CR-137926

FINAL REPORT

STUDY OF THE COST/BENEFIT TRADEOFFS FOR REDUCING THE ENERGY CONSUMPTION OF THE COMMERCIAL AIR TRANSPORTATION SYSTEM

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TRADEOFFS FOR REDUCING THE ENERGY
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16. ABSTRACT

This study was performed to assess practical means for achieving reduced fuel consumption in commercial air transportation. Five areas were investigated: current aircraft types, revised operational procedures, modifications to current aircraft, derivatives of current aircraft, and new near-term fuel conservative aircraft. As part of a multiparticipant coordinated effort, detailed performance and operating cost data in each of these areas were supplied to the contractor responsible for the overall analysis of the cost/benefit tradeoffs for reducing the energy consumption of the domestic commercial air transportation system.

A follow-on study was performed to assess the potential of an advanced turboprop transport aircraft concept. To provide a valid basis for comparison, an equivalent turbofan transport aircraft concept incorporating equal technology levels was also derived. The aircraft were compared on the basis of weight, size, fuel utilization, operational characteristics, and costs.

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FOREWORD

This document, LR 27769-2, is the final technical report of the Lockheed-California Company's contribution to a multicontractor analytical study entitled "Study of Cost/Benefit Tradeoffs For Reducing the Energy Consumption of the Commercial Air Transportation System" performed under Contract NAS 2-8612 for the National Aeronautics and Space Administration Ames Research Center, Moffett Field, California. The report presents the substance of work performed under the basic contract and under the basic contract Modification Number 1 section entitled "Turboprop/Turbofan, Short/Medium Range Configuration Analysis". An advanced wing aerodynamic investigation was also performed under contract Modification Number 1 and is reported in Lockheed-California Company report LR 27524 (NASA CR-137928) entitled "Advanced Airfoil Empirically Based Transonic Aircraft-Drag Buildup Technique", dated January 1976.

Lockheed-California Company document LR 27769-1, NASA CR-137927, is the contractually required companion summary report of LR 27769-2, NASA CR-137926.

Mr. Louis J. Williams of the Research Aircraft Technology Office at the NASA Ames Research Center was the technical monitor and advisor for the study.

The study was performed within the Advanced Design and Technologies Division of the Lockheed-California Company, Burbank, California, under the leadership of Mr. John P. Hopkins, Study Manager. Major Lockheed contributors to the study were:

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Special mention and appreciation is hereby expressed in the memory of Mr. John C. Heitmeyer for his outstanding technical contributions, leadership, and example as Lockheed Study Manager from the time of contract initiation until June 1975.

In addition to the above participants, the Hamilton Standard and Pratt and Whitney Aircraft Divisions of United Technologies Corporation and Eastern Airlines made major contributions to the Turboprop/Turbofan, Short/Medium Range Configuration Analysis section of Contract Modification Number 1. The Study Managers for these subcontractors were:

Mr. Bernard S. Gatzen - Hamilton Standard
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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

ILLUSTRATIONS

ILLUSTRATIONS (cont'd)

ILLUSTRATIONS (cont'd)

TABLES

TABLES (cont'd)

TABLES (cont'd)

TABLES (cont'd)

TABLES (cont'd)

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COST BENEFIT TRADEOFFS FOR REDUCING THE ENERGY CONSUMPTION OF THE COMMERCIAL AIR TRANSPORTATION SYSTEM

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Lockheed-California Company

SUMMARY

This study examines the practical means for achieving reduced fuel consumption in commercial air transportation. A supplemental study performed as a modification to the basic contract assesses the merits of advanced turboprop propulsion.

Aircraft performance and operating cost data are developed in Phase I of the study under four basic options for fuel conservation. These basic fuel conserving options are operational procedure changes, modifications to and derivatives of current aircraft, and new near-term designs. Aircraft performance and operating cost data on current domestic fleet aircraft are developed to provide a baseline for comparison purposes. NASA Specification No. 2-24968 dated June 3, 1974, Statement of Work Study Task 1.4.1.1 specifies development of data on the Lockheed L-1011 and L-188 Electra as a minimum. Phase II consisted of selecting the most promising options, performing option refinements, and preparing the resulting data in a form suitable for use in the overall fleet analysis studies which were conducted by a transportation systems analysis consulting organization.

The merit of an advanced turboprop propulsion system designed to operate at high Mach numbers was evaluated by integrating it with an airframe system designed for 1985 service introduction and comparing it with an equivalent mission, equal technology turbofan powered airplane.

Conclusions and recommendations drawn from Lockheed's role in the basic study effort are as follows:

- Changes to operational procedures offer an immediate and inexpensive method to conserve fuel and should be implemented on a priority basis.
- Of the near-term L-1011 modifications studied, the engine afterbody revision and wing tip extension offer even larger fuel savings benefits than changes in operational procedures. The engine afterbody modification should be retrofitted to fleet aircraft, as well as the wing tip extension where possible (dictated by takeoff gross weight requirements).
- Increased seating capacity and/or density in terms of a modification to the basic L-1011-1 aircraft offers the most dramatic efficiency gains but is dependent on continuation of demand growth and fuel availability.

- New near-term aircraft designs are not likely to be developed without increased density seating. A later airplane service introduction to allow incorporation of more of the technology advances, including a new turboprop propulsion system, may enhance the case for a new aircraft development. Development of the advanced technologies required is recommended.

It was concluded from the supplemental studies that an advanced turboprop propulsion system is a viable alternative to the turbofan, offering significant fuel and operating cost savings without compromising passenger comfort. To accomplish this requires that the following actions be implemented on a first priority basis:

- Demonstrate propeller efficiency levels of approximately 80 percent (installed) at a flight Mach number of 0.80.

- Perform experimental investigations of propfan/turboprop wing integration to establish that reasonable drag characteristics exist for practical prop-fan/turboprop power plants mounted on swept, supercritical wings.

- Determine sound levels generated by propfan/turboprop concepts operating at Mach 0.80 cruise and establish sound attenuation and weight penalty requirements for their satisfactory suppression.

INTRODUCTION

The dependence of the United States on foreign sources of petroleum to meet our ever increasing energy demands was brought to the forefront in late 1973 by the oil embargo. The restrictions placed on all forms of energy consumption by the fuel allocations imposed during that period resulted in the consideration of and in some cases the actual conversion to alternative forms of energy. However, the air transportation industry is, now and for the foreseeable future, totally dependent on petroleum fuel. The restrictions of 1973, led to a concerted effort by the air transportation industry to conserve fuel. The effort did not diminish with the relaxation of the imposed allocations; the more than doubled fuel cost becoming the driving force for fuel conservation. To remain economically viable while continuing to meet the forecast increasing demand for service requires that the industry make every effort to conserve fuel.

The study reported by this document examined the potential for improving the energy consumption of the commercial air transportation system from an airframe manufacturer's viewpoint. The Lockheed-California Company's share of this study was one part of a coordinated effort which included another airframe manufacturer, McDonnell Douglas, an airline operator, United Airlines, and a consultant organization specializing in air transportation economics and demand forecasting, United Technologies Research Center. The potential for fuel efficiency improvements in several specific areas was examined, followed by exploring the refinement of the most promising options. Characteristics, performance, operating cost and price information for the approved options were provided by the airframe and airline contractors and used as inputs by the consulting organization. This latter effort included the overall analysis of the effectis of introducing the fuel conserving options into demand projections and fleet operations models to arrive at a prediction of future fuel requirements, service levels and economics.

Baseline fuel and operating cost data were first established through tabulations of current fleet aircraft performance data on both a manufacturer's handbook basis and as reported to the Civil Aeronautics Board by the airline operators. The Lockheed L-1011 TriStar and L-188 Electra aircraft were studied as baseline aircraft in Task 1. Consideration of changes in operational procedures that result in improved fuel consumption was the Task 2 study effort. The Lockheed effort in this task was concentrated on the L-1011 aircraft. Task 3 was the preliminary design and evaluation of fuel conserving modifications to current aircraft, the modifications being limited to those that could be incorporated in current production or retrofitted to in-service aircraft. More extensive derivatives of current aircraft were considered in Task 4 followed by the design of all new, near-term fuel conservative aircraft in Task 5. Three payload/range size classes with both minimum direct operating cost and minimum fuel as design criteria were studied. In addition, both turbofan and turboprop propulsion systems were considered.

Because this study by necessity involved a coordinated effort among the several contractors and NASA, a study plan and study ground rules were established at the outset by the parties concerned. The study plan coordinating the work of all of the contractors was the responsibility of the consultant organization, United Technologies Research Center, and is discussed in their final report (Ref. 1). The NASA technical monitor, the airframe manufacturers, Lockheed and McDonnell Douglas, and the airline contractor, United Airlines, developed the study ground rules to be used in the aircraft performance and operating cost calculations. The flight profile used for all performance calculations is included as Figure 1 and the ground rules in terms of seating configurations, passenger and cargo allowances, and economic parameters is presented in Table 1.

A supplemental follow-on study, also reported in this document, examines the potential viability of an advanced turboprop transport which was compared with an equal technology advanced turbofan transport. This effort resulted from a modification to the original contract in order to more fully explore the high potential fuel savings indicated for the turboprop transport aircraft concept in the preliminary studies. The aircraft analyzed were designed for service in 1985 and therefore incorporated additional fuel conserving technologies expected to be available in that time frame. Both turbofan and turboprop aircraft were designed to cruise at Mach 0.8, the turboprop utilizing an advanced propeller to accomplish this.

Three subcontractors, the Pratt and Whitney Aircraft and the Hamilton Standard Divisions of United Technologies Corporation, and Eastern Airlines, assisted Lockheed in this supplemental study. Performance and economic ground rules consistent with the basic contract were maintained and preliminary data were supplied to the United Technologies Research Center for use in their air transportation system operations analysis studies.

Because of the large number of figures and tables required in the performance of this study, it was not practical to integrate them with the text material. Consequently, they have been sequentially incorporated at the end of the appropriate section, figures followed by tables.

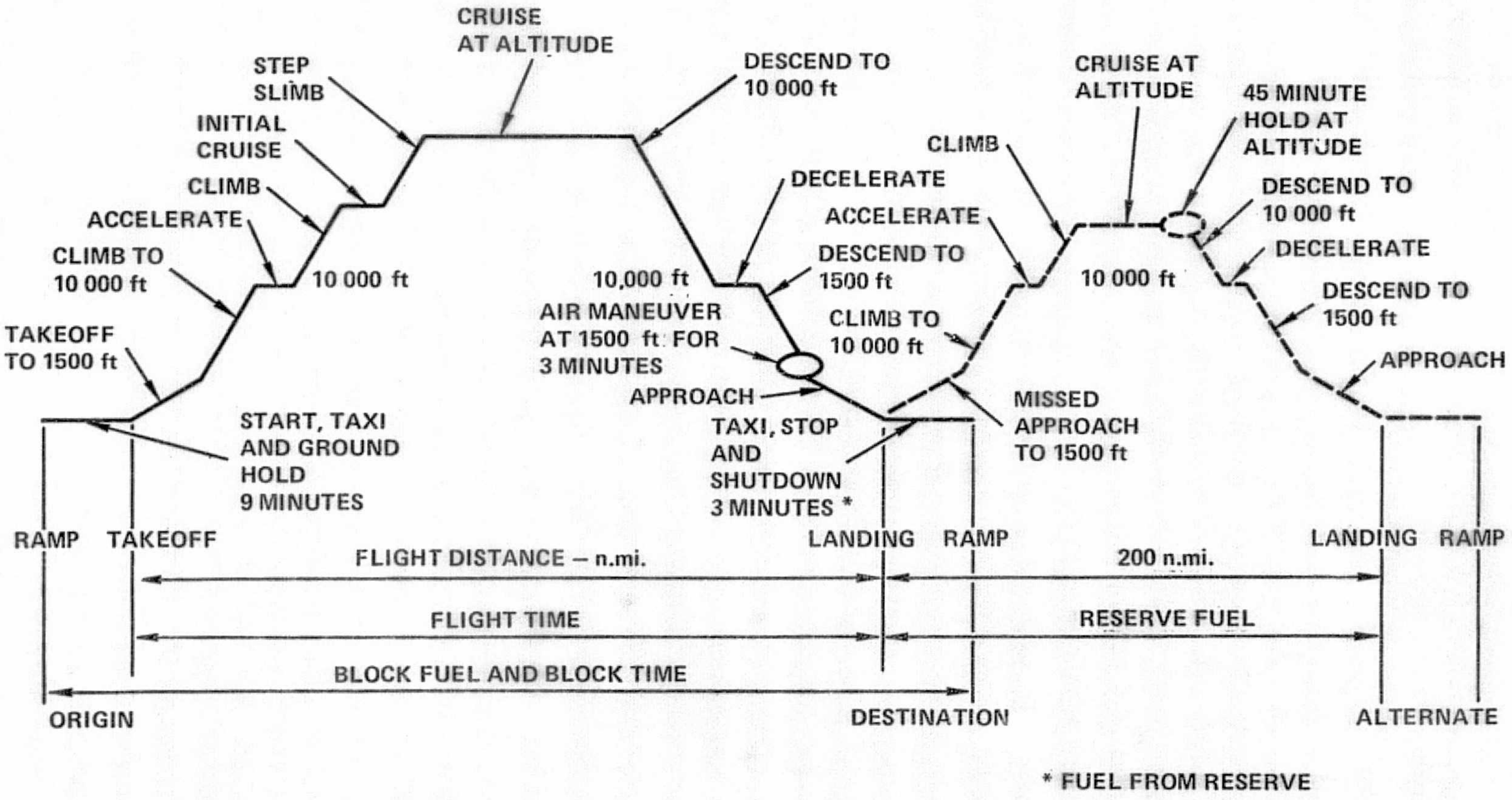

Figure 1.— Domestic mission flight profile

TABLE 1. - STUDY GROUND RULES

Interior Arrangements

10/90% First Class/Coach @ 38 in./34 in.
8 Abreast Seating (Baseline L-1011)
Lower Deck Galley Where Feasible

Payload Allowances

200 lb/Passenger (Including Baggage)
No Cargo Carried for Performance Analysis
Cargo Revenue = 10% of Total Revenue
Onboard Fuel Includes No Tankerage

Operational Parameters

Load Factor = 58% (100% for New Aircraft Design)
Fuel Heat Content = 18600 Btu/lb
Fuel Density = 6.8 lb/gal
Direct Operating Cost - Updated 1967 ATA
Indirect Operating Cost - Lockheed 1973 Coefficients

Economic Parameters

1973 Dollars
15¢/Gallon Fuel (All Tasks)
15¢/30¢/60¢/Gallon Fuel - New Airplane Designs
Depreciation Period = 16 Years with 10% Residual
Spares = 15% of Flyaway Cost
Insurance Rate = 1%
Production Quantity = 250 Aircraft
Inflation = 5%
Discount Rate = 8%

ABBREVIATIONS/SYMBOLS/CONVERSIONS

ABBREVIATIONS

ASM	Airplane Seat Nautical Mile, Sect - N.Mi.
ASSET	Advanced System Synthesis and Evaluation Technique (Lockheed computer program)
ASW	Antisubmarine warfare
ATA	Air Transport Association
ATC	Air Traffic Control
blk-hr	Block-hour
BDF	Blade passage frequency
Btu	British thermal unit
CAB	Civil Aeronautics Board
c.g.	Center of gravity
DOC	Direct operating cost
ECS	Environmental Control System
EPndB	Equivalent perceived noise level, decibels
EPR	Engine overall pressure ratio
FAR	Federal Air Regulation
FC	First class passenger designation
flt-hr	Flight-hour
ft	Feet
FWD	Forward
gal	Gallon
GSE	Government supplied equipment
IOC	Indirect operating cost
in.	Inch

IRAD	Independent research and development
KCAS	Calibrated airspeed, knots
KIAS	Indicated airspeed, knots
kt	knot
lb	Pound
LAM	Lambda, wing sweep, deg
LD-3	L-1011/DC-10 standardized half-size cargo container
LF	Load factor
LFL	Landing field length, ft
LRC	Long range cruise
MAC	Mean Aerodynamic Chord
MAD	Magnetic anomoly detection
MEW	Manufacturer's empty weight, lb
min	Minutes
MLG	Main landing gear
mph	Mile per hour
n.mi.	Nautical Mile
OEW	Operating empty weight, lb
Pax	Passenger
SFC	Specific fuel consumption, lb fuel/hr/lb thrust
shp	Shaft horsepower
SL	Sea level
SLS	Sea level static
TOFL	Takeoff field length, ft
TOGW	Takeoff gross weight, lb
UAL	United Airlines

UTRC	United Technologies Research Center
Y	Tourist class passenger designation
ZFW	Zero fuel weight, lb

Symbols

AR	Aspect ratio, b^2/S
b	Wing span, ft
c	Wing chord, ft
c_b	Propeller blade chord, ft
C_D	Drag coefficient
C_L	Lift coefficient
d	Distance between inner and outer fuselage walls
D	Drag force, lb
D_p	Propeller diameter, ft
dB	Decibel
F_N	Net thrust force, lb
f	frequency, hz
f_n	natural frequency, hz
f_r	Ring frequency, hz
Ka	Equivalent spring stiffness of air between fuselage walls
M	Mach number
M_H	helical tip Mach number
M_1	outer fuselage wall mass, slugs/ft^2
M_2	inner fuselage wall mass, slugs/ft^2
M_T	total fuselage wall mass, slugs/ft^2
q	Dynamic pressure, lb/ft^2
r_{LE}	Leading edge radius, in.
S	Wing area, ft^2

t/c	Thickness ratio
T/W	Thrust to weight ratio
V_T	True speed, kt
W/S	Wing loading, lb/ft^2
α	Angle of attack, degrees
η	Propeller efficiency
Λ	Wing sweep angle, degrees
ρ	density, slugs/ft^3
ρc	Impedance of air

Conversions

To Convert From	To	Multiply By
Fahrenheit	Celsius	$t_c = (5/9)(t_F-32)$
foot	meter	0.3048
foot^2	meter^2	0.09290304
foot^2	meter^3	0.028316846592
foot/second	meter/second	0.3048
gallon	meter^3	0.003785411784
horsepower (550 ft-lb/sec)	watt	745.69987
inch	meter	0.0254
knot	meter/second	0.5144444444
nautical mile	meter	1852
pound (force)	Newton	4.4482216152605
pound (mass)	kilogram	0.45359237

1. BASELINE TRISTAR AND ELECTRA AIRCRAFT DATA - TASK 1

The objective of this task is to establish the basis for comparison of the various fuel conserving options identified during the course of the study. Data for existing aircraft in the form of fuel consumption and operating costs were calculated using manufacturer's performance data and the standard flight profile ground rules established through agreement between NASA and the various contractor companies. The resulting calculated performance and cost data are compared with the airline-reported performance and cost data published annually by the Civil Aeronautics Board (CAB).

As stipulated by NASA Specification No. 2-24968 dated June 3, 1974, two Lockheed transport aircraft are considered; the L-1011 TriStar and the L-188 Electra. The calculated data for both aircraft are based on the use of the high-speed flight profiles which are representative of the typical airline operation for these aircraft prior to the September 1973 oil embargo by the OPEC countries; that period generally referred to as pre-energy crisis. The United States trunk airlines are required to report financial and operating statistics to the CAB in accordance with a uniform system (Form 41) and these data are summarized by the CAB in the Aircraft Operating Cost and Performance Report (Ref. 2). This report is the source of the airline operations data referred to in this section as CAB data.

1.1 L-1011 TriStar

For the base study year, 1973, two domestic airlines, Trans World and Eastern, operated the L-1011 TriStar. Since the route structures of these airlines are quite different, the CAB data for both are used. A comparison of the calculated fuel consumption and operating cost data and the data as reported by the CAB is shown in Figure 2 where the symbols representing the reported CAB data are plotted at the CAB average stage length for each airline.

Reference to Figure 2 shows significantly higher fuel consumption and cost exhibited by the CAB data. In terms of the fuel parameter, this is not unexpected since the 1973 reporting period reflects considerable L-1011 operating time with an interim engine which was substandard in fuel economy. In addition, the route structure of Eastern Airlines, which is mainly in the crowded East Coast corridor, tends to distort the comparison relative to the calculated flight profile because of off-optimum altitude operation requirements and an increased number of delays (both of which are results of crowded airspace). This situation causes large detrimental effects on fuel consumption not unique to the L-1011 aircraft. Since these actual operating conditions cannot be interpreted from the CAB data, an indication of the effect of non-optimum cruise altitude alone is shown on the fuel consumption curve of Figure 2. Changing the cruise altitude from the optimum 35 000 feet used in the calculated data to 31 000 feet increases the gallons per nautical mile by approximately ten percent as shown. During the early operation of the L-1011, as reflected by the 1973 data, Trans World Airlines also operated the airplane on the more crowded East Coast routes, therefore the off-optimum altitude effect is undoubtedly reflected in their reported fuel consumption.

In addition to the impact of the fuel consumption disparity, the direct operating cost comparison shown in Figure 2 is biased by differences in aircraft utilization. The calculated operating cost data assumed an average yearly utilization of 3285 block hours. The 1973 utilization attained by Eastern was 2742 block hours while that of Trans World was 2986 block hours. The effect of adjusting the calculated cost to these utilizations at the respective average stage lengths is also shown on Figure 2. As indicated, this single change in the input parameters has a significant impact on the operating cost levels.

Detailed comparisons of the performance and operating cost data at the CAB average stage lengths for the two reporting airlines are shown in Table 2. As an example of the care that must be exercised when comparing these kinds of data, note that the block fuel, although quite different on a total pounds basis, is considerably closer when compared in terms of gallons per block hour. This is caused by the difference in block speed reported versus calculated. The higher calculated speed gives a lower block time at the average stage length and thus raises the calculated fuel per block hour nearer to the CAB reported value.

The direct operating cost breakdown of Table 2 is presented for both the average yearly utilization of 3285 block hours and at the utilization as reported by each airline to the CAB. As previously noted on the graphic comparisons, the change in utilization substantially changes the total direct operating cost. Table 2 also shows that the DOC elements of insurance and depreciation are those affected by utilization. In addition, since these are procedural related costs rather than performance related, airline policy becomes a factor. For example, the Air Transport Association (ATA) equations use the straight line method for depreciation while the CAB allows the airlines to use the double declining balance method for the first seven years of the airplane's total depreciation period and the straight line method thereafter. The double declining balance method gives considerably higher depreciation costs during the early years of an airplane's service life.

Table 2 also shows that while the calculated crew cost is close to that reported by Trans World Airlines, there is a large difference in this cost element as reported by Eastern Airlines. This may be due to the nature of the Eastern route structure; shorter routes that allow less crew utilization, or simply to differences in labor contracts. It was concluded from the foregoing comparisons that the L-1011 airline data reported to the CAB for the base study year is distorted by the fact that the airplane was still in its introductory service life. For a better measure of the correspondence of the two data sources, performance and cost data for the L-188 Electra aircraft was utilized.

1.2 L-188 Electra

During the base study year of 1973, the Electra saw only limited airline service. The type of service which the aircraft provided, shuttle and backup to first line aircraft, was also considered to be nonrepresentative for purposes of this study. An earlier year, 1967, was selected for establishing the baseline data. That year represents an Electra operational period that is well down the learning curve, approximately ten years after initial airline service, thus eliminating any erratic performance and cost data caused by new airplane introduction. The CAB cost data are also directly comparable to the calculated costs based on the 1967 ATA methods.

In order to obtain a good representation of the L-188 Electra operating data, CAB data for six airlines was assembled. Table 3 presents a summary of these data as they appear in the CAB reports. The direct operating cost and performance data were averaged to obtain the figures shown in the far right column in Table 3.

An illustration of the fuel consumption and direct operating cost comparison is shown in Figure 3. The CAB data are shown for each of the six airlines as denoted by the symbols on the figure. The average block fuel, operating cost and block speed from Table 3 are also plotted and are noted by the solid symbols in Figure 3. Although differences are still apparent, especially in the direct operating costs for particular airlines, the comparison between the average CAB data and the calculated data shows a better correlation than the L-1011 results. Referring to Figure 3 and Table 3, the CAB data summary for the six airlines selected shows a spread in the reported stage lengths, ranging from 150 to 197 nautical miles. Use of the average stage length of 176 nautical miles for a detailed comparison of the fuel consumption and direct operating cost elements was therefore considered reasonable.

Breakdowns of the fuel consumption and direct operating cost comparisons between the calculated and CAB data are shown in tabular form in Table 4. The calculated data are shown in these tables for the 1967 CAB average utilization and at a payload commensurate with the average reported load factor of 57 percent. Since the ATA equations used for the calculation of direct operating cost are based on a statistical study of the 1967 reported costs, no cost modifiers were applied to these data to reflect the inflated 1973 dollar values.

In the performance section of the Table 4 comparison, the CAB reported block speed is lower than the calculated value. However, the difference of 10 knots represents a difference in fuel flow of approximately one percent and the corresponding impact on the direct operating cost would be less than 0.2 percent, an insignificant amount. This same difference in block speed however does affect the fuel consumption data when the reported CAB data in units of gallons per block hour are converted to the study units of gallons per nautical mile. A difference of less than one percent is magnified by a factor of six in the conversion. The effect of one parameter on another must receive careful consideration when making comparisons of this type. Note that at the average stage length being considered, a change in ground time of only three minutes would result in the same block speed. The fact that enroute winds are not taken into account in the calculated data also impacts the fuel consumption comparison as do factors such as fuel spillage and evaporation which are inherent in the CAB data.

The cost section of the Table 3 comparison shows that the largest disparity between the calculated and the CAB data is in the insurance cost. The two percent rate used in the ATA equations appears to overstate this cost. The fact that the Electra had been in operation for ten years in 1967 indicates that the book value of the airplane had decreased to the point where the insurance rates would be minimal as shown by the CAB data. The ATA equations also slightly overstate the maintenance cost, but it was felt that the comparison on this element was within reasonable tolerance. On the basis of the average of the six airlines selected, the calculated Electra direct operating cost and its elements appear to be reasonable as determined by using the study-adopted methodology.

While the foregoing comparisons are not conclusive, the results using the CAB summary data are not unexpected. Aircraft comparisons on the basis of the CAB data are difficult and as indicated may be misleading. Airlines reporting to the CAB are using the same or similar equipment under quite different operating conditions and route structures. Block fuel and speed discrepancies are a direct result of these differences in operating conditions. Operating cost levels are also affected by such factors as fuel price variation, lease versus purchase of aircraft, individual airline accounting practices, and capitalization and amortization policies. The particular point that an aircraft model is at during its service life for a reporting period affects the cost data; initial operations of a new airplane type, as noted in the L-1011 comparisons, produce erratic operating cost figures.

As was shown in the detailed Table 3 comparisons, differences in the total direct operating cost levels are a reflection of the wide excursions in the levels of each direct cost element between airlines. These excursions are, of course, associated with the variable factors which affect the individual accounts making up each direct cost element (crew, fuel and oil, maintenance, etc.). Although it is possible to eliminate some of these anomalies from the raw cost data by making adjustments using information contained in the Form 41 reports themselves, it was not possible during this study to normalize all of the reported data as this would require details on each variable factor from each individual airline.

1.3 Idealized Data

Tables 5 through 8 present the fuel consumption and operating cost data as calculated for the L-1011 TriStar. These data are tabulated for a series of stage lengths including the 1973 CAB average stage length. Fuel consumption is shown in terms of total block fuel and on both an airplane-nautical mile and a seat-nautical mile basis in Table 5. The seat-nautical mile fuel consumption is shown in units of seat-nautical miles per gallon and Btu's per seat-nautical mile. Total direct and total indirect operating costs are tabulated in Table 6 while the detailed breakdowns of these costs are shown in Tables 7 and 8. All of the cost data are presented in units of cents per available seat-nautical mile. In addition, the total cost data are presented in Table 6 in terms of dollars per block hour with the corresponding block speed at each stage length indicated in an adjacent column.

The average new price for the L-1011 in 1973 dollars based on a breakeven production quantity of 250 airplanes is as follows:

	Airplane	Spares
Airframe	$15 655 887	$2 348 383
Engine	4 054 433	608 165
TOTAL	$19 710 320	$2 956 548

Calculated fuel consumption data for the L-188 Electra are presented for various stage lengths in Table 9. These data were also calculated for the standard flight profile using the established study ground rules. Since the cost data for the Electra were based on the year 1967 rather than the base study year of 1973, as explained earlier, detailed cost data are not included. At this point in the study, it was decided with NASA concurrence, that the L-188 Electra should not be included in the current aircraft definition for purposes of the demand projections and fleet operations analysis (to be performed by United Airlines and United Technologies Research Center). Therefore, the Electra cost data, as calculated, were used to provide evidence of compatibility with the reported CAB data as previously discussed.

The price information for the Electra is as follows:

	Airplane	Spares
Airframe	$1 940 000	$194 000
Engine	360 000	144 000
TOTAL	$2 300 000	$338 000

These prices are for 1967 and were used in the calculation of the direct operating cost for comparison with the 1967 L-188 Electra CAB data.

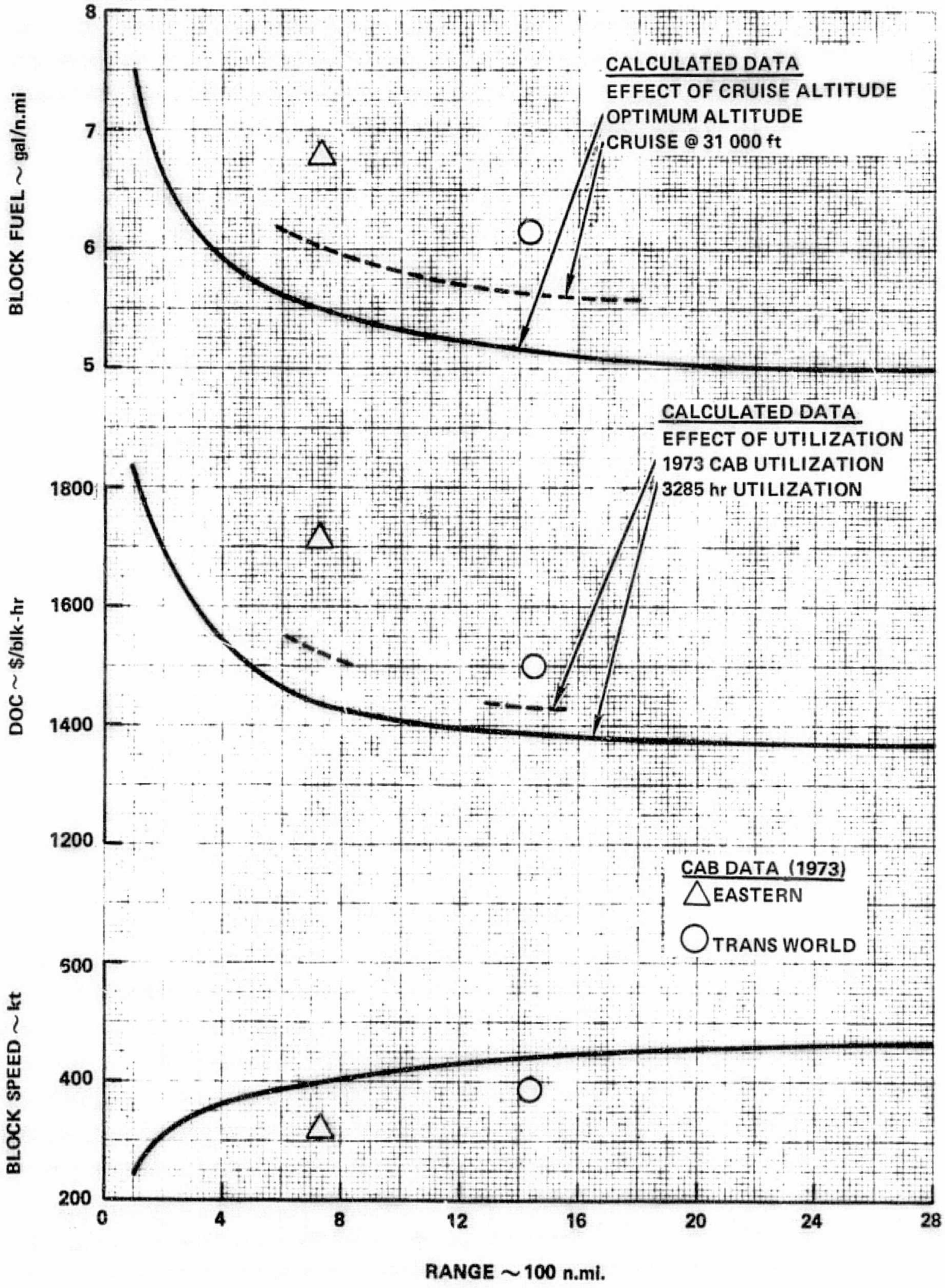

Figure 2.— Comparison of calculated and CAB data - L-1011 TriStar

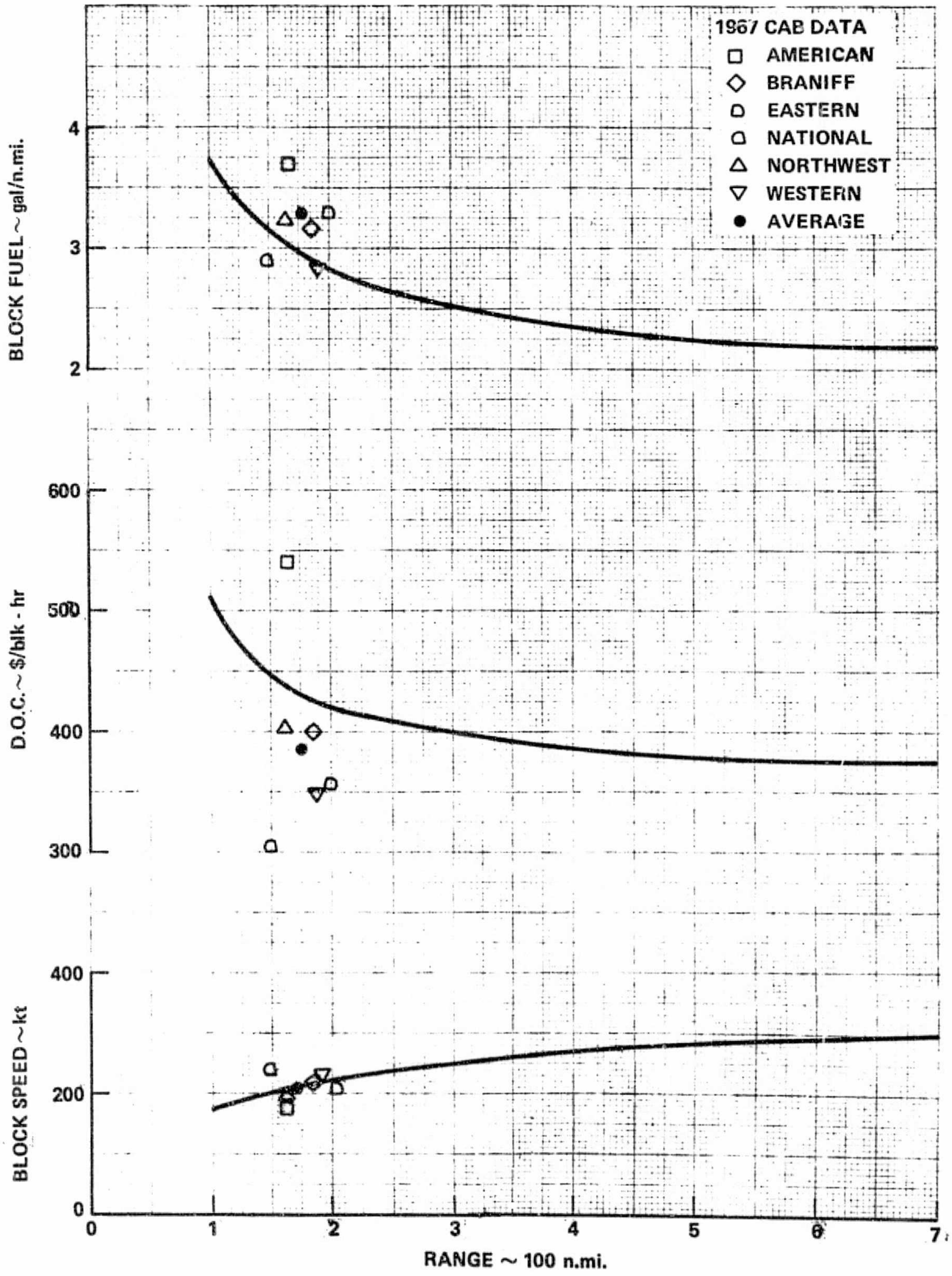

Figure 3. – Comparison of calculated and CAB data - L-188 Electra

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TABLE 2.- PERFORMANCE AND COST COMPARISON - L-1011 TRISTAR

Performance

Airline Stage Length (n.mi.)	EAL 724		TWA 1426	
Data Source	CAB	Calculated	CAB	Calculated
Available Seats	245	273	208	273
Load Factor (%)	41	41	43	43
Fuel Consumption:				
(lb)	33 970	28 800	59 042	49 440
(gal/blk-hr)	2277	2206	2399	2237
(gal/n.mi.)	6.90	5.85	6.09	5.10
(seat-n.mi./gal)	35.51	46.67	34.13	53.54
(Btu/seat-n.mi.)	3567	2707	3706	2365
Block Speed (kt)	330	377	394	439

Direct Operating Cost

Airline Stage Length (n.mi.)	EAL 724			TWA 1426		
Data Source	CAB	Calculated		CAB	Calculated	
Utilization (hr)	2743	3285	2743	2986	3285	2986
DOC ($/blk-hr):						
Crew	332	260	260	264	260	260
Fuel	324	337	337	308	342	342
Insurance	37	60	72	36	60	66
Maintenance	368	387	387	302	336	336
Airframe	135	115	115	89	95	95
Engine	100	124	124	84	114	114
Burden	133	148	148	129	127	127
Depreciation	553	388	465	582	389	428
Total DOC	1614	1432	1521	1492	1387	1432

TABLE 3.- L-188 ELECTRA CAB DATA - 12 MONTHS ENDING DECEMBER 31, 1967

Aircraft Operating Expenses DOC - $/Block Hr	Airline						CAB Average
	American	Braniff	Eastern	National	Northwest	Western	
Flying Operations							
Crew	131.40	91.73	113.17	81.60	94.52	88.37	104.07
Fuel and Oil	67.96	62.89	64.10	66.97	70.08	72.00	66.69
Insurance	2.40	4.46	4.22	4.74	3.84	1.04	3.61
Other	.10	.94	.52	.01	.54	0.00	.34
Maintenance-Flight Equipment							
Direct-Airframe and Other	85.85	67.67	47.33	50.86	51.15	54.79	57.65
Direct-Engine	69.49	58.18	44.27	36.71	43.45	41.24	48.13
Maintenance Burden	86.87	48.23	53.80	48.28	33.15	32.29	53.31
Depreciation and Rentals							
Depreciation-Airframe & Other	72.28	47.00	20.07	5.64	78.62	52.48	38.97
Depreciation-Engine	18.30	5.68	6.06	3.77	19.49	0.30	8.49
Obsolescence & Deterioration	5.18	1.38	1.26	4.87	5.41	6.23	3.57
Rentals	0.00	11.32	0.00	0.00	0.00	0.00	1.04
Total DOC $/Block-HR	539.82	399.49	354.80	303.46	400.25	348.74	385.88
Performance and Characteristics							
Average Stage Length (n.mi.)	164	183	197	150	162	189	176
Seat Load Factor (%)	60.0	53.3	57.2	56.5	51.9	57.2	56.6
Available Seats/Nautical Mile	75.0	80.9	82.9	81.6	77.0	94.2	82.1
Average Block Speed (mph)	214	249	235	279	225	256	233
(kt)	186	216	204	242	195	222	203
Fuel Consumed (gal/blk-hr)	681	682	666	691	643	634	691
(gal/n.mi.)	3.66	3.15	3.26	2.86	3.30	2.86	3.40
Cost of Fuel (¢/gal)	9.729	9.117	9.249	9.373	10.332	10.796	9.373

TABLE 4.- PERFORMANCE AND COST COMPARISON - L-188 ELECTRA

Performance

Data Source	CAB Average (1967)*	Calculated Data
Stage Length (n.mi.)	176	176
Available Seats	82	82
Fuel Consumption:		
(lb)	3938	3480
(gal/blk-hr)	668	619
(gal/n.mi.)	3.29	2.91
(seat-n.mi./gal)	24.92	28.18
(Btu/seat-n.mi.)	5075	4485
Block Speed (kt)	203	213

Direct Operating Cost

Data Source	CAB Average (1967)*	Calculated Data
Stage Length (n.mi.)	176	176
Load Factor (%)	57	57
Utilization (hr)	2515	2515
DOC ($/blk-hr):		
Flying Operations		
Crew	104.07	104
Fuel and Oil	66.69	71
Insurance and Other	3.95	18
Maintenance		
Airframe and Other	57.65	60
Engine	48.13	58
Burden	53.31	52
Depreciation and Rentals	52.07	70
Total DOC	385.88	433

*American, Braniff, Eastern, National, Northwest and Western

TABLE 5. - CLACULATED FUEL CONSUMPTION - L-1011 TRISTAR PRE-ENERGY CRISIS

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal/n.mi.	seat-n.mi./gal	Btu/seat-n.mi.
100	5 107	7.51	36.35	3480
200	8 938	6.57	41.55	3044
400	16 010	5.89	46.35	2729
600	23 082	5.66	48.23	2622
1000	36 538	5.37	50.81	2489
2000	68 754	5.06	54.00	2342
3000	101 952	5.00	54.60	2316
4000	138 981	5.11	53.42	2368
825	30 855	5.50	49.60	2550

TABLE 6. - CALCULATED TOTAL OPERATING COSTS - L-1011 TRISTAR PRE-ENERGY CRISIS

Stage Length n.mi.	Block Speed kt	Total DOC		Total IOC	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	240	1824	2.81	5512	8.48
200	305	1690	2.04	3650	4.41
400	360	1538	1.56	2530	2.57
600	388	1464	1.39	2028	1.92
1000	414	1412	1.25	1567	1.39
2000	449	1374	1.12	1201	0.98
3000	465	1366	1.08	1068	0.84
4000	472	1368	1.06	1080	0.84
825	405	1428	1.30	1735	1.57

TABLE 7.- DIRECT OPERATING COST BREAKDOWN - L-1011 TRISTAR PRE-ENERGY CRISIS

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4000	825
Crew	0.41	0.34	0.27	0.25	0.23	0.21	0.21	0.20	0.24
Insurance	0.09	0.08	0.07	0.06	0.05	0.05	0.05	0.04	0.05
Depreciation	0.61	0.52	0.41	0.37	0.35	0.32	0.31	0.30	0.36
Maintenance	1.29	0.71	0.48	0.40	0.32	0.26	0.24	0.24	0.34
Fuel (15¢/gal)	0.42	0.39	0.33	0.32	0.30	0.28	0.28	0.28	0.31
Total DOC	2.81	2.04	1.56	1.39	1.25	1.12	1.08	1.06	1.30

TABLE 8.- INDIRECT OPERATING COST BREAKDOWN -
L-1011 TRISTAR PRE-ENERGY CRISIS

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4000	825
System Expense	0.15	0.12	0.07	0.04	0.04	0.03	0.03	0.02	0.04
Local Expense	2.32	0.97	0.49	0.39	0.23	0.12	0.08	0.08	0.29
A/C Control Expense	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Hostess Expense	0.28	0.25	0.21	0.17	0.16	0.15	0.14	0.14	0.16
Food and Beverage	0.27	0.24	0.20	0.17	0.16	0.15	0.14	0.14	0.16
Passenger Service	3.14	1.40	0.79	0.52	0.31	0.16	0.11	0.10	0.36
Cargo Handling	1.50	0.80	0.40	0.25	0.15	0.08	0.05	0.05	0.19
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.53	0.36	0.16	0.15	0.11	0.09	0.08	0.07	0.13
Total IOC	8.48	4.41	2.57	1.92	1.39	0.98	0.84	0.84	1.57

TABLE 9.- CALCULATED FUEL CONSUMPTION - L-188 ELECTRA

Stage Length n.mi.	Block Fuel Consumption			
	lb	$\frac{\text{gal}}{\text{n.mi.}}$	$\frac{\text{seat-n.mi.}}{\text{gal}}$	$\frac{\text{Btu}}{\text{seat-n.mi.}}$
100	2 500	3.68	23.10	5475
200	3 800	2.79	30.47	4151
400	6 500	2.39	35.56	3557
600	9 000	2.21	38.46	3289
1000	14 000	2.06	41.26	3065
1500	20 300	1.99	42.71	2961
2000	26 800	1.97	43.15	2931
2300	30 500	1.95	43.59	2902
176	3 480	2.91	28.18	4485

2. TRISTAR FUEL CONSERVING OPERATIONAL PROCEDURES - TASK 2

The impact of operational procedures on the fuel usage of the L-1011 was investigated in this task. Fuel allocations following the oil embargo of 1973 forced the airlines to place more emphasis on fuel conservative operational procedures as a primary consideration in everyday operation. Prior to this time period, most airlines directed attention to procedures for saving fuel for purely economic reasons. Many identifiable fuel saving operational procedures noted in this study were implemented by certain airlines or all airlines before or during the course of this study. However, since identification of all fuel conserving procedures and the associated potential fuel savings were required in this task, the fact that a particular procedure was already in use was not used as a basis for exclusion.

Operational procedures that are available to the airlines for fuel savings were divided into two categories; flight profile management and aircraft configuration management. The first category encompasses those procedures which relate directly to the way the airplane is flown; all segments of the flight profile being examined to identify procedures which offer fuel savings. The second category, aircraft configuration management, includes maintenance-related items which can affect the performance of the airplane and also use-related procedures or procedures which may have in the past been determined by airline policy but which with changes can result in a net fuel savings. Included in this second category were items such as weight and center of gravity control.

Both the flight profile and aircraft configuration management categories of procedures include options over which the airline operator has some degree of control. Mitigating against some of these options are the limitations imposed by the equipment itself and the environment within which the airline must operate. Performance deterioration beyond the ability of normal maintenance to remedy, and the air traffic control system are representative of these limitations. Although the airline has no primary control over these externalities, they were included in this task since in many cases they can determine whether or to what extent certain fuel saving operational procedures can be implemented or should be implemented.

Identification of the magnitude of fuel conservation benefits to be realized from changes in operational procedures generally depends on the baseline performance assumed. The baseline flight profile adopted for this study necessarily assumed handbook performance under ideal conditions. Thus, for example, to ensure consistent data from the study airframe manufacturers, standard ground and flight delays and operation at optimum altitudes were used in establishing the performance of the several classes of airplanes considered.

A summary of the operating procedures considered in this task is shown in Table 10.

2.1 Flight Profile Management

The most significant payoffs in this category in terms of fuel savings are in the cruise speed and cruise altitude selection. Since on the majority of flights, the airplane is operated in cruise for the largest percentage of the total mission time, small gains in fuel efficiency result in the most significant improvements in terms of block fuel usage. Therefore, any procedure which can be used to ensure that the airplane is operated at optimum speed and altitude during cruise offers good potential for reduction in overall fuel usage.

In terms of percentage of block fuel, the other items included under flight profile management in Table 10 offer smaller savings. Except on the shorter stage lengths, the time spent in the takeoff, landing, climb, and descent phases of the flight are minimal, and, therefore, the large benefit from small increment fuel consumption improvement is not available.

2.1.1 Cruise speed. - Prior to the energy crisis, the normal L-1011 cruise speed in airline operation was Mach 0.85. This speed represented a good compromise between the various factors of fuel consumption, scheduling, and speed stability. With the advent of higher fuel costs, the fuel consumption factor became more critical, and a normal cruise speed closer to long range cruise speed is more common today. The relationship of these speeds in terms of fuel consumption can be seen by reference to a typical specific range curve as shown in Figure 4.

The most economical speed schedule would be one which allows the airplane to fly at the maximum nautical mile per pound for the particular instantaneous gross weight. Flight at these speeds in practice, however, is complicated by the reduced speed stability experienced in this regime. Since the data of Figure 4 are calculated from measured drag polars and engine specific fuel consumption curves, accountability of the relatively large thrust adjustments required to maintain a speed with reduced speed stability is not included. Experience has shown that a slightly higher cruise speed that is simpler to fly will give improved fuel consumption. Because of the difficulty in theoretically accounting for speed stability, a long-range cruise speed (LRC) has been defined within industry as that speed which gives a theoretical reduction of one percent in the maximum nautical mile per pound. Figure 4 shows that the LRC speed varies with gross weight and also that a constant Mach 0.82 schedule more closely approximates LRC over the typical range of cruise gross weights than does the Mach 0.85 speed schedule.

The relationship between the Mach 0.82 and Mach 0.85 speed schedules changes as cruise altitude is varied. This is depicted in Figure 5 where the fuel saved by cruising at Mach 0.82 in lieu of Mach 0.85 is shown. Several stage lengths are also indicated showing the significantly greater fuel savings at the longer stages.

Since operation at the various cruise speeds also entails changes in block time as well as block fuel, consideration was also given to this tradeoff. Figure 5 shows the additional block time required to obtain the fuel savings of the lower speed, Mach 0.82 cruise. Depending on cruise altitude, a savings in fuel of 1450 to 3200 pounds is realized at the expense of seven to eight minutes additional time at the 2000 mile stage length.

The practicality of flying a particular cruise speed schedule is an important consideration if the identifiable fuel savings are to be realized. In order to fly a constant speed schedule during cruise, the power must be changed as fuel is burned off. This can be seen by reference to Figure 6 where lines of constant throttle position have been superimposed on the nautical miles per 1000 pound fuel data of Figure 4. As an example, if the thrust required to achieve long-range cruise speed at an initial gross weight of 400 000 pounds was not reduced to maintain the desired speed as fuel was burned, but instead the speed was allowed to increase with no change in thrust setting, five percent more fuel would be burned on a 1300 mile stage length. While the average speed would be higher by approximately two percent, it would be obtained at the expense of the extra fuel consumed.

Since constant thrust changes to maintain a precise target speed are themselves undesirable from a fuel consumption standpoint, a practical gross weight/power reduction schedule must be determined. In the example described earlier, reference to Figure 6 shows that thrust adjustments at weight increments of approximately 10 000 pounds (40 minute intervals) should be made to approximate closely the long-range speed schedule. On the L-1011, this can be accomplished by setting scheduled engine pressure ratio (EPR) and then making any necessary thrust adjustment using the center engine. It has been established in practice that this procedure is practical up to the point where it becomes necessary to set the center engine EPR in excess of 0.015 more or less than the wing engines. If this occurs, the wing engine EPR should be increased or decreased 0.005 and the center engine again used for thrust trimming. This method of thrust setting, although a proven practical procedure, can also result in constant thrust changes if a tolerance is not established on the desired speed schedule. It has been found on the L-1011 that positive speed stability can be maintained by assuring that the actual speed is not permitted to drop more than 0.015 Mach, or five knots IAS below the desired LRC speed. Examination of Figure 6 shows that even if the target speed cannot be maintained, as long as positive speed stability exists, actual range is slightly improved at the lower speeds. Unless it is impossible to stay within the suggested speed range (operation at maximum cruise thrust), reduction in altitude should not be considered. It is much more economical to increase power (keeping within the prescribed limits) until the weight has reduced to the point where the recommended schedule can be maintained.

As mentioned above, the airplane's speed stability is an important factor when considering the practicalities of flying at the more fuel conservative speeds. Figure 7 is a plot of engine pressure ratio required versus Mach number for several gross weights and graphically illustrates speed stability, a measure of the airplane's ability to maintain a selected speed at a given thrust. Examination of this graph shows the sensitivity of the desired speed to small changes in EPR when cruising at, or near, the long-range cruise speed. The area between the EPR required (gross weight) line and any given thrust setting (maximum cruise the example) is the excess thrust available and can be used to accelerate the airplane to a speed where the thrust (EPR) available and the thrust required are equal. Once this stabilized speed is reached, any loss of speed due to turbulence will tend to be restored by the excess thrust available at the lower speed. The rate of change of excess thrust with changing speed is a measure of the airplane's speed stability. A large ratio is synonymous with a high degree of stability. Quite obviously, the airplane has lesser speed stability when operating near the long-range cruise speed than when operating at a higher speed. More attention is, therefore, required to conduct a long-range speed schedule operation. Use of the thrust trimming technique described earlier in this section provides a practical means of maintaining the desired speed schedules in the most efficient manner.

2.1.2 <u>Cruise altitude</u>. - Cruise altitude selection also has a powerful bearing on fuel consumption. Figure 8 shows the effect of altitude on specific range for the Mach 0.82, Mach 0.85, and the long-range speed schedule discussed in the previous section. A mid-cruise gross weight typical of transcontinental operation has been chosen for this illustration. Assuming that the airplane is flying at the Mach 0.85 schedule, the fuel consumption is reduced by eight percent by flying at 35 000 feet rather than 31 000 feet. A similar improvement is realized when operating at Mach 0.82, while the reduction is four to five percent when operating at long-range cruise speed. Note that the fuel consumption improves rapidly for each of the speed schedules as altitude is increased. This is true up to the point where a limit is reached; maximum cruise thrust, maximum operating speed, or speed for buffet onset.

As in the case of optimum cruise speed, optimum cruise altitude is a function of gross weight so that as fuel is consumed, the altitude for most economical cruise increases. Minimum fuel usage in cruise is therefore obtained by flying a long-range climbing cruise, i.e., cruise at long-range cruise speed at a continually increasing altitude. The ability to fly in this manner is limited by the current Air Traffic Control (ATC) system. On heavily traveled routes, it is common practice today to use a constant single altitude cruise procedure. On less heavily traveled routes a single-step cruise-climb is possible, using an altitude step of 4000 feet. The 4000-foot altitude increment is required under current ATC rules because the high altitude flight levels are at 2000-foot altitude increments with alternate flight levels designated for opposite directions of travel. On some designated one-way routes a cruise-climb using a 2000 foot step is currently practical; if pending efforts to reduce the required separation to 1000 feet are successful, the 2000-foot step could be used on a larger percentage of the routes.

Figure 9 shows the relationship of these cruise techniques for the L-1011. Ideally, the 4000-foot climb should be made in such a manner that the higher altitude is reached at the maximum cruise thrust point for the speed schedule being used. Figure 9 indicates the resulting altitudes referenced to the optimum cruise-climb schedule. Assuming that the 2000-foot step capability is available through a reduction in allowable separation, a small improvement in fuel usage results. Ability to conduct a cruise-climb gives an additional and larger improvement. However, this latter improvement, as depicted in Figure 9, also includes the incremental savings between flying a constant speed schedule and flying at the long range schedule which varies Mach as fuel is burned.

A step-climb cruise at optimum altitudes was used in the L-1011 baseline case data presented in the tables of Section 1. Relative to this base, therefore, the small improvement resulting from using 2000-foot steps can be credited. However, because ATC improvements are implied, this item was included in the improved ATC section of the operating procedures ultimately used in the UTRC Study.

2.1.3 Climb speed. - The third item included in the flight-profile management section of the Table 10 summary, climb speed, offers only slight fuel improvements relative to the baseline operation. On the L-1011, several climb schedules have been identified for the operators. These schedules have been optimized for different types of operation including long-range and high-speed. A normal climb-thrust rating has also been provided in addition to the usual maximum climb rating to achieve longer engine life potential.

Figure 10 shows the effect of the climb-speed schedule on climb fuel and time for three representative L-1011 climb schedules. The baseline for both the fuel and time plots is the long-range climb at 250/300/Mach 0.80 (250 KCAS to 10 000 feet, accelerate to 300 KCAS at 10 000 feet, maintain 300 KCAS while climbing to altitude where 300 KCAS = Mach 0.80, constant Mach 0.80 to cruise altitude). As shown, the long-range schedule offers fuel savings of from 300 to 600 pounds at the expense of two minutes of additional flight time for the typical 1000-nautical mile stage length compared to the high-speed schedule (250/375/Mach 0.83). These fuel and time increments take into account the necessity for comparing climb schedules at the same point in space; a Mach 0.82 cruise being used to accomplish this. A climb schedule that results in a shorter climb distance obviously entails a longer cruise segment and thus a cruise fuel increase. By adding this fuel penalty to the climb fuel, a true comparison of the advantages or disadvantages of different climb schedules on a mission profile is obtained.

The effects of using the normal climb power rating instead of the maximum climb power rating are shown in Figure 11. Several stage lengths are considered for each of three climb speed schedules. The additional cruise segment required to arrive at the same point in space as described above is presented for cruise at both Mach 0.82 and 0.85. Small but measurable fuel penalties are paid when using the normal climb rating which must be weighed against the improved engine life potential.

2.1.4 Descent speed. - Since, in normal operations, the descent from cruise altitude is conducted at flight idle thrust with the attendant low fuel flow, only small fuel savings can be identified between one descent speed schedule and another. Optimum long-range and high-speed schedules have been identified for the L-1011. The long-range schedule consists of flight at a constant Mach 0.80 down to the altitude where a calibrated airspeed of 300 KCAS is reached and then holding a constant 300 KCAS down to 10 000 feet whereupon a deceleration to the FAA required 250 KCAS speed is conducted, this speed then being maintained down to sea level. The high-speed descent schedule uses a constant Mach 0.85 to the altitude for 350 knots calibrated airspeed. Assuming that the airplane is at a final cruise altitude of 35 000 feet, a fuel saving of approximately 150 pounds can be realized by using the long-range speed schedule in lieu of the high-speed schedule for the descent.

Another important consideration in the descent is its initiation. Cruise should be maintained as long as practical by planning the descent so that arrival in the terminal area is accomplished with a minimum of low altitude level flight. In this way, the period of operation at the lower uneconomical altitudes is minimized. In this same vein, when it is known that holding will be required because of congestion in the terminal area, the hold should be conducted at the highest practical altitude. For example, Figure 12 shows that a hold performed at 15 000 feet in the clean configuration can save approximately four percent relative to one performed at 5000 feet with the flaps at the four degree position.

2.1.5 Takeoff. - The takeoff portion of the flight profile was also examined for potential fuel savings. However, even though the fuel flows are large during takeoff, they are relatively insensitive to thrust changes of the magnitude available using alternate takeoff procedures. These procedures consist of operation at reduced takeoff power settings where field length and/or gross weight permit. The potential for any significant fuel savings during the takeoff is further reduced by the short amount of time spent in this segment.

2.1.6 Landing. - As discussed above in the descent speed section, the descent should be delayed as long as is practical. Making up distance at the lower altitudes or while maneuvering in the landing configuration increases the fuel consumption. In the landing portion of the flight additional fuel savings are available by using the lowest of the landing flap positions consistent with the field conditions. On the L-1011, use of the 33-degree flap position results in a 120 pound fuel saving relative to the 42-degree flap position assuming an eight mile final with a 3 degree glide slope.

2.2 Aircraft Configuration Management

The second category identified under procedure changes relates to those items of the airplane configuration, both internal and external, which can affect the fuel consumption. Generally, these items are associated with the deterioration or wear of the equipment with age or to airline procedures which have become established from considerations other than fuel consumption.

2.2.1 Gross weight control. - The nautical mile per pound or fuel mileage of the aircraft for a given set of altitude, speed, and temperature conditions is a direct function of the gross weight of the aircraft. The lower the gross weight for a particular set of conditions, the better the fuel mileage. Therefore, if the weight at the end of a stage exceeds the minimum required to perform the mission, the potential for significant fuel savings exists. Any reduction that can be obtained in the landing weight represents a reduction throughout the mission, thus the fuel savings are multiplied. On a typical L-1011 transcontinental mission, each one percent in landing weight reduction translates to a one-half of one percent savings in fuel burned. Weight reductions can be obtained in two areas: fuel carried and operational empty weight.

The fuel remaining at the end of a mission consists of the reserve fuel and any fuel which is tankered from the origin to the destination. On many flights, more than the legally required reserves are carried either at the option of the captain or because the airline has built in extra fuel to their basic reserve requirements. Inclusion of fuel for diversion to a specified alternate airport under all conditions when no alternate is in fact required (FAR Part 121.619 and .621) is an example of the latter. For maximum fuel savings, the exact reserves required for the conditions of each flight should be determined.

Reclearance is another procedure which can be used to reduce fuel loads. This is the procedure where clearance is obtained for an airport short of the destination; subsequent inflight reclearance to the intended destination allows burning some of the original reserves thus giving a lower landing weight. Reclearance is currently used on some long haul segments to increase payload capability, but it is an equally viable procedure on flights which are not payload limited to effectively reduce landing weights.

Fuel tankering is the procedure whereby fuel over and above the amount required for a mission segment is carried to avoid refueling at the destination. Reasons for this operation include both fuel price and a reduction in time spent at an intermediate stop. Large amounts of fuel can be involved here as maximum landing weight may be the only restriction. From both the fuel conservation and operating cost standpoint, the extra fuel burned involved in tankering should be weighed against the particular advantages.

Increased operational empty weight is an obvious cause of additional fuel usage. Not so obvious, because of the gradual nature of the buildup, are the ways in which operational empty weight increases. It has been found that a one percent increase in empty weight can be expected in a five year period. Added equipment, structural modifications, heavier replacement interior trim and a general buildup of dirt, all contribute to empty weight growth.

Since weight has such a powerful effect on fuel consumption, reduction of empty weight should receive attention in addition to the control of its growth. Empty weight reductions are effective on every flight operated with the aircraft and are therefore more beneficial than reductions in fuel loads as discussed above. Some of the areas worthy of consideration in efforts to reduce empty weight include passenger service items, potable water, and emergency equipment. On large wide-bodied aircraft like the L-1011, large amounts of empty weight are made up of the food and beverage service, consumables and the potable water. If instead of a standard allowance for these items, planned quantities are carried for each trip, fuel savings can be realized. Loading of the meal service and water dependent on passenger load and trip length is one way of accomplishing this. Carriage of emergency equipment dependent on the particular trip can also effect fuel savings. This is typified by overwater equipment being carried on flights where it is not required. A problem here is the necessity to offload and later onload this equipment. Again the added time must be weighed against the potential fuel and cost savings.

2.2.2 Center of gravity control. - Control of the aircraft's center of gravity, to result in operation at a more aft c.g., offers potential fuel savings through a reduction in trim drag. On the L-1011, a fuel savings of nearly three percent can be identified for the complete center of gravity range. Figure 13 shows, however, that over the typical in-service range, the attainable savings are closer to one-half of one percent, and relative to the current operation of the L-1011, the savings are reduced to 0.2 percent. Strict control of passenger and cargo loading are necessary to accomplish this fuel savings. This problem is eased somewhat by the more sophisticated weight and balance systems available on the newer aircraft.

2.2.3 Aircraft cleanliness. - Besides the growth in operating empty weight as the airplane gets older, deterioration in its aerodynamic integrity is also experienced. The causes of aerodynamic deterioration can be divided into two areas: damaged surfaces and damaged seals.

On a high-speed transport like the L-1011, it is important that the design contours be maintained. Critical areas of the aircraft are the wing and tail leading edges, the forward fuselage, and the engine inlets. Small deviations in the design contours of these critical areas, caused by dents or improper repairs, change the airflow and cause increases in the boundary-layer thickness and thus the drag. Increased fuel flow is a direct result of the increased thrust required to maintain speed. Of the critical areas, the most important to monitor are the wing engine inlets. Here, a damaged contour can effect airflow to the engine as well as to external boundary-layer flow. In addition, the inlets are the most susceptible of the critical areas to ground service equipment damage.

There are two types of seals which require attention; those which are used to improve the aerodynamic characteristics of the airplane, and those used to seal the pressurized areas of the fuselage. Aerodynamic seals are provided for the most part to prevent airflow from occurring between an area of high static pressure and one at low static pressure. Areas such as these are the leading and trailing edge flaps. Leakage of air from the lower to the upper surface of a flap disturbs the flow causing an additional drag and thrust requirement. Prevention of this occurrence requires expeditious repair or replacement of these seals.

The other group of seals subject to deterioration are those used to seal the pressurized areas of the fuselage at the passenger and cargo doors. Because of the pressure differential, leakage around these seals causes a disruption of the boundary layer and a consequent increase in drag and fuel flow. Pressurized checks performed on the ground are a worthwhile means of determining problem areas. The ground equipment interface is the major cause of damaged seals in the door areas.

2.3 Externalities

The ability to implement the identifiable fuel savings is, to some extent, dependent on considerations beyond the control of the airline. Equipment limitations and limitations imposed by operations in controlled airspace restrict the airline operator's fuel saving capabilities. Engine deterioration beyond the control of normal maintenance procedures, altitude and speed assignments below desired optimums, and traffic imposed delays both in the air and on the ground are all areas that confound the best fuel conservation program.

Engine deterioration has become a major cause of fuel consumption penalties. This problem appears to be more severe with the new generation of high-bypass ratio engines than with the older low-bypass engines. While the engine manufacturers are currently addressing this problem and have identified some of the causes, the experience to date is as shown in Figure 14. As can be seen, large specific fuel consumption penalties have been experienced; as much as five percent for some engines. Until changes are incorporated by the engine manufacturers, there is little that can be done by the airlines beyond more stringent overhaul procedures. It is believed that a one percent improvement may be achievable with improved maintenance on the RB.211 engines powering the L-1011.

The air traffic control system has the largest effect on the ability of an airline to implement fuel conserving procedures. As much as a thirty to forty percent difference was observed during the course of this study between the ideal handbook data generated by the manufacturers and the operational service data as reported by the airline contractor. A large part of this difference is attributable to air traffic control required procedures which prevent the airlines from flying the ideal mission profile as assumed for the handbook calculations. The inability to fly at optimum altitudes because of air traffic will increase fuel consumption. Inability to conduct preferred climb schedules due to altitude clearance problems also increases fuel consumption. Holding times above planned allowances increase fuel consumption. Improvements in the air traffic control system, therefore, offer significant potential for fuel savings in that they would allow day-to-day operations more closely approximating the optimum.

The task of quantifying changes to the air traffic control system however is not simple. Determination of what changes are possible and the cost of implementation in terms of the ground and/or aircraft equipment is a study by itself, well beyond the scope of this study. Identification of reasonably attainable fuel savings with an improved air traffic control system was considered feasible. The magnitude of the fuel savings could then signal the need to determine the cost of the required changes to the system followed by a cost/benefit assessment.

2.4 Summary of Data

The assemblage of fuel-savings data to satisfy the requirements of the forecast studies involved a cooperative effort between the manufacturers and the airline contractor. To accomplish this, the fuel savings for the identified operational procedures changes were calculated by the manufacturers for their respective aircraft models. These identified changes were then combined and a list of block fuel reductions, with and without ATC improvements, was developed for each aircraft designated by NASA for use in the air transportation system analysis study. In this task, the Lockheed generated data for the L-1011 were combined with the McDonnell-Douglas generated DC-10 data for use by UTRC in the current three engine wide-bodied aircraft class. Figure 15 illustrates the relationship between the agreed to fuel savings and those identified for the L-1011.

During the preparation of the data discussed above, the fuel consumption and operating cost data for the L-1011 with selected operational procedure changes were generated. Although these data were not used directly in the air transportation system analysis study, they are presented in this section for completeness. The format and presentation are the same as that used for the L-1011 data of Task 1. Fuel consumption and operating cost for the L-1011 as operated in 1975 are presented in Tables 11 through 14. In the 1973 baseline flight profile of Task 1, the airplane was flown along a high-speed climb and cruise profile. For the 1975 basis of Tables 11 through 14, the climb speeds were slowed to the long-range schedule and the cruise speed was reduced from the pre-energy crisis Mach 0.85 to Mach 0.82. These changes are considered to be representative of the steps which were taken by the airlines to save fuel following the oil embargo. This level of performance is also considered to be representative of the current operation of the aircraft on a handbook basis. Tables 15 through 18 present the fuel consumption and operating cost data for the L-1011 assuming that some additional procedure changes are implemented. Included in these data are the low-speed climb and Mach 0.82 cruise of the 1975 basis L-1011 and in addition a general aerodynamic cleanup, a one percent aft movement of the center of gravity and a two thousand foot step-climb cruise. This cruise procedure would necessitate a change in the current altitude separation criteria: the current 2000 feet would have to be reduced to 1000 feet.

