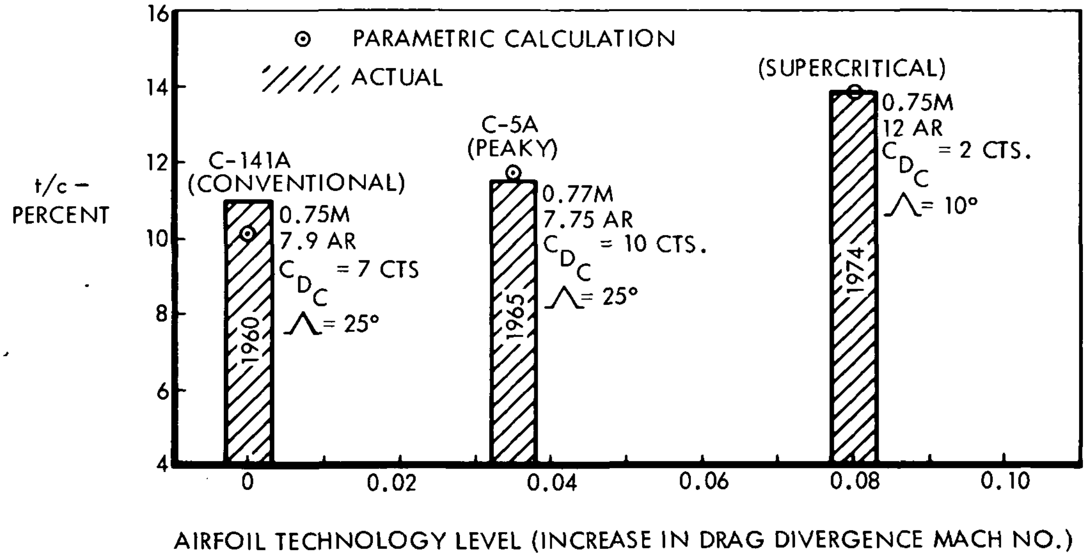


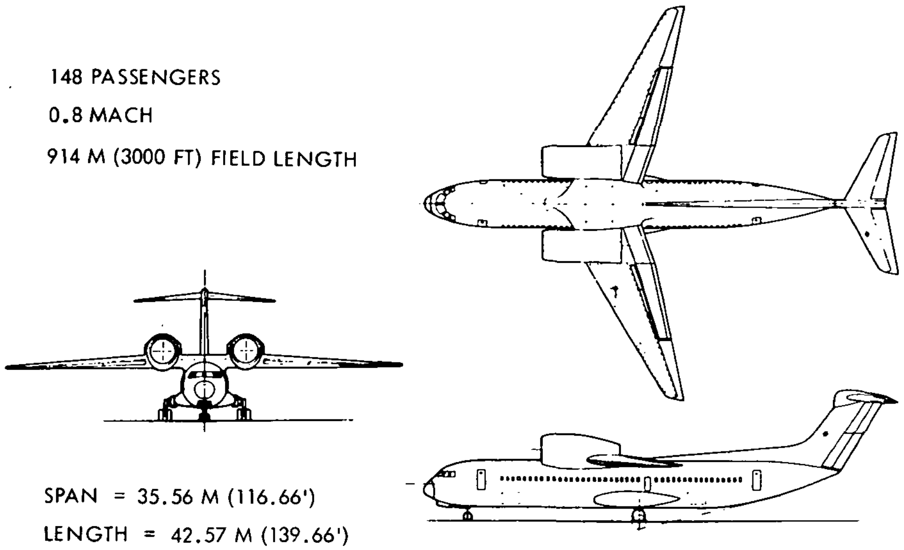
Figure 4 **Thickness/Chord Comparison of Aircraft with various Airfoil Technology Levels**

Baseline Hybrid OTW/IBF Aircraft

The concept of the hybrid OTW/IBF system was developed midway through the original Systems Study Contract. It was observed that an internally blown flap provided superior low-speed lift augmentation but required vectoring of the fan air to achieve the approach speeds and glide slopes required for landing performance. Thrust vectoring with low-noise engines was a costly penalty because of the large diameter of the exhaust nozzle associated with a low fan pressure ratio. Cruise performance penalties were minimized by location of the engines over the wing and use of Coanda attachment for thrust vectoring. Suitable cross-ducting of a small proportion of the fan air in the IBF system made it possible to achieve lift symmetry with an engine out for a two, three, or four engine configuration.

The baseline aircraft resulting from design refinement, and optimized for minimum direct operating cost at 1972 fuel prices (DOC-1) is shown in Figure 5. Detailed analysis covered the following areas:

- Nacelle inlet, exhaust and thrust reverser design; Coanda jet deflection.
- Mass flow split, ducting, and flap configuration.
- Limits on engine size related to wing area, expressed as thrust/wing area (T/S) limit.
- Aerodynamic performance and comparison of data from Lockheed and other wind tunnel tests.
- Weights of flap, ducting, wing box and/or the other components.



148 PASSENGERS
0.8 MACH
914 M (3000 FT) FIELD LENGTH

SPAN = 35.56 M (116.66')
LENGTH = 42.57 M (139.66')
HEIGHT = 11.78 M (38.66')

Figure 5 914m (3000 Ft.) OTW/IBF Vehicle

The engine is positioned so it can be lowered vertically forward of the wing front beam. The nacelle configuration of one of the candidate OTW/IBF engines is shown on Figure 6. These nacelles represent aerodynamically designed internal and external contours with no compromise for acoustics. However, acoustic materials are installed on walls of the inlet and exhaust ducts where this treatment does not interfere with the internal aerodynamic lines. The aft nacelle contains the thrust reverser which consists of an upward movable panel and blocker door arrangement to reverse the OTW portion of the fan exhaust stream; the IBF fan stream and the primary stream will remain unaltered. The lower aft nacelle will contain a "flow collection" device to route fan air flow into the IBF system for terminal area operation and that can then be shut down for cleaned up climb and cruise operation. The nacelle inlet/forebody shapes have been designed to provide good cruise recovery levels while maintaining reasonable losses for terminal area operation. The inlets have been designed to minimize the flow distortions due to upwash angles that might be experienced by over-the-wing mounted engines.

A subcontract with Detroit Diesel Allison covered studies of fan-air bleed systems for hybrid OTW/IBF aircraft, potential emergency or contingency ratings for engine loss conditions during terminal operations, surge margin requirements, and generation of additional noise data. The studies showed that a representative low-noise engine can tolerate diversion of up to 20 percent of the fan flow to a common plenum duct for IBF mass flow. An emergency power rating of 108 percent of nominal takeoff thrust could be achieved for 3 minutes on a hot day, provided that less than 96 percent of the engine life had been used. (No further application was made of this feature since the saving in engine size would be offset approximately by the reduction in engine usable life.)

The engine surge margin study was concerned with the characteristic of low fan pressure ratio engines which require a smaller nozzle area at cruise speed than that required during-terminal area operation. It was initially proposed that this area change could be achieved by the bleed system to the flap as shown in the left-lower diagram in Figure 7. The effect of this step change in area on surge margin is unacceptable when compared to the effect of a standard variable nozzle in the left-upper diagram. An alternate method of maintaining surge margin during flap operation is by variable pitch fan blade modulation as shown in the right-upper diagram. A further alternate is to modulate the flap nozzle as discussed in the lower-right of the figure.

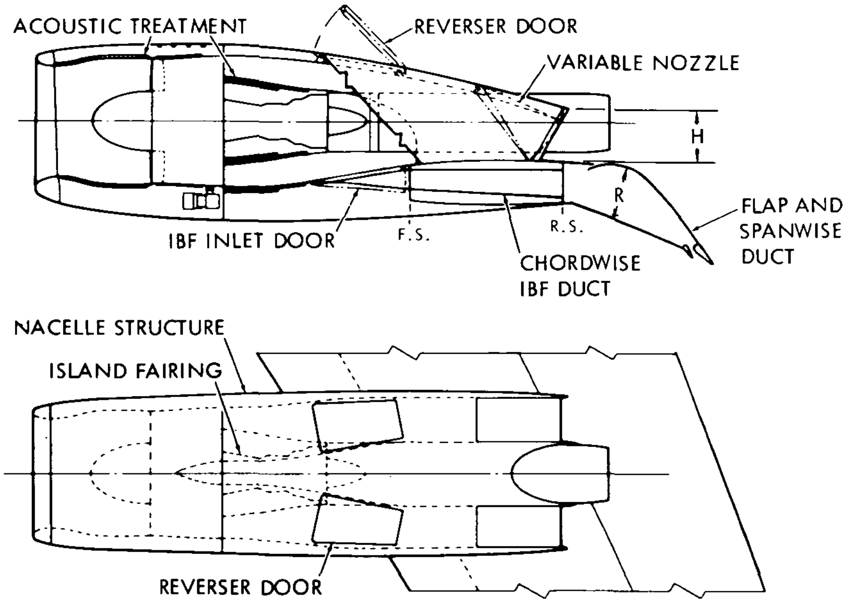
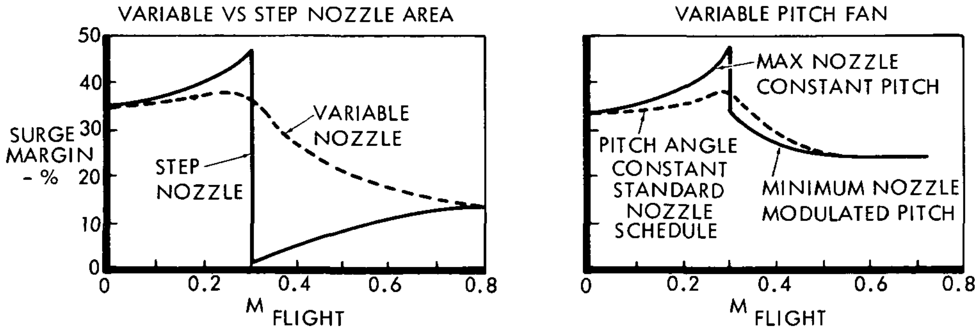
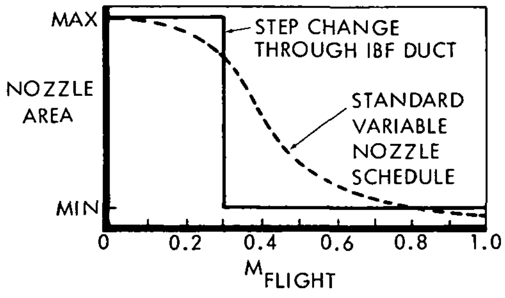


Figure 6 OTW/IBF Nacelle Installation





- o IBF BLEED MODULATION COULD REPLACE VARIABLE NOZZLE
- o REQUIRES FLOW THROUGH FLAP AT ALL TIMES UP TO CRUISE M, AND WITH FLAP RETRACTED.
- o LARGER LOSSES DURING CLIMB
- o FLAP AND DUCT SYSTEM SUBJECT TO PRESSURE FOR LONGER TIME PERIOD.

Figure 7 Methods for Maintaining Engine Surge Margin

Characteristics of aircraft resulting from design refinement are summarized in Table II. Each was designed for carrying 148 passengers for a stage length of 926 km (500 n.mi.) when operated from CTOL runways. Cruise speed and initial cruise altitude were M 0.8 and 9140m (30,000 ft.) respectively. Utilization of 3000 hrs per year was assumed in calculating the direct operating cost because of the CTOL longer-range capability. Although these aircraft were optimized for fuel prices at 1972 levels (identified as DOC-1), the table shows the effect of multiples of 2, 4, and 10 times that fuel price (identified as DOC-2, DOC-4, and DOC-10).

It may be noted that a 4-engine airplane was lighter in weight and lower in direct operating cost than a 2-engine configuration for 610m (2000 ft.) field performance. The 2-engine

148 Passengers
M 0.8 at 9140 m. (30,000 ft.)

926 Km Range with Design Field Length
2780 Km Range with CTOL Takeoff

Design Field Length - M	610	914	914	1,070
(Ft.)	(2,000)	(3,000)	(3,000)	(3,500)
Engine Fan Pressure Ratio	1.35	1.35	1.47	1.35
No. of Engines	4	2	2	2
Ramp Gross Weight - Kg	73,190	75,987	78,849	73,279
(Lb.)	(161,360)	(167,520)	(173,830)	(161,550)
Operating Weight - Kg	44,489	45,670	46,267	43,768
Lb	(98,080)	(100,680)	(102,000)	(96,490)
Wing Loading - Kg/sq. m.	467	449	459	471
(T.O. 926 Km Mission) Lb/sq. ft.	95.6	92.0	94.0	96.5
Wing Aspect Ratio	10	7.7	7.7	7.7
Wing Thickness/Chord	0.127	0.131	0.130	0.130
Thrust to Weight Ratio	0.43	0.49	0.47	0.46
Thrust/Engine - KN	74.3	175.5	172.0	160.3
Lb.	16,760	39,450	38,660	36,040
Cruise Thrust Setting	1.0	0.93	0.79	0.98
926 Km (500 n.m.) DOC-1 - ¢/ASSM	1.74	1.61	1.59	1.59
DOC-2 - ¢/ASSM	2.02	1.92	1.94	1.89
DOC-4 - ¢/ASSM	2.58	2.52	2.63	2.47
DOC-10 - ¢/ASSM	4.25	4.35	4.80	4.24
Mission Fuel - Kg	6,128	6,687	7,607	6,476
Lb	13,510	14,742	16,770	14,276
2780 Km (1500 n.m.) DOC-2	1.51	1.44	1.47	1.40
Mission Fuel - Kg	13,145	14,554	16,565	13,872
Lb	28,980	32,086	36,518	30,582
Complete Aircraft Price - $M	9.622	8.831	8.696	8.578
Engine Price - $M	3.128	2.110	1.902	2.045

Table II OTW/IBF Baseline Aircraft Characteristics

configuration would differ in the following ways:

- T/W 35% higher for the same wing loading
- Consequent higher engine weight and cascading increases in other component weights
- Inferior matching of cruise and takeoff thrust requirements giving lower cruise efficiency; engines would be operated at part power in cruise.

At 914m (3000 ft.) field performance and above the takeoff and cruise thrust requirements are better matched for a 2-engine airplane. Price advantages for 2 engines instead of 4 smaller ones combine to make the 2-engine configuration lower in DOC at M 0.8 and at 1972 fuel prices.

Fuel-Conservative Hybrid OTW/IBF Aircraft

The aircraft were re-optimized to determine the configuration, and design characteristics, which would give minimum direct operating cost at 2, 4, and 10 times 1972 fuel prices (DOC-2, DOC-4, and DOC-10), as well as defining characteristics for minimum fuel consumption. Because of the large number of cases to be considered, the aircraft were designed for 926 km (500 n.mi.) range only, with associated utilization of 2500 hours per year; the comparisons would be valid and could be applied to aircraft with extended range and CTOL takeoff. The following parameters were evaluated: design cruise speed and altitude; field length; engine FPR; number and size of engines; cruise power setting; aspect ratio; and wing loading.

Figures 8 and 9 show the effect of design cruise speed on fuel required for a 926 km (500 n.mi.) mission and on DOC-2. In both figures, the following are covered:

- two and four engines with 1.35 FPR.
- field lengths 610m, 914m, 1070m (2000, 3000 3500 ft.)
- Airplanes optimized (aspect ratio and cruise altitude selected) for minimum fuel consumption at each speed - - solid line
- Airplanes optimized for minimum DOC-2 -- dashed line

Figure 8 shows that four-engine airplanes provide minimum fuel consumption at all design speeds and field lengths. Design speed for minimum fuel is Mach 0.6 to 0.65.

Figure 9 shows that:

- differences in DOC between minimum fuel and minimum DOC designs are less than 2%.
- design speed for minimum DOC-2 is Mach 0.70 to 0.74
- four-engine designs provide lowest DOC-2 except for cruise speed above M 0.77 in the case of the 1070m (3500 ft.) design.

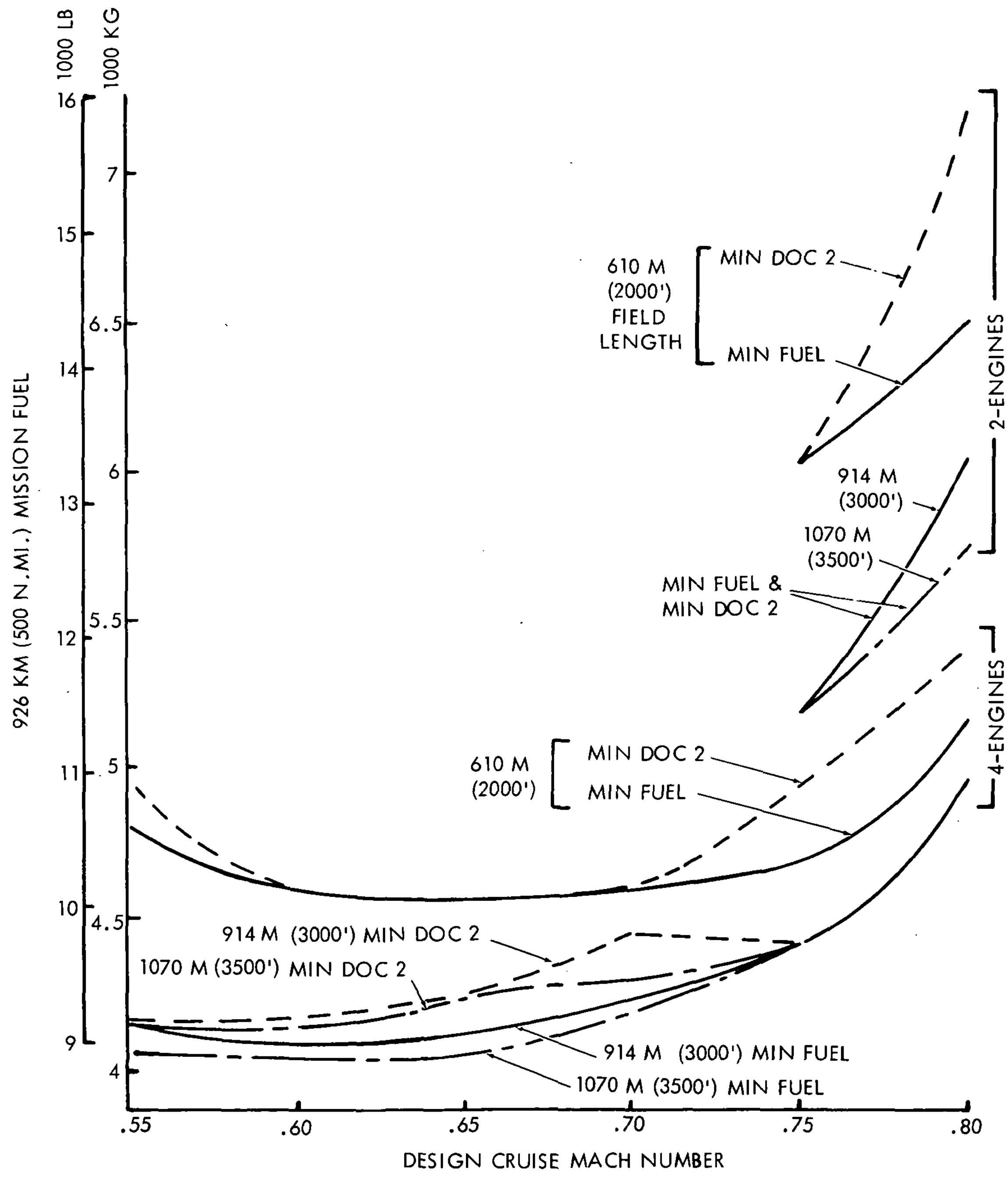


Figure 8 Mission Fuel versus Design Cruise Mach Number – 1.35 FPR OTW/IBF

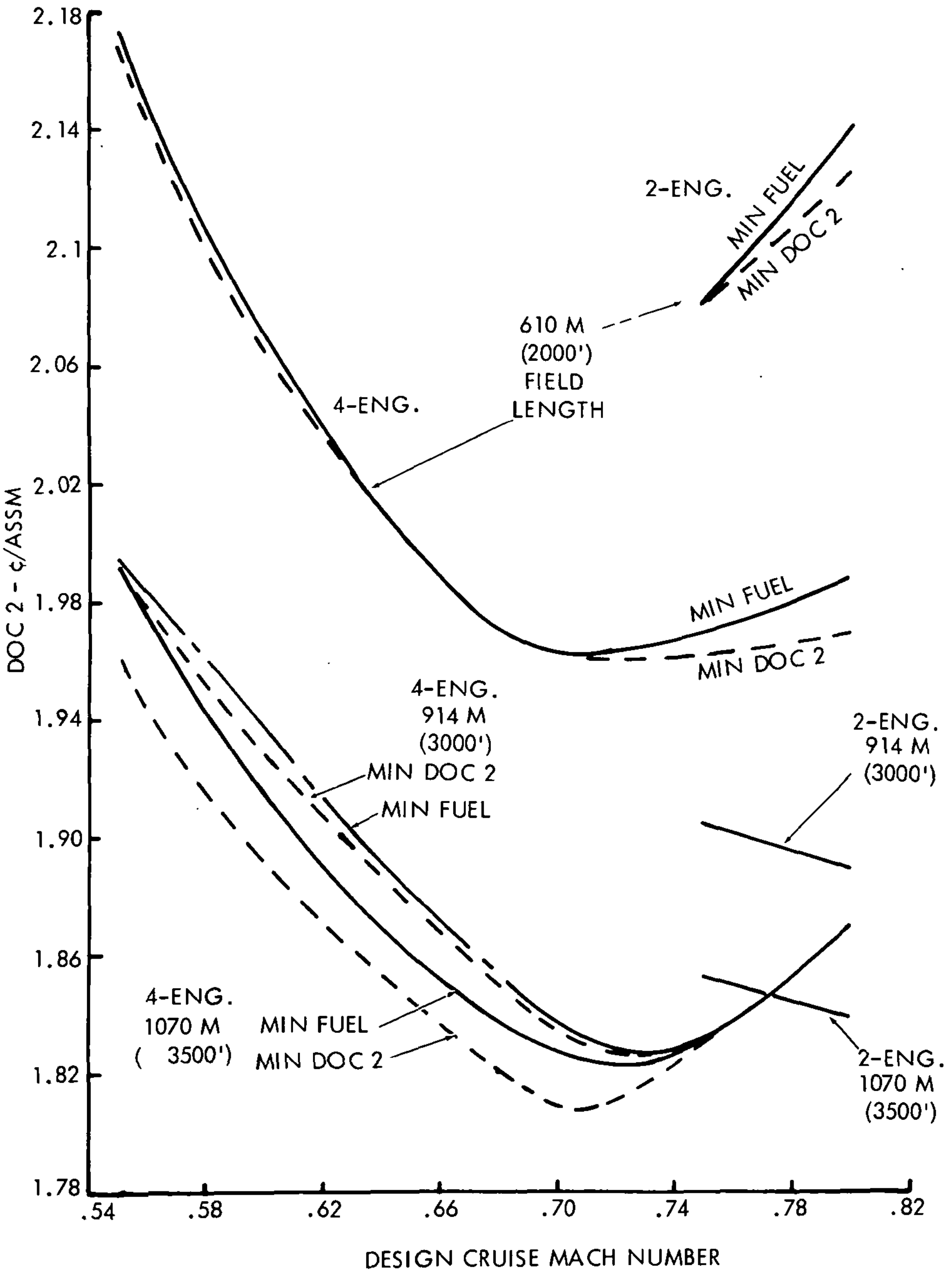


Figure 9 1.35 FPR OTW/IBF DOC-2 versus Design Cruise Mach Number

Figures 10, 11 and 12 show effect on fuel and direct operating cost of varying fuel costs and cruise speed, cruise altitude, and aspect ratio. The following are represented:

- two and four engines with 1.35 FPR
- field length 914m (3000 ft.)
- 926 Km (500 n.mi.) range
- Four-engine designs provide lower DOC at all fuel costs except for cruise speed above M 0.78 at a fuel cost of 11.5 ¢/gallon (DOC-1).
- Best design speed for minimum DOC-1 is M 0.80
- Optimum design speed decreases as fuel price increases; it is M 0.68 for minimum DOC-10 (fuel at $1.15/gallon)
- Best cruise altitude for minimum fuel and DOC -- 9140m (30,000 ft.)
- Aspect ratios and No. of engines for minimum DOC:

  7.73 for 11.5c/gal fuel (DOC-1) -- 2 engines
  12.25 for 23c/gal fuel (DOC-2) -- 4 engines
  14 for fuel at 46c/gal and above - - 4 engines

