NASA CR-159488
PWA-5594-48

(NASA-CR-159488) ENERGY EFFICIENT ENGINE: PROPULSION SYSTEM-AIRCRAFT INTEGRATION EVALUATION Topical Report, Mar. 1978 - Sep. 1978 (Pratt and Whitney Aircraft) 311 p HC A14/MF A01 CSCL 21E G3/07

N79-16850

Unclas 14058

ENERGY EFFICIENT ENGINE PROPULSION SYSTEM - AIRCRAFT INTEGRATION EVALUATION

by

R. E. Owens

UNITED TECHNOLOGIES CORPORATION
Pratt & Whitney Aircraft Group
Commercial Products Division

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NASA-Lewis Research Center
Contract NAS3-20646

FOREWORD

This report describes the work performed during 1978 by the Pratt & Whitney Aircraft Group, Commercial Products Division, of United Technologies Corporation, for the National Aeronautics and Space Administration, Lewis Research Center, under Contract NAS3-20646, as part of the Energy Efficient Engine Project. Mr. Neal T. Saunders is the NASA Energy Efficient Engine Project Manager, with Mr. Raymond S. Colladay serving as NASA's Assistant Project Manager responsible for this contract. Mr. Gerald Kraft is the NASA Project Engineer responsible for monitoring the Propulsion System-Aircraft Integration Evaluation (PS-AIE) portion of this contract, the subject of this report.

The manager of the Energy Efficient Engine Project at Pratt & Whitney Aircraft is Mr. W. B. Gardner.

This report was prepared by Mr. R. E. Owens, Pratt & Whitney Aircraft Research Engineer responsible for the PS-AIE, with the assistance of J.C. McCann, S.Tanrikut, D.R. Weisel and J.B. Wright.

Pratt & Whitney Aircraft was assisted in these evaluations by Boeing Commercial Airplane Company, Douglas Aircraft Company, and Lockheed California Company. Airframe company personnel responsible for this work were Mr. Paul Johnson (Boeing), Mr.Ron Kawai (Douglas), and Mr. Robert Tullis (Lockheed). Airframe company reports are included in the appendicies.

TABLE OF CONTENTS

Section	Title	Page
1.0	SUMMARY	1
2.0	INTRODUCTION	8
3.0	EVALUATION PROCEDURE	10
4.0	FLIGHT PROPULSION SYSTEM CHARACTERISTICS	13
	4.1 Configuration Description	13
	4.2 Cycle Selection	15
	4.3 Cycles and Performance	17
	4.4 Engine Weight, Price, and Maintenance Cost	21
5.0	AIRFRAME EVALUATION	29
	5.1 Aircraft and Mission Selection	29
	5.2 Engine Integration Considerations	45
	5.3 Airplane/Engine Peformance Comparison	52
6.0	ECONOMIC EVALUATION	63
	6.1 Economic Model Description	63
	6.2 Economic Evaluation Results	72
7.0	NOISE EVALUATION	81
	7.1 Introduction	81
	7.2 Acoustic Configuration	81
	7.3 Noise Prediction Methodology	84
	7.4 Predicted Noise Levels	86
8.0	EMISSIONS EVALUATION	91
	8.1 Predicted Emission Levels	91
	8.2 Emission Prediction Methodology	91
	8.3 Margins	93
9.0	EVALUATION OF THE FPS GROWTH POTENTIAL	95
	9.1 Thrust Growth Approach	95
	9.2 Performance Effects	95
	9.3 Noise Effects	99
	9.4 Emission Effects	100
10.0	GOAL ACHIEVEMENT PROBABILITY ANALYSIS	101
	10.1 Introduction	101
	10.2 TSFC Probability Assessment	101
	10.3 DOC Probability Assessment	103
	10.4 Noise Probability Assessment	105
	10.5 Emissions Probability Assessment	106

TABLE OF CONTENTS (Cont'd)

Section	Title	Page
11.0	CONCLUSIONS	109
12.0	REFERENCES	110
13.0	SYMBOLS-TERMINOLOGY	112
	APPENDICES	113
	A. Boeing	115
	B. Douglas	197
	C. Lockheed	235
	D. Distribution List	305

[redacted]

LIST OF ILLUSTRATIONS

Figure No.	Title	Page
Figure 1	Energy Efficient Engine Fuel Savings	4
Figure 2	Energy Efficient Engine DOC Improvement	5
Figure 3	Energy Efficient Engine Predicted Noise Levels	6
Figure 4	Propulsion System/Aircraft Integration Evaluation Procedure	10
Figure 5	Energy Efficient Engine Cross Section	14
Figure 6	Installation Sketch of STF505M-7D	15
Figure 7	The JT9D-7A/747-200 Installation Sketch	16
Figure 8	Boeing Advanced Airframe Structures	31
Figure 9	Boeing Airplane	32
Figure 10	Douglas Domestic Airplane	36
Figure 11	Douglas Intercontinental Airplane	37
Figure 12	Lockheed Traffic Forecast	38
Figure 13	Lockheed Total Long-Haul Aircraft Requirements in Year 2000	38
Figure 14	Lockheed Comparison of Refined Supercritical Wing of Study Airplane and of Current Technology Wing of L1011 Airplane	40
Figure 15	Effect of Composite Structure on Empty Weight of Lockheed Aircraft	41
Figure 16	Lockheed Domestic Airplane	42
Figure 17	Lockheed Intercontinental Airplane	43
Figure 18	Wing-Engine Placement Summary	47
Figure 19	Douglas Trijet (Typical) Reverse Flow, Directivity Requirements (Lockheed Trijet Requirements Are Similar)	49

LIST OF ILLUSTRATIONS (Con'd)

Figure No.	Title	Page
Figure 20	Boeing Twinjet Reverse Flow Directivity Requirements	50
Figure 21	STF505M-7D Reverse Thrust Capability (Sea Level Std + 14°C, 10% Leakage)	51
Figure 22	Customer Bleed Schedule, STF505M-7 Data Pack	52
Figure 23	Normal Customer Bleed Requirements	53
Figure 24	Boeing Airplane Weight Breakdown	55
Figure 25	Douglas Airplane Weight Breakdown	56
Figure 26	Lockheed Airplane Weight Breakdown	57
Figure 27	P&WA Aircraft Weight Breakdown	58
Figure 28	Thrust Size Required for Each Energy Efficient Engine Powered Aircraft	60
Figure 29	Fuel Savings Relative to the JT9D-7A Powered Aircraft (Design Mission)	61
Figure 30	Fuel Savings Relative to the JT9D-7A Powered Aircraft (Typical Mission)	61
Figure 31	Comparison of Direct Operating Costs	66
Figure 32	Utilization	66
Figure 33	Crew Cost	67
Figure 34	Relative Fuel Cost	67
Figure 35	Airframe Maintenance Costs	68
Figure 36	Engine Maintenance Costs	68
Figure 37	Depreciation Costs	69
Figure 38	Insurance Costs	70
Figure 39	Indirect Operating Cost Breakdown	71
Figure 40	STF505M-7D Savings in DOC Relative to the JT9D-7A for Typical Missions	73

LIST OF ILLUSTRATIONS (Con'd)

Figure No.	Title	Page
Figure 41	STF505M-7D Savings in DOC Relative to the JT9D-7A for Design Missions	74
Figure 42	DOC Breakdown (Boeing Domestic Twinjet, Typical Mission: 1,850 km)	74
Figure 43	DOC Breakdown (Douglas Domestic Trifjet, Typical Mission: 1,850 km)	75
Figure 44	DOC Breakdown (Douglas Intercontinental Trijet, Typical Mission)	76
Figure 45	DOC Breakdown (Lockheed Domestic Trijet, Typical Mission: 2,600 km)	77
Figure 46	DOC Breakdown (Lockheed Intercontinental Quadjet, Typical Mission: 5,560 km)	77
Figure 47	DOC Breakdown (P&WA Domestic Trijet, Typical Mission: 5,560 km)	78
Figure 48	DOC Breakdown (P&WA Intercontinental Quadjet, Typical Mission: 3,700 km)	78
Figure 49	Acoustic Configuration of STF505M-7D	82
Figure 50	STF505M-7D Nacelle Acoustic Treatment Design Features	83
Figure 51	Component Noise Level Predictions (P&WA Trijet)	87
Figure 52	Predicted Noise Levels at FAR Part 36 (1978) Certification Conditions	88
Figure 53	Thrust Growth Engine Noise	98
Figure 54	Thrust Growth Engine Design	99
Figure 55	TSFC and DOC Probability Assessment Process	101
Figure 56	Probability of Achieving TSFC Goal	102
Figure 57	DOC Probability Buildup (P&WA Domestic Trijet, Typical Mission)	104
Figure 58	Probability of Achieving DOC Goal	105

LIST OF ILLUSTRATIONS (Con'd)

Figure No.	Title	Page
Figure 59	Probability of Achieving Emission Goals	107
Figure 60	Probability of Achieving NO_x and Smoke Emission Goals	108

LIST OF TABLES

Table No.	Title	Page
1	Cycle and Performance Comparison of Energy Efficient Engine and JT9D-7A Engine	2
2	Airplane Definitions	3
3	Estimated Emissions and Smoke Characteristics	7
4a	EEE Performance Summary (STF505M-7D) (SI Units)	18
4b	EEE Performance Summary (STF505M-7D) (English Units)	19
5	Summary Comparison of EEE and JT9D-7A Engine	20
6	Performance Comparison of the EEE and JT9D-7A Fully Installed With Bleed and Power Extraction Standard Day	21
7	Energy Efficient Engine Weight Breakdown	23
8	EEE (STF505M-7D) Price and Maintenance Cost Component Breakdown	25
9	EEE Mean Time Betweend Repair By Module	27
10	Comparison of JT9D-7A and EEE	28
11	Boeing Aircraft Mission and Sizing Criteria	30
12	Douglas Aircraft Mission and Sizing Criteria	34
13	Lockheed Aircraft Mission and Sizing Criteria	39
14	Effects of Advanced Active Control System on Lockheed Aircraft	40
15	Pratt & Whitney Aircraft Mission and Sizing Criteria	45
16	Domestic Airplane Definitions Summary	46
17	Intercontinental Airplane Definitions Summary	46
18	Accessory Location Study Summary	48
19	P&WA Airplane Weight Breakdowns	59

LIST OF TABLES (Con'd)

Table No.	Title	Page
20	Energy Efficient Engine Fuel Burned Advantage Breakdown	62
21	Airline Operating Cost Model Elements	64
22	Economic Model Assumptions	65
23	Indirect Operating Cost Savings of EEE Relative to JT9D Reference Engine	79
24	Percent Return on Investment Advantage of EEE Over JT9D Reference Engine	80
25	90EPNdB Takeoff and Approach Noise Footprint Areas	89
26	Estimated Emissions and Smoke Characteristics	91
27	Landing and Takeoff Cycle	92
28	Summary of Margins	94
29	Thrust Growth Potential Summary Relative to Base Energy Efficient Engine	96
30	Effects of Growth Steps on Exhaust Emissions	100
31	Probability of Achieving Noise Goal	106

1.0 SUMMARY

NASA is sponsoring an Energy Efficient Engine Program that is intended to develop and demonstrate an advanced technology base for a new generation of more fuel-conservative engines for commercial transport use. This report summarizes a portion of the effort conducted under this program. The purposes of the Propulsion System-Aircraft Integration Evaluation (PS-AIE) portion of the Energy Efficient Engine program are to estimate the flight performance and operating economics of future commercial transports utilizing the Energy Efficient Engine and to assess the probability of meeting the NASA goals of at least 12% reduction in thrust specific fuel consumption (TSFC) and at least 5% reduction in direct operating costs (DOC), relative to the JT9D-7A reference engine, while meeting FAR Part 36 (1978) noise requirements and the proposed 1981 EPA exhaust emissions standards.

This report presents the results of the initial PS-AIE, in which Pratt & Whitney Aircraft was assisted by Boeing, Douglas, and Lockheed.

o ENGINE CYCLE AND PERFORMANCE/WEIGHT/COST CHARACTERISTICS

The cycle and performance differences between Energy Efficient Engine (EEE) used in this study and the JT9D-7A reference engine are summarized in Table 1. The JT9D-7A, installed in the Boeing 747-200 short-duct nacelle, was chosen as the reference point because it is the most widely used Pratt & Whitney Aircraft high bypass ratio turbofan.

The cycle changes shown in Table 1 were combined with advanced component technologies to produce a predicted thrust specific fuel consumption advantage of 14.9 percent at maximum cruise thrust, 10,670 meters, Mach 0.8. Performance values shown in the table include installation effects and isolated nacelle drag, but no customer bleed or horsepower extraction. This predicted TSFC advantage clearly surpasses the NASA goal of a 12 percent minimum reduction.

Total flight propulsion system weight of the Energy Efficient Engine is estimated to be 1.7 percent heavier than the JT9D-7A/-200 reference (scaled to equal cruise thrust). Price is predicted to be 0.7 percent higher than the reference, while maintenance cost is expected to be 3.2 percent lower. The predicted increases in weight and price are due primarily to the change from the very short duct -200 nacelle of the reference engine to the long duct, mixed flow, Energy Efficient Engine nacelle.

o AIRPLANE PERFORMANCE AND ECONOMICS

The advanced airplane configurations used by Boeing, Douglas, Lockheed and Pratt & Whitney Aircraft (P&WA) in the evaluation of the Energy

TABLE 1

CYCLE AND PERFORMANCE COMPARISON OF ENERGY EFFICIENT ENGINE AND JT9D-7A ENGINE

SUMMARY

	EEE	JT9D-7A
Takeoff Thrust, N (lbf)	182,880 (41,115)	204,720 (46,025)
Turbine Rotor Inlet Temp, °C (°F)		
Takeoff, +14°C (+25°F) Day	1369 (2495)	1260 (2300)
Max Climb, +10°C (18°F) Day	1321 (2410)	1169 (2135)
Max Cruise, Std. Day	1206 (2205)	1088 (1990)
Overall Pressure Ratio	38.6[a]	25.4[b]
Fan Bypass Ratio	6.51[a]	5.1[b]
Fan Pressure Ratio	1.74[a]	1.58[b]
Exhaust Type	Mixed	Separate
Max Cruise Installed Performance (10,670 m (35,000 ft) Mn = 0.8)		
Thrust, N (lbf)	43,260 (9726)	44,320 (9964)
TSFC, kg/hr/N (lbm/hr/lbf)	0.05874 (0.576)	0.06904 (0.677)
	-14.9%	

Notes: (a) Aerodynamic Design Point, 10,670 m (35,000 ft), MN = 0.8
(b) 10,670 m (35,000 ft) MN = 0.8 Max. Cruise

Efficient Engine are defined in Table 2. These study airplanes were chosen by each company as representative of the missions, technologies, and sizes likely to be required for early 1990's introduction into service.

Each of the airplane manufacturers and Pratt & Whitney Aircraft evaluated both the Energy Efficient Engine and the JT9D-7A reference* engine performance on design and typical missions. Figure 1 summarizes the fuel burned advantage shown by Energy Efficient Engine over the JT9D-7A in each airplane. The individual bars cover fuel burned for both design and typical missions. These results correlate well with

*Douglas used the JT9D-20 engine for reference. This engine is the same basic engine as the -7A, except adapted to the DC10-40 airplane.

TABLE 2

AIRPLANE DEFINITIONS

For Domestic Missions

	BOEING	DOUGLAS	LOCKHEED	P&WA
Type	Twinjet	Trijet	Trijet	Trijet
In Service Date	1990's	1990's	1990's	1990's
Design Range - km (n.mi.)	3700 (2000)	5560 (3000)	5560 (3000)	5560 (3000)
Passengers	196	458	500	440
Cruise Speed - Mach No.	0.8	0.8	0.8	0.8

For Intercontinental Missions

	DOUGLAS	LOCKHEED	P&WA
Type	Trijet	Quadjet	Quadjet
In Service Date	1990's	1990's	1990's
Design Range - km (n.mi.)	10190 (5500)	12040 (6500)	10190 (5500)
Passengers	438	500	510
Cruise Speed - Mach No.	0.8	0.8	0.8

design fuel fraction, which is the total design fuel load (mission + reserves) divided by design takeoff gross weight (TOGW). Average fuel saving for the Energy Efficient Engine over JT9D-7A is 16.6 percent on typical missions and 17.3 percent on design missions.

Airline operating economics were evaluated by Pratt & Whitney Aircraft, using the NASA approved economic model for all engine/airplane combinations. This model used 1977 dollars and assumed fuel prices of 10.6¢/liter (40¢/gal) domestic and 11.9¢/liter (45¢/gal) international. Direct operating cost reductions for the Energy Efficient Engine relative to JT9D-9A are shown in Figure 2. Since the primary advantage of the Energy Efficient Engine is reduced fuel consumption, the trends in DOC are quite similar to the fuel

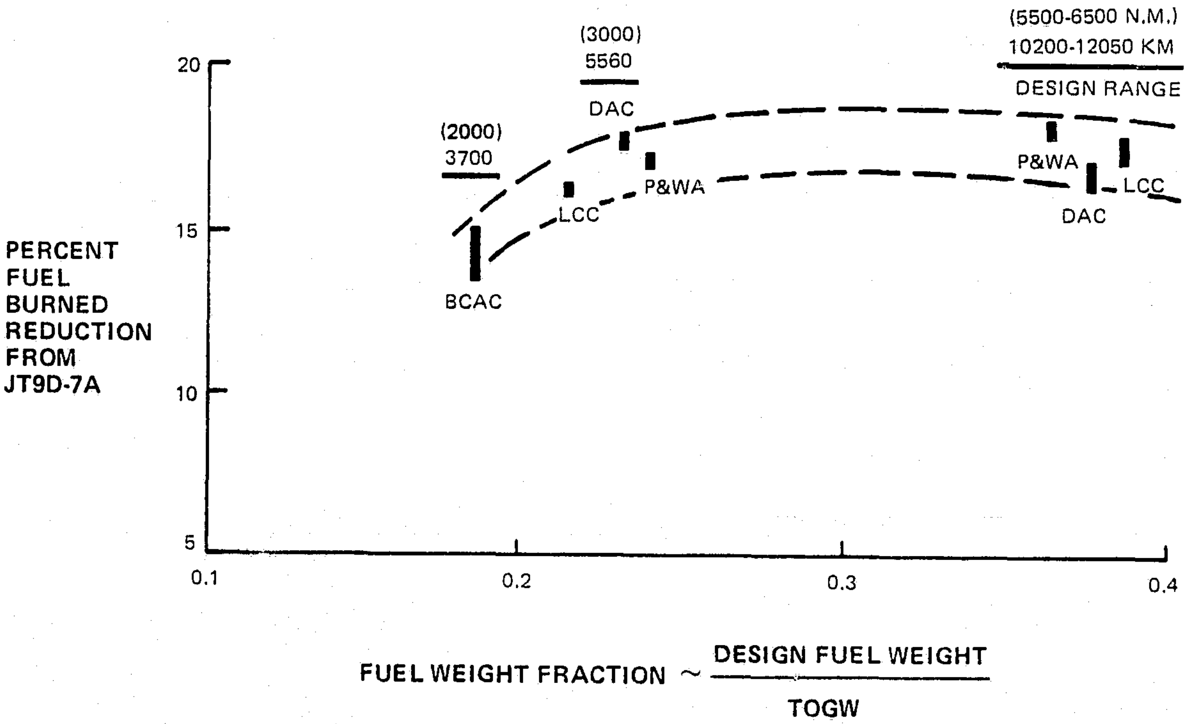


Figure 1 Energy Efficient Engine Fuel Savings -- The average fuel savings for all airplanes and missions considered is 17.0 percent.

burned trends. All airplanes show a DOC advantage greater than the NASA goal of five percent (minimum) on design missions, and all but the Boeing twinjet surpass five percent on typical missions. Average DOC reduction was 9.7 percent on design missions and 7.6 percent on typical missions.

o NOISE

Boeing, Douglas, and Lockheed supplied Pratt & Whitney Aircraft with FAR Part 36 noise flight conditions and airframe noise estimates for their Energy Efficient Engine powered study airplanes. Pratt & Whitney Aircraft defined an acoustic configuration and evaluated total airplane noise for each of these study airplanes and for the two Pratt & Whitney study airplanes. The results shown in Figure 3 indicate that the Energy Efficient Engine is predicted to meet FAR Part 36 (1978) noise limits in all study airplanes except the Boeing twinjet. In the relatively small Boeing twinjet it is currently predicted to slightly exceed the FAR Part 36 limit at takeoff, while meeting the approach and sideline limits.

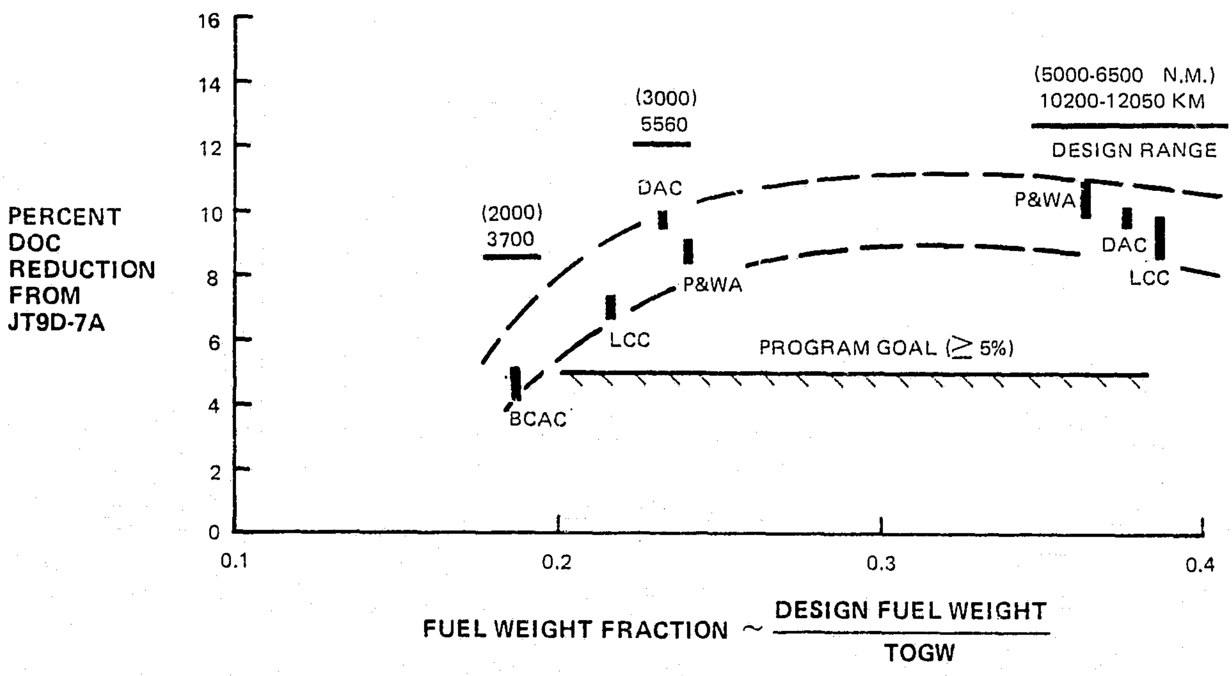


Figure 2 Energy Efficient Engine DOC Improvement -- The average DOC improvement for all airplanes and missions considered is 8.5 percent, well above the NASA goal of 5 percent improvement.

o EMISSIONS

The gaseous emissions estimates for the Energy Efficient Engine, shown in the Table 3, include allowances for engine-to-engine variations as well as deterioration and development margins. A comparison with the NASA goal of meeting the proposed 1981 EPA exhaust emissions standards shows that total unburned hydrocarbons (THC) and carbon monoxide (CO) emissions are well below goal limits, the smoke number meets the goal limit, and the oxides of nitrogen (NOx) emissions do not meet the goal limit.

o GROWTH POTENTIAL

The Energy Efficient Engine was designed to have the potential for thrust growth. To evaluate this potential, two specific growth steps were defined. One was a 15% thrust increase accomplished by increasing

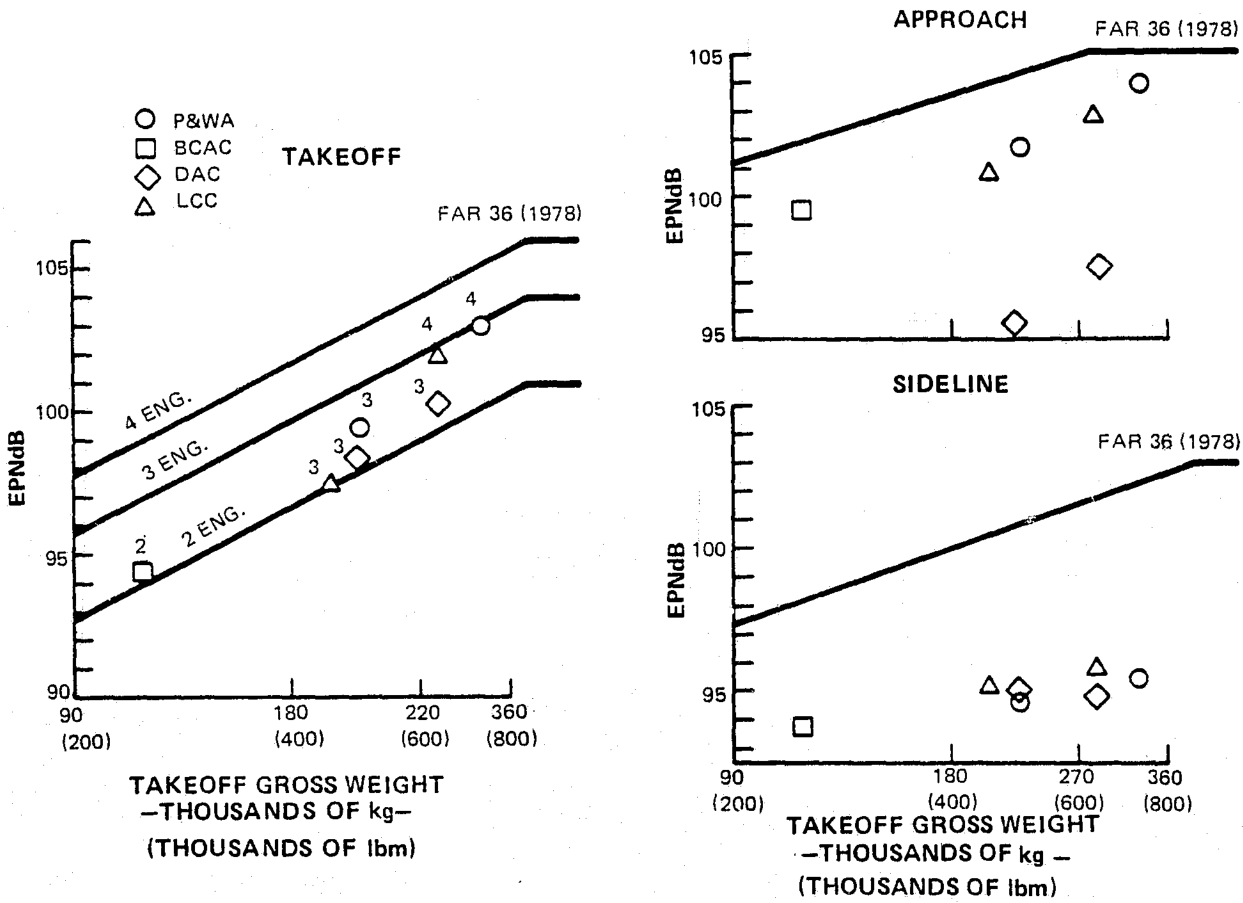


Figure 3 Energy Efficient Engine Predicted Noise Levels -- All study airplanes achieved the NASA goal of meeting FAR Part 36 (1978) noise certification requirements.

overall and fan pressure ratio and rotor inlet temperature, while preserving existing external nacelle lines. The second step provided a 25% thrust increase by increasing overall pressure ratio, rotor inlet temperature and total airflow, requiring a larger nacelle. Evaluation of these thrust growth strategies showed that growth can be achieved with small impact on the performance and environmental goals of the engine.

The larger growth step produces a 1.1% improvement in cruise TSFC over the base Energy Efficient Engine, while increasing fan and jet noise less than 1 dB each. CO and THC exhaust emissions are decreased by 0.2 and .05 EPAP, respectively, while NO_x emissions are increased by 1.0 EPAP.

TABLE 3

ESTIMATED EMISSIONS AND SMOKE CHARACTERISTICS

	EEE	GOAL (1981 EPA)
CO	2.0	3.0 EPAP*
THC	0.2	0.4 EPAP*
NO_x	4.3	3.0 EPAP*
Smoke No.	20 (Max)	20

*Environmental Protection Agency Parameter, lbm pollutant/1000 lbf thrust/hr/cycle

2.0 INTRODUCTION

The National Aeronautics and Space Administration has the responsibility for advancing technology to improve the energy efficiency of future commercial transport aircraft. One element of the plan for meeting this responsibility is the Energy Efficient Engine Program. The objective of this program is to develop and demonstrate advanced turbofan engine component technologies for achieving the NASA goals of at least a twelve percent reduction in thrust specific fuel consumption (TSFC) and at least a five percent reduction in direct operating cost,(DOC) compared with current commercial commercial engines while meeting FAR Part 36 (1978) noise requirements and proposed 1981 EPA exhaust emission standards. Pratt & Whitney Aircraft is a major participant in the Energy Efficient Engine Program through NASA Contract NAS3-20646, which covers a six-year duration (1978-83) and is intended to develop an initial engine design and advance the technology level for an engine that could be introduced into commercial service in the early 1990's.

This report presents the results of the initial Propulsion System-Aircraft Evaluation (PS-AIE) portion of the Energy Efficient Engine program. The purposes of this evaluation, which took place during the Energy Efficient Engine preliminary design task (Reference 1) in 1978, were to provide flight and economic performance estimates of future commercial transports using the current design of the Energy Efficient Engine propulsion systems and to assess the probabilities of meeting the NASA established goals for TSFC, DOC, noise, and emissions. Three airframe manufacturers--Boeing Commercial Airplane Company (BCAC), Douglas Aircraft Company (DAC), and Lockheed California Company (LCC)--assisted in the evaluation through subcontracted efforts. The PS-AIE will be updated periodically during the program as the results of the component development and testing become available.

Specific items evaluated in the initial PS-AIE and covered in this report include:

- Flight propulsion system (FPS) performance predictions (TSFC)
- FPS weight, price, maintenance cost estimates
- Definition of possible 1990's airplanes
- FPS/airplane integration effects and airplane fuel burned estimates*

*With the Energy Efficient Engine and the JT9D-7A as a reference.

- Predicted airline operating economics (DOC and ROI)
- Total engine and airplane noise predictions
- Exhaust emissions predictions
- Growth potential of FPS and effects on performance
- Probability of program goals achievement

3.0 EVALUATION PROCEDURE

The procedure followed in the initial PS-AIE is shown in Figure 4.

At the start of the evaluation Pratt & Whitney Aircraft and each of the three airframe manufacturers individually defined aircraft that would be suitable for introduction into commercial service in the early 1990's, reflecting their projections of the market conditions and technology levels that will prevail at that time. The definitions included design and typical mission range, number of passengers, design Mach number, configuration, and types and levels of advanced technologies.

Concurrently, Pratt & Whitney Aircraft in consultation with NASA defined an airline economic model for use in the evaluation. This model included methods for calculating direct and indirect operating costs (IOC), revenues, and return on investment. Fuel prices, labor rates, year-dollars, and airplane pricing formulas were specified in the model. The airplane definitions and economic model were approved by NASA.

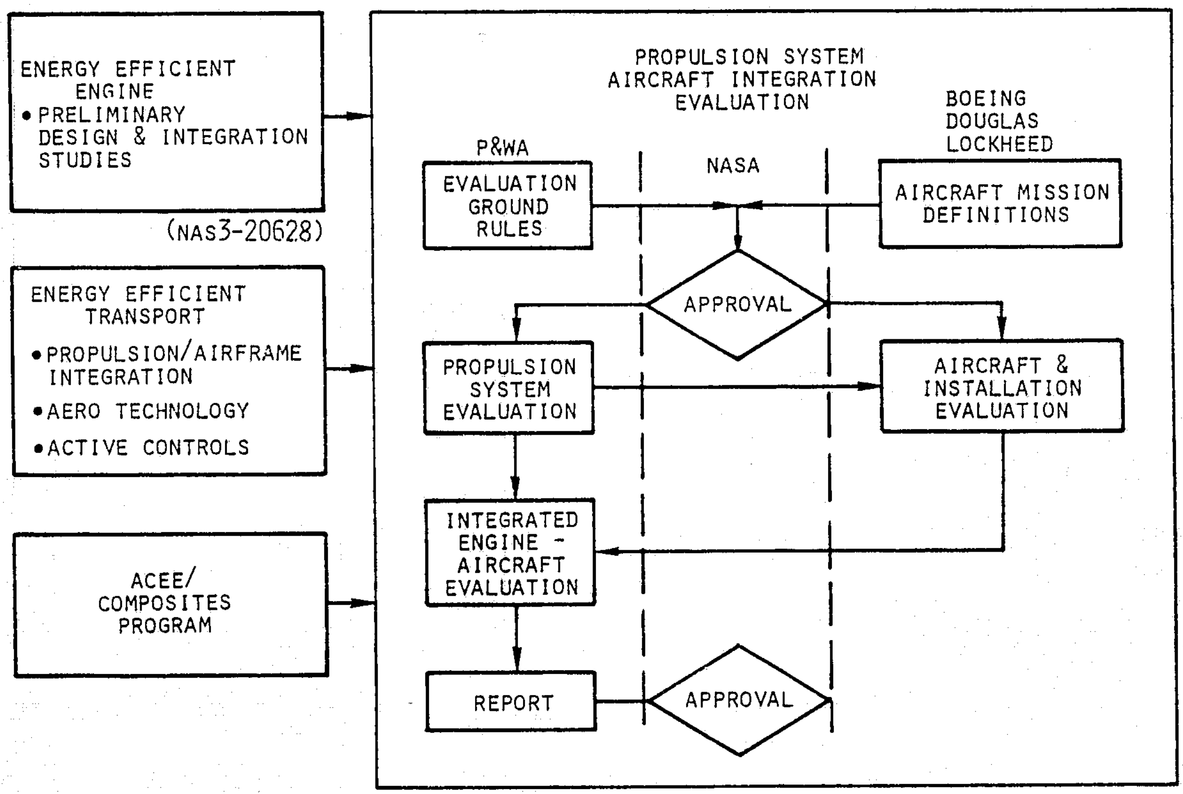


Figure 4 Propulsion System/Aircraft Integration Evaluation Procedure -- This procedure provided reliable estimates of the flight and economic performance of representative 1990's commercial aircraft employing the Energy Efficient Engine as their flight propulsion system.

Pratt & Whitney Aircraft, using computer simulations, produced installed engine performances that covered the flight envelope for both the Energy Efficient Engine and the reference JT9D-7A engine. The thrust and fuel flow simulations included the effects of isolated nacelle drag, customer bleed, and horsepower extraction. Other propulsion system characteristics--engine and nacelle weights, dimensions, and costs--were calculated in a consistent manner for both engines.

Since the PS-AIE and the engine preliminary design task were performed simultaneously, engine characteristics were changing up to the end of the PS-AIE. Because of the time required by the airframe manufacturers to size their airplanes and to perform mission analyses, as well as the time required to prepare a comprehensive engine performance data package, the engine performance and characteristics Pratt & Whitney Aircraft provided to the airframers had to be of an early version of the engine.

Data for this early version--the STF505M-7C presented in the May 1978 data pack--and for the JT9D-7A engine were used by the airframe manufacturers to size and evaluate the performance of their advanced airplanes and furnish Pratt & Whitney Aircraft with airplane data: weights and dimensions, aerodynamics, fuel burned on design and typical missions, engine size, and flight conditions and airframe noise at FAR 36 noise measuring points. Design and typical mission sensitivities to TSFC, propulsion system weight, and nacelle drag were also provided.

In addition, the airframe manufacturers assisted in the preliminary design of the nacelle and in establishing installation requirements for the propulsion system.

Pratt & Whitney Aircraft combined flight propulsion system costs with the airframe evaluations to determine airline operating costs--DOC, IOC, ROI--for all study airplanes for both the Energy Efficient Engine and the JT9D-7A. The NASA approved economic models were used for these evaluations.

Pratt & Whitney Aircraft also calculated exhaust emissions and noise for the Energy Efficient Engine and combined these with the aircraft-alone noise supplied by the airframe manufacturer to determine the total airplane noise for all study airplanes.

Using the data from the performance and environmental evaluations, the overall probabilities of the flight propulsion system meeting NASA program goals were assessed for TSFC, DOC, noise, and emissions.

The flight propulsion system described in this report represents the status at the end of the initial engine preliminary design efforts -- engine model STF505M-7D. Since the earlier STF505M-7C version was used in the evaluations by the airframers, it was necessary to adjust the airplane performance results to reflect the difference in performance and weight between the two models.

The cycles of the two engine versions were essentially the same. The difference between the engines was that the earlier STF505M-7C had assumed levels of component performance, duct losses, secondary flows, weights, etc., while the STF505M-7D had values representing the status at the end of the initial preliminary design effort. In some cases the latter version had not achieved the values assumed in the earlier version.

The net performance loss from the STF505M-7C to the STF505M-7D was about +0.6 percent in cruise TSFC and -4 percent in takeoff and cruise thrust. To determine the adjustment required to account for these differences, Pratt & Whitney Aircraft ran airplane performance analyses of both the STF505M-7C and the STF505M-7D engines in the study airplanes used by Pratt & Whitney Aircraft for the domestic and intercontinental missions at a variety of design and typical mission distances, covering the range of missions considered. Adjustments to such parameters as takeoff gross weight, fuel burned, and direct operating cost for each airplane-mission combination were assessed in this manner. The results shown in the main body of this report represent STF505M-7D characteristics; however, the results in the airframe manufacturer's reports in the appendices represent STF505M-7C characteristics.

4.0 FLIGHT PROPULSION SYSTEM CHARACTERISTICS

4.1 CONFIGURATION DESCRIPTION

The Energy Efficient Engine Design used in this study is an advanced, high bypass ratio, two spool turbofan engine with a full length nacelle and a mixed exhaust. The design and principal features of this engine are described in detail in Reference 1. A number of special features of this engine are shown in the cross section in Figure 5. Starting from the front, the 1.79 pressure ratio, 2.7 aspect ratio (AR), 26 blade, shroudless, hollow titanium fan is followed by 30 integral strut-fan exit guide vanes (10 structural, 20 non-structural). Fan blade containment is provided by a Kelvar wrap. The four stage, low-pressure compressor counter-rotates with the 14:1 pressure ratio, ten stage high-pressure compressor. The overall pressure ratio is 38.6:1.

Variable geometry is employed in the first four stages of the high-pressure compressor, and external active clearance control is employed on the remaining stages. The combustor is a two-stage annular configuration which was designed for low emissions. A single-stage, high rim speed high-pressure turbine is a key feature of the Energy Efficient Engine design. This single-stage turbine, employing single-crystal alloy blades, was a major contributor to the 40 percent overall reduction in the total number of engine airfoils, relative to the JT9D-7A. Both the high-pressure turbine and the four stage counter-rotating low-pressure turbine have active clearance control for tighter tip clearances at cruise.

The mixer is a short, scalloped, twelve-lobe design with a 0.5 L/D mixing length. A full authority digital electronic control is used.

An installation sketch of the Energy Efficient Engine is shown in Figure 6. Comparing this sketch with the JT9D-7A/200 installation in Figure 7 shows the difference between the short duct nacelle of the reference engine and the long duct mixed flow nacelle of the Energy Efficient Engine.

Key features of the long duct nacelle are an integrated engine/nacelle load sharing structure (which reduces rotor clearances and improves engine performance retention by reducing engine deflections), lightweight composite and honeycomb materials, acoustic treatment throughout, a fan-stream thrust reverser with twelve replaceable cascade racks, and core stream thrust spoiling by the mixer and primary nozzle in reverse thrust operation.

The overall engine design emphasizes mechanical simplicity, performance retention, maintainability, and a reasonable development risk, which, combined with the large fuel consumption benefit, results in a commercially acceptable energy efficient engine.

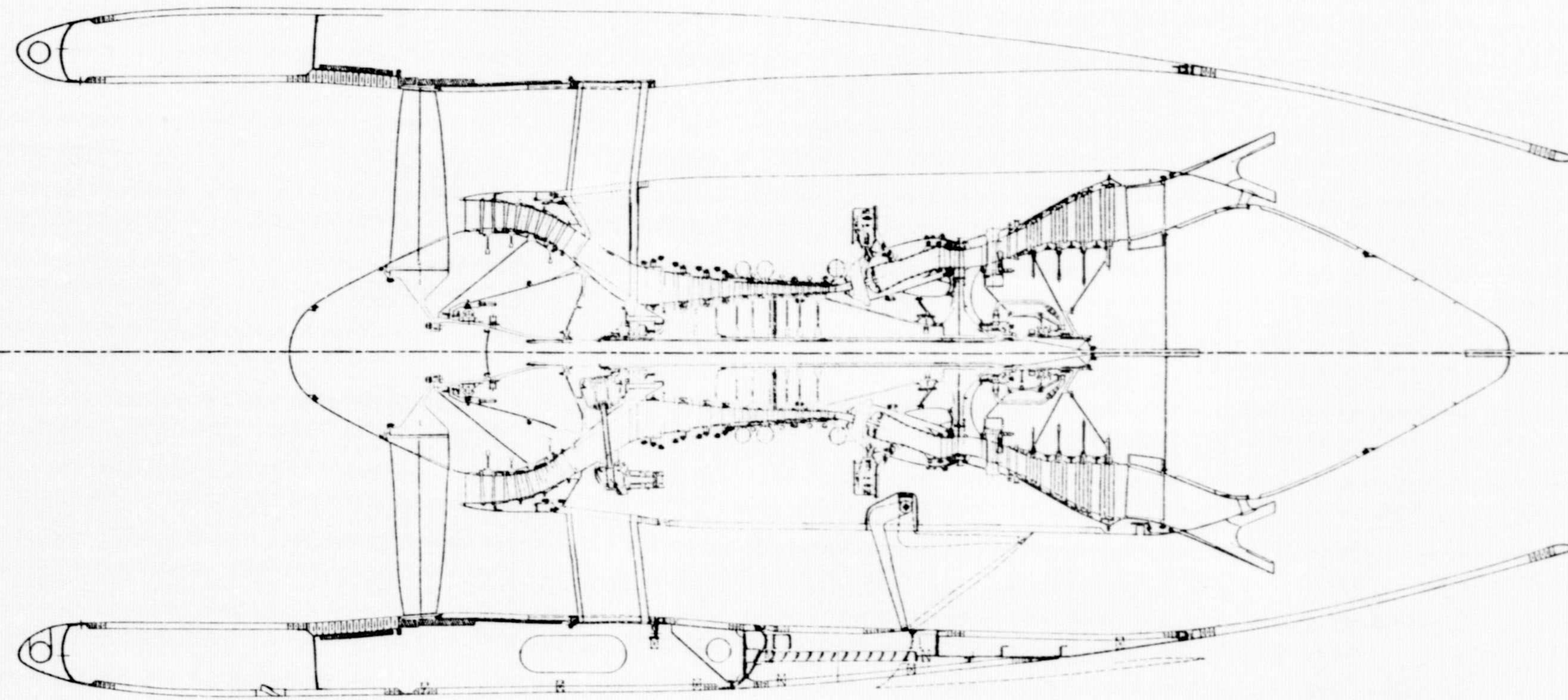


Figure 5 Energy Efficient Engine Cross Section -- The NASA specified goals for TSFC, DOC, noise, and emission will be achieved by means of the advanced technology concepts incorporated in the design.

ORIGINAL PAGE IS
OF POOR QUALITY

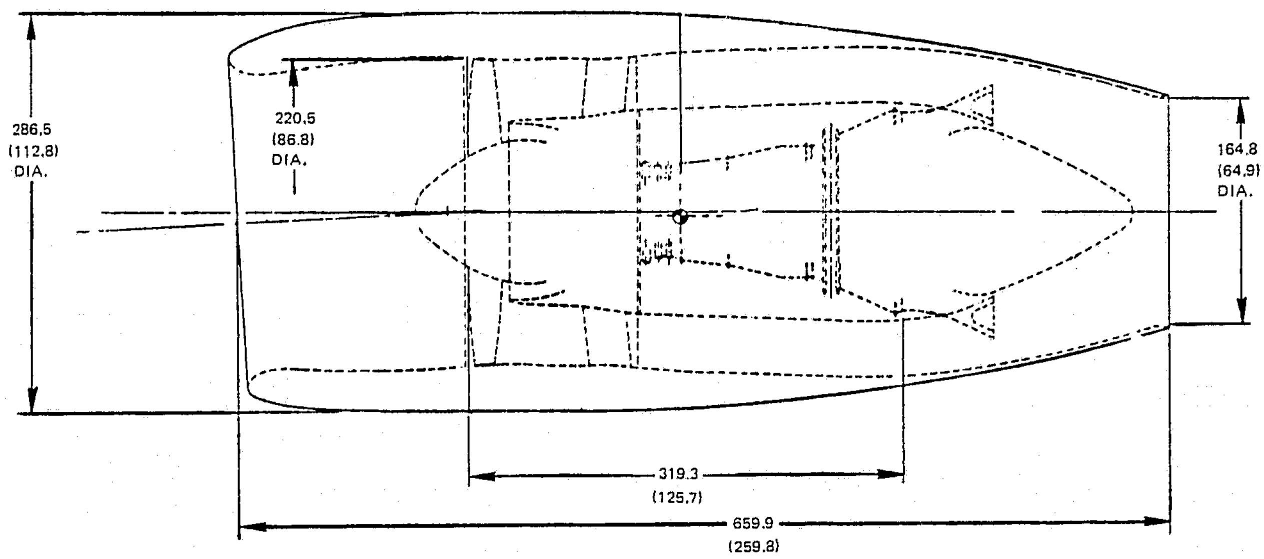


Figure 6 Installation Sketch of STF505M-7D

4.2 CYCLE SELECTION

Selection of the Energy Efficient Engine cycle was based on extensive cycle/configuration studies performed during the earlier Preliminary Design and Integration Studies, Reference 3. Studies completed under Task I of that contract were for initial configuration screening to determine the most promising engine types for further study. Four configurations were evaluated: two separate-exhaust configurations, one direct drive and one geared; and two mixed-exhaust configurations, one direct drive and one geared. The cycle for each configuration was based on work performed during an earlier NASA-sponsored program, the Low Energy Consumption Program (Reference 3). Performance, DOC, noise, and emissions estimates were obtained for each configuration.

Each of the four configurations were further studied over a wide range of cycle variations during Task II of Contract NAS3-20628. The range of the cycle parameters studied was 33 to 45 overall compression ratio (OPR), 1120° to 1290°C (2050° to 2360°F) rotor inlet temperature (RIT), and 6 to 11 bypass ratio (BPR). Boeing, Douglas, and Lockheed assisted in evaluating the fuel burned and DOC of

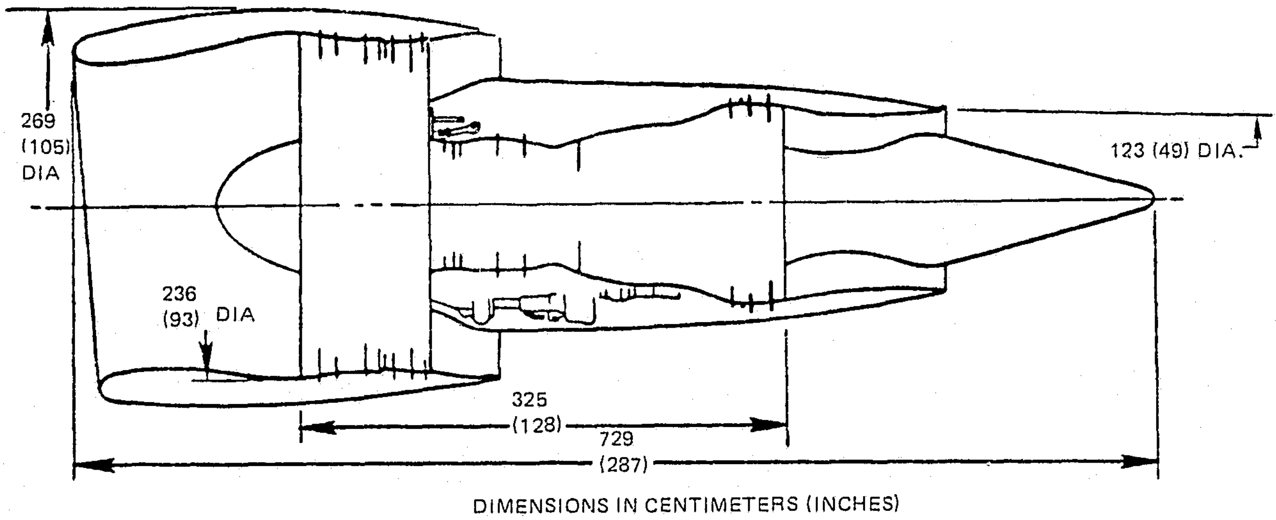


Figure 7 The JT9D-7A/747-200 Installation Sketch -- This engine was chosen as the reference for the Energy Efficient Engine because it is the most widely used Pratt & Whitney Aircraft high bypass ratio turbofan.

selected engines from this range--Pratt & Whitney Aircraft made a fuel burned and DOC analysis for all the engines studied. The results of Task II led to the selection of two mixed-flow engine configurations for further evaluation in Task III.

During Task III, key areas of technical concern were investigated for the mixed-exhaust configuration in direct drive and geared engines. Both single and two stage high pressure turbine versions were studied. Engine cycles representative of each configuration were chosen for these studies. All configurations were 38.6 OPR and 1204°C (2200°F) RIT. The direct-drive engines had a 1.74 fan pressure ratio (FPR) and a 6.5 BPR; the geared engines, a 1.52 FPR and a 9.1 BPR. Growth studies and performance/DOC risk studies were conducted for each of the four configurations; sufficient preliminary design work was completed to permit a feasibility evaluation and detailed comparison of the various configurations.

This study effort resulted in the selection of the following cycle for the Energy Efficient Engine: 38.6 BPR, 1204°C (2200°F) RIT, 1.74 FPR, and 6.55 BPR; direct drive, single-stage HPT, mixed exhaust. The selected OPR was the highest currently considered to be feasible from material and mechanical standpoints to obtain the lowest TSFC and fuel burned, consistent with the need for OPR increase to 45:1 for thrust growth. RIT was the optimum level for TSFC and slightly below the optimum for fuel burned. Higher RIT resulted in a significant increase in estimated DOC. The need for increases of up to 94°C (170°F) in RIT for thrust growth was also considered. The FPR/BPR was selected based on the optimum compromise between TSFC/fuel-burned and DOC. Reducing FPR (increasing BPR) reduced TSFC and mission fuel burned, but increased DOC.

The choice of direct drive was consistent with the FPR/BPR selection. The single-stage high-pressure turbine (HPT) configuration offered a simplified cooling system, requiring only two cooled rows for lower maintenance cost and improved DOC, relative to a two-stage HPT configuration. The selected mixed-exhaust system offered improvements in installed performance and DOC, relative to a separate flow configuration.

4.3 CYCLES AND PERFORMANCE

Engine cycle parameters, component performance levels, and engine overall performance are shown in Table 4a and Table 4b. Except for the last two flight conditions in the table, all the engine performance levels are for the uninstalled STF505M-7D engine (ideal inlet, zero nacelle drag, no customer air bleed or power extraction); the last two flight conditions in the table represent typical noise points and are fully installed with flight inlet, isolated nacelle drag, and typical customer bleed and power extraction. The aerodynamic design point (Table 4a) is used for component design and represents a typical cruise altitude and Mach number at a power setting between maximum cruise and maximum climb power. All cycle parameters are based on this condition. Table 4a uses Standard International (SI) units, while 4b is in English units.

A comparison of the Energy Efficient Engine (STF505M-7D) and the JT9D-7A is presented in Table 5. The takeoff thrust size (uninstalled) of the Energy Efficient Engine is somewhat less than that of the JT9D-7A, and the cycle pressure ratio, RIT, BPR, and FPR are higher. These cycle differences combined with the superior component technology and mixed-flow nacelle of the Energy Efficient Engine resulted in an estimated 14.9 percent improvement in installed (flight inlet, nacelle drag, but no customer bleed or power) cruise TSFC at the 10,670 m (35,000 ft), Mach number of 0.8, maximum cruise condition.

The Energy Efficient Engine and the JT9D-7A engine are further compared in Table 6. Net thrust, thrust specific fuel consumption, and fan total corrected airflow are included in the comparison. The performance levels in this table are fully installed including customer bleed and power extraction. The performance data is

TABLE 4 a

EEE PERFORMANCE SUMMARY
(STF505M-7D)
(SI Units)

	Aerodynamic Design Point	Maximum Cruise	Maximum Climb	Takeoff	Maximum Climb	85% Maximum Cruise	Typical Takeoff	Typical Approach
Altitude (m)	10,668	10,668	10,668	Sea Level	6,705	10,668	365.8	120
Mach Number	0.80	0.80	0.80	Static	0.700	0.800	0.245	0.208
Ambient Temp.	Std. Day	Std. Day	Std. Day	Std. Day+13.9°C	Std. Day+10°C	Std. Day	Std. Day+10°C	Std. Day+10°C
Inlet Recovery (%)	100	100	100	100	100	100	99.65	99.65
Power Extraction (kW)	0	0	0	0	0	0	112.6	112.6
Customer Bleed (kg/sec)	0	0	0	0	0	0	1.193	1.202
Thrust (w/drag) (N)	47,372	45,419	50,672	182,880	70,216	38,604	131,973	37,208
Fuel Flow (kg/hr)	2658	2549	2855	6133	4104	2179	5857	1795
TSFC (kg/hr/N)	0.056	0.056	0.056	0.034	0.058	0.056	0.044	0.048
Rotor Inlet Temp. (°C)	1225	1206	1257	136	1341	1138	1348	9139
Overall Pressure Ratio	38.6	37.4	40.5	30.2	34.5	33.5	29.1	11.9
Bypass Ratio	6.51	6.59	6.37	7.0	6.88	6.92	7.10	9.39
<u>Fan OD</u>								
$W\sqrt{\theta}/\delta$ kg/sec	513	607	624	541.6	589	583.5	538	350
PR	1.74	1.71	1.79	1.57	1.65	1.61	1.54	1.16
η (%)	87.3	37.3	87.1	88.2	87.5	85.9	88.0	87.0
RPM	3660	3614	3741	3626	3710	3444	3565	2219
<u>Fan ID and LPC</u>								
$W\sqrt{\theta}/\delta$ kg/sec	94.2	92.1	97.9	77.1	86	84.5	75.8	37.3
PR	2.755	2.70	2.85	2.36	2.59	2.51	2.31	1.43
η (%)	92.2	94.3	90.2	91.5	90.2	89.8	90.5	85.6
<u>HPC</u>								
$W\sqrt{\theta}/\delta$ kg/sec	40.0	39.7	40.3	37.2	38	38.7	37.2	27.5
PR	14.0	13.85	14.20	12.80	13.3	13.3	12.6	8.33
η (%)	88.2	88.3	88.0	88.9	88.4	88.7	88.3	86.4
RPM	12,362	12,291	12,473	13,006	12,801	12,046	12,905	11,251
<u>Burner</u>								
$W\sqrt{\theta}/\delta$ kg/sec	3.58	3.58	3.58	3.58	3.6	3.6	3.6	3.77
$\Delta P/P$	0.055	0.055	0.055	0.055	0.055	0.056	0.055	0.061
(%)	99.95	99.95	99.95	99.95	99.95	99.95	99.95	99.95
<u>HPT</u>								
$W\sqrt{T}/P$ ~ kg/sec (°K/kN/m²)	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.945
PR	4.0	4.0	4.0	4.0	4.03	4.05	4.03	3.95
η (%)	88.2	88.2	88.2	88.2	87.3	88.2	87.3	87.6
<u>LPT</u>								
$W\sqrt{T}/P$ ~ kg/sec (°K/kN/m²)	3.7	3.7	3.7	3.7	3.7	3.8	3.77	3.70
PR	5.6	5.5	5.7	4.9	5.37	5.33	4.86	2.65
η (%)	91.5	91.4	91.6	90.2	90.3	91.0	90.0	84.5
$\Delta P/P$ Trans Duct	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
$\Delta P/P$ TEGV	0.009	0.009	0.0094	0.0066	0.0083	0.0080	0.0065	0.0016
$\Delta P/P$ Duct	0.006	0.006	0.0059	0.0054	0.0061	0.0062	0.0056	0.0034
$\Delta P/P$ Core Mixer	0.0024	0.0024	0.0025	0.0019	0.0022	0.0022	0.0018	0.0005
$\Delta P/P$ Duct Mixer	0.0018	0.0018	0.0018	0.0017	0.0018	0.0018	0.0017	0.0012
$\Delta P/P$ Tailpipe	0.0034	0.0034	0.0034	0.0029	0.0032	0.0031	0.0030	0.0015
% Mixing	85	85	85	85	85	85	85	85
Nozzle Gross Thrust Coefficient	0.9958	0.9960	0.9955	0.990	0.996	0.996	0.9906	0.9935
Drag (N)	0	0	0	0	0	0	739	565
Turbine Cooling and Leakage Air (% WA Core)	15.95	15.95	15.95	15.45	15.45	15.95	15.45	15.45

TABLE 4 b

EEE PERFORMANCE SUMMARY
(STF505M-7D)
(English Units)

	Aerodynamic Design Point	Maximum Cruise	Maximum Climb	Takeoff	Maximum Climb	85% Maximum Cruise	Typical Takeoff	Typical Approach
Altitude (ft)	35,000	35,000	35,000	Sea Level	22,000	35,000	1200	394.0
Mach Number	0.80	0.80	0.80	Static	0.70	0.800	0.2455	0.208
Ambient Temp.	Std. Day	Std. Day	Std. Day	Std. Day +25°F	Std. Day+18°F	Std. Day	Std. Day+18°F	Std. Day+18°F
Inlet Recovery (%)	100	100	100	100	100	100	99.65	99.65
Power Extraction (hp)	0	0	0	0	0	0	151	151
Customer Bleed (lbm/sec)	0	0	0	0	0	0	2.63	2.65
Thrust (w/drag) (lbf)	10,650	10,211	11,392	41,115	15,786	8679	29,670	8365
Fuel Flow (lbm/hr)	5860	5620	6295	13,521	9047	4803	12,916	3959
TSFC (lbm/hr/lbf)	0.55	0.55	0.55	0.18	0.57	0.55	0.44	0.47
Rotor Inlet Temp. (°F)	2238	2203	2295	2495	2446	2081	2457	1683
Overall Pressure Ratio	38.6	37.4	40.5	30.2	34.5	33.5	29.1	11.9
Bypass Ratio	6.51	6.59	6.37	7.0	6.88	6.91	7.10	9.39
Fan OD								
$W\sqrt{\theta}/\delta$ lbm/sec	1352	1338	1375	1194	1297.5	1286.5	1187	772.2
PR	1.74	1.71	1.79	1.57	1.65	1.61	1.54	1.16
η(%)	87.3	87.3	87.1	88.2	87.5	86.9	88.0	87.0
RPM	3660	3614	3741	3626	3710	3444	3565	2219
Fan ID and LPC								
$W\sqrt{\theta}/\delta$ lbm/sec	207.7	203.1	215.8	170	188.6	186.3	167.2	82.2
PR	2.75	2.70	2.85	2.36	2.59	2.51	2.31	1.43
η(%)	89.3	89.5	89.0	91.5	90.2	89.8	90.5	85.6
HPC								
$W\sqrt{\theta}/\delta$ lbm/sec	88.1	87.5	88.9	82.0	84	85.3	82.0	60.7
PR	14.0	13.85	14.2	12.8	13.3	13.3	12.6	8.33
η(%)	88.2	88.3	88.0	88.9	88.4	88.7	88.8	86.4
RPM	12,362	12,291	12,473	13,006	12,801	12,048	12,905	11,251
Burner								
$W\sqrt{\theta}/\delta$ lbm/sec	7.9	7.9	7.9	7.9	7.9	8.0	7.9	8.32
$\Delta P/P$	0.055	0.055	0.055	0.055	0.055	0.056	0.055	0.061
η(%)	99.95	99.95	99.95	99.95	99.95	99.95	99.95	99.95
HPT								
$W\sqrt{T}/P$ ~ lbm/sec (°R/lbf/in.^{2})	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.2
PR	4.0	4.0	4.0	4.0	4.03	4.05	4.03	3.95
η(%)	88.2	88.2	88.2	87.3	87.3	88.2	87.3	87.6
LPT								
$W\sqrt{T}/P$ ~ lbm/sec (°R/lbf/in.^{2})	76.3	76.3	76.1	76.4	76.4	76.6	76.5	75.1
PR	5.6	5.5	5.7	4.9	5.37	5.33	4.86	2.65
η(%)	91.5	91.4	91.6	90.2	90.3	91.0	90.0	84.5
$\Delta P/P$ Trans Duct	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
$\Delta P/P$ TEGV	0.009	0.009	0.0094	0.0066	0.0083	0.0080	0.0065	0.0016
$\Delta P/P$ Duct	0.006	0.006	0.0059	0.0054	0.0061	0.0062	0.0056	0.0034
$\Delta P/P$ Core Mixer	0.0024	0.0024	0.0025	0.0019	0.0022	0.0022	0.0018	0.0005
$\Delta P/P$ Duct Mixer	0.0018	0.0018	0.0018	0.0017	0.0018	0.0018	0.0017	0.0012
$\Delta P/P$ Tailpipe	0.0034	0.0034	0.0034	0.0029	0.0032	0.0031	0.0030	0.0015
% Mixing	85	85	85	85	85	85	85	85
Nozzle Gross Thrust Coefficient	0.9958	0.9960	0.9955	0.990	0.996	0.996	0.9906	0.9935
Drag (lbf)	0	0	0	0	0	0	166	127
Turbine Cooling and Leakage Air (% WA Core)	15.95	15.95	15.95	15.45	15.45	15.95	15.45	15.45

TABLE 5

SUMMARY COMPARISON OF EEE AND JT9D-7A ENGINE

	EEE (STF505M-7D)	JT9D-7A
Takeoff Thrust, N (lbf)	182,880 (41,115)	204,720 (46,025)
Turbine Rotor Inlet Temp, °C (°F)		
Takeoff, +14°C (+25°F) Day	1369 (2495)	1260 (2300)
Max Climb, +10°C (18°F) Day	1321 (2410)	1169 (2135)
Max Cruise, Std. Day	1206 (2205)	1088 (1990)
Overall Pressure Ratio	38.6*	15.4**
Fan Bypass Ratio	6.51*	5.1**
Fan Pressure Ratio	1.74*	1.58**
Exhaust Type	Mixed	Separate (B747-200)
Max Cruise Installed 10,670m (35,000 ft) Mn = 0.8 TSFC, kg/hr/N (lbm/hr/lbf)	0.05874 (0.576)	0.06904 (0.677)
	← -14.9%	

*Aero Design Point
**10,670 m (35,000 ft) Mn = 0.8, Max. Cruise

representative of airplane mission and economic studies. As the comparison shows, the STF505M-7D has a significantly better specific fuel consumption than the JT9D-7A engine for a wide range of altitudes at higher power settings. However, because of the different off-design characteristics of mixed flow and separated-flow engines, this advantage diminishes at idle descent and becomes a penalty at the lower altitudes.

The thrust comparison shows an even greater difference. The STF505M-7D has power ratings that result in a greater maximum climb and maximum cruise thrust, relative to takeoff thrust, than the JT9D-7A. When both engines are scaled to the same takeoff thrust, the STF505M-7D has about four percent more climb thrust than the JT9D-7A at 6100 m (20,000 ft) at a Mach number of 0.7 and about 17 percent higher climb thrust at 10,670 m (35,000) at a Mach number of 0.8. The cruise thrust of the STF505M-7D is about seven percent higher than that of the JT9D-7A at 10,670 m/Mn 0.8, and about three percent higher at 13,720 m

TABLE 6

PERFORMANCE COMPARISON OF THE BASE SIZE EEE AND JT9D-7A
FULLY INSTALLED WITH BLEED AND POWER EXTRACTION
STANDARD DAY

Altitude M	(ft)	Mn	Power Setting	EEE (STF505M-7D) Relative to JT9D-7A % Difference Fnt	TSFC	W / total
0	(0)	0.0	Takeoff	-12.0	-10.2	-12.3
6100	(20000)	0.7	Max Climb	- 8.7	-12.2	-12.5
10670	(35000)	0.8	Max Climb	+ 3.4	-14.9	- 8.3
10670	(35000)	0.8	Max Cruise	- 5.7	-14.1	-10.9
13720	(45000)	0.8	Max Cruise	- 8.3	-12.8	-11.8
6100*	(20000)	0.7	Idle	+74.1	-64.4	-12.8
0	(0)	0.2	Idle	-55.2	+51.2	+ 1.3

*Fnt and TSFC are negative at 0.7 idle condition; STF 505M-7D has 74.1% more negative thrust and 64.4% less negative TSFC at this condition.

(45,000 ft) and a Mach number of 0.8. These rating differences improve the mission performance of the STF505M-7D engine. For example, if the engines were sized for climb or cruise, the required engine size and weight would be reduced. If the engines were sized for takeoff, the STF505M-7D would have had an improved time-to-climb and would have used less climb fuel.

Idle descent is another area of improved performance for the STF505M-7D engine. The off-design operating characteristics of the mixed-flow configuration combined with the idle ratings of the STF505M-7D result in a significant improvement in descent and taxi fuel consumed, even at those flight conditions where the idle descent TSFC of the STF505M-7D is worse.

4.4 ENGINE WEIGHT, PRICE, AND MAINTENANCE COST

4.4.1 Methodology

The methods employed for estimating price, weight, and maintenance cost are the same as used by Pratt & Whitney Aircraft on all study engines. These methods utilize detailed analyses of each component rather than simplistic statistical regressions.

Weight and price scaling techniques were used extensively. The scaling techniques are the result of past studies in which engines and nacelles were evaluated in several thrust sizes. The scaling studies were performed in sufficient detail in determine the effects of size on individual major parts and components. Total weight or cost represents the summation of the individual components.

4.4.1.1 Weight Estimating

Engine weight was estimated by analytical techniques that utilized computer programs for an accurate weight analysis; statistical procedures were not employed. The weight of each component was estimated in detail as the layout evolved.

Trade studies were also carried out to ensure that minimum weight configurations were considered and incorporated into the final engine definition where practical. Advanced technology items that influenced weight in such programs as the JT10D and Variable Stream Control Engine were evaluated for the Energy Efficient Engine and were incorporated into the design and weight estimate procedure, thus providing aggressive weight estimates that have a high degree of credibility and technical substantiation.

Nacelle weight was estimated by scaling similar components of existing nacelles to Energy Efficient Engine size and then adjusting the scaled weights to account for the use of advanced materials. Aggressive use of composites and titanium in the nacelle allowed weight reductions of 18 percent in the inlet, 27 percent in the fan cowl, and ten percent in the fan reverser and core cowl, compared with conventional metal construction.

Component weight breakdown of the STF505M-7D is shown in Table 7. Included for comparison are the bare engine, nacelle, and total weights assumed for the STF505M-7C at the beginning of the preliminary design--these weights were used by airplane manufacturers in their evaluations.

4.4.1.2 Price Estimating

The engine and spare part prices of the STF505M-7D model were established based on production cost-estimating procedures. A bill-of-materials was generated from design layouts of major parts that represented over 90 percent of the total engine cost.

Cost was first approximated by computer programs that operate on a library of components of reference engines. Similar components were scaled to the STF505M-7D flowpath and adjusted for number of parts, the material and labor cost of each element being analyzed separately. The many unique features of the Energy Efficient Engine design required an in-depth evaluation of many parts.

TABLE 7

ENERGY EFFICIENT ENGINE WEIGHT BREAKDOWN

Component	STF505M-7D Weight kg	(lbm)
Fan	821	(1810)
LPC	218	(480)
Intermediate/Fan Discharge	354	(780)
HPC	345	(760)
Diffuser/Burner	304	(670)
HPT	376	(830)
LPT	898	(1980)
Mixer/Plug	118	(260)
Controls/Accessories	300	(660)
Total Bare Engine*	3734	(8230)
Inlet	277	(610)
Fan Cowl	88	(195)
Fan Reverser/Core Cowl	796	(1755)
Tailpipe	125	(275)
Total Nacelle*	1286	(2835)
Total Flight Propulsion System*	5020	(11065)

*STF505M-7C levels were:

Bare Engine	3652	(8050)
Nacelle	1265	(2785)
Flight Propulsion System	4917	(10835)

An extensive data base was available for the detail evaluations, including both production and development engine part costs, material cost correlations and scaling relationships, and trade studies from other programs. Materials and manufacturing specialists from Pratt & Whitney Aircraft and from vendors were consulted when determining costs of unique processes and configurations, such as superplastic forming and diffusion bonding of the hollow fan blades and intermediate case struts. Advanced materials and manufacturing methods were evaluated by utilizing the Pratt & Whitney Aircraft Materials Engineering Research Laboratory and Manufacturing Research and Development Groups.

The engine cost estimates were reviewed by making detail comparisons with other engines. Differences between Energy Efficient Engine configurations and JT10D and JT9D configurations were analyzed to ensure that costs were reasonable.

The total estimated cost of the Energy Efficient Engine is a realistic manufacturing cost based on JT9D-7A production quantities. The changes in configuration evolving during the subsequent detailed design and development of the engine will be adjusted for by a design and development allowance based on trends of past programs.

Direct Operating Cost and Maintenance Cost required selling price rather than production cost levels. Therefore, the Financial Department generated the 1977 budgetary and planning prices. The pricing method used for the STF505-7D was consistent with that used for the JT9D-7A. A breakdown of the price of the Energy Efficient Engine by major component is shown in Table 8.

Nacelle price was estimated on a constant price per unit weight for both engines.

In addition to estimates for determining engine status, many trade studies were performed to ensure that applicable cost reduction proposals were incorporated.

4.4.1.3 Maintenance Cost Estimating

A comprehensive analysis was performed to estimate maintenance cost of the STF505M-7D engine. Maintenance cost includes cost of maintenance material, labor, and outside repair.

Outside repair cost is the cost for repairs not normally accomplished in the airline's repair shop; in this analysis these charges are included in the labor costs. All costs are for a mature engine expressed in 1977 dollars and represent a 15 year cumulative average for a fleet of aircraft introduced into service at the same time (block feed). A full burdened labor rate of $29.00 per manhour was used to convert manhours to dollars. Estimates were made for both intercontinental and domestic missions.

To establish a "hardpoint" base for maintenance cost studies, the maintenance cost of a mature JT9D-7A engine was established; the maintenance cost of the Energy Efficient Engine was evaluated against this base. A breakdown of maintenance costs of Energy Efficient Engine is shown in Table 8.

TABLE 8

EEE (STF505M-7D) PRICE AND MAINTENANCE COST COMPONENT BREAKDOWN

	Price	Maintenance Cost
Fan	14.5%	10.5%
LPC	5.5%	4.0%
Intermediate/Fan Discharge	9.0%	1.5%
HPC	11.5%	11.0%
Diffuser/Burner	7.5%	10.0%
HPT	10.5%	21.0%
LPT	25.5%	26.0%
Mixer/Plug	3.0%	0.5%
Controls/Accessories	10.5%	5.5%
Assembly, Test, and Line Maint.	2.5%	10.0%
Total	100.0%	100.0%

A preliminary analysis of nacelle maintenance cost performed in support of the accessory location study indicated that an Energy Efficient Engine type nacelle design could have an advantage over a JT9D-7A/-200 type installation in labor costs. This advantage would be partially offset by the lower mean time between repair of the Energy Efficient Engine relative to the JT9D-7A. For the purposes of airplane economics comparisons, the Energy Efficient Engine and JT9D-7A/-200 nacelle maintenance costs were assumed to be equal.

Maintenance Material Cost

The maintenance material cost (MMC) estimates were obtained from a computer program that simulated the operation and maintenance of a fleet of engines over a 15 year period. Approximately fifty groups of parts (highest MMC contributors) were modelled interactively by means of a Monte Carlo simulation. Mature scrap lives, module mean time between repair, and part prices provided the major input from which a 15 year cumulative average MMC estimate was derived. In addition to the fifty groups of parts, the MMC of disks (prorated over 15 years) and of miscellaneous parts (those not modelled individually) were added to obtain the total MMC estimate.

Mature JT9D-7A part scrap and repair lives were obtained by extrapolating field experience. The current experience positions were derived from the analysis of spare-part sales records, data obtained from various JT9D operators, and other sources within Pratt & Whitney Aircraft. The JT9D positions were used as a base for extrapolation to the Energy Efficient Engine lives, considering changes in design, advanced technologies, operating environment, and part repairability.

Spare part prices for both the mature JT9D-7A and STF505M-7 models, provided by the P&WA Financial Department, were based on production cost estimates. The pricing method was consistent for both engines and was based on 1977 dollars.

Maintenance Labor Cost Model

The maintenance labor cost (MLC) analysis covered maintenance performed on the flight line, in the operators shop, and on parts sent to a repair vendor. Manhours per repair and mean time between repair were estimated for each of the major sections (modules) of the engine. The maintenance labor cost in terms of manhours per engine flight hour was calculated by dividing the manhours per repair for each section by its mean time between repairs. The manhours per engine flight hour for the complete engine was obtained by summing the manhours per engine flight hour for the individual sections and adding estimated value for line maintenance separately.

The manhours per repair were derived through a comparative analysis of the projected mature JT9D-7A engine manhours. The manhours per repair for the JT9D-7A base was a detailed model in which manhours for module repairs was broken down into module disassembly/inspect/assembly and repair of major part types such as blades, vanes, outer air seals, etc. The manhours per Energy Efficient Engine repair estimates were generated from the mature JT9D model. Differences in engine design, operating environment, materials, size, etc. were taken into account in estimating the mahours.

Estimates of mean time between repairs were also made at the module level. These estimates (Table 9) reflected the total module repair rate independent of what module or part caused the shop visit. As was the case for the manhours per repair, a comparative analysis was performed using the mature JT9D-7A as a base. Differences in the engine design and operating temperatures, pressures, and speeds were taken into account in estimating the module mean time between repairs for the Energy Efficient Engine.

TABLE 9

EEE MEAN TIME BETWEEN REPAIR BY MODULE

Module	STF505M-7D MTBR (hr)
Fan	4400
LPC	6100
HPC	5400
Diffuser	7500
Burner	2750
HPT	2750
LPT	5000
All Causes	2300

4.4.2 Weight, Cost, and Maintenance Cost Comparison With the Reference Engine

The status of the Energy Efficient Engine (STF505M-7D) weight, price, and maintenance cost estimates at the end of the preliminary design phase is compared with the JT9D-7A reference engine in Table 10. The Energy Efficient Engine configuration provides reductions in bare-engine weight, price, and maintenance cost as a result of the mechanical simplicity achieved with advanced materials and manufacturing technology and with increased rotor speeds, high aerodynamic loadings, and advanced engine controls technology. Prime contributors to these benefits are the single-stage high-pressure turbine, the forty percent reduction in the number of engine airfoils, light-weight composite fan containment, full authority electronic control system, and the five bearing rotor support system located in two bearing compartments with two support frames. Although the nacelle design makes aggressive use of advanced materials, the change from the very short-duct, -200 nacelle to the long-duct mixed-flow nacelle increased total nacelle weight and price. Previous studies (NASA CR-135396, Reference 1) indicated, however, that these nacelle weight and price increases are more than offset in terms of fuel burned and DOC by the performance improvements offered by forced mixing of the exhausts. Nacelle maintenance costs were assumed to be equal for the purposes of this evaluation.

TABLE 10

COMPARISON OF JT9D-7A AND EEE

	JT9D-7A*	EEE (STF505M-7D) (%)
Weight		
Bare Engine	Base	- 3.1
Nacelle	Base	+18.5
Total	Base	+ 1.7
Price		
Bare Engine	Base	- 3.4
Nacelle	Base	+18.5
Total	Base	+ 0.7
Maintenance Cost	Base	- 3.2

*Scaled to STF505M-7D max. cruise thrust @ 10,670 m, M 0.8 (43.26 kN (9726 lbf))

5.0 AIRFRAME EVALUATION

5.1 AIRCRAFT AND MISSION SELECTION

Each of the airframe manufacturers--Boeing, Douglas, Lockheed-- as well as Pratt & Whitney Aircraft, recommended one domestic and one intercontinental range aircraft for use in the Propulsion System-Aircraft Evaluation (PS-AIE), each aircraft being suitable for early 1990's introduction into service. These aircraft and their mission definitions are described in the following sections, including the technology assumptions and marketing rationale used in their selection.

5.1.1 Boeing Aircraft & Mission Selection

5.1.1.1 Market Considerations and Design Constraints

Examination of the market situation indicated that airline requirements in the 1990's will be similar to those existing today. This prediction assumes that the air traveling community of the 1990's will be approximately the same percentage of the total population as today, with a small annual growth rate of four to six percent. Air cargo growth should be similar unless a large dedicated air freighter is developed, which might increase the growth rate.

The major airlines probably will retire many of the current narrow-body aircraft by the late 1980's. These aircraft include about 750 intercontinental range 707 and DC8 series airplanes, and over one thousand 727 domestic range airplanes. Therefore, barring unforeseen developments, a market should exist in the late 1980's for a large number of 180-220 passenger aircraft with domestic or intercontinental range capability. Accordingly, the design mission and sizing constraint selected for the Energy Efficient Engine study are shown in Table 11.

Boeing chose to concentrate on one airplane, examining only a domestic twinjet with wing mounted engines.

The takeoff field length of 1830 m (6000 ft) at sea level, 29°C (84°F), was chosen to approximate a hot day, reduced-range mission takeoff from Denver.

Since passengers have shown a preference for double-aisle seating, a wide body with a seven abreast, two aisle seating arrangement was chosen. The fuselage determined by this seating arrangement accommodates 17 LD-13 containers side by side in the cargo compartment.

TABLE 11

BOEING AIRCRAFT MISSION AND SIZING CRITERIA

Design Range, km (n.mi.)	3706 (2000)
Passengers, 15/85 split	196
Cruise Mach No.	0.80
Takeoff Field Length	2286 (7500)
Approach Velocity, m/s (kts)	64 (125)
Initial Cruise Alt., m (ft)	10,058 (33,000)
Typical Mission for Economic Evaluation:	
Range, km (n.mi.)	1853 (1000)
Passengers, (55% load factor)	108
Cruise Mach No.	0.80

5.1.1.2 Advanced Technology Features

Each technology area was reviewed and advanced technology features were identified as being available for a 1986 program start and an early 1990's inservice date. These features are discussed below.

Advanced aerodynamic features included: improved wing/airfoil design, wing/nacelle/strut design for minimum interference, and tailoring of the empennage to the wing-body flowfield. These features reduced cruise drag by two percent. In addition, the low speed (takeoff and landing) lift/drag was increased five percent through incorporation of sealed leading edge flaps, seals between nacelle struts and lateral edges of leading edge flaps, and aileron droop.

Advanced structural features depended on use of advanced aluminum alloys, high strength titanium, and composites, as shown in Figure 8.

Advanced flight control technology features incorporated in the airplane design were all-axes handling qualities stability augmentation systems, all flying tail, and double-hinged control surfaces.

Systems technology advancements applied to the design consisted of cabin air reconstitution and recirculation, integration of anti-icing with environmental control system, carbon brakes, and limited slip braking system.

CURRENT TECHNOLOGY	NEW TECHNOLOGY		
MATERIAL	MATERIAL	STRUCTURAL COMPONENT	WEIGHT SAVING % OF COMPONENT WEIGHT
STANDARD ALUMINUM ALLOYS (CURRENT 747)	ADVANCED ALUMINUM ALLOYS	●WING BOX ●FUSELAGE ●EMPENNAGE BOX	6% 4% 6%
CONVENTIONAL ALUMINUM CONSTRUCTION	ADVANCED COMPOSITE STRUCTURE (GRAPHITE)	●CONTROL SURFACES ●LANDING GEAR DOORS	25%
	CARBON	●MAIN LANDING GEAR BRAKES	40%
	TITANIUM FITTINGS	●LANDING GEAR SUPPORT ●SIDE OF BODY RIB ●EMPENNAGE BODY ATTACH ●ENGINE STRUT ATTACH ●FLAP SUPPORT	20%

Figure 8 Boeing Advanced Airframe Structures -- Advanced structural features in the Boeing airplane include advanced aluminum alloys, high strength titanium, and composites.

5.1.1.3 Aircraft Design Point Selection

Wing loading and thrust loading were chosen to minimize takeoff gross weight and block fuel, with the 1830 m (6000 ft) takeoff field length requirement limiting both parameters.

A configuration drawing of the Boeing aircraft is shown in Figure 9.

5.1.2 Douglas Aircraft and Mission Selection

5.1.2.1 Market Considerations and Design Constraints

Normal development and traffic growth trends indicate that a growth airplane (450 to 500 passengers) program is the most likely new

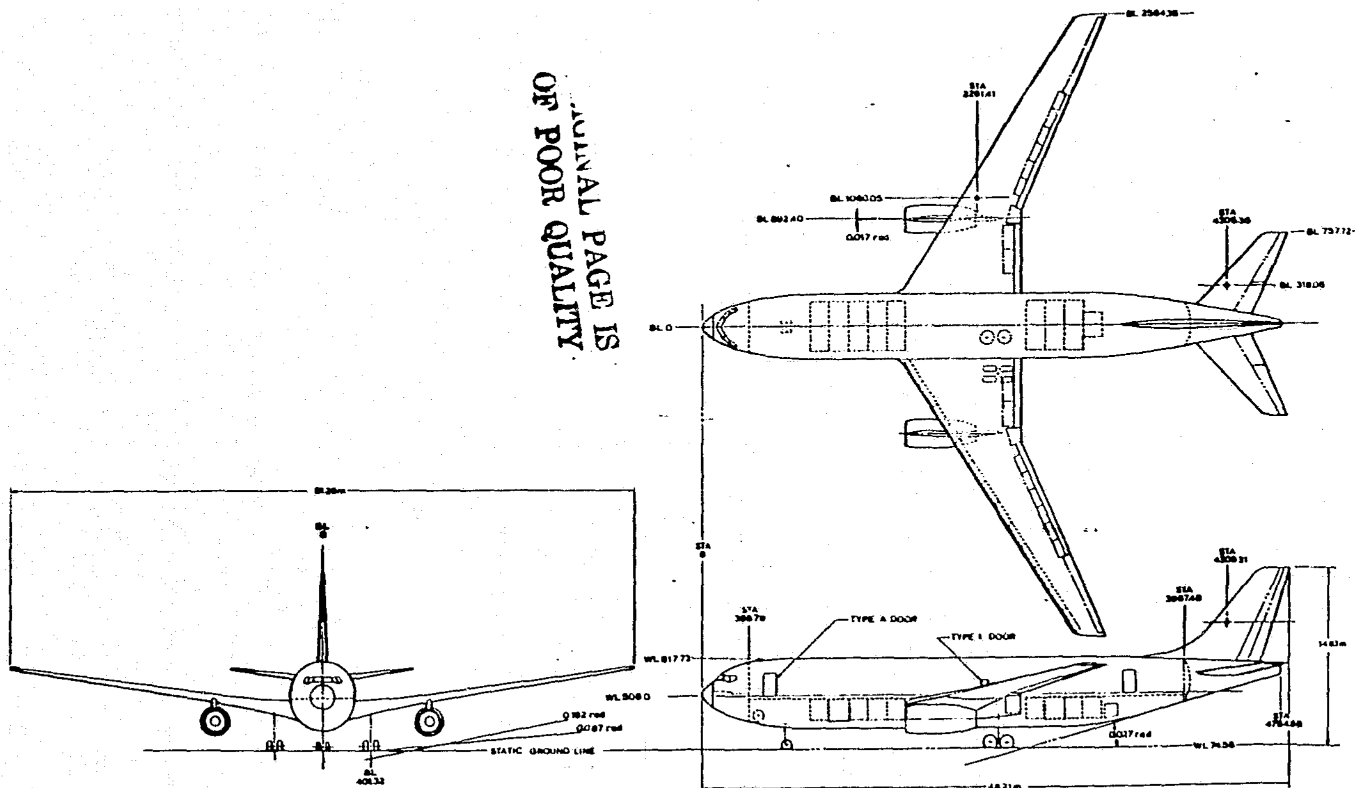


Figure 9 Boeing Airplane -- Boeing chose to concentrate on one airplane, a domestic twinjet with wing-mounted engines.

program to be initiated in the 1990's. Although an all new airplane is possible, an improved-technology derivative of a current wide-body transport is more likely. This growth airplane would probably have both a domestic and an intercontinental version, similar to the DC10 series.