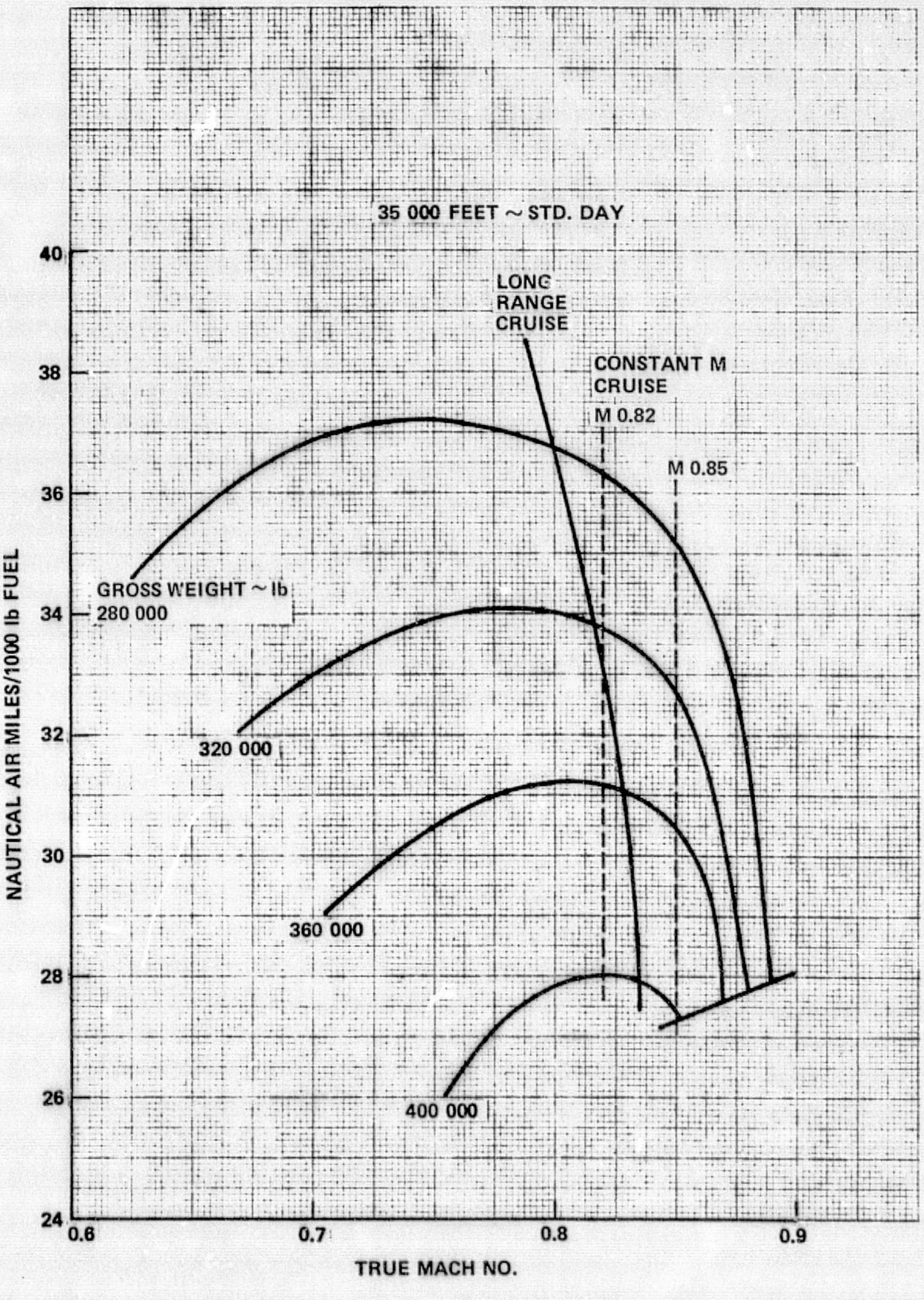


Figure 4.— L-1011 specific range

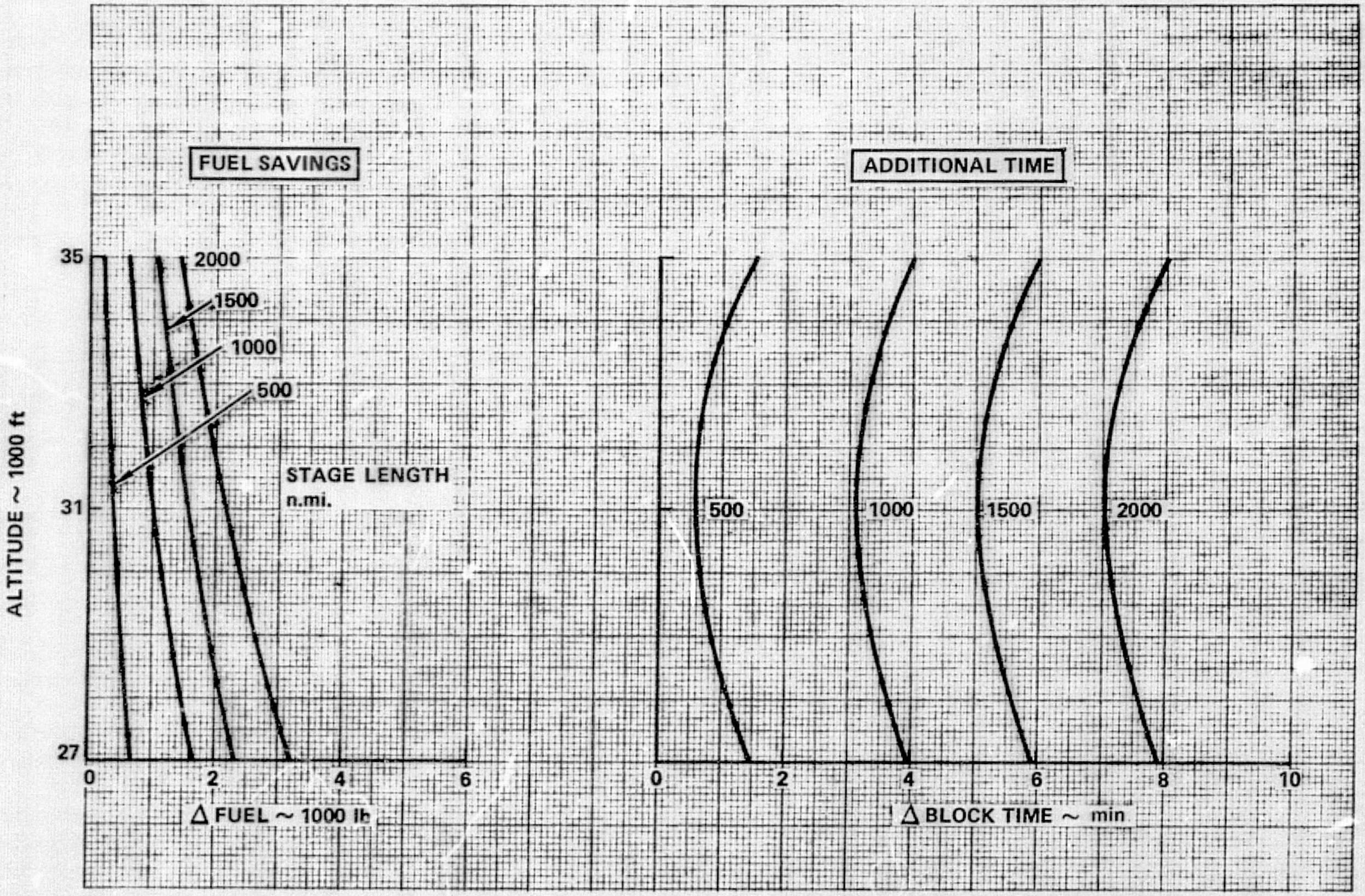


Figure 5.—L-1011 fuel and time differences M 0.82 ilo M 0.85

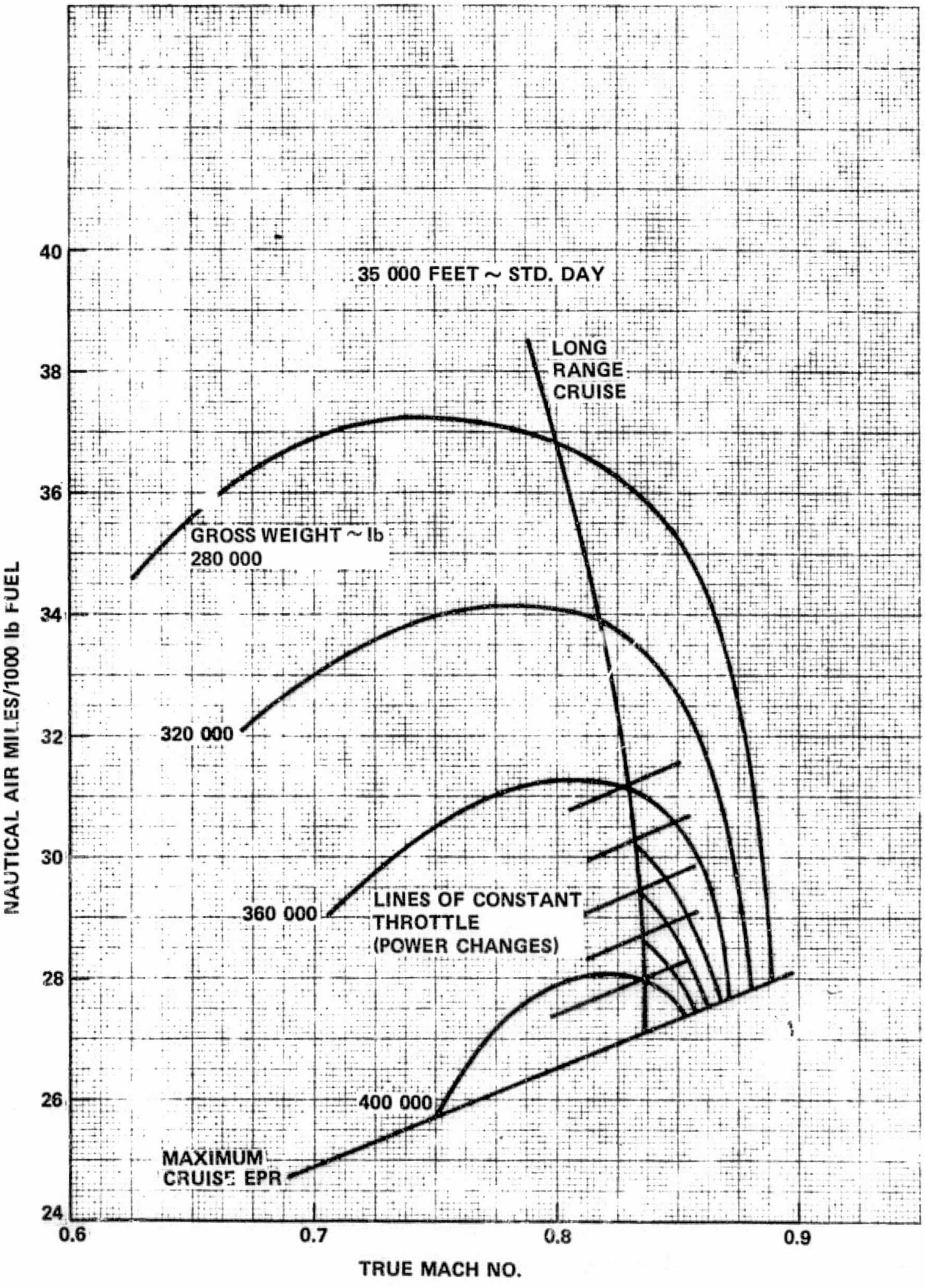


Figure 6.—Power changes required for LRC

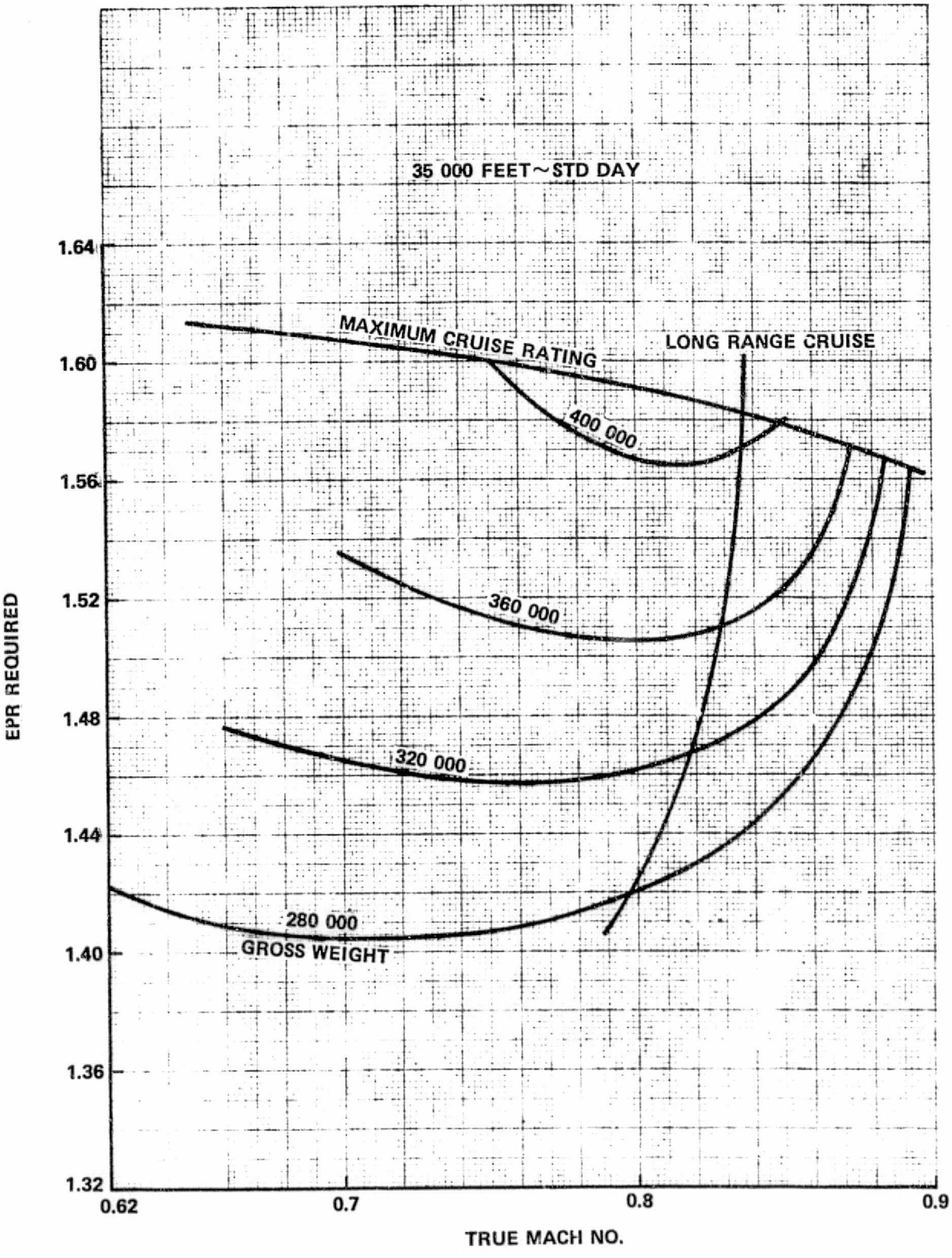


Figure 7.—EPR required

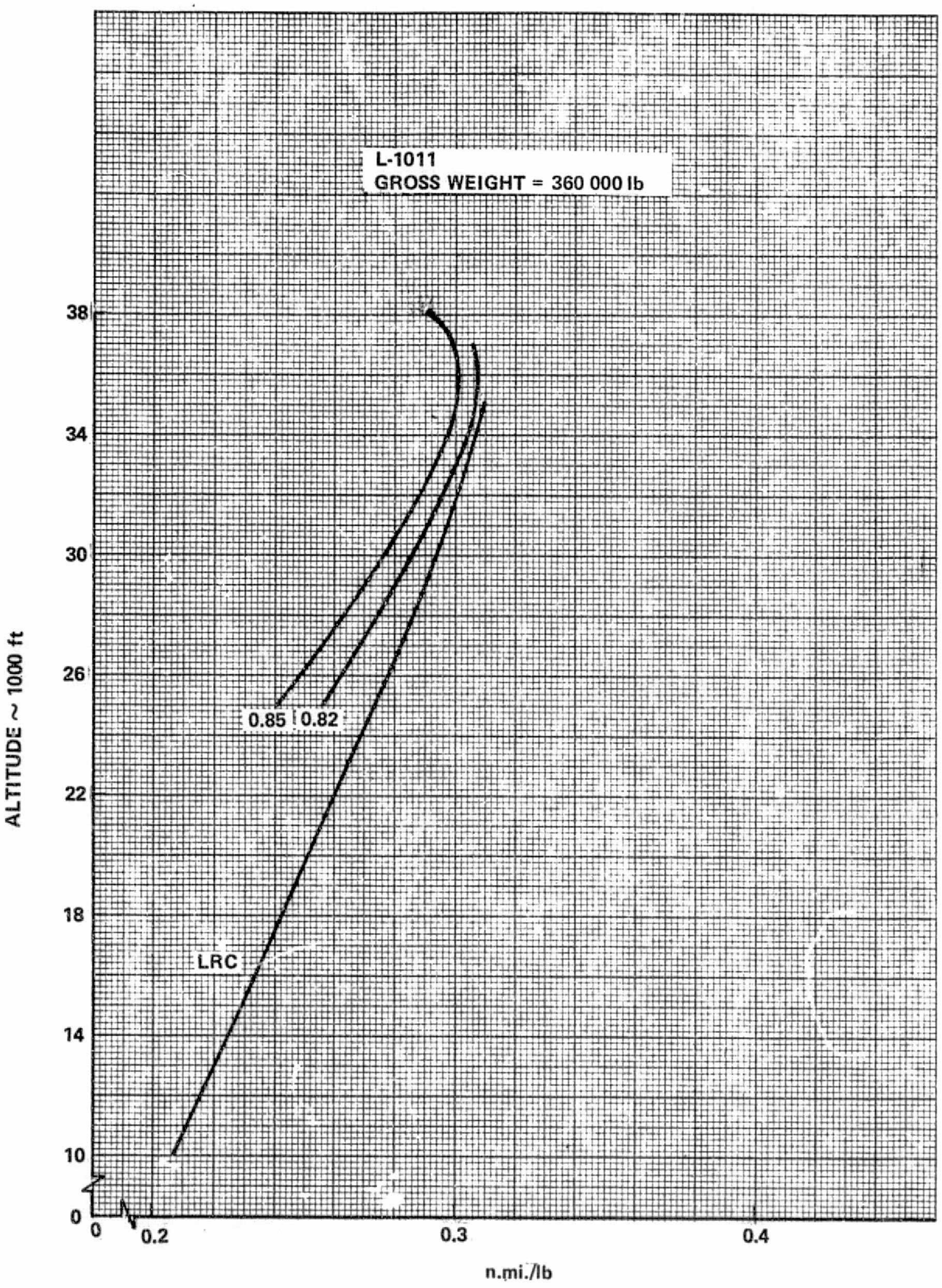


Figure 8.—Altitude effect on specific range

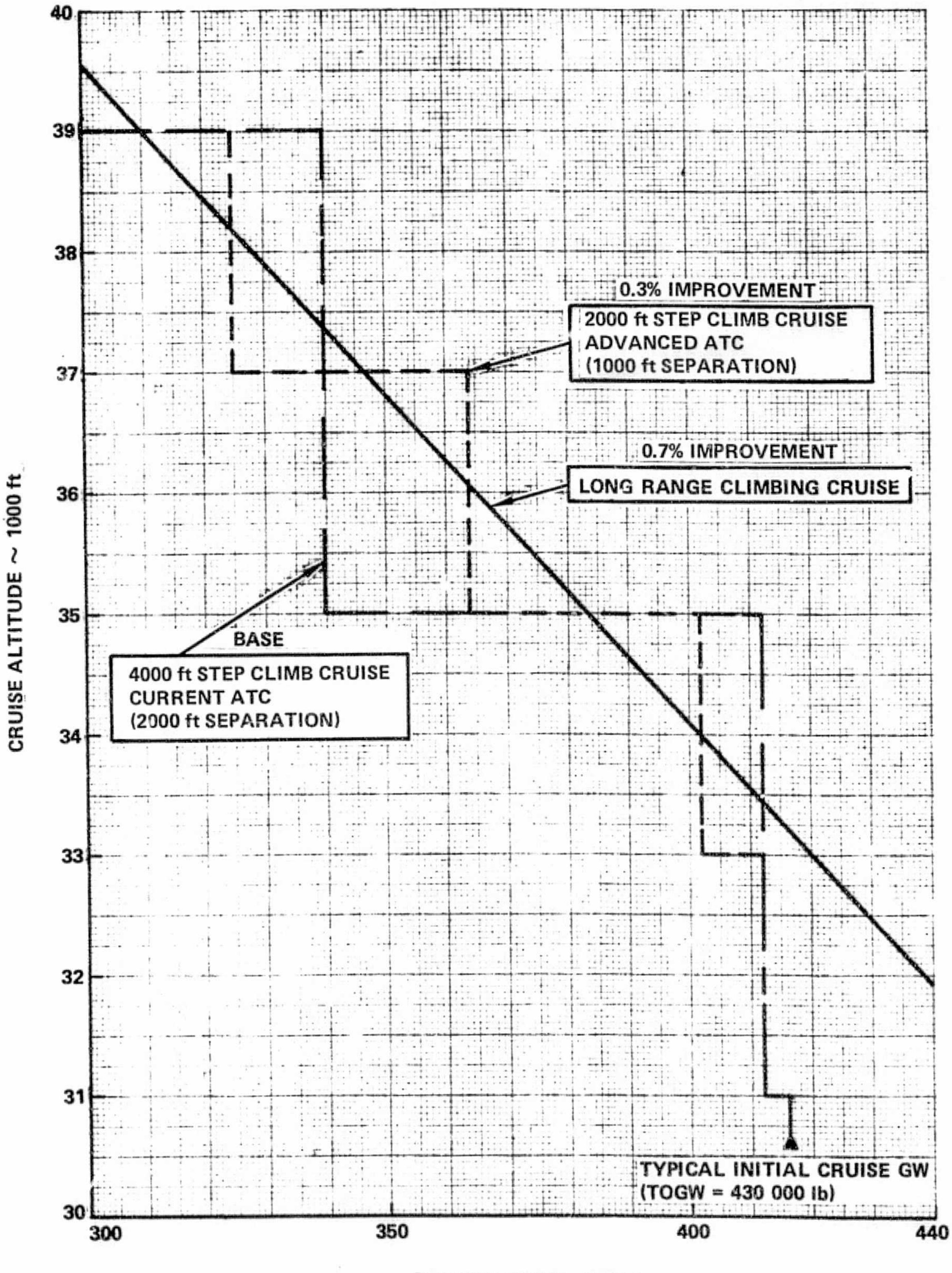


Figure 9.— L-1011 cruise procedures

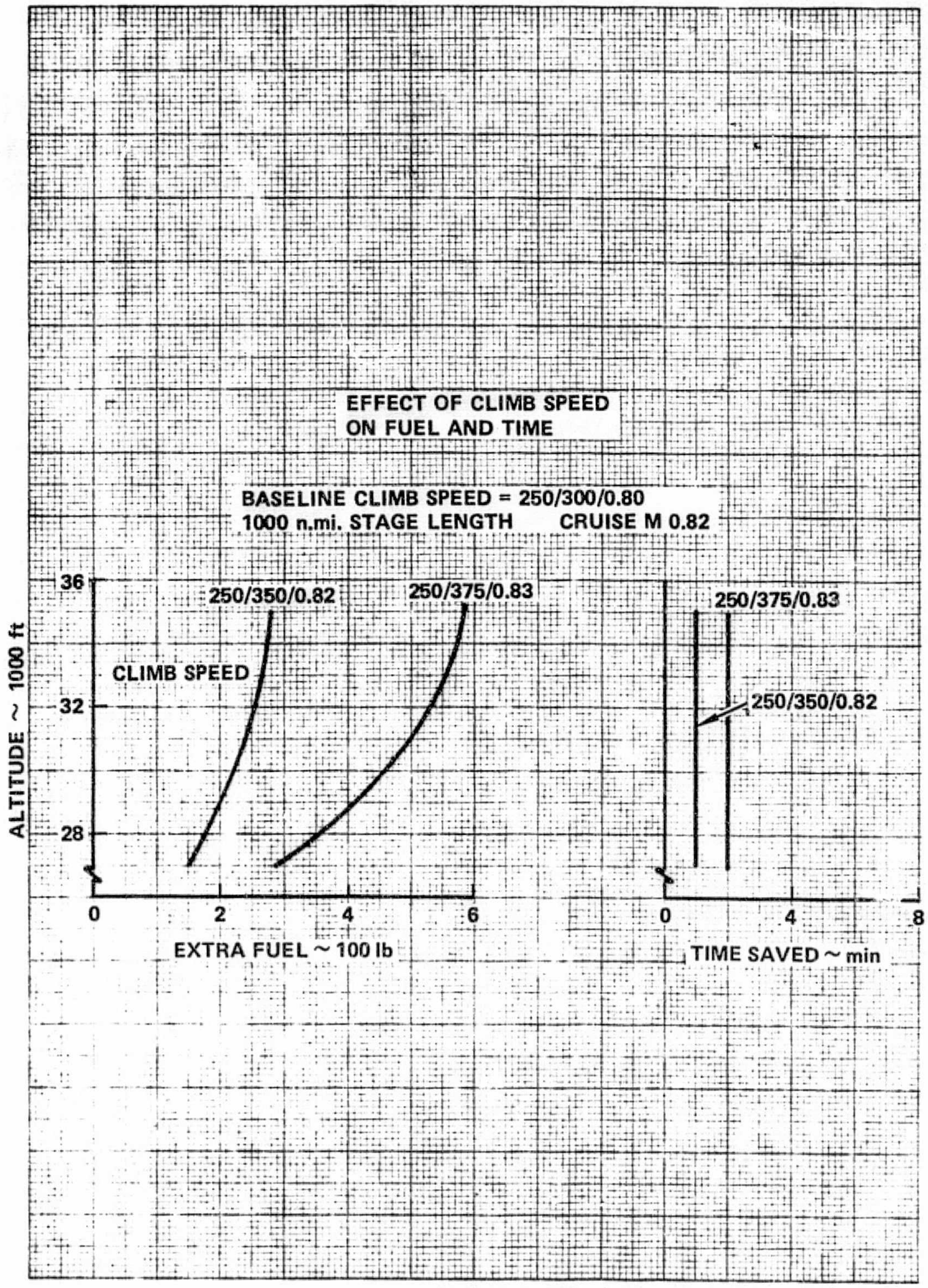


Figure 10.— Effect of climb speed. L-1011

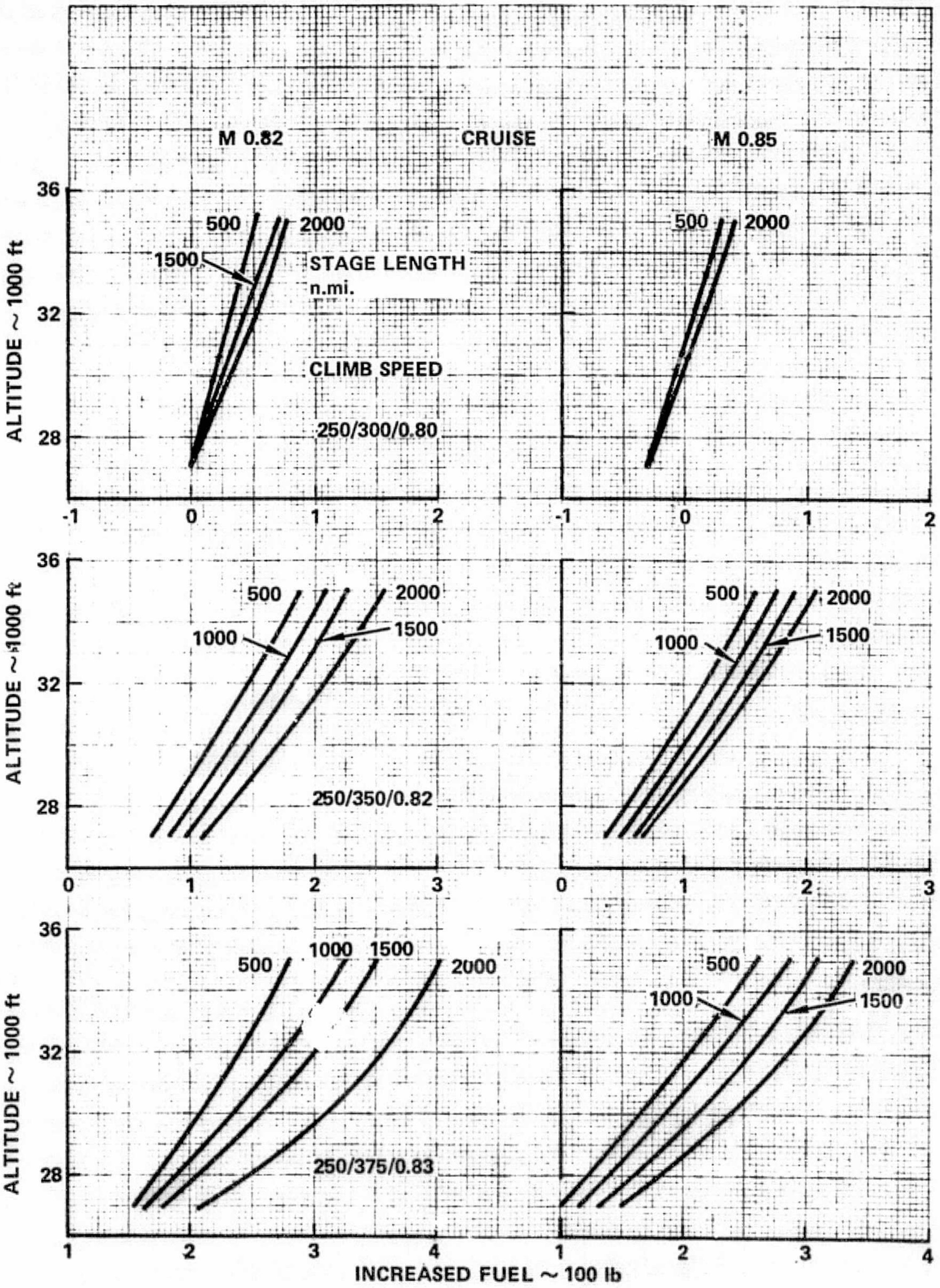


Figure 11.—Effect of using normal climb instead of maximum climb power

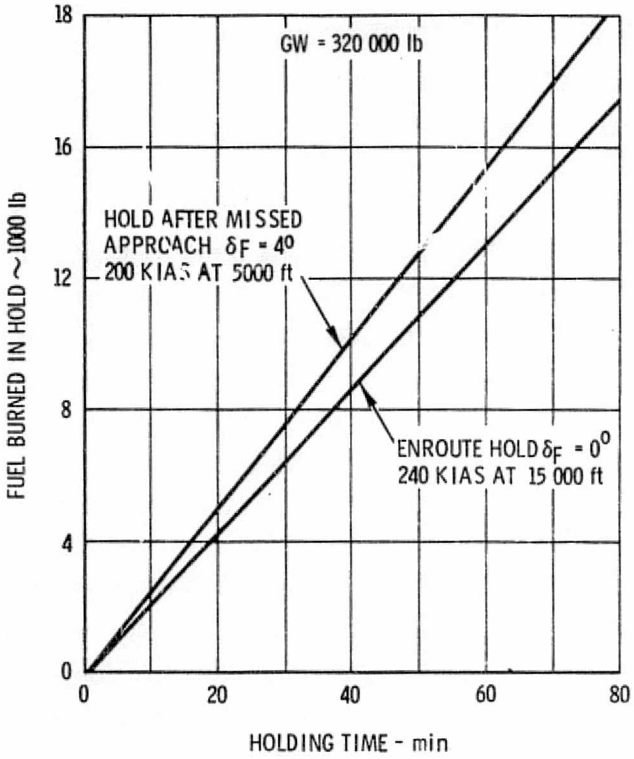


Figure 12. — L-1011 fuel burned in hold

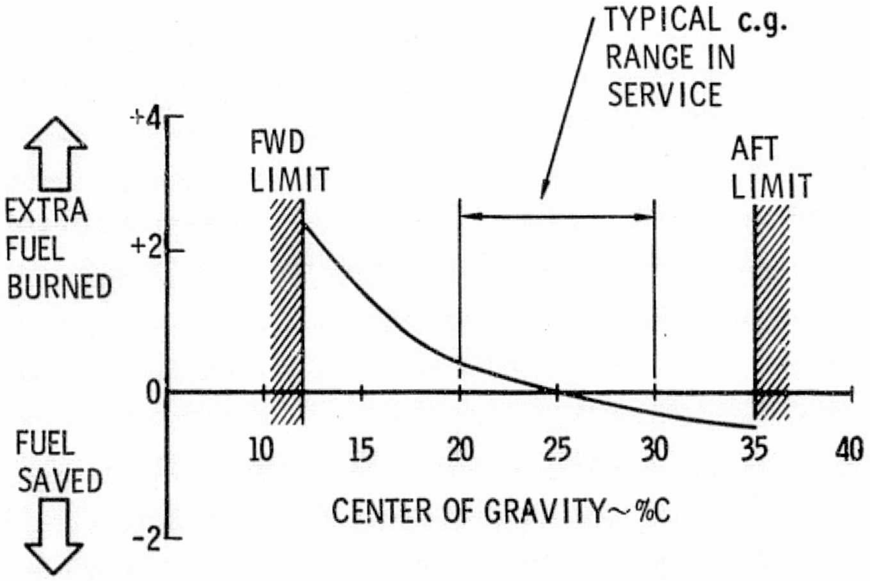


Figure 13. — L-1011 center of gravity control

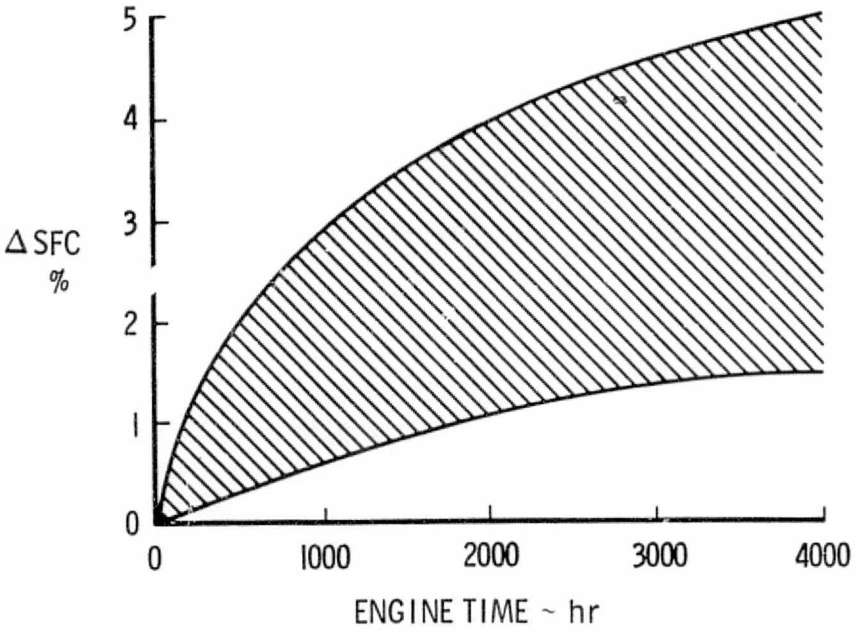
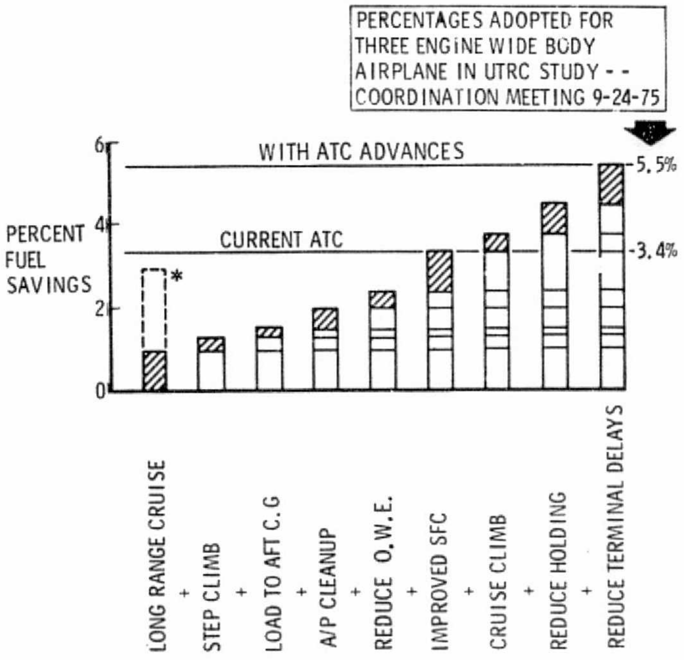


Figure 14.– Engine deterioration - SFC



*POTENTIAL IF
SLOWDOWN IS
FROM M = 0.85

Figure 15. – L-1011 operational procedures fuel savings summary

TABLE 10.- FUEL CONSERVING OPERATIONAL PROCEDURES

AIRLINE OPTIONS

Flight Profile Management

- Cruise Speed
- Cruise Altitude
- Climb Speed
- Descent Speed
- Takeoff
- Landing

Aircraft Configuration Management

- Gross Weight Control
    - Reserves
    - Tankerage
    - Operating Empty Weight
- Center of Gravity Control
- Aircraft Cleanliness

Externalities

- Engine Deterioration
- Air Traffic Control

TABLE 11. - CLACULATED FUEL CONSUMPTION - L-1011 TRISTAR (1975 BASIS)

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal / n.mi.	seat-n.mi. / gal	Btu / seat-n.mi.
100	5 089	7.48	36.50	3465
200	8 893	6.54	41.74	3030
400	15 871	5.84	46.79	2703
600	22 805	5.59	48.84	2590
1000	35 906	5.28	51.70	2446
2000	67 049	4.93	55.38	2284
3000	98 893	4.85	56.32	2246
4136	139 300	4.95	55.12	2295
825	30 294	5.40	50.52	2515

TABLE 12. - CALCULATED TOTAL OPERATING COSTS - L-1011 TRISTAR (1975 BASIS)

Stage Length n.mi.	Block Speed kt	Total DOC		Total IOC	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	233	1803	2.84	5394	8.50
200	296	1664	2.07	3730	4.65
400	349	1514	1.59	2540	2.67
600	376	1444	1.41	1978	1.93
1000	402	1396	1.27	1539	1.40
2000	436	1354	1.14	1177	0.99
3000	451	1338	1.10	1040	0.86
4136	458	1334	1.07	1050	0.84
825	392	1420	1.32	1675	1.56

TABLE 13.- DIRECT OPERATING COST BREAKDOWN - L-1011 TRISTAR (1975 BASIS)

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4136	825
CREW	0.41	0.34	0.28	0.26	0.24	0.22	0.22	0.22	0.25
INSURANCE	0.10	0.08	0.07	0.06	0.06	0.05	0.05	0.05	0.06
DEPRECIATION	0.61	0.52	0.42	0.38	0.35	0.33	0.32	0.32	0.36
MAINTENANCE	1.30	0.75	0.48	0.40	0.33	0.26	0.25	0.25	0.35
FUEL (15¢/gal)	0.42	0.38	0.34	0.31	0.30	0.28	0.27	0.27	0.30
TOTAL DOC	2.84	2.07	1.59	1.41	1.27	1.14	1.10	1.07	1.32

TABLE 14.- INDIRECT OPERATING COST BREAKDOWN -
L-1011 TRISTAR (1975 BASIS)

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4136	825
System Expense	0.15	0.12	0.06	0.04	0.04	0.03	0.03	0.03	0.04
Local Expense	2.32	1.14	0.57	0.39	0.23	0.12	0.08	0.08	0.28
A/C Control Expense	0.07	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.01
Hostess Expense	0.29	0.25	0.21	0.18	0.17	0.15	0.15	0.15	0.17
Food and Beverage	0.28	0.24	0.19	0.17	0.16	0.15	0.15	0.15	0.16
Passenger Service	3.14	1.41	0.78	0.52	0.31	0.16	0.11	0.11	0.37
Cargo Handling	1.50	0.81	0.39	0.25	0.15	0.08	0.05	0.05	0.18
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.54	0.40	0.21	0.15	0.11	0.09	0.08	0.08	0.12
Total IOC	8.50	4.65	2.67	1.93	1.40	0.99	0.86	0.84	1.56

TABLE 15.- CALCULATED FUEL CONSUMPTION - L-1011
WITH CHANGES IN OPERATIONAL PROCEDURES

Stage Length n.mi.	Block Fuel Consumption			
	lb	$\frac{\text{gal}}{\text{n.mi.}}$	$\frac{\text{seat-n.mi}}{\text{gal}}$	$\frac{\text{Btu}}{\text{seat-n.mi.}}$
100	5 002	7.36	37.11	3408
200	8 731	6.42	42.52	2974
400	15 471	5.69	48.00	2635
600	22 148	5.43	50.29	2515
1000	34 455	5.07	53.88	2347
2000	62 074	4.56	59.81	2115
3000	93 602	4.59	59.50	2126
4300	141 500	4.84	56.41	2242
825	29 340	5.23	52.40	2420

TABLE 16.- CALCULATED TOTAL OPERATING COSTS - L-1011
WITH CHANGES IN OPERATIONAL PROCEDURES

Stage Length n.mi.	Block Speed kt	Total DOC		Total IOC	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	233	1799	2.83	5394	8.50
200	294	1660	2.07	3630	4.52
400	354	1507	1.56	2480	2.57
600	375	1436	1.40	1978	1.93
1000	400	1380	1.26	1530	1.40
2000	437	1330	1.12	1178	0.99
3000	451	1325	1.08	1046	0.85
4300	460	1343	1.07	1060	0.84
825	392	1400	1.32	1685	1.59

TABLE 17.- DIRECT OPERATING COST BREAKDOWN - L-1011 WITH CHANGES IN OPERATIONAL PROCEDURES

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4300	825
Crew	0.41	0.35	0.27	0.26	0.24	0.22	0.21	0.20	0.25
Insurance	0.10	0.09	0.07	0.06	0.06	0.05	0.05	0.05	0.06
Depreciation	0.61	0.53	0.42	0.38	0.36	0.33	0.32	0.32	0.37
Maintenance	1.30	0.72	0.40	0.40	0.33	0.26	0.24	0.24	0.35
Fuel (15¢/gal)	0.41	0.38	0.32	0.30	0.28	0.26	0.26	0.26	0.29
Total DOC	2.83	2.07	1.56	1.40	1.26	1.12	1.08	1.07	1.32

TABLE 18.- INDIRECT OPERATING COST BREAKDOWN - L-1011 WITH CHANGES IN OPERATIONAL PROCEDURES

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4300	825
System Expense	0.15	0.11	0.06	0.04	0.04	0.03	0.03	0.02	0.04
Local Expense	2.32	1.14	0.53	0.39	0.23	0.12	0.08	0.08	0.30
A/C Control Expense	0.07	0.05	0.03	0.01	0.01	0.01	0.01	0.01	0.01
Hostess Expense	0.29	0.25	0.21	0.18	0.17	0.15	0.15	0.15	0.17
Food and Beverage	0.28	0.24	0.20	0.17	0.16	0.15	0.14	0.14	0.16
Passenger Service	3.14	1.31	0.70	0.52	0.31	0.16	0.11	0.10	0.39
Cargo Handling	1.50	0.79	0.39	0.25	0.15	0.08	0.05	0.04	0.18
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.54	0.40	0.22	0.15	0.11	0.09	0.08	0.08	0.11
Total IOC	8.50	4.52	2.57	1.93	1.40	0.99	0.85	0.84	1.59

3. TRISTAR FUEL SAVINGS MODIFICATIONS - TASK 3

Fuel conserving modifications of the L-1011 were studied in this task. For purposes of the study, modifications were defined as those fuel conserving improvements which could be incorporated either in new production airplanes or as retrofits to already delivered airplanes and were not of such a drastic nature as to remove the airplane from service for an undue length of time. An additional criterion was that the modifications were not so costly as to negate any fuel savings that might be identified; i.e., the modification must be cost effective.

The selection of fuel conserving aircraft modifications must take into consideration the time required for development, test, mod-incorporation, and recertification of the aircraft. Any modification which cannot be incorporated without lengthy development time is not likely to be a viable candidate. Derivative aircraft or all new aircraft offering substantially greater fuel efficiency would displace the modified aircraft too soon after introduction, and the cumulative fuel savings of the modified aircraft would therefore be small and the cost of the modification could not be rationally justified.

Potential modifications identified at the beginning of the study to be considered in this task were as follows:

- Wing tip treatment
- Propulsion improvements
- Increased seating density
- Less sophisticated high-lift devices
- Wing leading edge modifications

During the course of the study some of these modifications proved to be impractical and were therefore eliminated. On the other hand, study of these particular modifications led to the discovery of other potential fuel saving modifications.

3.1 Wing Tip Treatment

The initial modification considered in this study task was an increase in the aspect ratio of the L-1011 wing through a treatment of the wing tip. Fuel savings would be inherent due to a reduction in both cruise and second segment climb drag. A planar tip extension as well as a winglet were considered. The results of an experimental and analytical study conducted at Lockheed with independent development funds was drawn upon for this study subtask (Ref. 3). The experimental study involved wind tunnel tests of a 1/30 scale L-1011 model in both the Lockheed 8 by 12 foot low-speed and 4 by 4 foot transonic/supersonic tunnels. The wind tunnel models are shown in Figure 16.

The results of the experimental study showed that transonic flow effects severely degrade the performance of the winglet as compared to the tip extensions. A winglet which gave the same drag reduction as a comparable tip extension at low Mach number (M 0.2) was able to reduce the drag only one-half as much as the tip extension at cruise Mach number. Figure 17 presents these tunnel results at Mach 0.84. On the basis of the net drag reduction per bending moment increase, the tip extension is the more efficient system. The wind tunnel tests also indicated that the winglet gave a rapid increase in drag at the higher Mach numbers which would indicate reduced operational buffet limits and higher Mach induced buffet loads at operational limit speeds.

Several other areas such as high lift performance, handling qualities, flutter and aeroelastic effects, manufacturing costs and loads analysis have to be considered in selecting between the winglet and the tip extension as drag reducing devices in an airplane design. In the case of the tip extension, the investigation of these items is straightforward and well understood, whereas the impact of the winglet on many of these items is not known at the present time. This additional technological risk in the case of the winglet plus the unfavorable characteristics exhibited in the wind tunnel tests led to the recommendation that a planar tip extension be used as a modification to improve the fuel efficiency of the L-1011.

A three foot per side wing tip extension was selected for this study. This particular size was based on a study of the optimum increase in span from both a performance and cost standpoint. With a three foot extension, a three percent reduction in fuel consumption can be obtained and minimal wing structure changes are involved. For retrofit on in-service L-1011's, no rework or strengthening of the wing is required, however, a reduction in maximum takeoff weight from 430 000 pounds to 410 000 pounds will be required. For operators whose route structures do not require full takeoff gross weight, this retrofit may be suitable. Where full takeoff weight is required and the additional down-time and cost can be accepted, additional wing structural changes would allow retention of the 430 000 pound limit. Figure 18 shows that the same tip to wing joint interface of the basic L-1011 can be retained. Also, the existing tip section including the wing tip light installation can be utilized although some rework of the Number 4 leading edge slat is required. The existing anti-icing system was found to be sufficient, requiring no extension to the revised wing tips.

Tables 19 through 22 present the fuel consumption and operating cost data for the L-1011 with the three-foot wing tip extension. These data are tabulated for a series of stage lengths including the 1973 CAB average stage length as in Section 2. Note, however, that the maximum stage length shown is reduced somewhat from the basic L-1011 data presented earlier. This is caused by the reduced takeoff gross weight capability with the simplified tip modification used. The long-range climb and Mach 0.82 cruise performance are reflected in the data of Tables 19 through 22. This is consistent with the current (1975) operation of the airplane, as discussed in Section 2. As in the previous sections, fuel consumption is shown in terms of total block fuel and on both an airplane-mile and a seat-mile basis in Table 19. The seat-mile fuel consumption is shown both in units of seat-miles per gallon and Btu's per seat-mile. Total direct and indirect operating cost data are shown in Table 20 with the associated cost breakdowns following in Tables 21 and 22. All of the cost data are shown in terms of cents per available seat-nautical mile and the total operating costs are additionally shown in units of dollars per block hour with the applicable block speeds indicated.

The wing tip extension is assumed to be accomplished after the delivery of the 100th L-1011 and to be included thereafter. A 250 aircraft run was assumed. The additional cost for the tip extension and the pro rata share of the nonrecurring cost is included in the following airplane and spares prices.

	Airplane	Spares
Airframe	$15 673 944	$2 351 092
Engine	4 054 433	608 165
TOTAL	$19 728 377	$2 959 257

3.2 Propulsion Improvements

The engine offers perhaps the best opportunity for modifications to improve fuel consumption. Flight test costs alone can consume the potential savings of aircraft external aerodynamic modifications. For engine modifications, the certification flight testing required is usually not as extensive, since items such as aircraft handling qualities, stall characteristics and performance may not be required. Thus a gain of one percent in terms of engine specifics can be more cost effective than one percent gained through an external configuration modification.

Continuing research at Rolls Royce has identified fuel flow reductions on the order of two percent for improvements in internal components of the RB.211 engine. These modifications consist mainly of revised sealing and improved tip clearances to reduce leakage in the core engine. These changes could be incorporated by 1978 as indicated in Figure 19. Also shown in the figure are additional fuel flow reductions that could be realized by 1982. Included in the 1982 period are a mixed-flow exhaust and additional engine sealing.

A large improvement in the specific range of the L-1011 comes about through revision of the engine afterbody. The original configuration on the L-1011 incorporated a hot stream spoiler which deflected the core engine flow when reverse thrust was selected. Since the core engine reverse thrust contribution is very small due to the high bypass ratio of the RB.211, the performance effect of eliminating the hot stream spoilers is not significant. Removing the spoilers allows revision to the external contours of the engine afterbody; the fairings or stangs are removed and the core nozzle is reshaped which, combined with a lengthening and reshaping of the fan duct, allows improved flow over the afterbody. These changes are illustrated in Figure 20 which compares the original afterbody configuration with the modified 15 degree afterbody design. The center engine installation is shown; the wing engine installation is similar.

Flight tests with the 15 degree engine afterbodies showed a 3.4 percent improvement in fuel consumption out to a Mach number of 0.83. At higher Mach numbers even more significant savings were indicated caused by a delay in the drag rise characteristics. Figure 21 shows these trends with Mach number.

This modification has been sold to some of the current L-1011 operators and it is planned as standard production on new aircraft in the near future. In calculating the operating cost for this section of the study, $5000 was assumed to be added per airplane with the additional cost being incorporated into the engine price.

Tables 23 through 26 present the fuel consumption and operating cost data for the L-1011 incorporating 15 degree engine afterbodies. The presentation is as shown in the previous section, including the use of the long-range climb and Mach 0.82 cruise. The data of Tables 23 through 26 include only the improvement due to the 15 degree engine afterbody and do not include the additional potential of the internal engine improvements discussed above.

3.3 Increased Seating Density

A study of the potential for fuel saving through increased seating density in the basic L-1011-1 was accomplished. Under the study ground rules with a 10/90 split, 8 abreast seating configuration, the L-1011 carries 276 seats. The airplane has been certificated for as many as 400 passengers as exemplified by the Court Line delivery configuration shown in Figure 22. This configuration requires that two additional Type A entry doors be incorporated in place of the smaller standard Type 1 doors at the two aft fuselage locations. Attaining this high seating capacity also involves 10 abreast seating with a tight seat pitch of 30 inches. While this configuration would probably not be acceptable to domestic operators, it gives an indication of the upper limits of increased density in the L-1011 fuselage size.

The potential for fuel savings with the increased seating density approach lies in the additional seats flown for each unit of fuel. This provides savings in operating cost. Figure 23 shows that in a typical 2000-nautical mile L-1011 mission, very large fuel savings can be attained with increased seating. However, to retain consistency in the study an improvement of eight percent was calculated as being the attainable fuel savings while still complying with the seating-mix of the study. The eight percent savings could be accomplished, for example, by incorporating below deck seating for sixteen additional passengers. This change, which involves modifications to the airframe and eliminates the cargo capacity of the forward compartment, has been certified for L-1011 commercial service. The below deck capability of the wide-bodied fuselage offers the means for increasing passenger capacity without compromising main deck comfort levels. Additional savings in seat-miles per gallon could be attained by relaxing the study ground rules in terms of seat pitch and/or first class/tourist mix.

While seating density can have a dramatic effect on the seat-mile per gallon figure attainable, the practicality of this approach needs to be assessed. Definite fuel savings could be identified by substitution of high density aircraft on a study route structure but flying these same aircraft in an actual airline operation with a fixed number of passengers offers no real savings. With increased demand, this option offers very real benefits, and, in addition, it is an aircraft modification that can be accomplished in a short time period for minimum cost by the airline operator. Identification of where and when this particular fuel saving modification might be incorporated was deferred to the air transportation system analysis studies.

3.4 Less Sophisticated High-Lift Devices

Elimination of portions of the high lift system of the basic L-1011 was considered in this task. The purpose was to decrease operating empty weight which, as shown in Section 1, Task 1, can lead to significant fuel savings. Company funded wind tunnel tests were used to verify whether the flaps-deleted configurations were compatible with the lift and stability requirements of the airplane. It was concluded from the test results that the leading edge slats contribute a large portion of the maximum lift capability of the L-1011 wing and that deletion of any of the segments leads to an unacceptable degradation of this capability. A rapid drag increase occurs as the leading edge flow separates with slat deletion and this leads to an unacceptable alteration of the lift coefficient/angle-of-attack characteristics. Thus, while offering fuel savings through empty weight reductions, the possibility of deletion of leading edge slats on the L-1011 was removed from further consideration.

Elimination of trailing edge flap segments was also considered. With the larger component weights involved, it was considered that this modification might have potential payoff. Tests were conducted with the outboard trailing edge flaps retracted. The penalty in maximum lift capability was much smaller than the cases where the leading edge segments were deleted. The tests show that a reduction in the airplane's static stability is experienced, up to a nine percent reduction at full flap extension. This, however, was not considered to be an insurmountable problem.

The fuel savings, due to the deletion of the outboard trailing edge flaps, were then assessed relative to the cost of modification. The total reduction in empty weight amounts to 2372 pounds or approximately one percent. This translates to a 0.3 to 0.5 percent reduction in block fuel dependent on the mission range considered. This small reduction in block fuel could not be justified, however, on the basis of cost. Extensive flight testing to recertify the L-1011 in all flap deflected configurations would be required. A qualitative judgment, weighing the certification costs and time involved against the potential fuel and operating cost reduction, led to the elimination of this option. Further consideration might be justified in a new fuel conservative airplane design but as a modification this option was not effective.

3.5 Wing Leading Edge Modifications

The results of the wind tunnel tests discussed in Section 3.4 indicated that the present L-1011 leading edge slats are required to maintain suitable stability and performance. The incorporation of leading edge gloves which would effectively modify the wing airfoil sections leading to possible operating efficiencies was therefore considered to be impractical. The cost of a glove which incorporated the slat system would eliminate any possible benefits to be gained in fuel economy.

3.6 Drag Cleanup

Consideration of the wing leading edge modifications discussed in the above paragraphs led to a study of the effectiveness of the leading edge slats as installed on the production airplane. Flight tests have confirmed that a small amount of leakage is present between the lower and upper wing surfaces in the area of the leading edge slats. Improved inboard slat hold-downs and improved lower surface trailing edge slat seals have been tested and provide an improvement of 0.5 percent in the L-1011 cruise performance.

3.7 Summary of Data

At the conclusion of this study task, the following modifications were recommended for incorporation into the L-1011 fleet: 15° engine afterbodies, drag cleanup, extended wing tips, and internal propulsion improvements. The fuel savings identified for each of these modifications are summarized in Figure 24. The savings to be expected for the three time periods, 1975, 1978, and 1985, are indicated.

NASA designated McDonnell Douglas as the contractor responsible for summarizing the fuel savings and cost information for the modification options to be used by UTRC in the air transportation system analysis studies. In the UTRC study, the L-1011 and DC-10 were combined in the three-engined wide body class. Since the modifications to the DC-10 resulted in fuel savings approximately equal to those identified for the L-1011, the figure of 7.5 percent as indicated in Figure 24 was adopted for the UTRC studies.

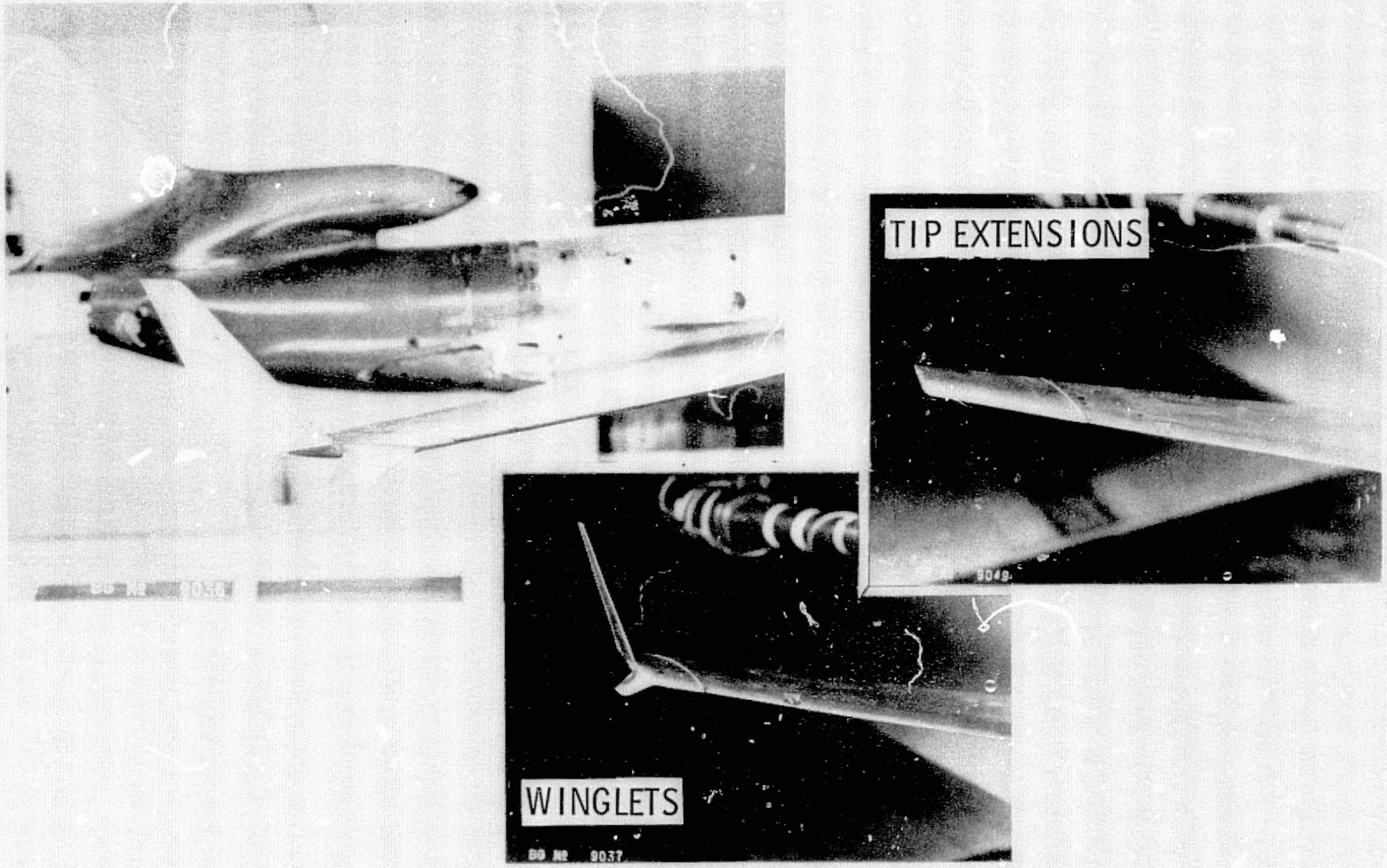


Figure 16.— L-1011 wing tip wind tunnel model

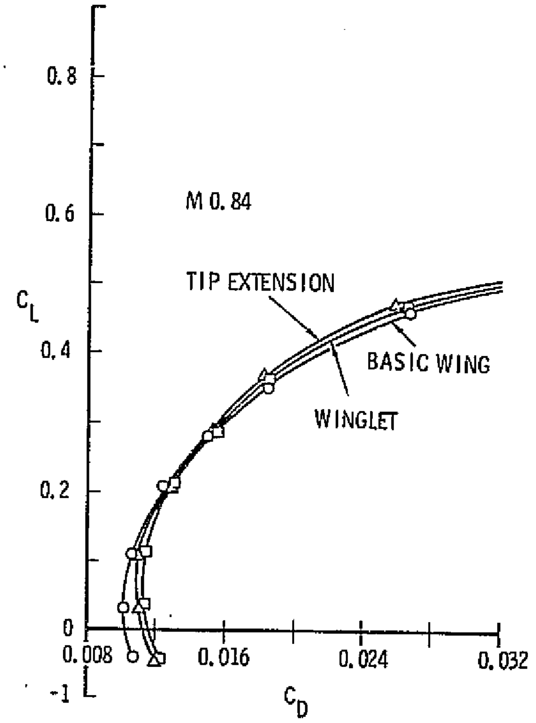


Figure 17. — L-1011 wing modification wind tunnel data comparison

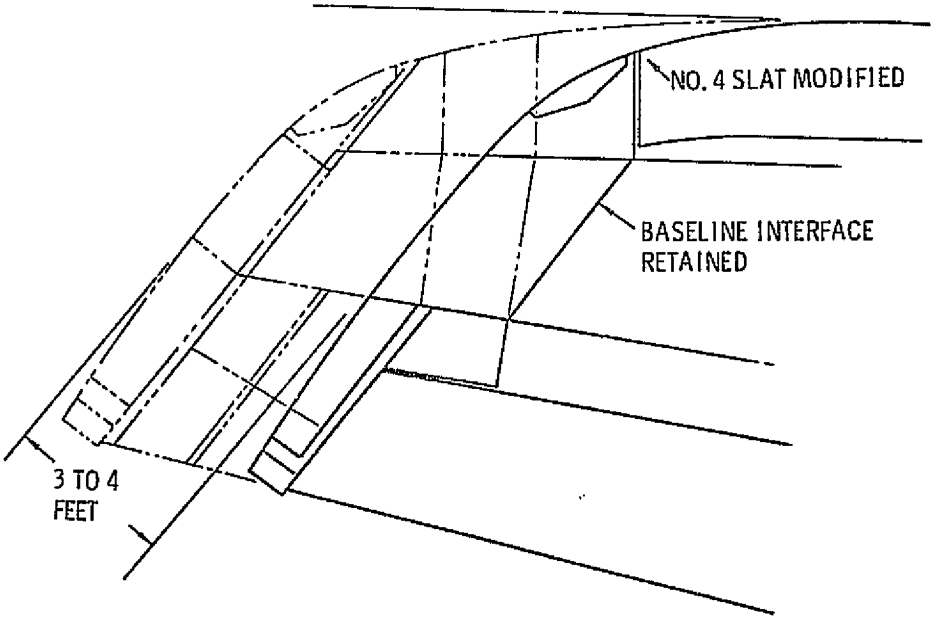


Figure 18. — L-1011 wing tip extension

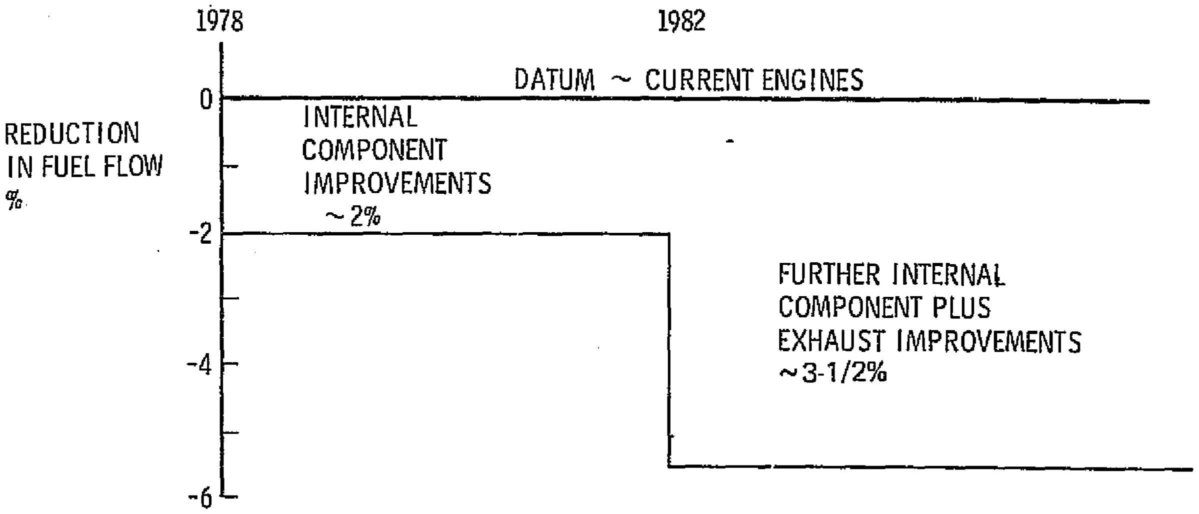
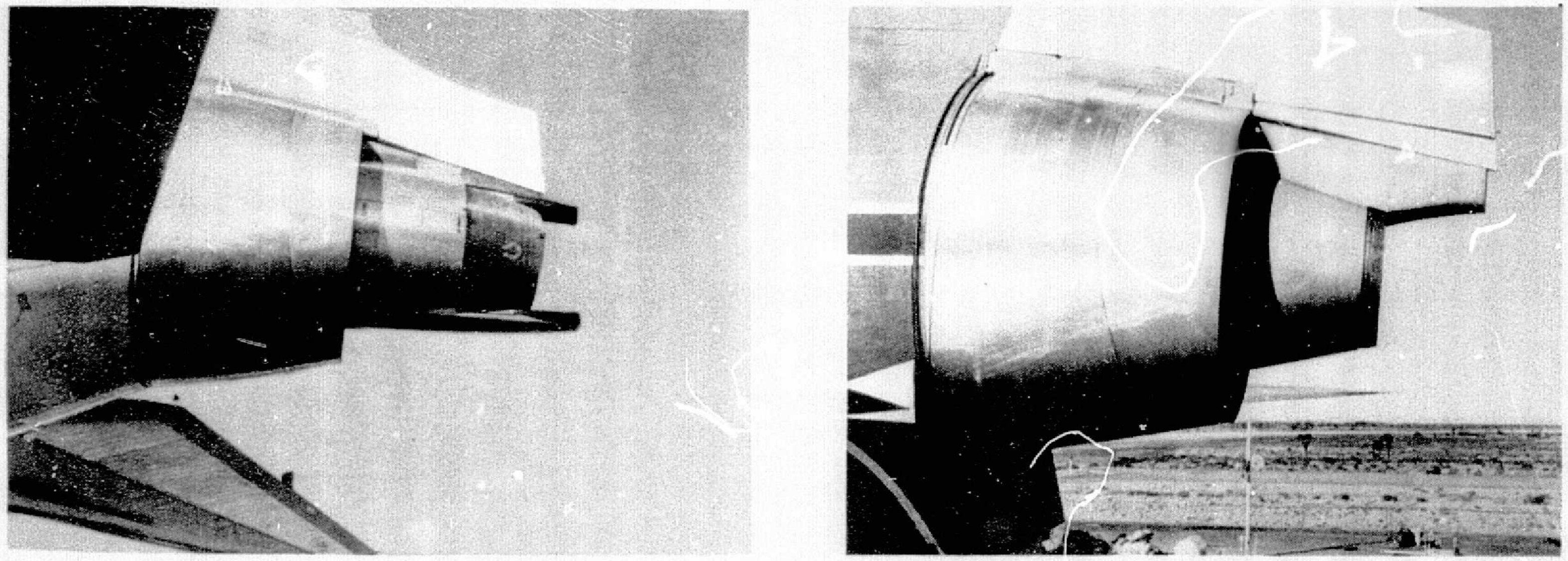


Figure 19.— Potential improvements to existing engines, L-1011/RB.211



BEFORE

AFTER

Figure 20.—RB.211 engine afterbody revision, L-1011

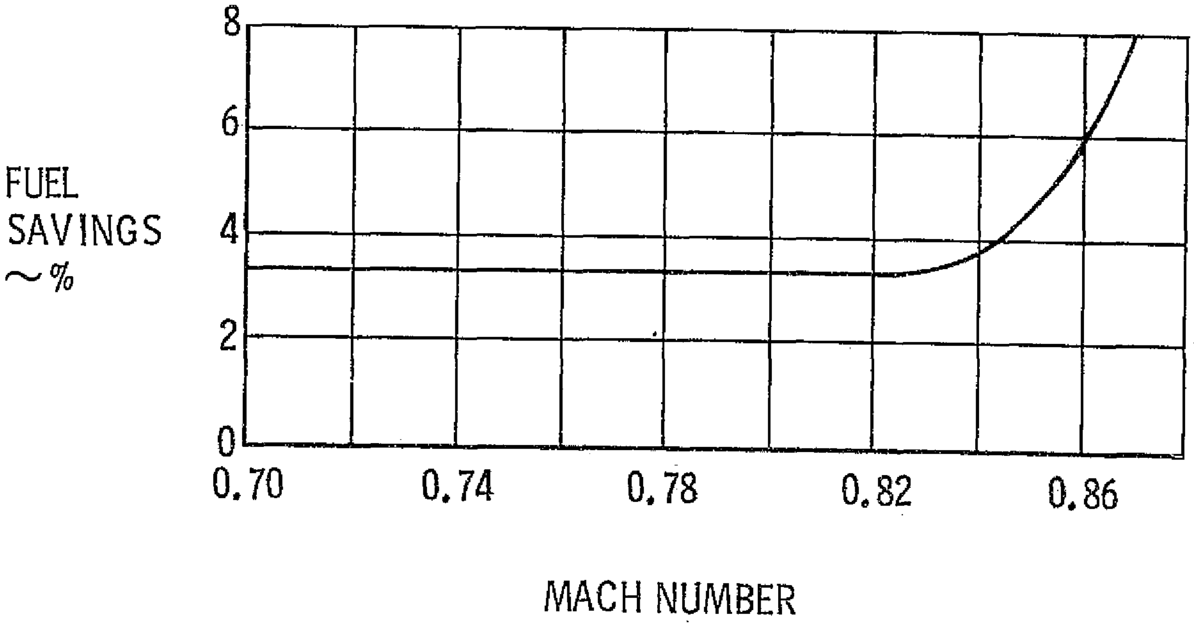


Figure 21.—RB.211 engine afterbody revision fuel savings, L-1011

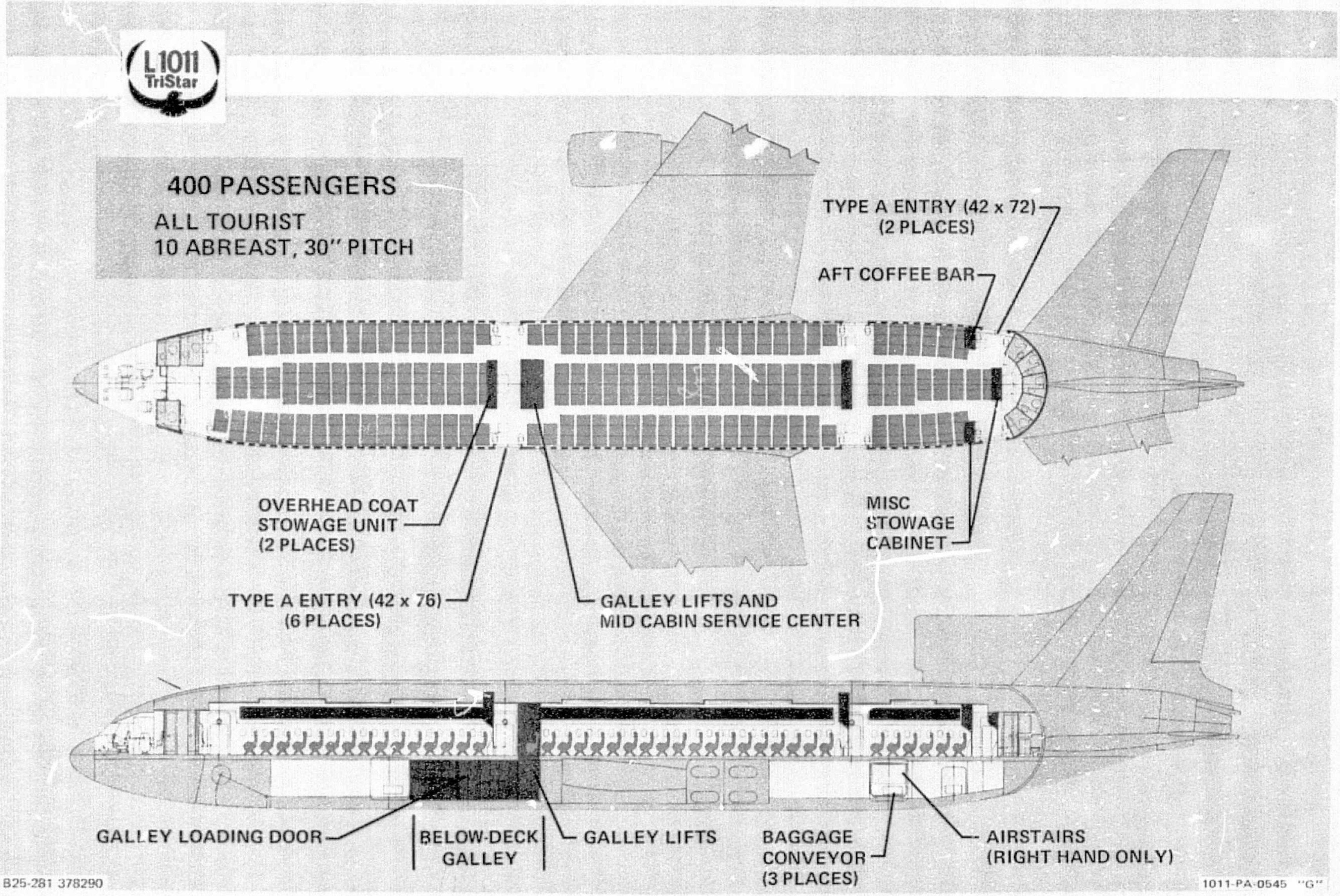


Figure 22.- L-1011 Court Line delivery configuration

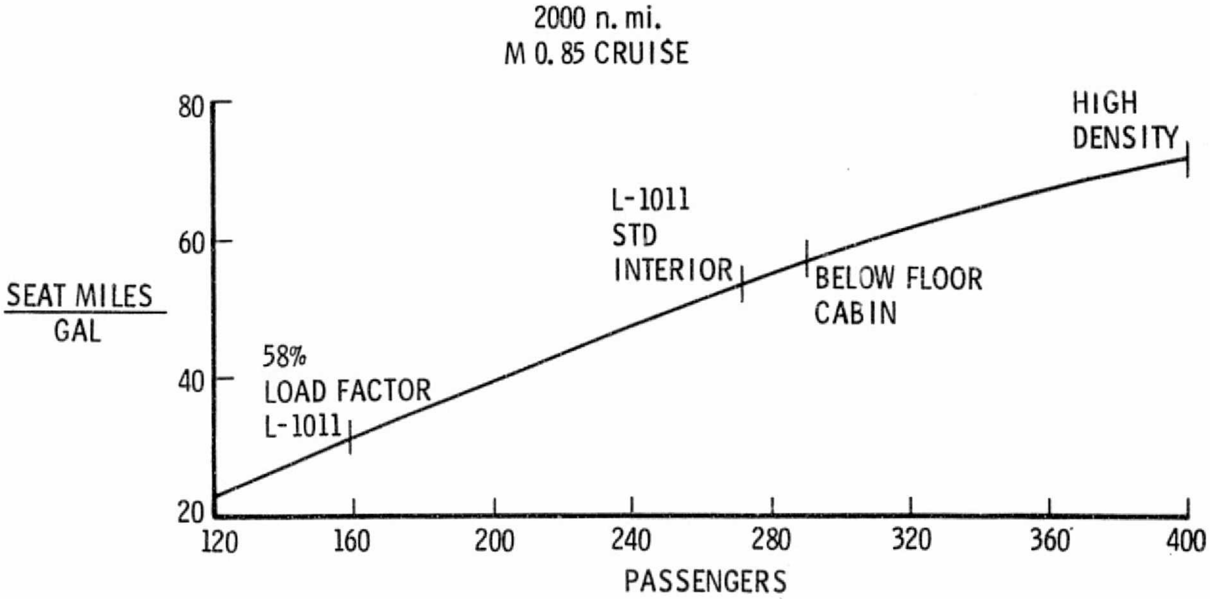


Figure 23.- Effect of passenger/seating density on fuel economy, L-1011

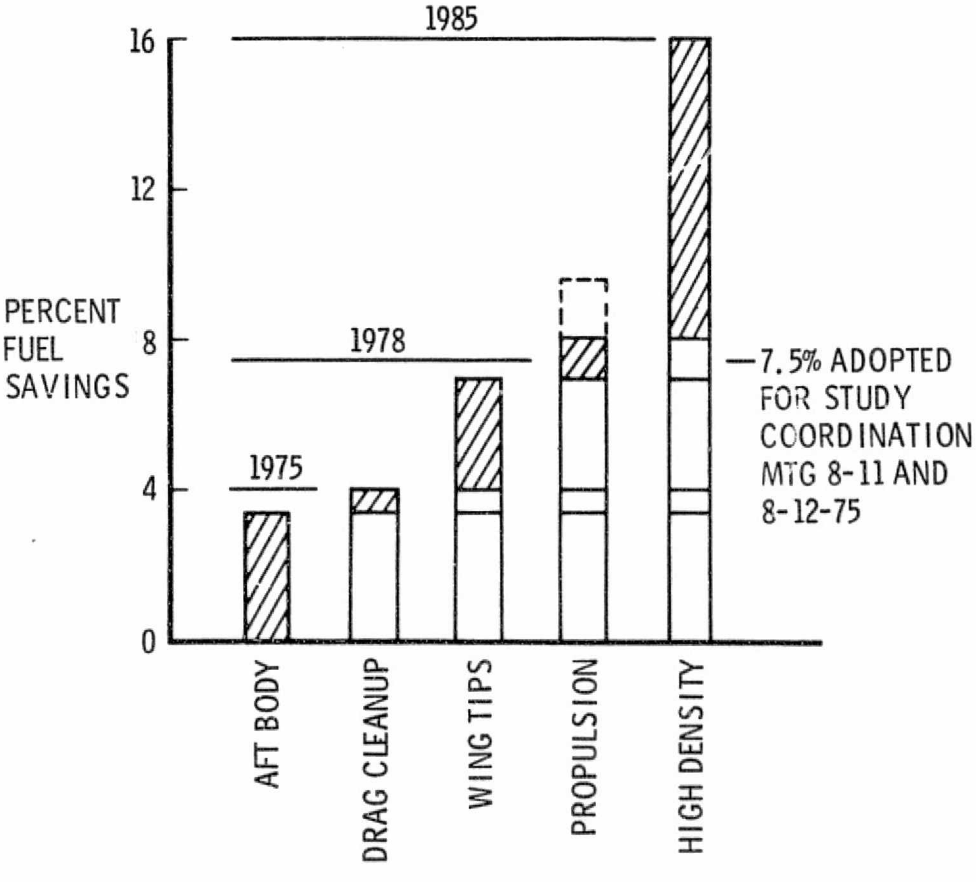


Figure 24. – L-1011 modifications fuel savings summary

TABLE 19.- CALCULATED FUEL CONSUMPTION - L-1011 WITH WING TIP EXTENSIONS

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal n.mi.	seat-n.mi. gal	Btu seat-n.mi.
100	4 962	7.30	37.40	3381
200	8 671	6.38	42.82	2954
400	15 474	5.69	47.98	2636
600	22 235	5.45	50.09	2525
1000	35 008	5.15	53.03	2385
2000	65 373	4.81	56.79	2227
3000	96 421	4.73	57.75	2190
3700	120 000	4.77	57.24	2210
825	29 453	5.25	52.00	2430

TABLE 20.- CALCULATED TOTAL OPERATING COSTS - L-1011 WITH WING TIP EXTENSIONS

Stage Length n.mi.	Block Speed kt	Total DOC		Total IOC	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	233	1745	2.75	5322	8.38
200	296	1630	2.03	3670	4.57
400	349	1497	1.58	2500	2.63
600	376	1437	1.40	1959	1.91
1000	402	1387	1.27	1522	1.39
2000	436	1346	1.13	1170	0.98
3000	451	1336	1.09	1043	0.85
3700	456	1342	1.08	1050	0.84
825	392	1405	1.33	1675	1.56

TABLE 21.- DIRECT OPERATING COST BREAKDOWN - L-1011 WITH WING TIP EXTENSIONS

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	3700	825
Crew	0.41	0.36	0.28	0.26	0.24	0.22	0.21	0.21	0.25
Insurance	0.10	0.09	0.07	0.06	0.06	0.05	0.05	0.05	0.06
Depreciation	0.61	0.53	0.43	0.38	0.36	0.33	0.32	0.32	0.37
Maintenance	1.30	0.69	0.48	0.40	0.33	0.26	0.24	0.24	0.35
Fuel (15¢/gal)	0.41	0.36	0.32	0.31	0.29	0.27	0.26	0.26	0.30
Total/DOC	2.75	2.03	1.58	1.40	1.27	1.13	1.09	1.08	1.33

TABLE 22.- INDIRECT OPERATING COST BREAKDOWN -
L-1011 WITH WING TIP EXTENSIONS

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	3700	825
System Expense	0.15	0.12	0.07	0.04	0.04	0.03	0.03	0.03	0.04
Local Expense	2.21	1.04	0.59	0.37	0.22	0.11	0.07	0.06	0.28
A/C Control Expense	0.07	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Hostess Expense	0.29	0.25	0.20	0.18	0.17	0.15	0.15	0.15	0.17
Food and Beverage	0.28	0.24	0.19	0.17	0.16	0.15	0.14	0.14	0.16
Passenger Service	3.14	1.48	0.77	0.52	0.31	0.16	0.11	0.09	0.38
Cargo Handling	1.50	0.80	0.36	0.25	0.15	0.08	0.05	0.05	0.17
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.53	0.36	0.20	0.15	0.11	0.09	0.08	0.08	0.12
Total IOC	8.38	4.57	2.63	1.91	1.39	0.98	0.85	0.84	1.56

TABLE 23. - CALCULATED FUEL CONSUMPTION - L-1011 W/15° ENGINE AFTERBODIES

Stage Length n.mi.	Block Fuel Consumption			
	lb	$\frac{\text{gal}}{\text{n.mi.}}$	$\frac{\text{seat-n.mi.}}{\text{gal}}$	$\frac{\text{Btu}}{\text{seat-n.mi.}}$
100	4 911	7.22	37.80	3346
200	8 582	6.31	43.26	2924
400	15 316	5.63	48.48	2609
600	22 007	5.39	50.61	2499
1000	34 649	5.10	53.58	2361
2000	64 702	4.76	57.38	2204
3000	95 432	4.68	58.36	2167
4270	139 500	4.80	56.82	2226
825	29 172	5.20	52.50	2400

TABLE 24. - CALCULATED TOTAL OPERATING COSTS - L-1011 W/15° ENGINE AFTERBODIES

Stage Length n.mi.	Block Speed kt	Total DOC		Total IOC	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	233	1794	2.83	5393	8.49
200	296	1656	2.06	3600	4.48
400	394	1505	1.59	2470	2.60
600	376	1434	1.40	1978	1.93
1000	402	1383	1.26	1534	1.40
2000	436	1342	1.13	1177	1.00
3000	451	1332	1.08	1048	0.85
4270	459	1338	1.07	1050	0.84
825	393	1395	1.30	1680	1.57

TABLE 25.- DIRECT OPERATING COST BREAKDOWN - L-1011 W/15° ENGINE AFTERBODIES

DOC Component / Stage Length (n.mi)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4270	825
Crew	0.41	0.36	0.29	0.26	0.24	0.22	0.21	0.21	0.25
Insurance	0.10	0.09	0.07	0.06	0.06	0.05	0.05	0.05	0.06
Depreciation	0.61	0.50	0.42	0.38	0.35	0.33	0.32	0.32	0.35
Maintenance	1.30	0.75	0.51	0.40	0.33	0.26	0.24	0.24	0.35
Fuel (15¢/gal)	0.40	0.37	0.32	0.30	0.29	0.27	0.26	0.26	0.29
Total DOC	2.83	2.06	1.59	1.40	1.26	1.13	1.08	1.07	1.30

TABLE 26.- INDIRECT OPERATING COST BREAKDOWN - L-1011 W/15° ENGINE AFTERBODIES

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4270	825
System Expense	0.15	0.11	0.06	0.04	0.04	0.03	0.03	0.02	0.04
Local Expense	2.32	0.97	0.55	0.39	0.23	0.12	0.08	0.07	0.28
A/C Control Expense	0.07	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Hostess Expense	0.29	0.25	0.21	0.18	0.17	0.15	0.15	0.15	0.17
Food and Beverage	0.28	0.24	0.19	0.17	0.16	0.15	0.14	0.14	0.16
Passenger Service	3.14	1.47	0.78	0.52	0.31	0.16	0.11	0.09	0.38
Cargo Handling	1.50	0.80	0.36	0.25	0.15	0.08	0.05	0.05	0.18
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.53	0.36	0.20	0.15	0.11	0.09	0.08	0.08	0.12
Total IOC	8.49	4.48	2.60	1.93	1.40	1.00	0.85	0.84	1.57

4. TRISTAR AND ELECTRA FUEL SAVING DERIVATIVES - TASK 4

This section reports compliance with NASA Specification No. 2-24968, Statement of Work Study Task 1.4.1.4 dated June 3, 1974, regarding analysis of fuel conservation potential of Lockheed existing-production aircraft derivatives suitable for fleet operating service prior to 1980. The noted NASA Specification, in effect, specifies analysis of derivatives of the Lockheed L-1011-1 and L-188 Electra aircraft. The Lockheed L-1011-1 is currently in production and will so continue for some time to come; however, the Lockheed L-188 Electra is no longer in production. Because the P-3C, the military version of the L-188 Electra is still in production, it is reasonable to assume that a new derivative L-188 could be produced off the same production line; therefore, a basic P-3C conversion for commercial use was considered which incorporates an interior arrangement and passenger capacity equivalent to the original L-188.

For the purpose of this study, a derivative aircraft is defined as a modified basic production aircraft whose modifications are cost effective and are such that they are not suitable for incorporation as a retrofit for delivered aircraft; i.e., the modifications are suitable only for new production aircraft. Aircraft modifications such as redesigned wings, incorporation of growth engines, and stretched or reduced fuselage lengths were investigated.

It was found that a redesigned wing, supercritical or otherwise, was not cost effective nor compatible with the pre-1980 initial operating capability requirement for any of the Lockheed airplanes. It was determined that their derivatives incorporating reduced or increased passenger-carrying capacities were plausible candidates for aiding air transportation system fuel conservation.

The following pages present the outcome of the Lockheed analyses involving the following derivative aircraft configurations:

1.	L-1011 Long Body	466 000 pounds TOGW	407 Pax
2.	L-1011 Short Body	325 000 pounds TOGW	200 Pax
3.	P-3 Commercial	L-188 Fuselage Length	85 Pax
4.	P-3 Commercial	Stretched Fuselage	105 Pax

Each derivative aircraft is summarily defined and four idealized calculated data tables for each present the fuel consumption and operating cost information. These four tables for each derivative aircraft have been developed using the applicable adopted study ground rules and methods as noted in study Task 1 for the baseline aircraft data development. These data are tabulated for a series of stage lengths including the estimated 1973 CAB average stage length. Fuel consumption is shown in terms of total block fuel and on both an airplane-nautical mile and a seat-nautical mile basis in the first table. The seat-nautical mile fuel consumption is shown in units of seat-nautical miles per gallon and Btu's per seat-nautical mile. Total direct and total indirect operating costs are tabulated in the second table while the detailed breakdowns of these costs are shown in the following two tables. All of the cost data are presented in units of cents per available seat-nautical mile. In addition, the total cost data is presented in the second table in terms of dollars per block hour with the corresponding block speed at each stage length indicated in an adjacent column.

4.1 L-1011 Long Body Derivative

Lockheed conducted extensive detailed design studies on stretched fuselage versions of the L-1011 TriStar aircraft during 1973 and 1974. One family of stretched versions incorporated a basic stretch of 360 inches with an airplane TOGW limit of 466 000 pounds. Propulsion options included three different Rolls Royce high-bypass ratio turbofan engines of 42 000, 43 500, and 48 000 pounds sea level static thrust each. Passenger capacities ranged from 407 to 500. One of these L-1011 derivatives was selected for evaluation in this study.

The L-1011 Long Body derivative considered in this study incorporates the addition of constant diameter barrel sections in the fuselage fore and aft of the wing. The engines are changed from the Rolls Royce RB.211-22B to the RB.211-524. Extending the fuselage increases the passenger capacity from 273 to 407. The aircraft takeoff gross weight is increased from 430 000 pounds to 466 000 pounds. The wing incidence is increased by 2° - 40' to maintain the same afterbody rotation ground clearance (main landing gear unchanged).

The L-1011 Long Body aircraft general arrangement is shown in Figure 25. Figure 26 indicates how the basic L-1011-1 airplane is stretched for the long body derivative. Table 27 is a summary of the aircraft characteristics. Table 28 and Figure 27 describe the aircraft interior arrangement. Table 29 presents a comparison of engine characteristics between the engines installed in the basic L-1011-1 aircraft and the engines installed in the long body derivative aircraft.

The operational equipment installed weight breakdown and the aircraft weight summary for the L-1011 Long Body derivative aircraft are presented in Tables 30 and 31, respectively.

The airplane direct operating costs (DOC's) are calculated for two pricing concepts for the derivative aircraft. One concept assumes that the aircraft are modified before the breakeven production quantity is reached and that the prorata share of the original basic model development cost is included in the airplane price along with the additional development cost for the modification. The other concept assumes that introduction of the derivative takes place after the 250 breakeven quantity and that the original basic model development cost is eliminated. The latter case is the most probable when considering the number of L-1011's produced to date and the scheduled time for derivative initial operating capability. The cost for the airplanes and spares are shown below.

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ORIGINAL PAGE IS POOR

Long Body L-1011 - Original R&D included

	Production Cost	Spares
Airframe	$21 277 225	$3 191 583
Engine	4 400 000	660 000
TOTAL	$25 677 225	$3 851 583

Long Body L-1011 - Original R&D excluded (Basis used for DOC calculations)

	Production Cost	Spares
Airframe	$18 858 417	$2 828 762
Engine	4 400 000	660 000
TOTAL	$23 258 417	$3 488 762

Table 32 presents the L-1011 Long Body derivative airplane total block fuel consumption for various stage lengths. Table 33 presents airplane total operating costs and block speeds for various stage lengths. Tables 34 and 35 are tabulations of the detailed cost increments which comprise the airplane total direct operating costs and total indirect operating costs in terms of cents per seat-nautical mile for the various stage lengths.

4.2 L-1011 Short Body Derivative

The initial basic engineering and economic data for this version of the TriStar were developed under Lockheed 1974 IRAD studies and adapted to this study. The results of the 1974 IRAD work are documented in Lockheed Report LR 27019, dated 10 January 1975, entitled L-1011 Short Range Derivative Study - 1974, (Lockheed Private Data). This IRAD study investigated two and three-engined shortened-fuselage derivatives of the L-1011-1 designed for the same short range mission. The basic aircraft design requirements utilized are shown in Table 36. A three-engined short-bodied L-1011 aircraft version was developed which utilized the Rolls Royce RB.211-22B engine operating at a 7 percent lower thrust level than the engines of the basic L-1011 configuration for purposes of improved operating economy. A twin-engined short-bodied L-1011 aircraft version was developed which utilized the Rolls Royce RB.211-524 engine.

The results of a comparison of the two and three-engined L-1011 derivatives in terms of economics ended in a stalemate; i.e., they were economically equivalent aircraft in terms of DOC on a cost/seat-nautical mile basis over a 500 nautical mile range. However, the takeoff performance of the three-engined version was clearly superior, providing generous takeoff margins which in turn gave more desirable hot day, high altitude airport capabilities for operational flexibility. The twin-engined version, using the full thrust rating of the RB.211-524 engines, did not meet the field length requirement even though its maximum TOGW was significantly less than that of the tri-jet.

Table 37 presents a listing of the changes in the basic L-1011-1 aircraft required to obtain the L-1011 three-engined short-bodied derivative selected for evaluation in this study. The resulting short-bodied L-1011 aircraft basic weights are also noted. Figure 28 presents the general arrangement of the short body airplane and indicates the overall length comparison with the baseline L-1011-1 TriStar. Figure 29 presents the short body airplane passenger accommodations and cabin interior arrangement.

As noted in the previous section regarding airplane direct operating cost calculations for the Long Body L-1011; the DOC calculations for the Short Body L-1011 aircraft were also performed using two pricing concepts, one which includes costs of basic model R&D (before breakeven), and one which excludes costs of basic model R&D (after breakeven). The latter pricing concept is likely to prevail in view of the Short Body derivative schedule for initial operating capability. The cost of the airplanes and spares under each of the pricing concepts follows:

Short Body L-1011 - Original R&D included

	Aircraft	Spares
Airframe	$14 865 567	$2 229 835
Engine	4 054 433	608 165
TOTAL	$18 920 000	$2 838 000

Short Body L-1011 - Original R&D excluded (Basis used for DOC calculations)

	Aircraft	Spares
Airframe	$12 446 759	$1 876 013
Engine	4 054 433	608 164
TOTAL	$16 501 192	$2 475 177

Table 38 presents the L-1011 Short Body derivative aircraft total block fuel consumption for various stage lengths. Table 39 presents airplane total operating costs and block speeds for various stage lengths. Tables 40 and 41 are tabulations of the detailed cost increments which comprise the airplane total direct operating costs and total indirect operating costs in terms of cents per seat-nautical mile for the various stage lengths.

4.3 P-3 Commercial-85 Pax and 105 Pax

The U.S. Navy land-based antisubmarine patrol P-3 aircraft was derived from the Lockheed L-188 Electra turboprop commercial airplane whose various interior arrangements accommodated 85 to 97 passengers. The Electra basic fuselage length was reduced by 88 inches forward of the wing for the conversion to the P-3. The current production P-3 ASW aircraft is designated P-3C. Figure 30 depicts the general arrangement of the P-3C aircraft.

This portion of the derivative aircraft analysis effort, under study Task 4 investigates the conversion of the P-3C airplane into a commercial transport. The major premise is that the conversion will be accomplished with minimum modification. The modifications and other cost factors used in the derivation of the direct and indirect expenses are outlined in the following. Two conversions are considered: 1) converting the P-3C back to the original L-188 configuration, and 2) stretching the fuselage to increase the capacity from 85 passengers to 105 passengers.

Deletions and additions to P-3C airframe

- Deletions
  - Wiring to bomb bay, avionics wing stores, and armament
  - Sonobuoy chutes
  - MAD boom
  - Flight station exit
  - ASW avionics racks and equipment
  - Window for periscope sextant
  - Water injection system
  - ASW antennas.
- Additions
  - 88 inch fuselage plug forward of the wing for 85 passenger configuration, and an additional plug for 105 passenger configuration also forward of the wing.
  - Passenger door and self-contained stairs
  - Passenger windows
  - Passenger accommodations
  - Convert bomb bay into baggage hold
  - Move electrical load center.

A quantity of 100 vehicles is assumed for the amortization of the R&D. The costs for the vehicles and spares are:

PRODUCTION COSTS ($-MILLIONS)

	85 Pass. Config.	105 Pass. Config.
Aircraft:		
Airframe	4.19	4.90
Engine	1.10	1.10
TOTAL	5.29	6.00
Spares:		
Airframe	0.629	0.735
Engine	0.165	0.165
TOTAL	0.794	0.900

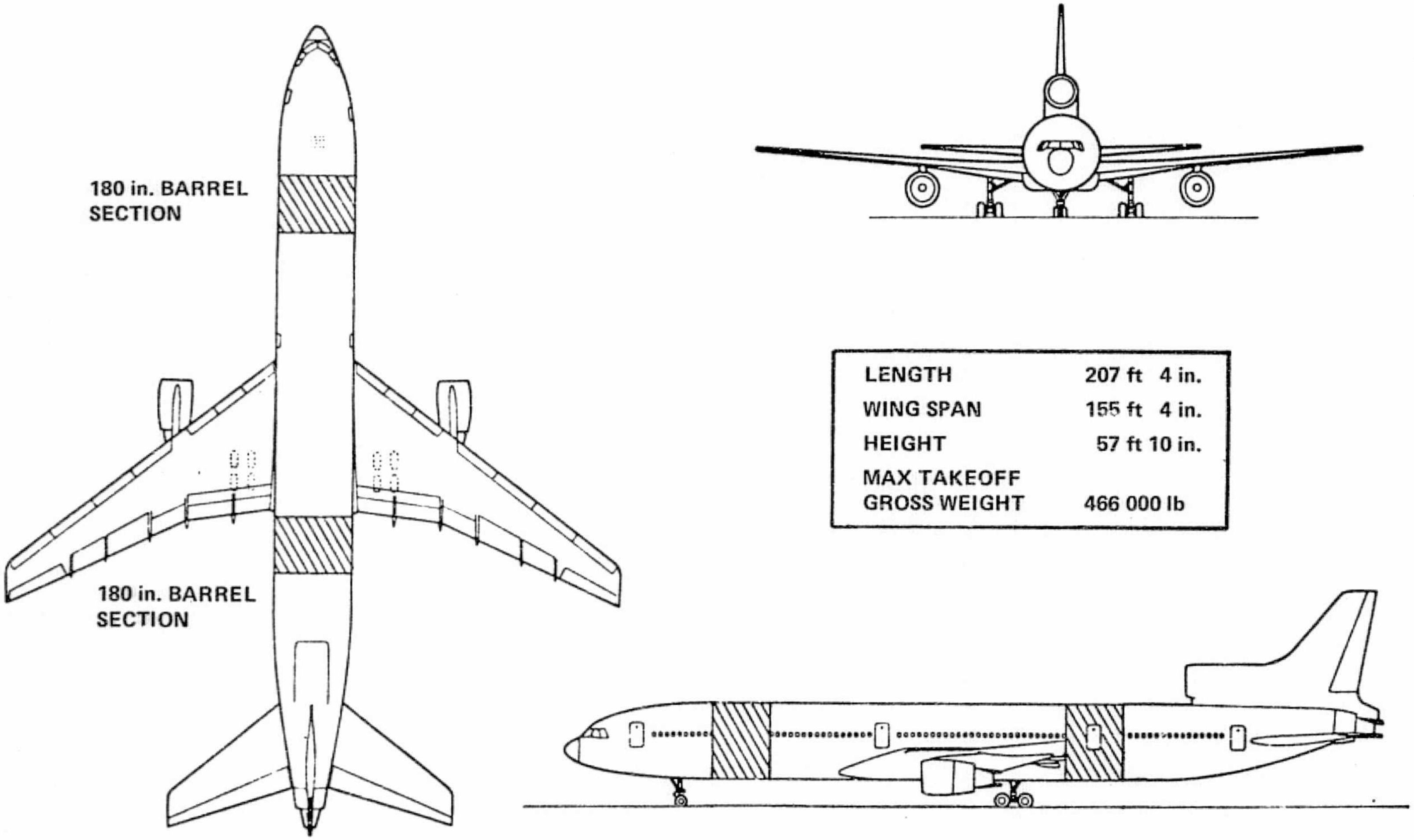
The airframe and engine costs are high because of the additional items and weight that are required for the ASW airframe. If these items and weight (bomb bay, etc.) are removed, the nonrecurring cost becomes high and the cost of their removal would cost as much per airplane as the additional weight would cost because of the low production quantity. The direct and indirect operating costs are tabulated in Tables 42 and 43. The block speed and fuel consumption data is shown on Figures 31 through 34.

The data shown by Figures 31 through 34 and data noted in Tables 42 and 43 were originally presented in LR 26986-5 Interim Study Report dated May 1975. This information has been extended to increased stage lengths and restructured in form to agree with the data format used in the other parts of this report. These new data are included as Tables 44 through 47 for the 85 passenger P-3 Commercial airplane, and Tables 48 through 51 are included for the 105 passenger P-3 Commercial airplane.

The commercial P-3 performs well in terms of fuel consumption but is high in DOC due to the high purchase cost in terms of passengers carried.