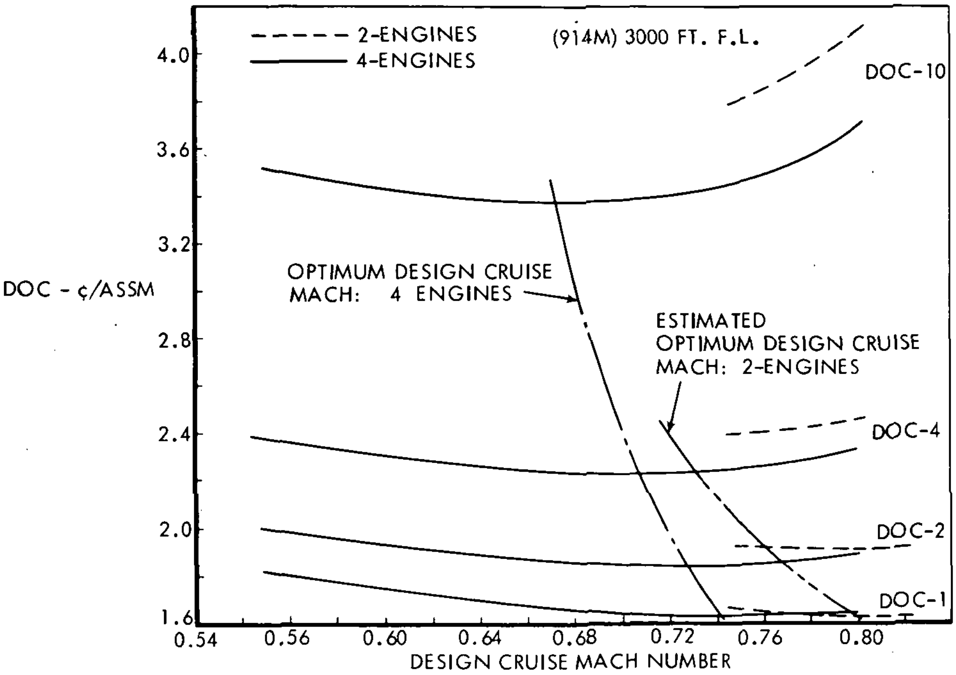


Figure 10 1.35 FPR OTW/IBF Effect of Fuel Price on Optimum Design Cruise Speed

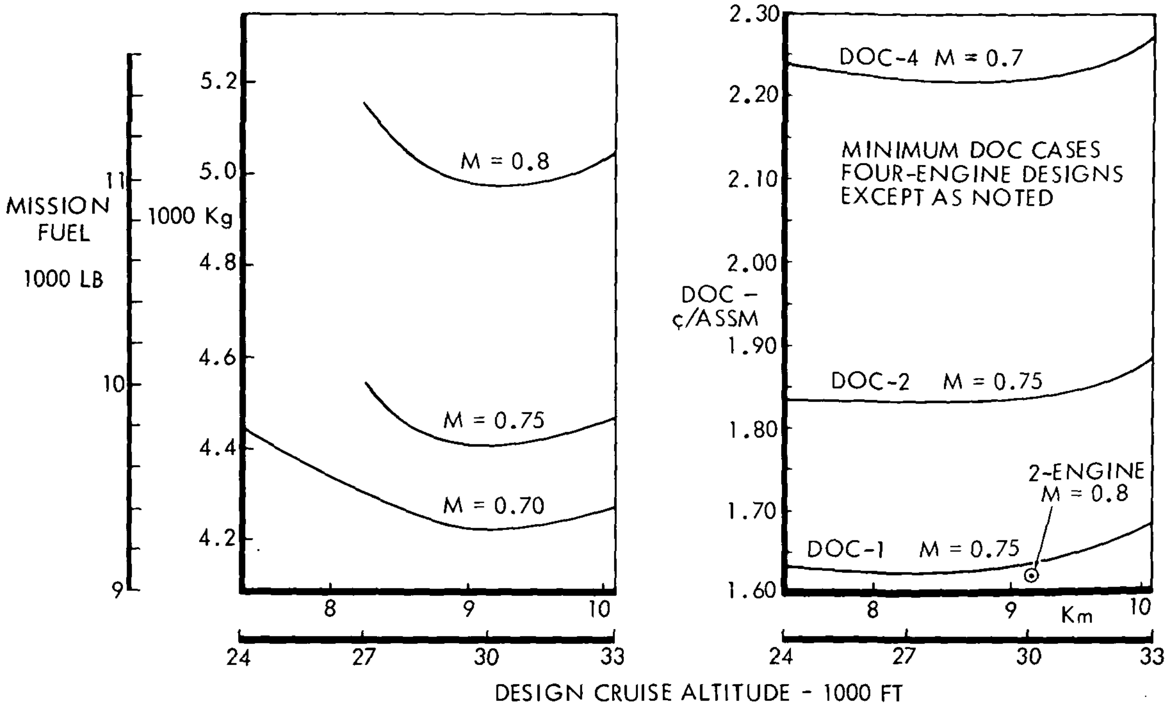


Figure 11 Effect of Cruise Altitude – 914m (3000 ft.) OTW/IBF 1.35 FPR

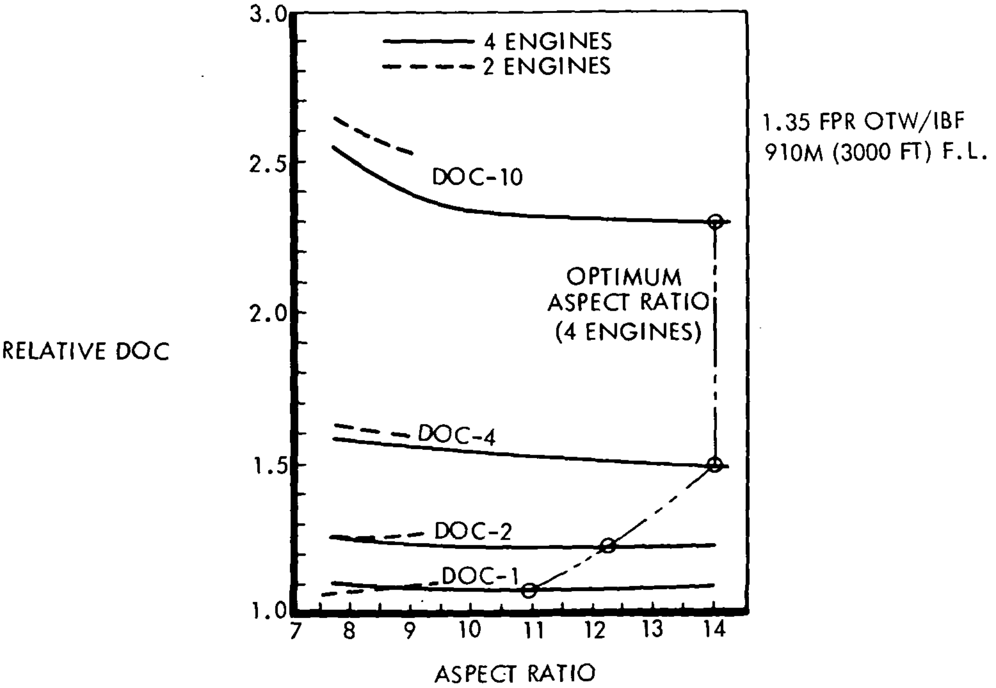


Figure 12 Effect of Fuel Price on Aspect Ratio Optimization

Table III summarizes the design characteristics of the OTW/IBF configurations designed for 148 passengers, 926 km (500 n.mi.) range, 914m (3,000 ft.) field length and optimized for minimum DOC-1, 2, 4, and 10 and for minimum fuel. For reference, the study airplane reported in NASA CR 114612 (Ref. 2) is also tabulated in the first column. The higher DOC-1 for this airplane, compared to the present study airplane shown in column 2, is due primarily to the higher-priced variable-pitch fan (pressure ratio 1.32) engine used in the reference 2 design. The data in column 2 reflect the refinement achieved in the present study in the airplane designed for minimum DOC-1. Also shown in this column are the DOC-2, DOC-4, and DOC-10 values for that same airplane. The third column shows that for minimum DOC-2, the design cruise speed decreased to Mach 0.75, the optimum number of engines increased from 2 to 4, and the gross weight decreased significantly. DOC's at different fuel prices are also shown for this airplane. Aircraft with minimum DOC-4 and DOC-10 were identical in the discrete designs examined; design speed and gross weight were further reduced. The last column shows that the aircraft consuming least fuel has a design speed of Mach 0.60. Because of the lower productivity associated with this speed, and higher crew and amortization costs per mile, the DOC is higher at all fuel prices evaluated -- up to 10 times 1972 fuel prices. The vehicle optimized for DOC-2 is illustrated in figure 13. The wing with aspect ratio 12 permits clearance between engines and fuselage so that a low-wing configuration can be used. This is more compatible for landing gear installation with the narrower 5-abreast fuselage.

	1.32 FPR V.P. DOC-1 REF. 2	OPTIMIZED FOR				
		DOC-1	DOC-2	DOC-4	DOC-10	MIN. FUEL
MACH NO.	0.8	0.8	0.75	0.70	0.70	0.60
NO. OF ENGINES	2	2	4	4	4	4
OWE - KG	44,570	43,450	36,510	35,290	35,290	34,870
(LB)	(98,250)	(95,790)	(80,490)	(77,800)	(77,800)	(76,880)
GROSS WEIGHT - KG	66,840	65,550	56,450	54,670	54,670	53,910
(LB)	(147,350)	(144,520)	(124,440)	(120,520)	(120,540)	(118,860)
RATED THRUST - KN	163.7	167.5	55.3	48.0	48.0	44.1
(LB)	(36,810)	(37,660)	(12,440)	(10,790)	(10,790)	(9,910)
MISSION FUEL - KG	6,330	6,030	4,400	4,210	4,210	$\boxed{4,070}$
(LB)	(13,960)	(13,300)	(9,700)	(9,290)	(9,290)	(8,975)
AR	7.0	7.73	12	14	14	14
*DOC-1 -- ¢/ASSM.	$\boxed{1.797}$	$\boxed{1.616}$	1.634	1.646	1.646	1.747
DOC-2 -- ¢/ASSM.	-	1.889	$\boxed{1.831}$	1.837	1.837	1.937
DOC-4 -- ¢/ASSM.	-	2.437	2.246	$\boxed{2.221}$	2.221	2.307
DOC-10 - ¢/ASSM.	-	4.08	3.441	3.373	$\boxed{3.373}$	3.422
$W/S_{T.O.}$ - KG/SQ. M.	455	449	554	530	530	457
(LB/SQ.FT)	(93.2)	(92.0)	(113.5)	(108.5)	(108.5)	(93.5)
90 EPNdB T.O. AREA SQ. KM	1.30	1.19	1.53	1.45	1.45	1.40
(SQ. MI.)	(0.5)	(0.46)	(0.59)	(0.56)	(0.56)	(0.54)
				IDENTICAL AIRPLANE		

* ENGINE PRODUCTION QUANTITY: 750 IN REF. 2
1500 IN PRESENT PHASE

Table III Fuel Conservative Airplane Characteristics, 1.35 FPR, OTW/IBF, 914m (3000 ft.) F.L.

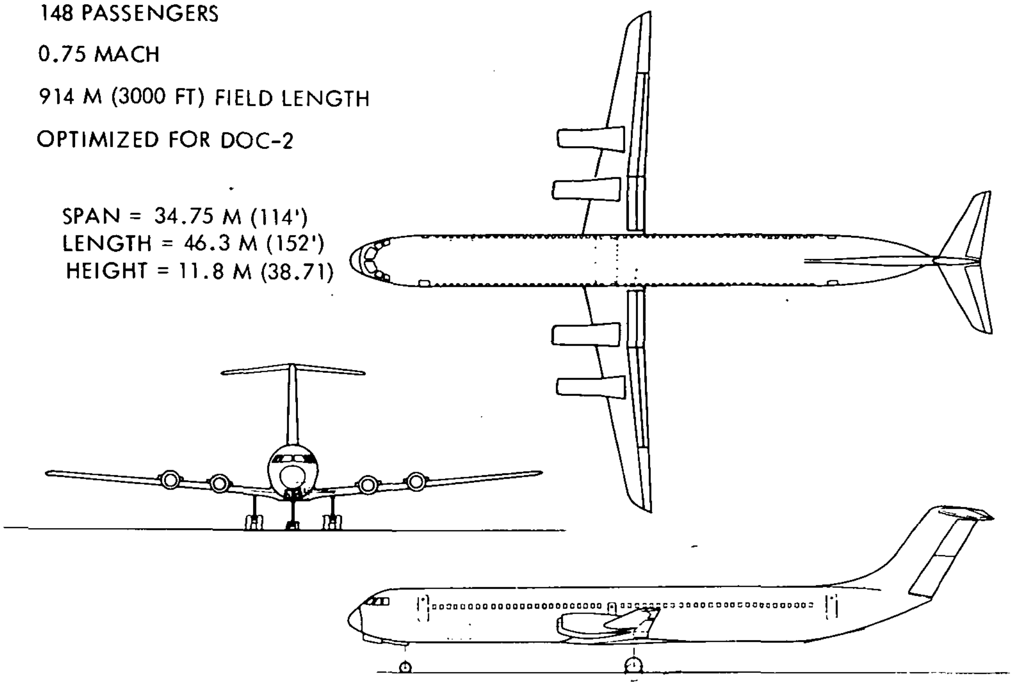


Figure 13 914m (3000 ft.) F.L. OTW/IBF Vehicle Optimized for DOC-2

OTW/IBF Mission Performance

A typical operational envelope for takeoff is shown in Figure 14.; this represents the baseline 914m (3000 ft.) OTW/IBF design having two 1.35 FPR engines and a 7.73 aspect ratio. The FAR XX second segment climb gradient of 1.73 degrees is critical. Liftoff occurs at 196 Km/hr. (106 knots) TAS at an angle of attack of 15 degrees. Takeoff field length as a function of takeoff weight is given in Figure 15.

Various climbout techniques were studied in order to minimize the takeoff noise foot print areas. The takeoff climbout profile shown in Figure 16 uses the technique adopted for the takeoff noise analyses. Gear retraction is assumed to occur 10 seconds after passing the 10.7m (35 ft.) screen, during which interval the aircraft accelerates 27.8 km/hr. (15 knots) TAS. From this point the climb is continued with all engines at maximum takeoff thrust and the flaps maintained at the take-off setting, until the FAR 36 minimum height for power cutback is attained. At this point, power is reduced to the level which permits zero climb gradient in the event of engine failure. The climb is then continued, maintaining the take-off flap setting, to the FAR 36 measuring point of 6.5 km (3.5 n.mi.) from brake release. For the baseline aircraft the height at this point is 994m (3260 ft.) above the runway.

The payload-range performance shown in Figure 17 illustrates the design in which maximum payload, 148 passengers, can be carried 2780 km (1500 n.mi.) with a CTOL takeoff. As shown, the maximum payload can be carried 926 km (500 n.mi.) with a takeoff distance of 914m (3000 ft.).

GROSS WEIGHT = 148,200 LB.
67,224 KG.

FLAPS = 12.7°

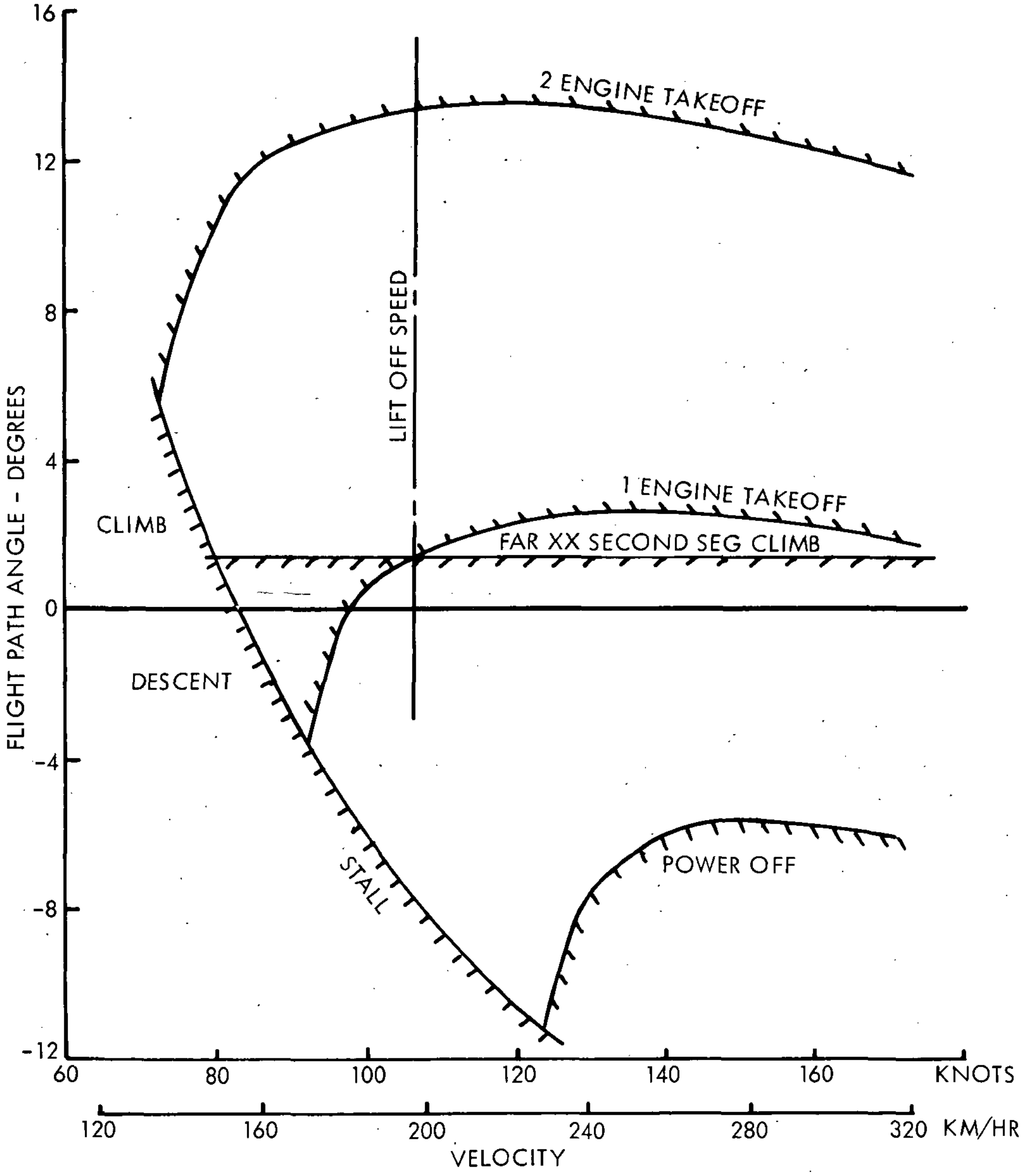


Figure 14 Takeoff Operational Envelope – 1.35 FPR OTW/IBF, 914m (3000 ft.) F.L.

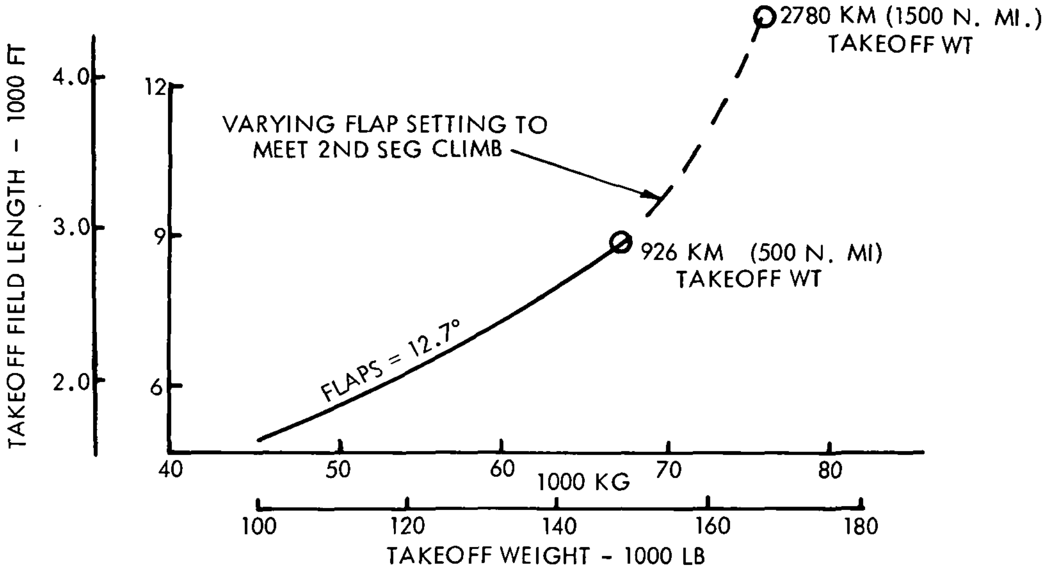


Figure 15 Takeoff Performance – 1.35 FPR OTW/IBF at 914m (3000 ft.) F.L.

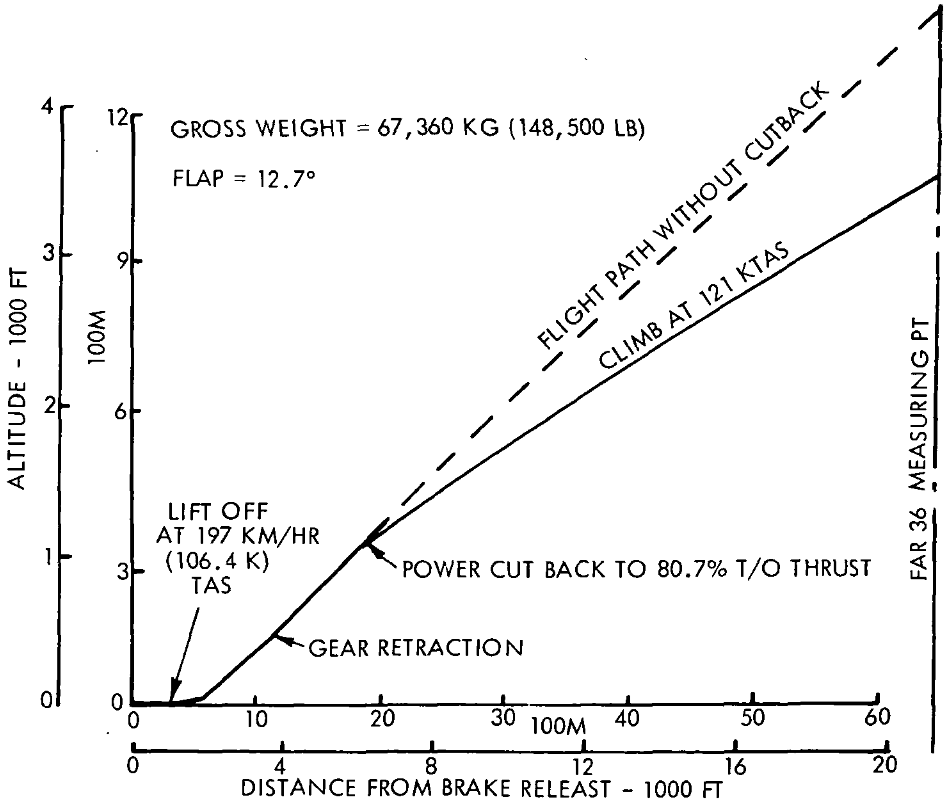


Figure 16 Takeoff Climbout Profile – 1.35 FPR OTW/IBF at 914m (3000 ft.)

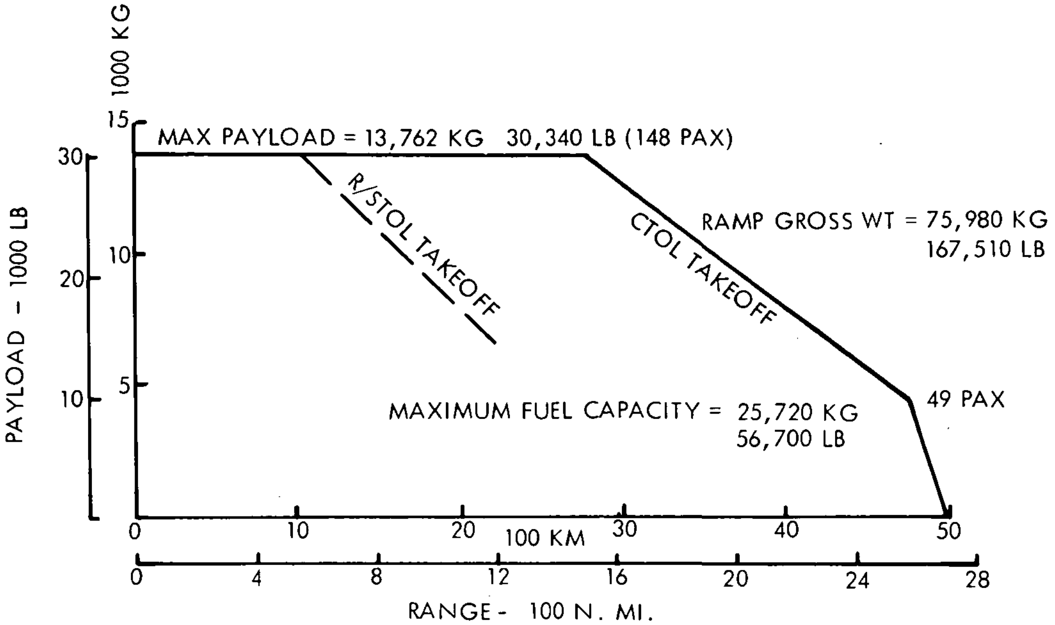


Figure 17 Payload-Range — 1.35 FPR OTW/IBF

Landing field length for the baseline aircraft is shown as a function of gross weight in Figure 18. Significant parameters for the landing approach profile used in the baseline aircraft noise analyses are:

Flap Setting	46 degrees
Glideslope	5.2 degrees
Approach Speed	182.2 km/hr. (98.4 knots) TAS
Power Setting	38 percent
Flare Distance	125m (410 ft.)
Ground Roll	455m (1390 ft.)
Approach C_L	3.00
Angle of Attack	6.9 degrees

To illustrate the effect on mission fuel and DOC of operating the airplane at other Mach numbers and altitudes than its design optimum, additional mission performance was computed for the baseline 1.35 FPR OTW/IBF airplane. The specific points identified in Figure 19 represent the design point airplanes for 926 km (500 n.mi.) R/STOL mission (lower point), and for the combined mission with CTOL capability for 2780 km (1500 n.mi.). Reducing the altitude from the design point of the combined mission airplane increases fuel consumption rapidly. Lowering the speed to 0.75m results in a small reduction in fuel consumption, while increasing altitude at the reduced Mach number further reduces the fuel used. However, decreasing the speed and increasing the altitude also increases the block-time as shown in Figure 20. Decreasing the altitude decreases the block-time due to the lower climb time.

