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Space Administration

ENERGY EFFICIENT ENGINE

FLIGHT PROPULSION SYSTEM
AIRCRAFT/ENGINE INTEGRATION EVALUATION

by

GENERAL ELECTRIC COMPANY

Prepared For

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16. Abstract

Aircraft/engine integration studies were conducted with Boeing, Douglas, and Lockheed Aircraft Companies as subcontractors to General Electric's Energy Efficient Engine Program. Economic evaluations of the preliminary design indicated that all NASA goals will be met or exceeded. Installed sfc, DOC, noise and emissions were evaluated. Aircraft installation considerations and growth were reviewed. Supplemental reports by Boeing, Douglas, and Lockheed are included.

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FOREWARD

This report presents the results of aircraft integration analyses of an advanced Flight Propulsion System (FPS) conducted by the General Electric Company. This work was performed for the National Aeronautics and Space Administration (NASA), Lewis Research Center, under Contract NAS3-20643 as part of the Aircraft Energy Efficiency (ACEE) Program, Energy Efficient Engine (E^3) Project. Mr. Neal T. Saunders is the NASA E^3 Project Manager; Mr. Lawrence E. Macioce is serving as NASA Assistant Project Manager. Mr. Roger Chamberlin and Mr. Anthony C. Hoffman were the NASA Project Engineers responsible for the effort associated with Energy Efficient Engine Propulsion System-Aircraft Integration reported here. Mr. Martin C. Hemsworth is Manager of the E^3 Project for the General Electric Company.

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1.0 SUMMARY

The NASA-GE Energy Efficient Engine (E^3) program is the latest in a series of progressive efforts to develop and demonstrate fuel-saving technology for future commercial transport engines. During this program, advanced compressors, fans, turbines, combustors, and exhaust mixers will be designed and run experimentally as test hardware, then combined in a core engine test vehicle and finally as an integrated-core, low spool vehicle.

Program design goals for a fully developed Flight Propulsion System (FPS) are as follows:

- Installed sfc

  ≥12% improvement over CF6-50C at Mach 0.8 10,668 m (35,000 ft), maximum cruise conditions

- SFC Deterioration Rate

  ≤0.5 of CF6-50C

- Direct Operating Cost

  ≥5% improvement over a scaled CF6-50C with same advanced aircraft

- Noise

  Meet FAR-Part 36 (March 1978) with provision for engine growth

- Emissions

  Meet EPA-proposed 1981 Standards

- Commercial Design Practices

In order to ensure that the E^3 Flight Propulsion System (FPS) represented a practical design fully capable of installation on advanced aircraft, aircraft/engine integration studies were included in the program. Through subcontracts with the major commercial aircraft companies (Boeing, Douglas, and Lockheed), mission evaluations of E^3 versus current (CF6-50C) technology were performed in advanced study aircraft to determine that the program economic goals would be met. An important part of the subcontract effort dealt with review and critique of the installation design to establish suitability of the E^3 engine for installation on advanced commercial aircraft of the late 1980's-early 1990's. Elements of the installation such as the inlet, thrust reverser, mount system, accessory package, and aft cowling were reviewed and, in many cases, changed to reflect aircraft company comments on aerodynamic and structural design of the installation.

The E^3 FPS status performance showed an improvement in uninstalled sfc of 13.3% over the CF6-50C, and an installed (no customer bleed or power extraction, but including isolated nacelle drag) sfc improvement of 14.2%. In addition, a fully installed (including nominal customer bleed and power extraction) sfc benefit of 0.4% was identified by means of a regenerative fuel heater that would extract waste heat from the customer Environmental Control System bleed air and return that heat to the fuel system. The fully-installed sfc benefit would then be 14.6% versus the CF6-50C. Over and above this, realization of improved performance retention (50% of the performance deterioration rate of the CF6-50C) would provide a further 1% equivalent sfc benefit over the service life of the engine, for a total improvement of 15.6%.

The mission evaluations by the aircraft companies showed improvements in block fuel of from 15.5% to 21.7% without credit for the improved performance retention and 16.3% to 22.9% with credit. Using a uniform set of DOC calculation ground rules to provide consistency of comparison across the range of study aircraft, improvements of 5.0 to 11.6% in DOC were calculated from E^3 technology without improved performance retention credit, and 5.3 to 12.4% with credit.

2.0 INTRODUCTION

Effective fuel saving technology is increasingly important to our national goal of energy self-sufficiency. Improvements in energy efficiency have increasing priority in commercial avaiation as fuel prices continue to escalate, and fuel costs represent an increasing part of the operating costs of commercial transport aircraft.

The purpose of the NASA-Sponsored Energy Efficient Engine (E^3) program is to develop and demonstrate the technology base for achieving higher thermodynamic and propulsive efficiency in future commercial turbofan engines. This technology must be realistically applicable in practical applications in order to contribute materially to fuel savings in commercial transports entering service beginning in the late 1980's-early 1990's time period. Within this framework, the General Electric Company, under contract with NASA, has undertaken the design of advanced engine components which will be demonstrated individually as component test vehicles and collectively in a core engine test and as a fully integrated core-low spool turbofan vehicle (ICLS). The basis for the design of these components is the E^3 Flight Propulsion System (FPS), the preliminary design of which was reviewed by NASA in November 1978 and approved by NASA shortly afterward.

The FPS represents a commercial design that could be certified for commercial service in the late 1980's-early 1990's time period. The conceptual design was evolved in NASA-sponsored studies over the 1974-1977 time period and is intended to satisfy the NASA-E^3 program design goals.

- Installed sfc

  ≥12% improvement over CF6-50C at Mach 0.8 10,668 m (35,000 ft), maximum cruise conditions

- SFC Deterioration Rate

  ≤0.5 of CF6-50C

- Direct Operating Cost

  ≥5% improvement over a scaled CF6-50C with same advanced aircraft

- Noise

  Meet FAR-Part 36 (March 1978) with provision for engine growth

- Emissions

  Meet EPA-proposed 1981 Standards

- Commercial Design Practices

A significant part of the design effort for the FPS was aircraft/engine integration. This work has been carried out to ensure that the FPS design took into account the practical requirements for installation on advanced commercial aircraft as the major aircraft companies foresaw these requirements in the E^3 application time frame. The economic benefits of E^3 technology over current technology were also evaluated using the General Electric CF6-50 production engine and nacelle as a current technology baseline. In order to enhance the realism of this work, subcontracts were established with Boeing, Douglas and Lockheed Aircraft Companies to perform advanced aircraft sizing and mission evaluation studies using scaled E^3 and CF6-50C engines and to review and critique the E^3 installation design. The Boeing study was based on an advanced domestic twin-engined aircraft with a design payload of 196 passengers. The Douglas and Lockheed studies were based on advanced derivatives of their DC-10 and L1011 trifans. These transcontinental aircraft were sized for design payloads of 458 and 500 passengers, respectively. In addition, Lockheed studied an intercontinental quad-fan version of their advanced aircraft with a 500-passenger design payload. These studies and reviews provided the basis for evaluating the economic benefits and suitability of the installation design for the E^3 FPS. These results are presented in this report.

3.0 DESCRIPTION OF THE E^3 FPS

The E^3 FPS design is described in detail in the Preliminary Analysis and Design Report that resulted from the November 1978 PDR. A compact summary of the design is presented here. Those interested in greater detail can obtain this from Reference 1.

The FPS design departs significantly from current practice in that much of the nacelle design is structurally integral with what is normally called the "bare engine". This is especially true of the fan cowling which is incorporated in the structure of the fan frame. The nacelle wrap (inlet, reverser, aft cowling and tailpipe, and engine buildup kit) is included in the FPS design which is, therefore, a complete propulsion system that includes everything below the strut on a pylon-mounted installation.

3.1 DESIGN FEATURES

The bare engine has many advanced design and performance features. A lightweight hybrid composite fan containment system has been integrated into the composite vane/frame assembly to reduce weight, enhance fan casing stiffness, and improve fan tip clearances.

Active clearance control has been incorporated into the aft portion of the compressor and for all stages of the high and low pressure turbines. Starting and off-design characteristics of the high pressure ratio core compressor will be enhanced through the provisions of variable geometry vanes and a starting bleed system. Off-design automatic flow matching of the core and quarter-stage booster is inherent in the quarter-stage design configuration due to the large fan duct bypass flow of the quarter stage. No moving parts will be required to achieve satisfactory flow matching under all operating conditions.

Control of the engine is through a full authority digital electronic control (FADEC) that will more accurately provide all the current engine control functions plus many other functions such as clearance control, etc. Emissions of the FPS will be significantly lower from current engines through the use of a double annular combustor design. This design employs two coannular sets of burners to provide proper fuel/air ratios from idle to maximum power.

Core-mounted accessories have been employed for the FPS to reduce nacelle drag. The accessories are enclosed from the inner engine cowl volume by a thermal isolation compartment. This compartment is isolated from the core engine and separately ventilated to ensure reliable service and increased safety. The basic engine design can accommodate a fan-case-mounted accessory package if desired.

The major installed and uninstalled FPS features are illustrated in Figures 1 and 2. Extensive use of composites has been assumed in the nacelle both for cost and weight reduction. The nacelle is slender, relative to current practice, with a highlight diameter to maximum diameter ratio of 0.86. Because of the compact design of the turbomachinery, the nacelle installed drag is reduced relative to the CF6-50C baseline engine. Important engine and nacelle dimensions are given in Table I.

Table I. E^3 Flight Propulsion System Status
Engine and Nacelle Dimensions.

TO Thrust, SLS, kN (lb)	162.4	(36,500)
Fan Diameter, cm (in.)	210.8	(83.0)
Max Nacelle Diameter, cm (in.)	248.9	(98.0)
Inlet Length from Fan Face, cm (in.)	159.0	(62.6)
Turbomachinery Length, Fan Front Flange to LP Turbine Aft Frame Flange, cm (in.)	318.0	(125.2)
Overall Nacelle Length, cm (in.)	603.3	(237.5)
Exhaust Nozzle Diameter, cm (in.)	159.0	(62.6)

The long-duct mixed-flow installation not only enhances the installed performance through an increased slenderness ratio and increased thermodynamic efficiency, it eliminates the need for a core thrust reverser. This is because deployment of the fan-stream-only reverser results in a sudden core jet expansion and consequent core thrust spoiling.

Acoustic suppression is provided by a combination of suppression material and design configuration. Advanced Kevlar-based bulk absorbers are utilized throughout the low temperature portions of the installations such as in the inlet and fan duct regions. Fan blade-to-vane spacing was established to minimize fan noise. The inlet is acoustically treated and sized to minimize forward-radiated fan noise. Turbine acoustic treatment is provided by carefully-chosen blade-to-vane spacing and selection of appropriate numbers of turbine blades. Astroquartz sound treatment is applied in the high temperature core exhaust. The mixed flow design also results in a reduced jet exhaust noise.

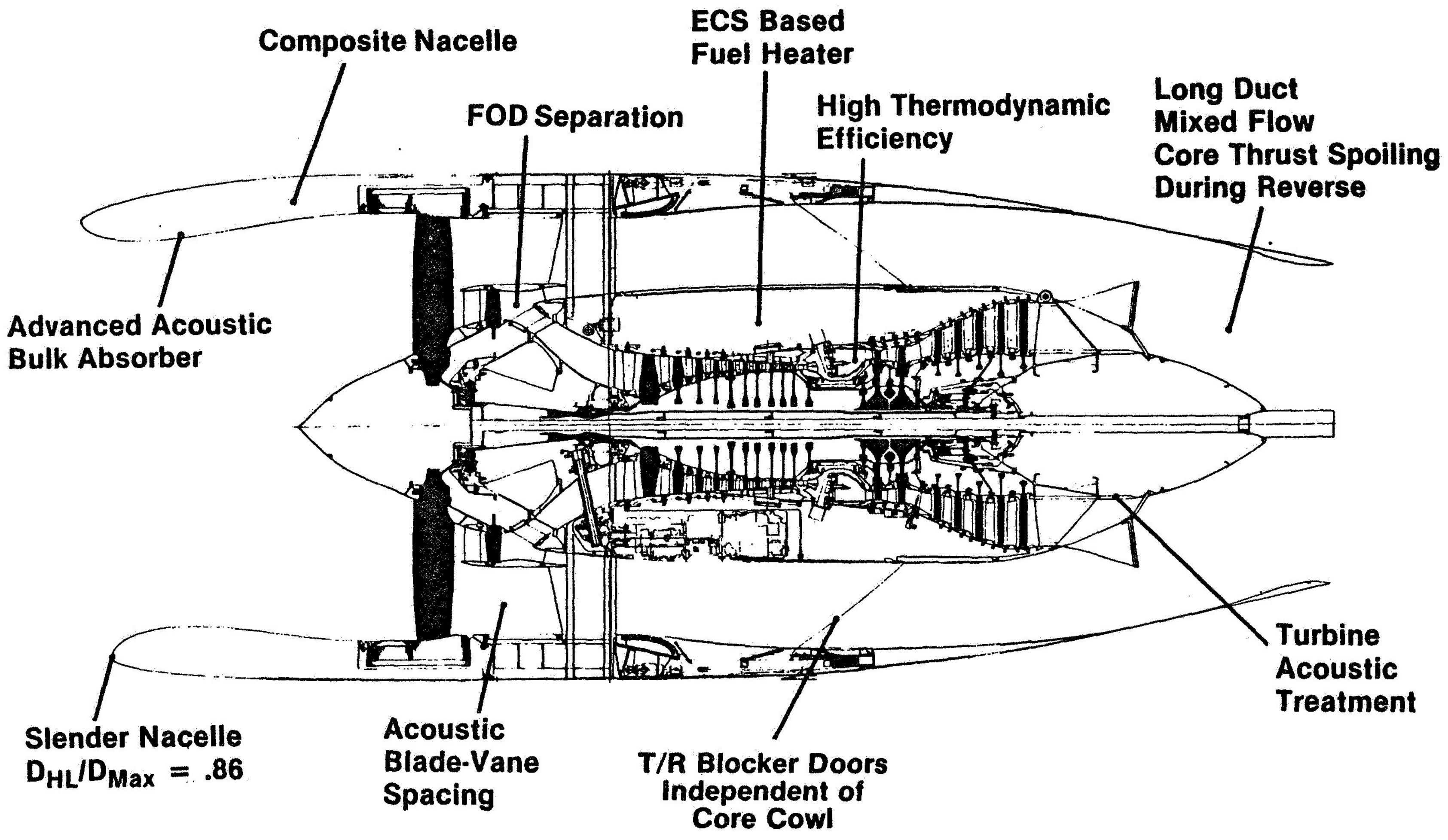


Figure 1. Installed E^3 FPS Features.

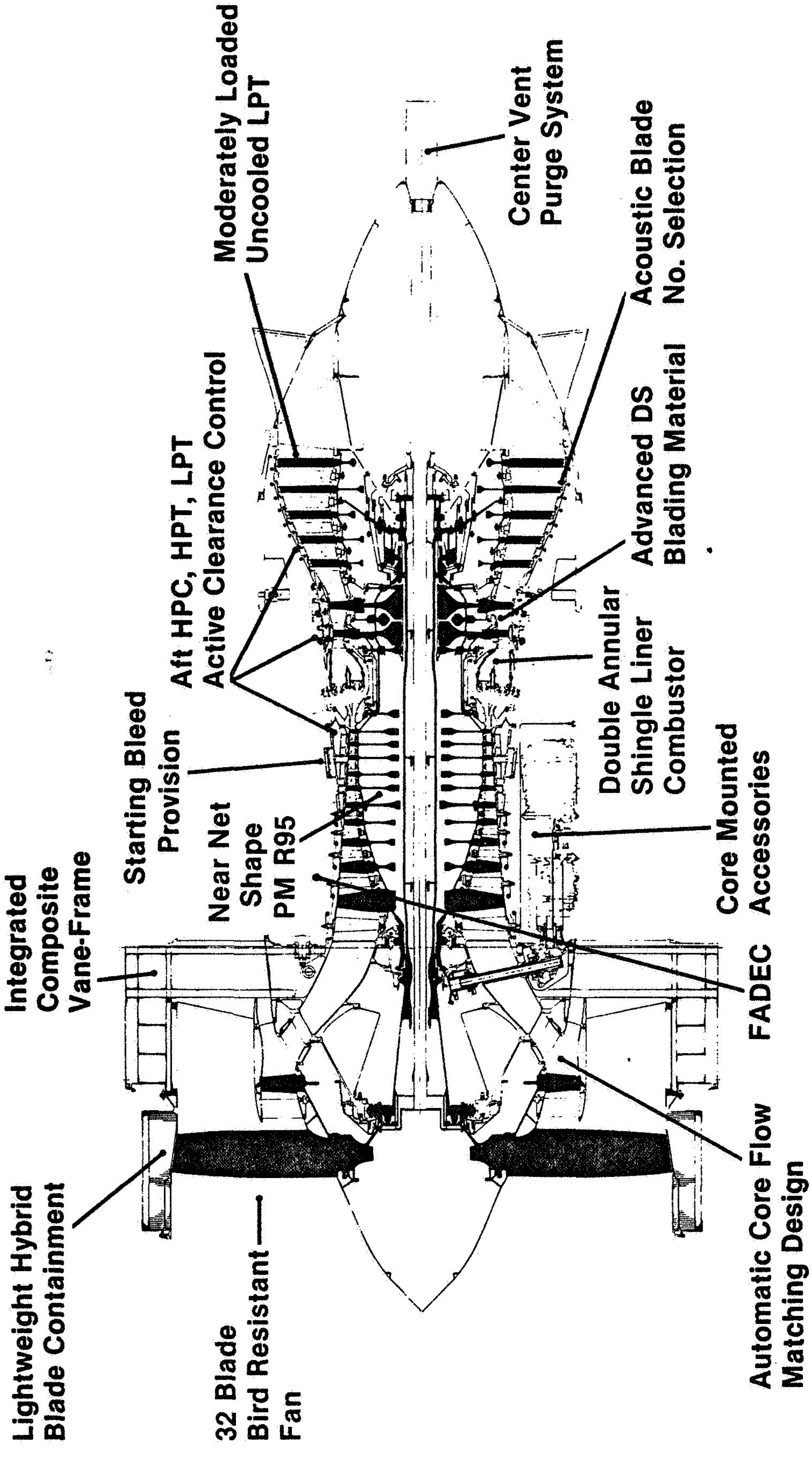


Figure 2. Uninstalled FPS Features.

Resistance of the compression portion of the engine to foreign object damage (FOD) has been enhanced by the use of the quarter-stage configuration which bleeds a significant portion (~40%) into the fan duct, thus bypassing around the core compressor the air most likely to have dust particles.

A regenerative fuel heater is proposed to extract heat from the customer Enviornmental Control System (ECS) air as an integral part of the engine thermodynamics. This system makes use of waste heat of the ECS air and reinjects it into the engine in the form of heated fuel. The proposed system also has the potential of possibly eliminating current ECS fan air coolers and fuel anti-icing heaters.

Table II compares the E^3 FPS and the CF6-50C on the basis of some important cycle parameters, installed performance, and installed engine weight. The installed performance is given two ways: including isolated nacelle drag but with and without nominal customer bleed, and power extraction.

The assessment of performance penalties for nominal bleed and power extraction is based on the assumption that engines with the same altitude climb thrust would be called upon to deliver the same quantities of customer bleed and power for aircraft services. To arrive at this equality, the CF6-50C was scaled to the E^3 FPS fully installed maximum climb thrust at the 10,668 m (35,000 ft)/0.8 Mach flight conditions with representative levels of customer bleed and power applied to both engines. These results, scaled to E^3 size, are shown in Table III.

Representative levels of customer bleed and power extraction are described for each of the advanced study aircraft in the appendices to this report. Although there is some variation in aircraft requirements among the study aircraft, the nominal levels shown in Table III are within the range of requirements and are, in fact, somewhat on the high side of the range.

The major difference between the E^3 FPS and CF6-50C cycles is the reduced specific thrust of the FPS as reflected in the large differences in fan pressure ratio and fan bypass ratio. This results in significantly increased propulsion efficiency. Thermodynamic engine efficiency has been improved through use of more efficient components, a higher overall engine pressure ratio, a significantly higher cruise turbine rotor inlet temperature and the mixed exhaust flow. On a comparable basis, a fully installed cruise sfc reduction of 14.6% has been projected for a fully developed FPS over the referenced CF6-50 engine.

Figure 3 illustrates what the engine would look like suspended from an aircraft pylon and with some of the required piping exposed. Use is made of the aft mounting ring to conduct starter air around the engine to the starter. Mounting of the engine is at three axial locations. The forward mount point takes thrust, side, and vertical loads; the middle mount point supplies roll reaction only; while the aft mount point takes vertical and side loads. The mount is essentially nonredundant under normal flight loads. This mount arrangement has been analyzed in a preliminary manner and results in very low

Table II. Comparison of E^3 FPS Status to Reference CF6-50C

	CF6-50C	E^3	Δ
10,668 m/0.8 M/Standard Day			
Maximum Climb Cycle Pressure Ratio	32	38	
Maximum Climb Bypass Ratio	4.2	6.8	
Maximum Cruise Cycle Pressure Ratio	30.1	36.0	
Maximum Cruise Bypass Ratio	4.34	6.93	
Maximum Cruise Turbine Rotor Inlet Temperature, ° C (° F)	1093 (2000)	1188 (2170)	
Maximum Cruise sfc			
- Installed, No Customer Bleed or Power Extraction	0.667	0.572	-14.2%
- Fully Installed, Nominal Customer Bleed and Power Extraction (See Table III)	0.701	0.599	-14.6%
SLS/30° C (86° F) Day			
Turbine Rotor Inlet Temperature @ TO, ° C (° F)	1340 (2445)	1343 (2450)	
Redline Temperature, ° C (° F)	1441 (2625)	1421 (2590)	
Installed Engine Weight*, kg (lb)	4472 (9860)	4082 (9000)	

*CF6-50 Scaled to E^3 FPS Maximum Climb Thrust.

Table III. Nominal Customer Bleed and Power Extraction,
10,668 m/0.8 M/Standard Day
(35,000 ft/0.8 M/Standard Day).

Engine	CF6-50C (Scaled)	E^3
SLTO Thrust - kN (lb)	174.0 (39,110)	162.4 (36,500)
Fully Installed MCL Thrust - kN (lb)	← Same →	
Customer Bleed - kg/sec (lb/sec)	0.95 (2.1)	0.95 (2.1)
Customer Power Extraction - kw (hp)	186 (250)	186 (250)

Customer bleed and power extraction levels are set equal for the E^3 FPS and the CF6-50 scaled to E^3 maximum climb thrust, fully installed at 10,668 m (35,000 ft), 0.8 M.

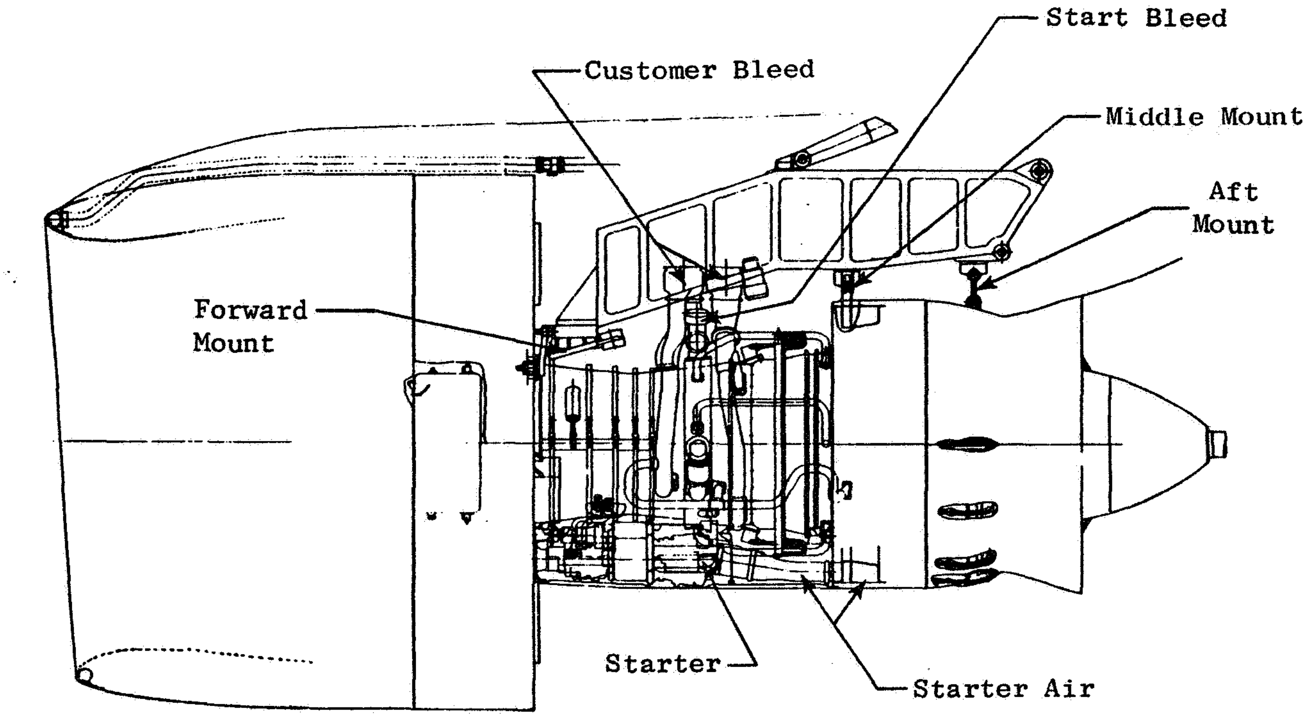


Figure 3. Installed Engine Piping and Mount Details.

levels of casing ovalization and bending. Analysis of this and other mount configurations is continuing in order to determine the optimum configuration for the FPS.