L-1011-300

360 INCH



LENGTH	207 ft 4 in.
WING SPAN	155 ft 4 in.
HEIGHT	57 ft 10 in.
MAX TAKEOFF GROSS WEIGHT	466 000 lb

Figure 25.— L-1011 long body derivative general arrangement

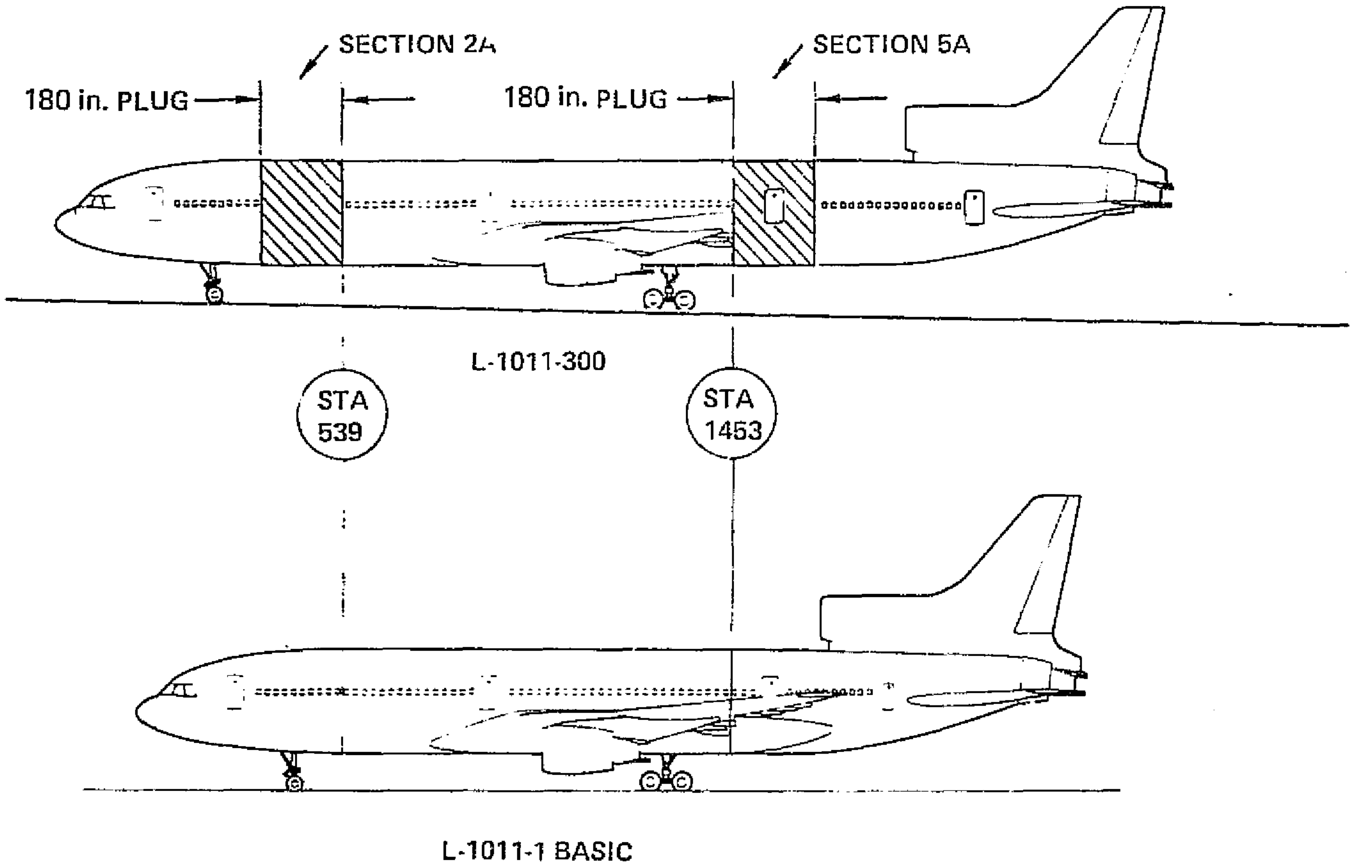


Figure 26.—L-1011 long body derivative fuselage extension diagram

L-1011-300

407 PASSENGERS

10/90 MIX

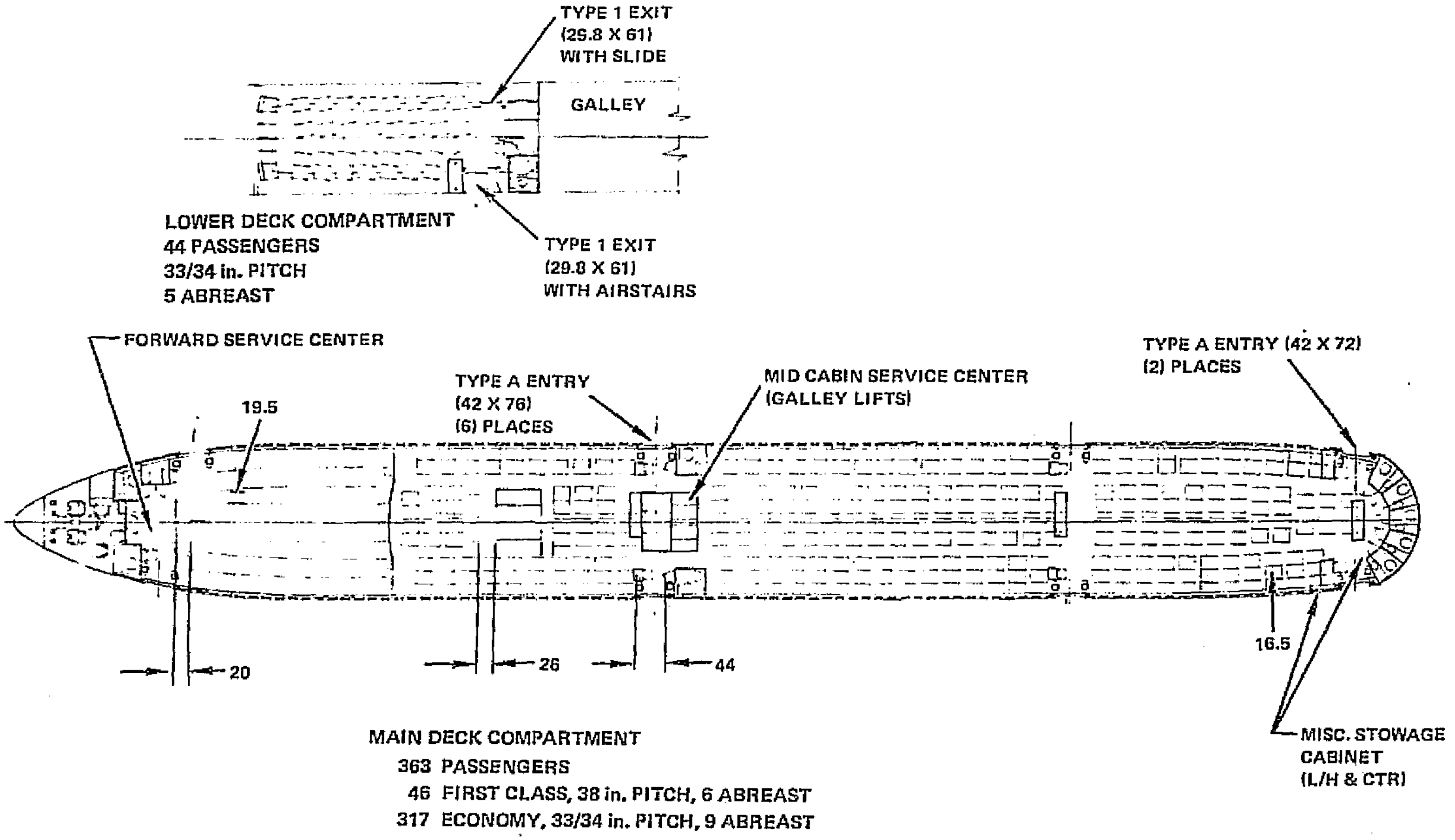


Figure 27.— L-1011 long body derivative interior arrangement

- SHORT RANGE 3 ENG TRANSPORT L-1011- DERIVATIVE
- BODY LENGTH 21' 8" LESS THAN L-1011-1

	WING	H/TAIL	V/TAIL
AREA sq ft	3456	1282	550
ASPECT RATIO	6.95	4	1.6
TAPER RATIO	0.30	0.33	0.30
SPAN	155 ft	71 ft 7 in.	29 ft 8 in.
ROOT CHORD	412 in.	323 in.	342 in.
TIP CHORD	123 in.	107 in.	102.6 in.
MAC	293.5 in.	233 in.	243.8 in.
SWEEP @ 1/4C	35°	35°	35°

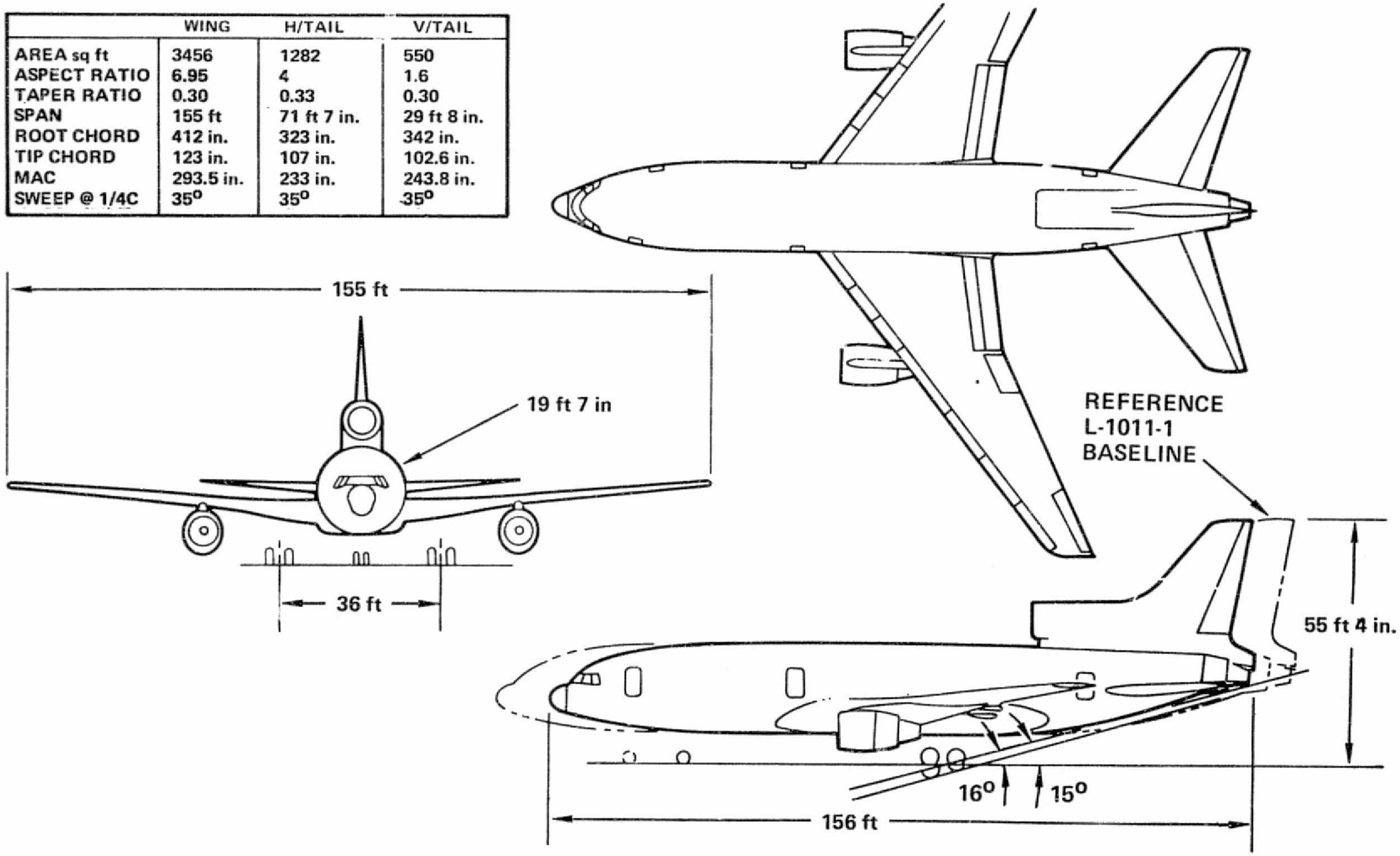


Figure 28.— L-1011 short body derivative general arrangement

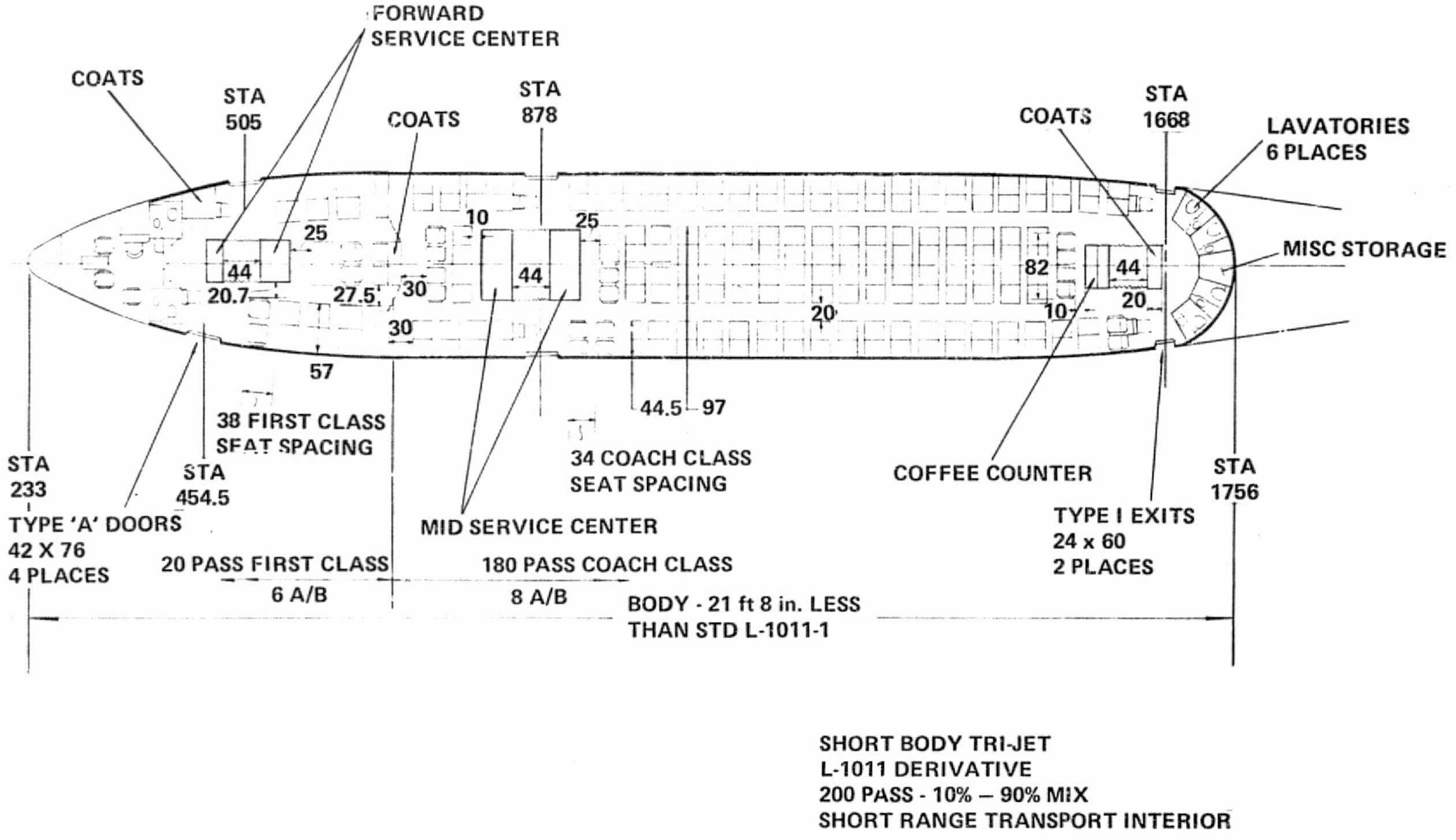


Figure 29.— L-1011 short body derivative interior arrangement

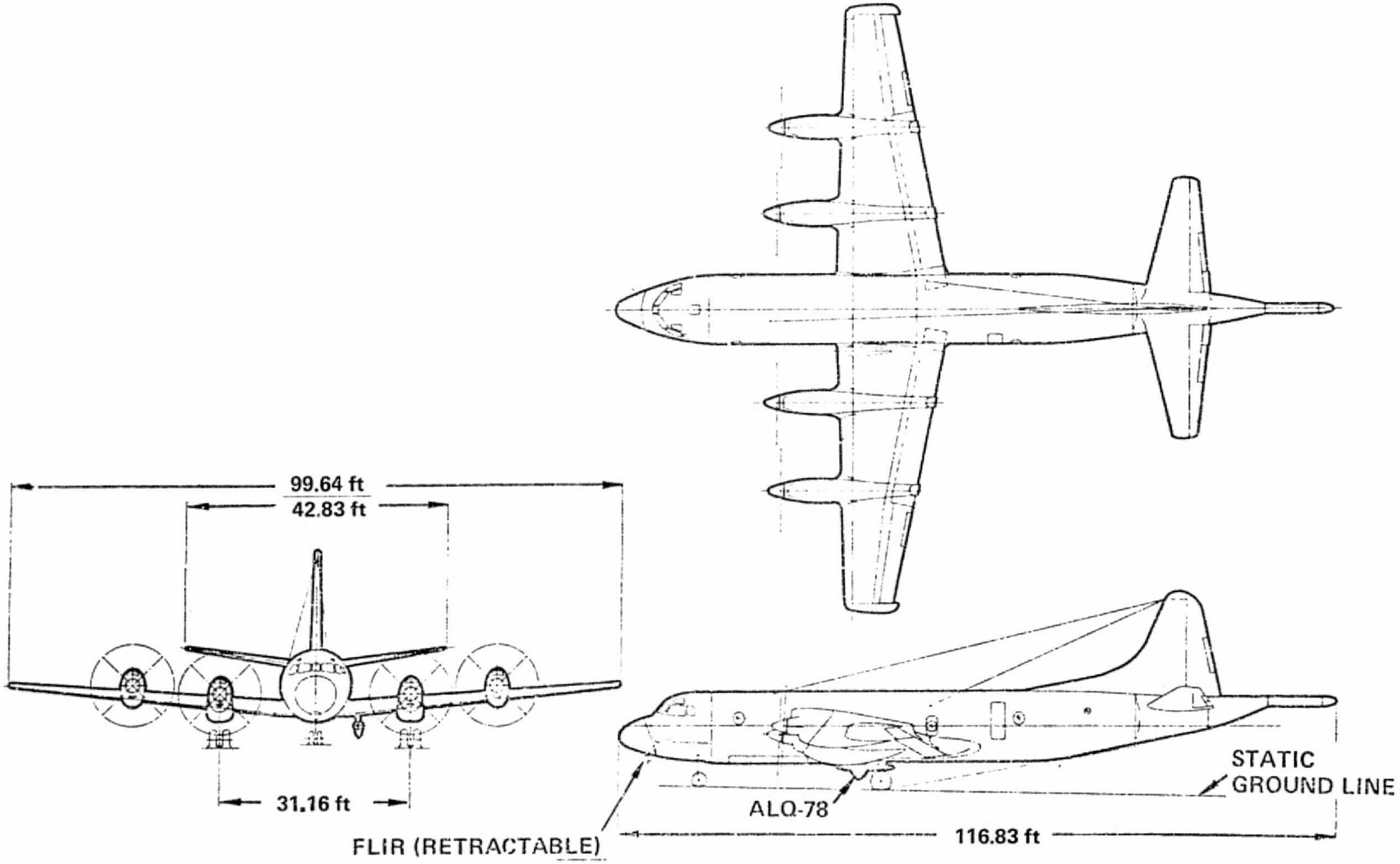


Figure 30.—P-3C general arrangement

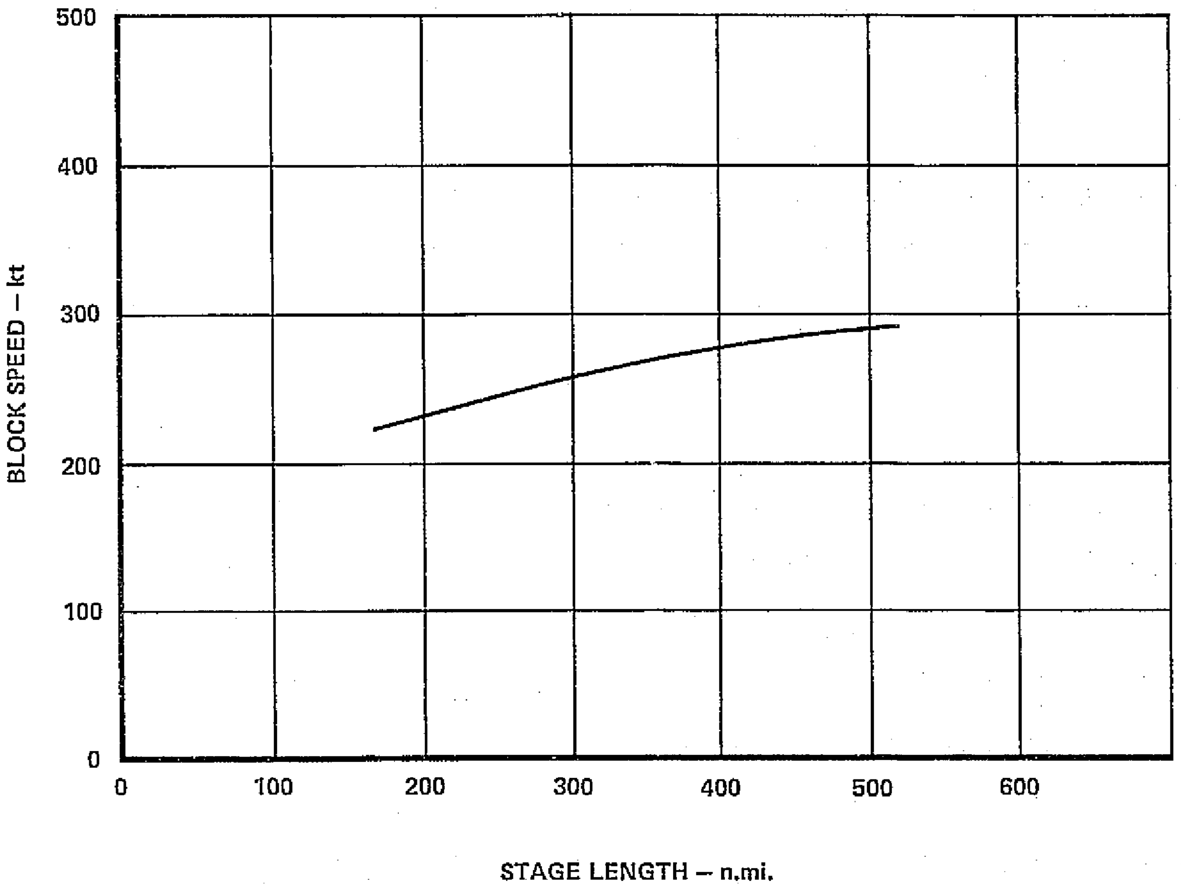


Figure 31.—Block speed vs range - commercial P-3 85 and 105 passenger configurations

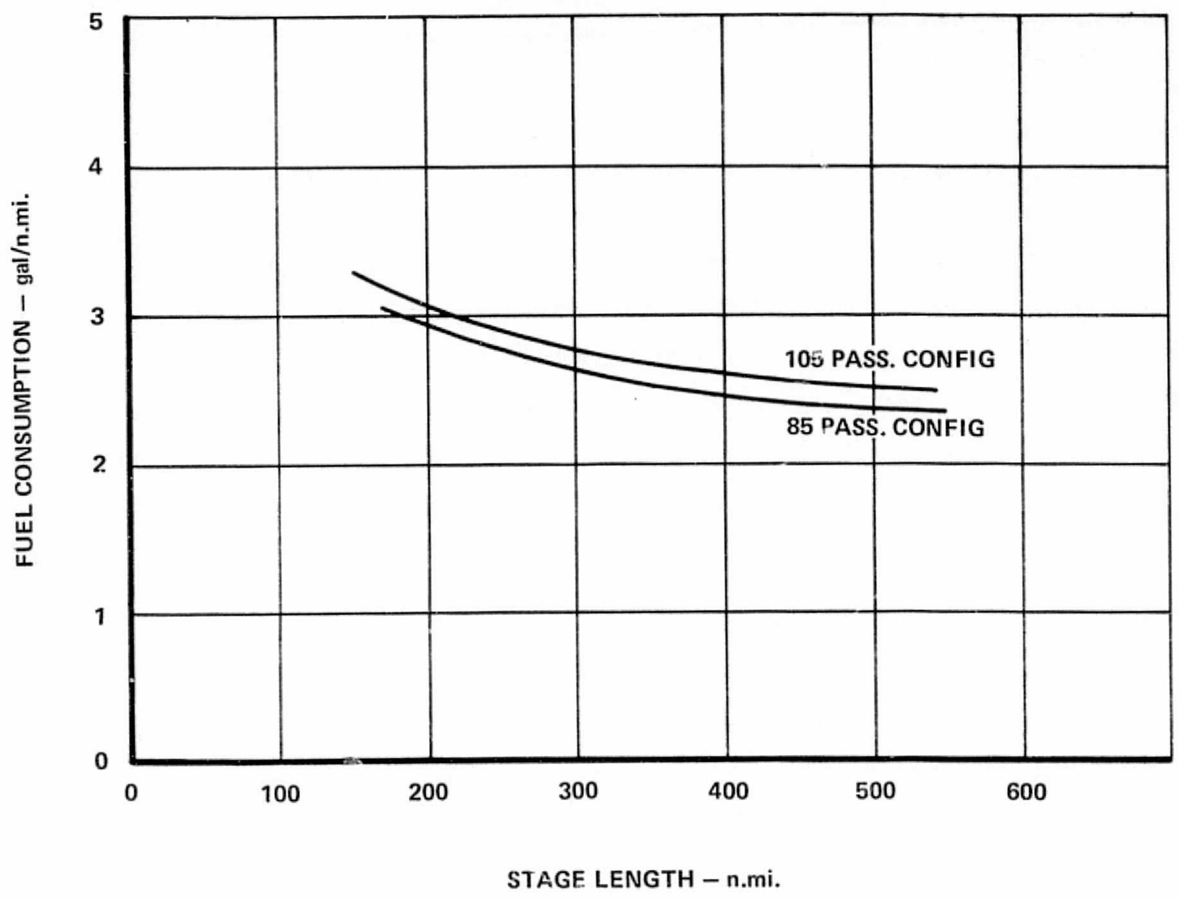


Figure 32.—Commercial P-3 fuel consumption (gal/n.mi.)

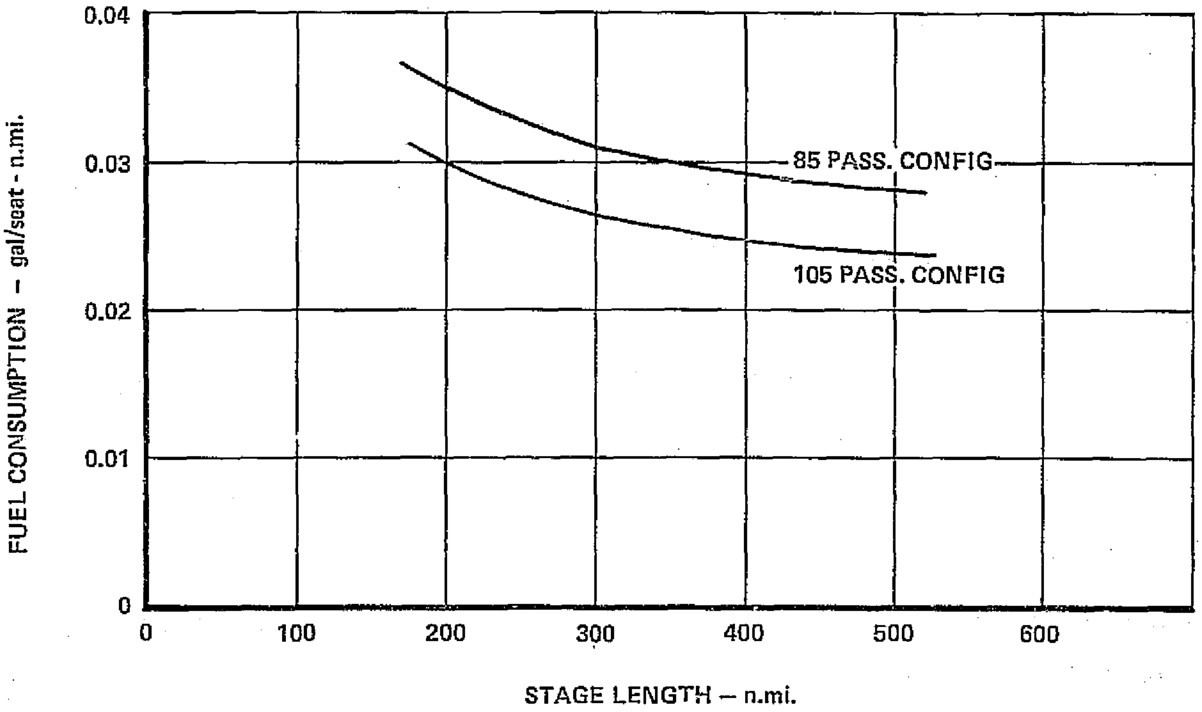


Figure 33.—Commercial P-3 fuel consumption (gal/seat - n.mi.)

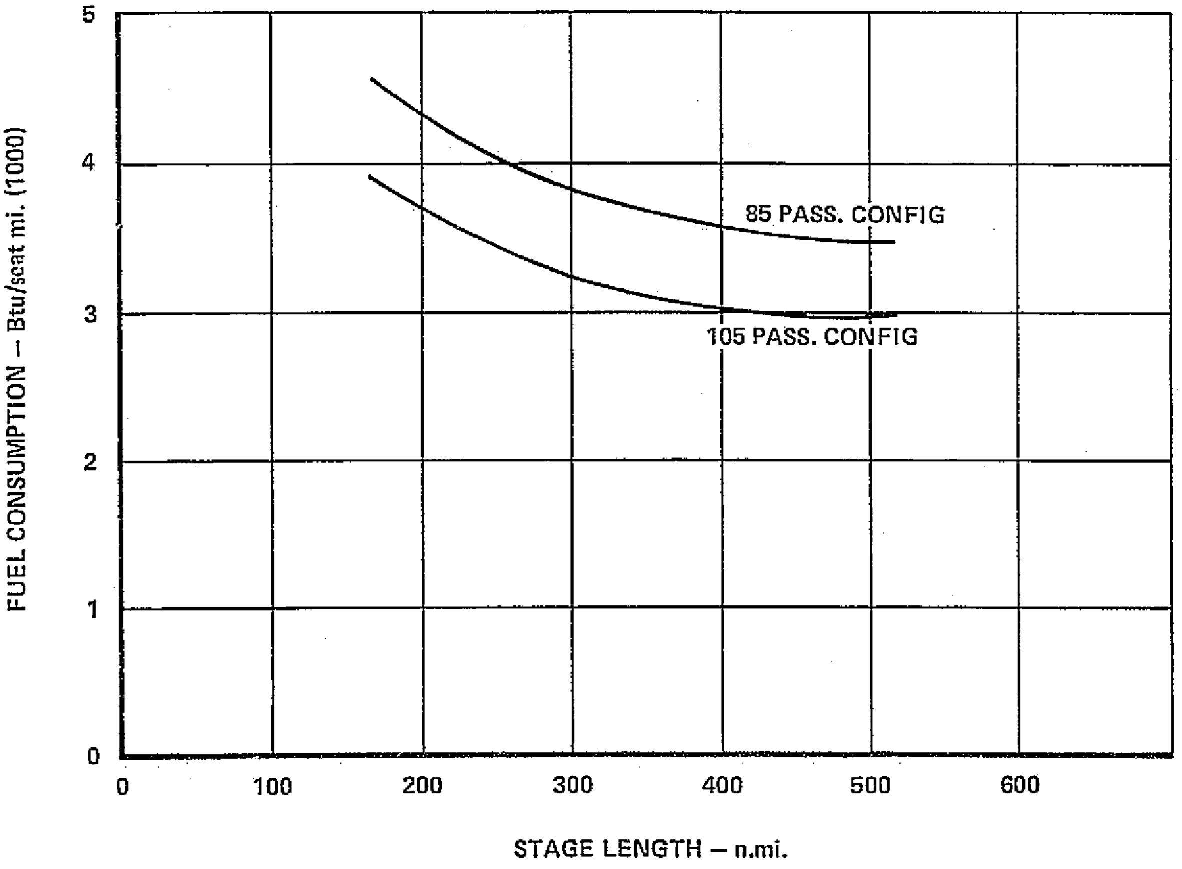


Figure 34.—Commercial P-3 fuel consumption (Btu/seat - n.mi.)

TABLE 27.- L-1011 LONG BODY DERIVATIVE CHARACTERISTICS SUMMARY - L-1011-300 RB.211-524 ENGINE

Configuration	360-2
Engine Thrust - SLS, 84 °F	48 000
Design Weights	
Takeoff	466 000
Landing	393 000
Max. Zero Fuel	363 000
Operating Empty	274 984
Wt. Limit Payload	88 016
Space Limit Payload*	90 170
Pass. - Cargo Accommodations	
Number of Passengers	407
Galley Location	Lower
LD-3 Containers	14
Performance	
Range, Full Pass. + Bag. - n.mi.*	1850
TOFL, SL Std. + 13.9 °C - ft	8450
LFL at Design Landing Wt. - ft	6070

*Based on 150 lb/passenger + baggage and cargo at 10 lb/cu ft

TABLE 28.- L-1011 LONG BODY DERIVATIVE INTERIOR ARRANGEMENT - L-1011-300

	10/90 FC/Economy
Galley Location	Lower
Y Seating (Abreast)	9
FC Seating (Abreast)	6
Food Service	1 Meal
Passenger (Total)	407
FC	46
Y	317
Lower Deck	44
Seat Pitch	
FC	38
Y	33/34
Lower Deck	33/34
Config. Number	360-2

TABLE 29. - ENGINE CHARACTERISTICS COMPARISON - L-1011-300

Rolls-Royce Engine	RB.211-22B	RB.211-524
Sea Level Static Thrust	42 000 lb	48 000 lb
Takeoff Flat Rating Temperature	84 °F	84 °F
Maximum Cruise Thrust	9400 lb	10 980 lb
Maximum Cruise Thrust Rating Temperature	86 °F	77 °F
Core Engine Afterbody	11°	15°

TABLE 30. - OPERATIONAL EQUIPMENT WEIGHT BREAKDOWN - L-1011-300

	Config. 360-2
Emergency Equipment	1283
Lavatory Chemical	342
Unusable Oil	126
Engine Oil	120
Flight Crew & Baggage 3 @ 190	570
Cabin Crew & Baggage 10 @ 150	1500
Flight Kits	75
Passenger Service Items	1140
Food and Beverage (Incl. Trays)	2624
Beverage Carts (3)	273
Water (Drinking & Washing)	833
Cargo Containers	3240
Total (lb)	12 126

TABLE 31.- L-1011 LONG BODY DERIVATIVE WEIGHT SUMMARY – L-1011-300

	Config. 360-2
MEW L-1011-1	224 807
Design Weights (430/440K)	748
Design Weights (466/440K)	3491
Fuselage Barrel Structure (30 Foot Extension)	6953
Structural Changes (Wing Incidence 2°40')	1707
Fuselage Structure Between Plugs	2490
Passenger Door Main Cabin (Type A ILO Type 2)	200
Propulsion (Noise Suppression)	500
Below Deck Passenger Compartment	9848
Delete Below Deck Galley	NA
Main Cabin Interior (30 Foot Extension)	5124
Systems (30 Foot Extension)	1337
Mid Cargo Compartment (Class C ILO Class D)	360
Forward Cargo Compartment (Delete C-1 Cargo Door)	-662
MEW L-1011-300 (30-Foot Extension)	256 903
Unusable Fuel	206
Operating Equipment	16 874
OEW L-1011-300 (30-Foot Extension)*	273 983
Space Limit Payload**	90 170
Weight Limit Payload	89 017

*RB211-22F Engines, add 1001 lb for RB211-524 engines

**Space limit payload = 150 lb/Pax + baggage and cargo at 10 lb/ft^3

TABLE 32.- CALCULATED FUEL CONSUMPTION - L-1011 LONG BODY -524 ENGINES

Stage Length n.mi.	Block Fuel Consumption			
	lb	$\frac{\text{gal}}{\text{n.mi.}}$	$\frac{\text{seat-n.mi}}{\text{gal}}$	$\frac{\text{Btu}}{\text{seat-n.mi.}}$
100	4 911	7.22	56.37	2244
200	8 840	6.50	61.62	2020
400	16 599	6.10	66.69	1896
600	24 064	5.90	69.00	1833
1000	38 306	5.63	72.25	1751
2000	75 138	5.52	73.67	1717
3000	113 935	5.59	72.87	1736
3275	125 500	5.62	71.81	1751
1170	44 315	5.57	73.00	1750

TABLE 33.- CALCULATED TOTAL OPERATING COSTS - L-1011 LONG BODY -524 ENGINES

Stage Length n.mi.	Block Speed kt	Total DOC		Total IOC	
		\$/blk-hr	¢/seat-n.mi.	\$/blk-hr	¢/seat-n.mi.
100	208	1910	2.25	6371	7.51
200	282	1803	1.57	4750	4.14
400	333	1675	1.24	3320	2.45
600	375	1615	1.06	2641	1.73
1000	408	1569	0.94	2094	1.26
2000	439	1535	0.86	1620	0.91
3000	451	1531	0.83	1449	0.79
3275	452	1532	0.83	1420	0.77
1170	415	1560	0.92	2000	1.18

TABLE 34. - DIRECT OPERATING COST BREAKDOWN - L-1011 LONG BODY - 524 ENGINES

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	3275	1170
Crew	0.33	0.26	0.20	0.18	0.17	0.16	0.15	0.15	0.17
Insurance	0.08	0.07	0.06	0.05	0.04	0.04	0.04	0.04	0.04
Depreciation	0.55	0.41	0.36	0.30	0.28	0.26	0.25	0.25	0.27
Maintenance	1.02	0.58	0.39	0.30	0.24	0.20	0.18	0.18	0.23
Fuel (15¢/gal)	0.27	0.25	0.23	0.22	0.21	0.21	0.21	0.21	0.21
Total DOC	2.25	1.57	1.24	1.06	0.94	0.86	0.83	0.83	0.92

TABLE 35. – INDIRECT OPERATING COST BREAKDOWN –
L-1011 LONG BODY -524 ENGINES

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	3275	1170
System Expense	0.12	0.08	0.04	0.03	0.03	0.02	0.02	0.02	0.03
Local Expense	1.68	0.80	0.45	0.28	0.17	0.08	0.06	0.05	0.15
A/C Control Expense	0.05	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Hostess Expense	0.30	0.22	0.18	0.16	0.15	0.14	0.14	0.13	0.15
Food and Beverage	0.31	0.25	0.20	0.17	0.16	0.15	0.14	0.13	0.16
Passenger Service	3.14	1.40	0.79	0.52	0.31	0.16	0.11	0.10	0.27
Cargo Handling	1.24	0.80	0.39	0.21	0.12	0.06	0.04	0.04	0.10
Other Passenger Expense	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.46	0.33	0.16	0.12	0.10	0.07	0.07	0.07	0.09
Total IOC	7.51	4.14	2.45	1.73	1.26	0.91	0.79	0.77	1.18

TABLE 36.- SUMMARY - SHORT RANGE L-1011 DESIGN REQUIREMENTS - 1974

Characteristics

- 200 Pax, 20F/180Y (L-1011-1 Comfort Standards)
- 5000 lb Maximum Cargo Capacity
- Minimum Service Above Deck Galley (One Meal Capacity)
- Seat Dimensions — Equivalent to L-1011-1 for 8 and 9 Abreast Seating
- Self Sufficiency — L-1011-1 Minus 10% GSE Value per Station
- Community Noise — FAR 36 Minus 8 EPNdB Takeoff and Minus 5 EPNdB Approach
- Fly-Thru-Capability — 1000 n.mi. Range at Full Pax Load after First Stop (Objective)

Performance

- Optimum Cruise Speed — 0.78 Mach
- Field Length — 7000 ft at S.L. and 84 °F for Full Payload Range Mission. A Range of 500 n.mi. Achievable with a TOFL of 6000 ft
- Range with Full Pax Load Plus 5000 lb Cargo — 1500 n.mi. (Domestic Reserves)
- Fuel Efficiency — Equivalent to L-1011 (200 Pax) Minus 10% in Pounds/Seat-Nautical Mile at 500 n.mi. Range

Economics

- Airplane DOC Maximum — 80% of L-1011-1 at 500 n.mi. (Objective 75%)
- Seat-Nautical Mile DOC — Equal to L-1011-1 at 500 n.mi. (Mixed Class and All-Coach Seating Standards)
- Fly-Away Price — In Proportion to L-1011-1 Fly-Away Price to Meet DOC Ratios as Above and Allow Program Profitability Based on a Low Risk Market of Approximately 325 Airplanes

Availability

- FAA Certification — First Quarter 1979

Suggested Design Limitation

- Simplified 2 and 3 Engine L-1011-1 Versions (Low Development Cost)

TABLE 37.- L-1011-1 AIRCRAFT MODIFICATIONS REQUIRED FOR SHORT BODY DERIVATIVE

(L-1011-Short Range Derivative Study - 1974)

L-1011-SR Definition

Selected Candidate Changes to the Basic L-1011-1 Airplane Which Define the Short Range Derivative Aircraft.

- Minimum Modification
- 3 RB.211-22B Engines, Derated 7%
- Shorten Fuselage 260 in.
  - 150 in. from Fwd End of Sec 3
  - 40 in. from Aft End of Sec 5
  - 70 in. from Fwd End of Sec 6
- Remove P4, Galley and C2 Doors
- Remove Below Deck Galley, Lifts and Provisions
- Remove 1 Aft Lavatory and Associated Systems
- Remove 1 ECS Pack and Associated Ducting
- Remove Aft Cargo System
- Redesign MLG Fairing - Fwd of FS901
  - Aft of FS1455
- Remove Outboard Flaps, Outboard Spoilers and Associated Systems - Replace with Fixed Structure
- Reduce Wing Skin and Stringer Gages
- Reduce Horizontal Stabilizer Skin Plank Gages
- Delete Food Carts

The Following Aircraft Weights are for the L-1011 Short Body Aircraft

TOGW	325 000 lb
ZFW	275 000 lb
OEW	210 154 lb

TABLE 38.- CALCULATED FUEL CONSUMPTION - L-1011 SHORT BODY

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal / n.mi.	seat-n.mi. / gal	Btu / seat-n.mi.
100	4 518	6.64	30.12	4199
200	7 858	5.78	34.60	3655
400	14 340	5.27	37.95	3333
600	20 332	4.98	40.16	3149
1000	31 430	4.62	43.29	2922
1500	45 574	4.47	44.74	2827
2000	59 128	4.35	45.98	2751
2600	76 612	4.33	46.19	2738
600	20 332	4.98	40.16	3149

TABLE 39.- CALCULATED TOTAL OPERATING COSTS - L-1011 SHORT BODY

Stage Length n.mi.	Block Speed kt	Total DOC		Total IOC	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	233	1565	3.37	4154	8.93
200	294	1460	2.48	2720	4.62
400	357	1328	1.86	1910	2.67
600	380	1268	1.67	1531	2.02
1000	413	1225	1.48	1197	1.45
1500	432	1202	1.39	1008	1.17
2000	442	1189	1.34	905	1.02
2600	448	1180	1.32	830	0.93
600	380	1268	1.67	1531	2.02

TABLE 40. - DIRECT OPERATING COST BREAKDOWN -
L-1011 SHORT BODY

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	1500	2000	2600	600
Crew	0.52	0.42	0.36	0.32	0.29	0.28	0.28	0.27	0.32
Insurance	0.11	0.10	0.08	0.07	0.06	0.06	0.06	0.06	0.07
Depreciation	0.71	0.58	0.45	0.43	0.40	0.38	0.37	0.37	0.43
Maintenance	1.52	0.90	0.55	0.47	0.38	0.33	0.31	0.29	0.47
Fuel (15¢/gal)	0.51	0.48	0.42	0.38	0.35	0.34	0.33	0.33	0.38
Total DOC	3.37	2.48	1.86	1.67	1.48	1.39	1.34	1.32	1.67

TABLE 41. - INDIRECT OPERATING COST BREAKDOWN - L-1011 SHORT BODY

IOC COMPONENT / Stage Length (n.mi.)	IOC ¢/seat-n.mi.								
	100	200	400	600	1000	1500	2000	2600	600
System Expense	0.18	0.14	0.07	0.05	0.04	0.03	0.03	0.03	0.05
Local Expense	2.39	1.14	0.58	0.40	0.24	0.16	0.12	0.09	0.40
A/C Control Expense	0.10	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.02
Hostess Expense	0.29	0.24	0.21	0.18	0.17	0.16	0.15	0.15	0.18
Food and Beverage	0.28	0.23	0.20	0.18	0.16	0.16	0.15	0.15	0.18
Passenger Service	3.14	1.38	0.74	0.52	0.32	0.21	0.16	0.12	0.52
Cargo Handling	1.75	0.84	0.40	0.29	0.18	0.11	0.09	0.07	0.29
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.58	0.35	0.20	0.16	0.13	0.11	0.10	0.09	0.16
Total IOC	8.93	4.62	2.67	2.02	1.45	1.17	1.02	0.93	2.02

TABLE 42. - 85-PASSENGER COMMERCIAL P-3

DOC $/blk-hr					
Range (n.mi.)	174	261	348	435	522
Crew	235	235	235	235	235
Fuel	103	103	103	103	103
Insurance	20	20	20	20	20
Depreciation	141	140	140	140	140
Maintenance	371	321	290	271	256
Total	870	819	788	769	754

IOC $/blk-hr					
System Expense	48	41	37	35	33
Local Expense	220	166	134	112	96
A/C Control	25	19	15	13	11
Hostess Expense	68	68	68	68	68
Food & Beverage	55	55	55	55	55
Passenger Service	338	257	205	172	148
Cargo Handling	44	34	27	22	19
Other Pass. Exp.	40	46	49	51	53
Other Cargo Exp.	0.4	0.5	0.5	0.6	0.6
Gen. & Admin.	82	71	65	61	57
Total	920	758	656	590	541

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TABLE 43. - 105-PASSENGER COMMERCIAL P-3

DOC $/blk-hr					
Range (n.mi.)	174	261	304	435	522
Crew	235	235	235	235	235
Fuel	109	109	107	107	109
Insurance	22	22	22	22	22
Depreciation	152	152	152	152	152
Maintenace	385	334	318	281	266
Total	903	852	834	797	784
IOC $/blk-hr					
System Expense	49	43	41	36	34
Local Expense	236	179	162	120	104
A/C Control	25	19	17	13	11
Hostess Expense	68	68	68	68	68
Food & Beverage	68	68	68	68	68
Passenger Service	417	317	287	213	183
Cargo Handling	48	37	33	24	21
Other Pass. Exp.	50	56	59	63	65
Other Cargo Exp.	0.4	0.5	0.5	0.6	0.6
Gen. & Admin	90	78	74	65	62
Total	1051	866	810	671	617

TABLE 44.- CALCULATED FUEL CONSUMPTION - P-3 COMMERCIAL 85 PAX

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal/n.mi.	seat-n.mi./gal	Btu/seat-n.mi.
100	2 500	3.68	23.10	5475
200	3 800	2.79	30.47	4151
400	6 500	2.39	35.56	3557
600	9 000	2.21	38.46	3289
1000	14 000	2.06	41.26	3065
1500	20 300	1.99	42.71	2961
2000	26 800	1.97	43.15	2931
2295	30 500	1.95	43.49	2908
300	5 182	2.54	33.50	3775

TABLE 45.- CALCULATED TOTAL OPERATING COSTS - P-3 COMMERCIAL 85 PAX

Stage Length n.mi.	Block Speed kt	Total DOC		Total IOC	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	170	861	5.98	1259	8.74
200	222	767	4.06	907	4.80
400	268	699	3.06	644	2.82
600	294	670	2.68	530	2.12
1000	314	643	2.41	432	1.62
1500	322	627	2.29	373	1.36
2000	327	618	2.22	341	1.23
2295	329	612	2.19	328	1.17
300	247	725	3.41	745	3.51

TABLE 46. - DIRECT OPERATING COST BREAKDOWN -
P-3 COMMERCIAL 85 PAX

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	1500	2000	2295	300
Crew	1.18	0.90	0.75	0.70	0.64	0.62	0.61	0.62	0.80
Insurance	0.13	0.10	0.08	0.08	0.07	0.07	0.07	0.07	0.08
Depreciation	0.95	0.73	0.60	0.57	0.51	0.50	0.49	0.49	0.65
Maintenance	3.05	1.83	1.21	1.01	0.81	0.74	0.70	0.70	1.43
Fuel (15¢/gal)	0.66	0.51	0.43	0.39	0.37	0.36	0.36	0.36	0.45
Total DOC	5.98	4.06	3.06	2.68	2.41	2.29	2.22	2.19	3.41

TABLE 47. - INDIRECT OPERATING COST BREAKDOWN -
P-3 COMMERCIAL 85 PAX

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.								
	100	200	400	600	1000	1500	2000	2295	300
System Expense	0.39	0.24	0.16	0.14	0.11	0.10	0.09	0.09	0.18
Local Expense	2.05	1.02	0.51	0.36	0.21	0.14	0.10	0.10	0.69
A/C Control Expense	0.23	0.11	0.06	0.04	0.02	0.01	0.01	0.01	0.08
Hostess Expense	0.47	0.36	0.30	0.28	0.26	0.25	0.25	0.25	0.32
Food and Beverage	0.38	0.29	0.24	0.22	0.21	0.20	0.20	0.20	0.25
Passenger Service	3.14	1.57	0.79	0.54	0.31	0.20	0.16	0.16	1.05
Cargo Handling	1.17	0.58	0.29	0.22	0.12	0.09	0.06	0.06	0.40
Other Passenger Expense	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.69	0.41	0.26	0.22	0.17	0.16	0.15	0.15	0.32
Total IOC	8.74	4.80	2.82	2.12	1.62	1.36	1.23	1.17	3.51

TABLE 48.- CALCULATED FUEL CONSUMPTION - P-3 COMMERCIAL 105 PAX

Stage Length n.mi.	Block Fuel Consumption			
	lb	$\frac{\text{gal}}{\text{n.mi.}}$	$\frac{\text{seat-n.mi.}}{\text{gal}}$	$\frac{\text{Btu}}{\text{seat-n.mi.}}$
100	2 669	3.92	26.79	4728
200	4 057	2.98	35.18	3593
400	6 939	2.55	41.18	3073
600	9 608	2.36	44.59	2837
1000	14 946	2.20	47.77	2648
1500	21 672	2.12	49.42	2559
2000	28 612	2.10	49.90	2534
2145	30 700	2.10	49.88	2535
300	5 549	2.72	39.00	3275

TABLE 49.- CALCULATED TOTAL OPERATING COSTS - P-3 COMMERCIAL 105 PAX

Stage Length n.mi.	Block Speed kt	Total DOC		Total IOC	
		\$/blk-hr	¢/seat-n.mi.	\$/blk-hr	¢/seat-n.mi.
100	170	896	5.03	1451	8.15
200	222	797	3.42	1044	4.47
400	268	726	2.58	738	2.62
600	294	697	2.26	600	1.94
1000	314	667	2.02	493	1.49
1500	322	650	1.92	425	1.26
2000	327	642	1.87	387	1.13
2145	328	640	1.86	382	1.11
300	250	750	2.86	855	3.26

TABLE 50. - DIRECT OPERATING COST BREAKDOWN - P-3 COMMERCIAL 105 PAX

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	1500	2000	2145	300
Crew	0.97	0.74	0.61	0.57	0.52	0.51	0.50	0.51	0.66
Insurance	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.07
Depreciation	0.81	0.62	0.51	0.48	0.44	0.43	0.42	0.42	0.55
Maintenace	2.57	1.54	1.01	0.84	0.68	0.60	0.58	0.59	1.18
Fuel (15¢/gal)	0.57	0.46	0.37	0.33	0.32	0.31	0.31	0.31	0.40
Total DOC	5.03	3.42	2.58	2.26	2.02	1.92	1.87	1.86	2.86

TABLE 51. - INDIRECT OPERATING COST BREAKDOWN -
P-3 COMMERCIAL 105 PAX

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.								
	100	200	400	600	1000	1500	2000	2145	300
System Expense	0.33	0.20	0.13	0.11	0.09	0.08	0.08	0.08	0.16
Local Expense	1.78	0.89	0.45	0.32	0.18	0.11	0.09	0.09	0.60
A/C Control Expense	0.19	0.09	0.05	0.04	0.02	0.02	0.01	0.01	0.07
Hostess Expense	0.38	0.29	0.24	0.22	0.21	0.21	0.20	0.20	0.26
Food and Beverage	0.38	0.29	0.24	0.22	0.21	0.21	0.20	0.20	0.26
Passenger Service	3.14	1.57	0.79	0.55	0.31	0.20	0.16	0.16	1.05
Cargo Handling	1.12	0.56	0.28	0.10	0.11	0.07	0.06	0.06	0.37
Other Passenger Expense	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.62	0.36	0.23	0.19	0.15	0.14	0.13	0.13	0.27
Total IOC	8.15	4.47	2.62	1.94	1.49	1.26	1.13	1.11	3.26

5. NEW NEAR-TERM (1980) FUEL SAVING AIRCRAFT - TASK 5

In addition to the methods studied to reduce the fuel consumption of the air transport fleet in the previous study tasks, a series of new fuel conserving aircraft was parametrically designed and evaluated. The purpose of this task was to evaluate the fuel savings to be realized if new near-term aircraft were designed from the outset with the current high and possibly higher future fuel cost environment as a design criterion. Near-term for purposes of this task was defined as 1980 initial operations capability.

The design mission requirements for the new aircraft of this task were defined by NASA in the proposal request. Three payload/range classes, with airplanes designed to four particular criteria in each class, were included. All of these aircraft were to incorporate turbofan engines, and in addition a turboprop aircraft was to be studied for one of the payload/ranges. The three size classes were a 200 passenger aircraft for a 1500 nautical mile design mission, and both a 200 and 400 passenger aircraft for a 3000 nautical mile mission. In designing aircraft for each of these missions, minimum direct operating cost as well as minimum fuel design criteria were utilized. The minimum direct operating cost criterion was further divided by the specification of three fuel costs: 15, 30, and 60 cents per gallon. The 200 passenger, 1500 nautical mile payload/range was stipulated for evaluation of the turboprop aircraft. Table 52 summarizes this matrix of payload/range and design criteria.

5.1 Turbofan Aircraft Designs

As a first step in the parametric evaluation of the Table 52 designs, preliminary sizing and conceptual design studies were performed. These studies established the basic configurations, sizes, and weights for the three classes of airplanes to be considered. Preliminary configuration drawings were then prepared and used as a basis for assessing the drag, propulsion, stability and control requirements, and the structural and weight relationships as required for each of the aircraft.

It was projected that for introduction in 1980 the most likely candidate airplanes in the payload/range classes being considered would incorporate wide-body fuselages and the current high-bypass ratio engines or derivatives of same. The L-1011 fuselage diameter was chosen with four conventional wing/pylon mounted high-bypass ratio turbofan engines being selected. Aircraft systems were chosen compatible with L-1011 design practice.

The 1980 service introduction was also a consideration in determining the fuel efficient technologies to be incorporated. A supercritical wing and limited use of advanced composites in cost effective secondary structure were selected as offering the most potential for incorporation in an airplane designed for 1980 service. Active flight controls and composite primary structure were eliminated as viable candidate technologies for this time period.

Aerodynamic, weight, and cost data representative of these advanced technologies were then generated in parametric form. Scalable engine data were generated in deck form based on the cycle performance and weight of the Rolls Royce RB.211 high-bypass ratio turbofan engine. The fuel consumption of the RB.211 class of engines is consistent with the expected capability of engines to be available for 1980 service. This is evidenced by the new ten-ton engines being developed today which exhibit SFC trends essentially the same as the current large high-bypass ratio engines.

With these component characteristics defined in parametric form, parametric aircraft studies were conducted using the Lockheed Advanced System Synthesis and Evaluation Technique (ASSET) computer program. This program was used to size preliminary design airplanes in each of the mission classes for a range of Mach numbers, wing aerodynamic parameters, wing, and thrust loadings. This design matrix is shown in Table 53; repeated for each of the three payload/range classes, 12 288 parametric airplane designs result. The selection of this matrix was based on extensive in-house preliminary studies; this accounts for the lower limit established on sweep angle for example where it was found that for the range of thickness ratios considered, only very small additional fuel and operating cost benefits were achieved with further reductions in sweep angle.

The automatic plotting capability of the ASSET program was used to generate carpet plots of takeoff gross weight, block fuel, and direct operating cost for each of the three fuel costs. The full range of wing aspect and thickness ratios shown in Table 53 were thereby combined for each of the selected wing and thrust loadings. Figures 35 through 39 present an example set of the ASSET generated autoplots; in this case for the 200 passenger, 3000 nautical mile airplane. These data represent one variation in the parameters of Mach number, wing sweep, and wing and thrust loading.

The minimum takeoff gross weight, minimum block fuel, and minimum direct operating costs were selected from these autoplots and tabulated along with the appropriate wing geometry (aspect and thickness ratios). Summary plots of the minimum values were then prepared over the range of thrust and wing loadings at each Mach number as shown in Figures 40 through 44. This presentation format allows incorporation of the field length constraint line which is shown as the dashed line on these figures.

Use of the tabulated minimum value data obtained from the autoplots and the plots exemplified by Figures 40 through 44 allowed the construction of the variation of wing geometry with Mach number for each of the payload/range combinations. An example is shown in Figure 45. In performing this step of the procedure, the minimum direct operating cost and minimum fuel criteria were used and were modified when necessary by the field length constraints. Note that in Figure 45, one curve represents all wing loadings since the geometry was found to be insignificantly affected over the range of wing loadings considered.

Final summary plots showing the variation of takeoff gross weight, block fuel, and direct operating cost with Mach number were then constructed (examples shown in Figures 46, 47, and 48). This was accomplished by again referring to the computer plotted data and the summary plots as shown in Figure 45. The final Mach numbers were selected from the data typified by Figures 46 through 48.

Tables 54 through 57 summarize the characteristics of the final selected design point airplanes for the minimum DOC and minimum fuel criteria. These tables were constructed from an additional set of ASSET computer output for each design-point airplane which was run at the specific wing geometry and cruise Mach number selected as discussed above. A complete set of geometry, weight, performance, and cost data was therefore available for each of the final selected airplanes. Examples of the ASSET printout data showing the detailed breakdown of these data are presented in Tables 58 through 61. The configuration geometry output data of Table 58 give sufficient details to allow a three-view general arrangement drawing to be constructed. The ASSET printout of Table 59 is an example of the weight output including a breakdown of the manufacturers empty weight into its major components. A summary of the airplane performance over the mission profile is shown by the example of Table 60 where the time, fuel, and distance variables are tabulated for each of the mission profile segments. The cost summary of Table 61 includes breakdowns of both the manufacturing and engineering costs as well as the direct operating cost information.

The effect of optimizing the wing for minimum direct operating cost at different fuel costs and for minimum fuel usage irrespective of cost is shown graphically in Figure 49. Here the wing geometry for the various designs have been overlaid in each payload/range size. Once the fuel price reaches approximately 30 cents per gallon, the sweep has been reduced to near the 25-degree limit imposed, and further fuel price increases call for increased aspect ratio. The minimum fuel designs have the highest aspect ratios. These trends are shown in Figures 50 through 52 where the wing design parameters plus cruise speed and takeoff gross weight have been plotted versus fuel cost. The parameters for the minimum fuel designs are also indicated as noted by the shaded symbols.

Tabular data in the format specified for the UTRC study are included as Tables 62 through 115. For that study the 15 cent fuel designs were eliminated so that these data are shown for the 30 and 60 cent fuel designs and for the minimum fuel designs. These data are tabulated for a series of stage lengths including one predicted to be the average CAB stage length assuming these aircraft were in service. Fuel consumption is shown in terms of total block fuel and on both an airplane-nautical mile and a seat-nautical mile basis. The seat-nautical mile figures are further subdivided into units of seat-nautical miles per gallon and Btu's per seat-nautical mile. Total direct and indirect operating costs are tabulated assuming fuel prices of 15, 30, and 60 cents per gallon. These total cost figures are shown in units of dollars per block hour with the corresponding block speeds indicated at each stage length and are also shown in units of cents per available seat-nautical mile. The latter units are also used for the detailed breakdowns of the direct and indirect costs Note that for the same airplane design a small change in the indirect operating costs is indicated as fuel price is varied. This is caused by the fact that the estimated IOC General and Administration Expense is a function of the direct operating cost.

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5.2 Turboprop Aircraft Designs

The 200 passenger/1500 nautical mile payload/range was stipulated for the turboprop design. In this aircraft size class, the turbofan parametric study airplanes optimized at cruise Mach values of 0.75 or higher. This indicates that the block-time factor is still a powerful one when considering direct operating cost as a design criterion even at elevated fuel prices. It was also shown that for aircraft powered by the turbofan engines investigated in this study, the high fuel cost/minimum direct operating cost design does not differ drastically from one designed strictly from a minimum fuel standpoint in terms of the design Mach number.

These high cruise speeds, considered in the context of the 1980 time period for this task, complicate the consideration of turboprop designs. Current propeller designs limit the design speed of a turboprop powered aircraft to approximately Mach 0.65, a speed that was judged to be unacceptable from the standpoint of compatibility with current aircraft that will still be in the fleet in 1980. Advanced propellers such as the Hamilton Standard Prop-Fan which would allow operation at speeds up to Mach 0.8 or better will not be available until sometime after the desired 1980 introduction date.

The turboshaft engine for use in the time period of this task was an additional consideration. While available turboshaft engines offer specific fuel consumption benefits relative to even the current high-bypass turbofan engines at competitive cruise speeds and larger benefits at reduced cruise speeds, none offer sufficient power for the size aircraft envisioned.

With these considerations as a basis, it was decided that for purposes of this task some relaxation of the ground rules should be accepted. It was, therefore, assumed that a current turboshaft engine could be made available in an appropriate size class for incorporation on an aircraft designed to cruise at lower Mach numbers with conventional propellers. At the other end of the speed spectrum an aircraft incorporating a new design engine and propeller was examined.

While several designs in each of these classifications were examined, typical examples are discussed here. The first of these, illustrated in the three-view drawing of Figure 53 is a four engined airplane designed to cruise at Mach 0.65 using a conventional four bladed propeller and an uprated version of the Rolls-Royce Tyne powerplant. A wide-body fuselage was used here for compatibility with the other aircraft of this task. The wing sweep has been reduced to a value of 15 degrees, sufficient for the lowered cruise speed. The high aspect ratio wing found to be optimum for the turbofan airplanes is retained. A design like this offers seat-mile per gallon figures approximately 25 percent better than the new near-term turbofan airplane. While these improvements are significant, the cruise speed incompatibility of this type of design could out-weigh the fuel savings.

Preliminary design turboprop airplanes designed to cruise at Mach 0.8 are typified in Figures 54 and 55. These airplanes were studied and performance data obtained using the available information on the Hamilton Standard Prop-Fan propeller concept and the Pratt and Whitney STS476 study turboshaft engine. While these data were preliminary in nature at the time of this study, it was felt that an indication of the performance levels attainable would at least help to define the potential of an advanced turboprop aircraft.

It was found again that the seat-mile per gallon levels attainable with the higher speed turboprops were sufficiently improved over the turbofans to call for additional study.

As discussed previously, the time period originally specified for introduction of the near-term aircraft in this task placed limitations on the study of the turboprop powered aircraft. The large fuel savings identified in the preliminary design turboprops, however, led to modifications of both of the airframe manufacturer's contracts. A more detailed design of a high speed turboprop and comparison with an equal technology turbofan aircraft was specified in the Lockheed study while McDonnell Douglas was assigned the task of studying a turboprop in the DC-9 size class. A complete discussion of the follow-on turboprop study is included in Section 7, Task 7 of this report.

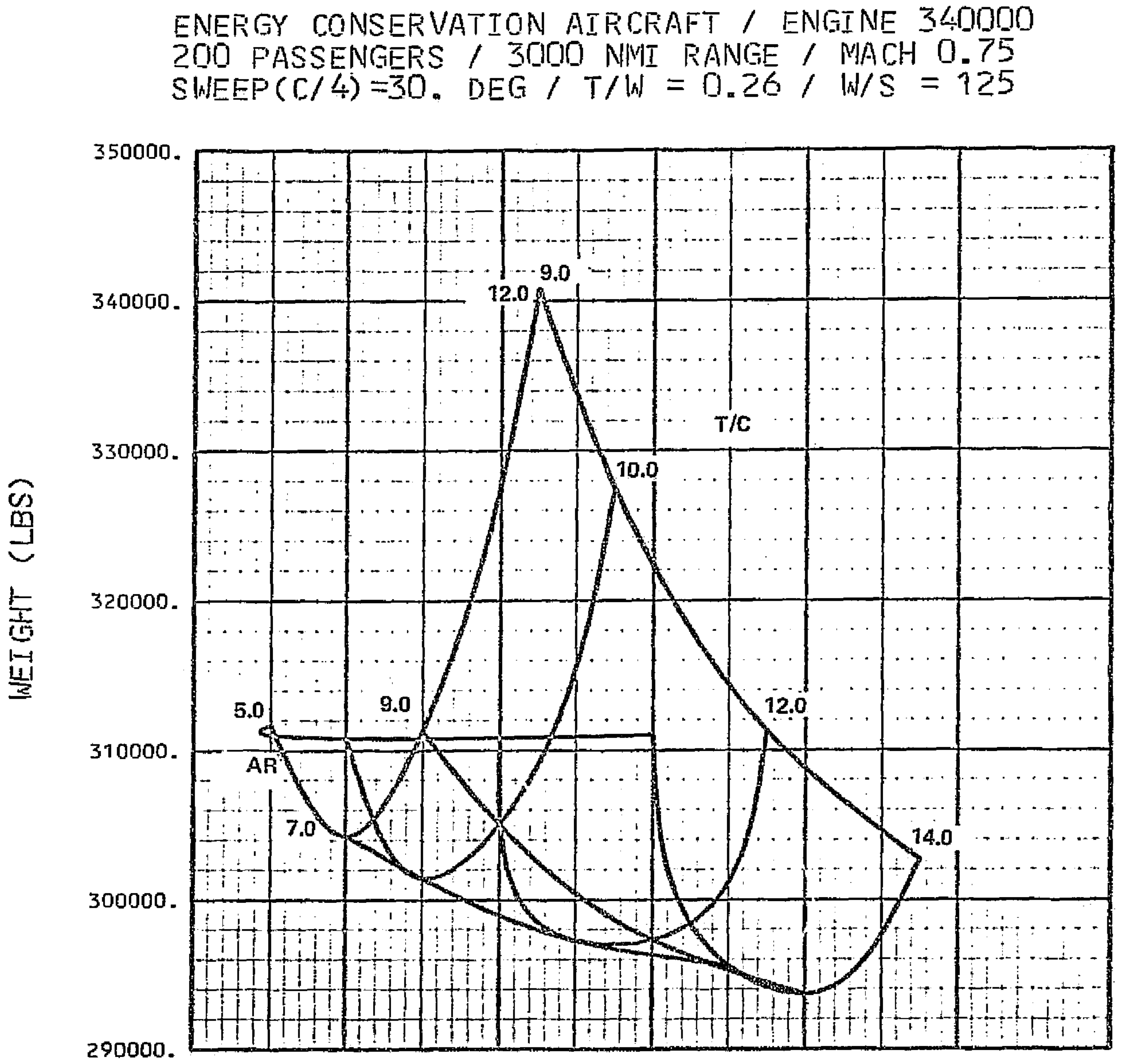


Figure 35.—ASSET autoplot - takeoff gross weight

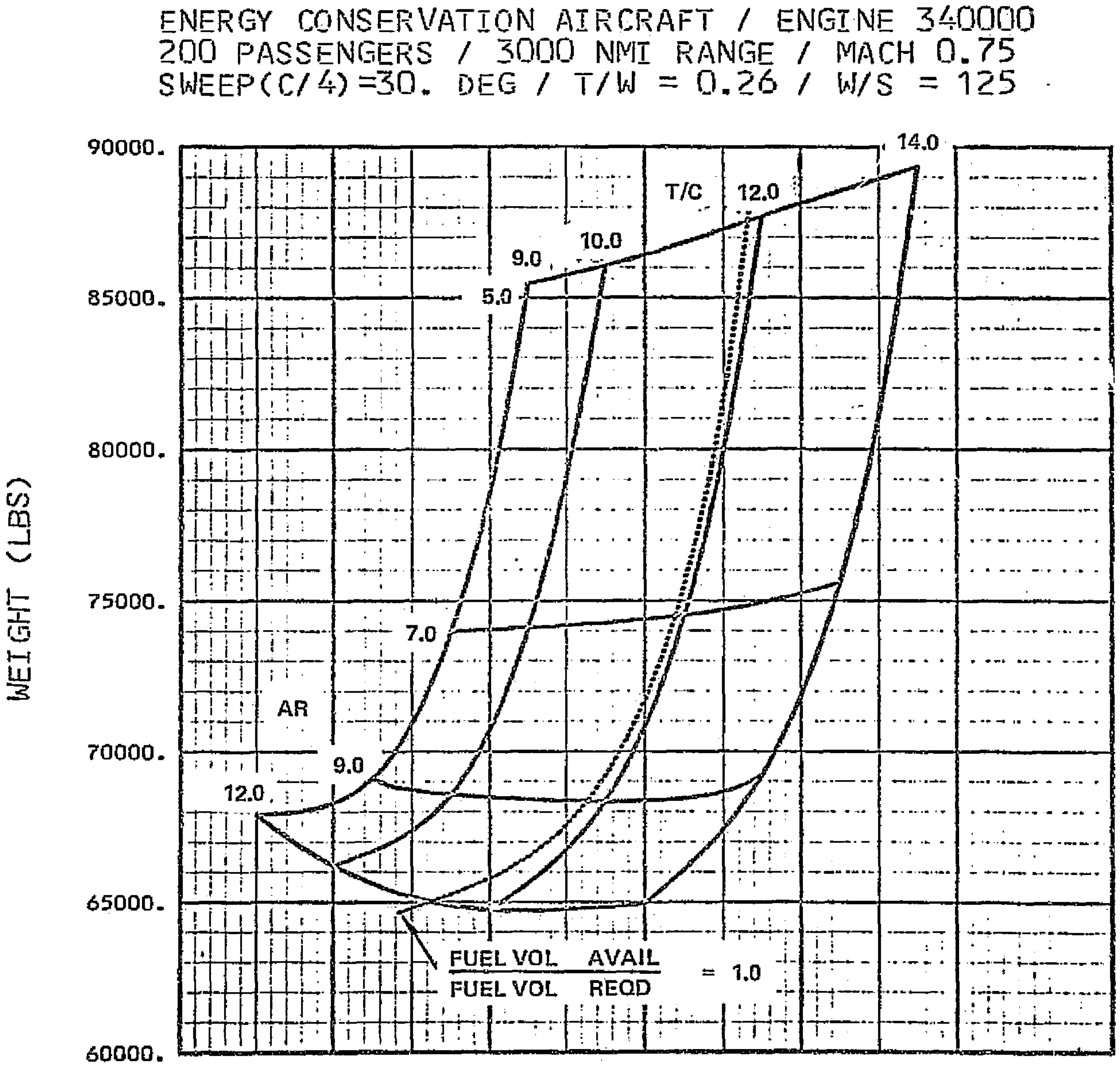


Figure 36.—ASSET autoplot - block fuel

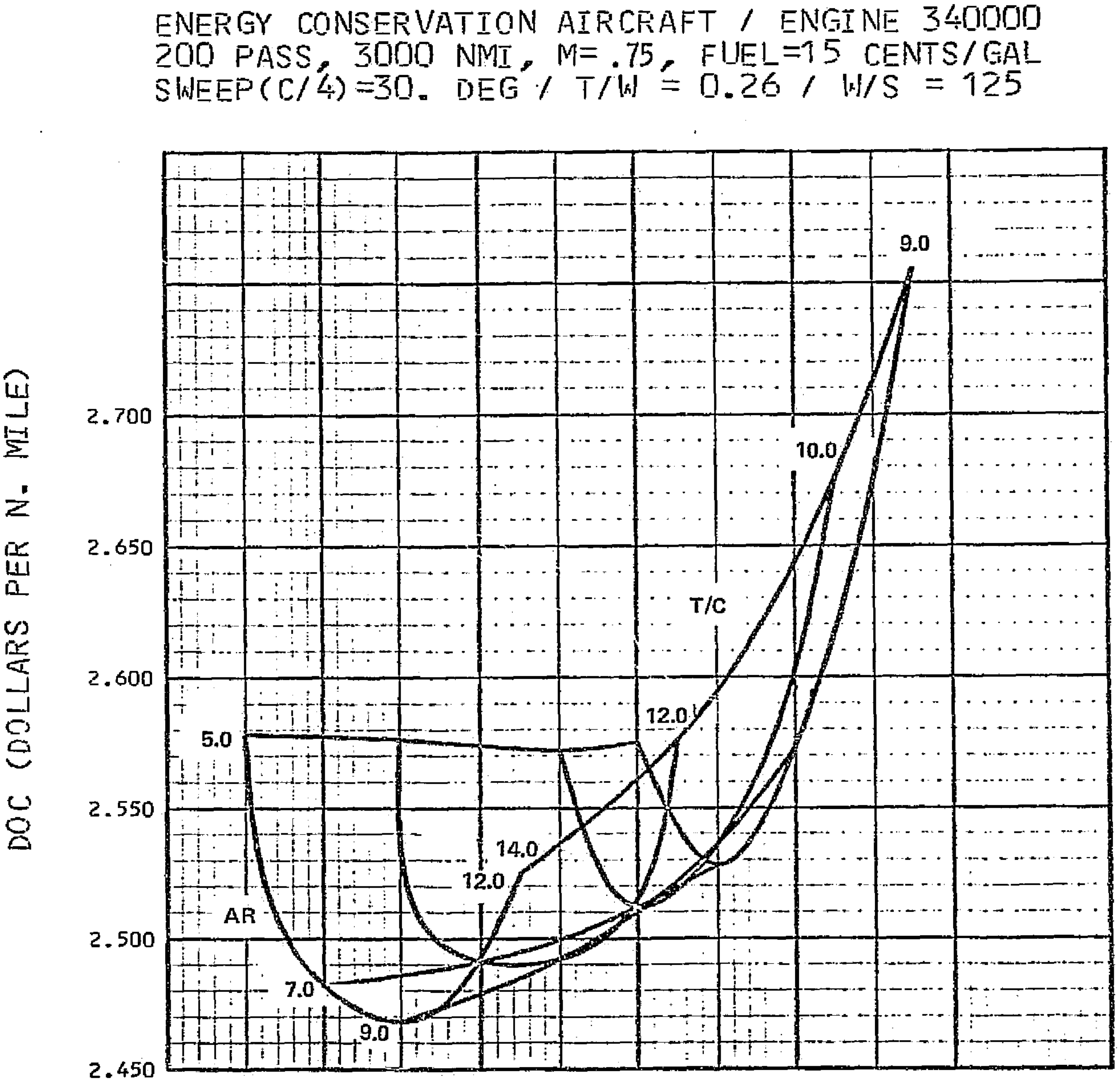


Figure 37.—ASSET autoplot - direct operating cost ($0.15/gal fuel)

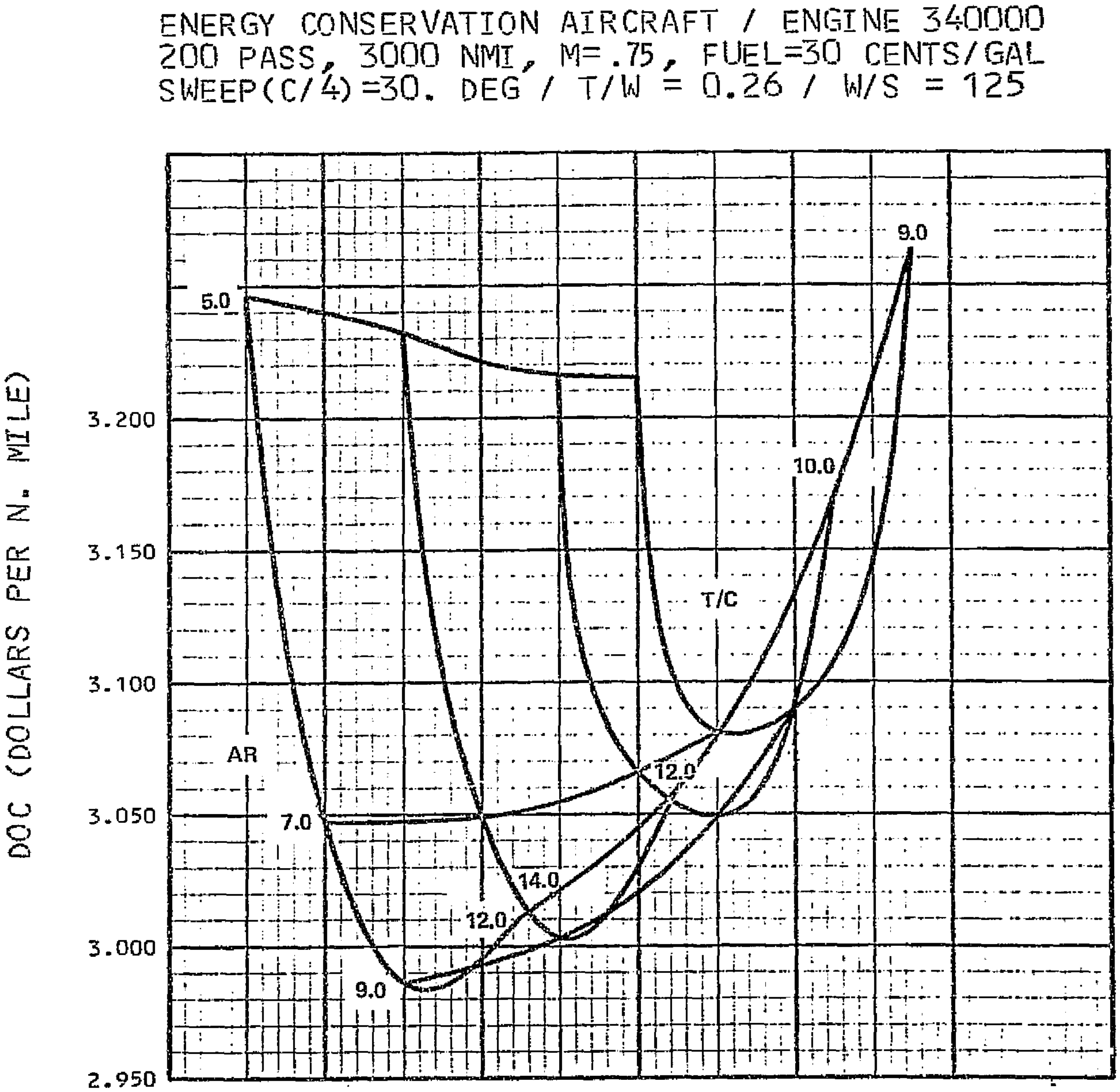


Figure 38.—ASSET autoplot - direct operating cost ($0.30/gal fuel)

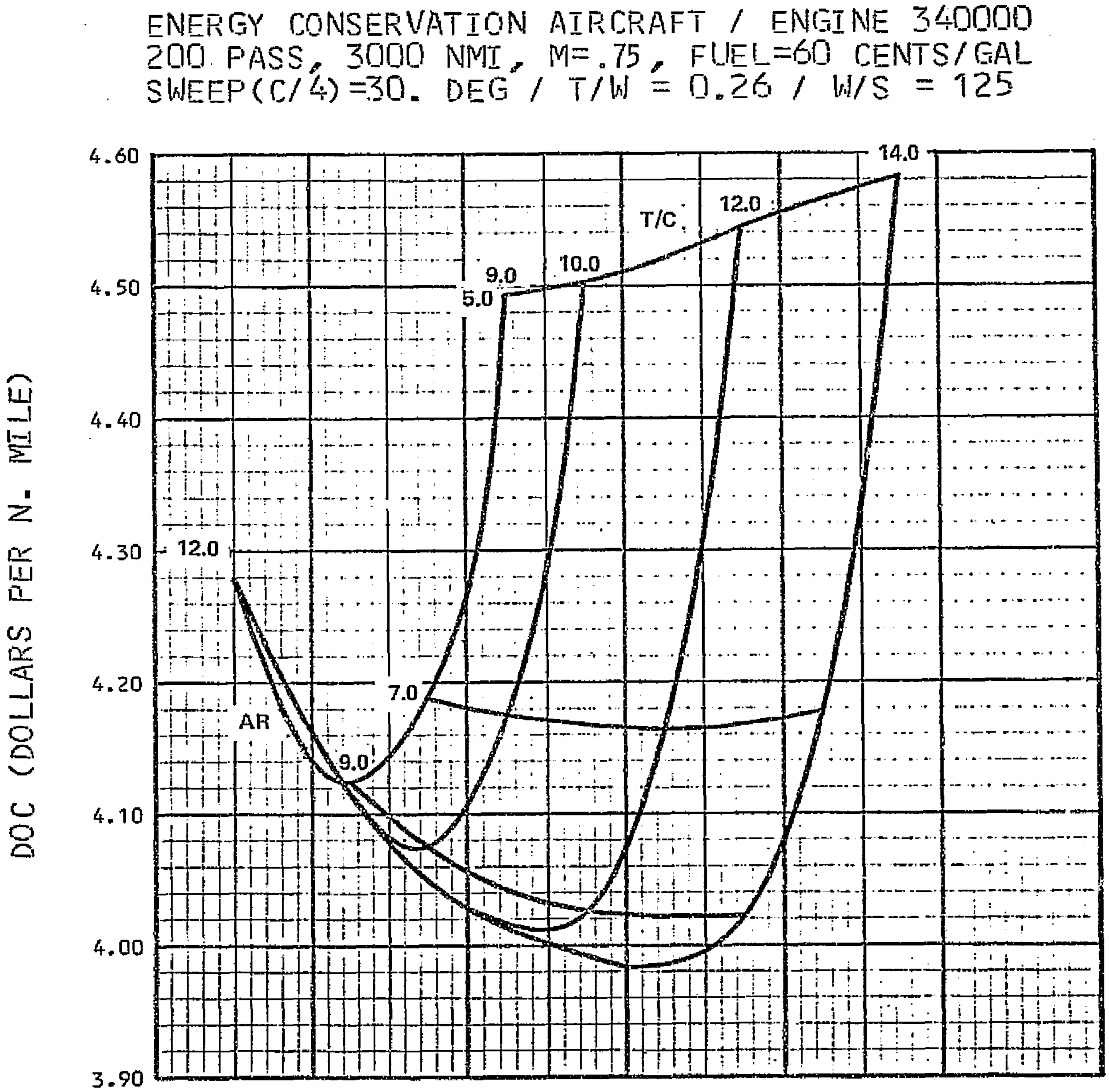


Figure 39.—ASSET Autoplot - Direct operating cost ($0.60/gal fuel)

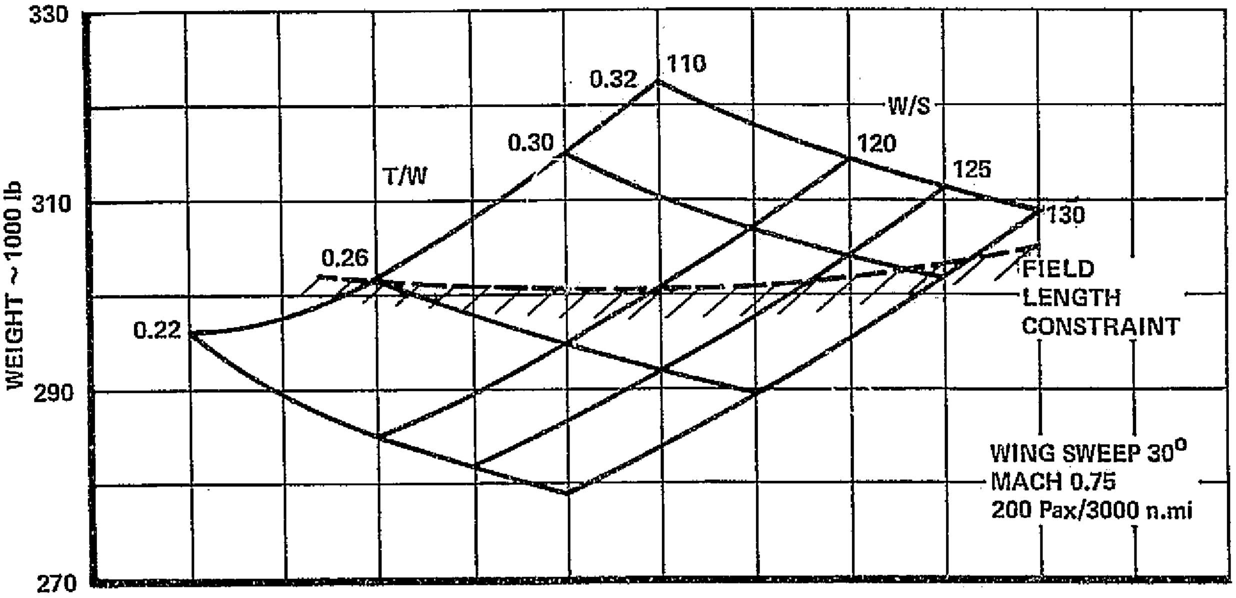


Figure 40.—Crossplot - takeoff gross weight

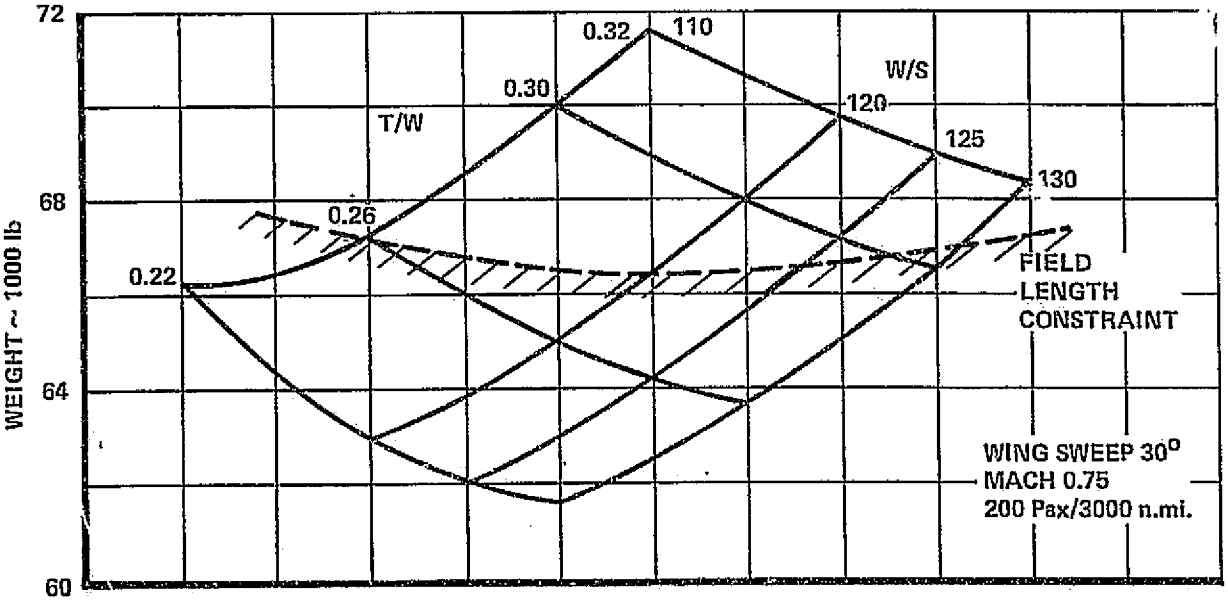


Figure 41.—Crossplot - block fuel

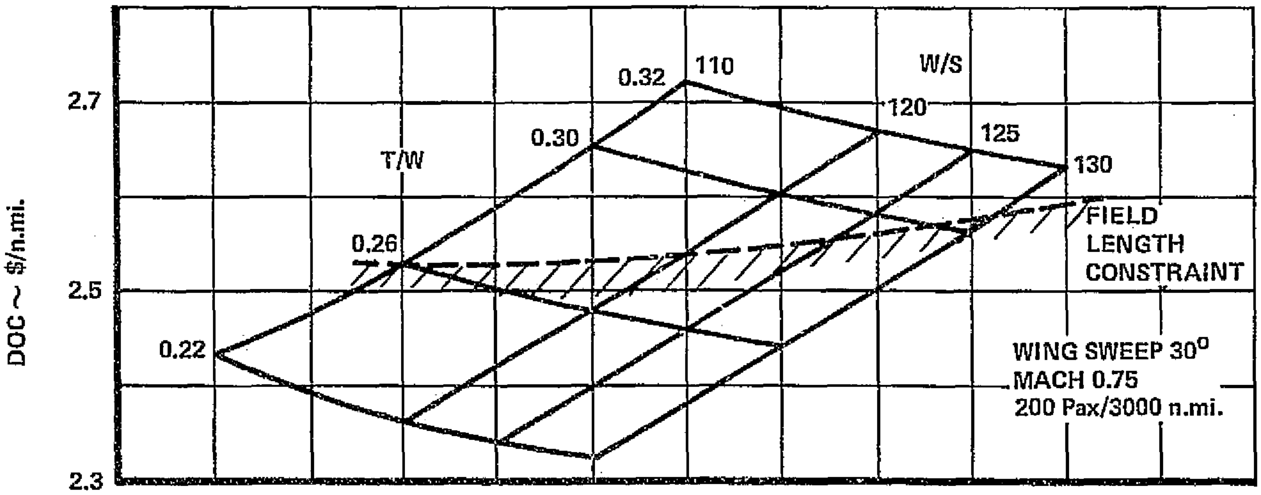


Figure 42.— Crossplot - direct operating cost ($0.15/gal)

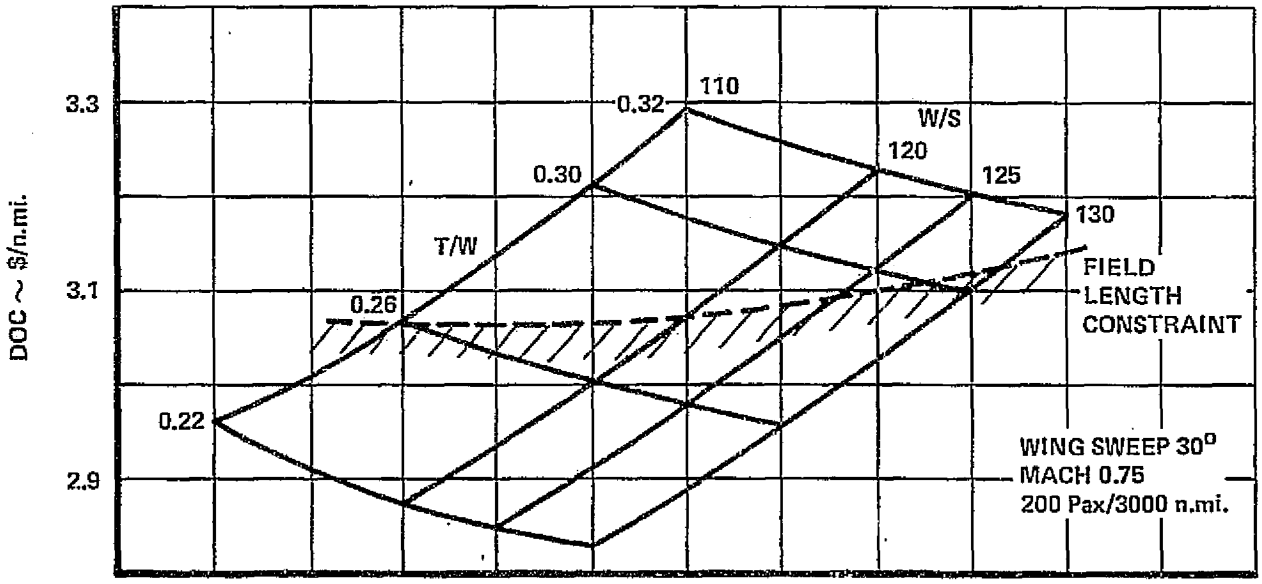


Figure 43.— Crossplot - direct operating cost ($0.30/gal)

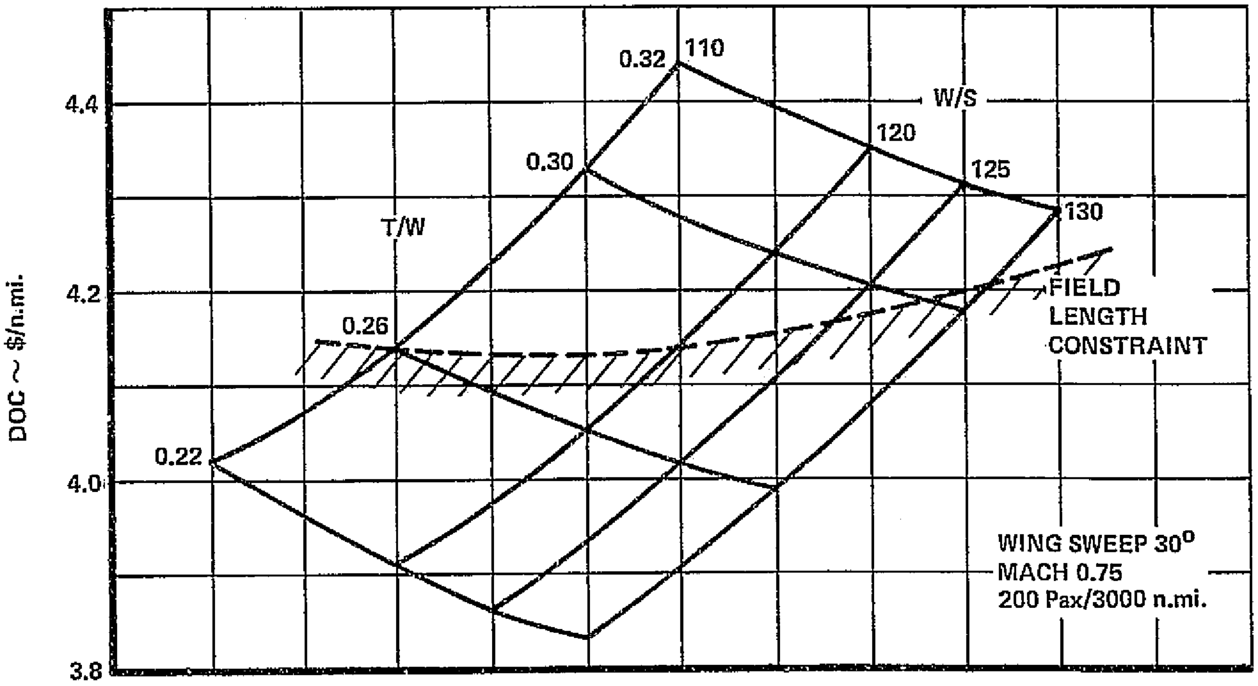


Figure 44.—Crossplot - direct operating cost ($0.60/gal)