A new aircraft is clearly needed to replace DC8's and 707's in domestic operations. But this need is expected to be fulfilled by the DCX-200 and/or 7X7 aircraft, which should be at their production peak in the mid to late 1980's. A replacement for these aircraft would not, therefore, be required in the early 1990's.

Similarly, the current wide-body transports should continue in production through the 1980's, with stretched versions based on the current wing being introduced in the early 1980's. If there were to be a technical breakthrough in laminar flow technology in the early 1980's, an airplane sized to replace the existing wide-body fleet would be a logical development since this fleet would be the largest user of aviation fuel. Such a high technology airplane would then be available for the 1990-1995's.

Assuming these marketing projections and that aircraft development will proceed along normal lines without a major technical breakthrough, Douglas based its airplanes on a DC10 trijet derivative with a stretched fuselage and an all new wing. Aircraft sizing and mission criteria are presented in Table 12.

Although the domestic and intercontinental airplanes have different thrust requirements, they are externally similar, having the same wing, fuselage, and empennage. However, the interior arrangements are different. The domestic airplane has a lower galley, allowing more seating but less cargo space (40 vs. 50 LD-3 containers) than the upper galley interior configuration of the intercontinental airplane. Fuselage diameter is the same as on current DC10 series aircraft, but the length of the fuselaqe has been stretched 18.4 m (60 ft).

5.1.2.2 Advanced Technology Features

A review of technology areas indicated that the advanced technology features described below would be available for 1990's application.

Advanced aerodynamic features included a thick supercritical high aspect ratio wing, winglets, and an advanced high lift system. The advantages of a supercritical wing of increased thickness, such as now flying on the YC-15, include lower weight, reduced drag, and improved CL buffet. Increasing wing aspect ratio from the current levels of 6 to 8-1/2 to 10 to 12 reduces induced drag, leading to reductions in engine size and fuel consumption. Winglet design technology, while not ready for the next generation of aircraft, should be sufficiently

TABLE 12

DOUGLAS AIRCRAFT MISSION AND SIZING CRITERIA

	Domestic Airplane	Intercontinental Airplane
Design Range, km (n.mi.)	5560 (3000)	10190 (5500)
Passengers, 10/90 split	458	438
Cruise Mach No.	0.80	0.80
Takeoff Field Length, m (ft)	2440 (8000)	3350 (11000)
Approach Velocity, m/sec (kts)	67 (130)	69 (135)
Initial Cruise Alt., m (ft)	10060 (33000)	9450 (31000)
Typical Mission for Economic Evaluation:		
Range, km (n.mi.)	1850 (1000)	2780 (1500)
Passengers (60% load factor)	275	263
Cruise Mach No.	0.80	0.80

advanced for inclusion in an early 1990's airplane. The advanced high lift system, consisting of a variable camber Krueger leading edge flap and a translating two segment trailing edge flap, will provide improved CL max and lift/drag. These improvements permit reductions in wing and engine size, and reduce approach noise.

Composite materials should be ready for application in the next generation of transport aircraft, and would be used in such areas as control surfaces, floor beams, fairings, and landing gear doors. Design, fabrication and repair techniques should have advanced by the early 1990's to allow applications to be expanded to provide essentially fully composite wings and empennage. The fuselage pressure shell, however, should still be of metal construction. The advantages of composites include significant weight reductions and the potential of reducing airplane price.

In the area of advanced controls, a longitudinal stability augmentation system would be incorporated to reduce empennage area and trim drag. Active controls would also be used for wing load alleviation.

Advanced systems features would include digital avionics, reduced bleed requirement air conditioning, advanced APU, advanced cockpit displays, and flight performance management systems.

5.1.2.3 Aircraft Design Point Selection

Wing area, common to the two airplanes, was set by the 1.3g buffet margin at the 9450 m (31,000 ft) initial cruise altitude requirement of the intercontinental aircraft. Thrust loadings for both airplanes were determined by the design takeoff field requirements.

General arrangement drawings for the two Douglas airplanes are presented in Figure 10 and Figure 11.

5.1.3 Lockheed Aircraft and Mission Selection

5.1.3.1 Market Considerations and Design Constraints

Lockheed used market projections to the year 2000 to establish total world-traffic demand (Figure 12). Range requirements for both domestic and intercontinental airplane designs were established from studies of traffic distribution patterns. Combining the world traffic forecast with traffic distribution provided an estimate of the number of aircraft that would be required to accommodate the market (Figure 13). From these data, the aircraft design range was established as 5600 km (3000 n.mi.) for domestic mission and 12,000 km (6500 n.mi.) for the intercontinental mission. These design ranges encompass all domestic routes and 93 percent of the total long range traffic projected for the year 2000.

The payload capability for both the domestic and intercontinental missions was selected as 500 passengers in a nine abreast, all tourist configuration. The choice was based on considerations of seat mile costs, airport congestion, scheduling flexibility, frequency of service, and number of aircraft required.

Market projections and airline preference indicated a cruise speed of Mach 0.85, especially for the longer range mission. Previous studies by Lockheed, however, showed that in a high fuel cost environment the lowest operating costs and optimum fuel utilization are attained at a cruise speed of Mach 0.8. In keeping with the fuel conservation aspects of Energy Efficient Engine program, a cruise speed of Mach 0.8 was selected. A summary of the mission and aircraft design criteria is presented in Table 13.

A three-engine configuration similar to the L1011 was chosen for the domestic airplane. A configuration with four wing-mounted engines was

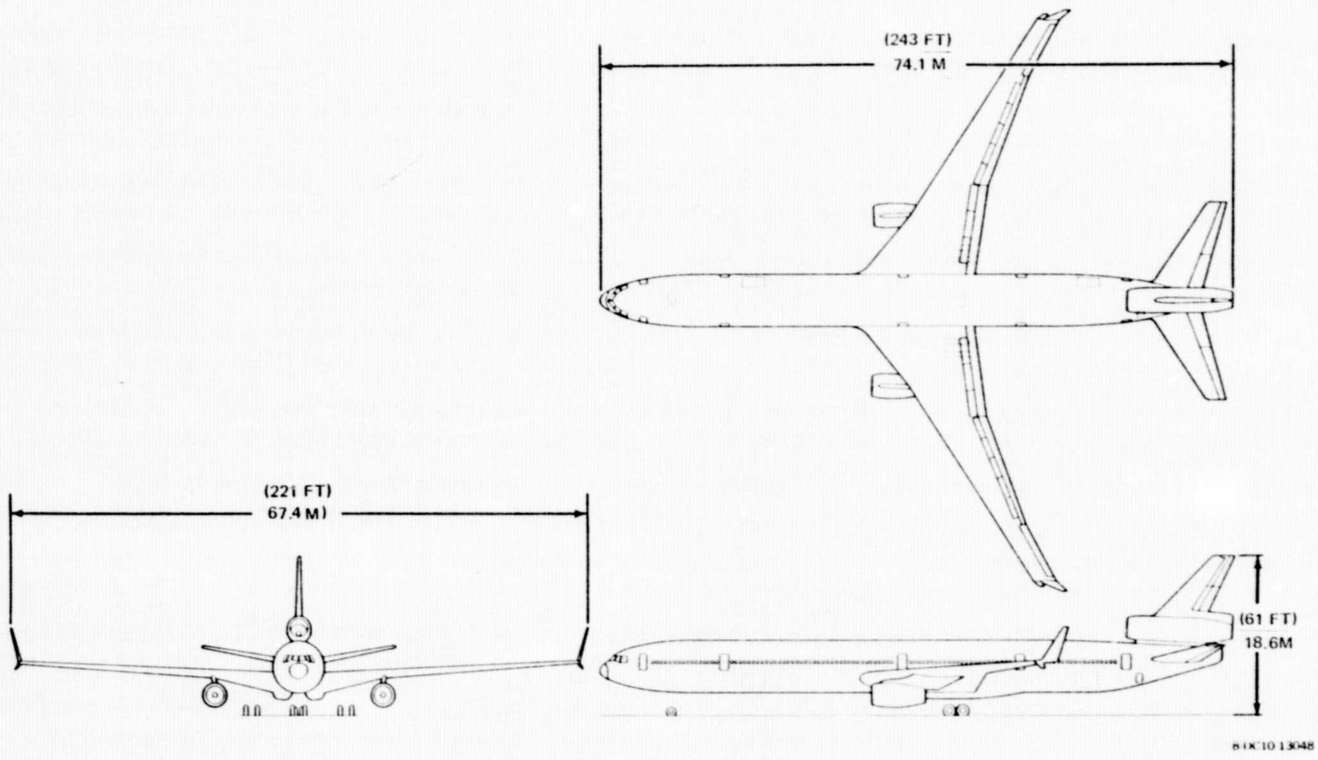


Figure 10   Douglas Domestic Airplane -- Both Douglas airplanes, the intercontinental as well as the domestic, are based on a DC10 trijet derivative with a stretched fuselage and an all new wing.

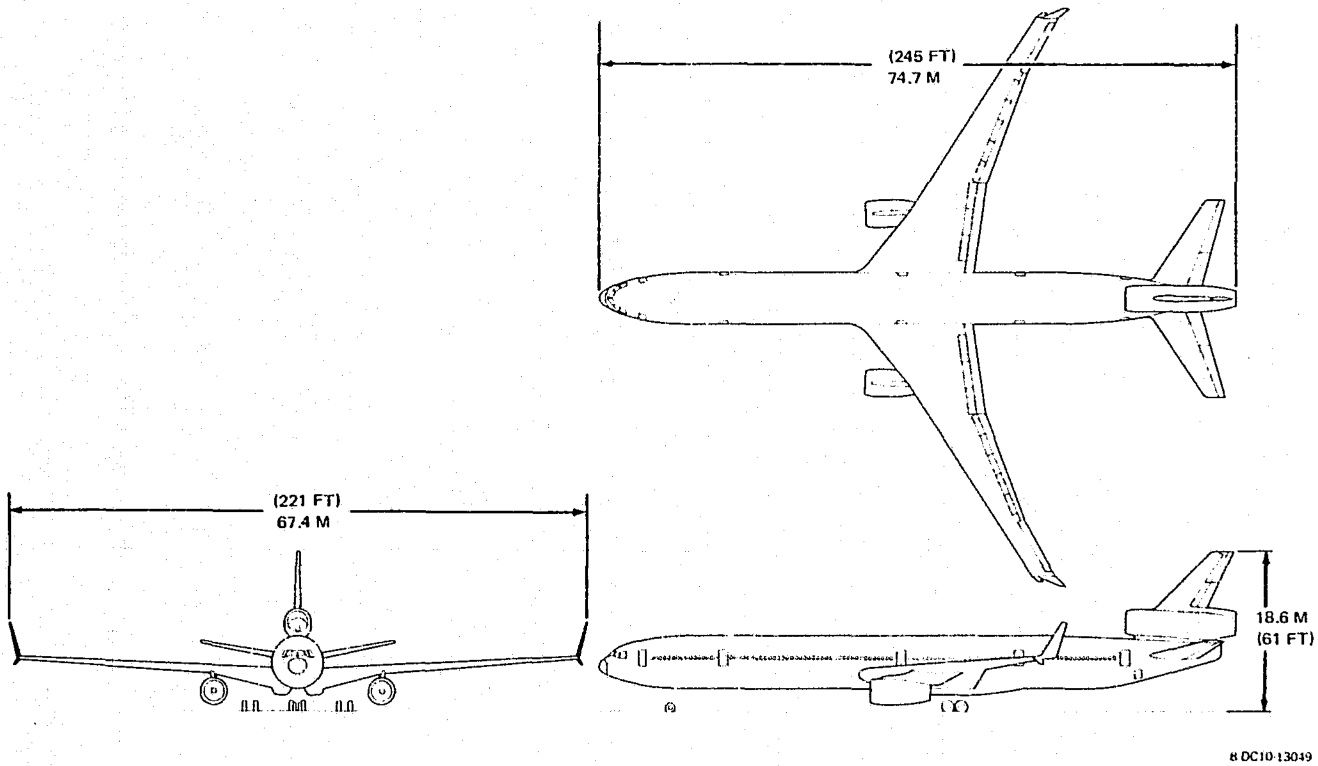


Figure 11 Douglas Intercontinental Airplane -- Although the domestic and intercontinental airplanes have different thrust requirements, they are externally similar, having the same wing, fuselage, and empennage.

MARKET	1975*	1990	1975 - 1990 AVG. ANNUAL GROWTH RATE	2000	1990 - 2000 AVG. ANNUAL GROWTH RATE
NO. AMERICA-EUROPE	16,986	34,979	4.9%	51,777	4.0%
EUROPE-ASIA/OCEANIA	4,071	15,864	9.5	28,410	6.0
NO. AMERICA-ASIA/OCEANIA	3,425	14,668	10.2	28,850	7.0
EUROPE-AFRICA	2,328	11,222	11.1	22,078	7.0
EUROPE-SO. AMERICA	1,644	8,025	11.0	15,787	7.0
NO. AMERICA-LATIN/SO. AMERICA	1,506	6,303	10.0	12,398	7.0
GROUP TOTAL	29,960	91,061	7.7%	159,394	5.8%

* LOCKHEED ESTIMATE

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 12 Lockheed Traffic Forecast -- Lockheed made projections of one-way daily passenger demand on major longhaul markets (over 4800 km).

AIRCRAFT SEATING CAPACITY

MILEAGE BLOCK KM	NMI	200	300	400	500	600
5560 - 7410	(3,000 - 4,000)	448	298	222	176	146
7410 - 9260	(4,000 - 5,000)	395	259	195	152	126
9260 - 11110	(5,000 - 6,000)	374	246	186	145	120
11110 - 12970	(6,000 - 7,000)	245	161	119	93	78
12970 - 14820	(7,000 - 8,000)	26	15	7	7	6
14820 - 16670	(8,000 - 9,000)	21	13	8	6	5
16670 - 18520	(9,000 - 10,000)	27	17	13	10	8
18520 - 20370	(10,000 - 11,000)	20	13	10	8	7
TOTAL		1,556	1,022	760	597	496

Figure 13 Lockheed Total Long-Haul Aircraft Requirements in Year 2000 -- Lockheed's projected requirements are based on daily service and a sixty percent load factor.

TABLE 13

LOCKHEED AIRCRAFT MISSION AND SIZING CRITERIA

	Domestic Airplane	Intercontinental Airplane
Design Range, km (n.mi.)	5560 (3000)	12,050 (6500)
Passengers 0/100 split	500	500
Cruise Mach No.	0.80	0.80
Takeoff Field Length, m (ft)	2130 (7000)	2900 (9500)
Approach Velocity, m/sec (kts)	69 (135)	69 (135)
Initial Cruise Altitude, m (ft)	10,670 (33,000)	10,670 (33,000)
Typical mission for economic evaluation:		
Range, km (n.mi.)	2590 (1400)	5560 (3000)
Passengers (55% load factor)	275	275
Cruise Mach No.	0.80	0.80

chosen for the intercontinental airplane. Passenger seating is nine abreast throughout, with a fuselage diameter similar to the L1011 and the length stretched to accommodate the additional passengers.

5.1.3.2 Advanced Technology Features

The levels of advanced technology appropriate for incorporation into the 1990's airframe design are discussed in the following paragraphs.

The primary advanced aerodynamic technology feature incorporated was a high aspect ratio supercritical wing. Figure 14 shows a comparison of the refined supercritical airfoil used in this wing and an airfoil of a current L1011 wing.

An advanced active controls system was incorporated in the aircraft design, providing load relief and relaxed static stability. This system is currently under development for the L1011. Wing load relief is accomplished by means of computer-controlled active ailerons which redistribute wing loadings, resulting in reduced bending moments and, hence, reduced wing and body structural weights. Relaxation of static stability results in a smaller horizontal tail size. The effects of these active controls on the aircraft configurations are shown in Table 14.

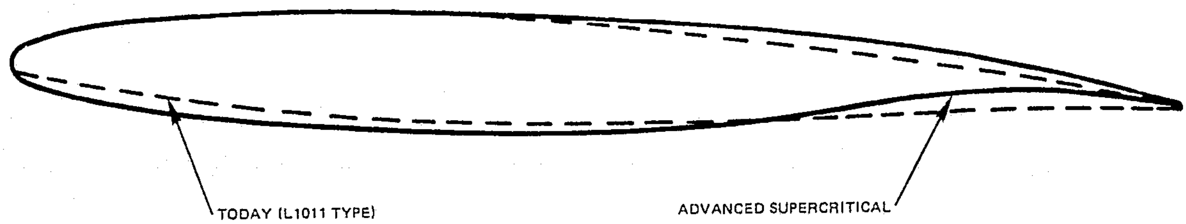


Figure 14 Lockheed Comparison of Refined Supercritical Wing of Study Airplane and of Current Technology wing of L1011 Airplane -- The primary advanced aerodynamic technology feature incorporated by Lockheed is a high aspect ratio supercritical wing.

TABLE 14

EFFECTS OF ADVANCED ACTIVE CONTROL SYSTEM ON LOCKHEED AIRCRAFT

Load Relief	Reduction (%)
Wing Weight	5.5
Body Weight	1.0
Relaxed Stability	
Tail Size	28

Advanced composites are used for the internal and external secondary structures and for a significant portion of the primary structure. The specific applications are:

External Secondary Structure

Flaps, slats, spoilers, gear doors

Internal Secondary Structure

Floor supports, beams, posts, dividers, doors fuel tank baffles

Primary Structure

Vertical fin, horizontal stabilizers, wing, fuselage, engine nacelle

The effect of composite structure on aircraft empty weight is shown in Figure 15.

COMPONENT	% WEIGHT REDUCTION	
WING	23	
TAIL	20	
BODY	7	
LANDING GEAR	4	
NACELLES	19	
AIR INDUCTION	19	
SURFACE CONTROLS	5	
FURNISHINGS	0	
	DOMESTIC	INTERCONTINENTAL
TOTAL REDUCTION IN MANUFACTURING EMPTY WEIGHT	8.7%	9.2%

Figure 15 Effect of Composite Structure on Empty Weight of Lockheed Aircraft -- Advanced Composites reduced the empty weight of the domestic airplane by 8.7 percent and the intercontinental airplane by 9.2 percent.

5.1.3.3 Aircraft Design Point Selection

The design points for the domestic and intercontinental airplanes were established by means of parametric studies based on the Lockheed Asset Synthesis Program. Wing and thrust loadings were chosen to minimize direct operating cost and mission fuel consumption. Takeoff distance was the limiting factor for both of the Energy Efficient Engine powered airplanes and for the JT9D-7A powered domestic airplane; cruise altitude was limiting for the JT9D-7A powered intercontinental airplane.

Lockheed's domestic and intercontinental airplane designs are shown in Figure 16 and Figure 17.

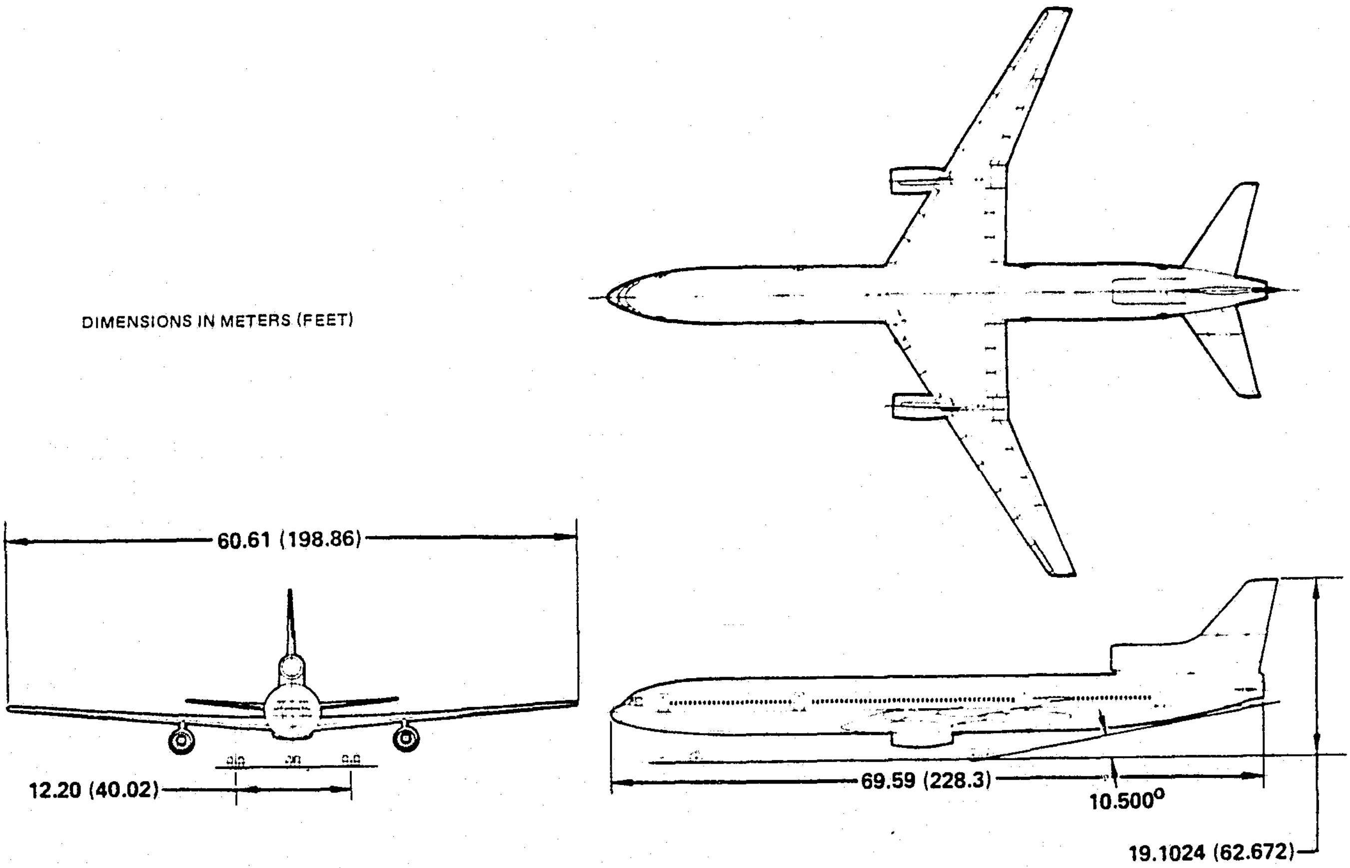


Figure 16 Lockheed Domestic Airplane -- Lockheed chose a three-engine configuration similar to the L1011 for its domestic airplane.

5.1.4 Pratt and Whitney Aircraft Study Airplane and Mission Selection

5.1.4.1 Market Considerations and Design Constraints

Studies conducted by P&WA in connection with the Energy Efficient Engine Preliminary Design and Integration Studies (Reference 2) indicated that there should be a very substantial market for large, wide-bodied aircraft in the 1990's. The existing first-generation wide-body transports (747, DC10, L1011) will have been in production for 20 years by the early 1990's. Traditionally, successful aircraft are replaced by newer designs at approximately 20 year intervals. The large, wide-body application, therefore, appears to be a natural one in which to introduce the Energy Efficient Engine.

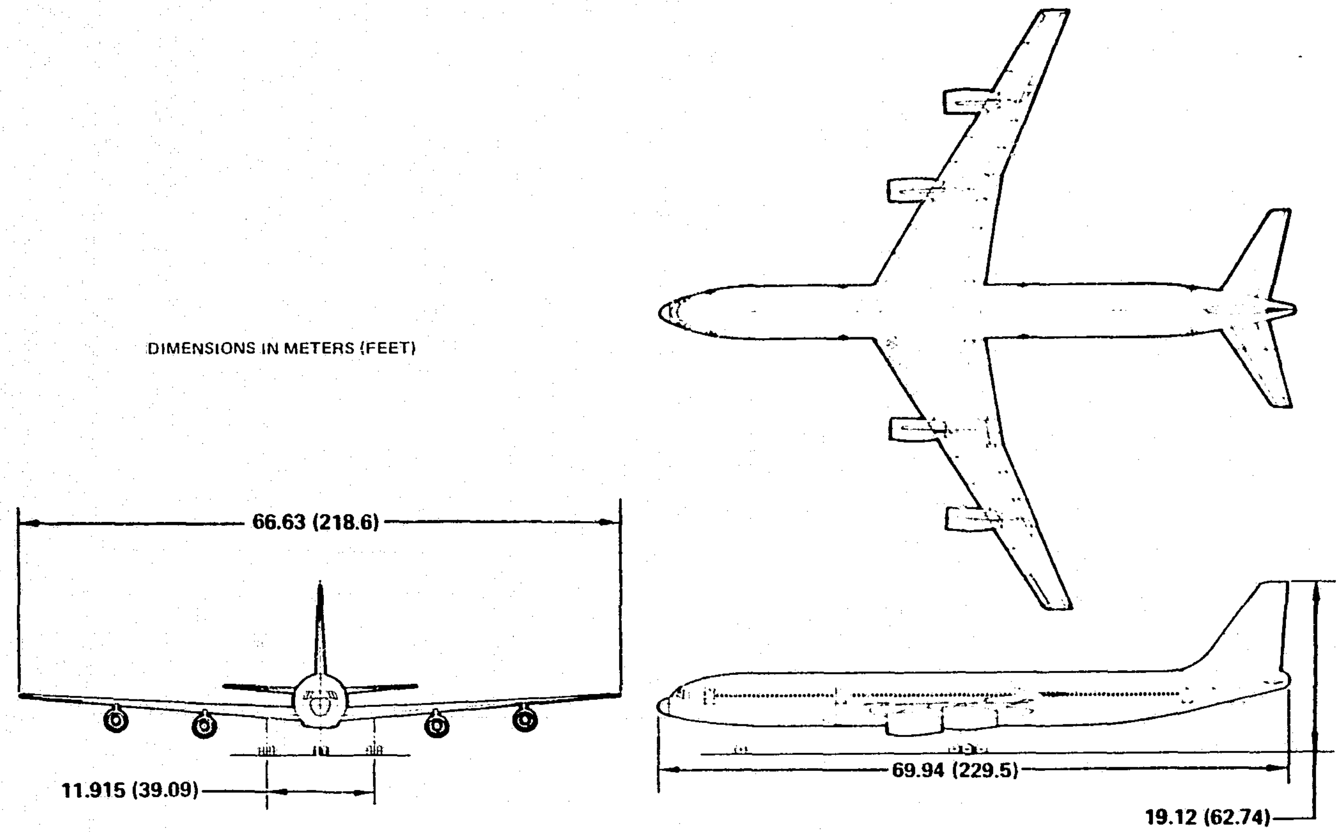


Figure 17 Lockheed Intercontinental Airplane -- Lockheed chose a four wing-mounted-engine configuration for its intercontinental airplane.

Our studies also showed a very large future market for smaller, shorter range airplanes (200 - 250 passengers, less than 5560 km (3000 n.mi.) range), but these airplanes, of which the 767 is a prime example, are scheduled to enter service in the early 1980's. Since these aircraft will not be ready for replacement in the 1990's, they are not considered to represent a practical first application for the Energy Efficient Engine. Later advanced versions of these aircraft will, of course, use engines with Energy Efficient Engine technology.

When replacement aircraft have entered the market, they have been consistently larger than their predecessors, reflecting the natural growth in market demand. Based on this trend, two aircraft, with passenger capacities larger than their present day counterparts, were chosen for the study. The first, a long range, four-engine transport with a nominal capacity of 510 passengers, is envisioned as a 747 (nominal 385 passengers) replacement. The second, a medium range, three-engine transport with a nominal capacity of 440 passengers, is designed for the DC10/L1011 market.

Both airplanes have fuselage widths similar to the Boeing 747. The passenger capacities assume nine abreast seating in tourist and six abreast in first class. The medium range domestic airplane has a 15/85% first class/tourist split, while the intercontinental range airplane has a 10/90% split.

A design cruise speed of Mach 0.8 was chosen as the best compromise between minimizing operating costs and conserving fuel. A summary of the mission and aircraft design criteria is presented in Table 15.

5.1.4.2 Design Features

Both airplane designs incorporate a number of advanced technology features. The chief aerodynamic design feature is an advanced, high aspect ratio, supercritical wing. Use of a supercritical airfoil allows wing thickness to be increased, which in turn reduces the wing weight penalty associated with increased aspect ratio. The wing also features an advanced leading and trailing edge flap system for improved low speed performance.

The structure weights of both airplanes reflect the assumption that composite materials will be used extensively in 1990's airplane designs. Composite materials are assumed for primary and secondary structures.

Active controls are used in the designs to reduce empennage area and to reduce wing loads.

TABLE 15

PRATT & WHITNEY AIRCRAFT MISSION AND SIZING CRITERIA

	Domestic Airplane	Intercontinental Airplane
Design Range, km (n.mi.)	5560 (3000)	10190 (5500)
Passengers (15/85 - 10/90 split)	440	510
Cruise Mach No.	0.80	0.80
Takeoff Field Length, m (ft)	2440 (8000)	3350 (11000)
Approach Speed, m/sec (kts)	69 (135)	69 (135)
Initial Cruise Altitude, m (ft)	10670 (35000)	10060 (33000)
Typical mission for economic evaluation:		
Range, km (n.mi.)	1300 (700)	3700 (2000)
Passengers (55% load factor)	242	281
Cruise Mach No.	0.80	0.80

5.1.4.3 Aircraft Design Point Selection

The design points for domestic and intercontinental airplanes were based on parametric studies conducted during an earlier NASA study, "Turbofan Engines Designed for Low Energy Consumption" (NAS3-19132). Initial cruise altitude determined the engine size required for both JT9D-7A and Energy Efficient Engine powered airplanes, domestic and intercontinental.

5.1.5 Study Aircraft Summary

Summaries of the domestic and intercontinental airplane configurations are presented in Table 16 and Table 17 for each of the three airframe manufacturers and Pratt & Whitney Aircraft.

5.2 ENGINE INTEGRATION CONSIDERATIONS

5.2.1 Installation Geometry Ground Rules

The three airframe manufacturers (Boeing, Douglas, Lockheed) each developed installation ground rules for mounting a mixed-flow, long-duct engine on their advanced airplanes. These ground rules incorporate each airframe manufacturer's best compromise among a number of such conflicting considerations as interference aerodynamics, wing flutter, jet wake impingement, pylon weight, and ground clearance.

TABLE 16

DOMESTIC AIRPLANE DEFINITIONS SUMMARY

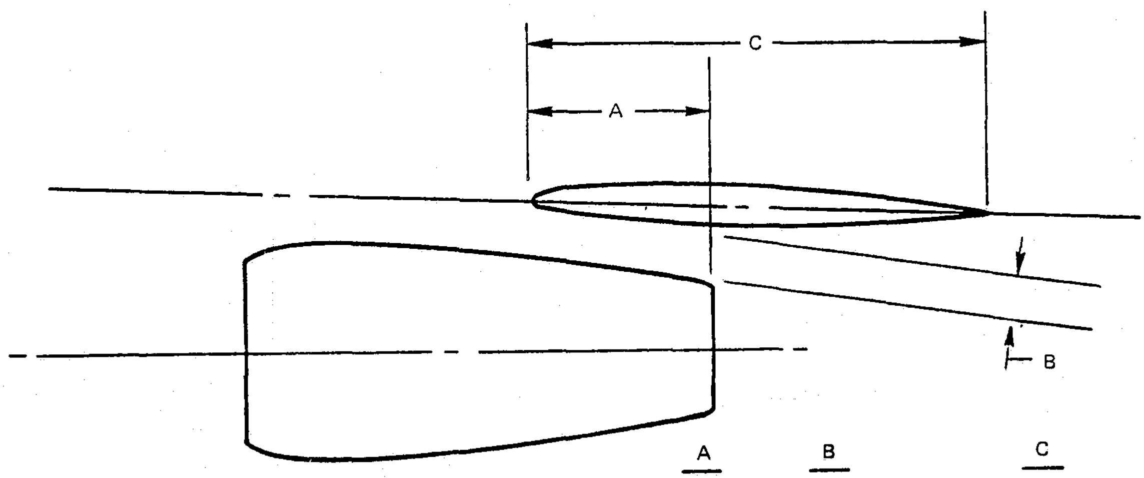
	BOEING	DOUGLAS	LOCKHEED	P&WA
TYPE	TWIN	TRIJET	TRIJET	TRIJET
IN SERVICE DATE	1990'S	1990'S	1990'S	1990'S
DESIGN RANGE ~ km (NM)	3700 (2000)	5560 (3000)	5560 (3000)	5560 (3000)
PASSENGERS	196	458	500	440
CRUISE SPEED ~ MACH NO.	0.8	0.8	0.8	0.8
FIELD LENGTH ~ m (FT)	1830 (6000)	2440 (8000)	2130 (7000)	2440 (8000)
CRUISE ALTITUDE ~ m (FT)	10670 (35000)	10060 (33000)	10670 (35000)	10670 (35000)
WING LOADING ~ $\frac{kg}{m^2}$ $\left(\frac{LBM}{FT^2}\right)$	439.4 (90.0)	522.4 (107.0)	560.5 (114.8)	569.4 (116.6)
ASPECT RATIO	10.24	9.83	10	12
TYPICAL RANGE ~ km (NM)	1850 (1000)	1850 (1000)	2590 (1400)	1300 (700)
TYPICAL PAYLOAD ~ %	55	60	55	55

TABLE 17

INTERCONTINENTAL AIRPLANE DEFINITIONS SUMMARY

	DOUGLAS	LOCKHEED	P&WA
TYPE	TRIJET	QUADJET	QUADJET
IN SERVICE DATE	1990'S	1990'S	1990'S
DESIGN RANGE ~ km (NM)	10190 (5500)	12040 (6500)	10190 (5500)
PASSENGERS	438	500	510
CRUISE SPEED ~ MACH NO.	0.8	0.8	0.8
FIELD LENGTH ~ m (FT)	3350 (11000)	3050 (10000)	3350 (11000)
CRUISE ALTITUDE ~ m (FT)	9450 (31000)	10360 (34000)	10060 (33000)
WING LOADING ~ $\frac{kg}{m^2}$ $\left(\frac{LBM}{FT^2}\right)$	670.9 (137.4)	644.6 (132.0)	673.8 (138.0)
ASPECT RATIO	9.83	10	12
TYPICAL RANGE ~ km (NM)	2780 (1500)	5560 (3000)	3700 (2000)
TYPICAL PAYLOAD ~ %	60	55	55

A composite of the wing-engine placements envisaged by each of the airframe manufacturers for the Energy Efficient Engine is presented in Figure 18. The variations in engine location from company to company are due to a number of factors, the primary one being the different relationships among the installation considerations (drag, weight, flutter, etc.) for different airplanes. Interference drag and wing



	A	B	C
BOEING	0.4 C	0.1 C	WING CHORD LENGTH
DOUGLAS	0.29C	0.13C	WING CHORD LENGTH
LOCKHEED	0.17C	0.17C	WING CHORD LENGTH

Figure 18 Wing-Engine Placement Summary -- The variations in engine location are due to differences in such considerations as drag, weight, and flutter for the different airplanes.

flutter are especially sensitive to individual design details. Airplane size and configuration are also factors: a smaller airplane has less wing-ground clearance, requiring the engine to be mounted closer to the wing. Comparing the 200-passenger Boeing twinjet installation with the 400/500-passenger Douglas and Lockheed trijet installations illustrates this point.

Since Douglas and Lockheed each had trijet airplanes, they also evaluated tail installations. These installations followed DC10 and L1011 practice, respectively, as can be seen in their configuration drawings (Figures 10, 11, 16, 17).

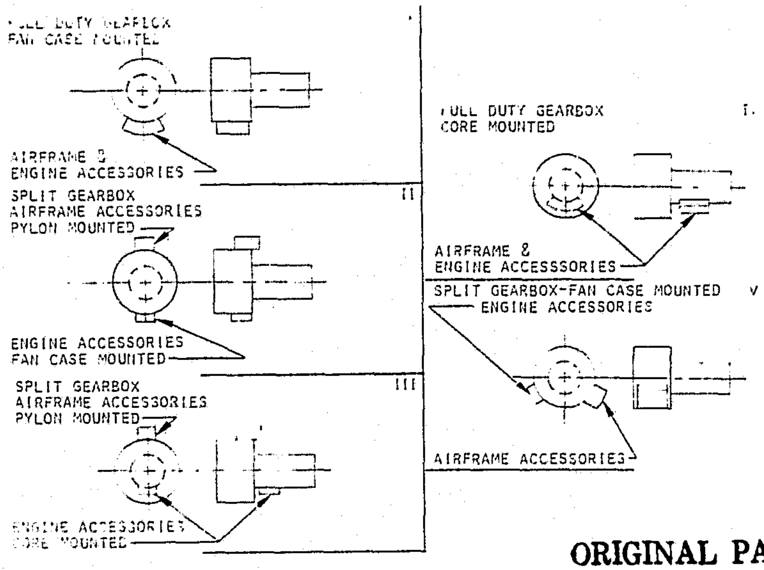
5.2.2 Engine and Airframe Accessory Location Assessments

Each of the airframe manufacturers assisted in the design of the nacelle during the Energy Efficient Engine Preliminary Design task (described in detail in Propulsion System Preliminary Design and Analysis Report, Reference 1). As part of this study, the airplane companies each performed a qualitative analysis of the merits of various accessory locations. These analyses are summarized in Table 18.

Results of a Pratt & Whitney Aircraft study on accessory locations, including some special concerns relating to the shroudless fan design, are also shown on this table. Preliminary design studies have

TABLE 18

ACCESSORY LOCATION STUDY SUMMARY



ORIGINAL PAGE IS OF POOR QUALITY

Number	Accessory Type & Location	Boeing Comments	Douglas Comments	Accessory Type & Location	Lockheed Comments	P&WA Comments
I	Full Duty on Fan Case Bottom	o Possible Fuel Spill Problem o Good Accessibility	o Perferred Location		o Good Accessibility o Acceptable Location	o Fan 2E Problem
II	Split - Airframe - Pylon Engine - Fan Case Bottom	o Split Accessories Unacceptable to Some Airlines	o Very Poor Accessibility o Unacceptable		o Good Aero Shape Nacelle o Requires Additional Work Stands	o Fan 2E Problem
III	Split - Airframe - Pylon Engine - Core	o Split Accessories Unacceptable to Some Airlines	o Very Poor Accessibility o Unacceptable		o Good Aero Shape Nacelle o Requires Additional Work Stands o Possibility	o Acceptable
IV	Full Duty on Core	o Hot Environment o Good Performance o Acceptable	o Poor Accessibility o Hot Environment		o Hot Environment o Poor Accessibility	o Reduces Accessibility to Engine o Acceptable
V	Split - Airframe - Fan Case Engine - Fan Case (120° Apart)	o Good Environment o Good Accessibility o Possible Drag and Weight Penalties o Split Accessories Unacceptable to some Airlines	o Good Accessibility o Possible Drag and Weight Penalties o May be Acceptable			o Requires Tailored Exit Guide Vanes in Fan Case o Acceptable

indicated that the fan may be sensitive to 2E (twice per revolution) disturbances, such as would be caused by two flow blockages 180 degrees apart and located a short distance downstream of the fan. Since the engine mounting system requires a wide (about 20 cm) strut at the top (or 12:00 position), it is desirable to avoid another wide strut, as would be required by a towershaft, at the bottom (or 6:00 position). Hence, accessory locations that require a towershaft through the fan duct at the 6:00 position are indicated as potential fan problems in Table 18.

These assessments indicate at least three accessory locations are acceptable to one or more of the airplane companies and also satisfy the fan 2E considerations: (III) pylon-mounted airframe accessories with core-mounted engine accessories, (IV) full-duty core-mounted accessories, (V) airframe and engine accessories mounted 120 degrees apart on fan case. The full-duty core-mounted accessory configuration was chosen for use in this study in order to have a common configuration for comparison purposes. In practice, however, accessory location would be determined by each airframe manufacturer to match each particular engine application.

5.2.3 Reverse Thrust Requirements

Reverse thrust level and directivity requirements are dependent on the airplane configuration. Figure 19 shows the Douglas trijet requirements (Lockheed trijet requirement is similar), and Figure 20 shows Boeing twinjet requirements. Reverse thrust directivity is necessary to prevent reingestion of engine exhaust, to avoid interference with control surfaces, and to prevent impingement of exhaust on airplane. The nacelle was designed with 12 replaceable fan

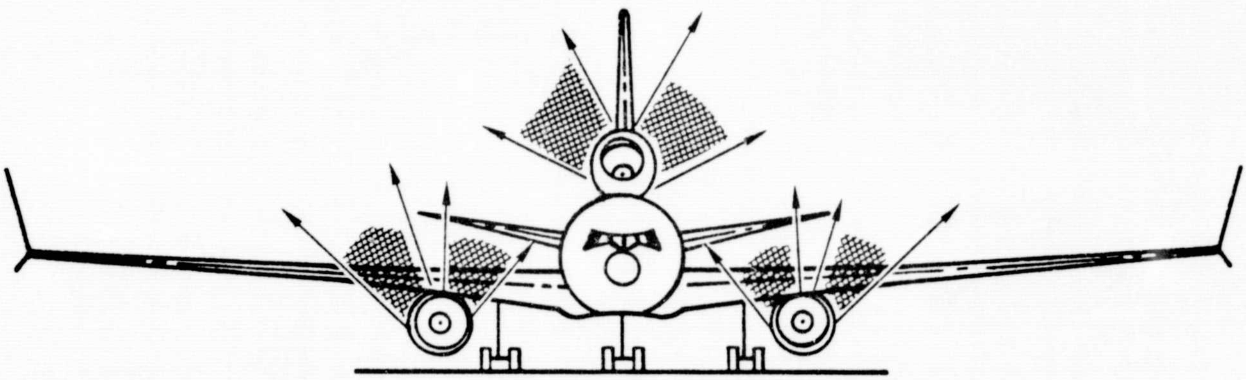


Figure 19 Douglas Trijet (Typical) Reverse Flow, Directivity Requirements (Lockheed Trijet Requirements are similar) -- Reverse thrust level and directivity requirements are dependent on airplane configuration.

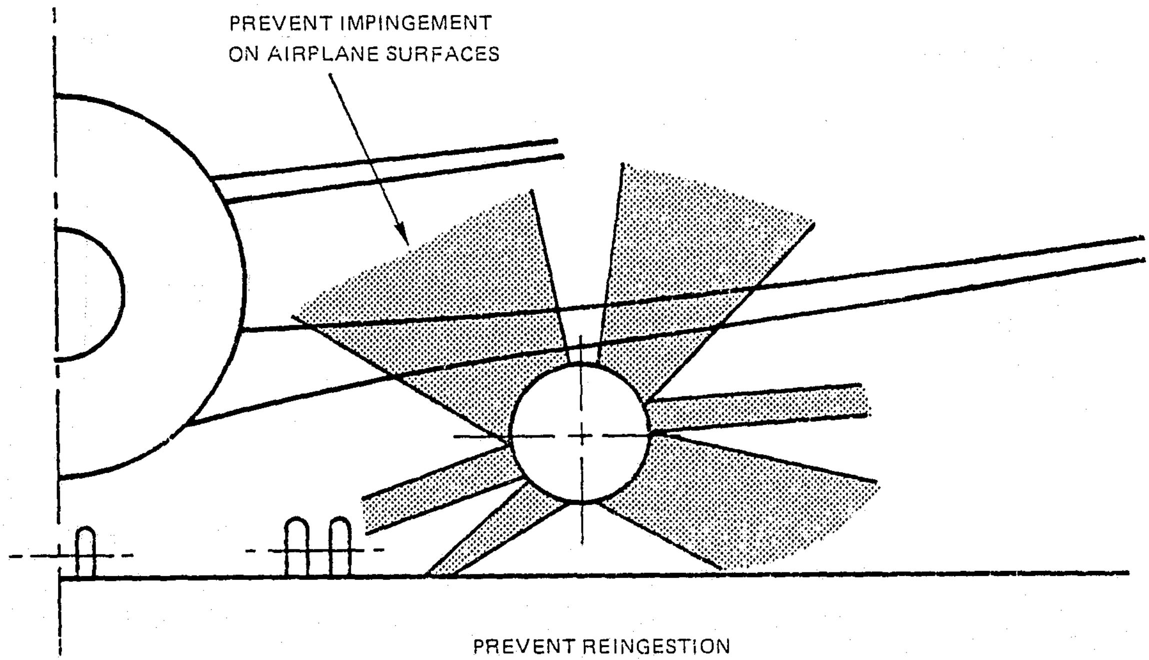


Figure 20 Boeing Twinjet Reverse Flow Directivity Requirements -- Energy Efficient Engine Nacelle was designed with twelve replaceable fan duct reverser cascade sections, permitting flow to be matched to the application.

duct reverser cascade sections in order to allow matching the reverse flow to the application.

The required levels of reverse thrust are more difficult to predict, since they can vary according to airline practice. Lockheed and Douglas have indicated that a reverse thrust level of about 35 to 40 percent of forward thrust would be appropriate. Figure 21 shows that the reverse thrust capability of the Energy Efficient Engine exceeds 35 percent to speeds less than 26 m/sec (50 knots). This performance is achieved without reversing the primary stream and without overspeeding the low pressure rotor or violating low pressure compressor surge margin requirements. Since the Energy Efficient Engine is a mixed-flow engine and the reverse blocker doors are upstream of the mixer, the effective nozzle area seen by the primary stream in reverse mode is uncertain. The performance shown in Figure 22 represents the most pessimistic case, where the primary flow fills only the primary mixer area and therefore actually provides some forward thrust. A ten percent leakage of duct flow past the blocker doors was assumed for this figure.

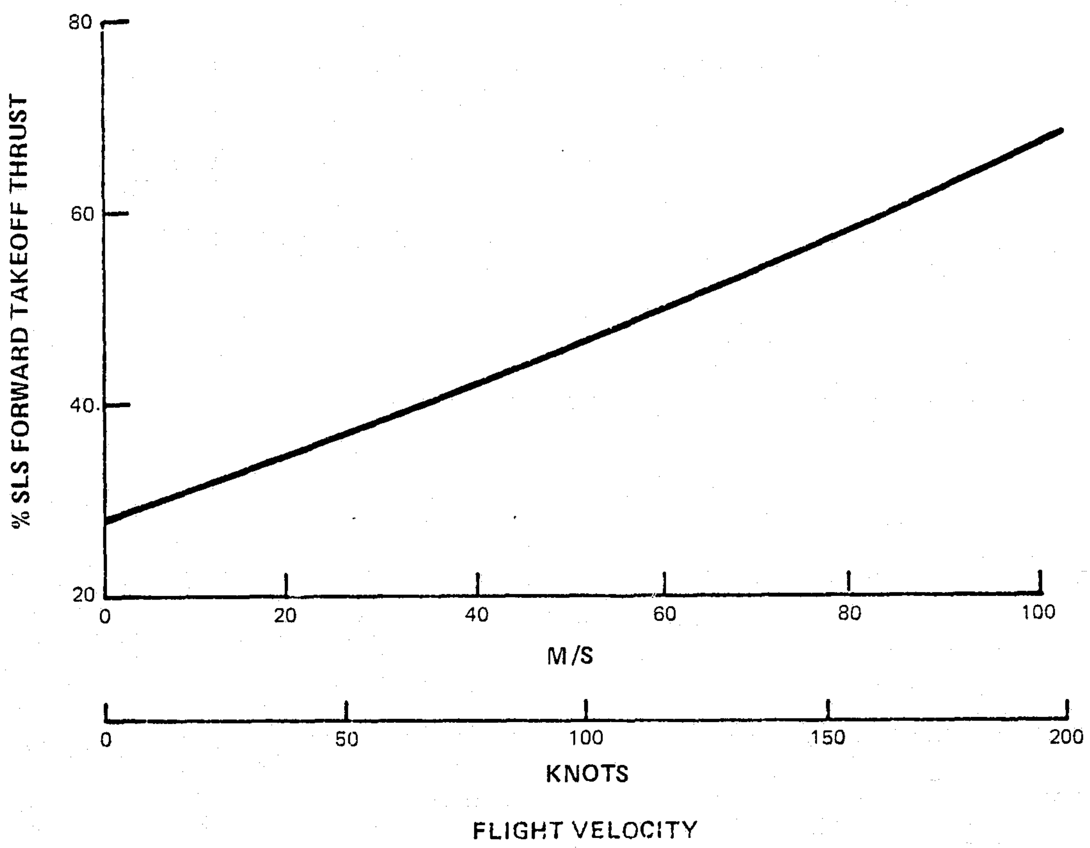


Figure 21 STF505M-7D Reverse Thrust Capability (Sea Level Std + 14°C, 10% Leakage) -- Reverse thrust capability exceeds 35 percent down to speeds close to twenty meters per second.

5.2.4 Customer Bleed and Horsepower Extraction

Bleed and horsepower extraction requirements were evaluated by each of the three airplane companies and by Pratt & Whitney Aircraft. Energy Efficient Engine and the JT9D-7A engine data packs provided to each airplane company included the bleed schedule shown in Figure 22 and a power extraction of 113 kW (151 hp) at all conditions. Bleed and horsepower influence coefficients for thrust and specific fuel consumption were also included in the data packs, permitting the engine performance to be modified to reflect specified requirements. The bleed requirements assessed by each airplane company are shown in Figure 23. Typical cruise power extraction requirements were assessed as 67 kW (90 hp) per engine by Boeing and 79 kW (106 hp) by Douglas. For the purposes of this study, Lockheed chose to use the bleed and horsepower levels provided by Pratt & Whitney Aircraft, and Boeing and Douglas chose to modify the engine performance to reflect the schedules shown in Figure 23.

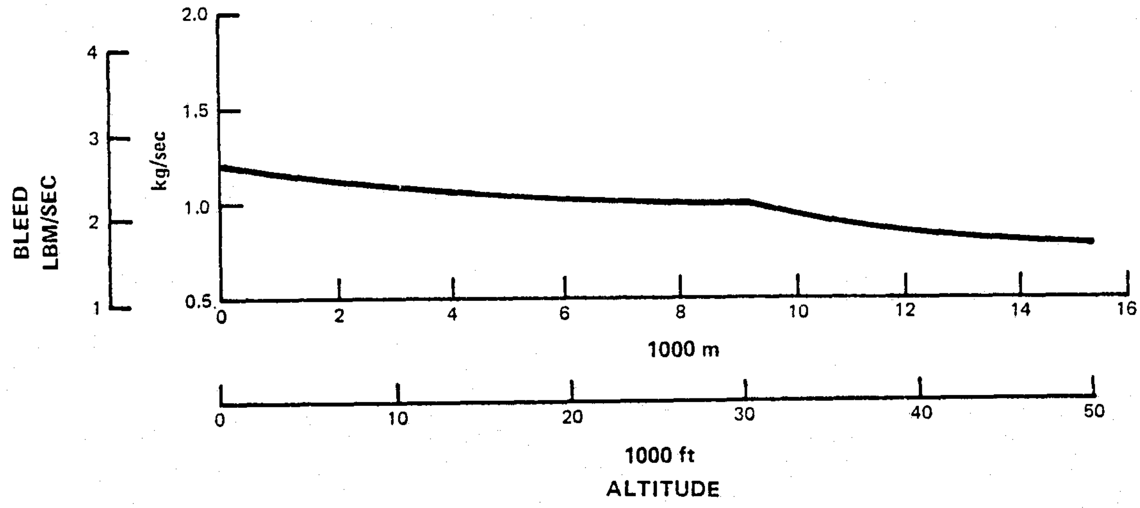


Figure 22 Customer Bleed Schedule, STF505M-7 Data Pack -- Bleed and power extraction influence coefficients for thrust and specific fuel consumption were included in the data pack to permit the performance to be modified for specific requirements.

5.3 AIRPLANE-ENGINE PERFORMANCE COMPARISON

The three airplane companies and Pratt & Whitney Aircraft evaluated the mission performance of both the Energy Efficient Engine and the JT9D-7A reference engine. The evaluation was based on the airplanes and missions described in Section 5.1 and the Pratt & Whitney Aircraft provided isolated nacelle engine data, modified and installed as described in Section 5.2.

5.3.1 Airplane Performance Evaluation

The following procedure is reasonably typical of that used by Pratt & Whitney Aircraft and the airplane companies to evaluate airplane performance for this study. The airplanes and missions are defined first. Next, the aerodynamic and weight methods, including scaling functions, are chosen consistent with the technology levels assumed for each airplane--these methods are unique to each company. The engine data provided by Pratt & Whitney Aircraft is then translated to a form suitable to each company's mission analysis program, including changes to customer bleed and/or horsepower extraction levels. Weight and aerodynamic penalties unique to each engine, such as interference

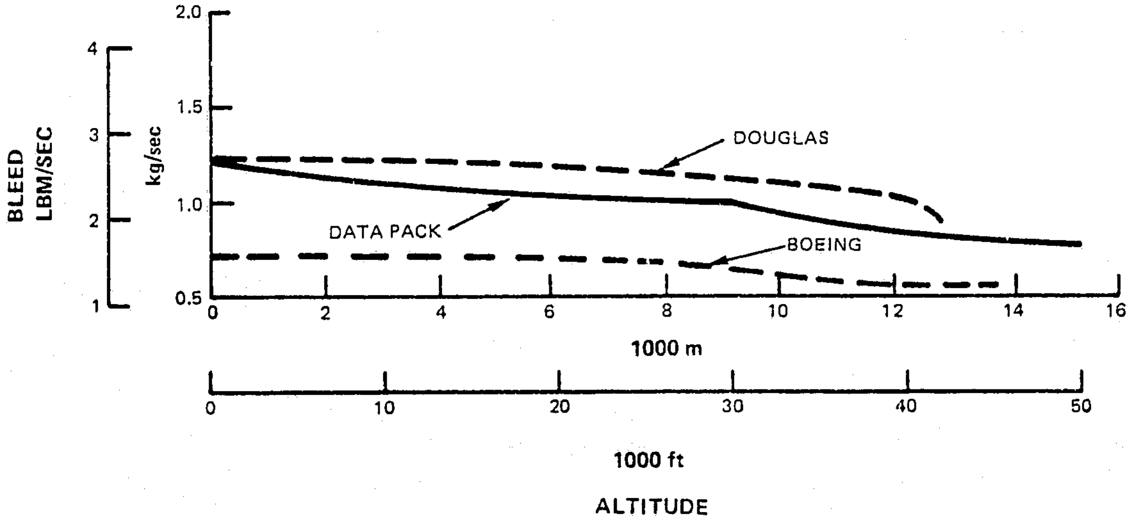


Figure 23 Normal Customer Bleed Requirements (anti-icing not included) -- Bleed and power requirements assessed by the airplane companies were similar to those assumed by Pratt & Whitney Aircraft.

drag and pylon weight are assessed, and engine and nacelle weights are included. Next, a takeoff gross weight (TOGW) is assumed and airplane component and engine sizes and weights determined from the sizing conditions (e.g., takeoff field length, minimum cruise altitude, wing loading). Airplane operating empty weight OEW can then be obtained and available fuel load determined by subtracting the OEW and payload from the TOGW.

The ability of this size airplane to perform the design mission is then assessed: The airplane is "flown" through the simulation of the design mission profile in order to determine if there is sufficient fuel, including reserves, at the assumed TOGW to fly the design range. If the range that can be flown with the available fuel is greater or less than the design range, a new TOGW is assumed, the airplane and engine are resized, new OEW and fuel available are calculated, and the mission is "reflown". This process is repeated until the range flown with available fuel (minus reserves) exactly matches the design range, determining the design TOGW and engine size, OEW, and airplane component weights and sizes.

Once sized for the design mission, the airplane can be "flown" on a typical mission. The typical mission is of primary importance in assessing the merits of an engine or airplane because it represents the average mission an airplane of this passenger capacity and range would fly in actual airline operation. Thus, the typical mission performance (fuel burned, operating costs) of the airplane more closely simulates the experience of an airline operating a fleet of these airplanes than does design mission performance. Definitions of typical missions for each airplane were presented in Section 5.1.

If any of the airplane design parameters, such as wing loading (TOGW/wing area) or thrust loading (total thrust/TOGW), are to be optimized, the process described above is repeated many times, and minimums of the chosen figure-of-merit (usually DOC or fuel burned) are determined. Each of the airplanes used by the airplane companies in this evaluation represent minimum fuel burned and/or DOC designs.

5.3.2 Airplane Peformance Results

Comparisons of the design mission takeoff gross weights for Energy Efficient Engine (STF505M-7D) and JT9D reference* engine powered airplanes are shown in Figure 24, Figure 25, Figure 26 and Figure 27. In all cases the reduction in total fuel (mission plus reserves) is the primary contributor to the TOGW advantage of the Energy Efficient Engine. Thus aircraft that have small design fuel fractions (total fuel/TOGW) tend to demonstrate less TOGW advantage for the Energy Efficient Engine.

The Pratt & Whitney Aircraft domestic and intercontinental study airplanes are used in Table 19 to further illustrate the effects of the Energy Efficient Engine on aircraft weight. The improved performance of this engine causes reductions in most structural component weights.

Figure 28 shows the takeoff thrust size required by each of the Energy Efficient Engine powered aircraft. For the PS-AIE evaluations, the engine is treated as a "rubber" engine: one scalable to any size. The takeoff thrust rating of the base size STF505M-7D is 182.8 kN (41,000 lbf). Except for the Douglas intercontinental airplane, thrust requirements are clustered in a band from 164 kN to 182 kN (32,000 lbf to 41,000 lbf)--the Douglas airplane is the only trijet among the intercontinental airplanes, accounting for its much larger thrust. Because of the advanced technologies included in both the airplanes and their flight propulsion systems, the levels of thrust required by these advanced airplanes are considerably lower than that of current airplanes of comparable payload and range.

---

*Lockheed, Boeing, and P&WA used the JT9D-7A engine with the 747-200 type nacelle as reference engine, Douglas used the JT9D-20 with DC10-40 type nacelle. The JT9D-20 is essentially the same as the -7A, except for accessory location.

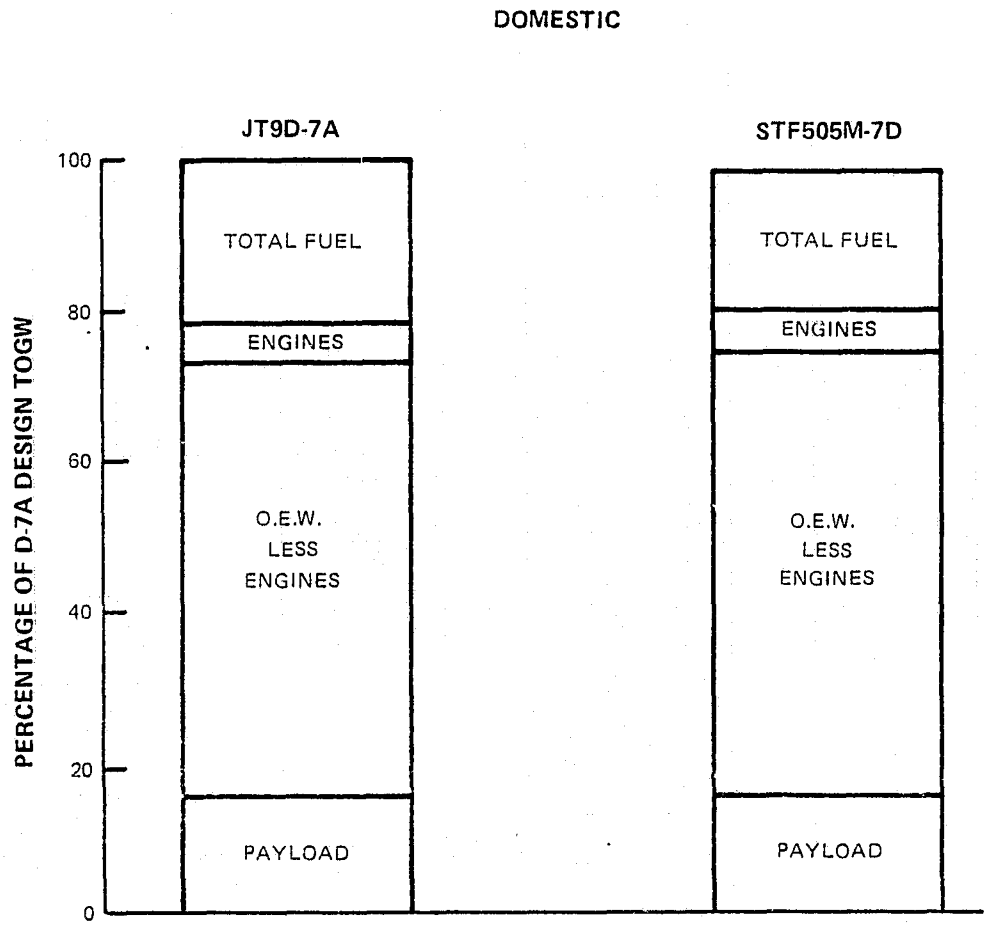


Figure 24 Boeing Airplane Weight Breakdown -- Boeing twinjet has lowest fuel fraction of the study airplanes.

The mission fuel-burned advantage of the Energy Efficient Engine compared with the JT9D-7A reference engine is shown in Figure 29 for design missions and in Figure 30 for typical missions. The results correlate well with design fuel fraction. Table 20 shows a mission segment breakdown of the Energy Efficient Engine fuel burned savings for P&WA study aircraft on typical missions. The large advantage of Energy Efficient Engine over the reference engine at off design flight conditions is evident in this Table. Overall, fuel-burned reductions vary from 13.5 percent for the Boeing twinjet on a typical mission to over 18 percent for the Lockheed and Pratt & Whitney Aircraft intercontinental airplanes and the Douglas domestic airplane on design missions. Average fuel-burned reduction is 16.6 percent on typical missions and 17.3 percent on design missions.

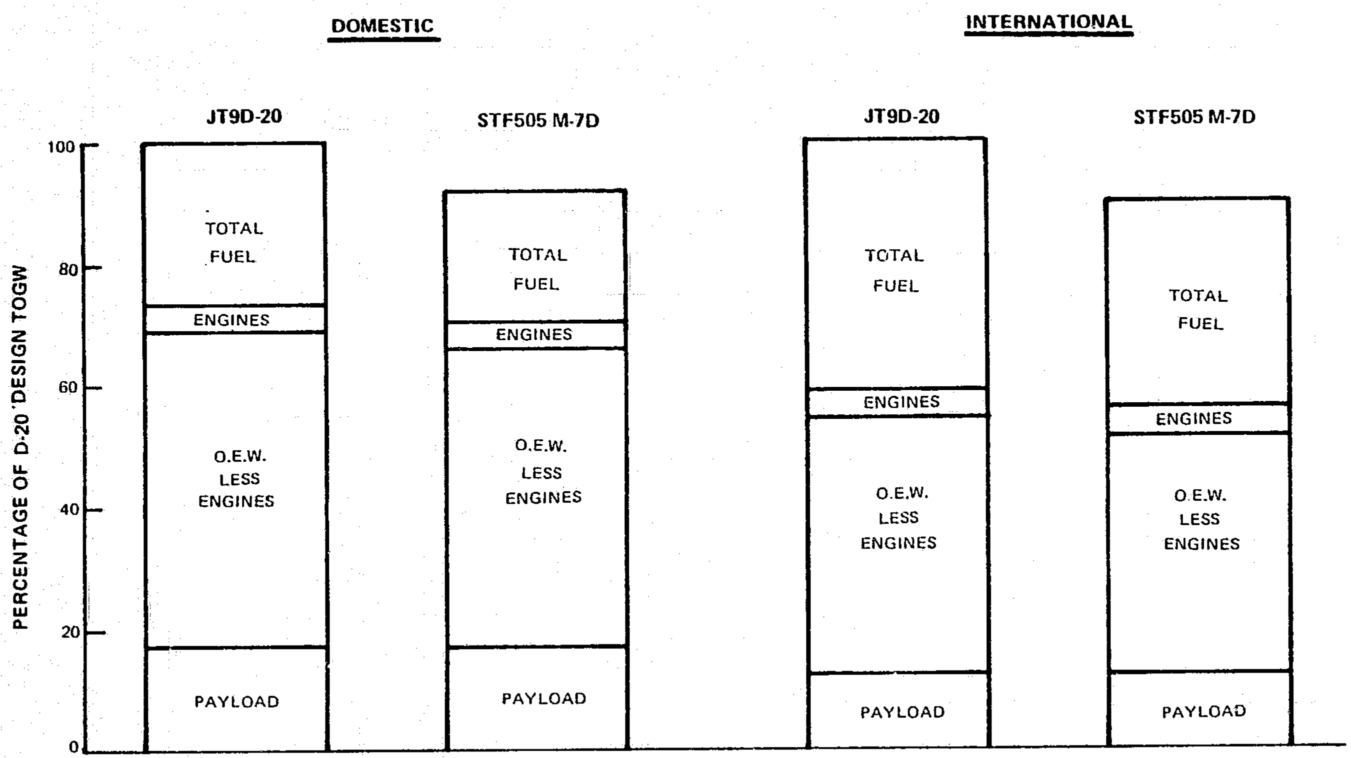


Figure 25 Douglas Airplane Weight Breakdown -- Douglas used the JT9D-20 engine with the DC10-40 nacelle as the reference engine/nacelle. the JT9D-20 is essentially the same as the JT9D-7A, differing in accessory location and nacelle design.

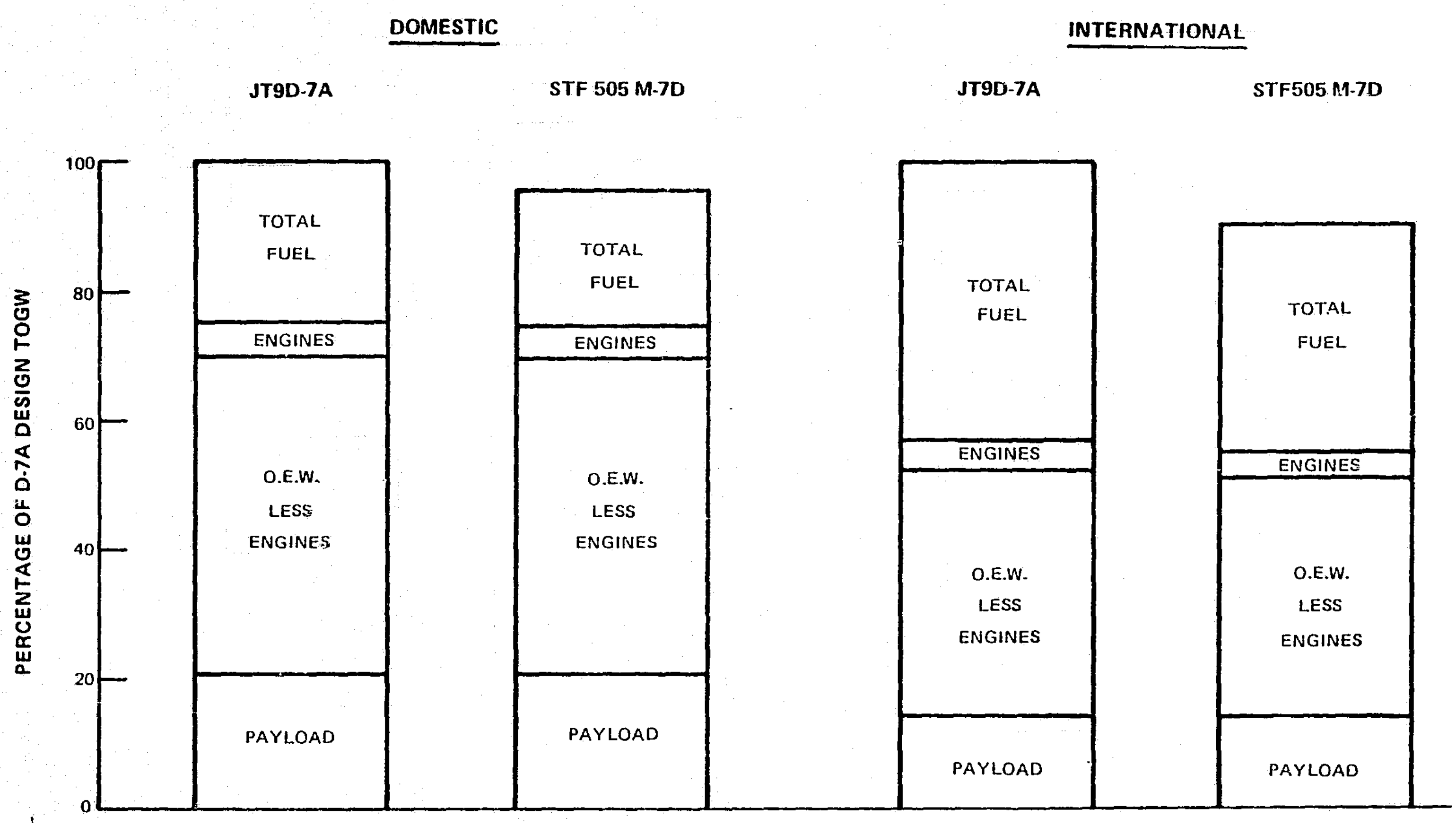


Figure 26 Lockheed Airplane Weight Breakdown -- The 12040 km design range intercontinental airplane has a much larger fuel fraction than the 5560 km domestic airplane.

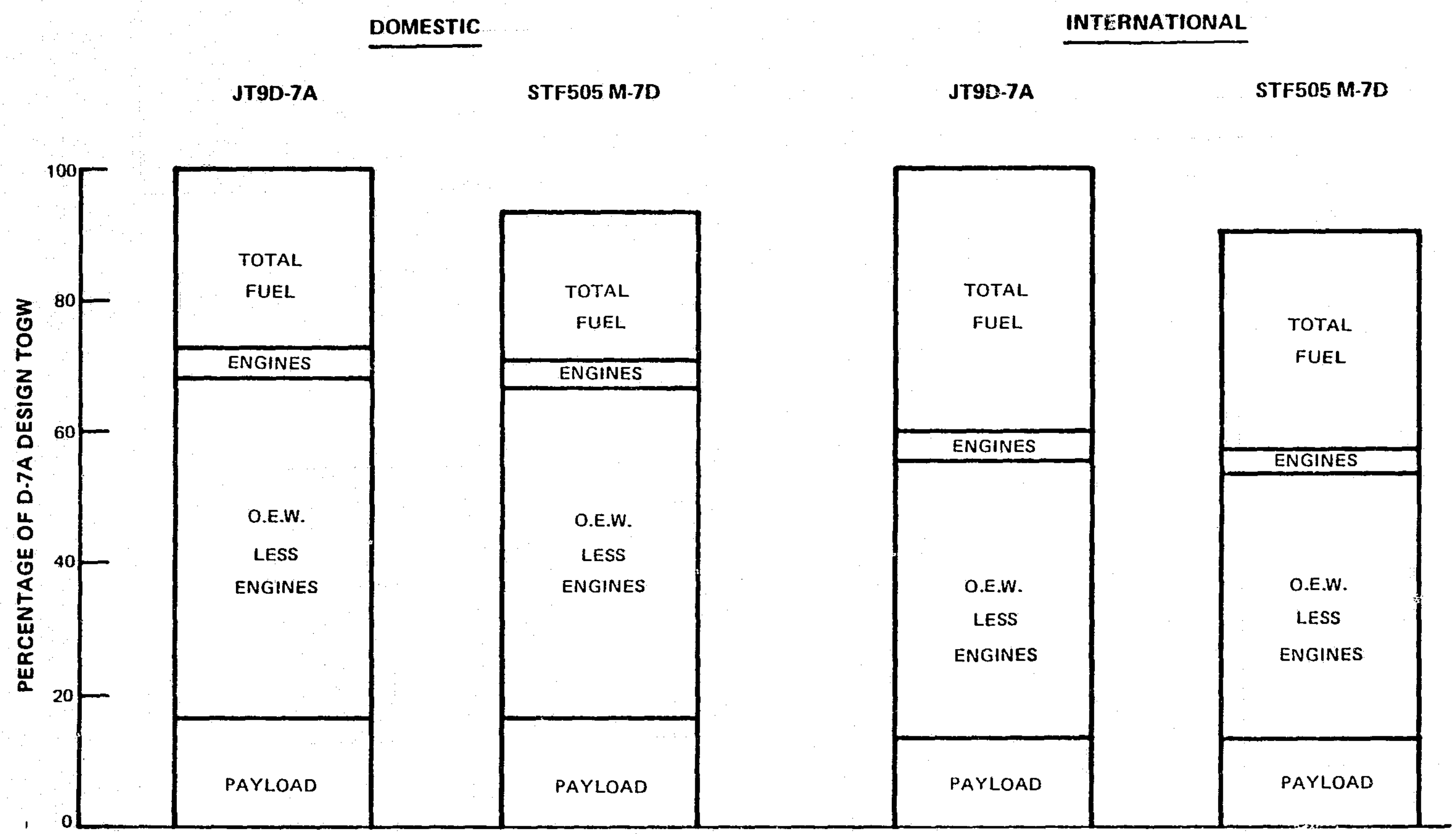


Figure 27 P&WA Aircraft Weight Breakdown -- Weight breakdowns of P&WA airplanes are similar to those of Douglas airplanes, especialy in the case of the domestic trijet.

TABLE 19

P&WA AIRPLANE WEIGHT BREAKDOWNS

	DOMESTIC				INTERCONTINENTAL			
	JT9D-7A		STF505 M-7D		JT9D-7A		STF505 M-7D	
	kg	(lbm)	kg	(lbm)	kg	(lbm)	kg	(lbm)
Wing	34024	(75009)	31535	(69523)	48017	(105859)	42866	(94503)
Fuselage	28648	(63157)	28543	(62925)	31609	(69686)	31552	(69560)
Empennage	3309	(7296)	3103	(6840)	4354	(9599)	3921	(8645)
Alighting Gear	12534	(27632)	12159	(26806)	15852	(34947)	15149	(33398)
Propulsion	19594	(43198)	17522	(38628)	26490	(58399)	23372	(51526)
Fixed Equip. & Systems	28499	(62828)	28206	(62182)	34070	(75111)	33514	(73886)
MEW	126608	(279120)	121067	(266904)	160392	(353601)	150376	(331518)
Std. & Oper. Items	12662	(27915)	12618	(27818)	17000	(37478)	16870	(37192)
OEW	139270	(307035)	133685	(294722)	177392	(391079)	167246	(368710)
Passengers & Baggage	40914	(90200)	40914	(90200)	49159	(108375)	49159	(108375)
Fuel	67014	(147739)	55784	(122981)	153243	(337839)	125126	(275852)
TOGW	247199	(544974)	230383	(507903)	379794	(837293)	341530	(752937)

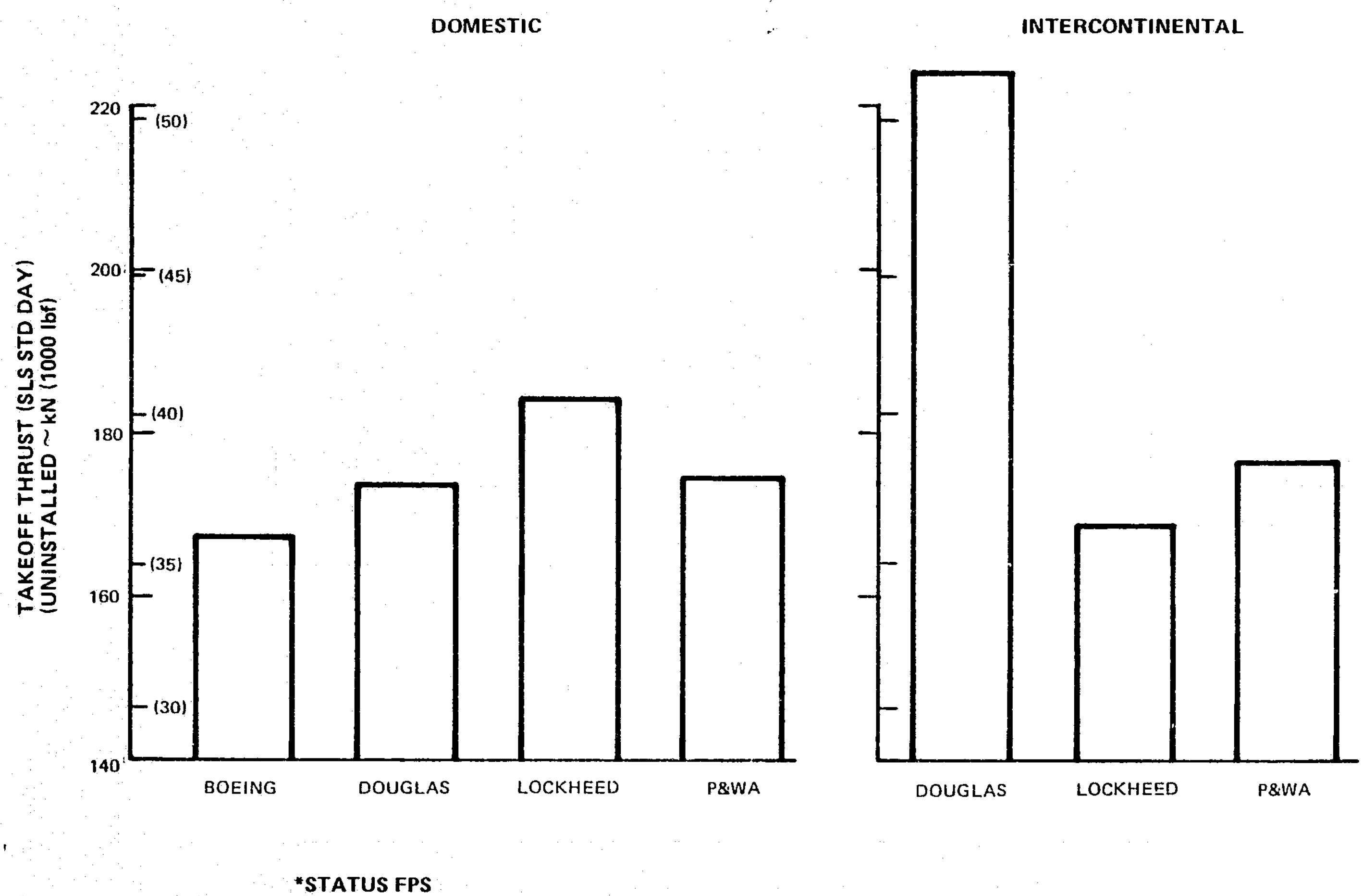


Figure 28 Thrust Size Required for Each Energy Efficient Engine Powered Aircraft -- For the evaluation, the engine was assumed scaleable to any size.

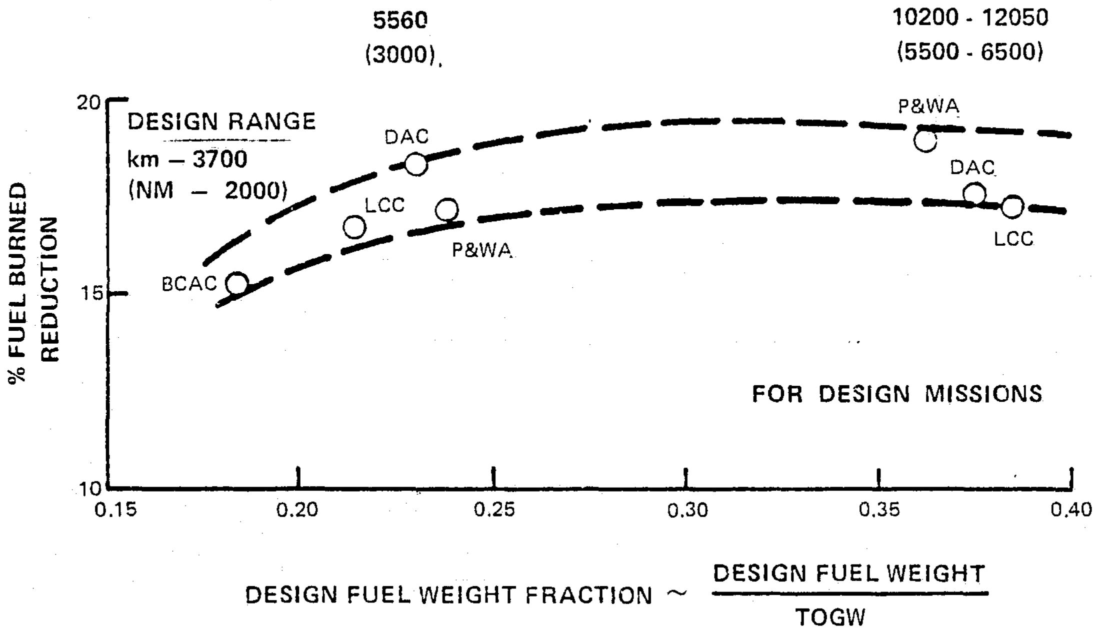


Figure 29 Fuel Savings Relative to the JT9D-7A Powered Aircraft (Design Mission) -- The advantage in fuel savings tends to peak and then level off because the STF505M-7D engine has its biggest advantage during climb and descent.

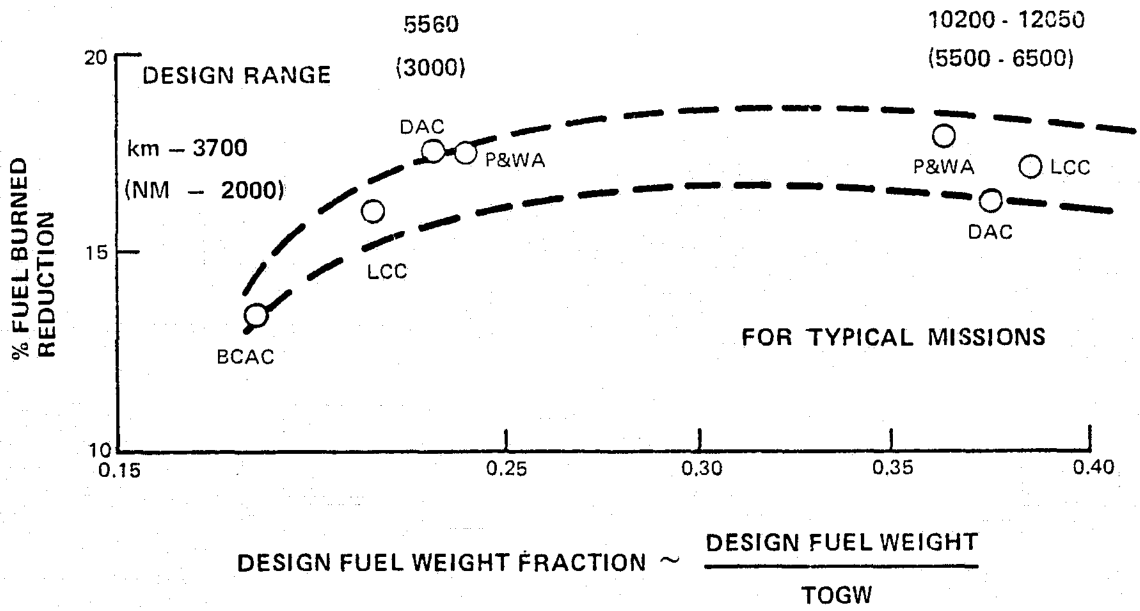


Figure 30 Fuel Savings Relative to the JT9D-7A Powered Aircraft (Typical Mission) -- The advantage of the STF505M-7D tends to peak and then level off because its biggest advantage is during climb and descent, not during cruise. As a result the effects of increased fuel fraction is somewhat offset at longer ranges.