3.2 DESIGN REQUIREMENTS

The design of the FPS has been conducted in accordance with General Electric's commercial engine practices. In particular, the hot section (i.e., combustor, HP turbine blades, etc.) design lives have been increased to help reduce engine maintenance costs. Past experience has shown that a large proportion of engine maintenance costs is distributed among relatively few hot section parts.

The growth requirements for the FPS were accommodated in the following manner. Provisions were made for anticipated growth in the rotor and stator structure; but the materials, cooling and aerodynamic designs were optimized for the FPS size and cycle. When evaluating FPS weight and cost, all provisions for growth are subtracted.

4.0 CYCLE AND PERFORMANCE

4.1 DERIVATION OF FPS CYCLE

The E^3 FPS preliminary design cycle is based on the results of a number of NASA Programs involving component and cycle technology studies (Reference 2). As shown in Figure 4, the development of the E^3 cycle began in 1974 with the STEDLEC (Study of Turbofan Engine Designed for Low Energy Consumption, Reference 3) study. This was an extensive cycle and technology study of turbofan engines which considered separate- and mixed-flow exhaust system, boosted and nonboosted, single stage HP turbine; and direct-drive and geared fan configurations. All engines were studied as installed on advanced transport aircraft for evaluation against the NASA performance and economic goals.

This was followed by the USTEDLEC (Unconventional STEDLEC, Reference 4) program which continued the turbofan studies along with turboprop engine and regenerative cycles. This study narrowed the candidates to four engine types with separate- and mixed-flow exhaust versions of direct-drive and geared fan configurations. Concurrent with this study was the AMAC program which defined an advanced, 10-stage, 23:1 pressure ratio compressor. This compressor was to be used with a two-stage, high pressure turbine in a nonboosted direct-drive turbofan engine.

The E^3 PD&I (Preliminary Design and Integration Studies, Reference 2) program evaluated four engine types using advanced components, cycles, and material technologies against the NASA goals on operating economics, fuel efficiency, and environmental factors. Mission studies were conducted by airframe contractors based on advanced transport aircraft designs. The final cycle from this study was selected as the proposal cycle for this contract.

The cycle selection process involved two phases. The first phase developed a family of engines which provided performance for a range of values of the significant cycle parameters. These were fan pressure ratio, bypass ratio, cycle pressure, HP turbine inlet temperature, and exhaust system type. These engines were then evaluated in the second phase by airframe subcontractors on a variety of missions which incorporated advanced concepts in transport aircraft designs. The aircraft designs included twin, trijet, and quadjet configurations. The mission studies were evaluated against the NASA goals for: economics (DOC), specific fuel consumption (sfc), fuel burned (W_f), emissions, and acoustics. The engines were scaled to meet specific thrust requirements.

The thrust size for the E^3 FPS design was selected by General Electric based on these mission studies and corporate evaluations of likely market requirements. The basic engine design and associated technology are scalable over a wide range of thrust requirements.

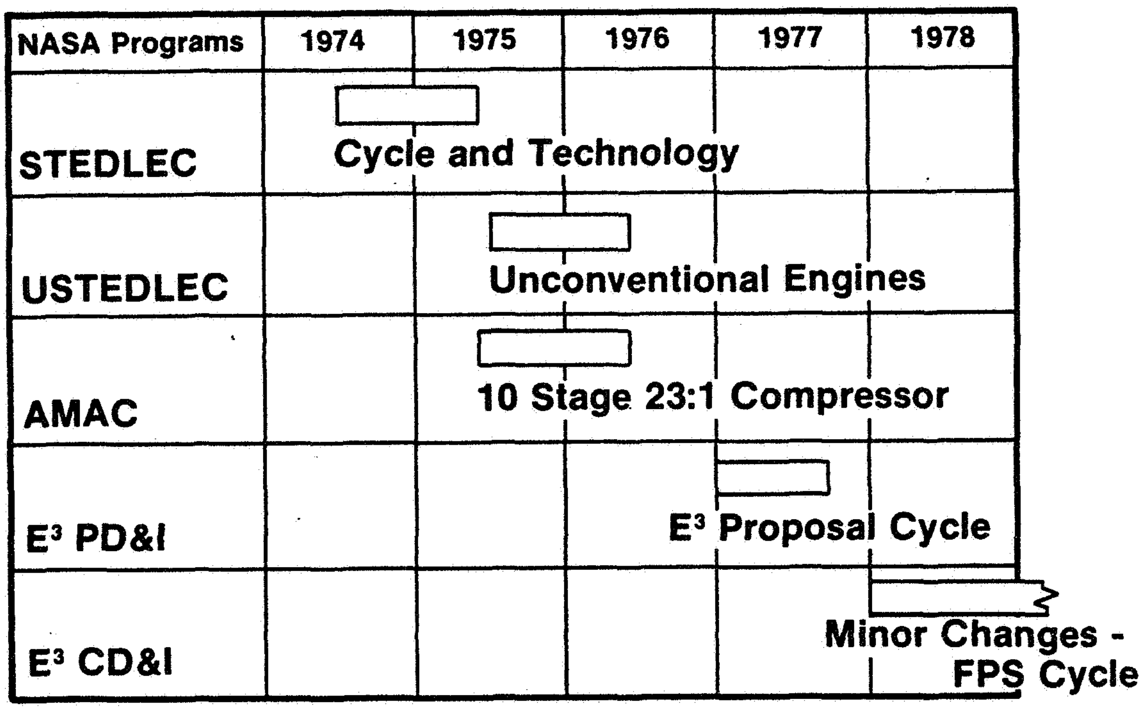


Figure 4. E^3 Cycle Selection.

4.2 FPS CYCLE DESCRIPTION

The E^3 cycle parameters are shown in Table IV for the three key rating points at maximum climb, maximum cruise, and SLS takeoff. The climb and cruise points are shown for a 10,668 m (35,000 ft), 0.8 Mach flight condition. All points are defined for dry air, zero bleed and power extraction, and 100% inlet ram recovery.

Table IV. E^3 FPS Cycle Definition.

Parameter	Maximum Climb	Maximum Cruise	Takeoff
Uninstalled sfc (Std. Day), kg/N-hr(lbm/lbf-hr)	0.0557 (0.546)	0.0553 (0.542)	0.0300 (0.294)
Overall Pressure Ratio	37.7	36.1	29.7
Bypass Ratio	6.8	6.9	7.3
Fan Bypass Pressure Ratio	1.65	1.61	1.50
Fan Hub Pressure Ratio	1.67	1.63	1.51
Compressor Pressure Ratio	23.0	22.6	20.0
HPT Rotor Inlet Temp. °C (° F)	1281 (2340)	1244 (2272)	1343 (2450)

The engine thrust is flat-rated over a range of ambient temperatures subject to a maximum HP turbine inlet temperature as shown below:

- Standard Day +15° C (+27° F) for takeoff
- Standard Day +10° C (+18° F) for climb and cruise

The temperatures shown in Table IV for each rating are at the flat-rating temperature condition.

The uninstalled sfc values shown are for a standard day ambient temperature. The maximum cruise sfc is the reference point for the NASA goal. This value is adjusted for an isolated nacelle drag to determine the installed sfc goal of the E^3 program.

The cycle data shown are calculated from the General Electric cycle model computer program system used on all engine programs. These are large scale computer programs which contain mathematical models of the engine components as thermodynamic maps, cooling and parasitic flows, pressure losses, Reynolds number effects, and exhaust system characteristics. Steady state performance is calculated with momentum balance, energy, and flow continuity maintained from station-to-station in the engine. The model also contains models of the 1962 U.S. standard atmosphere and thermodynamics using real gas effects including dissociation effects.

Table V shows the component efficiencies at the maximum cruise condition.

Table V. FPS Cycle - Maximum Cruise Component Performance.

Component	Performance
Fan Bypass, η	0.887
Fan Hub, η	0.892
Compressor, η	0.861
Combustor, η	0.995
HP Turbine, η	0.924
LP Turbine, η	0.917
Mixing Effectiveness	0.75

4.3 FPS PERFORMANCE PREDICTION VERSUS BASELINE CF6-50C

The E^3 sfc improvement goal of -12% is evaluated against a General Electric CF6-50C engine. The comparison is made for maximum cruise thrust at 10,668 m (35,000 ft), 0.8 Mach at standard day ambient temperature with zero bleed and power extraction and 100% inlet ram recovery.

Table VI shows that the E^3 sfc improvement is -13.3% uninstalled and -14.2% installed as an isolated nacelle. The data identify the source of the sfc improvement based on a cycle parameter comparison of the two engines.

Initial evaluation of the data shown could lead to misinterpretation of how the E^3 engine design provides the sfc improvement. For example, of the -4.1% improvement attributed to adiabatic efficiencies, -3% results from an improved fan. However, when considering a comparison of the two compressors, the E^3 engine has a component with a much higher pressure ratio (23:1 versus

Table VI. E^3 FPS/CF6-50C Reference Maximum Cruise SFC Comparison.

		FPS % Δ sfc	
●	Component Efficiencies	- 4.1	
●	Mixed Flow Exhaust	- 3.1	
●	Propulsive Efficiency (FPR-BPR)	- 2.5	
●	Increased Cycle Pressure Ratio (+20%)	- 1.0	
●	Increased HP Turbine Inlet Temperature, 79° C (+175° F)	- 1.5	
●	Cooling and Parasitic Flows	- 1.0	
●	Flowpath Pressure Losses	- 0.1	
	Uninstalled Δ sfc Improvement		- 13.3%
●	Reduced Isolated Nacelle Drag	- 0.6	
●	Integrated Aircraft Generator Cooler	- 0.3	
	Installed Δ sfc Improvement		- 14.2%
●	Bleed, HP Extraction	+ 0.4	
●	Fuel Heater, Customer Air	- 0.8	
	Fully Installed Δ sfc Improvement		- 14.6%

13:1) and represents a significant improvement in polytropic efficiency. With a higher pressure ratio compressor and advanced cooling flow technology, a higher thermal efficiency cycle can be obtained as evidence by the improvements due to cycle pressure ratio and HP turbine inlet temperatures. The propulsive efficiency improvement results from the lower fan pressure ratio and higher bypass ratio. The significant mixed flow improvement results from the fact that the CF6-50C has a separated flow exhaust system.

4.4 IMPROVED PERFORMANCE RETENTION

It is an important goal of the E^3 program that the high level of engine performance be retained over the long term as the engine is used in commercial service. Current turbofans exhibit a significant deterioration in performance with time in service. The E^3 engine has a design goal of halving the long-term performance loss rate exhibited by the baseline CF6-50C engine. This goal is illustrated by Figure 5. The net benefit to mission performance for improved performance retention was assessed at a 1% equivalent long-term sfc improvement over the current technology CF6-50C. Mission evaluations were made both with and without this benefit to illustrate its impact on program goals. The cruise sfc improvement over the CF6-50C did not include credit for this, however.

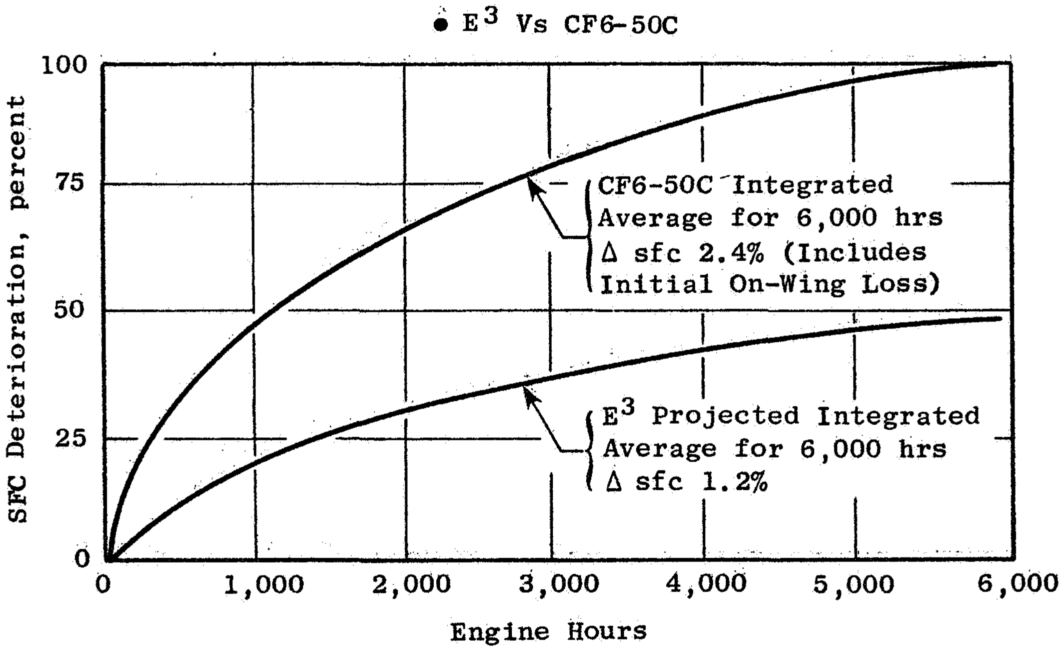
4.5 THRUST FLEXIBILITY AND GROWTH

The design of the FPS baseline engine considered growth requirements to properly assess the impact on the component design changes. Studies were conducted for balanced growth up to 20% in thrust with the constraint that the engine flowpath would remain unchanged. Flexibility for growth in steps was enhanced by the fan hub quarter-stage that could be modified to increase core engine boost.

Thrust growth levels of +5%, +10%, and +20% were evaluated and are summarized in the following tables. Table VII presents a summary of the major cycle parameters for the maximum climb and SLS takeoff conditions.

Table VIII identifies the components that require modification. Note that all the thrust growth configurations include a cooling flow modification to maintain constant turbine blade life.

The +20% growth engine requires changes to most of the components in the engine but not to the flowpath. The major items include: a new fan blade with higher tip speed and pressure ratio; a high flow compressor modification which will require some reblading and a new stator schedule; and some turbine aero changes. (The interim growth steps will overspeed the FPS fan blade to attain the required engine airflow.) The higher fan speed will permit a significant increase in hub boost of about 23%. These changes to the front of the engine require changes in the turbine diaphragms and mixer area split. The HP and LP turbine flow functions will be increased 3% and 13%, respectively. The mixer total area will remain unchanged in order to maintain the same nacelle size. The exhaust nozzle area will be decreased by approximately 2%.



Note: Improvement in performance retention (half the deterioration of CF6-50C) will result in additional ~ 1% improvement in fleet fuel consumption over the operational life of the engine.

Figure 5. Long Term Performance Retention.

Table VII. E^3 Growth Capability.

Maximum Climb - 10,668 m (35,000 ft)/0.8 M

	Net Thrust				
	FPS	Throttle Push +5%	+5%	+10%	+20%*
Uninstalled SFC (Standard Day) kg/N-hr (lbm/lbf-hr)	0.0557 (0.546)	0.0564 (0.553)	0.0562 (0.551)	0.0570 (0.559)	0.0574 (0.563)
Overall Pressure Ratio	37.7	39.0	42.3	42.7	45.0
Bypass Ratio	6.8	6.7	6.1	6.1	5.4
Fan Bypass Pressure Ratio	1.65	1.68	1.70	1.70	1.75
Fan Hub Pressure Ratio	1.67	1.70	1.90	1.87	2.05
Takeoff - SLS/30° C (86°F)					
Net Thrust, kN (lb)	162.36 (36,500)	170.50 (38,330)	170.50 (38,330)	178.60 (40,150)	194.83 (43,800)
HPT Rotor Inlet Temperature, ° C (° F)	1343 (2450)	1367 (2493)	1353 (2467)	1394 (2541)	1443 (2630)

*A larger fan might be considered for better sfc.

Table VIII. Growth Component Changes*.

Component Change Required	Throttle Push +5%	+5%	+10%	+20%
New Fan Blade				X
New Booster Blading		X	X	X
High Flow Compressor				X
Larger HPT Nozzle Area				X
Increased Cooling Flows	X	X	X	X
Larger LPT Flow Function		X	X	X
New Mixer - Same Total Area				X
Smaller Exhaust Nozzle				X

*Flowpath Unchanged

The identification of a +20% thrust growth path was a program requirement. The basic FPS rotors and static structures were designed to accommodate growth levels of pressure and rotor speed, although cooling flow allotments were based on FPS gas path temperatures. The +20% growth engine performance was poorer than the FPS in cruise sfc as a result of the constraint of constant flowpath. The most serious consequence of that constraint was that only a small (2.4%) increase in total airflow was available within the FPS fan diameter. As a result, most of the thrust increase was obtained from temperature and exhaust pressure ratio increses which led to a degradation in propulsive efficiency and a 2.7% cruise sfc increase over the FPS level. Another consequence was an estimated engine noise increase of 3 to 3.5 EPNdB at takeoff and 1 to 1.5 EPNdB at approach.

Exhaust emission characteristics also change when takeoff thrust has grown by 20% as evidenced by the resulting delta values shown below:

CO	-1.05	EPAP
HC	-0.02	EPAP
NO_x	+1.32	EPAP
Smoke	+4	SN

The primary cause of the changes in exhaust emissions is the increase in overall pressure ratio from 37.7 in the baseline engine to 45.0 in the growth engine (at maximum climb conditions). This increase in overall pressure ratio results in increased combustor inlet pressure and temperature at the prescribed EPA landing-takeoff cycle conditions which causes carbon monoxide and unburned hydrocarbons emissions to decrease and oxides of nitrogen and smoke emissions to increase.

Although significant thrust growth within the same flowpath/installation envelope is desirable, it is by no means the only practically useful way to obtain engine growth. If it is desired to achieve growth without sfc or noise penalties, a larger fan with greater airflow capacity could be used. In this case, cruise sfc and engine noise margin as the baseline FPS.

5.0 PROPULSION SYSTEM AIRCRAFT INTEGRATION EVALUATIONS

The aircraft integration effort was intended to ensure that the E^3 Flight Propulsion System (FPS) design was consistent with the anticipated requirements of advanced commercial aircraft in the late 1980's - early 1990's. For this purpose, subcontracts were established with the Boeing, Douglas, and Lockheed Aircraft Companies. Using appropriate projections of their advanced transport designs, the aircraft companies evaluated the E^3 FPS against the baseline CF6-50C current-technology engine nacelle to determine the advantage offered by E^3 technology in mission fuel consumption. The advantage in direct operating cost (DOC) due to E^3 technology was then evaluated by GE using calculation procedures coordinated by NASA to ensure a consistent evaluation for all the aircraft that were studied.

In addition to the direct mission economic evaluations that were performed, the aircraft company subcontracts provided for review and critique of the nacelle design, including inlet and afterbody aerodynamics, engine mounting, accessory gearbox arrangement, and thrust reverser and cowling mechanical design. Results of this effort will be discussed in Section 5.0.

The subcontracts with Boeing, Douglas and Lockheed called for evaluation of the E^3 FPS and the baseline CF6-50C engines appropriately scaled in thrust size on advanced commercial transport designs representative of each company's projections into the late 1980's - early 1990's. Boeing studied a twin-engined, 196-passenger airplane with a design range of 3704 km (2000 nmi). Douglas evaluated a three-engined, 458-passenger advanced derivative of their DC-10 aircraft with a 5556 km (3000 nmi) design range. Lockheed studied two aircraft: a three-engined, 500-passenger aircraft with a 5556 km (3000 nmi) design range; and a four-engined, 500-passenger aircraft with a 12,038 km (6500 nmi) design range, both advanced derivatives of their L1011 aircraft. All of the study aircraft incorporated advanced technology features as projected by the respective aircraft companies for commercial transport studies in the E^3 time period.

The aircraft companies provided descriptions of their study aircraft and associated technology features in reports that are appended to this report. The reader may refer to those reports for details concerning the advanced aircraft studied by each aircraft company.

The aircraft companies were provided with engine performance, weight, dimensions, price, and maintenance cost data for the baseline CF6-50C and E^3 engines, along with scaling data to permit them to scale both engines to match the different power requirements of their aircraft. They performed their sizing and mission evaluations for each aircraft at design payload/range and for off-design payload/range combinations selected as typical by each aircraft company. These results in turn were used as inputs to the economic analysis performed by General Electric. The E^3 FPS evaluations were made with and without the 1% improvement in long-term average sfc due to improved performance retention, which was a goal that was added to the E^3 requirements.

The block fuel improvement for E^3 technology is shown in Table IX. Improvements from 15.5 to 21.7% were realized without credit for improved performance retention. With credit for improved performance retention, savings from 16.3 to 22.9% were realized.

Table IX. Economic Benefits, Block Fuel.

	Mission	Range km (nmi)	W/O Perf. Ret. Benefit %Δ Block Fuel	W/Perf. Ret. Benefit %Δ Block Fuel
Boeing Twin Fan	Design	3704 (2000)	-17.4	-18.3
	Typical	1852 (1000)	-16.0	-16.9
	Typical	1232 (665)	-15.5	-16.3
Douglas Trifan	Design	5556 (3000)	-18.7	-19.8
	Typical	1852 (1000)	-17.2	-18.3
Lockheed Trifan	Design	5556 (3000)	-17.3	-18.3
	Typical	2593 (1400)	-16.3	-17.3
Lockheed Quadfan	Design	12038 (6500)	-21.7	-22.9
	Typical	5556 (3000)	-20.1	-21.2

The fuel savings results versus flight length are shown graphically in Figure 6. The benefits show a substantial increase with increasing distance and consequent increase in TOGW fuel fraction.

5.1 ECONOMIC STUDIES DIRECT OPERATING COST

The results of the aircraft company mission evaluations were used as inputs to a DOC analysis. The ground rules were established under NASA coordination to provide a consistent comparison of E^3 versus CF6-50 technology for all the different aircraft that were studied. The study ground rules, which drew heavily from the Boeing Company economic method for evaluating operating costs, are summarized as follows:

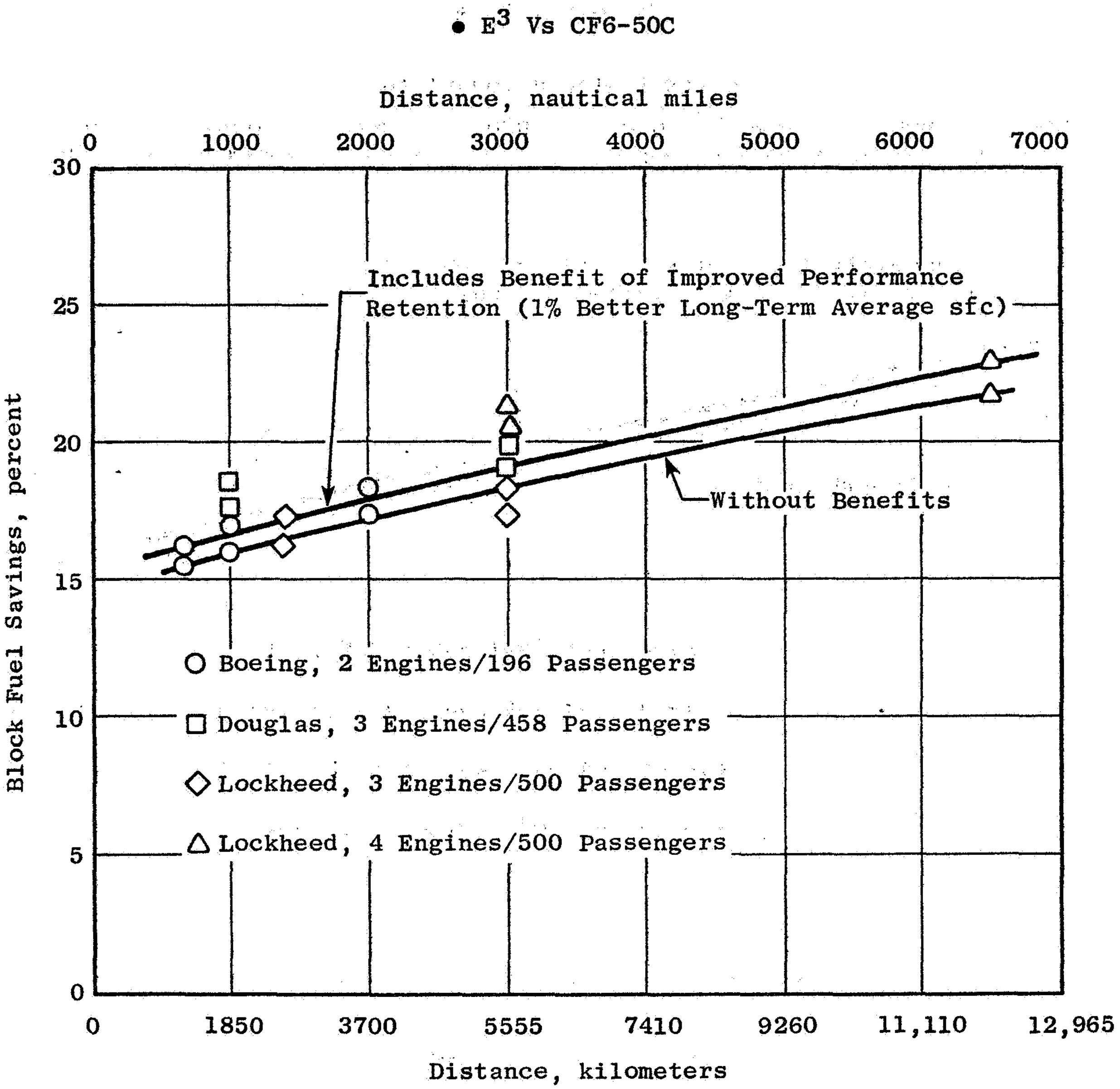


Figure 6. Block Fuel Savings.