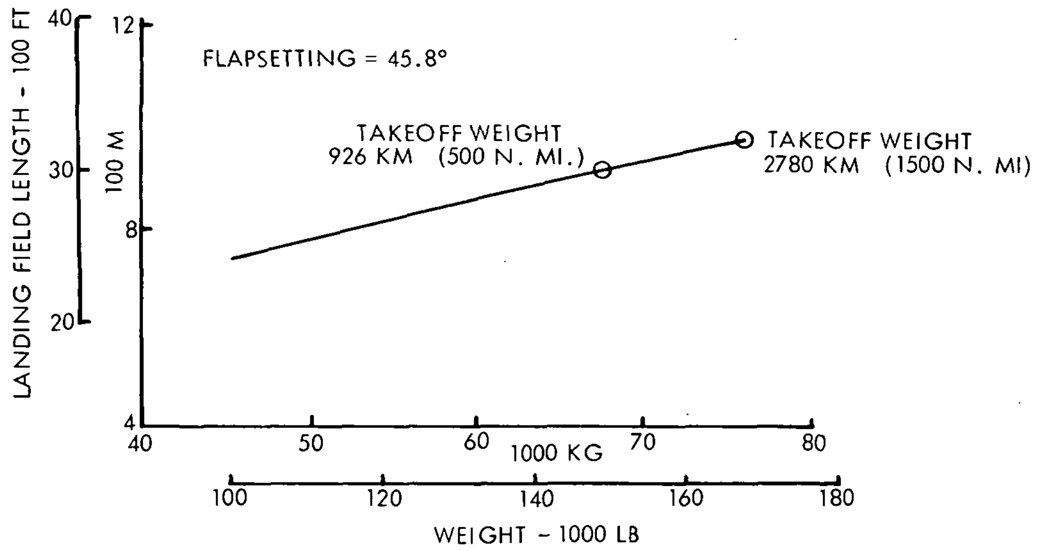


Figure 18 Landing Performance — 1.35 FPR OTW/IBF

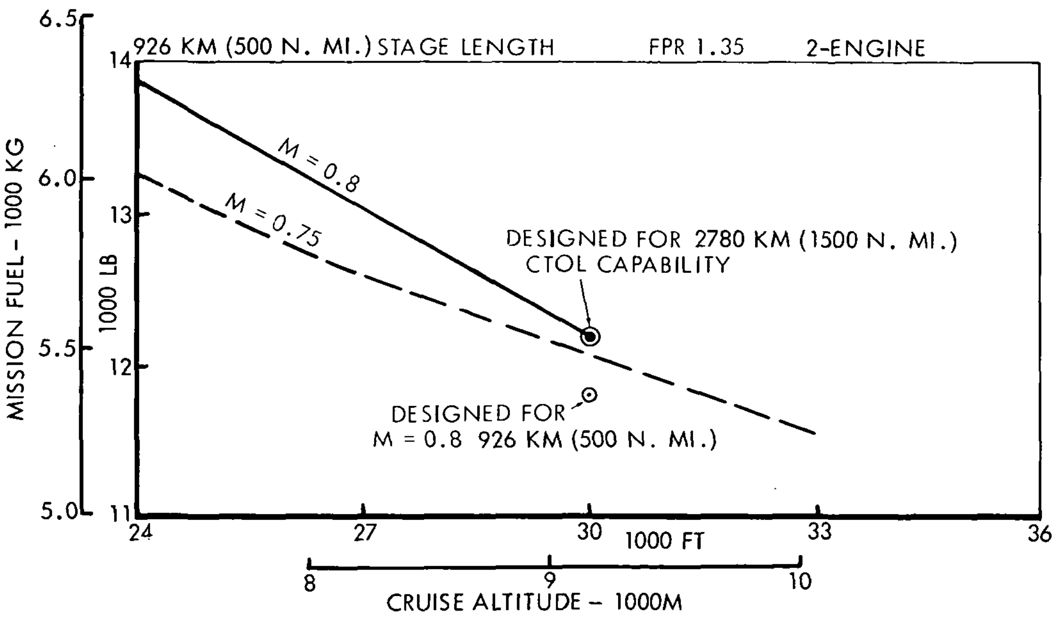


Figure 19 Fuel versus Altitude and Cruise Speed, Off-Design Operation
1.35 FPR OTW/IBF; 914m (3000 ft.) F.L.

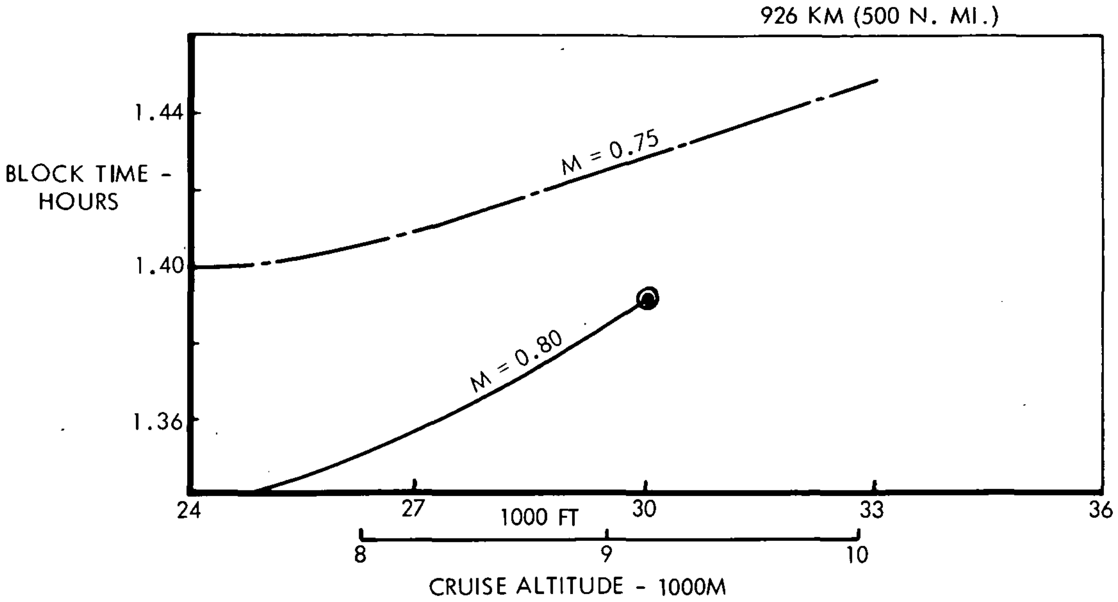


Figure 20 Block Time versus Altitude and Cruise Speed, Off-Design Operation: 1.35 FPR OTW/IBF; 914m (3000 ft.) F.L.

The combined effects of the changes in fuel consumption and block-time on DOC are shown in Figure 21. At a utilization of 2500 hours/year, the DOC-1 of the airplane with CTOL range capability of 2780 km (1500 n.mi.) is 1.7¢/ASSM compared with 1.62¢/ASSM for the airplane with 926 km (500 n.mi.) maximum range., The added flexibility of route scheduling and the use of some longer routes will allow the longer-range airplane to develop a higher utilization, shown at 2940 hours in Figure 21, which will provide DOC equal to or lower than that of the lighter airplane designed for short range only.

Augmentor Wing (AW) Aircraft

The augmentor wing concept utilizes a jet flap in which air from engines with high fan pressure ratios is ejected from the trailing edge. Excellent lift augmentation for terminal area performance is achieved and thrust is augmented through ejector action. Although the DOC was indicated to be higher than that of the hybrid OTW/IBF or the MF configurations in the reference 2 studies, it was not determined whether a two-engine AW configuration would change this conclusion. Accordingly, comparison of two and four engine configurations was undertaken in the present study, and the effect of higher fuel prices on design optimization was investigated.

Detailed studies were conducted on duct configuration, wing geometry optimization, flow split between leading and trailing edge, and T/S limitations. The resulting characteristics are summarized in Table IV for airplanes optimized for minimum DOC-1, DOC-2, and fuel. Comparison of 2- and 4-engine airplanes is shown under the DOC-1 column; in this concept the 4-engine configuration is superior because of the following factors:

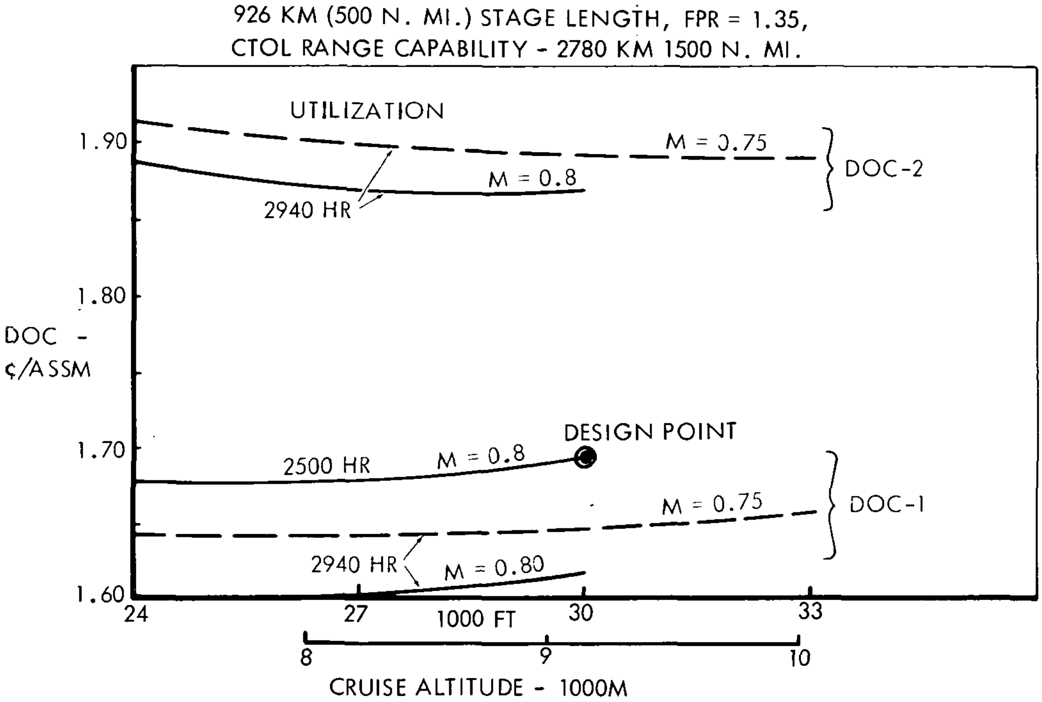


Figure 21 **DOC versus Altitude and cruise Speed, Off-Design Operation OTW/IBF 914m (3000 ft.) F. L.**

- o The wing loading for the 2-engine airplane is restricted to a lower value because duct volume requirements necessitate a larger wing.

- o Lower flap deflections associated with second-segment climb provide lower augmentation ratios for the 2-engine airplane defined in Table IV. This factor might be overcome by designing to fully deploy the augmentor at very small flap deflections. The associated reduction in thrust requirement would improve DOC-1 to approximately 1.97¢/ASSM and the ramp gross weight would be reduced to 82,000 kg (180,000 lb.).

- o Engine pricing for the 2-engine configuration was based on a production quantity of 750 engines; if the pricing were based on 1500 engines (300 aircraft plus 25 percent spares in a 4-engine design), the DOC would be reduced further to 1.89c/ASSM. However, it must be noted that the FPR 3.0 engine cannot be used for other powered lift or CTOL applications; the original engine pricing based on a fixed number of STOL aircraft sets is more realistic.

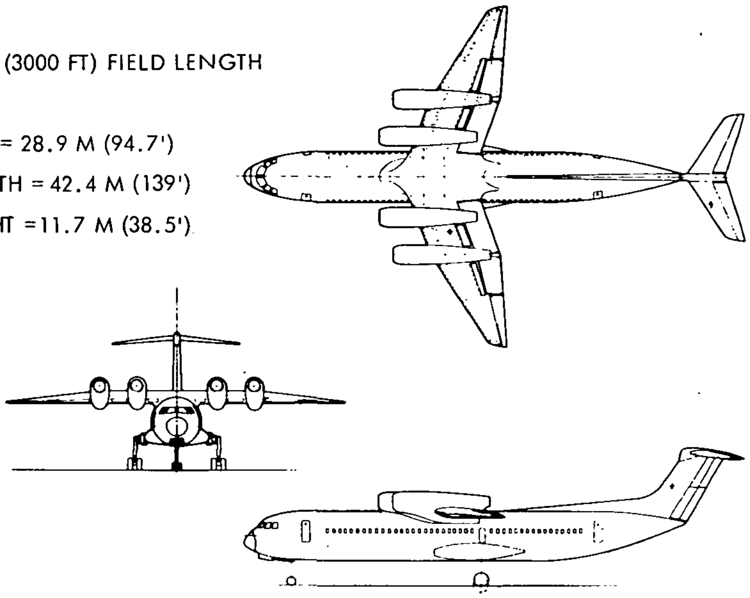
The 4-engine airplane optimized for DOC-1 is illustrated in Figure 22. The configuration features engines placed on the upper surface of the wing in order to maximize available volume for ducts by locating engines as far as possible inboard; the upper surface location permits a more inboard location for the same degree of interference drag. The wing planform has a constant chord section extending to the outboard engine for the purpose of maximizing at a given wing area the chord (and duct volume) at this location.

914 M (3000 FT) FIELD LENGTH

OPTIMIZED FOR	REF. 2 DOC-1	DOC-1		DOC-2		MIN. FUEL
NO. OF ENGINES	4	4	2	4	2 + 2	2 + 2
FPR	3.0	3.0	3.0	3.2	1.35 (3.0)	1.35 (3.0)
MACH NO.	0.8	0.8	0.8	0.75	0.75	0.75
CRUISE ALT. - M (FT)	9,140 (30,000)	9,140 (30,000)	9,140 (30,000)	9,140 (30,000)	9,140 (30,000)	9,140 (30,000)
AR	6.5	6.0	5.0	8.5	10.0	14.0
SWEEP - DEG.	30	20	20	10	10	10
$W/S_{T.O.}$ - KG/SQ.M (LB/SQ. FT)	473 (96.9)	512 (105.0)	369 (75.5)	491 (100.5)	547 (112.0)	503 (103.0)
$T/W_{T.O.}$	0.324	.347	.444	.305	.29 (.41)	.28 (.39)
RGW - KG (LB)	72,350 (159,503)	69,900 (154,100)	92,910 (204,830)	63,460 (139,900)	65,030 (143,370	69,070 (152,280)
OWE - KG (LB)	47,530 (104,779)	45,260 (99,790)	63,570 (140,150)	40,890 (90,150)	44,810 (98,790)	49,490 (109,100)
MISSION FUEL - KG (LB)	8,408 (18,537)	8,256 (18,200)	11,706 (25,806)	6,559 (14,460)	7,049 (12,540)	5,583 (12,309)
DOC-1 - ¢/ASSM	1.90	1.88	2.164	-	-	-
DOC-2 - ¢/ASSM	-	-	-	2.11	2.015	2.079
90 EPNdB T.O. AREA - SQ. KM (SQ. MI.)	- -	1.30 (0.5)	- -	< 1.30 (<0.5)	~1.30 (~0.5)	- -

Table IV AW Airplane Characteristics

The columns headed DOC-2 in Table IV reflect the characteristics of aircraft with further design refinement for reducing fuel consumption and minimizing DOC-2. A candidate engine with a fan pressure ratio of 3.2 (Ref. 9) was used because it showed significant improvement in SFC. A four-engine configuration similar to Figure22 has an aspect ratio of 8.5 and a design cruise of M 0.75, giving a significant reduction in mission fuel compared to the DOC-1 airplane. Further reduction in fuel and DOC-2 is attainable by an arrangement which uses two FPR 1.35 cruise engines combined with two FPR 3.0 load compressors for low speed high-lift operations. This is labeled 2 + 2 in Table IV. It is recognized that two sets of unlike engines would be regarded with disfavor by airline operators; however this arrangement gives the best fuel performance and lowest DOC-2 of any augmentor wing arrangement.



148 PAX

0.8 M

914 M (3000 FT) FIELD LENGTH

SPAN = 28.9 M (94.7')

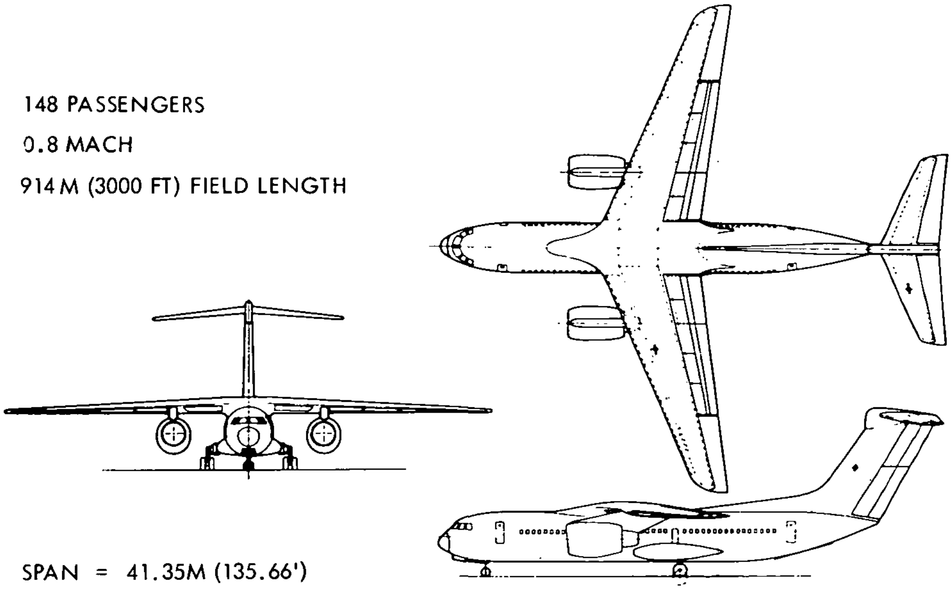
LENGTH = 42.4 M (139')

HEIGHT = 11.7 M (38.5')

Figure 22 914m (3000 ft.) AW vehicle – DOC-1

Mechanical Flap Aircraft

Aircraft for 914m. (3,000 ft.) field performance were defined using a high-performance double-slotted Fowler flap; maximum lift coefficient was 3.3. Landing approach speed of 182.2 km/hr. (99 knots) was the critical factor in establishing the wing loading at 287 kg/sq.m. (58.8 psf). The basic arrangement, shown in Figure 23, has a 6-abreast fuselage with high wing, tee tail and pylon-mounted nacelles.



148 PASSENGERS

0.8 MACH

914 M (3000 FT) FIELD LENGTH

SPAN = 41.35M (135.66')

LENGTH = 43.18M (141.66')

HEIGHT = 14.22M (46.66')

Figure 23 MF General Arrangement, FPR 1.35

Considerable improvement in installed engine performance (compared to previous studies Ref. 1 and 2) was achieved in the present study by utilizing nacelles designed for best aerodynamic performance with acoustic treatment installed on wall surfaces only. Preliminary design weight analyses with allowances for fatigue, gust loads, and flutter were made, along with control and ride quality investigations which indicated conceptually that augmentation systems could achieve satisfactory ride quality.

Characteristics of aircraft resulting from the design refinement are shown in Table V, including the extension of the designs to 1070m (3500 ft.) and 1220m (4000 ft.) field lengths. These aircraft were optimized for minimum DOC at 1972 fuel prices; the DOC values shown for different fuel prices are based on taking advantage of the 2780 km (1500 n.mi) range capability to increase the utilization of the aircraft to 3000 hours per year.

The designs were modified for fuel conservation and for minimum DOC at increased fuel prices by evaluating factors such as cruise speed and altitude, wing aspect ratio and sweep, and number of engines. The effect of cruise speed on mission fuel and DOC-2 is shown in Figure 24. (Airplane design range was 926 km (500 n.mi.) and utilization was 2500 hours per year for DOC calculations). The fuel penalty is high for higher cruise speed for the low wing loading airplane with 914 m (3000 ft.) field performance.

Effect of other fuel prices on design speed for minimum DOC is reflected in Figure 25 for the 1220m. (4000 ft.) MF airplane. Although the four-engine airplanes require less fuel, the two-engine airplanes provide minimum DOC at fuel prices up to those represented by DOC-4.

Tables VI and VII summarize the characteristics of MF configurations designed for 914m. (3000 ft.) and 1220m (4000 ft.) with 148 passengers and 926 km (500 n.mi.) range. The study airplanes defined in reference 2 are also tabulated. A significant improvement is shown in the present study, primarily due to the improved installed engine performance achieved by elimination of acoustic splitters in the nacelles. The airplane designed for 1220m. (4000 ft.) field performance and optimized for minimum DOC-2 is shown in Figure 26.

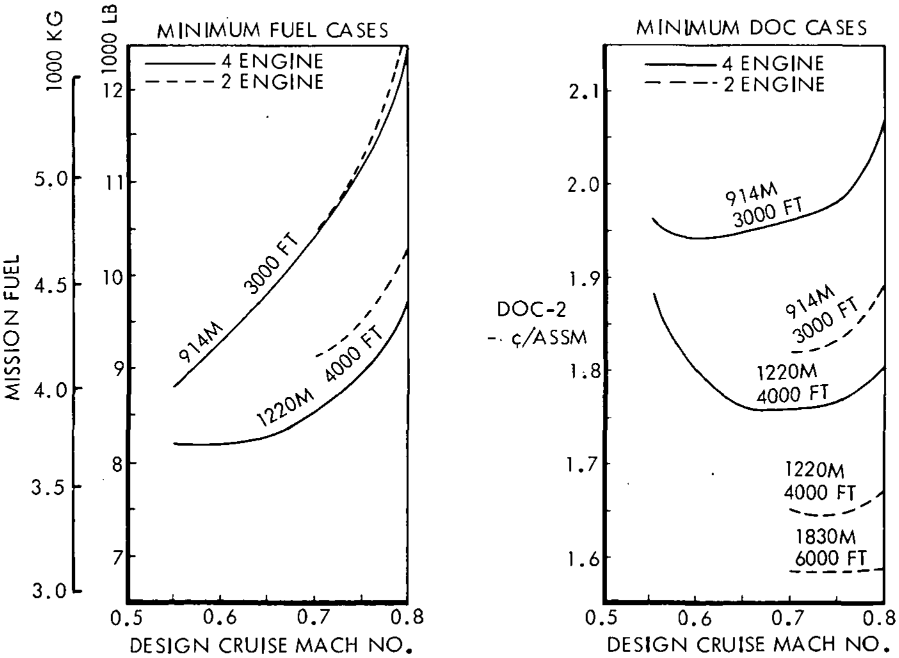


Figure 24 Effect of Design Cruise Speed — MF with 1.35 FPR Engines

148 PASSENGERS
MO.8 AT 9140 M (30000 Ft.) ALT.

TWO ENGINES, 20 DEG. SWEEP

926 KM (500 N.M.) RANGE WITH DESIGN FIELD LENGTH
2780 KM (1500 N.M.) RANGE WITH CTOL TAKEOFF

DESIGN FIELD LENGTH - M -(FT)	914 (3,000)	1,070 (3,500)	1,220 (4,000)	1,220 (4,000)
FAN PRESSURE RATIO/TYPE	1.35 F/P	1.35 F/P	1.35 F/P	1.47 F/P
WING ASPECT RATIO	7	8	10	10
RAMP GROSS WT. - KG	77,963	69,289	65,781	68,095
-(LB)	(171,877)	(152,753)	(145,020)	(150,121)
OPERATING WEIGHT - KG - (LB)	47,724 (105,212)	41,633 (91,784)	39,529 (87,144)	40,255 (88,745)
WING LOADING T.O. - KG/SQ.M	287	345	403	403
926 KM MISSION (LB/SQ. FT.)	(58.8)	(70.6)	(82.5)	(82.5)
T/W 926 KM MISSION	0.450	0.416	0.386	0.354
RATED THRUST/ENGINE - KN	168.6	139.7	123.8	114.9
-(LB.)	(37,898)	(31,401)	(27,826)	(25,830)
CRUISE THRUST SETTING	1.000	1.000	1.000	0.866
T/C	14.16	13.69	13.11	13.07
926 KM DOC-1 - ¢/ASSM	1.62	1.50	1.44	1.40
DOC-2-¢/ASSM	1.93	1.85	1.67	1.65
DOC-4-¢/ASSM	2.53	2.37	2.13	2.17
DOC-10-¢/ASSM	4.33	3.80	3.52	3.72
MISSION FUEL - KG	6593	5625	5088	5676
-(LB.)	(14,536)	(12,400)	(11,218)	(12,514)
2780 KM DOC-2-¢/ASSM	1.43	1.30	1.23	1.25
MISSION FUEL - KG	14,471	12,207	10,964	12,359
-(LB.)	(31,902)	(26,911)	(24,170)	(27,246)
COMPLETE A/C PRICE - $M	8.629	7.976	7.678	7.573
ENGINE PRICE - $M	2.081	1.948	1.868	1.652

Table V MF Baseline Airplane Characteristics

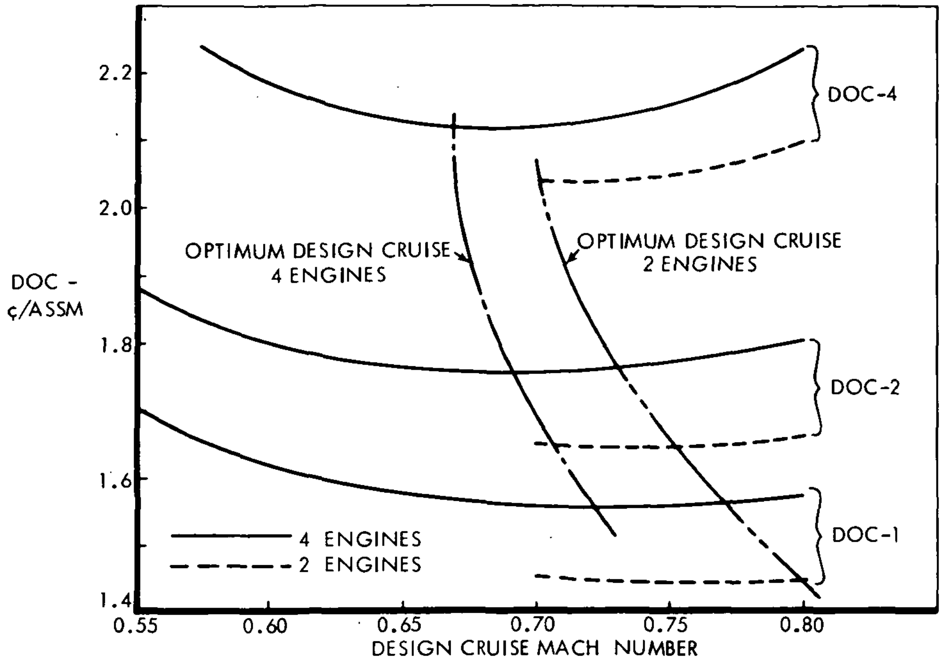


Figure 25 Effect of Fuel Price on Optimum Design Cruise Speed — 1220m (4000 ft.) Field Length MF