TABLE 20

ENERGY EFFICIENT ENGINE FUEL BURNED ADVANTAGE BREAKDOWN

2000 n.mi. Mission - P&WA Intercontinental Airplane

	JT9D-7A			STF505 M-7D			%Δ
	Distance km	Fuel kg	Fuel/Km kg/km	Distance km	Fuel kg	Fuel/km kg/km	Fuel/km
Taxi & Takeoff	-	1954	-	-	1280	-	
Climb	282	6512	23.09	317	5638	17.79	-23.0
Cruise	3213	30597	9.52	3197	25308	7.92	-16.8
Descent	209	751	3.59	190	431	2.27	-36.8
Total Mission	3704	39814	10.75	3704	32656	8.82	-18.0
Reserves	-	13590	-	-	11159	-	

700 n.mi. Mission - P&WA Domestic Airplane

	JT9D-7A			STF505 M7D			%Δ
Taxi & Takeoff	-	1225	-	-	817	-	
Climb	295	4967	16.84	351	4578	13.04	-22.6
Cruise	796	5938	7.46	757	4745	6.27	-16.0
Descent	205	550	2.68	188	308	1.64	-38.8
Total	1296	12679	9.78	1296	10448	8.06	-17.6
Mission Reserves	-	10685	-	-	9001	-	

6.0 ECONOMIC EVALUATION

Airline operating economics for the Energy Efficient Engine and the JT9D-7A reference engine were determined by combining the results of the airplane performance evaluation provided by the airframe manufacturers with the engine price and maintenance cost estimated by Pratt & Whitney Aircraft. The economic advantages of the Energy Efficient Engine were then determined by comparing the results obtained for the two engines. The NASA-approved economic model was used for this effort.

6.1 ECONOMIC MODEL DESCRIPTION

The Air Transport Association's (ATA) operating cost method, its formulas modified to reflect current airplane technology and airline environments, was used for the economic evaluation. The ATA method was originally published in 1967. The formula modifications were based on a 1977 Boeing update.

The elements of which direct operating cost (DOC) and indirect operating cost (IOC) are composed are presented in Table 21; the parameters controlling these elements are also identified. DOC includes most elements of operating cost directly influenced by airplane and/or engine performance. All other airline operating costs are included in IOC. Important assumptions upon which the economic evaluation was based are shown in Table 22.

6.1.1 Direct Operating Cost Model

This section discusses the effect of each DOC element on the Energy Efficient Engine/JT9D-7A comparison. The Pratt & Whitney Aircraft domestic trijet study airplane on a typical 1300 km (700 N.Mi.) mission is used to illustrate each effect. The overall DOC of this airplane with either STF505M-7D or JT9D-7A engines is compared in Figure 31.

Flight crew cost, which includes both wages and fringe benefits, varies with airplane design speed, utilization, size of crew, and with takeoff gross weight. Since both STF505M-7D and JT9D-7A airplanes use three-man crews and have a design speed of Mach 0.8, crew size and speed does not affect the comparisons. Utilization, shown in Figure 32, is also essentially the same for both engines on the same airplane and trip distance. Crew cost is, therefore, a function of TOGW only. Figure 33 shows the effect of TOGW on DOC; costs are per block hour and are shown as a percent of the total DOC of the JT9D-7A powered airplane.

Fuel cost reflects fuel burned on the mission (see Section 5.3) and fuel price. Fuel prices of 10.6¢/liter (40¢/gal.) domestic and

TABLE 21

AIRLINE OPERATING COST MODEL ELEMENTS

ELEMENTS	FUNCTION OF
Direct Operating Costs	
Flight Crew	TOGW, Speed, Utilization
Fuel	Block Fuel, Fuel Price
Airframe Maintenance	
Material	Airframe Weight, Flight Length
Labor	Airframe Weight, Flight Length
Engine Maintenance	
Material	Engine, Engine Size, Flight Length
Labor	Engine, Engine Size, Flight Length
Maintenance Burden	Airframe and Engine Maint. Labor
Insurance	Airplane and Engine Price, Utilization
Depreciation	Airplane and Engine Price, Utilization
Indirect Operating Costs	
Ground Property & Equipment	Max Landing Weight, Block Time
Airplane Related Costs	Max Landing Weight, No. of Seats, Block Time
Passenger Related Costs	No. of Passengers, Block Time
Cargo Related Costs	Tons of Cargo, Block Time
General and Administrative	Max Landing Weight, Operating Costs, Block Time

TABLE 22

ECONOMIC MODEL ASSUMPTIONS

- Dollars - 1977
- Flight Crew - 3 People
- Fuel Price - 10.6¢/liter (40¢/gal) Domestic, 11.9¢/liter 45¢/gal Intercontinental
- Maintenance - Labor Rate = $9.70/hr.
- Maintenance Burden - 200% of Labor Cost
- Non-Revenue Flying - 2% Factor Added to Fuel and Maintenance
- Ground Time - 15 min. Domestic, 20 min. International
- Insurance - 0.5% Fly-Away Cost Per Year
- Spares - 6% Airframe, 30% Engine
- Depreciation - 15 Year Straight Line to 10% Residual Value
- Utilization - (see Figure 32)

11.9¢/liter (45¢/gal.) international are used to represent 1985 prices expressed in 1977 dollars. Trip fuel and time used in economic calculations (referred to as block fuel and time) include standard ATA allowances and ground idle and taxi allowances derived from current airline experience (Table 22). Relative fuel costs for the STF505M-7D and JT9D-7A are shown in Figure 34. Comparing Figure 34 with other DOC component plots revealed that fuel cost was the primary difference between STF505M-7D and the JT9D-7A engines.

The airframe maintenance costs are presented in Figure 35; the costs include materials, labor, and burden. Flight length also affects airframe maintenance cost since many maintenance items such as brakes, are cycle dependent rather than time dependent (1 flight = 1 cycle). For this comparison, flight length was assumed to be a constant, making airframe weight the only variable. Airframe weight is, in turn, a function of design TOGW, which reflects the performance capabilities of the engine.

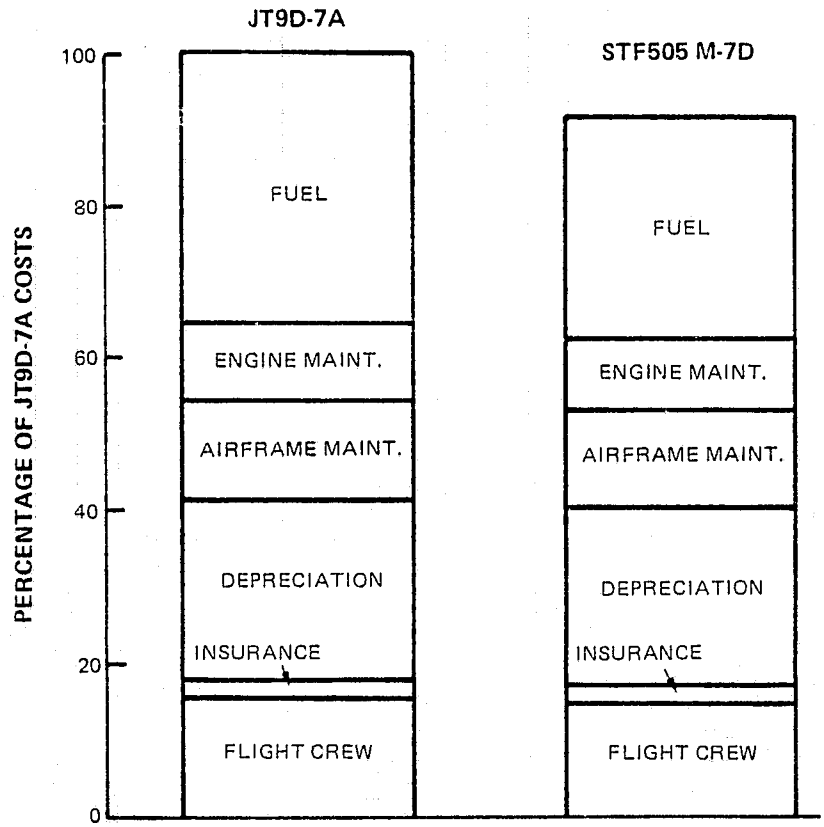


Figure 31 Comparison of Direct Operating Costs -- The P&WA domestic trijet on a typical mission was used for this comparison of STF505M-7D with JT9D-7A reference engine costs.

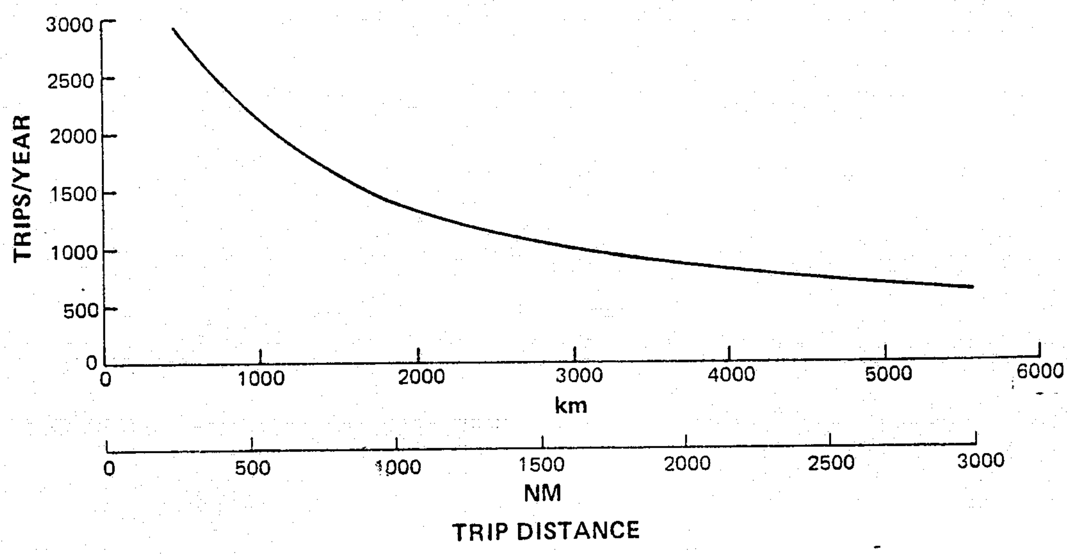


Figure 32 Utilization -- For a given airplane and trip distance, utilization is essentially the same for both engines.

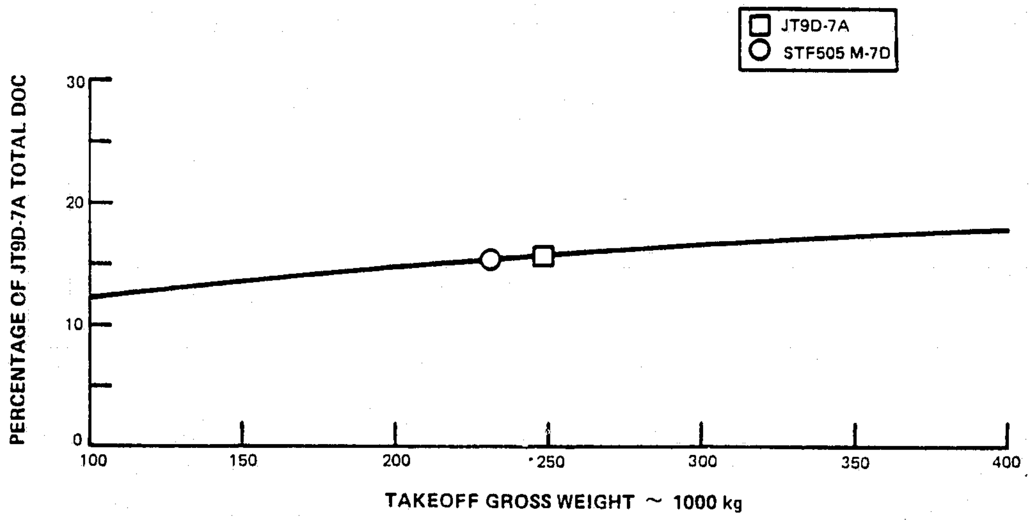


Figure 33 Crew Cost (P&WA Domestic Trijet, Typical Mission) -- Crew costs, which are primarily a function of TOGW, are similar for both engines.

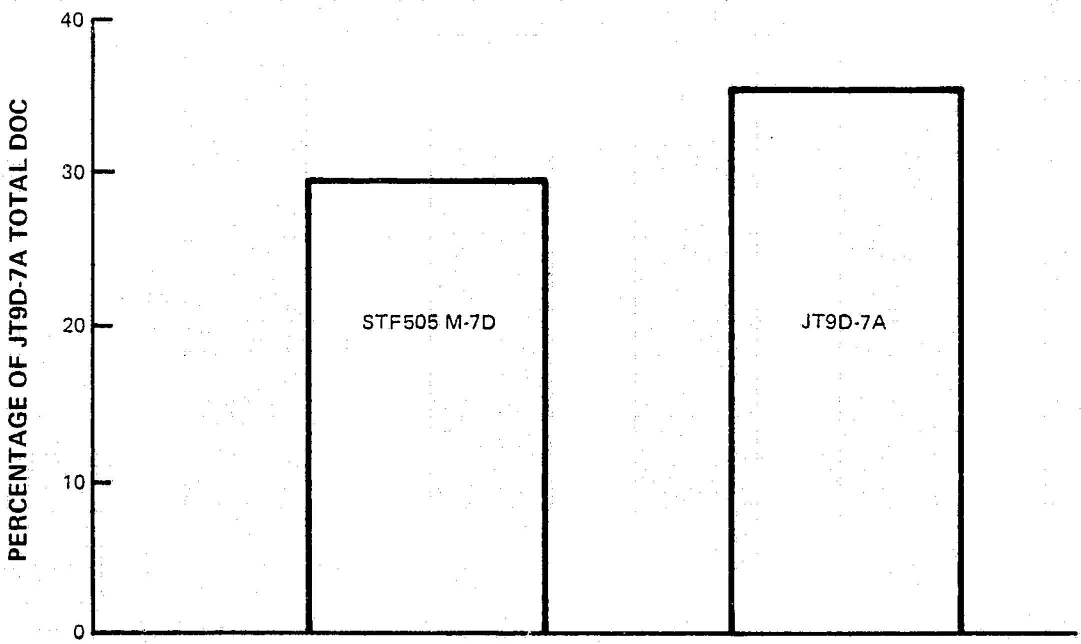


Figure 34 Relative Fuel Cost (P&WA Domestic Trijet, Typical Mission) -- Fuel costs are the main difference in the direct operating costs of the two engines.

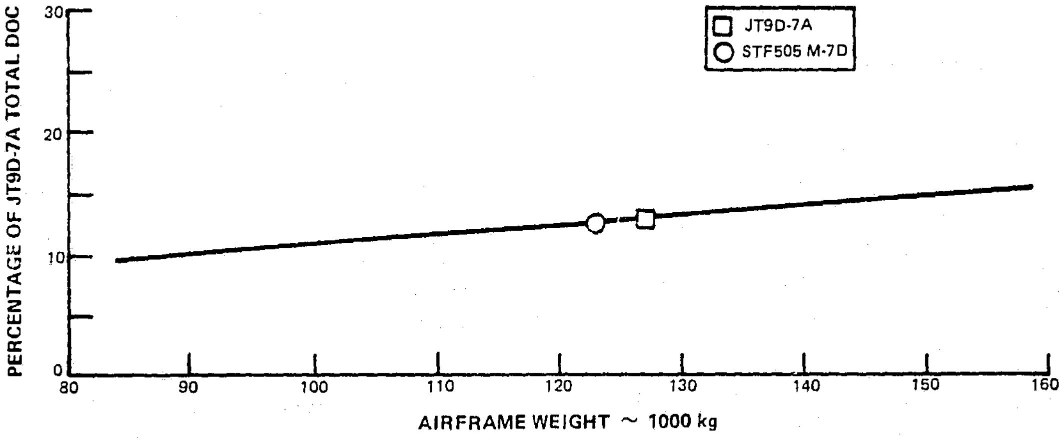


Figure 35 Airframe Maintenance Costs (P&WA Domestic Trijet, Typical Mission) -- Costs, which are dependent on airframe weight, include materials, labor, and burden, and are similar for both engines.

Engine maintenance costs for base size (scale factor of 1.0) STF505M-7D and JT9D engines were calculated as described in Section 4.3. The engine maintenance costs shown in Figure 36 have been scaled to the engine size required to fly the design mission and adjusted to the proper flight length. Engine maintenance, like airframe maintenance, is dependent on flight length and requires adjustment to the actual flight length of each airplane/mission. Since both engines are evaluated for the same missions, their adjustment is the same. Materials, labor, and burden were included in the maintenance cost.

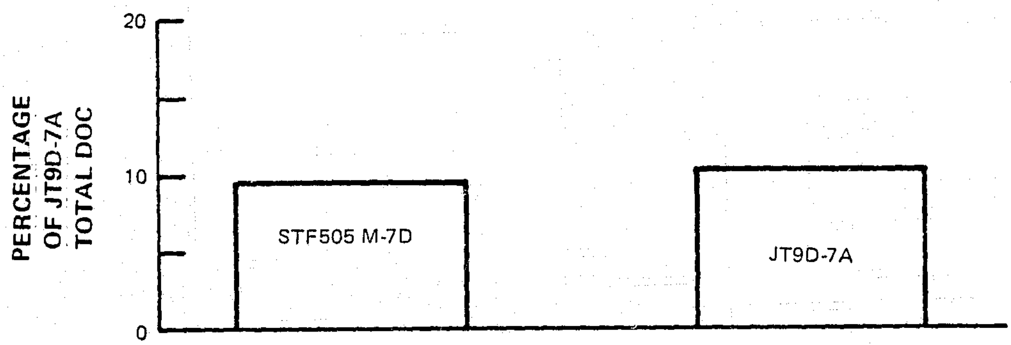


Figure 36 Engine Maintenance Costs (P&WA Domestic Trijet, Typical Mission) The STF505M-7D has a small advantage in engine maintenance costs over the JT9D-7A.

Depreciation, in dollars per block hour, is the total investment in the airplane (airframe and engine and spares) minus residual value (10% in this case) divided by depreciation period (15 years) and hours flown per year. The airframe price equation, based on a Pratt & Whitney Aircraft correlation of present airplanes, is

$$\text{Airframe Price} = 0.5 * \left(\frac{\text{airframe weight}}{1000}\right)^{0.7} * 10.0^{6} + \text{furnishings} + \text{avionics}$$

where:

Domestic Airplane $\begin{cases} (0.008 * \text{number of seats} -0.284) * 10^{6} \text{ (furnishings)} \\ (0.0022 * \text{number of seats} +1.54) * 10^{6} \text{ (avionics)} \end{cases}$

or

International Airplane $\begin{cases} (0.0089 * \text{number of seats} -0.31) * 10^{6} \text{ (furnishings)} \\ (0.0022 * \text{number of seats} +1.81) * 10^{6} \text{ (avionics)} \end{cases}$

The effect on depreciation of the domestic airframe price equation is shown in Figure 37, including six percent airframe spares. Base engine prices, calculated as described in Section 4-3, have been scaled to the engine size required for the design mission. The two points in the figure indicate the total effect of airframe and engine price on depreciation. The engine depreciation is for three engines and thirty percent spares.

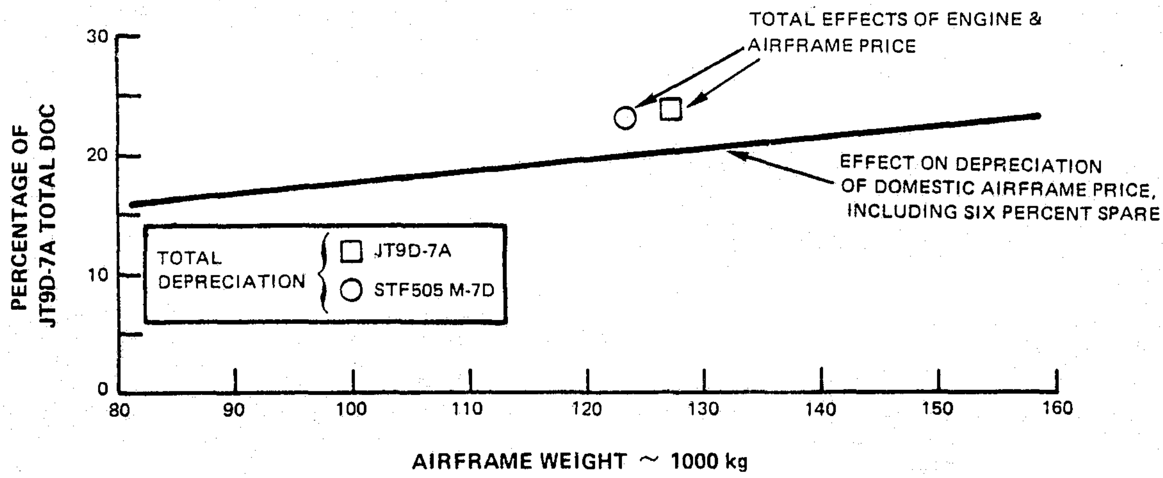


Figure 37 Depreciation Costs (P&WA Domestic Trijet, Typical Mission) -- Depreciation, for a given airplane configuration, is a function of airframe weight and engine price.

The insurance rate used was 0.5 percent per year of fly-away price, which is airplane price without spares. Figure 38 indicates that insurance has only a small effect on the DOC comparison. The line in the figure indicates the contribution of airframe price to insurance. The points indicate the sum of the airframe and engine insurance.

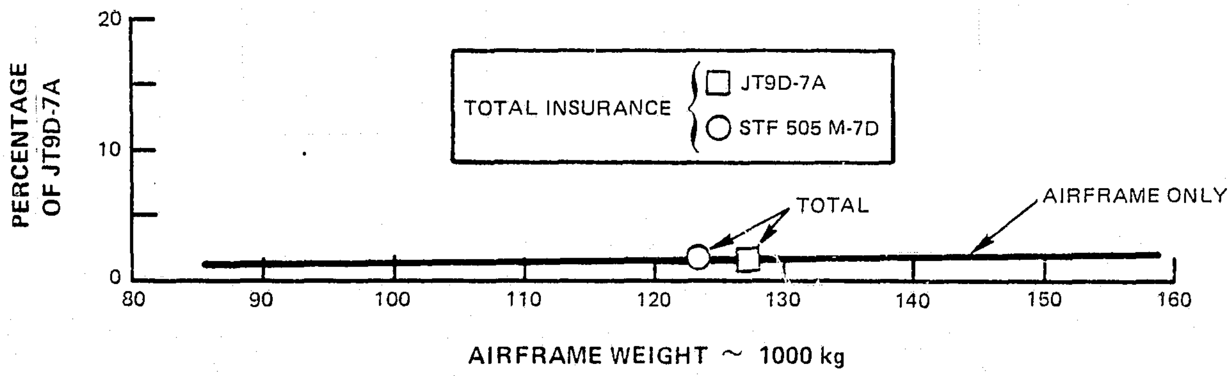


Figure 38 Insurance Costs (P&WA Domestic Trijet, Typical Mission) -- The insurance rate used was 0.5 percent per year fly-away price.

6.1.2 IOC and ROI Models

The IOC model was based on CAB data. For this model the costs are grouped into five categories:

1- Airplane Related

Aircraft handling, cabin crew, landing fees

2- Passenger Related

Passenger and baggage handling, ticket sales, commissions, advertising, food

3- Cargo Related

Cargo handling, insurances, sales, commissions, advertising

4- Ground Property and Equipment

Depreciation and maintenance of ground property and equipment

5- General and Administrative

The parameters upon which these categories are dependent are shown in Table 21. Indirect operating cost is determined primarily by speed of the airplane, trip distance, and number of passengers and/or tons of cargo. Variations in engine performance and characteristics affect IOC only through landing weight, which determines landing fees and is a factor in the correlation of ground property and general and administrative costs.

The IOC components for the STF505M-7D and JT9D-7A powered airplanes are compared in Figure 39. The Pratt & Whitney Aircraft domestic airplane was used as the basis for the comparison. The advantage of the STF505M-7D (1.6%) is primarily due to decreased landing fee costs (0.7% out of 1.6%), with ground properties and equipment (0.5%) and general and administrative (0.4%) accounting for the rest.

Since no cargo was assumed for this case, there were no cargo related costs. Cargo would not have changed the absolute IOC difference between engines because cargo related costs like passenger related costs are functions of the amount carried and are not influenced by engine performance or characteristics when identical missions are flown.

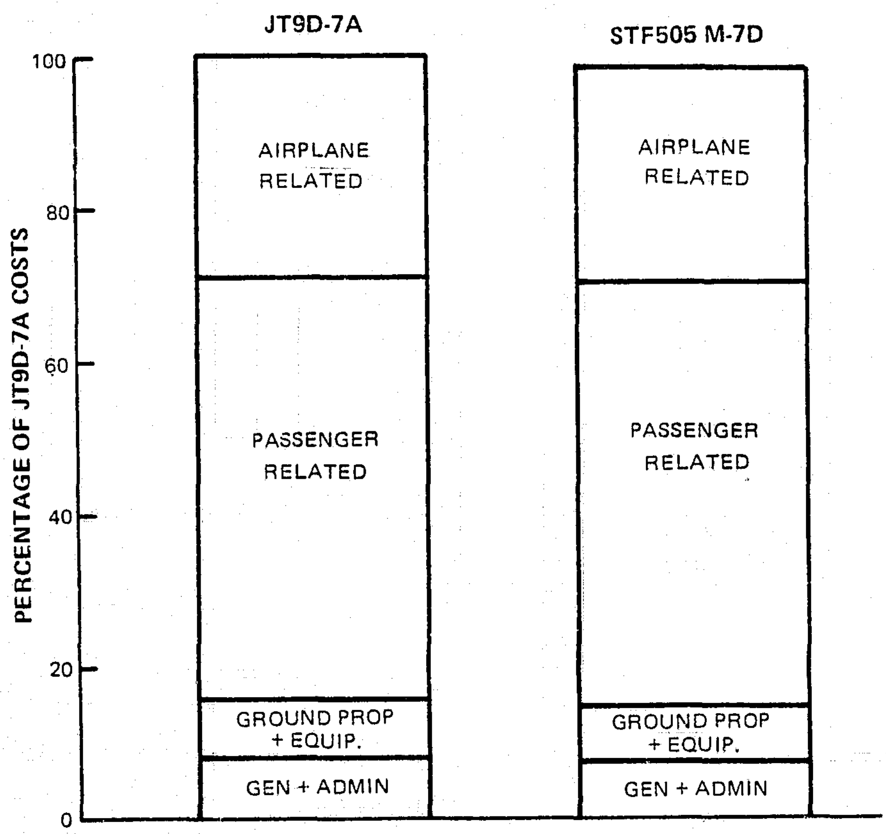


Figure 39 Indirect Operating Cost Breakdown (P&WA Domestic Trijet, Typical Mission) -- IOC is much less sensitive to engine performance differences than DOC is.

Return on investment (ROI) is calculated using a traditional discounted cash flow technique where the annual ROI is determined by zero present value of future cash flow benefits. Cash flow is defined as after-tax profits plus depreciation, where depreciation is a noncash expense.

Cash Flow = (Revenue - DOC - IOC - Taxes) + Depreciation (where tax rate = 50%)

As in DOC, a straight line depreciation over 15 years to a ten percent residual value was used for ROI.

Return on investment is sensitive to revenue and load factor assumptions. The following revenue functions were assumed for all airplanes:

Domestic Passenger Yield: $20.88 + 0.0362$/km (0.0582 $/s.m.)
International Passenger Yield: $23.42 + 0.0406$/km (0.0653 $/s.m.)
Cargo Yield: $145.0/ton + 0.0972$/ton-km ($131.6/ton +0.142 $/ton s.m.)

Typical mission load factors (ROI is shown only for typical missions) were chosen by each airframe manufacturer--Boeing and Lockheed chose 55% and Douglas chose 60%. A 55% load factor was also used for the P&WA study airplanes.

6.2 ECONOMIC EVALUATION RESULTS

The performance input from each of the three airframe manufacturers was used to compare the DOC, IOC, and ROI of the STF505M-7D with the reference JT9D-7A. The performance of the STF505M-7C powered airplanes was adjusted to reflect the STF505M-7D status characteristics, as explained in Section 3.3.

6.2.1 DOC Comparison

Figure 40 shows the results of the DOC comparison for the design missions; and Figure 41, for the typical missions. Figure 41 should come closest to approximating actual airline experience. These two plots show trends similar to the fuel-burned trends in Figure 29 and Figure 30. As shown in Section 6.1.1, the primary reason for the DOC advantage of the STF505M-7D is reduced fuel consumption. In general, airplanes with higher fuel fractions tend to have a greater DOC advantage for the STF505M-7D. Company-to-company variations at similar fuel fractions are due to difference in design systems and modeling techniques; for example, the rate at which airplane structure weight increases with increasing TOGW is different in each company's airplane model. Even with these differences, the variations of DOC advantages fall within a ±1% band.

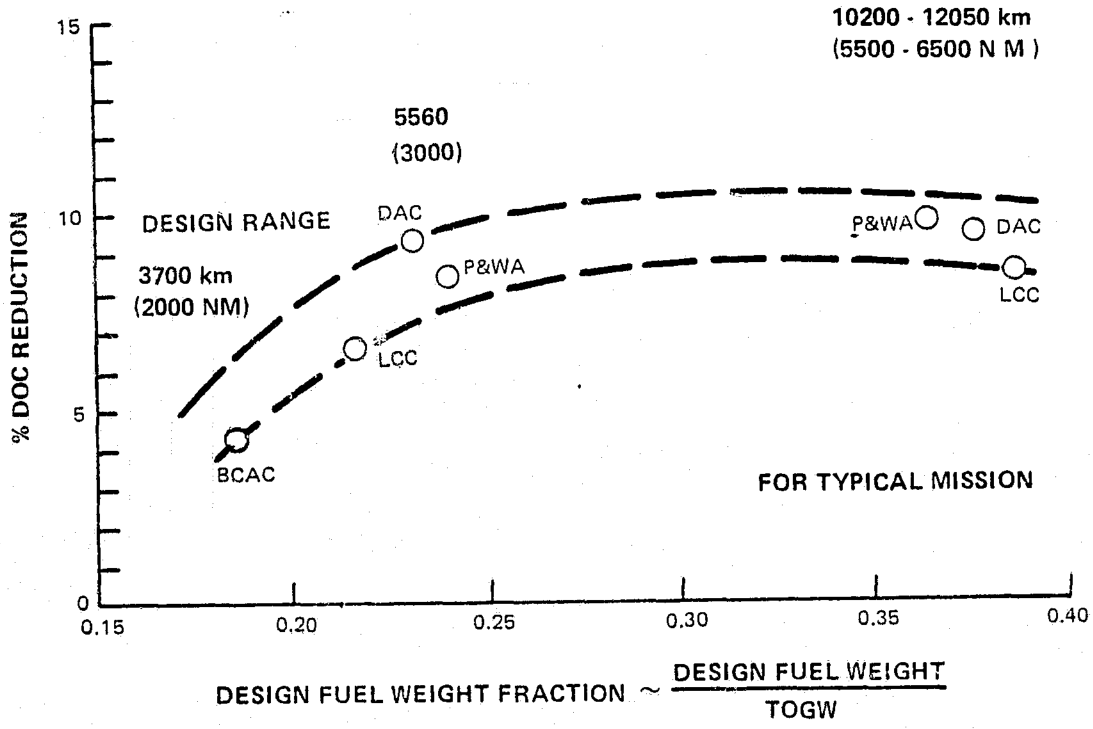


Figure 40 STF505M-7D Savings in DOC Relative to the JT9D-7A for Typical Missions -- The DOC trends for both the typical and design missions are similar to the fuel-burned trends. Average typical mission DOC savings for STF505M-7D is 7.6% well above the NASA goal of at least 5%

On design missions, all airplanes with STF505-7D engines show a greater than five percent reduction in DOC. The average savings is 9.7 percent. When flown on typical missions, all STF505M-7D airplanes except the Boeing domestic twinjet show DOC savings greater than five percent (average savings = 7.6%). Comparison of Figure 42 with the other DOC pie charts (Figure 43, Figure 44, Figure 45, Figure 46, Figure 47, Figure 48) clearly show why the Boeing STF505M-7D airplane has less of a DOC advantage. The fuel cost portion of DOC for the Boeing airplane is significantly lower (29% vs. 35 to 41%) than for the other airplanes, and improved fuel consumption is the prime attribute of the STF505-7D engine. The reason for the lower fuel cost contribution to DOC in the Boeing airplane is that in smaller, shorter-range airplanes--Boeing twinjet carries 196 passengers 3700 km (2000 N.Mi.) vs. 400-500 passengers and 5600 to 12,000 km (3000 to 6500 N.Mi.) in the other airplanes--DOC tends to be dominated by costs less sensitive to engine performance (like crew cost and depreciation). In the case of the Boeing airplane, the sum of crew

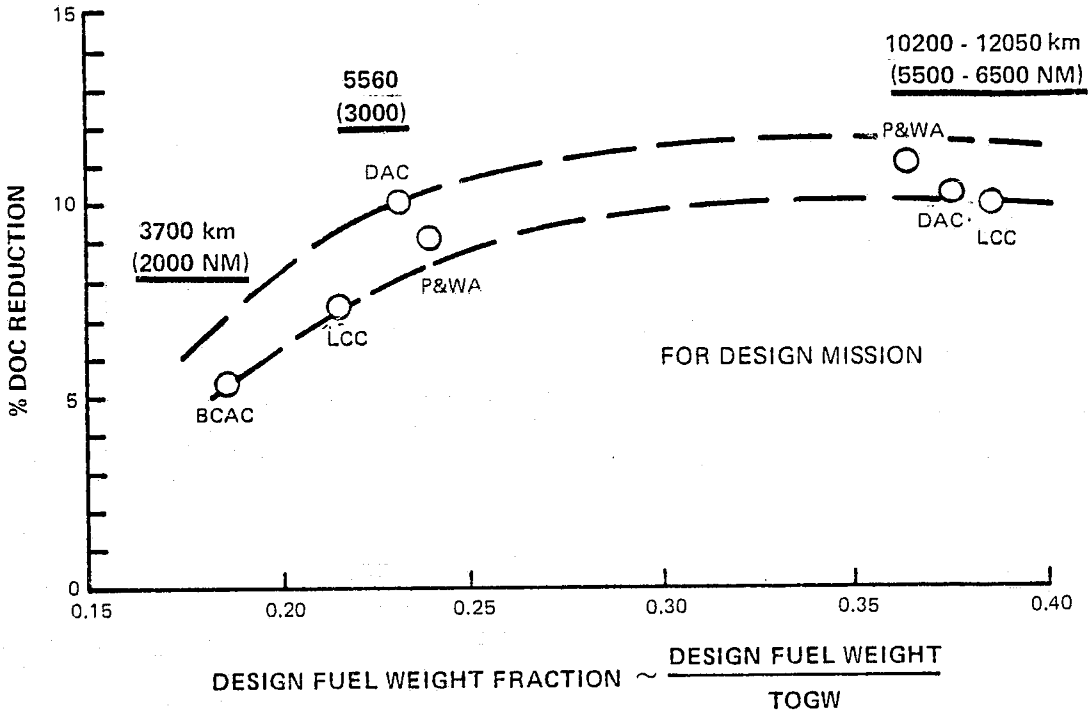


Figure 41 STF505M-7D Savings in DOC Relative to the JT9D-7A for Design Missions -- The main DOC advantage of the STF505M-7D for both typical and design missions is fuel consumption. Average design mission DOC advantage is 9.7%.

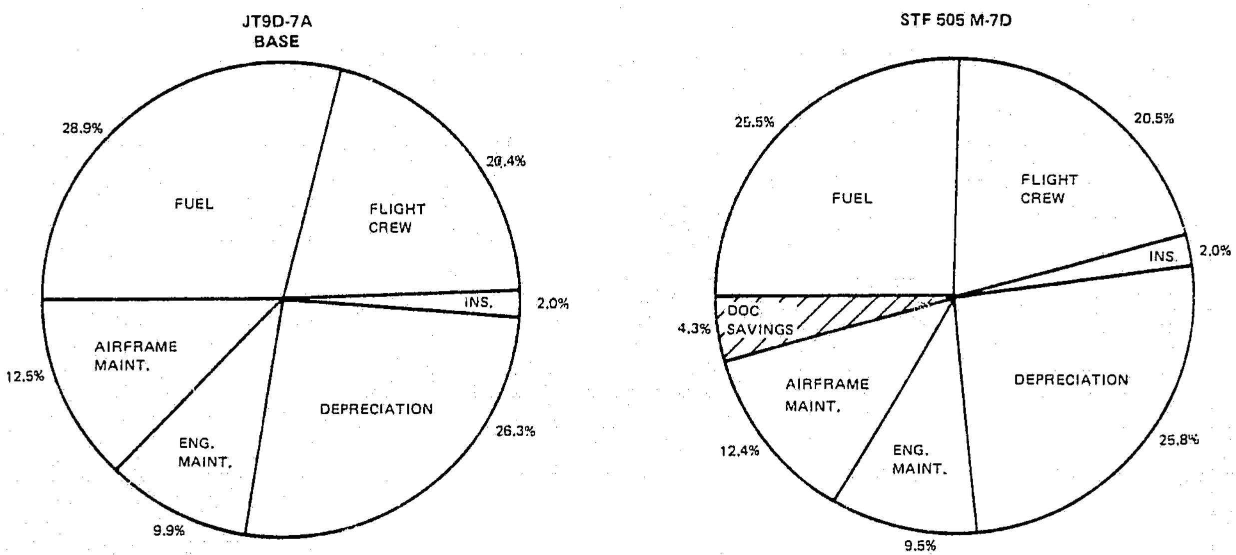


Figure 42 DOC Breakdown (Boeing Domestic Twinjet, Typical Mission: 1,850 km) -- The Boeing twinjet, which shows the least DOC advantage for STF505M-7D, has the smallest fuel cost portion of DOC (25.5 percent) of the study airplanes.

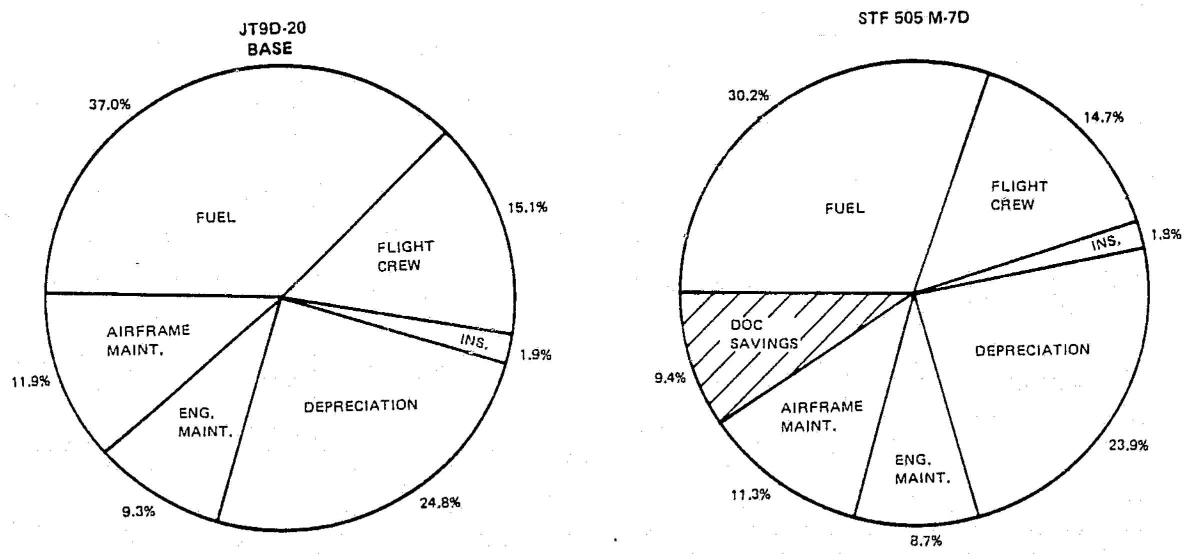


Figure 43 DOC Breakdown (Douglas Domestic Trijet, Typical Mission: 1,850 km) -- The Douglas trijet demonstrates the largest DOC advantage for domestic airplanes for the STF505M-7D (9.4%). Fuel cost of this airplane is 30.2% of DOC.

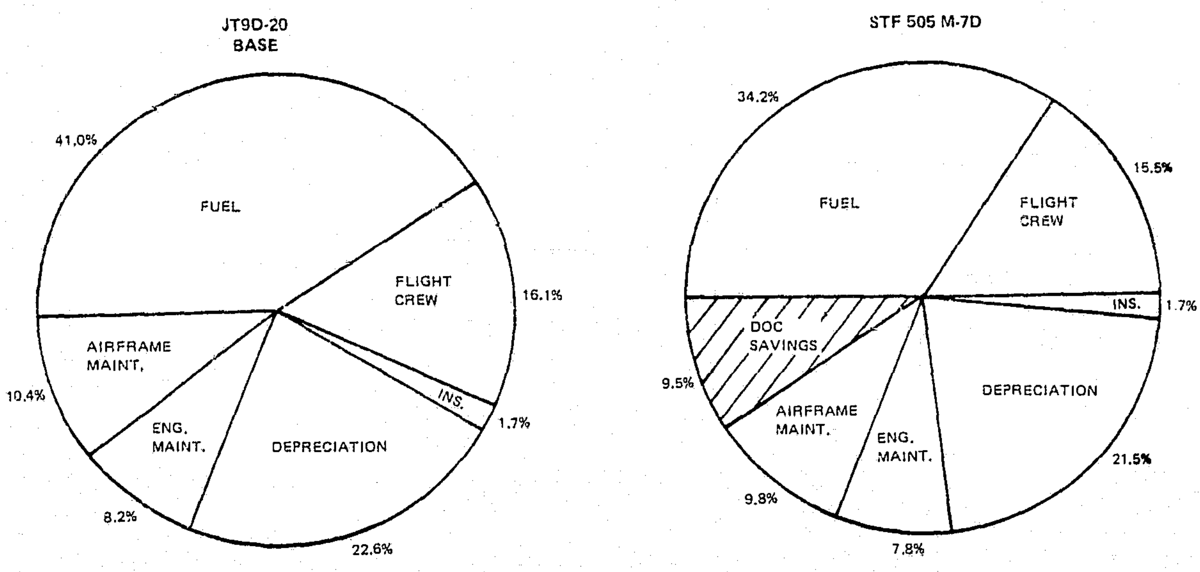


Figure 44 DOC Breakdown (Douglas Intercontinental Trijet, Typical Mission: 2,780 km) -- The fuel cost of the STF505M-7D airplane is 34.2 percent of DOC.

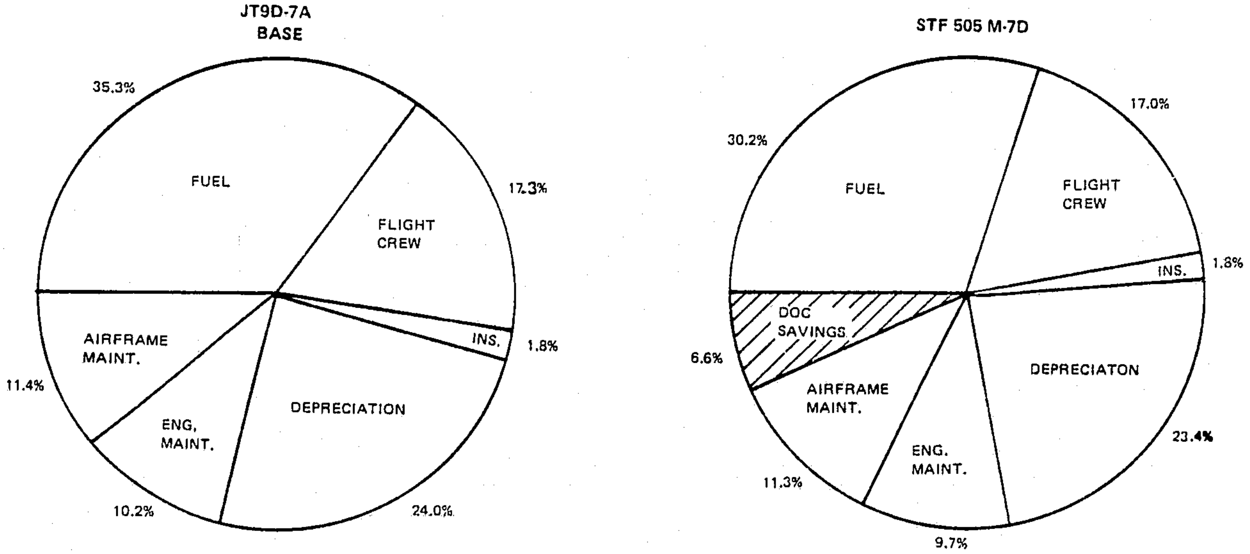


Figure 45 DOC Breakdown (Lockheed Domestic Trijet, Typical Mission: 2,600 km) -- The fuel cost of the STF505M-7D airplane is 30.2 percent of DOC.

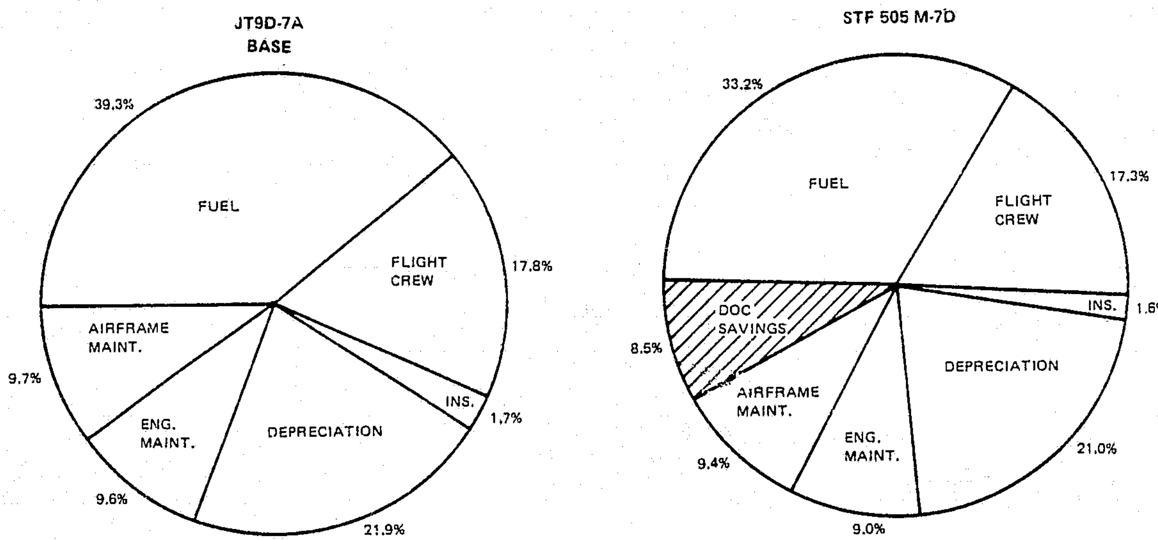


Figure 46 DOC Breakdown (Lockheed Intercontinental Quadjet, Typical Mission: 5,560 km) -- The fuel cost of the STF505M-7D airplane is 33.2 percent of IOC.

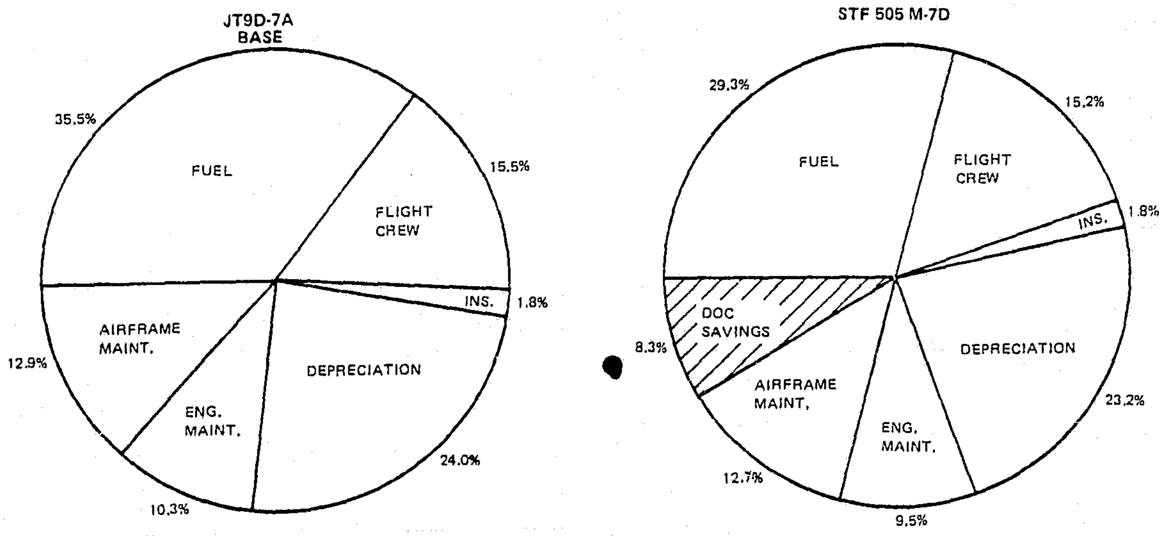


Figure 47 DOC Breakdown (P&WA Domestic Trijet, Typical Mission: 5,560 km) -- The DOC advantage of the STF505M-7D is between that of the Douglas and Lockheed domestic airplanes.

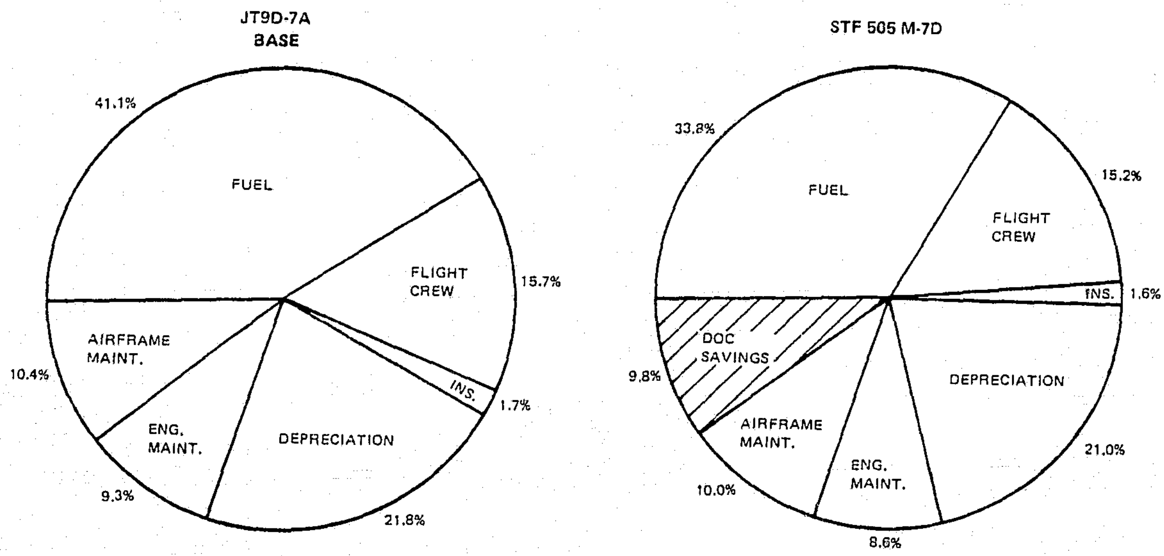


Figure 48 DOC Breakdown (P&WA Intercontinental Quadjet, Typical Mission: 3,700 km) -- The fuel cost of the STF505M-7D airplane is 33.8 percent of DOC.

costs and depreciation is sixty percent greater than fuel cost, while in the Lockheed intercontinental airplane, for example, the sum is equal to fuel cost.

6.2.2 IOC Comparison

The reductions in IOC for the STF505M-7D airplanes compared with the JT9D-7A airplanes are shown in Table 23. The advantage in IOC did not correlate with fuel fraction as well as DOC did because engine performance has little influence on IOC. Because the primary use of IOC was in calculating ROI, the results are only shown for the economically relevant typical missions. Design mission ROI has no significance as it does not reflect actual airline experience.

TABLE 23

INDIRECT OPERATING COST SAVINGS OF EEE
RELATIVE TO JT9D REFERENCE ENGINE %

	Domestic Airplane Percent Savings	Intercontinental Airplane Percent Savings
Boeing	0.6	-
Douglas	1.2	1.8
Lockheed	0.8	1.4
P&WA	1.6	2.1

6.2.3 ROI Comparison

The return on investment advantages of Energy Efficient Engine powered study aircraft over JT9D reference engine powered study aircraft are shown in Table 24. Since the Energy Efficient Engine , when sized for the aircraft application, generally combines a lower initial investment with improved total operating costs (relative to the JT9D-7A), the incremental ROI (or "hurdle rate") of Energy Efficient Engine is mathematically undefined. Incremental ROI is primarily useful for determining the desirability of modifications to existing systems, where the modification requires an initial additional investment, but lowers the future operating costs (or increases future revenues) of the system. When comparing the merits of two competing systems, as in the present study, the difference in their absolute ROI's (Table 24) is more useful.

TABLE 24

PERCENT RETURN ON INVESTMENT ADVANTAGE OF EEE OVER JT9D REFERENCE ENGINE

	Domestic Airplane Percent	Intercontinental Airplane Percent
Boeing	0.5	-
Douglas	2.4	2.8
Lockheed	1.4	2.4
P&WA	1.9	2.6

7.0 NOISE EVALUATION

7.1 INTRODUCTION

Predicted noise levels for study airplanes meet FAR Part 36-1978 certification requirements, generally by sufficient margin to provide a high probability of compliance. These noise levels were determined for all study airplanes by means of Pratt & Whitney Aircraft developed procedures to predict the noise characteristics of each source.

The major objecitve of this effort was to assess the noise levels of the study airplanes relative to FAR Part 36-1978 requirements for new type airplanes. This version of Part 36 includes two amendments added in 1978. The primary purpose of the first amendment (Amendment 8) was to adjust noise level limits and measuring locations to align with international noise certification standards recently adopted by the International Civil Aviation Organization. The second amendment (Amendment 9) provided modifications to the measurement and analysis procedures for conducting aircraft noise certification tests to improve uniformity and repeatability.

A second objective of this study was to determine the area within the approach and takeoff 90 EPNdB footprint of each study airplane.

To meet the above noise objectives, an acoustic configuration was defined for the two Pratt & Whitney Aircraft study airplanes. The same configuration then was assumed for five other study airplanes defined by the airframe manufacturers. This configuration, defined in greater detail in Section 7.2, included a long common flow exhaust system extensively lined with acoustic treatment.

Noise levels were calculated for the seven study airplanes, using procedures developed by Pratt & Whitney Aircraft to predict the characteristics of each noise component: fan, core (combustor), turbine, jet exhaust, and airframe. Discussions of the prediction methodologies used for each component noise source are contained in Section 7.3, and the estimated noise levels and the calculated probabilities with certification requirements of compliance are presented in Section 7.4. Section 7.4 also includes the estimated area within the approach and takeoff 90 EPNdB footprint for each study airplane.

7.2 ACOUSTIC CONFIGURATION

An overview of the acoustic configuration is shown in Figure 49.

Engine acoustic features included substantial spacing between the single-stage, shroudless, 26-blade fan and the strut -stator (4.3 blade-chord gaps at the outer radii) to minimize the fundamental blade passing noise generated by the rotor-strut stator interaction.

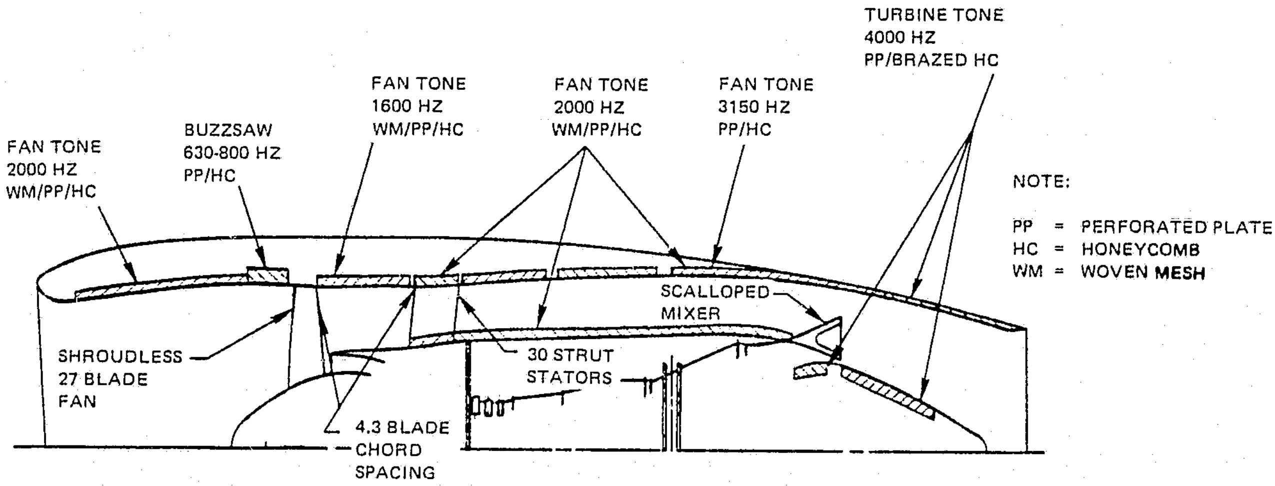


Figure 49 Acoustic Configuration of STF505M-7D -- Acoustic features include substantial spacing between fan and strut stators, mixed, long duct nacelle, and extensive acoustic treatment.

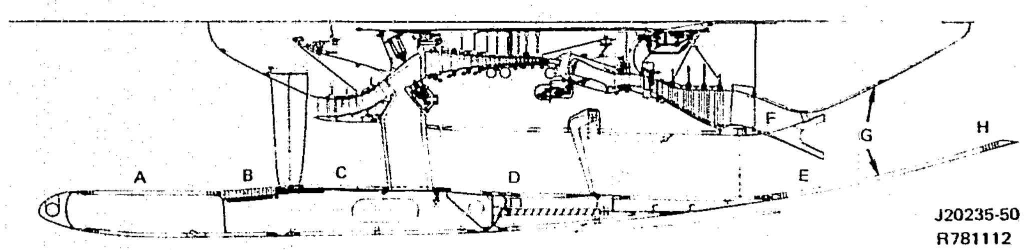
Aerodynamic and structural constraints prevented the selection of a large enough number of strut-stator vanes to acoustically "cut-off" this fan noise source. A large number of core stator vanes ensures that the fundamental noise from the fan/core stator interaction will be cut off and not propagate to the far field.

Acoustic treatment was extensively employed in the inlet and fan discharge duct in order to suppress blade passing tones and buzzsaw noise generated by the fan and tones generated by the turbine. Treatment requirements were determined from hardwall (untreated) noise estimates for both takeoff and approach conditions in order to define the dominant noise sources and their spectral characteristics. This information established the treatment-tuning requirements for obtaining approach and takeoff noise levels that meet program objectives. The tuning objectives for the various segments of treatment are shown in Figure 49. Treatment design features, based on factors such as tuning objectives, duct Mach number, and temperature are defined in Figure 50.

GENERAL LOCATION	CONSTRUCT.	HONEYCOMB CELL-SIZE (CM)	HONEYCOMB DEPTH (CM)	FLOW RESISTANCE OR SKIN POROSITY	HOLE DIA. (CM)	THICKNESS (CM)	TREATED AREA (SQ. M)
A	WM/PP/HC	0.953	3.378	79 RAYL	–	–	6.08
B	PP/BONDED HC	0.953	5.080	20%	0.203	0.127	2.10
C	WM/PP/HC	0.953	2.286	60 RAYL	–	–	3.28
D	WM/PP/HC	0.953	2.667	60 RAYL	–	–	24.24
E	PP/BONDED HC	0.953	1.524	8%	0.127	0.064/0.081	3.05
F	PP/BRAZED HC	0.953	1.397	13%	0.203	0.064	0.83
G	PP/BRAZED HC	0.953	1.118	8%	0.203	0.064	5.25
H	PP/BRAZED HC	0.953	2.159	11%	0.239	0.064	3.14

NOTE:

PP = PERFORATED PLATE
HC = HONEYCOMB
WM = WOVEN MESH



J20235-50
R781112

Figure 50 STF505M-7D Nacelle Acoustic Treatment Design Features -- Treatment design features are based on such factors as tuning objectives, duct Mach number, and temperature.

The scalloped exhaust mixer, included in the engine configuration for performance purposes, is not expected to benefit exhaust noise significantly.

7.3 NOISE PREDICTION METHODOLOGY

Airplane noise levels predicted in this study were performed on an individual component--fan, core, turbine, jet, airframe--basis. For most components the predictions were derived from a component data base established from engine noise measurements. Correlating parameters, developed from analytical procedures to condense data from several tests and configurations, were used to scale predicted noise levels from each component data base.

7.3.1 Fan Noise

Fan noise, dominant during both takeoff and approach, is the most important noise source. Since JT9D-7A and the Energy Efficient Engine fan sections have similar acoustic designs, the JT9D data base was used for the fan noise predictions. The similarities included single-stage configuration, inlet vanes, similar tip-speed/pressure-ratio relationships, and substantial fan-to-exit vane spacing.

An important feature of the JT9D data base is that all data were obtained with an Inflow Control Structure installed on the engine to simulate flight inflow conditions. Without the Inflow Control Structure, significant levels of inflow distortion exist during static testing that do not exist in flight. Inflow characteristics affect noise generation,thus, only with the proper simulation of inflow conditions can the static data be reliably used for estimating inflight fan noise.

The data base provided noise levels in each 1/3-octave band that contained fan noise as a function of fan tip Mach number for each measurement angle around the engine. The data base levels were corrected for differences in diameter, pressure ratio, spacing, and blade number between the JT9D and study engines.

One significant difference between the acoustic designs of the JT9D and Energy Efficient Engines fan section is that while the JT9D contains a large enough number of fan exit vanes to acoustically "cut-off" the fundamental blade passing tone generated by the fan-stator interactions, the Energy Efficient Engine does not. Structural and performance considerations for Energy Efficient Engine preclude the use of acoustically optimum numbers of vanes; therefore, the interaction that generates blade passing tone is "cut-on". Procedures do not exist to define analytically the impact on noise of these differences. It has been assumed that any adverse effect would be offset by the increased rotor-stator spacing of the Energy Efficient Engine, which is nearly double that of the JT9D.

The Energy Efficient Engine fan also differs from the JT9D fan in that it is shroudless. This difference is not expected to have a significant effect on noise. Any acoustic differences probably would favor the Energy Efficient Engine as lesser disturbances would be introduced into the flow that could interact with downstream stator vanes to generate noise.

7.3.2 Core Noise

Predictions of core noise generated by combustor burning processes were based on data base from a variety of Pratt & Whitney Aircraft engines and combustors. Predicted values were scaled from the data base by means of a correlating parameter that was developed analytically to collapse the data from the various sources. The correlating parameter included terms for fuel-air ratio, inlet temperature, a flow parameter, and number of fuel nozzles. The calculated values of the correlating parameter for the Energy Efficient Engine fell within the range of available data.

7.3.3 Turbine Noise

Turbine noise levels were predicted from a data base obtained from a variety of low and high bypass ratio engines tests. Values of correlating parameters used to scale the predictions fell within the range of existing data. The correlating parameter included terms for loading, tip speed, a flow parameter, blade-vane spacing, and size.

7.3.4 Jet Noise

Recently revised SAE procedures (SAE ARP 876, March 1978) that relate noise level primarily to the logarithm of the jet velocity were used for jet noise predictions. Mixing of 85 percent was assumed for the force mixed, common flow nozzle. This is consistent with the percent mixing assumed for performance calculations. To account for 85 percent mixing, the relationships in the SAE procedure were entered at a velocity that was 85 percent of the range between the nonmixed primary velocity and the fully mixed velocity.

7.3.5 Airframe Noise

Airframe noise levels for the Pratt & Whitney Aircraft study airplanes were estimated using a relationship between airframe noise data and the airplane takeoff gross weight. The data were obtained from various published data. (Reference 4, 5, 6). Airframe noise estimates for airframe company study airplanes were provided by the airframe manufacturers, and the levels were in general agreement with the procedures used by Pratt & Whitney Aircraft.

7.3.6 Acoustic Treatment

Separate procedures were used to predict the inlet and aft treatment effectiveness. The inputs for both procedures were the same: design frequency, duct parameters, and treatment type. Inlet attenuation spectra were obtained from a NASA-developed procedure based on mode cut-off ratio (reference 7).

Fan duct attenuation spectra were based on Pratt & Whitney Aircraft flow duct data. Predictions were obtained by applying to the predicted inlet and fan duct spectra: 1) a calibration factor obtained by comparing predicted and measured JT9D attenuation spectra and 2) a correction for treated area.

7.3.7 Calculation of Effective Perceived Noise Level

Using the previously described procedures, noise levels were predicted for each component in 10° increments (5° increments at critical angles). The predicted values were extrapolated to required values and tone corrected perceived noise levels (PNLT) were calculated at each angle from the 1/3-octave band levels for each source and the combined sources (total noise). Using the airplane altitude and airspeed for each case, angles were translated to time. From the total noise PNLT versus time relationships, effective perceived noise levels were calculated for comparison with noise certification requirements.

7.4 PREDICTED NOISE LEVELS

7.4.1 Component Noise Levels

The fan, as expected, was the dominant noise source at all conditions. At certain conditions, the jet and airframe also provided significant contributions to the total noise. Figure 51 shows the relative importance of each noise component for the three noise certification conditions -- approach, takeoff, and sideline -- for the Pratt & Whitney Aircraft trijet, which is a typical example. At approach the fan noise propagating forward from the inlet is the dominant source, and at the other two conditions the aft propagating fan noise is dominant. Airframe noise had the second highest noise level at approach, and jet noise was the second most important source at takeoff and sideline conditions. The figure also shows the reduction in fan and turbine noise (and total noise) that was predicted for the acoustic treatment.

7.4.2 Predicted Noise Levels Vs. Objectives (FAR Part 36)

Based on predicted noise levels, all study airplanes could comply with the noise certification requirements of FAR Part 36-1978. Figure 52 shows the noise levels for the various study airplanes and the FAR

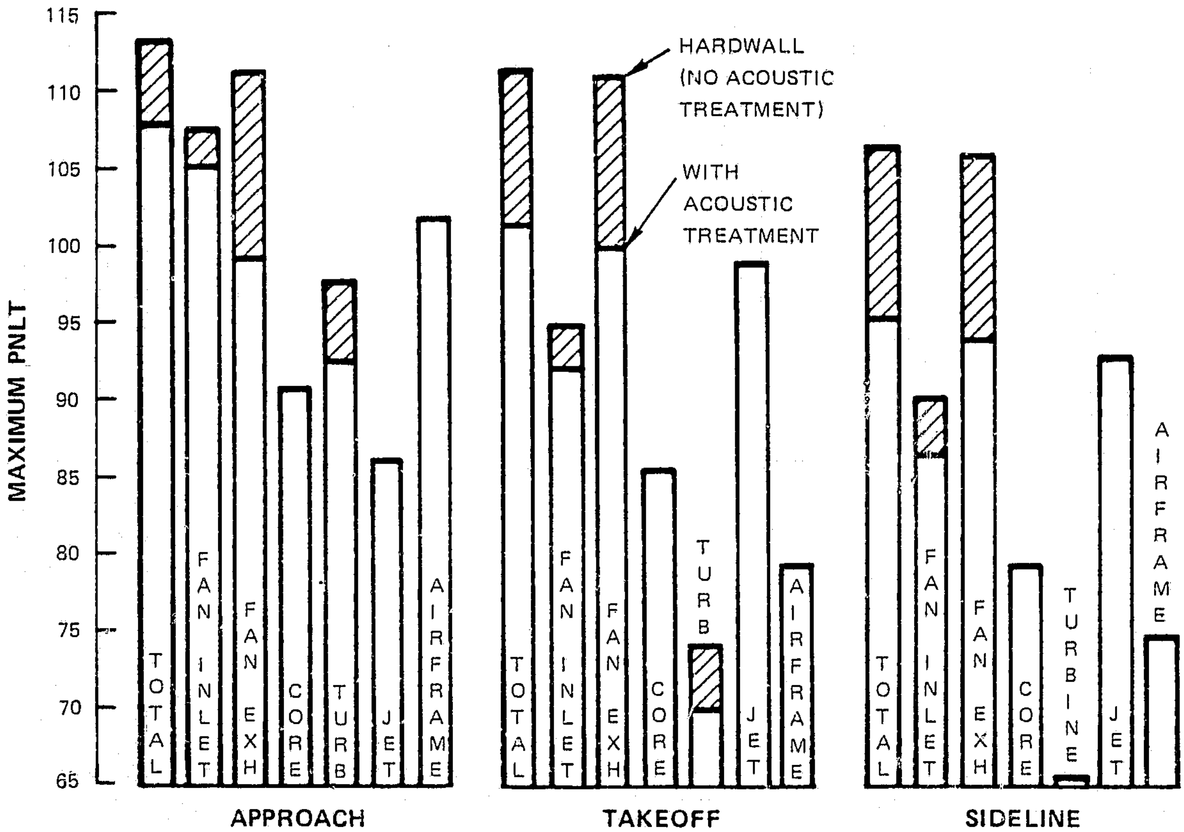


Figure 51 Component Noise Level Predictions (P&WA Trijet) -- The fan was the dominant noise source at all conditions.

requirements for the three certification conditions. It can be noted that the requirements for each condition were a function of airplane takeoff gross weight. In addition, for the takeoff condition, the requirement was a function of the number of engines. Noise levels for all study airplanes were well below the limits with one exception: The Boeing twinjet at takeoff exceeded the limit by one-half an EPNdB. This small exceedance would not prevent the airplane from meeting certification requirements as the regulations permit trading of a surplus at one condition for an exceedance of up to 2 EPNdB at another condition.

Also it should be noted that no attempt was made to refine for minimum noise the nacelle configuration of this airplane or any other study airplanes defined by the airframe manufacturers. The nacelle configuration optimized for the Pratt & Whitney Aircraft defined airplanes was used throughout this effort.

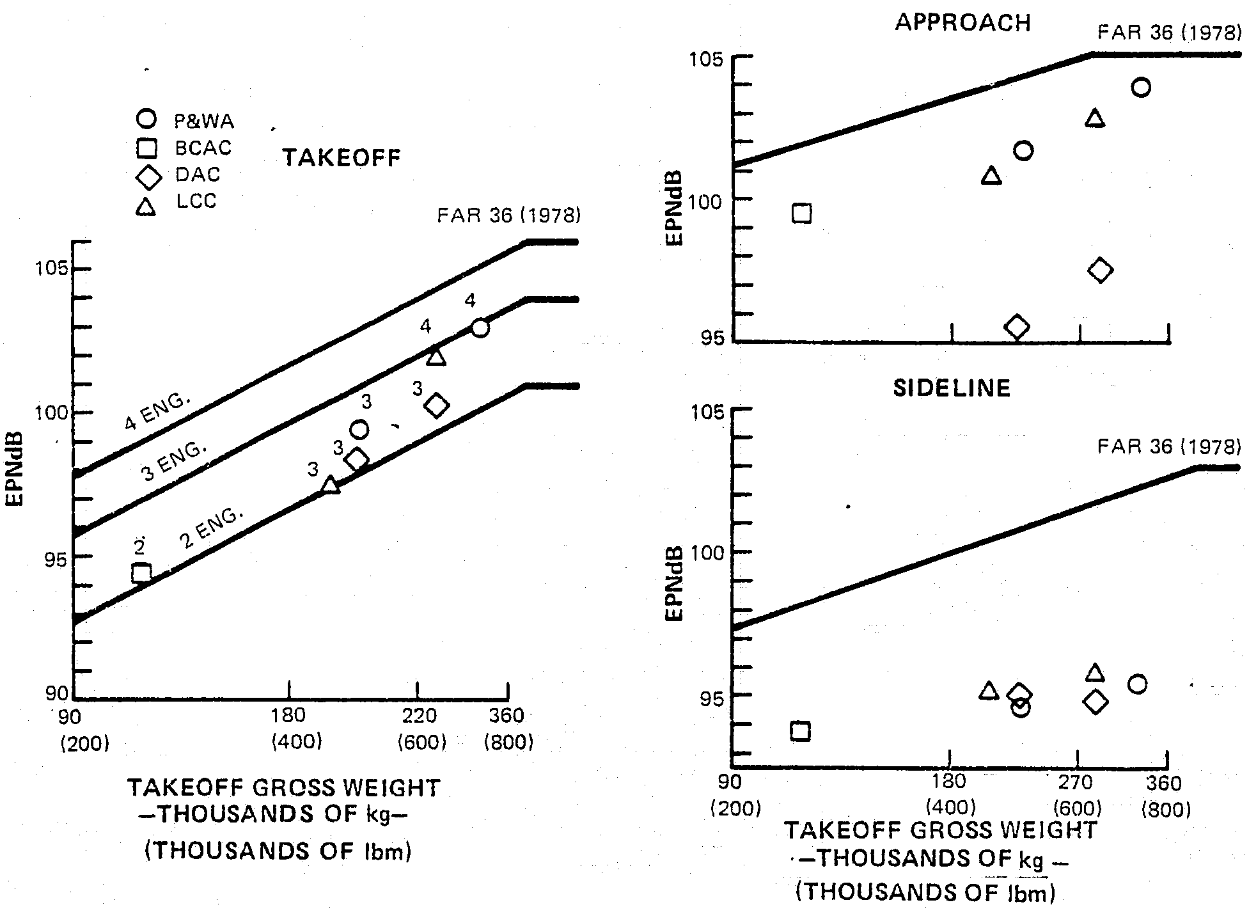


Figure 52 Predicted Noise Levels ar FAR Part 36 (1978) Certification Conditions -- The STF505M-7D achieves the NASA goal of meeting FAR part 36 (1978) noise certification standards.

At approach, the two Douglas trijets had significantly more margin below the limit than the other study airplanes. The lower estimated noise levels resulted primarily from the lower values of approach thrust required for the Douglas airplanes because of higher lift/drag designs and lower flap setting requirements.

Optimization for minimum noise of the performance of all study airplanes and of the nacelle configurations of the airframe manufacturer designed airplanes would decrease the nominal noise levels.

C-2

7.4.3 Noise Footprint Areas

The area covered by 90 EPNdB contours during landing, approach, and takeoff was calculated for each study airplane powered by the Energy Efficient Engine. These estimates are presented in Table 25. The noise contour area produced by the JT9D-7A powered Pratt & Whitney Aircraft intercontinental quadjet was also calculated for reference purposes. The JT9D-7A engine was assumed to be installed in a nacelle with a short fan-discharge duct, typical of current configurations.

TABLE 25

90EPNdB TAKEOFF AND APPROACH NOISE FOOTPRINT AREAS

Airplane	Footprint Area - sq. km
Boeing Twinjet	25.4
Douglas Domestic Trijet	30.0
Douglas International Trijet	34.7
Lockheed Trijet	33.4
Lockheed Quadjet	47.7
P&WA Trijet	37.6
P&WA Quadjet	50.2

The footprint areas of the Energy Efficient Engine powered study airplanes are 22 percent to 60 percent lower than the JT9D powered reference airplane. In terms of absolute values, the footprint areas of the study airplanes range from 50.2 square kilometers (19.4 square miles) for the Pratt & Whitney Aircraft intercontinental quadjet to 25.4 square kilometers (9.8 square miles) for the Boeing domestic twinjet.

It should be noted that values of footprint areas should be used for comparative purposes only, limited to the airplanes within this study. Footprint areas calculated in other studies may not be comparable as there are no standard procedures for calculating these areas. Also, absolute values of footprint areas should not be considered exact because of the uncertainties associated with the extrapolation of airplane noise levels to the long distances required in footprint calculations.

8.0 EMISSIONS EVALUATION

8.1 PREDICTED EMISSIONS LEVELS

Estimates of gaseous emissions and smoke levels for the Energy Efficient Engine cycle are presented in Table 26. These estimates are based on two-stage Experimental Clean Combustor Program (ECCP) combustor engine data for carbon monoxide (CO) and total unburned hydrocarbon (THC) emissions and on single-stage carburetor tube combustor rig data for oxides of nitrogen (NOx) and smoke emissions.

TABLE 26

ESTIMATED EMISSIONS AND SMOKE CHARACTERISTICS

	EPAP*
CO	2.0
THC	0.2
NO_x	4.3
Smoke No.	20 (max.)

*lbm pollutant/1000 lbf thrust/hr/cycle

8.2 EMISSION PREDICTION METHODOLOGY

The emissions, reported in an EPAP (Environmental Protection Agency Parameter), represent a weighted average of Emissions Index (EI) during a typical landing and takeoff (LTO) cycle within the airport environment. Emissions Index is composed of various engine power settings for a length of time typical of a particular class of aircraft. The power settings and time blocks corresponding to the Energy Efficient Engine class is shown in Table 27. The equation for the EPA parameter can be expressed as

$$EPAP = \frac{\sum_{i}^{cycle} (EI)_i \, (Wf)_i (TIM)_i}{\sum_{i}^{cycle} (TIM)_i \quad (FN)_i}$$

where W_{fi} = lbm/hr of fuel flow
EI_i = lbm of pollutant/1000 lbm of fuel
TIM_i = time in mode (Min)
FN_i = thrust (lbf)
subscript i = particular engine power setting or mode

The CO EPAP was calculated from the ECCP data on a combustor inlet temperature (Tt3) basis, and involved correcting the engine data for the Energy Efficient Engine pressure levels and evaluating the EI's at the appropriate combustor inlet temperatures. The THC EI's were observed to be approximately 1/10 of the CO values. The pressure correction for these constituents is linear:

$$CO)_{EEE} = CO)_{ref} \frac{P_{t3\ ref}}{P_{t3\ EEE}} \quad ; \quad THC)_{EEE} = 0.1\ CO)_{EEE}$$

TABLE 27

LANDING AND TAKEOFF CYCLE

Mode	Takeoff Thrust (%)	Time in Mode (min)
Taxi/Idle (out)	Assigned (mfg)*	19
Takeoff	100	0.7
Climb Out	85	2.2
Approach	30	4.0
Taxi/Idle (in)	Assigned (mfg)*	7

*Installed idle thrust of 5.5 percent is being employed for the Energy Efficient Engine.

The NO_x EPAP was calculated form rig data on a fuel-air ratio (f/a) basis. The data were corrected for pressure and temperature and correlated against measured fuel/air ratio. The NOx EI's corresponding to the Energy Efficient Engine fuel/air ratios were then employed to calculate the EPAP. The pressure/temperature correction utilized for the calculations was

$$NO_x)_{EEE} = NO_x)_{ref} \left[\frac{P_{t3EEE}}{P_{t3\ ref}}\right]^{1/2} \exp\left[\frac{T_{t3\ EEE} - T_{t3\ ref}}{288}\right]$$

$$\exp\left[18.8\ (H_{ref} - H_{EEE})\right] \frac{V_{ref}}{V_{EEE}}$$

where Pt3 = combustor inlet pressure
Tt3 = combustor inlet temperature (°K)
H - humidity (lbm H_2O/lbm air)
V = combustor reference velocity

The humidity and reference velocity terms drop out of the equation since the rig and combustor reference velocities are approximately equal and all data are corrected to the standard 60 percent relative humidity.

The maximum smoke level anticipated during the LTO cycle product was estimated from the rig data at a value of (f/a) Pt3 corresponding to takeoff conditions. The method of correlating smoke data from a particular combustor configuration has been employed by Pratt & Whitney Aircraft to account for variations in ambient effects in engine tests. The method also enables estimation of smoke levels for high pressure ratio engines operating at comparable f/a ratios.

8.3 MARGINS

The levels of gaseous emissions shown in Table 26 include allowances for engine-to-engine variations as well as deterioration and development margins. The breakdown of these margins are shown in Table 28.

The allowance for engine-to-engine variation was determined by means of a statistical analysis of a JT9D-7A pilot lot data, consisting of 19 engines. A 3σ level was chosen, which implies that all but 1.5 engines in 1000 will probably meet the requirement.

TABLE 28

SUMMARY OF MARGINS

Emissions	Engine-to-Engine Variation (%)	Deterioration Margin (%)	Development Margin (%)	Total (%)
CO	22	5	20	47
THC	46	5	20	71
NO_x	14	3	10	27

9.0 EVALUATION OF GROWTH POTENTIAL

9.1 THRUST GROWTH APPROACH

A thrust growth plan has been devised for the Energy Efficient Engine. The approach to thrust growth was developed under the earlier study contract, NAS3-20628, and reported in NASA CR-135396. Preliminary growth studies were conducted during the first two tasks of that contract, and detailed growth studies were conducted during Task III.

During the detailed growth studies of Task III, selected configurations were investigated. This investigation included analyses of cooling-air increases required to maintain hot-section life, changes in the aerodynamic performance of components resulting from changes in pressure ratio or cooling flows, and evaluation of the structural impact of changes in rotor speeds, pressure, and temperature levels. The investigation verified the feasibility of the chosen approach to engine thrust growth.

The selected growth path was defined in two growth steps:

A) An initial step of about 15 percent increased thrust, without major changes in nacelle geometry. This increase is to be accomplished by means of an increased overall pressure ratio, an increased fan pressure ratio, a small increase in fan airflow, and an increased rotor inlet temperature.

B) A final step of about 25 percent increased thrust that requires a new nacelle. The engine changes include an increased overall pressure ratio, an increased fan diameter, and an increased rotor inlet temperature.

Neither of the growth steps will require additional advances in technology (i.e., no improvements in materials, coatings, or aerodynamic technology were assumed).

9.2 PERFORMANCE EFFECTS

Changes in engine cycle, performance, airflow and diameter are summarized in Table 29 for the two growth steps. Thrust growth will be accompanied by a slight improvement in installed TSFC (flight inlet, nacelle drag, no bleed or power extraction) for step (A)and a significant improvement for step (B). The improved TSFC will be a result of increased overall compression ratio and rotor inlet temperature, which partially offsets the fuel consumption penalty of increased fan pressure ratio. In addition, the nacelle drag/thrust of step (A) is lower than the base because the greater thrust is achieved without an increase in nacelle diameter. For step (B), the improvement in TSFC is a direct result of the thermal efficiency

TABLE 29

GROWTH CYCLE PERFORMANCE AT AERODYNAMIC DESIGN POINT
RELATIVE TO BASE ENERGY EFFICIENT ENGINE

	Step A 15% Thrust Increase	Step B 25% Thrust Increase
Change in Corrected Airflow - kg/sec (lbm/sec)	+36 (+78)	+186 (+410)
Change in Fan Pressure Ratio	+0.07	0
Change in Bypass Ratio	-0.59	+0.82
Change in Overall Pressure Ratio	+6.4	+6.4
Change in Rotor Inlet Temperature °C (°F)	+37 (+67)	+95 (+172)
Change in Turbine Cooling Air (% Core Flow)	+3.3	+5.7
Change in Fan Diameter cm (in)	+3 (+1.1)	+27 (+10.7)
Change in TSFC (Percent)	-0.2	-1.1

improvement associated with the OPR/RIT increases, since fan pressure ratio is constant (propulsive efficiency is nearly constant). Drag/thrust for step (B) is nearly the same as for the base engine.