Element	Calculated Method
Price Escalation	All costs in 1977 dollars
Flight Crew Cost	Boeing 1977 method - three-man crew for all flights
Fuel	10.6¢/liter (40¢/gal.) Domestic 11.9¢/liter (45¢/gal.) International
Block Time	Boeing 1977 method
Insurance	0.5%
Aircraft Maintenance	Boeing 1977 method - include nacelle in airframe maintenance
Maintenance Burden	200% on labor only airframe and engine
Engine Maintenance	GE methods based upon mature engine - no derates. Include bare engine, engine accessories and reverser
Depreciation	Straight line, 15 years to 10%
Spares	Airframe 6%, engine 30% (total propulsion system including nacelle and reverser)
Utilization	Boeing 1977 method, as modified in December 1977, provides a constant number of trips per year as a function of range
Ground Time	Domestic Trunk - 15 Minutes U.S. International - 20 Minutes
Fuel	Weight 802.7 kg/m^3 (6.71 lbs/gal.)
Oil	Include oil cost at $2.64/liter ($10/gal.), 970.4 kg/m^3 (8.1 lb/gal.) usage, 0.061 kg/hr/engine (0.135 lb/hr/engine)
Airframe Weight	$W_{AF} = O_{WE}$ - (bare engine + reverser + engine access. + nacelle)
Engine Maturity	All engines are mature
Labor Rate	$9.70/hr in 1977 $
Landing Fees	Not included in DOC

Element	Calculated Method
Average Range	Using typical mission range supplied by the airframe companies
Average Load Factor	Use load factor supplied by airframe companies
Interest	There are no borrowed funds
Aircraft Price	Per Table X

NOTE: A 2% nonrevenue flight time shall apply to fuel and maintenance costs.

Table X. Airplane Pricing Functions.

Airplane Price = Bare Airframe + Furnishing + Avionics + Engines

Bare Airframe Price

Current, New and Derivative Wide Body = $0.5\ (W_{af}/1000)^{0.7}$

$W_{AF} = O_{WE}$ - (Bare Engine + Reverser + Engine Accessories + Nacelle)

Furnishing Price

Domestic Aircraft = $0.0080\ N_{seat} - 0.284$

International Aircraft = $0.0089\ N_{seat} - 0.315$

Avionics Price

Derivative and Wide Body Domestic = $0.0022\ N_{seat} + 1.54$

Derivative and Wide Body Over Water = $0.0022\ N_{seat} + 1.81$

Above Values in Millions 1977 $.

Significant engine inputs to the DOC calculations included sfc and weight (as they affected mission fuel and aircraft weight), engine price and maintenance cost. Table XI shows the status weight of the FPS engine by element for a 162.4 kN (36,500 lb) takeoff thrust size.

Table XI. Engine Weight Estimate by Module.

	FPS Status Wt. No Margin	
Bare Engine	kg	lb
Fan	1066	2350
LP Turbine	753	1660
Core	1007	2220
Other	463	1020
Total Bare Engine	3289	7250
Installation		
Inlet	161	355
Reverser and Duct	304	670
Core Cowl and Tailpipe	124	275
Engine Buildup	204	450
Total Installation	793	1750
Total Installed Weight	4082	9000

Table XII shows the status engine estimated selling price, by element, in 1977 dollars. The price was established on the basis of CF6-50C engine manufacturing costs, projected to a mature engine scaled to the E^3 engine design size and adjusted to account for design and manufacturing differences between the two engines.

Table XII. Estimated Engine Price - K$ (1977 Dollars).

	FPS Status	
Fan Module	$ 520	
LP Turbine Module	483	
Core Module	715	
Other Bare Engine	237	
Bare Engine Total		$1955
Inlet	$ 95	
Fan Reverser and Duct	240	
Core Cowl and Tailpipe	71	
Engine Buildup	172	
Installation Total		$ 578
Installed Engine Total		$2533

Table XIII shows the status estimated engine maintenance cost by element, in 1977 dollars, for a 162.4 kN (36,500 lb) takeoff thrust size. As with selling price, the maintenance costs were derived by comparison to a mature CF6-50C baseline.

Table XIII. Estimated Engine Maintenance Cost, 2-Hour Mission, No Derate.

Materials by Module	$/Engine Flight hr (1977 Dollars)
Fan	$ 1.55
LP Turbine	3.63
Core	14.32
Other	8.55
Total Materials	$28.05
Direct Labor (9.00/Hour)	12.73
Labor Burden (200%)	25.47
Total Maintenance Cost	$66.25

Table XIV compares the economic elements of the DOC analysis for the baseline CF6-50C and the E^3 FPS at its hardware design size and scaled to the same installed thrust as the CF6-50C engine at 35,000 ft/0.8 M maximum climb rated power. The CF6-50C versus the scaled E^3 provides a direct comparison of these engines for aircraft with similar cruising power requirements.

The scaled E^3 engine is somewhat lower in installed weight and significantly lower in maintenance cost, which contribute to lower DOC. However, the unit price is significantly higher, which raises DOC. The impact of these effects will be discussed shortly.

Table XV shows the DOC improvements calculated for the E^3 technology in all the study aircraft. The results are shown with and without credit for improved performance retention and are also presented graphically in Figure 7.

The major elements that constitute DOC are fuel and oil costs, depreciation, crew cost, airframe maintenance, engine maintenance, and insurance. The fractional contributions of each element to total DOC are shown in Table XVI for three typical aircraft/mission combinations. There is a noticeable increase in fuel cost fraction with increasing distance, as one would expect. These results are also presented graphically for all study aircraft in Figures 8 through 13.

Table XIV. Major Engine Inputs to DOC Analysis.

Engine	CF6-50C	E^3	
TO Thrust Size, kN (lb)	223.5 (50,250)	162.4 (36,500)	208.6 (46,900) (Scaled)**
Bare Engine Weight, kg (lb)	3,946 (8,700)	3,289 (7,250)	4,504 (9,930)
Engine + Nacelle Weight, kg (lb)	5,761 (12,700)	4,082 (9,000)	5,511 (12,150)
Engine Price, 1977 Dollars	2,281,000	2,533,000	2,951,000
Maintenance Materials, $/EF hr*	51.00	28.05	31.70
Maintenance Labor, $/EF hr*	15.50	12.73	14.38
Labor Burden (200%), $/EF hr*	31.00	25.47	28.78
Total Maintenance, $/EF hr*	97.50	66.25	74.86

*2-hr mission, no derate.

**Same maximum climb thrust at 10.7 km (35,000 ft) -0.8 M, installed as CF6-50C.

Table XV. Economic Benefits, Direct Operating Cost (NASA-Coordinated Rules).

	Mission	Range km (nmi)	W/O Perf. Retention Benefit % DOC	W/Perf. Retention Benefit % DOC
Boeing Twin Fan	Design	3,704 (2000)	-6.6	-6.9
	Typical	1,852 (1000)	-5.4	-5.6
	Typical	1,232 (665)	-5.0	-5.3
Douglas Trifan	Design	5,556 (3000)	-9.0	-9.5
	Typical	1,852 (1000)	-6.7	-7.1
Lockheed Trifan	Design	5,556 (3000)	-7.4	-8.0
	Typical	2,593 (1400)	-6.2	-6.8
Lockheed Quadfan	Design	12,038 (6500)	-11.6	-12.4
	Typical	5,556 (3000)	-9.9	-10.7

Table XVI. Distribution of DOC Elements, E^3 Engine with Credit for Improved Performance Retention.

Aircraft Type	Domestic Twin Fan	Domestic Trifan	Intercontinental Quadfan
Distance - km (nmi)	1232 (665)	1852 (1000)	5556 (3000)
Load Factor - %	55	60	55
Fuel and Oil - %	23.5	31.7	33.0
Depreciation - %	31.1	29.3	27.2
Crew - %	20.2	16.0	19.0
Airframe Maintenance - %	14.0	12.9	10.4
Engine Maintenance - %	8.9	7.9	8.4
Insurance - %	2.3	2.2	2.0

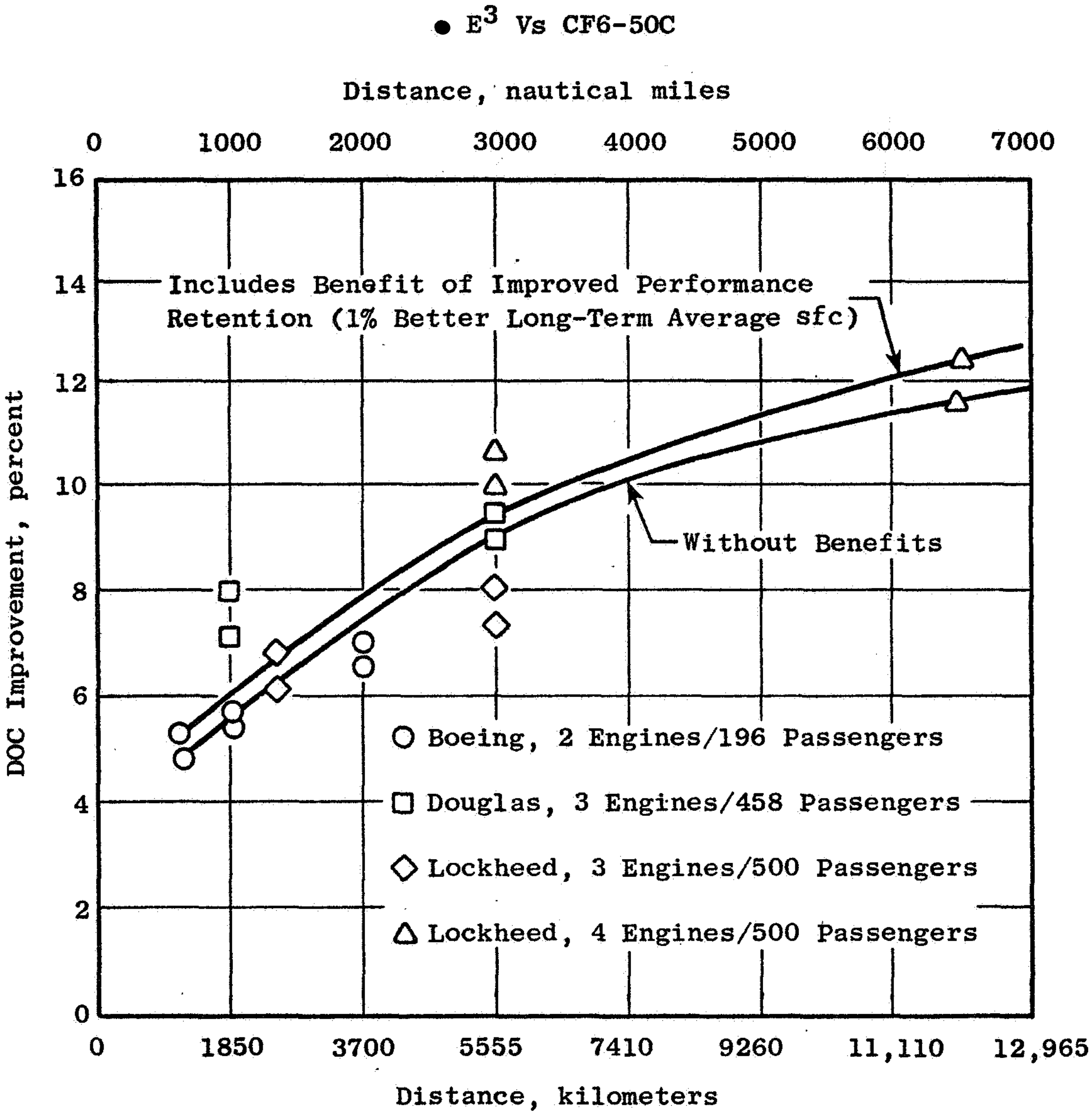


Figure 7. Direct Operating Cost (DOC) Improvement.

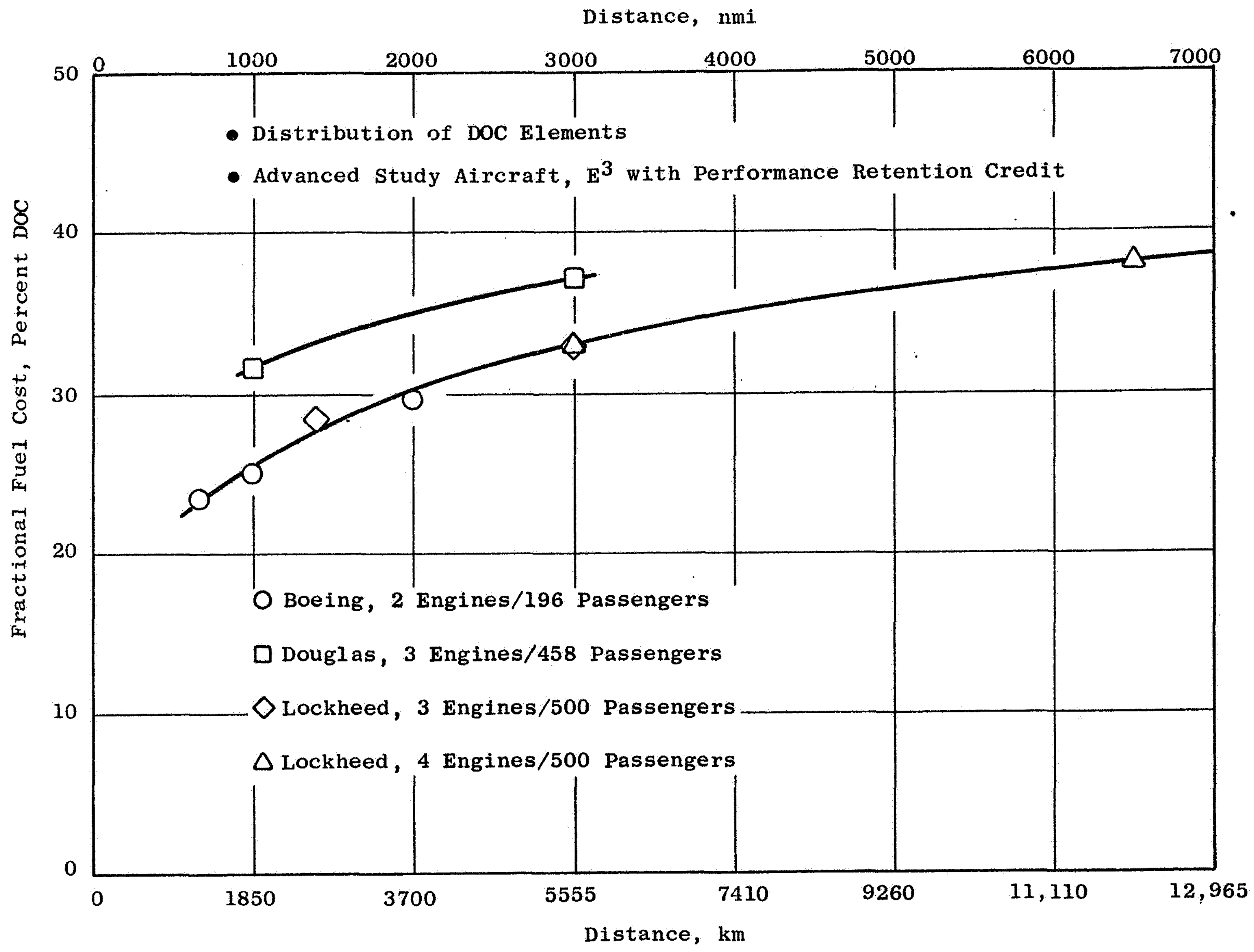


Figure 8. Fractional Fuel Cost.

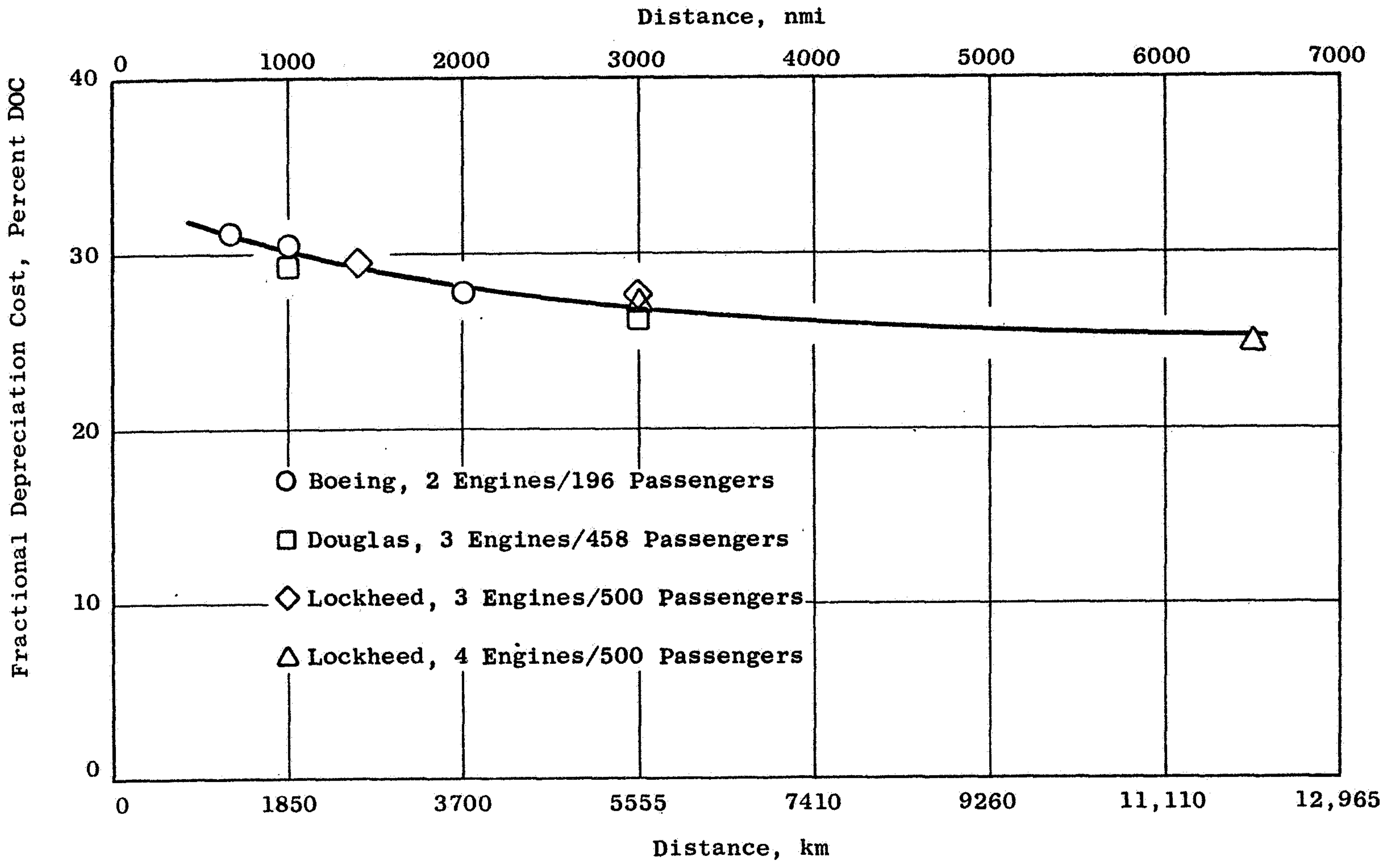


Figure 9. Fractional Depreciation Cost.

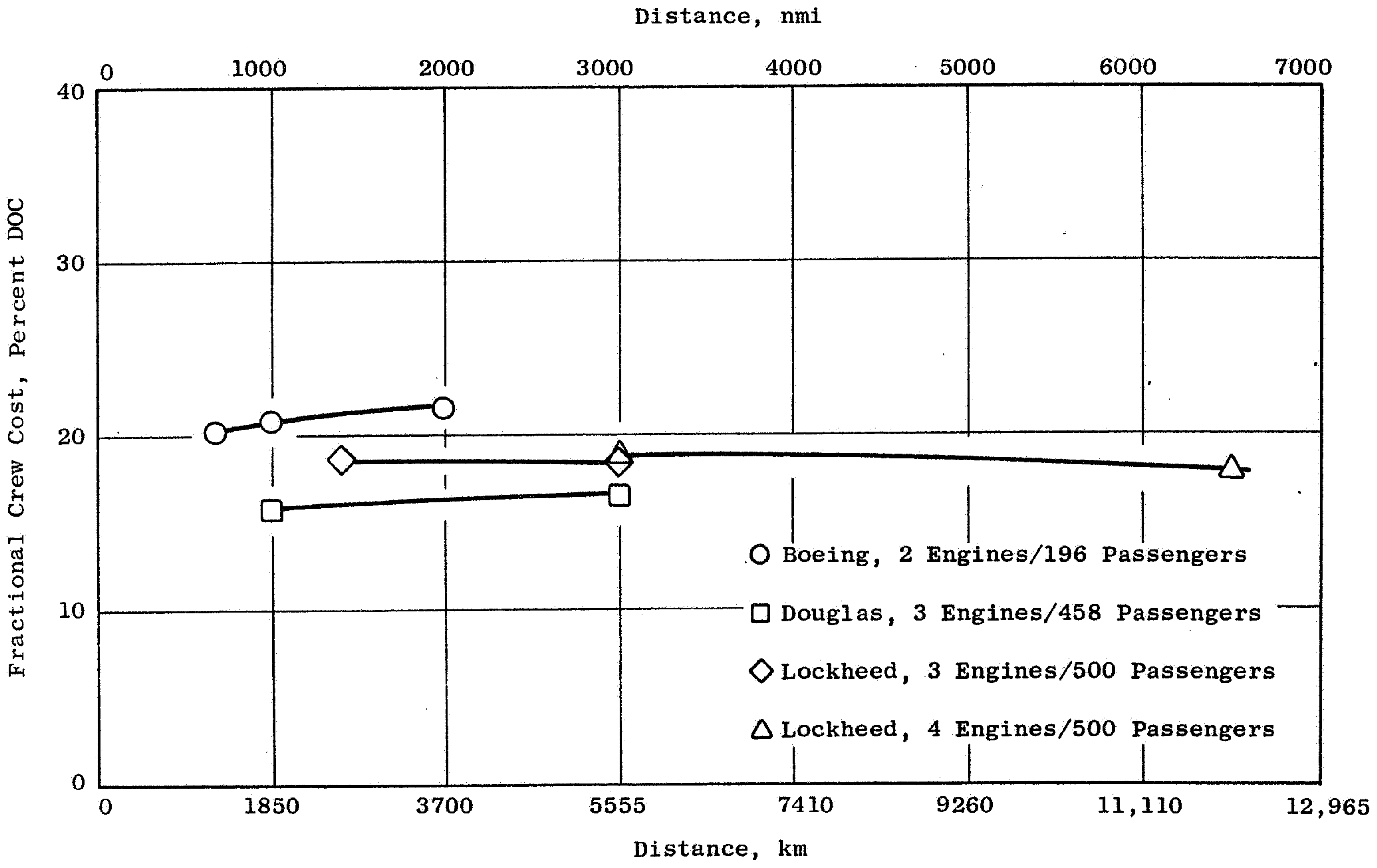


Figure 10. Fractional Crew Cost.