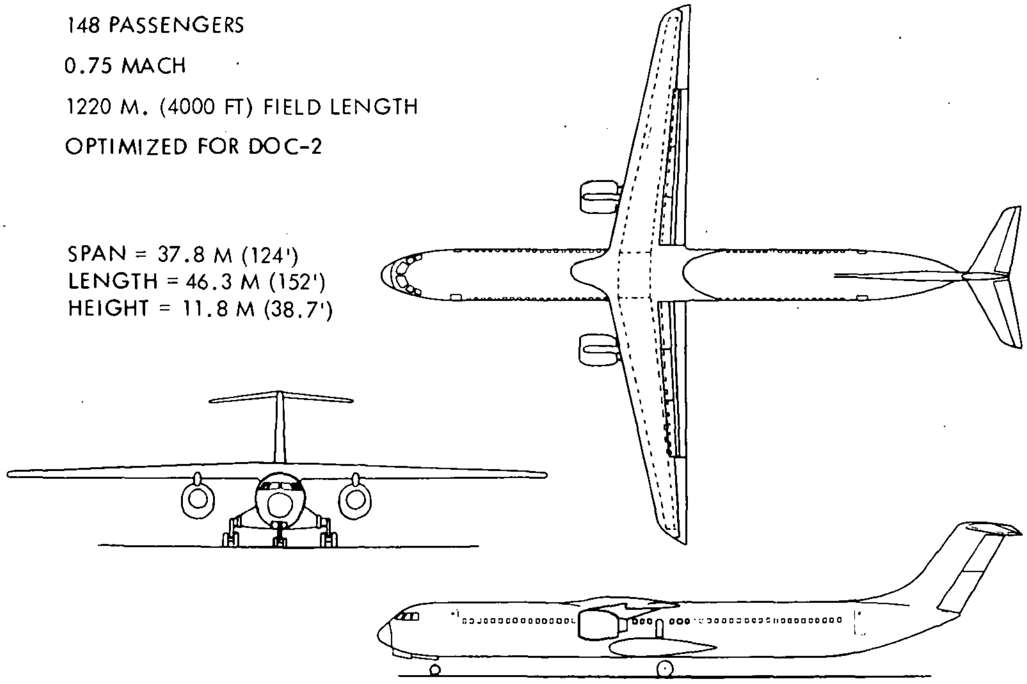


Figure 26 1220m (4000 ft.) MF Vehicle — DOC-2

	REF. 2	OPTIMIZED FOR					
	DOC-1	DOC-1		DOC-2	DOC-4	DOC-10	MIN FUEL
MACH NO.	0.8	0.8	0.75	0.70	0.70	0.60	0.55
NO. OF ENGINES	2	2	2	2	2	4	4
OWE - KG	52,590	46,870	41,760	40,020	40,020	38,270	35,290
(LB)	(115,940)	(103,330)	(92,060)	(88,230)	(88,230)	(84,380)	(77,800)
GROSS WEIGHT - KG	76,610	69,000	62,690	60,210	60,210	57,700	54,200
(LB)	(168,890)	(152,110)	(138,200)	(132,740)	(132,740)	(127,210)	(119,480)
RATED THRUST - KN	195.5	151.6	125.3	118.4	118.4	43.4	38.5
(LB)	(43,950)	(34,070)	(28,160)	26,610)	(26,610)	(9,760)	(8,660)
MISSION FUEL - KG	7,550	6,110	5,440	4,870	4,870	4,200	3,980
(LB)	(16,640)	(13,460)	(12,000)	(10,730)	(10,730)	(9,250)	(8,770)
AR	7.0	7.0	7.0	7-10	7-10	10	14
*DOC-1 -- ¢/ASSM.	1.931	1.632	1.582	1.597	1.597	1.75	1.828
DOC-2 -- ¢/ASSM.		1.912	1.832	1.818	1.818	1.94	2.010
DOC-4 -- ¢/ASSM.		2.472	2.328	2.262	2.262	2.32	2.376
DOC-10 -- ¢/ASSM.		4.152	3.760	3.589	3.589	3.46	3.472
$W/S_{T.O.}$ - KG/SQ.M.	302	287	287	287	287	287	287
(LB/SQ.FT)	(61.8)	(58.8)	(58.8)	(58.8)	(58.8)	(58.8)	(58.8)
90 EPNdB T.O. AREA SQ. KM	1.04	1.48	1.40	1.37	1.37	1.09	1.06
(SQ. MI.)	(0.4)	(0.57)	(0.54)	(0.53)	(0.53)	(0.42)	(0.41)

IDENTICAL AIRPLANE

* ENGINE PRODUCTION QUANTITY: 750 IN REF. 2 1500 IN PRESENT PHASE

Table VI Airplane Characteristics, 1.35 FPR, MF, 914m (3000 ft.) F.L.

	REF. 2	OPTIMIZED FOR				
	DOC-1	DOC-1	DOC-2	DOC-4	DOC-10	MIN. FUEL
MACH NO.	0.8	0.8	0.75	0.70	0.65	0.60
NO. OF ENGINES	2	2	2	2	4	4
OWE - KG	40,510	39,140	36,770	35,790	33,800	33,920
(LB)	(89,300)	(86,280)	(81,060)	(78,900)	(74,520)	(74,770)
GROSS WEIGHT - KG	62,120	59,400	56,460	55,340	52,590	52,530
(LB)	(136,950)	(130,950)	(124,480)	(122,000)	(115,950)	(115,800)
RATED THRUST - KN	150.3	114.3	111.0	104.8	40.9	38.0
(LB)	(33,800)	(25,690)	(24,950)	(23,560)	(9,190)	(8,550)
MISSION FUEL - KG	5,865	4,717	4,382	4,218	3,801	3,715
(LB)	(12,930)	(10,400)	(9,660)	(9,300)	(8,380)	(8,190)
AR	7.0	10.0	10.0	10.0	14.0	14
*DOC-1 -- ¢/ASSM.	1.681	1.446	1.45	1.466	1.626	1.70
DOC-2 -- ¢/ASSM.		1.67	1.648	1.659	1.798	1.87
DOC-4 -- ¢/ASSM.		2.10	2.05	2.044	2.142	2.21
DOC-10 -- ¢/ASSM.		3.408	3.25	3.20	3.174	3.23
$W/S_{T.O.}$ - KG/SQ.M.	455	391	393	379	403	361
(LB/SQ.FT)	(93.1)	(80.0)	(80.5)	(77.6)	(82.5)	(74.0)
90 EPNdB T.O. AREA SQ. KM	0.97	1.42	1.37	1.32	1.088	N/A
(SQ. MI.)	(0.375)	(0.55)	(0.53)	(0.51)	(0.42)	

* ENGINE PRODUCTION QUANTITY: 750 IN REF. 2
1500 IN PRESENT PHASE

Table VII Airplane Characteristics, 1.35 FPR, MF, 1220m (4000 ft.) F.L.

Other Concepts Evaluated for Fuel Conservation

The study completed in 1973, reference 2, included evaluation of externally blown flap, over the wing, boundary layer control, and internally blown flap lift concepts. These have been reexamined in the present study in the light of fuel conservation and increased fuel prices.

EBF Aircraft – Externally blown flap aircraft were optimized for minimum DOC-2 using 1.25 FPR engines with variable pitch fans. Previous analyses (Ref. 2) have indicated that the flap interaction noise component requires a lower exhaust velocity in the EBF system than in other systems to achieve comparable noise levels. The most effective way to reduce exhaust velocity is by selection of an engine with a lower fan pressure ratio; use of 1.25 FPR with the EBF system gives noise levels which are approximately equivalent to MF and OTW/IBF aircraft using 1.35 FPR engines.

Characteristics of the EBF aircraft are summarized in Table VIII. The cruise speed giving minimum DOC-2 is low, M 0.65, because of the 1.25 FPR engine. Fuel consumption is correspondingly low but DOC is relatively high because of the higher block time and lower productivity associated with M 0.65 cruise.

FIELD LENGTH - FT. (M.)	2000 (610)	3000 (914)
NO. OF ENGINES	4	4
FPR	1.25	1.25
MACH NUMBER	0.65	0.65
CRUISE ALTITUDE - FT. (M)	30,000 (9140)	30,000 (9140)
AR	10	10
SWEEP - DEG.	10	10
$W/S_{T/O}$ LB/SQ. FT. (KG/SQ.M)	66.6 (325)	81.0 (395)
$T/W_{T/O}$	0.423	0.325
RGW LB (KG)	147,760 (67,020)	124,270 (56,370)
OWE LB (KG)	99,780 (45,260)	81,250 (36,860)
MISSION FUEL - LB (KG)	11,030 (5000)	9760 (4430)
DOC-1 – ¢/ASSM	1.968	1.844
DOC-2 – ¢/ASSM	2.196	2.046

Table VIII EBF Airplane Characteristics, Optimized for Minimum DOC-2

OTW Aircraft — The over-the-wing concept is closely comparable to the four-engine hybrid OTW/IBF except, of course, the IBF component is deleted and the flap would be modified for Coanda turning aft of the nacelle, and slotted elsewhere. Table IX shows data from Reference 2 comparing the OTW to the EBF, AW, OTW/IBF, and MF concepts where the airplanes were optimized for 1972 fuel prices at two field lengths. Appropriate to the low fuel price, cruise speeds were M 0.8 and aspect ratios were 6.5 to 7. Nacelles contained splitters for noise reduction so that the aircraft in Table IX reflect significant performance and weight penalties compared to those in the present study which have engines with acoustic treatment on nacelle walls only. The excellent ranking of the OTW concept from the standpoint of fuel consumption and DOC-1 may be noted. Although no re-optimization for higher fuel prices was conducted in the present study, it is estimated that the "pure" OTW would be virtually equivalent to the 4 engine hybrid OTW/IBF in fuel consumption and in DOC at higher fuel prices. At 1972 fuel prices and M 0.8 design speeds the cost of 2 engines in the hybrid OTW/IBF gives it an advantage over the 4-engine OTW concept. This advantage is lost when cruise speeds are lowered to improve fuel consumption, resulting in a better match for the 4-engine airplanes in cruise and takeoff engine requirements.

BLC and IBF Concepts — Data on boundary layer control and internally blown flap concepts were presented in Reference 2. Both concepts require vectoring of the fan exhaust in order to achieve approach speeds and glideslopes for R/STOL performance unless separate propulsion units are used for flap blowing. In the latter case, the designs are uneconomic compared to other concepts, and are inferior to the 2 + 2 augmentor wing approach discussed previously; they likewise have the disadvantage of two sets of unlike engines.

148 PAX @ 0.8 M @ 9140 m. (30,000 FT.)

FIELD LENGTH	610 m. (2000 FT.)			914 m. (3000 FT.)			
CONCEPT	EBF	OTW	AW	EBF	OTW	OTW-IBF	MF
FPR	1.25	1.325	3.0	1.25	1.325	1.325	1.35
NO. ENGINES	4	4	4	4	4	2	2
ASPECT RATIO	6.5	6.5	6.5	6.5	6.5	7.0	7.0
SWEEP - DEG.	30	30	30	30	30	30	30
RGW - Kg (LB)	83,002 (182,989)	76,113 (167,800)	88,773 (195,710)	66,428 (146,449)	61,857 (136,372)	66,837 (147,350)	76,607 (168,890)
OWE - Kg (LB)	58,036 (127,947)	51,891 (114,400)	61,970 (136,620)	44,239 (97,531)	39,999 (88,183)	44,565 (98,250)	52,590 (115,940)
T/W	0.590	0.543	0.383	0.512	0.456	0.453	0.470
W/S - KG/SQ. M. (psf)	357 (73.2)	357 (73.2)	395 (81.0)	456 (93.3)	481 (98.6)	455 (93.2)	298 (61.0)
DOC (1) - ¢/ASSM	2.24	2.14	2.18	1.94	1.87	1.80	1.93
PNdB @ 152m. (500 FT.) SIDELINE	93.9	-	93.5	91.8	94.0	95.4	-
80 PNdB FOOTPRINT (Km^2) (SQ. MILES)	11.7 (4.5)	- (-)	7.3 (2.8)	16.8 (6.5)	9.8 (3.8)	7.3 (2.8)	- (-)
MISSION FUEL-Kg (LB)	8,237 (18,160)	7,743 (17,070)	10,569 (23,300)	6,319 (13,930)	6,028 (13,290)	6,332 (13,960)	7,548 (16,640)

Table IX Comparison of Lift Concepts — Reference 2

If BLC or IBF air was bled from the compressor or fan of low-noise engines mounted under the wing, the cruise drag and weight of thrust deflectors (Pegasus nozzles, for example) caused significant performance penalties related to the large diameter of the high bypass ratio engines. As a result, these aircraft were inferior to other concepts in weight, fuel consumption, and direct operating cost. However, as discussed earlier in this section under "Baseline Hybrid OTW/IBF Aircraft," the use of Coanda attachment for thrust vectoring of fan exhaust of engines mounted over the wing has been shown to have excellent potential. Thus the hybrid OTW/IBF concept was evolved and was covered in detail in this study.

Deflected Slipstream Turboprop Aircraft – Turboprop aircraft were analyzed because of their significance in fuel conservation. Rubberized T-56 and advanced turboprop engines were applied to 4-engine 148-passenger airplane designs. Both conventional and low-tip-speed propellers were investigated. Stall speed margins were based on power-on conditions with one engine out, corresponding to FAR XX requirements, and providing allowable wing loading higher than those based on power-off stall, as required by FAR Part 25.

The variation of fuel consumption with design cruise speed and field length is shown in Figure 27 for aircraft with rubberized T-56 engines. Fuel consumption is significantly lower than for fan-powered aircraft. The solid line represents aircraft with the current propeller which gives a 926m (500 ft.) sideline noise of 106 PNdB. A larger diameter slow-turning prop has been designed for potential use on the C-130 airplane and it gives a sideline noise level of 95 PNdB at 926m (500 ft.). Performance improvements with this quiet prop are rather spectacular for the shorter-field length aircraft optimized for low fuel. Higher terminal-area thrust, permitting higher wing loadings, are a principal cause for this improvement.

The improved performance with the quiet propeller is also reflected in the DOC-2 values in Figure 28. It is interesting to note that aircraft sized to cruise at M 0.55 or higher demonstrate a 1220m (4000 ft.) field performance because takeoff thrust and landing propulsive lift are matched at this field length to cruise-sized engines. Characteristics of aircraft designed for 914m (3000 ft.) field performance with different fuel price levels are shown in Table X.

The baseline performance data shown above were derived using the T56A-15 engine which, at 4591 prop shaft horsepower, develops 4,951 Kg (10,915 lb.) of static thrust with the quiet propeller. More advanced gas generator technology was evaluated, using the DDA501-M62 as representative of current technology, and also the gas generator defined in the DDA QCSEE engines as representative of 1980 technology. Typical results are shown in the following table:

Technology Level	Engine Price Per Pound of Cruise Thrust	Fuel Pass.-Mi./Gal. 100% L.F.	DOC-2	DOC-4	DOC-10
T56A-15	$119	78	1.63	1.935	2.85
501-M62	$184	84	1.66	1.94	2.78
1980-QCSEE	$351	94	1.81	2.06	2.82

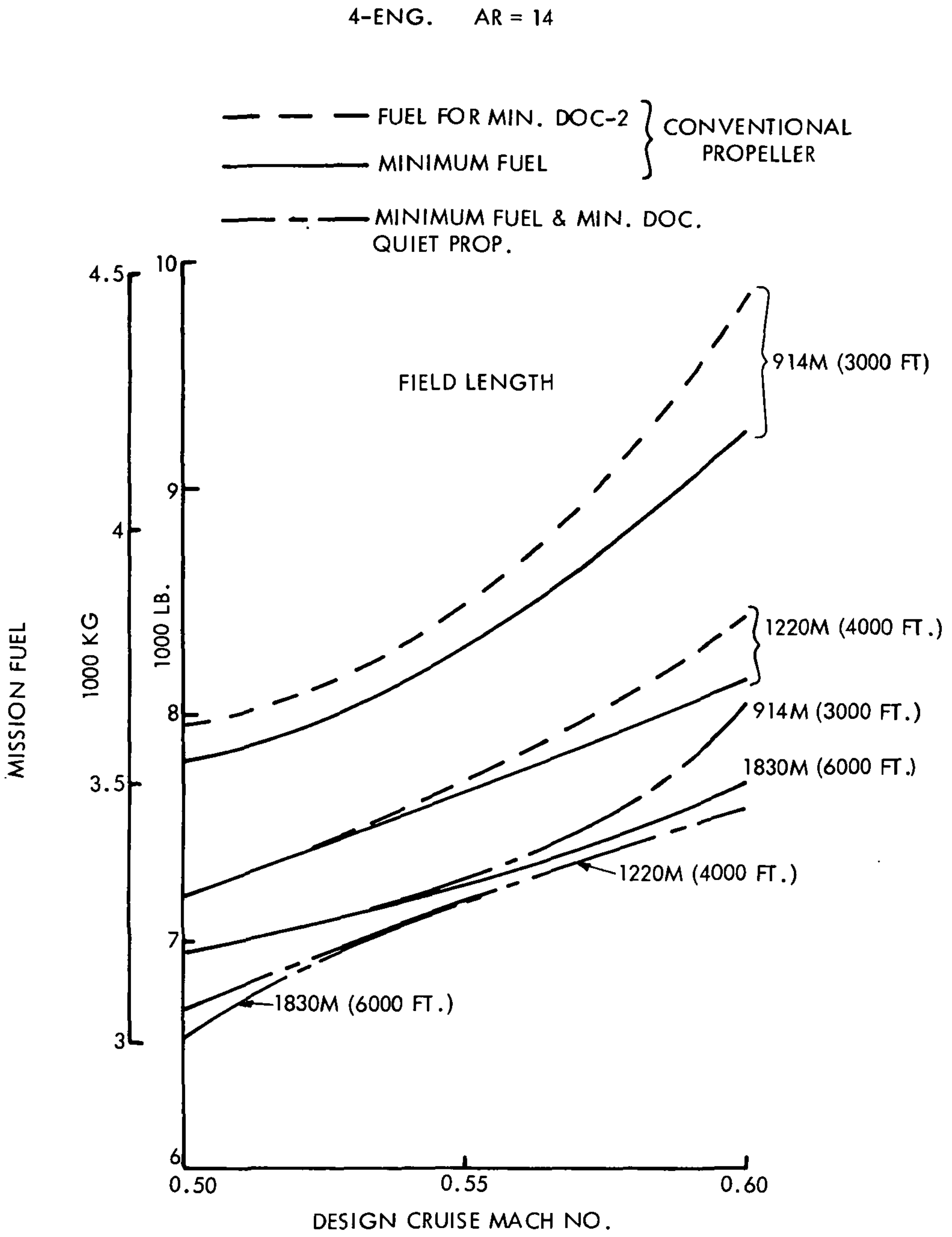


Figure 27 T-56 Mission Fuel versus Mach No.

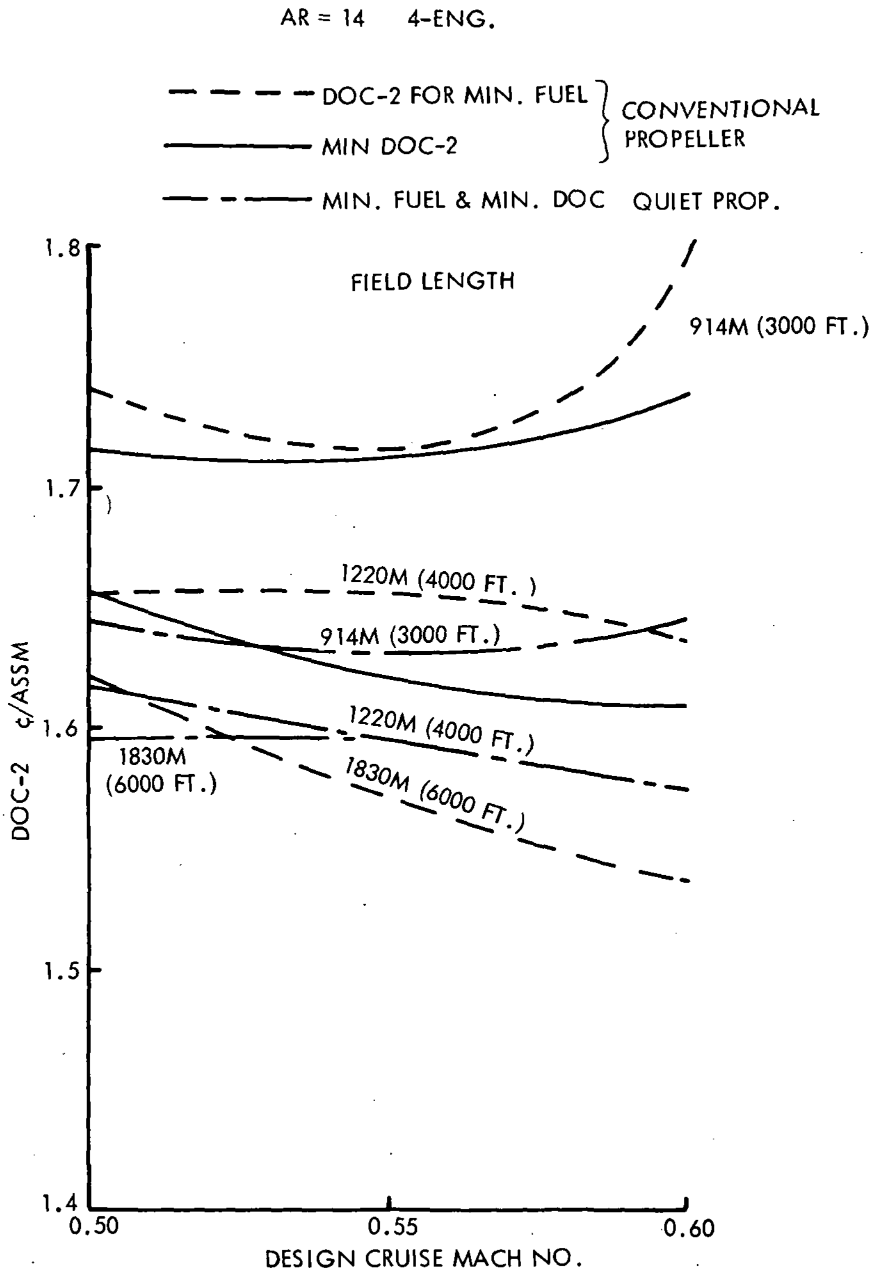


Figure 28 T-56 DOC-2 versus Mach No.

	OPTIMIZED FOR				
	DOC-1	DOC-2	DOC-4	DOC-10	MIN. FUEL
MACH NO.	0.60	0.55	0.55	0.50	0.50
NO. OF ENGINES	4	4	4	4	4
OWE - KG	35,690	34,805	34,805	34,360	34,360
(LB)	(78,680)	(76,730)	(76,730)	(75,750)	(75,750)
GROSS WEIGHT - KG	54,440	53,170	53,170	52,720	52,720
(LB)	(120,028)	(117,223)	(117,223)	(116,232)	(116,232)
MISSION FUEL - KG	3,656	3,293	3,292	3,148	$\boxed{3,148}$
(LB)	(8,060)	(7,260)	(7,260)	(6,940)	(6,940)
AR	14	14	14	14	14
DOC-1 -- ¢/ASSM.	$\boxed{1.473}$	1.477	1.477	1.500	1.500
DOC-2 -- ¢/ASSM.	1.642	$\boxed{1.629}$	1.629	1.643	1.643
DOC-4 -- ¢/ASSM.	1.977	1.935	$\boxed{1.935}$	1.935	1.935
DOC-10 -- ¢/ASSM.	2.985	2.851	2.851	$\boxed{2.805}$	2.805
W/S$_{T.O.}$ - KG/SQ.M.	391	387	387	371	371
(LB/SQ.FT)	(80.0)	(79.2)	(79.2)	(76.0)	(76.0)
INST. THRUST/ENG. - KN	40.1	37.8	37.8	35.6	35.6
(LB)	(9,019)	(8,502)	(8,502)	(7,996)	(7,996)
CRUISE POWER %	90	80	80	70	70
90 EPNdB AREA - SQ. KM	1.30	1.30	1.30	1.30	1.30
(ESTIMATE) (SQ. MI)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
		IDENTICAL AIRPLANE		IDENTICAL AIRPLANE	

Table X **T-56 and Quiet Propeller — 914m (3000 ft.) F.L.**

The analysis shows that the price advantage of the existing engine is an overriding factor in direct operating cost until fuel prices exceed four times the 1972 level (DOC-4). The aircraft size and passenger capacity would be modified to match the actual engine size in order to achieve the price benefit quoted for the T56. Thus a four-engine airplane matched to the T56A-15 engine with the quiet propellor would carry approximately 190 passengers. Although its fuel consumption and DOC would be significantly less than fan-powered aircraft, it is not likely to compete successfully for passengers in high-density routes for which its size would be suitable. However, a two-engine airplane (representative of a modernized Convair 580) would carry 80 to 90 passengers and should be a serious contender in the medium density short haul market, particularly at stage lengths below 700 Km (380n.mi.).