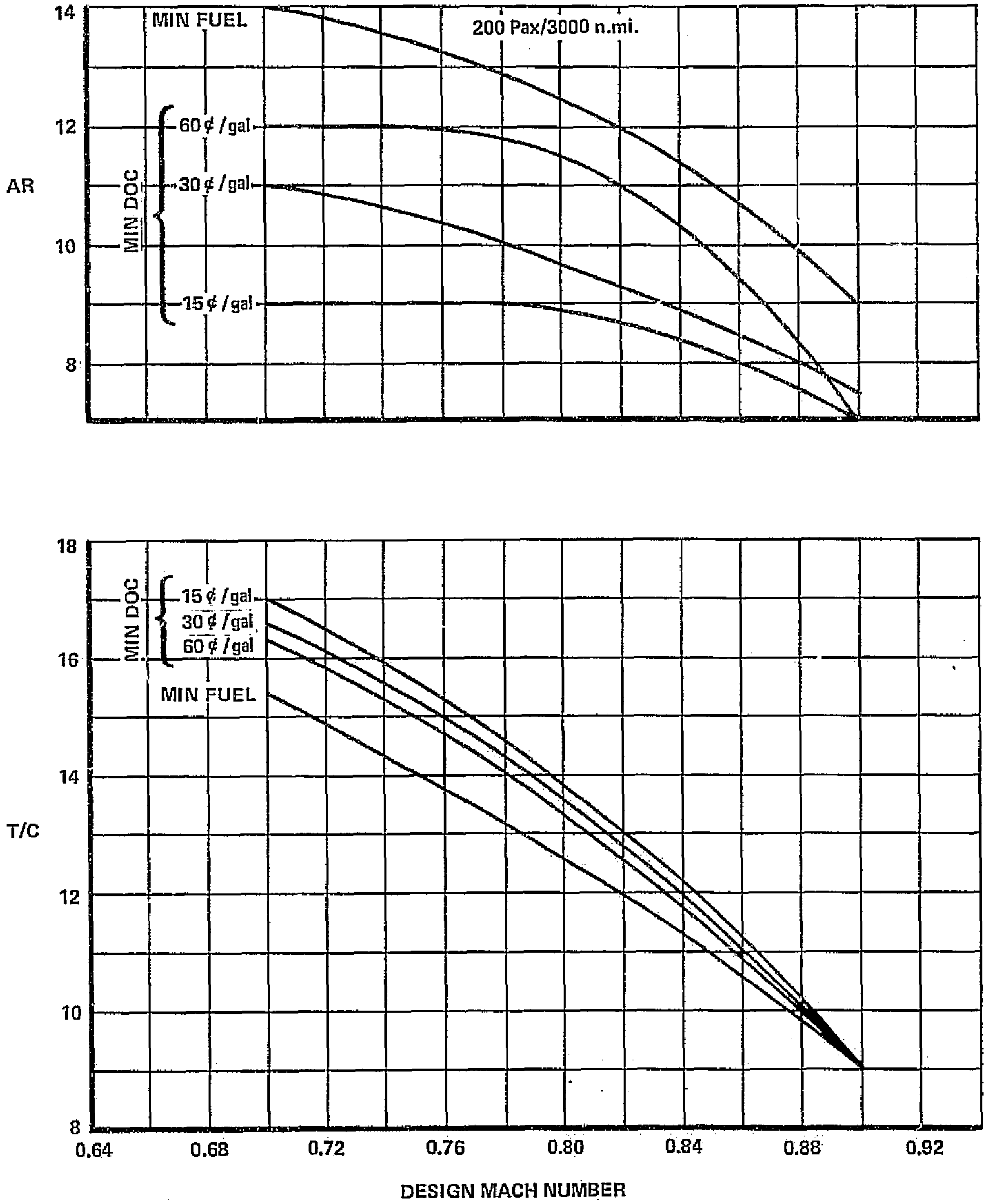


Figure 45.—Effect of design Mach number on wing geometry

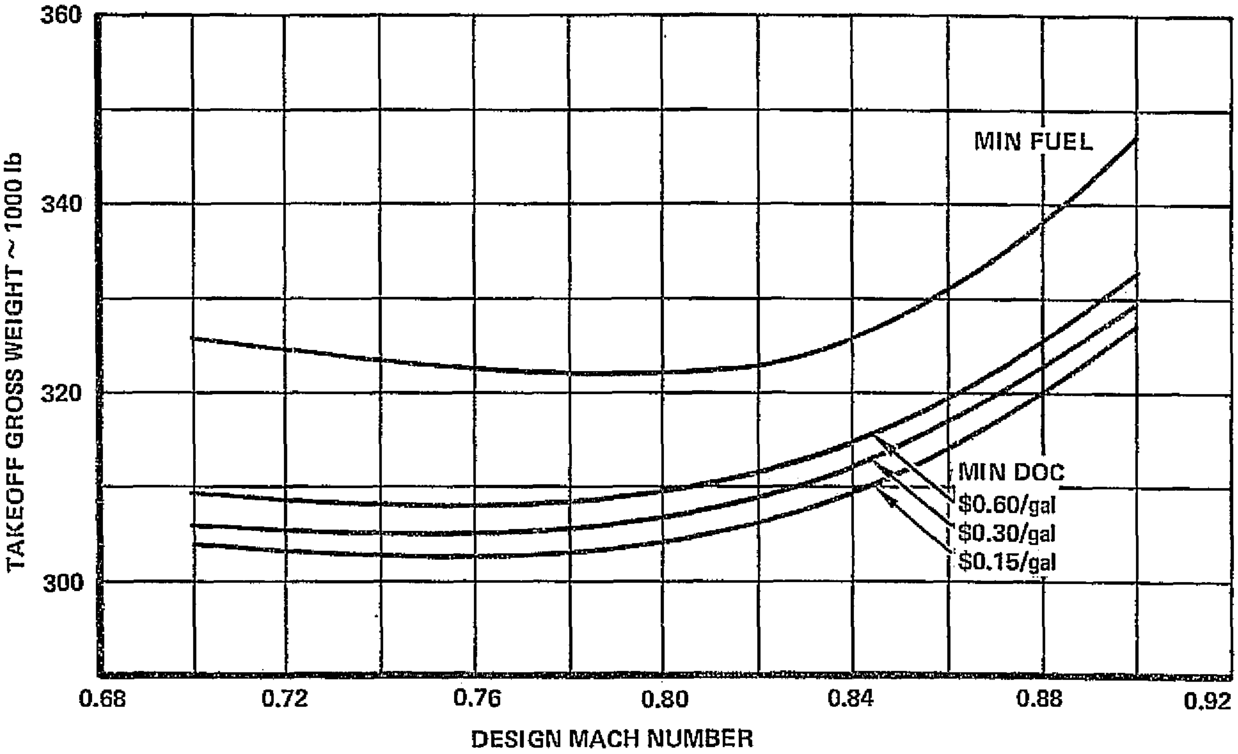


Figure 46.—Effect of design Mach number on takeoff gross weight

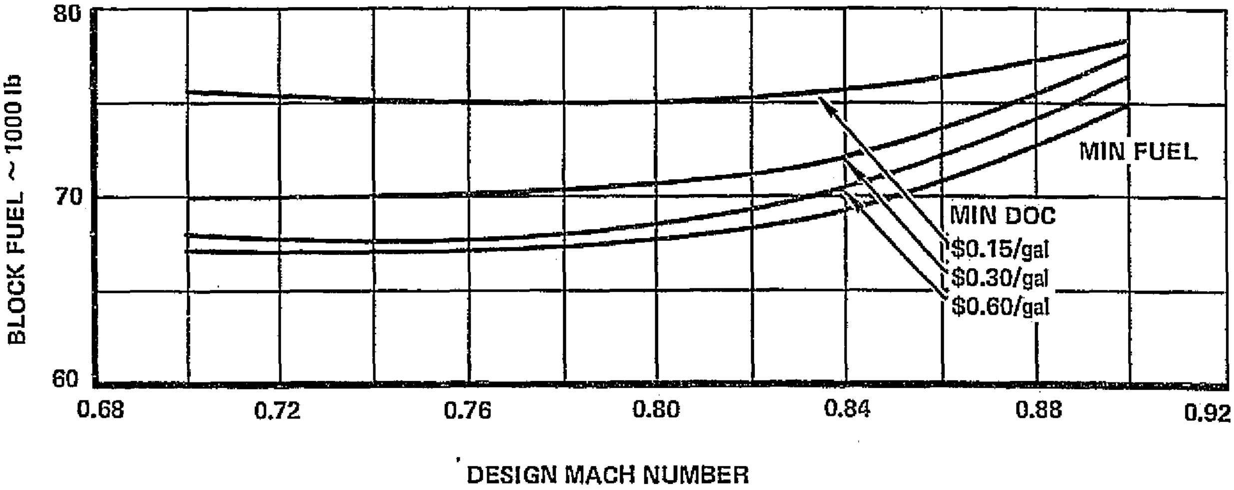


Figure 47.—Effect of design Mach number on block fuel

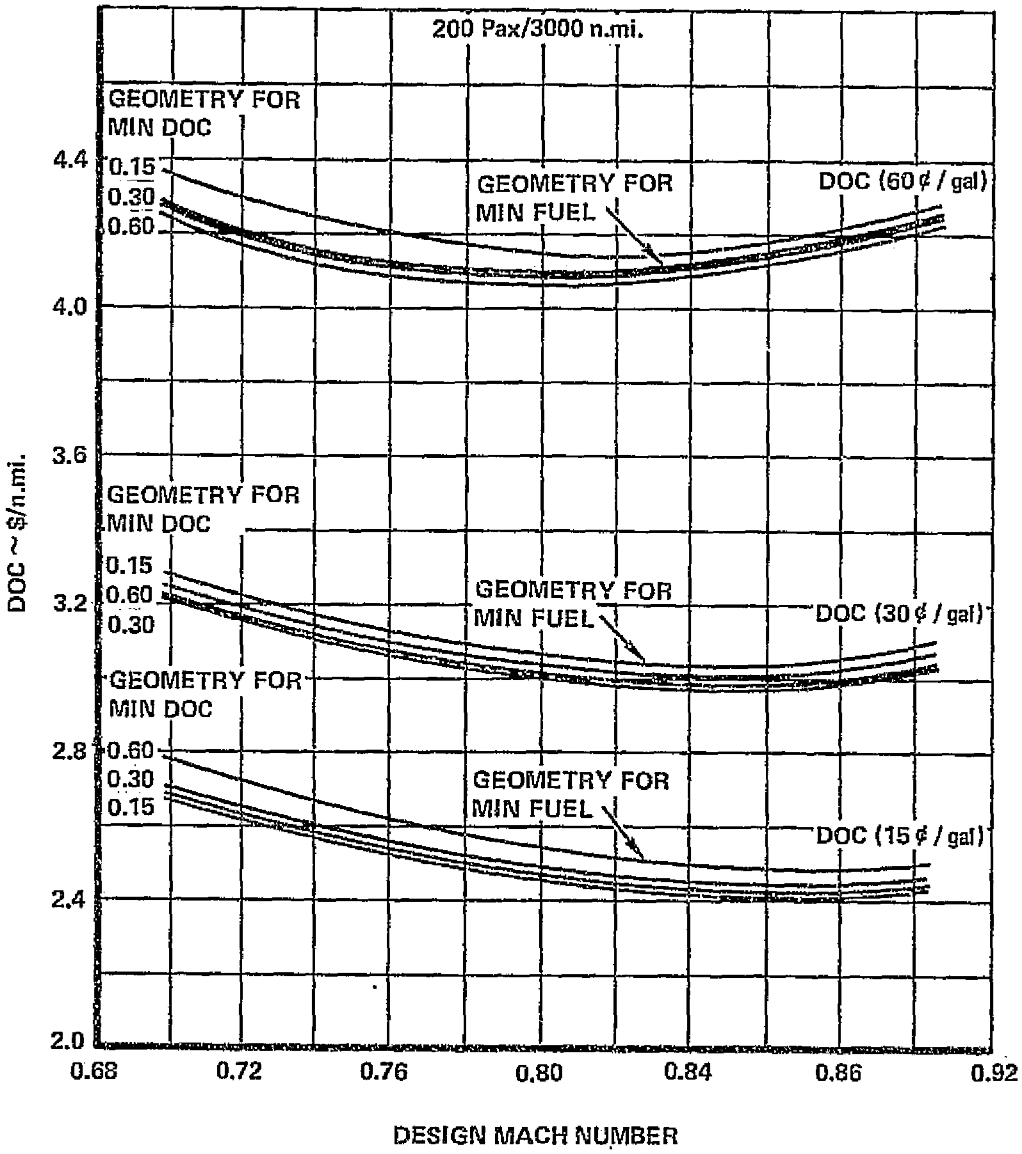
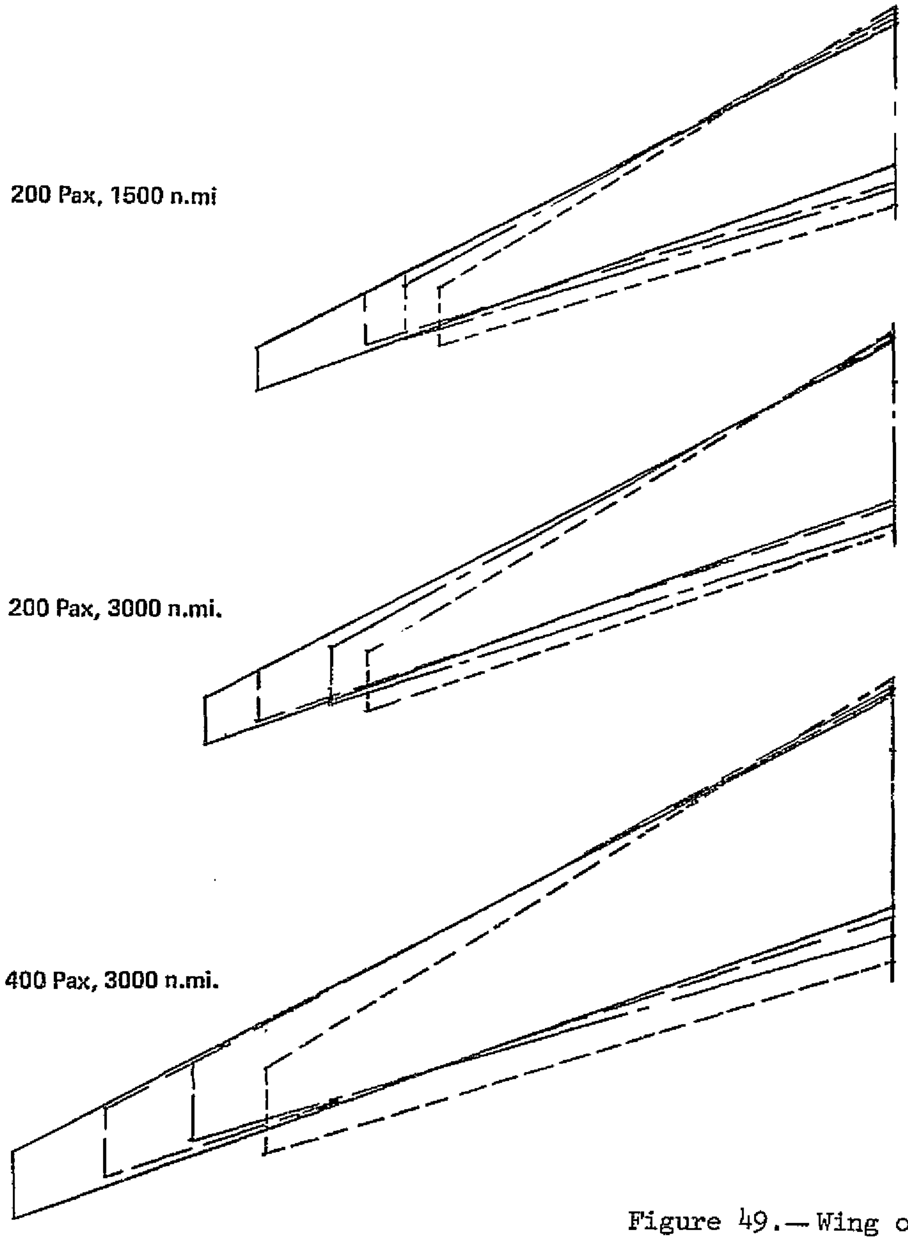


Figure 48.—Effect of design Mach number on direct operating cost



	MIN FUEL	FUEL PRICE [¢]		
		60	30	15
$\Lambda_{0.25c}$	25	25	26	28
AR	14	9.9	8.6	7.1
S[ft^2]	2144	2079	2057	2145
b [ft]	173.3	143.5	133	123.4

$\Lambda_{0.25c}$	25	25	26	28
AR	13.4	11.8	9.3	8.2
S[ft^2]	2612	2543	2527	2510
b[ft]	187.1	173.2	153	143.5

$\Lambda_{0.25c}$	25	25	25	28
AR	12.7	10.8	8.6	6.8
S[ft^2]	4477	4255	4200	4255
b[ft]	238.5	214.4	190	170.1

———————	MIN FUEL
—— —— ——	60 ¢
——— – ———	30 ¢
– – – – – –	15 ¢

Figure 49.— Wing optimization

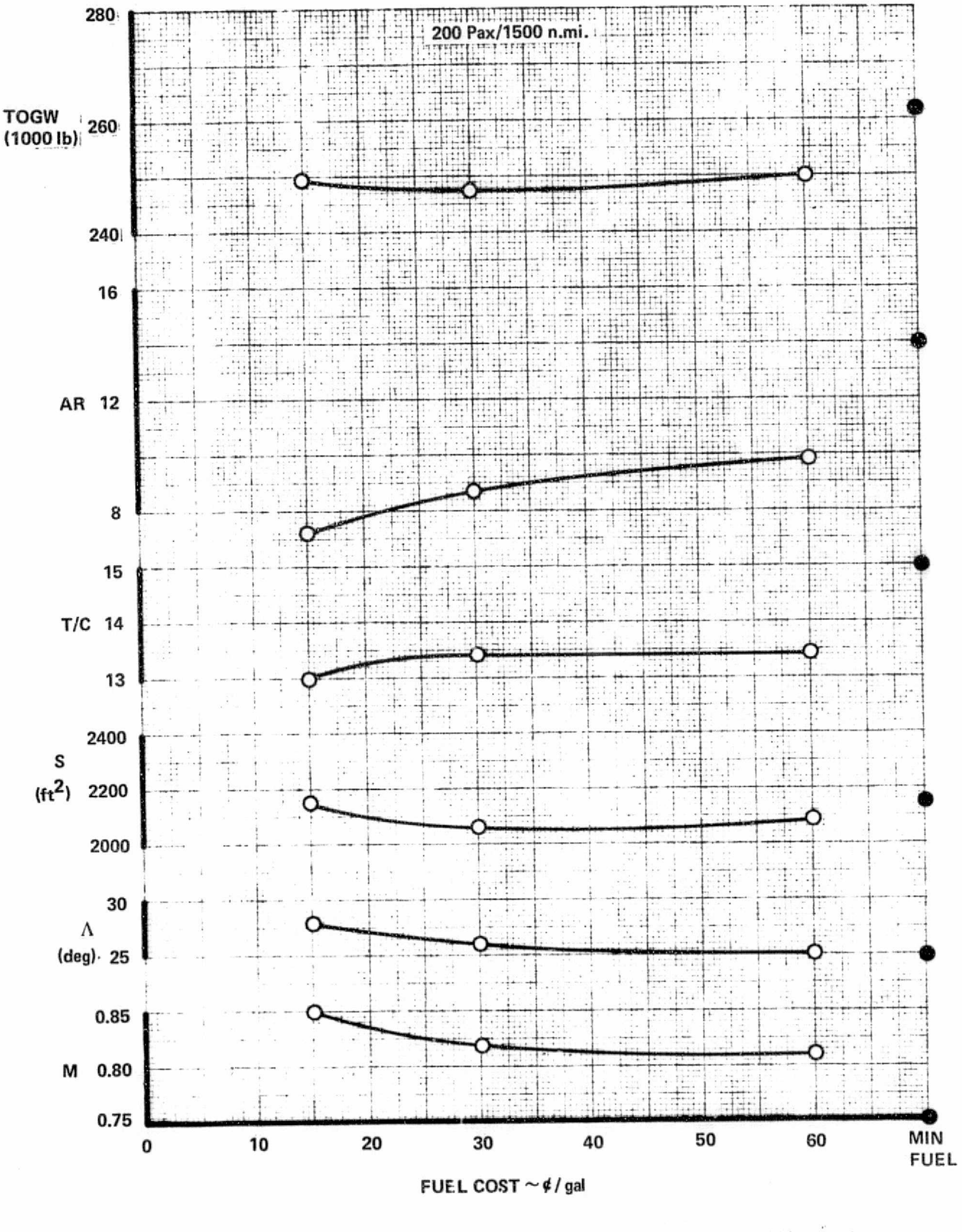


Figure 50.—Design trends with fuel cost - 200 pax 1500 n.mi.

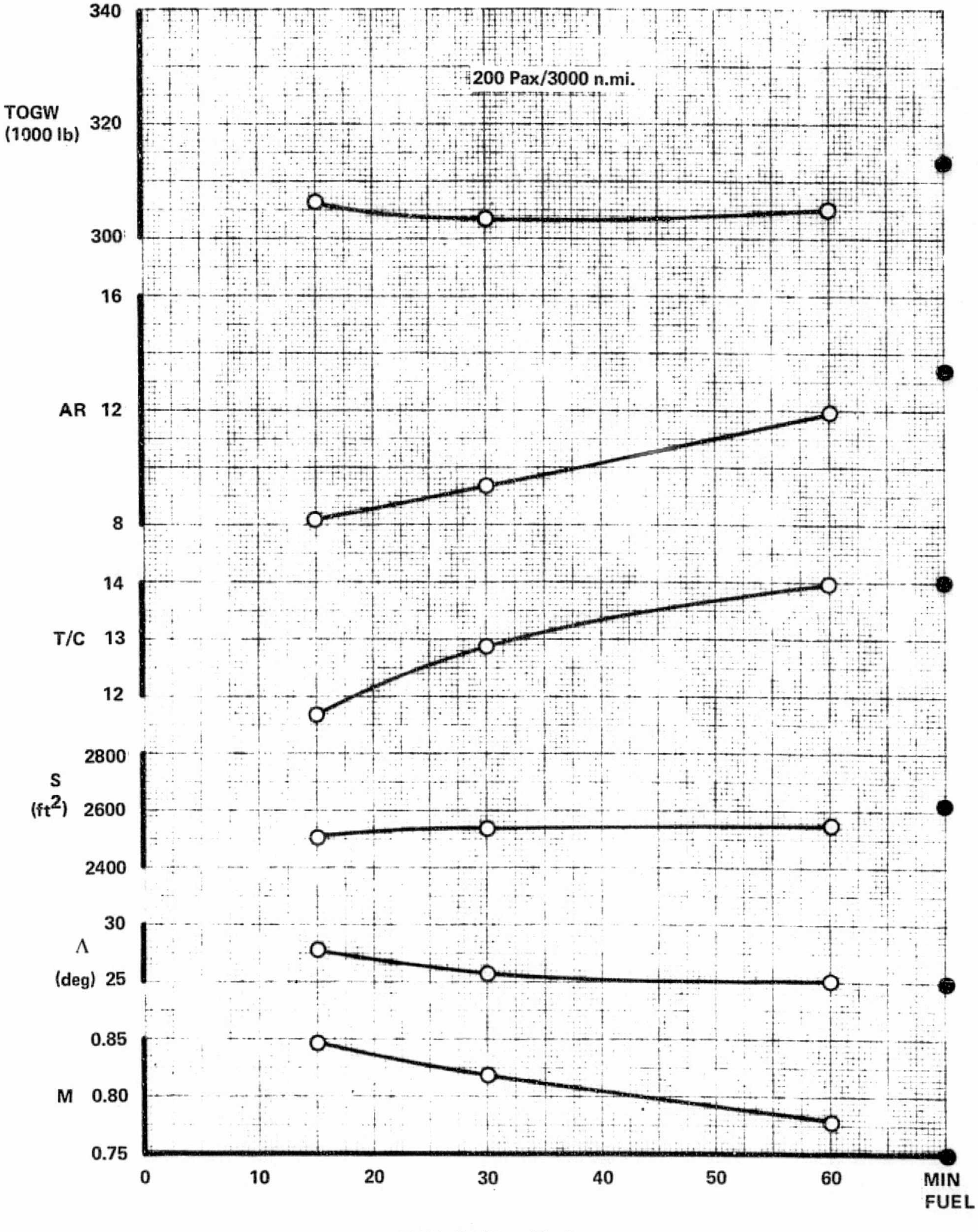


Figure 51.—Design trends with fuel cost - 200 pax 3000 n.mi.

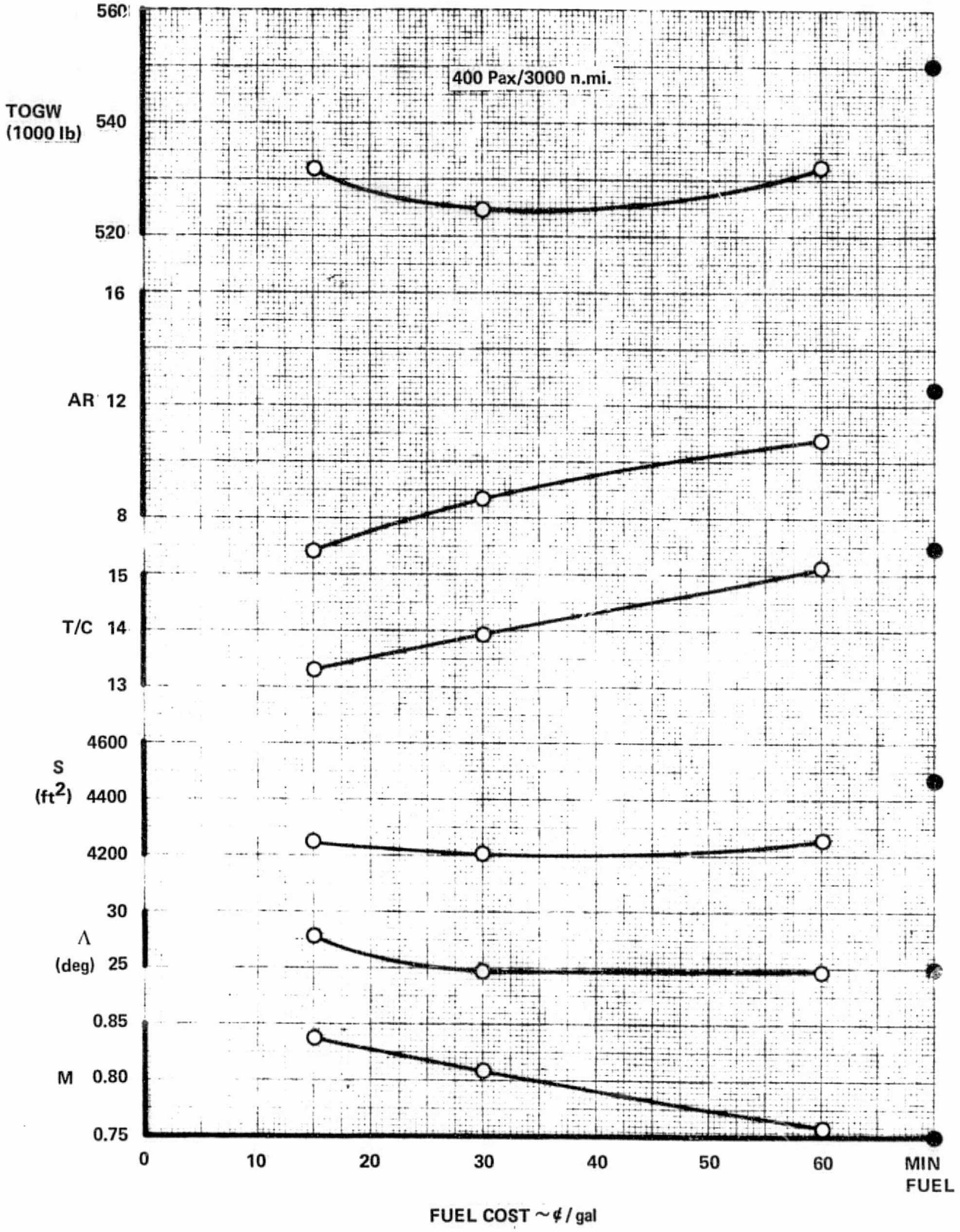


Figure 52.—Design trends with fuel cost - 400 pax 3000 n.mi.

CHARACTERISTICS	WING	HORIZ	VERT
AREA (ft^2)	2000	600	236
ASPECT RATIO	12	6	1.6
SPAN (ft)	154.9	60	19.43
ROOT CHORD (in.)	238.4	171.5	224.2
TIP CHORD (in.)	71.5	68.5	67.3
TAPER RATIO	0.30	0.40	0.30
MAC (in.)	169	125	153
SWEEP C/4 (deg)	15	20	35
T/C ROOT (%)	18	12	12
T/C TIP (%)	14	12	12

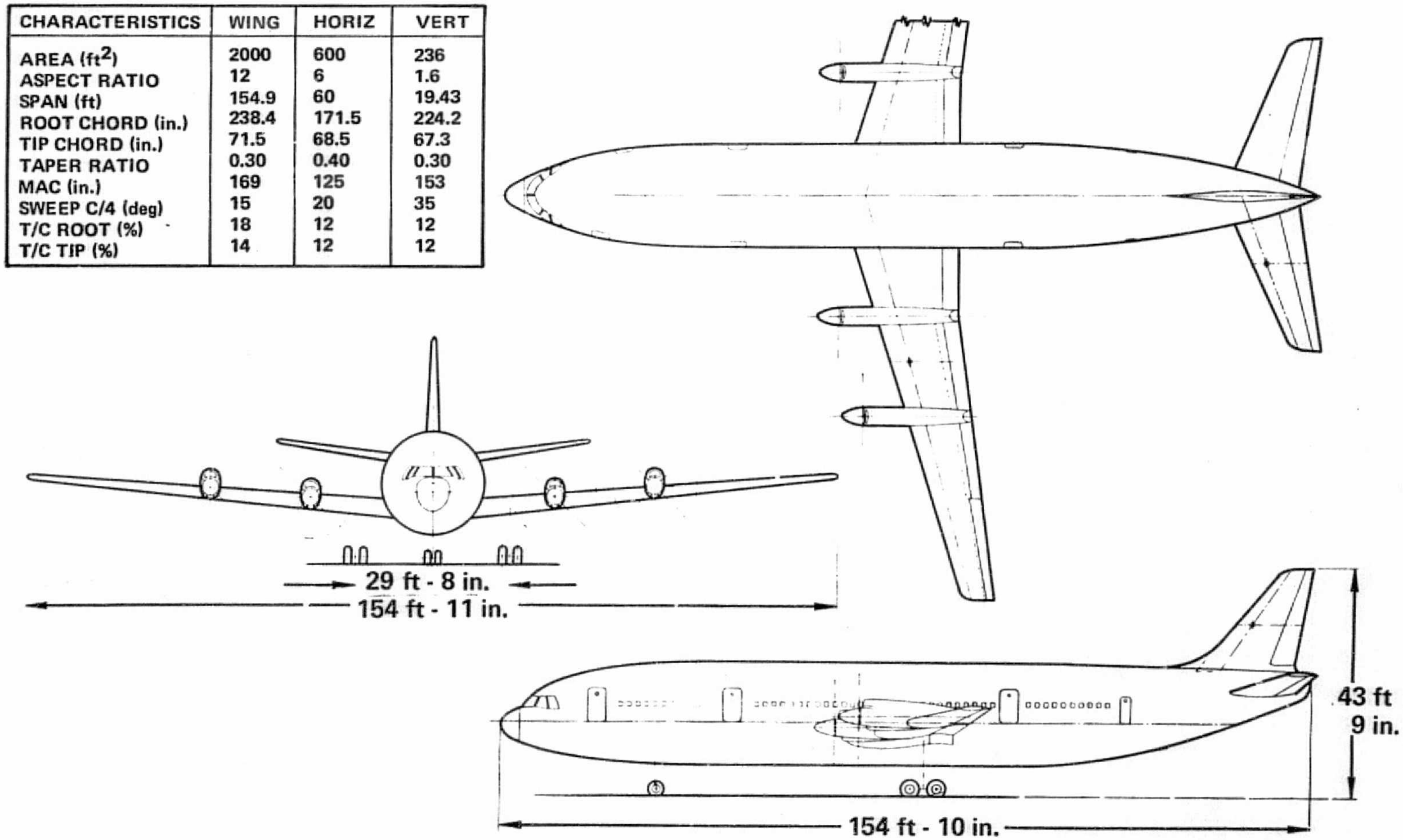


Figure 53.—M 0.65 turboprop transport

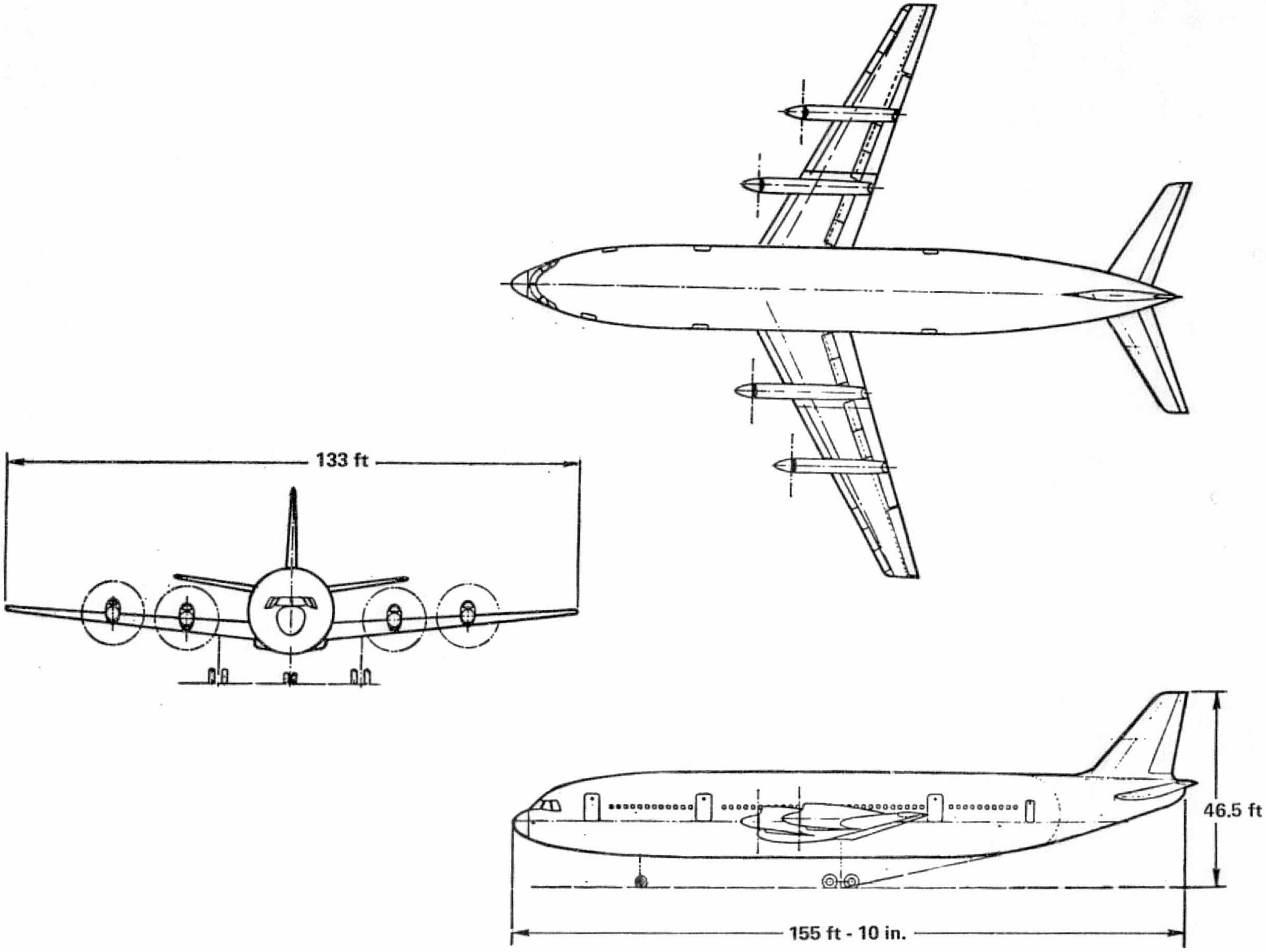


Figure 54.—M 0.80 turboprop concept - 4 engine

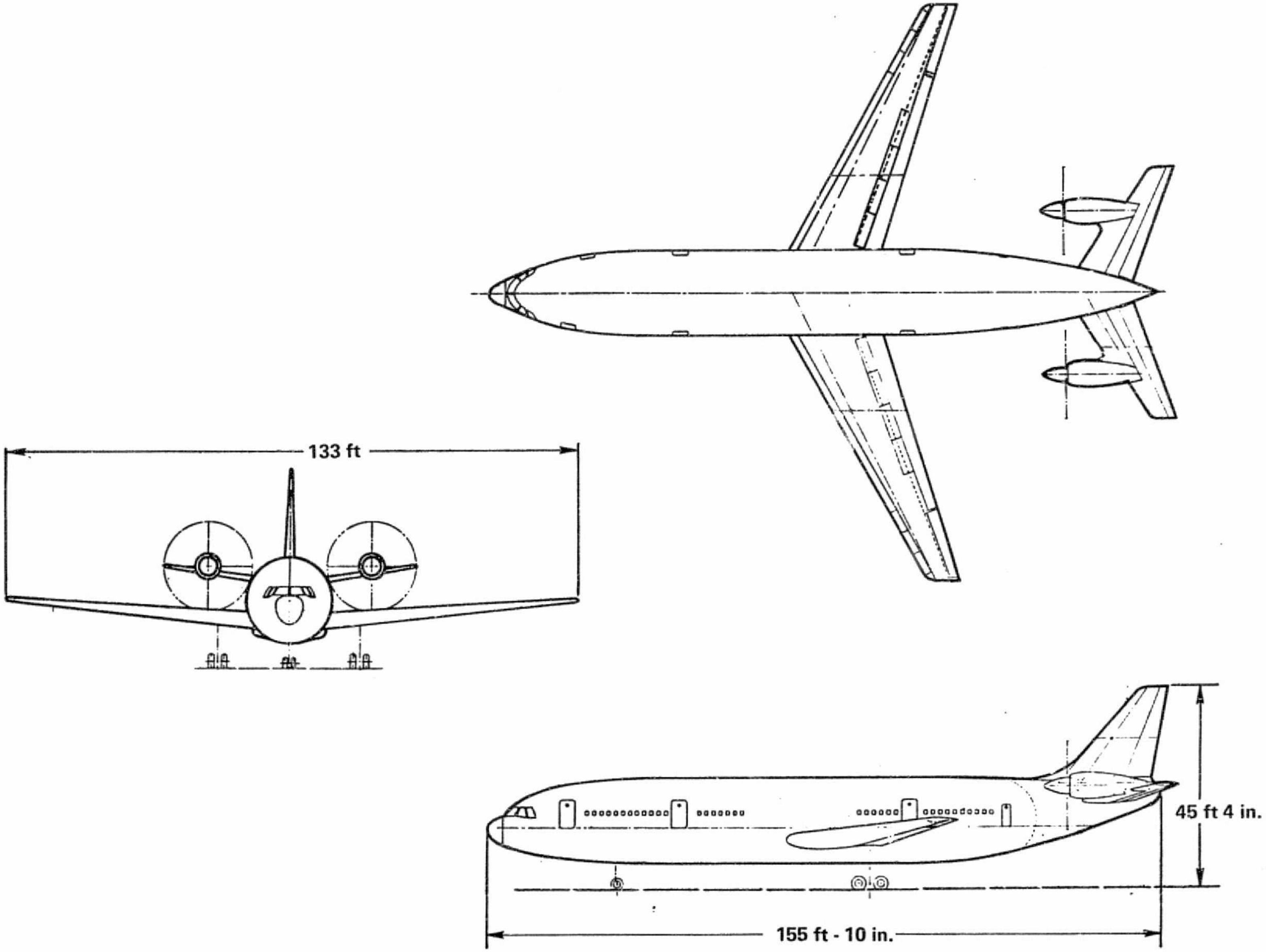


Figure 55.— M 0.80 turboprop concept - 2 engine

TABLE 52.- PAYLOAD/RANGE AND DESIGN CRITERIA

Size			
Passengers	200	200	400
Range (n.mi.)	1500	3000	3000
Design Criteria			
Minimum DOC (15¢/gal Fuel)	X	X	X
Minimum DOC (30¢/gal Fuel)	X	X	X
Minimum DOC (60¢/gal Fuel)	X	X	X
Minimum Fuel	X	X	X
Powerplants			
Turbofan	X	X	X
Turboprop	X		

TABLE 53.- NEW NEAR-TERM AIRCRAFT PARAMETRIC DESIGN MATRIX

M	0.70				0.75				0.82				0.90			
Sweep Angle	25	30	35	40	25	30	35	40	25	30	35	40	25	30	35	40
t/c	9	12	14	16	9	12	14	16	9	12	14	16	7	9	11	13
AR	7	9	12	14	7	9	12	14	7	9	12	14	5	7	9	12
W/S	110	120	125	130	110	120	125	130	110	120	125	130	110	120	125	130
T/W	.22	.26	.30	.32	.22	.26	.30	.32	.22	.26	.30	.32	.26	.28	.30	.34

TABLE 54.- CHARACTERISTICS SUMMARY - MINIMUM DOC WITH 15¢ PER GALLON FUEL

	Pax 200 Range 1500	Pax 200 Range 3000	Pax 400 Range 3000
M_{CRUISE}	0.85	0.85	0.84
AR	7.1	8.2	6.8
t/c	13.0	11.7	13.3
TOGW	248 816	306 177	531 918
Wing Area	2145	2510	4255
W/S	116	122	125
T/W	0.32	0.282	0.27
Total Thrust	79 620	86 340	143 616
Wing Sweep	28°	28°	28°
Block Fuel	36 401	74 162	134 133
Payload (58% Pax)	23 200	23 200	46 400
OEW	155 060	178 512	293 482

TABLE 55.- CHARACTERISTICS SUMMARY - MINIMUM DOC WITH 30¢ PER GALLON GUEL

	Pax 200 Range 1500	Pax 200 Range 3000	Pax 400 Range 3000
M_{CRUISE}	0.82	0.82	0.81
AR	8.6	9.3	8.6
t/c	13.4	12.8	13.9
TOGW	246 850	303 251	524 993
Wing Area	2057	2527	4200
W/S	120	120	125
T/W	0.32	0.28	0.27
Total Thrust	78 988	84 908	141 748
Wing Sweep	26°	26°	25°
Block Fuel	33 562	70 601	122 065
Payload (58% Pax)	23 200	23 200	46 400
OEW	160 634	179 572	300 066

TABLE 56.- CHARACTERISTICS SUMMARY - MINIMUM DOC WITH 60¢ PER GALLON FUEL

	Pax 200 Range 1500	Pax 200 Range 3000	Pax 400 Range 3000
M_{CRUISE}	0.81	0.78	0.76
AR	9.9	11.8	10.8
t/c	13.4	14	15.1
TOGW	249 529	305 145	531 863
Wing Area	2079	2543	4255
W/S	120	120	125
T/W	0.32	0.28	0.27
Total Thrust	79 848	85 440	143 600
Wing Sweep	25°	25°	25°
Block Fuel	32 354	66 275	115 556
Payload (58% Pax)	23 200	23 200	46 400
OEW	164 847	186 291	314 308

TABLE 57.- CHARACTERISTICS SUMMARY - MINIMUM FUEL

	Pax 200 Range 1500	Pax 200 Range 3000	Pax 400 Range 3000
M_{CRUISE}	0.75	0.75	0.75
AR	14.0	13.4	12.7
t/c	15.0	14.0	15.5
TOGW	261 547	313 394	550 630
Wing Area	2144	2612	4477
W/S	122	120	123
T/W	0.325	0.28	0.27
Total Thrust	85 000	87 748	146 464
Wing Sweep	25°	25°	25°
Block Fuel	30 777	65 144	113 466
Payload (58% Pax)	23 200	23 200	46 400
OEW	178 943	195 652	335 129

TABLE 38. - ASSET PRINTOUT - CONFIGURATION GEOMETRY

ENERGY CONSERVATION AIRCRAFT/200 PASS/3000 N.MI./M = 0.78 MISS

T/C	T/R	AR	LAM	W/S	T/W
14.00	0.30	11.80	25.00	120.0	0.280

Wing	Area (sq ft) 2542.9	Span (ft) 173.22	Taper Ratio 0.300	C/4 Sweep (deg) 25.000	L.E. Sweep (deg) 27.110	L.E.R/ Chord 0.0	
	CR (ft) 22.58	CT (ft) 6.78	MAC (ft) 16.10	CRE (ft) 20.80	S Wet (sq ft) 4586.0	Ref L (ft) 16.10	
Wing Tank	CBAR 1 (ft) 20.80	CBAR 2 (ft) 7.92	FTL (ft) 70.54	FVWING (cu ft) 2124.61	FVBOX (cu ft) 521.69		
Fuselage	Length (ft) 155.87	S Wet (sq ft) 7143.0	BWW (ft) 19.58	Equiv D (ft) 19.57	SPI (sq ft) 300.95		
	BW (ft) 19.58	BH (ft) 19.58	SBW (sq ft) 7143.00	FVB (cu ft) 3333.00			
Tail	Sht (sq ft) 689.63	SHTX (sq ft) 454.19	HT Ref L (ft) 12.10	SVT (sq ft) 529.45	SVTX (sq ft) 356.77	VT Ref L (ft) 16.60	
Propulsion	Eng L (ft) 7.85	Eng D (ft) 5.10	Pod L (ft) 11.44	Pod D (ft) 5.15	Pod S Wet (sq ft) 741.10	No. Pods 4.	Inlet L (ft) 0.0

TABLE 59. - ASSET PRINTOUT - WEIGHT BREAKDOWN

ENERGY CONSERVATION AIRCRAFT/200 PASS/3000 N.MI./M = 0.78 MISS

T/C	T/R	AR	LAM	W/S	T/W
14.00	0.30	11.80	25.00	120.0	0.280

		Pounds	0/0	Pounds	0/0
Design Gross Weight		305145.	100.00		
Fuel		78853.	25.84		
Zero Fuel Weight				226292.	
Payload		40000.	13.11		
Operating Weight Empty				186292.	61.05
Operational Items		10230.	3.35		
Standard Items		3311.	1.08		
Empty Weight-Mfg.				172752.	
Wing		39435.	12.92		
Tail		5332.	1.75		
Body		37089.	12.15		
Landing Gear		14132.	4.63		
Flight Controls		4244.	1.39		
Nacelles		4626.	1.52		
Propulsion System		27546.	9.03		
Engine	20912.				
Air Intake	903.				
Exhaust	4051.				
Cooling	0.				
Oil System (Less Oil)	11.				
Engine Controls	117.				
Engine Starting	361.				
Tanks	1191.				
Insulation	0.				
Fuel-Plumbing	0.				
Instruments		880.	0.29		
Hydraulics		1892.	0.62		
Electrical		6126.	2.01		
Electronics		2146.	0.70		
Furnishings and Equip.		22663.	7.43		
Air Conditioning		5258.	1.72		
Anti-Icing		266.	0.09		
Auxiliary Power Unit		1116.	0.37		
Miscellaneous		0.	0.0		
Design Reserve		0.	0.0		
No. of Passengers		200.			
No. of Crew		10.			
Structural T/C		17.33			
Fuel Volume Reqd		1550.1			
Wing Fuel Volume Available		2646.3			

TABLE 60. - ASSET PRINTOUT - MISSION SUMMARY

Energy Conservation Aircraft/200 Pass/3000 n.mi./M = 0.78 Miss

Segment	Init Altitude (ft)	Init Mach No.	Init Weight (lb)	Segmt Fuel (lb)	Total Fuel (lb)	Segmt Dist (n.mi.)	Total Dist (n.mi.)	Segmt Time (min)	Total Time (min)	Extern Store Tab ID	Engine Thrust Tab ID	Extern F Tank Tab ID	Avg L/D Ratio	Avg SFC (ff/t)
Takeoff														
Power 1	0	0	305 145	395	395	0	0	9.0	9.0	0	-340 101	0	0	1.655
Power 2	0	0	304 750	189	584	0	0	0.4	9.4	0	380 401	0	0	0.370
Climb	0	0.378	304 561	1649	2232	17	17	3.8	13.2	0	340 201	0	20.56	0.559
Accel	10 000	0.456	302 913	249	2481	3	20	0.6	13.8	0	340 201	0	19.17	0.537
Climb	10 000	0.547	302 664	8110	10 591	233	254	32.0	45.8	0	340 201	0	18.01	0.655
Cruise	37 000	0.780	294 554	54 124	64 714	2622	2876	351.7	397.5	0	-340 101	0	19.05	0.660
Descent	41 000	0.780	240 430	523	65 238	87	2963	12.3	409.8	0	340 301	0	15.96	-0.178
Decel	10 000	0.547	239 907	46	65 283	5	2967	0.8	410.7	0	340 301	0	17.07	4.473
Descent	10 000	0.456	239 861	479	65 762	35	3002	7.9	418.5	0	340 301	0	18.57	8.281
Cruise	41 000	0.780	239 382	19	65 781	1	3003	0.1	418.7	0	-340 101	0	18.86	0.663
Loiter	1500	0.410	239 364	494	66 275	0	3003	3.0	421.7	0	-340 101	0	17.67	0.730
Reset	0	0	238 869	0	66 275	0	3003	0	421.7	0	0	0	0	0
Reset	0	0	238 869	0	66 275	-3003	0	-421.7	0	0	0	0	0	0
Climb	0	0.378	238 869	1220	67 495	13	13	2.8	2.8	0	340 201	0	18.44	0.555
Accel	10 000	0.456	237 650	183	67 677	2	15	0.5	3.3	0	340 201	0	16.85	0.587
Climb	10 000	0.547	237 467	3266	70 943	74	89	10.6	13.9	0	340 201	0	14.89	0.645
Cruise	30 000	0.680	234 201	220	71 163	10	100	1.5	15.4	0	-340 101	0	17.83	0.656
Descent	30 000	0.780	233 981	355	71 518	54	154	8.0	23.5	0	340 301	0	14.83	-2.486
Decel	10 000	0.547	233 626	45	71 563	4	159	0.8	24.3	0	340 301	0	16.79	4.495
Descent	10 000	0.456	233 582	388	71 951	29	188	6.5	30.8	0	340 301	0	18.32	9.195
Cruise	30 000	0.680	233 194	247	72 197	12	200	1.7	32.5	0	-340 101	0	17.79	0.656
Cruise	0	0.378	232 947	314	72 511	0	200	2.0	34.5	0	-340 101	0	18.31	0.742
Cruise	30 000	0.680	232 633	6409	78 920	0	200	45.0	79.5	0	-340 101	0	17.64	0.657

TOGRWT = 305 145.0 Fuel A = 78 853.1 Fuel R = 78 920.0

TABLE 61. - ASSET PRINTOUT - COST SUMMARY

Wing		1 528 201.00		
Tail		263 451.95		
Body		1 547 845.00		
Landing Gear		311 303.69		
Flight Controls		240 992.94		
Nacelles		267 451.94		
Propulsion				
Engine	25 948.94			
Air Induction	52 192.23			
Fuel System	216 391.69			
Start System	5926.05			
Engine.Controls	2353.13			
Exh/Thrust Rev.	4944.67			
Lube System	2139.02			
Total Propulsion		309 895.56		
Instruments		104 757.19		
Hydraulics		131 543.69		
Electrical		523 111.94		
Electronic Racks		125 479.19		
Furnishing		476 589.06		
Air Conditioning		431 488.75		
Anti Icing		21 830.84		
APU		122 810.38		
Sys. Integration		217 340.75		
Total Empty Mfg. Cost			6 624 079.00	
Sustaining Engineer	469 994.13			
Technical Data	0			
Prod. Tooling Maint.	622 051.31			
Misc.	165 880.31			
Eng. Change Order	0			
Quality Assurance	619 286.56			
Airframe Warranty		425 064.44		
Airframe Fee		1 338 952.00		
Airframe Cost			10 265 306.00	
Engine Warranty		124 482.38		
Engine Fee		313 695.44		
Engine Cost			2 927 825.00	
Avionics Cost			500 000.00	
Research and Development			1 781 829.00	
Total Fly Away Cost				15 474 960.00

R and D	
Development Technical Data	9 498 358
Design Engineering	211 074 640
Development Tooling	125 910 928
Development Test Article	33 961 769
Flight Test	30 650 912
Special Support Equipment	2 532 895
Development Spares	31 828 526
Engine Development	0
Avionics Development	0
Total R and D	445 457 152

TABLE 61. - Concluded.

Direct Operating Cost-Dollars/n. mi.		0/0
Crew	0.6084	24.40
Airframe Labor and Burden Maint.	0.1946	7.80
Engine Labor and Burden Maint.	0.1509	6.05
Airframe Material Maint.	0.0820	3.29
Engine Material Maint.	0.1374	5.51
Fuel and Oil	0.4965	19.91
Insurance	0.1102	4.42
Depreciation (Including Spares)	0.7131	28.60
Total Doc $/n.mi.	2.4932	100.00

Range n.mi.	756	1130	1505	1879	2254	2629	3003
DOC C/ASM	1.5242	1.4012	1.3395	1.3024	1.2776	1.2599	1.2466
TB-hr	2.0038	2.8412	3.6785	4.5159	5.3533	6.1906	7.0280
$/Trp	2303	3167	4031	4895	5760	6624	7488

TABLE 62.- CALCULATED FUEL CONSUMPTION -
NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Fuel Consumption			
	lb	gal/n.mi.	seat-n.mi./gal	Btu/seat-n.mi.
100	3000	4.42	45.33	2790
200	5400	3.97	50.38	2511
400	9600	3.53	56.67	2232
600	13 800	3.38	59.13	2139
1000	21 700	3.19	62.67	2018
1500	31 400	3.08	64.97	1947
2000	41 700	3.07	65.23	1939
2449	51 134	3.07	65.14	1942
475	11 144	3.45	57.60	2190

TABLE 63.- CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	235	1326	2.85	3731	8.02
200	293	1190	2.02	2520	4.28
400	348	1106	1.59	1726	2.48
600	376	1070	1.43	1394	1.86
1000	410	1039	1.27	1106	1.35
1500	428	1028	1.20	940	1.10
2000	438	1011	1.16	849	0.97
2449	443	1010	1.14	840	0.95
475	360	1090	1.49	1570	2.15

*15¢/gal Fuel Cost

TABLE 64.- CALCULATED TOTAL OPERATING COSTS - NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	235	1482	3.19	3739	8.04
200	293	1383	2.35	2440	4.15
400	348	1293	1.86	1736	2.50
600	376	1264	1.69	1404	1.87
1000	410	1239	1.51	1116	1.36
1500	428	1222	1.43	930	1.09
2000	438	1216	1.39	860	0.98
2449	443	1213	1.37	820	0.93
475	360	1285	1.76	1590	2.18

*30¢/gal Fuel Cost

TABLE 65.- CALCULATED TOTAL OPERATING COSTS - NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi	$/blk-hr	¢/seat-n.mi.
100	235	1795	3.86	3756	8.08
200	293	1733	2.95	2460	4.18
400	348	1668	2.40	1756	2.52
600	376	1651	2.20	1424	1.90
1000	410	1638	2.00	1137	1.39
1500	428	1632	1.90	960	1.12
2000	438	1626	1.86	881	1.01
2449	443	1625	1.83	840	0.95
475	360	1660	2.27	1605	2.20

*60¢/gal Fuel Cost

TABLE 66. DIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	1500	2000	2449	475
Crew	0.48	0.40	0.32	0.30	0.27	0.26	0.26	0.25	0.31
Insurance	0.10	0.09	0.07	0.06	0.06	0.06	0.05	0.05	0.06
Depreciation	0.66	0.56	0.44	0.41	0.37	0.35	0.35	0.34	0.43
Maintenance	1.28	0.68	0.49	0.40	0.32	0.27	0.27	0.27	0.43
Fuel (15¢/gal)	0.34	0.29	0.27	0.26	0.24	0.24	0.24	0.23	0.26
Total DOC	2.85	2.02	1.59	1.43	1.27	1.20	1.16	1.14	1.49
Fuel (30¢/gal)	0.68	0.62	0.54	0.52	0.49	0.48	0.47	0.46	0.53
Total DOC	3.19	2.35	1.86	1.69	1.51	1.43	1.39	1.37	1.76
Fuel (60¢/gal)	1.35	1.22	1.08	1.03	0.98	0.95	0.94	0.92	1.04
Total DOC	3.8[illegible]	2.95	2.40	2.20	2.00	1.90	1.86	1.83	2.27

TABLE 67. INDIRECT OPERATING COST BREAKDOWN -
NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.*								
	100	200	400	600	1000	1500	2000	2449	475
System Expense	0.15	0.11	0.06	0.05	0.04	0.03	0.03	0.02	0.05
Local Expense	1.82	0.75	0.44	0.30	0.18	0.12	0.09	0.07	0.37
A/C Control Expense	0.10	0.06	0.03	0.02	0.01	0.01	0.01	0.01	0.02
Hostess Expense	0.29	0.25	0.20	0.18	0.17	0.16	0.16	0.15	0.19
Food and Beverage	0.28	0.24	0.19	0.17	0.16	0.15	0.15	0.14	0.18
Passenger Service	3.14	1.40	0.79	0.52	0.32	0.20	0.16	0.15	0.66
Cargo Handling	1.51	0.74	0.37	0.25	0.15	0.09	0.08	0.07	0.31
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.53	0.37	0.19	0.16	0.12	0.10	0.10	0.09	0.18
Total IOC	8.04	4.15	2.50	1.87	1.36	1.09	0.98	0.93	2.18

*30¢/gal Fuel Cost

TABLE 68. - CALCULATED FUEL CONSUMPTION -
NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/1500 N.M.I RANGE

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal / n.mi.	seat-n.mi. / gal	Btu / seat-n.mi.
100	3 000	4.41	45.35	2790
200	5 400	3.97	50.38	2511
400	9 500	3.49	57.27	2209
600	13 500	3.31	60.45	2092
1000	21 000	3.09	64.77	1953
1500	30 400	2.98	67.10	1885
2000	40 100	2.95	67.83	1865
2488	49 912	2.95	67.79	1866
475	11 047	3.42	58.50	2150

TABLE 69. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	TOTAL DOC*		TOTAL IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	230	1346	2.89	3742	8.05
200	287	1270	2.13	2420	4.25
400	344	1145	1.62	1719	2.49
600	374	1081	1.44	1397	1.86
1000	405	1043	1.29	1098	1.36
1500	423	1025	1.20	910	1.08
2000	432	1014	1.17	843	0.98
2488	438	1010	1.18	820	0.94
475	360	1120	1.53	1550	2.12

*15¢/gal Fuel Cost

TABLE 70. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	230	1503	3.23	3751	8.06
200	287	1395	2.44	2400	4.20
400	344	1300	1.89	1729	2.51
600	374	1270	1.69	1407	1.88
1000	405	1234	1.52	1109	1.37
1500	423	1212	1.43	940	1.11
2000	432	1208	1.40	853	0.99
2488	438	1210	1.38	820	0.94
475	360	1290	1.77	1600	2.19

*30¢/gal Fuel Cost

TABLE 71. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	230	1816	3.90	3767	8.10
200	287	1745	3.05	2460	4.31
400	344	1668	2.42	1748	2.53
600	374	1649	2.20	1427	1.90
1000	405	1616	2.01	1129	1.39
1500	423	1602	1.90	960	1.14
2000	432	1597	1.85	874	1.01
2488	438	1600	1.83	825	0.94
475	360	1660	2.27	1610	2.20

*60¢/gal Fuel Cost

TABLE 72. DIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	1500	2000	2488	475
Crew	0.48	0.40	0.33	0.30	0.28	0.26	0.26	0.26	0.31
Insurance	0.10	0.09	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Depreciation	0.67	0.53	0.45	0.42	0.39	0.36	0.36	0.36	0.43
Maintenance	1.30	0.80	0.51	0.41	0.33	0.28	0.27	0.27	0.46
Fuel (15¢/gal)	0.34	0.31	0.27	0.25	0.24	0.24	0.23	0.23	0.27
Total DOC	2.89	2.13	1.62	1.44	1.29	1.20	1.17	1.18	1.53
Fuel (30¢/gal)	0.68	0.61	0.53	0.51	0.47	0.46	0.45	0.45	0.51
Total DOC	3.23	2.44	1.89	1.69	1.52	1.43	1.40	1.38	1.77
Fuel (60¢/gal)	1.35	1.20	1.05	0.99	0.94	0.91	0.90	0.90	1.01
Total DOC	3.90	3.05	2.42	2.20	2.01	1.90	1.85	1.83	2.27

TABLE 73. INDIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/1500 N.MI. RANGE

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.*								
	100	200	400	600	1000	1500	2000	2488	475
System Expense	0.15	0.11	0.06	0.05	0.04	0.04	0.03	0.02	0.05
Local Expense	1.83	0.80	0.44	0.31	0.18	0.13	0.09	0.08	0.38
A/C Control Expense	0.10	0.07	0.03	0.02	0.01	0.01	0.01	0.01	0.02
Hostess Expense	0.29	0.25	0.20	0.18	0.17	0.16	0.16	0.15	0.18
Food and Beverage	0.28	0.24	0.19	0.17	0.16	0.15	0.15	0.14	0.17
Passenger Service	3.14	1.40	0.79	0.52	0.32	0.20	0.16	0.15	0.67
Cargo Handling	1.51	0.74	0.37	0.25	0.15	0.09	0.08	0.08	0.31
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.53	0.36	0.20	0.16	0.12	0.10	0.10	0.08	0.18
Total IOC	8.06	4.20	2.51	1.88	1.37	1.11	0.99	0.94	2.19

*30¢/gal Fuel Cost

TABLE 74. - CALCULATED FUEL CONSUMPTION - NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal/n.mi.	seat-n.mi./gal	Btu/seat-n.mi.
100	3 000	4.41	45.35	2790
200	5 400	3.97	50.38	2511
400	9 500	3.49	57.27	2209
600	13 300	3.26	61.35	2062
1000	20 000	2.94	68.00	1860
1500	29 000	2.84	70.34	1798
2000	38 000	2.79	71.58	1767
2537	48 117	2.79	71.71	1764
475	10 982	3.40	59.00	2125

TABLE 75. - CALCULATED TOTAL OPERATING COSTS - NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	220	1392	3.13	3639	8.19
200	280	1300	2.[illegible]	2345	4.16
400	329	1154	1.76	1670	2.55
600	353	1111	1.57	1348	1.91
1000	381	1068	1.40	1064	1.39
1500	392	1025	1.31	900	1.15
2000	405	1036	1.28	816	1.01
2537	410	1020	1.24	745	0.91
475	340	1125	1.67	1505	2.23

*15¢/gal Fuel Cost

TABLE 76. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		\$/blk-hr	¢/seat-n.mi.	\$/blk-hr	¢/seat-n.mi.
100	220	1542	3.47	3647	8.21
200	280	1425	2.53	2330	4.14
400	329	1329	2.03	1679	2.56
600	353	1287	1.82	1357	1.92
1000	381	1240	1.62	1073	1.41
1500	392	1218	1.55	910	1.16
2000	405	1209	1.49	826	1.02
2537	410	1208	1.47	790	0.96
475	340	1312	1.95	1550	2.30

*30¢/gal Fuel Cost

TABLE 77. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/1500 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		\$/blk-hr	¢/seat-n.mi.	\$/blk-hr	¢/seat-n.mi.
100	220	1841	4.14	3663	8.24
200	280	1760	3.12	2400	4.26
400	329	1678	2.56	1697	2.59
600	353	1638	2.32	1376	1.95
1000	381	1582	2.07	1091	1.43
1500	392	1562	1.99	925	1.18
2000	405	1554	1.92	844	1.04
2537	410	1553	1.89	810	0.99
475	340	1660	2.46	1560	2.32

*60¢/gal Fuel Cost

TABLE 78. DIRECT OPERATING COST BREAKDOWN -
NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/1500 N.MI. RANGE

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	1500	2000	2537	475
Crew	0.52	0.42	0.35	0.33	0.30	0.28	0.28	0.27	0.34
Insurance	0.12	0.10	0.08	0.07	0.07	0.07	0.06	0.06	0.07
Depreciation	0.76	0.60	0.51	0.48	0.44	0.42	0.42	0.42	0.50
Maintenance	1.41	0.80	0.55	0.45	0.37	0.31	0.30	0.29	0.51
Fuel (15¢/gal)	0.34	0.31	0.27	0.25	0.23	0.22	0.21	0.20	0.25
Total DOC	3.13	2.23	1.76	1.57	1.40	1.31	1.28	1.24	1.67
Fuel (30¢/gal)	0.68	0.61	0.53	0.50	0.45	0.43	0.43	0.43	0.53
Total DOC	3.47	2.53	2.03	1.82	1.62	1.55	1.49	1.47	1.95
Fuel (60¢/gal)	1.35	1.20	1.07	1.01	0.90	0.85	0.85	0.85	1.04
Total DOC	4.14	3.12	2.56	2.32	2.07	1.99	1.92	1.89	2.46

TABLE 79. INDIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/1500 N.MI. RANGE

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.*								
	100	200	400	600	1000	1500	2000	2537	475
System Expense	0.17	0.11	0.07	0.05	0.04	0.03	0.03	0.02	0.06
Local Expense	1.92	0.83	0.47	0.32	0.19	0.12	0.10	0.09	0.42
A/C Control Expense	0.10	0.07	0.03	0.02	0.01	0.01	0.01	0.01	0.03
Hostess Expense	0.31	0.25	0.21	0.19	0.18	0.17	0.17	0.16	0.20
Food and Beverage	0.29	0.24	0.20	0.18	0.17	0.16	0.16	0.15	0.19
Passenger Service	3.14	1.40	0.79	0.52	0.32	0.20	0.16	0.15	0.67
Cargo Handling	1.51	0.74	0.36	0.25	0.15	0.09	0.08	0.09	0.32
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.54	0.33	0.20	0.16	0.13	0.11	0.10	0.08	0.18
Total IOC	8.21	4.14	2.56	1.92	1.41	1.16	1.02	0.96	2.30

*30¢/gal Fuel Cost

TABLE 80. - CALCULATED FUEL CONSUMPTION -
NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal/n.mi.	seat-n.mi./gal	Btu/seat-n.mi.
100	3500	5.15	38.83	3255
200	6000	4.41	45.37	2790
400	10 500	3.86	51.81	2441
600	15 000	3.68	54.35	2325
1000	23 000	3.38	59.17	2139
2000	43 900	3.23	61.92	2041
3000	66 100	3.24	61.73	2049
3899	87 946	3.32	60.24	2098
570	14 302	3.69	54.70	2340

TABLE 81. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		\$/blk-hr	¢/seat-n.mi.	\$/blk-hr	¢/seat-n.mi.
100	203	1334	3.27	3519	8.62
200	265	1250	2.46	2750	5.16
400	340	1168	1.84	2000	2.95
600	378	1120	1.48	1466	1.94
1000	409	1078	1.32	1150	1.40
2000	436	1045	1.20	871	1.01
3000	448	1039	1.16	774	0.86
3899	452	1050	1.19	750	0.83
570	372	1125	1.49	1500	1.99

*15¢/gal Fuel Cost

TABLE 82. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	203	1495	3.66	3527	8.64
200	265	1440	2.82	2830	5.31
400	340	1373	2.15	1940	2.86
600	378	1331	1.76	1477	1.96
1000	409	1290	1.57	1161	1.42
2000	436	1260	1.45	883	1.01
3000	448	1260	1.41	785	0.88
3899	452	1272	1.44	790	0.87
570	372	1338	1.77	1525	2.02

*30¢/gal Fuel Cost

TABLE 83. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	203	1815	4.45	3544	8.68
200	265	1803	3.48	2850	5.34
400	340	1775	2.75	1980	2.92
600	378	1755	2.33	1500	1.99
1000	409	1713	2.09	1183	1.44
2000	436	1689	1.94	905	1.04
3000	448	1703	1.90	809	0.90
3899	452	1728	1.96	810	0.90
570	372	1755	2.33	1550	2.05

*60¢/gal Fuel Cost

TABLE 84. DIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	3899	570
Crew	0.57	0.48	0.37	0.31	0.29	0.27	0.26	0.26	0.31
Insurance	0.11	0.09	0.07	0.06	0.06	0.05	0.05	0.05	0.06
Depreciation	0.74	0.59	0.46	0.40	0.37	0.35	0.34	0.34	0.40
Maintenance	1.46	0.94	0.63	0.43	0.35	0.29	0.27	0.28	0.44
Fuel (15¢/gal)	0.39	0.36	0.31	0.28	0.26	0.25	0.25	0.26	0.28
Total DOC	3.27	2.46	1.84	1.48	1.32	1.20	1.16	1.19	1.49
Fuel (30¢/gal)	0.79	0.72	0.62	0.56	0.52	0.49	0.50	0.51	0.56
Total DOC	3.66	2.82	2.15	1.76	1.57	1.45	1.41	1.44	1.77
Fuel (60¢/gal)	1.57	1.38	1.22	1.12	1.03	0.99	0.99	1.03	1.12
Total DOC	4.45	3.48	2.75	2.33	2.09	1.94	1.90	1.96	2.33

TABLE 85. INDIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM 30¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

IOC Component / Stage Length (n.mi.)		IOC ¢/seat-n.mi.*							
	100	200	400	600	1000	2000	3000	3899	570
System Expense	0.17	0.13	0.09	0.05	0.04	0.03	0.03	0.03	0.05
Local Expense	2.23	1.10	0.59	0.37	0.22	0.11	0.07	0.07	0.38
A/C Control Expense	0.10	0.07	0.03	0.02	0.01	0.01	0.01	0.01	0.02
Hostess Expense	0.33	0.29	0.23	0.18	0.17	0.16	0.15	0.15	0.19
Food and Beverage	0.32	0.28	0.22	0.17	0.16	0.15	0.15	0.15	0.18
Passenger Service	3.14	1.90	0.78	0.52	0.32	0.16	0.11	0.11	0.54
Cargo Handling	1.55	0.93	0.47	0.26	0.16	0.08	0.05	0.05	0.27
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.58	0.38	0.20	0.16	0.13	0.10	0.10	0.10	0.16
Total IOC	8.64	5.31	2.86	1.96	1.42	1.01	0.88	0.87	2.02

*30¢/gal Fuel Cost

TABLE 86. - CALCULATED FUEL CONSUMPTION -
NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal/n.mi.	seat-n.mi./gal	Btu/seat-n.mi.
100	3 500	5.15	38.83	3255
200	6 000	4.41	45.35	2790
400	10 500	3.86	51.81	2441
600	14 300	3.50	57.14	2216
1000	21 900	3.22	62.11	2037
2000	41 500	3.05	65.57	1930
3000	62 300	3.05	65.57	1931
3945	83 477	3.11	64.31	1968
570	13 760	3.55	56.34	2245

TABLE 87. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	195	1338	3.41	3402	8.68
200	260	1265	2.44	2555	4.92
400	330	1180	1.78	1800	2.72
600	365	1118	1.53	1434	1.96
1000	394	1074	1.36	1119	1.42
2000	418	1040	1.24	851	1.02
3000	429	1032	1.20	756	0.88
3945	432	1045	1.21	750	0.87
570	362	1130	1.55	1450	1.98

*15¢/gal Fuel Cost

TABLE 88. - CALCULATED TOTAL OPERATING COSTS - NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	195	1492	3.80	3410	8.70
200	260	14[illegible]	2.76	2580	4.97
400	330	1360	2.06	1800	2.72
600	365	1314	1.80	1444	1.97
1000	394	1268	1.61	1129	1.43
2000	418	1234	1.47	861	1.03
3000	429	1232	1.44	767	0.89
3945	432	1240	1.43	780	0.90
570	362	1320	1.81	1475	2.02

*30¢/gal Fuel Cost

TABLE 89. - CALCULATED TOTAL OPERATING COSTS - NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	195	1800	4.59	3426	8.74
200	260	1775	3.42	2660	5.12
400	330	1736	2.63	1840	2.78
600	365	1705	2.33	1465	2.01
1000	394	1654	2.10	1150	1.46
2000	418	1624	1.94	882	1.05
3000	429	1632	1.90	788	0.92
3945	432	1646	1.90	820	0.95
570	362	1708	2.34	1500	2.05

*60¢/gal Fuel Cost

TABLE 90. DIRECT OPERATING COST BREAKDOWN -
NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	3945	570
Crew	0.60	0.48	0.37	0.32	0.30	0.28	0.27	0.27	0.33
Insurance	0.12	0.10	0.08	0.07	0.06	0.06	0.06	0.07	0.07
Depreciation	0.79	0.58	0.44	0.42	0.39	0.37	0.36	0.36	0.42
Maintenance	1.51	0.93	0.60	0.45	0.37	0.30	0.28	0.28	0.46
Fuel (15¢/gal)	0.39	0.35	0.29	0.27	0.25	0.23	0.23	0.23	0.27
Total DOC	3.41	2.44	1.78	1.53	1.36	1.24	1.20	1.21	1.55
Fuel (30¢/gal)	0.79	0.67	0.57	0.52	0.49	0.47	0.47	0.45	0.53
Total DOC	3.80	2.76	2.06	1.80	1.61	1.47	1.44	1.43	1.81
Fuel (60¢/gal)	1.57	1.33	1.14	1.07	0.98	0.93	0.93	0.92	1.07
Total DOC	4.59	3.42	2.63	2.33	2.10	1.94	1.90	1.90	2.34

TABLE 91. INDIRECT OPERATING COST BREAKDOWN -
NEW NEAR-TERM 60¢ FUEL DESIGN 200 PAX/3000 N.MI. RANGE

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.*								
	100	200	400	600	1000	2000	3000	3945	570
System Expense	0.18	0.14	0.08	0.05	0.04	0.03	0.03	0.03	0.05
Local Expense	2.24	1.30	0.55	0.37	0.23	0.11	0.08	0.08	0.38
A/C Control Expense	0.10	0.07	0.05	0.02	0.01	0.01	0.01	0.01	0.02
Hostess Expense	0.35	0.30	0.23	0.19	0.17	0.16	0.16	0.16	0.19
Food and Beverage	0.33	0.28	0.22	0.18	0.17	0.16	0.15	0.15	0.18
Passenger Service	3.14	1.40	0.74	0.52	0.32	0.16	0.11	0.09	0.53
Cargo Handling	1.55	0.85	0.40	0.26	0.16	0.08	0.05	0.05	0.27
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.58	0.40	0.22	0.17	0.13	0.11	0.10	0.10	0.17
Total IOC	8.70	4.97	2.72	1.97	1.43	1.03	0.89	0.90	2.02

*30¢/gal Fuel Cost

TABLE 92. - CALCULATED FUEL CONSUMPTION -
NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Fuel Consumption			
	lb	$\frac{\text{gal}}{\text{n.mi.}}$	$\frac{\text{seat-n.mi.}}{\text{gal}}$	$\frac{\text{Btu}}{\text{seat-n.mi.}}$
100	3 500	5.15	38.83	3255
200	6 000	4.41	45.35	2790
400	10 200	3.75	53.33	2372
600	14 300	3.50	57.14	2216
1000	21 900	3.22	62.11	2037
2000	41 000	3.01	66.45	1906
3000	61 000	2.99	66.89	1891
3964	82 392	3.06	65.36	1933
570	13 682	3.53	56.66	2232

TABLE 93. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	190	1358	3.60	3314	8.78
200	252	1295	2.43	2420	4.78
400	322	1209	1.87	1775	2.75
600	355	1138	1.60	1411	1.99
1000	381	1094	1.43	1102	1.44
2000	404	1056	1.31	837	1.04
3000	414	1046	1.26	744	0.90
3964	417	1055	1.27	750	0.90
570	352	1152	1.63	1450	2.06

*15¢/gal Fuel Cost

TABLE 94. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	190	1506	4.00	3322	8.80
200	252	1445	2.78	2600	5.14
400	322	1370	2.12	1800	2.79
600	355	1328	1.87	1421	2.00
1000	381	1281	1.68	1111	1.46
2000	404	1242	1.54	847	1.05
3000	414	1235	1.49	754	0.91
3964	417	1242	1.49	730	0.88
570	352	1330	1.90	1450	2.06

*30¢/gal Fuel Cost

TABLE 95. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	190	1802	4.78	3337	8.84
200	252	1783	3.48	2660	5.25
400	322	1743	2.70	1860	2.88
600	355	1708	2.41	1441	2.03
1000	381	1656	2.17	1132	1.48
2000	404	1613	2.01	867	1.07
3000	414	1612	1.95	774	0.94
3964	417	1630	1.96	760	0.91
570	352	1710	2.43	1500	2.13

*60¢/gal Fuel Cost

TABLE 96. DIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/3000 N.MI. RANGE

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	3964	570
Crew	0.63	0.52	0.40	0.34	0.31	0.30	0.29	0.29	0.35
Insurance	0.13	0.11	0.08	0.07	0.07	0.06	0.06	0.06	0.07
Depreciation	0.86	0.68	0.53	0.46	0.42	0.40	0.39	0.39	0.47
Maintenance	1.59	0.77	0.54	0.46	0.39	0.32	0.30	0.30	0.47
Fuel (15¢/gal)	0.39	0.35	0.30	0.27	0.24	0.23	0.22	0.23	0.27
Total DOC	3.60	2.43	1.87	1.60	1.43	1.31	1.26	1.27	1.63
Fuel (30¢/gal)	0.79	0.69	0.58	0.54	0.49	0.46	0.45	0.45	0.54
Total DOC	4.00	2.78	2.12	1.87	1.68	1.54	1.49	1.49	1.90
Fuel (60¢/gal)	1.57	1.39	1.16	1.07	0.98	0.93	0.91	0.92	1.08
Total DOC	4.78	3.48	2.70	2.41	2.17	2.01	1.95	1.96	2.43

TABLE 97. INDIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM MINIMUM FUEL DESIGN 200 PAX/3000 N.MI. RANGE

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.*								
	100	200	400	600	1000	2000	3000	3964	570
System Expense	0.19	0.14	0.07	0.05	0.04	0.04	0.03	0.02	0.05
Local Expense	2.30	1.26	0.61	0.38	0.23	0.12	0.08	0.07	0.41
A/C Control Expense	0.10	0.08	0.03	0.02	0.01	0.01	0.01	0.01	0.02
Hostess Expense	0.36	0.33	0.24	0.19	0.18	0.17	0.17	0.16	0.20
Food and Beverage	0.35	0.32	0.22	0.18	0.17	0.16	0.16	0.16	0.18
Passenger Service	3.14	1.58	0.78	0.52	0.32	0.16	0.11	0.10	0.53
Cargo Handling	1.55	0.77	0.37	0.26	0.16	0.08	0.05	0.04	0.27
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.60	0.43	0.24	0.17	0.13	0.11	0.10	0.09	0.18
Total IOC	8.80	5.14	2.79	2.00	1.46	1.05	0.91	0.88	2.06

*30¢/gal Fuel Cost

TABLE 98. - CALCULATED FUEL CONSUMPTION -
NEW NEAR-TERM 30¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal/n.mi.	seat-n.mi./gal	Btu/seat-n.mi.
100	6 400	9.41	42.51	2976
200	10 900	8.02	49.88	2534
400	18 500	6.80	58.82	2151
600	25 000	6.13	65.25	1938
1000	39 000	5.74	69.69	1814
2000	75 100	5.52	72.46	1746
3000	113 800	5.58	71.68	1764
4048	157 105	5.71	70.05	1805
1300	49 769	5.63	71.00	1775

TABLE 99. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 30¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	215	2129	2.45	6934	7.97
200	278	1995	1.80	4775	4.30
400	340	1830	1.35	3380	2.49
600	375	1692	1.13	2728	1.82
1000	403	1626	1.01	2131	1.32
2000	431	1578	0.92	1630	0.95
3000	443	1572	0.89	1451	0.82
4048	448	1595	0.89	4125	0.79
1300	416	1600	0.95	1875	1.12

*15¢/gal Fuel Cost

TABLE 100. - CALCULATED TOTAL OPERATING COSTS - NEW NEAR-TERM 30¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	215	2441	2.81	6951	8.00
200	278	2270	2.04	4910	4.33
400	340	2120	1.56	3450	2.54
600	375	2043	1.36	2747	1.83
1000	403	1979	1.23	2150	1.33
2000	431	1942	1.13	1649	0.96
3000	443	1949	1.10	1471	0.83
4048	448	1985	1.11	1440	0.80
1300	416	1960	1.17	1950	1.16

*30¢/gal Fuel Cost

TABLE 101. - CALCULATED TOTAL OPERATINT COSTS - NEW NEAR-TERM 30¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	215	3066	3.53	6984	8.03
200	278	2950	2.66	5100	4.59
400	340	2815	2.08	3550	2.62
600	375	2744	1.83	2784	1.86
1000	403	2685	1.66	2187	1.36
2000	431	2669	1.55	1688	0.98
3000	443	2704	1.53	1511	0.85
4048	448	2765	1.54	1500	0.84
1300	416	2680	1.60	1985	1.18

*60¢/gal Fuel Cost

TABLE 102. DIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM 30¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4048	1300
Crew	0.33	0.28	0.23	0.19	0.18	0.17	0.16	0.16	0.17
Insurance	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.04	0.04
Depreciation	0.54	0.47	0.37	0.31	0.29	0.27	0.27	0.27	0.28
Maintenance	1.14	0.66	0.46	0.34	0.28	0.22	0.21	0.21	0.25
Fuel (15¢/gal)	0.36	0.32	0.23	0.23	0.22	0.21	0.21	0.21	0.21
Total DOC	2.45	1.80	.135	1.13	1.01	0.92	0.89	0.89	0.95
Fuel (30¢/gal)	0.72	0.56	0.50	0.47	0.44	0.42	0.43	0.43	0.43
Total DOC	2.81	2.04	1.56	1.36	1.23	1.13	1.10	1.11	1.17
Fuel (60¢/gal)	1.44	1.18	0.96	0.94	0.88	0.84	0.85	0.86	0.86
Total DOC	3.53	2.66	2.08	1.83	1.66	1.55	1.53	1.54	1.60

TABLE 103. INDIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM 30¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.*								
	100	200	400	600	1000	2000	3000	4048	1300
System Expense	0.14	0.12	0.07	0.04	0.03	0.03	0.02	0.02	0.03
Local Expense	1.93	0.82	0.43	0.32	0.19	0.10	0.06	0.05	0.15
A/C Control Expense	0.05	0.04	0.03	0.01	0.01	0.01	0.01	0.01	0.01
Hostess Expense	0.29	0.25	0.19	0.17	0.16	0.15	0.14	0.13	0.15
Food and Beverage	0.30	0.26	0.20	0.17	0.16	0.15	0.15	0.14	0.15
Passenger Service	3.14	1.41	0.78	0.52	0.31	0.16	0.11	0.10	0.23
Cargo Handling	1.42	0.85	0.42	0.24	0.14	0.07	0.05	0.05	0.11
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.51	0.35	0.19	0.14	0.11	0.09	0.08	0.07	0.10
Total IOC	8.00	4.33	2.54	1.83	1.33	0.96	0.83	0.80	1.16

*30¢/gal Fuel Cost

TABLE 104. - CALCULATED FUEL CONSUMPTION - NEW NEAR-TERM 60¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal/n.mi.	seat-n.mi./gal	Btu/seat-n.mi.
100	6 400	9.41	42.51	2976
200	10 900	8.01	49.94	2534
400	17 800	6.54	61.16	2069
600	24 000	5.88	68.03	1860
1000	37 200	5.47	73.13	1730
2000	71 200	5.24	76.34	1655
3000	107 500	5.27	75.90	1666
4098	150 500	5.40	74.07	1708
1300	47 400	5.36	75.00	1700

TABLE 105. - CALCULATED TOTAL OPERATING COSTS - NEW NEAR-TERM 60¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	200	2059	2.57	6444	8.06
200	268	1940	1.82	4650	4.36
400	326	1770	1.36	3320	2.55
600	359	1673	1.16	2643	1.84
1000	386	1609	1.04	2068	1.34
2000	410	1559	0.95	1579	0.96
3000	417	1548	0.93	1401	0.84
4098	422	1560	0.92	1350	0.80
1300	397	1580	0.98	1850	1.15

*15¢/gal Fuel Cost

TABLE 106. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 60¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	200	2346	2.93	6459	8.07
200	268	2205	2.07	4650	4.36
400	326	2065	1.59	3325	2.56
600	359	1995	1.39	2659	1.85
1000	386	1931	1.25	2085	1.35
2000	410	1887	1.15	1596	0.97
3000	417	1883	1.13	1418	0.85
4098	422	1905	1.13	1420	0.84
1300	397	1910	1.19	1890	1.18

*30¢/gal Fuel Cost

TABLE 107. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM 60¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	200	2920	3.65	6489	8.11
200	268	2820	2.64	4825	4.52
400	326	2705	2.08	3450	2.65
600	359	2640	1.84	2694	1.87
1000	386	2576	1.67	2119	1.37
2000	410	2542	1.55	1631	0.99
3000	417	2554	1.53	1454	0.87
4098	422	2600	1.54	1450	0.86
1300	397	2560	1.60	1925	1.20

*60¢/gal Fuel Cost

TABLE 108. DIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM 60¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4098	1300
Crew	0.36	0.28	0.23	0.20	0.19	0.18	0.17	0.16	0.18
Insurance	0.09	0.08	0.06	0.05	0.05	0.05	0.05	0.05	0.05
Depreciation	0.61	0.52	0.40	0.34	0.32	0.30	0.29	0.29	0.31
Maintenance	1.15	0.62	0.42	0.35	0.28	0.23	0.22	0.22	0.24
Fuel (15¢/gal)	0.36	0.32	0.25	0.23	0.21	0.20	0.20	0.20	0.20
Total DOC	2.57	1.82	1.36	1.16	1.04	0.95	0.93	0.92	0.98
Fuel (30¢/gal)	0.72	0.57	0.48	0.45	0.42	0.40	0.40	0.41	0.41
Total DOC	2.93	2.07	1.59	1.39	1.25	1.15	1.13	1.13	1.19
Fuel (60¢/gal)	1.44	1.14	0.97	0.90	0.84	0.80	0.81	0.82	0.82
Total DOC	3.65	2.64	2.08	1.84	1.67	1.55	1.53	1.54	1.60

TABLE 109. INDIRECT OPERATING COST BREAKDOWN -
NEW NEAR-TERM 60¢ FUEL DESIGN 400 PAX/3000 N.MI. RANGE

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.*								
	100	200	400	600	1000	2000	3000	4098	1300
System Expense	0.13	0.11	0.06	0.04	0.03	0.03	0.02	0.02	0.03
Local Expense	1.96	0.85	0.46	0.33	0.20	0.10	0.07	0.06	0.16
A/C Control Expense	0.05	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Hostess Expense	0.31	0.25	0.19	0.17	0.16	0.15	0.15	0.15	0.16
Food and Beverage	0.33	0.28	0.22	0.18	0.17	0.16	0.16	0.15	0.16
Passenger Service	3.14	1.41	0.78	0.52	0.31	0.16	0.11	0.10	0.23
Cargo Handling	1.42	0.83	0.40	0.24	0.14	0.07	0.05	0.05	0.11
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.52	0.36	0.20	0.14	0.11	0.09	0.08	0.07	0.09
Total IOC	8.07	4.36	2.56	1.85	1.35	0.97	0.85	0.84	1.18

*30¢/gal Fuel Cost

TABLE 110. - CALCULATED FUEL CONSUMPTION -
NEW NEAR-TERM MINIMUM FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Fuel Consumption			
	lb	gal / n.mi.	seat-n.mi. / gal	Btu / seat-n.mi.
100	6 400	9.41	42.51	2976
200	10 900	8.01	49.94	2534
400	17 800	6.54	61.16	2069
600	24 000	5.88	68.03	1860
1000	37 200	5.47	73.13	1730
2000	71 000	5.22	76.63	1651
3000	106 000	5.20	76.92	1643
4107	148 389	5.31	75.33	1680
1300	47 294	5.35	75.00	1700

TABLE 111. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM MINIMUM FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	200	2139	2.67	6510	8.14
200	268	2000	1.88	4625	4.34
400	326	1830	1.41	3275	2.52
600	355	1725	1.21	2639	1.86
1000	382	1659	1.09	2065	1.35
2000	403	1604	0.99	1608	1.01
3000	412	1590	0.96	1397	0.85
4107	417	1610	0.97	1350	0.81
1300	392	1625	1.03	1850	1.17

*15¢/gal Fuel Cost

TABLE 112. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM MINIMUM FUEL DESIGN 400 PAX/3000 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	200	2426	3.03	6525	8.16
200	268	2275	2.13	4750	4.45
400	326	2125	1.63	3330	2.56
600	355	2044	1.44	2656	1.87
1000	382	1977	1.29	2082	1.36
2000	403	1926	1.19	1589	0.99
3000	412	1917	1.16	1415	0.86
4107	417	1925	1.15	1370	0.82
1300	392	1960	1.24	1890	1.19

*30¢/gal Fuel Cost

TABLE 113. - CALCULATED TOTAL OPERATING COSTS -
NEW NEAR-TERM MINIMUM FUEL DESIGN 400 PAX/300 N.MI. RANGE

Stage Length n.mi.	Block Speed kt	Total DOC*		Total IOC*	
		$/blk-hr	¢/seat-n.mi.	$/blk-hr	¢/seat-n.mi.
100	200	3000	3.75	6555	8.19
200	268	2880	2.70	4870	4.57
400	326	2745	2.11	3430	2.64
600	355	2681	1.89	2691	1.89
1000	382	2615	1.71	2116	1.39
2000	403	2568	1.59	1623	1.01
3000	412	2570	1.56	1449	0.88
4107	417	2580	1.55	1420	0.85
1300	392	2600	1.64	1910	1.20

*60¢/gal Fuel Cost

TABLE 114. DIRECT OPERATING COST BREAKDOWN -
NEW NEAR-TERM MINIMUM FUEL DESIGN 400 PAX/3000 N.MI. RANGE

DOC Component / Stage Length (n.mi.)	DOC ¢/seat-n.mi.								
	100	200	400	600	1000	2000	3000	4107	1300
Crew	0.37	0.27	0.24	0.21	0.20	0.18	0.18	0.18	0.19
Insurance	0.10	0.09	0.07	0.06	0.05	0.05	0.05	0.05	0.05
Depreciation	0.65	0.55	0.41	0.36	0.34	0.32	0.31	0.31	0.33
Maintenance	1.20	0.65	0.43	0.36	0.30	0.24	0.23	0.23	0.26
Fuel (15¢/gal)	0.36	0.32	0.25	0.23	0.21	0.20	0.20	0.20	0.20
Total DOC	2.67	1.88	1.41	1.21	1.09	0.99	0.96	0.97	1.03
Fuel (30¢/gal)	0.72	0.57	0.48	0.45	0.42	0.40	0.40	0.38	0.41
Total DOC	3.03	2.13	1.63	1.44	1.29	1.19	1.16	1.15	1.24
Fuel (60¢/gal)	1.44	1.14	0.96	0.90	0.84	0.80	0.79	0.78	0.81
Total DOC	3.75	2.70	2.11	1.89	1.71	1.59	1.56	1.55	1.64

TABLE 115. INDIRECT OPERATING COST BREAKDOWN - NEW NEAR-TERM MINIMUM FUEL DESIGN 400 PAX/3000 N.MI. RANGE

IOC Component / Stage Length (n.mi.)	IOC ¢/seat-n.mi.*								
	100	200	400	600	1000	2000	3000	4107	1300
System Expense	0.14	0.12	0.07	0.04	0.03	0.03	0.03	0.02	0.03
Local Expense	2.02	0.91	0.44	0.34	0.20	0.10	0.07	0.05	0.15
A/C Control Expense	0.05	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Hostess Expense	0.31	0.27	0.21	0.18	0.16	0.16	0.15	0.14	0.16
Food and Beverage	0.33	0.30	0.24	0.18	0.17	0.16	0.16	0.15	0.17
Passenger Service	3.14	1.37	0.73	0.52	0.31	0.16	0.11	0.10	0.23
Cargo Handling	1.42	0.85	0.42	0.24	0.14	0.07	0.05	0.05	0.11
Other Passenger Expense	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Other Cargo Expense	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General and Administration	0.53	0.36	0.20	0.15	0.11	0.09	0.08	0.07	0.10
Total IOC	8.16	4.45	2.56	1.87	1.36	0.99	0.86	0.82	1.19

*30¢/gal Fuel Cost

6. RECOMMENDATIONS OF FUEL SAVING OPTIONS - TASK 6

The objective of this task was the selection of the airplanes to be employed in the air transportation system analysis studies by United Technologies Research Center (UTRC). These airplanes were to include the current aircraft representative of the United States domestic fleet and airplanes selected by the airframe manufacturers from the foregoing tasks of the study. The latter includes selections from current aircraft operating with procedure changes, modifications to and derivatives of current aircraft and all new aircraft designs (Tasks 2 through 5).

Because one of the main results of the selection process was to arrive at a fleet mix of aircraft for the UTRC study that was representative of the average domestic fleet, United Airlines also submitted fuel and cost data for their fleet. In this way, current airplanes not included in the airframe manufacturers Task 1 studies were made available.