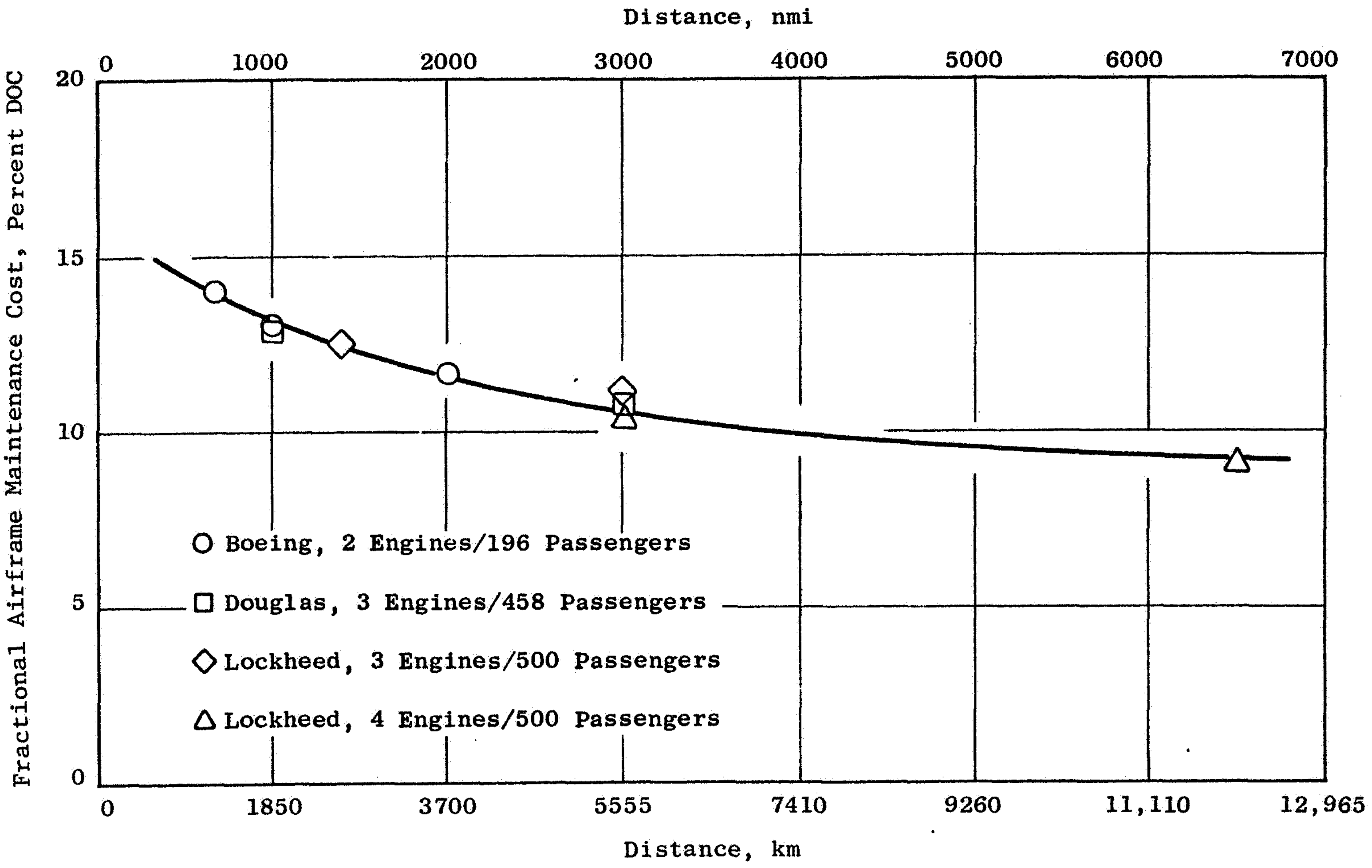


Figure 11. Fractional Airframe Maintenance Cost.

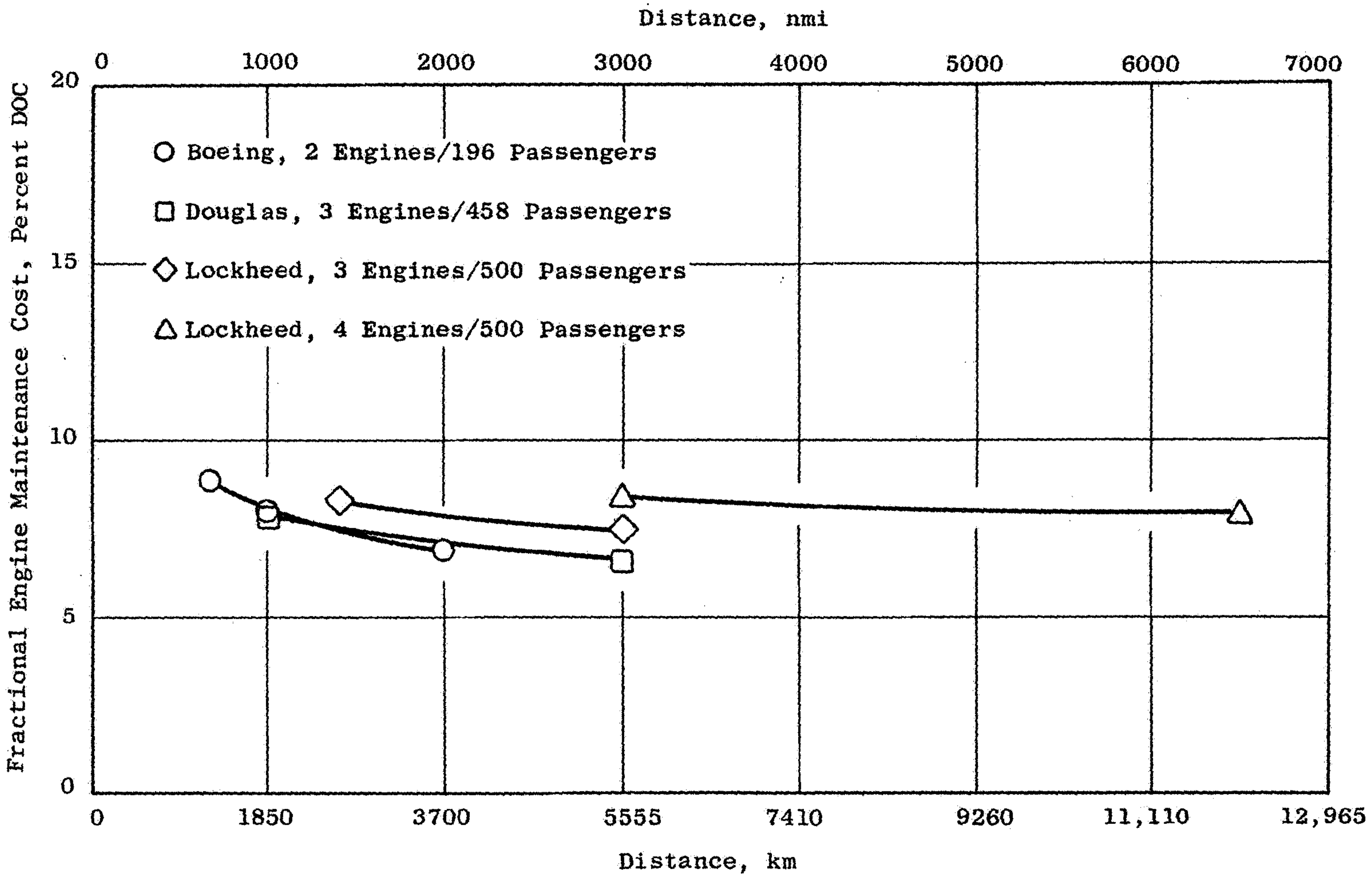


Figure 12. Fractional Engine Maintenance Cost.

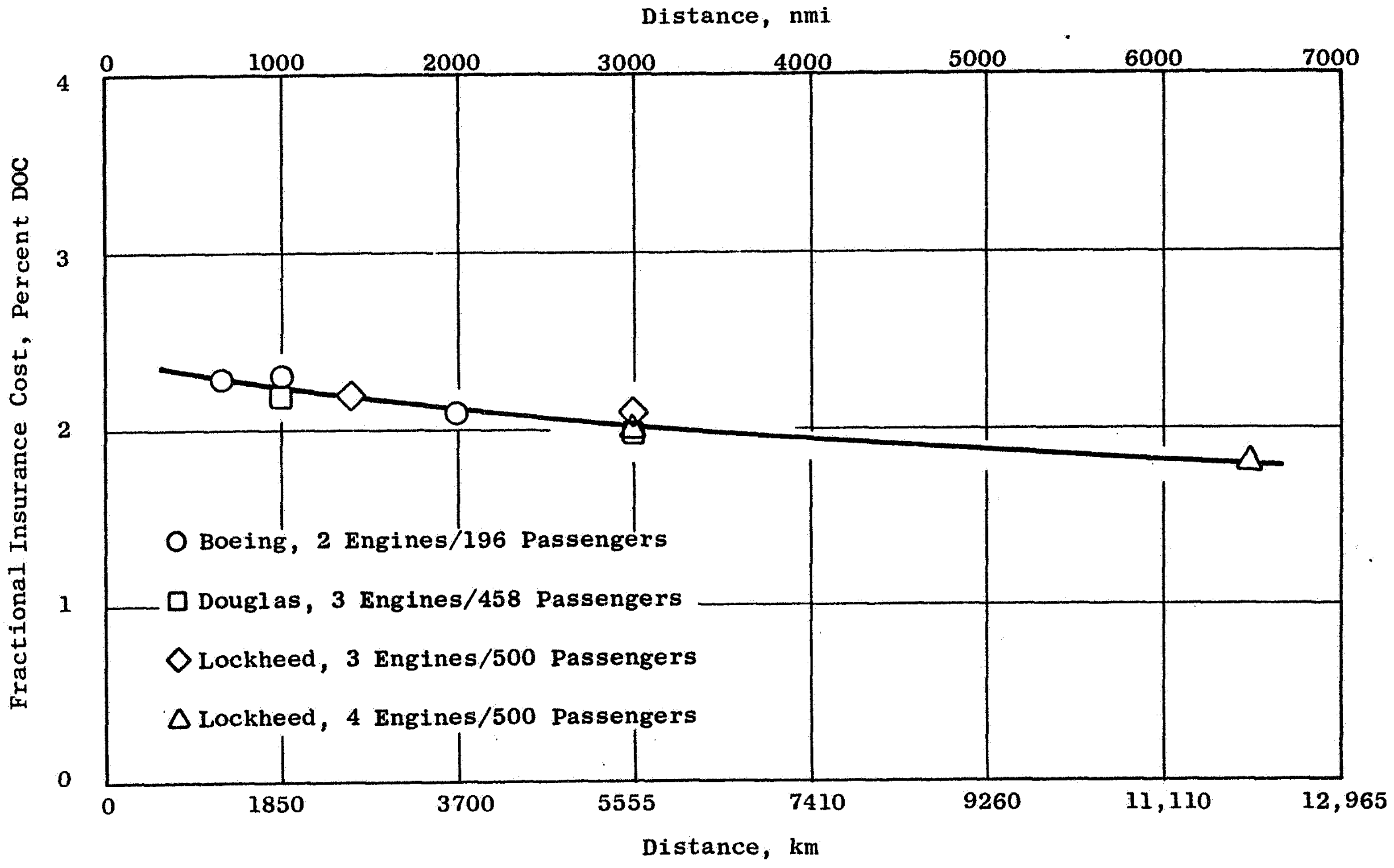


Figure 13. Fractional Insurance Cost.

The contribution of each element of DOC to the total improvement for E^3 versus CF6-50C technology is shown in Table XVII for the same three typical aircraft/mission combinations. The largest contributor to DOC improvement is fuel and oil costs. Maintenance cost also provides a significant benefit for the E^3 technology. However, the higher engine price for the E^3 engine results in an offset in favor of the CF6-50C. These results are presented graphically for all study aircraft in Figures 14 through 19.

5.2 ECONOMIC STUDIES - RETURN ON INVESTMENT

Return on Investment (ROI), usually defined as the discount rate that equates cash flows to initial investment, is an indicator of the overall economic worth of a change in technology. In order to evaluate the E^3 technology from the standpoint of the total economic system, NASA established a set of ground rules for an ROI calculation to be performed on the advanced study aircraft using baseline CF6-50C and E^3 engines. These ground rules, involving the calculation of Indirect Operating Cost (IOC) and ROI, are as follows:

INDIRECT OPERATING COST

Element	Calculation Method
Maximum Loading Weight	Use value supplied by airframe company or if none supplied, use the equation - Max Ldg. Wt. = TOGW x $(0.95 - 5 \times 10^{-5} \times$ Rn Des.) where Rn Des. = Design Range in Nautical Miles.
Seat Split	Use split supplied by airframe company.
Enplaned Ratio	For passengers and cargo use Boeing 1977 curve I-08.
Cargo	Use cargo supplied by airframe company - use powered loading.
Cash DOC	Defined as cash DOC = DOC - depreciation.

Table XVII. Contributors to DOC Improvement, E^3 with Credit for Improved Performance Retention Versus CF6-50C.

Aircraft Type	Domestic Twinfan	Domestic Trifan	Intercontinental Quadfan
Distance - km (nmi)	1232 (665)	1852 (1000)	5556 (3000)
Load Factor - %	55	60	55
Fuel and Oil - ΔDOC - %	-4.3	-5.1	-7.9
Depreciation - %	+1.6	+1.0	+0.8
Engine Maintenance - %	-2.2	-2.4	-2.8
Crew - %	-0.3	-0.3	-0.6
Airframe Maintenance - %	-0.2	-0.4	-0.3
Insurance - %	+0.1	+0.1	+0.1
Total ΔDOC - %	-5.3	-7.1	-10.7

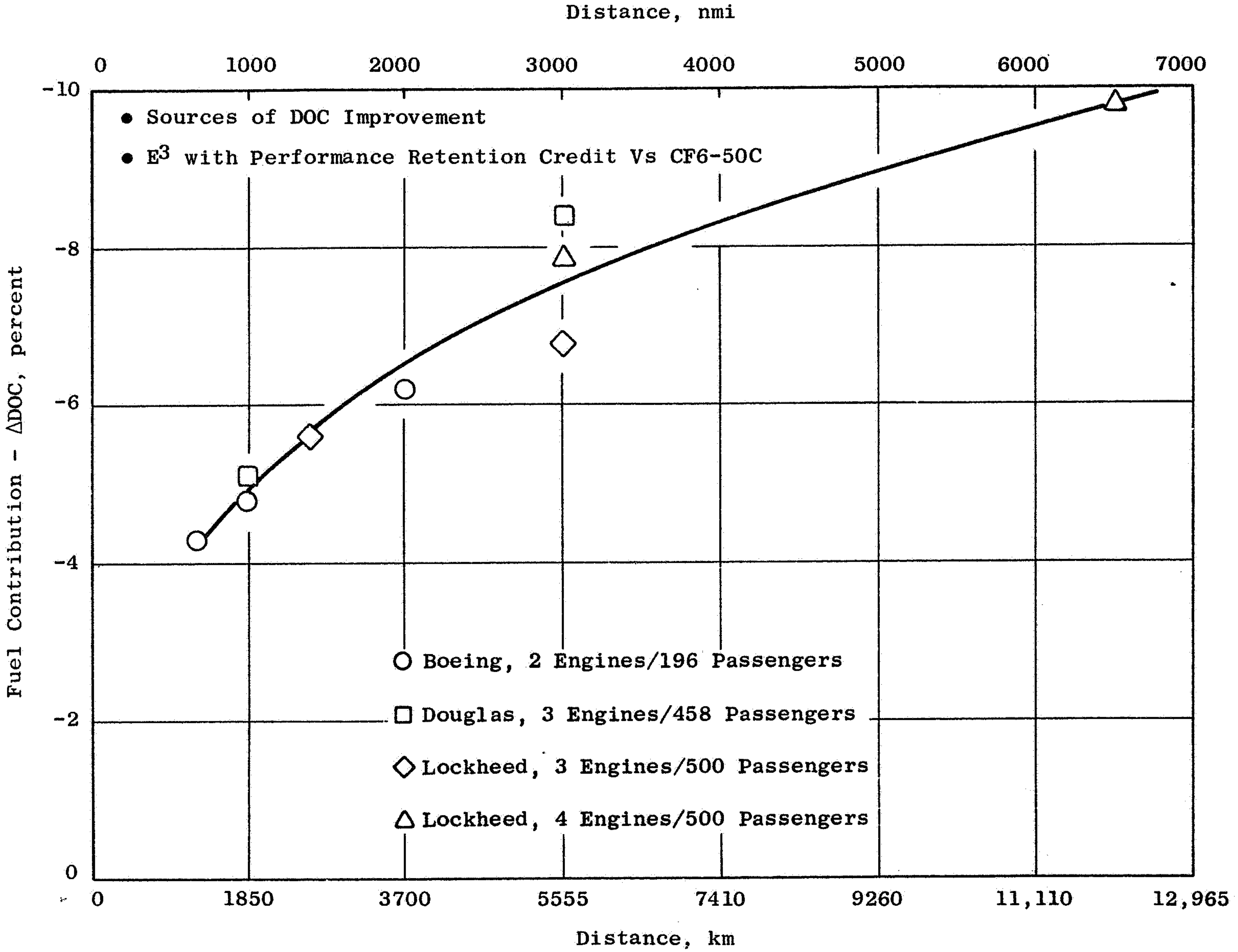


Figure 14. Fuel Contribution.

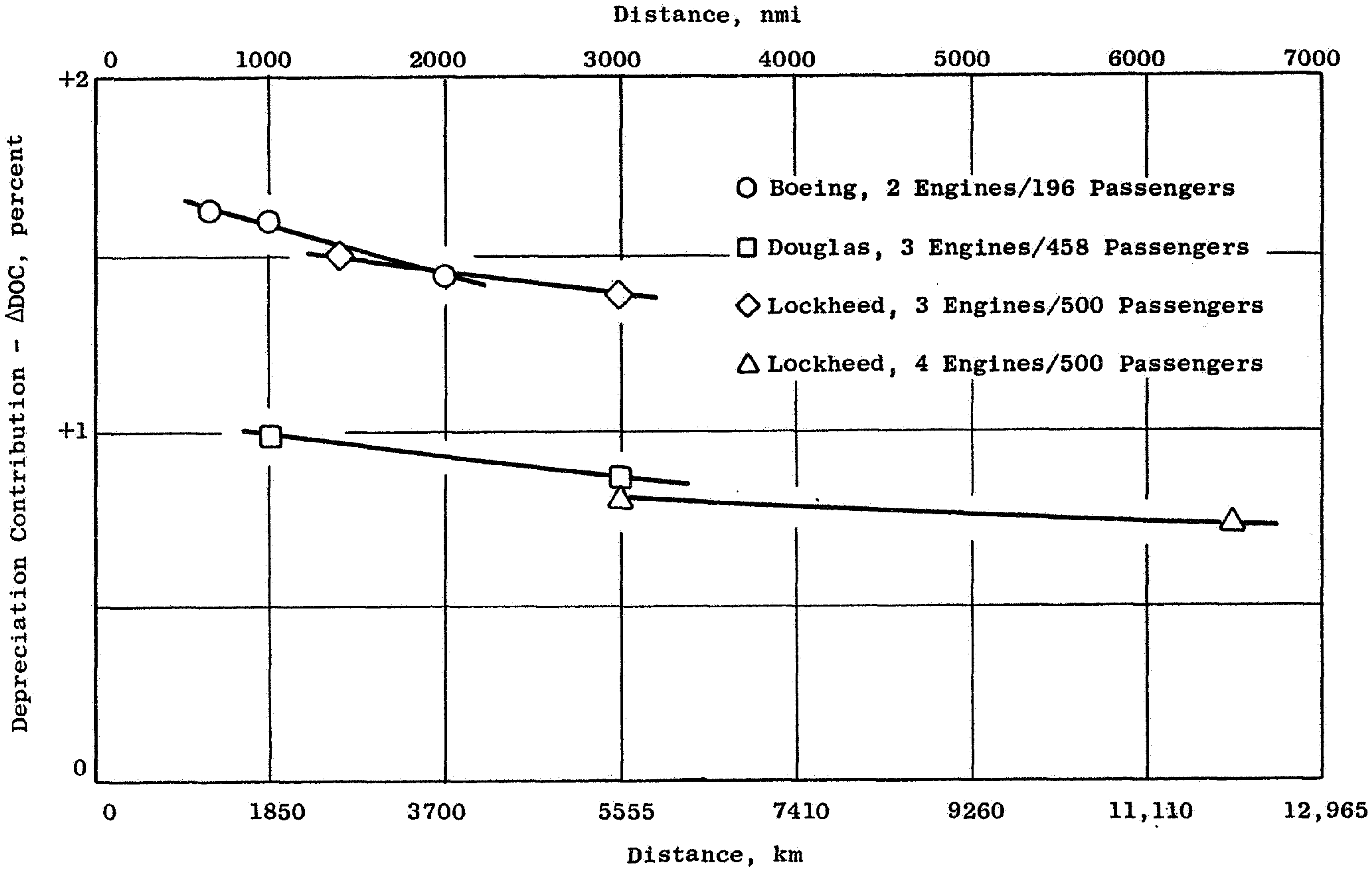


Figure 15. Depreciation Contribution.

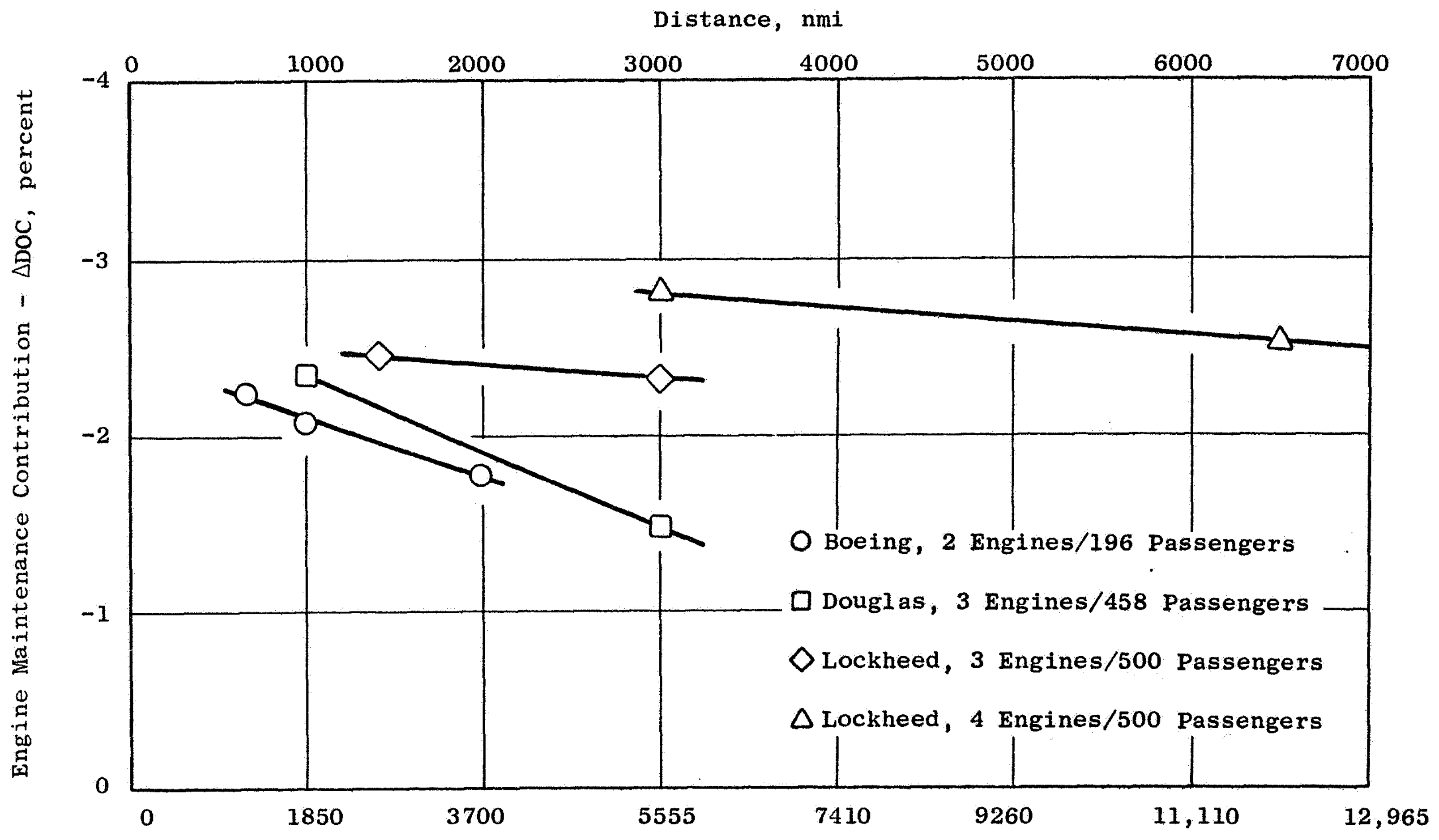


Figure 16. Engine Maintenance Contribution.