4. EVALUATION OF AIRCRAFT CONFIGURATIONS

Design For Fuel Conservation

This section compares the concepts and engines, and the relative importance of the various design parameters on the optimization of vehicles for fuel conservation. The magnitude of the fuel savings that are available and their effect on the economic operation of the vehicle may be considered by reference to Figure 29. An OTW/IBF vehicle designed for minimum DOC at 1972 fuel prices would be powered by two engines and would cruise at 0.8M. Its fuel consumption would be 5900 kg (13,000 lb.) for the 926 km (500n.mi.) mission and its DOC at 1972 fuel prices would be 1.62¢/ASSM. An alternate 0.8M vehicle design with four engines would result in a 16% reduction in fuel consumption but would incur a 1.5% increase in DOC-1. However, the 4-engine vehicle with the higher DOC-1 has a DOC-2 which is 1.3% lower than that of the 2-engined configuration.

If the airplane had been designed for minimum fuel consumption, the design cruise Mach number with 4 engines would have been 0.6M and the fuel consumption 4080 Kg (9000 lb.), a saving of 41%. The DOC-1 would have increased to 1.75¢/ASSM, an increase of 8%; the penalty at DOC-2 is still 2.6%. If the airplane had been optimized for DOC-2, a 4-engined, 0.73M configuration would have been selected. The fuel saving relative to the original 2-engined DOC-1 design would still be 27% and the DOC-2 would be actually 4% lower than the original design and 6% lower than the minimum fuel design. Thus it can be seen that by optimizing for the increased cost of fuel, large fuel savings can be achieved while still minimizing operating cost. To achieve the maximum fuel savings creates too large a penalty in DOC and results in cruise speeds which are probably unacceptably low.

Figure 30 illustrates the superiority of the 1.47 FPR engine for airplanes optimized for DOC-1 and not required to meet low noise criteria. The 2-engined 1.47 and 1.35 FPR configurations are slightly superior to their 4-engined counterparts at the high Mach numbers where the buckets occur in the DOC. It should be noted that the lower the FPR, the lower the Mach number at which the bucket occurs. Although the 1.25 FPR 2-engined configuration would have lower DOC at the higher Mach numbers than the 4-engined configuration shown, it will not be competitive with the other FPR airplanes. Additionally, reference to Figure 29 shows that doubling the fuel price with the 1.35 FPR engine changes the desired number of engines for minimum fuel or minimum DOC to four. The following paragraphs therefore compare 4-engine configurations.

Figure 31 presents mission fuel for OTW/IBF airplanes optimized for minimum fuel, and DOC-2 for airplanes optimized for minimum DOC-2, plotted against design cruise Mach number. It is apparent that the 1.35 FPR designs provide better fuel consumption than either the 1.25 or 1.47 FPR configurations over the desirable range of Mach numbers. It should be noted that the best fan engined design still consumes more than the T-56 turboprop deflected slipstream designs. The designs optimized for DOC-2 show the 1.47 FPR configurations to be slightly better than the 1.35 FPR and both of them to be definitely superior to the 1.25 FPR vehicles. Again, although its cruise speed is low, the T-56 provides better DOC than any of the fan-powered designs.

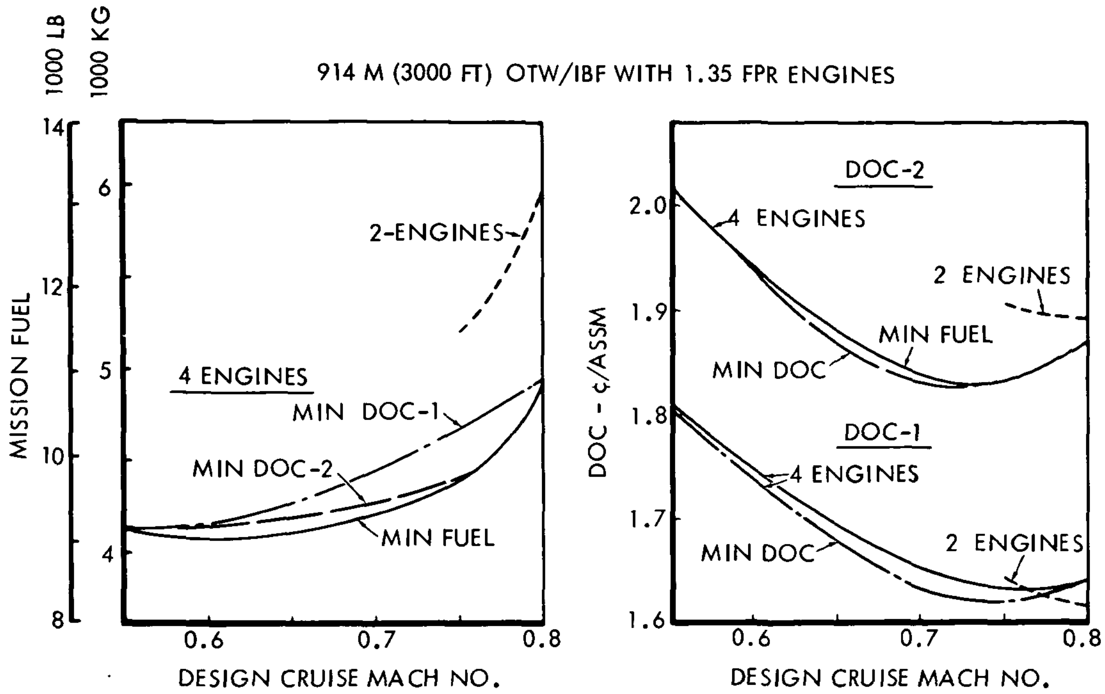


Figure 29 Effect of Design Cruise Speed

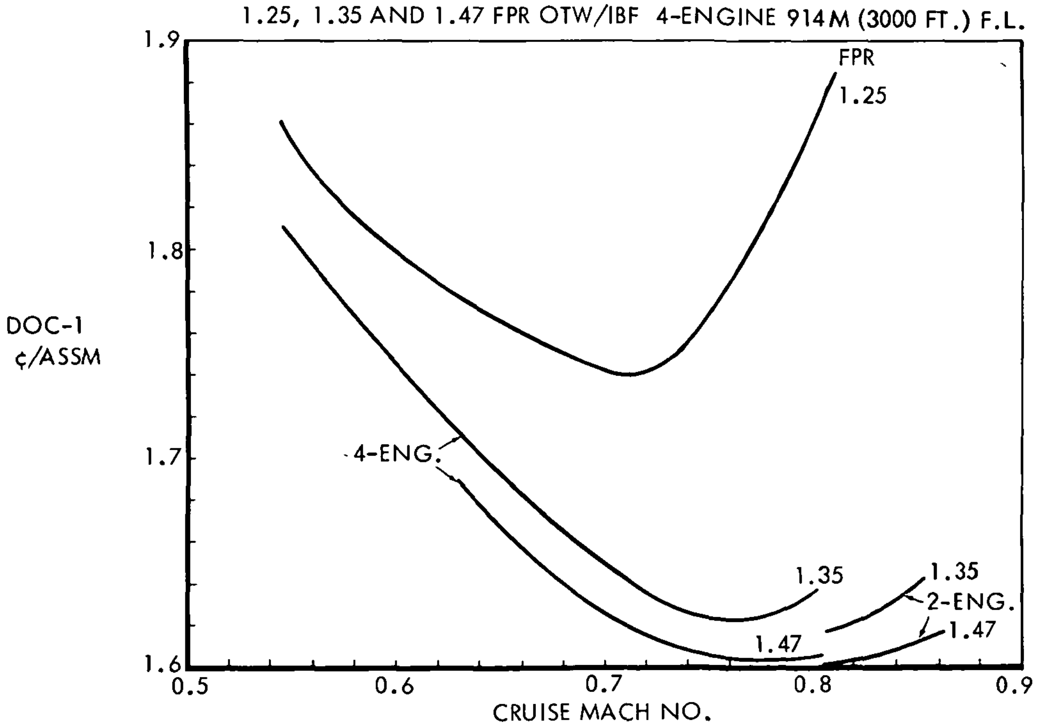


Figure 30 DOC-1 versus Cruise Mach No./OTW/IBF

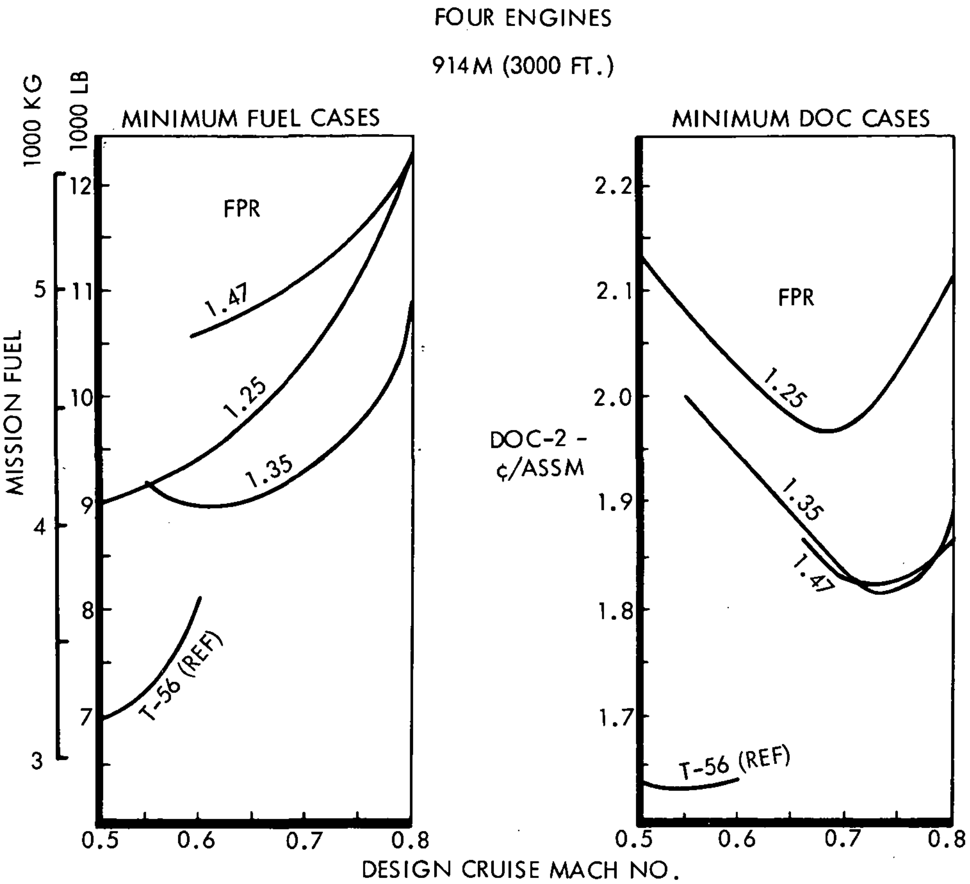


Figure 31 Fuel and Cost Effects of Engines and Speed – OTW/IBF

As shown earlier in the report, increase in fuel price reduces the design cruise Mach number for minimum DOC. Similarly, changes in fuel price modify the choice of FPR for minimum DOC as shown in Figure 32. Minimum DOC-1 is provided by a 1.47 FPR design at 0.8M while DOC-2 is lowest with either a 1.35 or 1.47 FPR and 0.73M. It can be concluded that 1.35 FPR would be an excellent choice for fuel prices of 2 to 10 times the 1972 price level.

Examination of the OTW/IBF data for the three FPR's studied, 1.25, 1.35, and 1.47, shows that optimizing airplanes for high-speed with the 1.25 and 1.35 FPR engines automatically provides a relatively short field length, suitable for STOL operation. This is not the case with the 1.47 FPR configurations which can be optimized for 0.8M and 1830m (6000 ft.) field length. In the case of the 1.25 FPR engine, the configuration sized for 0.8M cruise provided a field length of 640m (2100 ft.); in the 1.35 FPR case, the configuration sized for 0.8M provided field length of 914m (3000 ft.). This restriction in sizing flexibility is due to the high lapse rate with altitude of these low fan pressure ratio engines, requiring high values of static thrust to provide adequate cruise thrust at high speed. At lower Mach numbers the thrust required to cruise is lower and the configurations have longer field lengths unless they are overpowered at cruise.

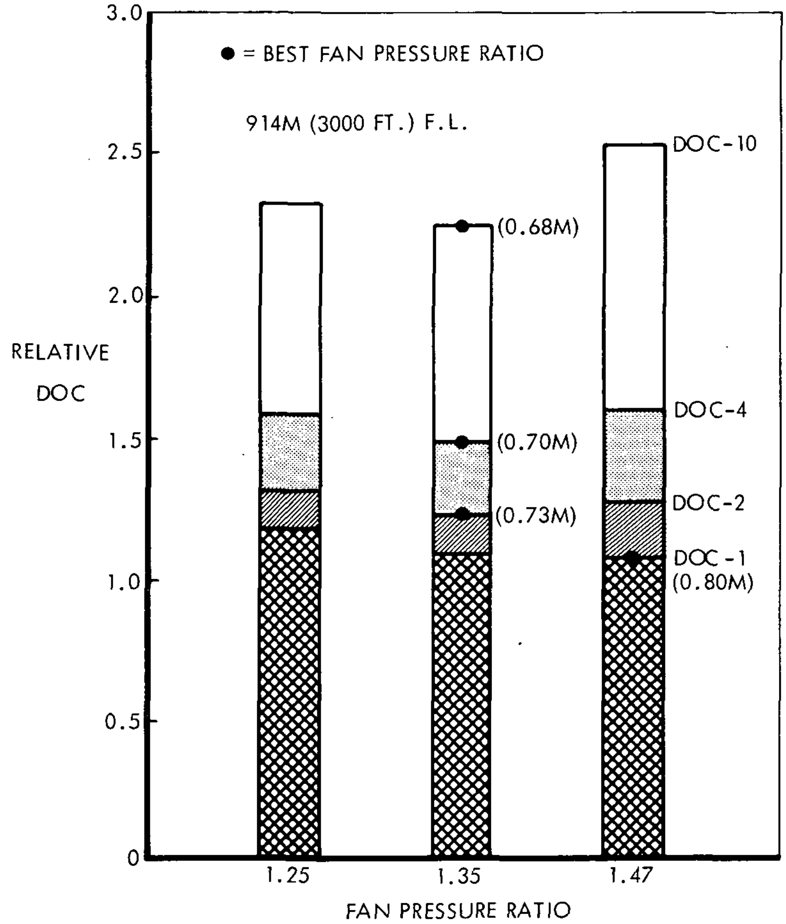


Figure 32 Effect of Fuel Cost on Optimum Fan Pressure Ratio — OTW/IBF

In the case of the MF concept, airplanes could be optimized for high-speed and both STOL and CTOL field lengths for all FPR examined. Due to the low wing loadings encountered, field lengths shorter than 914 (3000 ft.) were not considered for this concept. Figure 33 presents mission fuel for airplanes optimized for minimum fuel, and DOC-2 for airplanes optimized for minimum DOC-2, plotted against design cruise Mach number. The data are presented in the figure for a 1220m (4000 ft.) field length, which is an excellent choice for this concept since it provides an acceptably high wing loading and is superior in both fuel consumption and DOC to all alternate concepts except the T56 powered deflected slipstream aircraft. The MF results are similar to those shown for the OTW/IBF, in that the 4-engined 1.35 FPR designs provide minimum fuel consumption. However, minimum DOC-2 is provided by 2-engined designs compared to 4-engined designs for the OTW/IBF and the 1.35 FPR is shown to be superior to the 1.47 FPR. Throughout the Mach number range studied the 1.25 FPR is not competitive. At DOC-1 the 1.47 FPR is slightly superior to the 1.35 FPR.

The mission fuel and DOC-2 of T-56 aircraft, shown for reference in Figure 33, are significantly lower than the fan-powered aircraft. However, the lower cruise speed makes it doubtful if the turboprop airplane would be a practical contender for passenger acceptance in the longer stage lengths in the high density short-haul arena.

The effect of fuel price and field length on the choice of FPR for minimum DOC is shown in Figure 34. At 1220m (4000 ft.) and 1830m (6000 ft.) DOC-1 is minimum at 0.75M with a 1.47 FPR design while DOC-10 is minimum at 0.65M with a 1.35 FPR design. It can be concluded that of the three pressure ratios studied, the most suitable for future MF and OTW/IBF fuel conservative airplanes is the 1.35 FPR. This conclusion is further strengthened when noise criteria are considered.

Figure 35 presents mission fuel as a function of field length for 2- and 4-engined MF and OTW/IBF designs optimized for DOC-2. The 4-engined OTW/IBF is clearly superior in fuel consumption at field lengths shorter than 1070m (3500 ft.) while the 4-engined MF is superior at field lengths longer than 1220m (4000 ft.). It should be noted, however, that the 2-engined MF provides a lower DOC than the 4-engined configuration and therefore the primary comparison should be between the 4-engined OTW/IBF and the 2-engined MF.

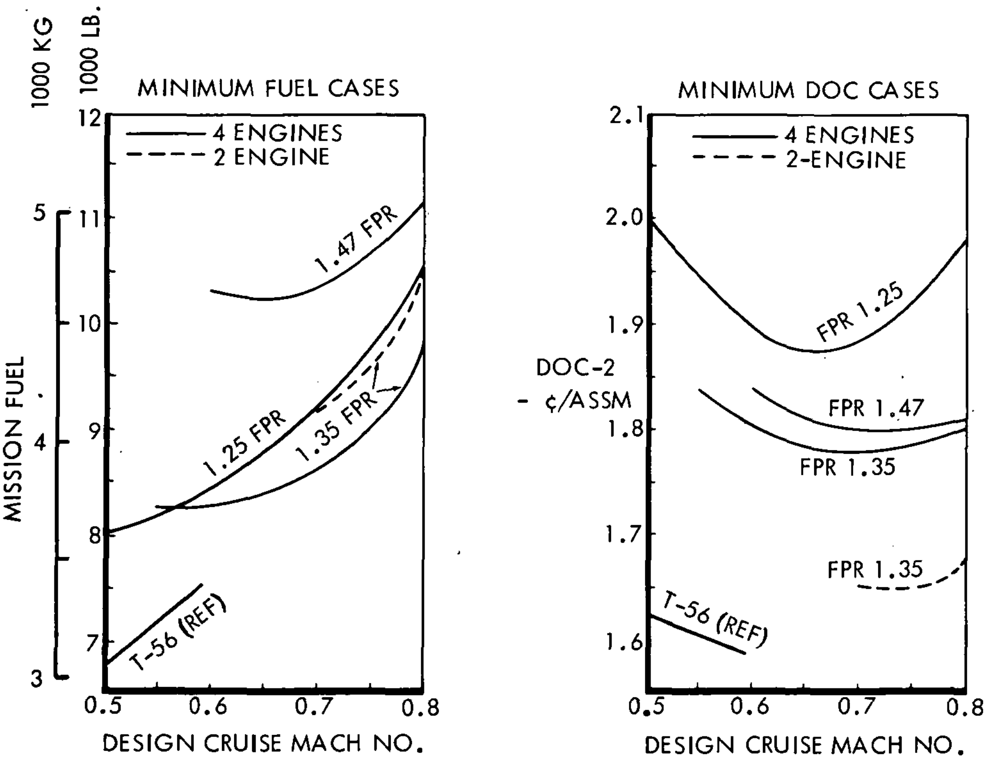


Figure 33 Fuel and Cost Effects of Engines and Design Cruise Speed — MF 1220m (4000 ft.)

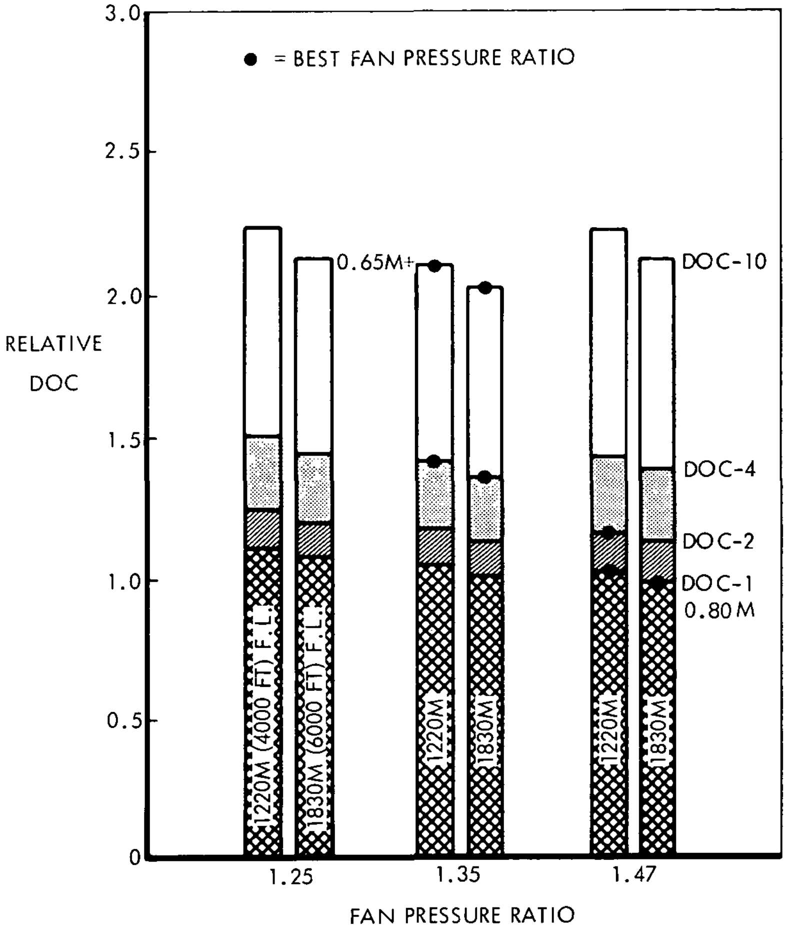


Figure 34 Effect of Fuel Cost on Optimum Fan Pressure Ratio – 1220m (4000 ft.) MF

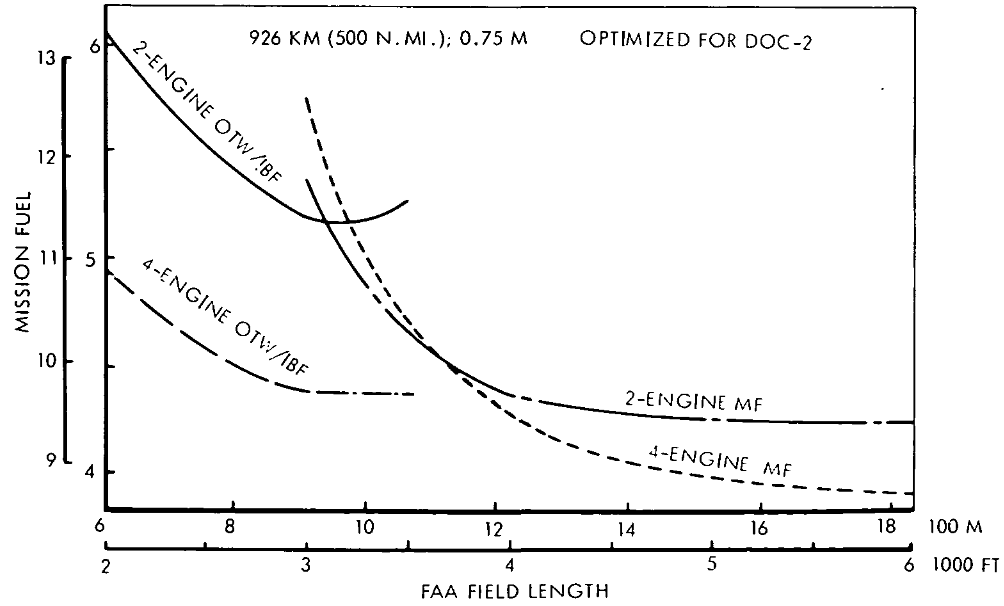


Figure 35 Effect of Field Length on Mission Fuel

The direct operating costs of these two concepts are compared in Figure 36 at two fuel price levels. At 914m (3000 ft.) the MF is slightly superior to the OTW/IBF at DOC-1, but at DOC-2 the concepts have almost identical costs. It must be noted that in both cases, DOC-1 and DOC-2, the optimum MF is 0.05M slower than the OTW/IBF. If both concepts are designed for the same Mach number, the OTW/IBF is slightly better than the MF.

The economics of the two concepts are so similar that the preference for one or the other for 914m (3000 ft.) field length operation must be based on some other criterion, such as ride quality, simplicity or fuel economy. In all cases, the OTW/IBF has a wing loading of not less than 449 Kg/sq.m. (92 lb./sq.ft.) compared with 287 Kg/sq.m. (58.8 lb./sq.ft.) for the MF. The unaugmented ride quality of the OTW/IBF will be noticeably better than the MF. For the MF to be acceptable a gust alleviation system must be developed and incorporated. The MF concept is simpler than the OTW/IBF because of the additional work required to design, develop, and prove the OTW/IBF flap, ducting, and nacelle installations.

For missions in which the T-56 turboprop deflected slipstream concept is acceptable from passenger appeal and cruise speed considerations, it should be considered because it provides better fuel consumption and DOC than either the MF or OTW/IBF at field length up to 1530m (5000 ft.) as shown in Figure 37. Also shown in Figure 37 are the EBF and AW concepts. The EBF, powered by the 1.25 FPR fan for noise considerations cruises at 0.65M and therefore has acceptably low fuel consumption but its DOC values are then unacceptably high. The AW concept has high fuel consumption and a high DOC even though this particular concept cruises with 1.35 FPR engines and only uses the FPR 3.0 load compressors in STOL terminal operations. The alternate AW concepts using FPR 3.0 to 3.2 engines for cruise and flap blowing have greater fuel consumption and higher DOC-2.