It became obvious at this stage of the study that, for a set of data to be representative of the average domestic fleet, it would necessarily have to include data from both the airframe and airline contractors. This in turn meant that performance data based on different sources would need to be made consistent. The airframe manufacturers used handbook (ideal) performance levels and generated their data using the agreed to flight profiles while the United Airlines data was representative of their fleet experience in day to day operation. Coordination among the contractors and NASA led to the recommendation that the United Airlines service data be used for the current aircraft task and that the manufacturers data be used in all of the other tasks with appropriate factors applied to result in estimated airline service data for all tasks. This method insured that the UTRC objective of estimating future fleet fuel usage as realistically as possible was met.

The factors applied to the airframe manufacturers handbook data (airline factors) account for air traffic control delays and routing, weather, performance deterioration, and the other items which make up the difference between ideal and in-service performance. These were developed by comparing block time and block fuel data for aircraft common to both the United and Douglas data base, the DC-10-10 and the DC-8-50. These comparisons, reproduced here as Figures 56 and 57, show that in terms of block time, the differences between handbook and in-service were in close agreement for both aircraft. A shift was noted in the block fuel comparisons, and it was assumed to be caused by the difference in service life of the DC-10-10 and the DC-8-50. The DC-10 aircraft in the United fleet showed closer correlation with the handbook calculated block fuel data than the DC-8-50 aircraft which are considerably older, and presumably, experiencing more performance deterioration. It was therefore decided to use an average factor based on these data as indicated by the fairing shown in Figure 57 to arrive at a mid-service life fleet of aircraft.

The airline factors plus the aircraft options to be considered in the UTRC fleet system studies were developed at a coordination meeting held on August 11 and 12, 1975, between the contractors and the NASA technical monitor. As discussed above, the factors are those shown in Figures 56 and 57. The aircraft options to be considered in three of the five classifications in the UTRC study, the source of these data and the usage of the airline factor were also determined at the coordination meeting. For completeness, these data as originally released by NASA are reproduced here as Tables 116, 117, and 118. In Table 116, Current Aircraft, note that an airline fuel factor was also applied at a constant percentage to the existing wide bodied aircraft. This was done to adjust the United Airline's data on these aircraft to mid-service life. Also note that in Tables 117 and 118, Modified and Derivative Aircraft, respectively, although usage of the airline factor is not specified, both the block time and block fuel factors were to be applied to these data as supplied by the airframe manufacturers. These airline adjustments are discussed in Reference 4.

Agreements on the remaining two tasks, Task 2, Operational Procedure Changes, and Task 5, New Near-Term Aircraft, were also concluded at the August 11-12, 1975 coordination meeting.

Lockheed and Douglas agreed on further coordination to (1) develop a list of fuel saving operational procedures which could be applied by UTRC on a basis consistent with their adopted baseline aircraft data, and (2) determine if common Lockheed/Douglas new near-term aircraft performance data could be derived. A list of percentage fuel savings for each aircraft in the UTRC base was developed for both the current air traffic control system and an advanced air traffic control system. These data are reproduced here as Table 119. An important point here is that it was not the intent of this study to identify the costs involved with an improved ATC System; rather the fuel savings which would be possible if such a system existed were to be identified. In this way, any large cumulative fuel savings resulting from the UTRC study could serve as an incentive for further study in this area.

In the new near-term aircraft of Task 5, it was determined that a common set of performance data could be generated from that developed by each airframe manufacturer. The derived airplane geometries in each of the payload/range classes were in close agreement so that average values of block fuel, block time and operating costs were reasonable to assume. The minimum fuel designs differed in the wing sweep parameter. The Douglas designs incorporated a straight wing while the Lockheed designs used a quarter chord sweep angle of 25 degrees. It was determined that the Douglas minimum fuel designs could possibly be oversized for present airports due to their large wing spans and in addition their low cruise Mach numbers might be incompatible with current airline fleets. On this basis, the Lockheed swept wing designs were used with the fuel and cost data modified to retain consistency with the averaged minimum cost design airplanes.

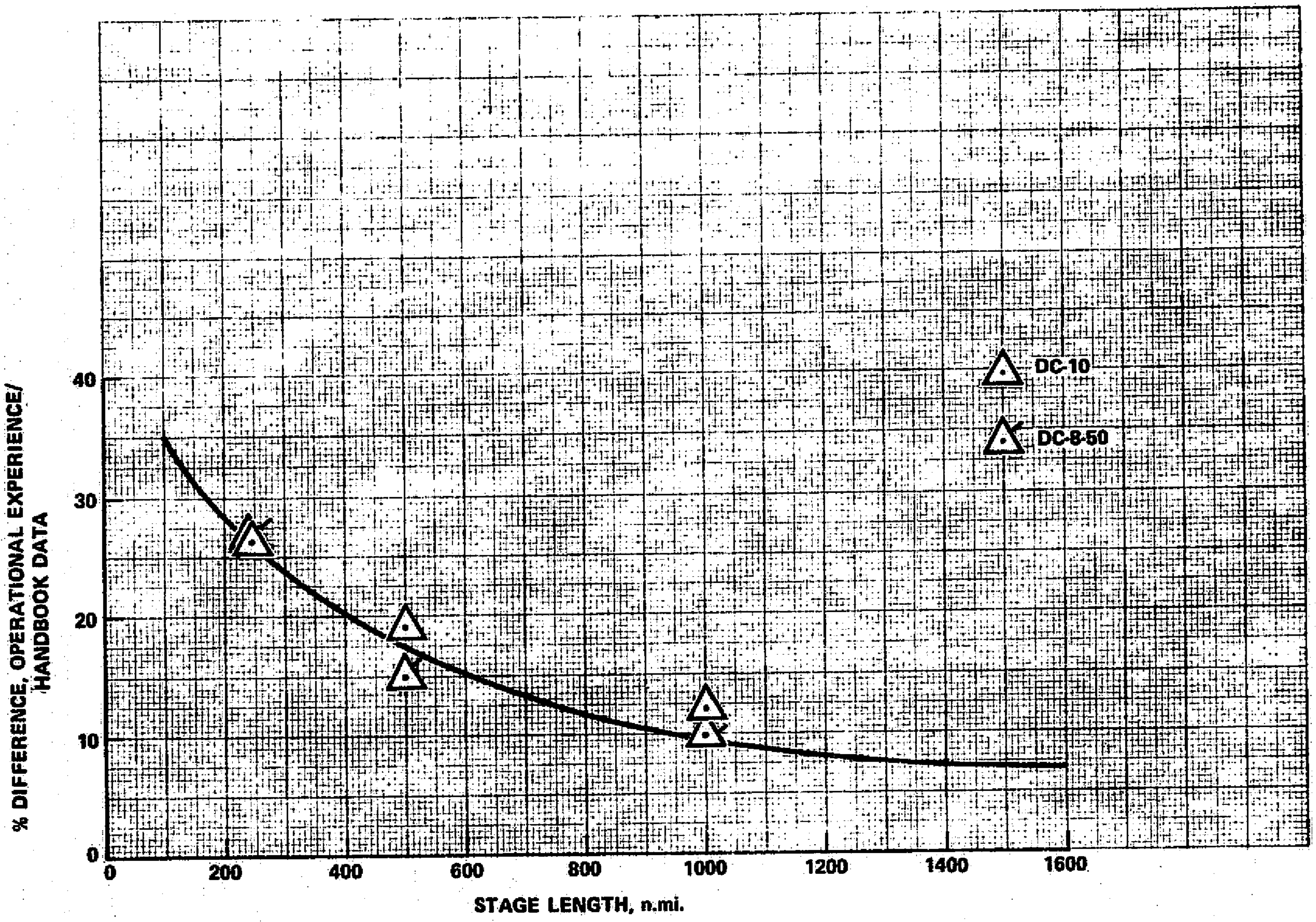


Figure 56.—Airline factor - block time

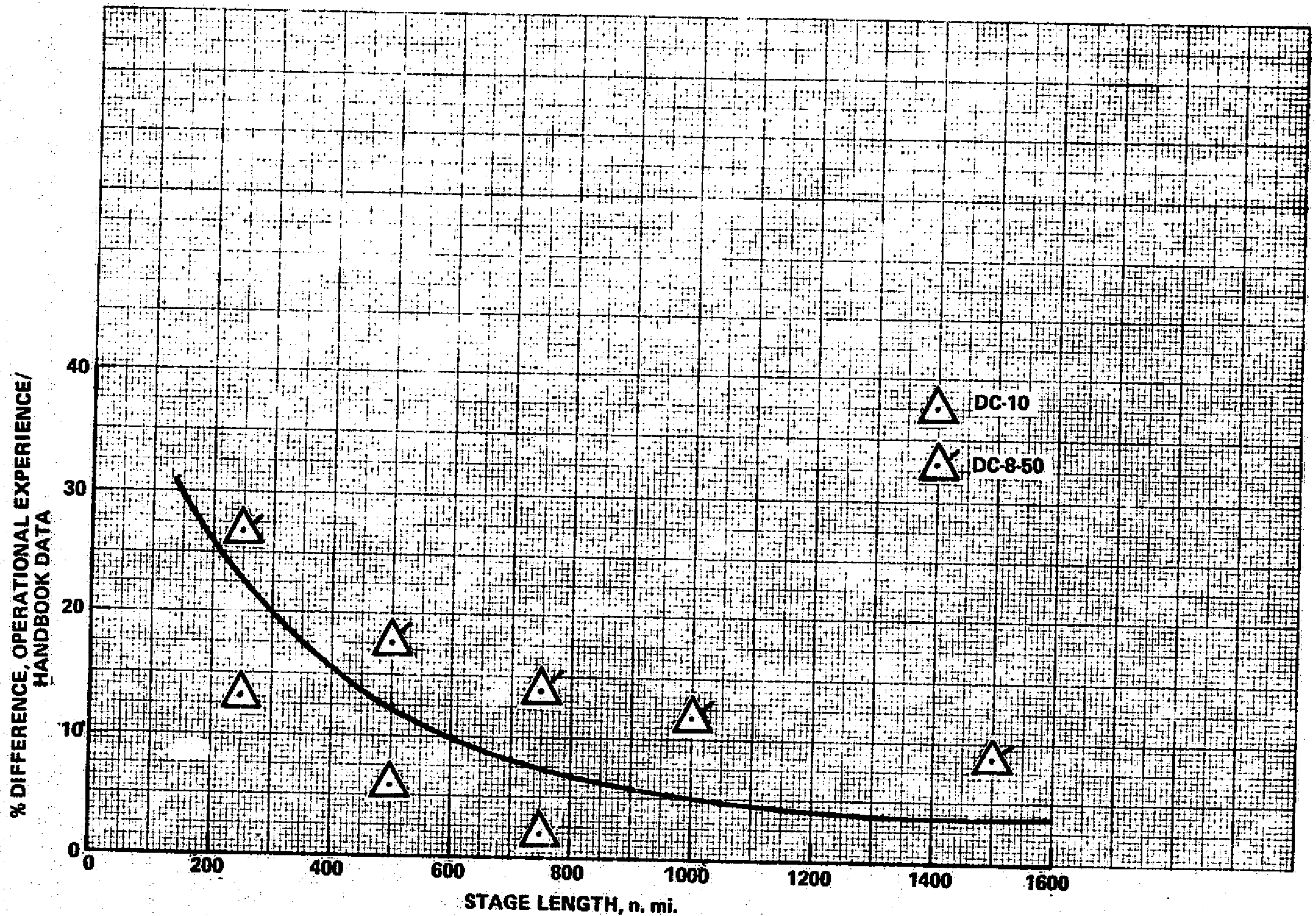


Figure 57.—Airline factor - block fuel

TABLE 116. - CURRENT AIRCRAFT-UTRC STUDY

Aircraft	Data Source	Airline Factor? Time	Airline Factor? Fuel
Existing:			
DC-9-10	DAC	Yes	Yes
727-100	UAL	No	No
DC-8-50 (707-120B, 720B)	UAL	No	No
DC-8-62 (707-320B)	UAL	No	No
DC-8-61	UAL	No	No
DC-8-20 (880, 720)	UAL	No	No
747-100	UAL	No	Yes (3½ %)
Existing & Eligible for New Buys:			
DC-9-30	DAC	Yes	Yes
737-200	UAL	No	No
727-200	UAL	No	No
DC-10-10 (L-1011-1)	UAL	No	Yes (4½ %)
747-200	UAL	No	Yes (3½ %)

TABLE 117. - MODIFICATIONS - UTRC STUDY

RETROFIT MODIFICATIONS
AERODYNAMIC ONLY

Aircraft	Modification	Average Fuel Saving
L-1011	Wingtip extensions (2-1/2%) and engine afterbody (3-1/2%)	7-1/2%
DC-10	Winglets (4%), wing root fairings and drag cleanup (5%)	
747		
DC-8-20, 50, 61 (707-120B, 720B)	Winglets (2%) and drag cleanup (3%)	5%
DC-8-62 (707-320B)	Winglets (2%)	2%
DC-9-10, 30 727-100, 200 737-200	Winglets (1-1/2%) and drag cleanup (2-1/2%)	4%

RETROFIT MODIFICATIONS
AERO AND ENGINE

(Includes all modifications in previous "Aerodynamic Only Retrofit Case" with the following additions:)

Aircraft	Modification	Average Fuel Saving
DC-8-20	Winglets, drag cleanup and JT8D Refan	35%
DC8-50, 61 (707-120B, 720B)	Winglets, drag cleanup and JT8D Refan	15%
DC8-62 (707-320B)	Winglets and JT8D Refan	12%

TABLE 118.- DERIVATIVES - UTRC STUDY

Aircraft	Passenger Payload	Range (n.mi.) @ 100% Passenger Payload
DC9-50 with winglets	117	2000
DC10-10 D1	200	2640
L-1011 Short Body	200	1920
DC10-40 D1 (DC10-30 + 30 ft stretch, 10 ft wingspan extension and winglets)	327	3500+
L-1011 Long Body	400	2160
727-300	157	1970

TABLE 119. - OPERATIONAL PROCEDURES CHANGES - UTRC STUDY

Aircraft Model	Designation UTRC Study	Baseline Mach	CAB Av. Block Distance (n.mi.)	Percentage Reduction in Block Fuel								
				With Current ATC						With Improved ATC		
											Reduced Delays	
				Reduce Speed to LRC	2000 Foot Step Climb	Load to Aft c.g.	A/P Cleanup	Reduce OEW 1%	Improved Engine Standard	Climbing Cruise	Holding	Terminal
In Production												
DC-9-30	O2ELBD	0.73	290	0*	0*	0.2	0.4	0.3	0.5	0*	1.6	2.5
B737-200	C2ELBB	0.73	266	0*	0*	0.2	0.4	0.3	0.5	0*	1.7	2.7
B727-200	C3ELB	0.80	421	0.2	0.1	0.2	0.5	0.5	0.5	0.1	1.1	1.7
DC-10-10 L-1011-1	O3EHB	0.83	870	1.0	0.3	0.2	0.5	0.4	1.0	0.4	0.7	1.0
B747-200	C4EHB	0.84	1616	1.2	0.5	0.2	0.5	0.5	1.0	0.5	0.4	0.5
Out of Production												
DC-9-10	Same	0.73	300	0.4	0*	0.2	0.4	0.2	0.5	0*	1.5	2.6
B727-100	Same	0.80	477	0.2	0.1	0.2	0.5	0.4	0.5	0.1	1.0	1.7
DC-8-20 (CV880, B720)	Same	0.80	862	1.0	0.3	0.2	0.5	0.4	0.3	0.4	0.8	1.9
DC-8-50 (B120B, 720B)	Same	0.80	731	1.0	0.3	0.2	0.5	0.4	0.3	0.4	0.8	1.9
DC-8-62 (B707-320B)	Same	0.80	1243	1.0	0.3	0.2	0.5	0.4	0.3	0.4	0.8	1.9
DC-8-61	Same	0.80	800	1.0	0.3	0.2	0.5	0.4	0.3	0.4	0.8	1.9

*No cruise, step cruise or cruise climb at 1973 CAB average block distance.

7. CONTRACT FOLLOW-ON 1985 TURBOPROP/TURBOFAN AIRCRAFT STUDY - TASK 7

The fuel saving advantages of the turboprop propulsion system, identified in Task 5, led to a modification to the contract encompassing additional follow-on studies of this propulsion system. The turboprop airplanes studied in Task 5 were limited to cruise speeds in the Mach 0.6 to 0.7 range by the conventional propeller designs employed. Utilization of these state-of-the-art propellers was dictated by the 1980 service introduction date specified in Task 5. Because operation at Mach 0.6 to 0.7 is not practical in the current air traffic control environment and since the longer block times adversely affect direct operating costs by increasing crew costs and decreasing utilization, the follow-on study envisioned turboprop operation at a more compatible cruise speed of Mach 0.80.

Conventional propellers exhibit a sharp falloff in efficiency beyond approximately Mach 0.65 as the compressibility effects on the blading become significant. A new design high speed propeller which delays these compressibility effects to higher Mach numbers has been identified by the Hamilton Standard Division of United Technologies Corporation (Refs. 5 and 6). This concept, designated the Prop-Fan, is a multibladed, highly loaded and variable pitch propeller that is envisioned to be used with an advanced turboshaft engine. The blades are thin, incorporate tip sweep, use supercritical airfoils, and are integrated with a spinner/nacelle shape designed to reduce the speed of the axial flow through the blades. The Prop-Fan would be able to operate at Mach numbers competitive with the turbofan. Figure 58, showing an airplane model developed under Lockheed independant development funds, typifies the Prop-Fan installation concept.

The objective of the follow-on effort, identified as Task 7 was to examine the potential of this new propulsion system when installed in an advanced technology airframe. Comparison of a propfan powered airplane with an equal technology airplane equipped with turbofan engines was the method used to assess the potential. The desired result of this comparison was the definition of the research and technology required to ultimately implement the propfan concept assuming that adequate benefits were shown.

In order to ensure that realistic propulsion data were utilized in the comparisons, an engine and propeller manufacturer were employed as subcontractors for this task. Both the Pratt and Whitney and the Hamilton Standard Divisions of United Technologies Corporation were included, and in addition, Eastern Air Lines was employed as consultant. Pratt and Whitney's responsibility included the supply of engine data for both the JT10D turbofan and a rematched version of the STS476 turboshaft engine. The JT10D is a ten tonne engine of high-bypass ratio which exhibits specific fuel consumption levels comparable to current high-bypass engines such as the RB.211, JT9D, and CF-6. The STS476 is a Pratt and Whitney study turboshaft engine with component technologies comparable to the JT10D. Hamilton Standard had responsibility for performance data on the Prop-Fan including assistance in the selection of the specific configuration (disc loading, blade number, and diameter) to be employed in this study. Eastern Airline's role as consultant included overall study assessment from an airline operators standpoint. As the largest current operator of the Electra turboprop aircraft, their experience was sought in the area of passenger acceptance, maintenance and costs.

Ground rules established for the comparison study are shown in Table 120. To take advantage of the extensive parametric study performed in Task 5, the airplane size of 200 passengers and the mission range of 1500 nautical miles were selected from the payload/range specified by the NASA in that task. The parametric airplanes of Task 5 were wide-bodied airplanes with four wing mounted engines; this configuration was maintained. An initial cruise altitude capability of at least 30 000 feet was chosen to maintain acceptable ride quality and to assure compatibility of the new design airplanes with a fleet composed of current and/or proposed transports. The field length and approach speed shown in Table 120 were selected from the ground rules used for the 200 passenger/1500 nautical mile range airplane in the Task 5 study.

The selection of a four engine design was questioned at the onset of the study since in terms of the size classes of turbofan engines currently available or proposed, a trijet design would be suitable for the design mission. Since the propfan concept results in much smaller diameters than conventional propellers, more latitude is available in terms of engine placement. Location of the propfan on the aft fuselage or tail surfaces is not therefore precluded because of diameter. The additional complexity of the aft mounted configuration, with possible adverse impact on fuel usage, was the deciding factor in the selection of the wing mounted configuration. For purposes of comparison, it was decided that the turbofan powered airplane should also incorporate wing mounted engines. The fact that this selection requires scaling of the JT10D turbofan engine to a smaller size not at present envisioned for production was not seen as a compromising factor.

The general approach taken in the study is shown in the block diagram presented as Figure 59. As discussed previously, the basic design configuration of the study airplanes was obtained from the parametric design studies of Task 5. A reoptimization of these baseline designs to include technologies commensurate with the desired 1985 service date was used to refine both the turbofan and turboprop designs. The final turbofan design, including the detailed performance characteristics, was determined at this stage of the study and the remainder of the effort was devoted to the detailed design and performance computations for the turboprop airplane. The general thrust requirements of the turboprop airplane were defined from the reoptimization study and further parametrics were used to define the sensitivities of airplane sizings to propeller diameter/disc loading. Using these data, the subcontractors, Pratt and Whitney and Hamilton Standard rematched the engine and propfan system to meet the airplane requirements. As shown in the last block in Figure 59, final aircraft assessments, the comparisons and the sensitivities to changes in the basic parameters were the concluding effort performed.

Selection of the 200 passenger/1500 nautical mile class of airplanes from Task 5 narrowed the choices to four point-design airplanes; those designed for minimum direct operating cost at the three fuel prices plus the minimum fuel airplane. The airplane designed for minimum direct operating cost with 60 cents per gallon fuel was selected with concurrence of the NASA as the baseline design for this study. The aspect ratio of this design, 9.9, was rounded to 10 and the wing thickness was modified to 12 percent from 13.4 percent. The thickness revision was due to results obtained from a refined process for drag analysis that became available. This procedure is documented in Reference 7 and results in a less optimistic drag level for wings employing supercritical airfoils.

Table 121 presents the advanced technologies incorporated into the baseline designs. Extensive in-house and contract studies (Ref. 8) indicate that for the 1985 time period, advanced composite materials will not be generally available for widespread replacement of aluminum in primary aircraft structure; thus, usage is limited primarily to secondary structure. Because development and manufacturing costs can negate the structural and weight benefits of advanced materials, only cost effective structure was considered. Preliminary analysis indicates the savings offered by composites are in applications that are suitable for either turbofan or turboprop aircraft. Therefore both aircraft concepts were treated equally.

In the study airplanes, secondary structure employing composite materials includes the fixed wing leading edge, fuel tank baffles, floor supports, interior doors, and dividers. The total empty weight reduction attributed to composite structure is 3.3 percent. While this reduction is small, it should be noted that resizing of the airplane is not included. The reduction in the fuel required to perform the design mission results in a general reduction in aircraft size and commensurate costs which could be credited to the use of composite materials.

Active controls can be used to conserve fuel for either turbofan or turboprop aircraft by allowing smaller, lighter airframes to accomplish the same mission. A three percent reduction in wing weight was obtained in the study airplanes by employing active ailerons to provide maneuver and gust load alleviation. This weight reduction occurs due to an inboard transfer of spanwise wing loads during critical maneuvers and gust loads. Relaxation of the static stability margins through the use of an active horizontal tail results in a reduction in tail size and a corresponding 30 percent reduction in tail weight. The automatic pitch control system can be incorporated to handle power-on effects which will be present with the turboprop installation. Total empty weight reduction due to incorporation of active controls on the study airplanes was 1.2 percent.

Incorporation of advanced composites and active controls commensurate with the 1985 study airplane time period resulted in a total empty weight reduction exclusive of resizing effects of 4.5 percent. To account for these weight benefits and also for the incorporation of the specific engines selected for both the turbofan and the turboprop design, further parametric studies were performed. For both airplanes, variations in wing and power loadings combined with the mission constraints were used to define the point design airplanes. In each case minimum direct operating cost was used as the selection criterion.

7.1 Turbofan Concept

Figure 60 depicts a summary of the parametric study used to resize the turbofan powered airplane. The minimum direct operating cost airplane is seen to be determined by the approach speed constraint, all airplanes which fall below the dashed line A in Figure 60 violate this constraint. If higher approach speeds were acceptable, the direct operating costs could be reduced to the minimum shown. The initial cruise altitude capability of 30 000 feet shown as the dashed line B would then limit the design slightly by requiring a greater thrust to weight ratio than the absolute minimum operating cost airplane shown. The 135 knot approach speed constraint was not relaxed thus assuring a design compatible with the current wide-bodied airplanes. Note that this speed is that which would be realized at the landing weight for the design mission. Speeds in excess of 135 knots would be attained at the shorter mission ranges when the payload carried exceeded the full passenger complement of 200. It was found that the desired takeoff field length of 7000 feet can be achieved by all of the airplanes represented in Figure 60.

The point-design turbofan airplane concept is shown in the general arrangement drawing of Figure 61. The aspect ratio 10 and sweep of 25 degrees for the supercritical wing are, as discussed previously, the results of the minimum operating cost/high fuel cost environment design philosophy. The very small horizontal tail surfaces are the result of the incorporation of active flight controls to allow relaxed static stability. When comparisons are made with the L-1011, it should also be noted that a relatively longer tail arm results since the mounting of all of the engines on the wing of the CL 1320-11 means that the wing is positioned considerably more forward on the fuselage. This weight and balance effect is an additional factor which, when combined with the active controls concept, allows the reduced tail size. As shown in Figure 61, the other aspects of the design are conventional. The four engines are mounted under the wing on pylons; this arrangement having been proven to offer the lowest drag and interference penalties while offering superior maintenance accessibility. In the CL 1320-11 design, engine ingestion of runway debris is not a concern; the clearance between the ground and the lower inlet lip is 76 inches. Part of this clearance is the result of the landing gear length being designed to maintain adequate tail clearance on aircraft rotation, but it is also partly the result of the relatively small engines required. As previously noted, the Pratt and Whitney JT10D-2 engine was scaled for this application; the resulting sea level static thrust rating is 14 672 pounds per engine.

The general characteristics of the CL 1320-11 turbofan design are shown in Table 122. Note that the takeoff weight has been considerably reduced from the weight required in the Task 5 airplane of the same mission capability. A large part of this reduction is the result of incorporating composites and active controls in the CL 1320-11, and the subsequent resizing of the airplane. This weight improvement is of course significant in providing additional fuel conservation in the CL 1320-11 design.

Engine features of the scaled JT10D-2 turbofan engine are highlighted in Table 123. This engine has an overall pressure ratio of 28:1 and a maximum combustor exit temperature of 2400 °F. Since the JT10D-2 is an engine in the advanced development stage, detailed performance data including scaling capability were already available. Concurrence from Pratt and Whitney in the use of the data plus additional costing and maintenance data relative to the study turboshaft engine were obtained.

7.2 Turboprop Concept

While the turboprop airplane can, in general, retain the geometry of the turbofan design, several considerations must be taken into account in its design. The propeller diameter, slipstream effects, the nacelle design, propeller induced loads, and acoustic treatment are all turboprop-unique considerations that must be dealt with. The Prop-Fan concepts being studied by Hamilton Standard include various propeller configurations in terms of blade number and tip speed. At the initiation of this study, their efforts indicated that an eight-bladed Prop-Fan operating at a tip speed of 800 feet per second was near optimum. Blade number and tip speed were therefore held constant. Installation guidelines also developed by Hamilton Standard were applied where appropriate.

7.2.1 Installation considerations. - Selection of the propeller disc loading and diameter is dependent upon the tradeoff between propeller efficiency and installation weights and the impact on airplane performance. A first approximation of these effects was obtained by consideration of the propeller weight plus mission fuel required variation with disc loading. This data is shown in Figure 62. Although the propeller efficiency increases as disc loading is decreased, the weight effect of the larger propellers effectively shifts the best disc loading to a higher value. In the Figure 62 data the best efficiency disc loading of approximately 28 horsepower per square foot becomes 36 horsepower per square foot when propeller weight is included. Note that these data are presented for Mach 0.8 cruise at 30 000 feet; disc loading varies with speed and altitude as a result of the horsepower changes. Three disc loadings, selected as indicated by the arrows in Figure 62, were then used in sensitivity studies to determine the variation in airplane performance.

The propeller sensitivity studies involved the parametric design of a large number of additional airplanes. For each of the selected disc loadings, the wing and thrust loading were varied in a fashion similar to that described previously (see Figure 60 for example). The same constraints in terms of altitude capability, approach speed, and takeoff field length were also employed. The characteristics of the optimum airplanes obtained for each propeller disc loading were then combined to arrive at the summary data shown in Figure 63. This curve represents an envelope of the airplanes selected from the parametric design studies again using minimum direct operating cost as the criterion. Even though the resulting variation is quite insensitive to propeller diameter, the smallest diameter gives the lowest operating cost. Note that the block fuel shown in the upper portion of Figure 63 is minimum at a larger diameter than is the case for the operating cost. The cost of the fuel saved does not compensate for the higher initial price paid for the aircraft with a larger diameter propeller.

Figure 64 shows a detailed breakdown of weight effects which produce the performance variation with propeller diameter. Note that the weight scale has been expanded here to better define the small differences. The propeller weight penalty paid for the improved efficiency of larger diameter is the major factor in driving the selection to the smaller diameter. This penalty is magnified as shown by the additional weight penalties which accrue when the larger diameter propeller is installed on the airplane. Additional structure is necessary in the components such as the gearboxes, nacelles, and the wing. All of these weight effects are multiplied and each of the other airplane structures are impacted as resizing is required to maintain the design mission range. The engine is the only component which decreases in weight as the propeller diameter increases; this is caused by the smaller torque requirements of the more efficient propeller.

Several nacelle configurations were considered in the design of the turboprop airplane. Representative configurations are shown in Figure 65. Of the over-wing designs studied, the one which employed an offset gearbox as shown at the upper left portion of the figure was judged superior, but it was rejected because of the possibility of excessive nacelle/wing interference drag and poorer accessibility compared to an underwing design. Of these latter configurations, the one with an inline gearbox (upper right portion of Figure 65) was eliminated due to the larger overall nacelle size dictated by the length of the inlet duct required to obtain a smooth airflow at the engine face. Annular inlets were also considered, but the scoop inlet, as used in the selected configuration, offers superior inlet pressure recovery. The offset gearbox employed in this configuration allows a more direct flow of air to the engine while keeping the required inlet length to a minimum. The aerodynamic shape of the nacelle is determined by the desired flow velocity through the root sections of the propeller. Guidelines established by Hamilton Standard were utilized. It is expected that the aerodynamic shape will dictate the overall nacelle size rather than any limitations imposed by the housing of necessary internal components.

Comparison of the selected nacelle configuration with the Lockheed Electra/ P-3 nacelle, Figure 66, shows the remarkable similarity in physical size even though the study turboprop produces over twice the shaft horsepower. Likewise, a comparison of the turboprop and turbofan nacelles of the final point-design airplanes shows the same similarity in physical size.

Propeller spacing guidelines postulated by Hamilton Standard, Figure 67, suggest an 80 percent diameter clearance between the fuselage and the inboard propeller to help alleviate passenger cabin noise. This compares to less than a 25 percent clearance on the Electra L-188. For the 25-degree wing sweep of the study airplane, the spacing between propellers is 33 percent diameter, again considerably more than on past turboprop airplanes. A six-foot clearance from propeller to ground was also specified. These guidelines were all considered in the final design point propfan airplane.

As a result of the diameter sensitivity studies which led to the adoption of a small propeller diameter, the landing gear length needed to maintain the six-foot ground clearance was not critical. In the final selected airplane design, the propeller clearance exceeds six feet and is nearly identical to the inlet to ground clearance of the turbofan airplane, Figure 68. The landing gear length for both airplanes was dictated by the limiting aircraft rotation angle on takeoff (12 degrees).

7.2.2 Performance considerations. - The basic characteristics of the turboprop installation introduce differences that require careful performance accountability when compared to the turbofan airplane. The most obvious of these is the drag treatment to allow for propeller slipstream effects. The velocity increment in the slipstream will cause an increase in the friction drag of the nacelle and that portion of the wing immersed in the slipstream (scrubbing drag). For the propeller diameter selected in this study, the velocity increment amounts to approximately 40 feet per second for the Mach 0.80 cruise case, giving an 0.8 percent increase in total airplane drag.

This same propeller slipstream velocity increment will also create higher local lift over the immersed portion of the wing, which will relieve the lift generation required by those portions of the wing outside the slipstream. This will offer a reduced wing angle-of-attack requirement and a favorable drag change, estimated to be 1.7 percent of airplane drag.

The effects of propeller slipstream on drag rise characteristics of swept supercritical wing aircraft have not been established at this time. Available information on conventional wings differs widely; while these effects would generally be considered to be unfavorable, beneficial effects were shown for a swept, high aspect ratio wing in Reference 9. This disparity may be because on swept wing airplanes the propeller disc plane is further forward of the wing leading edge. In view of these conflicting trends, zero influence of slipstream velocity on drag rise has been assumed. If necessary, local wing or nacelle contouring may offer a means for alleviating a possible problem.

Buoyancy or blockage effects of the spinner-nacelle-wing components on propeller performance were treated analytically. The reductions in propeller disc inflow characteristics were determined and their influence on propeller performance was predicted by Hamilton Standard. The impact is included in the installation effects.

Nacelle/wing interference is another area where the turboprop installation presents potential difficulties since the nacelle will be located closer to the wing. A wide range of data can be found. Figure 69 presented is the increase in nacelle drag when tested in the presence of a wing over and above that which is measured for the isolated nacelle. With conventional pylon-type mounting used in current turbofan installations, nacelle/wing interference is minimized. On the other hand, the Electra L-188 and past experience (Reference 10) indicates excessive interference drags for large nacelles near wing surfaces. Tests conducted on the Lockheed Jet Star slipper fuel tank, a configuration not unlike the proposed turboprop installation in terms of forebody length to diameter ratio, indicated slightly over 20 percent increase in the tank drag when installed on the wing. A conservative increase in nacelle drag of 30 percent was selected for the study airplane pending definitive tests.

During takeoff and other power-on flight conditions, the extended flaps and landing gear can interfere with the propeller ability to produce thrust by presenting a blockage in the propeller slipstream. Table 124 shows a comparison of the thrust interference factors used in this study with those of past propeller driven aircraft. The flap interference factor was determined by consideration of the geometric relationship of the flaps and propeller. The relative size of the propeller and flaps is expressed as a ratio of the flap chord to the propeller diameter while the distance between the propeller disc plane and the flaps in their extended positions is nondimensionalized by dividing by the propeller diameter. The relatively larger flap chord and small propeller diameter of the CL 1320-15 turboprop design give higher dimensional ratios and thus a larger interference factor as shown. Also noted is the fact that the landing gear of the present design offers no interference to the propeller as it is completely outside the slipstream.

The acoustic environment at the external fuselage wall caused by the propfan operating at supersonic tip speeds during cruise differs from the more familiar situation of earlier turboprop installations. The nature and character of the shock wave patterns shed from the propeller plus the frequency of blade passage and its associated harmonics become the dominant characteristics which must be considered. In this study, sufficient analysis was accomplished to independently predict the sound levels at the external fuselage wall for the selected propfan configuration. However, further trade studies on blade number, tip speed, tip to fuselage clearance, and fuselage diameter will be required in the future.

Figure 70 shows how, when operating at a supersonic helical tip Mach number, M_H, an external sound pressure is generated by impingement of the pressure field between the shock waves which have a fixed position relative to the rotating propeller blade. The pressure signature on the cabin wall has at any instant of time a sonic boom type N wave distribution along the streamwise direction between the bow shock and the trailing edge shock. The time dependence at the fuselage is caused by the blade rotation. Notice that the shock wave intersection with the fuselage is aft of the propeller disc plane, and moves farther aft as the propeller clearance is increased.

Figure 71 gives the necessary geometric data to determine the coordinate transformation between blade fixed coordinates and fuselage fixed coordinates at any instant of time as expressed parametrically via the blade position angle $\psi = \Omega t$. Since the shock strength depends on the slant clearance y'_{CL} which depends on, ψ, then the geometry of this figure allows the shock pressure vs time for any point on the fuselage to be calculated. The region between the two shocks is called the shock impingement region.

There is an additional pressure component called the scattered (or reflected) field. The scattered field arises because the normal component of the velocity field caused by the blade must be cancelled at the wall (considered rigid). In the shock impingement region, this defines the reflection factor. Outside the shock impingement region, the scattered field determines the entire sound field. It is found by solving the subsonic convected wave equation relative to fuselage coordinates with the flight speed as the convection velocity. The driving force for the scattered field is the negative normal component of the free velocity field imposed by the rotating blade in the shock impingement region, which acts like a loudspeaker diaphragm.

The analytical procedure used to calculate the external sound pressure in the shock impingement region ignoring the scattered (or reflected) field consists of two key steps. The first is determination of the pressure time history of the blade passage field which was accomplished by a superposition of the individual blade bow shock overpressures. A typical pressure time history is shown in Figure 72. The second step consists of a Fourier analysis of the time history which provides the sound pressure of the blade passage frequency and its harmonics.

Both blade design and atmospheric variables affect the results. The important blade design elements are the geometric variables of leading edge radius, thickness to chord ratio, and the operational variables of helical tip Mach number and advance angle. These were considered in the analysis which resulted in the external sound pressure levels shown in Table 125 compared to those predicted by Hamilton Standard. The sound pressure levels for the blade passage frequency are in close agreement. For the higher harmonics, the Lockheed estimate indicates a roll-off as the harmonic number increases, whereas Hamilton Standard predicts the same sound pressure level for the blade passage frequency and the higher harmonics. In Table 125 the helical tip Mach number of 1.06 is taken from the Hamilton Standard evaluation of the propeller sweep effect for the propfan.

For the eight-bladed, 800 foot per second propfan used in this study, an attenuation of 40 dB is required to achieve the target overall sound pressure level of 90 dB. Based on the assumption that the cabin wall exhibits mass-like behavior, suppression of the low frequency propeller tones of the order of 40 dB is believed attainable.

Figure 73 demonstrates the approximate frequency ranges associated with stiffness control and mass control noise transmission loss. The low point or dip in these curves is the transition point between the stiffness control region to the left and the mass control region to the right side of the figure. The narrow lines are based on data obtained from noise tests on a C-130 airplane; the solid line representing the bare untreated fuselage measurements and the dashed line the results obtained with a modest acoustical treatment. The heavy wide lines indicate the expected response of the CL 1320-15 turboprop, the dashed line representing what could be achieved with massive acoustical treatment applied to its double wall fuselage. Note the shifting to lower frequency of the stiffness to mass control transition point when acoustical treatment is applied.

Among the many natural modes of a thin walled cylinder is the breathing mode in which the cross section of the cylinder remains circular but fluctuates in area (uniformly over its entire length with no nodal lines). The natural frequency of this mode is called the ring frequency (f_r). The ring frequency is equal to the velocity of sound (of the material from which the cylinder is made) divided by its circumference. For an aluminum fuselage, for instance,

$$f_r = \frac{20\ 600}{\text{Circumference(ft)}} .$$

Although the breathing mode is probably never excited, it marks an important transition point in cylinder dynamic response. In particular, immediately above and below the ring frequency lies a large number of modes whose flexural wave speed is higher than the speed of sound in air. These modes, whose wave fronts travel predominately in the axial direction, are very efficient radiators of sound. Figure 74 illustrates that the modal density (i.e., the number of modes per one Hertz band width) of modes of the above type is very high near the ring frequency. The above considerations suggest that it may be unwise to have a propeller harmonic fall near the ring frequency. However, existing information is insufficient to confirm this. It is possible, for instance, that even though these modes exist in abundance, the propeller noise field may not be capable of exciting even one of them to a significant degree. Figure 74 indicates the relationship between the ring frequency and the first and second harmonics of the blade passage frequency for the CL 1320-15 turboprop airplane.

Table 126 shows the analytical relationship used to calculate the noise transmission loss through a double wall in which both walls behave as pure masses with no mechanical vibration paths between them. M_T represents the mass per square foot of the total wall and ρc is the impedance of air for a 6000 foot cabin pressurization (approximately 2.2 slugs/ft^{2}s).

The required acoustical treatment weights derived by this method represent developmental goals rather than state-of-the-art technology. It may, for example, be necessary to increase the number of propeller blades above those currently being considered in order to raise the blade passage frequency to a value that will allow the fuselage wall to exhibit mass-like behavior. Structural damping may also be required in order to approximate mass-like response.

The upper curve in Figure 75 provides estimates of the required acoustical treatment weight as a function of the external sound pressure level of the blade passage tone. The estimate is based on the relationship shown in Table 126. For a given external sound level, the difference between the upper and lower curves represents the increase in treatment weight above that required for an airplane powered by turbofans. For the point-design airplane a weight penalty of 3089 pounds relative to the turbofan airplane resulted from this additional acoustic treatment. The treated area on the study airplane includes the sidewalls of the entire occupied fuselage because of the concern for shock impingement pattern variations caused by flight and atmospheric conditions.

7.2.3 General arrangement. - The general arrangement of the resulting turboprop powered airplane, Figure 76, is not dramatically different from the turbofan. Overall dimensions of length and span are nearly identical. A rematch version of the Pratt and Whitney STS476 study turboshaft engine is used with the 12.6 foot diameter eight-bladed propfan which resulted from the final airplane synthesis.

Table 127 presents the general characteristics of the propfan design. In this table the figures for the turbofan airplane previously shown in Table 122 are repeated in the right hand column for comparison purposes. As noted, the takeoff weights required to perform the design mission are nearly identical. However, the operational empty weight of the turboprop design exceeds that of the turbofan design by six percent.

Engine features of the scaled STS476 turboshaft engine are shown in Table 128. These data represent the engine as rematched by Pratt and Whitney for the study airplane requirements and include a completely new compressor and low pressure turbine. In Table 128 the features of the JT10D-2 engine previously shown in Table 123 are repeated for comparison. As shown the sea level static thrust ratings are nearly equal. Note, however, that the maximum rating for the turboshaft engine occurs at the beginning of climb; this accounts for the two shaft horsepower ratings shown. While the combustor exit temperatures are equal, the overall pressure ratio of the STS476 engine is lower as the result of the loss of fan supercharging. While methods of regaining the supercharging at the cost of additional complexity are available with an attendant gain in SFC up to approximately three percent, Pratt and Whitney did not make this change for this study. The final technical memorandum received from Pratt and Whitney discusses the turboshaft engine in more detail and is included in this report as Appendix A.

Figure 77 summarizes and compares the installed thrust ratings of the turboprop and turbofan engines. Note that even though the static rating of the turboprop engine is lower, it develops a higher thrust as the ground roll commences. This is the result of the blades being in the stalled condition initially. The characteristic higher lapse rate of turboshaft engines is shown on the right side of Figure 77 which compares the maximum climb power of the two engines as altitude is varied.

Table 129 shows the difference in the installation losses assessed for each of the propulsion systems. Note the absence of compressor bleed on the turboprop system; air conditioning and pressurization are handled by mechanical drive alone. Other differences to be noted are the absence of the fan duct loss on the turboprop and the addition of gear efficiency.

7.3 Performance, Economic and Characteristics Comparisons

At this stage of the study, the turbofan and turboprop powered airplanes had both been developed using 1985 levels of technology. Both had been designed to the same payload-range requirements and to the same mission constraints. The airplanes are competitive in terms of cruise speed, cruise altitude, and block time, and both offer equal passenger comfort.

Significant differences appear when the fuel and cost to operate these aircraft are compared. These parameters were compared at the payload/range points denoted in Figure 78 by the circles. The shaded area in this figure represents the typical operational missions on which an airline might schedule the study aircraft. At the full design passenger payload and at the design range of 1500 nautical miles, the turboprop airplane consumes 17.8 percent less fuel with a 5.3 to 8.2 percent lower direct operating cost, as shown in Figure 79. The direct operating cost comparisons are made for fuel at the design cost of 60 cents per gallon, and also at a fuel cost of 30 cents per gallon. If the comparison is made at a typical in-service stage length of 475 nautical miles with the study load factor of 58 percent, Figure 80 shows that the turboprop airplane uses 20.4 percent less fuel while offering operating cost advantages of 8.5 and 5.9 percent for the two fuel costs.

These differences in fuel and operating costs are caused by differences in engine specifics, and airplane weight and drag. The most pronounced difference here is in the propulsion systems. At maximum cruise power the STS476 turboprop engine has better than a 19 percent lower specific fuel consumption while at the maximum climb power setting the difference exceeds 26 percent on the average and exceeds 30 percent at the lower altitudes, as noted in Figure 81. Since climb represents a much larger percentage of total mission time on the shorter 475 nautical mile mission (nearly 32 percent) compared to the 1500 nautical mile design mission (12 percent), greater fuel savings for the turboprop relative to the turbofan occur as range is decreased. If only the fuel used in climb is compared, Figure 82 shows that the turboprop uses close to 25 percent less fuel to arrive at the same point in space.

As indicated previously in the general characteristics comparison, the turboprop airplane's empty weight exceeds that of the turbofan airplane. Table 130 shows that this difference is 6.4 percent. The major difference in the component weights which cause this overall weight disparity are indicated in the table. The additional torsional loads introduced by the propeller account for two percent of the wing weight increase; further weight increases are caused by the multiplying factor of airplane resizing to perform the mission. Propeller loads are also the cause of the additional nacelle weight of the turboprop airplane. The total uninstalled propulsion system weight of the turboprop (including propeller and gearbox) is the major factor in the large installed weight penalty shown. Lower weights of some of the components needed to install the system partially compensate for this. The most significant item is in the provisions required to provide thrust reversal. The variable pitch feature of the propeller offers a means of providing reverse thrust without the cascade and blocker door or spoiler system required by the fixed pitch fan of the turbofan installation. Note that fan reverse only is used in the study turbofan concept; no provisions were made for reversing the flow of the primary jet exhaust. The largest weight increment shown in Table 130 is for the acoustic treatment in the turboprop airplane. This item is shown in the furnishings since the treatment area is the fuselage sidewall.

Differences in the drag of the two airplanes can be seen by examining the breakdown of Table 131. As in the previous table a comments column is used here to designate the major differences. The wing component drag on the turboprop airplane is slightly smaller by virtue of less wetted area and slipstream effects. The wing wetted area is reduced because of the larger nacelle/wing interface of the turboprop where no pylon is used. Some of this drag benefit is offset by the larger turboprop nacelle. However, the main difference between the nacelle drag components is caused by the higher wing/nacelle interference assessed for the turboprop installation. A compensating factor is the addition of the drag of the turbofan pylons. Table 131 shows that, when all of the drag components are summed, the total airplane drags are nearly identical.

Table 132 presents a breakdown of the flyaway costs and the direct operating cost factors. The figures in the top section of the table show that the turboprop flyaway cost exceeds that of the turbofan airplane. The airframe cost is higher mainly because of the additional acoustic treatment. Figures for the propulsion cost for each airplane were based on inputs from Pratt and Whitney and Hamilton Standard, see Appendices A and B. This is also the case for the engine-related direct operating cost factors shown in the bottom part of Table 132. Note that the DOC factors are those required to adjust the ATA formulas. Most of these factors are identical for both airplanes, however, a difference is noted in the maintenance cost factors. Airframe labor and airframe material per cycle were reduced on the turboprop because of the expected longer brake and wheel life resulting from superior thrust reversing performance. A breakdown of the direct operating cost comparison is shown in Figure 83. The lower block fuel of the turboprop airplane accounts for the improvement in operating cost. These data were calculated for a fuel price of 60 cents per gallon.

A table summarizing these performance and economic comparisons is presented as Table 133. Here the basic comparison is made at the 1500 nautical mile design range with full passenger payload while the percentage change in fuel and operating cost at the typical in-service stage length is also indicated.

The potential improvements that may be available by using more advanced technologies in the propulsion system were also assessed. Use of a dual-rotation propfan offers improvements in efficiency of approximately five percent due to swirl recovery. A parametric study using this concept with advanced technology propulsion system weights and costs was performed using inputs from the propulsion equipment subcontractors (Appendices A and B). Figure 84 presents the results of this study. The baseline comparisons at the 1500 mile design range from Figure 79 are repeated here for both the fuel and cost data with the bars on the left for the turboprop airplane and the bars on the right for the turbofan airplane. The center bar shows that a four percent additional improvement in block fuel is obtained using the dual-rotation propfan and that the direct operating cost is improved by an additional 1.5 percent. The higher cost of this system, both acquisition and maintenance, is compensated for in the direct operating cost by the lower fuel usage and by the comensurate resizing of the airplane. This can be seen by noting the significant reduction in takeoff weight required to perform the design mission. While the dual-rotation propfan concept introduces additional complexity, the fuel saved and subsequent smaller airplane may compensate.

7.4 Sensitivities

Since little experimental work has been done in recent years on advanced technology propellers, theoretical performance predictions were used quite extensively in this study task. Of the many variables that can affect the study results, propeller efficiency, engine SFC, nacelle-wing interference, engine weight, acoustic treatment, and maintenance cost are the most important. Variations in each of these parameters were studied separately and the effect on the block fuel and operating cost data expressed relative to the turbofan baseline is shown in Figures 85 through 90. The basic comparison at the 1500 nautical mile design point is shown at the circled point and the shaded band is shown to indicate reasonable ranges of variation. Each of the sensitivity trend curves reflect aircraft resizing to maintain study ground rule compliance. All of the operating costs shown in Figures 85 through 90 reflect a fuel cost of 60 cents per gallon.

The sensitivity of fuel savings and operating costs to variations in propeller efficiency are shown in Figure 85. It is seen that a five percent degradation in propeller efficiency from the baseline level degrades the fuel savings by five percent. This means that even with a propeller efficiency as low as 77 percent at Mach 0.80, the propfan/turboprop concept would realize a fuel advantage of 13 percent over the turbofan airplane. The engine SFC sensitivity, Figure 86, shows essentially the same variation in fuel and cost as above. This curve is slightly steeper since the impact of engine jet thrust has been considered during vehicle resizing.

The effect of change in nacelle/wing interference drag is shown in Figure 87. If the turboprop engine could be installed at the drag levels of a typical turbofan engine, a one percent improvement in the fuel and cost advantage result. If interference or drag rise effects on supercritical airfoils were to be excessive, fuel and cost advantages of the turboprop would degrade by one to two percent.

The sensitivity to propulsion system weight is shown in Figure 88. The benefits of applying further technology advances to save weight in the propeller, gearbox, and engine are indicated on this figure. Estimates of these weight savings were provided by Hamilton Standard and Pratt and Whitney, and the weight savings would delay the introduction into service to a time nearer 1990. The additional fuel and direct operating cost savings shown are attained at the expense of slightly higher aircraft acquisition costs.

The sensitivity of turboprop fuel and cost characteristics to acoustic treatment weight is shown in Figure 89. If exterior sound levels at the fuselage sidewall should prove to be 10 dB higher than currently predicted, the acoustic treatment weight penalty more than doubles to over 7000 pounds and the fuel advantage is degraded to approximately 15 percent. If research and testing indicates that the fuselage fore and aft area requiring noise treatment for shock impingement can be reduced 50 percent, and/or lighter methods of treatment can be found, the fuel and cost advantages could improve by approximately one percent.

The relationship between turboprop maintenance cost per flight hour and incremental direct operating cost, relative to the turbofan concept is shown in Figure 90. These costs are preliminary in nature, obviously, at this point in the development of the propfan/turboprop concept. Indicated is the rate calculated for this study and the approximate levels indicated by operators of the Electra aircraft. These Electra data must also be viewed as preliminary, since recent surveys of existing records have raised questions regarding inflation, consistency of maintenance procedures, accounting methods and aircraft/engine/propeller age. One conclusion that can be drawn from Figure 90 is that a ten fold increase in the study maintenance costs does not eliminate the direct operating cost advantage of the propfan/turboprop airplane. Even at these elevated levels, the propfan/turboprop has a five percent direct operating cost advantage for fuel at 60 cents per gallon, as well as the 18 percent block fuel advantage.

Maintenance hours and cost will be of major concern to those who consider operation of future turboprop powered airplanes. Loss of the improvements made in this area when the airlines transitioned from reciprocating powered/propeller driven aircraft to turbojet powered aircraft is certainly not desired. The turboprop concept studied here, however, is not a design that can be compared to these previous propeller driven aircraft that were based on 1950 levels of technology. Advances that have been made in modular design of the current turbofan engines would be applied to the propeller (propfan) and gearbox as well as to the engine in the propfan/turboprop concept. Two decades of gearbox technology advances reflecting helicopter transmission development are available. The elimination of high maintenance cost items such as fan thrust reversers and the alleviation of wheel and brake maintenance also work to the propfan/turboprop airplane's advantage. All of these items are significant in producing the projected reduced maintenance cost levels shown in Figure 90.

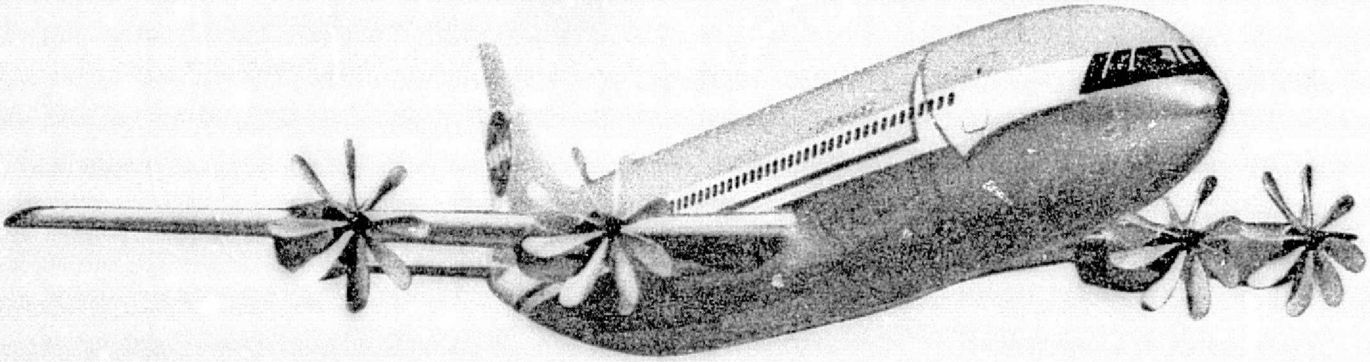


Figure 58.—Advanced turboprop airplane concept

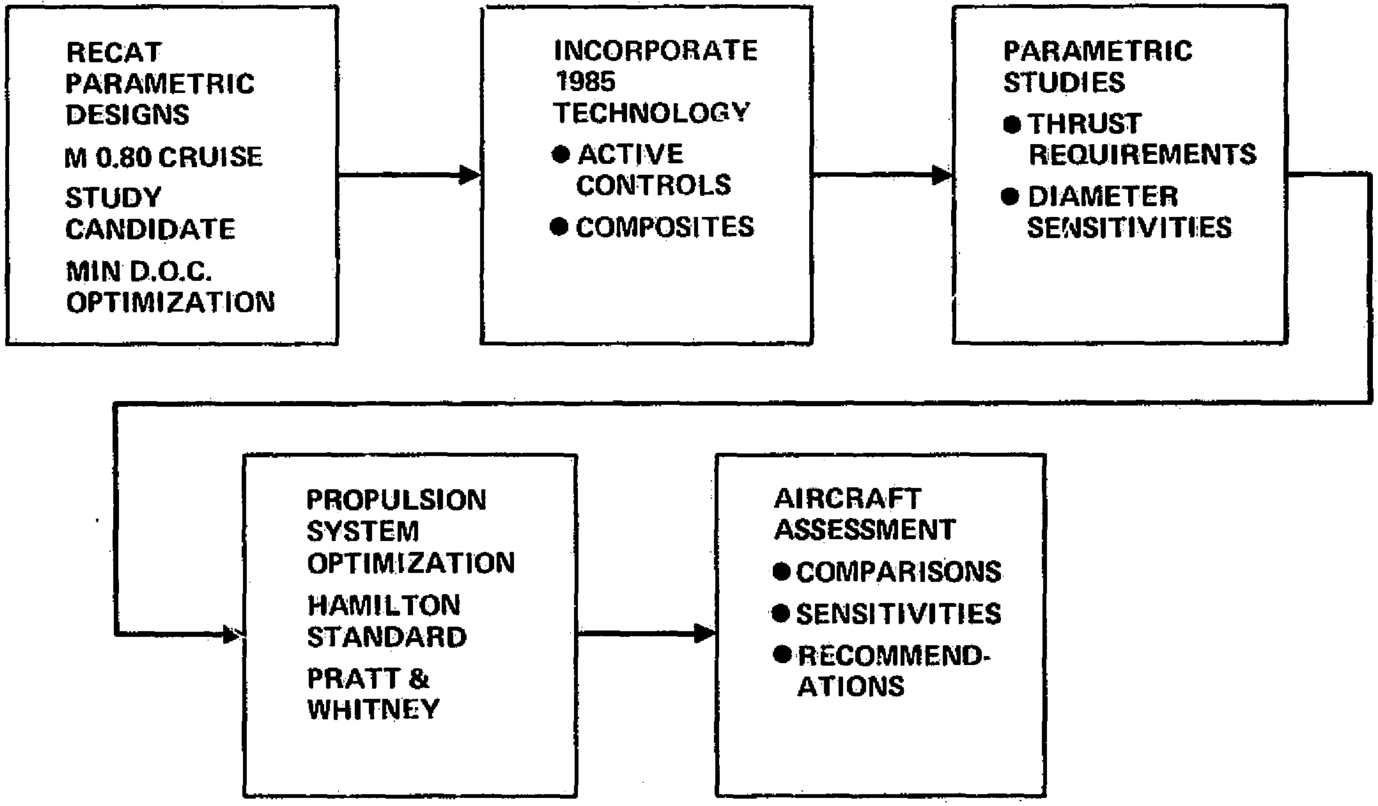
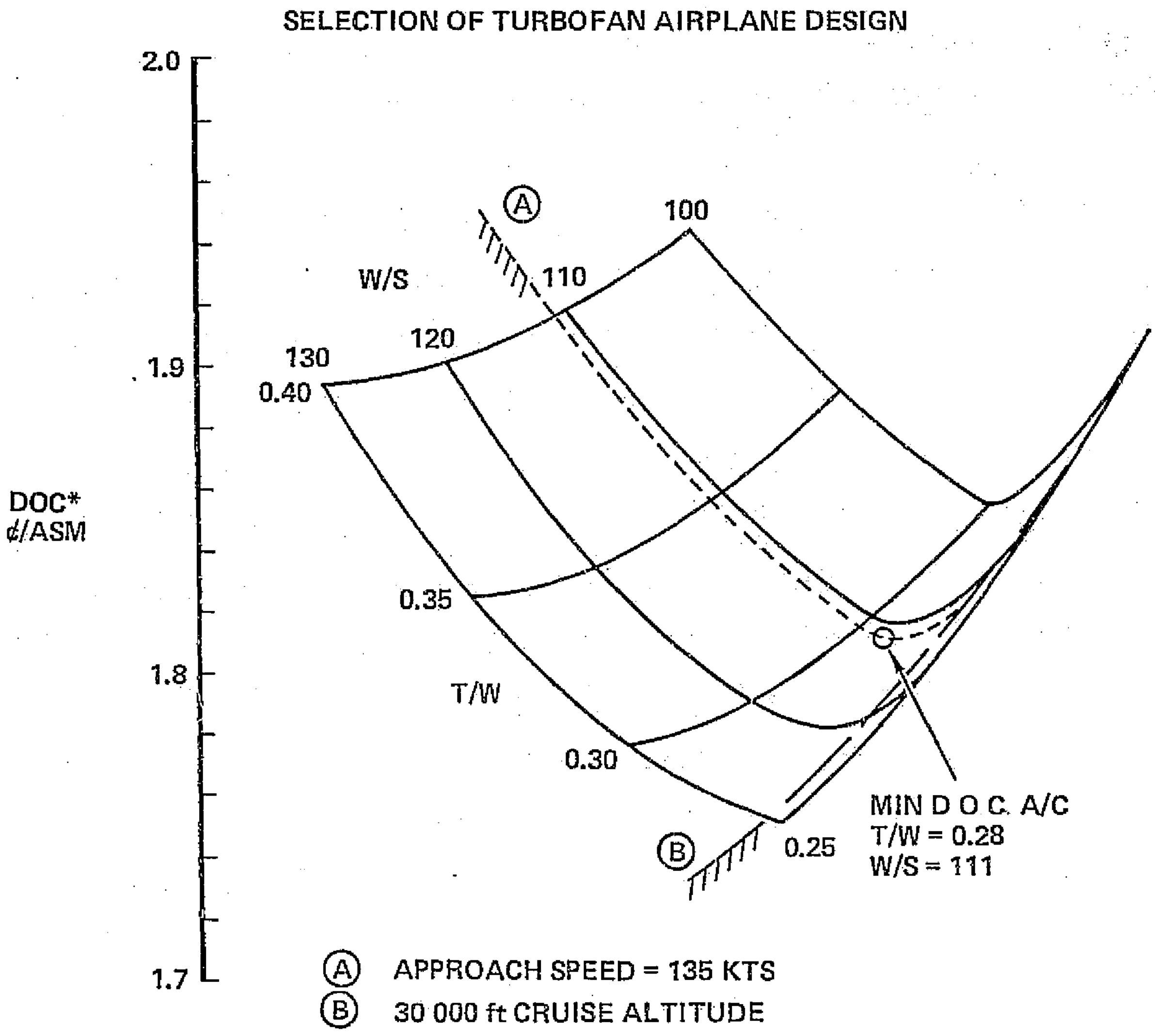


Figure 59.—Study flow



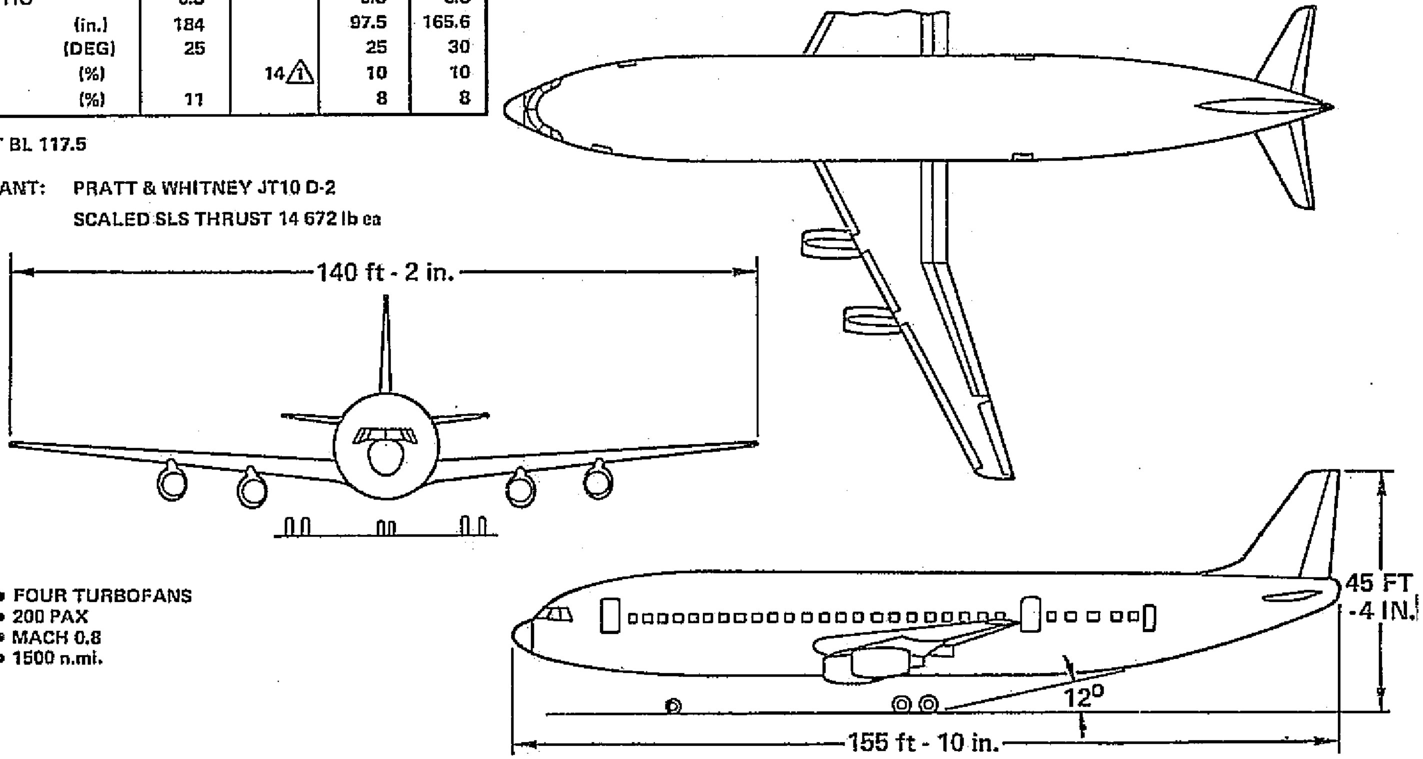
* 60¢/gal fuel cost

Figure 60.— Parametric study

CHARACTERISTICS		WING			
		BASIC	TOTAL	HORIZ	VERT
AREA	(ft^2)	1955	2209	275	253
ASPECT RATIO		10	–	5	1.6
SPAN	(ft)	139.8		37	20.1
ROOT CHORD	(in.)	258	303⚠1	137	232
TIP CHORD	(in.)	77		41	70
TAPER RATIO		0.3	–	0.3	0.3
MAC	(in.)	184		97.5	165.6
SWEEP	(DEG)	25		25	30
T/C ROOT	(%)		14⚠1	10	10
T/C TIP	(%)	11		8	8

⚠1 AT BL 117.5

POWER PLANT: PRATT & WHITNEY JT10 D-2
SCALED SLS THRUST 14 672 lb ea



- FOUR TURBOFANS
- 200 PAX
- MACH 0.8
- 1500 n.mi.

Figure 61.– General arrangement – turbofan aircraft

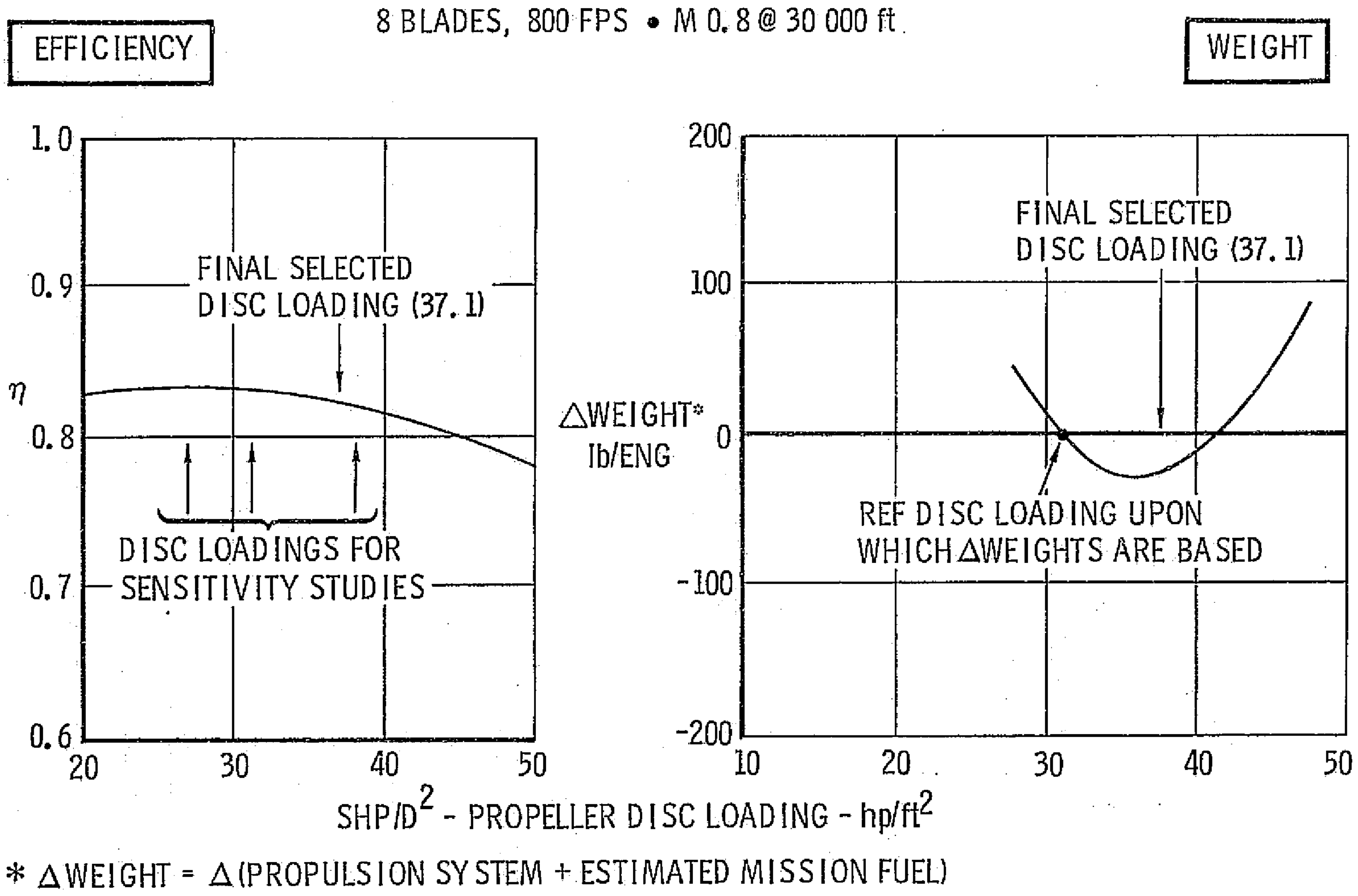
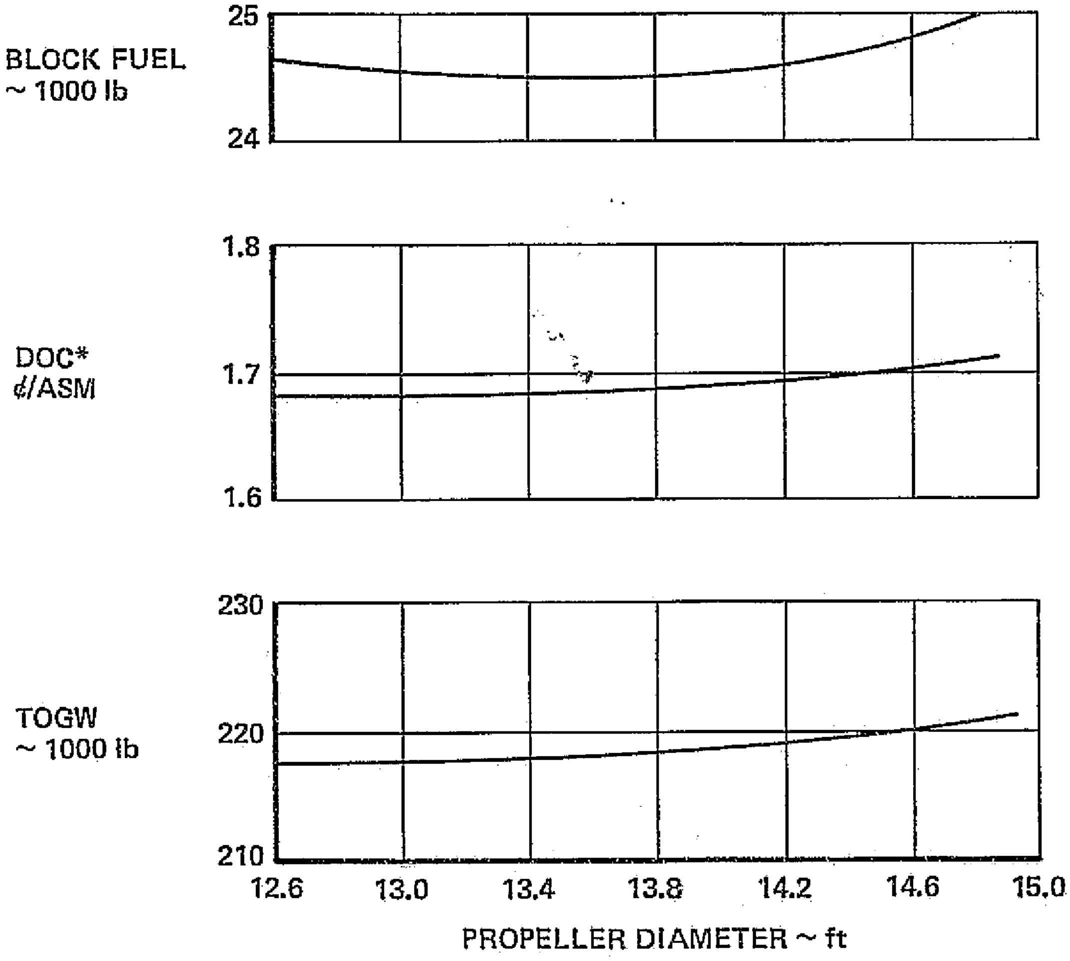


Figure 62.—Propeller selection



* 60¢/gal fuel cost

● NOTE: EFFECT OF AIRPLANE RESIZING INCLUDED

Figure 63.—Effect of propeller diameter on design

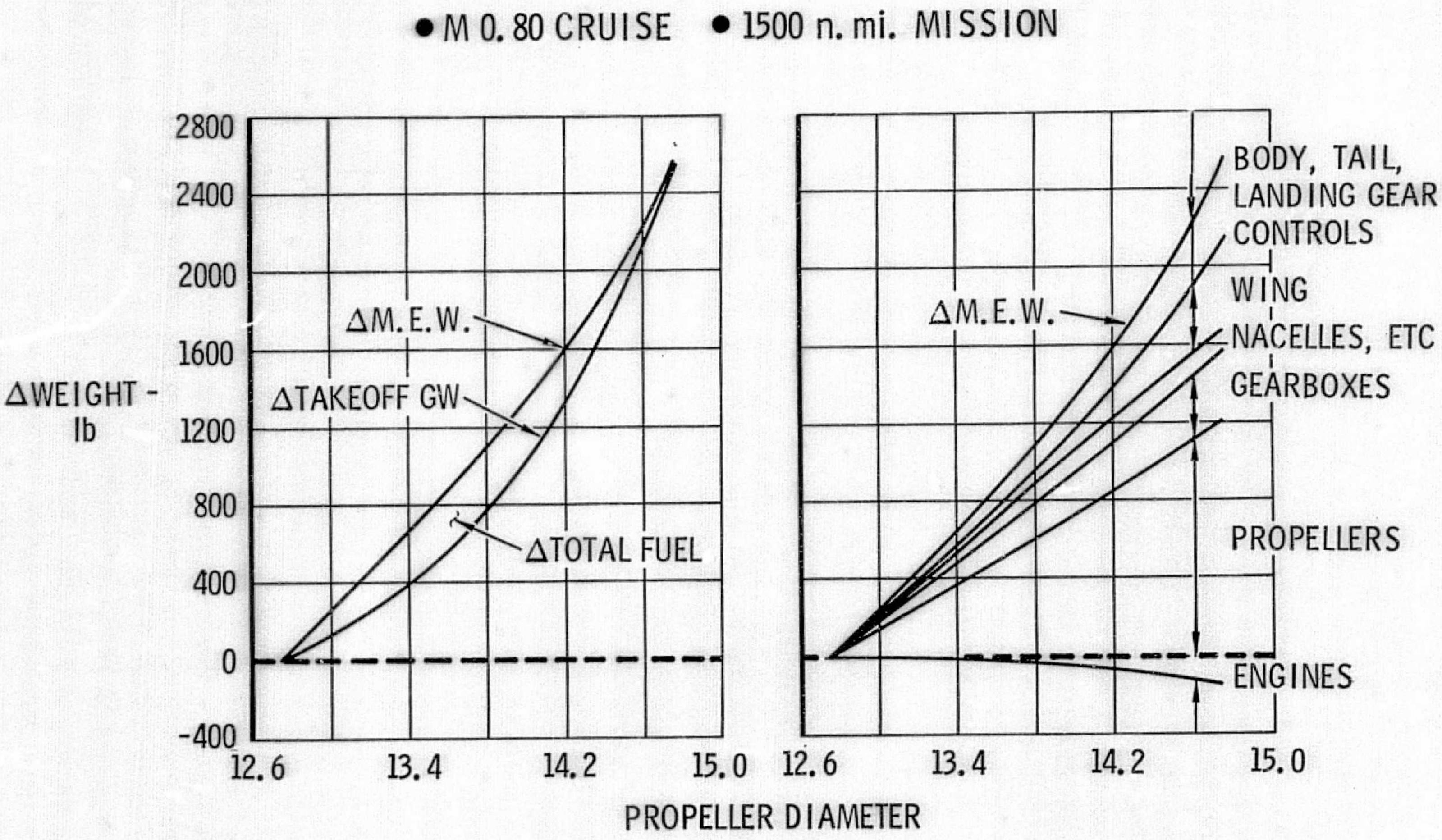


Figure 64.—Propeller diameter - weight sensitivity

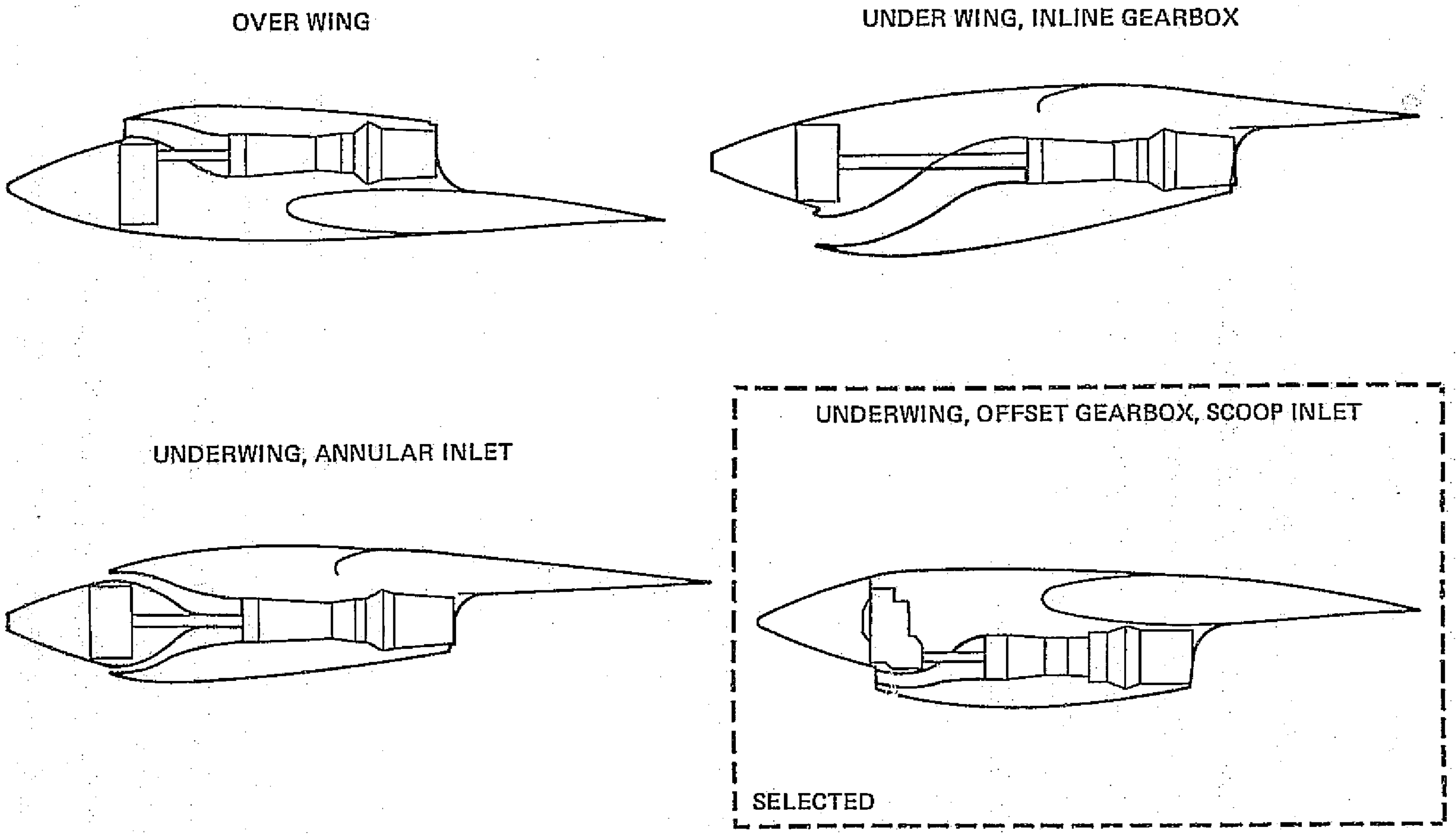


Figure 65.—Nacelle configurations

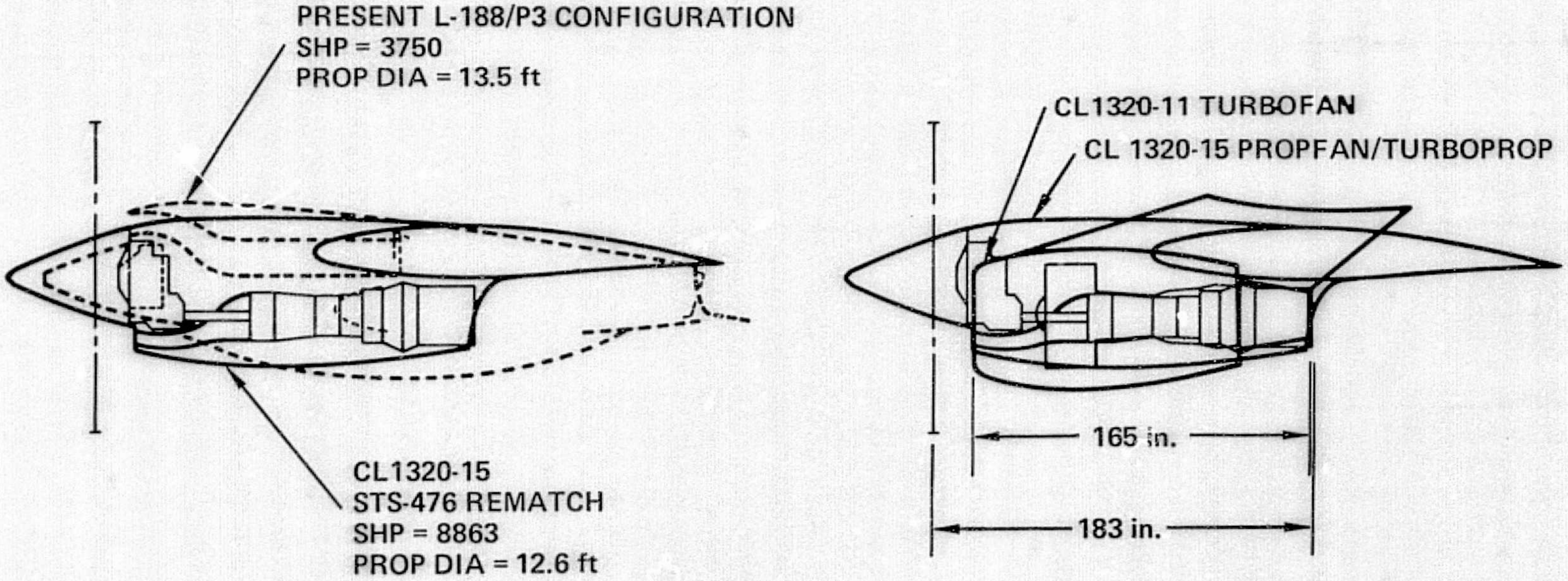


Figure 66.—Nacelle comparison

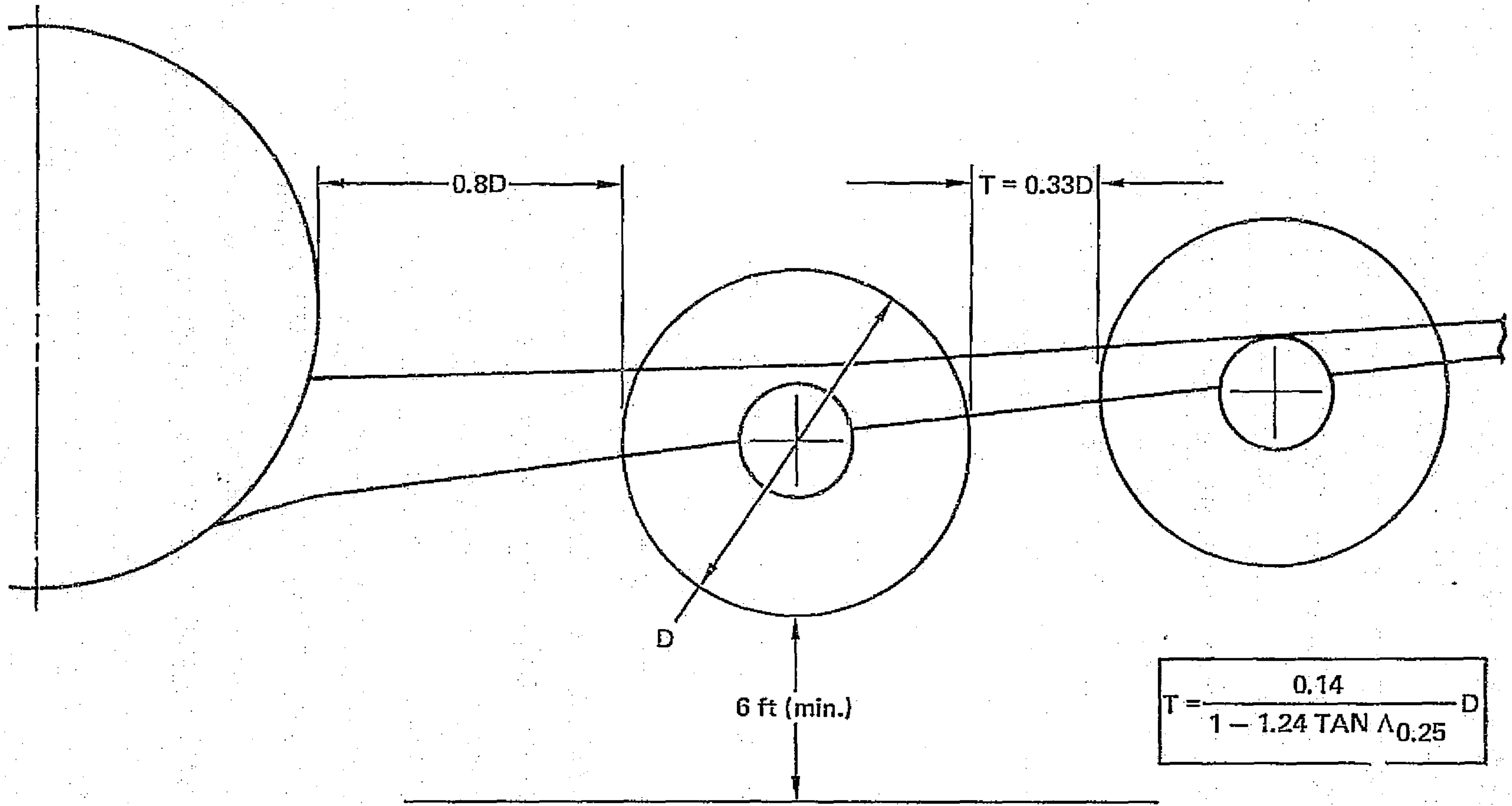
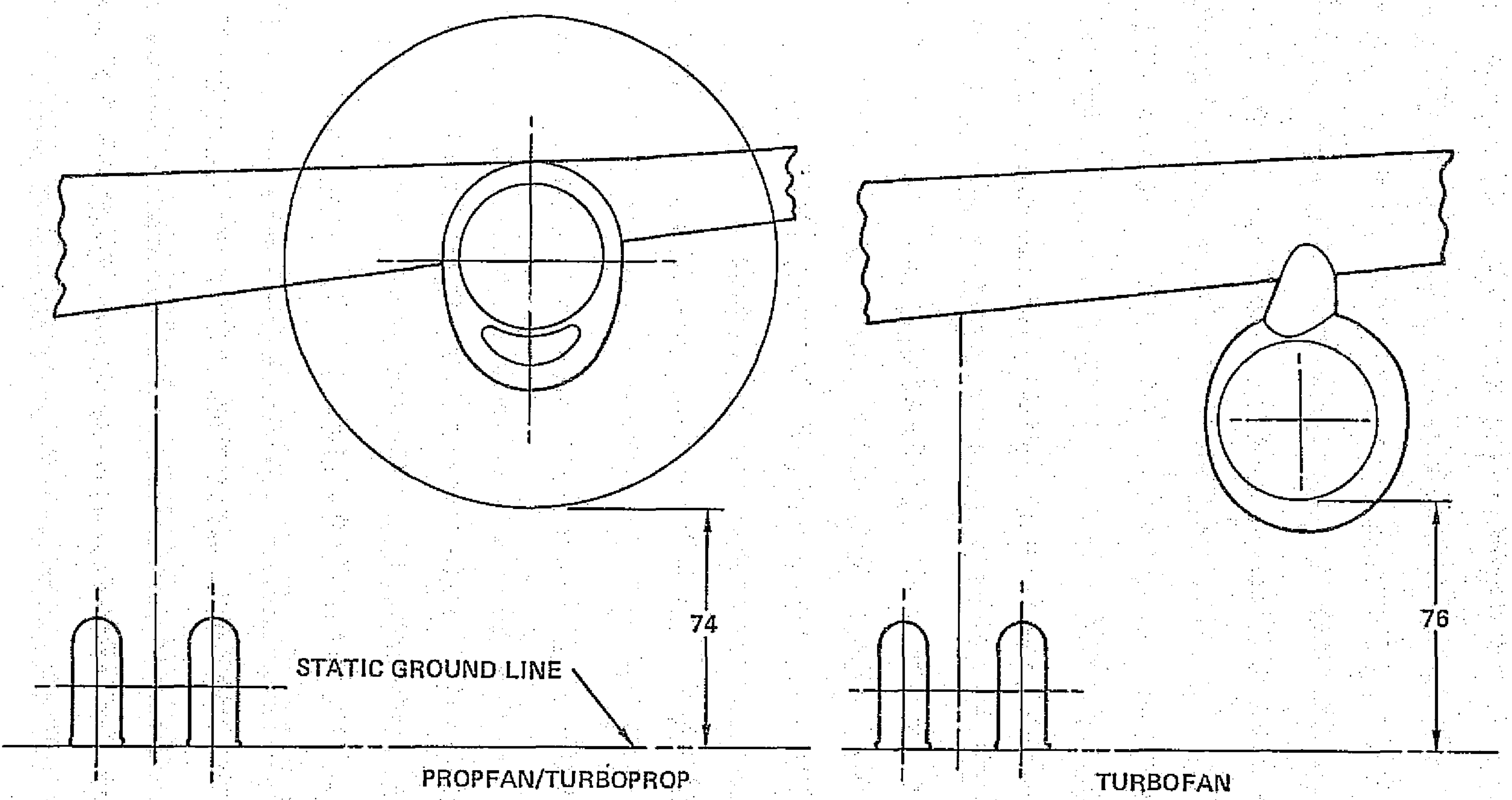
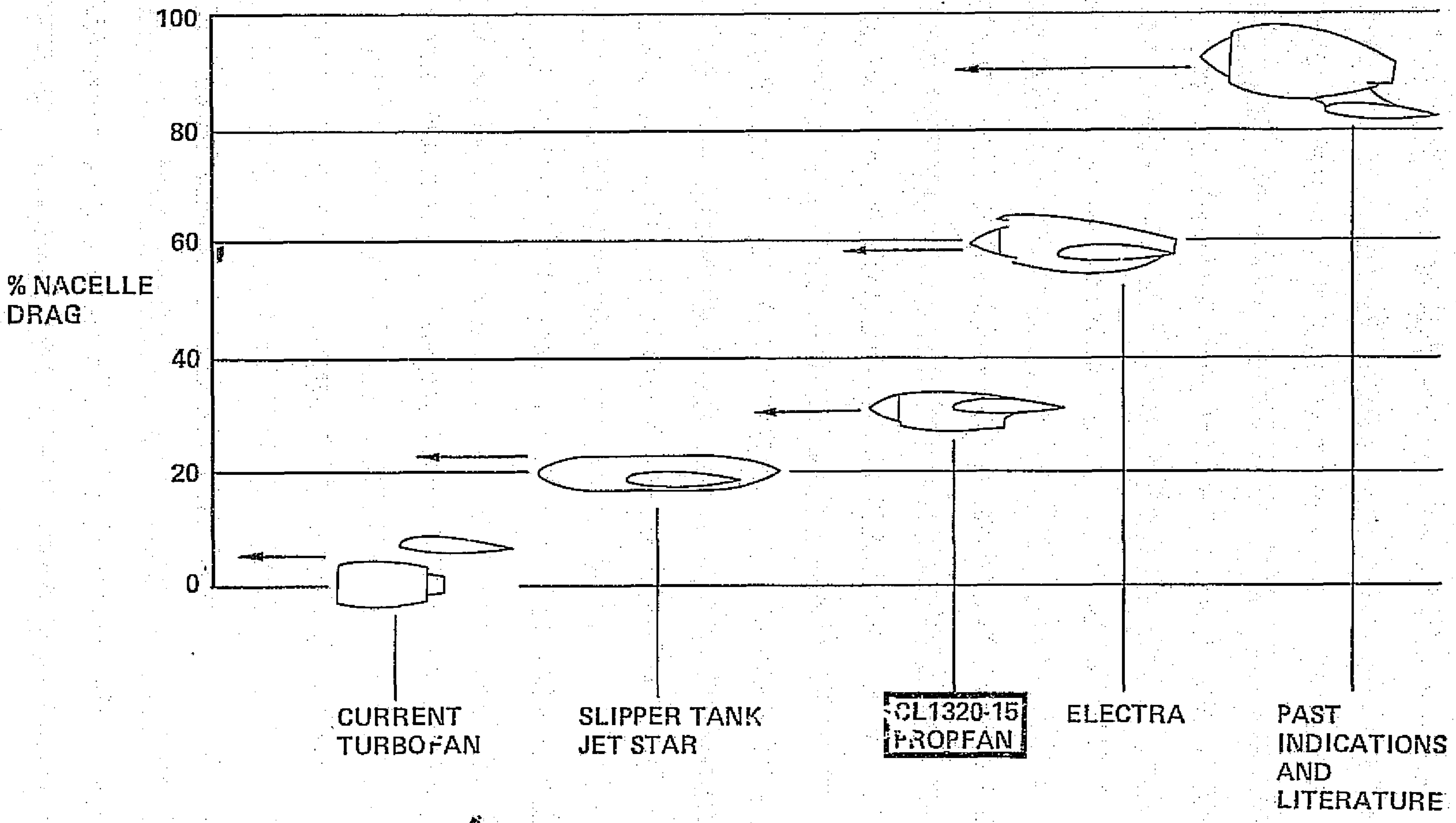