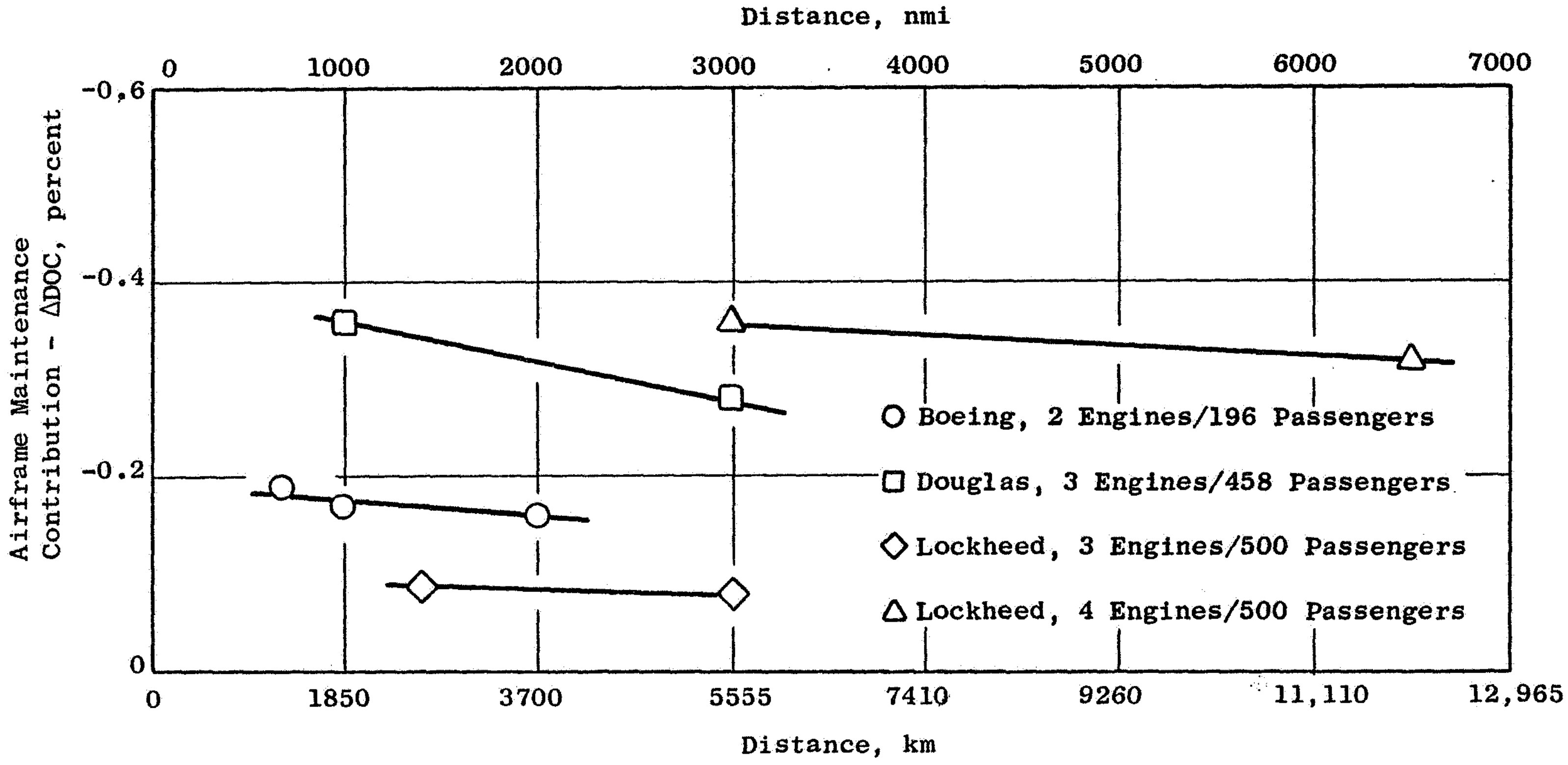


Figure 17. Airframe Maintenance Contribution.

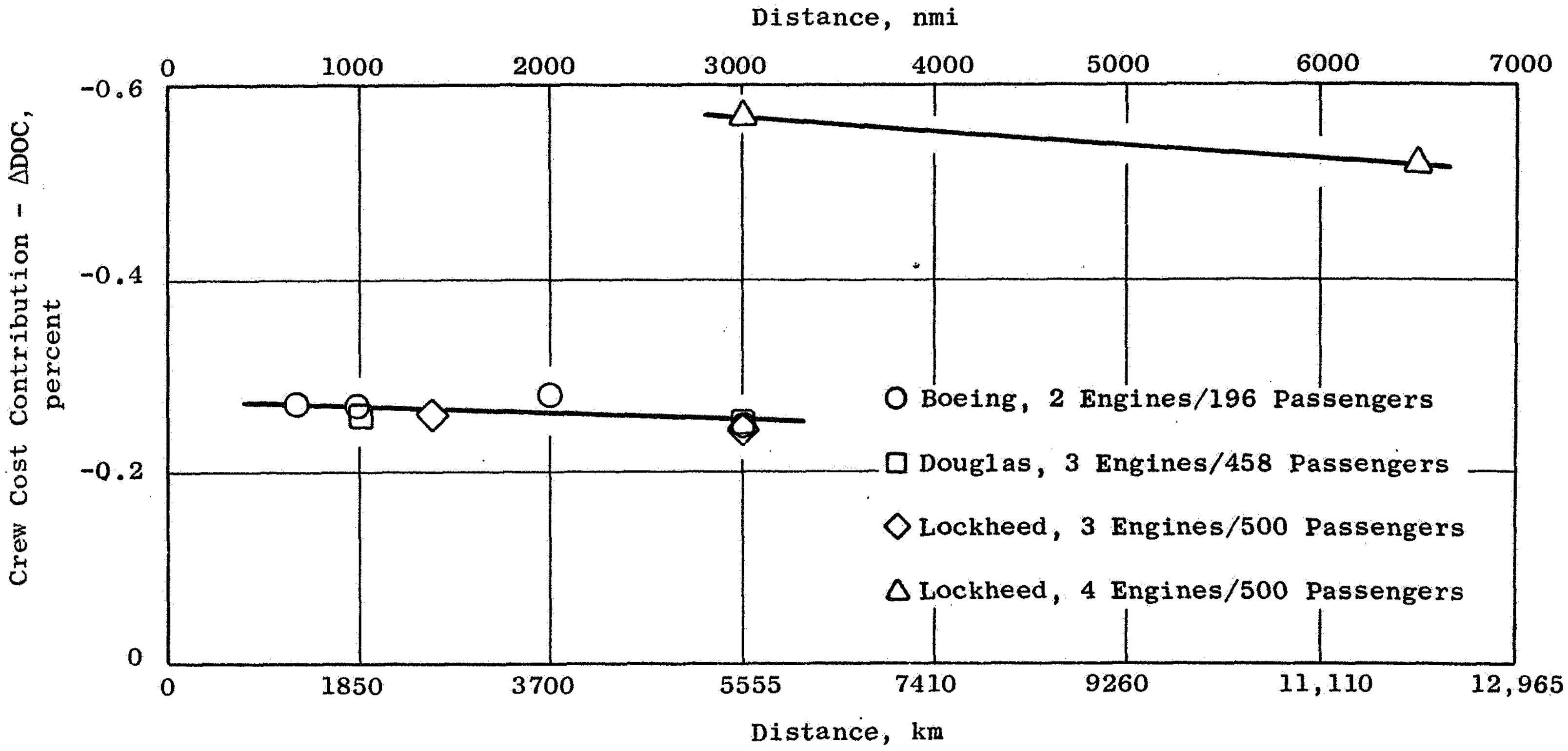


Figure 18. Crew Cost Contribution.

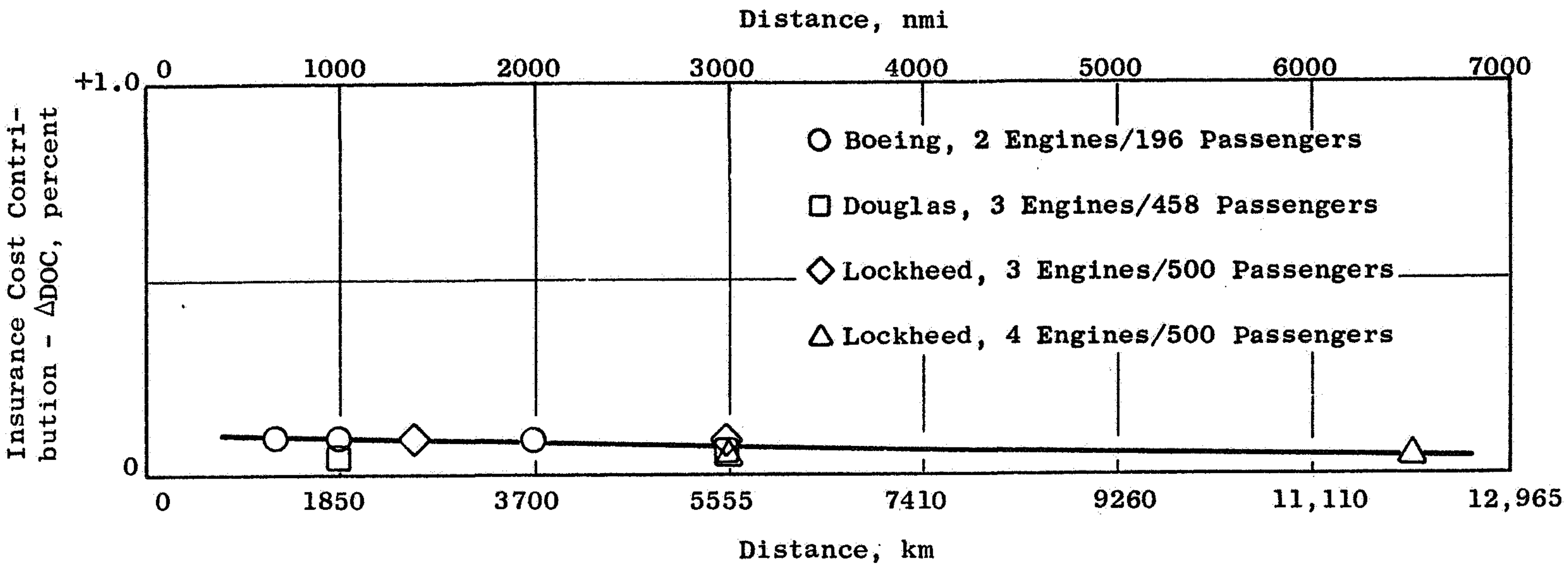


Figure 19. Insurance Cost Contribution.

RETURN ON INVESTMENT

Element	Calculation Method
Depreciation	Straight line 15 years to 10% residual
Quantity	Block Feed
Initial Investment	100% of aircraft, engines, and spares
Interest - Discounted Rate of Return	Based on no borrowed funds
Revenues	Domestic Passengers - \$/Trip = 20.88 + 0.0582 x Dist. St. Mi. International Passengers - 23.42 + 0.0653 x Dist. St. Mi. Cargo (Wide Body) \$/Ton - St. Mi. = $\frac{131.6}{\text{Dist. St. Mi.}} + 0.142.$
Average Range	Use typical mission supplied by airframe company
Cash Flow	No principal payment
Taxes	50%

NOTE: A 2% nonrevenue flight time shall apply to fuel and maintenance costs for both DOC and ROI.

Return on investment levels calculated by this method would differ significantly from ROI calculated by any particular airline, as the assumptions affecting costs and revenues are very operator-specific in practice. No airline would calculate ROI on the basis of no borrowed funds, for example. However, the difference in ROI for competing technologies would be indicative of their respective economic values. Hence, the results that are presented in this report are the differences in ROI between advanced aircraft using CF6-50C and E^3 propulsion technologies.

Table XVIII shows the results of these calculations for a domestic twin fan, a transcontinental trifan and an intercontinental quadfan with typical mission lengths and payloads.

Table XVIII. Improvement in Return on Investment for E^3 Versus CF6-50C Propulsion Technology (NASA-Coordinated Rules).

Aircraft	Domestic Twin Fan	Transcontinental Trifan	Intercontinental Quadfan
Design Range km (nmi)	3704 (2000)	5556 (3000)	12,038 (6500)
Typical Range km (nmi)	1232 (665)	1852 (1000)	5556 (3000)
Typical Load Factor - %	55	60	55
Fuel Price ¢/ℓ (¢/gal.)	10.6 (40)	10.6 (40)	11.9 (45)
Δ ROI - Improvement for E^3 Technology	+0.7	+0.5	+1.0

5.3 AIRCRAFT COMPANY COMMENTS ON FPS ECONOMICS

Although all aircraft company studies showed significant reductions in mission fuel consumption for the E^3 technology, the Boeing Company qualified their results in the areas of nacelle installation weight and engine price. They felt that the nacelle weight reported by General Electric for the E^3 system was lighter than they would have estimated for construction technology appropriate for the late 1980's-early 1990's. They also noted that the E^3 engine price was high relative to their Economics Department projections of future market requirements.

For a discussion of nacelle weights, see Section 5. The price difference of 20% was reviewed by General Electric and no obvious grounds were discovered to lower the GE projection at this time. However, the strong influence of engine price on economic benefits is fully noted and efforts will continue to be made throughout the program to arrive at a favorable balance between cost, weight, and performance.

6.0 NACELLE DESIGN

The E^3 FPS was designed with an integrated nacelle to permit a significant weight reduction for the total installed system. Major elements of the nacelle design included:

- Integral, composite construction of the fan frame, the outer portion of which forms the outer surface of the nacelle.
- Substantial use of composite materials in the inlet and aft cowling and in acoustic treatment of the exhaust flowpath.
- Lightweight fan containment based on the use of Kevlar fibers to trap and hold engine-generated debris in the event of fan damage.
- A long-duct mixed-flow exhaust system to enhance propulsive efficiency, achieving a higher level of engine performance with a smaller fan and low pressure turbine than would be required for a comparable separate flow system.
- A reverser contained entirely in the outer wall of the nacelle without need for bifurcation and cross-duct linkage. Extensive application of composite materials was made in the reverser to achieve light weight in the design.
- The engine-mount system chosen with particular attention to minimization of engine deflections due to mount loads in order to promote close control of turbomachinery clearances.
- The aerodynamic lines of the nacelle chosen for slimness and low cruise drag. To achieve as small an external nacelle profile as possible, the accessory package was installed in the core compartment.
- For ease of maintenance access to the core engine and accessories, the reverser designed in two halves hinged at the pylon attachment and latched at the bottom. In this way, the reverser provided access to the core component. The core cowl panels were hinged to the pylon to form a separate inner door system.

The aggressive use of advanced structural design and low-drag aerodynamics was established to contribute a 0.6% cruise drag reduction (out of 6%) and a 15 to 20% installation weight saving relative to the current technology of the CF6-50C nacelle that is the E^3 program baseline.

The general arrangement of the E^3 nacelle is shown in Figure 20.

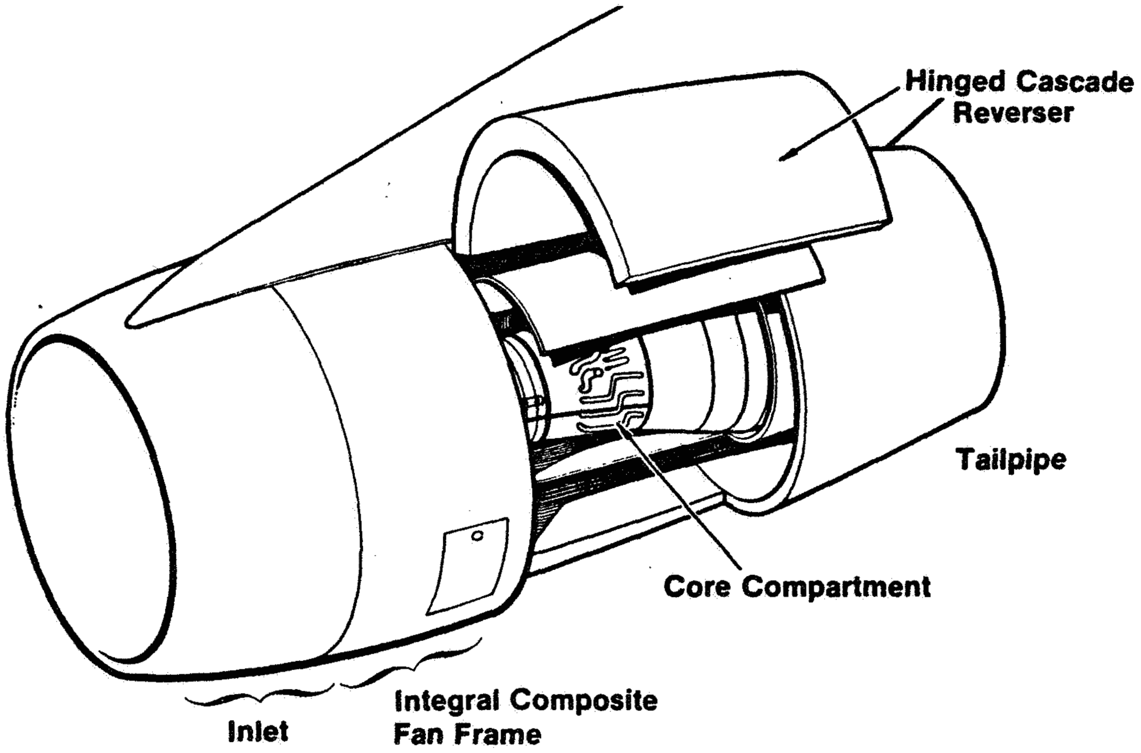


Figure 20. Nacelle General Arrangement.

6.1 FAN REVERSER

The preliminary fan thrust reverser design is of the fixed cascade, translating sleeve/blocker door configuration.

The reverser is made in symmetrical circumferential halves, each half being hinged to the aircraft pylon and latched to the other half along the bottom centerline allowing ready access to the engine. The reverser consists of the fixed support structure, including the cascade section, the outer translating sleeve, the blocker doors and linkage mechanism and the actuation system. As the actuation system is located outboard of the cascades, the cascade section is made in circular arc sectors with passageways (slots) between them for the blocker door links to pass through.

The reverser is contained entirely in the outer duct wall. There is no attachment to the core cowl which is independently hinged to the pylon to provide access to the core compartment. There are no links between the blocker doors and the core cowl-translation, and swingdown of the blocker doors is controlled by linkages contained in the outer cowl structure. The cascades are covered externally by the outer translating sleeve which incorporares the reverser sealing arrangement.

Figure 21 illustrates the reverser design in its stowed and deployed positions.

The aerodynamics of the reverser were based on previous General Electric experience with the large turbofan reverser designs. The desired fan operating line for reverse operation is 4% lower in pressure ratio at corrected airflow than the normal forward thrust mode fan operating line at static operating conditions. This was chosen in order to provide additional stall margin if required and to provide a reduction in core engine speed and turbine temperature at fan speed compared to forward mode operation.

Overall thrust effectiveness of the fan reverser is improved by the core thrust spoiling of the mixed exhaust system. In the reverse mode, the absence of bypass flow in the tailpipe causes a reduction in low pressure turbine back pressure which allows the core speed to be reduced relative to forward mode operation. This "rotor matching" effect causes a significant reduction in core stream thrust potential which is reduced still further by the aerodynamic spoiling effect of dump-diffusion out of the mixer core chutes into the tailpipe. These effects, which were evaluated in a cycle computer model, are based on previous scale model exhaust mixer tests.

The overall system reverse thrust effectiveness is shown in Figure 22 compared to a CF6-50C with and without the turbine reverser. The E^3 50 knots effectiveness of 45% compares closely to the 51% effectiveness achived with the CF6-50C with turbine reverser and exceeds the -50C level without turbine reverser.

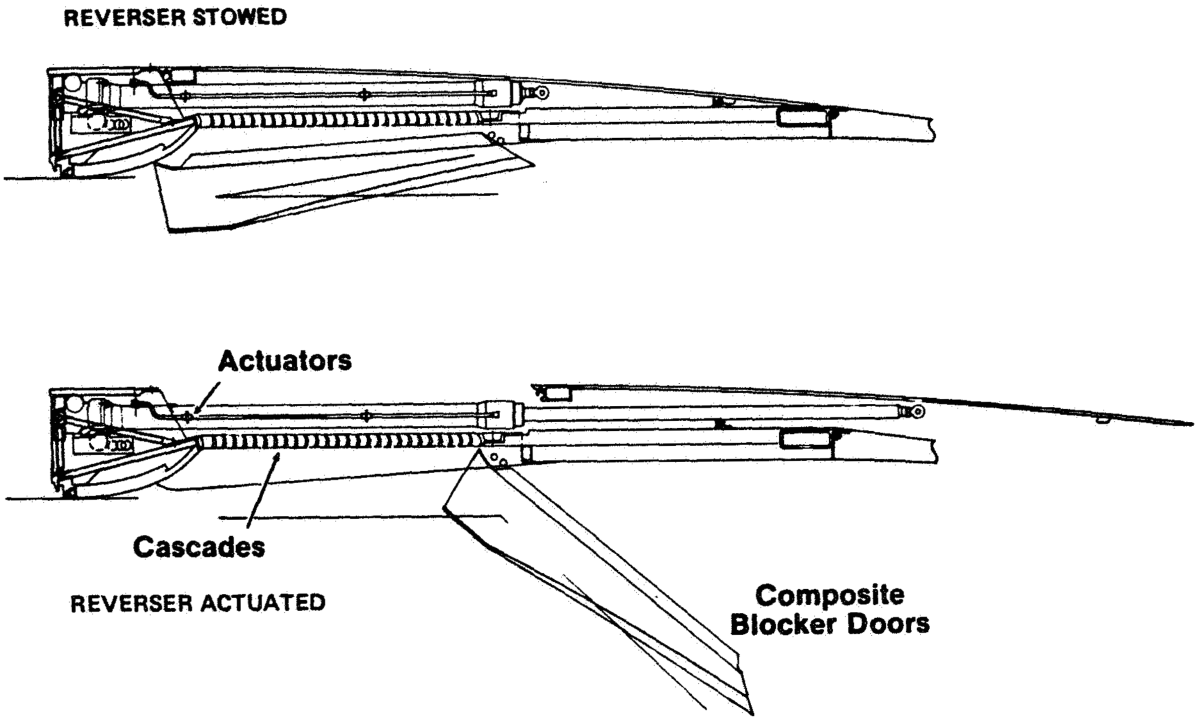


Figure 21. Thrust Reverser Actuation.

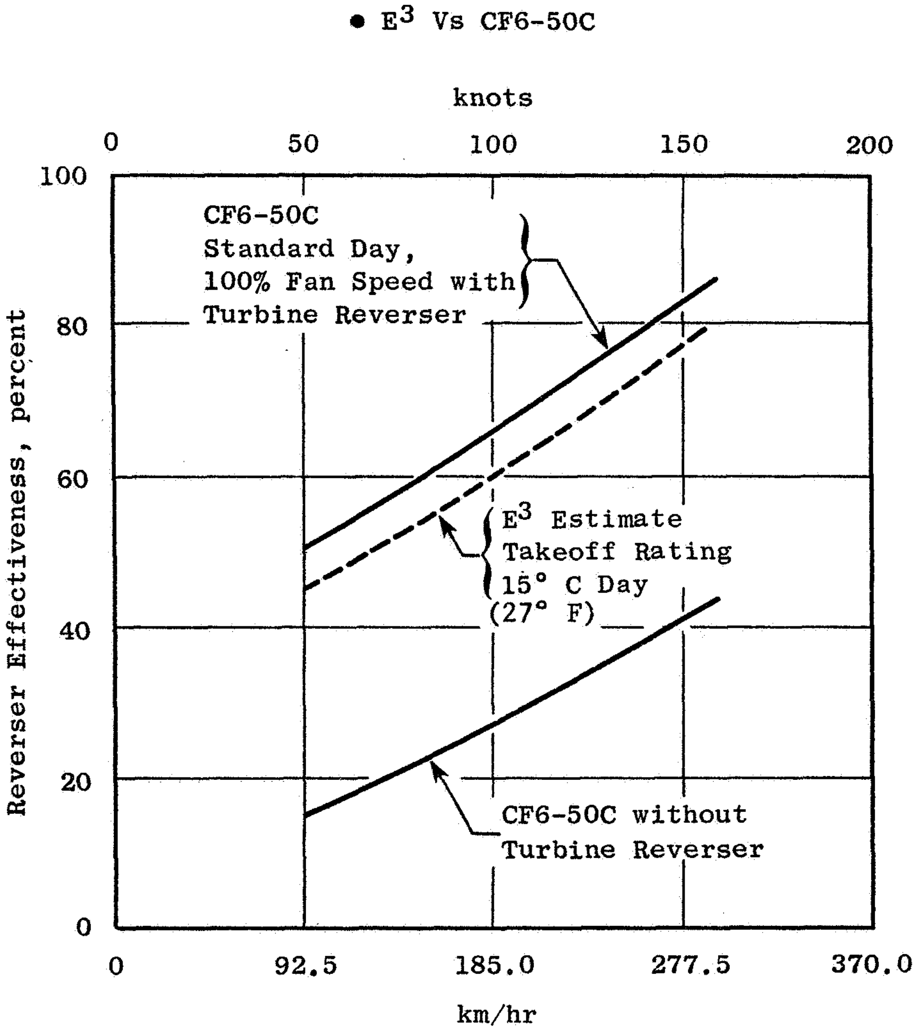


Figure 22. Overall Engine Reverse Thrust Comparison.