The effect of thrust growth on direct operating cost is difficult to assess, since the additional thrust can be used for many purposes, from reducing takeoff distance to increasing payload. The cycle changes used to achieve thrust growth produce DOC penalties, relative to the base EEE, of 0.6% for Step A and 1.2% for Step B, assuming no DOC benefit for increased thrust. These penalties are primarily due to the RIT increases. If the thrust increases are used to increase payload, then these penalties are more than offset, on a seat-kilometer cost basis.

Two stretched versions of the P&WA domestic study airplane were conceived to quantify the possible DOC value of these thrust growth steps. Passenger capacities were solved for to match both steps by holding design range and wing area constant while TOGW, OEW, fuel load and thrust were increased as required. The results show that, on a seat-kilometer cost basis, the DOC of the 15% growth airplane is 4.5% lower than that of the basic EEE powered airplane, and the DOC of the

25% growth airplane is 8.7% lower than the base EEE. Both advantages include the penalty for growth cycle changes.

The changes to the engine required to achieve growth steps are:

Step (A): Base single-stage fan is replaced with a single-stage design of higher pressure ratio, increased tip speed, and slightly greater specific flow and diameter. Low-pressure compressor has an additional supercharging stage. High-pressure compressor is aerodynamically unchanged, but operates at higher physical speed with increased gaspath temperature levels as a result of increased inlet temperature; pressure ratio and corrected airflow are unchanged from base. Combustor operates at higher exit temperature and higher vane cooling flow than base. High-pressure turbine cooling flows are increased to maintain life at the elevated rotor inlet temperature, and the turbine is rebladed (same annulus) because of changes in cooling air and expansion ratio. The low-pressure turbine has a cooled first vane row for hot section life, but no aerodynamic changes are required. The forced mixer/plug is revised to furnish the mixing plane area adjustments required by the cycle revisions. No significant changes in total mixing plane area or jet nozzle are required. No changes to the inlet throat geometry or the external forward nacelle lines are required, with the possible exception of an added section to extend the length.

Step (B): More extensive changes to the engine are required, some of which are illustrated on Figure 53. The base engine fan is replaced with a scaled-up fan having the same aerodynamic parameters. The low-pressure compressor has an added supercharging stage, as in Step A. The high-pressure compressor is unchanged aerodynamically, but operates at elevated pressures, temperatures, and rotor speed -- pressure ratio and corrected flow are unchanged from base. Burner exit temperature is increased, and first turbine vane cooling is increased beyond that required by Step (A). High-pressure turbines cooling flows are increased to maintain life, and the turbine is rebladed (same annulus) as in Step (A). Since the low-pressure rotor speed is decreased as a result of an increased fan diameter at the same corrected tip speed, the low-pressure turbine requires more extensive changes for Step (B) than are required for Step (A). The low-pressure turbine has increased elevation, requiring a new transition section between the turbines, and has an additional (fifth) stage. Both the low-pressure turbine first blade and first vane are cooled. Because of the increased airflow and cycle changes, mixing plane geometry differs from the base engine, requiring mixer/plug revisions. The entire nacelle for this growth engine is new.

9.3 NOISE EFFECTS

Thrust growth can be achieved with only a small impact on noise. The effects on engine noise of the two approaches for growth discussed in Section 8.1 are summarized in Figure 54. The increases in fan pressure ratio (Step A) and fan size (Step B) result only in a small

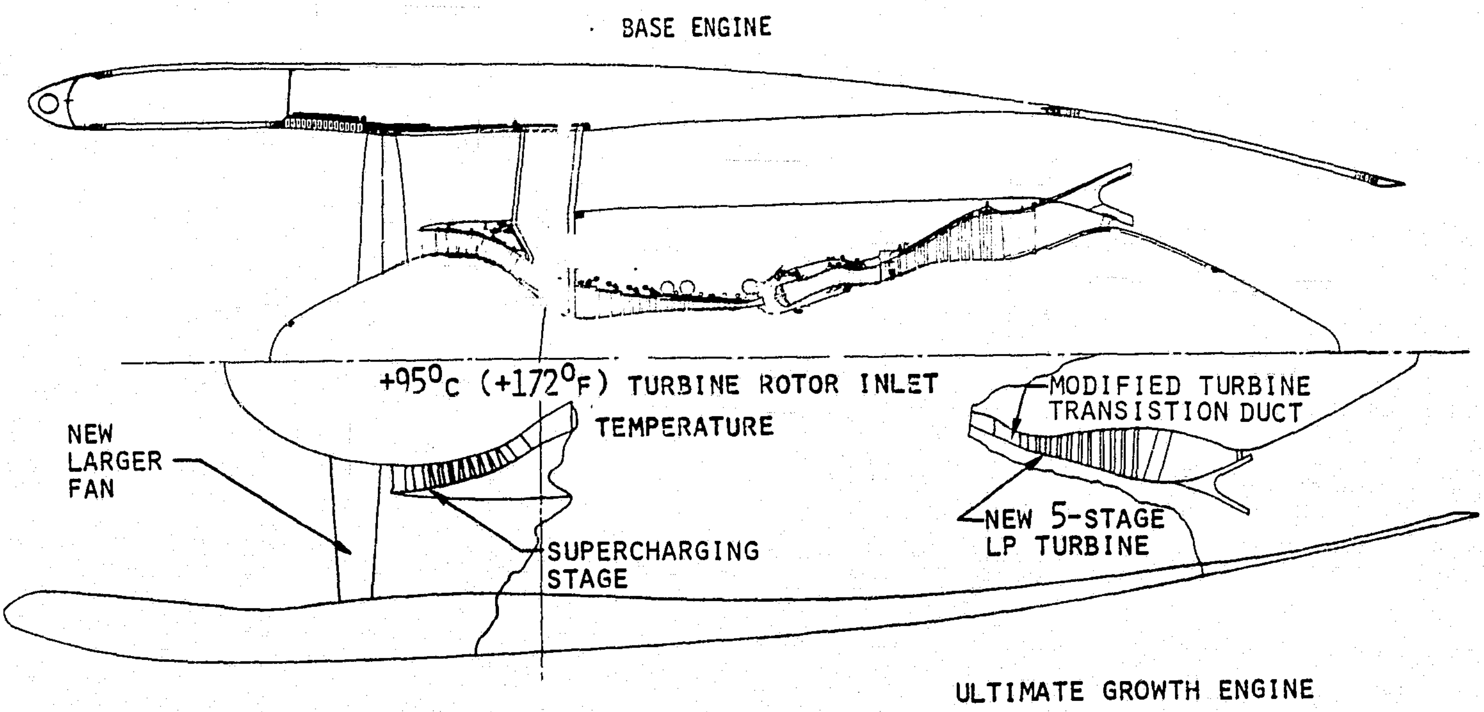


Figure 53 Thrust Growth Engine Design -- Thrust growth will be accomplished in two steps: an initial step of about 15 percent increased thrust without major changes in the nacelle, and a final step of 25 percent, requiring a new nacelle.

increase in fan noise: less than 1 dB. The increase in jet velocity associated with Step A resulted in an approximately 2 dB increase in jet noise. Extending this approach beyond a 15 percent thrust growth would result in additional jet noise which probably would be unacceptable. By increasing bypass ratio (Step B), the jet velocities can be reduced and a more substantial (25%) thrust growth can be obtained with small (1 dB) increases in jet noise.

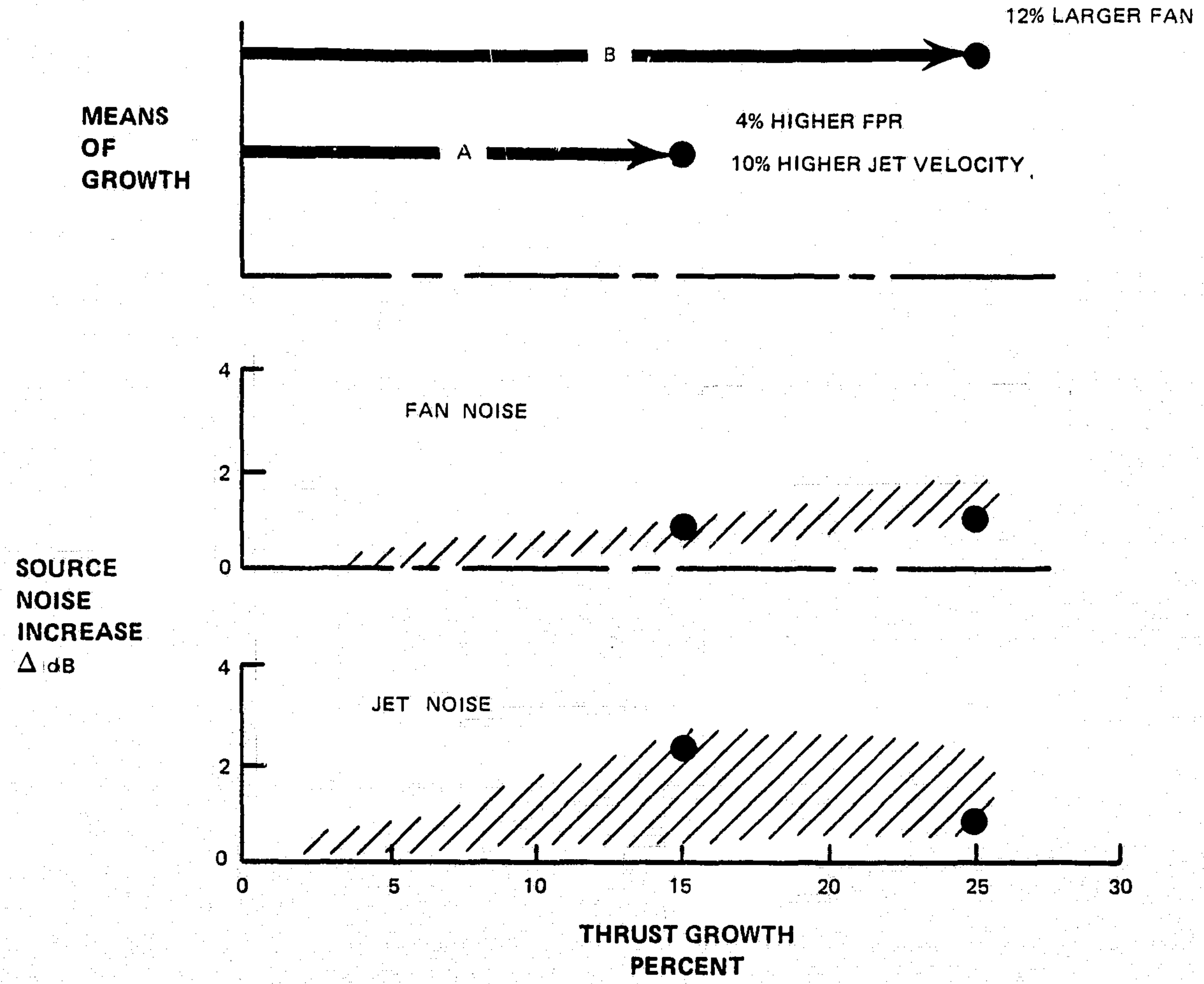


Figure 53 Thrust Growth Engine Noise -- Thrust growth can be achieved with only a small impact on noise.

The impact of thrust growth on airplane noise is more difficult to assess; thrust growth is usually accompanied by changes in the airplane configuration. However, if a constant thrust loading is assumed (takeoff gross weight increases at the same rate as engine thrust) the margin below the FAR Part 36-1978 noise limit would be retained as the noise limit increases with takeoff gross weight. Very heavy airplanes are possible exceptions at the approach condition because the approach limit is constant at takeoff gross weights above 280,000 kg (617,300 lbm).

9.4 EMISSIONS EFFECTS

The primary cause of the changes in exhaust emissions shown below is the increase in overall pressure ratio from 38.6 in the base engine to 45 in both growth engines. This increase causes carbon monoxide and unburned hydrocarbon emissions to decrease and oxides of nitrogen emissions to increase.

Projected Change in Exhaust Emissions Due to Growth Steps is shown in Table 30.

TABLE 30

EFFECTS OF GROWTH STEPS ON EXHAUST EMISSIONS

	EPAP	
	Step A	Step B
CO	-0.2	-0.2
THC	-0.05	-0.05
NO_x	+1.0	+1.0

10.0 GOAL ACHIEVEMENT PROBABILITY ANALYSIS

10.1 INTRODUCTION

The probability of achieving NASA-specified goals for the flight propulsion system in TSFC, DOC, noise, and emissions was evaluated during the PS-AIE. Evaluation of the DOC and noise goals required input from the airframe manufacturers.

10.2 TSFC PROBABILITY ASSESSMENT

The procedure by which the probability of meeting TSFC goals was determined is outlined in Figure 55. This process was performed in detail during the initial study phase of the Energy Efficient Engine

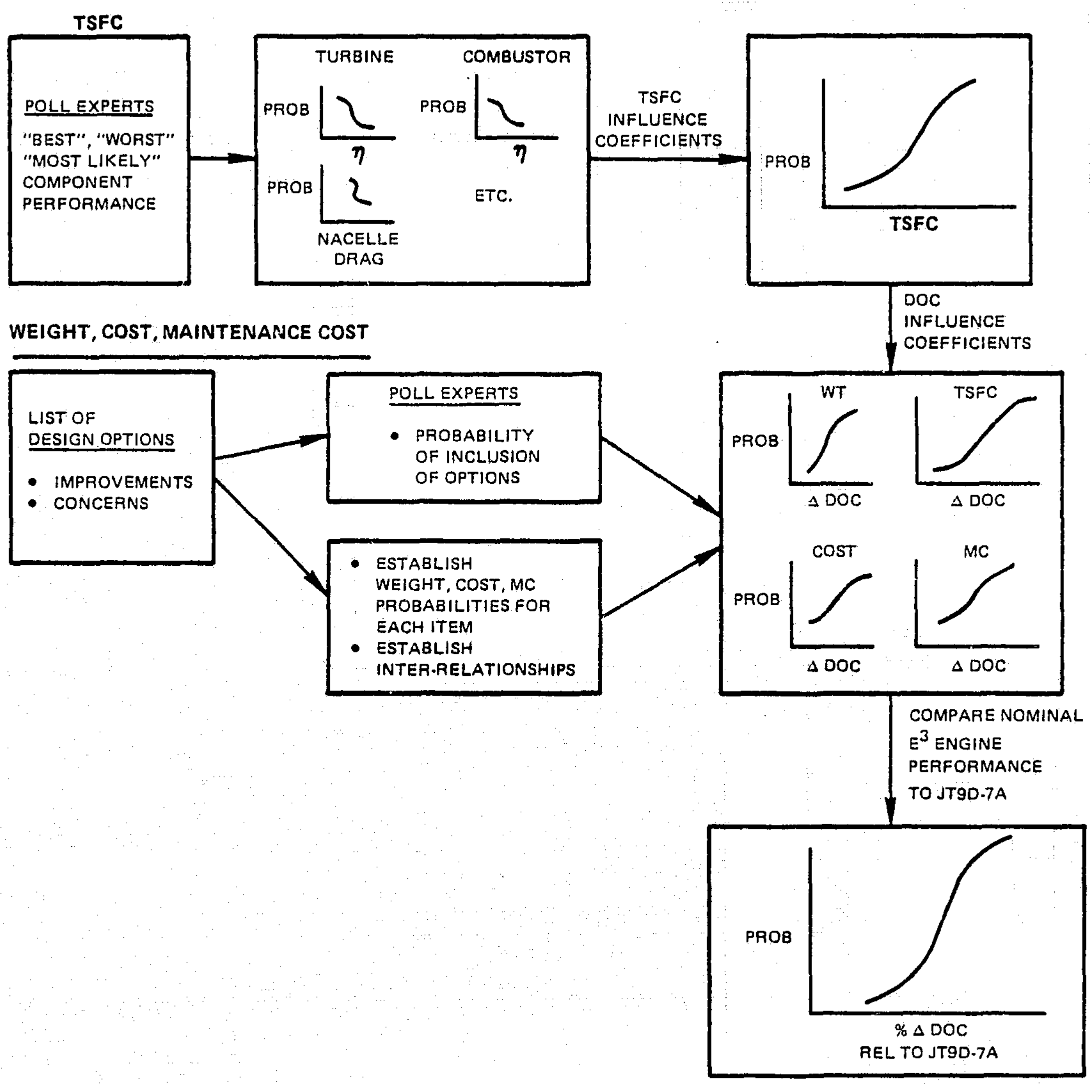


Figure 55 TSFC and DOC Probability Assessment Process -- Component performance and characteristics probabilities are statistically combined to predict overall probabilities of achieving TSFC and DOC goals.

Program (Contract NAS3-20628), and is described in the final report for that contract (Reference 2).

Experts for each component (fan, burner, turbine, ...) review their special area and estimate the "best possible", the "most likely", and the "worst possible" levels of component performance. These expert estimates for each component are then converted into component probability-of-achievement curves. The probability-of-achievement curves for all the components are combined statistically using TSFC influence coefficients to establish a curve of overall TSFC probability.

The TSFC probability for the current contract, NAS3-20646, was obtained by re-estimating the most likely component performance analyzing the overall performance of an engine composed of these most likely components, then shifting the overall TSFC probability curve to reflect the difference between this performance and that of the previous contract. This re-evaluation was based on the results of the Preliminary Design Analysis reported in Reference 1.

The TSFC values in Figure 56 are installed values and include flight inlet and nozzle effects, isolated and nacelle drag, but no bleed or

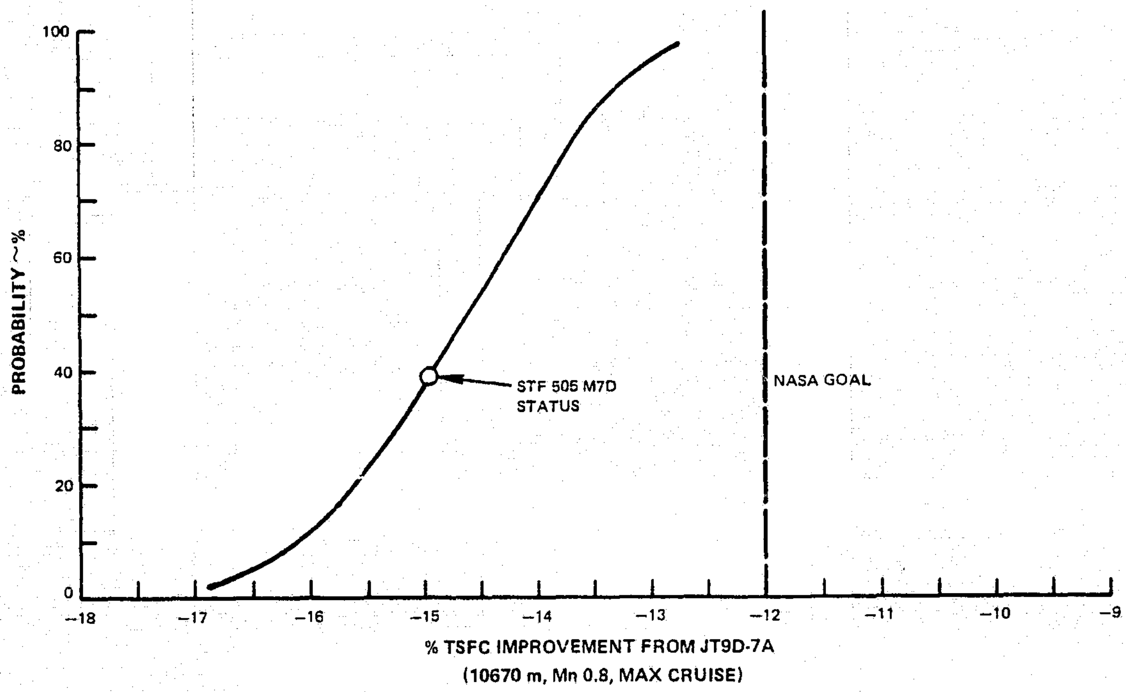


Figure 56 Probability of Achieving TSFC Goal -- The probability of meeting the NASA 12 percent TSFC improvement goal is greater than 99 percent.

horsepower extraction. The figure shows that the probability is very high (99%) for meeting the NASA goal of at least 12 percent TSFC improvement over the base JT9D-7A engine.

10.3 DOC PROBABILITY ASSESSMENT

The evaluation of the DOC probability (also shown in Figure 55) included the TSFC probability and required estimating engine weight, price, and maintenance cost probabilities. These other parameters, unlike TSFC, had not been evaluated in detail in the previous contract (NAS3-20628) effort and had to be completely determined during the present study.

The assessment of these parameters (weight, price, and maintenance cost) started with the development of a baseline engine configuration and the determination of the weights, prices, and maintenance costs of the individual component areas. The design was reviewed and a list of possible improvements to reduce the weight, price, or maintenance cost was developed. A list of possible design concerns that might increase these parameters was also compiled. Most items on these lists gave mixed results (e.g., an item might decrease weight but increase price and/or maintenance cost).

These lists, containing over 80 items, were shown to a number of experts in the various aspects of engine design who estimated the probability of the item being included in the final flight propulsion system. Simultaneously, weight, price, and maintenance cost probabilities were established for each item. The relationships among weight, price, and maintenance cost were also determined.

The estimates of the experts were used to establish probability-of-inclusion curves for each item. These curves were combined statistically, along with the weight, prices, and maintenance cost probabilities of each item (accounting for inter-relationships) to produce overall weight, price, and maintenance cost probabilities for the flight propulsion system. These probabilities, expressed in terms of percent variation in DOC from the baseline design, are shown in Figure 57. The Pratt & Whitney Aircraft domestic airplane was the basis for the influence coefficients used in this figure. A similar plot was prepared for the Pratt & Whitney Aircraft intercontinental airplane.

The TSFC probability curve, converted to DOC variation, is also shown in Figure 57. The nacelle was analyzed as a separate component for weight and cost and these effects are shown coupled in the figure. The curves were then combined to produce the overall DOC probability, still based on a nominal Energy Efficient Engine design.

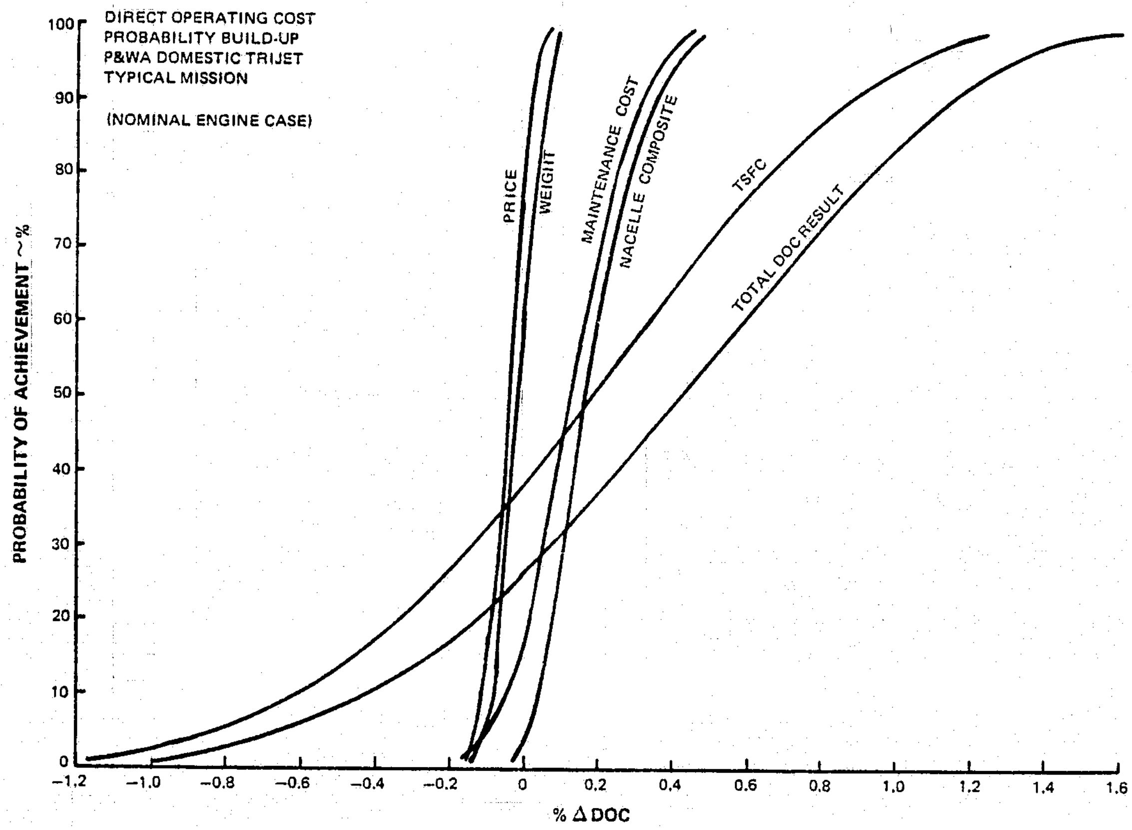


Figure 57 DOC Probability Buildup (P&WA Domestic Trijet, Typical Mission) -- TSFC, weight, price and maintenance cost probabilities were combined to predict the probability of meeting the DOC goal.

The airplane economic performance with the nominal engine was evaluated and compared with the JT9D-7A reference engine in both Pratt & Whitney Aircraft airplanes. On the basis of these comparisons, the overall DOC probability curves were converted to a JT9D-7A reference base, as shown in Figure 58. The relationships between DOC results for the Pratt & Whitney Aircraft and the airframe manufacture airplanes were used to establish probability curves for the airframe manufacturers' airplanes--also shown in Figure 58. The results shown are for typical missions.

The probability of meeting the NASA goal of a five percent DOC advantage over the JT9D-7A reference engine is greater than 99 percent on all airplanes except the Boeing twinjet. The reasons for the relatively low advantage in the Boeing twinjet are explained in Sections 5 and 6.

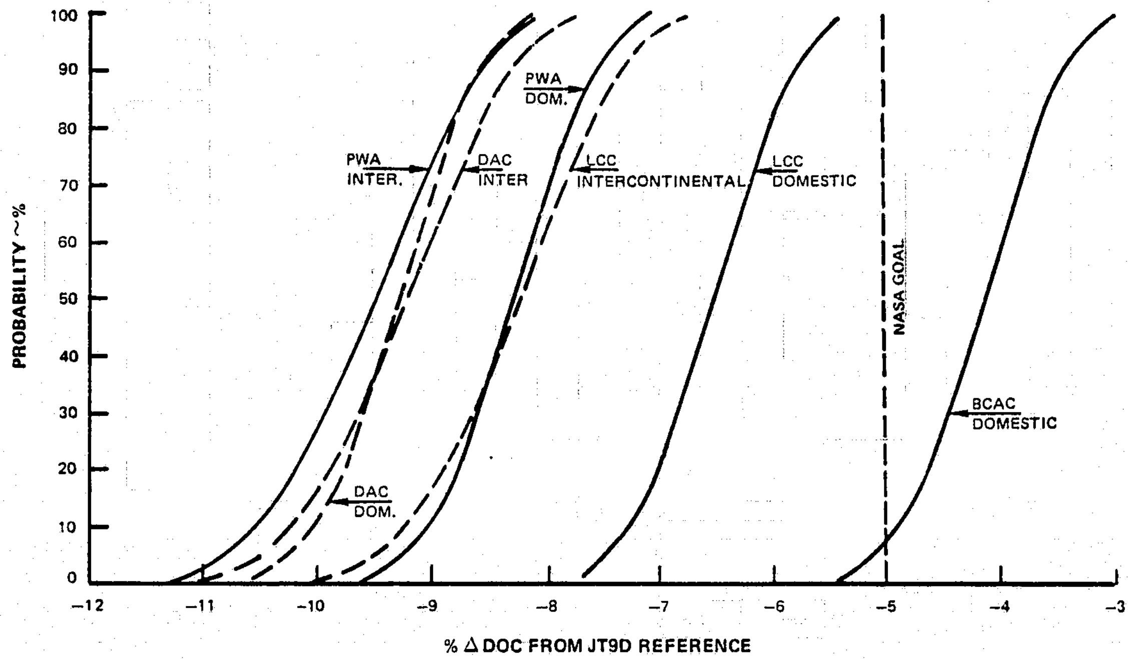


Figure 58 Probability of Achieving DOC Goal (Typical Mission) -- The average probability of meeting the NASA DOC goal of five percent is 86 percent.

10.4 NOISE PROBABILITY ASSESSMENT

Although the predicted noise values shown in Section 7 are generally well below the FAR 36-1978 requirement, it must be recognized that the predicted levels are nominal values. The uncertainties associated with these predictions must be taken into account when assessing the probability of an airplane complying with noise certification requirements. A manufacturer would want a relatively high probability before considering the risk acceptable and launching a development program. This probability can be calculated using statistical procedures. In this study the statistical methods took into account the predicted margin below each noise limit and the uncertainty or tolerance associated with the prediction. The standard deviations for the noise predictions were estimated to be 3 EPNdB for approach and 2.7 EPNdB for takeoff and sideline. The estimated probabilities for each study airplane are summarized in Table 31. As noted in Section 7, optimization for minimum noise of the performance of all study airplanes and of the nacelle configurations of the airframe manufacturer designed airplanes would increase the compliance probabilities.

TABLE 31

PROBABILITY OF ACHIEVING NOISE GOAL

Airplane	Probability of Meeting Goal*
BOEING DOMESTIC TWIN	63%
DOUGLAS DOMESTIC TRI	95
DOUGLAS INTERNATIONAL TRI	93
LOCKHEED DOMESTIC TRI	92
LOCKHEED INTERNATIONAL QUAD	86
P&WA DOMESTIC TRI	84
P&WA INTERNATINAL QUAD	79

*Goal is compliance with FAR Part 36 (1978)

10.5 EMISSIONS PROBABILITY ASSESSMENT

The probability margins applied to the gaseous exhaust emission estimates are discussed in Section 8.0. Figure 59 and Figure 60 show how these probability margins compare with the NASA goals of meeting the proposed 1981 EPA Emissions Standards. Pratt & Whitney Aircraft quoted estimated emissions are shown by the circles on each plot. The results indicate that the Energy Efficient Engine has a greater than 99 percent probability of meeting the CO and THC standards about a 10 percent probability of meeting the NO_x goal, and a 50 percent probability of meeting the maximum smoke standard.

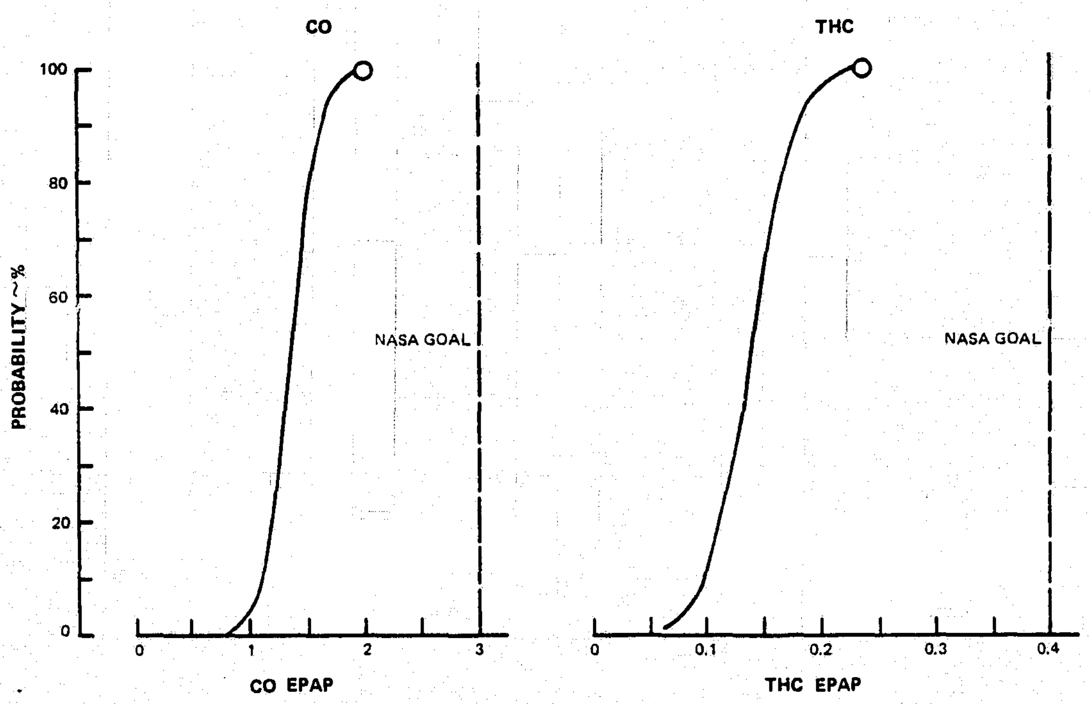


Figure 59 Probability of Achieving Emission Goals -- The probability of meeting CO and THC standards is greater than 99 percent.

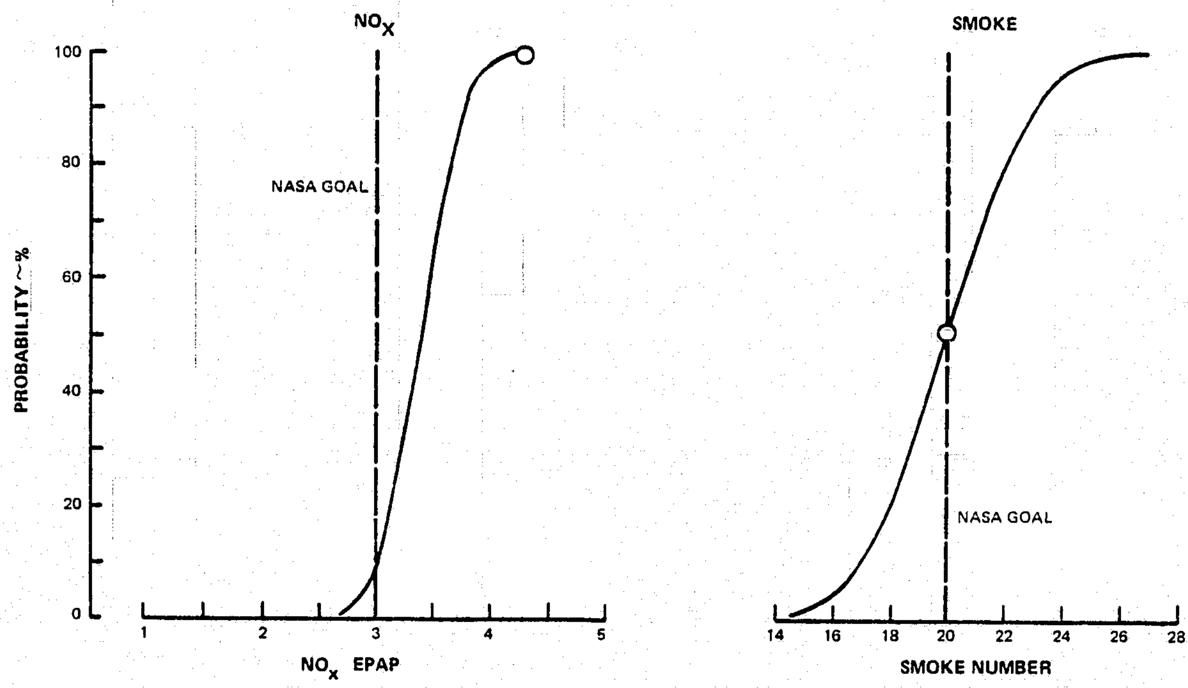


Figure 60 Probability of Achieving NO_x and Smoke Emission Goals -- The probability of meeting the NO_x goal is ten percent. There is probability of fifty percent of achieving the maximum smoke standard.

11.0 CONCLUSIONS

o The technologies being developed during the Energy Efficient Engine program offer substantial fuel burned and economic payoffs in a wide range of advanced commerical transport airplanes.

o The current design of the Energy Efficient Engine installed in medium to long range trijet or quadjet aircraft offers a high probability of meeting all NASA program goals in performance, economics, and environmental factors except for nitrous oxide exhaust emissions. In Boeing's shorter-range twinjet application, the current design of the Energy Efficient Engine also may not meet the NASA goals for either direct operating costs or noise.

o The Energy Efficient Engine design has the potential for thrust growth of up to 25% without significant impact on its ability to meet NASA program goals.

12.0 SYMBOLS & ABBREVIATIONS FOR PS-AIE REPORT

^oC	-	degrees Celsius
^oF	-	degrees Farhenheit
^oK	-	degrees Kelvin
APU	-	Auxiliary Power Unit
AR	-	aspect ratio
BCAC	-	Boeing Commercial Airplane Company, Division of the Boeing Company
BPR	-	bypass ratio
CAB	-	Civil Aeronautics Board
CL	-	lift coefficient
cm	-	centimeter
CO	-	carbon monoxide
DAC	-	Douglas Aircraft Company, Division of McDonnell Douglas Corporation
DOC	-	direct operating cost
ECCP	-	Experimental Clean Combustor Program
EEE	-	Energy Efficient Engine
EI	-	Emissions Index
EPA	-	Environmental Protection Agency
EPAP	-	EPA Parameter (measure of exhaust emissions)
EPNdB	-	effective perceived noise in decibels
FAR	-	Federal Airworthiness Regulations
FPR	-	fan pressure ratio
FPS	-	flight propulsion system
ft	-	feet
gal	-	gallons
hp	-	horsepower
HPC	-	high pressue compressor
HPT	-	high pressure turbine
hr	-	hour
in	-	inch
INS	-	insurance
IOC	-	indirect operating cost
kN	-	kilonewtons
kg	-	kilogram
km	-	kilometers
kW	-	kilowatt
lbf	-	pound force
lbm	-	pound mass
LCC	-	Lockheed California Company, Division of Lockheed Corporation
LPC	-	low pressure compressor
LPT	-	low pressure turbine
LTO	-	landing and takeoff cycle
m	-	meters
MEW	-	manufactuers empty weight
Mfg	-	manufacturer

Mn	-	Mach number
n.mi.	-	nautical miles
N	-	newtons
NOx	-	oxides of nitrogen
OEW	-	operating empty weight
OPR	-	overall pressure ratio
P	-	pressure
P&WA	-	Pratt & Whitney Aircraft
PR	-	pressure ratio
Prob	-	probability
R	-	efficiency
RIT	-	rotor inlet temperature
ROI	-	return on investment
δ	-	local total pressure/sea level standard pressure
s.m.	-	statute mile
T	-	total temperature
TEGV	-	turbine exit guide vane
THC	-	total unburned hydrocarbons
TOGW	-	takeoff gross weight
TSFC	-	thrust specific fuel consumption, fuel flow/thrust
W	-	mass flow
Wa	-	airflow
s	-	seconds
θ	-	local total/sea level standard temperature

REFERENCES

1. "Energy Efficient Engine Preliminary Design and Analysis Report" NASA CR-135396, (To be Published)

2. Gray,D.E.: "Energy Efficient Engine Preliminary Design and Integration Studies", NASA CR-135396.

3. Gray D.E.: "The study of Turbofan Engines Designed for low energy Consumption, NASA CR-135002, PWA-5318 April 1976

4. Revelle, J.D.: "The Calculation of Aerodynamic Noise Generated by Large Aircraft at Landing Approach", Acoustic Society of America, 87th Meeting, 26 April 1974

5. Putnam, T.W. and Lasagna, P.L.: "Measurements and Analysis of Aircraft Airframe Noise", AIAA Paper 75-510, March 1975

6. Blumenthal, V.L. et al, "Aircraft Environmental Problems", AIAA Paper 75-3, January 1973

7. Rice, E. J.: "Optimum Wall Impedance for Spinning Modes, a Correlation with Cutoff Ratio", AIAA Paper 78-193, Jan. 1978.

APPENDICES

The Appendices present the final reports prepared by each of the airframe subcontractors--Boeing, Douglas, and Lockheed--for Pratt & Whitney Aircraft. The reports provide the results of their performance comparisons and integration studies and summarize the subcontract effort in support of the preliminary nacelle design task.

During the nacelle design process--which included two design review/coordination meetings with each subcontractor--the airframers raised a number of concerns about the design. Pratt & Whitney Aircraft endeavored to account for these concerns as the nacelle design evolved. In cases where there were conflicting opinion among the airframers on aspects of the design, Pratt & Whitney Aircraft chose the approach most in keeping with the objectives and philosophy of the Energy Efficient Engine Program. In other cases, where satisfactory resolution of the concern would have required a detailed design effort beyond that appropriate to the purposes of this program, the concern was left unresolved.

The preliminary nacelle design resulting from this coordinated effort is described in the Energy Efficient Engine Preliminary Design and Analysis Report, Reference 1.

APPENDIX A

DOCUMENT NO. D6-48027

TITLE: ENERGY EFFICIENT ENGINE AND AIRPLANE INTEGRATION STUDY

MODEL

ISSUE NO. TO: (DATE)

Subcontract No. 20646-1
Under NASA Contract NAS3-20646

For

United Technologies Corporation
Pratt and Whitney Aircraft Group
Commercial Products Division
East Hartford, Connecticut

PREPARED BY R. H. Johnson 11-9-78
SUPERVISED BY D. E. Johnson 11-9-78
APPROVED BY B. C. Karcher 11-10-78
APPROVED BY A. Sigalla Nov 13, 78
C. W. Clay 11/14/78 (DATE)

114 INTENTIONALLY BLANK

LIST OF ACTIVE PAGES

SECTION	PAGE NUMBER	REV SYM	ADDED PAGES: PAGE NUMBER	REV SYM	PAGE NUMBER	REV SYM	PAGE NUMBER	REV SYM
	i							
	ii	A						
	iii	A						
	iv							
	v							
	vi							
	vii	A						
	viii							
	1							
	2							
	3	A						
	4							
	5							
	6							
	7							
	8							
	9	A						
	10	A						
	11							
	12							
	13							
	14							
	15							
	16							
	17							
	18							
	19							
	20							
	21							
	22	A						
	23							
	24							
	25							
	26							
	27							
	28							
	29	A						
	30							
	31							
	32							
	33	A						
	34							
	35							
	36	A						
	37							
	38							
	39							
	40	A						

SECTION	PAGE NUMBER	REV SYM	ADDED PAGES: PAGE NUMBER	REV SYM	PAGE NUMBER	REV SYM	PAGE NUMBER	REV SYM
	41							
	42							
	43	A						
	44							
	45							
	46							
	47							
	48							
	49							
	50							
	51							
	52							
	53							
	54							
	55							
	56							
	57	A						
	58							
	59							
	60							
	61							
	62							
	63							
	64							
	65	A						
	66							
	67							
	68	A						
	69							
	70							
	71							
	72							
	73							

D1 4100 7700 ORIG. 3/71

REVISIONS

REV SYM	DESCRIPTION	DATE	APPROVAL
A	Corrected typographical errors on Pages vii, 9, 10, 33, 43, 57, 65, and 68. Revised wording of second sentence on Page 3. Revised wording of first sentence, page 22, to correct "...maximum cruise speed of 0.8 Mach ---." to "---- cruise thrust, 0.8 Mach ----." Revised wording lines 4 through 8, page 29, to change standard day to $84^{O}F$ day. Page 36 revised 500M point to 6500M point. Page 40 revised signs of TOGW and SLST sensitivity to $\Delta F_{N\ TO}$.	12/12 12/12	RH R. Johnson

TABLE OF CONTENTS

	Page
1.0 SUMMARY INTRODUCTION	1
2.0 INTRODUCTION	5
3.0 SYMBOLS AND ABBREVIATIONS	7
4.0 AIRPLANE AND MISSION DEFINITION	9
4.1 Mission Selection	9
4.2 Advanced Technology Features	10
4.2.1 Aerodynamics	10
4.2.2 Weights and Structures	13
4.3 Airplane Geometry Guidelines	13
4.4 Engine Installation	16
4.4.1 Engine Placement	16
4.4.2 Nacelle Drag	16
4.4.3 Engine Bleed and Power Extraction	16
4.5 Preliminary Airplane Configuration	21
4.5.1 Airplane Description	21
4.5.2 Engine Description	21
4.6 Procedures for Determining Direct Operating Cost (DOC) and Return on Investment (ROI)	22
4.6.1 Direct Operating Cost	22
4.6.2 Return on Investment	27
5.0 AIRPLANE PERFORMANCE AND SENSITIVITY	29
5.1 Airplane Sizing	29
5.1.1 Airplane Performance and Characteristics	29
5.1.2 Airplane Weight	33
5.1.3 Airframe Noise and FAR 36 Flight Conditions	34
5.1.4 Engine and Airframe Noise	36
5.1.5 Airplane Drawings of Sized Airplane	37
5.1.6 Airplane Drag Polars	37

5.2 Airplane Sensitivity Factors 37
5.3 Takeoff Gross Weight and Fuel Burned Comparison 37
5.4 Typical Mission DOC and ROI 42

6.0 AIRCRAFT ENGINE INTEGRATION 51

6.1 Nacelle Arrangement and Construction 51
6.2 Airframe Accessory Requirements and Location 51
6.3 Maintainability, Accessibility, and Safety Requirements 58
6.4 Nacelle Mount System 58
6.5 Nacelle Design 66
6.6 Nacelle Weight Evaluation 66

7.0 CONCLUSIONS AND RECOMMENDATIONS 72

REFERENCES 73

LIST OF TABLES

		Page
1-1	Airplane Characteristics and Performance	2
1-2	Nominal Noise Estimates	3
4-1	Advanced Airframe Structure for E^3 Studies	14
4-2	DOC Elements	23
4-3	Basic Characteristics of Boeing 1977 Coefficients	23
4-4	Domestic Direct Operating Cost Formulas	24
4-5	Return on Investment Method	28
5-1	Airplane Characteristics and Performance	32
5-2	Weight Statement for P&WA E^3 Airplanes	33
5-3	Flight Conditions for FAR 36 Noise Calculations--77°F	35
5-4	Nominal Noise Estimates	36
5-5	Domestic Airplane Sensitivity Factors -- Model 768-867	40
5-6	Domestic Airplane Sensitivity Factors--Model 768-866	40
5-7	Economic Analysis	49
6-1	E^3 Engine Gearbox Location	57
6-2	Nacelle and Structural Design Load Factors	60
6-3	Engine Nacelle Airloads	61
6-4	Nacelle Weight Evaluation--Comparison of Boeing and P&WA Nacelles	67
6-5	Comparison of Boeing and P&WA Weight Reduction Factors	68

LIST OF FIGURES

		Page
4-1	Typical Mission Profile	11
4-2	Energy Efficient Engine Configuration (General Arrangement)--Model 768-865	12
4-3	Airplane Geometry Guidelines	15
4-4	Nacelle Placement Guidelines	17
4-5	Engine Placement Ground Rules	18
4-6	Installation Comparison	19
4-7	Bleed Airflow Requirement	20
4-8	F_W Factor for Crew Pay	25
4-9	Crew Utilization	26
5-1	Airplane Design Selection Chart--Model 768-867	30
5-2	Airplane Design Selection Chart--Model 768-866	31 A
5-3	Energy Efficient Engine Configuration (General Arrangement)--Model 768-867	38
5-4	Energy Efficient Engine Configuration (General Arrangement)--Model 768-866	39
5-5	Block Fuel Comparison	41
5-6	Design Mission Fuel Burned Comparison	43
5-7	Percent Block Fuel by Mission Profile Segment	44

		Page
5-8	Design Mission Flight Profile--Model 768-867	45
5-9	500 nmi Mission Flight Profile--Model 768-867	46
5-10	Design Mission Flight Profile--Model 768-866	47
5-11	500 nmi Mission Flight Profile--Model 768-866	48
6-1	P&WA Energy Efficient Nacelle	52
6-2	Hydraulic Loads	55
6-3	Electric Loads	56
6-4	Long Duct Nacelle Mount	59
6-5	Airloads--Maximum Takeoff	62
6-6	Airloads--Maximum Dynamic Pressure	63
6-7	Airloads--0-deg Flap, 1.3 V_{stall}	64
6-8	Airloads--0-deg Flap, 1.3 V_{stall}	65

1.0 SUMMARY

NASA objectives for the Energy Efficient Engine (E^3) program are to develop technology to achieve: (1) a 12% reduction in cruise specific fuel consumption, (2) 5% reduction in direct operating cost (DOC), and (3) reduction of engine performance deterioration common to current technology high-bypass-ratio engines. Future noise and emission requirements must also be met. Boeing's role in the E^3 program was to help determine if the P&WA E^3 engine cycle met NASA goals. In this capacity, Boeing defined an advanced technology airplane and provided mission performance, economics, noise, and nacelle assessment data with E^3 and current technology engines installed.

An advanced technology one-stop transcontinental airplane was selected for the Boeing study. Scalable STF505M-7C and JT9D-7A engine data supplied by P&WA were cycled with the airplane to achieve the most fuel-efficient and economical airplane for each engine installation. Table 1-1 shows the airplane design point performance and characteristics. The design-mission fuel burned for the STF505M-7C was 17.9% lower than for the JT9D-7A engine. Based on P&WA supplied maintenance cost and engine price data, the STF505M-7C also had 6% lower DOC than the JT9D-7A-powered airplane.

Table 1-1. Airplane Characteristics and Performance

	Domestic Airplane	
	JT9D-7A Engine	STF505M-7C
Design range, nmi	2000	2000
Design payload, passengers/lb	196/40 180	196/40 180
Number of crew	3	3
Cruise Mach number	0.80	0.80
Number of Engines	2	2
Takeoff thrust/engine, pounds (sea level without bleed or HPX)	37 280	35 820
TOGW, pounds	256 580	248 880
Operating weight empty, pounds	160 780	162 510
Block fuel, pounds		
--at design range and payload	41 410	34 290
--at 1000 nmi range, 108 passengers	19 140	16 060

Table 1-2 shows that airport and community noise levels for the STF505M-7C airplane meets FAR 36, amendment 8, requirements for a twin-engine airplane. A nominal noise estimate 3 EPNdB below FAR noise requirements is generally considered sufficient margin to ensure a certifiable engine installation. Using this criterion, the approach noise is marginal; however, no attempt was made in this preliminary estimate to refine the nacelle treatment to lowest noise levels. A

Table 1-2. Nominal Noise Estimate

	STF505M-7C	FAR 36 (1978)	
	EPNdB	Requirement EPNdB	EPNdB
Takeoff	91	93.9	-2.9
Sideline	91	98.3	-7.3
Approach	102	102.0	0

A

The fuel burned, economics, and noise results based on engine data supplied by P&WA for the STF505M-7C show that the NASA goals for the P&WA E^3 cycle could be met. However, Boeing's assessment of the engine data and nacelle design indicated a number of unresolved issues. These issues and the results of the Boeing evaluation follow.

- o Boeing evaluation of the STF505M-7C nacelle weights indicated the nacelle weight to be 1310 lb over the P&WA estimated weight. Boeing's weight estimate was based on methods reflecting low technical risk for commercial operation. This weight increase reduced fuel burned savings from 17.9% to 16.6% and reduced the DOC advantage from 6% to 5.7%.

- o The STF505M-7C engine price supplied by P&WA is too low according to Boeing projections. Boeing's assessment indicated a price increase of $590,000 per engine. The Boeing estimated price reduced the DOC advantage of the STF505M-7C from 6 to 4.2%, which is below the NASA 5% goal.

- o Nacelle assessment and evaluation requires continual review as the design evolves to ensure that the nacelle design meets airplane requirements and objectives, Boeing design practice, and airline and FAA certification requirements. During the Boeing assessment, several versions of the STF505M-7C nacelle design were reviewed. In P&WA's nacelle layouts, however, material callouts and construction details were too incomplete to conduct an indepth evaluation. Concerns based on a critique of the nacelle design were developed and coordinated with P&WA. Some nacelle design problems were identified. Much additional effort would be required to ensure a flight-acceptable nacelle installation, but no work of this type is being considered in future programs.

To ensure that the E^3 program results in an engine configuration that meets the program goals and that can be installed in a nacelle acceptable to the airframer and airlines, it is important for the airframer to be actively involved in the installation design and evaluation.

2.0 INTRODUCTION

The NASA Aircraft Energy Efficient program (ACEE) has the objective of improving the energy efficiency of future U.S. aircraft so that substantial fuel savings and economies can be achieved.

The "Energy Efficient Engine (E^3) Preliminary Design and Integration Study" is one of the elements of this program. The recommended advanced technology propulsion system resulting from this study is projected for use on airplanes introduced into service in the late 1980's or early 1990's. NASA goals for the E^3 program are a 12% improvement in installed cruise specific fuel consumption, a 5% improvement in DOC, and performance retention of 50% or more as compared with a current technology high-bypass-ratio turbofan engine.

The present study is a follow-on to work performed for Pratt & Whitney Aircraft (P&WA) under subcontract No. 20528-1 in support of P&WA prime contract NAS3-20628. Objective of the P&WA prime contract, NAS3-20628, was to evaluate advanced technology engine cycles and to select an advanced cycle that best fulfilled the NASA E^3 program goals. Objective of the current study was to evaluate the advanced technology turbofan engine comparing it with a current technology reference engine to determine if NASA goals will be met when these engines are installed on commercial airplanes of the late 1980's.

The tasks designed to accomplish this objective included:

a. Aircraft and Mission Definition. Under this task an advanced technology transport aircraft was defined with a design range, performance passenger capacity, and mission appropriate for domestic use.

b. Aircraft Performance and Sensitivity. This task evaluated a current technology reference engine, the JT9D-7A (ref. 3) scaled to the airplane requirements and a similarly scaled advanced technology engine, the STF 505M-7C (ref. 4), as installed in the advanced technology airplane. The aircraft size was optimized for each engine for the defined mission. Aircraft performance and mission sensitivities were then generated for the aircraft powered with the advanced engine.

c. Aircraft and Engine Integration. Under this task a P&WA nacelle was evaluated for nacelle construction, airframe accessory requirements and location, maintainability, accessibility and safety requirements.

Section 4.0 of this report reviews and updates the mission selection and airplane definition studies accomplished in earlier E^3 studies reported in reference 5. Mission definition differed from these earlier studies primarily in its reduction of takeoff field length (TOFL) requirement from 7500 to 6000 ft; the major airplane-configuration change was an aft relocation of the engine exhaust plane to 40% wing chord. The latter change was made as a result of a flutter-weight penalty trade study.

Section 5.0 summarizes the sizing studies of the JT9D-7A- and STF505M-7C-powered airplanes and compares the resulting performance, noise, and economics of the two airplanes. These studies were based on the P&WA-supplied engine performance, engine weight, engine noise, and engine economic data. DOC and ROI sensitivity to fuel price was determined by using fuel prices of 35, 40 and 45¢/gal. Also, an additional DOC and ROI calculation shows the impact of a Boeing estimated engine price that was about 50% higher than P&WA's estimate.

Section 6.0 comments on the Boeing assessment and evaluation of the P&WA-designed nacelle installation. Design comments, accessory requirements and location, design loads, mount structure, and a weight assessment are included in the critique of the P&WA nacelle design.

3.0 ABBREVIATIONS AND SYMBOLS

A/P	airplane
AR	aspect ratio
BLKF	block fuel, pounds
BLKT	block time, hours
c	local chord
C_L	wing lift coefficient, L/qS_{REF}
C_{LR}	C_L ratio
C_D	drag coefficient, D/qS_{REF}
C_{DNAC}	nacelle drag coefficient, D_{NAC}/qS_{NAC}
CET	combustor exit temperature, ^oF
D	airplane drag, pounds
dB(A)	weighted sound pressure level, decibels
D_{NAC}	nacelle drag, pounds
DOC	direct operating cost
E_3	energy efficient engine
EPNL	effective perceived noise level
EPNdB	effective perceived noise, decibels
f_{VB}	nacelle vertical bending frequency, Hertz
F_N	net thrust, pounds
FSPP	full standards prediction procedure
GL	ground line
ICAC	initial cruise altitude capability, feet
LE	leading edge
M	flight machine number
MCR	maximum cruise
MEW	manufacturer's empty weight, pounds
OEW	operational empty weight, pounds
q	dynamic pressure, lb/ft^2
PNL	perceived noise level

SFC	specific fuel consumption lb/hr-lb
SLST	sea level static thrust (uninstalled)
S_{REF}	wing reference area, ft^2
S_{NAC}	nacelle wetted area, ft^2
t/c	wing thickness-to-chord ratio, measured streamwise
TE	trailing edge
TOGW	takeoff gross weight, pounds
TOFL	takeoff field length, feet
WCP	wing chord plane
WRP	wing reference plane
VAPP	approach speed, keas
V_D	design dive speed
$\Lambda_{0.25C}$	sweepback angle at wing quarter chord, degrees

4.0 AIRPLANE AND MISSION DEFINITION

Selection of the design mission and a corresponding design payload and range was based on a projection of the commercial airplane market of the 1990's. Various design requirements, wing geometry, and advanced technology features were established for a 1990 domestic service airplane.

4.1 MISSION SELECTION

Examination of the possible 1990 market suggested that the future airline market would be similar to the existing marketplace. This prediction was based on the assumption that the air traveling community in the 1990's will constitute approximately the same percentage of the total population as today's air travelers, with a 4 to 6% annual growth. The air cargo market should experience similar growth.

Many of the current narrow body aircraft will be retired from active service by the major airlines in the late 1980's. These include the intercontinental range 707-320B and -320C models, the DC-8 Sixty series airplanes, and some of the early 727-200 model domestic airplanes.

Hence, there should be a market in the late 1980's for a large number of replacement aircraft in the 180 to 220 passenger size range. Accordingly, the design mission and sizing constraints selected for the E^3 study are:

	Domestic Airplane
Design range, nmi	2000
Nominal payload, passengers (15/85% mix)	196
Cruise Mach number	0.8
TOFL, feet (max)	6000
VAPP, knots (max)	125
ICAC, feet (min)	33 000
Reserves	ATA Domestic

A

The following off-design missions were selected for economic assessments:

	Domestic Airplane
Range, nmi	665
Payload, passengers (15/85% mix)	108
Cruise Mach number	0.8

A

A typical mission profile is shown in figure 4-1.

4.2 ADVANCED TECHNOLOGY FEATURES

An available aerodynamic and structural technology data base was used as a baseline for projecting advanced airplane technology for the E^3 program. Reviews in each technology identified advanced technology features assumed to be available for a 1986 program start and for in-service use in the early 1990's. The advanced technology features are summarized on airplane configuration drawing (fig. 4-2).

A further discussion of aerodynamics, weight, and structural advanced technology follows.

4.2.1 Aerodynamics

A baseline drag level was derived from representative wind tunnel model data. Improvements to this baseline drag data base were applied as follows:

a. Cruise--2% reduction in cruise drag was to be achieved by improved wing-airfoil design and improved component integration. In addition, it was assumed that an advanced active control system would produce zero trim drag.

b. Takeoff and Landing--a 5% improvement in lift-drag ratio was assumed for the domestic two-engine airplane. This reflected the following changes: sealed leading edge (LE) flaps, seals between nacelle struts and lateral edges of the LE flaps, and aileron droop for high lift.

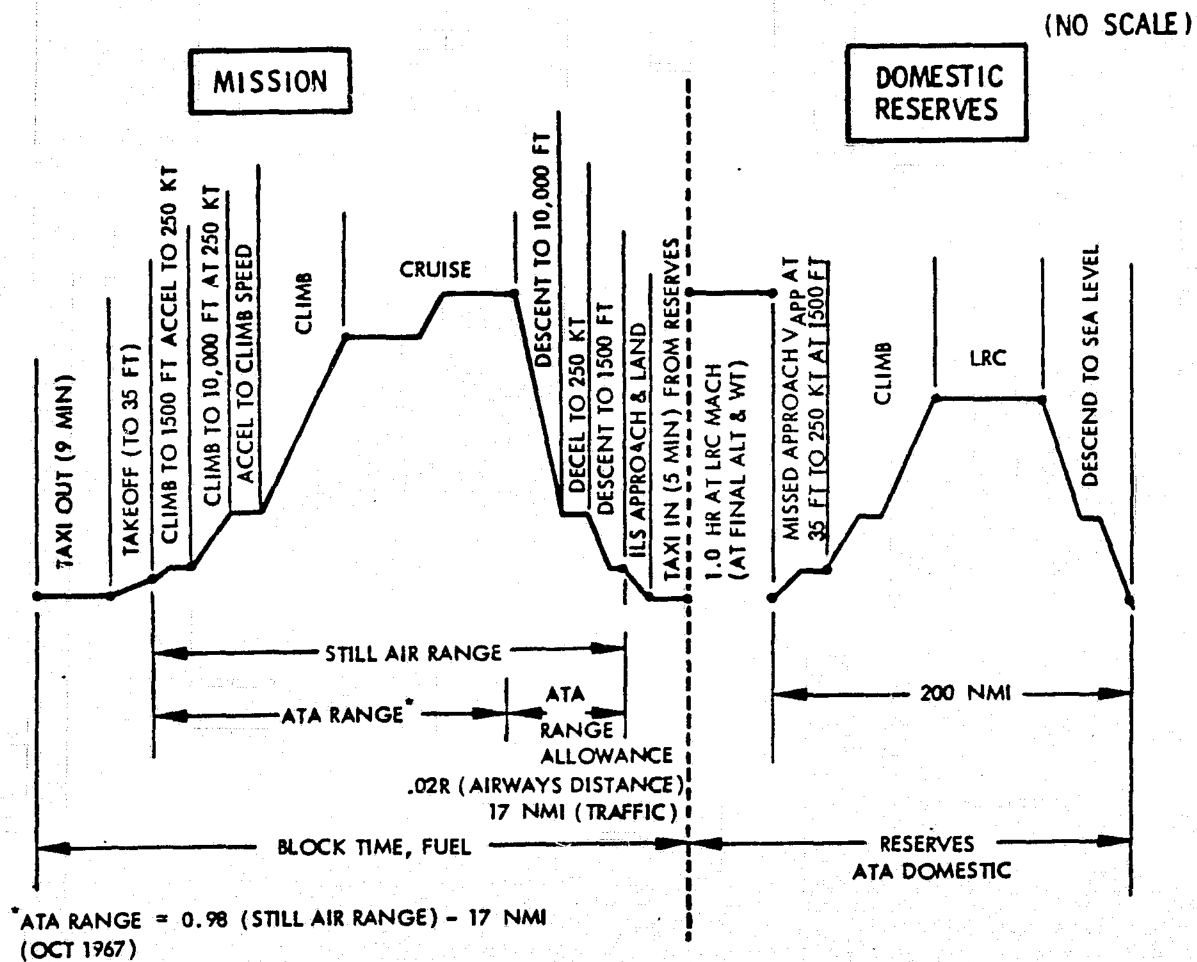


FIGURE 4-1 *Typical mission profile*

ADVANCED TECHNOLOGY APPLICATION

- NEW STRUCTURES TECHNOLOGY
  - ADVANCED ALUMINUM ALLOYS
    - WING UPPER SURFACE
    - WING LOWER SURFACE
    - WING SPARS AND RIBS
    - WING LE AND TE
    - FUSELAGE
    - EMPENNAGE
  - ADVANCED COMPOSITE STRUCTURES
    - ALL CONTROL SURFACES
    - LANDING GEAR DOORS
  - HIGH STRENGTH TITANIUM
    - FITTINGS:
      - LANDING GEAR SUPPORT
      - WING BODY ATTACHMENTS
      - EMPENNAGE BODY ATTACHMENTS
      - ENGINE AND STRUT SUPPORT STRUCTURE
      - FLAP SUPPORT FITTINGS
- AERODYNAMIC TECHNOLOGY
  - ADVANCED AIRFOIL/WING DESIGN
  - WING/STRUT/NACELLE DESIGN FOR FAVORABLE INTERFERENCE BETWEEN WING, NACELLE AND NOZZLE PRESSURE FIELD
  - EMPENNAGE DESIGN TO OPERATE EFFICIENTLY IN COMPLEX WING-BODY FLOW FIELD INTERFERENCE FREE
  - LEADING EDGE
    - VARIABLE CAMBER FLAPS 3 POSITION
  - TRAILING EDGE
    - DOUBLE SLOTTED TRAILING EDGE FLAPS
    - AILERON DROOP
- FLIGHT CONTROLS TECHNOLOGY
  - ALL AXES HANDLING QUALITIES SAS
  - ALL FLYING TAIL
  - DOUBLE HINGED CONTROL SURFACES
- SYSTEM TECHNOLOGY
  - CONVENTIONAL APU
  - AIR CYCLE COOLING SYSTEM
  - CABIN AIR RECONSTITUTED AND RECIRCULATED
  - INTEGRATE TAI WITH ECS
  - CARBON BRAKES AND LIMITED SLIP BRAKING

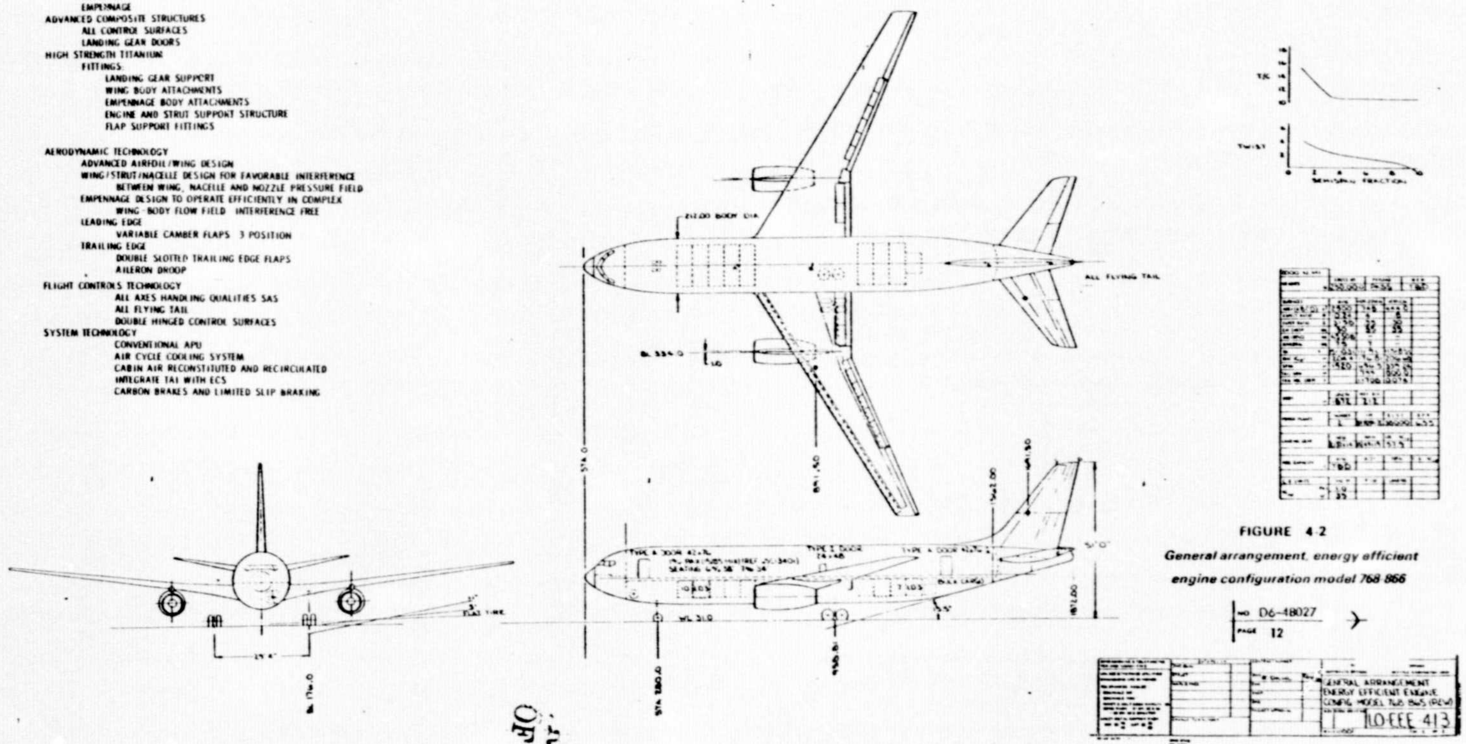


FIGURE 4-2

General arrangement, energy efficient engine configuration model 768-866

NO. D6-48027
PAGE 12

ORIGINAL PAGE IS
OF POOR QUALITY

4.2.2 Weights and Structures

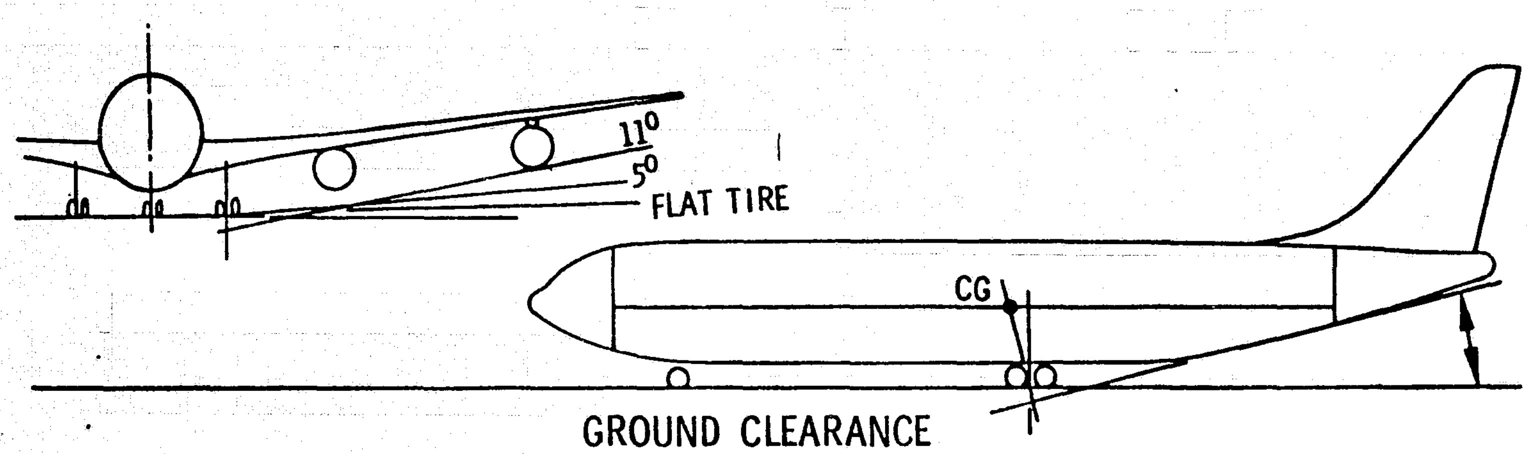
Possible application of advanced aluminum alloys and advanced composite structures on airframe components is shown with potential weight savings on table 4-1.

4.3 AIRPLANE GEOMETRY GUIDELINES

The airplane geometry guidelines shown in figure 4-3 were adopted to ensure adequate ground clearance during taxi, takeoff, and landing. These are the same guidelines used in the earlier study under subcontract No. 20628-1.

CURRENT TECHNOLOGY	NEW TECHNOLOGY		
MATERIAL	MATERIAL	STRUCTURAL COMPONENT	WEIGHT SAVING % OF COMPONENT WEIGHT
STANDARD ALUMINUM ALLOYS (CURRENT 747)	ADVANCED ALUMINUM ALLOYS	WING BOX FUSELAGE EMPENNAGE BOX	6% 4% 6%
CONVENTIONAL ALUMINUM CONSTRUCTION	ADVANCED COMPOSITE STRUCTURE (GRAPHITE)	CONTROL SURFACES LANDING GEAR DOORS	25%
	CARBON	MAIN LANDING GEAR BRAKES	40%
	TITANIUM FITTINGS	LANDING GEAR SUPPORT SIDE OF BODY RIB EMPENNAGE BODY ATTACH ENGINE STRUT ATTACH FLAP SUPPORT	20%

TABLE 4-1 *Advanced airframe structure for E^3 studies*



- TAKE OFF ROTATION

    15.5 DEGREES DOMESTIC

- TOUCH DOWN

    ROLL CLEARANCE ANGLE 11 DEGREES WITH GEAR EXTENDED

- TAXI

    ROLL CLEARANCE ANGLE 5 DEGREES WITH OLEO COMPRESSED

- NO GROUND CONTACT WITH FLAT TIRE AND COLLAPSED OLEO

FIGURE 4-3 ***Airplane geometry guidelines***

4.4 ENGINE INSTALLATION

4.4.1 Engine Placement

Engine placement guidelines were revisions of those used in the cycle selection studies. The revised guidelines established for chordwise engine placement (figs. 4-4 and 4-5) provided balance between interference drag and flutter weight penalty. Figure 4-6 compares the STF505M-7C and JT9D-7A installations using these guidelines.

Spanwise engine location was based on considerations of wing flutter, engine-out control, and landing gear length.

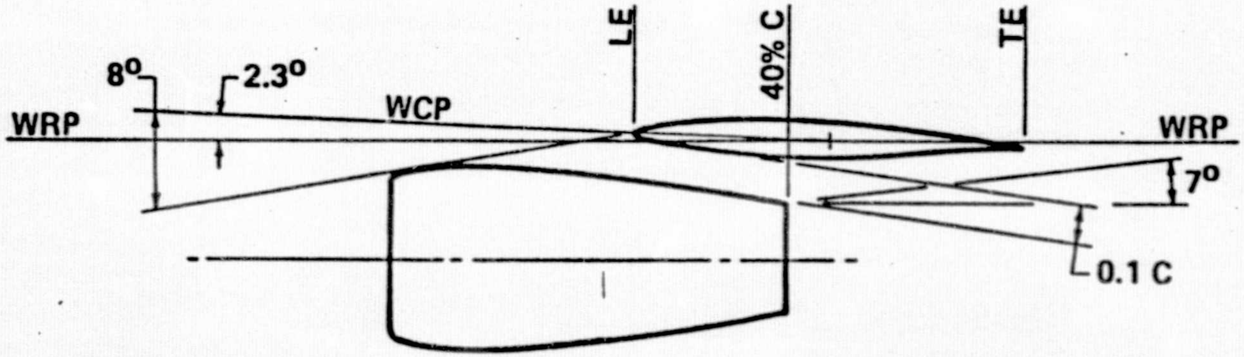
4.4.2 Nacelle Drag

Installed engine performance included cowl scrubbing drag where applicable. External drag of the nacelle and interference drag effects among wing, strut, and nacelle were included in airplane drag polars.

4.4.3 Engine Bleed and Power Extraction

Engine bleed air extraction values allowed cabin air ventilation at design cruise with sufficient margin for cabin altitude control. Recirculation reduced engine bleed requirements and fuel consumption due to air-conditioning by about 50%. Cabin bleed air requirements are shown in figure 4-7.

Engine shaft power extraction was based on load characteristics established by previous experience. Power extraction is split between airplane operational functions and passenger loading. Operational functions include basic hydraulic and electric loads for operating the airplane systems. Passenger loading directly affects galley loads and passenger lighting. This study used a base load of 180 hp/airplane, which is adequate for 200 passengers.



- **NACELLE PLACEMENT**

  NACELLE PRIMARY NOZZLE AT 40% OF CHORD.
  FAN COWL VERTICAL POSITION BELOW WING LOWER SURFACE BY 10% CHORD OR GREATER.

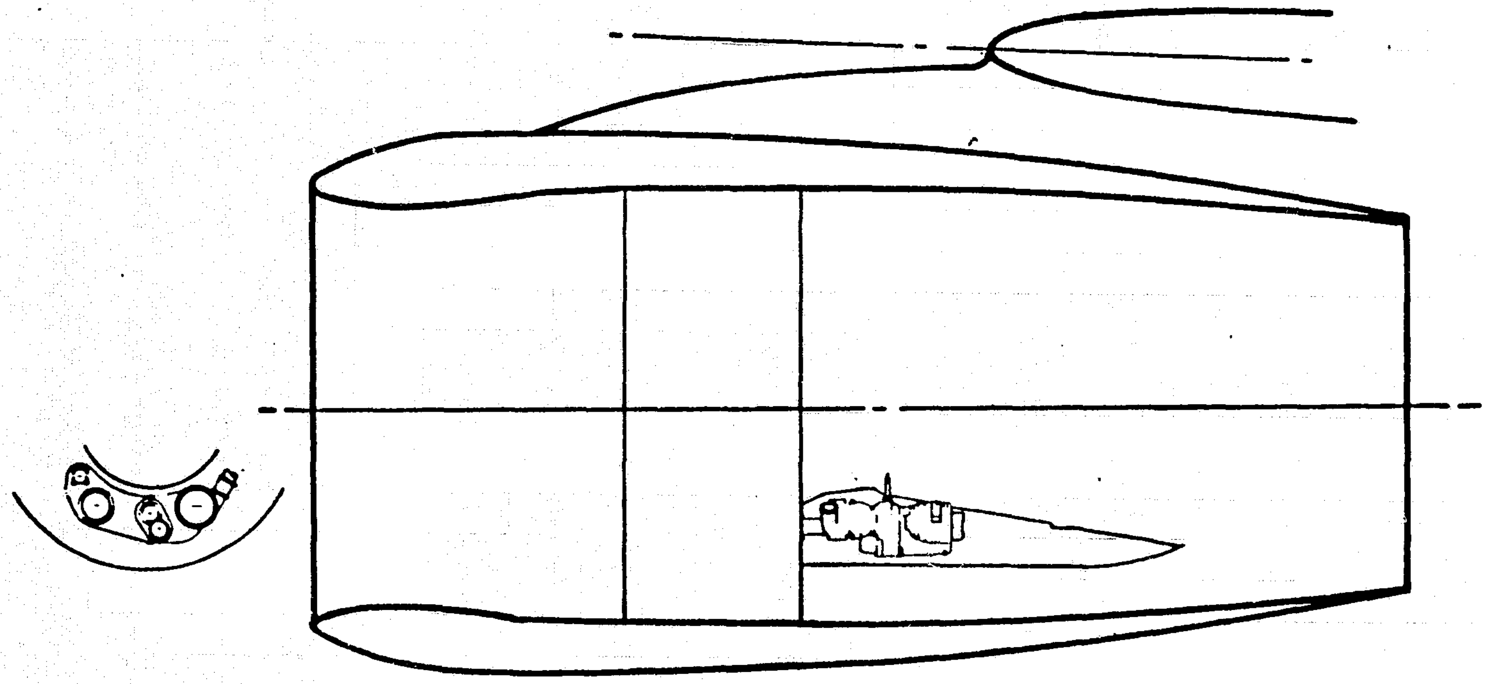
- **NO VORTEX SHEDDING OVER WING**

  FORWARD LIP OF COWL MUST BE BELOW AN 8-DEG LINE MEASURED WITH RESPECT TO LOCAL CHORD PLANE.

- **NO JET WAKE IMPINGEMENT**

  JET WAKE BASED ON EQUIVALENT DIAMETER AT THE PLANE OF PRIMARY NOZZLE AND EXPANDING 7 DEG MUST NOT CONTACT LOWER WING SURFACE.

FIGURE 4-4 *Nacelle placement guidelines*



- Strut profile will have no negative slope.
- Strut profile will not exceed WCP height at leading edge.
- Hilite clearance, 0.5 diameters to ground.
- Engine centerline horizontal and toed inboard, 1 deg.

FIGURE 4-5 ***Engine placement ground rules***

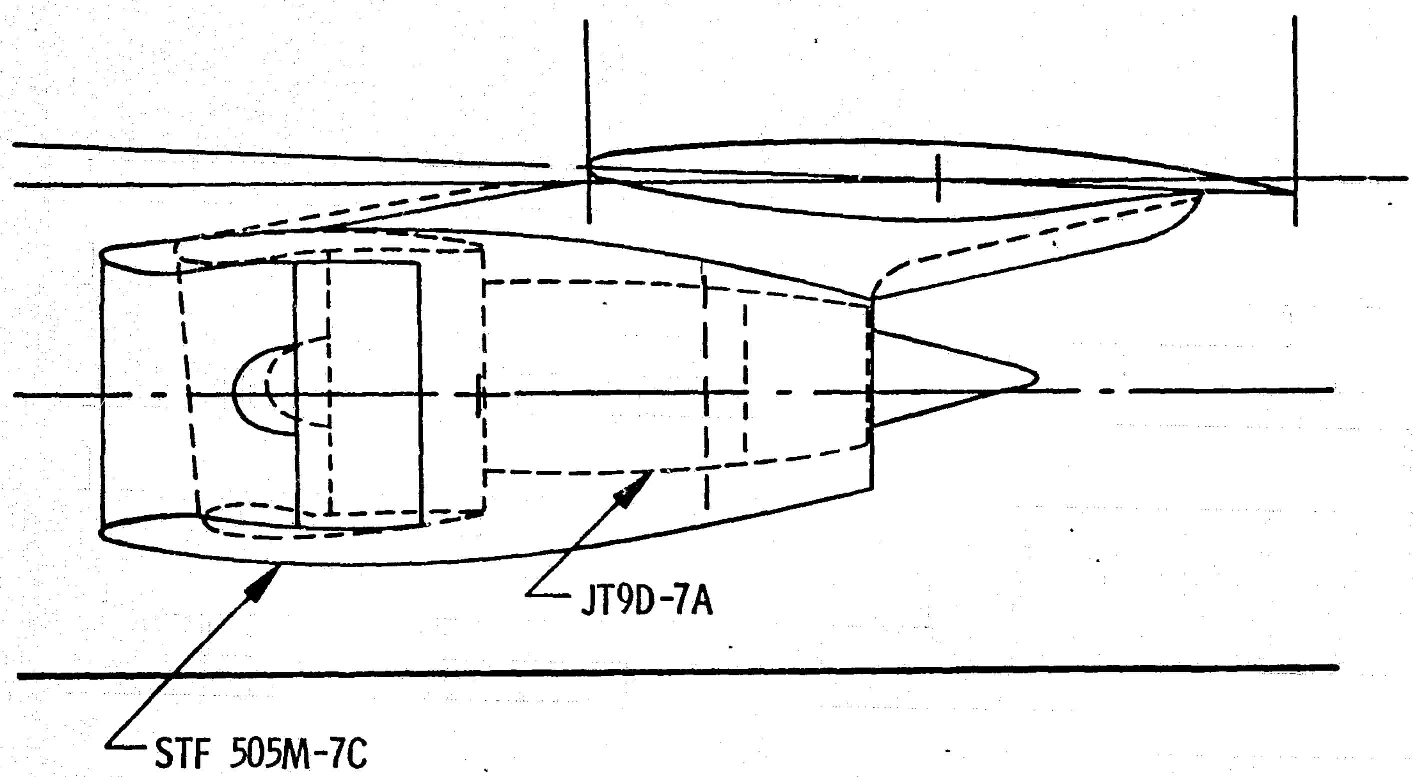
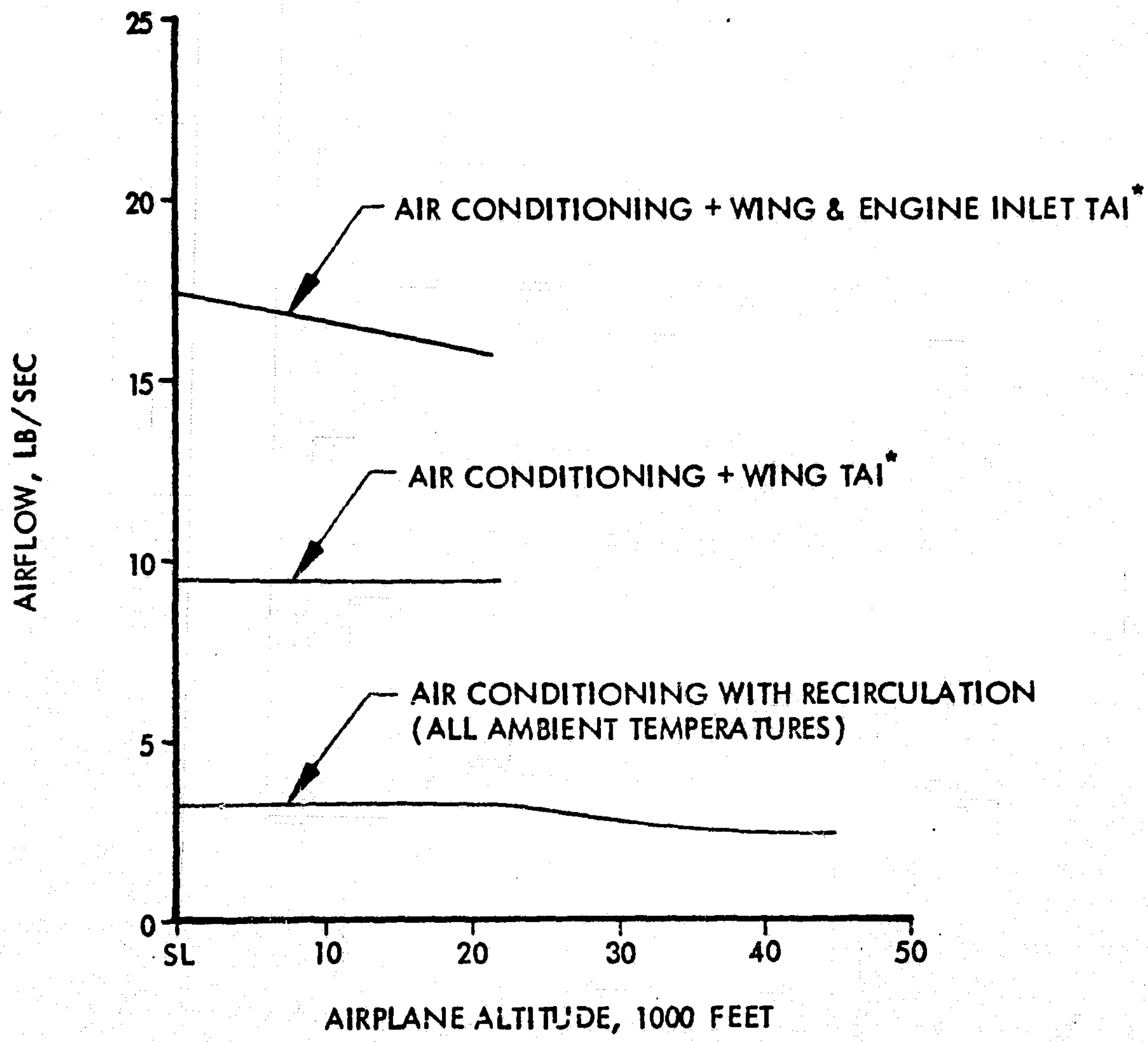


FIGURE 4-6 ***Installation comparison***



* ICING CONDITIONS DEFINED BY FAR 25.1419

FIGURE 4-7 ***Bleed airflow requirement***

Engine power extraction for airplane off-design operation (e.g., operation in icing conditions) was not required for the airplane parametric studies. System designs, however, considered off-design requirements.