Figure 67.—Propeller spacing requirements



- LANDING GEAR HEIGHTS DICTATED BY AIRCRAFT ROTATION

Figure 68.—Landing gear comparison



- GOAL OF 30% SELECTED

Figure 69.—Nacelle/wing interference

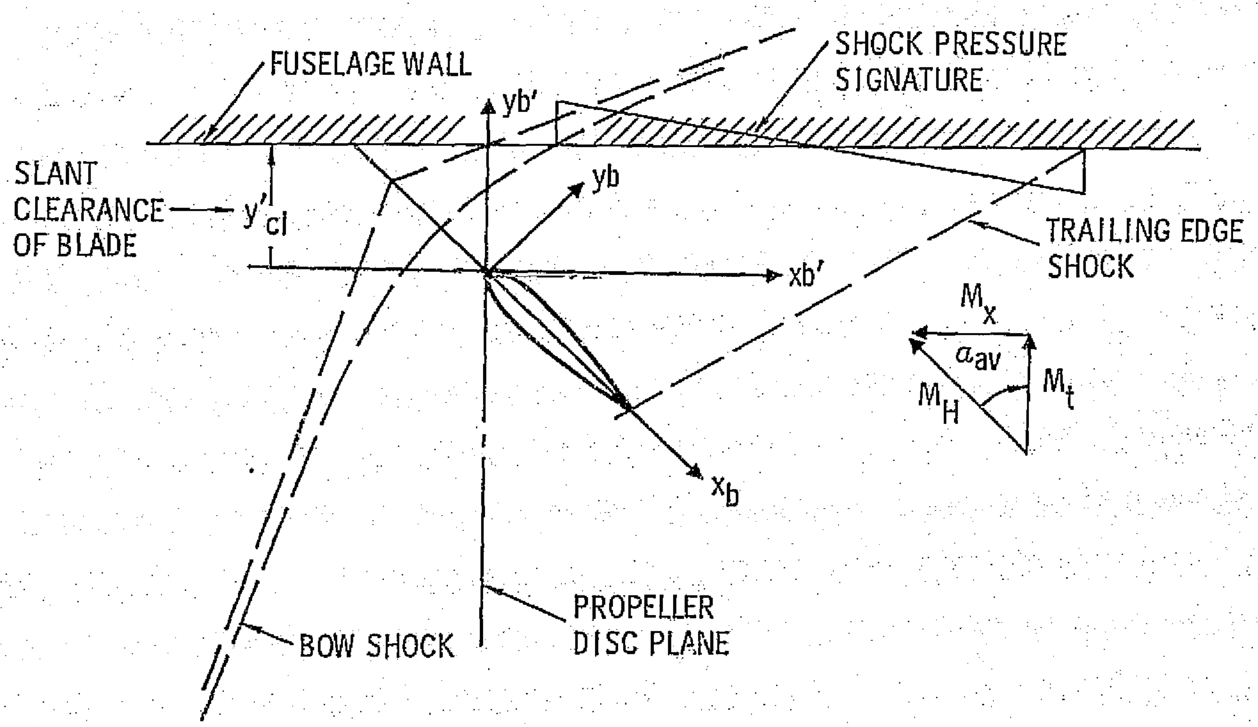


Figure 70. – External sound pressure analysis for supersonic propellers

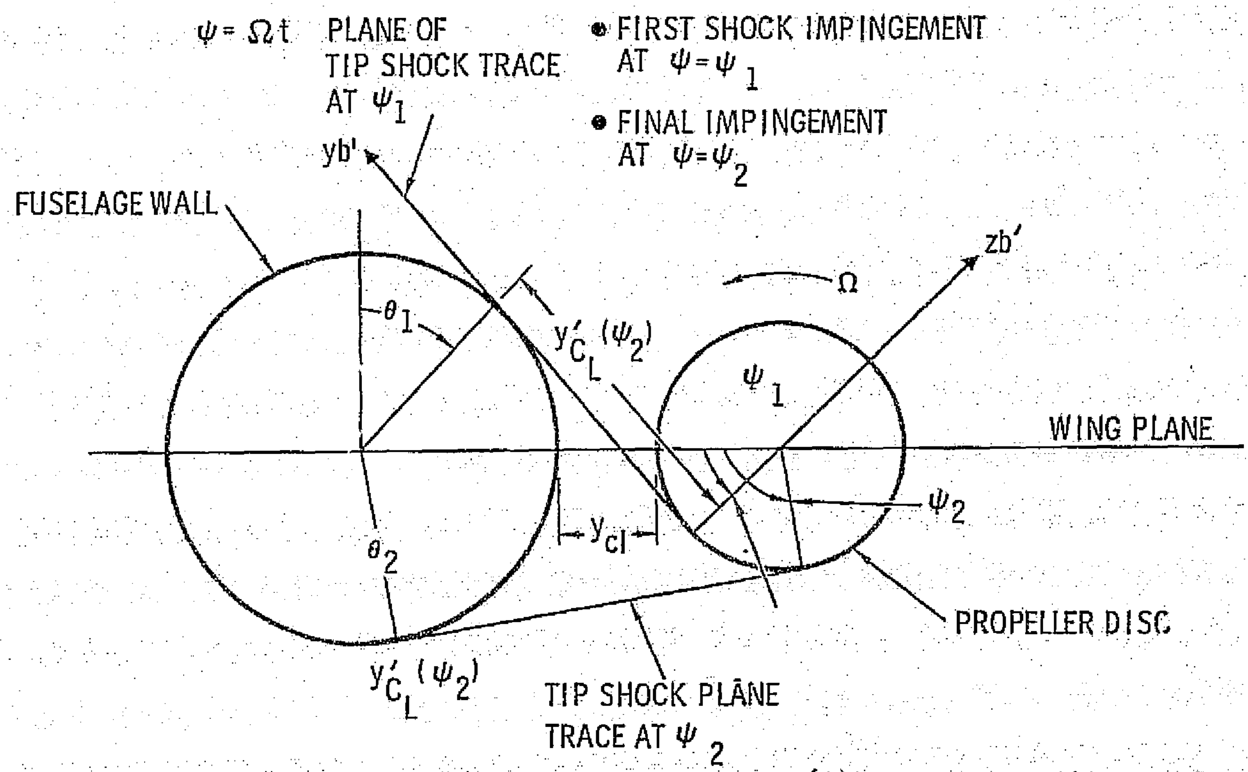


Figure 71. – Propeller blade slant clearance $y'_{CL}(\psi)$ vs blade position angle

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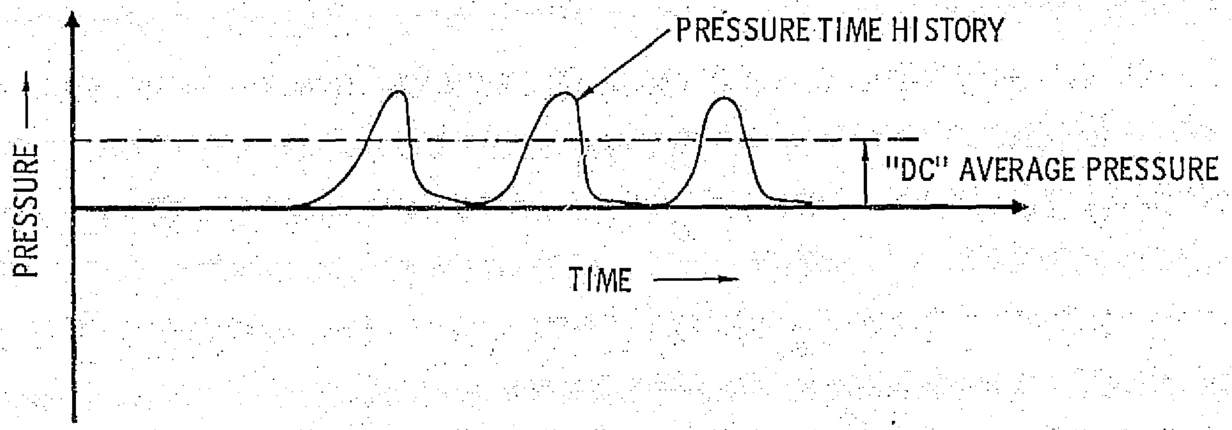

- TIME HISTORY EXHIBITS "AC" COMPONENT AND STEADY PRESSURE ("DC") COMPONENT ONLY "AC" COMPONENT PRODUCES FUSELAGE WALL VIBRATION

Figure 72.— Typical pressure time history

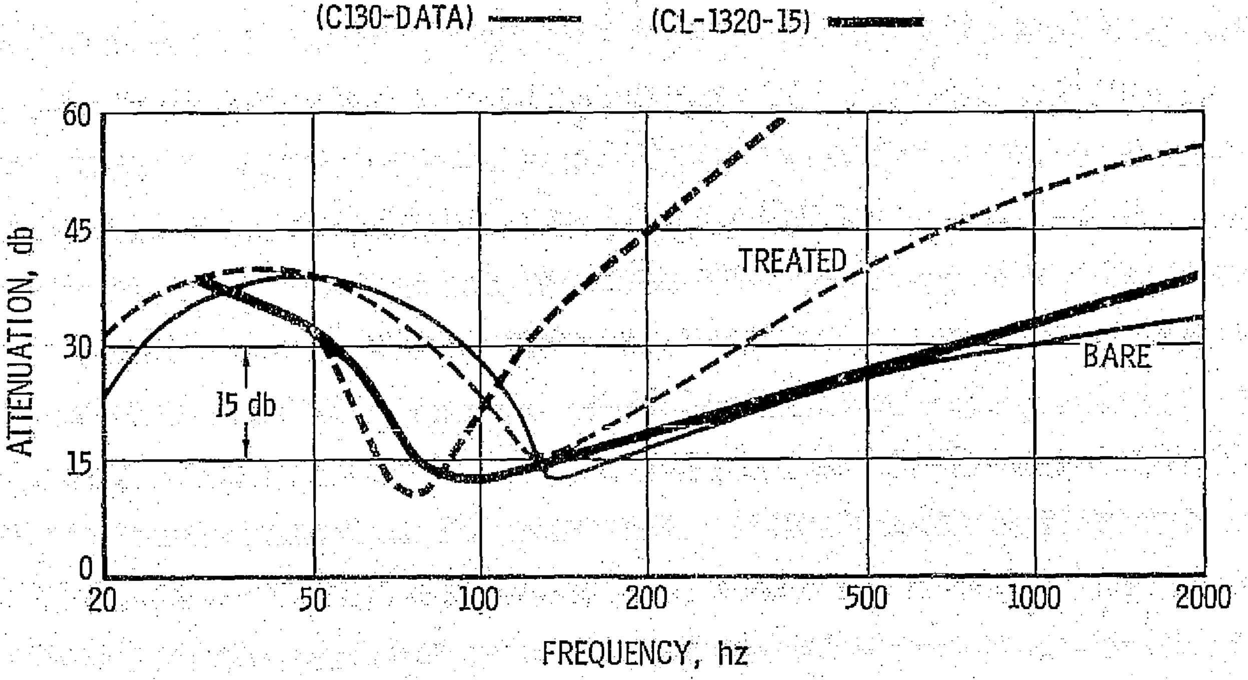

Figure 73. — Aircraft cabin noise reduction

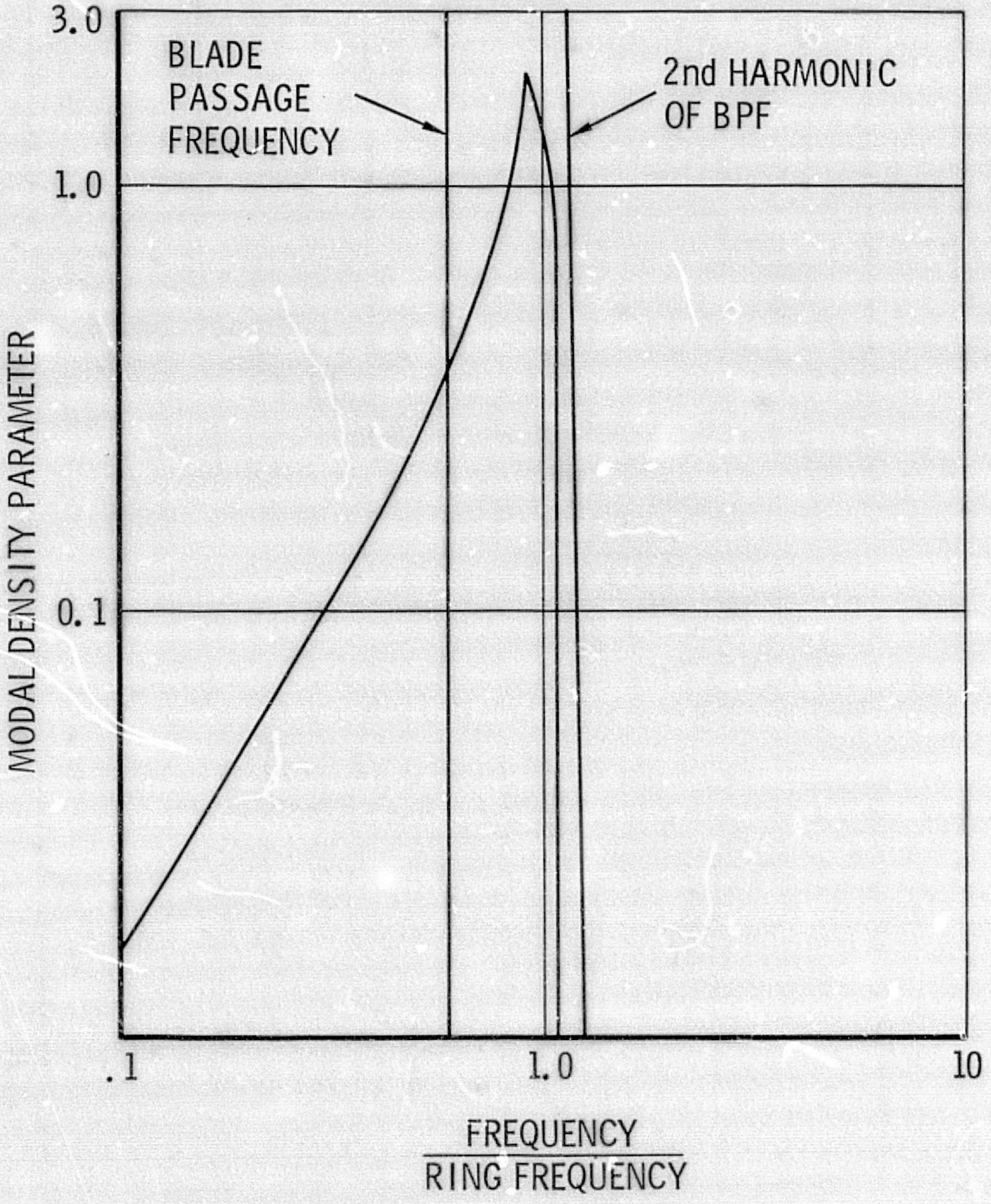

Figure 74.—Modal density for acoustically fast modes

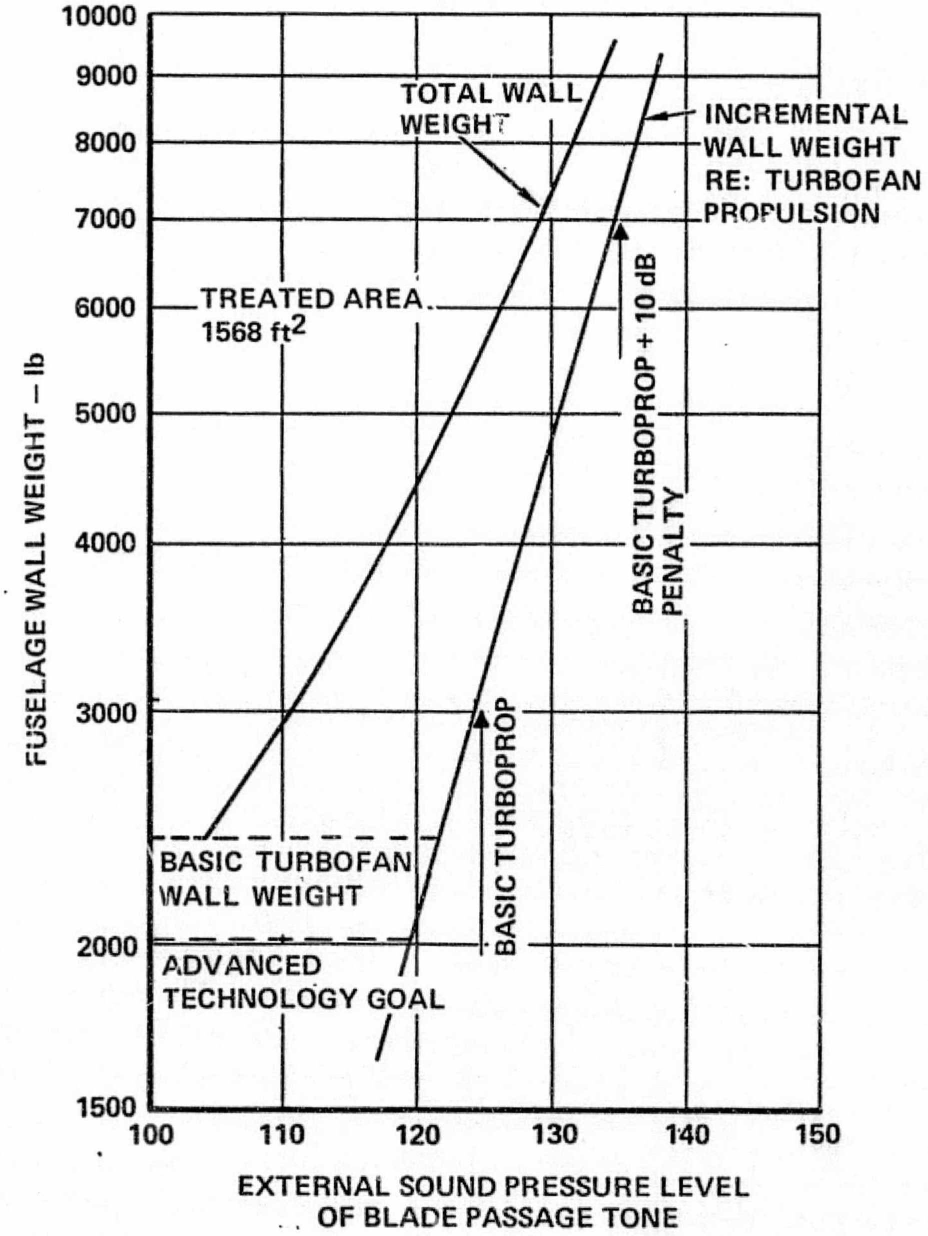

Figure 75.—Total and incremental cabin wall weight vs exterior noise level

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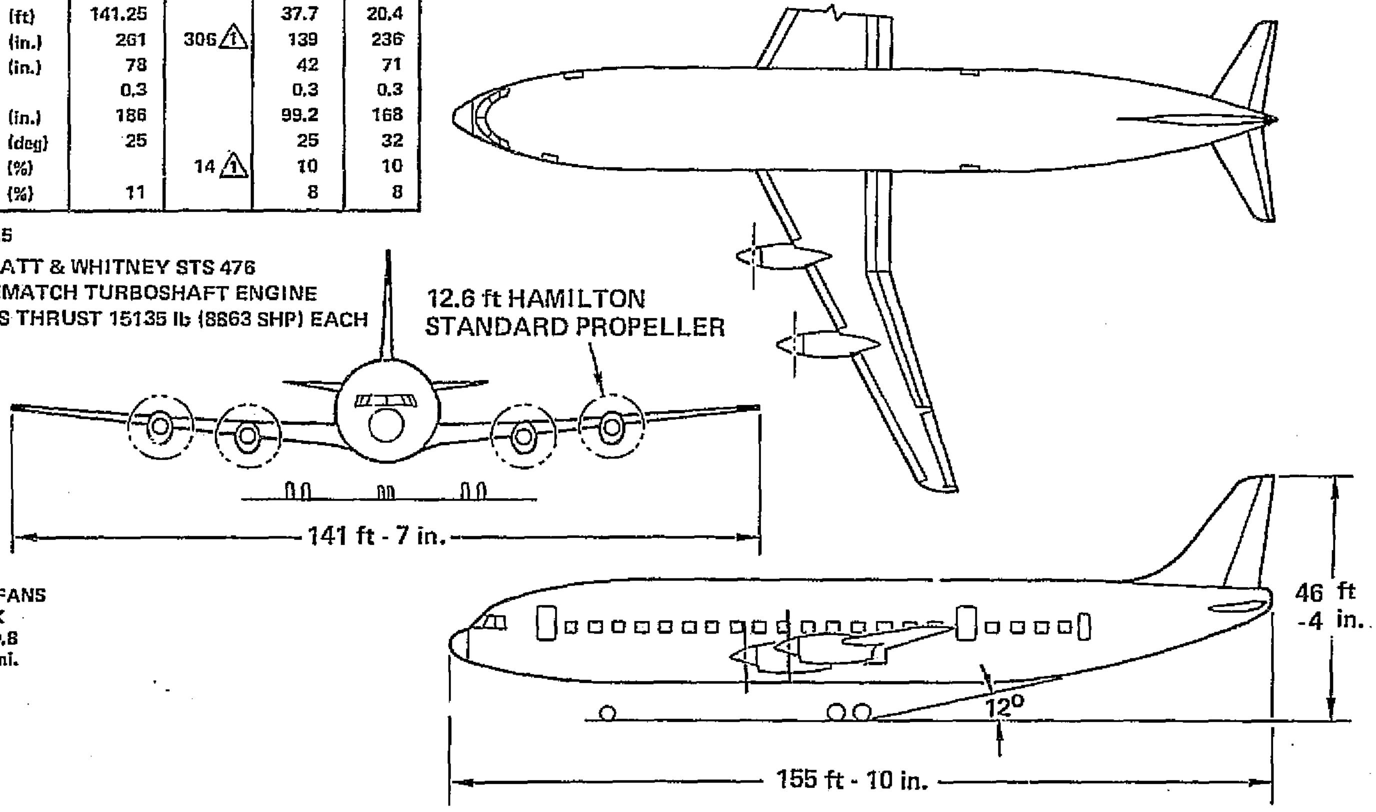
CHARACTERISTICS		WING		HORIZ	VERT
		BASIC	TOTAL		
AREA	(ft^2)	1995	2250	284	261
ASPECT RATIO		10	–	5	1.6
SPAN	(ft)	141.25		37.7	20.4
ROOT CHORD	(in.)	261	306 ⚠1	139	236
TIP CHORD	(in.)	78		42	71
TAPER RATIO		0.3		0.3	0.3
MAC	(in.)	186		99.2	168
SWEEP	(deg)	25		25	32
T/C ROOT	(%)		14 ⚠1	10	10
T/C TIP	(%)	11		8	8

⚠1 AT BL 117.5

POWER PLANT: PRATT & WHITNEY STS 476
REMATCH TURBOSHAFT ENGINE
SLS THRUST 15135 lb (8863 SHP) EACH



- 4 PROPFANS
- 200 PAX
- MACH 0.8
- 1500 n.mi.

Figure 76.— General arrangement - propfan aircraft

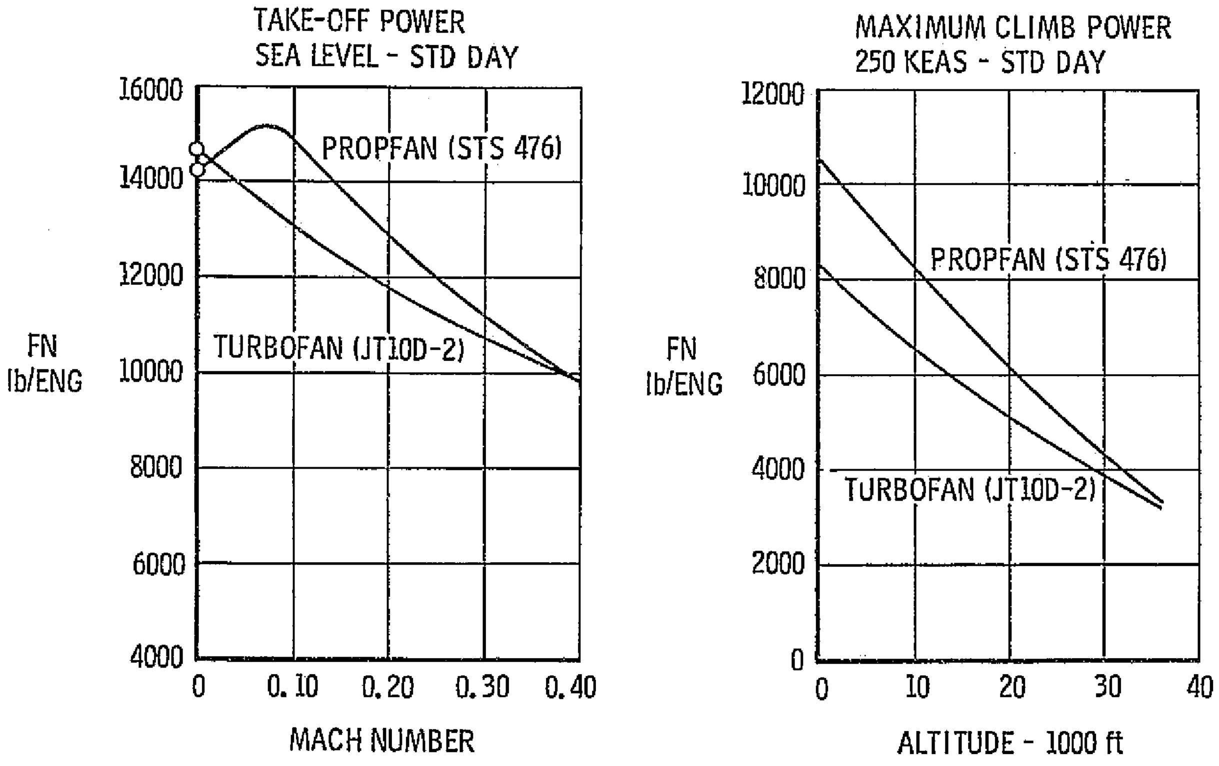


Figure 77. — Installed thrust comparison

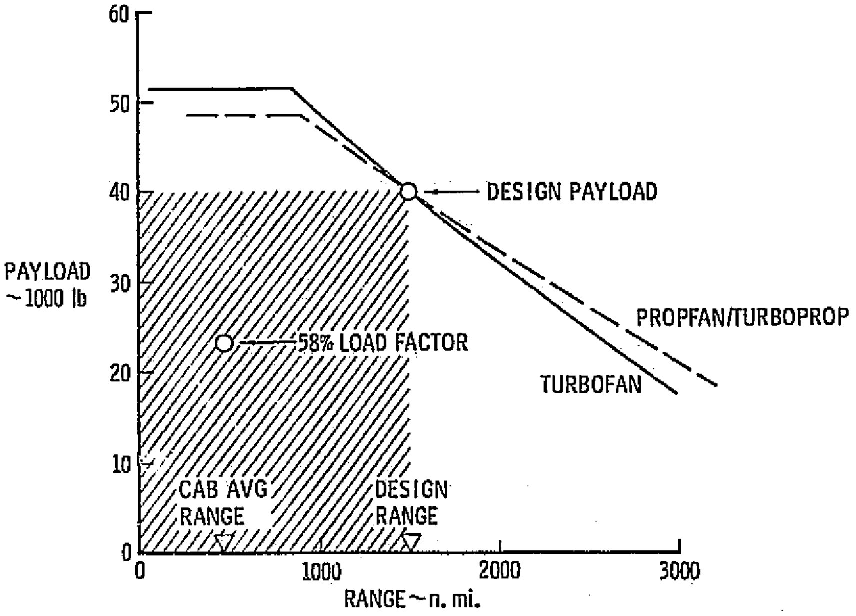


Figure 78.— Payload - range comparison

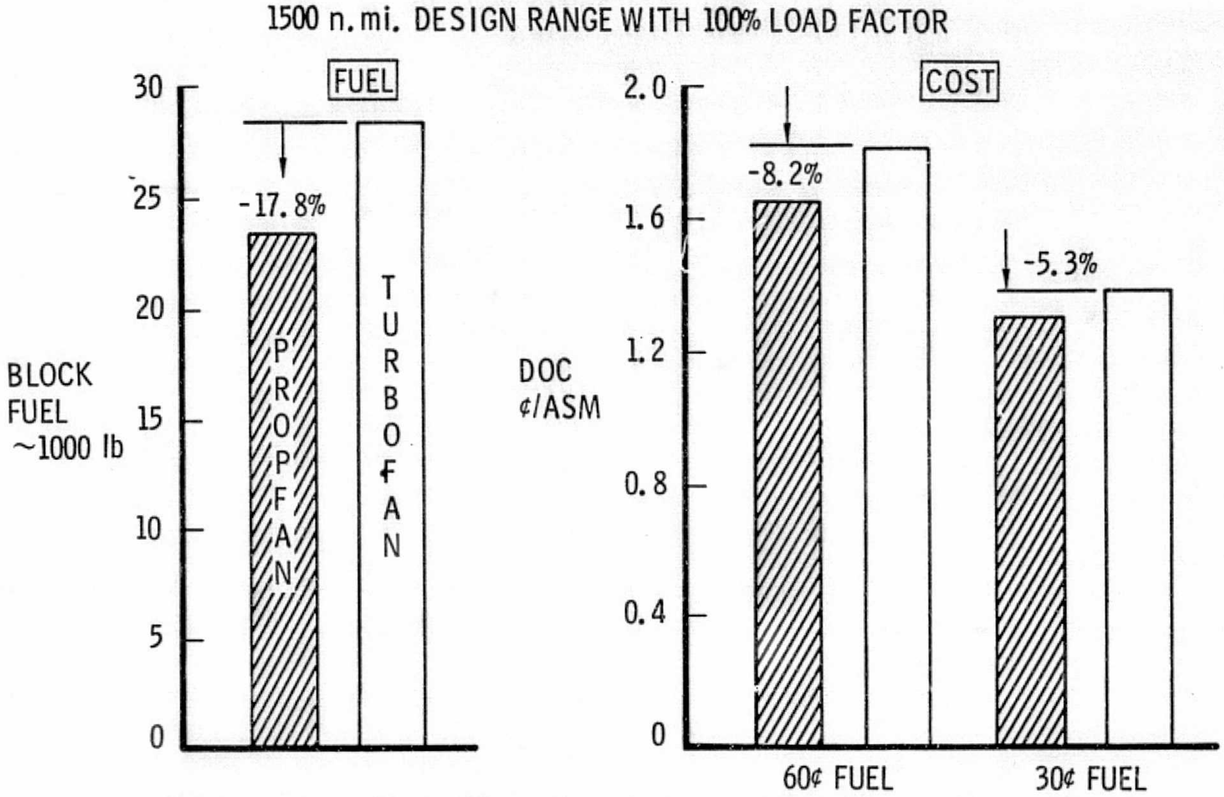


Figure 79. — Aircraft comparisons - 1500 n.mi. design range

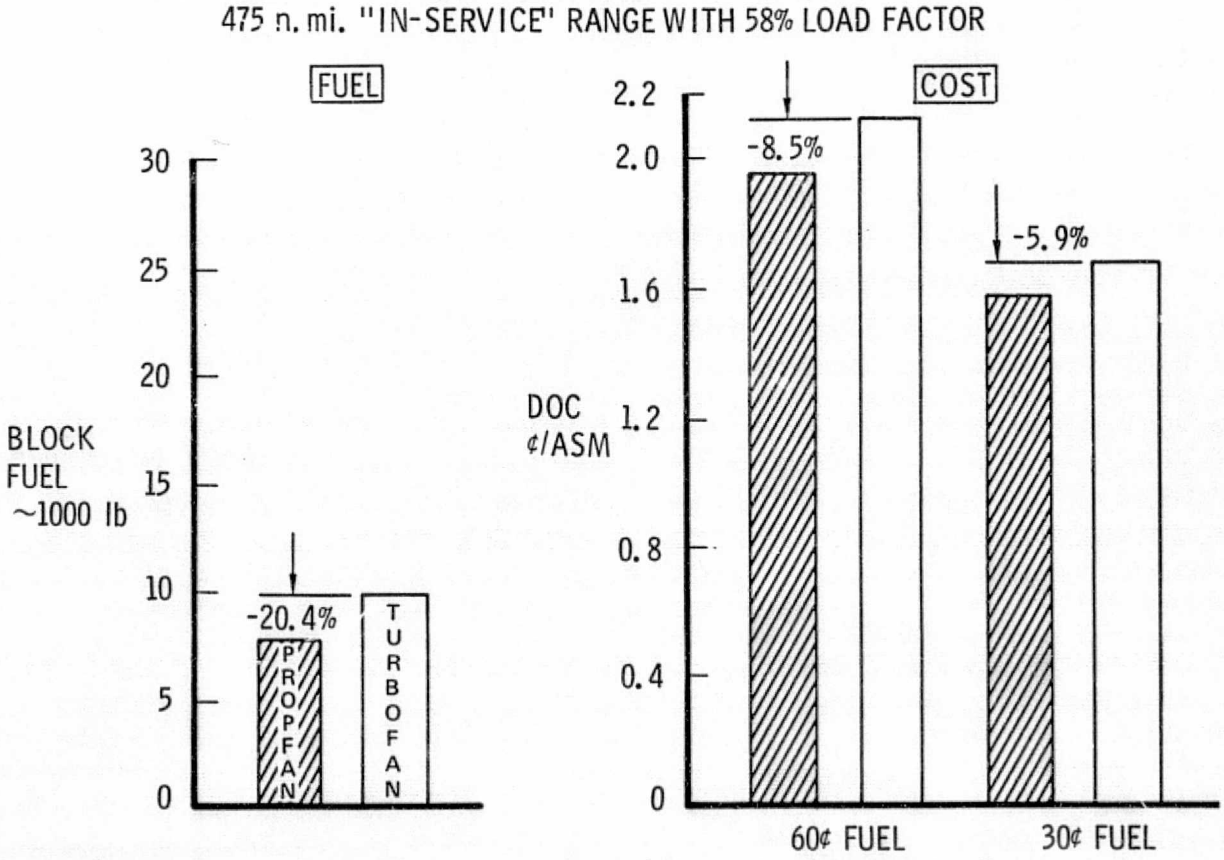


Figure 80. — Aircraft comparisons - 475 n.mi. "in-service" range

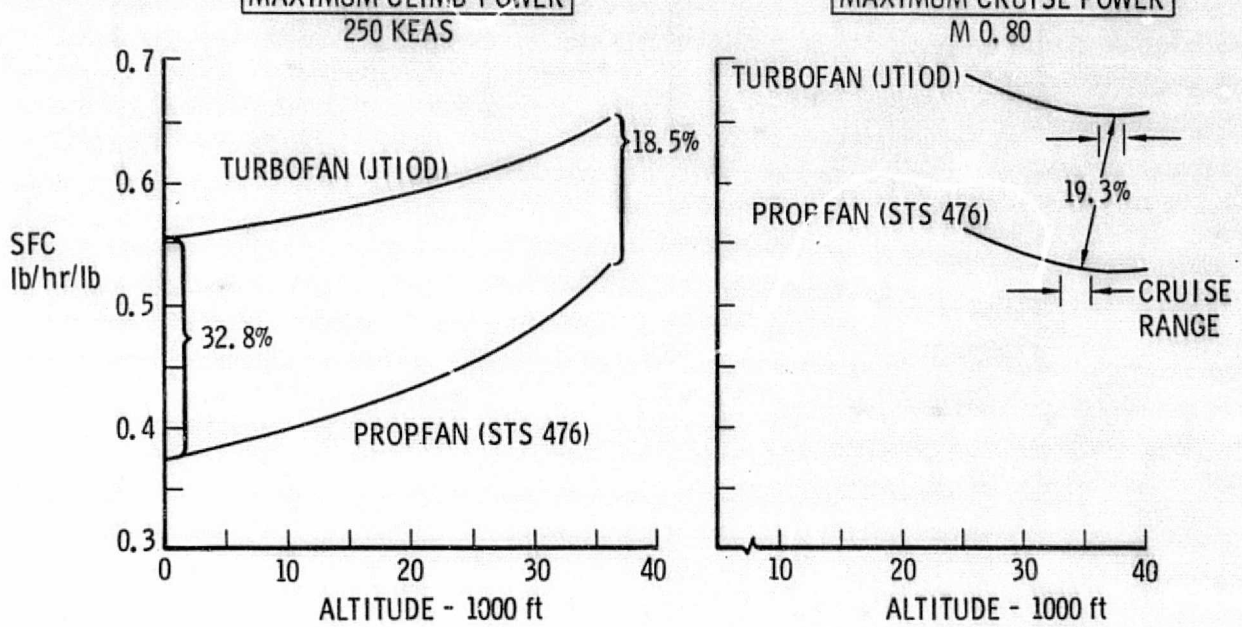


Figure 81. – Comparison of installed specific fuel consumption

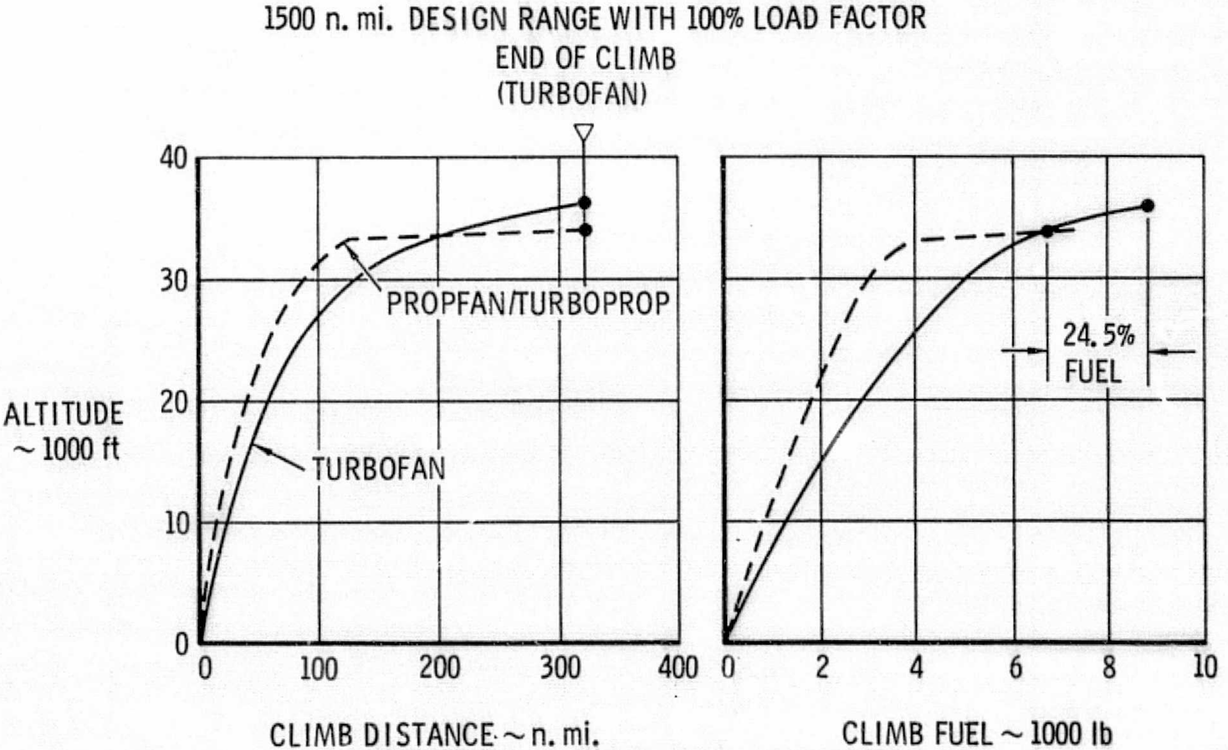


Figure 82. – Climb fuel comparison

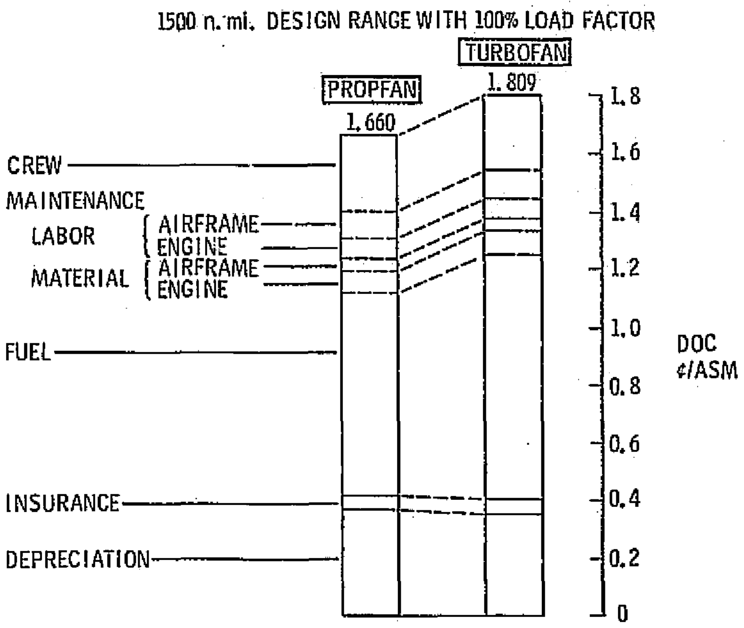
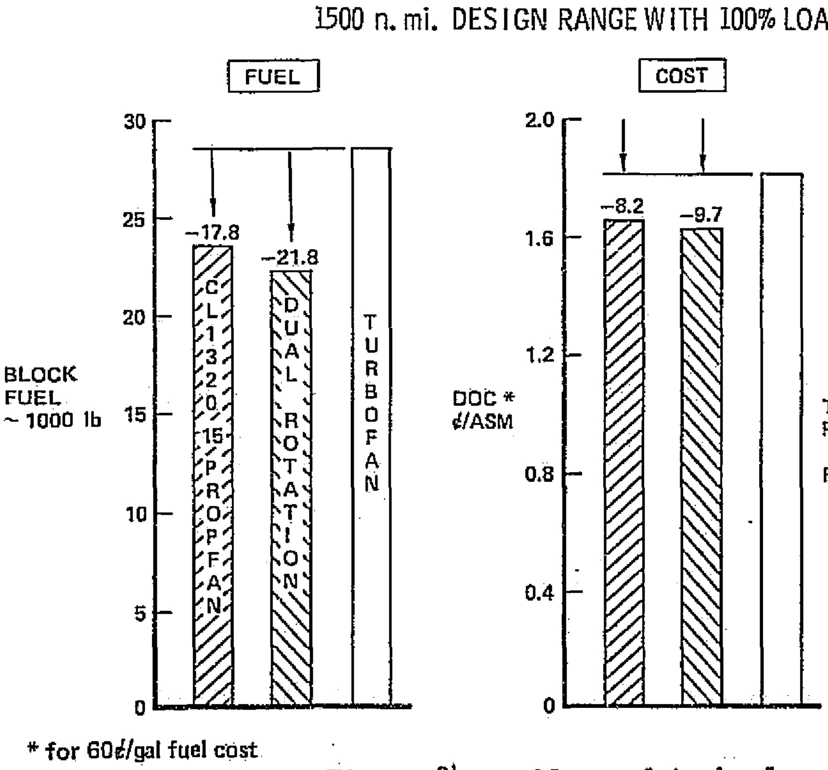


Figure 83. – Direct operating cost breakdown



- 12.2 FT DUAL-ROTATION 4 BLADED PROP FAN
- PROPELLER EFFICIENCY INCREASE ≈ 5%
- ADJUSTED COSTS
  LABOR, MATERIAL & ACQUISITION
- RESIZED AIRPLANE
- ADVANCED TECHNOLOGY ENGINE WEIGHTS

	BASE	W/DUAL ROTATION
TAKEOFF G.W. ~ lb	217 466	213 843
PROPULSION SYSTEM WT- lb	15 143	14 092
FLYAWAY COST – $	14.15M	14.18M

Figure 84. – Advanced technology potential

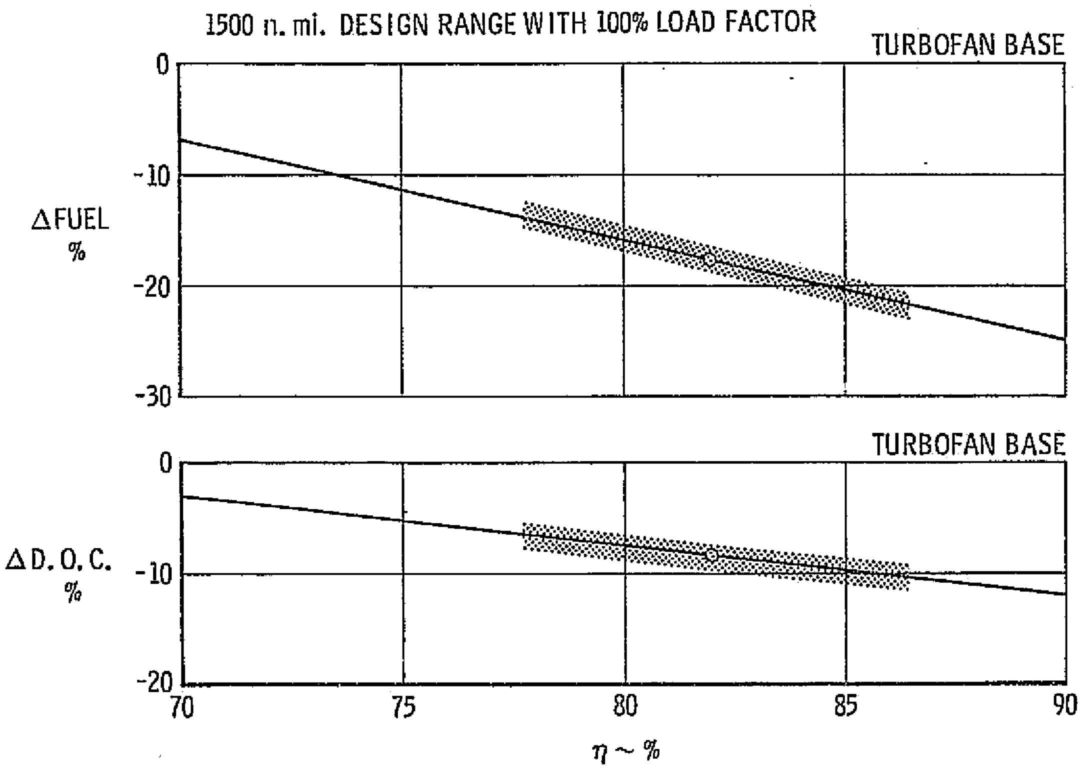


Figure 85. - Sensitivity - propeller efficiency

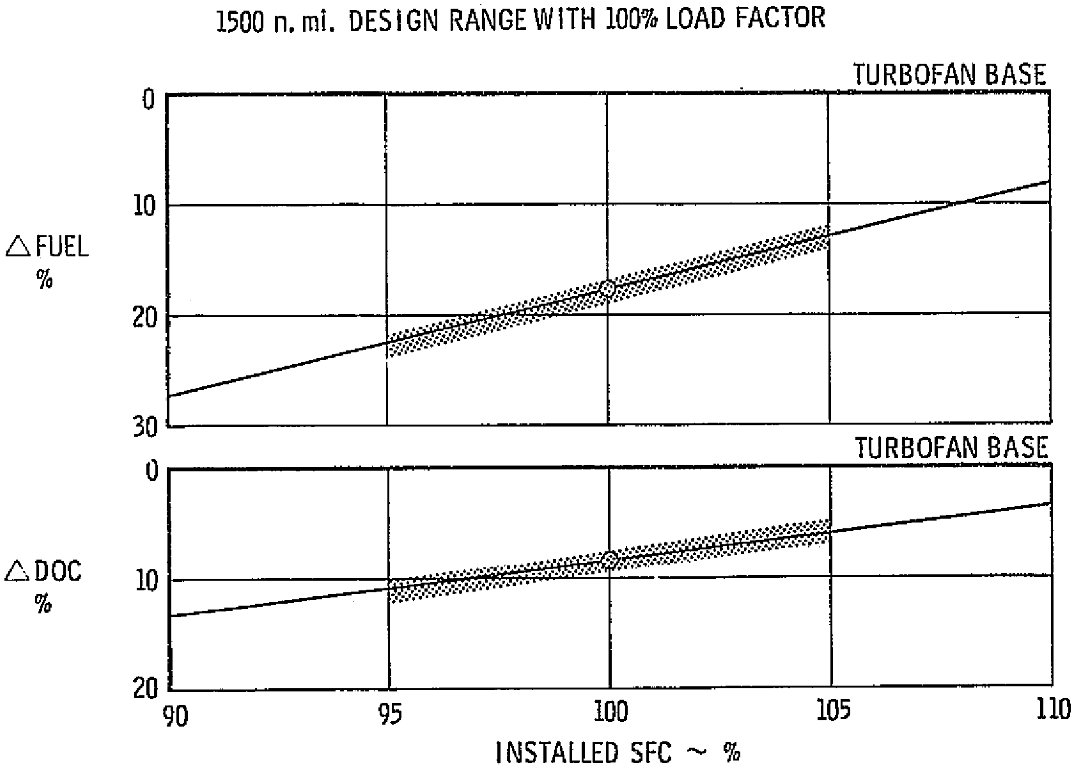


Figure 86. - Sensitivity - engine SFC

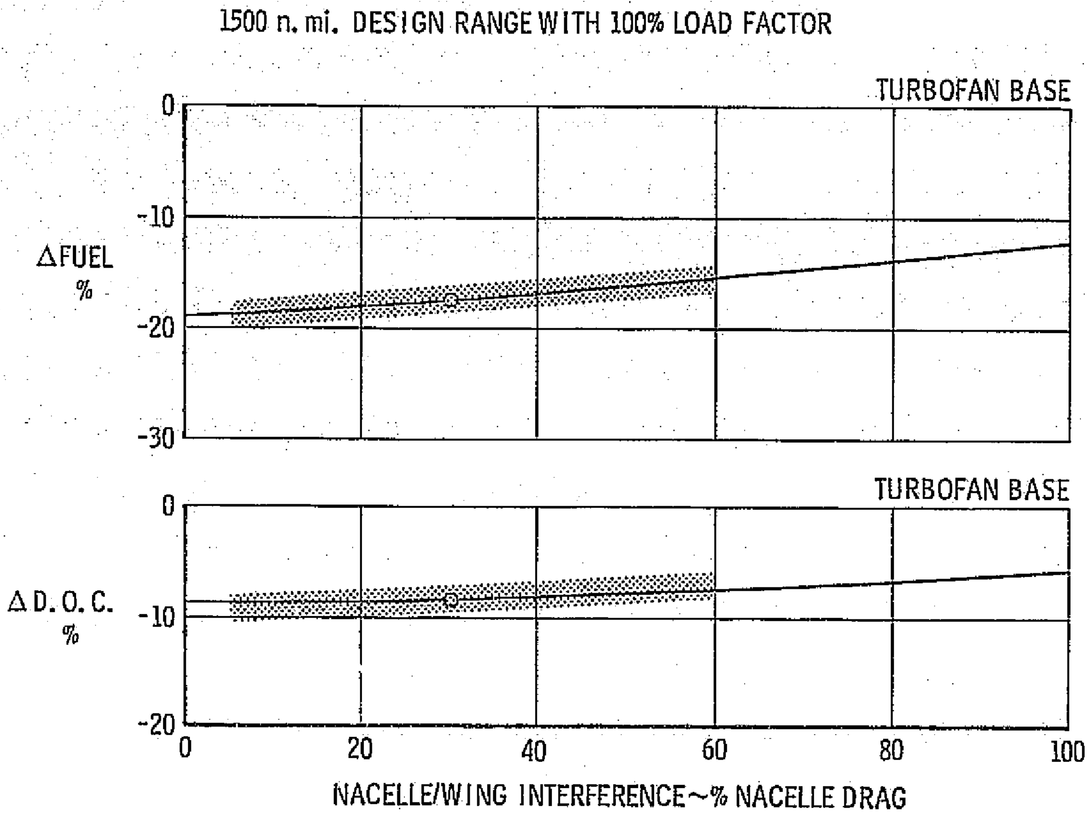


Figure 87.— Sensitivity - nacelle/wing interference

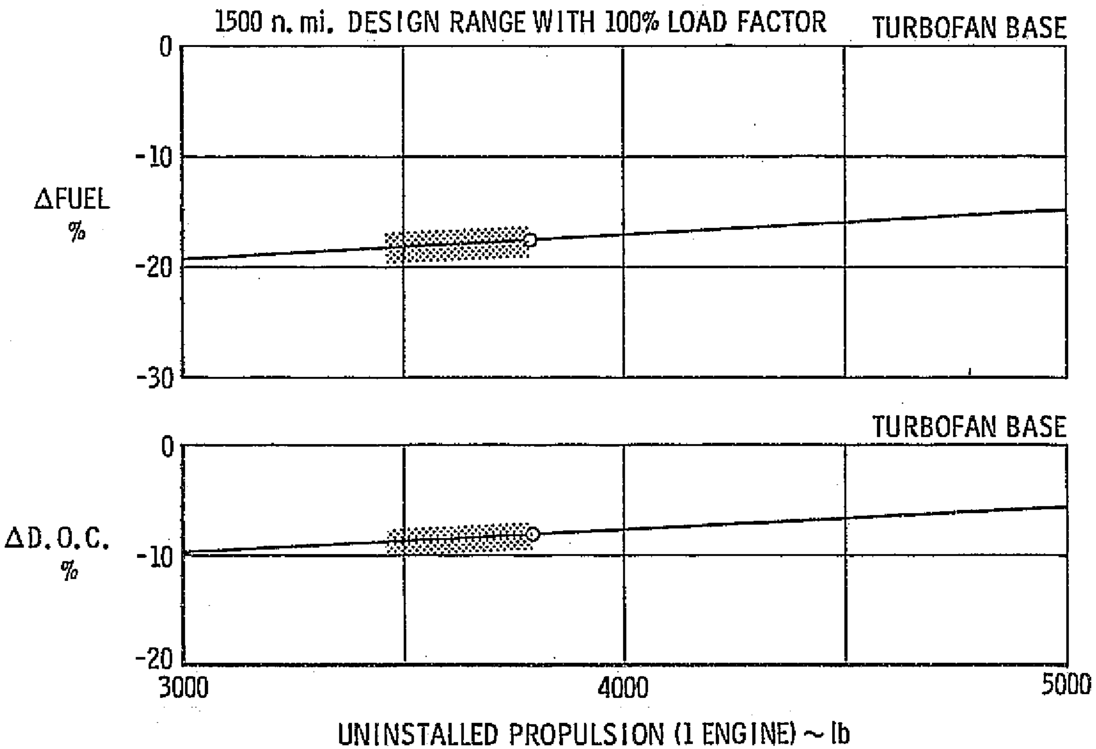


Figure 88. — Sensitivity - propulsion system weight

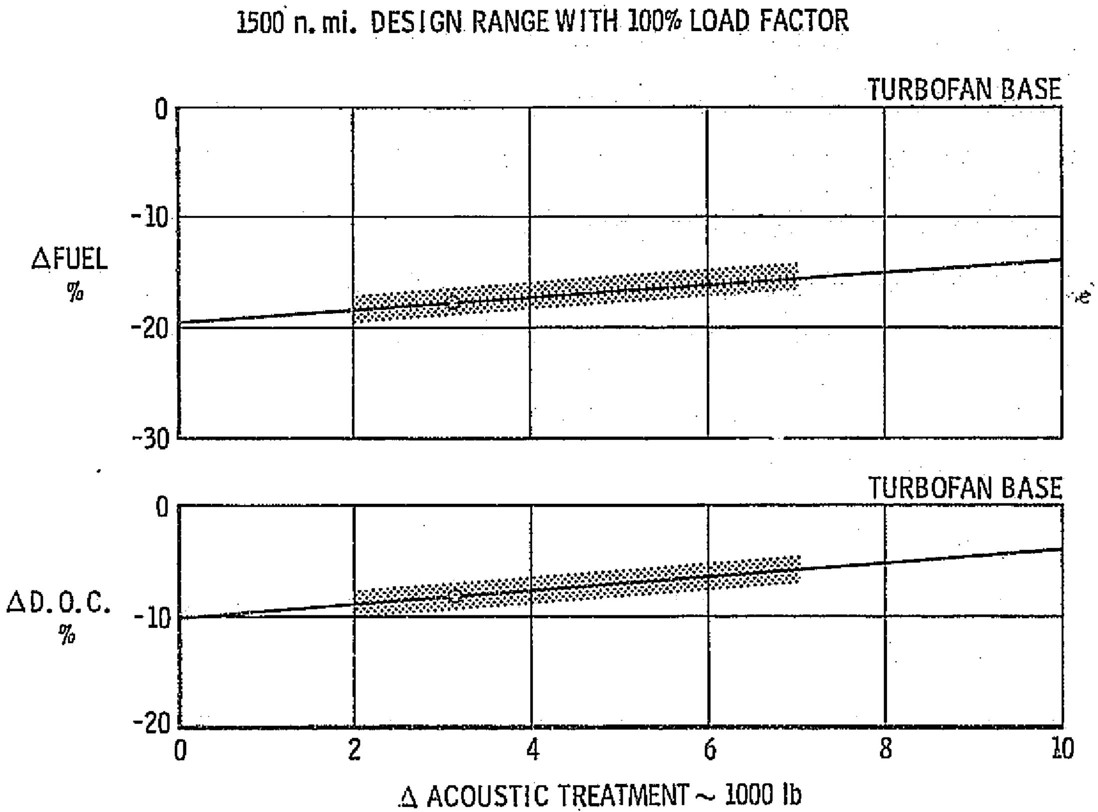


Figure 89. – Sensitivity - interior noise

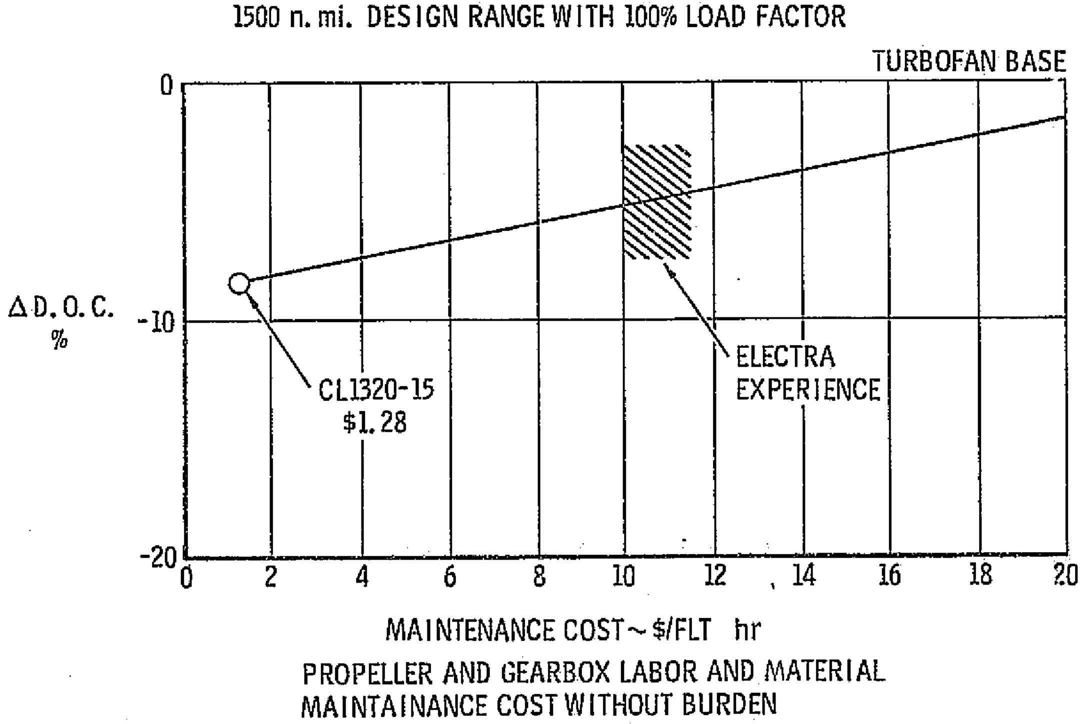


Figure 90. – Sensitivity - propeller and gearbox maintenance cost

TABLE 120.— GROUND RULES

- Configuration
  - 200 Passengers
  - Wide body fuselage
  - Four Engines

- Mission
  - M 0.80 Cruise, 1500 n.mi.
  - Initial Cruise Altitude 30 000 feet
  - Field Length 7000 feet
  - Approach Speed = 135 knots

TABLE 121. - ADVANCED TECHNOLOGIES INCORPORATION

• Supercritial Wing	
• Active Controls	
• Combined maneuver and gust load alleviation system reduces wing weight by 3%	
• Relaxed static stability margins and automatic pitch control system reduce horizontal tail weight by 30%	
• Reduction in MEW.	1.2%
• Advanced Composites	
• Incorporation in cost effective secondary structure and in primary and secondary vertical fin structure	
• Reduction in MEW.	3.3%
• Total reduction in MEW (No resizing).	4.5%

TABLE 122. - TURBOFAN AIRPLANE CHARACTERISTICS

Weights	CL 1320-11
Maximum Takeoff Gross Weight (lb)	217 015
Maximum Landing Gross Weight (lb)	205 000
Operational Empty Weight (lb)	138 402
Maximum Fuel Capacity (lb)	50 000
Power Plants	
Number and Type	4 JT10D-2 (Scaled)
Bypass Ratio	5.4
SLS Thrust/Engine (lb)	14 672
Body	
Length (ft)	155.8
Maximum Diameter (in.)	235
Accommodations	200 (10/90) 8 abreast

Wing and Empenage

	Wing	Horizontal Tail	Vertical Tail
Area (sq ft)	1955	275	253
Aspect Ratio	10	5	1.6
Span (ft)	139.8	37	20.1
Sweep (deg)	25	25	30
MAC (in.)	184	97.5	165.6

TABLE 123. - ENGINE FEATURES - P&W JT10D (SCALED) TURBOFAN

• Description	Twin spool. Design fan pressure ratio of 1.69 and bypass ratio of 5.4. Single stage fan, 12 stage comp. 2 stage HP turbine, 4 stage LP turbine
• Scaling Factor	0.618
• Installed Rating Thrust (SLS, Std) - lb	14 672
• Overall Pressure Ratio 36 000 FT M 0.80 CRUISE	28:1
• Max Combustor Exit Temp °F	2400
• Engine Length - in.	97.8
• Engine Diameter - in.	52.6

TABLE 124.- THRUST INTERFERENCE FACTORS

Thrust Reduced by Blockage of Propeller Slipstream

- Flap Interference

Airplane	Flap Chord Prop. Diam.	Prop to Flap Prop Diam.	Interference Factor
Constellation	0.230	1.27	0.97
Electra	0.256	1.40	0.96
CL1320-15	0.340	1.85	0.95

- Landing Gear Interference

CL1320-15 - No Interference - Factor = 1.0

TABLE 125.- EXTERNAL SPL RESULTS

$M_\infty = 0.8$ • 8 Blades • $D_p = 12.6$ ft • $V_T = 800$ ft/s

$r_{LE}/c_b = 0.0015$ • Clearance: 0.8 D_p • $M_H = 1.06$

		SPL	
Harmonic	Frequency	Lockheed	Ham Std.
Blade Passage	156 Hz	124 dB	126 dB
Second Harmonic	313 Hz	121 dB	126 dB
Third Harmonic	470 Hz	116 dB	126 dB
Fourth Harmonic	626 Hz	104 dB	126 dB

- Pulse time/blade passage period = 0.330
- Cosinisoidal pulse 

TABLE 126.- DOUBLE WALL MASS LAW -
"LIMP WALL" THEORY

$$\text{NOISE TRANSMISSION LOSS (NTL)} \Big\} = \underbrace{\underbrace{20 \text{ LOG } \frac{\pi M_T f}{\rho c}}_{\substack{\text{TOTAL WALL} \\ \text{MASS LAW} \\ \\ \text{6 dB PER OCTAVE}}} + \underbrace{20 \text{ LOG } \left(\frac{f^2}{f_n^2} - 1\right)}_{\substack{\text{DOUBLE WALL} \\ \text{INCREMENT} \\ \\ \text{12 dB PER OCTAVE}}}}_{\substack{\text{TOTAL INCREASE IN NTL} \\ \text{PER OCTAVE IS 18 dB.}}}$$

$$f_n = \frac{1}{2\pi}\sqrt{\frac{K_a}{\left(\frac{M_1 M_2}{M_1 + M_2}\right)}}$$

WHEN $M_1 = M_2$

$$f_n^2 \sim \frac{1}{M_T d}$$

TABLE 127. - PROPFAN AIRPLANE CHARACTERISTICS

Weights	CL 1320-15 (Propfan)	CL 1320-11 (Turbofan)
Maximum takeoff gross weight (lb)	217 466	217 015
Maximum landing gross weight (lb)	205 000	205 000
Operational empty weight (lb)	146 417	138 402
Maximum fuel capacity (lb)	50 000	50 000
Powerplants		
Number & Type	4 STS 476 rematch	4 JT10D-2 (Scaled)
Propeller	12.6 ft/8 bladed	--
SLS thrust/engine (lb)	14135 (8863 shp)	14672
Body		
Length (ft)	155.8	155.8
Maximum diameter (in.)	235	235
Accommodations (No. Pax)	200 (10/90%) 8 abreast	200 (10/90%) 8 abreast

Wing and Empenage	Wing	Horizontal Tail	Vertical Tail	Wing
Area (sq ft)	1995	284	261	1955
Aspect ratio	10	5	1.6	10
Span (ft)	141.3	37.7	20.4	139.8
Sweep (deg)	25	25	32	25
Mac (in.)	186	97.5	165.6	184

TABLE 128.- ENGINE FEATURES

	Propfan/Turboprop P&W Sts 476 Rematch (Scaled)	Turbofan P&W JT10D-2 (Scaled)
• Description	Turboshaft Engine of Comparable Technology to JT10D-2. New Compressor and LP Turbine. Engine Rescheduled to Meet LCC Requirements	Twin Spool. Design Fan Pressure Ratio of 1.69 and Bypass Ratio of 5.4. Single Stage Fan. 12 Stage Comp. 2 Stage HP Turbine, 4 Stage LP Turbine
• Scaling Factor	0.964	0.618
• Installed Rating		
Thrust (SLS, STD.) - lb	14 135	14 672
shp (SLS, STD.) - hp	8 863	
Max shp (250 KEAS, SL, + 18°F) - hp	10 488	
• Overall Pressure Ratio 36 000 ft M = 0.80 Cruise	20:1	28:1
• Max Combustor Exit Temp °F	2400	2400
• Engine Length - in.	84.3	97.8
• Engine Diameter - in.	21.8	52.6

TABLE 129.- ENGINE INSTALLATION LOSSES

Cruise M = 0.80

	Propfan	Turbofan
Inlet recovery, P_{T_2}/P_{T_o}	1.00	0.998
IP compressor bleed, %	0	2.0
Horsepower extraction	100	50
Fan duct loss % $\Delta P_T/P_T$	0	0.80
Gear efficiency	0.99	-
Core cowl drag % $\Delta FN/FN$	-	1.6

Notes (1) Exhaust nozzle thrust and airflow coefficients included in uninstalled engine performance

(2) Nacelle drag included in aircraft drag

TABLE 130. - EMPTY WEIGHT BREAKDOWN

Item	Propfan		Turbofan		Comment
Wing		24 368		23 563	Torsional loads
Tail		2 301		2 229	
Body		35 023		34 873	
Landing gear		10 071		10 050	
Flight controls		3 018		3 013	
Nacelles		2 819		1 997	Propeller loads
Propulsion system		16 471		13 436	
Engines (4)	8 408		10 497		
Propellers (4)	4 380		-		
Gearboxes (4)	2 360		-		
Air intake	311		390		Smaller turboprop inlet
Exhaust	191		1 715		Plain tailpipe vs fan reverser
Misc.	821		834		
Furnishings		24 870		21 781	Acoustic treatment
Electrical		5 017		5 008	
Air conditioning		4 349		4 349	
Misc		5 148		5 142	
M.E.W.		133 455		125 441	
			6.4%		

TABLE 131. - FRICTION DRAG BREAKDOWN

M 0.80 at 30 000 feet $q = 282$ lb/ft^2

Component	Propfan Turboprop		Turbofan		Comment
	D/q	C_D	D/q	C_D	
Fuselage	15.423	0.00773	15.423	0.00789	
Wing	11.848	0.00594	12.417	0.00635	Wing/Nacelle interface and slipstream effects
Horizontal tail	1.625	0.00081	1.571	0.00080	
Vertical tail	1.822	0.00091	1.768	0.00090	
Nacelles	2.808	0.00141	1.691	0.00086	Wing/Nacelle interference
Pylons	-	-	0.662	0.00034	Turbofan only
Total D/q	33.526		33.532		
Friction D (lb)	9 454		9 456		

TABLE 132.- COST FACTORS

1973 Dollars	Propfan	Turbofan	Comments
Cost Breakdown			
Flyaway cost (millions $)	14.15	13.39	
Airframe	10.34	10.09	
Propulsion	3.31	2.80	
Avionics	0.50	0.50	
D.O.C. Factors			
● Flight crew cost ($/hr)	223	223	1973 rates
● Maintenance cost			
– Labor rates ($/hr)	6.10	6.10	
– Maintenance factors			To adjust ATA formulas
Airframe labor/cycle and/hour	0.57	0.60	Propfan brakes & wheels
Airframe material/cycle	0.47	0.60	
Airframe material/hour	0.75	0.75	
Engine labor/cycle	0.60	0.60	Includes engine, gearbox and propeller for propfan/turboprop airplane
Engine labor/hr	0.78	0.75	
Engine material/cycle	0.49	0.60	
Engine material/hour	0.65	0.75	
– Burden (factor)	1.8	1.8	
● Fuel ($/lb)	0.088	0.088	
● Oil ($/lb)	1.0	1.0	
● Insurance (%)	1.0	1.0	
● Depreciation			
Years	16	16	
Spares (%)	15	15	
Salvage (%)	10	10	
● Utilization (hr/yr)	2900	2900	

TABLE 133. - SUMMARY - PROPFAN/TURBOFAN PERFORMANCE COMPARISONS

	1500 n.mi. Design Range 100% LF			@475 n.mi. 58% LF % Change
	Propfan CL 1320-13	Turbofan CL 1320-11	% Change	
Takeoff Gross Weight - lb	217 466	217 015	+0.2	
Block Fuel - lb	23 390	28 466	-17.8	-20.4
DOC (30¢/gal Fuel) - ¢/ASM	1.310	1.384	-5.3	-5.9
DOC (60¢/gal Fuel) - ¢/ASM	1.660	1.809	-8.2	-8.5
Takeoff Field Length - ft	4650	5578	-16.7	
Landing Field Length - ft	6057	6159	-1.6	
Flyaway Cost - M$	14.15	13.39	+6.0	

8. CONCLUSIONS AND RECOMMENDATIONS FOR TECHNOLOGY DEVELOPMENT AND FUTURE STUDY EMPHASIS - TASK 8

Lockheed's role in the basic study did not include participation in the air transportation system synthesis and evaluation task once the refined aircraft performance and operating cost data had been made available to the consultant organization. The analysis required to define the selected options, however, leads to the conclusions and recommendations discussed in the following paragraphs.

The first classification of fuel conserving options studied, changes to current aircraft operational procedures, can offer significant fuel savings benefits even though on an individual basis the fuel savings may be quite small. This is because implementation of procedure changes can be made on an immediate basis and on a large number of aircraft resulting in large cumulative savings over a period of time. Continued use of those operational procedures already implemented by many of the airlines is recommended. The operators with the support of the manufacturers should continue to pursue the implementation of additional procedure changes within the current air traffic control system. Since the most significant additional savings which can be obtained through changes in operational procedures are dependent on changes to the air traffic control system, it is recommended that studies be made to investigate the required improvements. This would allow a complete benefits analysis to be made which could aid in determining the direction to be taken in air traffic control in the future.

Of the L-1011 modifications considered, the revised engine afterbody and modest wing-tip extension offer even larger fuel savings on an individual aircraft basis than operational procedure changes. The possibility of retrofit of these options also provides the benefit of large cumulative savings. Strong consideration should be given to fleet retrofit of these options. In the case of the engine afterbody, general incorporation is recommended. The wing tip extension of the type studied should be retrofitted to those aircraft whose operators can accept the takeoff weight restriction penalty.

Increased seating density offers the largest potential fuel savings of the modifications studied but is dependent on continued increases in demand and on passenger acceptance. This type of modification is an option currently available to the airline operators. It requires no extensive research activity and involves minimum investment cost. In a limited fuel availability environment, increased seating density may become a requirement.

Derivatives of current aircraft are also dependent on demand in that the most beneficial appear to be high passenger capacity, stretched fuselage variants. The possible fuel savings must be traded against development cost and thus purchase price. In the time period studied (before 1980) only limited incorporation of fuel conservation technology is possible. For later service a greater degree of fuel conservation technology incorporation would result in considerably more cost effective derivatives.

The new near-term aircraft studied do not offer as significant fuel savings as the high-density derivative on a seat-mile basis, nor do they offer operating costs sufficiently lower to encourage purchase. When designed with minimum block fuel as the design criterion these aircraft may not be compatible with the current fleet. As with the derivative aircraft, a somewhat later introduction date may offer a beneficial alternative by allowing more of the fuel conservative technologies to be incorporated.

One of these technologies, the advanced turboprop propulsion system, would require a delay in introduction beyond the 1980 date specified by the basic contract Statement of Work. Because the potential of this propulsion system appeared to be so promising, a supplemental study contract was added to allow a more detailed study, including comparison with an equally advanced (1985) turbofan aircraft.

The results of this comparison study show that an advanced turboprop propulsion system is a viable alternative to the turbofan. The swept wing propfan/turboprop airplane offers a means of exploiting the inherent efficiency advantage of the turboshaft engine at the higher cruise speeds and altitudes required in today's air traffic environment. When compared on an equal technology and equal design mission basis, advanced turboprop airplanes offer significant fuel and operating cost savings over the equivalent turbofan airplane. These efficiencies can be obtained without compromise to passenger comfort.

As a result of this study the following recommendations for further research should be considered on a first priority basis to verify the concepts theorized here.

1. Demonstrate propeller efficiency levels of approximately 80 percent (installed) at a flight Mach number of 0.80.

2. Perform experimental investigations of propfan/turboprop wing integration to establish that reasonable drag characteristics exist for practical propfan/turboprop power plants mounted on swept, supercritical wings.

3. Determine sound levels generated by propfan/turboprop concepts operating at Mach 0.80 cruise and establish sound attenuation and weight penalty requirements for their satisfactory suppression.

APPENDIX A

Appendix A includes the final technical memorandum submitted to Lockheed by the Pratt and Whitney Aircraft Division of United Technologies Corporation in compliance with the terms of their subcontract. This memorandum reports on the work performed in support of Lockheed's Turboprop/ Turbofan, Short/Medium Range Configuration Analysis which is reported in Section 7 of this document. Also included in Appendix A is the data pack as received from Pratt and Whitney for the rematched STS-476 turboshaft engine.

Study of Turboprop Engine Characteristics for
Lockheed Vehicle Evaluation

Final Technical Memorandum

Pratt & Whitney Aircraft Support
Under Lockheed-California Purchase Order PO ATTON 2390G

Prepared by: D. E. Gray
D. E. Gray

Approved by:
J. W. Witherspoon

Date: February 17, 1976

Table of Contents

I. Introduction

P&WA support of the Lockheed/NASA-Ames sponsored turboprop study consisted of defining a turboshaft engine cycle with a level of technology similar to that of the JT10D-2 turbofan engine and matched to airplane requirements specified by Lockheed. The specifications included take-off and climb thrust levels required along an optimized climb path. The STS-476 study turboshaft engine, used as a baseline in the studies, was rematched on the basis of these requirements. A revised power turbine with reduced power extraction was utilized and the engine was rescheduled to match Lockheed thrust requirements. Hamilton Standard propeller and gearbox data were used in this evaluation.

Performance and installation information were generated by P&WA for the selected turboshaft engine. A generalized method for obtaining the approximate price and maintenance costs for turboshaft engines was derived relative to equivalent turbofan engines. The method is based on studies of the conversion of high bypass ratio turbofan engines by removing the fan section, increasing compressor speed to partially compensate for the loss of the fan supercharging, and modifying the LP turbine for the higher expansion ratio and the higher speed of the turboshaft engine.

Engine acoustic parameters were also obtained for the rematched STS-476 turboshaft engine. The results of the P&WA work are presented in the following sections of this memo.

II. Turboshaft Engine Description

The study turboprop considered in this study was based on component performance and technology levels similar to those of the JT10D-2 turbofan engine. An overall pressure ratio of 20:1 for the turboshaft engine was assumed for the high spool; a free turbine on a separate co-axial shaft was selected as the propeller drive system. The cruise design cycle definition of the turboprop is listed below:

Flight Condition: M 0.8, 30,000 feet ISA

Cruise Overall Pressure Ratio	20:1
Max. Combustor Exit Temperature	2400°F
Propeller Characteristics (Hamilton Standard)	
Propeller Diameter	12.8 feet
Propeller Tip Speed	800 fps
Number of Propeller Blades	8
Propeller Activity Factor	200/blade
Propeller Integrated Lift Coefficient - Cl_L	0.12

The relatively low overall pressure ratio of the turboshaft engine reflects the loss in supercharging which resulted from fan removal from the base turbofan. The effects of increasing pressure ratio on cruise TSFC were estimated as shown on Figure 1. Up to a 3.0 percent reduction is possible with pressure ratio increased to approximately 30:1; beyond this level, turbine cooling air, which was increased with overall pressure ratio to maintain a constant turbine airfoil metal temperature, penalized the cycle efficiency causing an upturn in TSFC. Low pressure compression stages that are geared to the propeller represent a method of supercharging the high spool to increase the overall pressure ratio. Additional compressor and engine control complexity would be required when off-design and transient operation is considered to assure efficient, stable engine operation. At this time, it is unclear as to whether the fuel savings potential would justify the increased complexity.

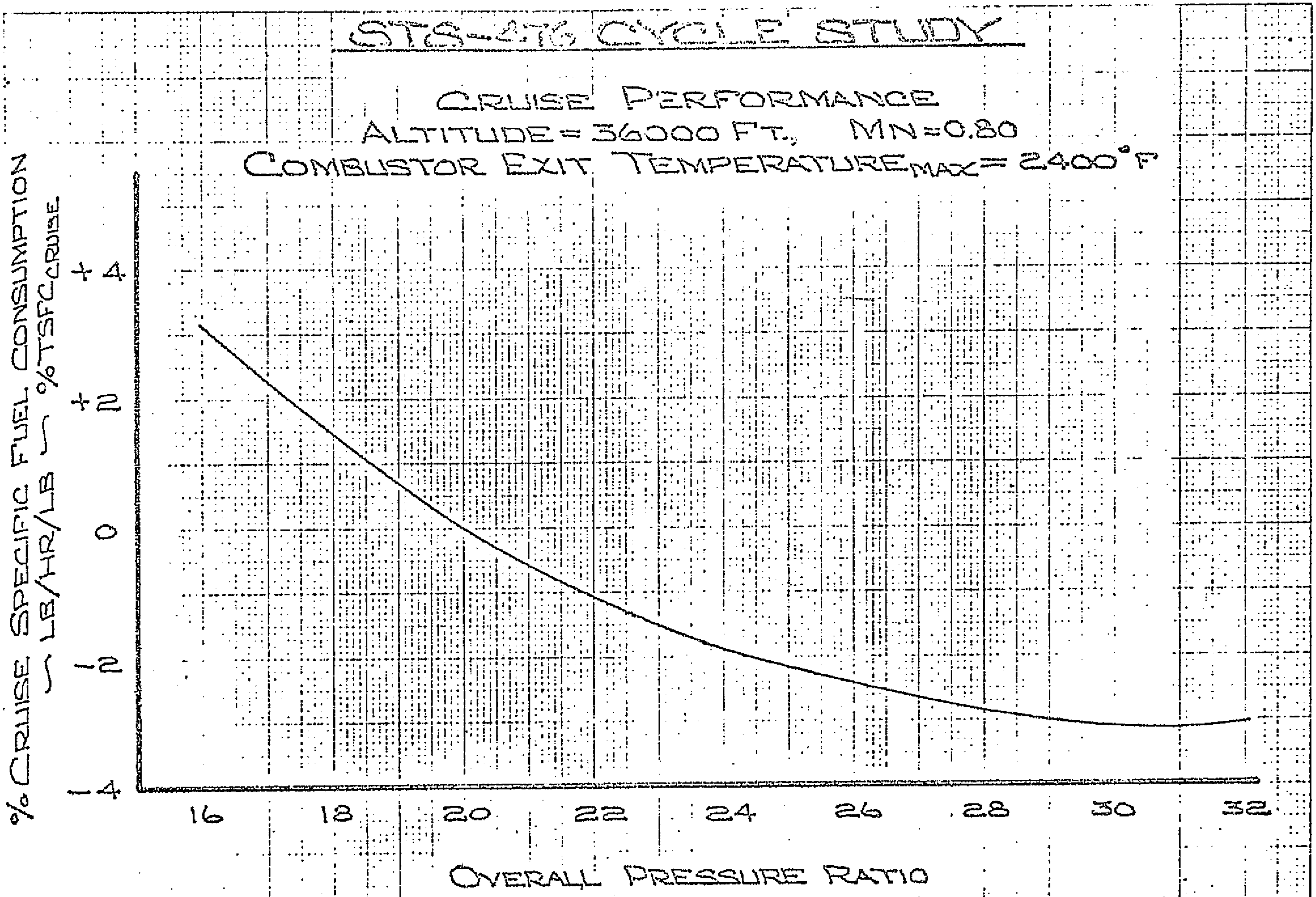

STS-476 CYCLE STUDY
CRUISE PERFORMANCE
ALTITUDE = 36000 FT., MN = 0.80
COMBUSTOR EXIT TEMPERATURE$_{MAX}$ = 2400°F
% CRUISE SPECIFIC FUEL CONSUMPTION ~ LB/HR/LB ~ %TSFC$_{CRUISE}$
+4
+2
0
-2
-4
16
18
20
22
24
26
28
30
32
OVERALL PRESSURE RATIO

FIGURE 1.

II. Engine Rematch to Lockheed Requirements

Our turboprop rescheduling effort was based on the requirements of the optimum airplane configuration specified by Lockheed. The evaluation involved the determination of propulsion system weight and performance changes with engine rematch and the conversion of the effects into TOGW, fuel use, and DOC utilizing LCC provided sensitivity factors.

A second element of the study considered gas generator combustor exit temperature scheduling based on climb thrust requirements. The engine was scheduled to match thrust output with the optimum climb speed schedule as defined by Lockheed..

The following table compares the engine cycle and performance characteristics of the STS-476 and an estimate of the rematched STS-476 engines. Differences in installation assumptions (horsepower extraction and gearbox efficiency) account for over half of the cruise TSFC difference between engines. The remainder is due to cycle refinements included in the Rematched STS-476 engine.

Based on propulsion system weight and TSFC sensitivities provided in Reference (a), the improvements in TOGW, Block Fuel and DOC were predicted. These results are, however, subject to the assumption that constant propeller diameter sensitivity factors are applicable to a non-constant propeller diameter situation.

Table 1

	STS-476 Rematch	STS-476
Cruise Design Pt. Cycle		
(30,000 feet - 0.8M)		
OPR	20.0	20.0
Max./(Design) CET °F	2400/(2165)	2400/(2160)
P_T nozzle/P_{amb}	1.4	1.25
Performance		
M. Cr. TSFC @ 36,000' -0.8M lb./hr./lb.	.524	.552
Design Engine Inlet Corrected Airflow	64.4 pps	66.8 pps

	STS-476 Rematch	STS-476
Engine Installation		
G.G. Weight lb.	2180	2480
Prop Diameter ft.	12.8	13.0
Prop Weight (SHP/D^2 = 34.1 HP/ft.^{2} @ 36,000' -0.8M, MCL Std. +18°F day)	1146	1150
Gearbox Weight lbs.	623	767
Max. SHP/Engine	10,880	12,150
Max. Engine Length in.	85.4	78.2
Max. Engine Case Diameter in.	32.7	33.1
Max. Flange Diameter in.	35.1	--
Airplane Installation		
Δ TOGW lb.	-8213 (-3.6%)	Base
Δ Block Fuel lb.	-1690 (-6.8%)	Base
Δ DOC ¢/ASM	-.047 (-2.7%)	Base

Figure 2 shows that the level of propeller disk loading (Propeller Diameter) does not appreciably affect the selection of gas generator nozzle expansion ratio. At each disk loading, an expansion ratio of around 1.4 results in minimum TSFC while specific thrust is near maximum. However, the curves would indicate some incentive to go to larger prop diameters (lower disk loadings) since both cruise fuel consumption and engine weight would be reduced.