6.2 ENGINE MOUNT SYSTEM

The mount system design was selected to achieve the following important objectives:

- Compatibility with aircraft pylon structural design requirements.
- Reduction or elimination of concentrated "punch" loads into the engine structure.
- Reduction of engine ovalization and bending loads due to mount reactions.

The mount system chosen for the E^3 engine is shown in Figure 23. It consists of a front mount with twin thrust links and a uniball to take vertical and side loads, a midmount to take out roll and side loads, and an aft mount taking vertical loads only. The mount reactions are shown schematically in Figure 24.

The front mount was derived from the improved CF6-50C mount with additional emphasis on lowering the thrust reaction line to be closer to the engine centerline to reduce the thrust-induced moment. The two links were made self-adjusting by means of a whiffletree arrangement, and this also helped to reduce load concentrations at the fan frame attachment points.

The mid and aft mounts were arranged to take out roll, side, and vertical forces. Reactions were distributed to avoid concentrated punch loads into the engine structure.

Structural analysis of the FPS engine in response to typical thrust, aerodynamic and maneuver loads shows encouragingly low engine deflections. Figure 25 shows maximum local deflections versus engine axial length for a takeoff rotation condition where these loads are relatively large. The maximum deflection of approximately 0.23 mm (9 mils) was found to occur over the turbine area. These deflections would be in addition to clearance changes resulting from thermal and elastic behavior of the engine.

Although the mount system described here achieves the goals established for the FPS, there was some concern expressed by the Boeing Company over possible redundancy problems with the arrangement. In response to this, General Electric is continuing to work on an alternate arrangement that could eliminate that concern and still achieve the design goals.

6.3 ACCESSORY PACKAGE

The accessory package for the FPS was designed to help reduce fuel consumption and direct operating cost (DOC).

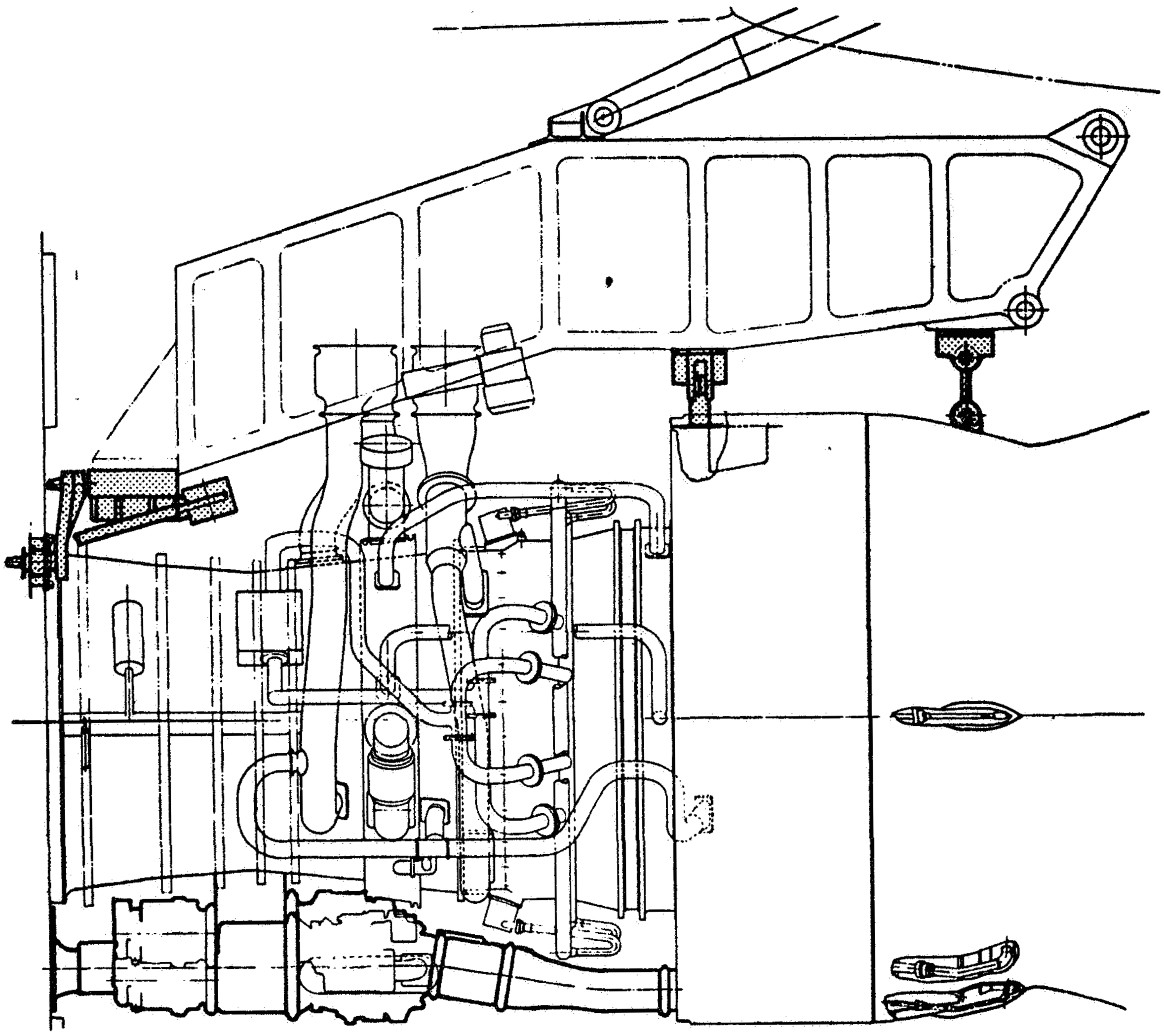


Figure 23. Engine Mount System.

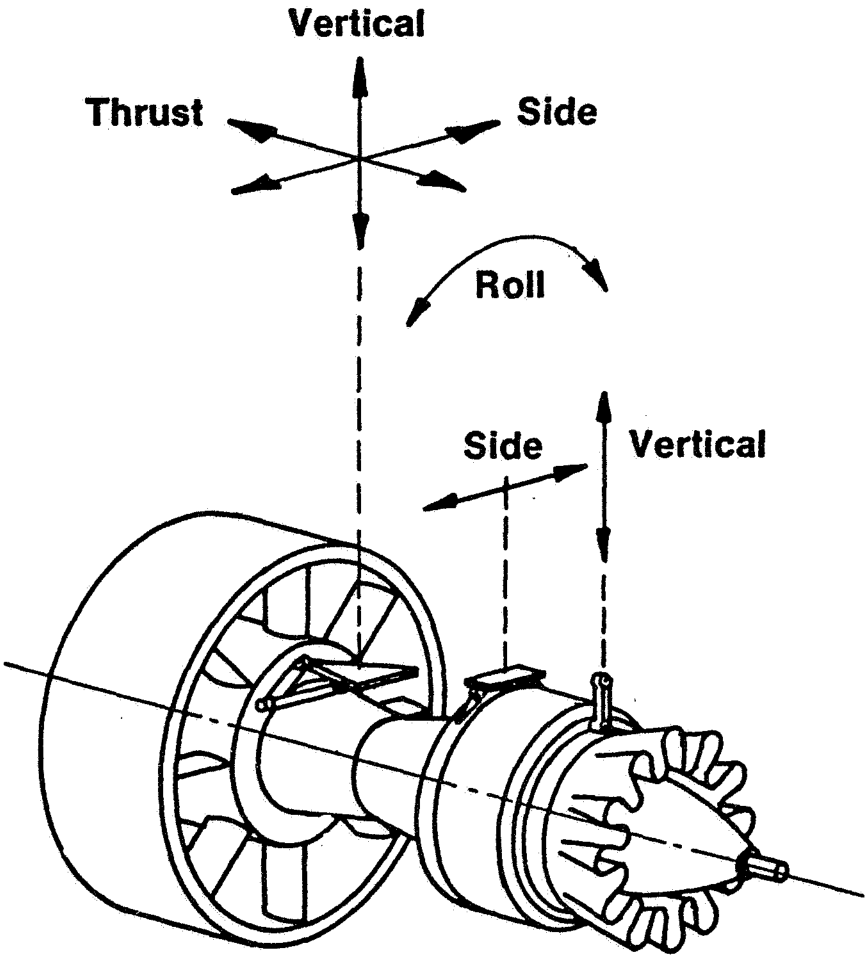


Figure 24. Mount Reactions Schematic.

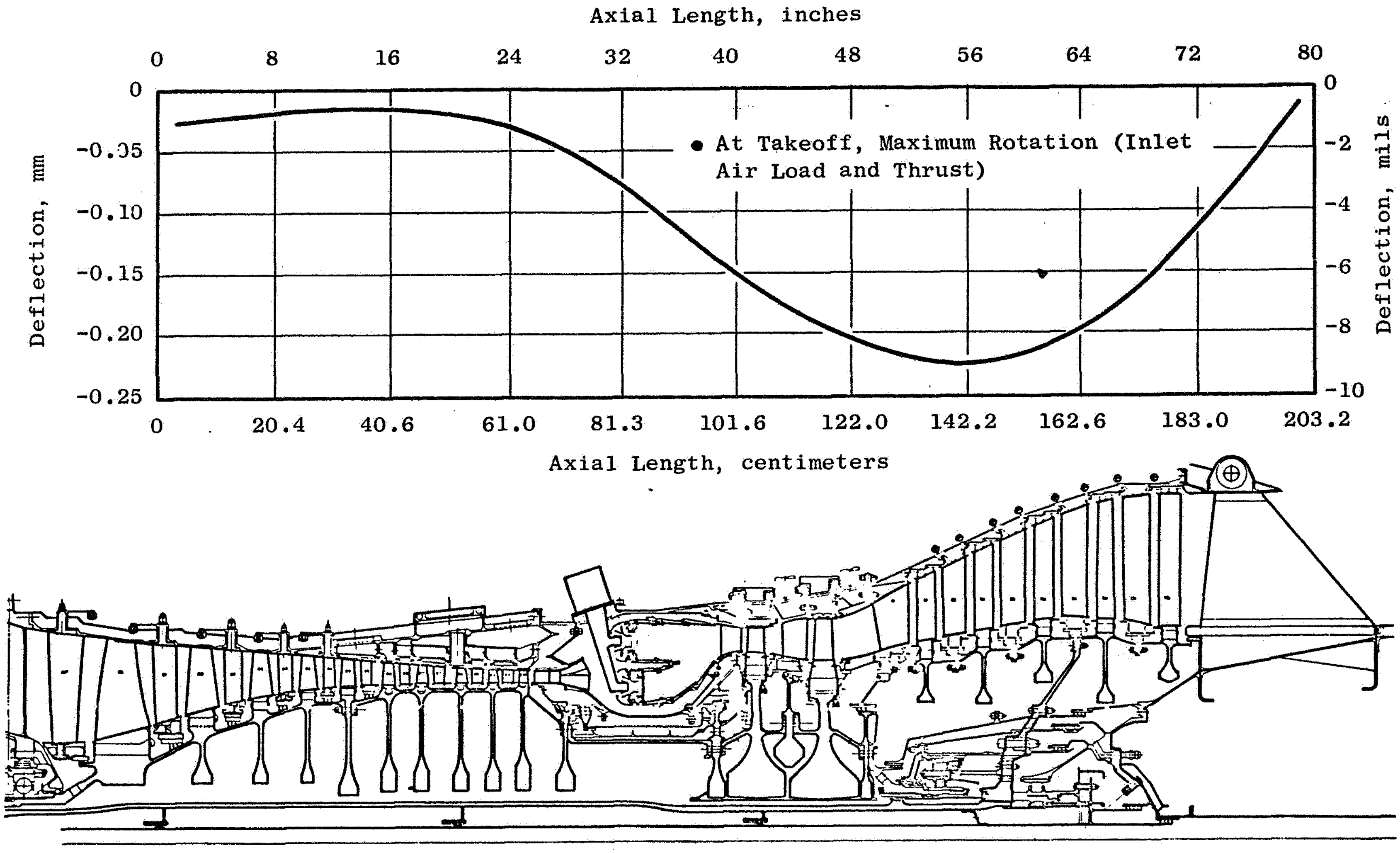


Figure 25. Preliminary E^3 Ovalization.

The principal choices for accessory arrangement were:

- Fan case bottom-mounted aircraft and engine accessories.
- Core-mounted aircraft and engine accessories, thermally isolated in a shielded and vented compartment.
- Pylon-mounted aircraft accessories with engine accessories in the core compartment.

Evaluation of these systems included consideration of differences in installation drag and pressure losses, weight, maintenance cost, and the impact of these on mission fuel and DOC. Summaries of these results are shown in Tables XIX and XX. As these results tend to favor the core compartment arrangement, this was chosen as the baseline configuration for the E^3 engine. However, the engine design retains the ability to be modified to other arrangements if desired by users.

Figures 26 and 27 show front and bottom views of the core-mounted accessory package chosen for the E^3 FPS. A side view is shown on Figure 23.

6.4 AIRCRAFT COMPANY COMMENTS

In order to ensure that the E^3 FPS design was consistent with the installation requirements of advanced commercial transports, the aircraft subcontracts with Boeing, Douglas, and Lockheed included reviews and critiques of the nacelle design. As a result, the major elements of the nacelle design, including choice of external aerodynamic lines, mount system, accessory arrangement, thrust reverser, and maintenance access provisions, were reviewed with the aircraft companies and many of their recommendations were incorporated in the design.

The Boeing Company expressed the view that the General Electric installation weight goals were optimistic for commercial service introduction in the late 1980's-early 1990's. It was their view that a substantial development effort that is not now in place would be required to achieve the technology required to meet those goals. General Electric concurs that the E^3 nacelle weight goals require aggressive development work in order to achieve them. However, based on its experience in designing and building reversers for the TF39 and CF6 engines, the composite nacelle structure experience on the QCSEE program and ongoing programs in nacelle structural development, General Electric believes that the E^3 technology projections are realistic.

Table XIX. Comparison of Accessory Location, Economic Summary.

Accessory Location	Fan Case	Core Compartment/	Pylon
% Δ SFC	0.3-0.7 Higher	Base	0-0.5 Higher
% Δ Block Fuel*	0.3-0.7 Higher	Base	0-0.5 Higher
Δ Weight - kg/Engine (lb/Engine)	22.7-56.7 Lighter (50-125) Lighter	Base	22.7-45.4 Heavier (50-100) Heavier
Δ Maintenance Cost, $/EF hr	$0.42-1.27 Lower	Base	$3.11 Higher
% Δ DOC*	0.1-0.2 Higher	Base	0.2-0.3 Higher

*Based on Economic Trades for Domestic Short Range Aircraft

Table XX. Nonquantitative Factors in Accessory Package Selection.

Fan Case Mount

- Must be Designed to Comply with FAA Wheels-Up Landing Regulation.
- Accessory Fairing Tends to Block Reverser if Side-Mounted.
- Aircraft Asymmetry or Left-Hand/Right-Hand Engines if Side-Mounted
- Best Accessibility of Candidate Configurations

Core Compartment Mount

- Some Airline Disfavor from Maintenance, Accessibility Aspect

Pylon Mount

- Airline Disfavor from Accessibility Aspect
- May have Significant Drag Penalty in Close Nacelle-Wing Placement
- Access and Mounting Problem with DACO-Type Tail Engine Installation

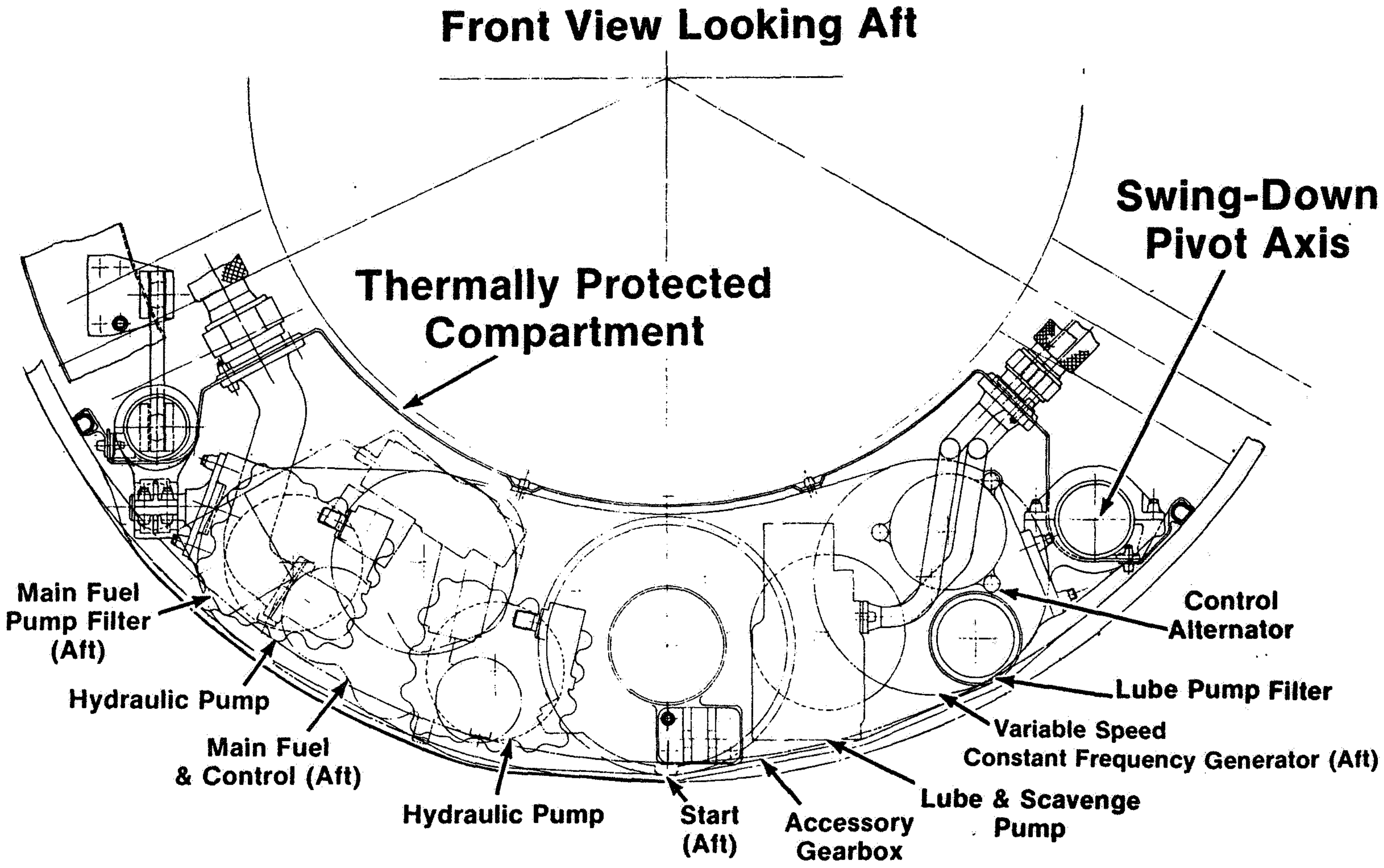


Figure 26. Accessory Package.

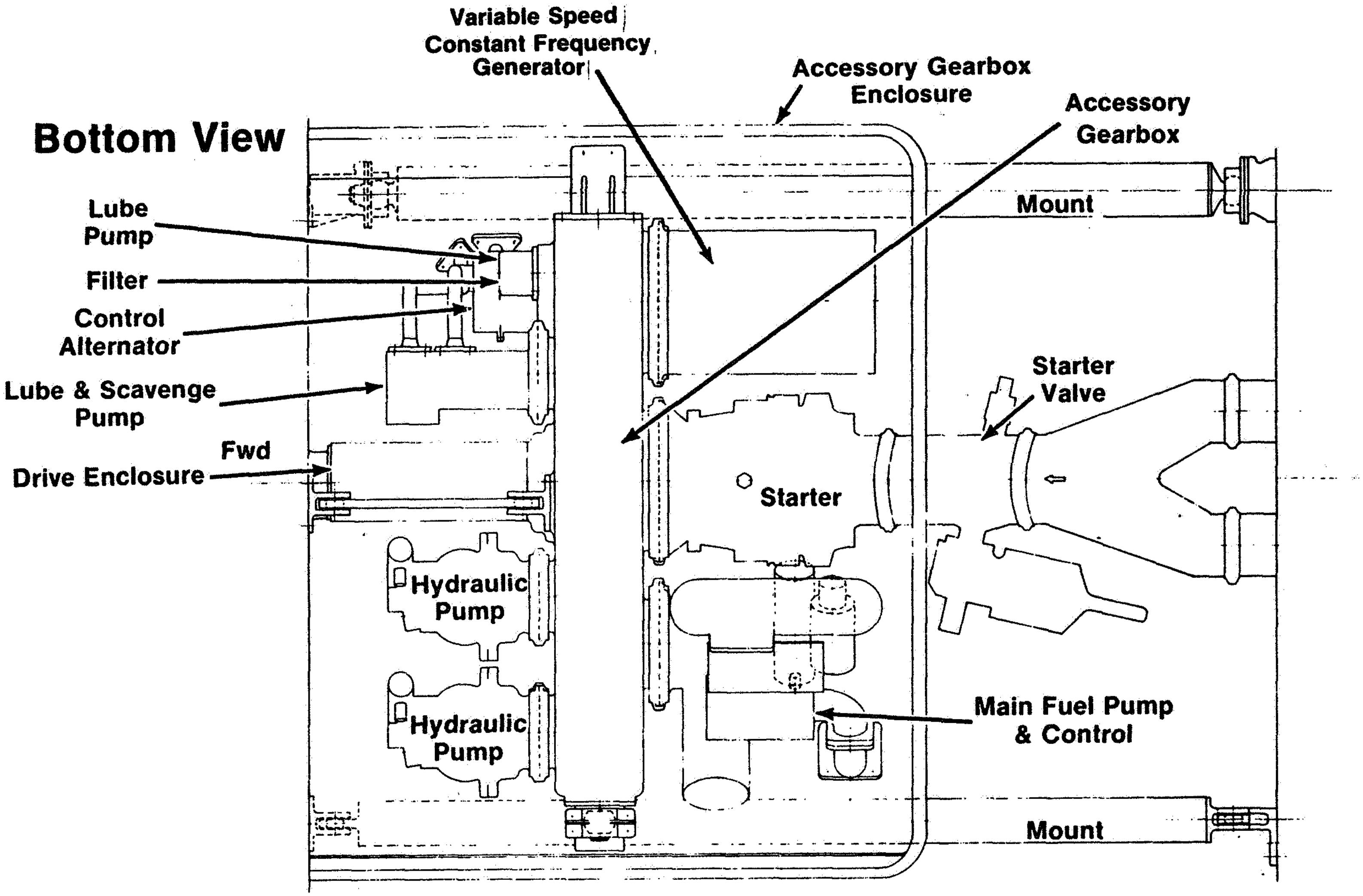


Figure 27. Accessory Package.

7.0 ENVIRONMENTAL CONSIDERATIONS

Part of the aircraft/engine integration effort provided for evaluation of the FPS design against the program goals for noise and exhaust emissions levels. For this purpose, aircraft noise contributions were estimated by the aircraft companies and combined with engine noise projections by General Electric. The exhaust emissions estimates were based on tests made with the double-annular combustor on other NASA-funded programs which are presented in References 5 and 6.

7.1 ACOUSTICS

Recent modifications to the FAR Part 36 noise regulations have significantly reduced the current noise limits for the next generation of commercial aircraft. In light of such changes, powerplants for these new generation aircraft must be designed employing advanced acoustic technology.

The Energy Efficient Engine (E^3) acoustics program has, as its primary objective, the acoustic design and demonstration of an advanced engine which will meet FAR Part 36 (1978) with a minimum 3 EPNdB margin at each monitoring condition on an advanced aircraft. To ensure that this objective is achieved, the acoustics program will monitor the design and development of each major engine component, incorporating advanced low noise design features consistent with program performance goals. In addition, supporting component test programs are in place to evaluate the integral vane-frame design and the mixer from an acoustic point of view.