4.5 PRELIMINARY AIRPLANE CONFIGURATION

4.5.1 Airplane Description

For the preliminary airplane, this study selected a twin-engine wide-body configuration with double-aisle seven-abreast seating. Wing geometry (AR = 10, $\Lambda_{0.25C}$ = 30 deg) was consistent with the cruise speed and takeoff and landing characteristics. The lower lobe cargo space was configured to accommodate 17 LD-3 containers side by side.

A preliminary drawing of the baseline airplane is shown in figure 4-2

4.5.2 Engine Description

Scalable JT9D-7A and STF505M-7C turbofan engines (refs. 3 and 4) were used for sizing the advanced technology airplanes. Both the current technology engine and advanced engine were installed to ensure only the differences in engines were reflected in the performance improvements resulting from this study. The JT9D-7A engine was installed in a short-fan-duct nacelle similar to the Boeing model 747 engine installation; the STF505M-7C was installed in a long-duct nacelle that included a forced mixer.

Main characteristics of the two engines at maximum cruise speed of 0.8 Mach and an altitude of 35 000 ft are:

	STF505M-7C	JT9D-7A
Bypass ratio	7.0	5.0
Installed SFC	0.56	0.68
Fan pressure ratio	1.74	1.58
Overall pressure ratio	38.6	25.4
Maximum turbine rotor inlet temperature (SLS hot-day takeoff)	2450°F	2290°F

4.6 PROCEDURES FOR DETERMINING DIRECT OPERATING COST (DOC) AND RETURN ON INVESTMENT (ROI)

The following method was used for determining the DOC and ROI of the airplane powered by the JT9D-7A and the STF 505M-7C advanced engine. The airplanes were sized to minimize fuel burned and airplane gross weight for the given engine. Then airplane block fuel and block time for a representative mission were used to determine the DOC and ROI based on 1977 dollars.

4.6.1 Direct Operating Cost

The Boeing DOC method has evolved over several years from the formulas published by the Air Transport Association of America in 1967. The DOC calculation includes cost of crew, fuel, airframe maintenance, engine maintenance, depreciation, and insurance. Utilization of the airplane is determined from the block time derived by mission analysis. The DOC calculation method is detailed in tables 4-2, 4-3 and 4-4 and in figures 4-8 and 4-9.

Crew cost	= f (TOGW, cruise speed, mission type)
+ Fuel	= fuel burn and fuel price specified
+ Airframe maintenance	= specified (Boeing)
+ Engine maintenance	= specified (engine manufacturer)
+ Depreciation	= f (useful life, residual value, utilization, initial price, spares price)
+ Insurance	= f (initial flyaway price)
=	DOC per trip
Utilization	= f (block time)

TABLE 4-2 DOC elements

Applicability	New airplanes, domestic trunk
Mission profile	1967 ATA with revised taxi, air maneuver, and airway distance factors
Utilization	Function of average block time, maximum of 15 trips/day
Cruise procedure	Minimum cost constant mach, step climb
Crew expense	Function of gross weight, speed and airplane utilization
Fuel price	35¢/gal U.S. domestic and local service
Maintenance	Mature-level maintenance based on current level with material escalation of 8% over 1976 Labor rate = \$9.70/man-hour Burden = 200% of direct labor
Depreciation	New—15 yr to 10% residual on airplane and spares
Insurance rate	0.5% of new airplane price
Assumed spares	6% of airframe price 30% of total engine price
Nonrevenue factor	2% added to fuel and maintenance for nonrevenue flying

TABLE 4-3 Basic characteristics of Boeing 1977 coefficients

	BOEING 1977
CREW PAY ($/BLK-HR)	
2-MAN CREW 1	$(29.87 F_w + 2.838) F_u + 19.80$
3-MAN CREW 1	$(33.54 F_w + 3.483) F_u + 29.70$
FUEL ($/U.S. GAL)	0.35
NONREVENUE FACTOR	1.02 ON FUEL AND MAINTENANCE
AIRFRAME MAINTENANCE–CYCLE MATERIAL ($/CYC) DIRECT LABOR (MH/CYC)	MATURE LEVEL MAINTENANCE BASED ON DETAILED ANALYSIS
AIRFRAME MAINTENANCE–HOURLY MATERIAL ($/FH) DIRECT LABOR (MH/FH)	
ENGINE MAINTENANCE–CYCLE MATERIAL /$/CYC) DIRECT LABOR (MH/CYC)	
ENGINE MAINTENANCE–HOURLY MATERIAL ($/FH) DIRECT LABOR (MH/FH)	
BURDEN (MH/DIRECT LABOR MH)	2.0
MAINTENANCE LABOR RATE ($/MH)	9.70
INVESTMENT SPARES RATIO	
AIRFRAME	0.06
ENGINE	0.03
DEPRECIATION SCHEDULE (YEARS/% RESIDUAL)	15/10
INSURANCE RATE (% OF TOTAL PRICE/YEAR)	0.5
UTILIZATION (BLK-HR/YEAR)	$U = \frac{4,000}{1 + \frac{1}{T_b + 0.5}} + 650$ (15 TRIPS/DAY MAXIMUM)

Definition of terms and units

TOGW	Maximum takeoff gross weight–lb
Ca	Airframe price–$
Ce	Engine price/engine–$ (excluding reverser)
Ne	Number of engines
T	Sea level static thrust–lb
M	High speed cruise mach number
Wa	Airframe weight–lb
FH	Flight-hours
MH	Man-hours
CYC	Cycle
T_b	Block time–hr

Notes:

1. See attachments for F_w and F_u crew pay factors
2. For flight-hours <2 use:

   Cost at 2 hr −0.73 (hourly cost) x (2 - flight-hours)

   For flight-hours >4 use:

   Cost at 4 hr + 1.53 (hourly cost) x (flight-hours - 4)

TABLE 4-4 *Domestic direct operating cost formulas*

REV SYM

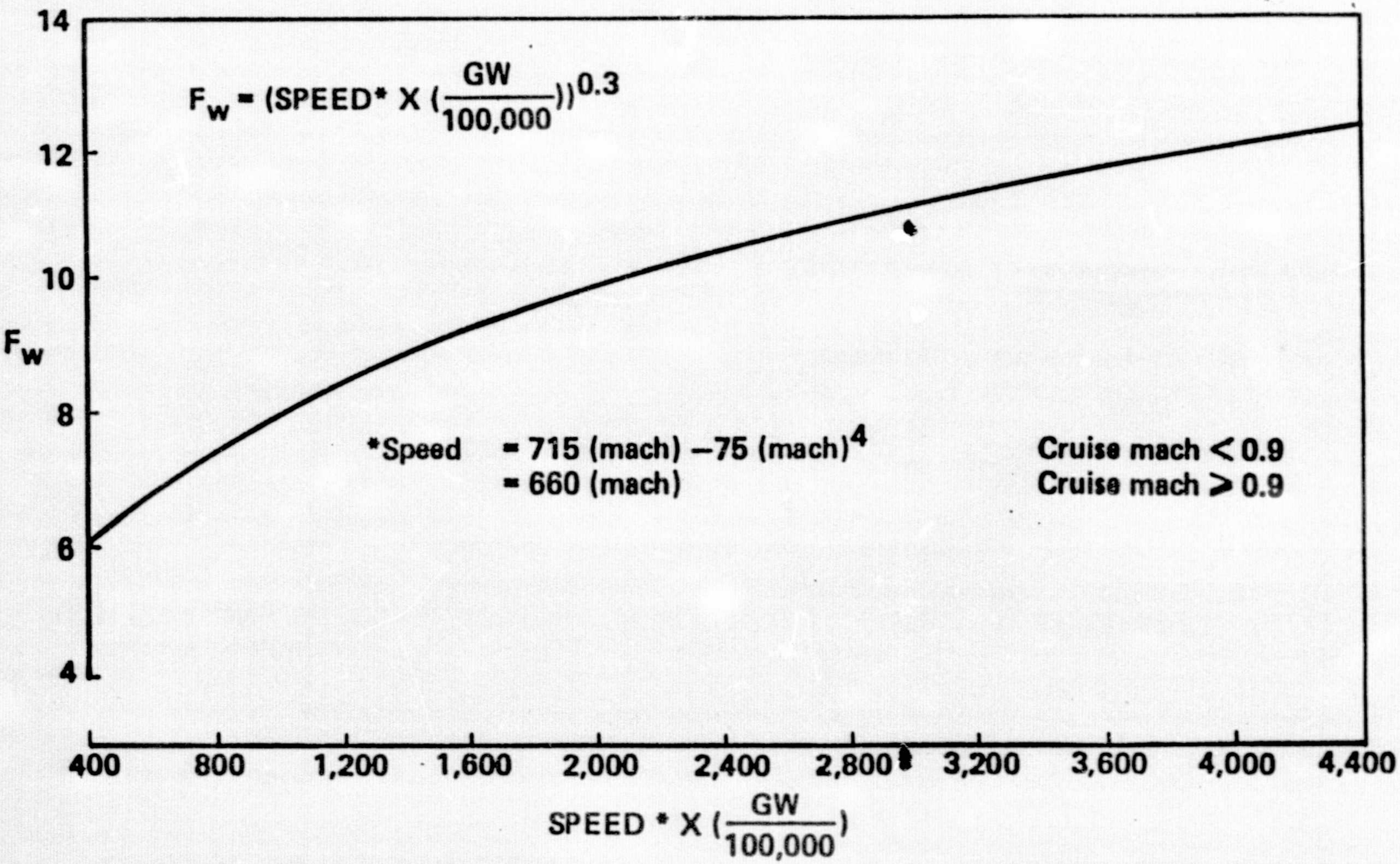


FIGURE 4-8 F_W *factor for crew pay*

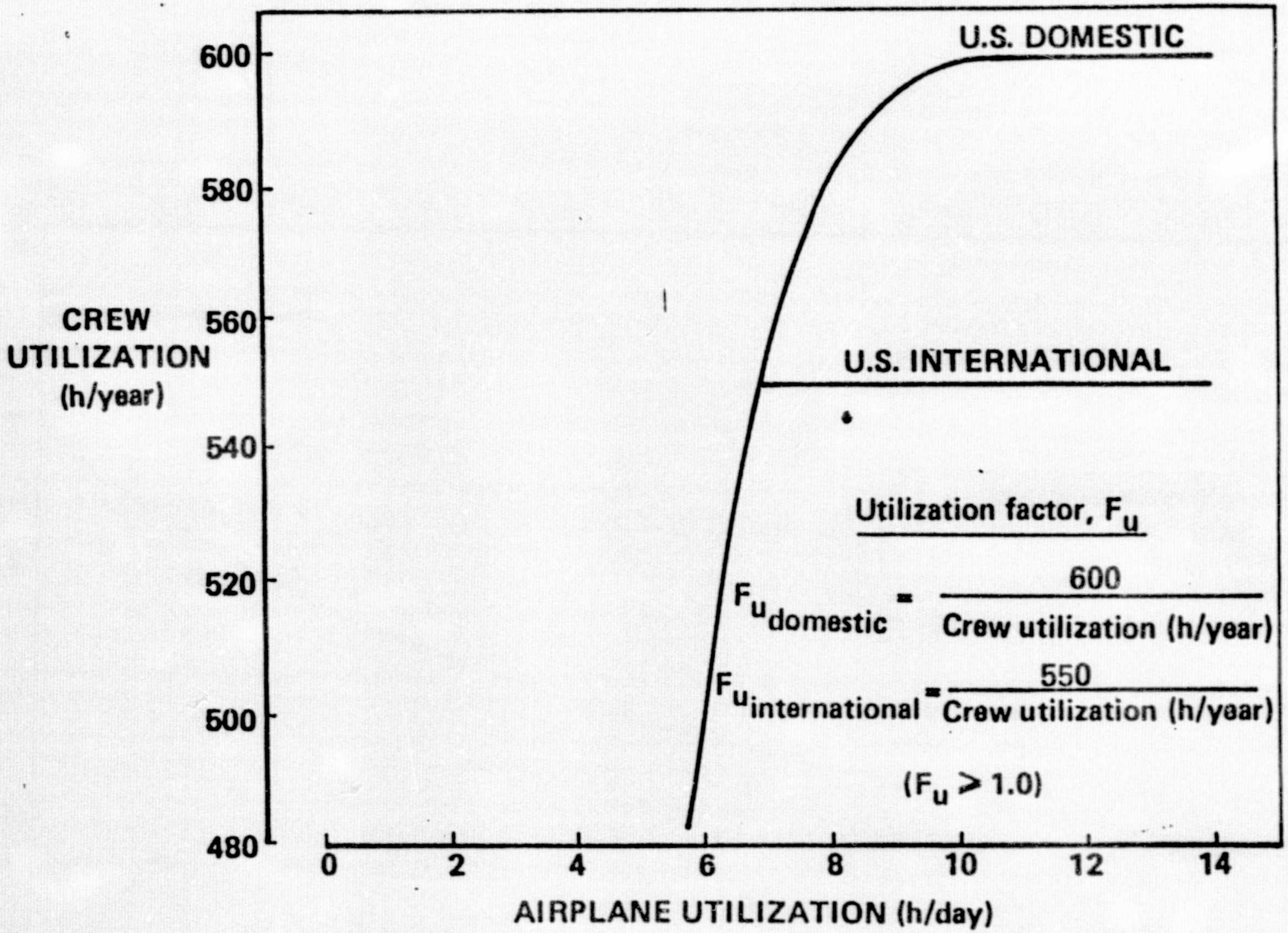


FIGURE 4-9 *Crew utilization*

4.6.2 Return on Investment

The Boeing economic analysis of the E^3 program used the discounted cash flow ROI method to evaluate each engine. ROI is the discount rate that makes the sum of the projected annual cost savings equal to the initial investment. It is the best comparator of alternative investment opportunities in a general business context. ROI recognizes the value of money over time, and it can be directly related to any airline's cost of capital to show how much a modification is above or below the hurdle rate. In this study's context, the hurdle rate is the ROI required before an airline would consider undertaking an investment opportunity. Cash flows were calculated using constant (1977) dollars to ensure consistent comparison of each concept.

It should be noted that there is an inherent uncertainty in any generalized figure of merit applied to a specific airline due to considerable variation in individual airline operations, rules, and evaluation criteria. Specific ROI analysis should be made using an airline's individual rules and hurdle criteria. A hurdle rate of 15% after taxes is considered an acceptable criterion.

In the E^3 study, the average range flown by domestic medium-range airplanes was determined, and a representative average range of 665 nmi was selected as a base for economic calculations. With a mission profile defined for the selected range, the initial investment, operational costs, and cash inflows were calculated for this profile and airplane utilization. The ROI was calculated with the method defined by table 4-5.

Definition:	ROI is the discount rate at which the net present value of future cash inflows (cost savings) is equal to the initial cash outlay (investment)

$$\text{Net present value (NPV)} = -C_{OUT} + \sum_{n=1}^{\text{useful life}} C_{IN}/(1+r)^n$$

When NPV = 0, r = ROI = discount rate

Calculations:

1. Before tax cash outflows (C_{OUT})
   - Incremental airplane price or modification cost
   - Additional spares inventory
2. Before tax cash inflows (annual) (C_{IN})
   - Cash operating cost savings
     - Fuel
     - Maintenance
3. After tax equivalence
   - Depreciation tax effects
   - Investment tax credit (if applicable)

TABLE 4-5 *Return on investment method*

5.0 AIRPLANE PERFORMANCE AND SENSITIVITY

5.1 AIRPLANE SIZING

Both the JT9D-7A and the E^3 powered airplane were sized to meet the same design mission. Design selection charts for the two airplanes are shown in figures 5-1 and 5-2. The wing loading for these airplanes was chosen for minimum BLKF and takeoff gross weight (TOGW) with an 84^{o}F-day sea-level takeoff field length (TOFL) constraint of 6000 ft determining the thrust loading. The takeoff constraint for the STF505M-7C required about 5% higher thrust-to-weight than the JT9D-7A. This was largely a result of relative increase in engine BPR and windmilling drag for the STF505-7C engine. A

5.1.1 Airplane Performance and Characteristics

Characteristics and performance of the JT9D-7A- and the STF505M-7C-powered airplanes are compared in table 5-1. Each airplane was designed to meet airplane and mission requirements (sec. 4.1). The BLKF and TOGW shown in table 5-1 are based on an airplane sizing program. A more detailed fuel burned comparison based on mission analysis is discussed in section 5.4.

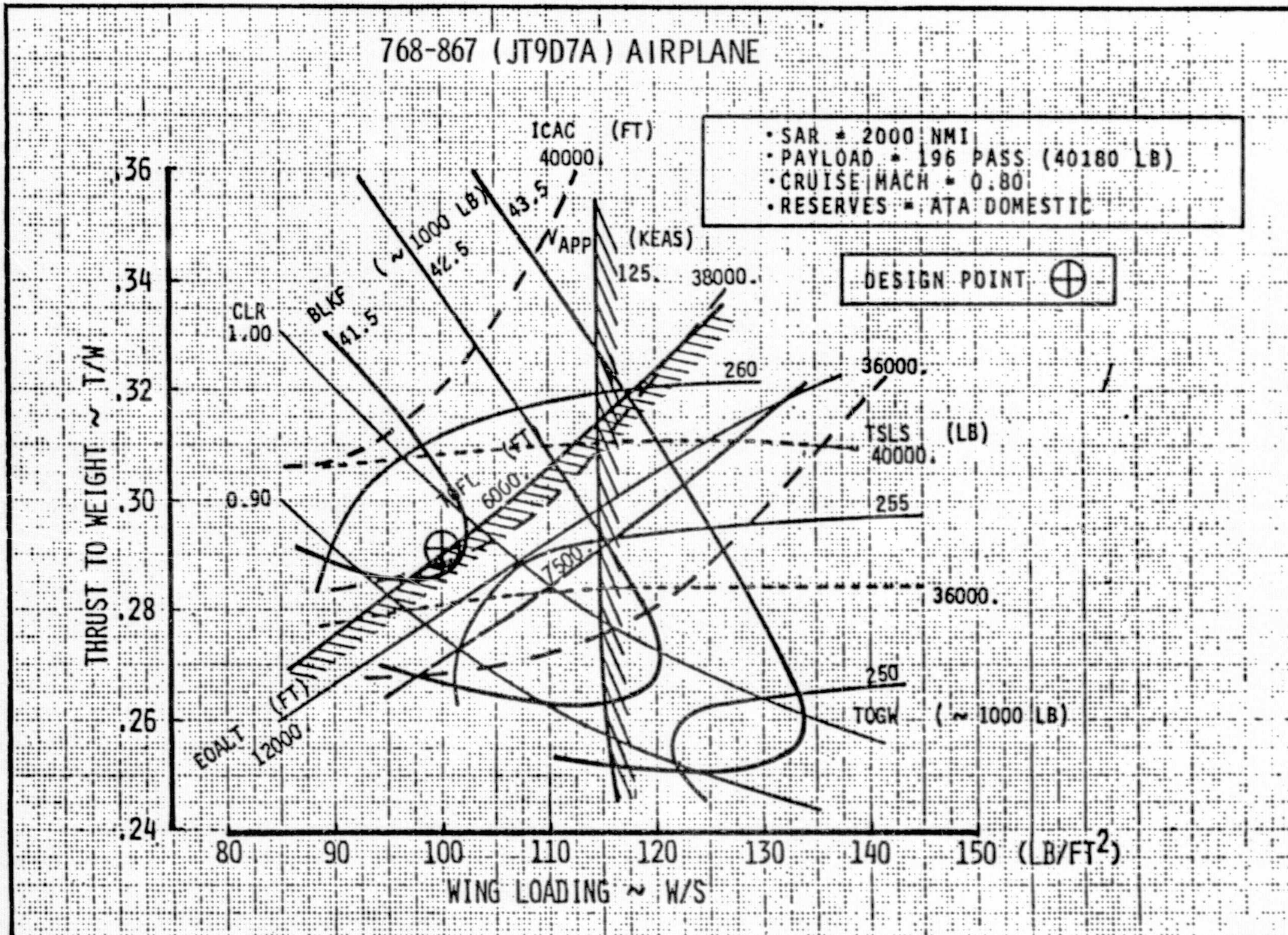


FIGURE 5-1 *Airplane design selection chart model 768-867*

REV SYM

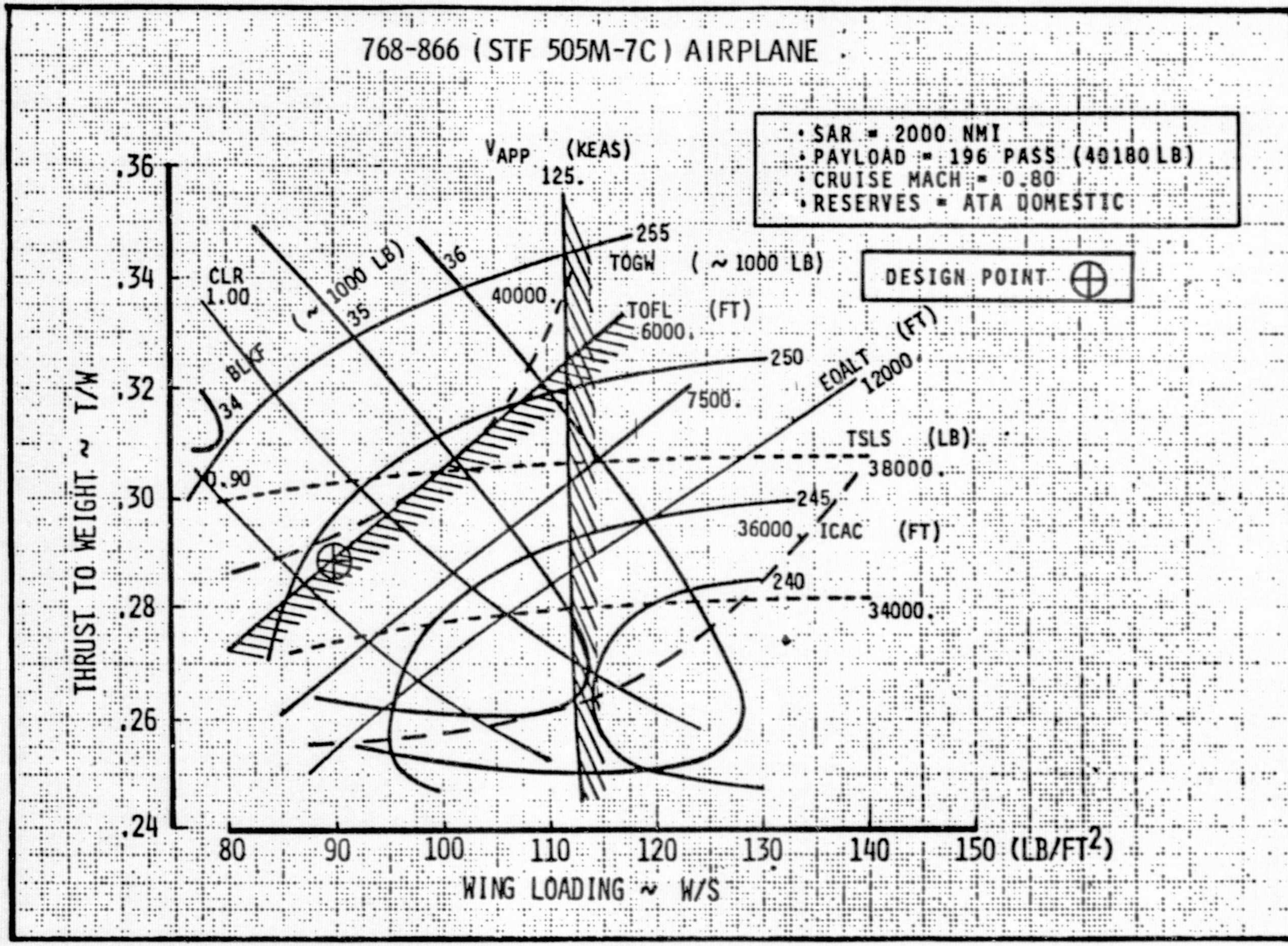


FIGURE 5-2 *Airplane design selection chart model 768-866*

Table 5-1 Airplane Characteristics and Performance

Engine	Domestic Airplane JT9D-7A Engine	Domestic Airplane STF505M-7C
Design range, nmi	2000	2000
Design payload, passengers/lb	196/40 180	196/40 180
Number of crew	3	3
Cruise Mach number	0.80	0.80
Number of engines	2	2
Takeoff thrust/engine, lb (sea level without bleed or HPX)	37 280	35 820
TOGW, lb	256 580	248 880
Operating weight empty, lb	160 780	162 510
Manufacturer empty weight, lb	149 380	151 110
Maximum landing weight, lb	229 960	223 060
Block fuel, lb		
--at design range and payload	41 410	34 290
--at 1000 nmi range, 108 passengers	19 140	16 060
Block time, hrs.		
--at design range and payload	4.69	4.69
--at 1000 nmi range, 108 passengers	2.51	2.51

Note: Above data based on P&WA engine performance, engine weight and nacelle weight.

5.1.2 Airplane Weight

Table 5-2 shows results of a weight analysis on domestic E^3 airplanes with the STF505M-7C and JT9D-7A engines. These weights reflect the advanced technology features discussed in section 4.2. The nacelle weights were supplied by P&WA and scaled to the appropriate thrust level. A preliminary balance analysis indicated acceptable loadability for both airplanes.

Table 5-2. Weight Statement for P&WA E^3 Airplanes

	Weight (LB)			
	Model 768-866 (STF505M-7C)		Model 768-867 (JT9D-7A)	
Wing	33 590		32 890	
Empennage	4790		4580	
Body	33 620		33 730	
Nacelle*	7900		6700	
Gear	12 870		12 760	
Total structure		(92 720)		(90 660)
Propulsion system		(16 280)		(16 290)
Fixed equipment and options		(42 110)		(42 430)
Standard and operational items		(11 400)		(11 400)
OEW		162 510		160 780

A

*P&WA provided nacelle weights used in above analysis.

Table 5-4. Nominal Noise Estimates

	STF505M-7C*	FAR 36-8 Requirement	Notes
Takeoff	91.0 dB	93.9 dB	No cutback at 6500 m point
Sideline	91.0 dB	98.3 dB	Sideline distance = 450m point
Approach	102.0 dB	102.0 dB	2000m from threshold (two extended flap segments, 3 deg glide slope)

* Note: Nominal noise estimates are shown--appropriate design and demonstration tolerances are required for certifiable/guarantee levels.

5.1.4 Engine and Airframe Noise

In the Boeing analysis, the acoustical design point was an 80% level of confidence of certification. This goal could be achieved with current and near-future lining technology. The estimated noise levels for the STF505M-7C were based on a nominal acoustic treatment to the engine and nacelle, not on a fully iterated lining design study.

Because quiet operation was not the prime objective in configuring this airplane, no adjustments were made to the performance or flight configuration for the purpose of lowering noise levels. Optimization of linings, flap settings, and thrust levels could improve the margin for the approach case. The above Table 5-4 shows nominal noise estimates.

5.1.5 Airplane Drawings of Sized Airplanes

Figures 5-3 and 5-4 show drawings of the JT9D-7A- and STF 505M-7C-powered airplanes.

5.1.6 Airplane Drag Polars

The airplane drag polars were derived from wind tunnel test data obtained from a model closely resembling the study configurations. Beyond that drag optimism associated with advanced technology was incorporated as discussed in section 4.2. Estimated drag of isolated nacelles and drag caused by interference between the nacelles and the airframe were included in the airplane polars.

5.2 AIRPLANE SENSITIVITY FACTORS

Sensitivities for airplanes are shown in tables 5-5 and 5-6. The airplanes are sized by TOFL and the sensitivity results are nonlinear for some parameters. In some cases, better airplane solutions (i.e., lower TOGW or BLKF) can be obtained by sizing to more stringent performance constraints. This, however, requires additional diagnostic point designs that are time-consuming and costly. It is recommended that the sensitivities be used with caution and not outside the amount of change shown.

5.3 TAKEOFF GROSS WEIGHT AND FUEL BURN COMPARISON

Figure 5-5 shows BLKF and BLKT versus range for both JT9D-7A- and STF 505M-7C-powered airplanes. For the domestic airplane on the average mission, the airplane with STF505M-7C engines uses 15.5% less fuel than the JT9D-7A airplane. For the design mission, the saving for the STF505M-7C-powered airplane is 17.9%. These savings represent about 3% improvement over the earlier study. This improvement is explained by a more accurate accounting of specific fuel consumption (SFC) reduction for the STF505M-7C engine during climb and descent mission segments.

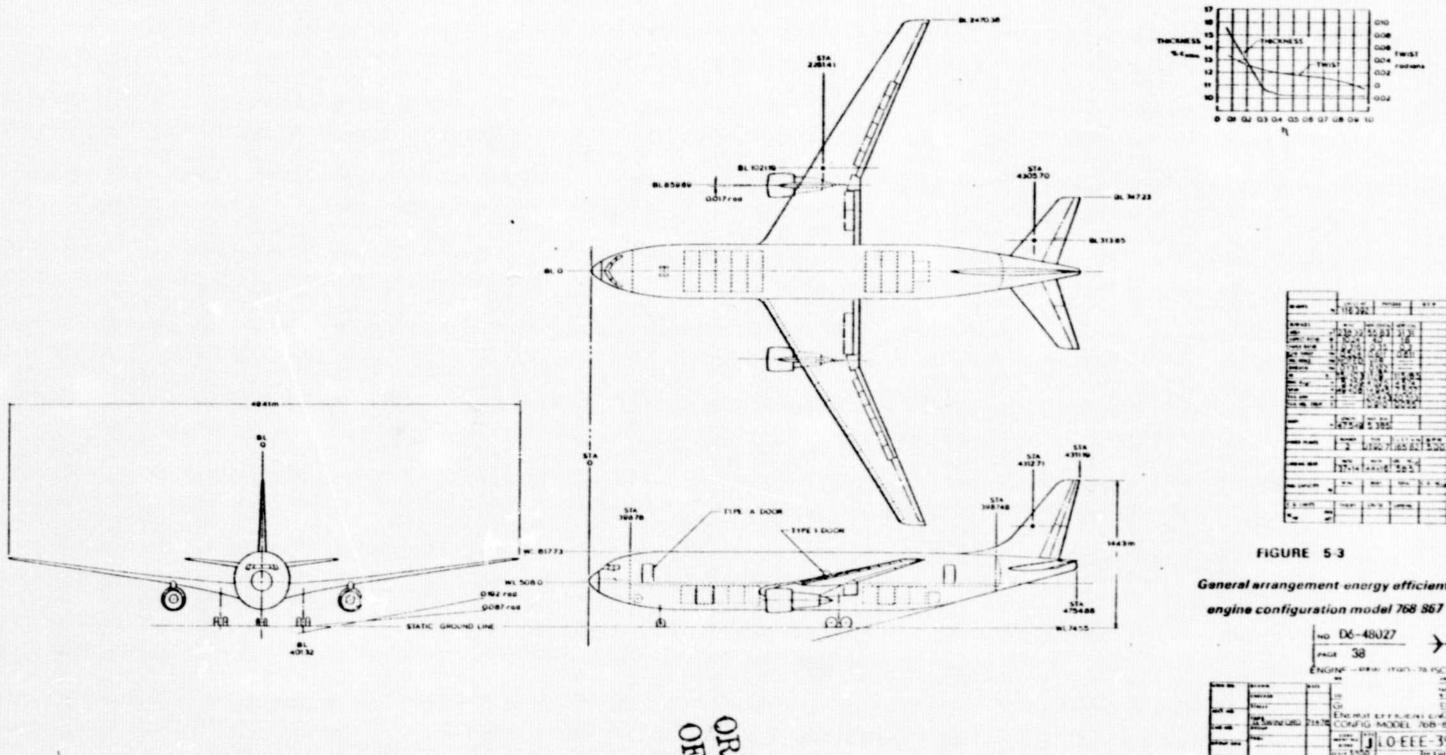


FIGURE 5-3

General arrangement energy efficient engine configuration model 768-867

ORIGINAL PAGE IS
OF POOR QUALITY

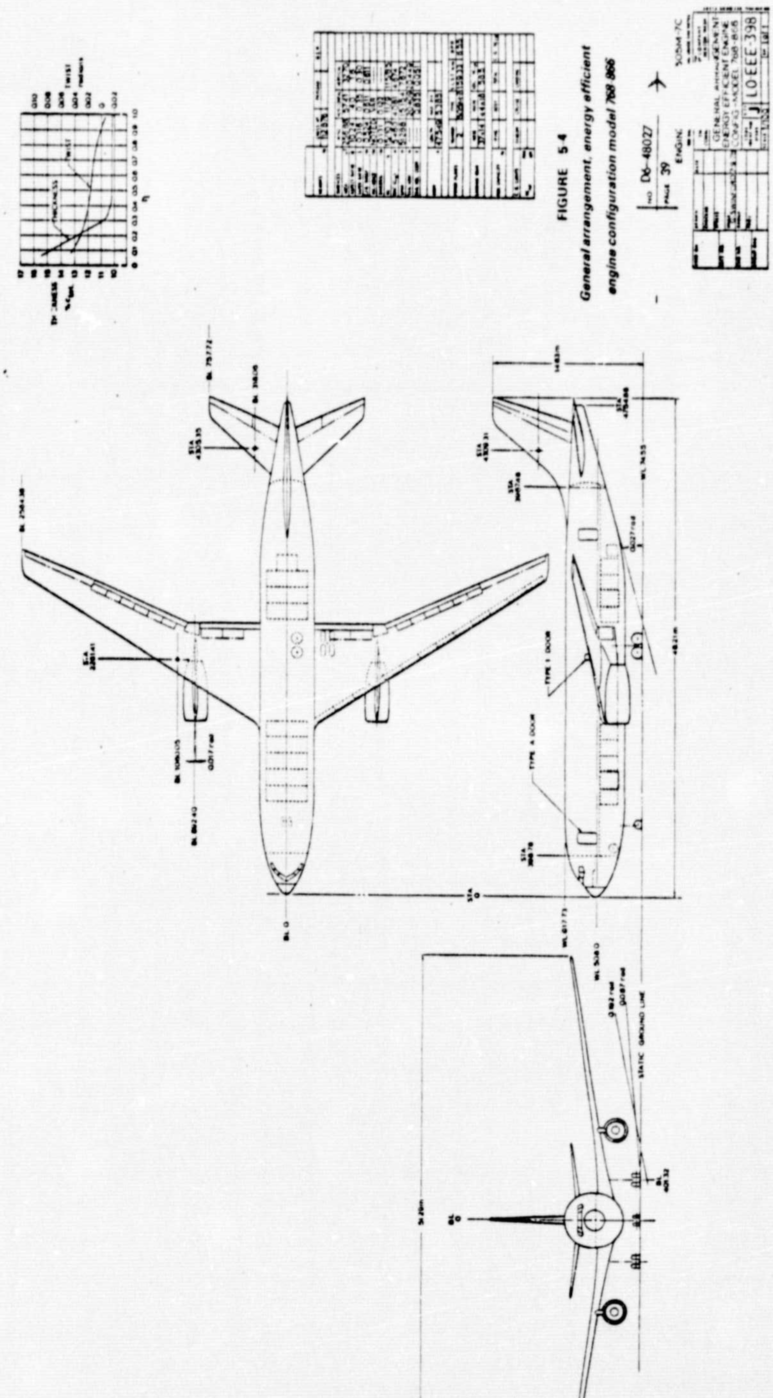


FIGURE 5-4

General arrangement, energy efficient engine configuration model 768-866

MODEL 768-867
(JT9D-7A ENGINE)
5% CHANGE

	BASE CYCLED	5% F_{NCR} +/-	5% SFC +/-	5% CR DRAG +/-	5% OEW +/-	5% F_{NTO} +/-
TOGW	256600	-0.2/+0.4	+1.6/-1.5	+2.0/-1.7	+6.2/-5.7	-0.4/+0.8
OEW	160780	-0.1/+0.2	+0.8/-0.8	+1.1/-0.9	+8.5/-7.9	-0.9/+1.2
MEW	149380	-0.1/+0.2	+0.9/-0.9	+1.2/-1.0	+8.8/-8.1	-1.0/+1.3
BLKF	41410	-0.6/+1.7	+4.7/-4.6	+6.2/-5.2	+4.2/-3.7	+1.1/+0.4
SLST	37280	-0.1/+0.4	+1.4/-1.4	+2.1/-1.9	+5.7/-5.3	-5.2/+6.2

196 PASSENGERS
2000 NMI RANGE
TOFL = 6000 FT
WING LOADING = 100 LB/SQ FT

TABLE 5-5 ***Domestic airplane sensitivity factors - model 768-867***

MODEL 768-866
(STF 505M-7C ENGINE)
5% CHANGE

	BASE CYCLED	5% F_{NCR} +/-	5% SFC +/-	5% CR DRAG +/-	5% OEW +/-	5% F_{NTO} +/-
TOGW	248900	-0.2/+0.3	+1.3/-1.3	+1.9/-1.8	+6.2/-5.9	-0.5/+0.8
OEW	162510	-0.1/+0.2	+0.7/-0.7	+0.9/-0.8	+8.5/-7.9	-0.9/+1.2
MEW	151110	-0.1/+0.2	+0.7/-0.7	+1.0/-0.9	+8.7/-8.2	-1.0/+1.2
BLKF	34290	-0.8/+1.6	+4.5/-4.4	+5.9/-5.3	+4.0/-3.7	+0.9/0.0
SLST	35820	-0.2/+0.3	+1.2/-1.2	+1.9/-1.8	+5.8/-5.4	-6.3/+5.4

A
A

196 PASSENGERS
2000 NMI RANGE
TOFL = 6000 FT
WING LOADING = 90 LB/SQ FT

TABLE 5-6 ***Domestic airplane sensitivity factors - model 768-866***

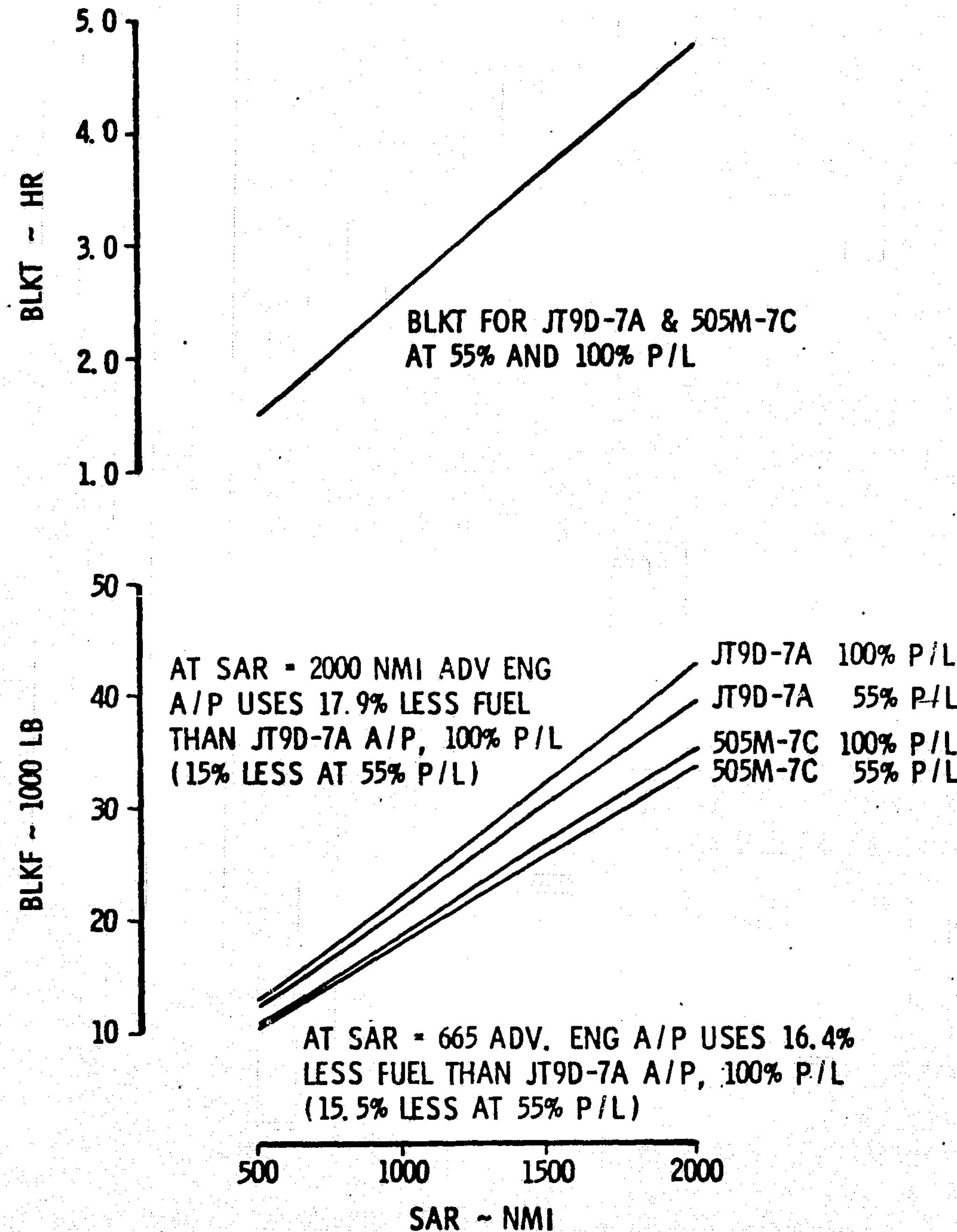


FIGURE 5-5 ***Block fuel comparison***

A comparison of design-mission fuel burned for the STF 505M-7C and JT9D-7A powered airplanes (fig. 5-6) shows cumulative fuel savings over the mission nearly constant. This was a result of minimal variation in SFC difference between the two engine-airframe combinations throughout the mission. A breakdown in fuel used during various mission segments is shown in figure 5-7. The large percentage of fuel burned during climb for typical stage lengths shows the importance of maintaining the advanced engine SFC improvement at climb power setting.

Figures 5-8 through 5-11 show the actual mission profiles (time and altitude versus distance) for both airplanes at mission ranges of 500 and 2000 nmi with 100% payload. The engine thrust level at the beginning and end of cruise are noted for support of engine duty cycle studies.

Overall fuel burned improvement for the STF505M-7C was about 15 to 18% for all payload-range combinations. Reduced engine-out windmilling drag could improve takeoff performance or reduce the engine size at a given TOFL constraint.

5.4 TYPICAL MISSION DOC AND ROI

Results of the economic analysis for the P&W E^3 program are presented in table 5-7. DOC and airplane ROI were calculated for three fuel prices using a 665 nmi typical mission range. Because the P&W engine price and overall maintenance costs decreased from the baseline JT9D-7A engine, incremental ROI's were mathematically undefined. Airplane ROI's were calculated instead to show the effects of the E^3 engine on the airplane's ROI. The following ROI assumptions were used in this analysis.

a. ROI is the rate that makes the present value of future net annual cash inflows equal to the outflow at the time of equipment acquisition.

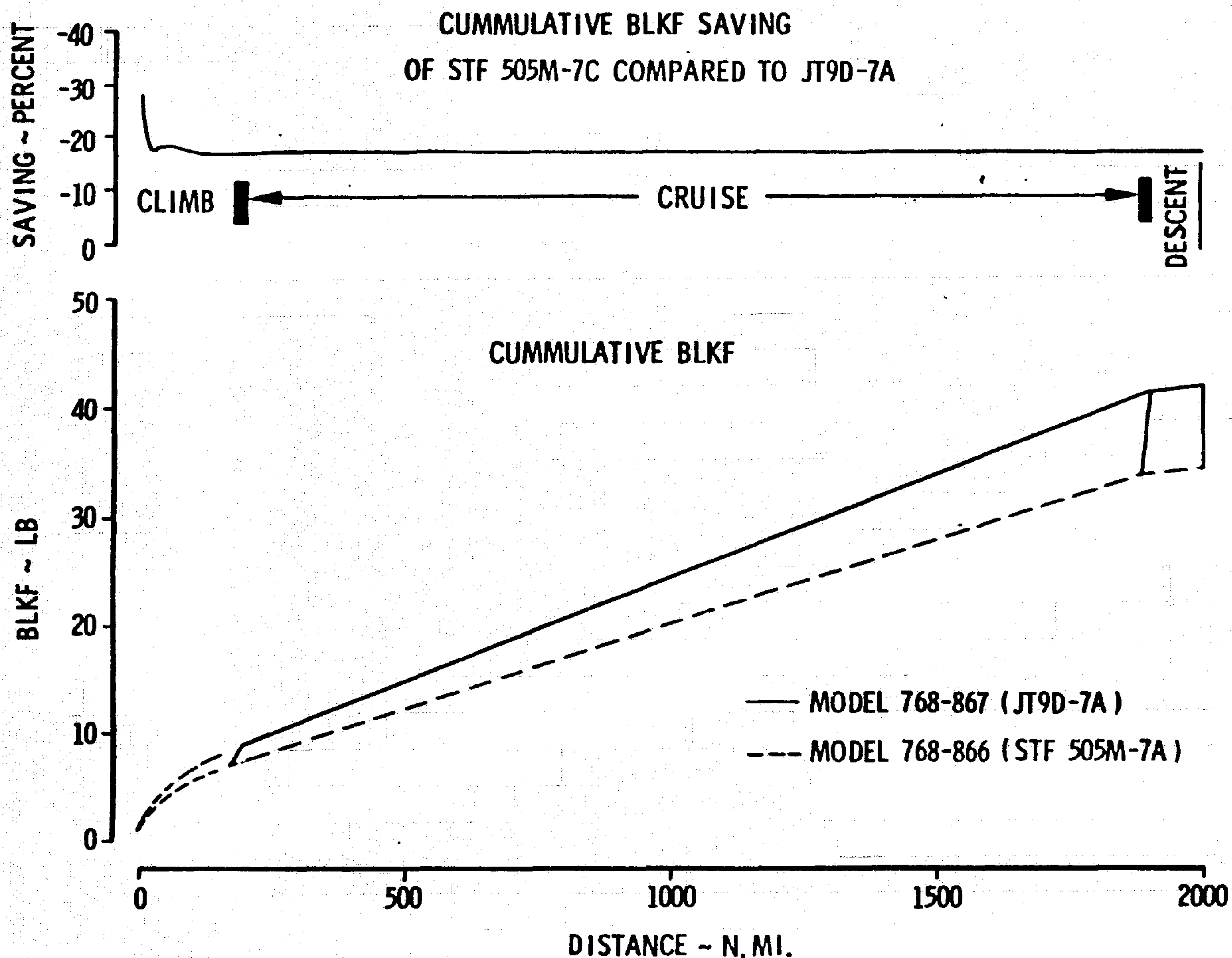


FIGURE 5-6 ***Design mission fuel burned comparison***

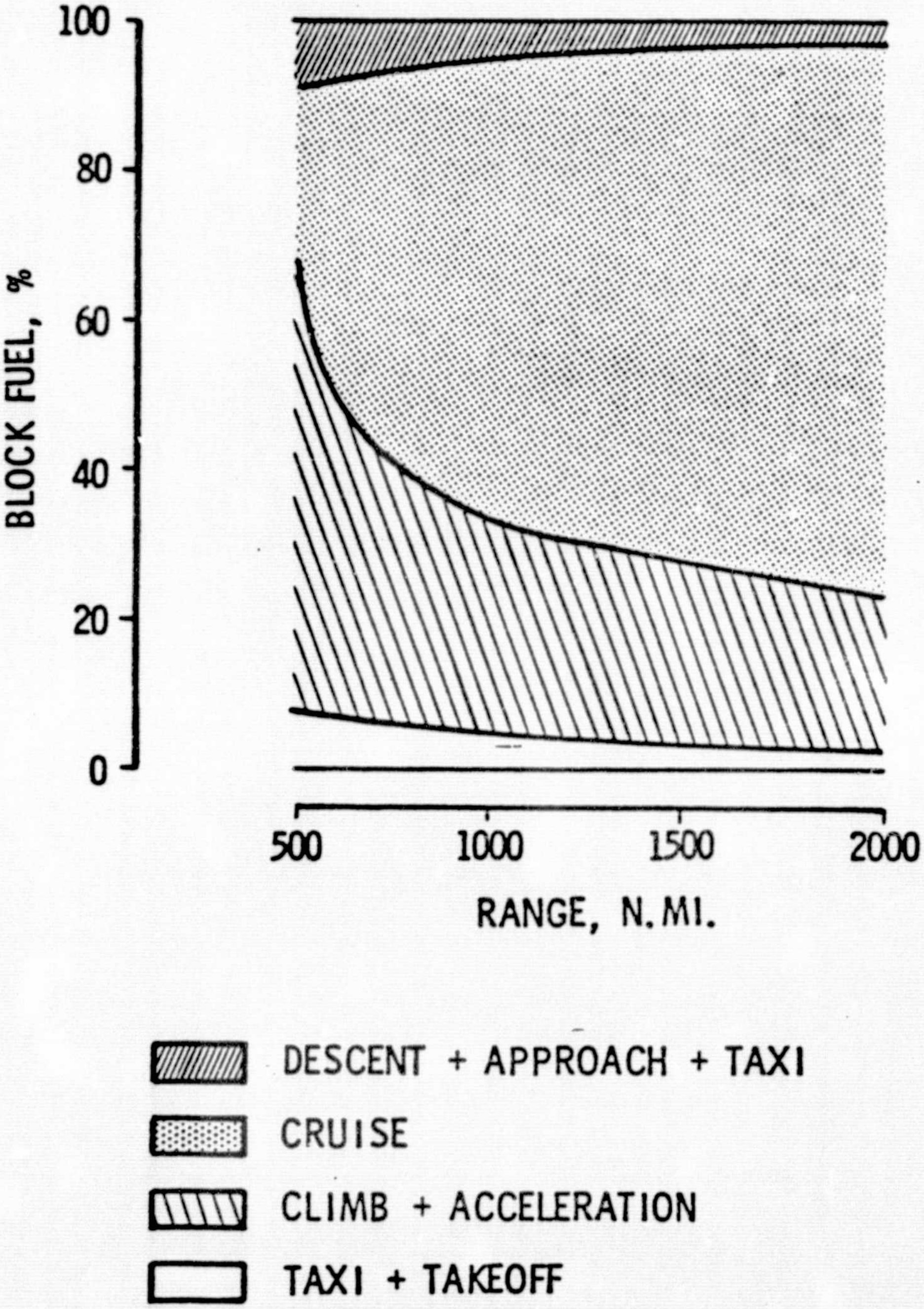


FIGURE 5-7 *Percent block fuel by mission profile segment*

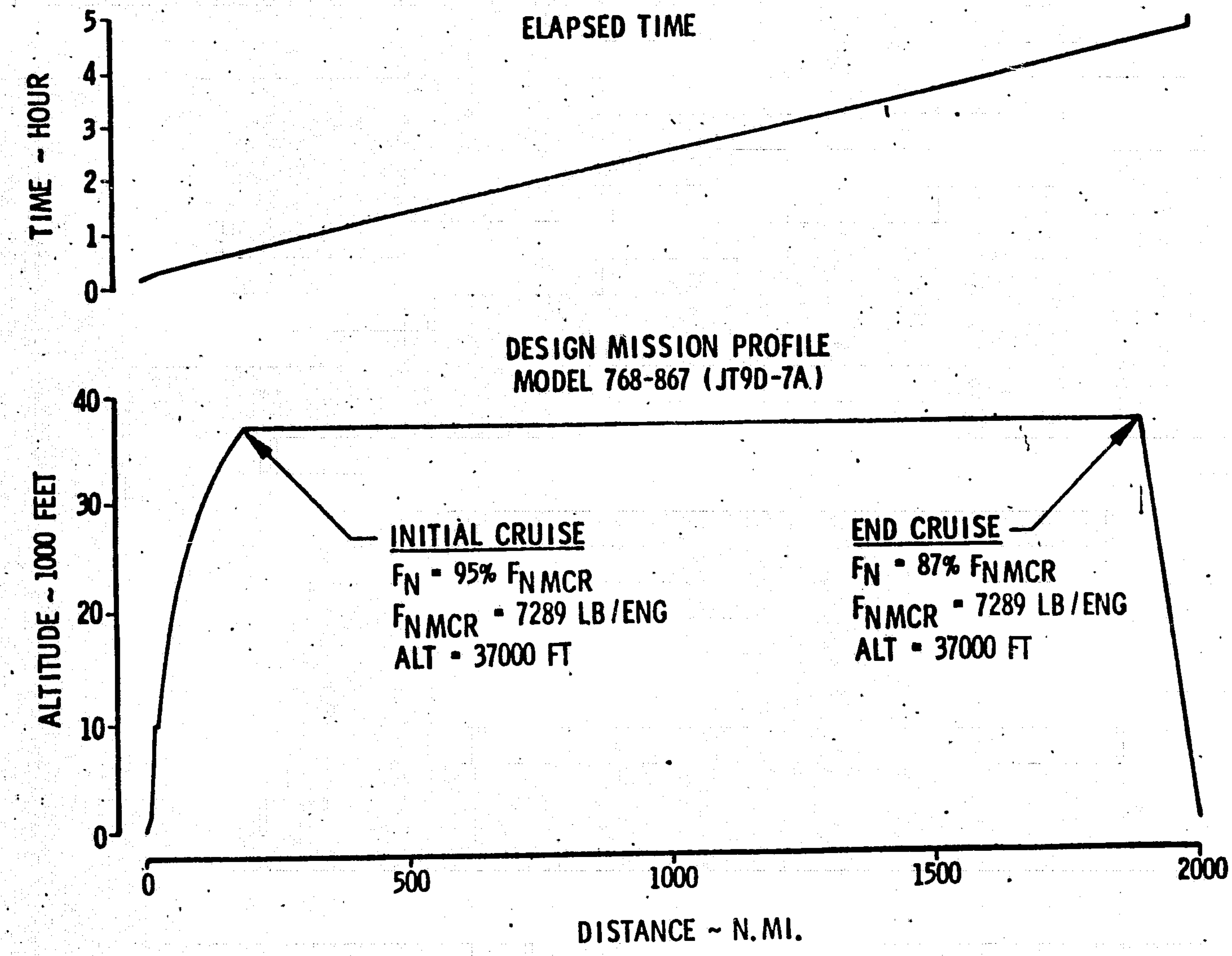


FIGURE 5-8 ***Design mission flight profile - model 768-867***

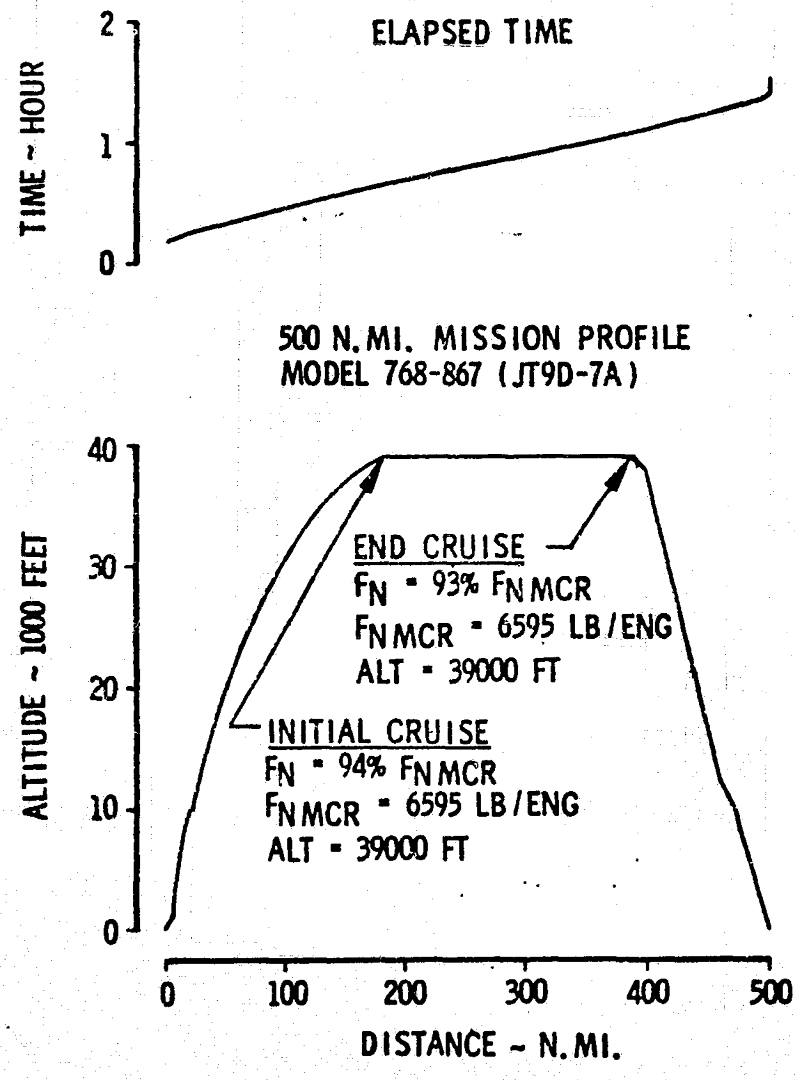


FIGURE 5-9 *500 nmi mission flight profile - model 768-867*

REV SYM

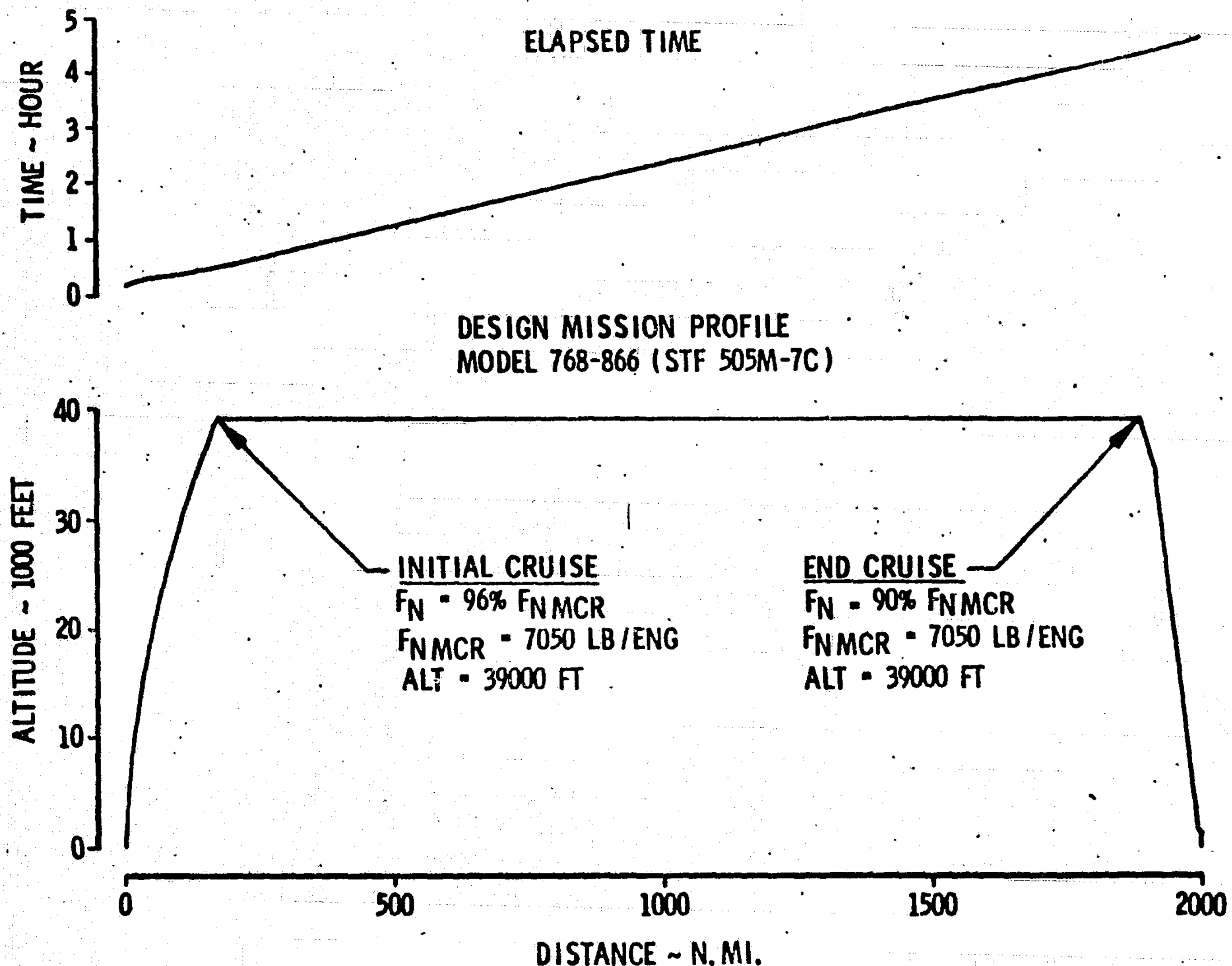


FIGURE 5-10 *Design mission flight profile - model 768-866*

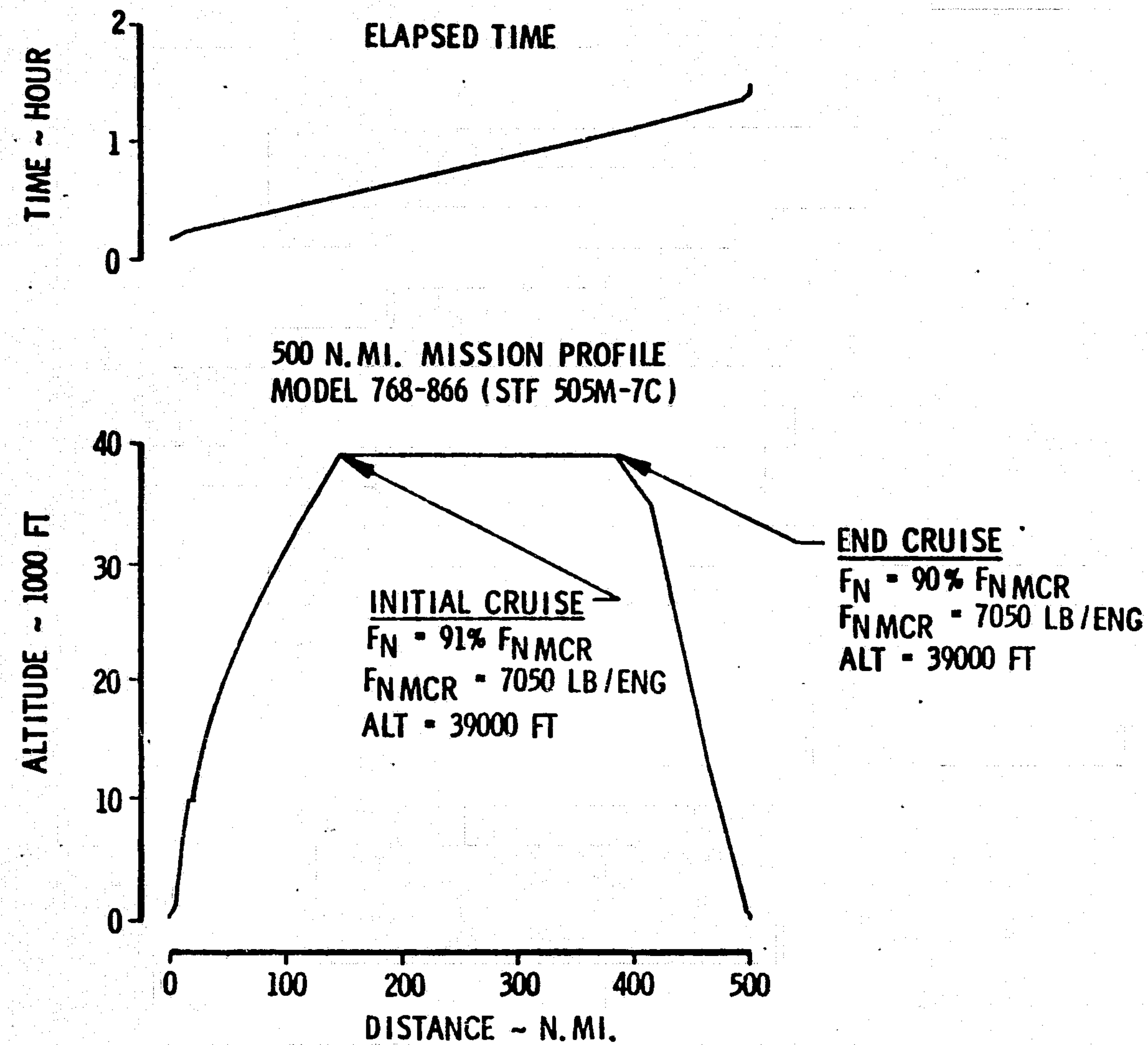


FIGURE 5-11 *500 nmi mission flight profile - model 768-866*

ENGINE	JT9D-7A			505M7C (P&W ENGINE PRICE)			505M7C (BOEING ENGINE PRICE)		
FUEL	.35/GAL	.40/GAL	.45/GAL	.35/GAL	.40/GAL	.45/GAL	.35/GAL	.40/GAL	.45/GAL
DOC:	5.259	5.467	5.675	4.966	5.139	5.312	5.066	5.239	5.412
FUEL	1.455	1.662	1.870	1.210	1.383	1.555	1.210	1.383	1.555
CREW	1.130	-	-	1.120	-	-	1.120	-	-
INSURANCE	.1096	-	-	.1081	-	-	.1142	-	-
BURDEN	.475	-	-	.482	-	-	.482	-	-
ENGINE LABOR	.0671	-	-	.0707	-	-	.0707	-	-
ENGINE MATERIAL	.299	-	-	.273	-	-	.273	-	-
AIRFRAME LABOR	.1703	-	-	.1703	-	-	.1703	-	-
AIRFRAME MATERIAL	.1239	-	-	.1239	-	-	.1239	-	-
DEPRECIATION	1.430	-	-	1.408	-	-	1.502	-	-
AIRPLANE AFTER TAX ROI (%)	10.9	10.3	9.6	12.1	11.6	11.0	11.3	10.8	10.2
INCREMENTAL AFTER TAX ROI* (%)							13.3	15.4	17.4

*APPLICABLE ONLY TO BOEING ENGINE PRICE

TABLE 5-7 Economic analysis

b. Cash flows and their timing are considered as follows:

Time prior to delivery	Percent (%) of price paid
15 mo	20
12 mo	5
9 mo	5
6 mo	5
0 mo (delivery)	65 + spares

c. Investment tax credit of 10% spread over the first three years of operation

d. Annual operating costs and revenue at stated missions and load factors

- o Accelerated depreciation for tax purposes (sum of years digits method)
- o Income taxes at 48%

e. Airplane life is 15 years and residual value is 10% of price plus spares (new airplane)

Boeing estimated an E^3 engine price that differed from the P&W engine price. Because this price was greater than the baseline JT9D-7A engine, incremental ROI could be calculated in addition to DOC and airplane ROI.

6.0 ENGINE/AIRPLANE INTEGRATION

This section describes the Boeing assessment and evaluation of the P&WA designed STF 505M-7C engine/nacelle installation defined by P&W layout No. L-109846. Comparison of nacelle features with Boeing standards and airline requirements is covered where appropriate.

6.1 NACELLE ARRANGEMENT AND CONSTRUCTION

The inlet and major nacelle dimensions were generally consistent with Boeing practice. Nacelle lines were not evaluated, but both the afterbody leaving angle and plug leaving angles exceeded the Boeing recommended value of 12 deg.

Being preliminary, this layout lacked numerous construction details, and in-depth critique of detail construction was not possible. Comments were provided on areas such as the thrust reverser where some detail was shown. Figure 6-1 represents the P&WA designed nacelle. Number codes on the figure have been keyed to the comments listed below.

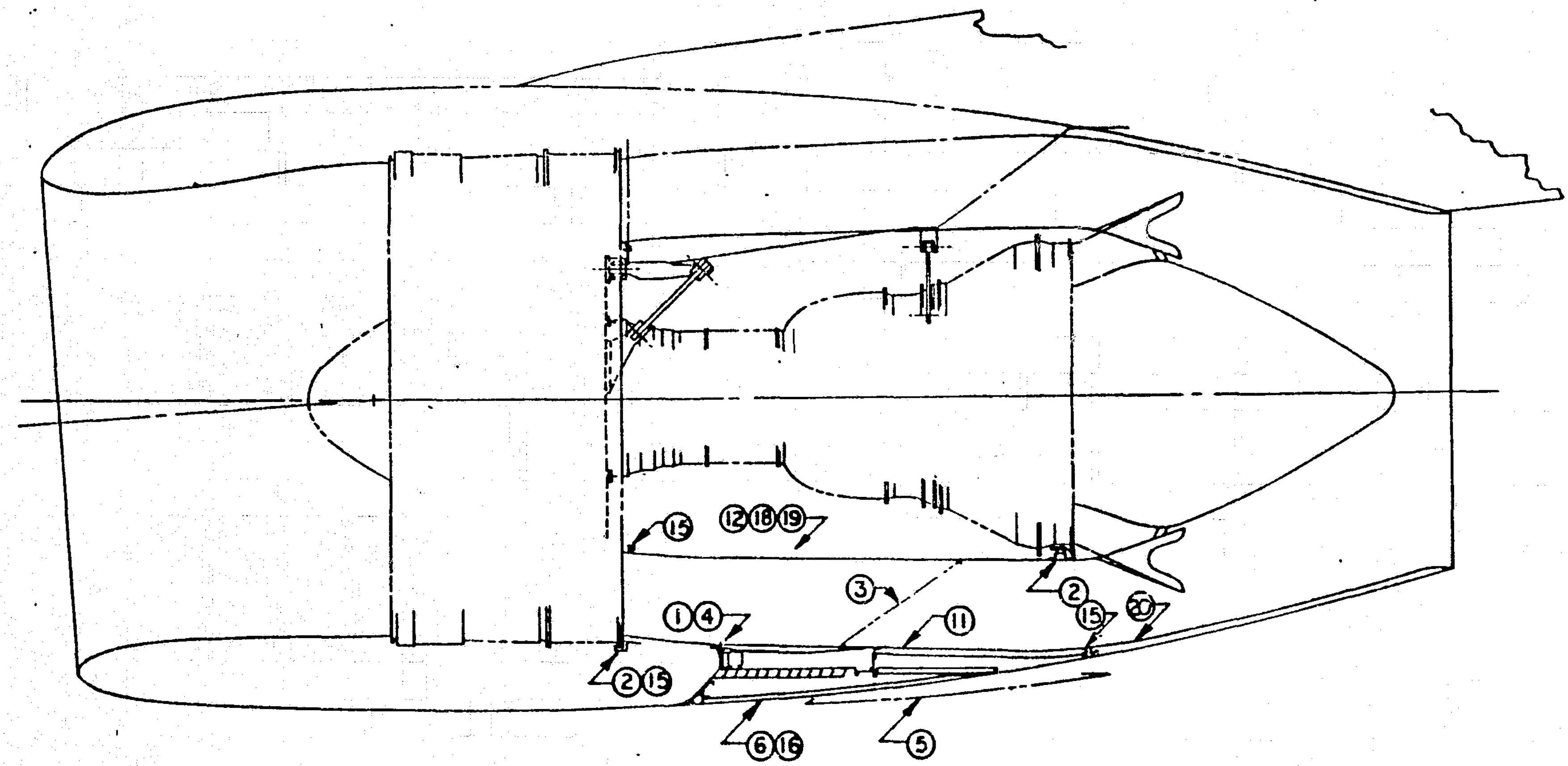
1. Interference between fan air blocker door (from hinge line forward) and trapezoidal doorframe will occur during translation. This condition is characteristic of the configuration (fixed doorframe in cowling).

2. No access means shown to latch "V" groove bands at either forward end of outer duct wall or aft end of the inner duct wall. In the case of the inner duct wall latch, aft end, no room is available for the latch.

3. Thrust reverser blocker door position is poor for turning performance in the reverse thrust mode.

4. Thrust reverser blocker door hingeline is not compatible in all drawing section views. Duct contour shown must be changed to accommodate a practical door hingeline, such as shown in the section view.

FOR ITEMS (7) (8) (9) (10) (13) (14) AND (17)
SEE L-109846 SHEET 2 (P&WA REF)



P&WA LAYOUT NO.
L-109846 SHEET 1 (REF)

FIGURE 6-1 ***P&WA energy efficient nacelle***

5. No radial structural tie is shown for the outer translating sleeve when in the reverse mode. Radial loading could be substantial due to existing leak paths.

6. Outer translating sleeve appears to be the duct pressure wall. This condition is not compatible with existing latching or hinging means from the standpoint of sealing or strength.

7. Access to inside latches is not clear.

8. Roller and track translation mechanisms have very short service lives and have been replaced in existing thrust reverser sleeves with sliders.

9. Upper and lower bifurcation joint loading not clear, as load paths are interrupted.

10. Transfer of cascade basket radial loads is not clear.

11. Honeycomb panel edge closeouts are not a practical design.

12. Cowl vent areas, drain means, and blow-out panel areas are not identified.

13. Thrust reverser cowl hinges, as shown, allow interference between the nacelle and the strut structure.

14. Tolerances in hinge support locking device becomes severe problem.

<u>Seals</u>

15. Seals at "V" grooves at, forward and aft ends of the "D" ducts are missing.

16. Bulb type seals around thrust reverser are not suitable for this type of service. A pressure-on-lip seal is recommended.

17. Longitudinal seals should be provided in thrust reverser cowl.

Drainage and Vents

18. No routing for engine accessory and strut drains is shown.

19. Cooling air and duct burst venting are not provided.

20. Acoustic surfaces shown should provide for fuel drainage in the area of the primary mixer.

6.2 AIRFRAME ACCESSORY REQUIREMENTS AND LOCATION

Hydraulic and electric loads are shown in figures 6-2 and 6-3. These loads can be handled by one hydraulic pump and one alternator on each engine gear box.

Gearbox and accessory location studies generally have shown the core mounting to have the least weight and best performance; however, accessibility, especially in a long duct nacelle, is not as good as for chin-mounted accesssories.

Table 6-1 presents a general study of accessory location. A numerical rating system, where 0 is unacceptable and 5 is the best or most acceptable, was used to obtain an overall figure of merit. Recent surveys of Boeing customers showed that chin mounting and core mounting had widest acceptance. There also appeared to be a strong feeling against split gearboxes. Gearboxes apparently are high-maintenance items and airlines believe that splitting a gearbox increases its maintenance problems significantly. Another important consideration was the fuel spill requirement (DOT/FAA order 8110.19) that specifies that no fuel may be spilled during a wheels-up landing. The chin-mounted gearbox and engine fuel pump would be difficult to certify to this requirement.

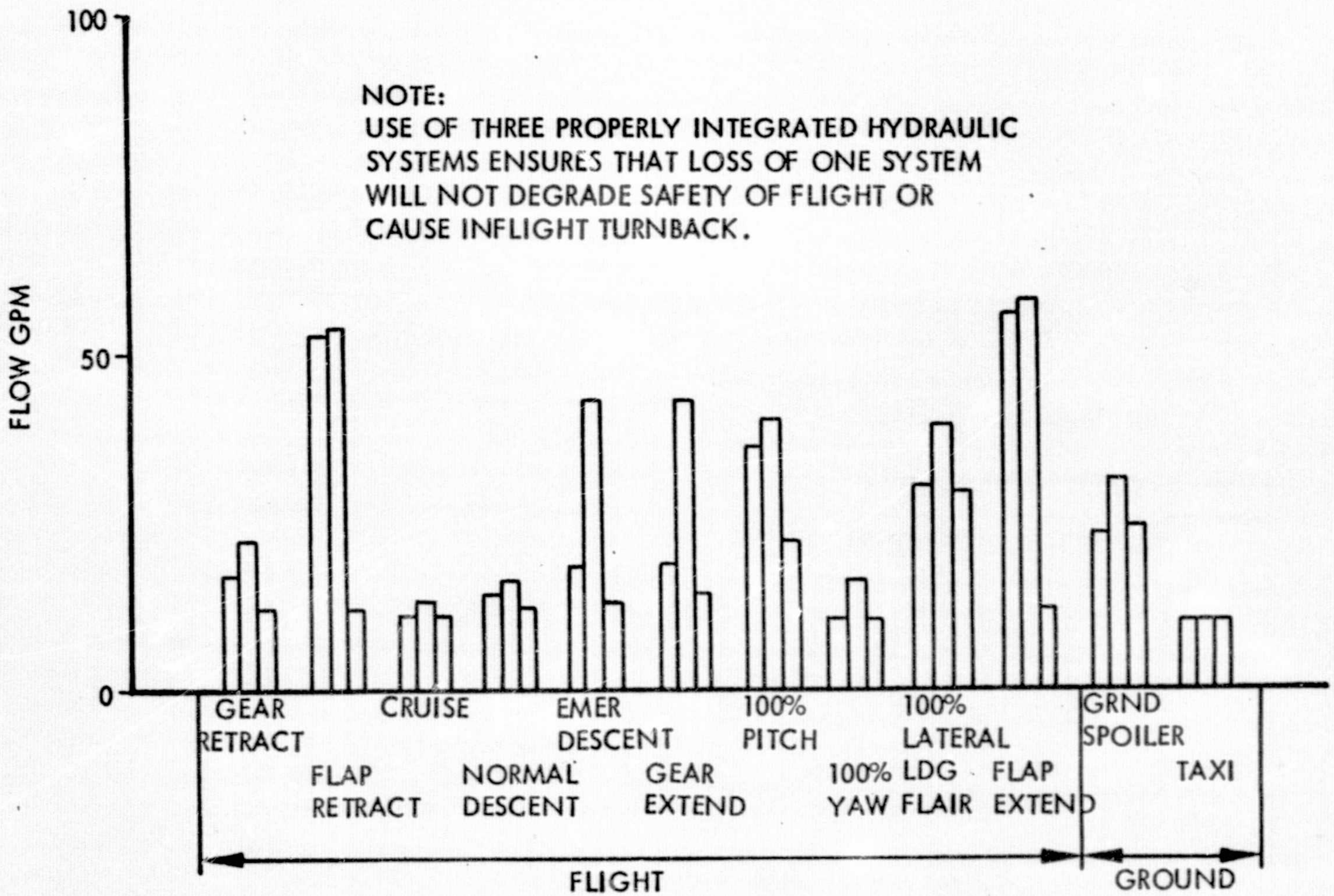


FIGURE 6-2 ***Hydraulic loads***

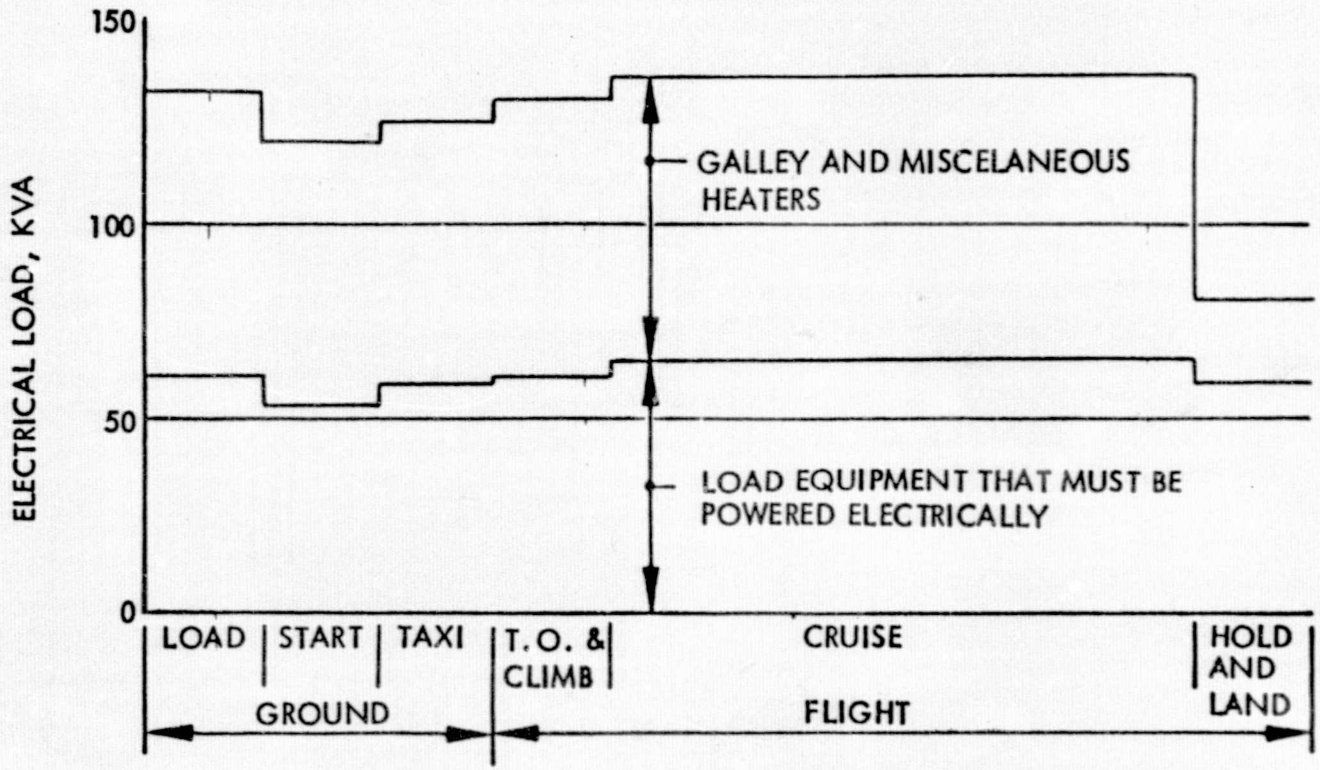


FIGURE 6-3 *Electric loads*

Table 6-1 E^3 Engine Gear Box Location Study

	Core Mount	Split Fuel Pump Top	Fuel Pump Bottom	Split Fan Frame at 60° and 270°	Fan Chin
Fuel Spill per DOT/FAA order 8110.19	5	5	0	5	0
Accessibility to accessories	4	3	3	5	5
Heat rejection	2	5	5	5	5
Accessibility to variable IGV	2	5	5	5	5
Compatibility with load reduction	5	5	5	5	5
Compatibility with zero moment mount	2	5	5	5	5
Customer Acceptance	4	0	0	0	5
	24	28/0	23/0	35/0	30/0

Note: Rating 0 to 5, with 5 most acceptable and 0 not acceptable

A

Table 6-1 reflects these considerations and shows the core-mounted gearbox to be the only acceptable location.