Figure 3 shows the effect on airplane TOGW, block fuel and DOC of varying the design nozzle expansion ratio of the gas generator. The propulsion system weight and TSFC sensitivity curves, Reference (a), Enclosures 1 and 2, were used to develop the changes in TOGW, block fuel and DOC. Two methods of selecting the propeller size from the data of Figure 2 were assumed. At a nozzle expansion ratio of 1.4, a 13 foot diameter propeller was assumed which resulted in a propeller disk loading (SHP/D_p^2) of 33.0 HP/ft.^{2} at the 36,000 ft., 0.8 Mn maximum climb, standard plus 18°F day operating condition. Propeller performance was then estimated and the engine rescaled to give constant thrust for a 13 foot diameter propeller and a propeller with an SHP/D_p^2 = 33.0 HP/ft.^{2} at the other nozzle expansion ratios.

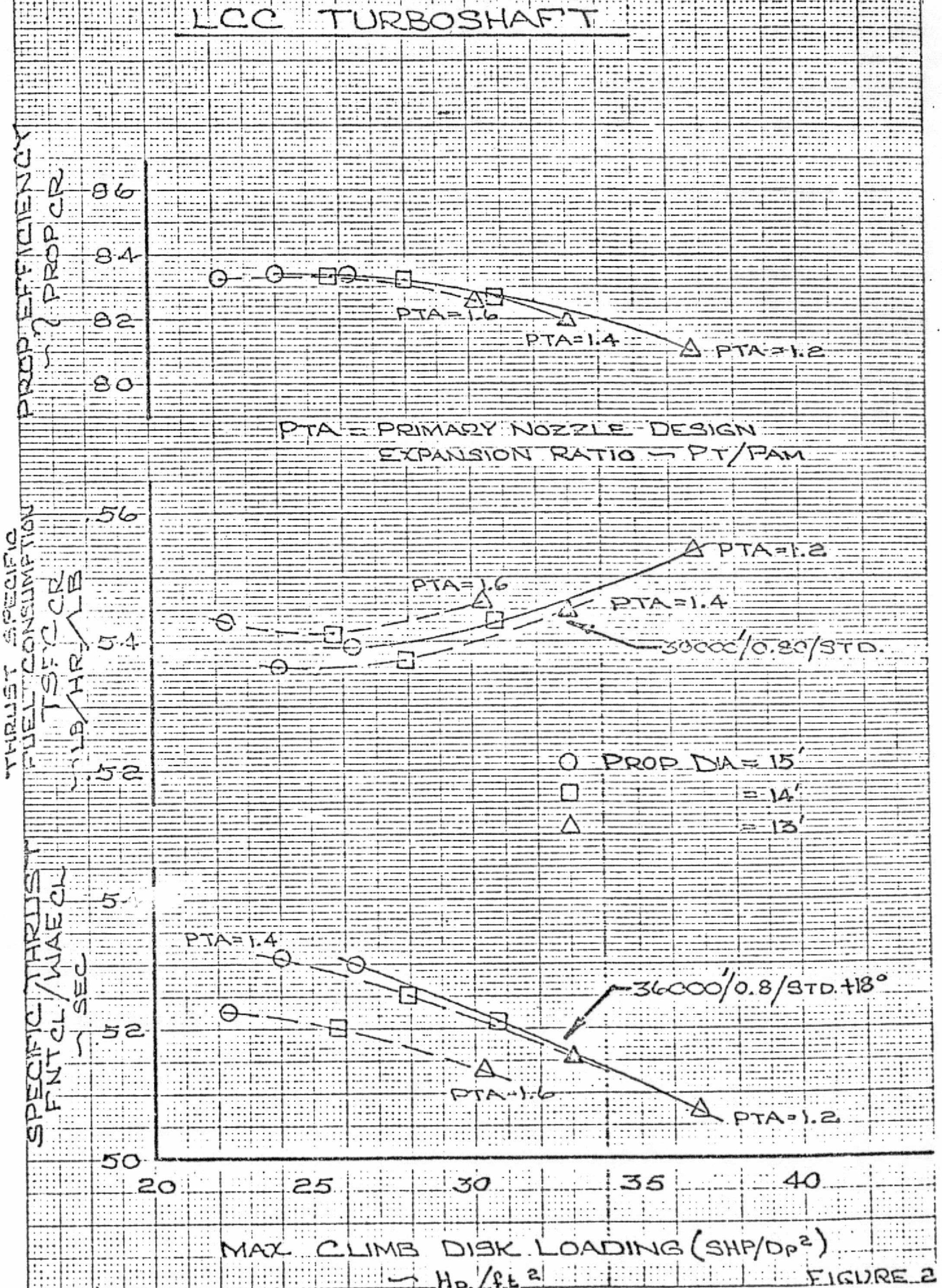
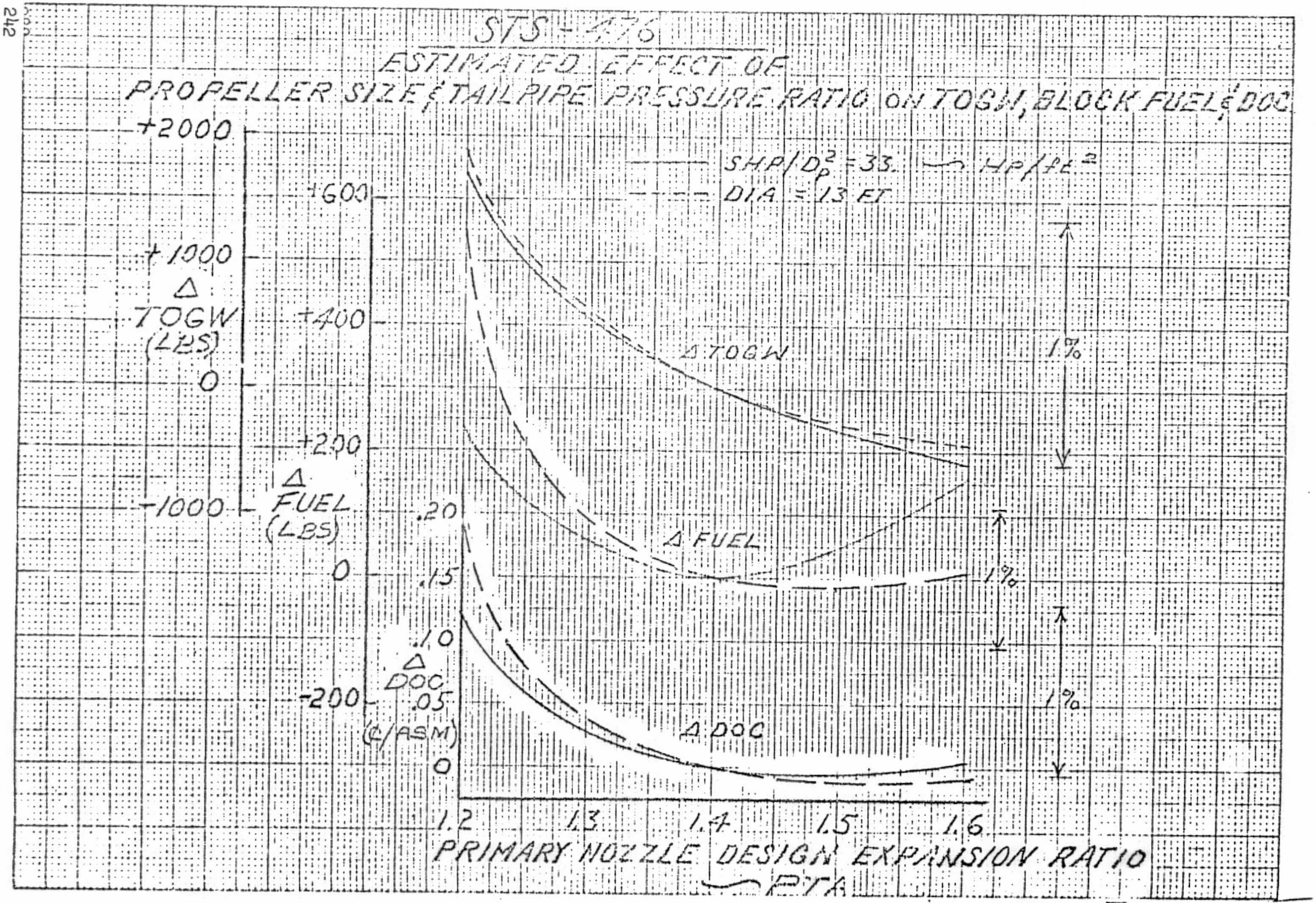

LCC TURBOSHAFT
PROP EFFICIENCY
~ η PROP CR
86
84
82
80
PTA=1.6
PTA=1.4
PTA=1.2
PTA = PRIMARY NOZZLE DESIGN
EXPANSION RATIO ~ PT/PAM
THRUST SPECIFIC
FUEL CONSUMPTION
TSFC CR
~ LB/HR/LB
.56
.54
.52
PTA=1.2
PTA=1.6
PTA=1.4
30000'/0.80/STD.
○ PROP DIA = 15'
□ = 14'
△ = 13'
SPECIFIC THRUST
FNTCL/WAECL
~ SEC
54
52
50
PTA=1.4
36000'/0.8/STD+18°
PTA=1.6
PTA=1.2
20
25
30
35
40
MAX CLIMB DISK LOADING (SHP/Dp²)
~ Hp/ft²

FIGURE 2



STS-476

ESTIMATED EFFECT OF PROPELLER SIZE & TAILPIPE PRESSURE RATIO ON TOGW, BLOCK FUEL & DOC

FIG. 3

The shaft horsepower output to residual thrust relationship changes as the nozzle design expansion ratio changes; therefore, a 13 foot diameter and a 33.0 SHP/D_p^2 propeller result in the same propeller only at a 1.4 nozzle expansion ratio. At nozzle expansion ratios below 1.4, a constant 13 foot diameter propeller represents disk loadings greater than 33.0, whereas at pressure ratios above 1.4, a 13 foot diameter prop has disk loadings less than 33.0.

Figure 3 indicates that approximately a 1.4-1.5 nozzle expansion ratio is optimum for either a constant disk loading or prop diameter when using the Reference (a) sensitivity factors. Based on these trends, a 1.4 cruise nozzle expansion ratio level was selected for use with the rematched STS-476 engine.

Climb Thrust Scheduling

Figure 4 shows the maximum climb and a reduced climb thrust requirement determined by Lockheed. Included on this curve is the estimated maximum climb thrust of the STS-476 engine (scaled) and the rematched STS-476 engine if the engine were rated at maximum temperature on a hot day during the entire 250 KEAS climb. Since weight in the propeller and gearbox can be saved by reducing the low altitude climb and take-off thrust, the rematched STS-476 has been rated to meet the reduced climb thrust requirements indicated on the figure. Figure 5 shows the standard and hot day (standard +18°F) climb temperature schedules that match the 250 KEAS reduced climb thrust schedule as a function of altitude.

The propeller and gearbox maximum horsepower requirement was set at sea level, 250 KEAS, Hot Day (std. +18°F) climb operating condition. Table I (Section III) shows the maximum SHP value used in establishing the prop and gearbox weights.

REMATCHED
STS-476
CLIMB SCHEDULE

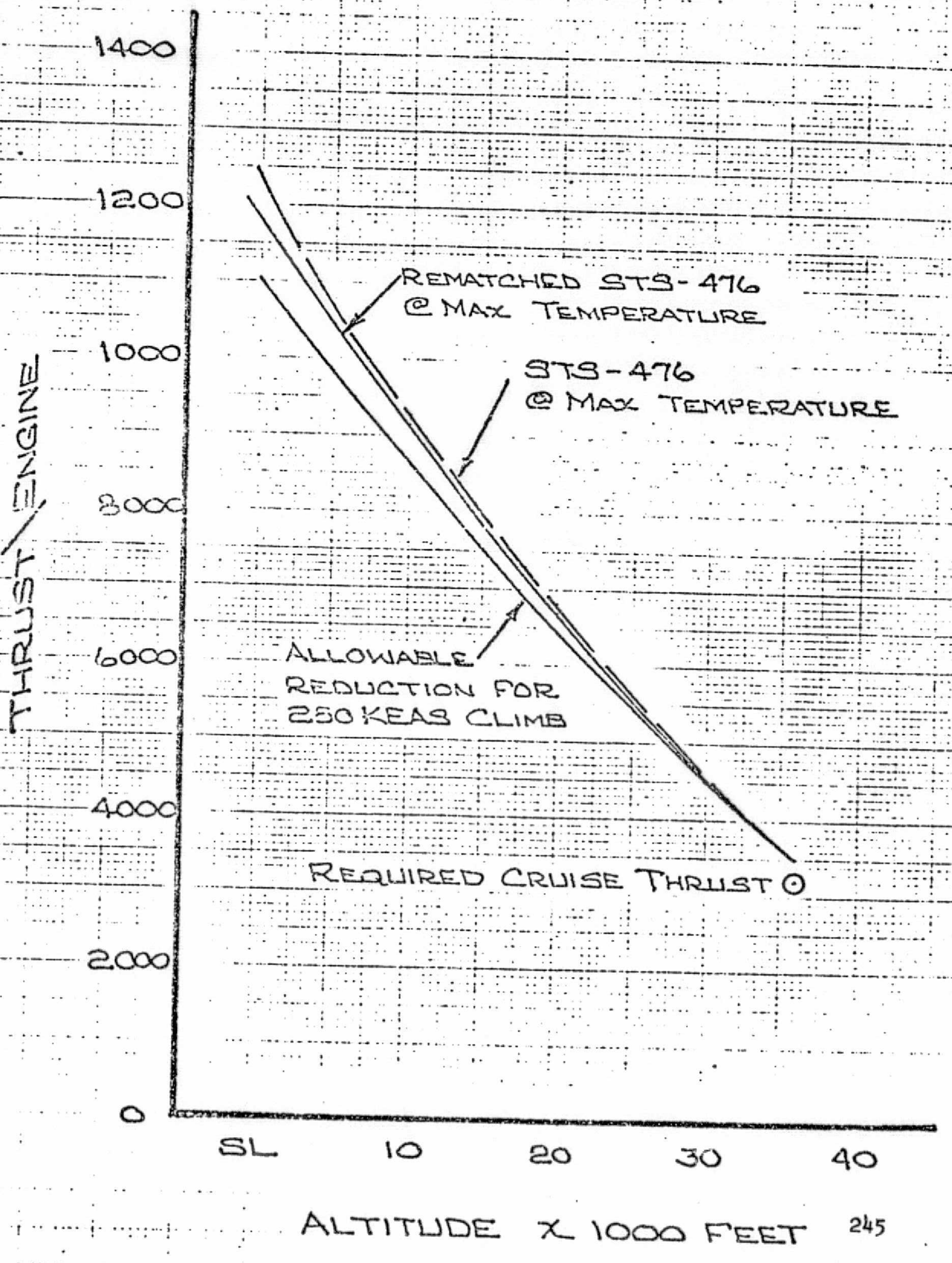
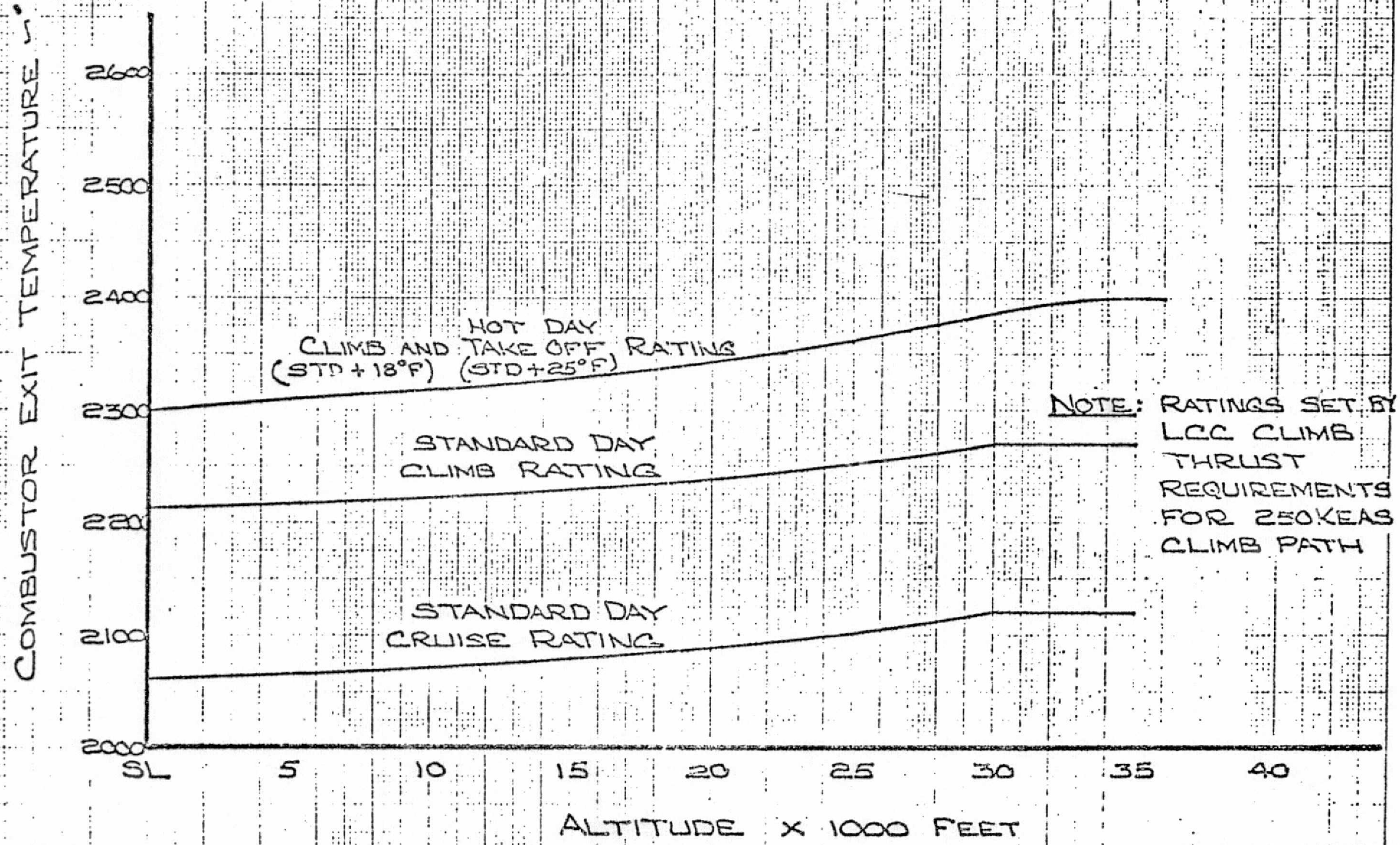


FIGURE 4

REMATCHED STS-476 RATING TEMPERATURES



<u>NOTE</u>: RATINGS SET BY LCC CLIMB THRUST REQUIREMENTS FOR 250 KEAS CLIMB PATH

2-13-76

FIGURE 5

IV. Engine Performance Data

The following tables and figure present preliminary performance and installation information on the Rematched STS-476 study turboshaft engine.

Where possible, both gas generator and propeller performance parameters are provided. Propeller characteristics used in this study were provided by Hamilton Standard. As the engine is scaled to meet the airplane requirements, the propeller must also be scaled at constant power loading in order for the performance to remain valid.

Table II

Rematched STS-476 Performance Assumptions

• Ambient Conditions	U.S. Standard Atmosphere, 1962
• Fuel Lower Heating Value	18,400 BTU/lb.
• Inlet Ram Recovery	1.0 Everywhere
• Propeller Characteristics	Hamilton Standard
• Propeller Diameter	12.8 feet
• Reference Exhaust System	
Nozzle Gross Thrust Coefficient	Figure 6
Nozzle Flow Coefficient	Figure 6
Flange to Nozzle Throat Pressure Losses	$\Delta P/P_t$
Primary	.005
• Horsepower Extraction from Free Turbine Spool (No external bleed assumed)	100
• Free Turbine Speed RPM	8547
• Gear Efficiency Assumed	.99
• Propeller Tip Speed ft./sec.	800
• External Drags	None

PRATT AND WHITNEY AIRCRAFT
STS 476
TURBOSHAFT ENGINE
ESTIMATED NOZZLE PERFORMANCE

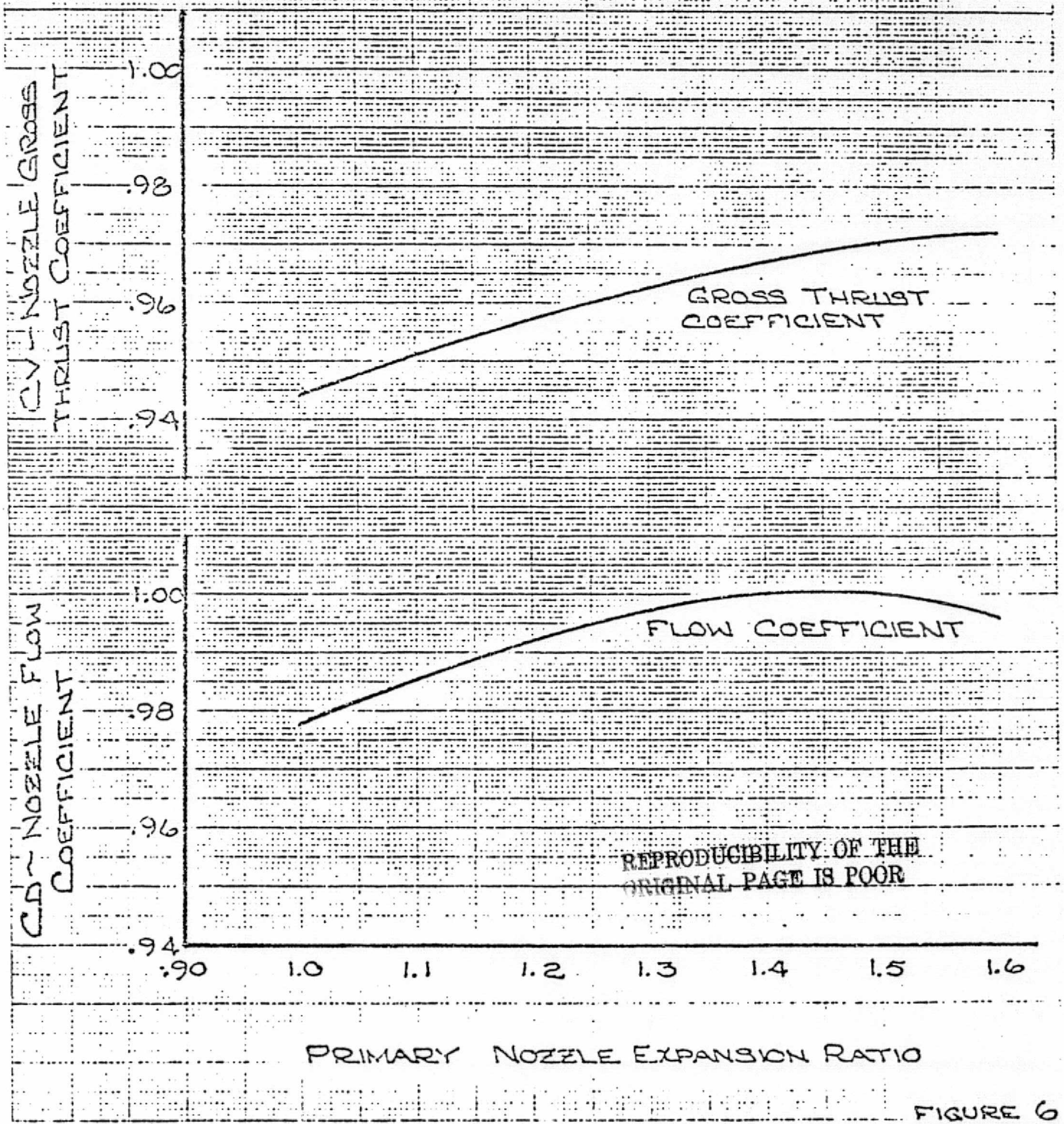


FIGURE 6

Table III

Definition of Terms

Mn	Flight Mach number
Alt.	Geopotential Altitude, U.S. Standard Atmosphere, 1962 - ft.
DTAM	Ambient Temperature Minus Standard Ambient Temperature
Prop. SHP	Horsepower Delivered at Propeller Shaft (Gearbox SHP in X Gear ETA)
Fn Res.	Gas Generator Net Thrust, lb.
HPX	Horsepower Extracted from the Free Turbine Rotor for Accessory Drives, hp
BSFC	Prop shaft HP Specific Fuel Consumption, lb./hr./HP
WFT	Gas Generator Fuel Flow lb./hr.
W_{ae2}	Primary (Compressor Inlet) Corrected Airflow, lb./sec.
PTA	Primary Nozzle Expansion Ratio PT/P_{am}
Net Thrust	Total Net Thrust (Fn prop. + Fn res.) lbs.
TSFC	Thrust Specific Fuel Consumption lb./hr./lb.
ETA Prop.	Propeller Efficiency %

Table IV

Matrix of Data Provided in Data Pack

I. Take-off and part power data (standard and standard +25°F days)

Mach No. - 0., 0.1, 0.2, 0.3, 0.4

Altitudes (ft.) - Sea level, 2,000, 5,000

II. Maximum Climb and part power (standard day)

Altitudes - Sea level, 10,000, 20,000, 28,250, 30,000, 36,000

Speed - 250 KEAS

III. Part power tables - Max. climb and part power (standard day)

Altitudes	Mach Numbers						
0	0.35	0.50	0.60				
1,500	0.35	0.50	0.60				
5,000	0.35	0.50	0.60	0.65			
10,000	0.35	0.50	0.60	0.65			
20,000	0.35	0.50	0.60	0.65	0.75	0.80	0.85
25,000	0.35	0.50	0.60	0.65	0.75	0.80	0.85
30,000		-	0.60	0.65	0.75	0.80	0.85
35,000			0.60	0.65	0.75	0.80	0.85
40,000			0.60	0.65	0.75	0.80	0.85

V. Engine Installation Information

Engine weight and dimensional estimates were made for the rematched STS-476 turboshaft engine in a 3190 lb. cruise thrust size as specified by Lockheed. Scaling factors were generated to allow engine resizing over a ±10 percent thrust range.

A. Engine Dimensions

An installation sketch, including the principal engine dimensions, is included in Figure V-1. Dimensional scaling information is presented below.

$$\text{Turboshaft Diameters} = \text{Base Engine Diameter} \left(\frac{\text{Fn Cruise}}{3190}\right)^{0.5}$$

$$\text{Turboshaft Length (front-to-rear flange)} = 85.4 \left(\frac{\text{Fn Cruise}}{3190}\right)^{0.35}$$

Fn cruise at 0.8M, 36,000 feet ISA

B. Base Engine Weight

The rematched STS-476 turboshaft engine weight is 2180 pounds. This weight includes the gas generator, propeller drive turbine and shaft, engine controls, and engine accessories. The weight levels are similar to the JT10D-2 turbofan engine technology and reflect the same design philosophy in trading engine weight, performance, and cost.

Engine weight scaling can be accomplished over a ±10 percent range by applying the following:

$$\text{Turboshaft Weight} = 2180 \left(\frac{\text{Fn Cruise}}{3190}\right)^{0.995}$$

C. Potential Weight Reduction

Advanced technology (1985+) turbofan/turboshaft engine studies conducted under NASA contract have resulted in weight trends which, when applied to the Rematched STS-476 turboshaft, indicate the potential for improving its weight by 5 percent. The achievement of the additional weight reduction may entail redefinition of the engine cycle: for example, cycle pressure ratio readjustment may improve the power output to weight ratio. Verification of this potential requires a more detailed engine configuration definition than could be accomplished within the scope of this program.

VI. Engine Cost Estimates

Turboshaft engine price and maintenance costs were estimated relative to an equivalent turbofan engine. The method is based on generalized studies of the conversion of high bypass ratio turbofan engines into turboshaft engines by removing the fan section, increasing compressor speed to partially compensate for the loss of fan supercharging, and modifying the LP turbine to provide the higher work output and increased speed desired in the turboshaft engine.

A. Initial Turboshaft Price

The price of a turboshaft engine with technology comparable with a baseline typical high bypass ratio turbofan may be approximated as follows:

1. Reference turboshaft SHP = 1.46 turbofan thrust at 0.8M, 36,000 ft., Max. Cruise Rating.
2. Reference turboshaft price = 0.86 turbofan price.
3. $$\text{Turboshaft price} = \text{Reference turboshaft price} \times \left(\frac{\text{Turboshaft SHP}}{\text{Reference Turboshaft SHP}}\right)^{0.3}$$
   @ 0.8M, 36,000', Max. Cruise

B. Turboshaft Maintenance

Material and labor maintenance requirements were estimated for the rematched STS-476 turboshaft engine by utilizing a generalized procedure similar to that used to derive relative price.

Maintenance labor requirements of a turboshaft engine were estimated to be .017 manhours per engine flight hour less than the baseline turbofan engine. Maintenance labor costs may be assumed to remain constant regardless of engine size within the study range.

Maintenance material costs, excluding burden, can be approximated relative to a typical high bypass ratio turbofan as follows:

1. Turboshaft reference SHP = 1.46 turbofan thrust at 0.8M, 36,000 feet, Max. Cruise Rating.

2. Reference turboshaft MMC $\doteq$ 0.92 turbofan MMC.

3. Turboshaft MMC = Reference turboshaft MMC X $\left(\frac{\text{Turboshaft SHP}}{\text{Reference Turboshaft SHP at 0.8M, 36,000', Max. Cruise}}\right)^{0.3}$

Engine Acoustic Parameters

Sufficient information is provided in the "data pack" to permit calculation of noise levels at FAR points by Lockheed. Some information that is not specificly provided, but that can be easily derived, is presented below for the Rematched STS-476 engine.

Gas Generator Nozzle Parameters

- Gas Generator Nozzle Throat Area = 374.3 in.^{2}
- Gas Flow (lb./sec.) = $\left(\text{Wae2 X } \frac{\delta_{t2}}{\sqrt{\theta_{t2}}}\right) + \left(\frac{\text{WFT}}{3600}\right)$
- Absolute Jet Velocity = $\frac{\text{Fn res. X 32.2}}{\text{Gas Flow}} + \frac{\text{Wae2 X Vo}}{\text{Gas Flow}}$

Vo = Flight Speed (ft./sec.)

Fn res = Gas Generator net Thrust (lb.)

Wae2 = Compressor Inlet Corrected Airflow (lb./sec.)

WFT = Gas Generator Fuel Flow (lb./hr.)

Other information which may be useful in estimating turbine noise follows.

• Rear Turbine Blade Tip Speed	1130 ft./sec.
• Number of Rear Turbine Stage Vanes	75
• Number of Rear Turbine Stage Blades	66

- Turbine Blade to Vane Spacing – $\frac{\text{Average Vane to Blade Tip Axial Space}}{\text{Average Vane Axial Tip-Chord}} = 0.35$

The gas flow rate and nozzle area may be scaled directly with engine thrust size. The remaining parameters remain constant.

During airplane approach, the prop-fan and free turbine RPM can be reduced to 20 percent if this is desirable for noise considerations.

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                             PRATT AND WHITNEY AIRCRAFT
              REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
         U.S. STANDARD ATMOSPHERE, 1962          100 PERCENT RAM RECOVERY
                             99 PERCENT GEAR EFFICIENCY
                              FREE TURBINE RPM=8547.

                                TAKE OFF PERFORMANCE
                                  STANDARD DAY TAM
 MN      ALT       DTAM   PROP SHP     FN RES.     HPX     BSFC       WFT      WAE     PTA
 MN      ALT       DTAM NET THRUST   TSFC   ETA PROP
 0.0           0.   0.0    9194.02   1216.14   100.00   0.404   3714.50   54.88   1.12
 0.0           0.   0.0   14665.45   0.253  0.0
 0.0           0.   0.0    7739.07   1019.86   100.00   0.419   3243.00   50.67   1.10
 0.0           0.   0.0   14060.68   0.231  0.0
 0.0           0.   0.0    6350.65    837.12   100.00   0.441   2798.72   46.32   1.08
 0.0           0.   0.0   13212.64   0.212  0.0
 0.0           0.   0.0    5072.79    678.85   100.00   0.472   2393.58   42.00   1.07
 0.0           0.   0.0   12103.21   0.198  0.0
 0.0           0.   0.0    3979.61    543.79   100.00   0.512   2039.24   38.04   1.05
 0.0           0.   0.0   10849.12   0.188  0.0
 0.0           0.   0.0    3053.63    431.75   100.00   0.567   1730.25   34.35   1.04
 0.0           0.   0.0   10175.55   0.170  0.0
 0.0           0.   0.0    2278.08    344.11   100.00   0.640   1458.98   30.88   1.03

 0.0           0.   0.0    1650.92    272.04   100.00   0.742   1225.73   27.76   1.03

 0.0           0.   0.0    1125.76    209.67   100.00   0.907   1021.05   24.80   1.02



                                TAKE OFF PERFORMANCE
                           STANDARD PLUS 25 DEGREES F TAM

 0.0           0.  25.0    9637.74   1250.29   100.00   0.405   3898.87   55.54   1.13
 0.0           0.  25.0   14143.99   0.276  0.0
 0.0           0.  25.0    8201.64   1066.84   100.00   0.418   3429.81   51.60   1.11
 0.0           0.  25.0   13784.98   0.249  0.0
 0.0           0.  25.0    6836.38    879.29   100.00   0.436   2981.74   47.41   1.09
 0.0           0.  25.0   13098.30   0.228  0.0
 0.0           0.  25.0    5553.74    719.29   100.00   0.462   2566.81   43.20   1.07
 0.0           0.  25.0   12203.15   0.210  0.0
 0.0           0.  25.0    4432.09    584.60   100.00   0.497   2201.65   39.27   1.06
 0.0           0.  25.0   11092.95   0.198  0.0
 0.0           0.  25.0    3466.82    473.81   100.00   0.543   1880.98   35.64   1.05
 0.0           0.  25.0    9918.56   0.190  0.0
 0.0           0.  25.0    2644.67    373.20   100.00   0.604   1597.60   32.18   1.04

 0.0           0.  25.0    1965.17    304.52   100.00   0.689   1353.26   29.05   1.03

 0.0           0.  25.0    1403.66    236.62   100.00   0.810   1136.83   26.08   1.02
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                    PRATT AND WHITNEY AIRCRAFT
         REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
       U.S. STANDARD ATMOSPHERE, 1962          100 PERCENT RAM RECOVERY
                      99 PERCENT GEAR EFFICIENCY
                       FREE TURBINE RPM=8547.

                        TAKE OFF PERFORMANCE
                          STANDARD DAY TAM
 MN       ALT      DTAM   PROP SHP    FN RES.     HPX     BSFC       WFT      WAE     PTA
 MN       ALT      DTAM  NET THRUST   TSFC    ETA PROP
0.10       0.      0.0    9248.54   1028.96   100.00   0.403   3724.08   54.73   1.12
0.10       0.      0.0   15459.98   0.241    0.317
0.10       0.      0.0    7781.67    851.98   100.00   0.418   3252.37   50.56   1.10
0.10       0.      0.0   14055.63   0.231    0.344
0.10       0.      0.0    6396.83    677.03   100.00   0.439   2807.41   46.22   1.08
0.10       0.      0.0   12586.64   0.223    0.376
0.10       0.      0.0    5110.73    536.08   100.00   0.470   2401.41   41.93   1.07
0.10       0.      0.0   11021.03   0.218    0.416
0.10       0.      0.0    4015.37    413.47   100.00   0.510   2046.42   37.99   1.05
0.10       0.      0.0    9435.16   0.217    0.456
0.10       0.      0.0    3082.39    320.34   100.00   0.564   1737.97   34.34   1.04
0.10       0.      0.0    8625.97   0.201    0.547
0.10       0.      0.0    2305.06    240.17   100.00   0.636   1465.26   30.87   1.03

0.10       0.      0.0    1676.23    176.81   100.00   0.735   1231.67   27.77   1.03

0.10       0.      0.0    1145.12    128.99   100.00   0.896   1026.49   24.83   1.02



                        TAKE OFF PERFORMANCE
                    STANDARD PLUS 25 DEGREES F TAM

0.10       0.     25.0    9687.19   1074.54   100.00   0.404   3912.41   55.45   1.13
0.10       0.     25.0   15435.16   0.253    0.308
0.10       0.     25.0    8255.88    890.89   100.00   0.417   3440.49   51.50   1.11
0.10       0.     25.0   14158.36   0.243    0.334
0.10       0.     25.0    6877.56    721.91   100.00   0.435   2990.88   47.31   1.09
0.10       0.     25.0   12775.50   0.234    0.364
0.10       0.     25.0    5586.20    580.18   100.00   0.461   2574.89   43.11   1.07
0.10       0.     25.0   11376.76   0.226    0.402
0.10       0.     25.0    4469.46    452.66   100.00   0.494   2209.93   39.22   1.06
0.10       0.     25.0    9866.80   0.224    0.438
0.10       0.     25.0    3501.72    353.46   100.00   0.539   1888.95   35.62   1.05
0.10       0.     25.0    8464.29   0.223    0.481
0.10       0.     25.0    2671.47    268.23   100.00   0.601   1604.63   32.17   1.04

0.10       0.     25.0    1995.63    201.19   100.00   0.682   1360.31   29.06   1.03

0.10       0.     25.0    1425.17    151.38   100.00   0.802   1142.82   26.10   1.02
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                        PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
     U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                        99 PERCENT GEAR EFFICIENCY
                         FREE TURBINE RPM=8547.

                          TAKE OFF PERFORMANCE
                           STANDARD DAY TAM
  MN      ALT    DTAM  PROP SHP    FN RES.     HPX    BSFC      WFT      WAE    PTA
  MN      ALT    DTAM NET THRUST  TSFC  ETA PROP
 0.20       0.    0.0   9404.04    863.13  100.00  0.400   3758.20   54.38   1.13
 0.20       0.    0.0  13426.02   0.280   0.542
 0.20       0.    0.0   7923.21    689.56  100.00  0.414   3281.14   50.22   1.11
 0.20       0.    0.0  12037.80   0.273   0.581
 0.20       0.    0.0   6515.42    533.51  100.00  0.435   2833.34   45.94   1.09
 0.20       0.    0.0  10573.69   0.268   0.626
 0.20       0.    0.0   5224.37    401.15  100.00  0.464   2425.55   41.72   1.07
 0.20       0.    0.0   9031.22   0.269   0.671
 0.20       0.    0.0   4119.84    289.86  100.00  0.502   2068.96   37.84   1.06
 0.20       0.    0.0   7519.29   0.275   0.712
 0.20       0.    0.0   3173.17    207.48  100.00  0.554   1757.92   34.23   1.04

 0.20       0.    0.0   2388.29    135.44  100.00  0.622   1484.33   30.83   1.03

 0.20       0.    0.0   1744.26     91.57  100.00  0.716   1248.87   27.79   1.03

 0.20       0.    0.0   1208.75     45.66  100.00  0.863   1042.85   24.90   1.02



                          TAKE OFF PERFORMANCE
                     STANDARD PLUS 25 DEGREES F TAM

 0.20       0.   25.0   9861.81    899.96  100.00  0.400   3948.81   55.10   1.13
 0.20       0.   25.0  13444.24   0.294   0.529
 0.20       0.   25.0   8401.09    729.66  100.00  0.413   3471.29   51.16   1.11
 0.20       0.   25.0  12180.23   0.285   0.566
 0.20       0.   25.0   7006.86    572.20  100.00  0.431   3018.10   47.02   1.09
 0.20       0.   25.0  10814.97   0.279   0.608
 0.20       0.   25.0   5708.64    440.68  100.00  0.456   2600.83   42.90   1.08
 0.20       0.   25.0   9407.38   0.276   0.653
 0.20       0.   25.0   4577.32    327.67  100.00  0.488   2233.35   39.06   1.06
 0.20       0.   25.0   7966.00   0.280   0.694
 0.20       0.   25.0   3600.34    236.76  100.00  0.531   1910.09   35.50   1.05
 0.20       0.   25.0   6614.20   0.289   0.736
 0.20       0.   25.0   2760.15    163.25  100.00  0.589   1625.11   32.12   1.04

 0.20       0.   25.0   2074.01    104.50  100.00  0.665   1378.63   29.05   1.03

 0.20       0.   25.0   1497.85     61.38  100.00  0.775   1160.72   26.17   1.02
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                         PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
      U.S. STANDARD ATMOSPHERE, 1962          100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                          FREE TURBINE RPM=8547.

                             TAKE OFF PERFORMANCE
                              STANDARD DAY TAM
  MN      ALT     DTAM  PROP SHP    FN RES.     HPX    BSFC       WFT      WAE     PTA
  MN      ALT     DTAM NET THRUST   TSFC   ETA PROP
 0.30      0.      0.0    9673.55   700.45  100.00   0.394   3814.48    53.79   1.13
 0.30      0.      0.0   11604.22  0.329   0.687
 0.30      0.      0.0    8159.25   533.23  100.00   0.408   3329.41    49.68   1.11
 0.30      0.      0.0   10232.87  0.325   0.724
 0.30      0.      0.0    6720.43   390.87  100.00   0.428   2875.12    45.46   1.09
 0.30      0.      0.0    8779.84  0.327   0.760
 0.30      0.      0.0    5413.85   268.64  100.00   0.455   2464.51    41.35   1.07
 0.30      0.      0.0    7305.27  0.337   0.791
 0.30      0.      0.0    4290.95   172.53  100.00   0.491   2106.33    37.60   1.06
 0.30      0.      0.0    5698.50  0.357   0.813
 0.30      0.      0.0    3329.35    95.39  100.00   0.538   1792.22    34.08   1.05
 0.30      0.      0.0    4814.59  0.372   0.863
 0.30      0.      0.0    2524.90    37.24  100.00   0.600   1516.08    30.78   1.04

 0.30      0.      0.0    1866.69    -2.65  100.00   0.685   1278.16    27.81   1.03

 0.30      0.      0.0    1315.48   -36.64  100.00   0.813   1069.86    25.01   1.02



                             TAKE OFF PERFORMANCE
                        STANDARD PLUS 25 DEGREES F TAM

 0.30      0.     25.0   10144.89   736.91  100.00   0.395   4008.82    54.51   1.14
 0.30      0.     25.0   11891.95  0.343   0.673
 0.30      0.     25.0    8654.08   570.85  100.00   0.407   3524.15    50.63   1.11
 0.30      0.     25.0   10419.89  0.338   0.710
 0.30      0.     25.0    7217.19   427.24  100.00   0.424   3061.37    46.50   1.09
 0.30      0.     25.0    8064.48  0.338   0.746
 0.30      0.     25.0    5901.87   307.17  100.00   0.447   2640.97    42.48   1.06
 0.30      0.     25.0    7683.66  0.344   0.779
 0.30      0.     25.0    4759.84   206.19  100.00   0.477   2272.61    38.78   1.06
 0.30      0.     25.0    6355.35  0.358   0.805
 0.30      0.     25.0    3766.98   123.56  100.00   0.517   1946.53    35.32   1.05
 0.30      0.     25.0    5086.19  0.383   0.821
 0.30      0.     25.0    2910.55    59.35  100.00   0.570   1659.27    32.04   1.04

 0.30      0.     25.0    2205.01    12.25  100.00   0.640   1410.15    29.06   1.03

 0.30      0.     25.0    1613.10   -23.50  100.00   0.737   1189.31    26.24   1.03
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                         PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
       U.S. STANDARD ATMOSPHERE, 1962          100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                           FREE TURBINE RPM=8547.

                            TAKE OFF PERFORMANCE
                             STANDARD DAY TAM
   MN       ALT      DTAM  PROP SHP    FN RES.     HPX     BSFC      WFT      WAE     PTA
   MN       ALT      DTAM NET THRUST   TSFC   ETA PROP
  0.40        0.      0.0  10051.26    541.34   100.00   0.387   3891.99    52.96    1.14
  0.40        0.      0.0  10140.66   0.384   0.775
  0.40        0.      0.0   8484.12    384.27   100.00   0.400   3395.85    48.91    1.11
  0.40        0.      0.0   8788.08   0.386   0.804
  0.40        0.      0.0   7066.06    251.22   100.00   0.419   2933.49    44.79    1.09
  0.40        0.      0.0   7416.77   0.396   0.830
  0.40        0.      0.0   5684.98    135.51   100.00   0.443   2519.48    40.85    1.08
  0.40        0.      0.0   6243.44   0.404   0.872
  0.40        0.      0.0   4537.54     50.30   100.00   0.476   2157.84    37.24    1.06

  0.40        0.      0.0   3549.85    -16.90   100.00   0.518   1839.98    33.85    1.05

  0.40        0.      0.0   2724.33    -70.24   100.00   0.573   1560.37    30.69    1.04

  0.40        0.      0.0   2042.11   -101.37   100.00   0.646   1318.45    27.81    1.03

  0.40        0.      0.0   1468.55   -126.22   100.00   0.753   1106.46    25.12    1.03



                            TAKE OFF PERFORMANCE
                         STANDARD PLUS 25 DEGREES F TAM

  0.40        0.     25.0  10542.89    576.87   100.00   0.388   4091.67    53.69    1.14
  0.40        0.     25.0  10295.58   0.397   0.766
  0.40        0.     25.0   8997.64    418.16   100.00   0.399   3594.06    49.84    1.12
  0.40        0.     25.0   8995.59   0.400   0.792
  0.40        0.     25.0   7525.65    282.29   100.00   0.415   3123.99    45.82    1.10
  0.40        0.     25.0   7706.69   0.405   0.820
  0.40        0.     25.0   6186.69    171.73   100.00   0.436   2699.16    41.95    1.08
  0.40        0.     25.0   6442.69   0.419   0.845
  0.40        0.     25.0   5023.02     82.05   100.00   0.463   2327.41    38.40    1.07

  0.40        0.     25.0   4004.00      8.29   100.00   0.499   1997.14    35.06    1.05

  0.40        0.     25.0   3127.27    -52.03   100.00   0.546   1706.53    31.91    1.04

  0.40        0.     25.0   2393.24    -86.51   100.00   0.607   1453.15    29.03    1.04

  0.40        0.     25.0   1782.34   -117.82   100.00   0.690   1229.20    26.32    1.03
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                          PRATT AND WHITNEY AIRCRAFT
           REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962         100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                           FREE TURBINE RPM=8547.

                            TAKE OFF PERFORMANCE
                              STANDARD DAY TAM
 MN       ALT      DTAM  PROP SHP    FN RES.     HPX     BSFC       WFT      WAE     PTA
 MN       ALT      DTAM NET THRUST   TSFC  ETA PROP
0.0      2000.    0.0   8892.60   1186.03  100.00   0.400   3560.58   55.98   1.13
0.0      2000.    0.0  13699.48   0.256   0.0
0.0      2000.    0.0   7531.40    997.79  100.00   0.414   3118.79   51.86   1.11
0.0      2000.    0.0  13384.91   0.233   0.0
0.0      2000.    0.0   6208.05    821.11  100.00   0.434   2695.89   47.48   1.09
0.0      2000.    0.0  12615.82   0.214   0.0
0.0      2000.    0.0   4966.84    666.49  100.00   0.464   2304.77   43.04   1.07
0.0      2000.    0.0  11600.27   0.199   0.0
0.0      2000.    0.0   3901.40    534.99  100.00   0.503   1962.89   38.97   1.06
0.0      2000.    0.0  10417.92   0.188   0.0
0.0      2000.    0.0   3000.05    427.10  100.00   0.555   1665.77   35.19   1.05
0.0      2000.    0.0   9613.28   0.173   0.0
0.0      2000.    0.0   2244.41    332.90  100.00   0.625   1402.61   31.59   1.04

0.0      2000.    0.0   1632.41    264.59  100.00   0.722   1178.26   28.39   1.03

0.0      2000.    0.0   1117.52    208.57  100.00   0.878    981.38   25.36   1.02



                            TAKE OFF PERFORMANCE
                      STANDARD PLUS 25 DEGREES F TAM

0.0      2000.   25.0   9292.50   1225.58  100.00   0.402   3733.97   56.63   1.13
0.0      2000.   25.0  13338.69   0.280   0.0
0.0      2000.   25.0   7957.12   1037.88  100.00   0.414   3291.37   52.72   1.11
0.0      2000.   25.0  13074.67   0.252   0.0
0.0      2000.   25.0   6656.04    863.78  100.00   0.431   2867.62   48.55   1.09
0.0      2000.   25.0  12471.95   0.230   0.0
0.0      2000.   25.0   5417.55    711.31  100.00   0.456   2469.16   44.24   1.08
0.0      2000.   25.0  11654.55   0.212   0.0
0.0      2000.   25.0   4335.44    574.83  100.00   0.489   2117.89   40.22   1.06
0.0      2000.   25.0  10633.69   0.199   0.0
0.0      2000.   25.0   3396.68    463.14  100.00   0.532   1807.87   36.47   1.05
0.0      2000.   25.0   9517.31   0.190   0.0
0.0      2000.   25.0   2592.69    368.41  100.00   0.592   1534.86   32.92   1.04

0.0      2000.   25.0   1932.49    291.21  100.00   0.672   1298.61   29.67   1.03

0.0      2000.   25.0   1385.04    230.80  100.00   0.788   1090.90   26.64   1.02
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                         PRATT AND WHITNEY AIRCRAFT
        REMATCHED- ST5476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
     U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                         FREE TURBINE RPM=8547.

                           TAKE OFF PERFORMANCE
                            STANDARD DAY TAM
 MN      ALT      DTAM  PROP SHP     FN RES.     HPX    BSFC      WFT      WAE    PTA
 MN      ALT      DTAM NET THRUST   TSFC   ETA PROP
0.10    2000.     0.0    8945.98   1011.40   100.00   0.399   3571.44   55.85   1.13
0.10    2000.     0.0   14800.79   0.241   0.311
0.10    2000.     0.0    7576.30    836.85   100.00   0.413   3128.29   51.75   1.11
0.10    2000.     0.0   13508.39   0.232   0.337
0.10    2000.     0.0    6241.80    679.36   100.00   0.433   2705.15   47.40   1.09
0.10    2000.     0.0   11126.31   0.225   0.370
0.10    2000.     0.0    5005.09    532.22   100.00   0.462   2313.75   42.99   1.07
0.10    2000.     0.0   10666.25   0.217   0.408
0.10    2000.     0.0    3935.58    411.12   100.00   0.501   1969.99   38.91   1.06
0.10    2000.     0.0    9134.85   0.216   0.447
0.10    2000.     0.0    3028.61    317.87   100.00   0.552   1672.44   35.16   1.05

0.10    2000.     0.0    2265.97    242.60   100.00   0.622   1409.22   31.60   1.04

0.10    2000.     0.0    1655.73    173.37   100.00   0.715   1183.69   28.39   1.03

0.10    2000.     0.0    1138.44    128.21   100.00   0.867    986.57   25.39   1.02


                           TAKE OFF PERFORMANCE
                       STANDARD PLUS 25 DEGREES F TAM

0.10    2000.    25.0    9355.05   1041.94   100.00   0.400   3744.76   56.49   1.13
0.10    2000.    25.0   14746.41   0.254   0.302
0.10    2000.    25.0    8003.18    875.00   100.00   0.413   3301.46   52.61   1.11
0.10    2000.    25.0   13570.54   0.243   0.327
0.10    2000.    25.0    6689.30    717.30   100.00   0.430   2875.16   48.43   1.10
0.10    2000.    25.0   12279.81   0.234   0.357
0.10    2000.    25.0    5458.31    569.32   100.00   0.454   2477.02   44.16   1.08
0.10    2000.    25.0   10951.91   0.226   0.393
0.10    2000.    25.0    4374.20    442.51   100.00   0.486   2124.79   40.15   1.06
0.10    2000.    25.0    9546.05   0.223   0.430
0.10    2000.    25.0    3426.99    349.90   100.00   0.530   1814.82   36.43   1.05
0.10    2000.    25.0    8179.48   0.222   0.472
0.10    2000.    25.0    2619.98    266.23   100.00   0.588   1541.35   32.90   1.04

0.10    2000.    25.0    1955.57    200.67   100.00   0.667   1304.51   29.67   1.03

0.10    2000.    25.0    1407.49    147.36   100.00   0.779   1096.81   26.67   1.02
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                        PRATT AND WHITNEY AIRCRAFT
         REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
      U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                          FREE TURBINE RPM=6547.

                            TAKE OFF PERFORMANCE
                              STANDARD DAY TAM
   MN       ALT      DTAM   PROP SHP    FN RES.     HPX     BSFC       WFT      WAE     PTA
   MN       ALT      DTAM NET THRUST   TSFC   ETA PROP
  0.20     2000.     0.0    9102.63     851.98   100.00   0.396   3605.27   55.51   1.13
  0.20     2000.     0.0   12897.20 ✓ 0.280    (0.533)
  0.20     2000.     0.0    7704.34     688.63   100.00   0.410   3155.79   51.40   1.11
  0.20     2000.     0.0   11615.39   0.272    0.572
  0.20     2000.     0.0    6364.64     535.95   100.00   0.429   2730.17   47.11   1.09
  0.20     2000.     0.0   10248.02   0.266    0.615
  0.20     2000.     0.0    5111.23     402.37   100.00   0.457   2335.35   42.74   1.07
  0.20     2000.     0.0    6786.11   0.266    0.661
  0.20     2000.     0.0    4029.99     297.07   100.00   0.494   1990.86   38.74   1.06
  0.20     2000.     0.0    7327.43   0.272    0.703
  0.20     2000.     0.0    3113.46     214.22   100.00   0.543   1691.89   35.06   1.05

  0.20     2000.     0.0    2346.37     141.51   100.00   0.608   1427.20   31.55   1.04

  0.20     2000.     0.0    1723.48      89.28   100.00   0.697   1200.60   28.41   1.03

  0.20     2000.     0.0    1197.42      49.38   100.00   0.836   1001.35   25.43   1.02



                             TAKE OFF PERFORMANCE
                        STANDARD PLUS 25 DEGREES F TAM

  0.20     2000.    25.0    9514.39     884.08   100.00   0.397   3780.40   56.15   1.14
  0.20     2000.    25.0   12881.67 ✓ 0.293    0.521
  0.20     2000.    25.0    8143.81     722.74   100.00   0.409   3331.41   52.27   1.12
  0.20     2000.    25.0   11717.38   0.284    0.557
  0.20     2000.    25.0    6821.46     567.61   100.00   0.425   2901.18   48.12   1.10
  0.20     2000.    25.0   10441.55   0.278    0.598
  0.20     2000.    25.0    5566.33     440.21   100.00   0.449   2500.11   43.90   1.08
  0.20     2000.    25.0    9107.89   0.274    0.643
  0.20     2000.    25.0    4475.24     323.33   100.00   0.480   2146.21   39.96   1.06
  0.20     2000.    25.0    7742.65   0.277    0.685
  0.20     2000.    25.0    3524.61     235.89   100.00   0.521   1835.15   36.31   1.05
  0.20     2000.    25.0    6442.53   0.285    0.727
  0.20     2000.    25.0    2706.05     165.69   100.00   0.577   1560.67   32.85   1.04

  0.20     2000.    25.0    2030.04     110.75   100.00   0.651   1322.39   29.66   1.03

  0.20     2000.    25.0    1473.11      65.82   100.00   0.756   1113.14   26.71   1.03
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                     PRATT AND WHITNEY AIRCRAFT
      REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
   U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                     99 PERCENT GEAR EFFICIENCY
                     FREE TURBINE RPM=8547.

                       TAKE OFF PERFORMANCE
                         STANDARD DAY TAM
   MN     ALT     DTAM  PROP SHP    FN RES.     HPX    BSFC      WFT      WAE    PTA
   MN     ALT     DTAM NET THRUST  TSFC  ETA PROP
  0.30   2000.    0.0    9367.69    696.99  100.00  0.391  3660.44   54.92   1.14
  0.30   2000.    0.0   11199.45  0.327  0.678
  0.30   2000.    0.0    7937.05    536.68  100.00  0.403  3202.51   50.84   1.11
  0.30   2000.    0.0    9919.42  0.323  0.715
  0.30   2000.    0.0    6564.20    395.97  100.00  0.422  2769.32   46.59   1.09
  0.30   2000.    0.0    8560.16  0.324  0.752
  0.30   2000.    0.0    5291.01    278.16  100.00  0.448  2372.89   42.36   1.08
  0.30   2000.    0.0    7149.91  0.332  0.785
  0.30   2000.    0.0    4198.18    179.58  100.00  0.483  2026.18   38.48   1.06
  0.30   2000.    0.0    5794.61  0.350  0.809
  0.30   2000.    0.0    3264.24    105.34  100.00  0.528  1724.29   34.88   1.05
  0.30   2000.    0.0    4577.63  0.377  0.829
  0.30   2000.    0.0    2477.26     46.32  100.00  0.588  1457.19   31.47   1.04

  0.30   2000.    0.0    1838.77      2.30  100.00  0.668  1228.16   28.42   1.03

  0.30   2000.    0.0    1300.01    -28.75  100.00  0.790  1027.38   25.54   1.02



                       TAKE OFF PERFORMANCE
                   STANDARD PLUS 25 DEGREES F TAM

  0.30   2000.   25.0    9789.67    730.44  100.00  0.392  3838.73   55.57   1.14
  0.30   2000.   25.0   11241.66  0.341  0.665
  0.30   2000.   25.0    8382.93    574.38  100.00  0.403  3381.07   51.70   1.12
  0.30   2000.   25.0   10063.88  0.336  0.701
  0.30   2000.   25.0    7026.55    430.33  100.00  0.419  2944.08   47.60   1.10
  0.30   2000.   25.0    8802.49  0.334  0.738
  0.30   2000.   25.0    5752.53    312.90  100.00  0.441  2538.95   43.48   1.08
  0.30   2000.   25.0    7487.43  0.339  0.772
  0.30   2000.   25.0    4646.02    208.96  100.00  0.470  2183.01   39.65   1.07
  0.30   2000.   25.0    6213.45  0.351  0.800
  0.30   2000.   25.0    3681.46    129.97  100.00  0.508  1869.60   36.11   1.05
  0.30   2000.   25.0    4994.69  0.374  0.818
  0.30   2000.   25.0    2848.27     66.93  100.00  0.559  1593.07   32.75   1.04

  0.30   2000.   25.0    2156.84     19.76  100.00  0.627  1352.31   29.65   1.03

  0.30   2000.   25.0    1584.10    -15.87  100.00  0.720  1140.19   26.77   1.03
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                        PRATT AND WHITNEY AIRCRAFT
           REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962          100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                          FREE TURBINE RPM=8547.

                           TAKE OFF PERFORMANCE
                             STANDARD DAY TAM
   MN      ALT     DTAM   PROP SHP    FN RES.     HPX    BSFC       WFT      WAE     PTA
   MN      ALT     DTAM  NET THRUST   TSFC   ETA PROP
  0.40    2000.     0.0    9732.72    550.72   100.00   0.384   3737.01   54.10    1.14
  0.40    2000.     0.0    9829.90   0.380   0.769
  0.40    2000.     0.0    8255.86    391.99   100.00   0.396   3267.48   50.07    1.12
  0.40    2000.     0.0    8555.31   0.362   0.797
  0.40    2000.     0.0    6843.21    261.13   100.00   0.413   2825.63   45.90    1.10
  0.40    2000.     0.0    7261.59   0.389   0.825
  0.40    2000.     0.0    5548.43    151.95   100.00   0.437   2424.86   41.82    1.08
  0.40    2000.     0.0    5960.20   0.405   0.847
  0.40    2000.     0.0    4430.21     66.23   100.00   0.468   2074.96   38.09    1.07

  0.40    2000.     0.0    3474.15     -1.71   100.00   0.509   1769.31   34.63    1.05

  0.40    2000.     0.0    2665.55    -54.15   100.00   0.562   1498.47   31.34    1.04

  0.40    2000.     0.0    2003.80    -88.70   100.00   0.632   1265.85   28.39    1.03

  0.40    2000.     0.0    1447.07   -115.08   100.00   0.734   1062.16   25.63    1.03


                           TAKE OFF PERFORMANCE
                       STANDARD PLUS 25 DEGREES F TAM

  0.40    2000.    25.0   10177.70    581.80   100.00   0.385   3920.63   54.76    1.15
  0.40    2000.    25.0    9941.75   0.394   0.760
  0.40    2000.    25.0    8712.34    431.63   100.00   0.396   3448.72   50.90    1.13
  0.40    2000.    25.0    8726.14   0.395   0.786
  0.40    2000.    25.0    7320.40    296.51   100.00   0.410   3004.33   46.91    1.10
  0.40    2000.    25.0    7517.83   0.400   0.815
  0.40    2000.    25.0    6627.52    178.06   100.00   0.430   2593.13   42.90    1.08
  0.40    2000.    25.0    6295.96   0.412   0.838
  0.40    2000.    25.0    4898.70     93.93   100.00   0.457   2233.22   39.21    1.07

  0.40    2000.    25.0    3903.03     25.29   100.00   0.491   1917.72   35.82    1.06

  0.40    2000.    25.0    3049.39    -32.44   100.00   0.537   1637.56   32.59    1.05

  0.40    2000.    25.0    2335.82    -75.62   100.00   0.596   1392.67   29.60    1.04

  0.40    2000.    25.0    1742.94   -102.15   100.00   0.676   1177.99   26.83    1.03
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                              PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                              99 PERCENT GEAR EFFICIENCY
                              FREE TURBINE RPM=8547.

                               TAKE OFF PERFORMANCE
                                 STANDARD DAY TAM
  MN      ALT     DTAM  PROP SHP    FN RES.    HPX     BSFC       WFT      WAE    PTA
  MN      ALT     DTAM NET THRUST   TSFC   ETA PROP
  0.0     5000.   0.0   8449.31   1134.90  100.00   0.395   3337.53   57.70   1.14
  0.0     5000.   0.0  12791.69   0.261    0.0
  0.0     5000.   0.0   7202.48    964.62  100.00   0.407   2934.25   53.66   1.12
  0.0     5000.   0.0  12391.98   0.237    0.0
  0.0     5000.   0.0   5977.45    799.78  100.00   0.426   2544.12   49.28   1.10
  0.0     5000.   0.0  11740.92   0.217    0.0
  0.0     5000.   0.0   4815.71    650.35  100.00   0.453   2179.95   44.77   1.08
  0.0     5000.   0.0  10870.89   0.201    0.0
  0.0     5000.   0.0   3787.07    518.55  100.00   0.489   1853.33   40.45   1.06
  0.0     5000.   0.0   9789.15   0.189    0.0
  0.0     5000.   0.0   2919.16    413.35  100.00   0.538   1571.04   36.50   1.05
  0.0     5000.   0.0   8809.28   0.178    0.0
  0.0     5000.   0.0   2187.94    326.18  100.00   0.604   1322.23   32.75   1.04

  0.0     5000.   0.0   1592.81    258.68  100.00   0.696   1107.99   29.35   1.03

  0.0     5000.   0.0   1103.95    200.26  100.00   0.836    923.06   26.22   1.02



                               TAKE OFF PERFORMANCE
                           STANDARD PLUS 25 DEGREES F TAM

  0.0     5000.  25.0   8788.43   1167.65  100.00   0.397   3490.51   58.23   1.14
  0.0     5000.  25.0  12114.06   0.288    0.0
  0.0     5000.  25.0   7572.34    996.91  100.00   0.408   3086.12   54.40   1.12
  0.0     5000.  25.0  12038.23   0.256    0.0
  0.0     5000.  25.0   6373.74    833.58  100.00   0.423   2695.94   50.23   1.10
  0.0     5000.  25.0  11551.48   0.233    0.0
  0.0     5000.  25.0   5226.34    686.72  100.00   0.445   2327.61   45.90   1.08
  0.0     5000.  25.0  10851.87   0.214    0.0
  0.0     5000.  25.0   4183.86    556.22  100.00   0.477   1993.65   41.66   1.07
  0.0     5000.  25.0   9950.90   0.200    0.0
  0.0     5000.  25.0   3286.94    445.66  100.00   0.517   1700.87   37.75   1.05
  0.0     5000.  25.0   8926.95   0.191    0.0
  0.0     5000.  25.0   2515.42    361.33  100.00   0.574   1444.20   34.10   1.04

  0.0     5000.  25.0   1873.08    283.11  100.00   0.651   1218.58   30.83   1.03

  0.0     5000.  25.0   1352.34    222.97  100.00   0.757   1023.89   27.51   1.03
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                    PRATT AND WHITNEY AIRCRAFT
      REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
   U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                    99 PERCENT GEAR EFFICIENCY
                    FREE TURBINE RPM=8547.

                       TAKE OFF PERFORMANCE
                         STANDARD DAY TAM
  MN     ALT     DTAM  PROP SHP    FN RES.     HPX     BSFC      WFT     WAE    PTA
  MN     ALT     DTAM NET THRUST  TSFC  ETA PROP
 0.10   5000.    0.0    8499.02   974.84  100.00   0.394  3348.00   57.57   1.14
 0.10   5000.    0.0   13832.06  0.242   0.302
 0.10   5000.    0.0    7244.91   815.71  100.00   0.406  2943.27   53.54   1.12
 0.10   5000.    0.0   12689.82  0.232   0.327
 0.10   5000.    0.0    6013.46   663.11  100.00   0.424  2551.81   49.17   1.10
 0.10   5000.    0.0   11437.76  0.223   0.357
 0.10   5000.    0.0    4848.15   525.03  100.00   0.451  2186.74   44.68   1.08
 0.10   5000.    0.0   10154.86  0.216   0.395
 0.10   5000.    0.0    3815.39   406.13  100.00   0.487  1859.28   40.38   1.06
 0.10   5000.    0.0    8693.59  0.214   0.433
 0.10   5000.    0.0    2946.53   310.57  100.00   0.535  1576.96   36.45   1.05
 0.10   5000.    0.0    7488.46  0.211   0.486
 0.10   5000.    0.0    2210.19   239.18  100.00   0.601  1328.44   32.75   1.04

 0.10   5000.    0.0    1616.34   171.69  100.00   0.689  1113.14   29.35   1.03

 0.10   5000.    0.0    1122.47   128.39  100.00   0.827   928.21   26.25   1.02



                       TAKE OFF PERFORMANCE
                  STANDARD PLUS 25 DEGREES F TAM

 0.10   5000.   25.0    8839.72  1007.17  100.00   0.396  3501.40   58.11   1.14
 0.10   5000.   25.0   13749.66  0.255   0.295
 0.10   5000.   25.0    7617.04   847.02  100.00   0.406  3096.38   54.30   1.12
 0.10   5000.   25.0   12701.17  0.244   0.318
 0.10   5000.   25.0    6412.69   691.67  100.00   0.422  2703.82   50.11   1.10
 0.10   5000.   25.0   11540.24  0.234   0.346
 0.10   5000.   25.0    5257.30   562.69  100.00   0.444  2335.39   45.82   1.08
 0.10   5000.   25.0   10331.80  0.226   0.380
 0.10   5000.   25.0    4217.54   436.18  100.00   0.474  1999.96   41.59   1.07
 0.10   5000.   25.0    9057.82  0.221   0.418
 0.10   5000.   25.0    3313.39   341.98  100.00   0.515  1707.14   37.71   1.05
 0.10   5000.   25.0    7766.21  0.220   0.458
 0.10   5000.   25.0    2539.81   263.39  100.00   0.571  1449.41   34.05   1.04

 0.10   5000.   25.0    1896.70   195.56  100.00   0.645  1224.02   30.62   1.03

 0.10   5000.   25.0    1372.68   144.56  100.00   0.749  1028.78   27.51   1.03
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                      PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
       U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                     99 PERCENT GEAR EFFICIENCY
                      FREE TURBINE RPM=6547.

                        TAKE OFF PERFORMANCE
                          STANDARD DAY TAM
  MN     ALT ,   DTAM  PROP SHP    FN RES.    HPX    BSFC      WFT     WAE    PTA
  MN     ALT     DTAM NET THRUST  TSFC  ETA PROP
 0.20   5000.    0.0   8643.12    630.69  100.00  0.391  3379.88   57.22  1.14
 0.20   5000.    0.0  12111.25   0.279   0.521
 0.20   5000.    0.0   7369.54    678.18  100.00  0.403  2970.04   53.19  1.12
 0.20   5000.    0.0  10975.65   0.271   0.557
 0.20   5000.    0.0   6125.64    532.43  100.00  0.420  2575.00   48.86  1.10
 0.20   5000.    0.0   9740.58   0.264   0.600
 0.20   5000.    0.0   4945.01    406.14  100.00  0.446  2206.96   44.42  1.08
 0.20   5000.    0.0   8419.43   0.262   0.646
 0.20   5000.    0.0   3901.63    298.55  100.00  0.481  1877.78   40.17  1.06
 0.20   5000.    0.0   7039.57   0.267   0.689
 0.20   5000.    0.0   3027.61    212.39  100.00  0.527  1595.09   36.34  1.05
 0.20   5000.    0.0   5796.59   0.275   0.736
 0.20   5000.    0.0   2283.86    146.08  100.00  0.589  1344.50   32.67  1.04

 0.20   5000.    0.0   1679.09     94.20  100.00  0.672  1128.56   29.35  1.03

 0.20   5000.    0.0   1179.29     54.42  100.00  0.799   942.27   26.30  1.02


                        TAKE OFF PERFORMANCE
                   STANDARD PLUS 25 DEGREES F TAM

 0.20   5000.   25.0   8993.74    859.06  100.00  0.393  3534.82   57.76  1.15
 0.20   5000.   25.0  12054.66   0.293   0.509
 0.20   5000.   25.0   7749.61    706.15  100.00  0.403  3123.99   53.93  1.12
 0.20   5000.   25.0  11018.09   0.284   0.544
 0.20   5000.   25.0   6524.63    565.15  100.00  0.418  2728.52   49.80  1.10
 0.20   5000.   25.0   9875.91   0.276   0.583
 0.20   5000.   25.0   5362.83    438.44  100.00  0.439  2356.71   45.54  1.09
 0.20   5000.   25.0   8670.89   0.272   0.627
 0.20   5000.   25.0   4308.06    328.53  100.00  0.469  2020.11   41.37  1.07
 0.20   5000.   25.0   7413.40   0.272   0.672
 0.20   5000.   25.0   3401.18    239.60  100.00  0.507  1725.94   37.57  1.06
 0.20   5000.   25.0   6177.63   0.279   0.714
 0.20   5000.   25.0   2619.15    170.52  100.00  0.560  1467.37   33.98  1.04

 0.20   5000.   25.0   1964.44    114.70  100.00  0.631  1240.43   30.61  1.04

 0.20   5000.   25.0   1433.93     69.83  100.00  0.728  1044.03   27.55  1.03
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                              PRATT AND WHITNEY AIRCRAFT
              REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
          U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                              99 PERCENT GEAR EFFICIENCY
                               FREE TURBINE RPM=8547.

                                 TAKE OFF PERFORMANCE
                                  STANDARD DAY TAM
 MN       ALT      DTAM   PROP SHP    FN RES.     HPX     BSFC       WFT      WAE     PTA
 MN       ALT      DIAM NET THRUST   TSFC   ETA PROP
 0.30    5000.     0.0    8889.04    692.86  100.00   0.386   3432.73    56.63    1.15
 0.30    5000.     0.0   10576.41    0.325   0.665
 0.30    5000.     0.0    7583.43    541.78  100.00   0.397   3013.65    52.60    1.12
 0.30    5000.     0.0    9431.75    0.326   0.701
 0.30    5000.     0.0    6317.54    403.32  100.00   0.414   2614.09    48.35    1.10
 0.30    5000.     0.0    8210.03    0.318   0.739
 0.30    5000.     0.0    5107.22    291.14  100.00   0.439   2240.45    43.97    1.08
 0.30    5000.     0.0    6908.87    0.324   0.775
 0.30    5000.     0.0    4054.23    192.27  100.00   0.471   1909.95    39.87    1.07
 0.30    5000.     0.0    5628.91    0.339   0.802
 0.30    5000.     0.0    3161.50    119.70  100.00   0.514   1625.49    36.14    1.05
 0.30    5000.     0.0    4427.91    0.367   0.815
 0.30    5000.     0.0    2404.69     59.39  100.00   0.571   1371.96    32.57    1.04

 0.30    5000.     0.0    1785.68     15.25  100.00   0.646   1153.71    29.33    1.03

 0.30    5000.     0.0    1274.65    -19.31  100.00   0.758    965.77    26.38    1.03



                                 TAKE OFF PERFORMANCE
                            STANDARD PLUS 25 DEGREES F TAM

 0.30    5000.    25.0    9248.50    721.53  100.00   0.388   3590.20    57.17    1.15
 0.30    5000.    25.0   10571.02    0.340   0.653
 0.30    5000.    25.0    7975.62    572.17  100.00   0.398   3171.08    53.35    1.13
 0.30    5000.    25.0    9522.46    0.333   0.688
 0.30    5000.    25.0    6722.15    434.63  100.00   0.412   2768.48    49.26    1.11
 0.30    5000.    25.0    8387.84    0.336   0.725
 0.30    5000.    25.0    5535.67    318.69  100.00   0.432   2391.83    45.07    1.09
 0.30    5000.    25.0    7192.74    0.333   0.761
 0.30    5000.    25.0    4466.22    219.99  100.00   0.460   2052.89    41.02    1.07
 0.30    5000.    25.0    5992.21    0.343   0.792
 0.30    5000.    25.0    3545.23    142.10  100.00   0.496   1757.28    37.33    1.06
 0.30    5000.    25.0    4846.02    0.363   0.814
 0.30    5000.    25.0    2751.94     77.56  100.00   0.544   1496.73    33.84    1.05
 0.30    5000.    25.0    3930.77    0.381   0.858
 0.30    5000.    25.0    2083.07     29.10  100.00   0.609   1267.82    30.57    1.04

 0.30    5000.    25.0    1536.91     -4.62  100.00   0.696   1069.27    27.60    1.03
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                           PRATT AND WHITNEY AIRCRAFT
            REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
      U.S. STANDARD ATMOSPHERE, 1962         100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                           FREE TURBINE RPM=8547.

                             TAKE OFF PERFORMANCE
                               STANDARD DAY TAM
  MN      ALT    DTAM - PROP SHP   FN RES.    HPX    BSFC      WFT      WAE    PTA
  MN      ALT    DTAM NET THRUST   TSFC  ETA PROP
 0.40    5000.    0.0   9241.68    556.50  100.00  0.379  3506.19   55.80   1.15
 0.40    5000.    0.0   9344.13   0.375  0.759
 0.40    5000.    0.0   7882.20    410.60  100.00  0.390  3074.85   51.79   1.13
 0.40    5000.    0.0   8187.27   0.376  0.787
 0.40    5000.    0.0   6575.95    281.37  100.00  0.406  2666.56   47.62   1.11
 0.40    5000.    0.0   7006.58   0.380  0.816
 0.40    5000.    0.0   5341.69    175.56  100.00  0.428  2287.90   43.37   1.09
 0.40    5000.    0.0   5802.31   0.394  0.840
 0.40    5000.    0.0   4269.43     85.54  100.00  0.458  1954.20   39.42   1.07

 0.40    5000.    0.0   3355.35     20.86  100.00  0.497  1666.46   35.83   1.06

 0.40    5000.    0.0   2579.43    -32.10  100.00  0.547  1410.09   32.40   1.05

 0.40    5000.    0.0   1939.66    -69.08  100.00  0.613  1188.77   29.28   1.04

 0.40    5000.    0.0   1407.19    -53.95  100.00  0.709   997.23   26.42   1.03



                             TAKE OFF PERFORMANCE
                        STANDARD PLUS 25 DEGREES F TAM

 0.40    5000.   25.0   9614.21    585.82  100.00  0.381  3667.12   56.34   1.16
 0.40    5000.   25.0   9412.22   0.390  0.751
 0.40    5000.   25.0   8287.70    440.79  100.00  0.390  3235.71   52.53   1.13
 0.40    5000.   25.0   8312.68   0.389  0.776
 0.40    5000.   25.0   6498.04    309.04  100.00  0.404  2824.79   48.52   1.11
 0.40    5000.   25.0   7200.27   0.392  0.805
 0.40    5000.   25.0   5776.46    203.04  100.00  0.423  2441.10   44.42   1.09
 0.40    5000.   25.0   6075.71   0.402  0.831
 0.40    5000.   25.0   4691.66    111.63  100.00  0.447  2099.24   40.53   1.08
 0.40    5000.   25.0   5095.89   0.412  0.868
 0.40    5000.   25.0   3754.12     40.85  100.00  0.480  1801.32   37.00   1.06

 0.40    5000.   25.0   2936.63    -12.03  100.00  0.524  1537.74   33.65   1.05

 0.40    5000.   25.0   2249.04    -55.71  100.00  0.580  1305.28   30.49   1.04

 0.40    5000.   25.0   1684.26    -84.85  100.00  0.655  1103.48   27.62   1.03
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                         PRATT AND WHITNEY AIRCRAFT
         REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
     U.S. STANDARD ATMOSPHERE, 1962         100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                           FREE TURBINE RPM=6547.

                MAXIMUM CLIMB PERFORMANCE 250KEAS CLIMB PATH
                              STANDARD DAY TAM
        MN      ALT      DIAM  PROP SHP    FN RES.     HPX     BSFC      WFT      WAE     PTA
        MN      ALT      DIAM NET THRUST   TSFC   ETA PROP

MAX CL 0.38        0.     0.0   10663.28    652.66  100.00   0.364   4105.56   54.96   1.15
       0.38        0.     0.0   11055.77   0.371  0.747
MAX CR 0.38        0.     0.0    8327.73    410.63  100.00   0.403   3355.91   48.89   1.11
       0.38        0.     0.0    9027.25   0.372  0.794
       0.38        0.     0.0    6868.49    273.79  100.00   0.422   2897.17   44.75   1.09
       0.38        0.     0.0    7627.89   0.380  0.821
       0.38        0.     0.0    5549.27    166.05  100.00   0.448   2485.95   40.77   1.08

       0.38        0.     0.0    4422.29     75.14  100.00   0.481   2128.24   37.15   1.06

       0.38        0.     0.0    3457.64      1.04  100.00   0.525   1814.97   33.78   1.05

       0.38        0.     0.0    2636.82    -46.25  100.00   0.583   1536.68   30.56   1.04

       0.38        0.     0.0    1968.75    -79.52  100.00   0.659   1297.75   27.69   1.03




MAX CL 0.46    10000.     0.0    9284.79    560.89  100.00   0.366   3398.05   60.18   1.20
       0.46    10000.     0.0    8565.53   0.397  0.768
MAX CR 0.46    10000.     0.0    7499.90    375.52  100.00   0.377   2824.62   54.44   1.15
       0.46    10000.     0.0    7066.25   0.399  0.799
       0.46    10000.     0.0    6330.50    254.90  100.00   0.389   2460.06   50.26   1.13
       0.46    10000.     0.0    6085.62   0.404  0.823
       0.46    10000.     0.0    5215.63    150.76  100.00   0.406   2119.11   45.97   1.10
       0.46    10000.     0.0    5077.41   0.417  0.844
       0.46    10000.     0.0    4187.64     69.54  100.00   0.432   1808.84   41.75   1.09
       0.46    10000.     0.0    4210.73   0.430  0.883
       0.46    10000.     0.0    3318.47      3.59  100.00   0.464   1541.37   37.92   1.07

       0.46    10000.     0.0    2578.16    -41.64  100.00   0.507   1306.63   34.36   1.06

       0.46    10000.     0.0    1956.06    -82.43  100.00   0.562   1099.04   30.98   1.04
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                              PRATT AND WHITNEY AIRCRAFT
                 REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
             U.S. STANDARD ATMOSPHERE, 1962          100 PERCENT RAM RECOVERY
                              99 PERCENT GEAR EFFICIENCY
                              FREE TURBINE RPM=6547.

                      MAXIMUM CLIMB PERFORMANCE 250KEAS CLIMB PATH
                                   STANDARD DAY TAM
          MN      ALT      DTAM  PROP SHP    FN RES.    HPX    BSFC      WFT     WA2     PTA
          MN      ALT      DTAM NET THRUST   TSFC  ETA PROP

MAX CL  0.56   20000.     0.0    7840.39    523.90  100.00  0.353  2765.75   65.05   1.28
        0.56   20000.     0.0    6461.43   0.428  0.795
MAX CR  0.56   20000.     0.0    6537.56    341.77  100.00  0.357  2332.14   59.67   1.22
        0.56   20000.     0.0    5454.96   0.428  0.821
        0.56   20000.     0.0    5666.41    236.54  100.00  0.363  2056.00   55.77   1.18
        0.56   20000.     0.0    4742.71   0.434  0.835
        0.56   20000.     0.0    4799.37    147.14  100.00  0.373  1790.70   51.57   1.15
        0.56   20000.     0.0    4033.71   0.444  0.850
        0.56   20000.     0.0    3952.16     67.10  100.00  0.389  1537.41   47.09   1.12
        0.56   20000.     0.0    3322.33   0.463  0.865
        0.56   20000.     0.0    3161.91      5.96  100.00  0.413  1307.42   42.68   1.10
        0.56   20000.     0.0    2633.02   0.497  0.872
        0.56   20000.     0.0    2493.46    -40.99  100.00  0.444  1106.74   38.58   1.08

        0.56   20000.     0.0    1929.63    -76.65  100.00  0.483   931.61   34.81   1.06



MAX CL  0.67   28250.     0.0    6585.65    458.76  100.00  0.347  2285.32   67.15   1.36
        0.67   28250.     0.0    4647.72   0.471  0.809
MAX CR  0.67   28250.     0.0    5827.01    337.45  100.00  0.344  2002.85   64.02   1.31
        0.67   28250.     0.0    4294.87   0.466  0.824
        0.67   28250.     0.0    5146.70    239.77  100.00  0.346  1780.83   60.31   1.26
        0.67   28250.     0.0    3785.85   0.470  0.837
        0.67   28250.     0.0    4467.14    153.19  100.00  0.351  1566.92   56.33   1.22
        0.67   28250.     0.0    3275.60   0.478  0.848
        0.67   28250.     0.0    3791.19     78.38  100.00  0.359  1362.30   52.07   1.18
        0.67   28250.     0.0    2756.60   0.494  0.857
        0.67   28250.     0.0    3116.69     15.45  100.00  0.374  1165.49   47.47   1.15

        0.67   28250.     0.0    2486.04    -33.42  100.00  0.396   985.70   42.84   1.12

        0.67   28250.     0.0    1958.53    -69.12  100.00  0.425   831.69   38.70   1.09
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                         PRATT AND WHITNEY AIRCRAFT
              REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
           U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                         FREE TURBINE RPM=8547.

                 MAXIMUM CLIMB PERFORMANCE 250KEAS CLIMB PATH
                              STANDARD DAY TAM
         MN      ALT     DTAM  PROP SHP    FN RES.    HPX    BSFC       WFT      WAE     PTA
         MN      ALT     DTAM NET THRUST   TSFC   ETA PROP

MAX CL   0.69   30000.    0.0    6308.22    442.02  100.00  0.346   2183.55   67.25   1.39
         0.69   30000.    0.0    4496.47   0.486   0.805
MAX CR   0.69   30000.    0.0    5652.99    333.42  100.00  0.342   1930.84   64.70   1.33
         0.69   30000.    0.0    4025.29   0.480   0.818
         0.69   30000.    0.0    5018.64    239.42  100.00  0.343   1721.41   61.10   1.29
         0.69   30000.    0.0    3563.36   0.483   0.830
         0.69   30000.    0.0    4369.19    154.61  100.00  0.347   1516.59   57.14   1.24
         0.69   30000.    0.0    3081.53   0.492   0.840
         0.69   30000.    0.0    3732.35     78.93  100.00  0.354   1322.14   52.96   1.20
         0.69   30000.    0.0    2547.96   0.509   0.846
         0.69   30000.    0.0    3085.76     16.44  100.00  0.367   1133.00   48.37   1.16

         0.69   30000.    0.0    2472.79    -32.24  100.00  0.388    958.82   43.67   1.13

         0.69   30000.    0.0    1950.92    -67.74  100.00  0.414    808.53   39.42   1.10



MAX CL   0.80   36000.    0.0    5462.63    396.86  100.00  0.342   1868.42   67.64   1.49
         0.80   36000.    0.0    3510.09   0.551   0.804
MAX CR   0.80   36000.    0.0    4988.92    307.03  100.00  0.335   1671.47   65.84   1.43
         0.80   36000.    0.0    3190.70   0.524   0.814
         0.80   36000.    0.0    4502.57    229.88  100.00  0.334   1506.78   62.88   1.38
         0.80   36000.    0.0    2864.56   0.526   0.823
         0.80   36000.    0.0    3962.62    149.96  100.00  0.336   1331.62   58.98   1.32
         0.80   36000.    0.0    2484.69   0.536   0.830
         0.80   36000.    0.0    3426.23     78.00  100.00  0.340   1165.28   54.89   1.26
         0.80   36000.    0.0    2094.25   0.556   0.829
         0.80   36000.    0.0    2685.12     16.08  100.00  0.348   1004.41   50.44   1.21
         0.80   36000.    0.0    1690.76   0.594   0.818
         0.80   36000.    0.0    2354.58    -33.29  100.00  0.363    853.95   45.77   1.17

         0.80   36000.    0.0    1869.45    -69.39  100.00  0.384    718.49   41.22   1.13
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                         PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                           99 PERCENT GEAR EFFICIENCY
                            FREE TURBINE RPM=8547.

                   PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                               STANDARD DAY TAM
         MN      ALT      DTAM  PROP SHP    FN RES.     HPX    BSFC       WFT     WAE    PTA
         MN      ALT      DTAM NET THRUST   TSFC   ETA PROP

MAX CL 0.35       0.      0.0  10554.47    701.20  100.00  0.386   4078.95   55.17   1.14
       0.35       0.      0.0  11456.92   0.356   0.724
MAX CR 0.35       0.      0.0   8232.05    453.87  100.00  0.405   3336.82   49.12   1.11
       0.35       0.      0.0   9433.43   0.354   0.775
       0.35       0.      0.0   6786.12    313.26  100.00  0.425   2880.95   44.95   1.09
       0.35       0.      0.0   8602.17   0.366   0.805
       0.35       0.      0.0   5479.67    196.94  100.00  0.451   2471.27   40.93   1.07

       0.35       0.      0.0   4354.87    105.06  100.00  0.485   2113.38   37.25   1.06

       0.35       0.      0.0   3383.43     41.35  100.00  0.532   1799.89   33.82   1.05

       0.35       0.      0.0   2577.81    -14.22  100.00  0.591   1523.78   30.59   1.04

       0.35       0.      0.0   1919.01    -55.90  100.00  0.670   1285.73   27.67   1.03



MAX CL 0.50       0.      0.0  10877.10    417.56  100.00  0.377   4097.84   52.71   1.15
       0.50       0.      0.0   9272.53   0.442   0.826
MAX CR 0.50       0.      0.0   8833.83    224.63  100.00  0.391   3456.71   47.75   1.12
       0.50       0.      0.0   7593.51   0.455   0.847
       0.50       0.      0.0   7326.19     92.55  100.00  0.408   2987.60   43.78   1.10
       0.50       0.      0.0   6311.36   0.473   0.861
       0.50       0.      0.0   5981.75     -1.51  100.00  0.430   2572.61   40.07   1.08
       0.50       0.      0.0   5128.18   0.502   0.870
       0.50       0.      0.0   4805.21    -76.14  100.00  0.459   2207.41   36.62   1.07

       0.50       0.      0.0   3792.56   -136.76  100.00  0.497   1885.61   33.38   1.05

       0.50       0.      0.0   2943.69   -179.59  100.00  0.544   1602.31   30.38   1.04

       0.50       0.      0.0   2238.46   -206.62  100.00  0.606   1357.44   27.63   1.03
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                    PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
      U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                    .99 PERCENT GEAR EFFICIENCY
                    FREE TURBINE RPM=1547.

               PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                          STANDARD DAY TAM
        MN      ALT     DTAM  PROP SHP    FN RES.     HPX    BSFC        WFT      WAE     PTA
        MN      ALT     DTAM NET THRUST   TSFC   ETA PROP
MAX CL  0.60      0.     0.0  10890.00    205.46   100.00   0.370    4034.28    50.12    1.15
        0.60      0.     0.0   7896.71   0.511   0.860
MAX CR  0.60      0.     0.0   9355.50     68.45   100.00   0.380    3557.95    46.59    1.13
        0.60      0.     0.0   6738.14   0.528   0.868
        0.60      0.     0.0   7799.61    -51.02   100.00   0.395    3080.08    42.82    1.11
        0.60      0.     0.0   5548.29   0.555   0.874
        0.60      0.     0.0   6424.35   -141.95   100.00   0.414    2659.66    39.34    1.09
        0.60      0.     0.0   4472.74   0.595   0.874
        0.60      0.     0.0   5210.74   -211.09   100.00   0.439    2286.95    36.05    1.07

        0.60      0.     0.0   4153.96   -261.94   100.00   0.471    1958.22    32.98    1.06

        0.60      0.     0.0   3268.96   -297.87   100.00   0.511    1669.20    30.15    1.05

        0.60      0.     0.0   2528.95   -321.88   100.00   0.561    1418.87    27.56    1.04
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REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

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                        PRATT AND WHITNEY AIRCRAFT
           REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962          100 PERCENT RAM RECOVERY
                        99 PERCENT GEAR EFFICIENCY
                         FREE TURBINE RPM=6547.