The acoustic design of the Energy Efficient Engine is summarized in Figure 28 which shows the pertinent low noise design features, including:

- High Bypass Ratio
- Low Velocity, Mixed Flow Jet
- Moderate Tip Speed Fan
- Integral Vane-Frame with Wide Blade-to-Vane Spacing
- Long Duct Nacelle
- Reduced Turbine Source Noise
- Advanced Bulk Absorber Acoustic Treatment

The basic cycle and bypass ratio resulted from previous fuel efficient engine studies for NASA (Reference 2). The acoustic design, while drawing on

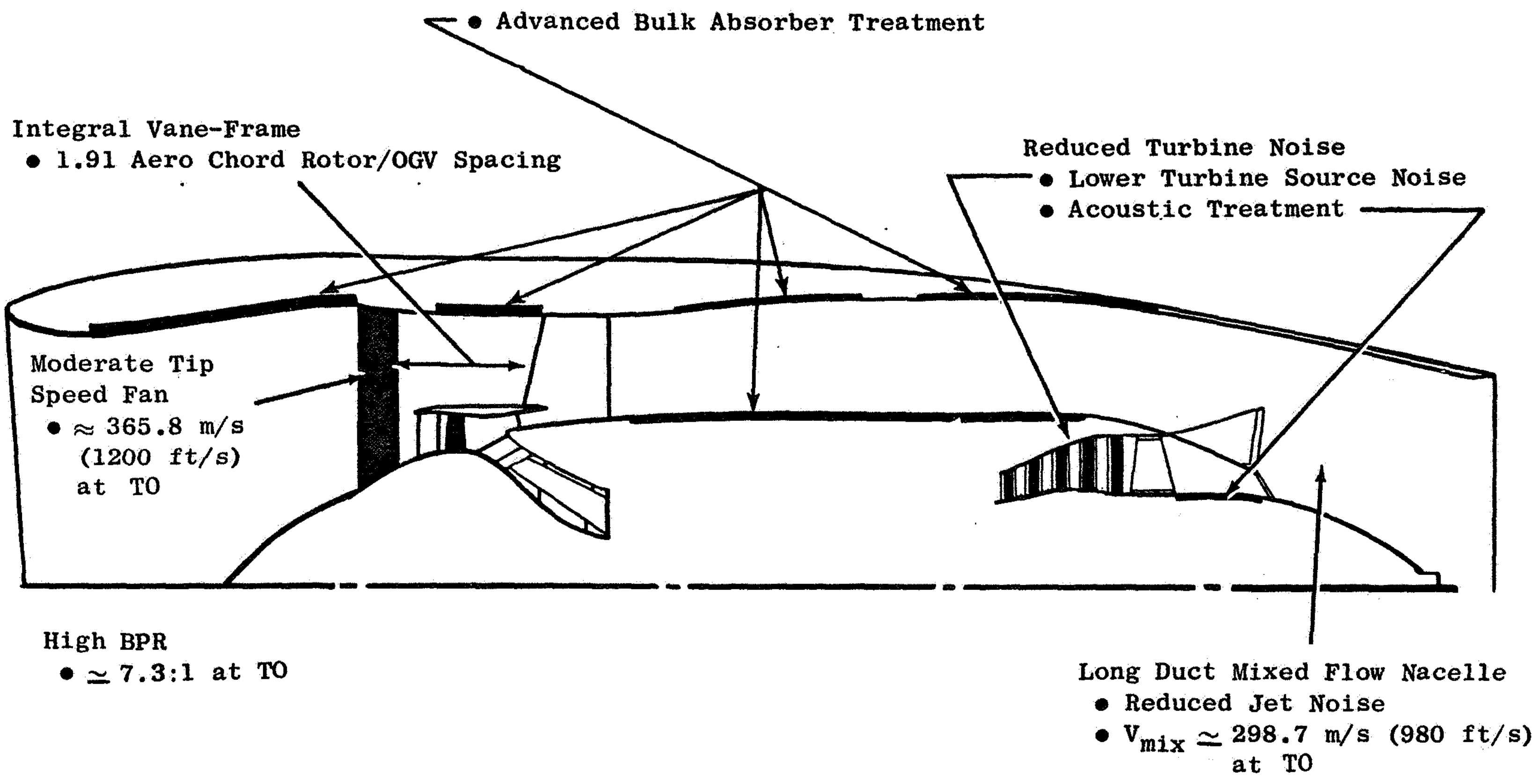


Figure 28. Energy Efficient Engine - Low Noise Design Features.

Table XXI. Flight Noise Estimates for E^3 Advanced Aircraft.

	Boeing Twin Jet	Lockheed Trijet	Lockheed Quadjet	Douglas Trijet
TOGW - kg =	110,524	205,416	284,335	225,370
(lb) =	(243,660)	(452,857)	(626,841)	(496,850)
SLS F_n - N =	167,734	181,287	167,988	183,391
(lb) =	(37,710)	(40,757)	(37,767)	(41,230)
TAKEOFF				
Level EPNdB	88.7	93.7	98.3	94.4
Margin Re: FAR 36 (1978)	-5.0	-6.7	-5.9	-6.5
SIDELINE				
Level EPNdB	89.0	91.6	92.8	92.2
Margin Re: FAR 36 (1978)	-9.2	-8.9	-8.9	-8.7
APPROACH (With A/F Noise)				
Level EPNdB	99.3	100.8	101.1	97.9
Margin Re: FAR 36 (1978)	-2.6	-3.2	-3.9	-6.6
AIRFRAME SUPPLIED (Aircraft Noise)				
Level EPNdB	93.2	95.9	96.0	92.3

previous studies, evolved as the detailed characteristics of the advanced study aircraft became better defined. System noise studies were carried out in areas such as fan inlet and turbine to evaluate various methods of reducing total system noise and permit the various advanced engine aircraft systems to meet the program objective.

Incorporating the results of the various component noise reduction studies, the flight noise levels for various advanced aircraft powered by the FPS were estimated. The aircraft performance characteristics, including airframe noise at approach, were provided by the Boeing Commercial Aircraft Company and the Douglas Aircraft Company as part of a subcontract to the overall E^3 program. These aircraft, therefore, represent a wide spectrum of design philosophies and a typical cross section of what is anticipated for the future needs of the commercial aircraft market. Table XXI shows the resultant system noise levels for each aircraft, and the associated margin relative to FAR 36 (1978), including that all aircraft meet FAR 36 (1978) with at least 3 EPNdB margin at each point, except the Boeing twin jet which has 2.6 EPNdB margin at approach.

Figure 29 shows a comparison of noise footprint contours for a typical current and future trijet aircraft near a major metropolitan airport. The advanced engine/aircraft system offers a 50% reduction in noise exposure area when compared to current aircraft. This reduction in noise exposure area significantly diminishes the community noise problem near high density airports.

In conclusion, incorporation of advanced low noise design features, including bulk absorber acoustic treatment, reduced turbine noise, and integral vane-frame, permit advanced aircraft powered by the General Electric Energy Efficient Engine to meet the FAR 36 (1978) noise regulation goal with a 3 EPNdB margin.

7.2 EXHAUST EMISSIONS

The overall objectives and goals of the combustion system for the E^3 are to design and develop an advanced combustor configuration which will meet the E^3 program goals for CO, HC, and NO_x emissions which are equivalent to the current requirements proposed by the Environmental Protection Agency (EPA) for Class T2 aircraft engines newly certified after 1981. These requirements are shown in Table XXII.

Table XXII. E^3 Combustor - Emission Goals (EPA 1981 Standards) for Newly Certified Engines.

• Carbon Monoxide (CO)	lb/1000 lb Thrust - Hours Per Cycle	3.0
• Hydrocarbons (HC)		0.4
• Nitrogen Oxides (NO_x)		3.0
• Smoke	SAE Smoke Number	20.0

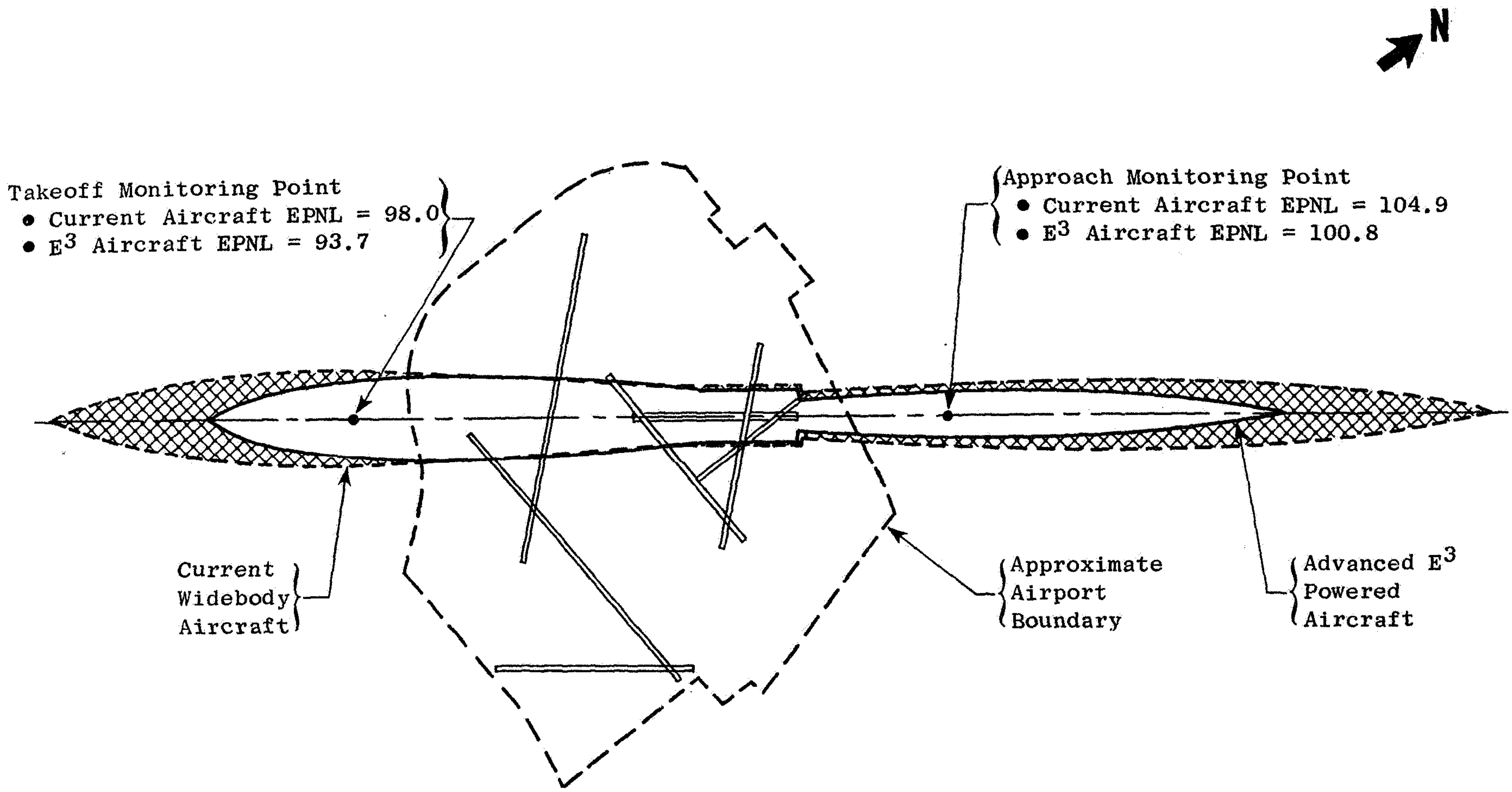


Figure 29. Noise Exposure Areas for Lockheed Trijet Near Chicago O'Hare Airport, 90 EPNdB.

The major emphasis in the combustion system design is directed at meeting the technically challenging emissions and life goals of the program; however, the combustion system also must provide the characteristics required for operation of a typical modern turbofan engine.

The performance parameters generally considered most important in a combustion system are shown in Table XXIII. It should be noted that not only is high combustion efficiency required at SLTO conditions for this design, but must be maintained at a level greater than 99.5% at idle in order to meet the CO and HC emissions goals of the program.

Table XXIII. E^3 Combustor - Key Performance/Operating Requirements.

•	Combustion Efficiency @ SLTO (%)	99.5	(Min.)
•	Total Pressure Drop @ SLTO (%)	5.0	(Max.)
•	Exit Temperature Pattern Factor @ SLTO	0.250	(Max.)
•	Exit Temperature Profile Factor @ SLTO	0.125	(Max.)
•	Altitude Relight Capability, m (ft)	9,144 (30,000)	(Min.)
•	Ground Idle Thrust (% of SLTO)	6.0	(Max.)

The design condition generally selected for evaluating combustor performance is the sea level takeoff condition. However, in the case of emissions, the definition of design conditions is much more complicated. The EPA requirements are based on a prescribed landing-takeoff cycle consisting of specific operating times at idle, approach, climbout, and takeoff power settings. The emissions are then based on the total weight of pollutants emitted per unit of thrust per hour over the prescribed cycle. Therefore, the design conditions selected for evaluating emissions are directly related to the cycle conditions which exist at each of the prescribed power settings.

The predicted emissions levels for this double-annular dome combustor design are shown in Figure 30. These predictions were based on existing data developed in the NASA-GE ECCP (Reference 5) and NASA-GE QCSEE (Reference 6) double-annular dome combustor programs with appropriate adjustments made to the data to account for differences in combustor size and inlet operating conditions for the different engine cycle.

These estimates were based primarily on data from component tests of development combustors where dimensional tolerances and combustor inlet operating conditions can be controlled to the prescribed cycle conditions. For

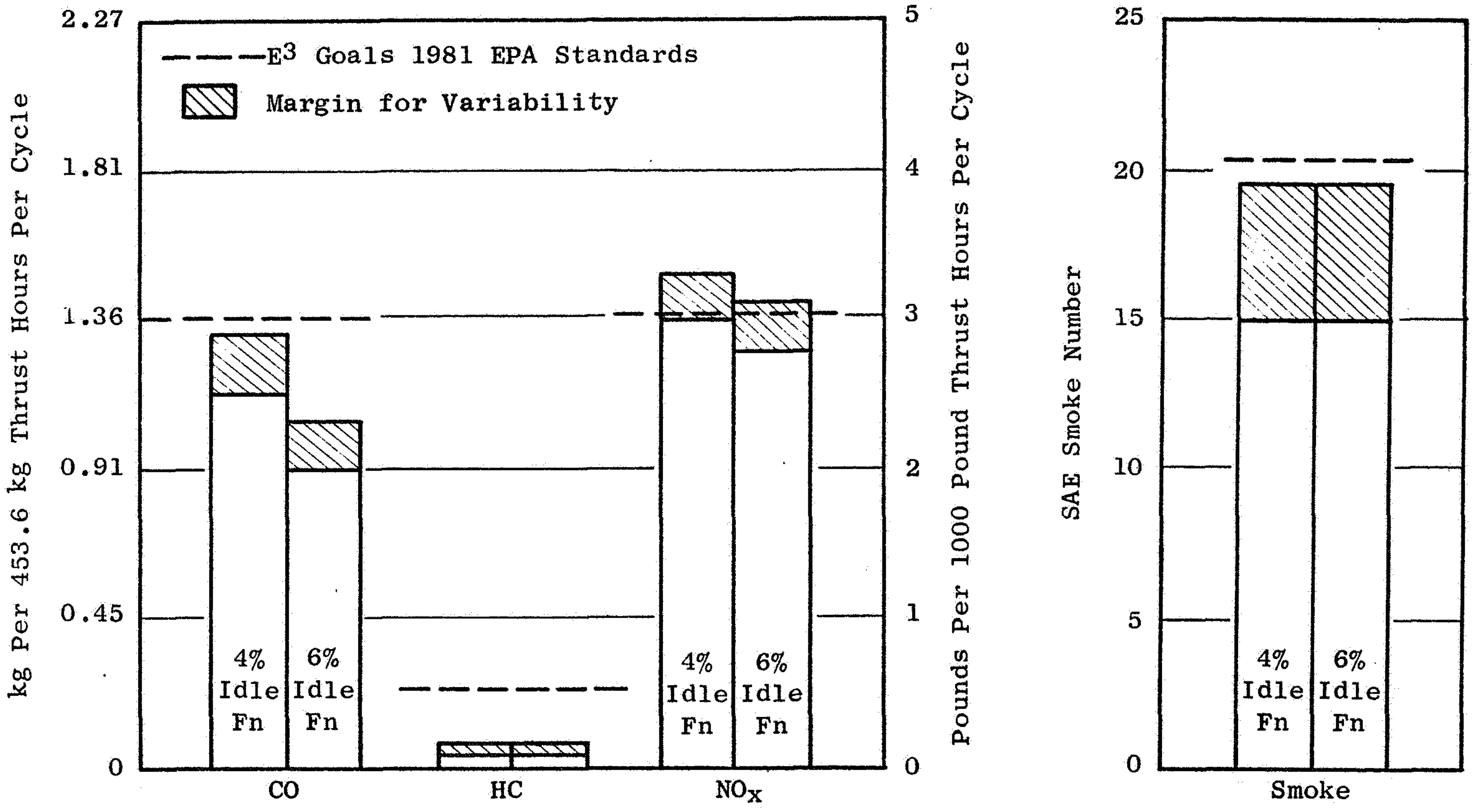


Figure 30. E^3 Double Annular Combustor Predicted Emission Characteristics.

the case of a production engine, some added margin equivalent to 2 standard deviations is required to account for engine-to-engine variation as well as measurement variations. Based on variability data obtained at General Electric, a variability margin of about 20% is considered necessary for CO emissions, whereas a much larger variability margin of about 40% is considered necessary for HC emissions. The emissions of NO_x are somewhat more repeatable and are expected to vary only about 10% from the average level.

Even after applying these variabiity factors to the E^3 emissions estimates, based on previous development test results, it is expected that, at completion of the initial E^3 combustor development program, the CO and HC emissions levels will meet or closely approach the E^3 program emissions goals with a prescribed ground idle thrust of 4% takeoff thrust. For ground idle operation with 6% takeoff thrust, ample margin would be available for both CO and HC emissions compared to the program goals. However, in the case of NO_x emissions, although the average engine would be expected to meet the goals, there would be a small percentage of engines under adverse conditions which would not meet the program goals. Smoke is expected to meet the standard even when the large variability in smoke levels is taken into consideration.

8.0 PROBABILITY OF MEETING PROGRAM GOALS

Probability of meeting program goals was assessed previously in Reference 2. The probability analysis dealt primarily with the projected performance of engine components and the resultant performance of the engine system. The analysis was updated to reflect the projected performance of the FPS and ICLS vehicles at the time of the November 1978 PDR, and expanded to include consideration of the probability of meeting the other program goals for DOC, noise, and emissions.

8.1 PERFORMANCE GOAL

The probability assessment of the E^3 engine performance level is shown in Figure 31. Two curves are shown; one for the programmed effort culminating in the running of the ICLS vehicle in 1982, and one projected for full development and certification in the late 1980's-early 1990's. These curves show a 90% probability of achieving the ICLS performance projection of 12.2% sfc improvement in the course of the current E^3 program, and an equal certainty of achieving the FPS projection of 14.6% in a follow-on full-scale development program.

8.2 WEIGHT, PRICE, AND MAINTENANCE PROJECTIONS

Figures 32 through 34 show the probability assessment for achieving the FPS weight, price, and maintenance cost projections through a full-scale development program. Curves for the ICLS are not shown, as these goals for a service-type engine can only truly be demonstrated by proceeding to full development and certification.

8.3 DOC GOAL

The probabilities of meeting performance, weight, price, and maintenance projections can be combined to assess the probability of achieving the FPS DOC projections, using DOC sensitivity factors. As has been shown, the DOC improvement for E^3 technology is dependent strongly on average flight distance. So, too, are the sensitivities of DOC to performance, weight, price, and maintenance cost. To simplify the projected probability of meeting the E^3 program goal of 5% DOC improvement for a fully developed service engine, the DOC sensitivities were applied for a short-range domestic twin fan, a medium-range domestic trifan, and a long-range intercontinental quadfan. These results are shown in Figure 35. This presents the probability of each of these aircraft to deviate from their FPS projected ΔDOC. When these deviations are superimposed on the FPS projection for each aircraft, the result is shown in Figure 36.

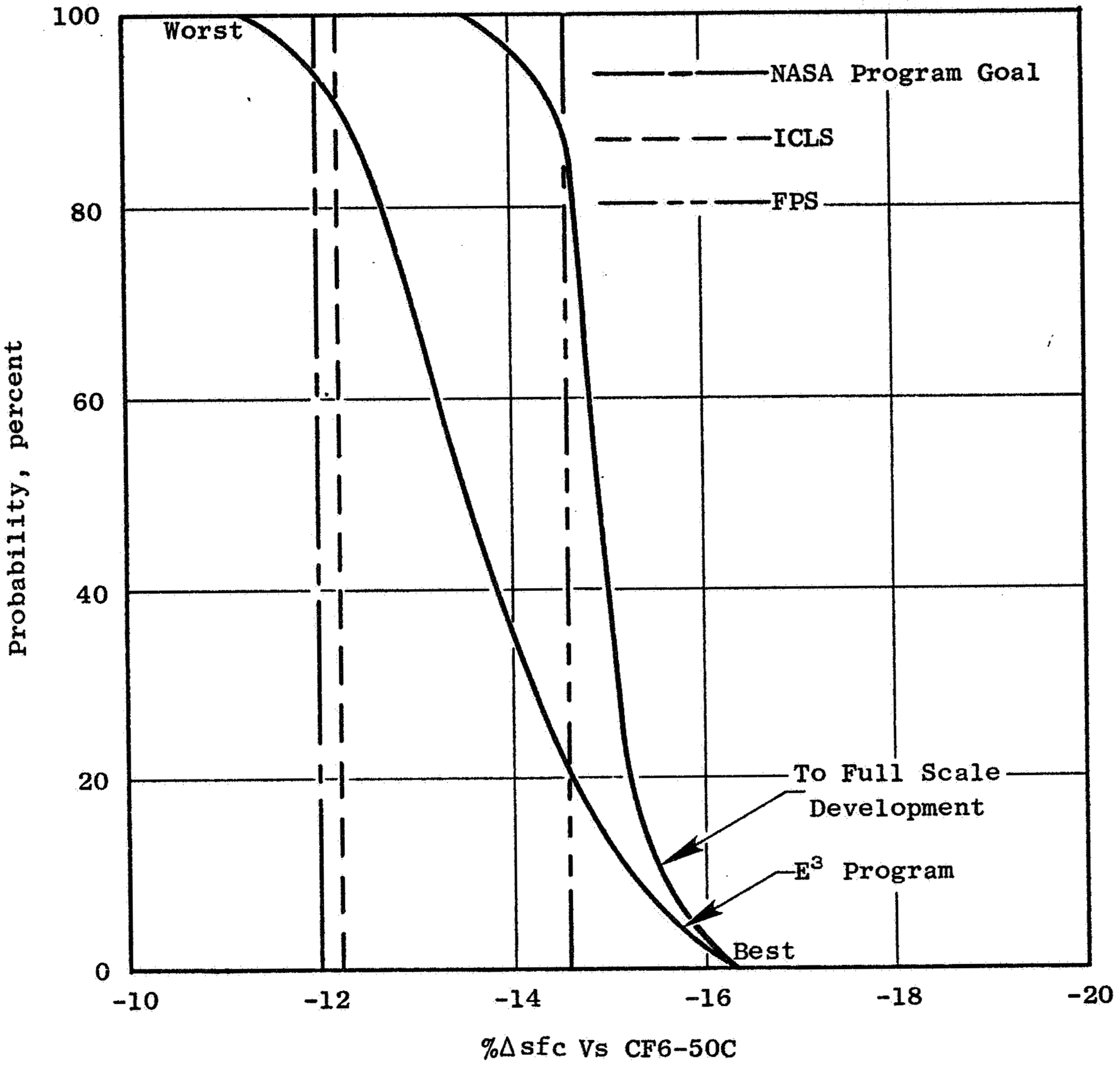


Figure 31. Probability of Achieving SFC Goals.