6.3 MAINTAINABILITY, ACCESSIBILITY, AND SAFETY

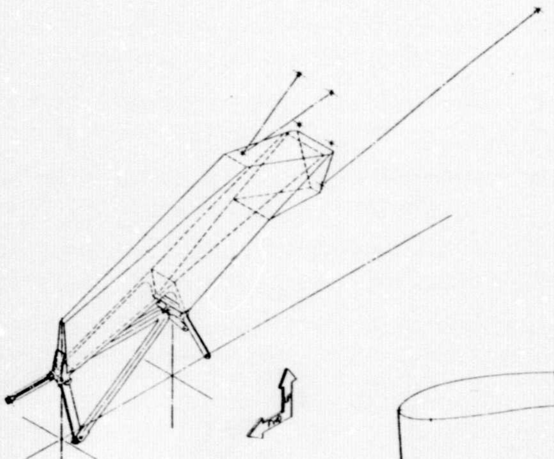
Maintainability, accessibility, and safety provisions were reviewed and found to be generally acceptable. The reference layout did not contain sufficient detail, nor was it sufficiently complete, to warrant detailed study of these features.

6.4 MOUNTING SYSTEM

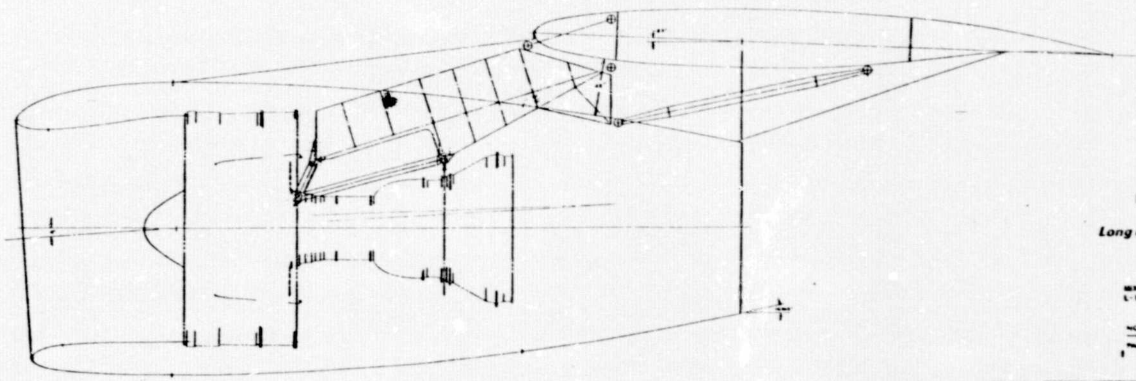
Boeing's practice is to design mount systems so that the mount can accept all engine models that might be used on a given airplane. Since P&WA's mount system does not have this flexibility, Boeing made the preliminary design mount system shown in figure 6-4 as an alternative to the P&WA mount.

The P&WA mount's overall design is within the scope of Boeing design practices. Sufficient span is provided between front and rear mount points. The 45 deg thrust reaction angle is higher than advisable and can result in high-thrust link loads. The pin-and-ball front mount carries vertical and horizontal loads in pin bending and could be loaded excessively. A structural assessment of the engine mount and link details, however, showed no missing load paths for the ultimate loads of table 6-2 and did not reveal any excessively loaded members.

The loads of table 6-2 give Boeing engine mount design criteria. Table 6-3 summarizes resultant airloads that occur once per flight. Figures 6-5, -6, -7, and -8 illustrate the airloads on the nacelle from which the resultants of table 6-3 were derived. These loads were estimated using data from flight test, wind tunnel test, and analysis. They were based on a 45 500 lb SLST engine and must be scaled to the E^3 thrust levels for use in designing E^3 nacelle components.



ISOMETRIC VIEW - ENGINE MOUNT & STRUCTURAL STRUT



E³ NACELLE - LH SIDE VIEW

FIGURE 6-4

Long duct nacelle mount

NACELLE CONFIGURATION, E³ ENGINE, FULL LONG DUCT WITH MIXER - P&WA

LO-EEE-330

Table 6-2 Nacelle and Strut Design Load Factors

The nacelle, nacelle strut and primary engine mounts shall be designed for the following inertia load conditions which are assumed to occur only once in the lifetime of the airplane:

Condition	Ultimate load factors
Vertical	6.5 6.5 + 1.5 T(c) -3.5 -3.5 + T(c)
Thrust	3.0 T(max) + 3.0 vertical 3.0 T(max) + 1.5 vertical 3.0 T(R) 3.0 T(R) + 3.0 vertical
Side	± 3.0
Gyroscope	± 2.25 rad/sec yaw + 1.5T(c) + 1.5 vertical ± 2.25 rad/sec. pitch + 1.5T(c) + 3.75 vertical
Engine seizure	Torque equivalent to stopping rotating mass in approximately 0.60 sec

T(max) = maximum takeoff thrust at sea level

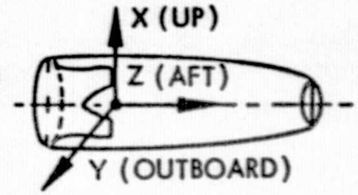
Where: T(C) = cruise thrust (maximum or minimum, whichever is critial)

T(R) = reverse thrust

Note: For design purposes, these ultimate factors shall be applied at the nacelle and content weight and C.G. exclusive of thrust and contents.

NOTE:
THE FOLLOWING RESULTANT AIRLOAD CONDITIONS ARE OCCURING ONCE PER FLIGHT AND THE ASSOCIATED VERTICAL LOAD FACTOR IS 1.0 g.

SIGN CONVENTION



RIGHT HAND RULE FOR MOMENTS

CONDITION:	ALT. FEET	V_e KNOTS	THRUST LB/ENG	F_x LBS	F_y LBS	F_z LBS	M_x 10^3 IN. LBS	M_y 10^3 IN. LBS	M_z 10^3 IN. LBS
MAX. TAKE OFF [1]	0	126.0	36000	3945	2890	-2960	162.3	-317.0	-11.0
MAX. Q	20000	372.3	15600	-3270	-2370	-4550	-104.6	207.3	6.1
1.3 V_{STALL}, 0^0 FLAPS	17000	161.2	18500	6220	3800	-3350	184.8	-334.8	-12.7
1.3 V_{STALL}, 10^0 FLAPS	17000	161.2	18500	3070	2140	-1550	150.0	-283.6	-10.2

[1] $\alpha_W \approx 16$ DEG. AND $\alpha_{INLET} \approx 12$ DEG.
BASED ON SLS THRUST F = 45,500 LBS
SCALE: LOADS BY $\sqrt{F}$
MOMENTS BY $(F)^{1/4}$

TABLE 6-3 ***Engine nacelle airloads***

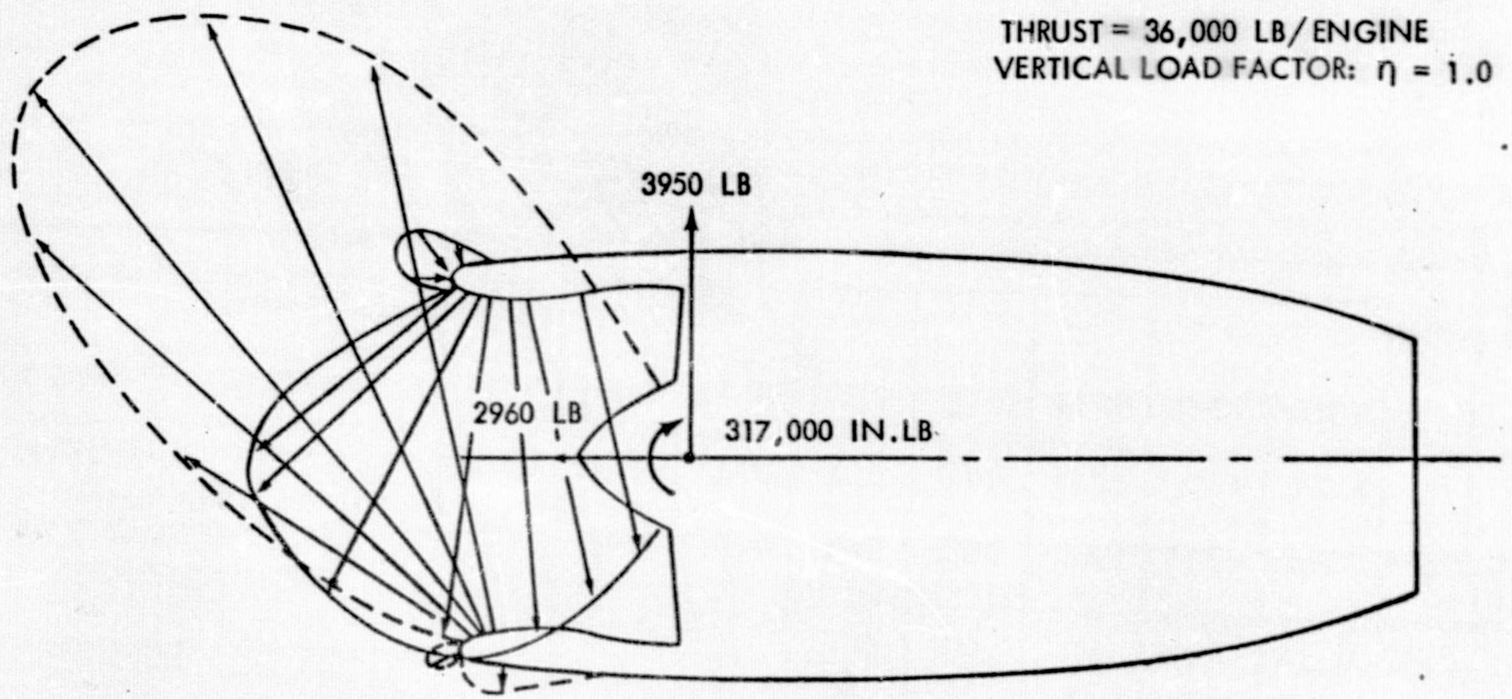


FIGURE 6-5 ***Airloads - maximum takeoff***

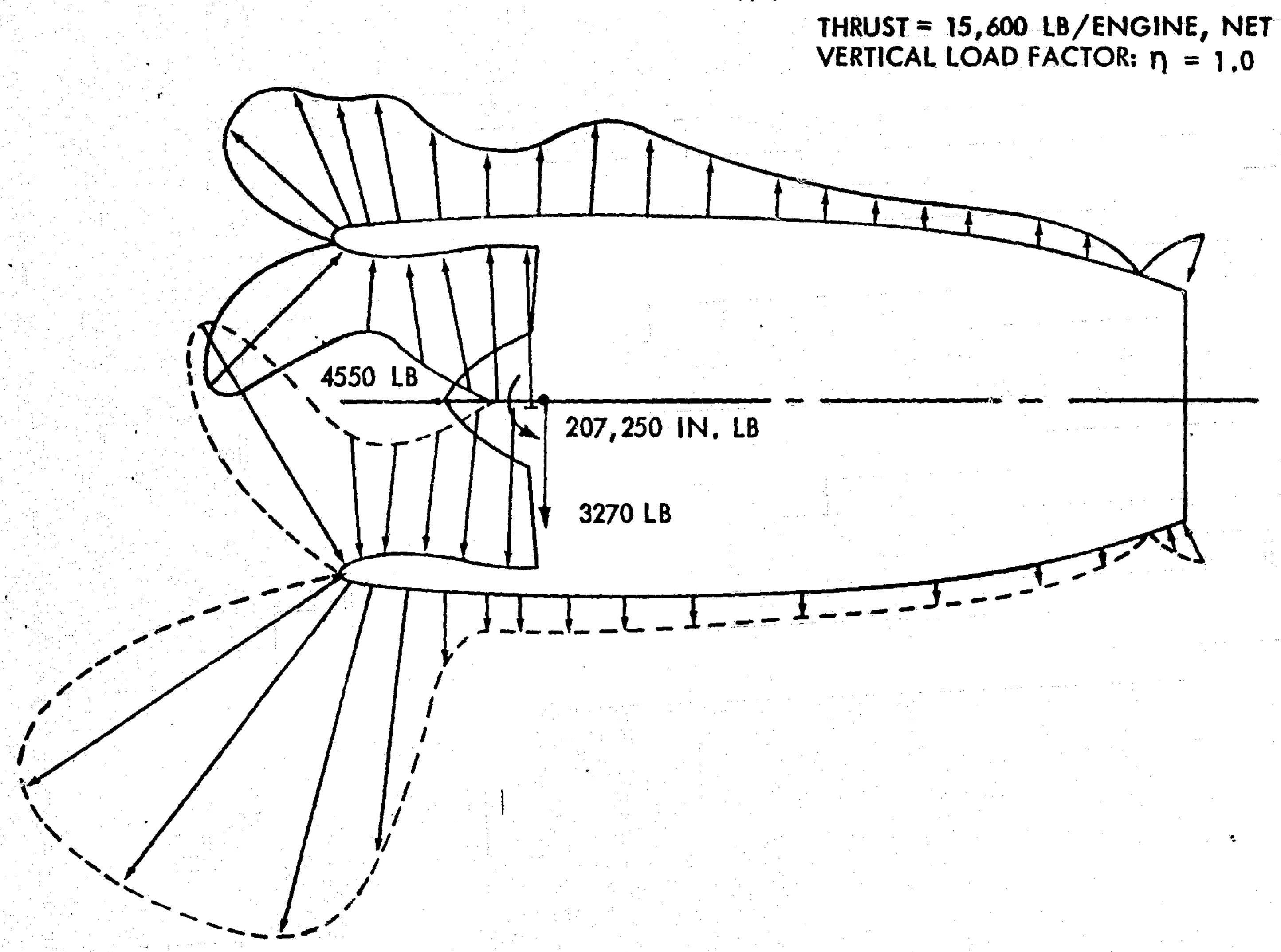


FIGURE 6-6 *Airloads - maximum dynamic pressure*

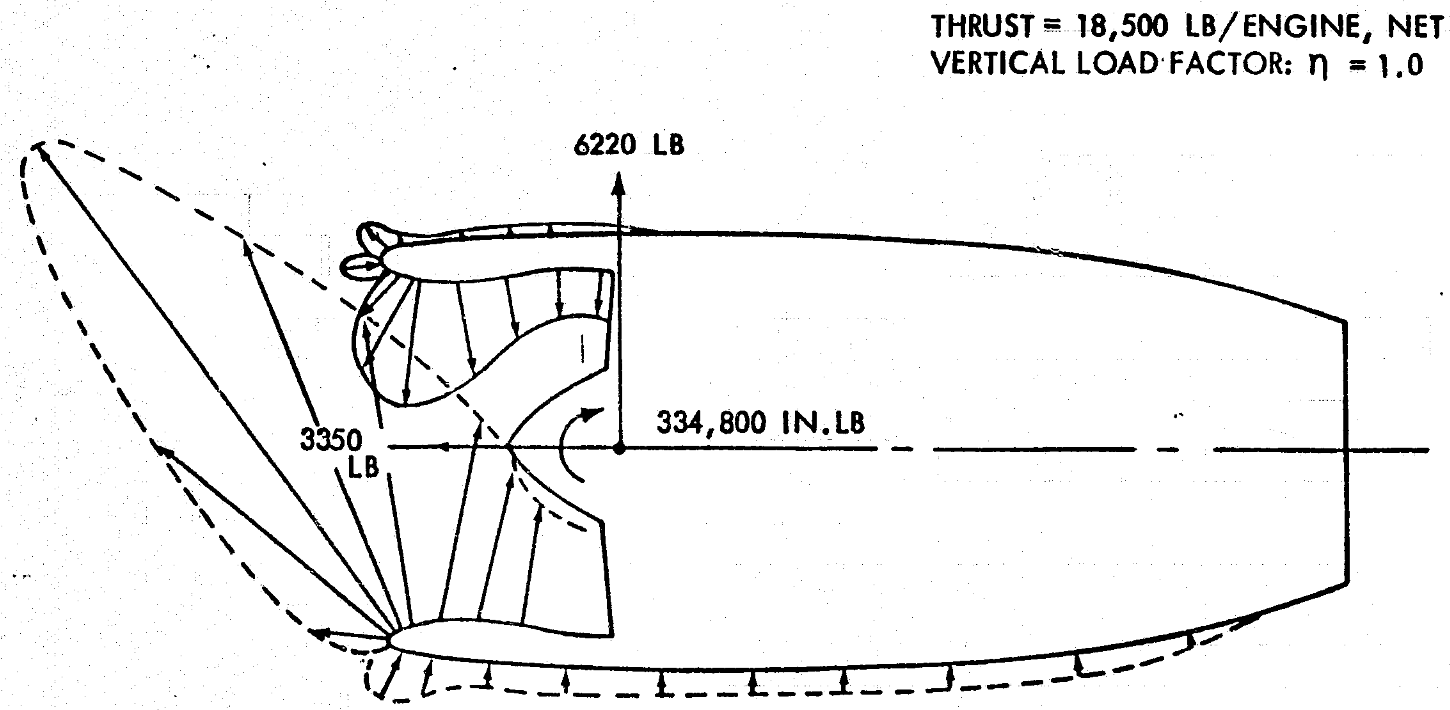


FIGURE 6-7 *Airloads - 0°flap 1.3 V_{stall}*

REV SYM A

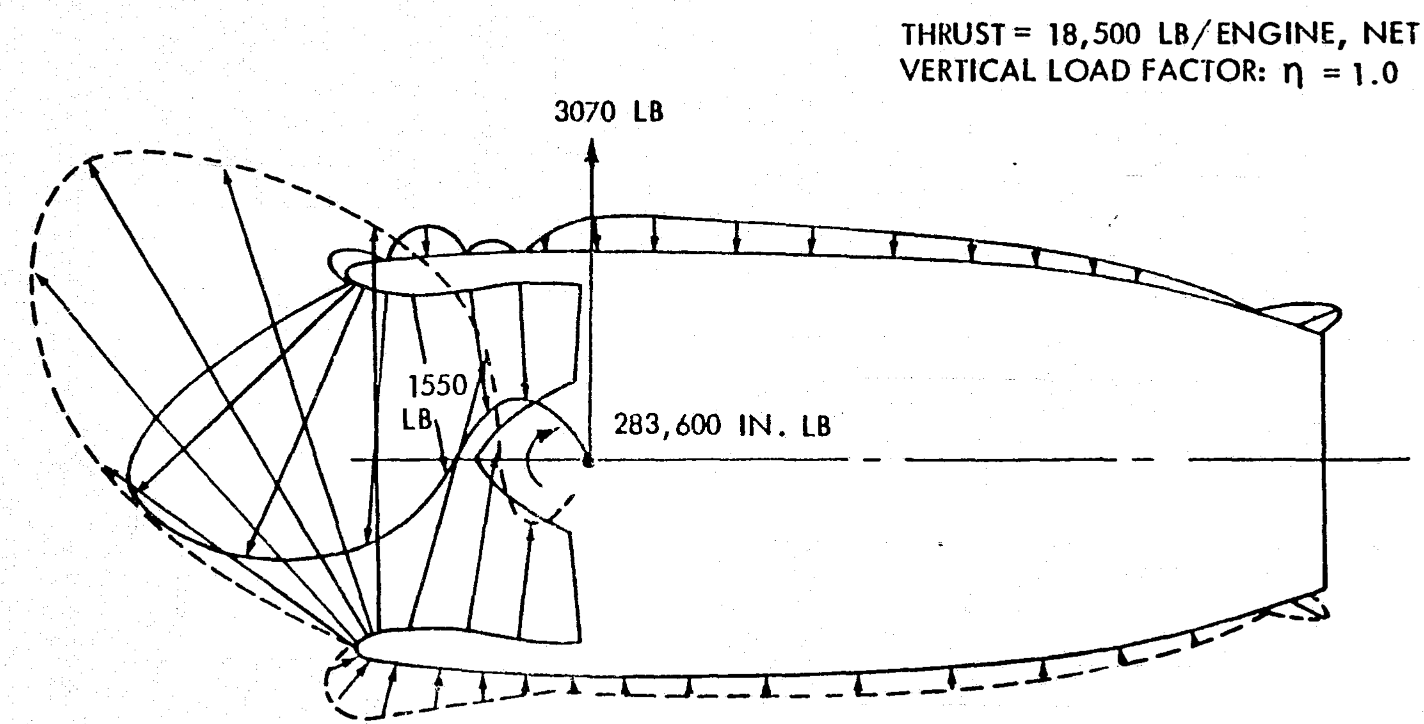


FIGURE 6-8 *Airloads - 10° flap 1.3 V_{stall}*

6.5 NACELLE DESIGN

With the exception of the tailpipe material, Boeing was in general agreement with the materials shown on the reference P&WA nacelle layout. Boeing had good results with Kevlar/aluminum containment structures in laboratory experiments and the fan containment concept shown appeared feasible. Boeing used Dyna Rohr in the inlet cowling of the 737 for about two years and experience was acceptable.

Graphite/Kevlar fabric skins, with a metal core on the exterior of the inlet cowl, would be particularly vunerable to lightning strikes unless a lightning protective surface and possibly a nonmetallic core are used. Use of aluminum brazed titanium honeycomb for the core cowl structure is satisfactory provided cowl skin temperatures do not exceed 800°F. Because the tailpipe could be subjected to temperatures above 1000°F, aluminum brazed titanium honeycomb is not recommended. Inconel would be a logical material selection for the tailpipe.

In Boeing practice, new materials selected for application to flight structures are subjected to a rigorous time consuming test and evaluation program. This evaluation consists of laboratory tests of candidate materials, destructive tests to determine allowables, noncritical service testing of lightly loaded structure, and noncritical service tests of loaded structure. This evaluation process may take several years, the actual time depending on the severity of the intended application. Candidate materials may be dropped at any time during the evaluation process.

6.6 NACELLE WEIGHT EVALUATION

Table 6-4 compares Boeing and P&WA estimates of the P&WA-designed E^3 long-duct mixed-flow nacelle. The engine and nacelle used in this comparison was sized to 42 200 lb SLST to be consistent with P&WA-supplied nacelle component weight data. The table shows a 1400 lb difference between Boeing and P&WA weight estimates. At the 35 820 lb SLST determined in the E^3 airplane studies (table 5-1) this weight difference scales to 1310 lb per nacelle. Using airplane sensitivity factors and neglecting secondary effects

Table 6-4. STF505M-7C Nacelle Weight Evaluation and Comparison of Boeing and PWA Nacelle Weights

Nacelle component	Nacelle weight (lb/pod) SLST = 42 200 lb		Weight difference (PWA minus Boeing)	
	Boeing Estimate	PWA Estimate	lb	%
Inlet	984*	587	-397	-40.4
Fan cowl	164	136	-28	-17.1
Fan duct, reverser and core cowl	2179	1656	-523	-24.0
Mixer	108	111	+3	+2.8
Plug	87	104	+17	+19.5
Tailpipe	877	266	-611	-69.7
Development margin	Included above	140	+140	-
Total nacelle	(4399)	(3000)	(-1399)	(-31.8)

(*Includes 90 lb fan blade containment allowance)

on airplane OEW, the total engine and nacelle weight difference of 2620 lb/airplane comes to 440 lb BLKF, or about 1.3% BLKF increase.

The nacelle weight differential resulted from different design philosophies used for evaluating the nacelle weight. Design features incorporated by P&WA involved higher risk than Boeing considered acceptable in the E^3 advanced airplane design. Also, according to Boeing analysis, the advanced technology weight reduction factors used in the P&WA weights analysis could not be duplicated by replacing conventional structures with lighter weight components. Table 6-5 compares the Boeing and P&WA advanced technology weight reduction factors. Further details of the weights analysis are given in table 6-6.

TABLE 6-5. Comparison of Boeing and P&WA Advanced Technology Weight Reduction Factors

Nacelle Component	Weight Reduction Factor (%)	
	Boeing	PWA
Inlet	5	18
Fan cowl	20	27
Fan duct, reverser, core cowl	4.6	10
Mixer	0	0
Plug	0	0
Tailpipe	0	0

A

Table 6-6 Weight Analysis Summary

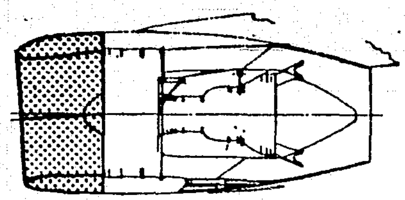
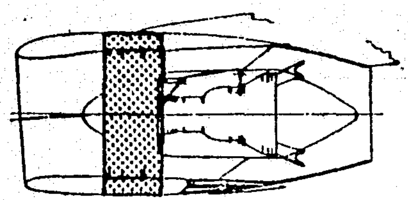
Nacelle Component	Substructure and Material	Remarks
Inlet Cowl 	Lip: spun or explosion formed aluminum sheet. Bulkhead: built-up aluminum webs, chords and stiffener. Cowling: Graphite/Kevlar fabric outer skin, nonmetallic heat resistant phenolic (HRP) core, Dyna-Rohr inner face structural acoustic panels. Attach ring: machined aluminum Anti-icing components: aluminum spray tube, aluminum and Iconel ducting, aluminum mixing chamber	Weight estimate includes 5% reduction to reflect Graphite/Kevlar application to outer skin. The inner skin construction appears to be same as used on JT9D nacelles, hence no potential for weight saving. P&WA quoted 18% weight reduction does not appear achievable.
Fan Cowl 	Outer skin: Graphite/Kevlar Inner core: nonmetallic HRP Hinges, latches, hold-open rods access doors, fire shield, and cowl hinge supports on strut.	Data base used consisted of cowls with both skin-stringer and fiberglass-and -aluminum sandwich construction. No clear weight advantage for either type was apparent. Based on amount of composites, 20% weight reduction was used in the Boeing weight estimate. Amount of composites identified by P&WA did not appear sufficient to justify 27% weight reduction.

Table 6-6 Weight Analysis Summary (continued)

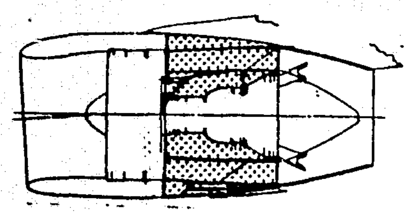
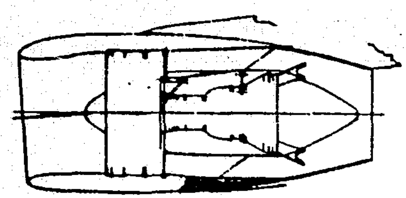
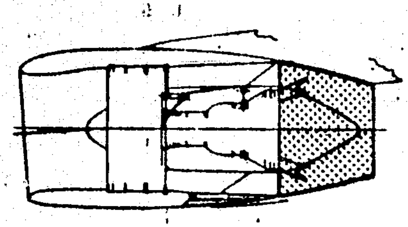
Nacelle Component	Substructure and Material	Remarks
Fan duct and core cowl **(D-duct construction assumed)** 	Outer fairing: Graphite/ kevlar with nonmetallic HRP core Outer fan duct walls and bifurcations: aluminum sandwich Dyna-Rohr panels Inner fan duct walls: titanium sandwich Bumper blocks, rings and longerons: aluminum built-up structures	Outer surface weight was reduced 25% to account for composites. Relative to total fan-duct and -core cowl weight, this is about 5.5% reduction. Design complexities need further investigation and refinement before the P&WA 10% reduction can be realized. Fan reverser weight provisions for installation are included with reverser.
Fan Reverser 	Cascades: chopped carbon-epoxy Blocker doors: Dyna-Rohr structural acoustic panels Cascade supports: aluminum frame Linkages: aluminum Actuators: ball-screw Reverser drive: pneumatic motor	P&WA data showed reverser cascades to be the only area of advanced technology. Cascade weight saving of 15% due to use of composites is about 2.5% of total fan reverser weight. Combined fan-reverser and fan-duct weight reduction factor is 4.6%. Fan-reverser design needs refinement to be acceptable.

Table 6-6 Weight Analysis Summary (continued)

Nacelle Component	Substructure and Material	Remarks
Mixer, plug and tailpipe 	Mixer lobes: single-thickness titanium Lobe support struts and ring: Iconel Lobe fairing: aluminum Plug: Iconel, thickness as required by minimum welding gage criteria.	Data base for mixer includes experimental work on daisy-lobe mixers and analytical studies for the JT8D and JT9D long-duct mixers. P&WA gave minimum design definition. Insufficient structural depth for frames and for nozzle to fan duct attachment were Boeing concerns. Difference in design philosophy in this area accounts for significant part of weight difference.

7.0 CONCLUSIONS AND RECOMMENDATIONS

1. NASA's stated fuel consumption goal is a 12% reduction of cruise TSFC. For the Boeing study, this was interpreted to mean a 12% reduction of airplane BLKF. Under this interpretation, the STF505M-7C as installed in the Boeing Model 768-866 surpasses the fuel consumption goal by 4 1/2 to 6%, depending on the propulsion system weight used in the airplane performance study.

2. Boeing evaluation indicated the STF505M-7C nacelle to be about 1310 lb heavier than the P&WA weight estimate. Using the heavier nacelle increases the fuel burned by about 1.3%.

3. The NASA goal of 5% DOC reduction is bettered by 1% using P&WA supplied engine performance, weight, and economic data. However, Boeing considers the engine price quoted by P&WA unrealistically low for E^3 technology levels. When the $590,000 higher Boeing price estimate is applied, the DOC improvement drops from 6 to 4.2%. The DOC reduction due to the higher Boeing weight estimate would cut back the improvement to about 4%, which does not meet NASA's goal of 5% DOC reduction.

4. Engine noise estimates based on a preliminary engine noise treatment show that FAR 36 amendment 8 can be met. No attempt was made to refine the nacelle treatment for lowest noise levels. It was concluded that current and near-future noise treatment technology could attain certifiable noise levels.

5. To ensure that the E^3 program results in an engine configuration that meets program goals and that can be installed in a nacelle acceptable to the airframer and airlines, the airframer should be actively involved in the installation design and evaluation. It is therefore recommended that the balance of the E^3 program include continuing active participation by the airframe contractors.

REFERENCES

1. EEE Component Development and Integration Program Boeing, subcontract No. 20646-1.

2. EEE Component Development and Integration Program, Boeing subcontract No. 20628-1.

3. Preliminary Performance and Installation Data for the JT9D-7A Turbofan Engine, Pratt and Whitney Aircraft, February 14, 1977.

4. Preliminary Performance and Installation Data for the STF 505M-7C Turbofan Engine, Pratt and Whitney Aircraft, May 1, 1978.

5. "Energy Efficient Engine and Integration Studies for Pratt and Whitney Aircraft," D6-44689, December 6, 1977.

6. Pratt and Whitney Nacelle Study, layout No. L-109846 sheets 1 and 2, June 6, 1978.

APPENDIX B

194

PAGE INTENTIONALLY BLANK

STUDY TRANSPORTS

POWERED BY ENERGY EFFICIENT ENGINES

OCTOBER 1978

198

PAGE INTENTIONALLY BLANK

STUDY TRANSPORTS POWERED

BY ENERGY EFFICIENT ENGINES

This report summarizes work done under Pratt & Whitney Purchase Order 20646-2 as part of Pratt & Whitney's prime contract NAS 3-30646, Energy Efficient Engine (E^3) Component Development and Integrated Program.

This report completes the requirements of paragraph 2.1.1 and 2.1.2 of Task I and paragraph 2.2.1 of Task II of the Purchase Order Statement of Work.

Prepared by [signature]
R. T. Kawai
ACEE Propulsion Systems Project Manager

[signature]
J. H. Lindley
Advanced Engineering Project Engineer

Approved by [signature]
W. J. Lawton
Advanced Engineering Chief Program Engineer
Commercial Systems

[signature]
L. A. Wright, Director
Design Engineering - Power Plant

[signature]
M. Klotzsche
Director, Program Engineering - ACEE

PREFACE

This report presents results of a study conducted by the Douglas Aircraft Company as a subcontractor to Pratt & Whitney Aircraft to investigate applications of engines based on use of NASA supported Engergy Efficient Engine (E^3) Technology. This work was done under Purchase Order 20646-2 as a part of the Pratt & Whitney prime contract NAS 3-30646.

The studies reported herein were conducted to identify commercial transport aircraft which could possibly use engines based on technology from the NASA sponsored E^3 program, provide descriptions and characteristics of such aircraft and investigate airframe/propulsion integration.

This study was conducted from March through August 1978.

CONTENTS

	PAGE
1.0 Introduction	1
2.0 Study Aircraft	1
2.1 Advanced Technology Features	1
2.1.1 Advanced Wing Design	1
2.1.2 Advanced High Lift System	3
2.1.3 Longitudinal Stability Augmentation System	3
2.1.4 Wing Load Alleviation	4
2.1.5 Composite Structure	5
2.1.6 Systems	6
2.2 Aircraft Descriptions	6
2.2.1 Aircraft Characteristics	6
2.2.2 Airplane Drag	13
2.2.3 Weight	13
2.2.4 Sensitivity Factors	18
2.2.5 Noise	18
2.2.6 Secondary Power	18
2.2.7 Comparison Between E^3 and JT9D	23
2.3 Airframe/Propulsion System Integration	26
2.3.1 Study Installations	26
2.3.2 Preliminary 1990 Propulsion System Requirements	26
Appendix I	34

1.0 INTRODUCTION

This study is based on aircraft which are advanced technology derivatives of DC-10 aircraft. This selection was arrived at from a solicitation of the views of Douglas marketing and engineering personnel.

Taking into consideration traffic growth forecasts, airline fleet compositions and technology development activities, the logical transports to utilize engines based on NASA E^3 technology in the early 1990 time period appeared to be aircraft with increased seating capacity relative to the DC-10 and design emphasis on reduced fuel consumption. The need to minimize new development costs resulted in the selection of stretched DC-10's employing advanced technologies. A domestic and an international version incorporating a 65-foot fuselage stretch and a common area advanced technology wing were configured to acquire a large market base.

2.0 STUDY AIRCRAFT

2.1 ADVANCED TECHNOLOGY FEATURES

The selection of advanced technology features was based on results from recent studies and on-going technology development programs.

2.1.1 Advanced Wing Design

One of the prominent features of the advanced airplane is the new high aspect ratio wing using supercritical airfoil sections and winglets. Fundamentally, the supercritical airfoil generates greater amounts of lift for a given thickness and drag than a conventional airfoil. The distinguishing geometric characteristics are a slightly blunter nose, a flatter upper surface and a highly cambered thin trailing edge relative to a conventional airfoil.

The benefits provided by the supercritical airfoil for wing design can be utilized in several ways. From purely aerodynamic considerations the cruise speed and lifting capability (buffet boundary) could be increased for the same wing sweep and thickness. Because of the emphasis on fuel efficiency, the application of supercritical airfoil technology to the E^3 aircraft has been to increase wing thickness while still achieving some benefits in buffet boundary. The increased wing thickness provides a structural weight advantage as well as an increase in takeoff and landing $C_{L_{max}}$. The increased $C_{L_{max}}$, improved buffet boundary and weight reduction due to the thickness increase, result in a reduction in wing area (and thus further weight reduction). Part of this weight reduction has been utilized to increase the wing aspect ratio to reduce induced drag. Winglets in conjunction with the moderately high wing aspect ratio will provide a large induced drag reduction without the excessive wing span and the consequent large airport gate space requirements that result from the use of very high aspect ratios.

The wing design incorporates airfoil shape and thickness variations across the span to counteract wing-fuselage interference and other three-dimensional planform effects and to maintain as much of the two-dimensional drag-divergence Mach number capability of the advanced airfoils as possible. The wing twist and taper ratio are selected to produce minimum induced drag, considering the tradeoffs in wing weight and stalling characteristics.

NASA has done exploratory development of these advanced airfoils including flight testing on an F-8 research airplane. Douglas has designed, developed and flight tested supercritical airfoils on two different wings on the YC-15 AMST prototype aircraft. Results from recent EET wind tunnel programs have substantiated that these advanced airfoils will provide the desired characteristics for a high aspect ratio wing application.

The winglet concept as well as the supercritical wing were wind tunnel tested by Dr. Whitcomb of NASA Langley, and have been under study for a number of aircraft applications. A joint USAF/NASA program is currently pursuing winglet installation on a KC-135A aircraft. In preparation for this activity, extensive wind tunnel testing at cruise speed and low-speed high-lift conditions has been conducted.

A winglet development program for potential application to the Douglas DC-10 is currently active. The winglet design has taken into account the experimental results of Dr. Whitcomb. This design, in various forms according to the specific model of DC-10, was successfully wind tunnel tested at cruise speed in the NASA Langley eight-foot wind tunnel in 1978 as part of the NASA

ACEE program, and demonstrated the performance potential compared to wing tip extensions. The program will continue development through 1979 in the low-speed high-lift regime and will evaluate the stability and control characteristics. Other concurrent work at Douglas is investigating the structural and other facets of the winglet installation. Continuation of on-going efforts forms the basis for the advanced wing design in the 1990 E^3 airplanes.

2.1.2 Advanced High-Lift System

The high-lift system features two-segment trailing edge flaps in conjunction with a variable camber Krueger leading edge flap. The two-segment flap provides high extension capability and the large chord forward segment and smaller chord auxiliary flap provide an optimum camber distribution. The flap is continuous from the side of the fuselage to 80 percent of the wing span, avoiding the high-speed (inboard) aileron cutout and the associated loss of lift and increase in drag. The full-span leading edge Krueger flap will allow for tailoring to provide good stall characteristics and control stall progression across the span.

This high-lift system design will provide excellent $C_{L_{max}}$ capability and very high lift-to-drag ratios allowing the use of a small wing area and engine thrust size. Maximum flap deflection is limited to 30 degrees to reduce approach noise by minimizing both approach thrust and airframe generated noise. An additional benefit is reduced fuel consumption.

Development work on this high-lift system design is proceeding, leading to application in the next generation Douglas transport aircraft. Extensive two dimensional wind tunnel testing and analytical configuration studies have been conducted in the last few years. Based on these results, three dimensional development testing will be conducted shortly in conjunction with the NASA ACEE program.

2.1.3 αLongitudinal Stability Augmentation System (αLSAS)

The proposed E^3 aircraft configurations include a static stability augmentation system that allows operation at a center-of-gravity range aft of that of an unaugmented aircraft. The αLSAS system provides angle-of-attack stability characteristics similar to those of the DC-10. The more aft center-of-gravity location reduces the aerodynamic balancing down load carried by the horizontal tail. This results in lower trim drag and a weight savings due to the smaller horizontal tail and wing required. The αLSAS system provides positive stability for all flight conditions, ensuring the proper sense for control column motions and forces required for maneuvering the aircraft. The system employs pitch rate, pitch attitude and normal acceleration as feedback parameters to independent augmentation computers which provide control inputs in series with pilot commands to the four elevator segments and the horizontal stabilizer.

In order to explore thoroughly the requirements and interrelationships of aircraft configuration, flying qualities, safety and reliability, control system design and economics, Douglas has embarked on a study utilizing an advanced derivative of the DC-10 transport. A substantial portion of this task is proceeding under the ACEE program. During 1977 an extensive piloted simulation, to explore aircraft flying qualities on the Douglas six-degree of motion simulator, was conducted. During 1978 a further piloted simulation, which includes the effect of control system characteristics including failure cases and transient phenomena, is being conducted.

2.1.4 Wing Load Alleviation

The use of control surface movement to regulate the net load and its distribution on the wing structure can be used to reduce bending moments and therefore reduce weight.

An additional advantage is that ride quality will be improved. Principally, the application of these functions will be applied to the control of maneuver loads and gust loads.

The use of active systems for flutter suppression, which alters the apparent mass or stiffness, or aerodynamic damping, is expected to be employed to provide appropriate flutter speed margins. Even in the extremely unlikely event of complete system failure, the aircraft will not be flutter critical within the normal operating envelope.

The use of control devices to limit load are not uncommon. However, the full application of wing load alleviation in a transport aircraft involves careful consideration not only of the technical factors, but also the regulatory requirements and operating factors such as dispatch reliability. Advanced techniques to improve the design processes are under development, for example, by NASA in the ACEE program. In this program, large-scale drones, using a high aspect ratio supercritical wing with active controls, will be tested to correlate design techniques. A number of other applications are also under study or development. In the transport field, a significant interest has developed into applications for current transports or their derivatives. The Lockheed L-1011 experimental development, conducted partly under the ACEE program, is now flying. At Douglas, design is proceeding for a system related to the DC-10. Activity in this field is also to be pursued in combination with the ACEE program.

2.1.5 Composite Structure

Major advanced composite technology development activities have been underway for several years. Douglas composite programs, with major funding support from NASA, are leading to widespread application of composites in future transport aircraft. Current NASA sponsored advanced composite programs at Douglas include development of the DC-10 rudder, vertical tail and a wing study.

Expected application areas for composite materials in the next generation of transport aircraft include control surfaces, floor beams, fairings, landing gear doors and carbon brakes. If emphasis is placed on continued composite technology development, by the early 1990's, design, fabrication and repair techniques should have advanced to the point that application areas may be expanded to include wing and empennage primary structure. Use of composites in primary structures for the E^3 study aircraft is assumed. The fuselage pressure shell will still be of metal construction and will not have changed noticeably from current DC-10 designs except for the increased use of bonded metal structure and improved alloys. Composite advantages include significant structural weight reduction, and with the falling price of composite materials relative to metals, minimum price escalation due to inflation.

2.1.6 Systems

Improvements in all aircraft systems are expected. Some of these are:

- o Digital avionics - reduced weight and improved reliability and capability.
- o Flight performance management - reduced aircraft operational fuel consumption.
- o Air conditioning - reduced engine bleed requirements.
- o APU - reduced weight and fuel consumption.
- o Advanced cockpit displays - reduced weight and improved performance.

These improvements, relative to current aircraft systems, can be incorporated into future aircraft designs and are assumed in the 1990 E^3 study aircraft.

2.2 AIRCRAFT DESCRIPTIONS

Using the advanced technologies described with results from on-going studies and technology development programs, aircraft sizing studies were conducted using Douglas computer programs. The design requirements for the two aircraft, shown in Table 1, are based to a great extent on the DC-10-10 transcontinental and DC-10-30 intercontinental range aircraft. Design cruise Mach number was reduced from the DC-10 levels to reduce fuel consumption. The domestic and international aircraft are shown in Figures 1 and 2. The only major external difference between the two versions other than engine size is that the two wheel centerline main landing gear on the domestic aircraft is replaced with a four wheel assembly to cope with the international aircraft's higher weights.

2.2.1 Aircraft Characteristics

The aircraft characteristics are shown in Table 2. The aircraft incorporate a DC-10 fuselage stretched 65 feet, a new high aspect ratio wing with super-critical airfoils and winglets, a new empennage and advanced aircraft systems. The basic mixed class seating capacity is 458 passengers in the domestic version with lower deck galley and 438 in the intercontinental version with upper galleys. Interior arrangements for the two configurations showing the main and lower deck layouts are presented in Figures 3 and 4. Oversize cargo doors permit the accommodation of pallets in both the forward and center cargo compartments. The aft bulk cargo compartment is the same size as in the

TABLE 1

AIRCRAFT DESIGN REQUIREMENTS

	DOMESTIC	INTERNATIONAL
MIXED CLASS SEATS	450	450
RANGE (N MI)	3,000	5,500
CRUISE MACH NO.	0.80	0.80
TAKEOFF FIELD LENGTH (FT) MTOW, SL, 84°F	8,000	11,000
APPROACH SPEED (KEAS) PASSENGERS, BAGGAGE, RESERVES	130	135
INITIAL CRUISE ALTITUDE (FT)	33,000	31,000

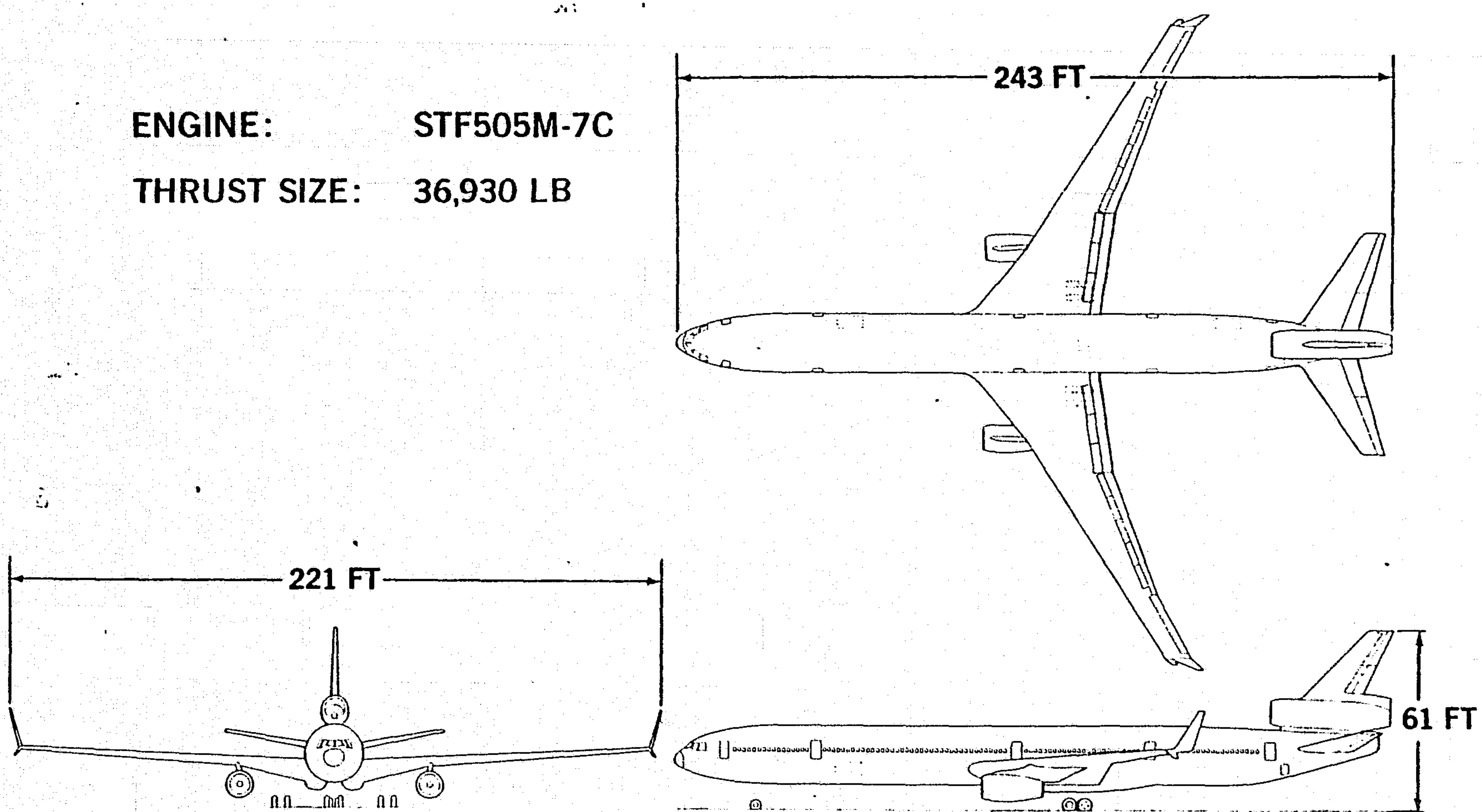
7-GEN-22377A

FIGURE 1

GENERAL ARRANGEMENT — DOMESTIC VERSION

ENGINE: STF505M-7C

THRUST SIZE: 36,930 LB



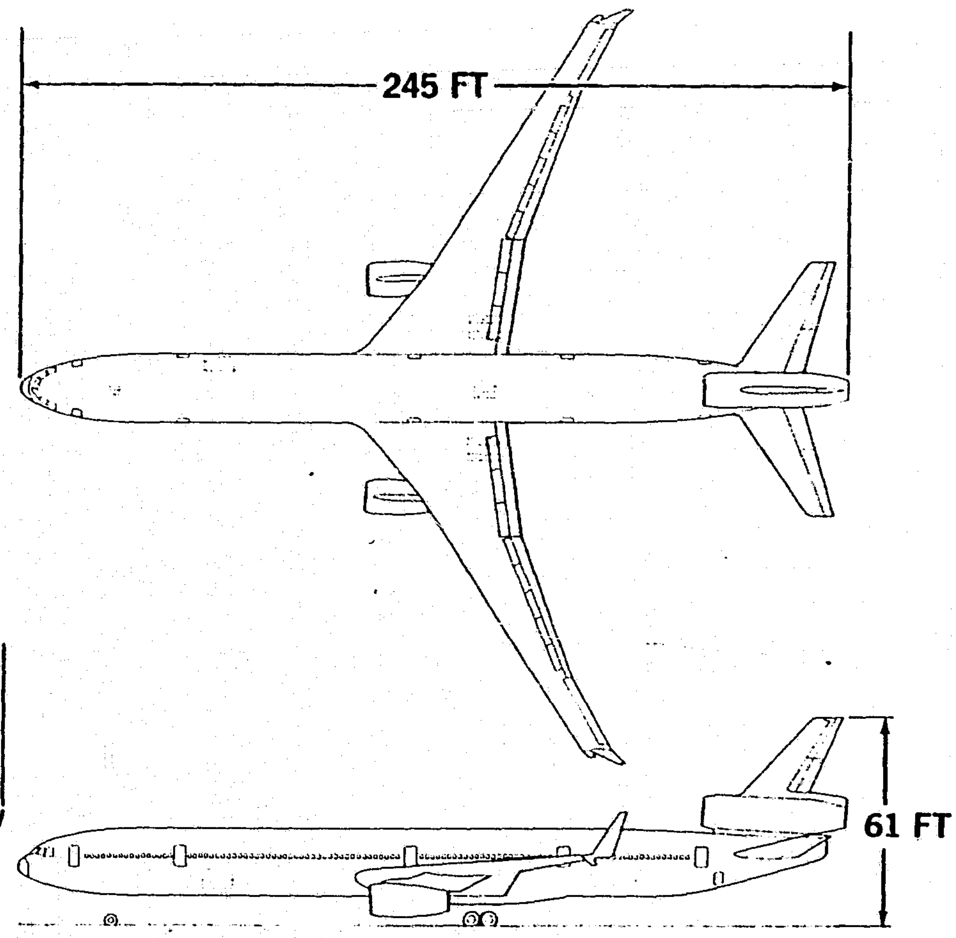
8-DC10-13048

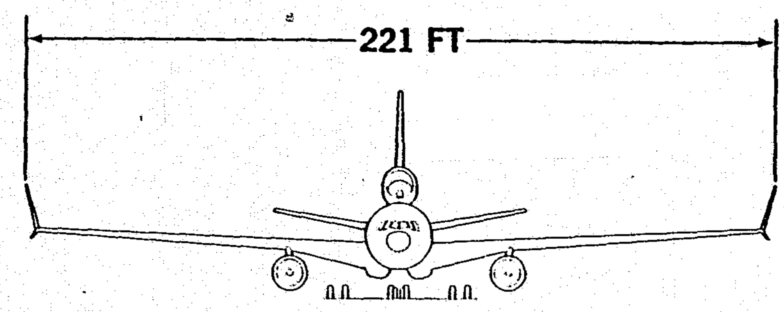
FIGURE 2

GENERAL ARRANGEMENT – INTERNATIONAL VERSION

ENGINE: STF505M-7C

THRUST SIZE: 47,570 LB





8-DC10-13049

TABLE 2

AIRCRAFT CHARACTERISTICS

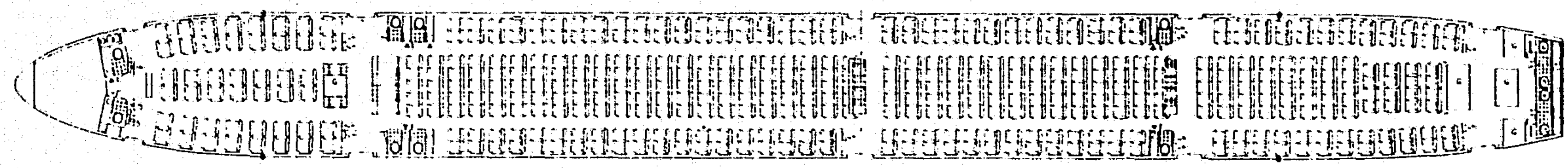
P&W STF505M-7C ENGINES

	DOMESTIC	INTERNATIONAL
MIXED CLASS SEATS	458	438
DESIGN RANGE (NAUTICAL MILES)	3,000	5,500
ENGINE THRUST SIZE (LB/ENGINE)	36,930	47,570
ADJUSTED WING AREA (SQUARE FEET)	4,640	4,640
WEIGHTS:		
MAXIMUM TAKEOFF (LB)	496,000	638,000
MAXIMUM LANDING (LB)	456,000	506,000
OPERATOR'S EMPTY (LB)	286,820	309,170
PERFORMANCE:		
CRUISE MACH NUMBER	0.80	0.80
TAKEOFF FIELD LENGTH, MTOGW, SL, 84°F (FT)	8,000	11,000
APPROACH SPEEDS, PASSENGERS, BAGS, RESERVES (KEAS)	124	129
THRUST LIMITED INITIAL CRUISE ALTITUDE (FT)	34,400	33,300
BUFFET LIMITED INITIAL CRUISE ALTITUDE (FT)	36,500	31,000
FUEL BURNED AT DESIGN RANGE (LB) (100% PASSENGER LOAD FACTOR)	99,380	207,630
TYPICAL STAGE LENGTH (NAUTICAL MILES)	1,000	1,500
FUEL BURNED AT TYPICAL RANGE (LB) (60% PASSENGER / 30% CARGO LOAD FACTORS)	32,800	51,340

FIGURE 3

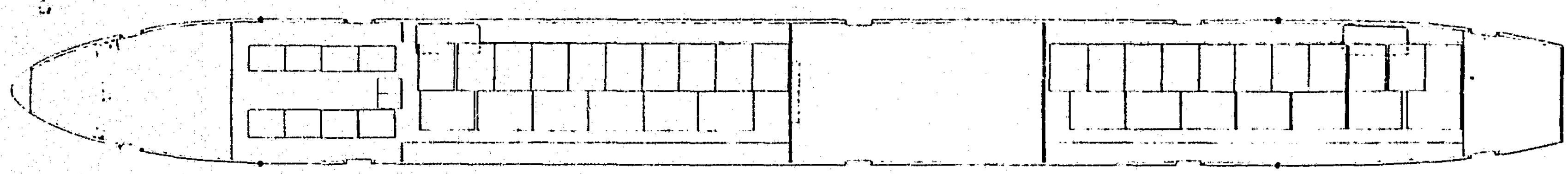
DOMESTIC AIRCRAFT INTERIOR

LOWER GALLEY



46 FIRST CLASS 412 COACH

458 TOTAL



FORWARD: 20 LD-3 OR SIX 88- BY 125-IN. PALLETS

CENTER: 22 LD-3 OR SEVEN 88- BY 125-IN. PALLETS

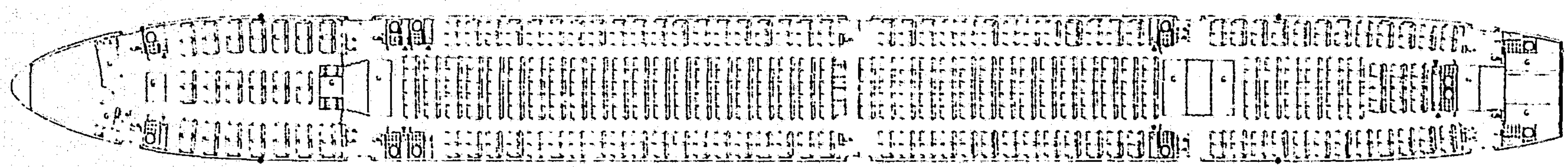
AFT: 510 CU FT BULK

J113870C
7-DC10-11428A

FIGURE 4

INTERNATIONAL AIRCRAFT INTERIOR

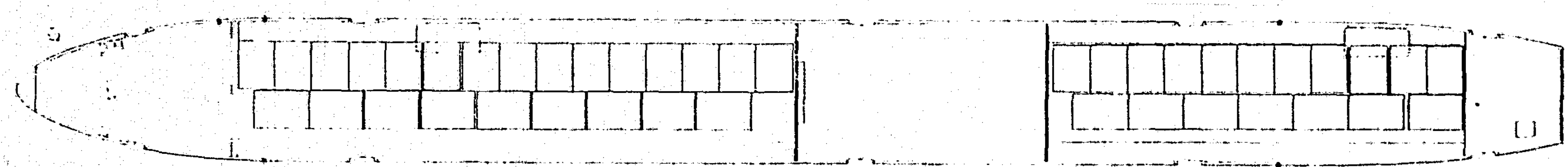
UPPER GALLEY



40 FIRST CLASS

398 COACH

438 TOTAL



FORWARD: 30 LD-3 OR NINE 88- BY 125-IN. PALLETS

CENTER: 22 LD-3 OR SEVEN 88- BY 125-IN. PALLETS

AFT: 510 CU FT BULK

J113871A
7-DC10-11429A

DC-10-30. The flight crew consists of a three man cockpit crew and 15 cabin attendants.

Wing area, common to the two versions, is set by the 1.3 g buffet margin at the 31,000 foot initial cruise altitude requirement of the intercontinental range aircraft. The wing design incorporates the results of the latest wind tunnel tests and analytical studies. Lateral control is provided by spoilers and the all-speed outboard aileron. This allows the flap to extend from the side of the body to 80 percent span without interruption, and with the limited flap deflection of 30 degrees, results in lower required thrust levels and less noise. Wing load alleviation consisting of maneuver and gust load alleviation is used to reduce wing weight.

Horizontal tail aspect ratio has been increased compared to the current DC-10 to reduce trim drag.

The wing, horizontal tail and vertical tails utilize composites in primary and secondary structures to minimize weight.

The scaled thrust sizes of the P&W STF505M-7C engines are set by the design takeoff field length requirements for both versions of the aircraft. The thrust limited initial cruise altitudes exceed requirements by 1400 and 2300 feet respectively for the domestic and international aircraft, indicating a small surplus of cruise thrust relative to the takeoff rating.

2.2.2 Airplane Drag

The airplane parasite and induced drag are shown in Table 3. Nacelle drag is included in the engine data. The compressibility drag increment is shown in Figure 5. The takeoff and landing drag polars are presented in Figure 6.

2.2.3 Weight

Airframe weight breakdowns are shown in Table 4. The weights are based on technology advancements including widespread use of advanced composites.

TABLE 3

AIRCRAFT DRAG

AIRCRAFT WITH STF505M-7C ENGINES

Reference Area:	Trapezoidal Wing Area = 4,208 ft^2
Parasite Drag:	f = 67.64 ft^2 (excludes nacelles)
Induced Drag:	$AR_{trapezoidal}$ = 10.85
	e = 0.953 (includes winglet effects)

FIGURE 5

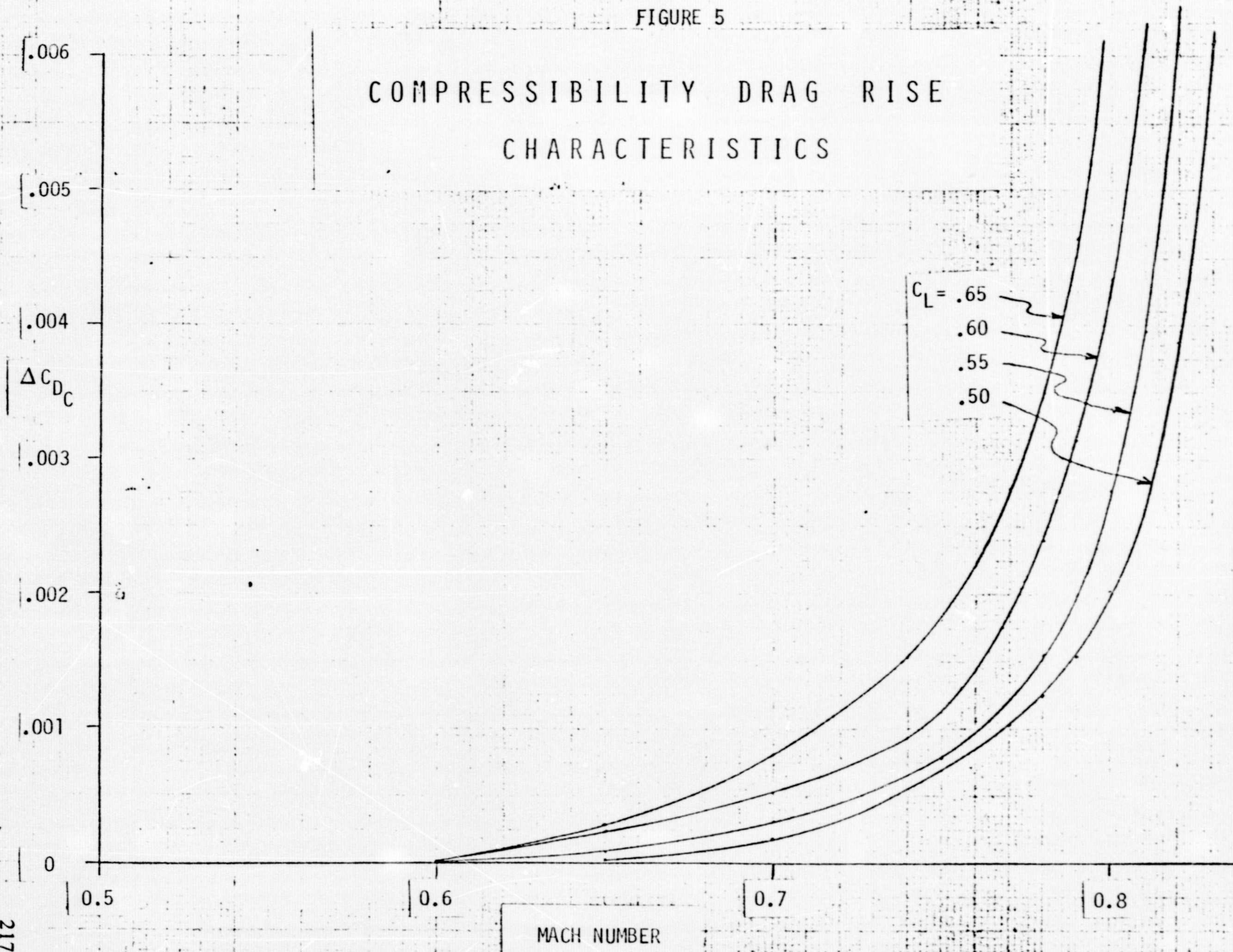
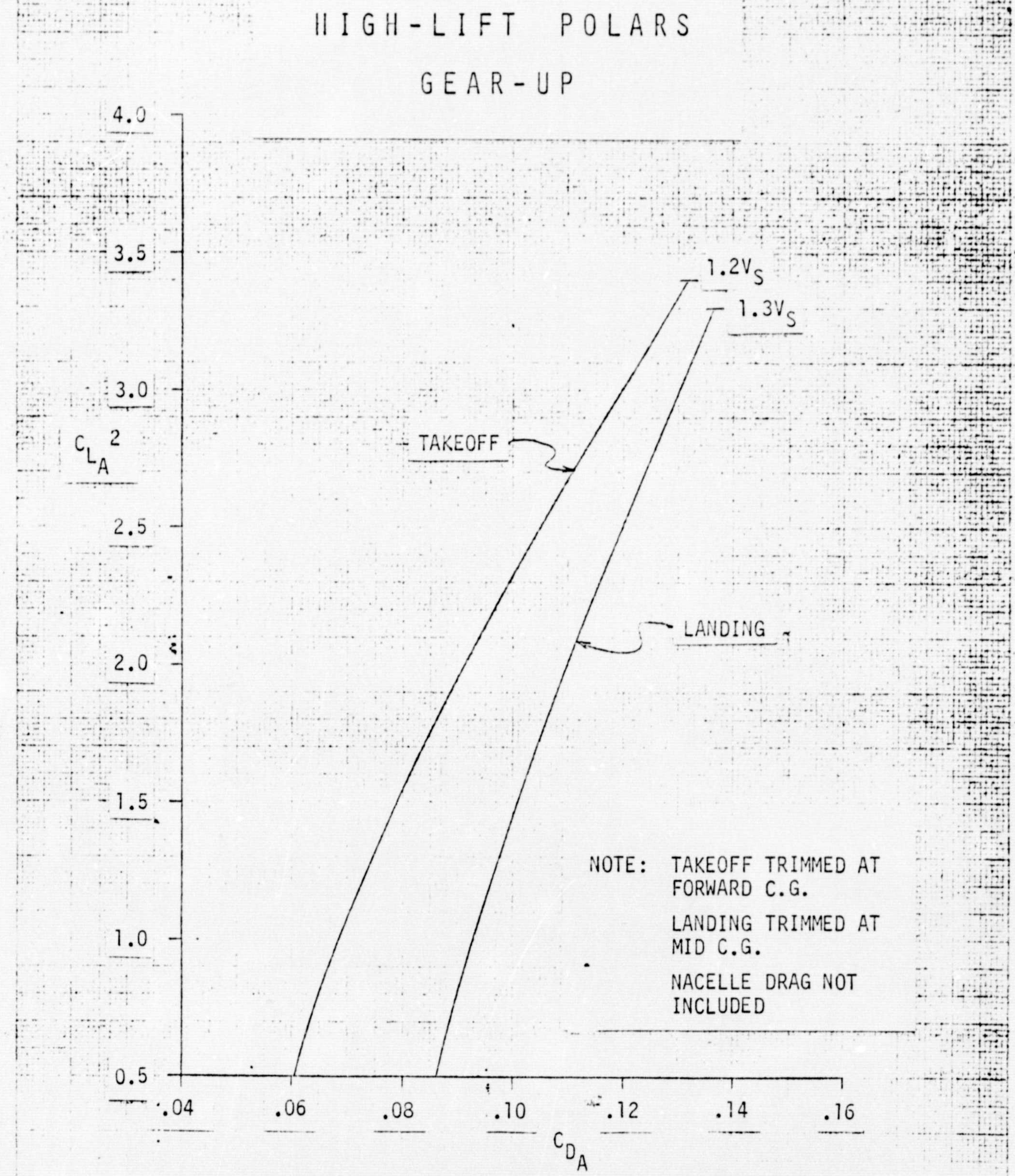

COMPRESSIBILITY DRAG RISE
CHARACTERISTICS
.006
.005
.004
.003
.002
.001
0
ΔC_{D_C}
C_L = .65
.60
.55
.50
0.5
0.6
0.7
0.8
MACH NUMBER

FIGURE 6



K+E ALBANENE® TRACING PAPER LA 6074

TABLE 4

AIRCRAFT WEIGHT BREAKDOWNS

STF505M-7C ENGINES

	DOMESTIC	INTERNATIONAL
WING	54,690	59,200
HORIZONTAL TAIL	4,220	4,700
VERTICAL TAIL	1,960	2,130
FUSELAGE	61,910	63,040
LANDING GEAR	20,230	26,490
PROPULSION*	34,010	44,270
APU	1,435	1,435
FUEL SYSTEM	2,130	2,130
FLIGHT CONTROLS AND HYDRAULIC SYSTEM	10,470	10,470
INSTRUMENTS	1,750	1,750
AIR CONDITIONING AND PNEUMATICS	4,965	4,965
ELECTRICAL	6,460	6,460
AVIONICS	2,700	3,060
FURNISHINGS	53,290	51,980
ICE PROTECTION	650	650
HANDLING GEAR	60	60
MANUFACTURER'S EMPTY WEIGHT	260,930	282,790
OPERATOR'S ITEMS	25,890	26,380
OPERATOR'S EMPTY WEIGHT	286,820	309,170

*Includes lower vertical tail

2.2.4 Sensitivity Factors

Sensitivity factors were generated and are shown in Table 5. These factors provide a means to assess the impact of perturbations in specific fuel consumption, engine weight and nacelle drag on aircraft weights, engine size and fuel burned for the study missions.

2.2.5 Noise

The airframe or non-propulsive noise with flight conditions and engine power settings at the FAR noise measuring points are shown in Table 6. Tabulated noise spectral data are presented in Appendix I.

2.2.6 Secondary Power

The secondary power requirements have been estimated and the mechanical power requirements are shown in Table 7. For hydraulic power, the time average cruise requirement in still air (without turbulence) is 31 horsepower per engine. This is based on hydraulic pumps in average condition with nominal aircraft hydraulic system leakage. The maximum or sizing requirement for hydraulic power is for two pumps per engine operating at full capacity. One hundred seventy five horsepower per engine is required for pumps that have had considerable usage.

The time average accessory gearbox power required by the generators is 75 horsepower per engine. This is based on a survey made on power usage in the DC-10. The DC-10 average power usage was scaled up to provide for the increase in number of passengers in this study. The maximum or sizing requirement is 257 horsepower per engine.

The average pneumatic power required in the form of compressor bleed is shown in Figure 7.

The maximum bleed case is for one pneumatic system out and an engine out, under icing conditions. For this case, at a 15,000 foot hold condition, it is estimated that one engine must provide 0.7 pounds/second inlet cowl anti-ice with a bleed temperature greater than 500°F plus 5 pounds/second wing anti-ice flow at a temperature greater than 400°F plus 2.7 pounds/second to provide air

TABLE 5

SENSITIVITY FACTORS

P&W STF505M-7C ENGINES

	+ 5% TSFC	+ 1000 LB. WEIGHT PER ENGINE	+ 20% ISOLATED NACELLE DRAG
DOMESTIC			
MAX TAKEOFF WEIGHT	+ 2.4%	+ 1.2%	+ 0.7%
OPERATOR'S EMPTY WEIGHT	+ 1.7%	+ 1.8%	+ 0.5%
ENGINE THRUST SIZE	+ 2.1%	+ 1.3%	+ 0.7%
FUEL BURNED			
- DESIGN MISSION	+ 6.1%	+ 0.9%	+ 1.8%
- TYPICAL MISSION	+ 6.0%	+ 1.0%	+ 1.4%
INTERNATIONAL			
MAX TAKEOFF WEIGHT	+ 4.0%	+ 1.2%	+ 0.9%
OPERATOR'S EMPTY WEIGHT	+ 2.4%	+ 1.7%	+ 0.6%
ENGINE THRUST SIZE	+ 4.3%	+ 1.3%	+ 1.0%
FUEL BURNED			
- DESIGN MISSION	+ 7.5%	+ 1.0%	+ 1.5%
- TYPICAL MISSION	+ 5.8%	+ 0.9%	+ 1.0%

TABLE 6

CONDITIONS AT FAR-36 MEASURING POINTS

SCALED STF505M-7C ENGINES

Aircraft	Condition	Geometric Altitude (FT)	True Airspeed (KN)	Installed Thrust per Engine (% Takeoff)	Airframe Generated Noise (EPNdB)
Domestic	Sideline	850	150	100	76.8
	Takeoff	1500	151	100	78.1
	Cutback	1412	151	69	78.5
	Approach	394	146	18	91.6
International	Sideline	850	167	100	79.7
	Takeoff	1152	167	100	83.1
	Cutback	1072	167	70	83.7
	Approach	394	153	18	92.7

TABLE 7

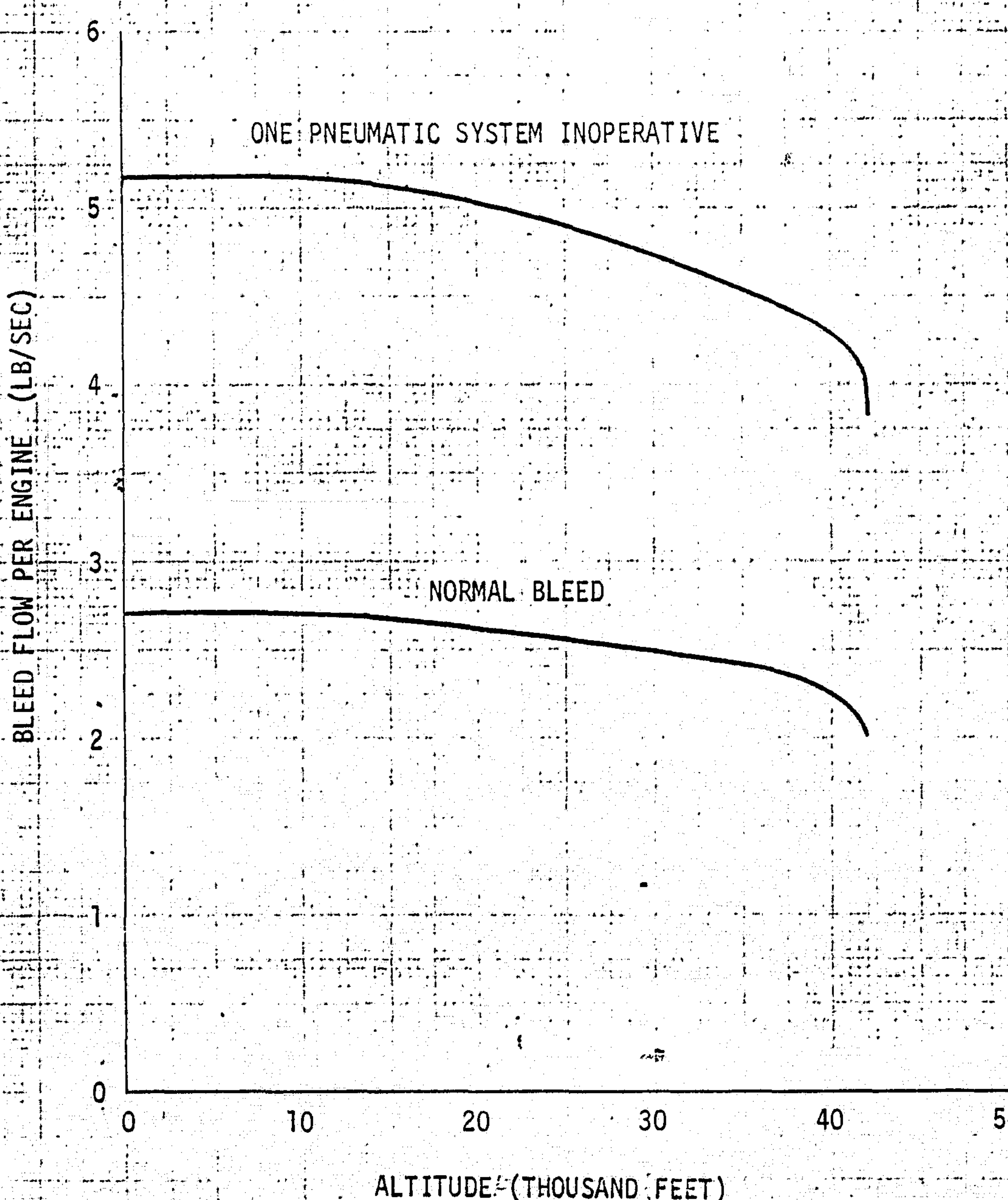
ACCESSORY GEARBOX POWER REQUIREMENTS

TYPE	SOURCE	TIME AVERAGE CRUISE POWER IN STILL AIR	SIZING REQUIREMENT
Hydraulic Power	Two 35 GPM Pumps per Engine	31 HP/Engine	175 HP/Engine
Electric Power	One 120 KVA Generator per Engine	75 HP/Engine	257 HP/Engine

FIGURE 7

E3 STUDY AIRCRAFT COMPRESSOR BLEED AIR REQUIRED

ICE PROTECTION NOT INCLUDED



PREPARED BY: REFERENCE MODEL REPORT NO. PAGE NO. REVISED DATE

FORM 25-86-4 REV. 6-71

to drive one air conditioning pack. The sizing case therefore requires a total of 8.4 pounds/second with the engine at 40 to 60% of climb thrust.

The above values reflect preliminary analyses of a current test program to reduce bleed flow requirements for wing anti-icing.

Further evaluations may result in requirements to revise the wing anti-icing flow requirements. In addition, potential means to reduce bleed flow requirements have been identified but sufficient work has not been done to reflect these reductions in this study.

2.2.7 Comparison Between E^3 And JT9D

In order to determine the fuel consumption benefits from E^3 engine technology, the advanced technology airplanes were sized using JT9D engines for the same payload and missions. The results are shown in Table 8. Table 9 shows a comparison between the airplanes sized with E^3 technology and JT9D engines.

TABLE 8

AIRCRAFT CHARACTERISTICS

P&W JT9D-20 ENGINES

	DOMESTIC	INTERNATIONAL
MIXED CLASS SEATS	458	438
DESIGN RANGE (NAUTICAL MILES)	3,000	5,500
ENGINE THRUST SIZE (LB/ENGINE)	42,150	53,600
ADJUSTED WING AREA (SQUARE FEET)	5,260	5,260
WEIGHTS:		
MAXIMUM TAKEOFF (LB)	548,000	723,000
MAXIMUM LANDING (LB)	482,000	542,000
OPERATOR'S EMPTY (LB)	309,070	336,870
PERFORMANCE:		
CRUISE MACH NUMBER	0.80	0.80
TAKEOFF FIELD LENGTH, MTOGW, SL, 84°F (FT)	8,000	11,000
APPROACH SPEEDS, PASSENGERS, BAGS, RESERVES (KEAS)	120	126
THRUST LIMITED INITIAL CRUISE ALTITUDE (FT)	34,100	32,700
BUFFET LIMITED INITIAL CRUISE ALTITUDE (FT)	37,100	31,000
FUEL BURNED AT DESIGN RANGE (LB) (100% PASSENGER LOAD FACTOR)	124,260	256,880
TYPICAL STAGE LENGTH (NAUTICAL MILES)	1,000	1,500
FUEL BURNED AT TYPICAL RANGE (LB)		
(60% PASSENGER / 30% CARGO) LOAD FACTORS)	41,210	63,160

TABLE 9

COMPARATIVE AIRCRAFT CHARACTERISTICS

Engine	Domestic JT9D-20	Domestic STF505M-7C	International JT9D-20	International STF505M-7C
Maximum Takeoff Weight (LB)	548,000	496,000	723,000	638,000
Operator's Empty Weight (LB)	309,070	286,820	336,870	309,170
Takeoff Thrust (LB)	42,150	36,930	53,600	47,570
Design Range (N MI)	3,000	3,000	5,500	5,500
Fuel Burned At Design Range (LB)	124,260	99,380	256,880	207,630
Relative Fuel Burned At Design Range (LB)	---	-20%	---	-19%
Typical Range (N MI)	1,000	1,000	1,500	1,500
Fuel Burned At Typical Range (LB)	41,210	32,800	63,160	51,340
Relative Fuel Burned At Typical Range (LB)	---	-20%	---	-19%

2.3 AIRFRAME/PROPULSION SYSTEM INTEGRATION

Preliminary propulsion system integration requirements were investigated. Study engine installations provided by Pratt & Whitney were reviewed and requirements for installation in the E^3 study aircraft were determined.

2.3.1 Study Installations

Table 10 summarizes preliminary results of evaluations of the study engine installations provided by Pratt & Whitney. The evaluations were preliminary assessments of the aerodynamic lines and general arrangements.

The aerodynamic critique on P&W Drawings L-108594 dated 1/15/78 and L-109846 dated 6/8/78 indicates a potential for excessive nozzle afterbody angle. These statements are based on a certain degree of uncertainty because the angles exceed those for which data is available.

The adequacy of flow directivity in the reverser configuration column refers to the ability to incorporate a directed flow reverser which will preclude debris ingestion due to reverse flow impingement on the ground.

Pylon-mounted accessories are judged unacceptable because it would require special equipment in order to conduct servicing, inspection and maintenance, particularly on the tail engine. Airframe accessories must be easily removed and replaced without requiring the airplane to fly to a maintenance base. In addition, the pylon-mounted accessories can preclude simultaneous maintenance or servicing the engine and accessories because the open engine cowl door would interfere with access to the pylon. Further, the additional time required would result in additional flight delays and cancellations.

Experience with fan cowl-mounted accessories has demonstrated that this arrangement is satisfactory for maintainability. By comparison, the other arrangements are judged to be poor.

2.3.2 Preliminary 1990 Propulsion System Requirements

New engines are introduced because they result in a major improvement in economics, provide the thrust requirement for a new airplane size, or both. In the 1990's, a new engine based on E^3 technology will be expected to improve economics because the thrust sizes of interest are expected to be

TABLE 10

INSTALLATION STUDIES SUMMARY

STUDY INSTALLATION			Nacelle Dimensions (Inches)				
				C_L to Max R			
Pratt & Whitney Drawing Number	Douglas Interpretation Dwg. No.	Description	Length	Top	Side	Bottom	Aerodynamic Critique
L-108594 dtd. 1-15-78	---	STF 505 M-7 Engine - wing instl. Split accessory arrangement fan mounted engine accessories with airframe accessories in pylon	252.7	55.0	55.3	55.0	Nozzle afterbody angle may be excessive. Outside of data base.
L-108594 and L-108623 dtd. 5-5-78	J-112536	Wing Instl. - STF505 M-7 Split accessory arrangement core mounted engine accessories with airframe accessories in pylon - P&W design fan reverser	258.0	55.0	55.3	55.0	Acceptable
	J-112539	Tail instl. - STF 505 M-7 Adaptation of J-112536 for different location		53.4	62.0	53.4	Acceptable
L-108594 modified per L-108613 dtd. 4-18-78	J-112540	Wing instl. STF 505 M-7 Full duty core-mounted accessory package DAC type fan reverser.	258.0	55.0	55.3	55.0	Acceptable
	J-112541	Wing Instl. - STF 505 M-7 Full duty core-mounted accessory pkg. DAC design fan reverser. Study dwg. for nacelle seals & latches	258.0	55.0	55.3	55.0	Acceptable
L-109846 dtd. 6-8-78	----	STF 505 M-7 Engine - wing instl. Split accessory pkg., core mounted engine accessories with airframe accessories in pylon P&W design fan reverser.	262.0	55.0			Nozzle afterbody angle may be excessive. Outside of data base.
L-109846 and L-108620 dtd. 5-5-78	J-112545	Wing instl. - split accessories at 4 and 8 o'clock on fan case	262.0	55.1	56.0	56.8 (60 @ 4 & 8 o'clock)	
L-109846 marked up for slim nacelle line	----	Wing instl.					