                 PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                              STANDARD DAY TAM
          MN     ALT     DTAM  PROP SHP   FN RES.    HPX    BSFC      WFT     WAE    PTA
          MN     ALT     DTAM NET THRUST  TSFC   ETA PROP


MAX CL   0.35   1500.    0.0  10311.98   707.96  100.00  0.384  3962.43  56.08  1.15
         0.35   1500.    0.0  11169.45  0.355   0.717
MAX CR   0.35   1500.    0.0   8691.28   462.64  100.00  0.402  3250.03  50.05  1.12
         0.35   1500.    0.0   9255.40  0.351   0.768
         0.35   1500.    0.0   6696.69   327.31  100.00  0.420  2810.22  45.88  1.10
         0.35   1500.    0.0   7695.49  0.356   0.799
         0.35   1500.    0.0   5406.30   208.70  100.00  0.446  2408.64  41.73  1.08
         0.35   1500.    0.0   6710.13  0.359   0.850
         0.35   1500.    0.0   4296.72   118.89  100.00  0.479  2059.25  37.97  1.06

         0.35   1500.    0.0   3350.88    49.90  100.00  0.523  1753.99  34.47  1.05

         0.35   1500.    0.0   2556.27    -9.04  100.00  0.580  1483.79  31.14  1.04

         0.35   1500.    0.0   1906.63   -47.53  100.00  0.657  1251.96  28.17  1.03



MAX CL   0.50   1500.    0.0  10684.97   460.65  100.00  0.373  4062.22  54.21  1.16
         0.50   1500.    0.0   9307.10  0.426   0.821
MAX CR   0.50   1500.    0.0   8670.78   246.98  100.00  0.388  3366.91  48.66  1.13
         0.50   1500.    0.0   7487.30  0.450   0.843
         0.50   1500.    0.0   7206.76   119.25  100.00  0.404  2912.61  44.65  1.10
         0.50   1500.    0.0   6250.92  0.466   0.859
         0.50   1500.    0.0   5885.03    19.15  100.00  0.426  2505.42  40.81  1.08
         0.50   1500.    0.0   5064.43  0.493   0.869
         0.50   1500.    0.0   4737.74   -61.61  100.00  0.454  2148.72  37.28  1.07

         0.50   1500.    0.0   3739.98  -114.96  100.00  0.491  1836.10  33.99  1.06

         0.50   1500.    0.0   2909.52  -165.60  100.00  0.536  1559.90  30.91  1.04

         0.50   1500.    0.0   2213.75  -190.35  100.00  0.597  1320.67  28.10  1.04
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                          PRATT AND WHITNEY AIRCRAFT
             REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
          U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                           FREE TURBINE RPM=8547.

                   PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                                STANDARD DAY TAM
       MN      ALT     DTAM  PROP SHP   FN RES.     HPX    BSFC      WFT.     WAE    PTA
       MN      ALT     DTAM NET THRUST   TSFC  ETA PROP

MAX CL 0.60    1500.    0.0  10890.00   248.95  100.00   0.367   3995.06   51.53   1.16
       0.60    1500.    0.0   7947.74  0.503  0.857
MAX CR 0.60    1500.    0.0   9176.73    95.72  100.00   0.378   3464.53   47.45   1.13
       0.60    1500.    0.0   6659.96  0.520  0.867
       0.60    1500.    0.0   7666.58   -28.86  100.00   0.391   2999.57   43.62   1.11
       0.60    1500.    0.0   5499.37  0.545  0.874
       0.60    1500.    0.0   6320.77  -118.09  100.00   0.410   2589.56   40.05   1.09
       0.60    1500.    0.0   4444.45  0.583  0.875
       0.60    1500.    0.0   5124.86  -186.20  100.00   0.434   2225.64   36.68   1.07

       0.60    1500.    0.0   4089.81  -238.45  100.00   0.466   1905.40   33.55   1.06

       0.60    1500.    0.0   3218.13  -274.70  100.00   0.504   1622.92   30.63   1.05

       0.60    1500.    0.0   2492.50  -299.35  100.00   0.553   1379.20   27.99   1.04
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                              PRATT AND WHITNEY AIRCRAFT
              REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
          U.S. STANDARD ATMOSPHERE, 1962          100 PERCENT RAM RECOVERY
                              99 PERCENT GEAR EFFICIENCY
                              FREE TURBINE RPM=8547.

                         PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                                     STANDARD DAY TAM
          MN       ALT      DTAM  PROP SHP    FN RES.    HPX    BSFC       WFT      WAE     PTA
          MN       ALT      DTAM NET THRUST  TSFC   ETA PROP

MAX CL  0.35      5000.     0.0    9718.87    709.19   100.00   0.379   3686.28    58.16    1.16
        0.35      5000.     0.0   10478.82   0.352   0.702
MAX CR  0.35      5000.     0.0    7719.83    478.47   100.00   0.394   3042.36    52.23    1.13
        0.35      5000.     0.0    8796.92   0.346   0.752
        0.35      5000.     0.0    6435.45    345.05   100.00   0.410   2638.72    48.02    1.10
        0.35      5000.     0.0    7592.50   0.348   0.786
        0.35      5000.     0.0    5220.98    225.50   100.00   0.433   2261.34    43.67    1.09
        0.35      5000.     0.0    6319.17   0.358   0.815
        0.35      5000.     0.0    4154.52    138.16   100.00   0.465   1930.47    39.66    1.07

        0.35      5000.     0.0    3254.29     65.05   100.00   0.505   1643.59    35.98    1.05

        0.35      5000.     0.0    2486.37     12.53   100.00   0.559   1389.64    32.49    1.04

        0.35      5000.     0.0    1855.25    -24.19   100.00   0.631   1169.86    29.31    1.04



MAX CL  0.50      5000.     0.0   10401.72    504.53   100.00   0.368   3828.77    56.62    1.18
        0.50      5000.     0.0    8956.10   0.428   0.810
MAX CR  0.50      5000.     0.0    8263.67    281.39   100.00   0.381   3151.85    50.75    1.14
        0.50      5000.     0.0    7157.59   0.438   0.835
        0.50      5000.     0.0    6913.60    158.48   100.00   0.395   2733.71    46.69    1.11
        0.50      5000.     0.0    6067.66   0.451   0.852
        0.50      5000.     0.0    5653.63     55.14   100.00   0.415   2348.78    42.61    1.09
        0.50      5000.     0.0    4959.23   0.474   0.865
        0.50      5000.     0.0    4555.40    -25.52   100.00   0.442   2011.93    38.87    1.07

        0.50      5000.     0.0    3610.57    -82.66   100.00   0.476   1718.83    35.42    1.06

        0.50      5000.     0.0    2808.48   -128.72   100.00   0.519   1458.48    32.16    1.05

        0.50      5000.     0.0    2143.55   -159.43   100.00   0.575   1233.08    29.19    1.04
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                         PRATT AND WHITNEY AIRCRAFT
            REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                          FREE TURBINE RPM=8547.

                  PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                             STANDARD DAY TAM
     MN      ALT      DTAM  PROP SHP    FN RES.     HPX    BSFC       WFT     WAE    PTA
     MN      ALT      DTAM NET THRUST  TSFC  ETA PROP

MAX CL 0.60   5000.     0.0  10888.16    362.80  100.00  0.360   3917.92   55.08   1.19
       0.60   5000.     0.0   8064.15   0.486   0.846
MAX CR 0.60   5000.     0.0   8738.35    148.47  100.00  0.371   3245.14   49.51   1.15
       0.60   5000.     0.0   6444.70   0.504   0.862
       0.60   5000.     0.0   7333.10     30.73  100.00  0.384   2815.01   45.59   1.12
       0.60   5000.     0.0   5367.86   0.524   0.871
       0.60   5000.     0.0   6040.90    -65.77  100.00  0.401   2423.91   41.73   1.10
       0.60   5000.     0.0   4349.97   0.557   0.875
       0.60   5000.     0.0   4908.64   -134.86  100.00  0.424   2082.71   38.21   1.08

       0.60   5000.     0.0   3928.28   -188.26  100.00  0.454   1782.93   34.93   1.07

       0.60   5000.     0.0   3098.11   -232.50  100.00  0.490   1517.07   31.84   1.05

       0.60   5000.     0.0   2398.86   -256.12  100.00  0.536   1286.78   29.03   1.04
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                         PRATT AND WHITNEY AIRCRAFT
            REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
         U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY ,
                          FREE TURBINE RPM=6547.

                   PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                               STANDARD DAY TAM
          MN      ALT      DTAM   PROP SHP    FN RES.     HPX    BSFC      WFT      WAE    PTA
          MN      ALT      DTAM NET THRUST   TSFC   ETA PROP

MAX CL  0.35   10000.      0.0    8871.23    704.75  100.00   0.373  3310.68   61.26   1.19
        0.35   10000.      0.0    9516.54   0.346   0.681
MAX CR  0.35   10000.      0.0    7159.20    490.95  100.00   0.385  2753.86   55.42   1.15
        0.35   10000.      0.0    8105.99   0.340   0.729
        0.35   10000.      0.0    6043.61    367.85  100.00   0.398  2402.39   51.25   1.12
        0.35   10000.      0.0    7113.45   0.338   0.765
        0.35   10000.      0.0    4961.25    258.57  100.00   0.417  2068.63   46.83   1.10
        0.35   10000.      0.0    6025.50   0.343   0.797
        0.35   10000.      0.0    3956.57    166.62  100.00   0.445  1762.18   42.42   1.08

        0.35   10000.      0.0    3107.37     95.97  100.00   0.482  1497.61   38.40   1.06

        0.35   10000.      0.0    2391.24     40.57  100.00   0.530  1266.34   34.66   1.05

        0.35   10000.      0.0    1786.93     -0.92  100.00   0.594  1062.18   31.14   1.04



MAX CL  0.50   10000.      0.0    9484.75    533.88  100.00   0.363  3441.08   59.65   1.20
        0.50   10000.      0.0    8243.61   0.417   0.796
MAX CR  0.50   10000.      0.0    7667.48    325.76  100.00   0.373  2858.36   53.94   1.16
        0.50   10000.      0.0    6757.75   0.423   0.822
        0.50   10000.      0.0    6470.16    206.43  100.00   0.384  2486.82   49.75   1.13
        0.50   10000.      0.0    5757.71   0.432   0.840
        0.50   10000.      0.0    5341.91    106.35  100.00   0.401  2144.35   45.57   1.11
        0.50   10000.      0.0    4760.75   0.449   0.857
        0.50   10000.      0.0    4304.30     27.36  100.00   0.426  1832.19   41.44   1.09
        0.50   10000.      0.0    3850.30   0.476   0.870
        0.50   10000.      0.0    3423.46    -34.29  100.00   0.457  1563.24   37.70   1.07

        0.50   10000.      0.0    2672.28    -79.71  100.00   0.496  1325.47   34.18   1.06

        0.50   10000.      0.0    2039.73   -115.48  100.00   0.548  1117.26   30.90   1.04
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                         PRATT AND WHITNEY AIRCRAFT
            REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
          U.S. STANDARD ATMOSPHERE, 1962    .     100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                          FREE TURBINE RPM=8547.

                  PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                               STANDARD DAY TAM
       MN     ALT     DTAM  PROP SHP    FN RES.    HPX     BSFC      WFT     WAE    PTA
       MN     ALT     DTAM NET THRUST   TSFC   ETA PROP

MAX CL 0.60   10000.   0.0  10005.14    434.56  100.00   0.355   3554.10   58.32   1.22
       0.60   10000.   0.0   7556.49   0.470   0.837
MAX CR 0.60   10000.   0.0   8102.08    216.17  100.00   0.364   2946.15   52.66   1.17
       0.60   10000.   0.0   6105.22   0.483   0.854
       0.60   10000.   0.0   6849.18     99.37  100.00   0.374   2562.32   48.58   1.14
       0.60   10000.   0.0   5140.62   0.498   0.865
       0.60   10000.   0.0   5671.63      3.89  100.00   0.389   2208.40   44.49   1.12
       0.60   10000.   0.0   4217.29   0.524   0.873
       0.60   10000.   0.0   4615.56    -71.64  100.00   0.410   1892.27   40.62   1.09
       0.60   10000.   0.0   3361.29   0.563   0.874
       0.60   10000.   0.0   3705.91   -127.86  100.00   0.437   1619.08   37.08   1.08

       0.60   10000.   0.0   2923.62   -165.32  100.00   0.471   1376.80   33.76   1.06

       0.60   10000.   0.0   2264.99   -197.01  100.00   0.514   1164.06   30.65   1.05



MAX CL 0.65   10000.   0.0  10310.91    378.87  100.00   0.351   3617.37   57.57   1.23
       0.65   10000.   0.0   7254.01   0.499   0.84[illegible]
MAX CR 0.65   10000.   0.0   8344.79    162.71  100.00   0.359   2994.96   51.93   1.18
       0.65   10000.   0.0   5843.19   0.513   0.867
       0.65   10000.   0.0   7069.43     40.40  100.00   0.368   2604.01   47.91   1.14
       0.65   10000.   0.0   4906.30   0.531   0.876
       0.65   10000.   0.0   5863.23    -51.53  100.00   0.383   2244.06   43.89   1.12

       0.65   10000.   0.0   4799.91   -123.49  100.00   0.402   1927.58   40.18   1.10

       0.65   10000.   0.0   3869.96   -175.24  100.00   0.427   1651.51   36.75   1.08

       0.65   10000.   0.0   3073.78   -217.27  100.00   0.457   1404.79   33.49   1.06

       0.65   10000.   0.0   2396.53   -240.40  100.00   0.497   1190.57   30.51   1.05
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                         PRATT AND WHITNEY AIRCRAFT
             REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
          U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                          FREE TURBINE RPM=8547.

                    PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                                STANDARD DAY TAM
          MN     ALT      DTAM   PROP SHP    FN RES.     HPX    BSFC       WFT      WAE    PTA
          MN     ALT      DTAM NET THRUST   TSFC  ETA PROP

MAX CL  0.35   20000.     0.0    7065.10    643.00   100.00   0.367   2569.78   66.57   1.23
        0.35   20000.     0.0    7540.11   0.341   0.650
MAX CR  0.35   20000.     0.0    5936.74    491.30   100.00   0.371   2202.12   62.02   1.19
        0.35   20000.     0.0    6642.14   0.332   0.684
        0.35   20000.     0.0    5129.58    387.69   100.00   0.379   1943.65   57.96   1.16
        0.35   20000.     0.0    5957.61   0.326   0.716
        0.35   20000.     0.0    4340.10    295.19   100.00   0.391   1696.73   53.69   1.14
        0.35   20000.     0.0    5253.39   0.323   0.754
        0.35   20000.     0.0    3555.75    211.64   100.00   0.410   1459.20   49.07   1.11
        0.35   20000.     0.0    4453.56   0.328   0.787
        0.35   20000.     0.0    2810.73    140.43   100.00   0.440   1236.78   44.28   1.09

        0.35   20000.     0.0    2171.58     82.85   100.00   0.479   1040.25   39.70   1.07

        0.35   20000.     0.0    1644.96     37.84   100.00   0.530    871.70   35.59   1.05



MAX CL  0.50   20000.     0.0    7579.39    554.58   100.00   0.357   2704.68   65.59   1.26
        0.50   20000.     0.0    6689.85   0.404   0.763
MAX CR  0.50   20000.     0.0    6346.83    380.82   100.00   0.361   2290.95   60.42   1.21
        0.50   20000.     0.0    5730.52   0.400   0.794
        0.50   20000.     0.0    5492.96    277.13   100.00   0.368   2019.71   56.46   1.18
        0.50   20000.     0.0    5008.44   0.403   0.812
        0.50   20000.     0.0    4653.07    188.82   100.00   0.379   1761.66   52.27   1.15
        0.50   20000.     0.0    4296.20   0.410   0.832
        0.50   20000.     0.0    3823.41    106.83   100.00   0.395   1511.88   47.70   1.12
        0.50   20000.     0.0    3558.57   0.425   0.851
        0.50   20000.     0.0    3045.58     43.29   100.00   0.422   1283.97   43.16   1.10

        0.50   20000.     0.0    2390.41     -7.64   100.00   0.454   1085.72   38.95   1.08

        0.50   20000.     0.0    1835.34    -43.22   100.00   0.497    912.07   35.05   1.06
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REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

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                         PRATT AND WHITNEY AIRCRAFT
            REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                          FREE TURBINE RPM=8547.

                  PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                              STANDARD DAY TAM
         MN      ALT      DTAM  PROP SHP     FN RES.    HPX     BSFC       WFT      WAE     PTA
         MN      ALT      DTAM NET THRUST    TSFC   ETA PROP

MAX CL  0.60    20000.     0.0    8048.48    499.30   100.00   0.350   2813.40   64.53   1.29
        0.60    20000.     0.0    6295.48   0.447   0.815
MAX CR  0.60    20000.     0.0    6648.16    312.75   100.00   0.353   2366.66   59.07   1.23
        0.60    20000.     0.0    5259.64   0.450   0.835
        0.60    20000.     0.0    5806.06    206.85   100.00   0.359   2085.58   55.19   1.19
        0.60    20000.     0.0    4559.10   0.457   0.848
        0.60    20000.     0.0    4922.25    113.47   100.00   0.369   1814.28   50.98   1.16
        0.60    20000.     0.0    3854.95   0.471   0.860
        0.60    20000.     0.0    4057.89     57.20   100.00   0.384   1558.14   46.59   1.13
        0.60    20000.     0.0    3160.96   0.493   0.871
        0.60    20000.     0.0    3258.09    -23.33   100.00   0.407   1325.83   42.26   1.10
        0.60    20000.     0.0    2494.18   0.532   0.874
        0.60    20000.     0.0    2582.32    -67.89   100.00   0.436   1124.84   38.31   1.08

        0.60    20000.     0.0    2086.43   -100.72   100.00   0.472    947.60   34.61   1.07



MAX CL  0.65    20000.     0.0    8293.76    470.15   100.00   0.346   2868.87   63.79   1.30
        0.65    20000.     0.0    6077.52   0.472   0.826
MAX CR  0.65    20000.     0.0    6901.51    277.38   100.00   0.349   2409.47   58.31   1.23
        0.65    20000.     0.0    5061.01   0.476   0.849
        0.65    20000.     0.0    5969.37    168.81   100.00   0.354   2121.89   54.47   1.20
        0.65    20000.     0.0    4380.26   0.484   0.862
        0.65    20000.     0.0    5074.29     78.55   100.00   0.364   1845.06   50.30   1.16
        0.65    20000.     0.0    3691.66   0.500   0.872
        0.65    20000.     0.0    4193.37      0.51   100.00   0.378   1584.12   45.97   1.13

        0.65    20000.     0.0    3381.89    -58.25   100.00   0.399   1349.55   41.76   1.11

        0.65    20000.     0.0    2695.25   -101.24   100.00   0.426   1146.84   37.94   1.09

        0.65    20000.     0.0    2107.54   -133.06   100.00   0.459    967.43   34.35   1.07
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                        PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
       U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                        99 PERCENT GEAR EFFICIENCY
                        FREE TURBINE RPM=8547.

                 PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                             STANDARD DAY TAM
        MN     ALT      DIAM  PROP SHP    FN RES.    HPX    BSFC      WFT     WAE    PTA
        MN     ALT      DIAM NET THRUST   TSFC   ETA PROP

MAX CL 0.75   20000.    0.0    8833.34    411.66  100.00  0.338   2989.39   62.08   1.33
       0.75   20000.    0.0    5592.19   0.535  0.829
MAX CR 0.75   20000.    0.0    7360.60    207.64  100.00  0.340   2505.39   56.67   1.26
       0.75   20000.    0.0    4599.86   0.545  0.844
       0.75   20000.    0.0    6364.14     95.00  100.00  0.345   2200.88   52.83   1.21
       0.75   20000.    0.0    3932.08   0.560  0.850
       0.75   20000.    0.0    5420.68     -0.14  100.00  0.353   1911.15   48.75   1.18
       0.75   20000.    0.0    3264.28   0.565  0.851
       0.75   20000.    0.0    4498.30    -75.91  100.00  0.365   1640.75   44.59   1.14

       0.75   20000.    0.0    3670.49   -131.81  100.00  0.382   1403.65   40.71   1.12

       0.75   20000.    0.0    2954.56   -171.41  100.00  0.405   1195.89   37.13   1.10

       0.75   20000.    0.0    2340.47   -200.86  100.00  0.433   1012.40   33.77   1.06



MAX CL 0.80   20000.    0.0    9123.87    383.13  100.00  0.335   3053.50   61.11   1.35
       0.80   20000.    0.0    5358.63   0.570  0.822
MAX CR 0.80   20000.    0.0    7607.11    174.70  100.00  0.336   2556.10   55.74   1.27
       0.80   20000.    0.0    4385.90   0.563  0.835
       0.80   20000.    0.0    6602.70     56.81  100.00  0.340   2243.83   51.94   1.22
       0.80   20000.    0.0    3724.02   0.603  0.838
       0.80   20000.    0.0    5611.25    -38.60  100.00  0.347   1947.21   47.92   1.18
       0.80   20000.    0.0    3062.02   0.636  0.833
       0.80   20000.    0.0    4668.78   -115.13  100.00  0.358   1672.55   43.86   1.15
       0.80   20000.    0.0    2610.77   0.641  0.880
       0.80   20000.    0.0    3835.45   -169.16  100.00  0.374   1434.29   40.17   1.12

       0.80   20000.    0.0    3101.55   -208.49  100.00  0.394   1222.98   36.69   1.10

       0.80   20000.    0.0    2473.01   -257.80  100.00  0.419   1036.95   33.44   1.08
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                     PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                     99 PERCENT GEAR EFFICIENCY
                      FREE TURBINE RPM=6547.

              PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                          STANDARD DAY TAM
      MN     ALT     DTAM  PROP SHP   FN RES.   HPX    BSFC      WFT     WAE   PTA
      MN     ALT     DTAM NET THRUST  TSFC  ETA PROP

MAX CL0.85  20000.   0.0    9439.30   352.21  100.00  0.331  3122.17  60.10  1.36
      0.85  20000.   0.0    4851.25  0.644  0.764
MAX CR0.85  20000.   0.0    7873.75   141.08  100.00  0.332  2611.44  54.80  1.28
      0.85  20000.   0.0    3916.93  0.667  0.768
      0.85  20000.   0.0    6833.06    17.82  100.00  0.335  2288.33  50.99  1.24
      0.85  20000.   0.0    3280.16  0.698  0.765
      0.85  20000.   0.0    5817.58   -79.78  100.00  0.341  1985.74  47.06  1.19
      0.85  20000.   0.0    2659.36  0.747  0.754
      0.85  20000.   0.0    4158.87  -156.50  100.00  0.351  1706.58  43.12  1.16
      0.85  20000.   0.0    2139.93  0.797  0.757
      0.85  20000.   0.0    4011.09  -209.81  100.00  0.365  1465.34  39.55  1.13

      0.85  20000.   0.0    3262.51  -247.97  100.00  0.384  1252.17  36.23  1.11

      0.85  20000.   0.0    2614.48  -275.51  100.00  0.406  1062.20  33.06  1.09
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                          PRATT AND WHITNEY AIRCRAFT
            REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
         U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                           FREE TURBINE RPM=8547.

                   PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                               STANDARD DAY TAM
        MN      ALT      DTAM  PROP SHP   FN RES.    HPX    BSFC      WFT     WAE    PTA
        MN      ALT      DTAM NET THRUST  TSFC   ETA PROP

MAX CL 0.35    25000.     0.0    5928.02    571.80  100.00  0.369  2186.04   67.51  1.25
       0.35    25000.     0.0    6450.61   0.339   0.641
MAX CR 0.35    25000.     0.0    5298.25    478.25  100.00  0.367  1943.46   65.25  1.22
       0.35    25000.     0.0    5910.54   0.329   0.663
       0.35    25000.     0.0    4660.32    389.99  100.00  0.372  1733.85   61.63  1.19
       0.35    25000.     0.0    5374.29   0.323   0.691
       0.35    25000.     0.0    3993.79    364.55  100.00  0.381  1523.12   57.42  1.16
       0.35    25000.     0.0    4790.58   0.318   0.726
       0.35    25000.     0.0    3336.08    227.42  100.00  0.396  1321.82   52.92  1.13
       0.35    25000.     0.0    4167.29   0.317   0.763
       0.35    25000.     0.0    2678.64    160.31  100.00  0.420  1126.06   47.99  1.11
       0.35    25000.     0.0    3459.67   0.325   0.796
       0.35    25000.     0.0    2079.69    101.57  100.00  0.455   946.74   42.99  1.08

       0.35    25000.     0.0    1579.49     56.81  100.00  0.501   791.51   38.39  1.07



MAX CL 0.50    25000.     0.0    6488.52    517.79  100.00  0.358  2323.86   67.16  1.29
       0.50    25000.     0.0    5749.46   0.401   0.752
MAX CR 0.50    25000.     0.0    5699.18    396.63  100.00  0.357  2034.62   63.94  1.24
       0.50    25000.     0.0    5194.27   0.392   0.777
       0.50    25000.     0.0    4986.58    300.97  100.00  0.362  1804.37   60.06  1.21
       0.50    25000.     0.0    4602.48   0.392   0.797
       0.50    25000.     0.0    4282.11    217.26  100.00  0.370  1584.22   55.96  1.17
       0.50    25000.     0.0    3949.50   0.396   0.816
       0.50    25000.     0.0    3580.32    141.38  100.00  0.383  1371.46   51.48  1.14
       0.50    25000.     0.0    3366.50   0.405   0.838
       0.50    25000.     0.0    2890.87     76.94  100.00  0.404  1168.82   46.73  1.11
       0.50    25000.     0.0    2751.83   0.425   0.855
       0.50    25000.     0.0    2263.67     26.07  100.00  0.435   984.56   41.98  1.09

       0.50    25000.     0.0    1746.31    -12.52  100.00  0.473   826.66   37.70  1.07
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                         PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
       U.S. STANDARD ATMOSPHERE, 1962         100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                           FREE TURBINE RPM=6547.

                    PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                               STANDARD DAY TAM
        MN      ALT      DIAM   PROP SHP    FN RES.     HPX    BSFC       WFT     WAE    PTA
        MN      ALT      DIAM NET THRUST   TSFC  ETA PROP

MAX CL  0.60   25000.    0.0    6970.73    490.10   100.00  0.350   2441.11   66.71   1.32
        0.60   25000.    0.0    5552.32   0.440  0.805
MAX CR  0.60   25000.    0.0    6019.52    344.82   100.00  0.350   2106.12   62.60   1.26
        0.60   25000.    0.0    4816.18   0.437  0.823
        0.60   25000.    0.0    5266.54    245.13   100.00  0.354   1864.87   58.74   1.22
        0.60   25000.    0.0    4224.39   0.441  0.837
        0.60   25000.    0.0    4531.67    158.97   100.00  0.361   1635.25   54.69   1.19
        0.60   25000.    0.0    3630.68   0.450  0.849
        0.60   25000.    0.0    3791.68     82.93   100.00  0.373   1413.28   50.26   1.15
        0.60   25000.    0.0    3035.32   0.466  0.863
        0.60   25000.    0.0    3073.99     20.69   100.00  0.392   1204.45   45.63   1.12
        0.60   25000.    0.0    2439.89   0.494  0.872
        0.60   25000.    0.0    2430.09    -27.15   100.00  0.419   1017.89   41.16   1.10

        0.60   25000.    0.0    1898.50    -63.74   100.00  0.452    857.37   37.14   1.08



MAX CL  0.65   25000.    0.0    7229.83    477.58   100.00  0.346   2503.73   66.32   1.34
        0.65   25000.    0.0    5406.53   0.463  0.819
MAX CR  0.65   25000.    0.0    6197.66    320.11   100.00  0.346   2145.46   61.82   1.27
        0.65   25000.    0.0    4647.92   0.462  0.838
        0.65   25000.    0.0    5427.68    217.95   100.00  0.350   1898.68   57.99   1.23
        0.65   25000.    0.0    4068.50   0.467  0.852
        0.65   25000.    0.0    4672.54    129.55   100.00  0.356   1664.04   53.97   1.19
        0.65   25000.    0.0    3491.23   0.477  0.864
        0.65   25000.    0.0    3912.01     52.94   100.00  0.367   1436.71   49.56   1.16

        0.65   25000.    0.0    3160.03     -8.67   100.00  0.385   1224.63   45.03   1.13

        0.65   25000.    0.0    2528.03    -54.97   100.00  0.410   1037.05   40.72   1.10

        0.65   25000.    0.0    1982.66    -87.22   100.00  0.441    874.52   36.80   1.08
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                         PRATT AND WHITNEY AIRCRAFT
           REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                           FREE TURBINE RPM=6547.

                   PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                              STANDARD DAY TAM
       MN      ALT     DTAM   PROP SHP    FN RES.    HPX    BSFC       WFT     WAE    PTA
       MN      ALT     DTAM NET THRUST  TSFC  ETA PROP

MAX CL 0.75   25000.    0.0   7789.58    448.98  100.00  0.338  2636.56  65.20   1.38
       0.75   25000.    0.0   5060.77   0.521  0.820)
MAX CR 0.75   25000.    0.0   6597.67    268.58  100.00  0.338  2231.93  60.07   1.30
       0.75   25000.    0.0   4250.33   0.525  0.836
       0.75   25000.    0.0   5766.91    161.69  100.00  0.341  1972.68  56.32   1.25
       0.75   25000.    0.0   3687.88   0.535  0.844
       0.75   25000.    0.0   4984.54     69.11  100.00  0.346  1725.83  52.35   1.21
       0.75   25000.    0.0   3121.78   0.555  0.848
       0.75   25000.    0.0   4187.92     -9.28  100.00  0.356  1489.73  48.10   1.17
       0.75   25000.    0.0   2552.92   0.584  0.846
       0.75   25000.    0.0   3420.73    -69.58  100.00  0.371  1269.87  43.72   1.14

       0.75   25000.    0.0   2751.18   -111.59  100.00  0.392  1079.52  39.73   1.11

       0.75   25000.    0.0   2185.35   -143.64  100.00  0.418   913.47  36.08   1.09



MAX CL 0.80   25000.    0.0   8075.81    435.22  100.00  0.335  2704.30  64.43   1.40
       0.80   25000.    0.0   4683.19   0.554  0.814
MAX CR 0.80   25000.    0.0   6620.09    242.47  100.00  0.334  2279.13  59.12   1.32
       0.80   25000.    0.0   4070.16   0.560  0.829
       0.80   25000.    0.0   5987.75    134.11  100.00  0.336  2014.34  55.43   1.27
       0.80   25000.    0.0   3521.54   0.572  0.836
       0.80   25000.    0.0   5159.04     37.69  100.00  0.341  1760.10  51.48   1.22
       0.80   25000.    0.0   2955.93   0.595  0.836
       0.80   25000.    0.0   4338.36    -40.69  100.00  0.350  1517.90  47.28   1.18
       0.80   25000.    0.0   2386.45   0.636  0.827
       0.80   25000.    0.0   3558.94   -101.21  100.00  0.364  1295.37  43.04   1.15

       0.80   25000.    0.0   2883.09   -143.85  100.00  0.383  1103.78  39.23   1.12

       0.80   25000.    0.0   2300.68   -173.72  100.00  0.406   935.02  35.69   1.10
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                         PRATT AND WHITNEY AIRCRAFT
           REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962         100 PERCENT RAM RECOVERY
                        99 PERCENT GEAR EFFICIENCY
                         FREE TURBINE RPM=8547.

                  PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                              STANDARD DAY TAM
        MN      ALT      DTAM  PROP SHP    FN RES.    HPX    ESFC      WFT     WAE    PTA
        MN      ALT      DTAM NET THRUST   TSFC  ETA PROP

MAX CL  0.85   25000.    0.0    8359.41    417.58  100.00  0.331  2769.31  63.46   1.42
        0.85   25000.    0.0    4469.56   0.620  0.761
MAX CR  0.85   25000.    0.0    7054.07    216.17  100.00  0.330  2329.70  58.14   1.35
        0.85   25000.    0.0    3678.71   0.633  0.770
        0.85   25000.    0.0    6202.04    106.44  100.00  0.332  2058.53  54.52   1.28
        0.85   25000.    0.0    3151.64   0.653  0.771
        0.85   25000.    0.0    5339.64      7.53  100.00  0.336  1795.44  50.55   1.23
        0.85   25000.    0.0    2610.65   0.688  0.765
        0.85   25000.    0.0    4500.35    -72.91  100.00  0.344  1548.09  46.44   1.19
        0.85   25000.    0.0    2090.71   0.740  0.755
        0.85   25000.    0.0    3711.12   -133.45  100.00  0.357  1323.45  42.37   1.15

        0.85   25000.    0.0    3024.51   -177.03  100.00  0.373  1129.06  38.68   1.12

        0.85   25000.    0.0    2424.70   -204.22  100.00  0.395   957.92  35.27   1.10
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                            PRATT AND WHITNEY AIRCRAFT
              REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
          U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                            99 PERCENT GEAR EFFICIENCY
                             FREE TURBINE RPM=8547.

                      PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                                 STANDARD DAY TAM
        MN      ALT     DTAM  PROP SHP    FN RES.     HPX    BSFC      WFT     WAE    PTA
        MN      ALT     DTAM NET THRUST   TSFC   ETA PROP

MAX CL 0.60   30000.    0.0    5851.77    449.22  100.00  0.354  2068.95   67.66   1.34
       0.60   30000.    0.0    4749.73   0.436   0.797
MAX CR 0.60   30000.    0.0    5298.46    359.87  100.00  0.349  1848.15   65.75   1.30
       0.60   30000.    0.0    4319.00   0.428   0.811
       0.60   30000.    0.0    4743.23    277.02  100.00  0.350  1661.28   62.58   1.26
       0.60   30000.    0.0    3883.42   0.428   0.825
       0.60   30000.    0.0    4124.31    195.21  100.00  0.355  1464.93   58.55   1.22
       0.60   30000.    0.0    3382.22   0.433   0.838
       0.60   30000.    0.0    3514.75    123.56  100.00  0.364  1277.93   54.28   1.18
       0.60   30000.    0.0    2882.59   0.443   0.852
       0.60   30000.    0.0    2900.45     61.80  100.00  0.378  1096.89   49.62   1.15
       0.60   30000.    0.0    2376.85   0.461   0.866
       0.60   30000.    0.0    2314.37     11.42  100.00  0.401   928.69   44.79   1.12

       0.60   30000.    0.0    1804.30    -27.09  100.00  0.432   779.67   40.21   1.09



MAX CL 0.65   30000.    0.0    6082.71    444.86  100.00  0.350  2127.42   67.43   1.37
       0.65   30000.    0.0    4646.66   0.458   0.812
MAX CR 0.65   30000.    0.0    5485.98    346.34  100.00  0.345  1892.48   65.25   1.32
       0.65   30000.    0.0    4201.65   0.456   0.826
       0.65   30000.    0.0    4885.13    257.19  100.00  0.346  1692.80   61.81   1.27
       0.65   30000.    0.0    3747.90   0.452   0.840
       0.65   30000.    0.0    4252.94    172.76  100.00  0.351  1492.06   57.82   1.23
       0.65   30000.    0.0    3259.65   0.458   0.853
       0.65   30000.    0.0    3626.91    101.04  100.00  0.359  1301.29   53.61   1.19
       0.65   30000.    0.0    2771.67   0.470   0.865
       0.65   30000.    0.0    2998.96     36.60  100.00  0.372  1116.21   48.99   1.15

       0.65   30000.    0.0    2396.95    -12.25  100.00  0.394   944.42   44.21   1.12

       0.65   30000.    0.0    1880.73    -48.85  100.00  0.423   794.67   39.81   1.10
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PRATT AND WHITNEY AIRCRAFT
REMATCHED STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
U.S. STANDARD ATMOSPHERE, 1962 100 PERCENT RAM RECOVERY
99 PERCENT GEAR EFFICIENCY
FREE TURBINE RPM=8547.

PART POWER PERFORMANCE FROM MAXIMUM CLIMB
STANDARD DAY TAM

	MN	ALT	DTAM	PROP SHP	FN RES.	HPX	BSFC	WFT	WAE	PTA
	MN	ALT	DTAM	NET THRUST	TSFC	ETA PROP				
MAX CL	0.75	30000.	0.0	6635.50	445.21	100.00	0.342	2266.66	67.05	1.42
	0.75	30000.	0.0	4423.72	0.512	0.813				
MAX CR	0.75	30000.	0.0	5877.44	315.64	100.00	0.337	1982.37	63.80	1.35
	0.75	30000.	0.0	3897.34	0.509	0.827				
	0.75	30000.	0.0	5206.26	216.77	100.00	0.339	1762.43	60.10	1.30
	0.75	30000.	0.0	3429.17	0.514	0.837				
	0.75	30000.	0.0	4537.78	130.45	100.00	0.342	1552.15	56.21	1.25
	0.75	30000.	0.0	2952.99	0.526	0.844				
	0.75	30000.	0.0	3875.17	52.18	100.00	0.348	1350.33	52.01	1.21
	0.75	30000.	0.0	2469.00	0.547	0.846				
	0.75	30000.	0.0	3213.51	-11.78	100.00	0.360	1157.57	47.53	1.17
	0.75	30000.	0.0	2585.62	-59.85	100.00	0.379	980.16	42.96	1.13
	0.75	30000.	0.0	2055.80	-94.81	100.00	0.403	828.66	38.91	1.11
MAX CL	0.80	30000.	0.0	6939.29	446.83	100.00	0.338	2342.67	66.75	1.45
	0.80	30000.	0.0	4318.87	0.542	0.807				
MAX CR	0.80	30000.	0.0	6076.82	299.52	100.00	0.334	2027.16	62.86	1.37
	0.80	30000.	0.0	3749.26	0.541	0.821				
	0.80	30000.	0.0	5380.08	197.89	100.00	0.335	1799.89	59.16	1.32
	0.80	30000.	0.0	3287.25	0.548	0.831				
	0.80	30000.	0.0	4696.22	107.69	100.00	0.337	1584.33	55.31	1.27
	0.80	30000.	0.0	2816.95	0.562	0.835				
	0.80	30000.	0.0	4011.76	27.68	100.00	0.343	1377.11	51.15	1.22
	0.80	30000.	0.0	2331.14	0.591	0.831				
	0.80	30000.	0.0	3332.37	-37.11	100.00	0.354	1179.77	46.73	1.18
	0.80	30000.	0.0	2694.89	-84.22	100.00	0.371	1000.90	42.34	1.14
	0.80	30000.	0.0	2155.33	-119.16	100.00	0.393	847.32	38.42	1.11

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

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                         PRATT AND WHITNEY AIRCRAFT
            REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
        U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                          FREE TURBINE RPM=8547.

                  PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                              STANDARD DAY TAM
       MN     ALT     DTAM  PROP SHP     FN RES.    HPX    BSFC      WFT     WAE    PTA
       MN     ALT     DTAM NET THRUST   TSFC  ETA PROP

MAX CL 0.85  30000.    0.0   7245.40    448.49  100.00   0.334  2418.91   66.27   1.49
       0.85  30000.    0.0   4016.06   0.602  0.757
MAX CR 0.85  30000.    0.0   6291.76    282.77  100.00   0.330  2075.30   61.89   1.39
       0.85  30000.    0.0   3429.80   0.605  0.765
       0.85  30000.    0.0   5570.71    177.36  100.00   0.330  1840.41   58.19   1.33
       0.85  30000.    0.0   2979.97   0.618  0.773
       0.85  30000.    0.0   4864.45     84.76  100.00   0.333  1618.31   54.37   1.28
       0.85  30000.    0.0   2530.57   0.640  0.773
       0.85  30000.    0.0   4156.13      2.46  100.00   0.338  1404.91   50.23   1.23
       0.85  30000.    0.0   2077.79   0.676  0.768
       0.85  30000.    0.0   3458.51    -61.90  100.00   0.348  1203.53   45.90   1.18
       0.85  30000.    0.0   1667.79   0.722  0.769
       0.85  30000.    0.0   2816.88   -110.66  100.00   0.363  1023.34   41.71   1.15

       0.85  30000.    0.0   2260.65   -143.14  100.00   0.383   866.73   37.84   1.12
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                         PRATT AND WHITNEY AIRCRAFT
           REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
      U.S. STANDARD ATMOSPHERE, 1962          100 PERCENT RAM RECOVERY
                         99 PERCENT GEAR EFFICIENCY
                         FREE TURBINE RPM=6547.

                  PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                               STANDARD DAY TAM
         MN     ALT     DTAM  PROP SHP    FN RES.    HPX    BSFC      WFT     WAE    PTA
         MN     ALT     DTAM NET THRUST  TSFC  ETA PROP

MAX CL  0.60   35000.   0.0    4613.0     364.3    100.0   0.353   1630.6   67.71   1.35
        0.60   35000.   0.0    3828.1    0.426   0.796
MAX CR  0.60   35000.   0.0    4386.02    326.91  100.00   0.351  1540.12   66.89   1.33
        0.60   35000.   0.0    3652.07   0.422  0.804
        0.60   35000.   0.0    4059.19    275.87  100.00   0.350  1419.34   65.24   1.30
        0.60   35000.   0.0    3394.89   0.418  0.815
        0.60   35000.   0.0    3590.94    207.89  100.00   0.353  1265.96   61.71   1.25
        0.60   35000.   0.0    3014.91   0.420  0.830
        0.60   35000.   0.0    3083.98    141.22  100.00   0.359  1108.25   57.39   1.21
        0.60   35000.   0.0    2590.89   0.428  0.843
        0.60   35000.   0.0    2583.97     84.47  100.00   0.371   958.58   52.86   1.17
        0.60   35000.   0.0    2175.14   0.441  0.859
        0.60   35000.   0.0    2084.83     35.85  100.00   0.391   814.67   47.89   1.14

        0.60   35000.   0.0    1622.54     -2.53  100.00   0.421   682.32   42.84   1.11



MAX CL  0.65   35000.   0.0    4853.52    369.50  100.00   0.350  1699.68   67.69   1.37
        0.65   35000.   0.0    3794.50   0.448  0.811
MAX CR  0.65   35000.   0.0    4573.05    322.54  100.00   0.347  1585.68   66.72   1.35
        0.65   35000.   0.0    3582.16   0.443  0.819
        0.65   35000.   0.0    4201.95    264.45  100.00   0.346  1452.59   64.71   1.31
        0.65   35000.   0.0    3298.83   0.440  0.830
        0.65   35000.   0.0    3701.79    191.19  100.00   0.348  1289.99   60.96   1.27
        0.65   35000.   0.0    2907.99   0.444  0.844
        0.65   35000.   0.0    3183.30    123.31  100.00   0.355  1129.23   56.70   1.22
        0.65   35000.   0.0    2496.62   0.452  0.857
        0.65   35000.   0.0    2669.58     65.53  100.00   0.366   975.87   52.19   1.18

        0.65   35000.   0.0    2156.59     17.20  100.00   0.384   826.57   47.25   1.14

        0.65   35000.   0.0    1685.14    -20.14  100.00   0.412   694.70   42.34   1.11
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                      PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
    U.S. STANDARD ATMOSPHERE, 1962         100 PERCENT RAM RECOVERY
                      99 PERCENT GEAR EFFICIENCY
                      FREE TURBINE RPM=6547.

                 PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                              STANDARD DAY TAM
        MN      ALT      DTAM  PROP SHP    FN RES.    HPX     BSFC       WFT     WAE    PTA
        MN      ALT      DTAM NET THRUST   TSFC  ETA PROP

MAX CL  0.75   35000.     0.0     5442.48    399.27  100.00   0.345   1877.62   67.75   1.45
        0.75   35000.     0.0     3718.93   0.505  0.809
MAX CR  0.75   35000.     0.0     4968.83    313.51  100.00   0.338   1681.75   66.03   1.40
        0.75   35000.     0.0     3383.88   0.497  0.820
        0.75   35000.     0.0     4495.23    239.04  100.00   0.338   1518.96   63.17   1.35
        0.75   35000.     0.0     3050.32   0.498  0.830
        0.75   35000.     0.0     3947.41    158.91  100.00   0.340   1343.09   59.27   1.29
        0.75   35000.     0.0     2653.22   0.506  0.836
        0.75   35000.     0.0     3402.14     88.37  100.00   0.345   1174.48   55.11   1.24
        0.75   35000.     0.0     2248.77   0.522  0.842
        0.75   35000.     0.0     2857.22     27.32  100.00   0.354   1012.82   50.65   1.20
        0.75   35000.     0.0     1863.31   0.544  0.852
        0.75   35000.     0.0     2319.16    -20.38  100.00   0.371    860.43   45.91   1.16

        0.75   35000.     0.0     1830.72    -57.27  100.00   0.395    722.85   41.27   1.12



MAX CL  0.80   35000.     0.0     5686.35    406.29  100.00   0.341   1941.39   67.47   1.48
        0.80   35000.     0.0     3640.91   0.533  0.805
MAX CR  0.80   35000.     0.0     5172.54    310.09  100.00   0.335   1731.27   65.47   1.42
        0.80   35000.     0.0     3290.05   0.526  0.815
        0.80   35000.     0.0     4652.50    225.64  100.00   0.334   1554.28   62.27   1.36
        0.80   35000.     0.0     2936.40   0.529  0.824
        0.80   35000.     0.0     4082.25    144.66  100.00   0.336   1372.43   58.37   1.31
        0.80   35000.     0.0     2541.83   0.540  0.831
        0.80   35000.     0.0     3525.23     70.45  100.00   0.340   1199.87   54.27   1.25
        0.80   35000.     0.0     2136.85   0.562  0.829
        0.80   35000.     0.0     2959.59      8.35  100.00   0.349   1032.80   49.81   1.21
        0.80   35000.     0.0     1718.10   0.601  0.817
        0.80   35000.     0.0     2410.62    -41.15  100.00   0.364    877.43   45.17   1.16

        0.80   35000.     0.0     1914.90    -76.70  100.00   0.386    738.88   40.71   1.13
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                         PRATT AND WHITNEY AIRCRAFT
          REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
       U.S. STANDARD ATMOSPHERE, 1962         100 PERCENT RAM RECOVERY
                          99 PERCENT GEAR EFFICIENCY
                           FREE TURBINE RPM=6547.

                 PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                              STANDARD DAY TAM
     MN     ALT      DTAM  PROP SHP    FN RES.     HPX    BSFC      WFT     WAE    PTA
     MN     ALT      DTAM NET THRUST  TSFC  ETA PROP

MAXCL 0.85  35000.    0.0    5956.08    413.88  100.00  0.338  2010.92  67.18  1.52
     0.85   35000.    0.0    3411.38  0.589  0.757
MAXCR 0.85  35000.    0.0    5380.35    304.60  100.00  0.331  1780.50  64.74  1.45
     0.85   35000.    0.0    3048.83  0.584  0.767
     0.85   35000.    0.0    4815.86    212.20  100.00  0.330  1590.45  61.27  1.38
     0.85   35000.    0.0    2690.33  0.591  0.774
     0.85   35000.    0.0    4229.89    127.32  100.00  0.332  1403.05  57.40  1.32
     0.85   35000.    0.0    2309.36  0.608  0.776
     0.85   35000.    0.0    3654.66     51.84  100.00  0.335  1226.13  53.37  1.27
     0.85   35000.    0.0    1934.77  0.634  0.775
     0.85   35000.    0.0    3071.12    -12.31  100.00  0.343  1054.16  48.94  1.22
     0.85   35000.    0.0    1563.68  0.674  0.772
     0.85   35000.    0.0    2508.48    -61.88  100.00  0.357   895.64  44.40  1.17

     0.85   35000.    0.0    2007.10    -96.68  100.00  0.377   755.98  40.15  1.14
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                     PRATT AND WHITNEY AIRCRAFT
      REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
    U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                     99 PERCENT GEAR EFFICIENCY
                      FREE TURBINE RPM=8547.

                PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                          STANDARD DAY TAM
        MN     ALT     DTAM  PROP SHP    FN RES.    HPX    BSFC       WFT     WAE    PTA
        MN     ALT     DTAM NET THRUST   TSFC   ETA PROP

MAX CL 0.60   40000.    0.0    3679.49    300.12  100.00  0.358   1317.45   67.72   1.36
       0.60   40000.    0.0    3068.96   0.429   0.795
MAX CR 0.60   40000.    0.0    3431.60    258.09  100.00  0.354   1215.58   66.56   1.33
       0.60   40000.    0.0    2874.08   0.423   0.805
       0.60   40000.    0.0    3176.53    219.45  100.00  0.353   1121.72   65.00   1.30
       0.60   40000.    0.0    2675.21   0.419   0.816
       0.60   40000.    0.0    2810.62    165.33  100.00  0.356   1001.24   61.53   1.25
       0.60   40000.    0.0    2374.38   0.422   0.830
       0.60   40000.    0.0    2408.49    112.53  100.00  0.364    876.17   57.18   1.21
       0.60   40000.    0.0    2036.73   0.430   0.844
       0.60   40000.    0.0    2009.31     67.26  100.00  0.377    756.80   52.57   1.17
       0.60   40000.    0.0    1703.24   0.444   0.860
       0.60   40000.    0.0    1608.41     28.24  100.00  0.399    641.15   47.46   1.14

       0.60   40000.    0.0    1235.95     -2.06  100.00  0.433    534.61   42.25   1.11



MAX CL 0.65   40000.    0.0    3865.77    305.36  100.00  0.355   1371.74   67.70   1.38
       0.65   40000.    0.0    3041.11   0.451   0.810
MAX CR 0.65   40000.    0.0    3575.49    256.69  100.00  0.350   1251.68   66.42   1.35
       0.65   40000.    0.0    2820.53   0.444   0.820
       0.65   40000.    0.0    3291.40    210.37  100.00  0.349   1148.40   64.49   1.31
       0.65   40000.    0.0    2600.05   0.442   0.831
       0.65   40000.    0.0    2898.52    152.81  100.00  0.352   1020.50   60.75   1.27
       0.65   40000.    0.0    2291.32   0.445   0.844
       0.65   40000.    0.0    2486.77     98.87  100.00  0.359    892.74   56.49   1.22
       0.65   40000.    0.0    1962.89   0.455   0.858
       0.65   40000.    0.0    2076.37     52.76  100.00  0.371    770.35   51.90   1.18

       0.65   40000.    0.0    1666.31     13.86  100.00  0.392    652.63   46.87   1.14

       0.65   40000.    0.0    1266.88    -15.66  100.00  0.423    544.88   41.80   1.11
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                    PRATT AND WHITNEY AIRCRAFT
        REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
     U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                      99 PERCENT GEAR EFFICIENCY
                       FREE TURBINE RPM=8547.

                PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                          STANDARD DAY TAM
        MN      ALT     DTAM  PROP SHP   FN RES.    HPX    BSFC      WFT      WAE    PTA
        MN      ALT     DTAM NET THRUST  TSFC   ETA PROP

MAX CL 0.75   40000.    0.0   4263.48    317.87  100.00  0.348  1483.51   67.49   1.45
       0.75   40000.    0.0   2932.98   0.506  0.810
MAX CR 0.75   40000.    0.0   3894.61    250.48  100.00  0.341  1329.62   65.83   1.40
       0.75   40000.    0.0   2670.01   0.498  0.820
       0.75   40000.    0.0   3528.07    192.41  100.00  0.341  1202.93   63.07   1.35
       0.75   40000.    0.0   2416.20   0.499  0.830
       0.75   40000.    0.0   3093.45    128.37  100.00  0.344  1062.95   59.13   1.29
       0.75   40000.    0.0   2092.30   0.508  0.838
       0.75   40000.    0.0   2661.52     71.39  100.00  0.349   929.29   54.95   1.24
       0.75   40000.    0.0   1768.50   0.525  0.842
       0.75   40000.    0.0   2226.45     23.05  100.00  0.359   800.17   50.41   1.20
       0.75   40000.    0.0   1487.33   0.538  0.868
       0.75   40000.    0.0   1796.42    -15.78  100.00  0.377   678.04   45.56   1.16

       0.75   40000.    0.0   1404.76    -44.58  100.00  0.404   568.13   40.82   1.12



MAX CL 0.80   40000.    0.0   4460.54    322.50  100.00  0.344  1534.50   67.23   1.48
       0.80   40000.    0.0   2874.51   0.534  0.806
MAX CR 0.80   40000.    0.0   4060.09    248.00  100.00  0.337  1369.88   65.32   1.42
       0.80   40000.    0.0   2599.65   0.527  0.816
       0.80   40000.    0.0   3653.43    181.98  100.00  0.337  1231.03   62.17   1.37
       0.80   40000.    0.0   2521.36   0.530  0.824
       0.80   40000.    0.0   3202.11    116.13  100.00  0.339  1086.31   58.23   1.31
       0.80   40000.    0.0   2004.30   0.542  0.830
       0.80   40000.    0.0   2757.78     57.94  100.00  0.344   949.16   54.10   1.25
       0.80   40000.    0.0   1679.38   0.565  0.828
       0.80   40000.    0.0   2309.53      7.84  100.00  0.354   816.52   49.60   1.21
       0.80   40000.    0.0   1343.49   0.608  0.814
       0.80   40000.    0.0   1668.94    -31.18  100.00  0.370   691.96   44.85   1.16

       0.80   40000.    0.0   1472.22    -59.27  100.00  0.395   581.16   40.31   1.12
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                    PRATT AND WHITNEY AIRCRAFT
         REMATCHED  STS476 TURBOSHAFT ENGINE ESTIMATED PERFORMANCE
       U.S. STANDARD ATMOSPHERE, 1962        100 PERCENT RAM RECOVERY
                    99 PERCENT GEAR EFFICIENCY
                    FREE TURBINE RPM=6547.

               PART POWER PERFORMANCE FROM MAXIMUM CLIMB
                         STANDARD DAY TAM
       MN      ALT     DTAM  PROP SHP    FN RES.    HPX    BSFC       WFT     WAE    PTA
       MN      ALT     DTAM NET THRUST  TSFC  ETA PROP

MAX CL 0.85  40000.    0.0    4668.51   329.96  100.00  0.340  1589.02  66.93  1.52
       0.85  40000.    0.0    2695.20  0.590  0.756
MAX CR 0.85  40000.    0.0    4228.40   245.26  100.00  0.334  1410.52  64.66  1.45
       0.85  40000.    0.0    2414.97  0.584  0.766
       0.85  40000.    0.0    3784.92   171.64  100.00  0.333  1260.34  61.21  1.39
       0.85  40000.    0.0    2130.42  0.592  0.774
       0.85  40000.    0.0    3316.52   104.66  100.00  0.335  1111.00  57.29  1.33
       0.85  40000.    0.0    1825.67  0.609  0.776
       0.85  40000.    0.0    2860.45    43.73  100.00  0.339   970.14  53.20  1.27
       0.85  40000.    0.0    1526.44  0.656  0.775
       0.85  40000.    0.0    2396.07    -7.45  100.00  0.348   833.25  48.72  1.22
       0.85  40000.    0.0    1230.59  0.677  0.773
       0.85  40000.    0.0    1946.92   -47.20  100.00  0.363   706.67  44.11  1.17

       0.85  40000.    0.0    1545.92   -74.83  100.00  0.385   595.07  39.77  1.14
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APPENDIX B

Appendix B includes the final data package and associated reference material transmitted to Lockheed by the Hamilton Standard Division of United Technologies Corporation in compliance with the terms of their subcontract. These data cover the work performed in support of Lockheed's Turboprop/Turbofan, Short/Medium Range Configuration Analysis which is reported in Section 7 of this document.

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

Please address answer to:
Mail Stop No. 1a-3-6

February 20, 1976

Lockheed California Company
P. O. Box 551
Burbank, California 91503

Attention: Mr. John Hopkins, Department 7521, Building 63-3

Subject: Prop-Fan Transport Study

Reference: LCC (Hopkins) letter to HS (Gatzen) dated 11-20-75

Dear John,

In accordance with Enclosure 2 of the reference letter, HS and PWA have each prepared a data package for the subject study. The enclosed HS data are as follows:

1. System Description - SK 91423 and Enclosure 1
2. Propulsion System Weights - Enclosure 2
3. Propulsion System Costs - Enclosure 3 & 4
4. Acoustic Estimates - Enclosure 5
5. Impact of Advanced Technology - Enclosure 6
6. Scale Factors: Enclosures 2, 3, 4, 5, & 6

If questions arise concerning these data, please feel free to contact me.

Very truly yours,
HAMILTON STANDARD
Division of United Technologies Corporation

B. S. Gatzen

BSG/eh

Enclosures: SK 91423 and Nos. 1 thru 6

cc: Messrs. D. Gray (PWA)
S. Stahr (Eastern)
L. Williams (NASA-Ames)

NOTE: On May 1, 1975, the name of United Aircraft Corporation was changed to United Technologies Corporation.

TELEPHONE (203) 623-1621 ——— TELEX 9-9288 ——— TWX 710-420-0584

Enclosure 1

Prop-Fan Technical Data*

Diameter	12.8 feet
Tip Speed - Fan	800 feet per second
No. Blades	8
AF	200 per blade
Int. Coefficient of Lift	0.12
Max Climb Design Point	34.1 SHP/D^2 @ 0.8 Mn, 36000 feet, +18°F
Maximum Power	10880 HP @ 250 KTS, S.L., +18°F
Engine RPM	8547
Gear Ratio	7.158

* For other technical data, see drawing SK 91423

Enclosure 2

Propulsion System Weights

Prop-Fan Rotor	1145.9 Pounds	
Prop-Fan Gearbox	622.6 "	
Prop-Fan Engine	2180.0 "	(Per PWA)
	3948.5 Pounds uninstalled	
*Nacelle	1184.5 "	
	5133.0 Pounds installed	

Scaling: All scaling is accomplished as constant cruise SHP/D^2. This scaling also assumes an engine horsepower lapse rate equal to that of the baseline so that if cruise horsepower changes, the maximum horsepower also changes. For ±10% cruise thrust, the rotor weight change is ±143.6 pounds and the gearbox weight change is ±95.6 pounds. The nacelle weight change is a function of the total uninstalled weight change. For scaling over a small diameter range, maintain an installed to uninstalled weight ratio of 1.3.

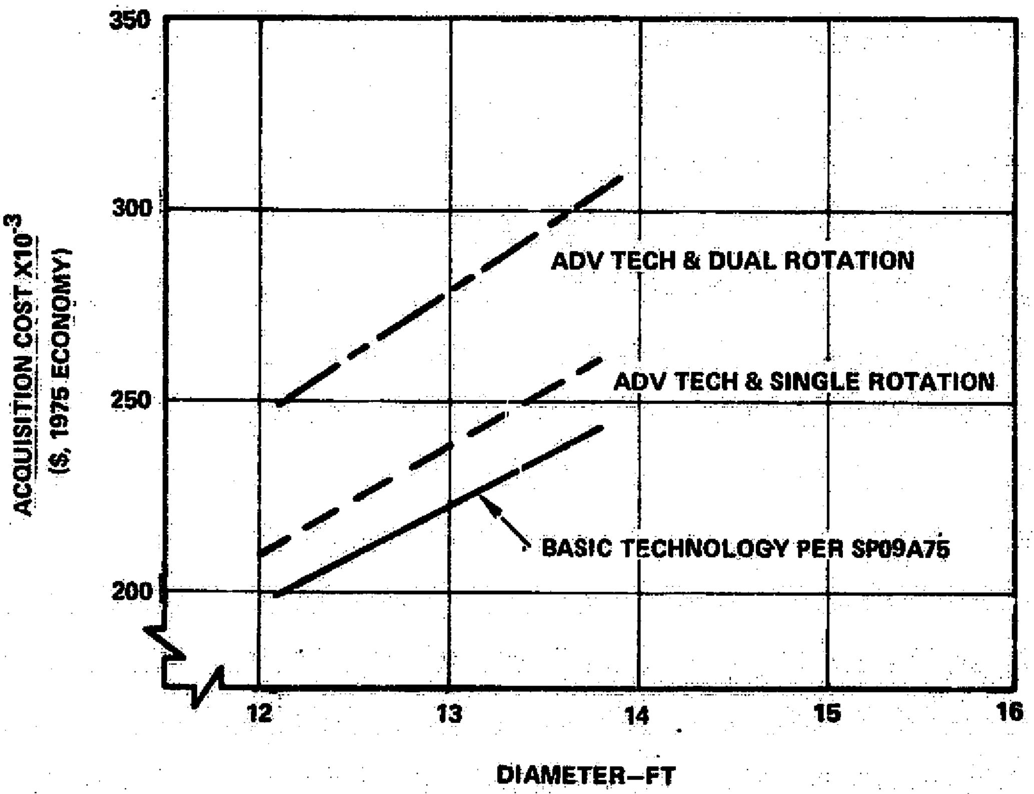
* The items included in the nacelle are those required for a fully installed Prop-Fan package and are those listed in SP09A75, dated 10-6-75.

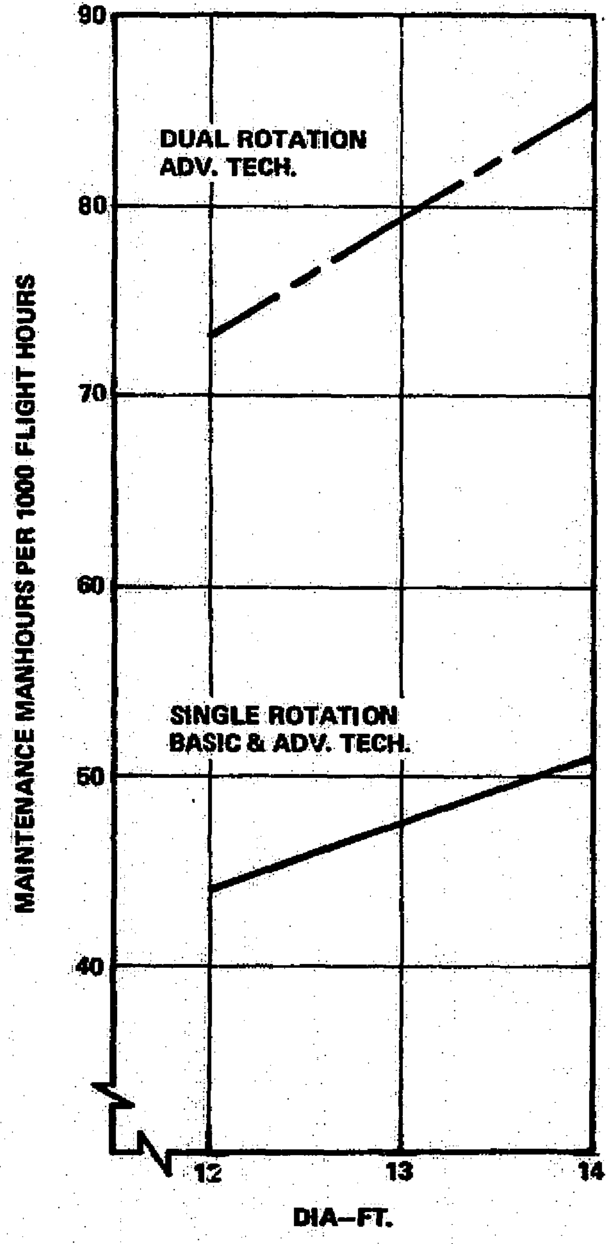
ENCLOSURE 3
PROP-FAN ACQUISITION COSTS

8 BLADES
800 FPS
0.8 MACH NO.
SHP/D^2 = 34.1 @ 36,000 FT.

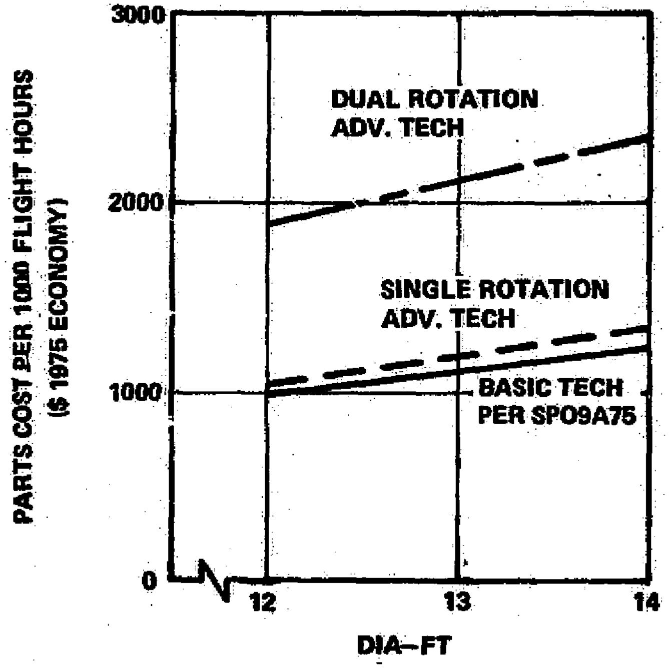
INCLUDES ROTOR, GEARBOX, AND RELATED EQUIPMENT
1610 UNITS OVER TEN YEARS
350 AIRCRAFT AND 15% SPARES

12.8′ BLADE DIA.





ENCLOSURE 4
PROP-FAN MAINTENANCE COSTS
8 BLADES, 800 FPS
0.8 MN, SHP/D^2 = 34.1 @ 36,000 FT
ROTOR, GEARBOX, AND RELATED EQUIPMENT
1610 UNITS OVER TEN YEARS



Enclosure 5

Acoustic Estimates

The near and far field noise predicted for the Prop Fan is as follows:

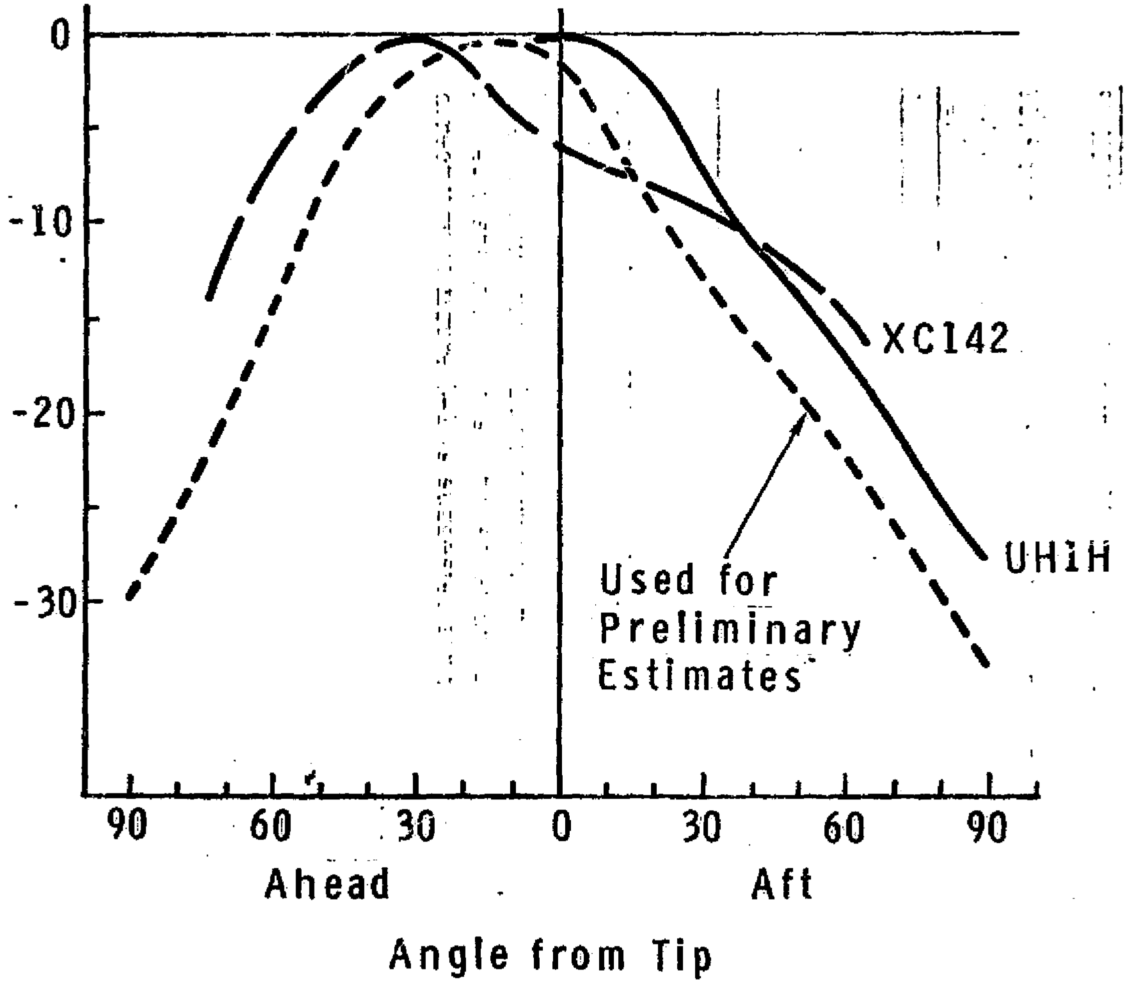
Far Field Noise - 12.8 ft diameter, 800 ft/sec tip speed, 10,000 shaft horsepower per engine, 175 knots forward speed, four engines, takeoff condition
90 EPNdB under the takeoff path with 2000 ft altitude
85 EPNdB under the takeoff path with 3000 ft altitude
89 EPNdB at a .35 Nautical Mile Sideline Location

12.8 ft diameter, 2000 shaft horsepower per engine, 135 knots forward speed, four engines, approach condition at 370 ft altitude
94.5 EPNdB at 800 ft/sec tip speed
86 EPNdB at 600 ft/sec tip speed

Near Field Noise - 0.8 Mach Number cruise at 36,000 ft altitude, 800 ft/sec tip speed
0.8 Diameter tip clearance, 5,000 shaft horsepower per engine, four engines
137dB overall is the estimated level

Based on experience with the XC142 VTOL aircraft propeller the near field level is expected to consist of a series of tones at blade passage frequency and its harmonics. For study purposes the above overall level may be assumed to be composed of 12 harmonics of equal amplitude. Each harmonic would then be 126dB. Based on XC142 tests at 1000 ft/sec tip speed and Bell UH1H flight test data the directivity of figure 5-1 is suggested for the Prop Fan.

PRELIMINARY PROP FAN DIRECTIVITY



Enclosure 6

Advanced Technologies

1. Advanced level of technology weights:

Rotor	-10.8%
Gearbox	- 6%

These are reductions from the data supplied on Enclosure 2. Although advanced technology reductions have not been estimated for all of the nacelle components, a 47% reduction in weight is anticipated for the gearbox heat exchanger, oil tankage, and oil.

2. Advanced level of technology performance:

Dual rotation Prop-Fans improve the net efficiency in cruise by five (5) efficiency points. Sized at the same SHP/D^2 for max climb/cruise at 36,000 feet and 0.8 Mn, the dual rotation Prop-Fan diameter is 12.47 feet instead of the basic 12.8 feet. The weights for the advanced 12.47 foot dual rotation Prop-Fan are 1035 pounds for the rotor and 641 pounds for the gearbox. For scaling at the same diameter, the advanced technology dual rotation Prop-Fan weight is arrived at by applying the following factors to the single rotation, basic technology (per Enclosure 2):

Rotor	- 5.45%
Gearbox	+15.6%
Heat Exchanger, Oil Tankage, and Oil	-37.5%

.8 Mn PROP-FAN DESCRIPTION

Configuration

The Prop-Fan nacelle arrangement shown in SK 91423 is one of several potential concepts for installation on a 0.8 Mach aircraft. These concepts include over-the-wing and under-the-wing engines, inline gearbox and engine, offset gearbox and engine, and several Prop-Fan locations with respect to the wing.

The drawing depicts an under-the-wing engine with an offset gearbox. This was selected for further study based on several features: The under-the-wing location of the engine allows easier access to the engine and engine accessories for normal inspection and maintenance. In addition, an offset gearbox arrangement is shown rather than an inline since it allows an inlet which provides a higher pressure ratio at the engine compressor face and it allows easy access for the pitch control input.

The nacelle downtilt angle and the distance between the rotor plane and wing quarter chord are shown so as to minimize 1P excitation factor due to the wing wash and steady aeroelastic effects while maintaining whirl flutter stability. The nacelle and spinner shapes were selected to provide more nearly optimized installed prop-fan performance. With the nacelle frontal area dictated by aerodynamic requirements, wide latitude is available in gearbox and engine installation arrangement.

Point Design

The weights given below describe a Prop-Fan consisting of an eight bladed rotor assembly and a gearbox assembly and the lubrication/cooling system. The rotor assembly consists of the Prop-Fan blades, spinner, disk, and pitch control system. The weights were calculated on the basis of $SHP/D^2 = 66.4$ and TS = 800 ft/sec.

Weight For Equal Thrust Prop-Fans
@ .8Mn, 36,000 feet

	"Basic" Wt. For Basic Perf.	"Advanced" Wt. For Basic Perf.	"Advanced" Wt. For Adv. Perf.
12.8' dia.rotor (basic)	1145.9	1022.1	--
12.47' dia. rotor (adv. counterrotating)	--	--	1035
Gearbox wt.	622.6	585.2	641
Oil, tankage, and heat exchanger	75	40	45
Total	1843.5	1647.3	1721

The "basic" weights represent a level of technology which is expected to be available for commercial service in the mid 1980's based on currently expected R&D funding. An "advanced" level of technology would offer further improvements in weight and performance which could be available in the same time period if additional R&D funding is applied. Column two shows the estimated weight of the basic configuration utilizing advanced material and manufacturing technology. Additionally, the advanced level of technology could also allow development of a counterrotating configuration which results in an aerodynamic efficiency increase. The improved performance allows the Prop-Fan diameter to be reduced from 12.8 to 12.47 feet at constant SHP/D^2, tip speed, and installed thrust at 0.8 Mach number and 36,000 feet altitude. The weight of this configuration utilizing advanced technology for both aerodynamic and mechanical improvements is shown in column three.

Blades and Spinner

The "basic" blades consist of a hollow high strength steel structural member or spar, an external carbon epoxy hybrid shell shaped to the correct airfoil contour, aluminum honeycomb fill between shell and spar, and a titanium leading edge erosion sheath. The spinner is a fiberglass composite structure. Advanced technology would lead to development of a hollow titanium spar with an attendant weight reduction.

Disk

The "basic" disk assembly consists of the disk, blade retention balls and integral races, clamps and pitch change trunnions. The steel disk is integral with the fan tailshaft which transfers Prop-Fan loads to the gearcase and mounts. Studies between titanium disks and steel disks with integral retention have shown little differences in weight based on present day fracture mechanic allowables. With advance in the state-of-the-art of fracture mechanics titanium weight saving in the disk and tailshaft is envisioned.

Pitch Change System

The"basic"weights are based on a mechanical pitch change actuator utilizing a harmonic drive, although other concepts including hydraulic pistons and vane motors would be considered before arriving at a final concept. Theharmonic drive concept is presently being developed for the QCSEE program and has the advantages of high reliability, light weight, reasonable production cost and good maintainability. The system features an in-place blade angle lock and a redundant remote blade angle control. Advanced development of the harmonic drive and improved manufacturing technique would show weight saving.

Reduction Gearing

The reduction gearing is sized for infinite life based on maximum engine torque with maximum allowable stresses consistent with today's state-of-the-art gearboxes. The weight is based on the use of a titanium welded housing, vacuum melt AMS 6265 steel for gears and Vimvar double vacuum melt M50 for bearings. The gearing system module has a calculated MTBF of approximately 40,000 hours. For advanced technology, improvements in gear and bearing geometry and materials are envisioned.

Cooling and Lubrication

Gearbox cooling is accomplished by use of a separate heat exchanger. An overall gearbox efficiency of 99% is obtained by the use of proper oil management, baffling and scavenging techniques. A centrifugal air oil separator is used to minimize oil tankage weight. Advanced technology weight saving would be based on the development of high temperature (450°F) gearboxes and lubricants.

Accessories

Weight for accessory drives such as aircraft hydraulics and electrical power were not included in the gearbox weight. It is felt that powering the accessory drives from the Prop-Fan gearbox would increase these gearbox weights but would maximize overall engine cycle efficiency and would simplify the engine accessory gearbox and may simplify accessory cooling.

Installation

While not contractually a responsibility of HS, a study was made to evaluate overall nacelle installed weight. For purposes of this study the gearbox and engine are considered to be rigidly coupled to maintain a minimum misalignment angle for the engine output shaft. Another possible advantage for rigid coupling of engine and gearbox is the use of helical gears to balance engine turbine and propeller thrust loads. One way of achieving rigid coupling is to utilize the engine inlet in the structural loop. To minimize engine case deflection, it is assumed the entire gearbox/engine structure is mounted to the wing by the primary isolation mounts at the gearbox and only a steady rest at the aft end of the engine. The nacelle buildup weight includes all the structure and fairings that couple the Prop-Fan and engine to the wing, engine inlet, engine shaft, exhaust, fire control systems, gearbox cooling system, starting and fuel system, aircraft hydraulics, electrical power, and pneumatic systems and finally the Prop-Fan control and engine linkage.

The total uninstalled weight was obtained by adding the Prop-Fan/gearbox weight to the engine weight (including the engine accessory gearbox). A ratio of total installed weight to uninstalled weight of 1.3 has been established for a Prop-Fan based on the above study.

APPENDIX C

Appendix C includes a summary of the remarks made by Mr. R. Scott Stahr of Eastern Air Lines at the Final Oral Reviews for this study. Mr. Stahr spoke at Lockheed's request as a part of Eastern's subcontract in support of Lockheed's Turboprop/Turbofan, Short/Medium Range Configuration Analysis as reported in Section 7 of this document.

Summary of the remarks made by R. S. Stahr (on behalf of Eastern Airlines) at the occasion of the Final Oral Report on the RECAT Study Contract at NASA Headquarters on April 22, 1976, Washington, D.C.

ELECTRA EXPERIENCE

Eastern was pleased to participate in this study as a part-time consultant to Lockheed. Although it is true that Lockheed selected us because of our experience with the Electra, we did not elect to do an extensive research job into Electra propulsion system operating cost for one basic reason. We were afraid that if we did produce a report with cost data, no matter how much we put into the report in the way of qualifications, people might misconstrue the data as implying that an advanced turboprop would have similar problems. We don't think it will.

There are at least two fundamental aspects of the design of the Allison 501D13 engine which have presented an operating cost handicap. The first is the fixed shaft. That is, the propeller is driven by a turbine on the same shaft as the compressor. As a consequence, the propeller, along with the engine, must idle at a relatively high speed and even though in flat pitch, when on the ground at the ramp, a great deal of disturbance is made of the air near the ground. This results in sand and grit ingestion by the compressor and the erosion of blades and seals. This was a significant problem throughout our operating experience with the Electra but does not need to be a factor in an advanced turboprop design such as the ones being discussed here today.

Secondly, there have been advances in reduction gear box design. It has been difficult to maintain alignment of the gears to the degree of precision required for this type equipment, but Allison had developed an improved gear box in the midst of our service experience with the 501D13. If the Electra had not already been relegated to a Shuttle backup function, we probably would have instituted this design change in our fleet.

With those few disclaimers about our Electra experience, I would now like to address the topic at hand.

FUTURE DEMANDS

The text for my "sermon" is taken from Alvin Toffler's recently published book, The Eco-Spasm Report:

- "For if eco-spasm tells us anything, it is that we cannot escape the future by turning our backs on it. Foresight is uniquely human and it is essential for survival." Page 103

- "This means that, as the industrial countries advance into super-industrialism they will have to base their continued affluence on something other than plentiful raw materials: an increased ability to do, as Buckminster Fuller puts it, 'more with less'. Page. 79

  While it does not mean the end of technological advance, it does mean radical conservation policies. It means a high order of imagination. And it means that tax and other incentives ought to be placed on the rapid development of low-energy and resource-conserving products. Instead of awarding indiscriminate tax credits for corporate investment, why not target these specifically for investments in new, ecologically sound, socially valuable technologies?"

WHAT WE DON'T WANT

Eastern is not interested in bringing back the Electra. The last of those aircraft in our fleet are set for retirement in 1977. Eastern is not interested in introducing a new aircraft in the 1980's that flies slower than we currently operate our B-727 and DC9 fleets. (Incidentally, our standard cruise policy on the 727 is Mach .80 and on the DC9-30 fleet, it is Mach .75.) We are not interested in a new aircraft that rides rough. We are not interested in a new aircraft that will have a significant noise or vibration problem as far as passenger perception is concerned.

In summary, we are not interested in marketing "An Ecological Wonder" that has to be sold to the traveling public despite a few compromises in passenger confort.

THE SUBJECT AT HAND

But that's not what I heard these other gentlemen talking about here today. The goal of this advanced turboprop research program, (as I understand it) is to find out if a system can be developed that will meet our current cruise speeds and meet current passenger comfort levels. Then, finally to determine the net fuel saving and operating cost benefits, if any, when the speed and comfort criteria are achieved. It's pretty clear that a lot of testing still lies ahead of us to get the answers to those questions. However, I am here today to advise you that the management of Eastern Airlines is completely open-minded to the possibilities of an advanced turboprop aircraft. In fact, Frank Borman, our President, has passed the word down to his Engineering Department that in every contact with NASA, or other branches of the U. S. Government and industry engaged in research and development, "Press on for improved fuel consumption."

ACTION

Let's talk about action. I'd like to talk about action under five categories. Change - Risk - Excitement - Blunder - Success.

Change: It is quite clear that we will have to change some attitudes. There are a group of people in our own industry who have a "jet set" mind-set. Attitudes are difficult to change, but if the rewards are great enough, it can be done. Perhaps you may recall back in the 1950's there were some folks who thought that the fan engine would never happen.

Risk: To acquire knowledge requires effort. Theories must be confirmed by test. Tests cost money. The acquisition of knowledge requires an investment. Any investment connotes an element of risk. In our opinion, the type of program laid out by NASA for obtaining knowledge about the potential of the advanced turboprop is logical and the risk is well worth taking.

Excitement: Whenever a new concept is being considered, it offers up choices. Choices imply decisions. Decisions sometimes provoke controversy. At the very least, they generate intense competition. The struggle of the advanced turboprop to gain recognition is bound to have its share of this kind of excitement.

Blunder: No one likes to make blunders. We're all familiar with some of the big ones that have been made in our industry. At this point in time, it is our view that one of the biggest blunders we could make would be to ignore the advanced turboprop and set its research program aside.

Success: The formula is not easy. We see the need for a high degree of cooperation by many different elements in our industry. There will have to be cooperation between aircraft, engine, and propeller manufacturers in the area of design criteria. There will have to be cooperation between the manufacturers and the FAA in the development of certification criteria. The latter may be particularly challenging considering the FAA's attention to containment problems presented by the hi-bypass-ratio turbofan engines. Finally, and most important, there will have to be cooperation between the airlines. In my judgment, a strong consensus would have to be developed that the turboprop has a valid place in the aircraft fleets of our future. Anything less than unanimity could present insurmountable problems. All it would take would be one airline who broke ranks and decided to run a vigorous advertising campaign about "those other guys with the eggbeater airplanes" to create an untenable marketing situation. The airlines will need to work especially close regarding the development of promotion, publicity, and advertising programs. I, personally, think that Borman's proposal for an ATA New Aircraft Procurement Office can work. It will go a long way toward developing the means by which this kind of airline consensus can be developed.

SAFETY

We've given some thought to the question of propeller blade failures. Our first reaction was just like anybody who doesn't know too much about it. We were scared to death. But, as we began digging into the facts, I mean real experience with propellers and with fans, we got some surprises.

- First, we found that the safety record of propeller blades on turbine engines (leaving out piston engines altogether) is actually very good. One might almost say, incredibly good.
- The next surprise we got is that the designers of fan blades have 'fessed up to what a sizeable challenge the design of a ducted fan blade is. All the modes of vibration and oscillation, flexurals and torsionals, and combinations thereof. Just when the guy thinks he's got it all together, the FAA says, "Now handle a four-pound bird."

Having pursued that line of questioning, we then went and put the propeller designer through the same third-degree. Another surprise. The propeller designers are pretty relaxed about the bird-strike case.

Two reasons: 1. He's got a fairly big beefy meat cleaver to start with. 2. He's got a Beta control. It's working all the time he's in flight to optimize the angle of incidence, blade relative to the air. Net result: "meat cleaver" always hits the bird at the optimum angle to slice it. Then we pulled the string on the propeller-designer. We said "O.K., how about the reverse case?" That set him back on his heels a bit, at first. However, the record still stands. One manufacturer claims 54 million prop-flying-hours without a single separation of a propeller blade in flight (speaking of just turbine engine prop experience). The one partial blade failure that they had was on the ground during reversing. It was not due to a bird strike; it was a fatigue failure occasioned by a ding on the prop that hadn't been properly maintained (military environment).

The point I'm trying to make is that we do quite a lot of worrying about safety when a new design is presented to us for evaluation. We sometimes get the feeling from a lot of the fancy brochures put out by the manufacturers that they aren't worrying about safety. (But, they really do.) In any case, you can be sure that we'll continue to stir the safety pot with respect to blade retention and bird-strike tolerance for sometime to come.

Lift Augmentation with Power Increase

There's another area that comes under the category of safety. I call it "Lift Augmentation with Power Increase". Going back in history a little bit, I'm sure many of you can remember when all of the airlines' airplanes were powered by propeller-driving engines. In those "Good Ole Days" the pilot making an approach knew that he could always get a little boost in lift by advancing his throttles, to help him recover from a dip below the glideslope. It was also sometimes helpful to correct for errors in flare or sudden loss in airspeed due to windshear near the ground. Since about 1958 when we began to introduce jets, we've had to start telling ourselves a new story: "No boost in lift with throttle advance; gotta rotate the nose." It took a while to get the message across to the throttle-jockeys that had lived all their lives on DC3's, 4's, 6's, 7's, Connies, etc. But they learned. Finally. It hasn't been a problem for our more recent crops of pilots who did most of their early flying on jet aircraft with the military. However, we still have wind shear. One of my tasks at Eastern is to participate in the evaluation of incidents and accidents. One of the conclusions that I've personally come to, after several years of this sort of activity, is that we still have unknowns. We know just about all there is to know about how our airplanes perform in various situations. We know what the engines will do. We even have a pretty good handle on weather phenomena. But we still have some unknowns in the human psychology area, especially when you tangle all this stuff together...airplanes, engines, and weather...with people-pilots. For example, how do you convince a pilot who has just flown through a windshear that has knocked 25 knots off of his approach speed, that he should yank the nose up and start a go-around? How does he know that that 25 knots less in airspeed is all he's going to experience? How do you make sure that he's not so fascinated with that loss in airspeed that he doesn't notice a sharp change in his rate of descent? At the precise moment he needs to?

The point of all those questions is that I don't think it would be a bad thing at all for our industry to acquire some new airplanes that experienced Lift Augmentation with Power Increase. ('Specially for our medium and short haul routes.)

WHERE DO WE GO FROM HERE?

It seems pretty clear to me that if you can develop for us a design option which offers us an 18% net saving in fuel, plus an 8% saving in direct operating cost, plus a noticeable increment in reduced takeoff and sideline noise, with no major penalties in operating reliability, and no degradation of safety, then we have to give that design option a pretty good look-see. And, to my way of thinking, it's an attractive-enough package to justify a very vigorous NASA R&D program. By that, I mean even more vigorous than that spelled out in NASA's Aircraft Fuel Conservation Technology Task Force report last September.

Fleet Simplicity

There's another reason for considering acceleration of the program. If there's anything we've learned clearly over the last ten or twelve years, it's that we can run a better airline and make more profit with a minimum number of aircraft-types and engine-types in operation. Basically, Eastern is now down to two engine-types, the JT8D and the RB.211. When I joined Eastern in 1964, we had six. A tremendous amount of executive talent and energy has gone into the decision-making process to manage our fleet down to the simplicity status we now have achieved. We will give ground from that position very grudgingly. When and if we decide to procure some airplanes built around medium-sized/hi-bypass-ratio engines such as the CFM56 or JT10D, it will be because we have convinced management that that is the small engine of the future, - "the JT8D of the 1980's and '90's." It won't be because management wants to give Engineering another toy to play with around the Christmas tree!

Inadequate Technology Assessment

Now, to get to the point. One of my concerns, and at this point I have to say that this is primarily a personal concern, not a corporate concern, is that we may be waltzing up toward a repetition of an error we made in the late 50's. Think back. There was a lot of uncertainty and indecision in the airline ranks about the "Fan Engine". Except for a few "radical" prophets, nobody gave the fan engine very much chance of happening. When it finally did get provoked into existence, most airlines had already started their jet aircraft fleet equipment program. Quite a few Boeing and Douglas airplanes were ordered with the JT3C and JT4C engines. Those airplanes were put into service starting in late 1958 on through '59 and '60. Then in 1961, the fan engine arrived, and almost overnight all of the straight-jet airplanes became obsolete. Even with the screaming banshee problem we had with the early JT3D engines on approach (before P&W came up with the "hush-kit"), it was obvious to anyone who went out around an airport and listened that the JT3D had made a substantial reduction in the takeoff and sideline noise problem. Even with the reliability problems that plagued the pioneers throughout 1961 and some of the following years, it was also immediately obvious that the fuel consumption benefits (even with 10¢ a gallon fuel!) made the fan-engine economically worthwhile. Then the additional range flexibility opened up a whole new market for the manufacturers.

But, the problem was that many of the airlines had already started to equip with straight-jet-powered airplanes before the fan came along. The less-visionary carriers, like Eastern, were saddled with these noisier and less fuel-efficient aircraft for a long time.

"No Easy Victories"

My point is clear, but the solution to the problem I pose is not. I wish that the advanced turboprop development program could be accelerated to the point where we could choose between it and the hi-bypass-ratio ducted fan before we buy another new airplane type. Frankly, I don't see how anyone can make it go that fast. But I'd sure like NASA to give it a "good college try".

I'd like to close by thanking Lockheed for giving Eastern the opportunity to participate in this interesting program.

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