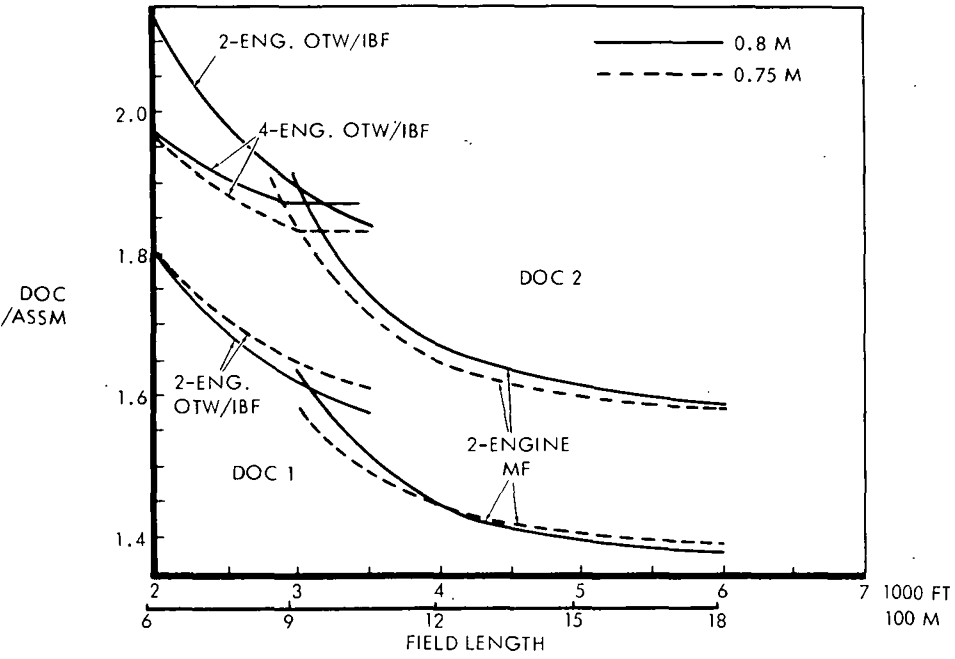


Figure 36 Effect of Field Length on DOC

At field lengths longer than 914m (3000 ft.), Figure 37 shows the MF to have the best operating cost at DOC-2 and good fuel economy. AT 1220m (4000 ft.) field length the wing loading is sufficiently high that ride quality will be acceptable. At this field length, the MF concept must be considered the best fan-powered concept for which an experimental data base exists. A more advanced propulsive lift arrangement has been suggested (Ref. 10) but has not been evaluated in this study because of lack of experimental confirmation.

The mission fuel and DOC-2 values of the recommended airplanes for field lengths of 610m, 914m, 1220m, and 1830m (2000 ft., 3000 ft., 4000 ft., and 6000 ft.) are summarized in Table XI.

Design for Noise Constraints

Noise analyses and tradeoffs were conducted to determine the economic penalty associated with the various potential noise requirements, such as FAR 36, 10 and 15 dB less than FAR 36, 95 EPNdB at the 926m (500 ft.) sideline, 80 EPNdB at Sperry Box, and footprint area and length for various noise level contours. The analyses were arranged to indicate the effect of concepts, fan pressure ratio, field length and fuel price variations on the various noise level parameters.

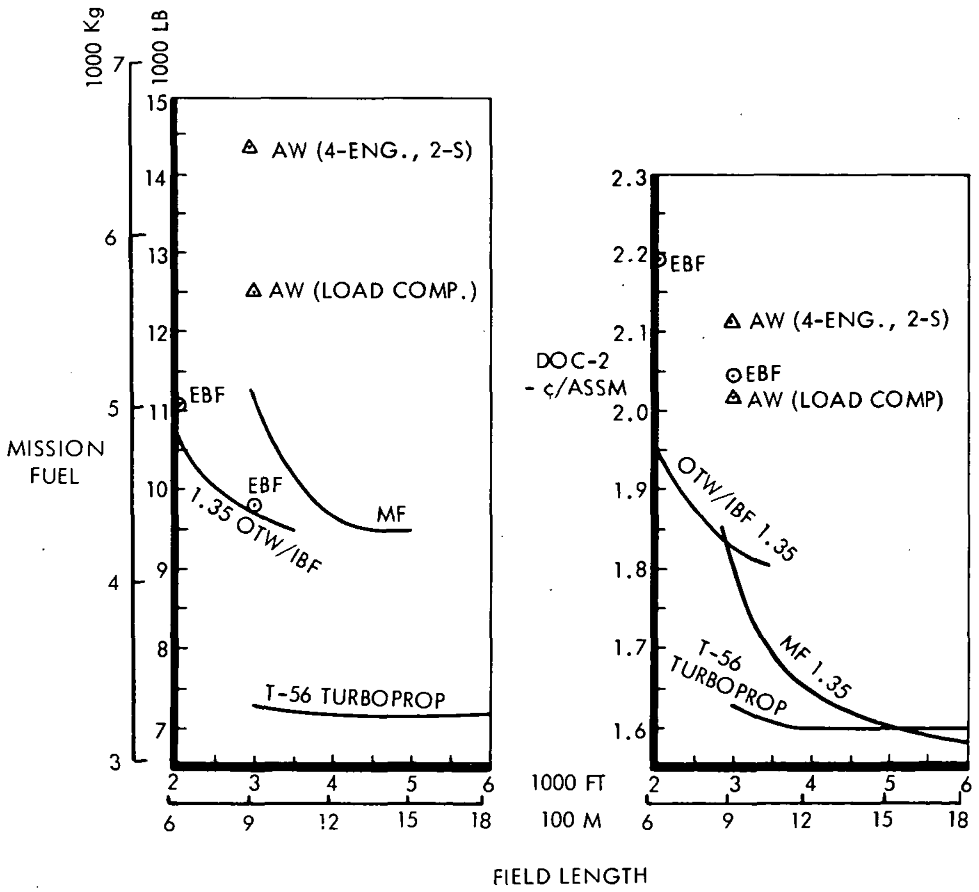


Figure 37 Comparison of Concepts – Minimum DOC-2 Cases

500 N. MI. (926 KM) STAGE LENGTH; 148 PASSENGER AIRCRAFT

NOISE LEVEL: 95 TO 100 EPNdB AT 500 FT. (152M) SIDELINE (FAR 36 MINUS 15 TO 20 dB)

AIRCRAFT OPTIMIZED FOR MINIMUM DOC AT 2 X FUEL PRICE (DOC-2)

FIELD LENGTH FT. (M)	BEST FAN-POWERED AIRCRAFT - M 0.75			TURBO-PROP - M 0.55	
	LIFT CONCEPT (NO. ENGINES)	DOC-2 ¢/ASSM	MISSION FUEL LB (KG)	DOC-2 ¢/ASSM	MISSION FUEL LB (KG)
2000 (610)	HYBRID OTW/IBF (4)	1.96	10,110 (4586)		
3000 (914)	HYBRID OTW/IBF (4)	1.83	9.700 (4400)	1.63	7,260 (3293)
3000 (914)	MF (2)	1.83	11,810 (5357)		
4000 (1220)	MF (2)	1.65	9,660 (4382)	1.59	7,170 (3252)
6000 (1830)	MF (2)	1.58	9,430 (4277)		
CURRENT CTOL - REF.		(1.6)	13,400 (6078)		

Table XI **Summary of Fuel Consumption**

Hybrid OTW/IBF Aircraft Noise — The characteristics of the OTW/IBF aircraft which furnished the principal correlations of noise level, fuel consumption, and economics at different fuel price levels are summarized in Table XII. The first column describes the 1.25 FPR airplane with the minimum DOC-2. The second column summarizes the baseline 1.35 FPR airplane (with dual range capability for R/STOL and CTOL takeoff) which was shown earlier in Table II. Gross weight and noise analyses represent the R/STOL takeoff condition. Columns 3 and 5 represent the fuel-conservative airplanes which were shown earlier in Table III; minor differences in weights and configuration are due to a slight additional refinement of the design which was applied to the airplanes described in Table III.

The results of noise contour analyses are presented in Table XIII and XIV. The sideline and flyover noise levels for the aircraft with 1.35 FPR engines are illustrated in Figure 38 as a function of the design optimization basis. It may be noted that the sideline noise decreases from 97.4 EPNdB for the 2-engine airplane optimized for DOC-1, flying at M0.8 to an estimated 94.4 EPNdB for a 4-engine airplane optimized for minimum fuel and flying at M0.6. Variation of cruise speed, and consequent installed thrust level, is the primary cause of the variations in sideline noise level; vehicles optimized for higher fuel prices, or minimum fuel, are designed for lower cruise speed, with lower installed thrust and lower sideline noise level.

The flyover noise level is more powerfully affected by climb gradient than by slight variation in source noise level so the opposite trend occurs with increase in fuel price as the basis of optimization. The noise level at the FAR 36 measuring point varies from 78.1 EPNdB for the two-engine M0.8 airplane optimized for DOC-1 to an estimated 87 EPNdB for the four-engine minimum-fuel airplane. These levels correspond to 20 and 10 dB, respectively, below the FAR 36 requirements of 98 and 97 for these aircraft. A splitter installed in the inlet of the DOC-2 airplane was effective in reducing these levels approximately 3dB.

FIELD LENGTH 914 m. (3000 FT.)

ENGINE FPR	1.25	1.35	1.35	1.35* (S)	1.35	1.47	1.47* (S)
NO. OF ENGINES	4	2	4	4	4	4	4
AR	14.0	7.73	10.0	10.0	14.0	14.0	14.0
A/C OPTIMIZ BASIS	DOC-2	DOC-1	DOC-1/-2	DOC-2	DOC-4/-10	DOC-2	DOC-2
CR. ALTITUDE - m.	7620	9140	8230	8230	9140	9140	9140
(1000 FT.)	25	30	27	27	30	30	30
DES. CR. MACH NO.	0.70	0.80	0.75	0.75	0.70	0.75	0.75
RAMP GROSS WT.- 1000 Kg	56.7	68.1	56.0	56.5	54.2	59.1	59.1
(1000 LB)	124.9	150.2	123.5	124.5	119.4	130.3	130.3
RATED THRUST - KN	61.2	175.5	55.0	56.1	47.9	54.7	55.2
(1000 LB)	13.67	39.45	12.27	12.53	10.69	12.20	12.33
T.O. W/S - Kg/Sq. m.	6813	449	583	583	530	542	542
psf	139.8	92.0	119.5	119.5	108.5	111.0	111.0
T/W INST.	0.391	0.480	0.363	0.363	0.327	0.343	0.343
T.O. FLAP - DEGREES	39.0	12.7	31.5	31.5	35.0	38.0	38.0
DIST. TO 10.7 m (35') : m	690.7	564.8	709.9	709.9	718.1	728.8	728.8
(FT.)	2266	1853	2329	2329	2356	2391	2391
VELOCITY - Km/hr.	207	224	207	207	202	209	209
(KTS)	112	121	112	112	109	113	113
SEC. SEGM CLB. - DEG.	8.12	13.48	7.02	7.02	6.25	6.86	6.86
DIST OF CUTBACK - m.	2114	1810	2370	2370	2569	2417	2417
(FT.)	6935	5939	7777	7777	8430	7930	7930
CUTBACK POWER SETTING	0.76	0.81	0.83	0.83	0.79	0.74	0.74
CLB. ANGLE AFTER CB	3.87	9.49	4.10	4.10	3.19	2.87	2.87
APPROACH ANGLE - DEG.		5.2	5.2	5.2	4.2		
APP. POWER SETTING		0.38	0.67	0.67	0.71		
APP. VEL. - Km/hr.	182.2	182.2	182.2	182.2	176.7		
(KTS)	98.4	98.4	98.4	98.4	95.4		

* SPLITTER INSTALLED IN INLET

Table XII OTW/IBF Aircraft for Noise Analysis

ENGINE FPR	1.25	1.35	1.35	1.35*(S)	1.35	1.47	1.47*(S)
NO. OF ENGINES	4	2	4	4	4	4	4
AR	14.0	7.73	10.0	10.0	14.0	14.0	14.0
SIDELINE NOISE							
EPNdB @ 152 m. (500 FT)	90.3	97.4	95.2	92.5	94.7	106.5	102.7
305 m. (1000 FT)	84.8	91.9	89.8	87.0	89.3	100.7	97.3
FAR 36 PT.	76.9	87.9	80.0	77.2	79.5	90.3	87.6
TAKEOFF FLYOVER							
EPNdB @ 1220 m. (4000 FT)	97.0	98.3	103.3	100.6	103.8	115.0	111.2
@ 1830 m. (6000 FT)	93.6	95.6	99.9	97.2	100.3	111.5	107.7
FAR 36 PT	79.9	78.1	85.3	82.1	86.2	98.2	94.9
TAKEOFF AREAS:							
SQ. KM. @ 95 EPNdB	0.205	0.533		0.326	0.567	6.570	3.286
90 EPNdB	0.531	1.202	1.518	0.824	1.448	16.298	9.800
85 EPNdB			4.454	2.328		38.350	
80 EPNdB	4.094	6.842	11.209	6.350	12.159	79.965	50.757
SQ. MI. @ 95 EPNdB	0.079	0.206		0.126	0.219	2.537	1.269
90 EPNdB	0.205	0.464	0.586	0.318	0.559	6.293	3.784
85 EPNdB			1.720	0.899		14.808	
80 EPNdB	1.581	2.642	4.328	2.452	4.695	30.877	19.599
TAKEOFF FOOTPRINT LENGTH:							
KM @ 95 EPNdB	1.386	1.601		1.685	2.303	9.312	6.440
90 EPNdB	2.090	2.176	3.672	2.295	3.652	15.270	11.628
80 EPNdB	6.442	5.605		8.070	12.582	34.878	27.517
FT @ 95 EPNdB	4,546	5,253		5,529	7.556	30,550	21,130
90 EPNdB	6,856	7,139	12,047	7,529	11,980	50,100	38,150
80 EPNdB	21,135	18,389		26,477	41,280	114,430	90,280

* SPLITTER INSTALLED IN INLET

Table XIII Summary of OTW/IBF Noise – Field Length 914m (3000 ft.)

914 m. (3000 FT.) FOUR-ENGINE AIRCRAFT OPTIMIZED FOR DOC-2.

ENGINE FPR	1.25	1.35		1.47
NO. OF ENGINES	4	4	2	4
FLYOVER EPNdB				
610 m. (2000 FT.) FROM THRESHOLD	96.9		98.4	117.2
1.85 Km (1 N.M.) FROM THRESHOLD	88.7	92.6	90.3	109.3
AREAS: 90 EPNdB - SQ. Km	0.290	0.844	0.477	17.01
- (SQ. MILES)	0.112	0.326	0.184	6.567
80 EPNdB - SQ. Km	3.328	6.974	4.752	76.57
- (SQ. MILES)	1.285	2.693	1.835	29.567
LENGTHS: 90 EPNdB - m.	1.554			
- (FT.)	5,100			
80 EPNdB - m.			6,200	49,500
- (FT.)	17,800	25,500	20,600	105,500

Table XIV OTW/IBF Approach Footprints

Area and length of the 90 EPNdB footprints are shown in Figure 39. The overriding effect of the climb gradient of the 2-engine airplane which provides minimum DOC-1 is marked as is the effect of the splitter in the inlet of the DOC-2 airplane.

The direct operating cost at twice 1972 fuel prices (DOC-2) is shown in Figure 40 as a function of sideline noise level. Figures 41 and 42 show DOC-2 as a function of flyover noise level and takeoff footprint area. It may be noted that DOC-2 increases slightly as the noise level decreases from that of the 1.47 FPR engines to that of the 1.35 FPR engine, then sharply increases for the quieter FPR 1.25 engine. Thus, the knee of the curve is represented by the aircraft with FPR 1.35 engines and the economics associated with Part 36 minus 14 to 16 db.

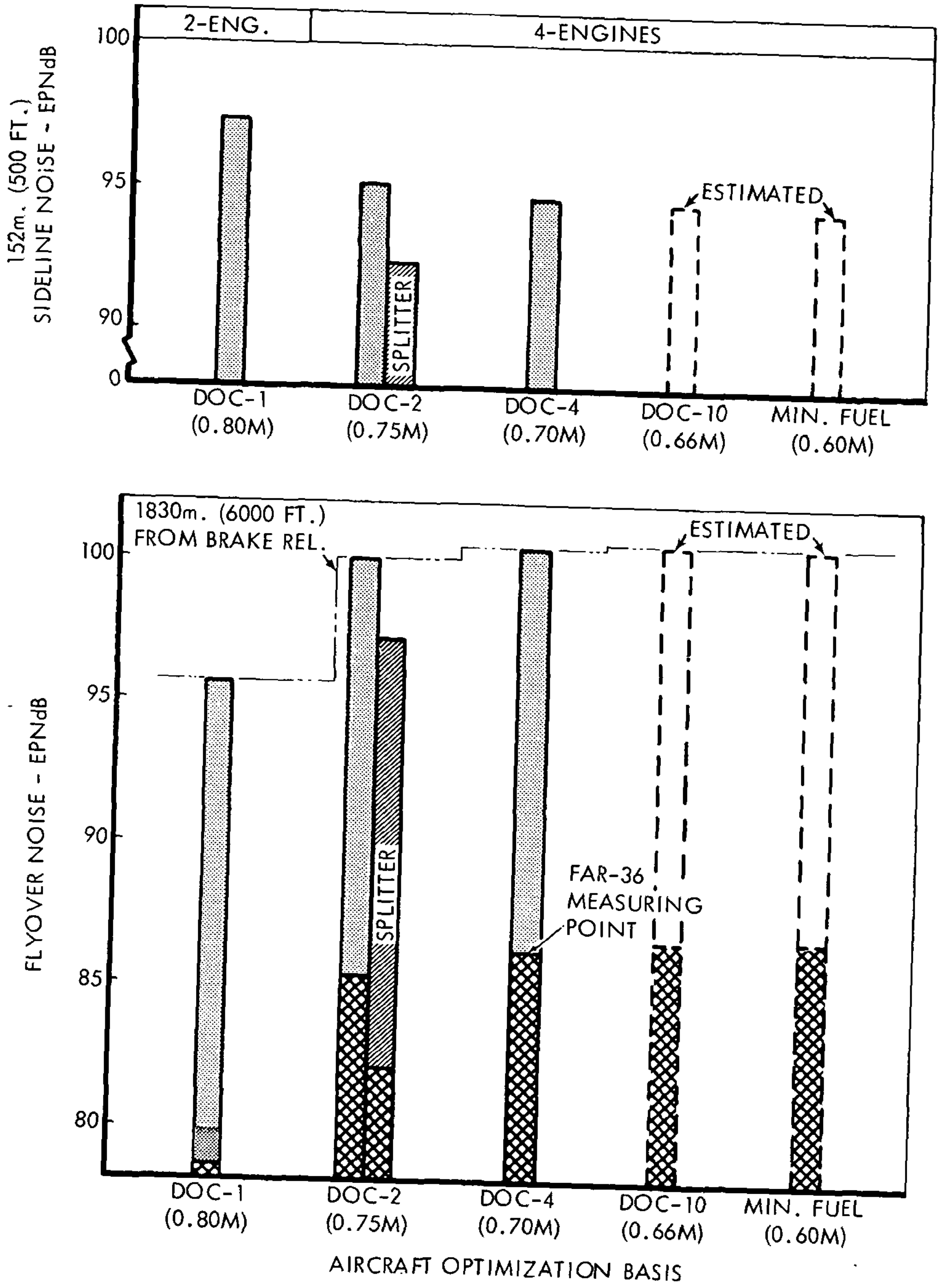


Figure 38 Variation of Noise Level with Fuel Conservation Optimization — 1.35 FPR, OTW/IBF, 914m (3000 ft.) F.L.

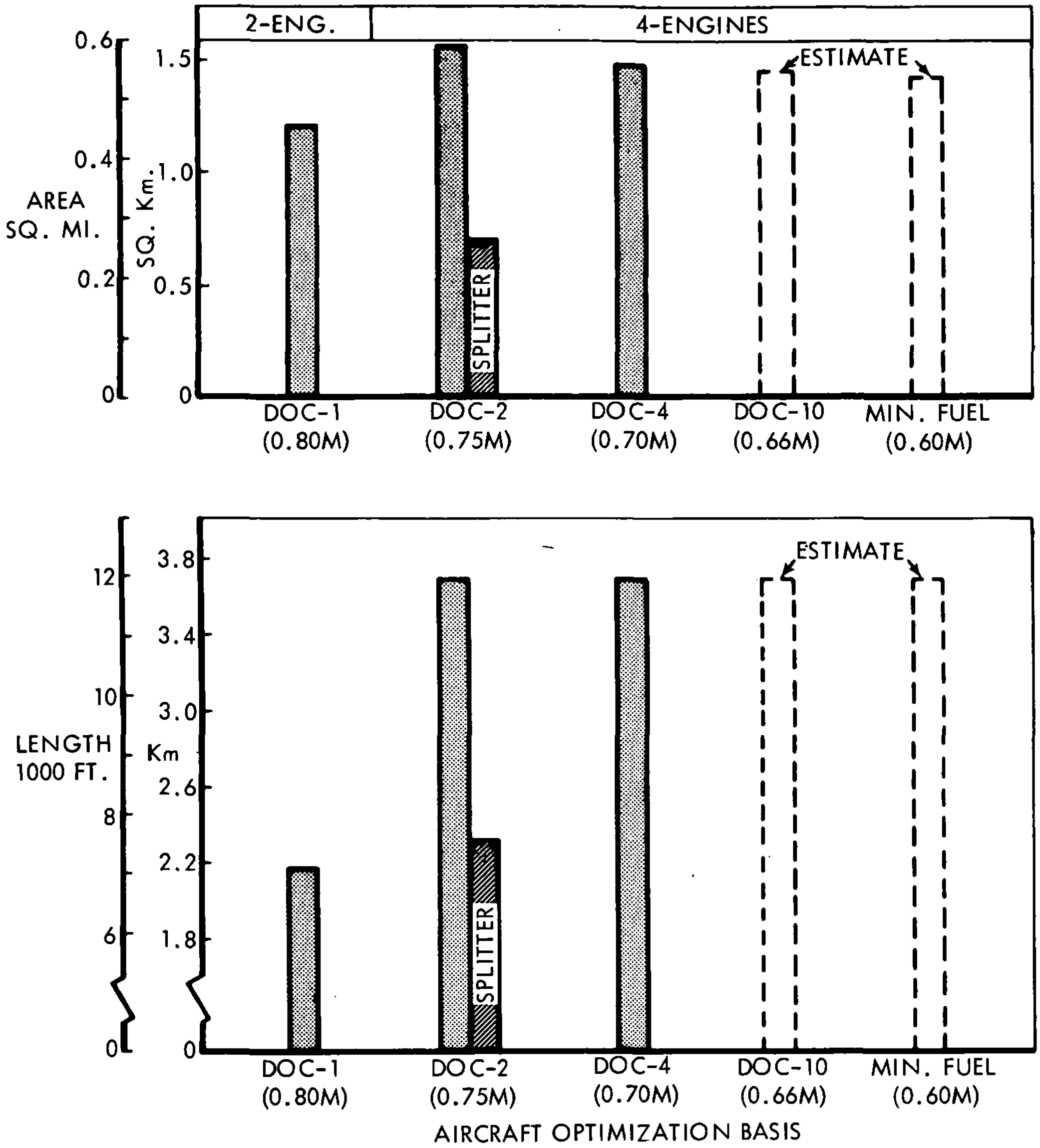


Figure 39 **90 EPNdB T.O. Footprint Area and length Variation with Fuel Conservation Optimization – 1.35 FPR. OTW/IBF, 914m (3000 ft.) F.L.**

The effects of an inlet splitter on DOC-2 and on noise level of the 1.47 and 1.35 FPR engines are shown in Figures 40, 41 and 42. Reductions of 2 to 3 dB were achieved with approximately the same penalty in performance and costs which would be obtained by the same noise reduction achieved by lowering the engine fan pressure ratio. The curves show an indication of greater superiority than this in the inlet splitter approach when applied to the 1.35 FPR engine. However, this apparent indication is considered misleading since the fairing of the curve might well pass through the point represented by the splitter if the cost penalty for the variable pitch fan were eliminated from the 1.25 FPR case. This trend is shown with a dotted line in the figures.