TABLE 10 (CONTINUED)

INSTALLATION STUDIES SUMMARY

Douglas Interpretation Dwg. No.	Structural Critique	Reverser Configuration	Accessory Configuration	Maintainability	Comments
---	Appears reasonable	Does not appear to have adequate flow directivity provisions	Pylon mounted accessories unacceptable for tail engine	Poor	Special ground stands for accessory maintenance and replacement is unacceptable
J-112536	Appears reasonable	Does not appear to have adequate flow directivity provisions	Pylon mounted unacceptable plus potential reduced reliability for engine accessories	Poor	See above
J-112539	Appears reasonable	----	Pylon mounted unacceptable	Very poor	See above
J-112540	Appears reasonable	Appears reasonable	Potential reduced reliability for accessories	Poor	See above
J-112541	Appears reasonable	Appears reasonable	Potential reduced reliability for accessories	Poor	Study of nacelle seals and latches
----	Appears reasonable	Does not appear to have adequate flow directivity provisions	Pylon mounted unacceptable	Poor	See above
J-112545	Appears reasonable	-----	Appears reasonable	Good	May have weight and performance penalty for addition power take-off shaft
----	Insufficient information to evaluate				

available from current and derivative versions of JT8D refan, JT9D, JT10D, CFM56, CF6 and RB211 engines. Since the E^3 goal is to reduce specific fuel consumption by 12% and DOC by 5%, other cost components cannot increase, and may have to decrease to provide sufficient incentive for development of a new engine. It is therefore expected that other costs should improve, or at worse, remain the same. This needs to be accomplished while meeting more stringent regulations and requirements.

Maintenance

The installation maintainability goals should be comparable to today's standards. This requires access to all borescope ports without removal of any component. Elapsed time goals are shown in Table 11.

Thrust Reversers

Thrust reversers should be improved compared to current designs. Specific needs are listed below.

1. Fan thrust reversers with efflux directivity that minimizes debris kickup while enabling routine use down to zero speed are desired. Directivity tailoring capability must exist to match airframe requirements to maintain airplane control and drag.
2. The overall reverser effectiveness goal is 40% for the primary plus fan on wing engines. Tail engine reversing effectiveness can be lower to prevent aircraft pitchup.
3. Current fail-safe design practice for ground only reversing will be maintained. The reversers will maintain their position in the event of an actuation system failure.
4. A hydraulic actuation system is preferred with reverser hydraulic fluid isolated from other airframe hydraulic fluid.

Ozone

Consideration should be given to providing bleed air for cabin air conditioning that has an ozone concentration of less than 0.1 ppm. Since elevating the temperature of air containing ozone will destroy the ozone, heating and cooling the bleed air may be a viable way to reduce the ozone concentration in the cabin.

TABLE 11

INSTALLATION
ELAPSED TIME GOALS

DESCRIPTION	ELAPSED TIME (Minutes)
Engine	
Build Up Neutral QEC from Basic Engine	2000
Build UP Neutral QEC to Wing QEC	45
Build UP Neutral QEC to Tail QEC	30
Convert Wing QEC to Tail QEC	45
Convert Tail QEC to Wing QEC	45
Change Wing Engine (Including Access Time and GSE)	60
Change Tail Engine	90
Components/Accessories	**Remove and Replace**
Integrated Drive Generator	35
Hydraulic Pump	15
Fire Detector	15
Main Fuel Control	25
Fuel Pump	60
Fuel Heater	30
Primary Nozzle	90
Exhaust Plug with Primary Nozzle Removed	10
Exhaust Plug with Primary Nozzle Installed	15
Fuel Heater Air Shutoff Solenoid Valve	10
Anti-Icing Air Shutoff Actuator Valve	20

TABLE 11 (CONTINUED)

INSTALLATION
ELAPSED TIME GOALS

DESCRIPTION

Components/Accessories	ELAPSED TIME (Minutes) Remove and Replace
Differential Pressure Switch	6
Nose Cowl Anti-Icing Pressure Regulator and Shutoff Valve	7
Starter	20
Starter Shutoff Valve	5
Hydraulic Filters	5
Fuel Flow Transmitter	11
Ignition Exciter	7
Ignition Plugs	7
Pressure Ratio Bleed Control	8
Compressor Stator Control	23
Fan Air Case Cooling Shutoff Valves	7
Bleed (Air/Fuel) Converter Valve	12
Bleed Control Valves	7
Pneumatic Pressure Regulating Valves	7
Bleed Check Valves	4

Bleed Air Cleanliness

Bleed ports must be designed to prevent the ingestion of solid particles that enter the engine inlet, or liquids (such as might be generated within the engine by fluid leakage), without unnecessarily sacrificing total pressure recovery.

Because an engine compressor acts as a centrifugal separator, clean air may be extracted at the compressor inside diameter without significant loss of ram pressure. The associated disadvantages are the cost of making hollow stator vanes suitable for conducting this air to the outside diameter of the engine, and the pressure drop of the flow traversing these relatively small passages.

Outside diameter ports that are protected by locating them in a shadow zone sacrifice ram pressure but may be designed to provide clean air as long as the engine is running. When the engine is stopped, fluids can draw into such openings if they occur at a low point.

Desirable Stage Locations For Bleed Ports

Bleed air must be available from the compressor discharge to accommodate operation at engine idle.

For economy reasons, bleed must be available at the lowest stage that will satisfy air conditioning system pressure requirements at maximum altitude with the lowest engine power useful for cruise. If the maximum altitude for the baseline airplane is 39,000 feet, a bleed pressure of 20 psig would permit using DC-10 type components. Pressures as low as 15 psig could be considered if the associated economy improvement would justify the development of new and possibly more complicated air conditioning components.

An additional, lower stage port located so that the discharge temperature closely approached but did not exceed 450°F on a hot day sea level takeoff would eliminate the need for precooling low stage bleed, and would open the possibility of eliminating all precooling. Complete elimination of precooling could only be justified by a thorough investigation. Changing from DC-10 to DC-9 pneumatic system concepts for providing suitable ice protection bleed temperatures would probably be required. The investigation would have to include a study of the pressure suitability of the next lower stage pressure whenever high stage bleed exceeds 450°F at idle power on a hot day. Any pressure above 25 psig at this lower stage would be satisfactory.

A completely independent port for engine inlet ice protection air supply is desired, located at compressor discharge, or preferably a lower stage if it would provide 400°F at engine idle power with ambient temperatures at the low limit of the FAA icing envelope.

Containment

In addition to rotor blade containment requirements of FAR Part 33, any blade fragment exiting from the engine shall not have sufficient energy to penetrate nacelle structure or systems.

APPENDIX C

LR 28664
23 JUNE 1978

FINAL REPORT

ENERGY EFFICIENT ENGINE COMPONENT DEVELOPMENT AND INTEGRATION STUDY

Subcontract 20646-3

TABLE OF CONTENTS

Section		Page
	LIST OF FIGURES	v
	LIST OF TABLES	vii
1	INTRODUCTION AND SUMMARY	1-1
2	STUDY EFFORT	2-1
2.1	MISSION AND DESIGN DEFINITION	2-1
2.2	PROPULSION SYSTEM — AIRCRAFT INTEGRATION	2-1
2.2.1	STF505M-7C Engine Evaluation	2-1
2.2.2	Sensitivity Analysis	2-3
2.2.3	Airframe Noise Estimates	2-4
2.2.4	Engine Bleed Requirements and Power Extraction	2-4
2.3	ENGINE INSTALLATION	2-11
2.3.1	Nacelle Configuration	2-11
2.3.2	Nacelle-Wing Interference	2-12
2.3.3	Accessory Location	2-12
2.3.4	Access Provisions	2-13
2.3.5	Thrust Reverser	2-13
2.3.6	Center Engine Installation	2-16
2.4	PERFORMANCE AND ECONOMIC COMPARISONS	2-16
3.	CONCLUSIONS AND RECOMMENDATIONS	3-1
APPENDIX A	DIRECT OPERATING COST (DOC) CALCULATIONS — E^3 AIRCRAFT	A-1

LIST OF FIGURES

Figure		Page
1	General Arrangement Domestic Aircraft (STF505M-7C Engine)	1-7
2	General Arrangement Intercontinental Aircraft (STF505M-7C Engine)	1-9
3	Wing Engine Installation Layout	1-11
4	Center Engine Installation	1-13
5	Wing Engine Location	1-15
6	ASSET Synthesis Cycle	2-4
7	Domestic Aircraft Sensitivity Factors for ΔTSFC	2-5
8	Domestic Aircraft Sensitivity Factors for ΔEngine Weight	2-6
9	Domestic Aircraft Sensitivity Factors for ΔNacelle Drag	2-7
10	Intercontinental Aircraft Sensitivity Factors for ΔTSFC	2-8
11	Intercontinental Aircraft Sensitivity Factors for ΔEngine Weight	2-9
12	Intercontinental Aircraft Sensitivity Factors for ΔNacelle Drag	2-10
13	Thrust Reverser Flow Directivity	2-15
14	Block Fuel Advantage with STF505M-7C Engine	2-17
15	DOC Advantage with STF505M-7C Engine	2-18
16	Size Advantage with STF505M-7C Engine	2-20

LIST OF TABLES

Table		Page
1	Reference Aircraft Design and Performance Characteristics	1-3
2	E^3 Aircraft Design and Performance Characteristics	1-5
3	Design and Technology Features-1990's Transport Aircraft	2-2
4	Airframe Noise Estimates (STF505M-7C Engine)	2-11
5	E^3 Accessory Location	2-14

SECTION 1

INTRODUCTION AND SUMMARY

This study was accomplished by the Commercial Advanced Design Division of the Lockheed-California Company for the Pratt and Whitney Aircraft Group in support of their "Energy Efficient Engine Component Development and Integration Program," The effort required was in accordance with Pratt and Whitney Subcontract 20646-3 and consisted of the initial Propulsion System - Aircraft Integration Evaluation as specified by Task 1. This initial evaluation was in support of Pratt and Whitney's engine preliminary design effort and two additional evaluations will be made by Lockheed during the program as follows:

- Initiation of engine core manufacturing and testing - mid 1980
- Completion of integrated core/low spool testing - mid 1983

This evaluation is an update or follow-on to the previous Lockheed study effort in support of the "Energy Efficient Engine Preliminary Design and Integration Study," Pratt and Whitney Subcontract Number 20628-3 which included the following:

- Definition of airframe design and technology features
- Aircraft and mission definition
- Aircraft performance and mission sensitivities
- Aircraft-engine integration evaluation

During the previous study effort, Lockheed Report LR 28351, two aircraft configurations were developed; one for a domestic mission and one for an intercontinental mission. These domestic and intercontinental aircraft (using the JT9D-7A engine) were characterized for the following technology features and mission criteria:

- Technology Features
  - Supercritical wing
  - Active controls
  - Advanced composite structure
- Mission Criteria

	Domestic	Intercontinental
Design Range (n.mi.)	3,000	6,500
No. passengers	400	400
Cruise speed	M 0.8	M 0.8
Typical range	1,400	3,000
Configuration	3-Engine-Wide Body	4-Engine-Wide Body

For this study, reevaluation of aircraft technology features and mission criteria resulted in the retention of previously established criteria, except for the passenger/payload capacity. A payload capacity of 100,000 pounds (500 passengers) was incorporated in lieu of 80,000 pounds (400 passengers) previously used. This change was made based on a review by Lockheed's Marketing Development Division relative to potential market demand in the 1990's time frame. Reference aircraft design and performance characteristics consistent with the increased payload capacity are included in Table 1. These configurations were established as baseline aircraft to be used for comparison with aircraft incorporating the Energy Efficient Engine.

The Energy Efficient Engine cycle selected by Pratt and Whitney for installation on the domestic and intercontinental aircraft is the STF 505M-7C with the following characteristics, as compared to the current JT9D-7A engine:

	JT9D-7A	STF505M-7C
Technology Level	Current	1990's
Fan Drive	Direct	Direct
Exhaust	Separate	Mixed
Bypass Ratio	5.0	6.55
Overall Ratio	25.4	38.6
Turbine Inlet Temp	2290	2450

TABLE 1. REFERENCE AIRCRAFT DESIGN AND PERFORMANCE CHARACTERISTICS

	Domestic	Intercontinental
Mission Characteristics		
Design Range (n.mi.)	3000	6500
Typical Range (n.mi.)	1400	3000
Cruise Speed (Mach)	0.8	0.8
No. Passengers	500	500
Init. Cruise Altitude (ft)	35,000	33,000
Field Length (ft)	6970	9398
Approach Speed (kt)	135	128
Design Characteristics		
Configuration	3 Engine-Trijet	4 Engine-Quadjet
Power Plant	JT9D-7A	JT9D-7A
Sweep (.25c)	30°	30°
W/S (lb/ft^2)	118	134
T/W	0.260	0.220
AR	10	10
t/c (%)	13	13
TOGW (lb)	481,357	707,924
OEW (lb)	261,934	303,985
Wing Span (ft)	202.0	229.8
Body Length (ft)	228.3	229.5
Body Diameter (ft)	19.6	19.6
Performance Characteristics		
Thrust/Engine (SLS, lb)	41,718	38,936
Block Fuel-Design (lb)	99,999	263,686
Block Fuel-TYP. (lb)	43,352	101,781
DOC-Design (¢/ASM)	1.227	1.414
DOC-TYP. (¢/ASM)	1.336	1.407

Table 2 is a tabulation of the aircraft design and performance characteristics of the domestic and intercontinental aircraft with the STF505M-7C engine. Comparison of this data with the performance of the reference aircraft (JT9D-7A engine) indicates mission fuel and direct operating cost (DOC) savings with the STF505M-7C engine as follows:

	Fuel		DOC	
	Design	Typical	Design	Typical
Domestic	18.1%	18%	5.9%	5.4%
Intercontinental	20.1%	19.1%	9.2%	8.1%

General Arrangement Drawings, depicting the domestic and intercontinental aircraft with the STF505M-7C engine, are included as Figures 1 and 2. The size of the STF505-M-7C engine, as supplied by Pratt and Whitney, is compatible (thrust class, reverse thrust level, and power extraction) with the Lockheed specified mission/payload characteristics for 1990's aircraft.

Installation layout drawings using the STF505M-7C engine on the domestic aircraft are included as Figures 3 through 5, and depict location of aircraft accessories in the engine pylon and placement of the nacelle with respect to the wing consistent with minimization of interference drag penalties.

The results of this phase of the Energy Efficient Engine Component Development and Integration study are as follows:

- The NASA defined goals for minimum fuel and DOC savings of 12% and 5% respectively are attained with the STF505M-7C engine.
- Installation of the STF505M-7C engine (with mixed exhaust), without a penalty for interference drag, appears feasible.
- Pylon mounting of the aircraft accessories is an acceptable configuration and enhances the aerodynamic characteristics of the STF505M-7C nacelle.
- Incorporation of the STF505M-7C engine results in aircraft configurations, sized for long range and large payload capacity, which are compatible with existing airport facilities (field length, wing span, body length, etc.)

TABLE 2. E^3 AIRCRAFT DESIGN AND PERFORMANCE CHARACTERISTICS

	Domestic	Intercontinental
Mission Characteristics		
Design Range (n.mi.)	3000	6500
Typical Range (n.mi.)	1400	3000
Cruise Speed (Mach)	0.8	0.8
No. Passengers	500	500
Init. Cruise Altitude (ft)	37,000	34,000
Field Length (ft)	6976	9460
Approach Speed (kt)	135	131
Design Characteristics		
Configuration	3 Engine-Trijet	4 Engine-Quadjet
Power Plant	STF505M-7C	STF505M-7C
Sweep (.25c)	30°	30°
W/S (lb/ft^2)	114.8	132
T/W	0.255	0.220
AR	10	10
t/c%	13	13
TOGW (lb)	454,013	630,491
OEW (lb)	255,937	286,974
Wing Span (ft)	198.9	218.6
Body Length (ft)	228.3	229.5
Body Diameter (ft)	19.6	19.6
Performance Characteristics		
Thrust/Engine (SLS, lb)	38,591	34,677
Block Fuel-Design (lb)	81,862	210,888
Block Fuel-Typ. (lb)	33,513	82,387
DOC-Design (¢/ASM)	1.155	1.285
DOC-TYP. (¢/ASM)	1.263	1.293

CHARACTERISTICS	WING	HORIZONTAL TAIL	VERTICAL TAIL
AREA SQ M (SQ FT)	[illegible]	[illegible]	[illegible]
ASPECT RATIO	10	[illegible]	[illegible]
SPAN M (FT)	60 61 (198 86)	[illegible]	[illegible]
ROOT CHORD M (IN)	[illegible]	[illegible]	[illegible]
TIP CHORD M (IN)	[illegible]	[illegible]	[illegible]
TAPER RATIO	0 30	0 30	0 30
MAC M (IN)	[illegible]	[illegible]	[illegible]
SWEEP RAD (DEG)	0 524 (30)	0 524 (30)	0 611 (35)
T/C ROOT %	12	10	10
T/C TIP %	12	10	10

GROSS WEIGHT - 205 940 KG (454 013 LB)

POWER PLANT (3) P&W STF505M-7 TURBOFAN

INSTALLED THRUST - 171 653 N (38 591 LB)

PASSENGERS - 500

RANGE - 3,000 N M

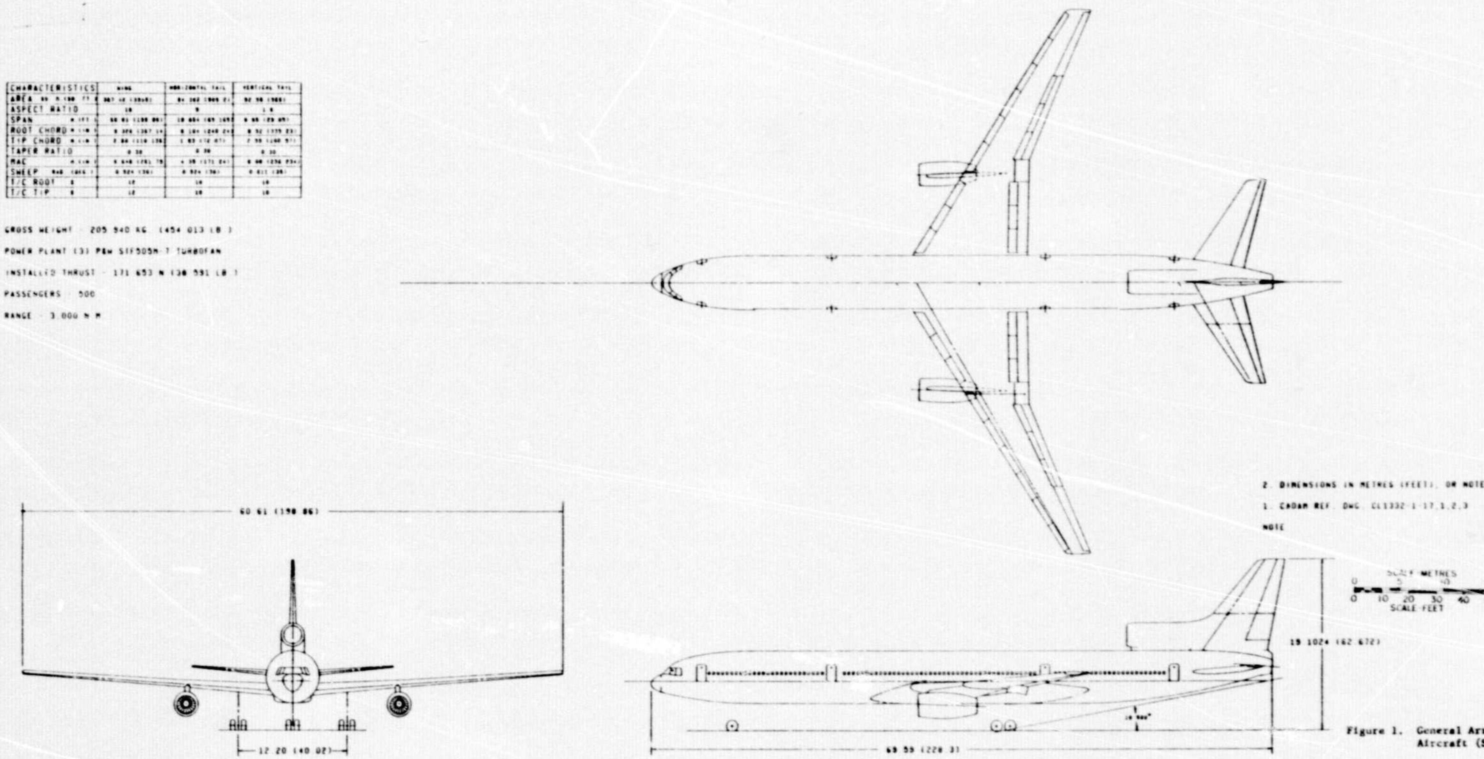


Figure 1. General Arrangement Domestic Aircraft (STF505M-7C Engine)

CHARACTERISTICS	WING	HORIZONTAL TAIL	VERTICAL TAIL
AREA SQ M (SQ FT)	443.72 (4776)	91.95 (989.7)	60.56 (652.0)
ASPECT RATIO	10	5	1.6
SPAN M (FT)	66.63 (218.6)	21.45 (70.4)	9.85 (32.32)
ROOT CHORD M (IN)	10.25 (403.4)	6.60 (259.90)	8.47 (332.8)
TIP CHORD M (IN)	3.07 (121.0)	1.98 (77.6)	2.84 (111.8)
TAPER RATIO	0.30	0.30	0.30
MAC M (IN)	7.87 (309.8)	4.71 (185.5)	6.67 (262.8)
SWEEP RAD (DEG)	0.524 (30)	0.529 (30)	0.524 (30)
T/C ROOT %	12	10	10
T/C TIP %	12	10	10

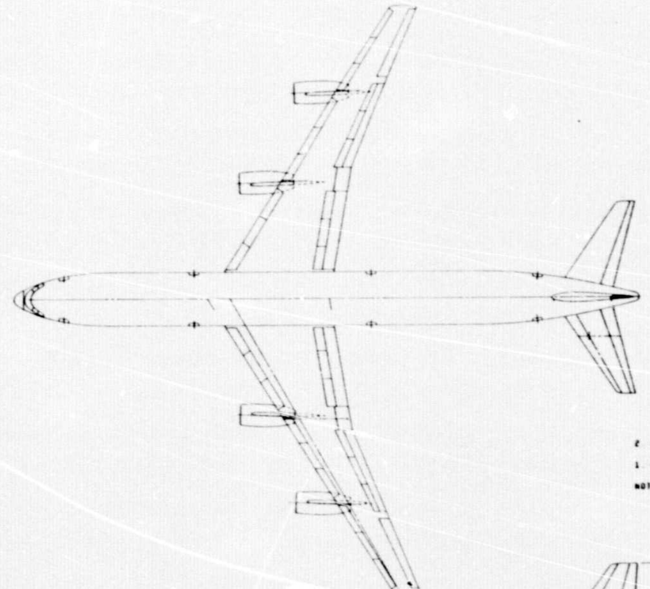
GROSS WEIGHT - 285 361 KG (630 491 LB)

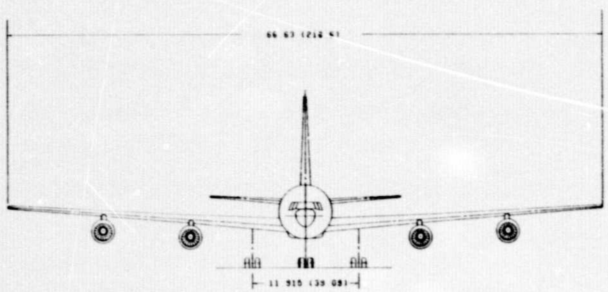
POWER PLANT (4) P&W STF 505M-7 TURBOFAN

INSTALLED THRUST - 154 243 N (34 677 LB)

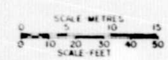
PASSENGERS - 500

RANGE - 6,500 N M





2. DIMENSIONS IN METRES (FEET), OR NOTED
1. CADAM REF DWG CL1332-10-1,1,2,3
NOTE



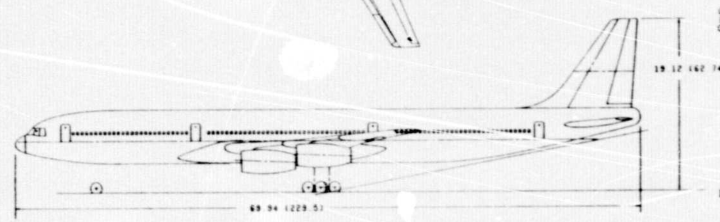


Figure 2. General Arrangement Intercontinental Aircraft (STF505M-7C Engine)

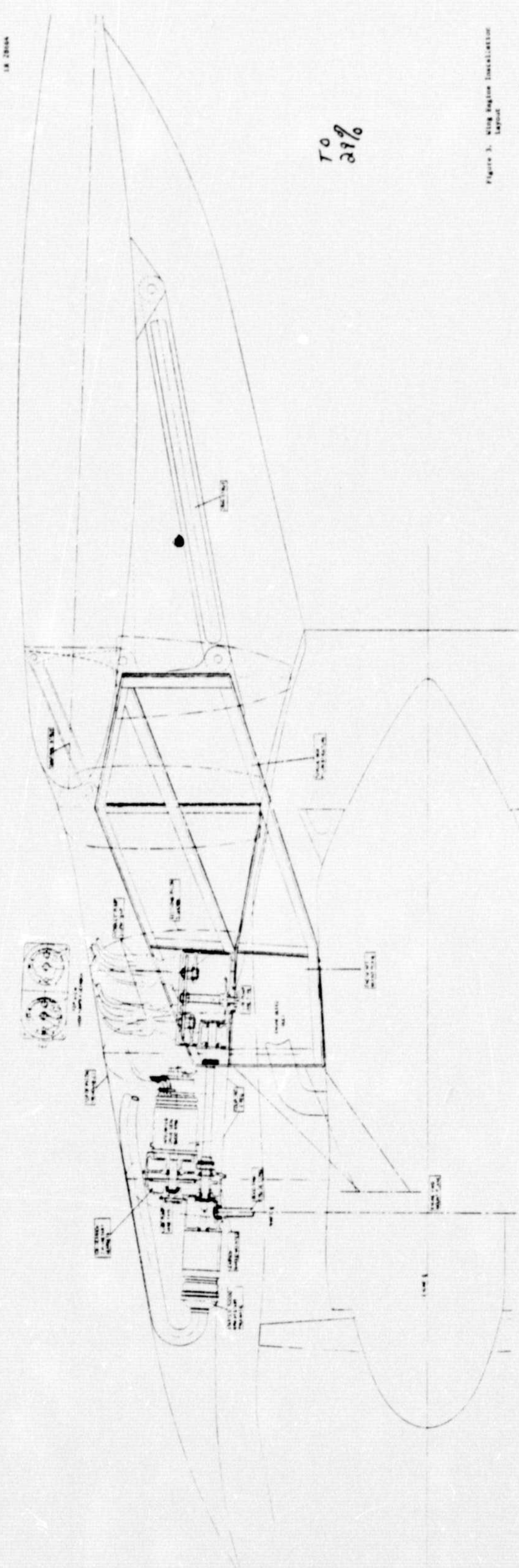


Figure 3. Wing Engine Installation Layout

ORIGINAL PAGE IS
OF POOR QUALITY

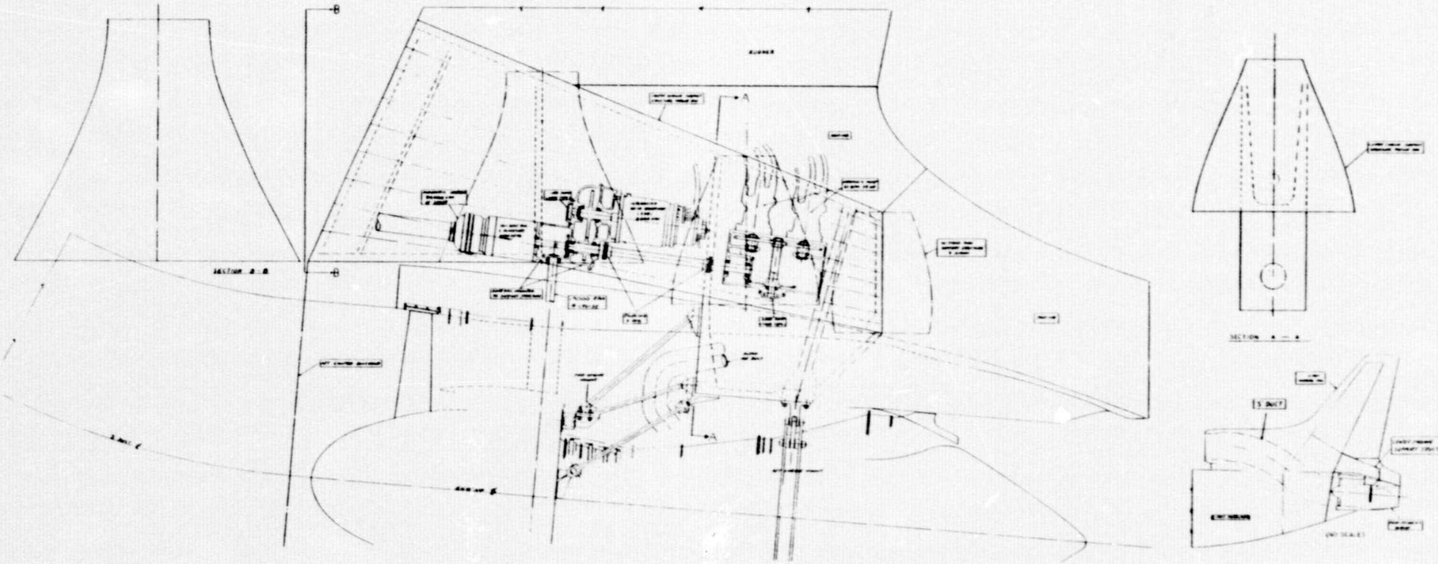


Figure 4. Center Engine Installation Layout

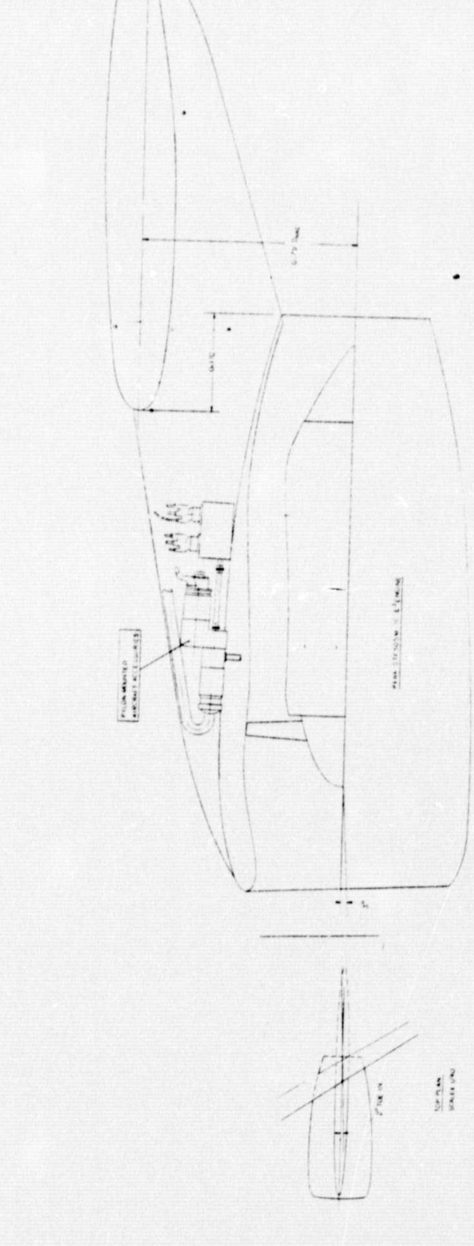


Figure 5. Wing Engine Location

1-15

ORIGINAL PAGE IS
OF POOR QUALITY

SECTION 2

STUDY EFFORT

The study effort by Lockheed in support of Pratt and Whitney's Energy Efficient Engine Component Development and Integration Program consisted of an evaluation of integrating the E^3 propulsion system with the domestic and intercontinental aircraft, as envisioned for the 1990's time frame. The evaluation included first establishing aircraft mission and design definitions and then incorporating the advanced technology engine into the aircraft configurations for comparison with the reference aircraft (JT9D-7A engine).

2.1 MISSION AND DESIGN DEFINITION

Mission and design definitions, along with applicable advanced technology features, were established for both the domestic and intercontinental aircraft during the previous study effort (Lockheed Report LR 28351). On initiation of this effort, those definitions were reviewed, and updated where applicable, for the purpose of establishing reference (baseline) configurations and performance characteristics for comparison of those aircraft with the E^3 engine. Definition of the domestic and intercontinental aircraft is included in Table 3.

2.2 PROPULSION SYSTEM — AIRCRAFT INTEGRATION

2.2.1 STF 505M-7C Engine Evaluation

Performance, weight, and pertinent installation data for an advanced technology energy efficient engine (identified as STF505M-7C) was supplied by Pratt and Whitney for incorporation into the reference aircraft. Both the domestic and intercontinental aircraft were previously optimized (for minimum fuel usage and DOC) using the Pratt and Whitney STF505M-7 Engine. Since the STF505M-7C represented only a slight variation, previously established

TABLE 3. DESIGN AND TECHNOLOGY FEATURES-1990'S TRANSPORT AIRCRAFT

	Domestic	Intercont.
Aircraft Type	Wide body trijet 235 in. fuse. dia. 9 abreast seating	Wide body quadjet 235 in. fuse dia. 9 abreast seating
No. Engines and Location	2-wing mounted 1-center mounted	4-wing mounted
Payload Capacity (lb)	100,000 (500 pax)	100,000 (500 pax)
TOGW Class (lb)	500,000	750,000
Engine Thrust (lb)	45,000	46,000
Mission Characteristics		
Design Range (n.mi.)	3,000	6,500
Typical Range (n.mi.)	1,400	3,000
Typ. Range L.F.	0.55	0.55
Cruise Speed	M0.8	M0.8
Cruise Alt. (ft)	35,000	35,000
TOFL (ft)	7,000	10,000
App. Speed (kt)	135	135
Advanced Technology		
Supercrit. Wing	~3% reduction of wing wt - increased thickness of airfoil • AR = 10 • t/c = 13% • Sweep = 30°	~3% reduction of wing wt - increased thickness of airfoil • AR = 10 • t/c = 13% • Sweep = 30°
Active Controls • Load Relief • Relaxed Stability	-5.5% wing wt. -1% body wt. -28% tail size	-5.5% wing wt. -1% body wt. -28% tail size
Advanced Composites • Primary Struct. • Secondary Struct.	-8.7% M.E.W.	-9.2% M.E.W.

design parameters were retained and aircraft performance evaluated using the revised data for the STF505M-7C Engine. Design and performance characteristics are shown in Table 2 and detailed tabulations of aircraft design and performance characteristics are included as Appendix A to this report.

Performance evaluation of the domestic and intercontinental aircraft with the STF505M-7C engine was accomplished using the Lockheed Parametric Analysis (ASSET) Program, Figure 6. The ASSET Analysis Program is a Lockheed proprietary synthesis model to parametrically size and determine the weight, performance, and cost of aircraft sized to meet given mission profiles, payload capacity, and structural criteria using a preselected optimization criteria. For this study, minimum mission fuel and direct operating cost were the optimization criteria utilized for sizing both the domestic and intercontinental aircraft. The procedure for calculating DOC, and the associated cost factors, for this study effort are included in Appendix A.

2.2.2 Sensitivity Analysis

Sensitivity factors were calculated for each aircraft, with the STF505M-7C engine, to assess the effects of changes in cruise TSFC, engine weight, and isolated nacelle drag on aircraft performance. As specified by the subcontract, the following sensitivity factors were calculated:

	±5% TSFC	±1000 lb Eng. Wt.	±2% Nac. Drag
TOGW	X	X	X
OEW	X	X	X
Engine Thrust	X	X	X
Mission Fuel			
Design	X	X	X
Typical	X	X	X

The resultant sensitivity factors are depicted in Figures 7 through 12.

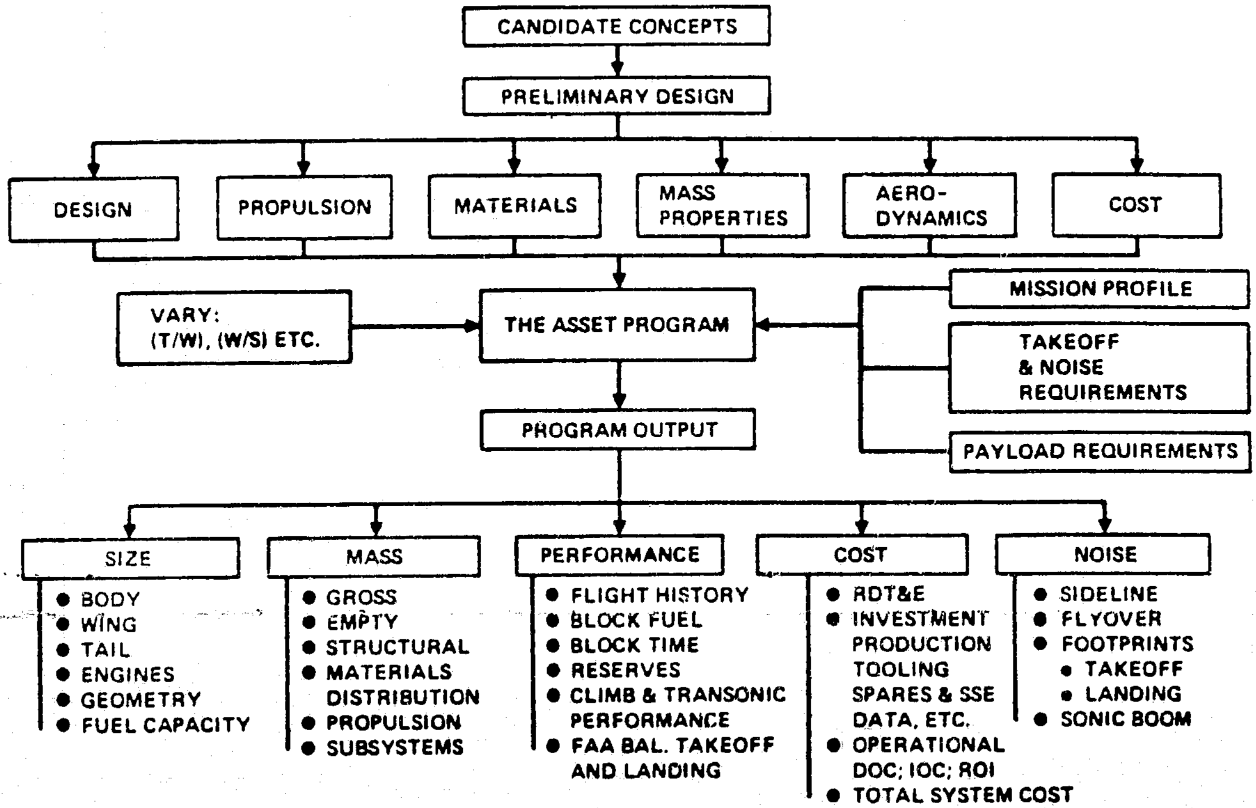


Figure 6. ASSET Synthesis Cycle

2.2.3 Airframe Noise Estimates

Estimates of airframe noise levels at the 1969 FAR 36 measuring points, along with the aircraft conditions, were made for the domestic and intercontinental aircraft with the STF505M-7C engine. These estimates are included as Table 4.

2.2.4 Engine Bleed Requirements and Power Extraction

For this study effort, engine bleed and power extraction requirements were included in the engine performance decks supplied by Pratt and Whitney. Estimates of the bleed and power extraction requirements for a 500 passenger aircraft for introduction into service in the early 1990's are:

- Bleed Air - 9 lb/sec for ECS and anti-icing
- Power Extraction - 370 hp for hydraulic pumps and generators.

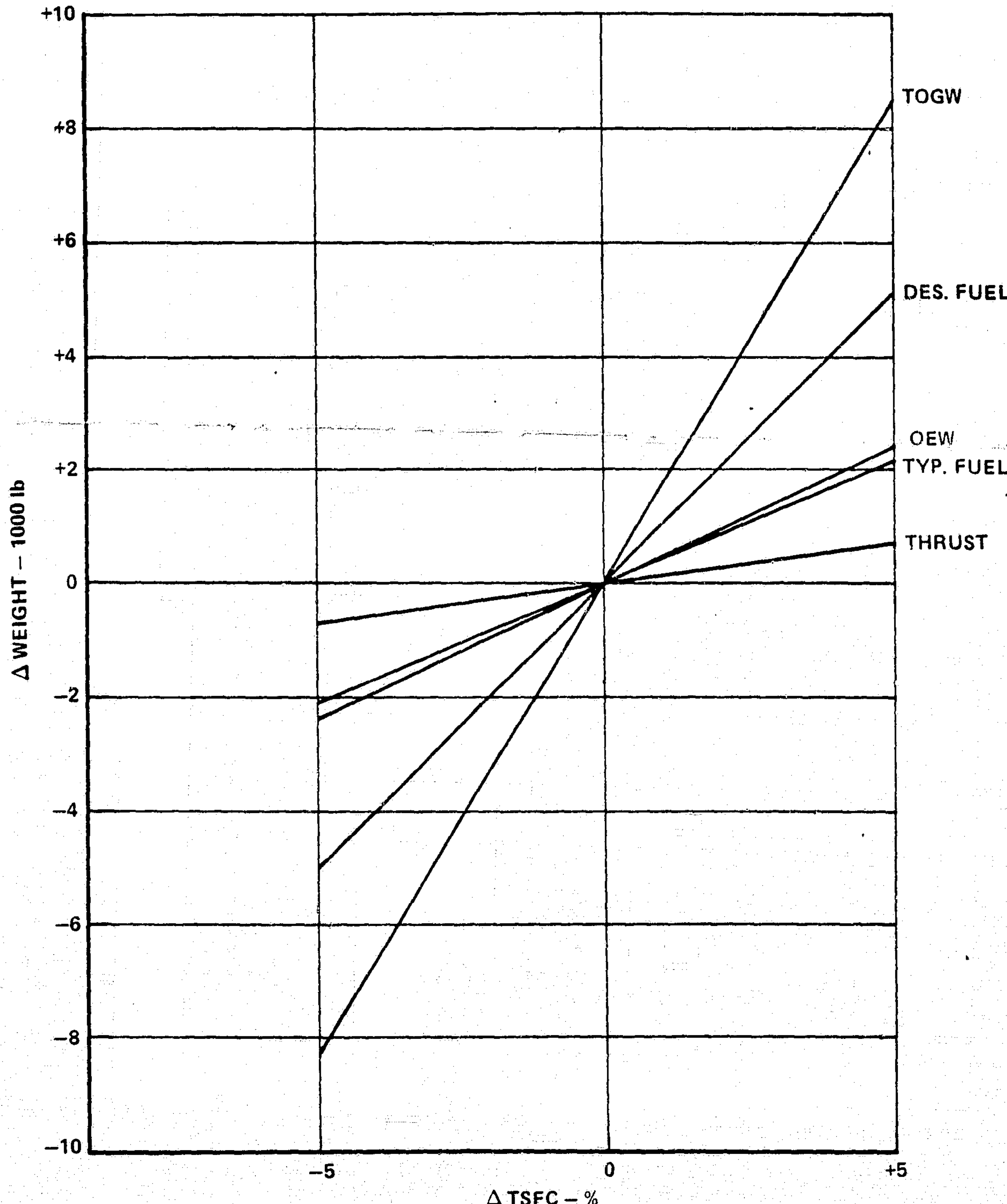


Figure 7. Domestic Aircraft Sensitivity Factors for ΔTSFC

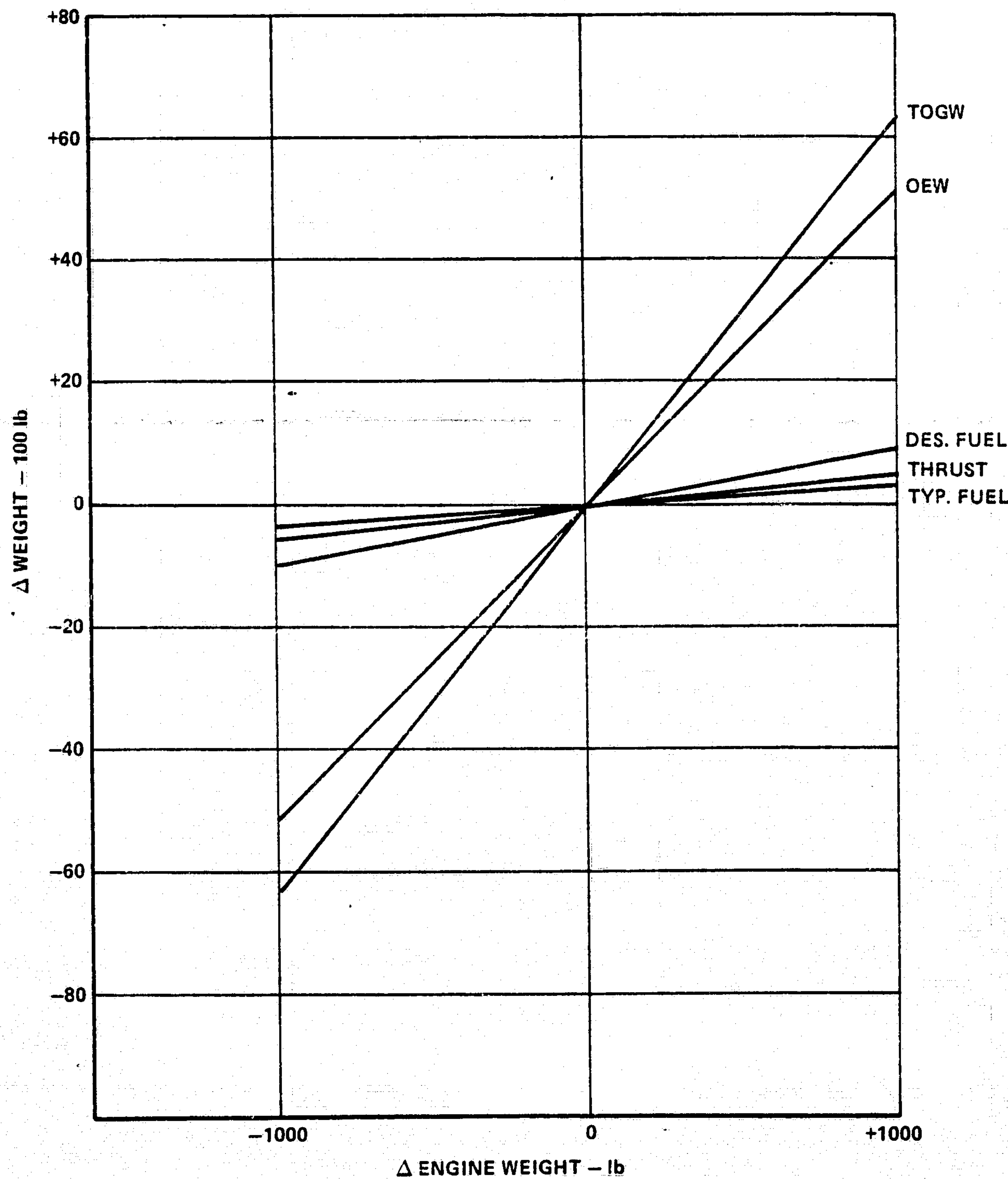


Figure 8. Domestic Aircraft Sensitivity Factors for ΔEngine Weight

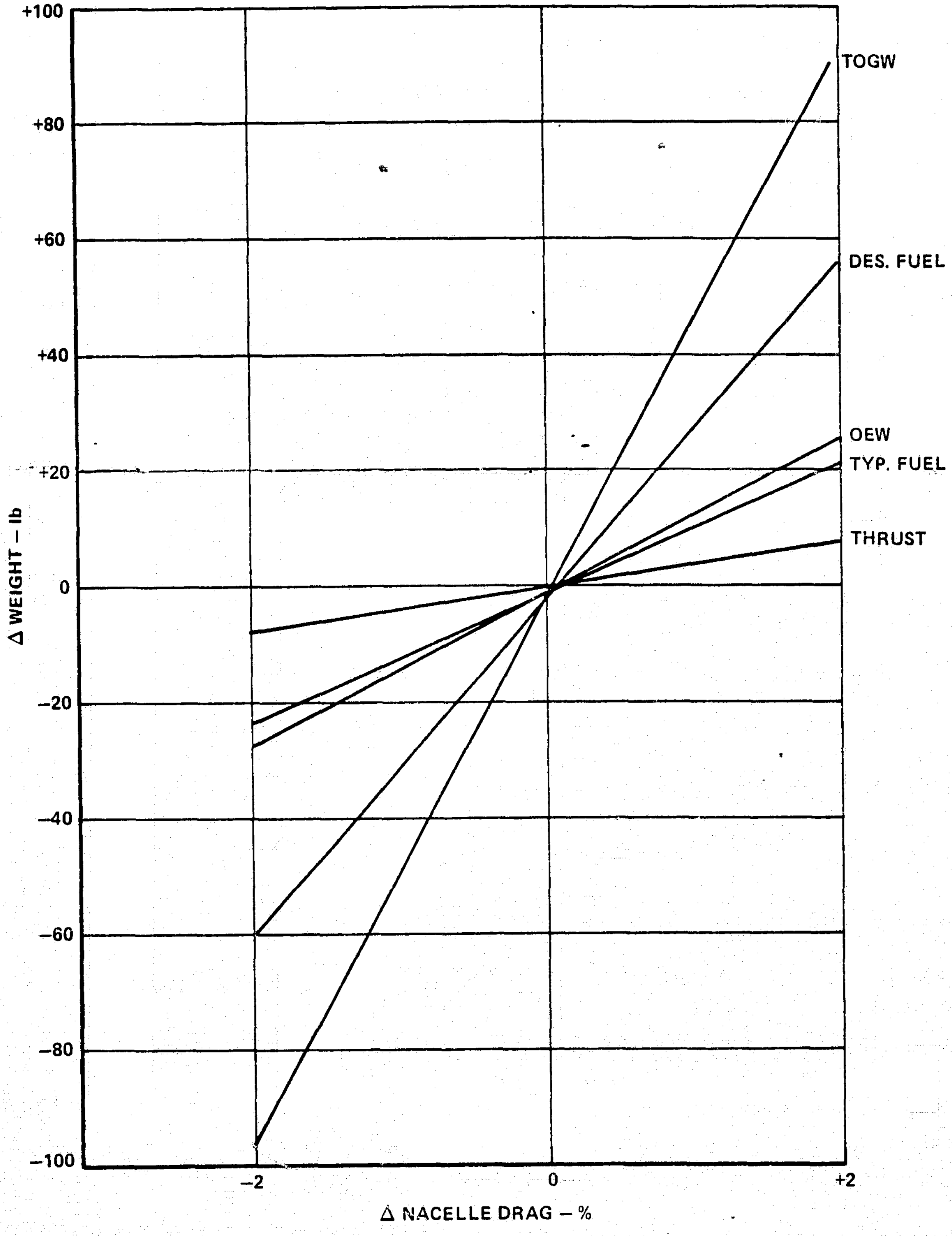


Figure 9. Domestic Aircraft Sensitivity Factors for ΔNacelle Drag

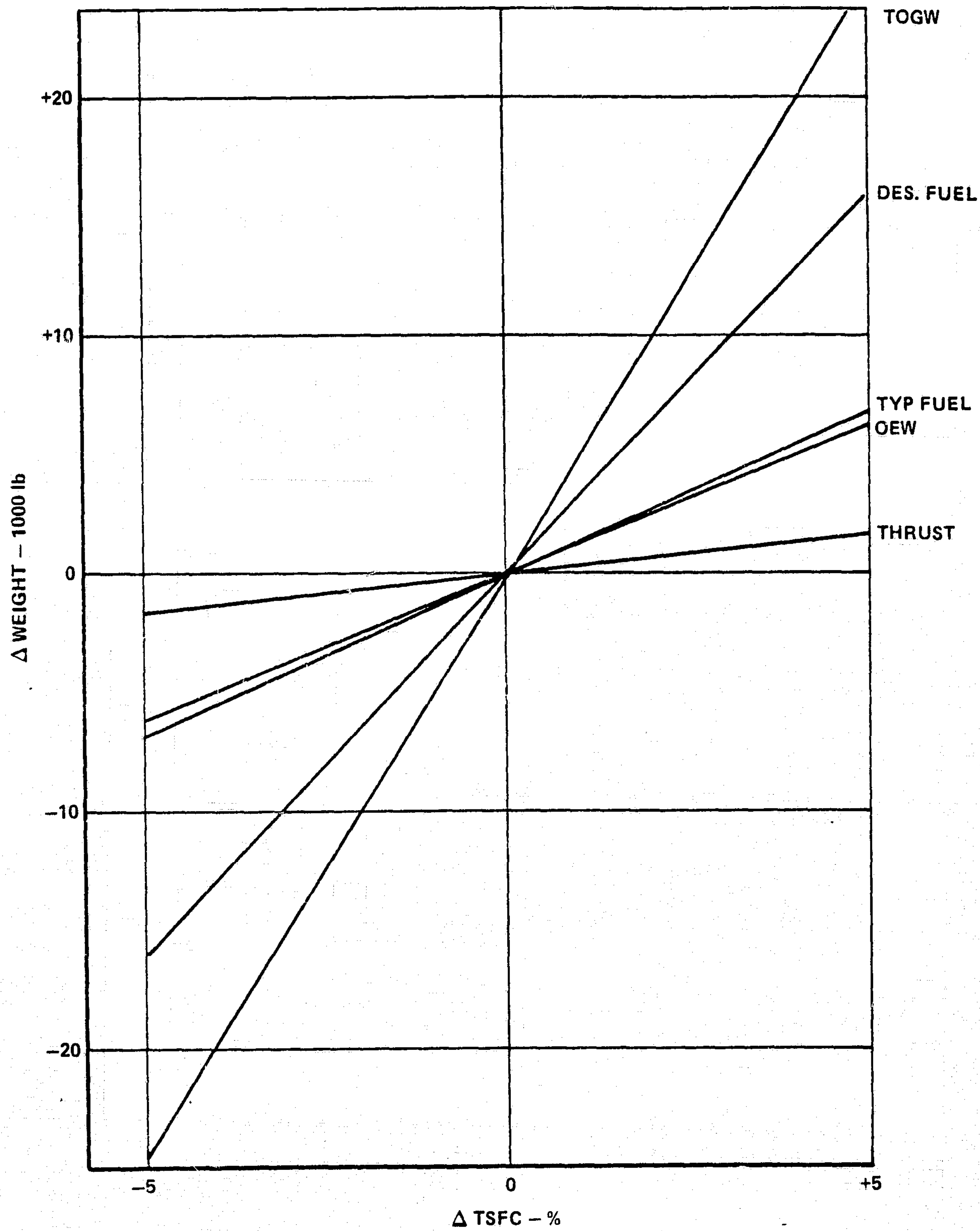


Figure 10. Intercontinental Aircraft Sensitivity Factors for ΔTSFC

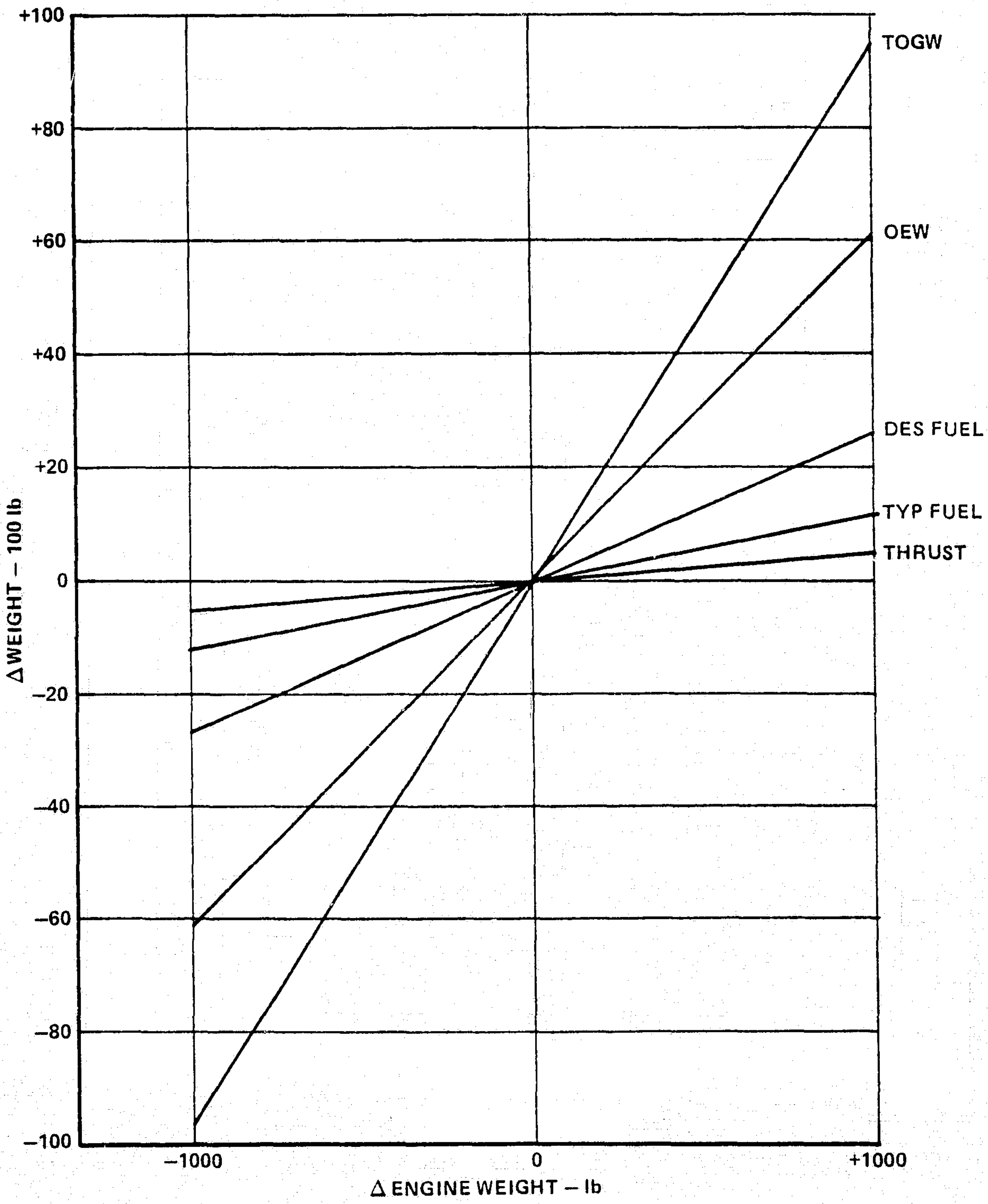


Figure 11. Intercontinental Aircraft Sensitivity Factors for ΔEngine Weight

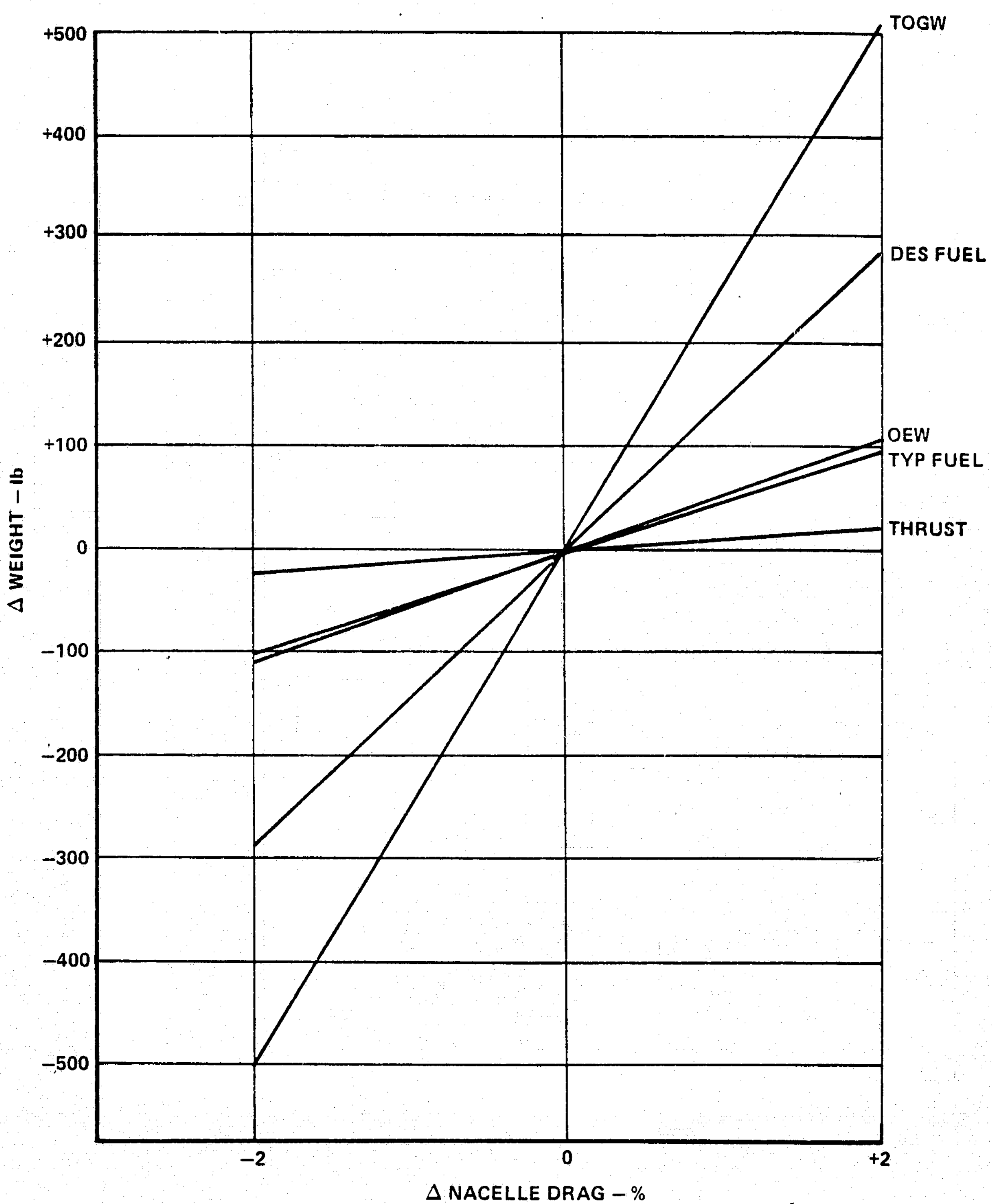


Figure 12. Intercontinental Aircraft Sensitivity Factors for ΔNacelle Drag

TABLE 4. AIRFRAME NOISE ESTIMATES (STF505M-7C ENGINE)

Condition	Domestic	Intercontinental
Approach (42° Flap, Geardown, 3° Glide)		
Landing Weight (lb)	372,000	419,600
Approach Speed (knots)	136	131.5
Altitude (ft)	394	394
Airframe Noise (EPNdB)	96.0	95.8
Takeoff (25° Flap, Gear Up)		
Climb Angle	6.1°	4.53°
TOGW (lb)	454,013	630,491
Altitude (ft)	1,710	1,101
Distance (n.mi.)	3.5	3.5
Speed (knots)	152.5	159.6
Airframe Noise (EPNdB)	84.3	89.6
Sideline Point		
Airframe Noise (EPNdB)	81.0	82.9

These estimates are based on use of current state-of-the-art accessories for the 1990's time frame. Significant savings in mission fuel are possible by using advanced secondary power systems such as large capacity generators and an all electric aircraft to minimize or eliminate engine bleed requirements. Lockheed believes such a system is feasible for aircraft introduced into service in the 1990's time frame.

2.3 ENGINE INSTALLATION

2.3.1 Nacelle Configuration

The nacelle attributes (dimensions and weight) for the STF505M-7C engine were supplied by Pratt and Whitney. The STF505M-7C engine uses a mixed flow exhaust which requires a full length cowl. As previously detailed

(Report LR 20351), use of the full length nacelle requires consideration of the following installation items:

- Potential of interference drag - particularly for wing mounted engine
- Increase in wetted area drag of nacelle
- Potential of increased nacelle weight due to full length cowl
- Access to engine hot section and to engine and airframe accessories.

2.3.2 Nacelle-Wing Interference

Figure 5 depicts installation of the STF505M-7C engine to the wing of the domestic aircraft. Placement of the engine with respect to the wing is consistent with previous Lockheed experience for elimination or minimization of interference drag. Aerodynamic assessments of this installation indicate no drag penalty imposed by wing/nacelle interference. Development testing (wind tunnel tests) and/or tailoring will be required prior to actual installation of the STF505M-7C mixed flow engine on the E^3 aircraft. For the aircraft performance analysis, zero interference drag was used, which is compatible with experience on the L-1011 commercial aircraft.

2.3.3 Accessory Location

Figures 3 and 4 depict location of aircraft accessories for both the wing and center mounted engines. Aircraft accessories are located in the pylon to provide an improved aerodynamic contour nacelle. All aircraft accessories are current state of the art with no consideration given for decreasing the size by use of advanced technologies which may be available for the 1990's time frame. Included in the design layouts is an assessment of the pylon structure, sized for strength and stiffness requirements. Shape and size of the pylon is consistent with the incorporation of aircraft accessories, pylon structure, bleed lines, bleed air heat exchanger, fuel lines, hydraulic lines, electrical harnesses, and throttle controls. This pylon layout was used for assessment of drag interference effect.

Based on the preliminary design layouts, it appears that pylon mounting of the aircraft accessories, along with the required aircraft plumbing and electrical harnesses is a feasible configuration.

During this study effort, various aircraft accessory locations were considered, as shown in Table 5, which indicates an assessment of the advantages and disadvantages of each location. Locating the aircraft accessories in the engine pylon with the engine accessories core mounted seems to be desirable particularly for minimization of nacelle drag. Attempts to pylon mount all accessories, for best nacelle aerodynamic shape, requires an increase in pylon size and probable adverse effect on interference drag.

Assessment of maintainability and reliability were also made for pylon mounted aircraft accessories. Reliability of components will be enhanced due to the improved environment (as compared to the engine core). Maintainability aspects should be similar to those with accessories mounted external to the fan case except that an additional work stand (similar to that required for the center engine on the L-1011) will be required for pylon mounted accessories. Aircraft accessories, plumbing, and shafting will incorporate the required disconnects to allow all aircraft accessories to remain in place during engine removal.

2.3.4 Access Provisions

Access to the engine core and the core mounted engine accessories will be provided by using large cowl doors (similar to those of the JT9D-7A). For the pylon mounted aircraft accessories, maintainability requirements dictate removal of the top of the pylon to provide ready access to components. Since the pylon skin is only subjected to aerodynamic loads, removal of panels for access can be accomplished with nonstructural, quick turn type fasteners.

2.3.5 Thrust Reverser

Reverse thrust is provided by a set of cascades, located in the engine fan stream, which are uncovered by a translating cowl during the reverse thrust operating mode. The required levels of reverse thrust are approximately 35 percent of the forward thrust requirement, which is consistent with the sizing criteria incorporated into the STF505M-7C engine by Pratt and Whitney. Flow directivity is required to minimize impingement on the aircraft control surfaces and to minimize reingestion into the engine. A schematic of the expected flow directivity requirements is shown in Figure 13.

TABLE 5. E^3 ACCESSORY LOCATION

Aircraft Accessories	Engine Accessories	Advantage	Disadvantage
Pylon Mount	Pylon Mount	• Best aero shape nacelle • Improved component environment • Access to engine not req. for component maint. • Utilize integral gearbox	• Large pylon • High speed shaft from engine to pylon • Possible effect on interference drag • Requires additional work stands
Pylon Mount	Cowl Mount	• Good aero shape nacelle • Improved component environment • Engine access not req. for aircraft accessories	• Large pylon • Requires added gearbox, high speed shaft, etc. • Requires additional work stands • Aircraft and engine components in separate locations
Pylon Mount	Core Mount	• Good aero shape nacelle • Improved component environment - aircraft accessories • Engine access not req. for aircraft accessories	• Large pylon • Requires added gearbox, high speed shaft, etc. • Requires access to engine hot section for maint. of engine components • Hot environment for engine components • Aircraft and engine components in separate locations
Cowl Mount	Cowl Mount	• Improved component environment • Utilize integral gearbox • Enhances accessibility to components • Small pylon	• Large nacelle • Revision to nacelle structure and thrust reverser
Core Mount	Core Mount	• Utilize integral gearbox • Small pylon • Rigid mount for all components	• Large nacelle • Hot environment for all components • Requires access to engine hot section for component maint. • Revision to nacelle structure and thrust reverser

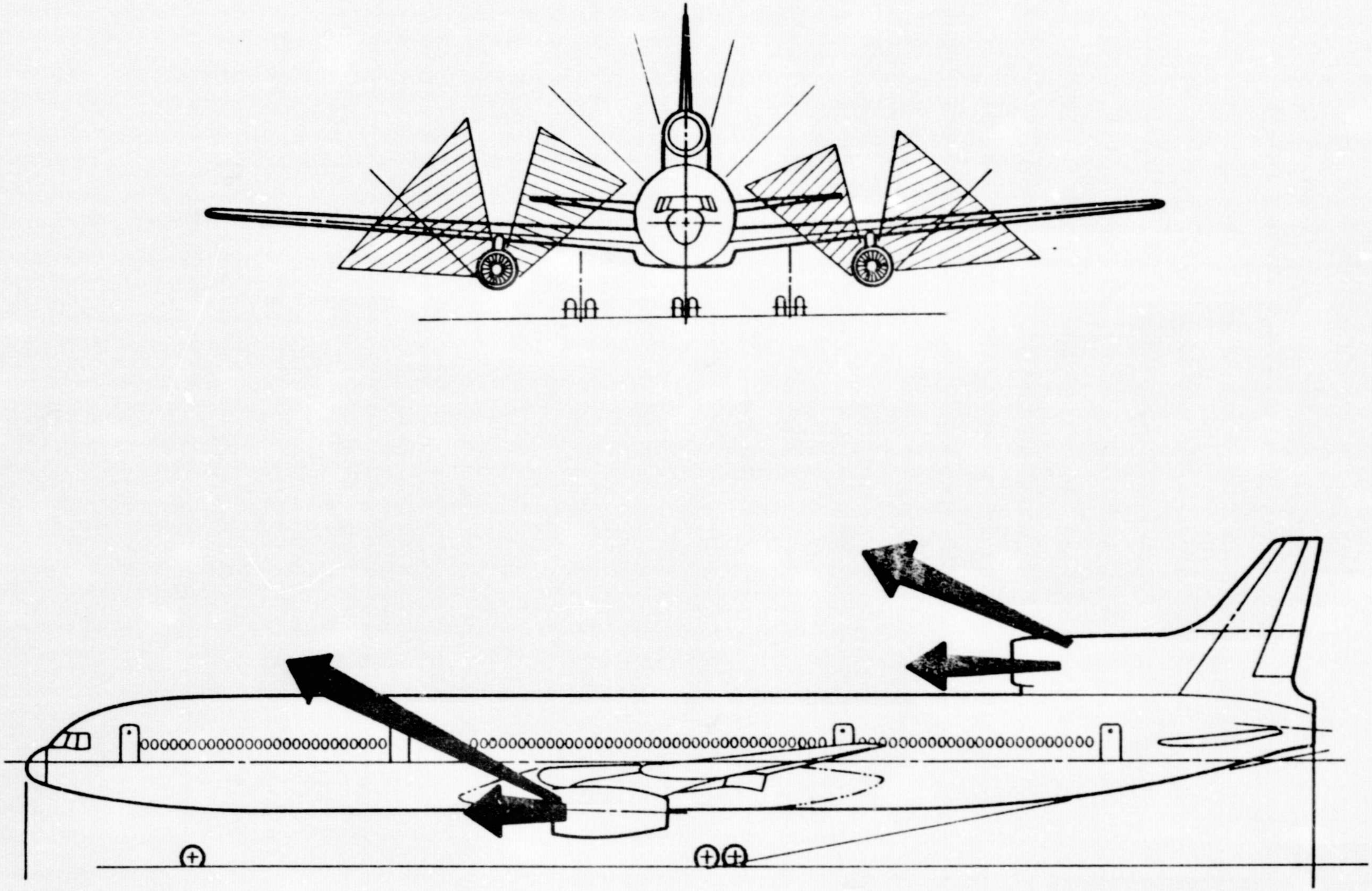


Figure 13. Thrust Reverser Flow Directivity

2.3.6 Center Engine Installation

Primary concern for installation of the mixed flow nacelle in the center engine location is the nacelle overall length and the potential effect on interference and possible scrape of the nacelle during takeoff rotation. For the domestic aircraft design, the STF505M-7C center engine was located such that ground clearance at the nacelle aft end during takeoff rotation was consistent with the current L-1011 installation. Also, the "S" duct inlet configuration of the L-1011 was retained to maintain existing L-1011 flow characteristics to the center engine. As is the case with the wing engine installation, future aerodynamic development testing (wind tunnel tests) and possible tailoring will be required to minimize interference effects. For this study effort, zero interference drag (consistent with L-1011 experience) was utilized for the center engine installation.

2.4 PERFORMANCE AND ECONOMIC COMPARISONS

The previously stated objectives for the Energy Efficient Engine Program with regards to fuel and operating cost savings are:

- Reduction in specific fuel consumption of 12 percent minimum.
- Reduction in direct operating costs of 5 percent minimum.

Figures 14 and 15 show the savings in block fuel and DOC, of the domestic and intercontinental aircraft with the STF505M-7C engine when compared to the reference aircraft (JT9D-7A engine). The results show significant savings for the STF505M-7C engine as follows:

	Domestic		Intercontinental	
	Des. Range	Typ. Range	Des. Range	Typ. Range
Block Fuel	-18.1%	-18%	-20.1%	-19.1%
DOC	- 5.9%	- 5.4%	- 9.2%	- 8.1%

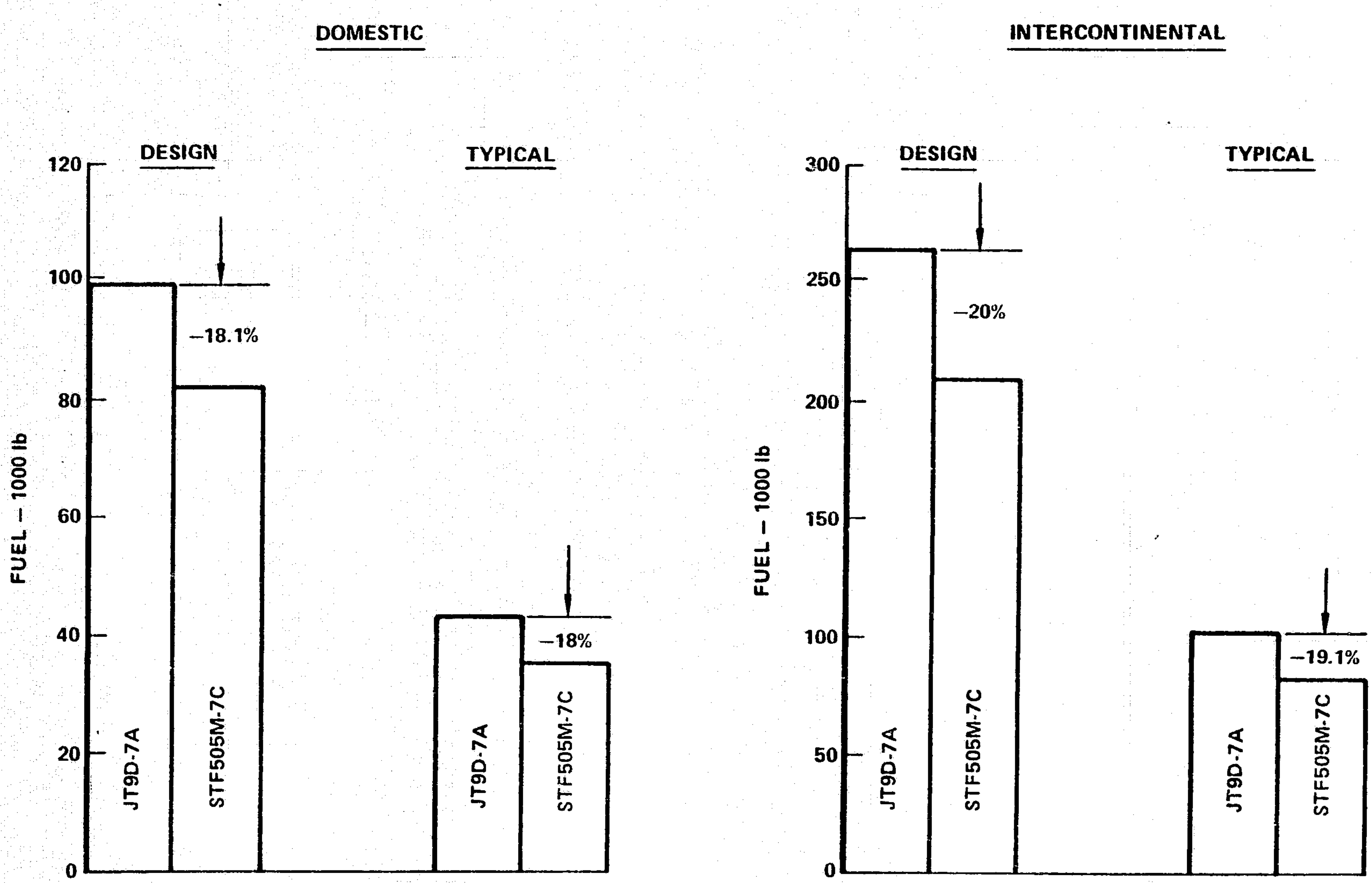


Figure 14. Block Fuel Advantage with STF505M-7C Engine

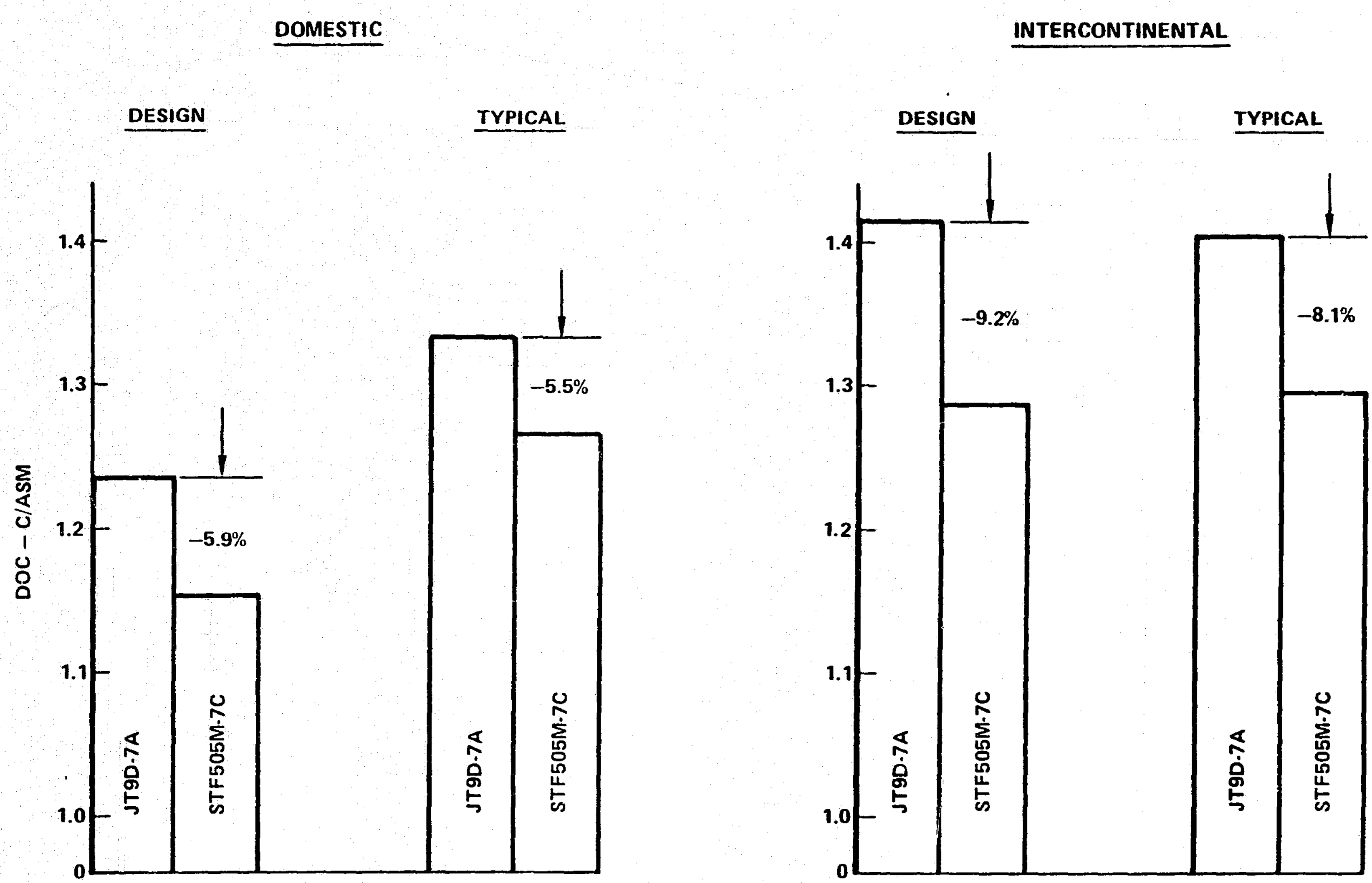


Figure 15. DOC Advantage with STF505M-7C Engine

Figure 16 depicts the advantages in aircraft size when the STF505M-7C engine is used. Incorporation of the energy efficient engine provides an aircraft design, for large payload capacity and long range capability, which is well within the capabilities of current airport facilities and also provides significant future growth capability.