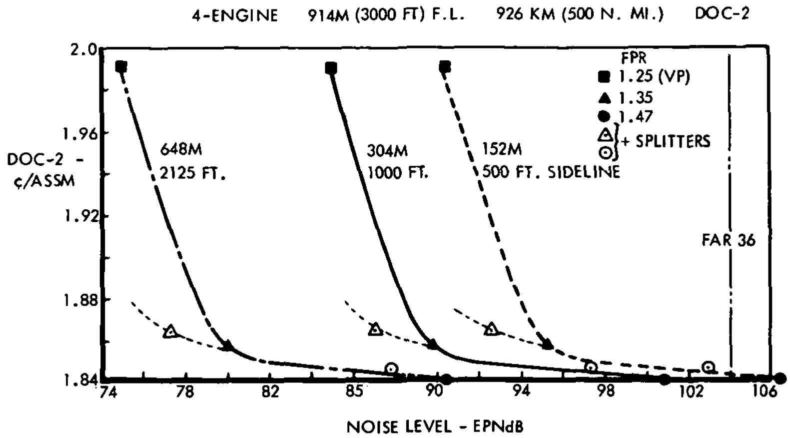


Figure 40 DOC versus Sideline Noise Level – OTW/IBF

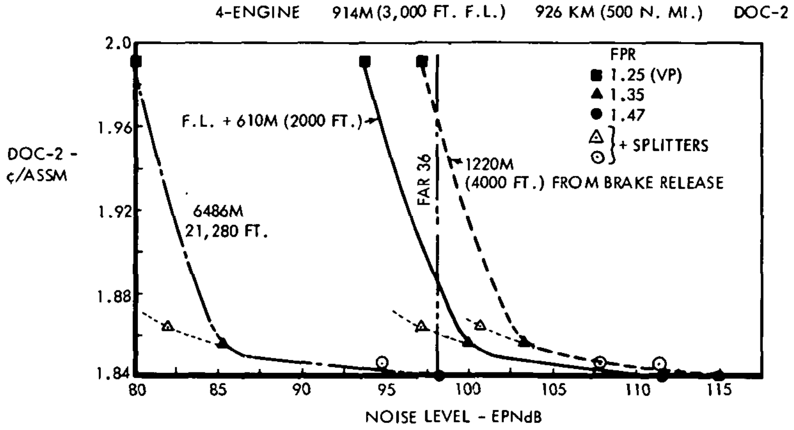


Figure 41 DOC versus Flyover Noise Level – OTW/IBF

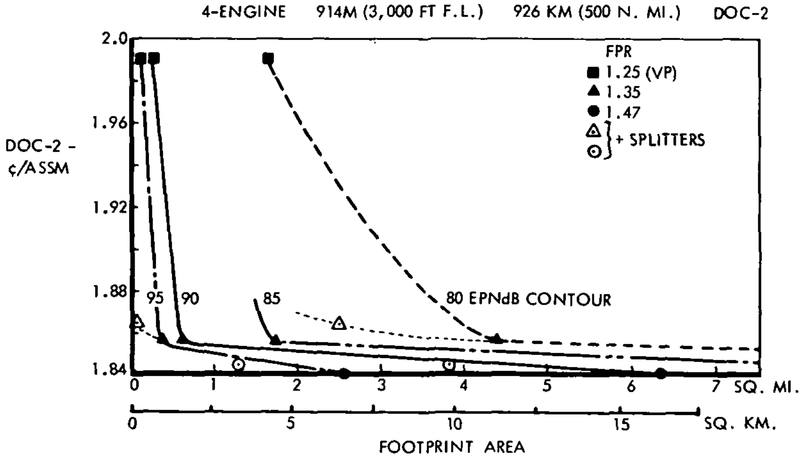


Figure 42 DOC versus Takeoff Footprint Area – OTW/IBF

Augmentor Wing Aircraft Noise – A summary of the aircraft and noise footprint characteristics is given in Table XV . The noise data are based on a fan inlet attenuation of approximately 30 dB and exhaust noise attenuation based on the data of references 32 and 33. Noise contours are plotted in Figure 43.

Mechanical Flap Aircraft Noise – The engines used in mechanical flap aircraft design and noise analyses were the same as those used on the OTW/IBF aircraft. Wall treatment in an aerodynamic nacelle was the only noise attenuation applied in contrast to the heavily-treated engines in Reference 2. As a consequence, suppressed fan noise in the current study was approximately 4 dB above that of the same engines in previous studies. (Installed engine performance was correspondingly better in the current study.) Typical component noise levels are presented in Table XVI. A significant difference from the hybrid OTW/IBF levels is in the higher level of aft noise for the 1.25 and 1.35 FPR engines as a consequence of the short nacelle without fan duct treatment (compared to the long exhaust duct for the OTW/IBF and the wing shielding effect of the upper surface engine location). Because of the criticality of aft noise, it was concluded that splitters or other additional inlet treatment would be ineffective and uneconomical because the performance loss would be increased considerably without significant improvement in noise.

914 m. (3000 FT.) FIELD LENGTH

4 ENGINES FPR 3.0 FIXED PITCH DIRECT DRIVE TIP SPEED 481 mps (1577 fps)

SINGLE ENGINE THRUST 64.9 KN (14,586 LB) GROSS WEIGHT 68,897 Kg (154,097 LB)

T.O. FLAP SETTING 14 DEGREES CLIMB VELOCITY 224 Km/HR (121 KTS)

SIDELINE NOISE: EPNdB @ DIST:

95 @ 152 m. (500 FT.)
88 @ 305 m. (1000 FT.)
80 @ 648 m. (0.35 N.M.)

APPROACH NOISE: EPNdB @ DIST:

90 @ 1850 m. (1 N.MI.)

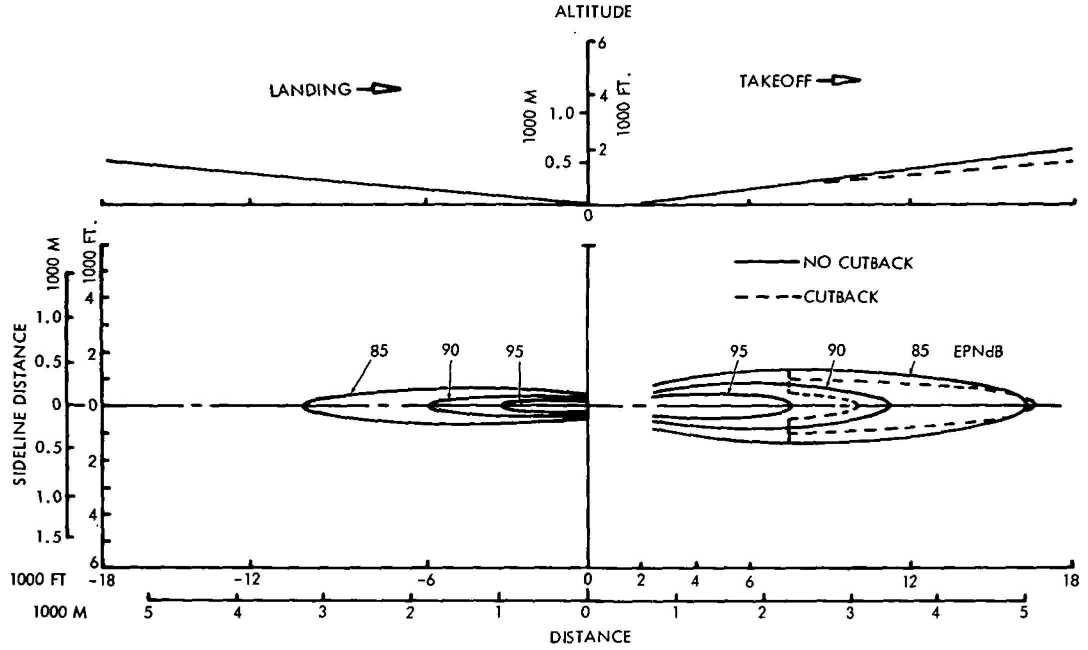
TAKEOFF FLYOVER NOISE: EPNdB @ DIST:

95 @ 2290 m. (7500 FT.)
90 @ 3050 m. (10,000 FT.)
85 @ 5180 m. (17,000 FT.)
82 @ 7920 m. (26,000 FT.)

FOOTPRINTS:

CONTOUR	APPROACH				TAKEOFF AREA		TOTAL AREA	
	LENGTH		AREA					
	m.	FT.	SQ. Km	SQ. MI.	SQ. Km	SQ. MI.	SQ. Km	SQ. MI.
95 EPNdB	914	3000	0.39	0.15	0.52	0.2	0.91	0.35
90 EPNdB	1830	6000	0.65	0.25	0.78	0.3	1.42	0.55
85 EPNdB	3200	10500	1.04	0.4	2.72	1.05	3.76	1.45
80 EPNdB	5180	17000	2.85	1.1	5.96	2.3	8.81	3.4

Table XV Augmentor Wing Noise Analysis



FPR = 3.0

Figure 43 AW Noise Footprint Contours

SHIELDING AND EGA NOT INCLUDED. WALL TREATMENT ONLY.

FPR	1.25	1.35	1.47

SINGLE ENGINE

S.L.S. THRUST - LB (KN)	42,000 (187)		35,412 (157.5)		9,757 (43.4)	
NOISE LEVELS - PNdB	FWD	AFT	FWD	AFT	FWD	AFT
FAN, UNSUPPRESSED	96.5	101.2	100.8	103.6	106.1	N/A
FAN, SUPPRESSED	92.5	93.9	96.5	96.7	102.1	
FAN JET	70.6	77.5	79.2	84.4	78.3	
PRI JET	55.4	62.1	57.1	62.3		
CORE	67.5	74.1	81.0	86.3	85.5	
TURBINE	68.2	82.3	68.9	80.8	63.4	

ALL ENGINES

AERO NOISE - PNdB	80.5	81.4	80.4	81.4	75.6	N/A
TOTAL NOISE - PNdB	96.5	99.1	100.7	102.1	108.7	
NO. OF ENGINES	2		2		4	

Table XVI MF Component Noise Summary at Maximum 152m, (500 ft.) Sideline Noise Location

The MF aircraft analyzed for noise represent the effects of differences in engine fan pressure ratio, design field length, and fuel conservation optimization. Aircraft characteristics are summarized in Table XVII; minor differences from corresponding aircraft in Tables VI and VII are due to final design refinements applied to the latter cases. Noise levels and footprint areas are summarized in Table XVIII.

The effect of variation in fuel price, as a basis of design optimization, on noise levels and footprint areas is illustrated in Figure 44. It is indicated that, as the fuel price increases, the sideline and flyover noise levels of optimized airplanes decrease very slightly because thrust levels are reduced, compatible with reductions in cruise speed. The significant change occurs in takeoff footprint area and length when the optimum configuration changes from 2 to 4 engines. Aircraft optimized for DOC-1, -2, and -4, have 2 engines; power cutback at 305m (1000 ft.) altitude was employed and the 90 EPNdB footprint length is approximately the same as the distance to power cutback. Aircraft designed for DOC-10 and minimum fuel have 4 engines and power cutback is permitted by FAR 36 at 214m (700 ft.) altitude. In spite of a lower climb gradient for the 4-engine airplanes, this cutback point is at a shorter distance from brake release, and the 90 EPNdB footprint terminates when power is cut back. The coincidence of the 90 EPNdB footprint with the power cutback location is associated only with aircraft and engines for which the noise level is 95 to 97 EPNdB at a sideline distance of 152m (500 ft.). The 4-engine OTW/IBF aircraft shown in Figure 38 exhibited a flyover noise level above 90 EPNdB after power was cutback because the combination of propulsive lift and higher wing loading did not permit as great a reduction in power.

ENGINE FPR	1.35	1.35	1.35	1.35	1.35	1.25	1.47	1.35
NO. OF ENGINES	2	2	2	2	4	4	4	2
DES. FIELD LENGTH - m.	914	914	1220	1220	1220	1220	1220	1830
(FT.)	3000	3000	4000	4000	4000	4000	4000	6000
ASPECT RATIO	7.0	10.0	10.0	10.0	10.0	10.0	14.0	10.0
A/C OPTIMIZ BASIS	DOC (1)/(2)	DOC (4)/(10)	DOC (2)	DOC (1)	DOC (2)	DOC (2)	DOC (2)	DOC (2)
CR. ALT. - m.	9140	10,060	9140	9140	8230	7620	10,060	8230
(1000 FT.)	30	33	30	30	27	25	33	27
DES. CR. MACH NO.	0.75	0.70	0.75	0.80	0.75	0.65	0.75	0.75
RAMP GR. WT. - 1000 Kg	62.6	61.0	55.5	59.9	53.6	51.8	56.2	53.2
(1000 LB)	138.0	134.5	122.3	132.1	118.2	114.2	123.8	117.3
RATED THRUST - KN	127	117	107	119	46.7	46.4	43.4	90.3
(1000 LB)	28.54	26.29	23.97	26.78	10.49	10.44	9.76	20.30
T.O. W/S - Kg/Sq. m.	278	282	393	391	403	403	403	454
psf	57.0	57.7	80.5	80.0	82.5	82.5	82.5	93.0
T/W INST.	0.379	0.355	0.359	0.375	0.325	0.323	0.292	0.317
T.O. FLAP - DEG.	13.5	21.5	24.0	16.3	25.0	29.0	33.0	2.5
DIST. TO 10.7 m (35 FT) - m.	719	719	954	969	1058	1059	1058	1521
(FT.)	2360	2360	3130	3179	3471	3475	3470	4989
VELOCITY - Km/hr.	224	219	252	257	252	250	246	296
(KTS)	121	118	136	139	136	135	133	160
SEC. SEGM. CLB. - DEGREES	11.5	11.0	10.4	10.9	8.8	8.2	7.9	9.1
DIST. TO CUTBACK - m.	2243	2307	2645	2587	2459	2567	2595	3460
(FT.)	7360	7570	8677	8489	8069	8421	8514	11,351
CUTBACK POWER SETTING	0.78	0.75	0.79	0.79	0.59	0.63	0.59	0.72
CLB ANGLE AFTER CUTBACK	7.9	7.1	7.2	7.5	3.1	3.2	2.6	5.6
APPROACH ANGLE - DEG.	5.2	5.2	4.4	4.4	4.4	4.4	4.4	3.5
APP. POWER SETTING	0.33	0.26	0.31	0.34	0.38	0.38	0.33	0.13
APP. VEL. - Km/hr.	181	182	216	216	216	216	216	273
(KTS)	97.9	98.5	116.6	116.6	116.6	116.6	116.6	147.2

Table XVII MF Aircraft for Noise Analysis

ENGINE FPR	1.35	1.35	1.35	1.35	1.35	1.25	1.47	1.35
NO. OF ENGINES	2	2	2	2	4	4	4	2
ASPECT RATIO	7.0	10.0	10.0	10.0	10.0	10.0	14.0	10.0
FIELD LENGTH - m.	914	914	1,220	1,220	1,220	1,220	1,220	1,830
(FT.)	3,000	3,000	4,000	4,000	4,000	4,000	4,000	6,000
SIDELINE NOISE								
EPNdB @ 152 m. (500')	98.0	97.8	96.5	96.9	95.6	91.5	104.8	95.0
305 m. (1000')	92.0	91.7	90.5	90.9	89.5	85.4	98.7	-
FAR 36 PT.	88.3	88.0	86.8	87.2	80.3	76.1	88.0	85.3
TAKEOFF FLYOVER								
EPNdB @ 1220 m. (4000')	102.1	102.2	106.1	106.5	109.9	106.3	119.7	104.4
1830 m. (6000')	98.6	98.6	97.3	97.4	98.9	95.4	109.0	-
FAR 36 PT.	79.9	80.0	80.0	80.0	81.6	80.8	94.1	80.3
TAKEOFF AREAS								
SQ. Km @ 95 EPNdB	0.704	0.689	0.645	0.676	0.624	0.308	2.903	0.676
90 EPNdB	1.401	1.362	1.362	1.422	1.098	0.756	7.728	1.502
85 EPNdB	3.097	-	-	-	2.111	-	-	2.665
80 EPNdB	7.666	7.290	6.974	7.254	5.918	4.558	34.14	-
SQ. MI. @ 95 EPNdB	0.272	0.266	0.249	0.261	0.241	0.119	1.121	0.261
90 EPNdB	0.541	0.526	0.526	0.549	0.424	0.292	2.984	0.580
85 EPNdB	1.196	-	-	-	0.815	-	-	1.029
80 EPNdB	2.960	2.815	2.693	2.801	2.285	1.760	13.181	-
FOOTPRINT LENGTH								
M. @ 95 EPNdB	1,984	1,998	2,134	2,142	2,347	1,730	5,779	2,624
90 EPNdB	2,212	2,212	2,540	2,554	2,347	2,553	10,242	3,456
80 EPNdB	6,419	6,483	6,485	6,504	8,129	7,297	22,620	-
FT. @ 95 EPNdB	6,508	6,556	7,002	7,029	7,700	5,675	18,894	8,609
90 EPNdB	7,258	7,256	8,332	8,379	7,700	8,375	33,604	11,339
80 EPNdB	21,059	21,269	21,277	21,339	26,669	23,941	74,214	-
APPROACH NOISE								
EPNdB @ 610 m. (2000')	97.2	-	96.4	-	-	95.6	102.8	93.5
1850 m. (1 N.MI.)	88.8	-	88.1	-	92.6	87.3	94.5	85.4
90 EPNdB AREA SQ. Km	0.334	-	0.243	0.285	0.844	0.186	1.106	0.101
(SQ. MI.)	0.129	-	0.094	0.110	0.326	0.072	0.427	0.039

Table XVIII Summary of MF Noise

Noise Characteristics of Other Concepts — Except for the noise analyses of Reference 2, no detailed noise analyses of the other lift concepts discussed in Section 3 have been performed. An appraisal of the noise characteristics is presented in the following paragraphs:

- **EBF Noise** — The noise level of the EBF aircraft with 1.25 EPR engines has been changed from the levels shown in Reference 2 by the use of nacelles with wall treatment only. This change makes the fan noise approximately the same level as the flap interaction noise. No detailed analysis has been conducted but it is estimated that the noise characteristics of the aircraft will be approximately the same as those of the OTW/IBF aircraft wih 1.35 FPR engines.

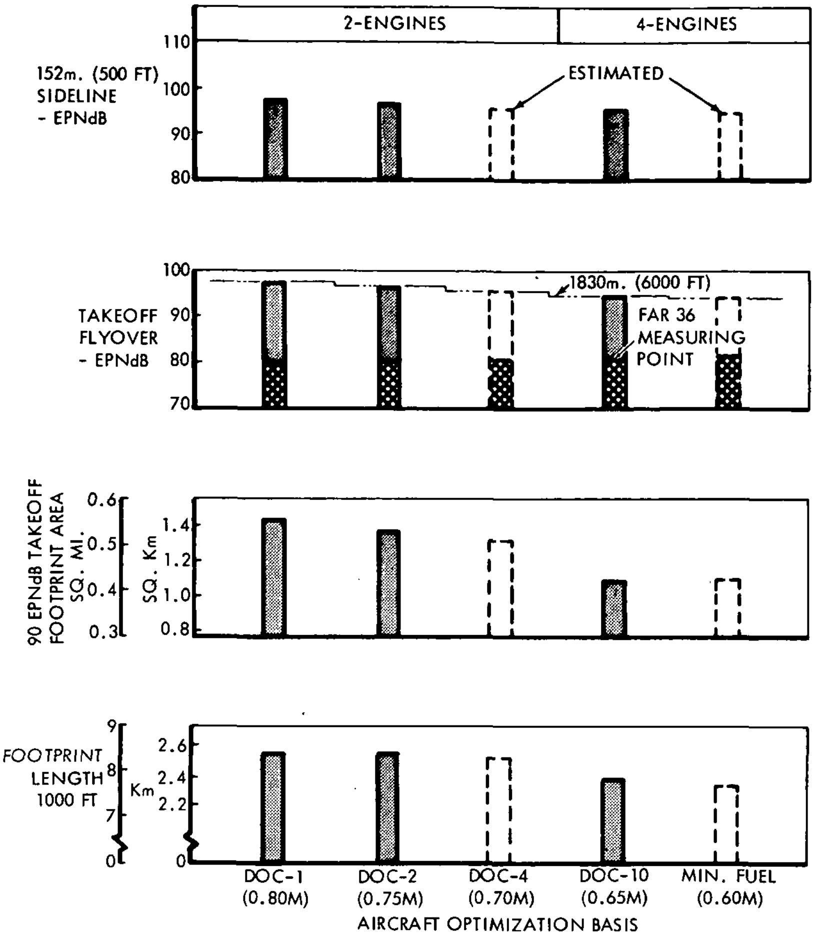


Figure 44 **Effect of Fuel Conservation Optimization Basis on Noise — 1.35 FPR, MF, 1220m (4000 ft.) F.L.**

- o **OTW Noise** — The use of 1.35 FPR engines with wall treatment in the over-the-wing configuration is expected to give about the same aircraft noise characteristics as the OTW/IBF configuration. The slot jet in the OTW/IBF aircraft contributes insignificantly to the total noise. Differences between the OTW and OTW/IBF will be principally those caused by difference in total installed thrust and differences in climb gradient.

- o **Deflected Slipstream Noise** — Community noise data were analyzed in considerable detail for C-130 aircraft with T-56 turboprop engines in connection with studies of this airplane for Eastern Air Lines and American Airlines. Noise measurements have been made with the current 4.1m (13.5 ft.) diameter propellor which showed a maximum 152m. (500 ft.) sideline level of 106 PNdB. Noise levels with the quiet propellor 4.9m. (16 ft.) diameter, tip speed, 194m./sec. (635 fps) have been subject to detailed analysis in these earlier studies and a prediction of 95 PNdB at 152m. (500 ft.) has a high confidence level. Although no detailed contour data have been obtained, it is estimated that the aircraft in the current study will have noise characteristics similar to those of the mechanical flap aircraft with 1.35 FPR engines.

Effect of Noise and Field Length Constraints – Table XIX summarizes the effect of noise constraints on airplane configuration, DOC-2 and fuel consumption with no restriction on the performance factors. With cruise speed and block time unrestricted, the two-engine mechanical flap aircraft with 1830m. (6000 ft.) field length and FPR 1.35 engines satisfies many noise restrictions with no penalty indicated for DOC-2 or fuel. For purposes of further comparisons, the 1830m. (6000 ft.) MF airplane is used as a basis for expressing penalties. If field lengths for short haul aircraft are restricted to 1220m. (4000 ft.) or less, as suggested throughout the study, the penalties for meeting the different potential requirements are those indicated in Table XX. Most of the cases are best satisfied with MF aircraft. Significant increases in DOC and fuel penalties are indicated if 90 EPNdB requirements of less than 1.0 sq. km. (0.39 sq. mi.) area, or 2.3 km. (7500 ft.) footprint length are imposed.

The concept of a "Sperry box" limitation of 80 EPNdB at the borders of a rectangular area 1830m (6000 ft.) long by 610m (2000 ft.) wide is outside the limits of the configurations analyzed in this study. Extrapolation of the data would indicate that the aircraft would have to be much smaller than the 148-passenger configurations. Aircraft meeting 80 EPNdB at the takeoff flyover point would require a climb capability of reaching approximately 305m (1000 ft.) in 1220m (4000 ft.) from brake release, and a 152m (500 ft.) sideline noise level on the order of 85 EPNdB. These characteristics could be achieved by a small, low-wing-loading airplane, but DOC penalties for the high-density scenario would be on the order of 400 percent. It appears that this requirement may be feasible only for commuter operations and applicable in the high density area only if city-center operations are ever realized.

	LIFT CONCEPT	NO. ENG.	FPR	FIELD LENGTH M (FT)	CRUISE SPEED	PAX	DOC-2 ¢/ASSM	FUEL KG (LB)
MIN DOC-2 CASE:	MF	2	1.47	1,830 (6,000)	0.75	148	~1.59	–
MIN DOC FOR FAR36-5	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
MIN DOC FOR FAR36-10	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
MIN DOC FOR FAR36-15	MF	2	1.35	1,220 (4,000)	0.75	148	1.641	4,318 (9,519)
MIN DOC FOR 95 EPNdB @ 152 M (500')	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
MIN DOC-2 FOR 90 EPNdB FOOTPRINT:								
2.60 SQ. KM (1 SQ.MI.)	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
1.3 SQ. KM (0.5 SQ.MI.)	MF	2	1.35	1,220 (4,000)	0.75	148	1.641	4,318 (9,519)
.83 SQ. KM (0.32 SQ. MI.)	OTW/IBF (WITH SPLITTERS)	4	1.35	914 (3,000)	0.75	148	1.863	4,790 (10,560)
.75 SQ. KM (0.29 SQ. MI.)	MF	4	1.25	1,220 (4,000)	0.65	148	1.887	4,027 (8,877)
MIN DOC-2 FOR 90 EPNdB FOOTPRINT LENGTH:								
6.48 KM (3.5 N.MI.)	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
3.704 KM (2.0 N.MI.)	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
1.85 KM (1.0 N.MI.)	OTW/IBF	2	1.35	< 914 (3,000)	0.75	148	1.90	6,350 (14,000)
1220 M (4000 FT)	OTW/IBF	2	1.25	610 (2,000)	0.75	148	2.3	6,804 (15,000)

Table XIX DOC and Fuel Penalties – No Performance Constraints

	Lift Concept	No. of Engines	Engine FPR	Field Length m (ft)	Cruise Speed M	DOC 2 Penalty %	Fuel Penalty %
Reference	MF	2	1.35	1830 (6000)	0.75	0	0
FAR 36 - 10 - 15	MF	2	1.35	1220 (4000)	0.75	3.0	4.3
95 EPNdB @ 152m (500 FT.)	MF	2	1.32	1220 (4000)	0.75	4	5
90 EPNdB Footprint Area =							
2.60 Sq. Km. (1.00 Sq. Mi.)	MF	2	1.40	1220 (4000)	0.75	3	4
1.30 Sq. Km. (0.50 Sq. Mi.)	MF	2	1.33	1220 (4000)	0.75	4	5
0.83 Sq. Km. (0.32 Sq. Mi.)	OTW/IBF	4 Splitter	1.35	914 (3000)	0.75	17	14
0.75 Sq. Km. (0.29 Sq. Mi.)	MF	4	1.25	1220 (4000)	0.65	18	(- 4)
90 EPNdB Footprint							
Length = 1.85 Km (1.0 n.m.)	OTW/IBF	2	1.35	850 (2800)	0.75	20	50
1220m (4000 FT)	OTW/IBF	2	1.25	610 (2000)	0.75	40	60

Table XX DOC and Fuel Penalties at Field Length 1220m (4000 ft.)