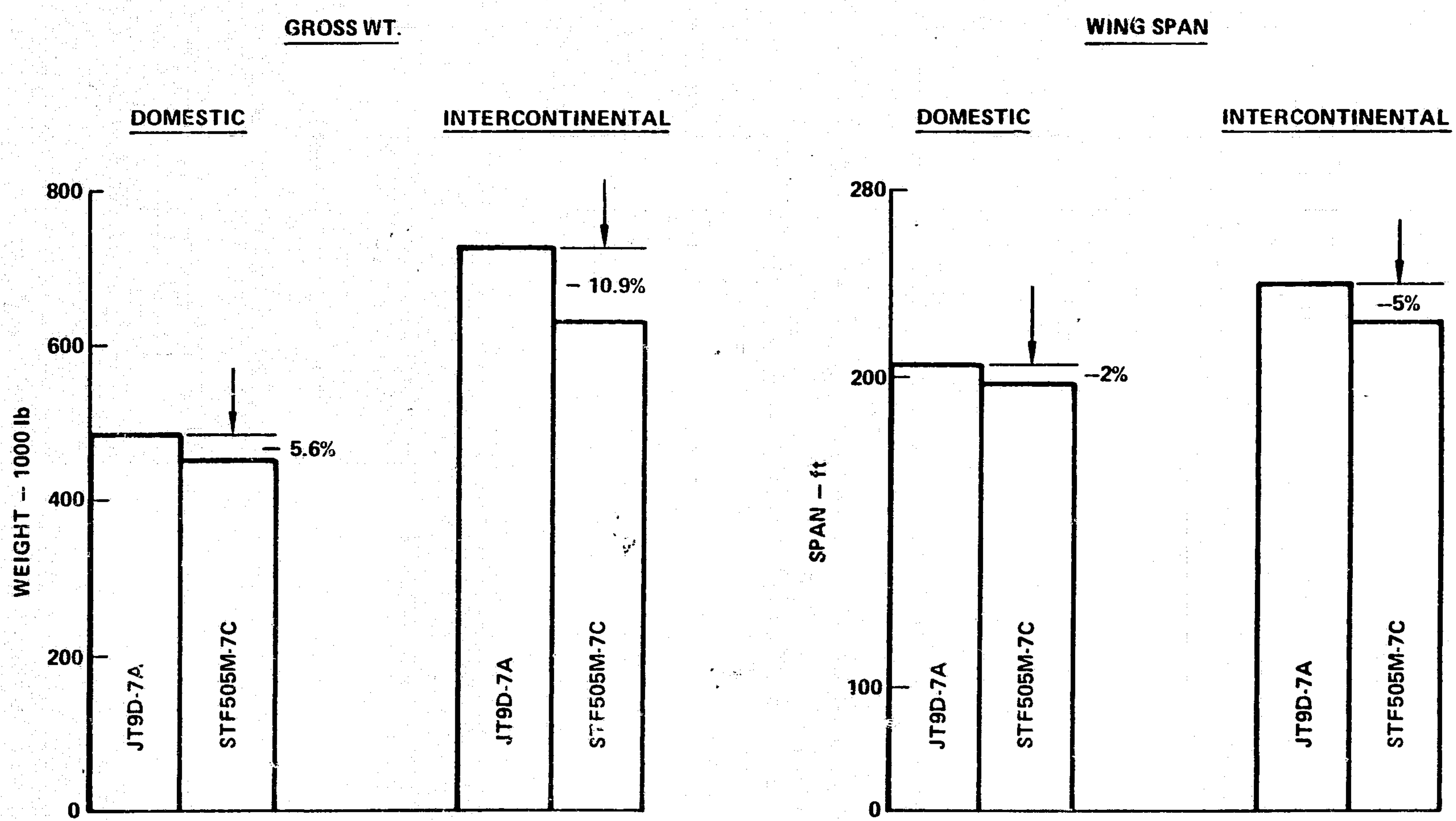


Figure 16. Size Advantage with STF505M-7C Engine

SECTION 3

CONCLUSIONS AND RECOMMENDATIONS

The results of this study, accomplished with the STF505M-7C engine design and performance characteristics provided by Pratt and Whitney, show that:

- The NASA specified goals for minimum fuel and DOC savings are exceeded with the STF505M-7C direct drive, mixed exhaust high bypass turbofan engine.

- Installation of the mixed exhaust, high bypass turbofan on both the domestic and intercontinental aircraft appears to be feasible with no penalty for interference drag.

- Pylon mounting of the aircraft accessories is an acceptable configuration and enhances the aerodynamic characteristics of the STF505M-7C nacelle.

- Incorporation of the STF505M-7C engine results in aircraft configurations, sized for long range and large payload capacity, which are compatible with existing airport facilities (field length, wing span, body length, and gross weight).

- Size of the STF505M-7C engine, as supplied by Pratt and Whitney, is compatible with the Lockheed specified mission and payload characteristics for the 1990's aircraft.

APPENDIX A

DIRECT OPERATING COST (DOC) CALCULATIONS — E^3 AIRCRAFT

The following factors and formulas were used in calculating Direct Operating Cost (DOC) for the E^3 aircraft. All costs are in January 1976 dollars:

	3-Engine Domestic	4-Engine Intercont.
Crew Cost	$397/blk-hr	$476/blk-hr
Fuel Cost		
Cost of Fuel	$0.308/gal	$0.387/gal
Cost of Oil	$1.00/lb	$1.00/lb
Non Revenue Flying Factor	1.0123	1.0123
Salvage Value (SV)	4%	4%
Life	16 YRS	16 YRS
Insurance Rate (IR)	0.304%	0.304%
Labor Rate (LR)	$9.00/hr	$9.00/hr
Maint. Burden Factor (MBF)	2.23	2.23
Airframe Labor/Cycle (AFLC)	0.52	0.52
Airframe Labor/Flt-Hr (AFLH)	0.52	0.52
Airframe Matl/Cycle (AFMC)	0.68	0.68
Airframe Matl/Flt-Hr (AFMH)	0.68	0.68
Engine Labor/Cycle (ELC)	0.62	0.62
Engine Labor/Flt-Hr (ELH)	0.62	0.62
Engine Matl/Cycle (ELC)	1.31	1.31
Engine Matl/Flt-Hr (EMH)	1.31	1.31

FORMULAS — DOC CALCULATIONS

Fuel Cost (FC)	=	(Cost Fuel x Blk Fuel/Blk Time) + (No. Engines x 0.135 Cost of Oil) x (Non Revenue Flying Factor)
Unit Air Vehicle Cost (UAVC)	=	Airframe + Engine + Avionics + RDT&E/No. of Aircraft
Depreciation Cost (DC)	=	(UAVC + Spares - SV)/Life
Insurance Cost (IC)	=	(UAVC x IR)
Airframe Weight (AFW)	=	(MEW - Engine and Thrust Reverser/10^3)
Airframe Cost (AFC)	=	(UAVC - Engine and Thrust Reverser/10^6)
Thrust (T)	=	Total Max. SLS, Uninstalled - Std Day (Sum of All Engines)/10^3
Engine Price (EP)	=	Total Constant Price Including Thrust Reverser (Sum of all Engines)/10^5
No. of Engines (NENG)		
Flight Time (FT)		
AF Labor/Cycle	=	[(0.05 x AFW) + 6 - 630/(120 + AFW)] x LR x AFLC
AF Labor/Flt Hr	=	[(0.05 x AFW) + 6 - 630/(120 + AFW)] x 0.59 x FT x LP x AFLH
AF Matl/Cycle	=	6.24 x AFC x AFMC
AF Matl/Flt-Hr	=	3.08 x AFC x FT x AFMH
Eng. Labor/Cycle	=	(0.3 x NENG + 0.03 x T) x LR x ELC
Eng. Labor/Flt-Hr	=	(0.6 x NENG + 0.027 x T) x LR x FT x ELH

FORMULAS — DOC CALCULATIONS (Continued)

Eng. Matl/Cycle	=	2 x NENG x EP x EMC
Eng. Matl/Flt-Hr	=	2.5 x NENG x EP x FT x EML
Maintenance Burden	=	(Total AF Labor + Total Eng Labor) x MBF
Total Maintenance	=	Sum of all Airframe and Engine Maintenance + Burden

SUMMARY ID NO. 1 ASSET PARAMETRIC ANALYSIS MAY 31 1978

AIRCRAFT MODEL —CL 1332-17
I.O.C. DATE —1985
DESIGN SPEED —SUBSONIC

ENGINE I.D. -- 416000
SLS SCALE 1.0 = 40850
NUMBER OF ENGINES = 3.

WING QUARTER CHORD SWEEP = 30.00 DEG
WING TAPER RATIO = 0.300

ORIGINAL PAGE IS OF POOR QUALITY

1 W/S	114.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 T/W	0.255	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 AR	10.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 T/C	13.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 SWEEP	30.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 FPR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 OPR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 TIT	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9 NPR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10 AUG T	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11 RADIUS N. MI	3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 GROSS WEIGHT	454014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 FUEL WEIGHT	93041	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 OP. WT. EMPTY	255973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 ZERO FUEL WT.	355973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 THRUST/ENGINE	38591	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 ENGINE SCALE	0.945	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 WING AREA	3955.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19 WING SPAN	198.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 H. TAIL AREA	908.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21 V. TAIL AREA	566.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22 ENG. LENGTH	10.24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23 ENG. DIAMETER	7.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24 BODY LENGTH	228.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25 WING FUEL LIMIT	3.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA																
26 RDTE - BIL.	2.452	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27 FLYAWAY - MIL.	50.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 INVESTMNT-BIL.	1.140	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 DOC - C/SM	1.155	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30 IOC - C/SM	1.028	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31 ROI A.T. - O/O	35.85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MISSION PARAMETERS																
32 MISN V1(1,1)	37000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 MISN V2(1,1)	61862	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 MISN V1(2,1)	41000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 MISN V2(2,1)	35513	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTRAINT OUTPUT																
36 TAKEOFF DST(1)	6976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 CLIMB GRAD(1)	0.1141	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38 TAKEOFF DST(2)	6595	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39 CLIMB GRAD(2)	0.0419	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40 CTOL LNDG D(1)	5116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 AP SPEED-KT(1)	136.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42 SEP(1) - FPS	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 SEP(2) - FPS	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ORIGINAL PAGE IS OF POOR QUALITY

P&WA E^3 DOMESTIC (STF505M-7C)

276

A-5

E**3 AIRCRAFT / 500 PASS / 3000 N MI / M = .80 MISS

T/C	AR	W/S	T/W
13.00	10.00	114.6	0.255

WEIGHT STATEMENT

	WEIGHT(POUNDS)		
GROSS WEIGHT	(454013.)		
FUEL AVAILABLE	98041.		
EXTERNAL	0.		
INTERNAL	98036.		
ZERO FUEL WEIGHT	355973.		
PAYLOAD	100000.		
PASSENGERS	85000.		
BAGGAGE	0.		
CARGO	15000.		
STORES	0.		
OPERATIONAL EMPTY WEIGHT	255973.		
OPERATIONAL ITEMS	16186.		
STANDARD ITEMS	5407.		
EMPTY WEIGHT	234379.		
STRUCTURE	135447.		
WING	48166.		
ROTOR	0.		
TAIL	5755.		
BODY	56544.		
ALIGHTING GEAR	18820.		
ENGINE SECTION AND NACELLE	6162.		
PROPULSION	29263.		
CRUISE ENGINES	22659.		
LIFT ENGINES	0.		
THRUST REVERSER	4408.		
EXHAUST SYSTEM	0.		
ENGINE CONTROL	197.		
STARTING SYSTEM	532.		
PROPELLERS	0.		
LUBRICATING SYSTEM	0.		
FUEL SYSTEM	1467.		
DRIVE SYSTEM (POWER TRANS)	0.		
SYSTEMS	69670.		
FLIGHT CONTROLS	4416.		
AUXILIARY POWER PLANT	1116.		
INSTRUMENTS	925.		
HYDRAULIC AND PNEUMATIC	2679.		
ELECTRICAL	5953.		
AVIONICS	2200.		
ARMAMENT	0.		
FURNISHINGS AND EQUIPMENT	44293.		
AIR CONDITIONING	7682.		
ANTI-ICING	406.		
PHOTOGRAPHIC	0.		
LOAD AND HANDLING	0.		

WEIGHT FRACTION	(PERCENT)
FUEL	21.59
PAYLOAD	22.03
OPERATIONAL ITEMS	4.76
STRUCTURE	29.83
PROPULSION	6.45
SYSTEMS	15.35
TOTAL	(100.)

P&WA E^3 DOMESTIC
(STF505M-7C)

LR28664

L-93 AIRCRAFT / 500 PASS / 3000 N MI / M = .80 MISS

T/C	AR	W/S	T/W
13.00	10.00	114.8	0.255

C O N F I G U R A T I O N   G E O M E T R Y

BASIC WING--	AREA(SQ FT)	SPAN(FT)	TAPER RATIO	C/4 SWEEP	L.E. SWEEP	MAC(FT)	
	3954.8	198.67	0.300	30.000	32.260	21.81	
WING PANELS--	**AREA(SQ FT)**	**EXP. AREA**	**AVG T/C**	**L.E. SWEEP**	**SFLF(SQ FT)**	**REF L(FT)**	
	2528.2	1786.7	13.00	32.260	0.0	29.31	
	1814.6	1814.6	13.00	32.260	0.0	16.35	
TOTAL WING--	**AREA(SQ FT)**	**EFF AR**	**AVG T/C**	**CR(FT)**	**CT(FT)**	**MAC(FT)**	**L(FT)**
	4342.8	9.11	13.00	40.06	9.17	25.36	71.94
FUSELAGE--	**LENGTH(FT)**	**S WET(SQ FT)**	**BWW(FT)**	**EQUIV D(FT)**	**SPI(SQ FT)**		
	228.33	12604.5	19.58	19.58	300.95		
	HW(FT)	**BH(FT)**	**SBW(SQ FT)**				
	19.58	19.58	11599.00				
HORZ. TAIL 1--	**SHT1(SQ FT)**	**SHX1(SQ FT)**	**REF L1(FT)**	**L HT1(FT)**	**HT1 VOL COEF**		
	900.74	586.29	13.24	87.19	0.9186		
HORZ. TAIL 2--	**SHT2(SQ FT)**	**SHX2(SQ FT)**	**REF L2(FT)**	**L HT2(FT)**	**HT2 VOL COEF**		
	0.0	0.0	0.0	228.33	0.0		
VERT. TAIL 1--	**SVT1(SQ FT)**	**SVX1(SQ FT)**	**REF L1(FT)**	**L VT1(FT)**	**VT1 VOL COEF**		
	565.97	565.97	20.63	91.76	0.0660		
VERT. TAIL 2--	**SVT2(SQ FT)**	**SVX2(SQ FT)**	**REF L2(FT)**	**L VT2(FT)**	**VT2 VOL COEF**		
	0.0	0.0	0.0	228.33	0.0		
PROPULSION--	**ENG L(FT)**	**ENG D(FT)**	**POD L(FT)**	**POD D(FT)**	**POD S WET**	**NO. PODS**	**INLET L(FT)**
	10.24	7.03	21.19	8.23	1095.03	2.	29.23
FUEL TANKS--	**WING(CU FT)**	**BOX(CU FT)**	**FUS(CU FT)**				
	4561.10	1320.93	9999.00				
WETTED VOLUMES--	**BODY**	**WING**	**TAILS**	**PODS**	**PYLONS**	**PONTOONS**	**TOTAL**
	53236.40	5331.89	1050.19	2251.84	0.0	0.0	61870.31

P&WA E[3] DOMESTIC
(STF505M-7C)

DRAG COEFFICIENTS--NO EXTERNAL STORES

ALTITUDE = 0. FEET

LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
MACH NO.							
0.200	0.01836	0.01808	0.01873	0.02042	0.02320	0.02684	0.03193
0.400	0.01660	0.01631	0.01696	0.01865	0.02143	0.02508	0.03016
0.750	0.01530	0.01501	0.01566	0.01732	0.02003	0.02362	0.02848
0.800	0.01602	0.01563	0.01617	0.01766	0.02004	0.02329	0.02810
0.820	0.01694	0.01612	0.01648	0.01801	0.02082	0.02518	0.03286
0.850	0.01943	0.01732	0.01722	0.01915	0.02365	0.03234	0.04848
0.900	0.02653	0.02214	0.02117	0.02420	0.03365	0.05275	0.08674

ALTITUDE = 10000. FEET

LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
MACH NO.							
0.200	0.01906	0.01878	0.01942	0.02112	0.02389	0.02754	0.03263
0.400	0.01720	0.01691	0.01756	0.01926	0.02203	0.02568	0.03076
0.750	0.01581	0.01552	0.01617	0.01784	0.02055	0.02414	0.02899
0.800	0.01653	0.01614	0.01668	0.01817	0.02056	0.02380	0.02861
0.820	0.01745	0.01663	0.01699	0.01852	0.02133	0.02568	0.03337
0.850	0.01993	0.01782	0.01772	0.01965	0.02415	0.03285	0.04896
0.900	0.02703	0.02263	0.02166	0.02470	0.03415	0.05324	0.08724

ALTITUDE = 20000. FEET

LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
MACH NO.							
0.200	0.01992	0.01964	0.02029	0.02198	0.02476	0.02840	0.03349
0.400	0.01794	0.01766	0.01830	0.02000	0.02278	0.02642	0.03151
0.750	0.01645	0.01616	0.01681	0.01847	0.02118	0.02477	0.02963
0.800	0.01716	0.01677	0.01731	0.01880	0.02118	0.02443	0.02924
0.820	0.01807	0.01725	0.01761	0.01914	0.02195	0.02631	0.03399
0.850	0.02055	0.01844	0.01834	0.02027	0.02477	0.03346	0.04960
0.900	0.02763	0.02324	0.02227	0.02530	0.03475	0.05385	0.08784

ALTITUDE = 30000. FEET

LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
MACH NO.							
0.200	0.02095	0.02067	0.02131	0.02301	0.02579	0.02943	0.03452
0.400	0.01882	0.01854	0.01918	0.02088	0.02366	0.02730	0.03239
0.750	0.01720	0.01691	0.01756	0.01922	0.02193	0.02552	0.03038
0.800	0.01791	0.01751	0.01805	0.01954	0.02193	0.02518	0.02999
0.820	0.01881	0.01799	0.01836	0.01988	0.02269	0.02705	0.03473
0.850	0.02128	0.01917	0.01907	0.02100	0.02550	0.03420	0.05033
0.900	0.02835	0.02396	0.02299	0.02603	0.03547	0.05457	0.08856

ALTITUDE = 40000. FEET

LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
MACH NO.							
0.200	0.02215	0.02186	0.02251	0.02420	0.02698	0.03063	0.03571
0.400	0.01984	0.01956	0.02021	0.02190	0.02468	0.02832	0.03341
0.750	0.01807	0.01778	0.01843	0.02009	0.02280	0.02639	0.03125
0.800	0.01877	0.01838	0.01892	0.02041	0.02279	0.02604	0.03085
0.820	0.01967	0.01885	0.01921	0.02074	0.02355	0.02790	0.03559
0.850	0.02213	0.02002	0.01992	0.02185	0.02635	0.03504	0.05118
0.900	0.02919	0.02460	0.02383	0.02686	0.03631	0.05541	0.08940

P&WA E^3 DOMESTIC
(STF505M-7C)

DRAG COEFFICIENTS--NO EXTERNAL STORES

ALTITUDE = 50000. FEET

LIFT COEF.= / MACH NO.	0.0	0.10	0.20	0.30	0.40	0.50	0.60
0.200	0.02376	0.02347	0.02412	0.02582	0.02659	0.03224	0.03732
0.400	0.02121	0.02043	0.02158	0.02327	0.02605	0.02969	0.03478
0.750	0.01923	0.01894	0.01959	0.02125	0.02396	0.02755	0.03241
0.800	0.01992	0.01953	0.02067	0.02156	0.02395	0.02719	0.03200
0.820	0.02081	0.01999	0.02056	0.02188	0.02469	0.02905	0.03674
0.850	0.02327	0.02115	0.02105	0.02298	0.02748	0.03618	0.05231
0.900	0.03030	0.02591	0.02494	0.02797	0.03742	0.05652	0.09051

ALTITUDE = 60000. FEET

LIFT COEF.= / MACH NO.	0.0	0.10	0.20	0.30	0.40	0.50	0.60
0.200	0.02570	0.02542	0.02606	0.02776	0.03053	0.03418	0.03927
0.400	0.02286	0.02258	0.02323	0.02492	0.02770	0.03134	0.03643
0.750	0.02062	0.02033	0.02048	0.02265	0.02535	0.02895	0.03380
0.800	0.02131	0.02091	0.02145	0.02294	0.02533	0.02858	0.03339
0.820	0.02218	0.02137	0.02173	0.02326	0.02606	0.03042	0.03811
0.850	0.02462	0.02251	0.02241	0.02434	0.02684	0.03754	0.05367
0.900	0.03164	0.02725	0.02628	0.02931	0.03876	0.05786	0.09185

FM DES = 0.8035 CL DES = 0.5566

P&WA E^3 DOMESTIC
(STF505M-7C)

M I S S I O N   S U M M A R Y

5**3 AIRCRAFT / 500 PASS / 3000 N MI / M = .80 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)	MAX OVER PRES
TAKEOFF POWER 1	0.	0.0	454013.	0.	0.	0.	0.	0.0	0.0	0.	416401.	0.	0.0	0.317	0.0
POWER 2	0.	0.0	454013.	825.	825.	0.	0.	1.3	1.3	0.	416401.	0.	0.0	0.317	0.0
CLIMB	0.	0.378	453188.	7129.	7954.	90.	90.	16.1	17.5	0.	416201.	0.	19.87	0.507	0.0
ACCEL	30000.	0.692	446059.	659.	8613.	14.	104.	2.0	19.5	0.	416201.	0.	19.15	0.559	0.0
CLIMB	30000.	0.800	445400.	2053.	10666.	52.	156.	6.7	26.2	0.	416201.	0.	19.24	0.569	0.0
CRUISE	37000.	0.800	443347.	66885.	77551.	2594.	2750.	339.1	365.3	0.	-416101.	0.	19.65	0.569	0.0
DESCENT	41000.	0.800	376462.	128.	77679.	29.	2779.	3.8	369.1	0.	416301.	0.	18.55	-1.499	0.0
DECEL	30000.	0.863	376334.	29.	77708.	6.	2785.	0.9	370.0	0.	416301.	0.	17.99	-0.656	0.0
DESCENT	30000.	0.692	376305.	641.	78349.	89.	2875.	16.8	386.8	0.	416301.	0.	19.31	-0.617	0.0
CRUISE	41000.	0.800	375664.	2980.	81329.	125.	3000.	16.4	403.2	0.	-416101.	0.	19.53	0.570	0.0
LOITER	1500.	0.335	372684.	533.	81862.	0.	3000.	3.0	406.2	0.	-416101.	0.	19.51	0.560	0.0
RESET	0.	0.0	372151.	0.	81862.	-3000.	0.	0.0	406.2	0.	0.	0.	0.0	0.0	0.0
RESET	0.	0.0	372151.	0.	81862.	0.	0.	0.0	406.2	0.	0.	0.	0.0	0.0	0.0
CLIMB	0.	0.378	372151.	1620.	83482.	13.	13.	2.8	409.0	0.	416201.	0.	19.21	0.479	0.0
ACCEL	10000.	0.456	370531.	0.	83482.	0.	13.	0.0	409.0	0.	416201.	0.	19.24	0.487	0.0
CLIMB	10000.	0.456	370531.	3609.	87091.	52.	65.	8.9	417.9	0.	416201.	0.	19.15	0.535	0.0
CRUISE	30000.	0.725	366922.	688.	87779.	25.	90.	3.5	421.4	0.	-416101.	0.	18.23	0.581	0.0
DESCENT	30000.	0.692	366234.	375.	88154.	62.	152.	10.9	432.4	0.	416301.	0.	19.12	-0.582	0.0
DECEL	10000.	0.456	365859.	0.	88154.	0.	152.	0.0	432.4	0.	416301.	0.	19.16	-0.542	0.0
DESCENT	10000.	0.456	365859.	240.	88394.	24.	177.	5.4	437.7	0.	416301.	0.	19.16	-0.674	0.0
CRUISE	30000.	0.725	365619.	632.	89026.	23.	200.	3.3	441.0	0.	-416101.	0.	18.21	0.581	0.0
CRUISE	1500.	0.378	364986.	378.	89404.	0.	200.	2.0	443.0	0.	-416101.	0.	19.42	0.604	0.0
CRUISE	30000.	0.725	364608.	6632.	96036.	0.	200.	45.0	488.0	0.	-416101.	0.	18.19	0.581	0.0

WTO = 454013.3 FUEL A= 98140.5 FUEL F= 96036.2

P&WA E^3 DOMESTIC (STF505M-7C)

A L T E R N A T E   M I S S I O N   N O . 1   S U M M A R Y

E**3 AIRCRAFT   / 55? LF   / 1400 N MI / M = .80 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)	MAX OVER PRES
TAKEOFF POWER 1	0.	0.0	370456.	0.	0.	0.	0.	0.0	0.0	0.	416401.	0.	0.0	0.317	0.0
POWER 2	0.	0.0	370456.	825.	825.	0.	0.	1.3	1.3	0.	416401.	0.	0.0	0.317	0.0
CLIMB	0.	0.375	369631.	5180.	6005.	64.	64.	11.6	13.0	0.	416201.	0.	19.12	0.506	0.0
ACCEL	30000.	0.552	364451.	447.	6452.	10.	74.	1.3	14.3	0.	416201.	0.	17.63	0.559	0.0
CLIMB	30000.	0.800	364003.	2402.	8654.	67.	141.	8.7	23.0	0.	416201.	0.	18.45	0.568	0.0
CRUISE	41000.	0.800	361601.	22873.	31527.	1009.	1150.	131.9	154.9	0.	-416101.	0.	19.43	0.572	0.0
DESCENT	42000.	0.800	338929.	150.	31676.	34.	1184.	4.4	159.4	0.	416301.	0.	18.04	-3.037	0.0
DECEL	30000.	0.800	338779.	28.	31704.	6.	1190.	0.8	160.2	0.	416301.	0.	17.08	-0.657	0.0
DESCENT	30000.	0.692	338751.	609.	32313.	85.	1275.	16.0	176.2	0.	416301.	0.	18.56	-0.617	0.0
CRUISE	43000.	0.560	338142.	2716.	35029.	125.	1400.	16.4	192.6	0.	-416101.	0.	19.39	0.573	0.0
LOITER	1500.	0.320	335426.	484.	35513.	0.	1400.	3.0	195.6	0.	-416101.	0.	19.46	0.562	0.0
RESET	0.	0.0	334942.	0.	35513.	-1400.	0.	0.0	195.6	0.	0.	0.	0.0	0.0	0.0
RESET	0.	0.0	334942.	0.	35513.	0.	0.	0.0	195.6	0.	0.	0.	0.0	0.0	0.0
CLIMB	0.	0.378	334942.	1426.	36939.	11.	11.	2.5	198.0	0.	416201.	0.	18.41	0.479	0.0
ACCEL	10000.	0.456	333516.	0.	36939.	0.	11.	0.0	198.0	0.	416201.	0.	18.48	0.487	0.0
CLIMB	10000.	0.456	333516.	3112.	40050.	45.	56.	7.7	205.7	0.	416201.	0.	18.37	0.515	0.0
CRUISE	30000.	0.730	330405.	880.	40930.	34.	90.	5.0	210.7	0.	-416101.	0.	17.99	0.581	0.0
DESCENT	30000.	0.592	329525.	356.	41286.	59.	149.	10.4	221.0	0.	416301.	0.	18.33	-0.582	0.0
DECEL	10000.	0.456	329169.	0.	41286.	0.	149.	0.0	221.0	0.	416301.	0.	18.37	-0.542	0.0
DESCENT	10000.	0.456	329169.	228.	41514.	23.	172.	5.1	226.1	0.	416301.	0.	18.37	-0.674	0.0
CRUISE	30000.	0.700	328941.	713.	42227.	28.	200.	4.0	230.1	0.	-416101.	0.	17.95	0.581	0.0
CRUISE	1500.	0.378	328228.	361.	42587.	0.	200.	2.0	232.1	0.	-416101.	0.	18.71	0.618	0.0
CRUISE	30000.	0.695	327868.	7829.	50416.	0.	200.	45.0	277.1	0.	-416101.	0.	18.01	0.580	0.0

P&WA E^3 DOMESTIC
(STF505M-7C)

ORIGINAL PAGE IS OF POOR QUALITY

COST SUMMARY

RDT AND E

	TOTAL *
DEVELOPMENT — NONRECURRING	
ENGINEERING	939.79
TOOLING	536.76
TEST ARTICLES	72.93
DATA	0.0
SYSTEMS ENG/MNGMT	0.0
CRUISE ENGINE	0.0
LIFT ENGINE	0.0
FAN	0.0
AVIONICS	0.0
OTHER SYSTEMS	0.0
FACILITIES	0.0
TOTAL AIR VEHICLE	1549.48
INTEGR LOGISTICS SUPPORT	
PLANNING	9.92
TRAINING	3.37
HANDBOOKS	18.42
SSE	4.86
TOTAL ILS	36.56
TOTAL DVLPMNT-NONREC	1586.04
DEVELOPMENT - RECUR(PROTOTYPES)	
AIR VEHICLE	696.26
SPARES	179.40
TOTAL DVLPMNT-RECUR	875.66
GOVMNT DVLPMNT COST	0.0
TOTAL DVLPMNT COST	2461.71

PRODUCTION

	MATERIAL	LABOR	TOTAL PER PROD A/C**
STRUCTURE	4157.66	13344.82	17502.48
WING	1867.10	2730.86	4597.96
ROTOR	0.0	0.0	0.0
TAIL	185.19	423.77	608.97
BODY	1249.46	9179.36	10428.82
ALIGHTING GEAR	613.34	31.64	644.98
ENG SECT + NACELLE	242.57	979.19	1221.76
ENG SECTION	0.0	0.0	0.0
NACELLE	183.21	889.81	1073.02
AIR INDUCTION	54.36	94.38	148.74
PROPULSION	116.91	122.03	236.94
ENGINE INSTALL	0.0	29.57	29.57
THRUST REVERSER	0.0	5.75	5.75
EXHAUST SYSTEM	0.0	0.0	0.0
ENGINE CONTROLS	3.39	5.43	8.82
STARTING SYSTEM	53.32	10.05	63.36
PROPELLER INSTALL	0.0	0.0	0.0
LUBRICATING SYSTEM	0.0	0.0	0.0
FUEL SYSTEM	60.20	71.24	131.44
DRIVE SYS(PWR TRN)	0.0	0.0	0.0
SYSTEMS	2733.71	7563.46	10297.17
FLIGHT CONTROLS	479.15	361.13	840.28
AUX POWER PLANT	175.23	22.78	148.01
INSTRUMENTS	66.61	64.95	131.56
HYDRAULIC + PNEUM	133.21	361.05	494.26
ELECTRICAL	409.14	1165.16	1574.29
AVIONIC INSTALL	29.44	329.63	359.08
ARMAMENT	0.0	0.0	0.0
FURN AND EQUIP	1067.15	4694.40	5761.55
AIR CONDITIONING	402.50	536.03	938.53
ANTI-ICING	21.27	28.33	49.60
PHOTOGRAPHIC	0.0	0.0	0.0
LOAD AND HANDLING	0.0	0.0	0.0
SYSTEMS INTEGR	505.95	589.89	1095.84
TOTAL COST	7514.22	21620.14	29134.37
TOTAL HRS **		773.99	773.99
ENG CHANGE ORDERS			958.35
SUSTAINING ENG COST			1782.17
PROD TOOLING COST			1569.48
QUALITY ASSURANCE			2912.44
MISCELLANEOUS ***			1006.55
TOTAL AIRFRAME COST			37363.32
ENGINE COST			3910.11
AVIONICS COST			267.19
TOTAL MANUFACTURING COST			41540.62
WARRANTY			225.23
TOTAL PRODUCTION COST			41765.84

PROCUREMENT

	PER PROD A/C**
TOTAL PRODUCTION	41765.84
INTEGR LOGISTICS SUPPORT	
PLANNING	30.39
TRAINING	10.33
TRAINERS	360.68
HANDBOOKS	39.95
FACILITIES	0.0
SSE - CFE	20.88
SSE - GFE	751.07
TOTAL ILS	1213.31
INITIAL SPARES COST	5646.86
PRODUCTION DEVELOPMENT	
ENGINEERING	314.89
TOOLING	-131.60
ENGINES	0.0
TOTAL PROD DEV	183.28
TOTAL PROCUREMENT	48809.28

* - MILLIONS OF DOLLARS

** -1000 OF DOLLARS OR HOURS PER PROD A/C

*** - INCLUDES PROD DATA, SYSTEMS ENGR AND OTHER SYSTEMS

P&WA E[3] DOMESTIC
(STF505M-7C)

ORIGINAL PAGE IS OF POOR QUALITY

OPERATIONAL COSTS

DIRECT OPERATIONAL COST (DOC)	C/SM***	PERCENT
FLIGHT CREW	0.18932	16.39467
FUEL AND OIL	0.24881	21.54591
INSURANCE	0.02000	1.73171
DEPRECIATION	0.43912	38.02652
MAINTENANCE	0.25753	22.30119
TOTAL DOC	1.15477	100.000

INDIRECT OPERATIONAL COST (IOC)	C/SM***	PERCENT
SYSTEM	0.02099	2.04297
LOCAL	0.05911	5.75242
AIRCRAFT CONTROL	0.00159	0.15460
CABIN ATTENDANT	0.20980	20.41618
FOOD AND BEVERAGE	0.13482	13.11982
PASSENGER HANDLING	0.12880	12.53341
CARGO HANDLING	0.05700	5.54671
OTHER PASSENGER EXPENSE	0.32984	32.09718
OTHER CARGO EXPENSE	0.00583	0.56699
GENERAL + ADMINISTRATION	0.07984	7.76982
TOTAL IOC	1.02763	100.000

MISC. DATA	
RANGE (N. MI.)	2999.95
BLOCK SPEED (MPH)	419.39
BLOCK TIME (HRS)	7.15
FLIGHT TIME (HRS)	7.15
AVG STAGE LENGTH (N. MI.)	1144.00
AVG CARGO PER FLIGHT	17413.00
UTILIZATION (HRS PER YR)	3636.00
FLIGHTS PER A/C PER YEAR	508.31
FARE ($)	268.79

*** - CENTS PER SEAT N. MILE

RATE OF RETURN ON INVESTMENT

YEAR	AVG NO AIRCRAFT DURING YEAR	AIRCRAFT ADDED DURING YEAR	AVERAGE INVESTMENT DURING YEAR $M	CUMULATIVE DEPRECIATION $M	AVERAGE BOOK VALUE OF FLEET $M	REVENUE $M	INTEREST EXPENSE $M	OPERATING EXPENSE $M	CASH FLOW $M	ROI PERCENT
1	6.3	10.0	356.34	21.38	334.96	262.44	34.21	104.00	-76.15	28.76
2	16.3	10.0	926.49	76.97	849.52	662.34	83.47	270.40	14.57	29.16
3	20.0	0.0	1140.30	145.39	994.91	839.81	93.05	332.80	184.17	30.16
4	20.0	0.0	1140.30	213.81	926.49	839.81	82.10	332.80	189.65	31.79
5	20.0	0.0	1140.30	282.22	858.07	839.81	71.15	332.80	195.12	33.69
6	20.0	0.0	1140.30	350.64	789.66	839.81	60.21	332.80	200.59	35.92
7	20.0	0.0	1140.30	419.06	721.24	839.81	49.26	332.80	206.07	38.56
8	20.0	0.0	1140.30	487.48	652.82	839.81	38.31	332.80	211.54	41.77
9	20.0	0.0	1140.30	555.89	584.40	839.81	27.37	332.80	217.01	45.72
10	20.0	0.0	1140.31	624.31	515.99	839.81	16.42	332.80	222.49	50.72

AVG ROI OVER THE 10 YEAR PERIOD = 35.85 PERCENT

P&WA E^3 DOMESTIC
(STF505M-7C)

ORIGINAL PAGE IS OF POOR QUALITY

PRECEDING PAGE BLANK NOT FILMED

LR 28664

A-13

OPERATIONAL COSTS

DIRECT OPERATIONAL COST (DOC)

	C/SM***	PERCENT
FLIGHT CREW	0.20661	16.35633
FUEL AND OIL	0.23133	18.31395
INSURANCE	0.02182	1.72765
DEPRECIATION	0.47920	37.93774
MAINTENANCE	0.32417	25.66426
TOTAL DOC	1.26312	100.000

INDIRECT OPERATIONAL COST (IOC)

	C/SM***	PERCENT
SYSTEM	0.02649	1.94654
LOCAL	0.12667	9.28102
AIRCRAFT CONTROL	0.00340	0.24943
CABIN ATTENDANT	0.22895	16.77467
FOOD AND BEVERAGE	0.14713	10.77972
PASSENGER HANDLING	0.27600	20.22153
CARGO HANDLING	0.12214	8.94912
OTHER PASSENGER EXPENSE	0.32984	24.16634
OTHER CARGO EXPENSE	0.00583	0.42689
GENERAL + ADMINISTRATION	0.09842	7.21079
TOTAL IOC	1.36467	100.000

MISC. DATA

RANGE (N. MI.)	1399.95
BLOCK SPEED (MPH)	384.31
BLOCK TIME (HRS)	3.64
FLIGHT TIME (HRS)	3.64
AVG STAGE LENGTH (N. MI.)	1144.00
AVG CARGO PER FLIGHT	17413.00
UTILIZATION (HRS PER YR)	3636.00
FLIGHTS PER A/C PER YEAR	998.16
FARE ($)	125.44

*** - CENTS PER SEAT N. MILE

RATE OF RETURN ON INVESTMENT

YEAR	AVG NO AIRCRAFT DURING YEAR	AIRCRAFT ADDED DURING YEAR	AVERAGE INVESTMENT DURING YEAR $M	CUMULATIVE DEPRECIATION $M	AVERAGE BOOK VALUE OF FLEET $M	REVENUE $M	INTEREST EXPENSE $M	OPERATING EXPENSE $M	CASH FLOW $M	ROI PERCENT
1	6.3	10.0	456.34	21.48	334.96	240.49	34.21	114.76	-92.50	23.87
2	16.3	10.0	926.49	76.97	549.52	645.27	83.47	298.37	-27.95	24.15
3	20.0	0.0	1140.30	145.39	994.91	769.56	93.05	367.23	131.84	24.90
4	20.0	0.0	1140.30	213.81	926.49	769.56	82.10	367.23	137.31	26.14
5	20.0	0.0	1140.30	282.22	858.07	769.56	71.15	367.23	142.78	27.59
6	20.0	0.0	1140.30	350.64	789.66	769.56	60.21	367.23	148.26	29.29
7	20.0	0.0	1140.30	419.06	721.24	769.56	49.26	367.23	153.73	31.31
8	20.0	0.0	1140.30	487.48	652.82	769.56	38.31	367.23	159.20	33.75
9	20.0	0.0	1140.30	555.89	584.40	769.56	27.37	367.23	164.68	36.76
10	20.0	0.0	1140.30	624.31	515.99	769.56	16.42	367.23	170.15	40.58

AVG ROI OVER THE 10 YEAR PERIOD = 29.24 PERCENT

P&WA E^3 DOMESTIC
(STF505M-7C)

TAKEOFF PERFORMANCE

WEIGHT CLRUN VSTALL	POWER CDRUN VRFPS	FLAP CLSTOP V1 FPS	POLAR CDSTOP VLOFPS	ENGOP CLLO V2 FPS	FNLO XG FT	GRAD XG1 FT	GRDCEO XROTFT	GRDCAE XOB FT	XFIELD XTO FT
454013.	402.	25.00	1.	3.		0.1141	1.0000	1.0000	6975.9
3.7962	0.0994	0.1575	0.1582	1.4486	1.2000				
196.59	225.41	228.41	244.10	251.29	4435.7	0.0	815.4	814.3	6066.0

P&WA E^3 DOMESTIC
(STF505M-7C)

A-14

ORIGINAL PAGE IS
OF POOR QUALITY

NOISE TAKEOFF + CLIMB-OUT PATH
POWER SETTING = 402. OPER. ENGINES = 3.

	TIME	DISTANCE	ALTITUDE	VELOCITY	GAMMA	DELTA	ABS ALT	SPD SND	MACH	PRS ALT	CL
1	0.0	0.0	0.0	0.0	0.0	2.000	0.0	1144.09	0.0	0.0	0.796
2	36.01	4435.7	0.0	228.41	0.0	2.000	0.0	1144.09	0.200	0.0	0.796
3	39.46	5251.7	0.0	244.10	0.0	13.916	0.0	1144.09	0.213	0.0	1.959
4	42.75	6066.[illegible]	35.0	251.29	4.922	13.769	35.0	1143.97	0.220	33.2	1.852
5	45.16	6673.7	100.0	251.52	5.665	10.663	100.0	1143.73	0.220	95.0	1.535
6	48.64	7538.3	200.0	251.88	6.533	10.795	200.0	1143.38	0.220	190.4	1.535
7	77.01	14620.9	1000.0	254.74	6.279	10.830	1000.0	1140.52	0.223	952.1	1.536
8	113.36	23951.3	2000.0	258.39	6.035	10.840	2000.0	1136.94	0.227	1903.9	1.537
9	150.65	33604.9	3000.0	262.12	5.793	10.847	3000.0	1133.35	0.231	2855.4	1.538
10	188.96	43671.2	4000.0	265.92	5.553	10.854	4000.0	1129.75	0.235	3806.6	1.538
11	228.39	54164.7	5000.0	269.80	5.314	10.859	5000.0	1126.14	0.240	4757.5	1.539
12	269.03	65183.9	6000.0	273.77	5.078	10.865	6000.0	1122.51	0.244	5708.0	1.539
13	311.98	76711.2	7000.0	277.81	4.840	10.870	7000.0	1118.88	0.248	6658.2	1.540
14	354.37	88814.3	8000.0	281.95	4.606	10.874	8000.0	1115.24	0.253	7608.1	1.540
15	399.33	101546.6	9000.0	286.17	4.375	10.877	9000.0	1111.59	0.257	8557.7	1.540
16	445.01	114968.3	10000.0	290.49	4.147	10.880	10000.0	1107.93	0.262	9506.9	1.541

P&WA E^3 DOMESTIC
(STF505M-7C)

LOW SPEED POLAR --- 42.0 DEG FLAP

CL	DCLFLP	CD0	CDCLN	DCDFLP	DCDSLT	CDIND	DCDGND	CD0G	CDIG
-0.30000	0.65651	0.01713	0.05411	0.06288	0.06327	0.01072	-0.00536	0.15400	0.14864
0.0	0.65651	0.01713	0.03311	0.06288	0.05048	0.00226	-0.00113	0.13275	0.13162
0.30000	0.65651	0.01713	0.02141	0.06288	0.03927	0.00310	-0.00155	0.12238	0.12083
0.60000	0.65651	0.01713	0.01723	0.06288	0.02964	0.01146	-0.00573	0.12111	0.11538
0.90000	0.65651	0.01713	0.01902	0.06288	0.02158	0.02578	-0.01289	0.12737	0.11448
1.20000	0.65651	0.01713	0.02772	0.06288	0.01510	0.04702	-0.02351	0.14213	0.11862
1.50000	0.65651	0.01713	0.04495	0.06288	0.01014	0.07679	-0.03840	0.16694	0.12854
1.80000	0.65651	0.01713	0.07268	0.06288	0.00571	0.11706	-0.05853	0.20278	0.14425
2.10000	0.65651	0.01713	0.11184	0.06288	0.00123	0.16876	-0.08438	0.25000	0.16562
2.40000	0.65651	0.01713	0.15536	0.06288	0.0	0.22481	-0.11241	0.30482	0.19242
2.70000	0.65651	0.01713	0.20702	0.06288	0.0	0.28901	-0.14451	0.36902	0.22452

POLAR TABLE -- OUT OF GROUND -- GEAR UP

1011.00000	-0.30000	0.0	0.30000	0.60000	0.90000	1.20000	1.50000	1.80000	2.10000	2.40000	2.70000
42.00000	0.15400	0.13275	0.12238	0.12111	0.12737	0.14213	0.16694	0.20278	0.25000	0.30482	0.36902

POLAR TABLE -- IN GROUND -- GEAR UP

1011.00000	-0.30000	0.0	0.30000	0.60000	0.90000	1.20000	1.50000	1.80000	2.10000	2.40000	2.70000
42.00000	0.14864	0.13162	0.12083	0.11538	0.11448	0.11862	0.12854	0.14425	0.16562	0.19242	0.22452

MAXIMUM LIFT COEFFICIENT --- CLMX(NPCL) = 2.66091

P&WA E^3 DOMESTIC
(STF505M-7C)

LANDING DIST	LANDING WT	X.N,FT	XROLL,FT	XBRAKE,FT	TOT DIST,FT	FIELD L	VAPPR,KTS
	372151.00	1142.95	224.1	2296.81	3669.55	6115.97	136.15

P&WA E^3 DOMESTIC
(STF505M-7C)

SUMMARY ID NO. 1 — A S S E T   P A R A M E T R I C   A N A L Y S I S — MAY 31 1978

AIRCRAFT MODEL --CL 1332-15 — ENGINE I.D. -- 416000 — WING QUARTER CHORD SWEEP = 30.00 DEG
I.O.C. DATE --1985 — SLS SCALE I.D. = 40850 — WING TAPER RATIO = 0.300
DESIGN SPEED --SUBSONIC — NUMBER OF ENGINES = 4.

1 W/S	132.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 T/W	0.22[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 AP	10.[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 T/C	13.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 SWEEP	30.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 FPR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 OPR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 TIT	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9 NPR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10 AUG T	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11 RADIUS N. MI	650[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 GROSS WEIGHT	630491	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 FUEL WEIGHT	243517	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 OP. WT. EMPTY	286974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 ZERO FUEL WT.	386974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 THRUST/ENGINE	34677	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 ENGINE SCALE	0.844	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 WING AREA	4776.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19 WING SPAN	218.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 H. TAIL AREA	949.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21 V. TAIL AREA	652.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22 ENG. LENGTH	9.79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23 ENG. DIAMETER	6.67	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24 BODY LENGTH	224.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25 WING FUEL LIMIT	1.62[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA																
26 RDTE - BIL.	2.761	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27 FLYAWAY - MIL.	55.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 INVESTMNT-BIL.	1.262	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 DOC - C/SM	1.285	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30 IOC - C/SM	1.222	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31 ROI A.T. - O/O	24.19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MISSION PARAMETERS																
32 MISN V1(1,1)	3400[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 MISN V2(1,1)	210888	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 MISN V1(2,1)	41[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 MISN V2(2,1)	82337	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTRAINT OUTPUT																
36 TAKEOFF DST(1)	9460	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 CLIMB GRAD(1)	0.083[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38 TAKEOFF DST(2)	6417	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39 CLIMB GRAD(2)	0.0359	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40 CTOL LNDG D(1)	5323	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 AP SPEED-KT(1)	131.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42 SEP(1) - FPS	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43 SEP(2) - FPS	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

ORIGINAL PAGE IS
OF POOR QUALITY

E**3 AIRCRAFT / 500 PASS / 6500 N MI / M = .80 MISS

T/C	AR	W/S	T/W
13.00	10.00	132.6	0.220

W E I G H T   S T A T E M E N T

	WEIGHT(POUNDS)	WEIGHT FRACTION	(PERCENT)
GROSS WEIGHT	(630491.)		
FUEL AVAILABLE	243517.	FUEL	38.62
EXTERNAL	0.		
INTERNAL	243517.		
ZERO FUEL WEIGHT	386974.		
PAYLOAD	100000.	PAYLOAD	15.86
PASSENGERS	85000.		
BAGGAGE	0.		
CARGO	15000.		
STORES	0.		
OPERATIONAL EMPTY WEIGHT	286974.		
OPERATIONAL ITEMS	16209.	OPERATIONAL ITEMS	3.96
STANDARD ITEMS	8788.		
EMPTY WEIGHT	261977.		
STRUCTURE	154187.	STRUCTURE	24.45
WING	60859.		
ROTOR	0.		
TAIL	6374.		
BODY	55176.		
ALIGHTING GEAR	24474.		
ENGINE SECTION AND NACELLE	7304.		
PROPULSION	34932.	PROPULSION	5.54
CRUISE ENGINES	26802.		
LIFT ENGINES	0.		
THRUST REVERSER	5474.		
EXHAUST SYSTEM	0.		
ENGINE CONTROL	236.		
STARTING SYSTEM	709.		
PROPELLERS	0.		
LUBRICATING SYSTEM	0.		
FUEL SYSTEM	1711.		
DRIVE SYSTEM (POWER TRANS)	0.		
SYSTEMS	72859.		
FLIGHT CONTROLS	4850.		
AUXILIARY POWER PLANT	1116.		
INSTRUMENTS	1137.		
HYDRAULIC AND PNEUMATIC	3612.		
ELECTRICAL	6850.		
AVIONICS	2900.	SYSTEMS	11.56
ARMAMENT	0.		
FURNISHINGS AND EQUIPMENT	44293.		
AIR CONDITIONING	7682.		
ANTI-ICING	420.		
PHOTOGRAPHIC	0.		
LOAD AND HANDLING	0.		
		TOTAL	(100.)

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

E**3 AIRCRAFT / 500 PASS / 6500 N MI / M = .80 MISS

T/C	AR	W/S	T/W
13.00	10.00	132.0	0.220

C O N F I G U R A T I O N   G E O M E T R Y

BASIC WING--	AREA(SQ FT)	SPAN(FT)	TAPER RATIO	C/4 SWEEP	L.E. SWEEP	MAC(FT)	
	4776.4	218.55	0.300	30.000	32.260	23.97	
WING PANELS--	AREA(SQ FT)	EXP. AREA	AVG T/C	L.E. SWEEP	SFLE(SQ FT)	REF L(FT)	
	3061.2	2239.0	13.00	32.260	0.0	32.53	
	2191.6	2191.6	13.00	32.260	0.0	17.97	
TOTAL WING--	AREA(SQ FT)	EFF AR	AVG T/C	CR(FT)	CT(FT)	MAC(FT)	L(FT)
	5252.8	9.09	13.00	44.20	10.09	27.94	79.06
FUSELAGE--	LENGTH(FT)	S WET(SQ FT)	BWW(FT)	EQUIV D(FT)	SPI(SQ FT)		
	229.49	11940.0	19.58	19.58	300.95		
	BW(FT)	BH(FT)	SBW(SQ FT)				
	19.58	19.58	11940.00				
HORZ. TAIL 1--	SHT1(SQ FT)	SHX1(SQ FT)	REF L1(FT)	L HT1(FT)	HT1 VOL COEF		
	989.70	752.34	13.86	106.36	0.9195		
HORZ. TAIL 2--	SHT2(SQ FT)	SHX2(SQ FT)	REF L2(FT)	L HT2(FT)	HT2 VOL COEF		
	0.0	0.0	0.0	229.49	0.0		
VERT. TAIL 1--	SVT1(SQ FT)	SVX1(SQ FT)	REF L1(FT)	L VT1(FT)	VT1 VOL COEF		
	652.85	652.85	22.15	105.63	0.0661		
VERT. TAIL 2--	SVT2(SQ FT)	SVX2(SQ FT)	REF L2(FT)	L VT2(FT)	VT2 VOL COEF		
	0.0	0.0	0.0	229.49	0.0		
PROPULSION--	ENG L(FT)	ENG D(FT)	POD L(FT)	POD D(FT)	POD S WET	NO. PODS	INLET L(FT)
	9.79	6.67	20.27	7.80	1987.61	4.	0.0
FUEL TANKS--	WING(CU FT)	BOX(CU FT)	FUS(CU FT)				
	6243.23	1641.47	4999.00				
WETTED VOLUMES--	BODY	WING	TAILS	PODS	PYLONS	PONTOONS	TOTAL
	51825.04	7293.75	1260.59	3877.83	0.0	0.0	64257.20

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

ORIGINAL PAGE IS
OF POOR QUALITY

DRAG COEFFICIENTS--NO EXTERNAL STORES

ALTITUDE = 0. FEET

MACH NO. \ LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
0.200	0.01742	0.01714	0.01778	0.01948	0.02225	0.02590	0.03099
0.400	0.01574	0.01546	0.01611	0.01780	0.02058	0.02422	0.02931
0.750	0.01454	0.01425	0.01490	0.01656	0.01927	0.02286	0.02772
0.800	0.01527	0.01487	0.01541	0.01690	0.01929	0.02254	0.02735
0.820	0.01619	0.01537	0.01573	0.01726	0.02007	0.02443	0.03211
0.850	0.01869	0.01658	0.01647	0.01841	0.02291	0.03160	0.04774
0.900	0.02580	0.02141	0.02044	0.02347	0.03292	0.05202	0.08601

ALTITUDE = 10000. FEET

MACH NO. \ LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
0.200	0.01808	0.01780	0.01845	0.02014	0.02292	0.02656	0.03165
0.400	0.01632	0.01603	0.01668	0.01837	0.02115	0.02479	0.02988
0.750	0.01503	0.01474	0.01539	0.01705	0.01976	0.02335	0.02821
0.800	0.01575	0.01536	0.01590	0.01739	0.01978	0.02303	0.02783
0.820	0.01667	0.01585	0.01622	0.01774	0.02055	0.02491	0.03259
0.850	0.01917	0.01705	0.01695	0.01888	0.02338	0.03208	0.04821
0.900	0.02627	0.02188	0.02091	0.02394	0.03339	0.05249	0.08648

ALTITUDE = 20000. FEET

MACH NO. \ LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
0.200	0.01890	0.01862	0.01927	0.02096	0.02374	0.02738	0.03247
0.400	0.01702	0.01673	0.01738	0.01908	0.02185	0.02550	0.03059
0.750	0.01563	0.01534	0.01599	0.01766	0.02036	0.02396	0.02881
0.800	0.01635	0.01596	0.01650	0.01799	0.02037	0.02362	0.02843
0.820	0.01726	0.01645	0.01681	0.01834	0.02114	0.02550	0.03319
0.850	0.01975	0.01764	0.01754	0.01947	0.02397	0.03266	0.04880
0.900	0.02684	0.02245	0.02148	0.02452	0.03397	0.05306	0.08706

ALTITUDE = 30000. FEET

MACH NO. \ LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
0.200	0.01989	0.01960	0.02025	0.02194	0.02472	0.02836	0.03345
0.400	0.01796	0.01757	0.01822	0.01992	0.02269	0.02634	0.03142
0.750	0.01634	0.01605	0.01670	0.01837	0.02108	0.02467	0.02952
0.800	0.01706	0.01667	0.01721	0.01870	0.02108	0.02433	0.02914
0.820	0.01797	0.01715	0.01751	0.01904	0.02185	0.02620	0.03389
0.850	0.02045	0.01834	0.01824	0.02017	0.02467	0.03336	0.04950
0.900	0.02755	0.02314	0.02217	0.02520	0.03465	0.05375	0.08774

ALTITUDE = 40000. FEET

MACH NO. \ LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
0.200	0.02102	0.02073	0.02138	0.02308	0.02585	0.02950	0.03459
0.400	0.01883	0.01855	0.01919	0.02089	0.02366	0.02731	0.03240
0.750	0.01717	0.01668	0.01753	0.01920	0.02190	0.02550	0.03035
0.800	0.01783	0.01749	0.01803	0.01952	0.02190	0.02515	0.02996
0.820	0.01876	0.01797	0.01833	0.01985	0.02266	0.02702	0.03471
0.850	0.02126	0.01914	0.01904	0.02097	0.02547	0.03417	0.05030
0.900	0.02832	0.02393	0.02296	0.02599	0.03544	0.05454	0.08853

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

DRAG COEFFICIENTS--NO EXTERNAL STORES

ALTITUDE = 50000. FEET

LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
MACH NO.							
0.200	0.02255	0.02227	0.02242	0.02461	0.02734	0.03103	0.03612
0.400	0.02013	0.01965	0.02050	0.02219	0.02497	0.02861	0.03370
0.750	0.01827	0.01798	0.01863	0.02030	0.02300	0.02660	0.03145
0.800	0.01899	0.01858	0.01912	0.02061	0.02300	0.02625	0.03106
0.820	0.01987	0.01905	0.01941	0.02094	0.02375	0.02811	0.03579
0.850	0.02233	0.02022	0.02012	0.02205	0.02655	0.03524	0.05138
0.900	0.02938	0.02444	0.02402	0.02705	0.03650	0.05560	0.08959

ALTITUDE = 60000. FEET

LIFT COEF.=	0.0	0.10	0.20	0.30	0.40	0.50	0.60
MACH NO.							
0.200	0.02440	0.02412	0.02476	0.02646	0.02924	0.03288	0.03797
0.400	0.02175	0.02142	0.02206	0.02376	0.02654	0.03018	0.03527
0.750	0.01960	0.01931	0.01996	0.02162	0.02433	0.02792	0.03278
0.800	0.02029	0.01990	0.02044	0.02193	0.02431	0.02756	0.03237
0.820	0.02118	0.02036	0.02072	0.02225	0.02506	0.02941	0.03710
0.850	0.02362	0.02151	0.02141	0.02334	0.02784	0.03654	0.05267
0.900	0.03065	0.02626	0.02529	0.02832	0.03777	0.05687	0.09086

FM DES = 0.8035 CL DES = 0.5566

P&WA E[3] INTERCONTINENTAL
(STF505M-7C)

M I S S I O N   S U M M A R Y

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

E**3 AIRCRAFT / 500 PASS / 6500 N MI / M = .80 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)	MAX OVER PRES
TAKEOFF POWER 1	0.	0.0	630491.	0.	0.	0.	0.	0.0	0.0	0.	416401.	0.	0.0	0.318	0.0
POWER 2	0.	0.0	630491.	991.	991.	0.	0.	1.3	1.3	0.	416401.	0.	0.0	0.318	0.0
CLIMB	0.	0.378	629500.	11257.	12248.	120.	120.	21.4	22.8	0.	416201.	0.	20.19	0.510	0.0
ACCEL	30000.	0.692	618243.	1089.	13337.	20.	140.	2.7	25.5	0.	416201.	0.	20.37	0.560	0.0
CLIMB	30000.	0.800	617154.	1792.	15129.	36.	176.	4.6	30.1	0.	416201.	0.	20.41	0.573	0.0
CRUISE	34000.	0.800	615362.	190883.	206012.	6074.	6250.	793.0	823.2	0.	-416101.	0.	20.34	0.571	0.0
DESCENT	42000.	0.800	424479.	172.	206184.	33.	6282.	4.2	827.4	0.	416301.	0.	18.68	-1.938	0.0
DECEL	30000.	0.800	424307.	35.	206219.	6.	6289.	0.9	828.3	0.	416301.	0.	18.15	-0.639	0.0
DESCENT	30000.	0.692	424272.	771.	206990.	90.	6378.	16.9	845.2	0.	416301.	0.	19.60	-0.619	0.0
CRUISE	42000.	0.800	423500.	3205.	210194.	122.	6500.	15.9	861.1	0.	-416101.	0.	20.07	0.575	0.0
LOITER	1500.	0.435	423297.	694.	210888.	0.	6500.	3.0	864.1	0.	-416101.	0.	19.20	0.635	0.0
RESET	0.	0.0	419603.	0.	210888.	-6500.	0.	0.0	864.1	0.	0.	0.	0.0	0.0	0.0
RESET	0.	0.0	419603.	0.	210888.	0.	0.	0.0	864.1	0.	0.	0.	0.0	0.0	0.0
CRUISE	42000.	0.800	419603.	17030.	227918.	0.	0.	86.4	950.5	0.	-416101.	0.	20.02	0.576	0.0
TAKEOFF POWER 1	0.	0.0	402573.	0.	227918.	0.	0.	0.0	950.5	0.	416401.	0.	0.0	0.318	0.0
POWER 2	0.	0.0	402573.	991.	228909.	0.	0.	1.3	951.8	0.	416401.	0.	0.0	0.318	0.0
CLIMB	0.	0.378	401581.	1694.	230603.	11.	11.	2.4	954.2	0.	416201.	0.	19.12	0.480	0.0
ACCEL	10000.	0.456	399887.	0.	230603.	0.	11.	0.0	954.2	0.	416201.	0.	19.19	0.489	0.0
CLIMB	10000.	0.456	399887.	3657.	234260.	44.	55.	7.5	961.7	0.	416201.	0.	19.08	0.516	0.0
CRUISE	30000.	0.705	396231.	1058.	235318.	35.	90.	5.1	966.8	0.	-416101.	0.	18.56	0.589	0.0
DESCENT	30000.	0.692	395172.	442.	235760.	61.	151.	10.7	977.5	0.	416301.	0.	19.04	-0.584	0.0
DECEL	10000.	0.455	394731.	0.	235760.	0.	151.	0.0	977.5	0.	416301.	0.	19.08	-0.544	0.0
DESCENT	10000.	0.457	394731.	282.	236042.	24.	175.	5.3	982.8	0.	416301.	0.	19.09	-0.676	0.0
CRUISE	30000.	0.705	394446.	705.	236747.	25.	200.	3.6	986.4	0.	-416101.	0.	18.53	0.589	0.0
CRUISE	1500.	0.377	393693.	6384.	243131.	0.	200.	30.0	1016.4	0.	-416101.	0.	19.37	0.628	0.0

LR 28664

ALTERNATE MISSION NO. 1 SUMMARY

P&WA E^3 INTERCONTINENTAL (STF505M-7C)

E**3 AIRCRAFT / 55% LF / 3000 N MI / M = .80 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)	MAX OVER PRES
TAKEOFF POWER 1	0.	0.0	455488.	0.	0.	0.	0.	0.0	0.0	0.	416401.	0.	0.0	0.318	0.0
POWER 2	0.	0.0	455488.	991.	991.	0.	0.	1.3	1.3	0.	416401.	0.	0.0	0.318	0.0
CLIMB	0.	0.378	454497.	6320.	7311.	65.	65.	11.8	13.1	0.	416201.	0.	19.98	0.508	0.0
ACCEL	30000.	0.692	448177.	534.	7845.	10.	75.	1.3	14.5	0.	416201.	0.	18.53	0.560	0.0
CLIMB	30000.	0.800	447643.	2857.	10702.	67.	141.	8.7	23.1	0.	416201.	0.	19.28	0.570	0.0
CRUISE	41000.	0.800	444786.	67138.	77840.	2609.	2750.	341.1	364.2	0.	-416101.	0.	20.02	0.576	0.0
DESCENT	44000.	0.800	377646.	197.	78037.	37.	2787.	4.8	369.1	0.	416301.	0.	18.26	1.630	0.0
DECEL	30000.	0.800	377451.	33.	78070.	6.	2793.	0.8	369.9	0.	416301.	0.	17.06	-0.659	0.0
DESCENT	30000.	0.692	377418.	726.	78796.	84.	2877.	15.9	385.8	0.	416301.	0.	18.67	-0.619	0.0
CRUISE	44000.	0.800	376692.	2925.	81721.	123.	3000.	16.0	401.8	0.	-416101.	0.	19.86	0.579	0.0
LOITER	1500.	0.400	373767.	666.	82387.	0.	3000.	3.0	404.8	0.	-416101.	0.	18.20	0.649	0.0
RESET	0.	0.0	373101.	0.	82387.	-3000.	0.	0.0	404.8	0.	0.	0.	0.0	0.0	0.0
RESET	0.	0.0	373101.	0.	82387.	0.	0.	0.0	404.8	0.	0.	0.	0.0	0.0	0.0
CRUISE	45000.	0.800	373101.	7278.	89654.	0.	0.	40.5	445.3	0.	-416101.	0.	19.86	0.580	0.0
TAKEOFF POWER 1	0.	0.0	365823.	0.	89664.	0.	0.	0.0	445.3	0.	416401.	0.	0.0	0.318	0.0
POWER 2	0.	0.0	365823.	991.	90656.	0.	0.	1.3	446.6	0.	416401.	0.	0.0	0.318	0.0
CLIMB	0.	0.378	364832.	1514.	92170.	10.	10.	2.2	448.8	0.	416201.	0.	18.28	0.480	0.0
ACCEL	10000.	0.456	363318.	0.	92170.	0.	10.	0.0	448.8	0.	416201.	0.	18.38	0.489	0.0
CLIMB	10000.	0.455	363318.	3224.	95394.	38.	48.	6.6	455.4	0.	416201.	0.	18.25	0.516	0.0
CRUISE	33000.	0.675	360094.	1199.	96593.	42.	90.	6.3	461.7	0.	-416101.	0.	18.46	0.587	0.0
DESCENT	30000.	0.682	358895.	419.	97012.	58.	148.	10.1	471.9	0.	416301.	0.	18.22	-0.584	0.0
DECEL	10000.	0.456	358476.	0.	97012.	0.	148.	0.0	471.9	0.	416301.	0.	18.26	-0.544	0.0
DESCENT	10000.	0.456	358476.	267.	97279.	23.	171.	5.0	476.8	0.	416301.	0.	18.26	-0.676	0.0
CRUISE	30000.	[illegible]	358209.	838.	98117.	29.	200.	4.4	481.2	0.	-416101.	0.	18.42	0.587	0.0
CRUISE	1500.	0.379	357371.	6111.	104227.	0.	200.	30.0	511.2	0.	-416101.	0.	18.58	0.641	0.0

ORIGINAL PAGE IS OF POOR QUALITY

C O S T   S U M M A R Y

RDT AND E

	TOTAL *
DEVELOPMENT - NONRECURRING	
ENGINEERING	1101.52
TOOLING	586.66
TEST ARTICLES	77.93
DATA	0.0
SYSTEMS ENG/MNGMT	0.0
CRUISE ENGINE	0.0
LIFT ENGINE	0.0
FAN	0.0
AVIONICS	0.0
OTHER SYSTEMS	0.0
FACILITIES	0.0
TOTAL AIR VEHICLE	1755.11
INTEGR LOGISTICS SUPPORT	
PLANNING	11.07
TRAINING	3.76
HANDBOOKS	25.38
SSE	5.42
TOTAL ILS	45.63
TOTAL DVLPMNT-NONREC	1811.73
DEVELOPMENT - RECUR(PROTOTYPES)	
AIR VEHICLE	754.41
SPARES	194.73
TOTAL DVLPMNT-RECUR	944.13
GOVMNT DVLPMNT COST	0.0
TOTAL DVLPMNT COST	[illegible]760.87

PRODUCTION

	MATERIAL	LABOR	TOTAL PER PROD A/C**
STRUCTURE	4877.67	14185.95	19063.61
WING	2355.34	3427.99	5783.33
ROTOR	0.0	0.0	0.0
TAIL	204.81	466.34	671.15
BODY	1217.24	8898.64	10115.88
ALIGHTING GEAR	796.32	40.88	837.20
ENG SECT + NACELLE	303.95	1352.11	1656.06
ENG SECTION	0.0	0.0	0.0
NACELLE	268.91	1299.59	1568.50
AIR INDUCTION	35.05	52.52	87.56
PROPULSION	145.11	144.13	289.24
ENGINE INSTALL	0.0	34.75	34.75
THRUST REVERSER	0.0	7.10	7.10
EXHAUST SYSTEM	0.0	0.0	0.0
ENGINE CONTROLS	4.06	6.46	10.52
STARTING SYSTEM	70.97	13.31	84.28
PROPELLER INSTALL	0.0	0.0	0.0
LUBRICATING SYSTEM	0.0	0.0	0.0
FUEL SYSTEM	70.08	82.52	152.60
DRIVE SYS(PWR TRN)	0.0	0.0	0.0
SYSTEMS	[illegible]9C9.45	7968.47	10877.92
FLIGHT CONTROLS	525.38	394.01	919.39
AUX POWER PLANT	125.02	22.63	147.66
INSTRUMENTS	81.73	79.30	161.03
HYDRAULIC + PNEUM	179.29	483.54	662.83
ELECTRICAL	470.02	1331.93	1801.95
AVIONIC INSTALL	38.75	431.68	470.43
ARMAMENT	0.0	0.0	0.0
FURN AND EQUIP	1065.43	4663.73	5729.16
AIR CONDITIONING	401.85	532.53	934.38
ANTI-ICING	21.98	29.12	51.10
PHOTOGRAPHIC	0.0	0.0	0.0
LOAD AND HANDLING	0.0	0.0	0.0
SYSTEMS INTEGR	564.61	655.04	1219.65
TOTAL COST	8496.84	22953.52	31450.35
TOTAL HRS **		821.72	821.72
ENG CHANGE ORDERS			1033.03
SUSTAINING ENG COST			1996.31
PROD TOOLING COST			1666.28
QUALITY ASSURANCE			3092.07
MISCELLANEOUS ***			1068.63
TOTAL AIRFRAME COST			40306.64
ENGINE COST			4871.79
AVIONICS COST			751.00
TOTAL MANUFACTURING COST			45929.41
WARRANTY			244.78
TOTAL PRODUCTION COST			46174.18

PROCUREMENT

	PER PROD A/C**
TOTAL PRODUCTION	46174.18
INTEGR LOGISTICS SUPPORT	
PLANNING	33.09
TRAINING	11.25
TRAINERS	360.68
HANDBOOKS	48.11
FACILITIES	0.0
SSE - CFE	23.09
SSE - GFE	751.07
TOTAL ILS	1227.29
INITIAL SPARES COST	6332.06
PRODUCTION DEVELOPMENT	
ENGINEERING	346.11
TOOLING	-174.83
ENGINES	0.0
TOTAL PROD DEV	171.28
TOTAL PROCUREMENT	53904.78

* - MILLIONS OF DOLLARS

** -1000 OF DOLLARS OR HOURS PER PROD A/C

*** - INCLUDES PROD DATA, SYSTEMS ENGR AND OTHER SYSTEMS

P&WA E^3 INTERCONTINENTAL (STF505M-7C)

OPERATIONAL COSTS

DIRECT OPERATIONAL COST (DOC)

	C/SM***	PERCENT
FLIGHT CREW	0.21053	16.65159
FUEL AND OIL	0.37466	29.15416
INSURANCE	0.01859	1.44648
DEPRECIATION	0.40065	31.66334
MAINTENANCE	0.26655	20.74645
TOTAL DOC	1.28493	100.000

INDIRECT OPERATIONAL COST (IOC)

	C/SM***	PERCENT
SYSTEM	0.02280	1.86485
LOCAL	0.09396	7.68796
AIRCRAFT CONTROL	0.00209	0.17046
CABIN ATTENDANT	0.25247	20.65401
FOOD AND BEVERAGE	0.07881	6.44740
PASSENGER HANDLING	0.13403	10.96482
CARGO HANDLING	0.04262	3.48703
OTHER PASSENGER EXPENSE	0.48400	39.59520
OTHER CARGO EXPENSE	0.00595	0.48683
GENERAL + ADMINISTRATION	0.10563	8.64141
TOTAL IOC	1.22237	100.000

MISC. DATA

RANGE (N. MI.)	6500.00
BLOCK SPEED (MPH)	439.66
BLOCK TIME (HRS)	14.78
FLIGHT TIME (HRS)	14.78
AVG STAGE LENGTH (N. MI.)	2547.00
AVG CARGO PER FLIGHT	18386.00
UTILIZATION (HRS PER YR)	4133.00
FLIGHTS PER A/C PER YEAR	279.56
FARE ($)	504.40

*** - CENTS PER SEAT N. MILE

- -

RATE OF RETURN ON INVESTMENT

YEAR	AVG NO AIRCRAFT DURING YEAR	AIRCRAFT ADDED DURING YEAR	AVERAGE INVESTMENT DURING YEAR	CUMULATIVE DEPRECIATION	AVERAGE BOOK VALUE OF FLEET	REVENUE	INTEREST EXPENSE	OPERATING EXPENSE	CASH FLOW	ROI
			$M	$M	$M	$M	$M	$M	$M	PERCENT
1	6.3	10.0	394.42	23.67	370.76	253.69	37.86	142.38	-116.21	20.15
2	16.3	10.0	1025.50	85.20	940.30	660.11	92.39	370.18	-66.88	20.33
3	20.0	0.0	1262.15	162.92	1101.23	812.45	102.99	455.60	101.68	20.88
4	20.0	0.0	1262.15	236.65	1025.50	812.45	90.87	455.60	107.74	21.83
5	20.0	0.0	1262.15	312.38	949.77	812.45	78.76	455.60	113.80	22.93
6	20.0	0.0	1262.15	388.11	874.04	812.45	66.64	455.60	119.86	24.23
7	20.0	0.0	1262.15	463.84	798.31	812.45	54.52	455.60	125.92	25.76
8	20.0	0.0	1262.15	539.57	722.58	812.45	42.41	455.60	131.98	27.63
9	20.0	0.0	1262.15	615.30	646.85	812.45	30.29	455.60	138.03	29.92
10	20.0	0.0	1262.15	691.03	571.12	812.45	18.17	455.60	144.09	32.83

AVG ROI OVER THE 10 YEAR PERIOD = 24.19 PERCENT

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

OPERATIONAL COSTS

DIRECT OPERATIONAL COST (DOC)

	C/SM***	PERCENT
FLIGHT CREW	0.22[illegible]	17.50067
FUEL AND OIL	0.31715	24.53334
INSURANCE	0.01942	1.5022[illegible]
DEPRECIATION	0.427[illegible]	33.02[illegible]52
MAINTENANCE	0.30298	23.43542
TOTAL DOC	1.29285	100.000

INDIRECT OPERATIONAL COST (IOC)

	C/SM***	PERCENT
SYSTEM	0.02596	1.64738
LOCAL	0.20361	12.92086
AIRCRAFT CONTROL	0.00451	0.28649
CABIN ATTENDANT	0.26381	16.74072
FOOD AND BEVERAGE	0.08235	5.22581
PASSENGER HANDLING	0.29040	18.42819
CARGO HANDLING	0.09235	5.86053
OTHER PASSENGER EXPENSE	0.48400	30.71364
OTHER CARGO EXPENSE	0.00595	0.37763
GENERAL + ADMINISTRATION	0.12290	7.79872
TOTAL IOC	1.57585	100.000

MISC. DATA

RANGE (N. MI.)	3000.00
BLOCK SPEED (MPH)	420.76
BLOCK TIME (HRS)	7.13
FLIGHT TIME (HRS)	7.13
AVG STAGE LENGTH (N. MI.)	2547.00
AVG CARGO PER FLIGHT	18336.00
UTILIZATION (HRS PER YR)	4133.00
FLIGHTS PER A/C PER YEAR	579.67
FARE ($)	232.80

*** - CENTS PER SEAT N. MILE

RATE OF RETURN ON INVESTMENT

YEAR	AVG NO AIRCRAFT DURING YEAR	AIRCRAFT ADDED DURING YEAR	AVERAGE INVESTMENT DURING YEAR $M	CUMULATIVE DEPRECIATION $M	AVERAGE BOOK VALUE OF FLEET $M	REVENUE $M	INTEREST EXPENSE $M	OPERATING EXPENSE $M	CASH FLOW $M	ROI PERCENT
1	6.3	10.0	394.42	23.67	370.76	242.98	37.86	155.90	-128.43	16.85
2	16.3	10.0	1025.50	85.20	940.30	631.74	92.39	405.33	-98.65	16.95
3	20.0	0.0	1262.15	160.92	1101.23	777.53	102.99	498.87	62.59	17.33
4	20.0	0.0	1262.15	236.65	1025.50	777.53	90.87	498.87	68.65	18.02
5	20.0	0.0	1262.15	312.38	949.77	777.53	78.76	498.87	74.71	18.82
6	20.0	0.0	1262.15	388.11	874.04	777.53	66.64	498.87	80.77	19.75
7	20.0	0.0	1262.15	463.84	798.31	777.53	54.52	498.87	86.82	20.87
8	20.0	0.0	1262.15	539.57	722.58	777.53	42.41	498.87	92.88	22.22
9	20.0	0.0	1262.15	615.30	646.85	777.53	30.29	498.87	98.94	23.88
10	20.0	0.0	1262.15	691.03	571.13	777.53	18.17	498.87	105.00	25.99

AVG ROI OVER THE 10 YEAR PERIOD = 19.73 PERCENT

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

OPERATIONAL COSTS

DIRECT OPERATIONAL COST (DOC)	C/SM***	PERCENT
FLIGHT CREW	0.22626	17.50067
FUEL AND OIL	0.31718	24.53339
INSURANCE	0.01942	1.50227
DEPRECIATION	0.42751	33.02652
MAINTENANCE	0.30298	23.43542
TOTAL DOC	1.29285	100.000

INDIRECT OPERATIONAL COST (IOC)	C/SM***	PERCENT
SYSTEM	0.02596	1.64738
LOCAL	0.20361	12.92088
AIRCRAFT CONTROL	0.00451	0.28649
CABIN ATTENDANT	0.26381	16.74072
FOOD AND BEVERAGE	0.08235	5.22581
PASSENGER HANDLING	0.29040	16.42819
CARGO HANDLING	0.09235	5.86053
OTHER PASSENGER EXPENSE	0.48400	30.71364
OTHER CARGO EXPENSE	0.00595	0.37763
GENERAL + ADMINISTRATION	0.12290	7.79872
TOTAL IOC	1.57585	100.000

MISC. DATA	
RANGE (N. MI.)	3000.00
BLOCK SPEED (MPH)	420.76
BLOCK TIME (HRS)	7.13
FLIGHT TIME (HRS)	7.13
AVG STAGE LENGTH (N. MI.)	2547.00
AVG CARGO PER FLIGHT	18386.00
UTILIZATION (HRS PER YR)	4133.00
FLIGHTS PER A/C PER YEAR	579.67
FARE ($)	232.80

*** - CENTS PER SEAT N. MILE

RATE OF RETURN ON INVESTMENT

YEAR	AVG NO AIRCRAFT DURING YEAR	AIRCRAFT ADDED DURING YEAR	AVERAGE INVESTMENT DURING YEAR $M	CUMULATIVE DEPRECIATION $M	AVERAGE BOOK VALUE OF FLEET $M	REVENUE $M	INTEREST EXPENSE $M	OPERATING EXPENSE $M	CASH FLOW $M	ROI PERCENT
1	6.3	10.0	394.4[illegible]	23.67	370.76	242.98	37.86	155.90	-128.43	16.85
2	16.3	10.0	1025.50	85.20	940.30	631.74	92.39	405.33	-98.65	16.95
3	20.0	0.0	1262.15	160.92	1101.23	777.53	102.99	498.87	62.59	17.33
4	20.0	0.0	1262.15	236.65	1025.50	777.53	90.87	498.87	68.65	18.02
5	20.0	0.0	1262.15	312.38	949.77	777.53	78.76	498.87	74.71	18.82
6	20.0	0.0	1262.15	388.11	874.04	777.53	66.64	498.87	80.77	19.75
7	20.0	0.0	1262.15	463.84	798.31	777.53	54.52	498.87	86.82	20.87
8	20.0	0.0	1262.15	539.57	722.58	777.53	42.41	498.87	92.88	22.22
9	20.0	0.0	1262.15	615.30	646.85	777.53	30.29	498.87	98.94	23.88
10	20.0	0.0	1262.15	691.03	571.13	777.53	18.17	498.87	105.00	25.99

AVG ROI OVER THE 10 YEAR PERIOD = 19.7[illegible] PERCENT

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

ORIGINAL PAGE IS OF POOR QUALITY

TAKEOFF PERFORMANCE

WEIGHT CLRUN VSTALL	POWER CDRUN VRTFPS	FLAP CLSTOP V1 FPS	POLAR CDSTOP VLOFPS	ENGOP CLLO V2 FPS	 FNLO XG FT	GRAD XG1 FT	GRDCFD XROTFT	GRDCAE XOB FT	XFIELD XTO FT
630491.	432.	25.00	1.	4.		0.0830	1.0000	1.0000	9460.5
0.7979	0.1605	0.1593	0.1593	1.9829	1.2000				
210.61	248.53	248.53	262.92	265.27	6467.4	0.0	893.8	865.3	8226.5

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

NOISE TAKEOFF+CLIMB-OUT PATH
POWER SETTING = 462. OPER. ENGINES = 4.

	TIME	DISTANCE	ALTITUDE	VELOCITY	GAMMA	DELTA	ABS ALT	SPD SND	MACH	PRS ALT	CL
1	0.0	0.0	0.0	0.0	0.0	2.000	0.0	1144.09	0.0	0.0	0.798
2	47.55	6467.4	0.0	248.53	0.0	2.000	0.0	1144.09	0.217	0.0	0.798
3	51.06	7361.2	0.0	260.92	0.0	14.041	0.0	1144.09	0.228	0.0	1.983
4	54.35	8226.5	35.0	265.27	4.633	14.364	35.0	1143.97	0.232	33.2	1.919
5	57.19	8977.5	100.0	265.51	4.966	11.304	100.0	1143.73	0.232	95.0	1.594
6	61.63	10151.9	200.0	265.89	4.769	11.450	200.0	1143.38	0.233	190.4	1.594
7	98.46	19967.6	1000.0	268.91	4.550	11.503	1000.0	1140.52	0.236	952.1	1.595
8	146.07	32823.4	2000.0	272.77	4.345	11.507	2000.0	1136.94	0.240	1903.9	1.596
9	195.25	46297.6	3000.0	276.70	4.144	11.508	3000.0	1133.35	0.244	2855.4	1.596
10	245.14	60445.7	4000.0	280.71	3.942	11.506	4000.0	1129.75	0.248	3806.6	1.596
11	299.91	75334.3	5000.0	284.81	3.743	11.508	5000.0	1126.14	0.253	4757.5	1.596
12	353.76	91039.3	6000.0	288.99	3.544	11.507	6000.0	1122.51	0.257	5708.0	1.596
13	410.91	107646.8	7000.0	293.27	3.348	11.505	7000.0	1118.88	0.262	6658.2	1.596
14	470.61	125256.0	8000.0	297.63	3.153	11.502	8000.0	1115.24	0.267	7608.1	1.595
15	533.14	143981.3	9000.0	302.09	2.961	11.499	9000.0	1111.59	0.272	8557.7	1.595
16	598.85	163955.9	10000.0	306.65	2.771	11.495	10000.0	1107.93	0.277	9506.9	1.595

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)

ORIGINAL PAGE IS
OF POOR QUALITY

LOW SPEED POLAR --- 42.0 DEG FLAP

CL	DCLFLP	CDO	CDCLN	DCDFLP	DCDSLT	CDIND	DCDGND	CDOG	CDIG
-0.30000	0.65651	0.01620	0.05319	0.06288	0.06327	0.01072	-0.00536	0.15307	0.14771
0.0	0.65651	0.01620	0.03218	0.06288	0.05048	0.00226	-0.00113	0.13182	0.13069
0.30000	0.65651	0.01620	0.02048	0.06288	0.03927	0.00310	-0.00155	0.12145	0.11990
0.60000	0.65651	0.01620	0.01631	0.06288	0.02964	0.01146	-0.00573	0.12018	0.11445
0.90000	0.65651	0.01620	0.01809	0.06288	0.02158	0.02578	-0.01289	0.12644	0.11355
1.20000	0.65651	0.01620	0.02679	0.06288	0.01510	0.04702	-0.02351	0.14120	0.11769
1.50000	0.65651	0.01620	0.04402	0.06288	0.01014	0.07679	-0.03840	0.16601	0.12762
1.80000	0.65651	0.01620	0.07176	0.06288	0.00571	0.11706	-0.05853	0.20186	0.14332
2.10000	0.65651	0.01620	0.11091	0.06288	0.00123	0.16876	-0.08438	0.24907	0.16469
2.40000	0.65651	0.01620	0.15443	0.06288	0.0	0.22481	-0.11241	0.30390	0.19149
2.70000	0.65651	0.01620	0.20609	0.06288	0.0	0.28901	-0.14451	0.36810	0.22359

POLAR TABLE -- OUT OF GROUND -- GEAR UP

1011.00000	-0.30000	0.0	0.30000	0.60000	0.90000	1.20000	1.50000	1.80000	2.10000	2.40000	2.70000
42.00000	0.15307	0.13182	0.12145	0.12018	0.12644	0.14120	0.16601	0.20186	0.24907	0.30390	0.36810

POLAR TABLE -- IN GROUND -- GEAR UP

1011.00000	-0.30000	0.0	0.30000	0.60000	0.90000	1.20000	1.50000	1.80000	2.10000	2.40000	2.70000
42.00000	0.14771	0.13069	0.11990	0.11445	0.11355	0.11769	0.12762	0.14332	0.16469	0.19149	0.22359

MAXIMUM LIFT COEFFICIENT --- CLLMX(NPUL) = 2.66091

P&WA E^3 INTERCONTINENTAL
(STF505M-7C)