NOISE REQUIREMENT	LIFT CONCEPT	NO. OF ENGINES	ENGINE FPR	FIELD LENGTH m. (FT.)	DOC-2 PENALTY PCTG	FUEL PENALTY PCTG
REFERENCE	MF	2	1.35	1830 (6000)	0	0
FAR 36 - 10 OR 15	MF*	2	1.35	914 (3000)	15	27
FAR 36 - 15	OTW/IBF	4 (SPLITTER)	1.35	914 (3000)	17	14
95 EPNdB @ 152 m. (500 FT.)	OTW/IBF	4	1.35	914 (3000)	15	6
90 EPNdB AREA						
2.6 SQ. Km (1 SQ.MI.)	MF*	2	1.40	914 (3000)	14	27
1.3 SQ. Km (0.5 SQ.MI.)	OTW/IBF	4	1.37	914 (3000)	15	6
0.83 SQ. Km (0.32 SQ.MI.)	OTW/IBF	4 (SPLITTER)	1.35	914 (3000)	17	14
90 EPNdB LENGTH						
2.3 Km (7500 FT.)	OTW/IBF	4 (SPLITTER)	1.35	914 (3000)	17	14
1.86 Km (1 N.MI.)	OTW/IBF	2	1.35	850 (2800)	20	50
1.22 Km (4000 FT.)	OTW/IBF	2	1.25	610 (2000)	40	60

* MF AT LOW WING LOADING REQUIRES RIDE QUALITY GUST ALLEVIATION AND DEMONSTRATION FOR PASSENGER ACCEPTABILITY ON LONGER STAGE LENGTHS.

Table XXI DOC and Fuel Penalties at Field Length 914m (3000 ft.) or Less – M 0.75.

The penalties for different noise requirements with field length restricted to 914m. (3000 ft.) are given in Table XXI. This comparison was also restricted to designs for Mach 0.75 cruise speed. The low wing loading mechanical flap aircraft designed to cruise at Mach 0.70 would be approximately one percent lower in DOC and nine percent better in fuel consumption. It is concluded that most of the prospective noise requirements can be met with 914m. (3000 ft.) aircraft at a total penalty of 17 percent compared to a 1830m. (6000 ft.) airplane. Penalties for mechanical flap and hybrid OTW/IBF are about equal from the standpoint of noise level and direct operating cost at twice 1972 fuel prices; the hybrid is superior in fuel consumption and its DOC would become superior with further increases in fuel price.

It is suggested that attention be given to restricting the 90 EPNdB contour to 1 sq. km. (0.39 sq. mi.) in area and 2.3 km. (7500 ft.) in length. Cost and fuel penalties increase for more stringent requirements. Shorter footprint lengths would require shorter field length requirements and would change the optimum design from four to two engines in the OTW/IBF aircraft.

The effect of field length on direct operating costs and fuel consumption can be summarized for three potential noise requirements as follows (Ref. is the 1830m. (6000 ft.) aircraft meeting FAR 36-10):

Field Length		% Penalties for Meeting					
		FAR 36-15		90 EPNdB 1 Sq. Km (.386 Sq. Mi.)		90 EPNdB 2.3 Km (7550 Ft.) Long	
Meters	Feet	DOC	Fuel	DOC	Fuel	DOC	Fuel
1830	6000	3	4	10	10	17	14
1220	4000	3	4	10	10	17	14
914	3000	17	14	16	10	17	14

To meet FAR 36 minus 15, the landing field length must be reduced below 1830m (6000 ft.) because of approach noise. If the requirement is 1 sq. km (0.3959 mi.) for the 90 EPNdB foot print, the penalty is 10 percent in DOC and fuel and no additional penalty is incurred for reduction in field length to 1220m (4000 ft.). If the length of the 90 EPNdB foot print is required to be 2.3 km (7500 ft.), the 914m (3000 ft.) field length is required and the DOC and fuel penalties are 17% and 15%, respectively.

5. COMPROMISE SOLUTIONS

Previous sections have shown that noise criteria, field performance, and fuel price all have a strong effect on economics. Compromise solutions for the high-density short-haul air transportation system will be examined for combinations of these factors, with some reference to the long haul and low-density short haul scenarios.

It is proposed that a valid simplification can be made by establishing the assumption that fuel prices will be stabilized at two to four times 1972 levels, and that equitable return on investment will be possible by adjustment of fare levels; it appears that such fare adjustmens would not be so radical as to alter the passenger preference for air travel.

Commonality of Engine Requirements with Long-Haul

The assumption of engine commonality between short- and long-haul applications has a significant effect on short-haul economics. Therefore, the potential environment and characteristics of advanced long-haul aircraft should be evaluated. At the projected fuel prices it is suggested that long-haul aircraft may be designed for cruise speeds at or below M 0.8 for best economy. Such an aircraft might have to compete with a M 0.86 airplane for passengers; in the past, higher speeds have been considered a prime attraction. Airline decision on specifying new long-haul equipment might be based on a direct operating cost differential in which M 0.8 aircraft were five to ten percent lower than M 0.86 aircraft. At 50 percent load factor, this differential would represent a cost per passenger of \$2 to \$4 on a 3704 km (2000 n. mi.) trip and a penalty in block time of about 18 minutes (out of 4 hours). It is difficult to predict whether the passenger would select the slower airplane if there were freedom to set competitive fares with a differential of this amount -- only one to two percent of the total fare.

It is recognized that analyses of the effect of fuel shortages and higher fuel prices on long haul are underway under NASA sponsorship. These could have significant impact on the conclusions reached for short-haul economics and engine selection. It is concluded from the above cursory analysis that the choice of engine -- bypass ratio and fan pressure ratio -- on the basis of lower cruise speeds for long-haul aircraft is not definitive from the standpoint of economics and fuel consumption alone. If fuel prices more than triple or if fuel allotments force a higher importance to fuel conservation it is much more likely that design speeds would be lowered and that fan pressure ratios of the order of 1.35 would be selected for advanced long-haul and short-haul airplanes.

Noise criteria for long-haul aircraft should also be examined in considering the engine commonality aspect. It is estimated that current intermediate bypass engines can be used with advanced aircraft to satisfy a FAR 36 minus 10 dB requirement although design approach speeds may need to be lowered slightly to satisfy approach noise. (Lowering approach speed decreases the aerodynamic source noise and permits a higher glide path, if Microwave Landing System equipment is available, while still maintaining the same acceptable rate of descent; engine noise effect is decreased because less power is carried on the engines and the height of the airplane is increased over the measuring point.) Probably only small decreases in approach speed would be necessary although these would require slightly larger wings and some increase in cost.

If FAR 36 minus 15 dB were imposed (intermediate in the CARD study 1981 research goal, Ref. 11) the principal penalty would be the further reduction in approach speed toward the equivalent of a 1220m (4000 ft.) airplane. (This appears to be a quantifiable solution; other means of reducing approach noise might be developed.) Engine fan pressure ratios of 1.35 to 1.40 would be required; this in turn would force cruise speed down but the associated fuel savings might well compensate for the penalty of the larger wing required for approach. Restriction of footprint areas for long-haul aircraft would tend to have the same effects as a FAR 36 minus 15 criteria. Definitive analyses of these aspects of long-haul systems are needed; they were, of course, outside the scope of the present study.

From the foregoing, it is concluded that in-depth analyses are needed of aircraft and engines which are designed for fuel economy and for noise characteristics which differ from those in previous developments. For example, engines could be designed, at a given noise level, for optimizing the lapse rate to fit airplane requirements for minimum fuel consumption and desired field length such as M 0.75 at 9140m (30,000 ft.) and 1830m (6000 ft.) field length (in the current study, the airplanes were optimized to fit the engines, including their lapse rates). The engine designs in the QCSEE program were biased towards minimum exhaust velocity because of the emphasis on flap interaction noise in the under-wing EBF concept. Thus, engines have not been optimized for the conditions of minimum fuel consumption and acceptably low noise in the currently favored concepts of hybrid OTW/IBF and mechanical flap aircraft. A closely integrated aircraft/engine design study is strongly recommended. The results of the design studies in the pre-hardware phases of the QCSEE program should now be extended to cover the current conditions, closely integrated with the airplane designs.

It is further concluded that the best engine characteristics will be most dependent on noise requirements -- different from those imposed in the pre-hardware phases of the QCSEE program. The data described previously, showed marked superiority in aircraft fuel consumption and direct operating cost at favorable noise levels for the FPR 1.35 engine with a geared stage-and-a-half fan. The indications are that an upper limit of 1.35 to 1.4 would be imposed by the noise levels which have been recommended for serious consideration. Breakdown of noise sources into components indicate that exhaust noise and suppressible fan noise both require a limit of this sort. The question of gearing the fan, compared with direct drive, will remain uncertain at these fan pressure levels especially until maintenance uncertainties are pinned down. Use of a 1-1/2 stage fan appears beneficial, but has not been thoroughly evaluated. Tradeoff shows the cost of a variable pitch fan is not warranted in the current over-the-wing nacelle design. However, different mountings and nacelle configurations might alter this tradeoff; in a mechanical flap under-wing installation the variable pitch feature and conventional thrust reverser are close to a standoff.

In summary, the current data indicate that a fixed-pitch geared 1-1/2 stage fan engine with FPR of 1.35 is close to optimum from the standpoint of noise and fuel consumption at acceptable cruise speeds for short and long haul air transportation. A definitive aircraft/engine analysis is recommended to define firmly the commonality of short and long haul requirements and to establish in more detail the engine characteristics.

Aircraft Design for 1220m. (4000 Ft.) Field Length

The mechanical flap aircraft using two 1.35 FPR engines is capable of meeting FAR 36 minus 15, with a DOC-2 penalty of 3 percent compared to the 1830m. (6000 ft.) airplane meeting FAR 36 minus 10. Its 90 EPNdB footprint is 1.36 sq. km (0.526 sq. mi.) for takeoff and 0.243 sq. km (0.094 sq. mi.) for landing. Takeoff footprint length is 2539m (8330 ft.) and approach footprint length is 1448m (4750 ft.). Design cruise speed is M 0.75 at 9140m (30,000 ft.). Fuel consumption is 4 percent more than the 1830m. (6000 ft.) 2-engine airplane and 5 percent more than a 4-engine 1220m. (4000-ft.) airplane; DOC-2) of the 2-engine airplane is lower.

It is suggested that this airplane has excellent potential for application in many areas where the 1220m. (4000 ft.) field length is appropriate. In many ways this conclusion coincides with the conclusions reached in planning the Europlane program. The airplane differs from the Europlane in using an advanced (rubberized) engine, in passenger size because of convenience in making comparisons in the study, and in placement of the engines on the wing (the Europlane engine placement was constrained by the forward fan noise dominance of the RB211 engines). If an engine of about 110 kN (25,000 lb.) thrust were developed, two, three, or four engine airplanes with passenger capacities of 150, 200, or 250 could be developed.

Aircraft with 1220m. (4000 ft.) field length could partially relieve airport congestion by use of secondary airports and permit continued growth of air transportation in the cases where additional runways of this length could be provided on hub airports. Noise criteria permitting a 90 EPNdB footprint, 1448m. (4750 ft.) long and 0.78 km. (0.3 sq. mi.) in area beyond each end of the runway would contribute no penalty in DOC or fuel. Conversely, the airplane described is the most economical airplane meeting those noise criteria. More stringent noise criteria would cause increasing cost penalties. The airplane should also be of significant interest to airlines for operation from CTOL runways if credit for its low noise could be gained in a fleet noise improvement if an averaging criteria were established.

It is also concluded that the weight and cost penalty for a heavier fuel load to provide a longer range capability with CTOL takeoff would be more than counterbalanced by increased flexibility and utilization. Range with full payload should probably be increased to 1110 km (600 n. mi.) for R/STOL takeoff and 2780 km (1500 n. mi.) with CTOL takeoff.

Implementation of this aircraft requires primarily the propulsion development. A significant first step is obtaining answers to the questions of engine optimization. A quiet clean R/STOL integrated airframe/engine study program is suggested. Following that study, and utilizing the technology from the QCSEE program, the development of an operational engine could be undertaken. The economic environment of the U.S. airline and aircraft industry would be the determining factor as to whether this development could be based on private enterprise risk funding.

The airframe technology is essentially in hand; a wing with an advanced airfoil and aspect ratio of 10 for M 0.75 cruise does not require extensive new programs. The higher, and possibly increasing fuel price is bringing closer the day when it will pay to replace aircraft having specific fuel consumption greater than 0.8. However, the engine development would be the pacing factor, placing the initial operation of the airplane described in the mid-1980's.

Aircraft Design for 914m. (3000 ft.) Field Length

The hybrid OTW/IBF airplane using two 1.35 FPR engines is capable of providing 90 EPNdB contours less than 0.65 sq. km (0.25 sq. mi.) and 1890m. (6200 ft.) beyond each end of the runway. A four-engine airplane with splitters in the inlet of the 1.35 FPR engines is also capable of meeting this requirement. Fuel consumption for the two-engine airplane designed for M 0.75 is 25 percent higher than for the 1830m. (6000 ft.) MF airplane; for the four-engine hybrid, it is 8 percent higher. DOC-2 for either is 17 percent higher.

Mechanical flap aircraft with a low wing loading are capable of meeting these requirements at essentially the same DOC and fuel consumption as the two-engine hybrid; the four-engine hybrid is significantly superior in fuel consumption. The augmentor wing and externally blown flap aircraft are significantly higher in DOC. The deflected slipstream turboprop aircraft is superior in fuel consumption to all concepts and approximately equivalent in DOC if a new engine must be developed to match the desired aircraft size; as previously stated, because of its low speed the turboprop airplane is not considered competitive in the high-density arena.

Since there is no demand currently for an implementation decision, it is suggested that several years are available in which additional data can be obtained, such as the following:

- Clarification of the land-side costs and needs for congestion relief associated with 610m. to 1220m. (2000 to 4000 ft.) short haul runways.
- Demonstration of the gust alleviation technology and passenger acceptance of associated ride quality for an airplane with 293 kg/sq. m. (60 psf) wing loading.
- Establishment of rational specific noise criteria for long haul aircraft using existing runways and for short-haul aircraft using additional runways not now contributing to community noise.
- Establishment of specific performance certification criteria (modification and implementation of a modified FAR Part XX).
- Further development and demonstration of propulsive lift.

On the latter point, the long duct nacelle used conservatively in the performance analyses of the OTW/IBF causes relatively high losses in cruise. There is considerable potential for improvement in this area but experimental data are lacking. An improvement of 15 percent in DOC and ten percent in fuel consumption was estimated for an engine pylon mounted above and forward of the wing, shown in Figure 45 (Reference 10). This arrangement minimizes internal performance losses, wing scrubbing and interference effects, nacelle drag, and nacelle weight. The effectiveness of the high-lift nozzle deflector for inducing lift augmentation has not been quantified.

If moderate lift augmentation can be achieved, it would make the OTW concept (possibly combined with IBF) an overwhelmingly superior approach at field lengths up to 1830m. (6000 ft.).

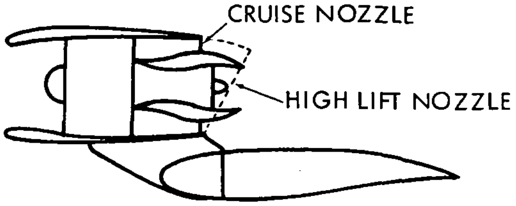


Figure 45 Potential High Performance Upper Surface Blowing System

It is concluded that the hybrid OTW/IBF concept with design cruise speed of M 0.75 and FPR 1.35 engines should be considered the best potential solution for 914m. (3000 ft.) field performance on the basis of lower fuel consumption and further potential for improvement. The versatility of full-load long-range performance should be incorporated; using CTOL runways a 2780 km (1500 n. mi.) range can be provided with a takeoff field length of 1280 m. (4200 ft.). If 1.35 FPR engines with 57.8 kN (13,000 lb.) thrust were developed, aircraft sized for 90, 120, or 150 passengers could be designed with 2, 3 or 4 engines.

Aircraft Design for 610m. (2000 ft.) Field Length

The choice of lift concept for this field length is clear cut; the four-engine hybrid OTW/IBF has a DOC-2 only 23 percent higher than the 1830m. (6000 ft.) MF airplane and 7 percent higher than the 914m. (3000 ft.) hybrid. (The MF cannot be considered below 914m. (3000 ft.). Previous estimates of the penalty of reduction in field length from 914m. to 610m. (3000 to 2000 ft.) were 15 percent (Ref. 1) and 20 percent (Ref. 3). Whereas the previous estimates represented a DOC penalty of 50 percent over CTOL, the current conservative optimization of the hybrid OTW/IBF indicates that 610m. (2000 ft.) field performance may well be economically viable. These results would have significant consequences in conserving real estate.

No specific noise analyses were conducted for this airplane but it is estimated that footprint areas and lengths would be equivalent to those of the 914m. (3000 ft.) aircraft and possibly smaller because of the inherently higher takeoff and approach gradients.

Recommended Compromise Concept

The potential of the OTW/IBF for 914 and 610m. (3000 and 2000 ft.) field lengths and small noise footprints indicates that it should be pursued in research and development programs. Implementation decisions are downstream so that confirmation of the results of current analyses can be obtained and a minimum risk program could be initiated in the 1980's. Decisions and actions which are appropriate are the following:

- Continuation of the Quiet STOL Research Airplane program.
- Implementation of further analytical and experimental development of improved nacelle and engine installations with emphasis on improving cruise performance and determining the optimum installation for both high speed and low speed considerations.

- Analytical refinement of engine design characteristics for fuel and noise improvement through an integrated airframe/engine study in the fan pressure ratio range of 1.3 to 1.4 for noise.
- Initiation of a quiet fuel-conservative engine development with technology drawn from the QCSEE program and guidance from the integrated airframe/engine study.

For the high-density arena, the aircraft should be designed with full-load capability for 2780 km (1500 n. mi.) range with CTOL takeoff, along with R/STOL capability for 1110 km (600 *n.* mi.).

6. CONCLUSIONS AND RECOMMENDATIONS

Detailed conclusions and recommendations in a narrow context have been developed in many of the preceding sections of this report. Sections 4 and 5 have coalesced these and presented separate discussions of the major issues, i.e. fuel conservation, noise and compromise solutions. The following summarizes the broader conclusions reached with respect to the short haul transport system, the R/STOL vehicle, its propulsion system, and R/STOL technology. Finally, the principal recommendations arising from these conclusions are presented.

Short Haul System

- The potential fuel savings which can be achieved by optimizing the vehicle configuration, mission speed and altitude are on the order of 25% (relative to minimum cost vehicles without energy conservation considerations).
- The optimization of the R/STOL vehicle for elevated fuel prices entails a significant speed reduction of the order of 0.05 M for each doubling of fuel price. However, the minimum attainable DOC at high fuel prices is not very much less than that of a faster vehicle optimized for a lower fuel cost but using high-priced fuel; the competitive disadvantages which result from optimistic fuel predictions may be less serious than those resulting from undue pessimism. The choice of cruise speed should be biased accordingly and a minimum of 0.75 appears to be the best compromise.
- The preferred R/STOL system for the high density short haul arena has the capability of 2780 km. (1500 n.mi.) with full load and CTOL takeoff distances. This flexibility permits route scheduling on the same basis as current airplanes performing this mission; increased utilization more than compensates for the weight and cost penalties of providing the extra capability.
- The choice of field length requirements for R/STOL vehicles in the short haul mode must be based on further evaluation of the land-side costs and environment. Design refinements indicate that short field lengths entail only modest DOC and fuel penalties which will potentially be more than offset by savings in real estate and congestion relief. Direct operating costs for field lengths of 610m., 914m. and 1220m. (2000, 3000, and 4000 ft.) aircraft are estimated to be 24%, 17% and 3% higher than for vehicles designed for 1830m. (6000 ft.) field length.
- Minimum DOC designs for R/STOL vehicles meet a noise goal of FAR 36 - 15 dB but still lower noise levels cause rapidly escalating costs.
- The Sperry box 80 PNdB noise criterion is neither attainable nor appropriate to high density short haul vehicles operating from existing CTOL airports with supplementary STOL runways or from secondary airports. Similarly, a 152m. (500 ft.) sideline measuring point is of no practical significance since it is contained within the airport boundaries. Practical attention should therefore be directed towards criteria which recognize the importance of the takeoff flyover noise and the area of the "objectionable level" footprint which impacts the community.

R/STOL Vehicle

- In many areas a 1220 m. (4000 ft.) field length is appropriate and a twin-engine mechanical flap airplane is clearly superior to other concepts for which there is an experimental data base. Using engines with fan pressure ratio of 1.35 and a design cruise speed of M 0.75, its noise footprint and fuel consumption are highly attractive. For shorter field lengths, wing loadings below 400 kg/sq. m. (80 psf) are required and both ride quality and fuel consumption become questionable. At 914 m. (3000 ft.) field length, the direct operating cost with fuel at twice the 1972 price is a standoff with the hybrid OTW/IBF concept.

- At a field length of 914m. (3000 ft.) or less, the hybrid OTW/IBF aircraft is recommended because of lower fuel consumption, better ride quality, speed advantage, and potential for further improvement. The 610m. (2000 ft.) hybrid aircraft is now estimated to have a cost penalty which may be economically viable -- 24 percent increase in DOC over CTOL aircraft compared to the 50 percent penalty previously estimated.

- The augmentor wing is non-competitive with respect to both DOC and mission fuel. This conclusion is reached regardless of the degree of optimism applied in this study to the basic concept and is not changed by the alternate cruise blowing or load-compressor AW concepts.

- The externally blown flap achieves direct operating costs comparable to the basic AW and is therefore economically not competitive although it has a minimum fuel consumption of the same order as the OTW/IBF. A prime factor in this determination is the lower optimum EBF cruise speed arising from the use of a low (1.25) FPR engine to compensate for the unshielded flap interaction noise of this concept.

- The deflected slipstream (turboprop) concept appears to advantage with respect to both DOC and fuel consumption. The cost superiority is especially significant if the aircraft are sized to match an existing engine (T-56) and at design cruise speeds of less than M 0.6. It is concluded that new large aircraft would not compete successfully for passengers in stage lengths of more than 700 km. (380 n. mi.). However, there are at least two areas in which this type of performance may have superior potential: small aircraft designed for shorter stage lengths in which block time and ride quality of lower wing loading may be acceptable, such as the lower density short haul where the Convair 580 and deHavilland Twin-otter are now performing so successfully; adaptation of existing aircraft to particular short stage length segments of the high density market, such as the proposed amphibian C-130.

R/STOL Propulsion

- The optimum R/STOL engine for both MF and OTW-IBF applications, at 914m (3000 ft.) field length and fuel at 23¢/gal., has been shown to have a fan pressure ratio within the range 1.30 - 1.40. On the basis of the discrete engines (with some differences in fan configuration, etc.) which have provided propulsion data, a fixed pitch, 1-1/2 stage fan, 1.35 FPR engine was preferred. At higher fuel prices and associated optimum cruise speeds of M 0.75 and below the 1.35 FPR engine gives lowest DOC and fuel consumption in CTOL field lengths as well.

- The fan pressure ratio for minimum DOC at 11.5¢/gal. for fuel has been indicated to be nominally 1.47 at all field lengths. However, the cost advantage with respect to the 1.35 FPR engine is trivial at this now-unattainable fuel price. Moreover, the noise penalty is substantial in terms of flyover noise and footprint area. Hence no wholly satisfactory application for this CTOL engine in a STOL vehicle can be foreseen.

R/STOL Technology

- Recent experimental data have validated the performance potential of the hybrid OTW/IBF concept. However, research and development are needed to expand the data base so that the best compromise solutions can be selected considering cruise performance minimizing SFC losses, high lift performance, and noise level in terminal operations. Higher, and possibly increasing, fuel prices dictate that the expanded data base should emphasize low-sweep wings with aspect ratios of 10 to 14, cruise speeds below Mach 0.8, and 4-engine airplanes. Since fuel consumption is better with 4-engine rather than 2-engine designs, the pure OTW system requires further evaluation; additional data are needed to establish the optimum amount of flap blowing, if any, for a given set of requirements.

- The plenum IBF duct system has been shown to be superior to the independent ducts of Reference 2 design studies and can be reconciled with stable operation of low FPR engines in parallel. The particular advantages of this arrangement include minimal duct pressure losses both in normal engine operation (no crossflow) and with sufficient crossflow for use of flap trailing edge nozzles to provide engine-out (roll) trimming. Moreover the minimal encroachment on fuel storage volume permits the use of the higher wing loadings required by minimum cost and fuel conservative vehicles.

- The use of the thicker supercritical airfoil in a 0.75 Mach number application avoids significant weight and aeroelastic penalties at the higher aspect ratios and lower sweep angles appropriate to the fuel conservative vehicles.

Recommendations

The recommendations arising from this study may be summarized as follows:

- Use supercritical airfoil technology at speeds below 0.8 M -- since the wing depth it affords is necessary to avoid structural weight and stiffness penalties at the higher aspect ratios envisioned for fuel conservative aircraft.

o Continue propulsive lift research to refine high lift technology for STOL, RTOL and CTOL rather than for early application to specific STOL designs. Additional study and R&D is needed with regard to:

(a) Commonality of the 1.35 FPR engine for both the short haul and longer-range missions.

(b) The fuel consumption and economics of intermediate and long range commercial aircraft related to future noise criteria.

(c) Low wing loading aircraft for the lower density short haul arena if short field lengths are required.

(d) Integration of the engine design with the aircraft optimization to develop a refined definition of the preferred FPR, number of fan stages, and specific fan features including gearing and fixed or variable pitch provisions.

o Increase research on gust alleviation and ride quality for mechanical flap airplanes with wing loadings of the order of 200-400 kg/sq.m. (40-80 psf).

o Develop additional analyses of advanced engine characteristics for fuel conservation for which 1.35 FPR is recommended since it meets the recommended noise criteria and provides good fuel and DOC economics at both current and inflated fuel prices.

o Adopt realistic noise criteria which specifically address the impact of the airplane upon community noise at critical points in its flight path. Suggested maxima are:

For CTOL long-range missions: Average fleet noise FAR 36 −10 dB.
For short-haul missions impacting new areas of the community:

A 90 EPNdB footprint area beyond each end of the runway which does not exceed 0.65 sq. km. (0.25 sq. stat. mi.)

A 90 EPNdB footprint which does not extend more than 1.6 km (1 stat. mi.) beyond each end of the runway.

o Study the land-side economics of providing terminal facilities which are compatible with the preceding noise criteria.

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