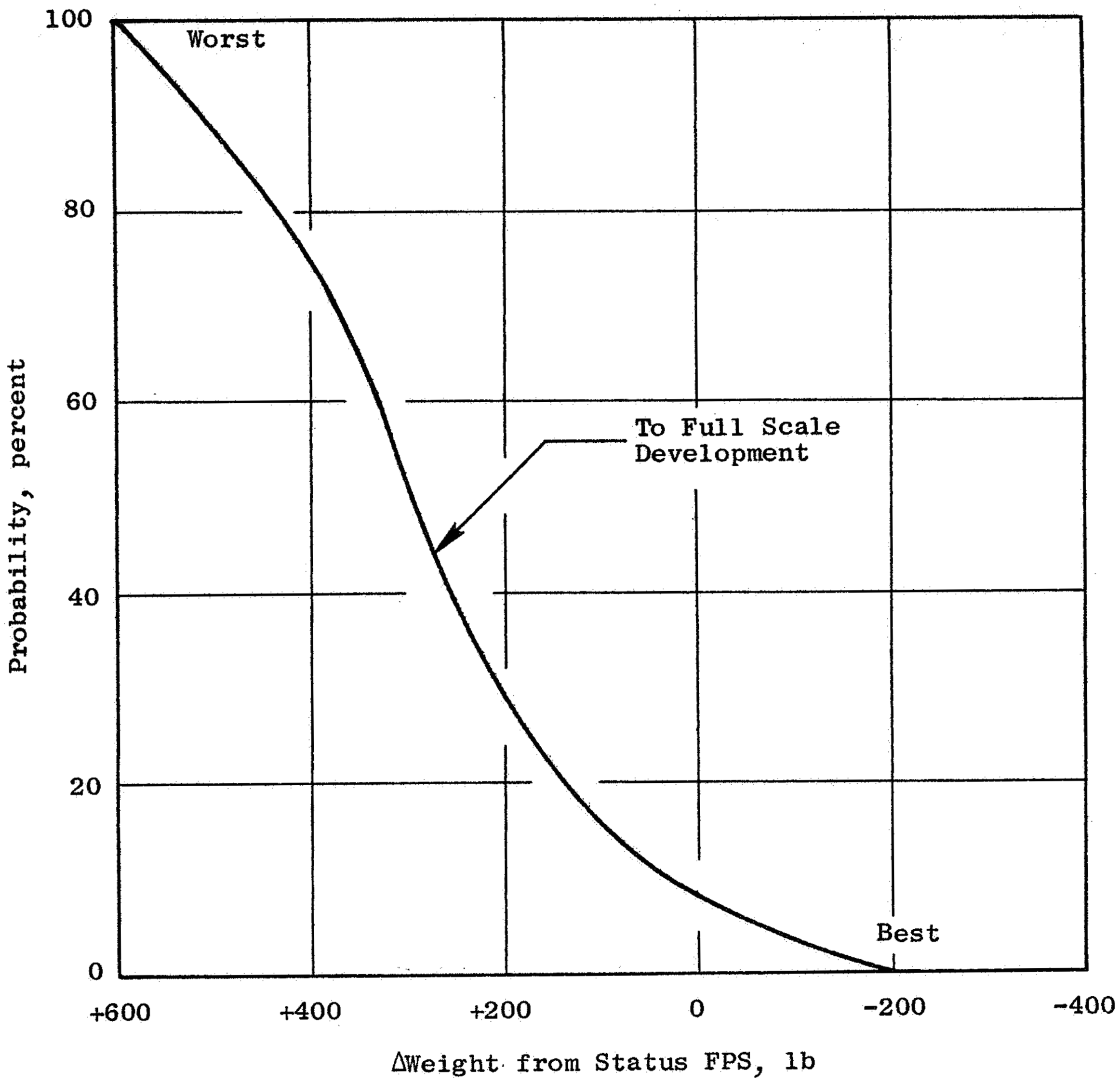


Figure 32. Probability of Achieving FPS Weight Projection.

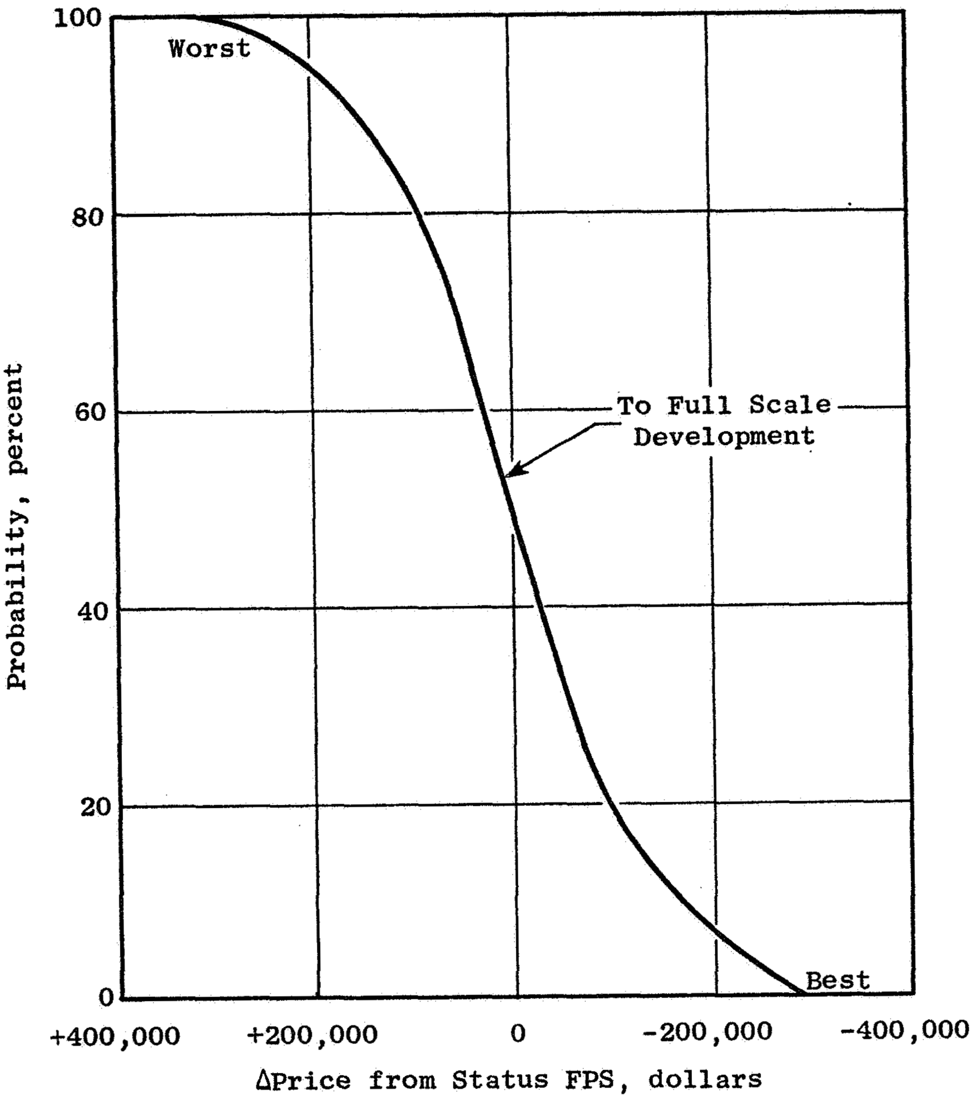


Figure 33. Probability of Achieving FPS Price Projections.

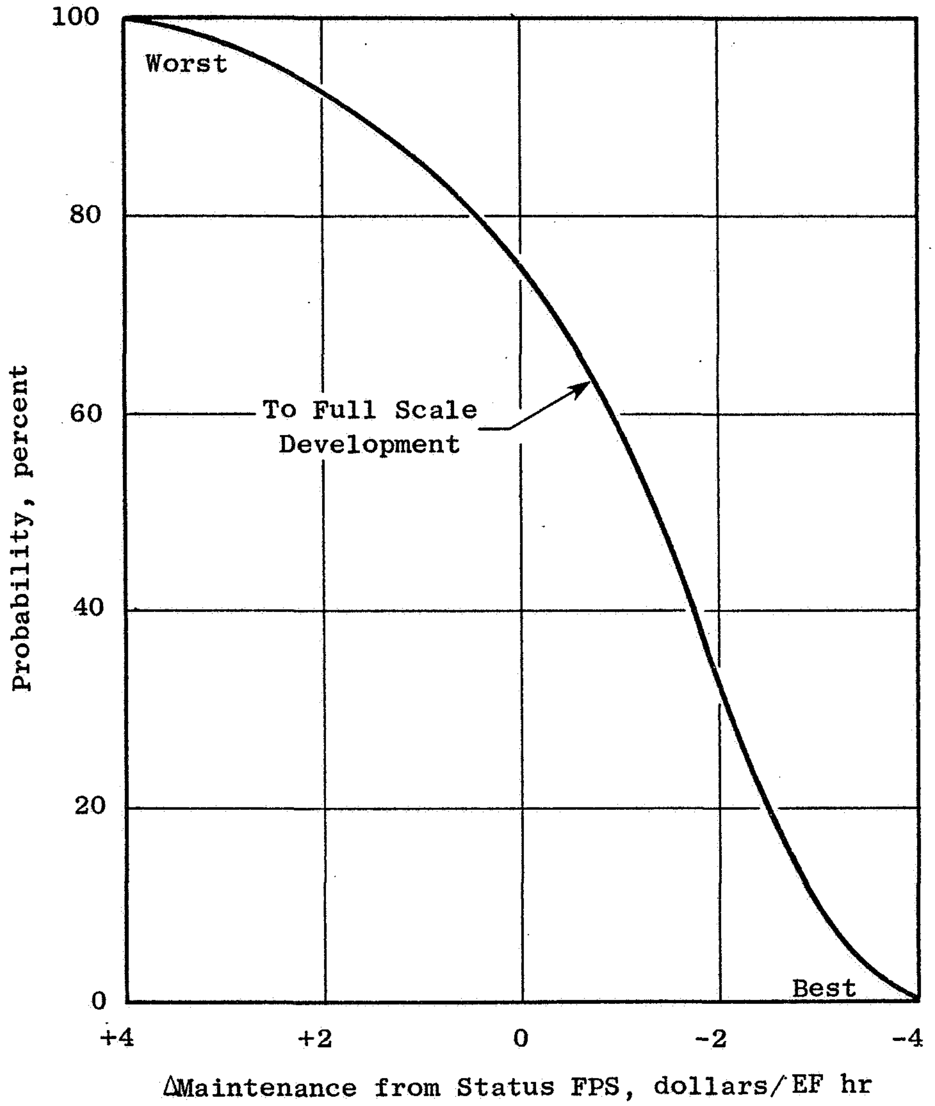


Figure 34. Probability of Achieving FPS Maintenance Cost Projections.

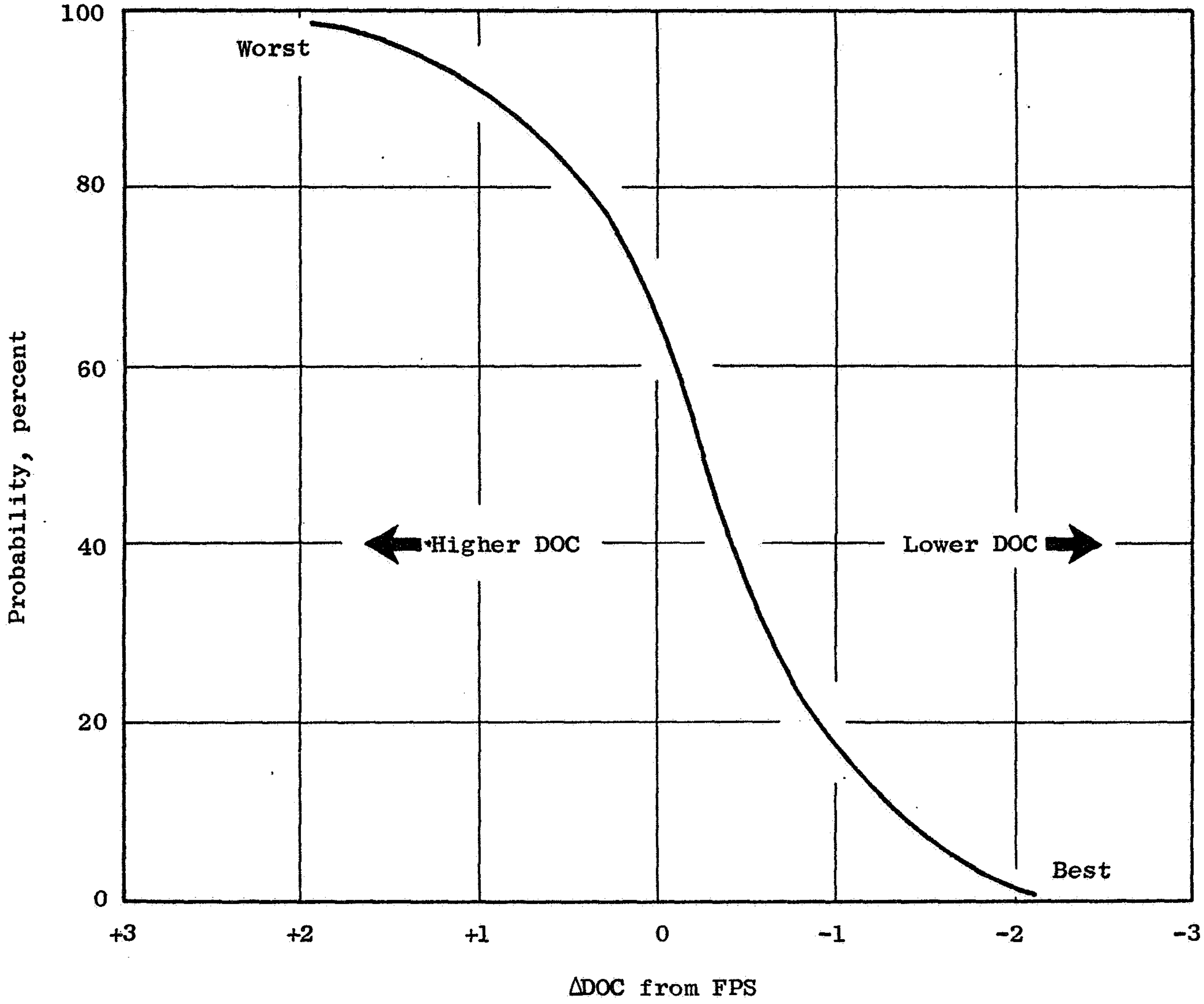


Figure 35. Probability of Meeting Projected DOC.

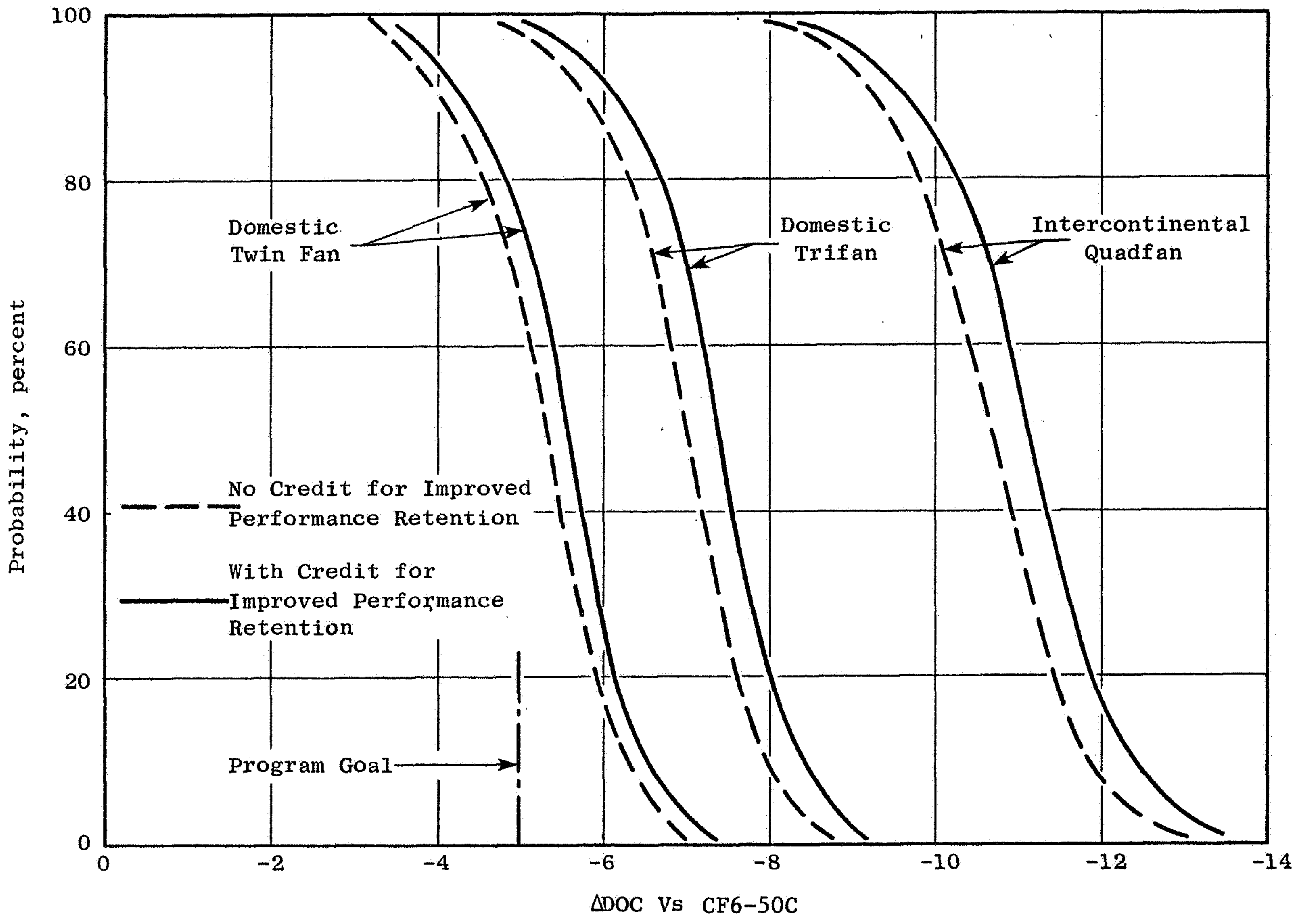


Figure 36. Probability of Meeting DOC Goal.

8.4 NOISE GOALS

The probability of metting the noise goals has been calculated for the various aircraft used in the E^3 acoustics evaluations. The calculation assumed standard deviations of 1.3, 1.4, and 1.7 EPNdB at takeoff, sideline, and approach, respectively. These are based on past experience and include:

- Measurement scatter
- Treatment effectiveness
- Air attenuation
- Prediction accuracy
- Source features
- Sideline shielding.

A Monte Carlo simulation (Reference 7) was further used to model noise level distribution. The resulting probabilities of meeting FAR 36 (1978) Noise Rules are shown in Table XXIV.

Table XXIV. Probabilities of Meeting FAR 36 (1978) Noise Rule Without Trades.

Aircraft	Probability of Certification Without Trades (%)
Boeing Twin Jet	94
Lockheed Trijet	97
Lockheed Quadjet	99
Douglas Trijet	99

8.5 EMISSIONS GOALS

Estimated probabilities for meeting emission goals are presented in Figures 37 through 40. These curves were developed using the following standard deviations:

CO	10%
HC	20%
NO_x	5%
Smoke	12.5%

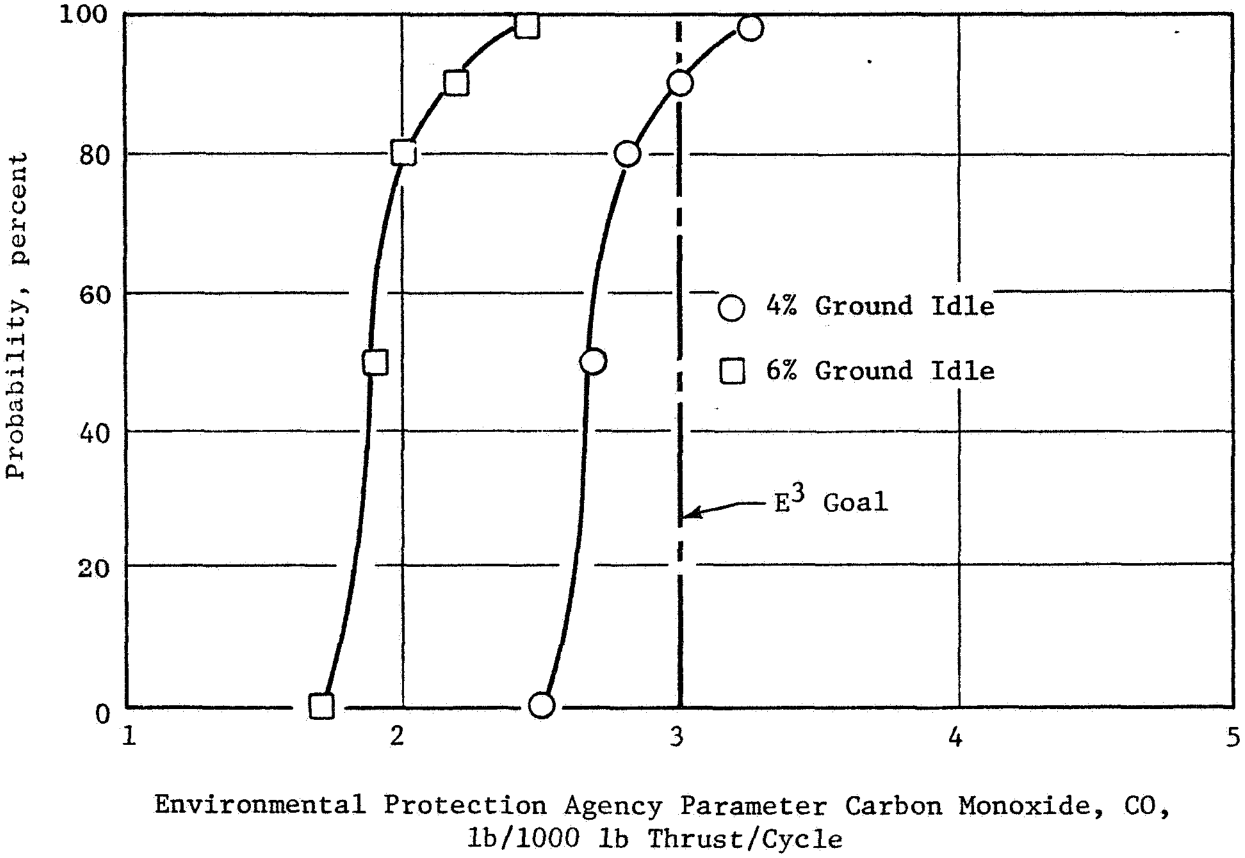


Figure 37. Probability of Meeting CO Emissions Goal.

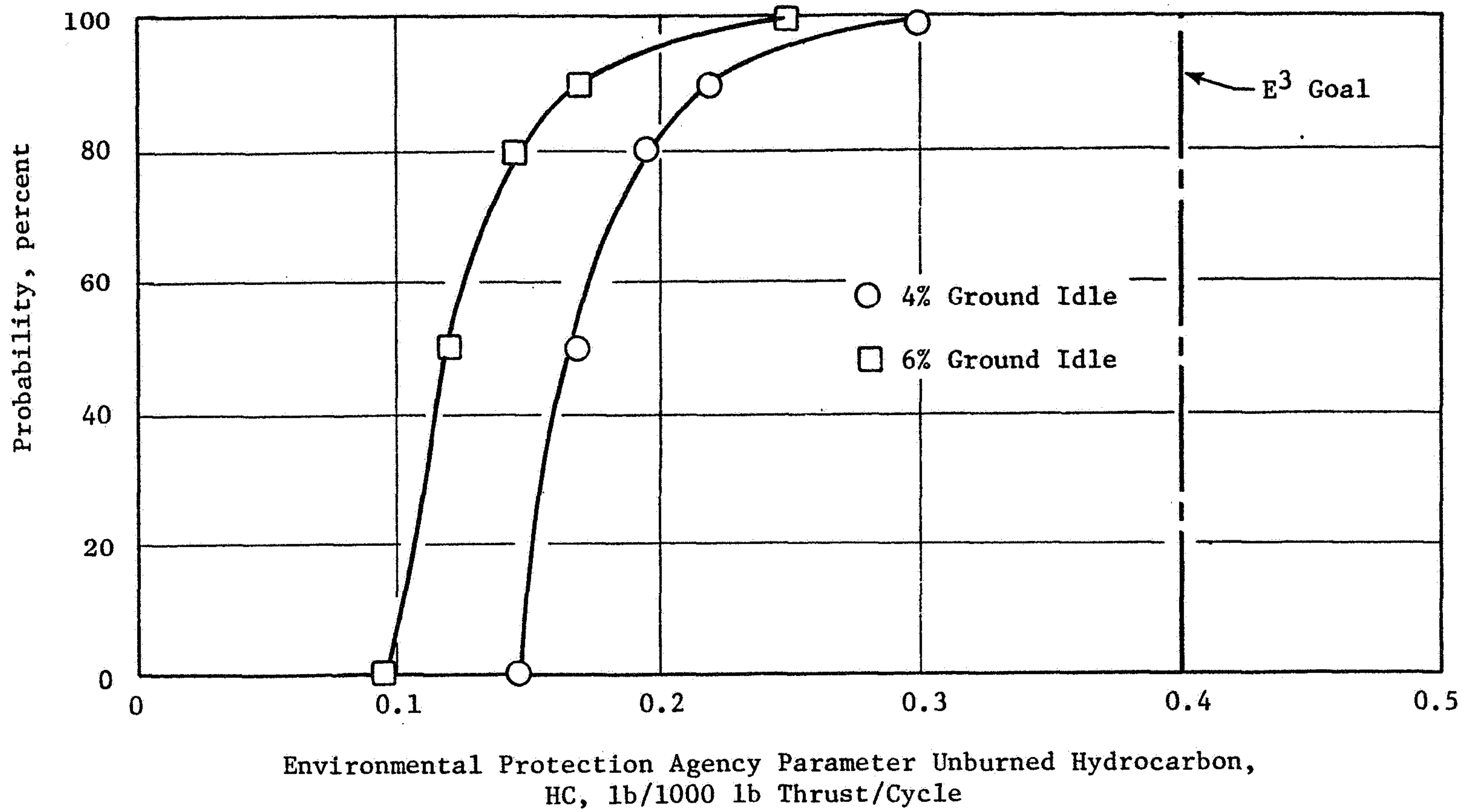


Figure 38. Probability of Meeting HC Goal.

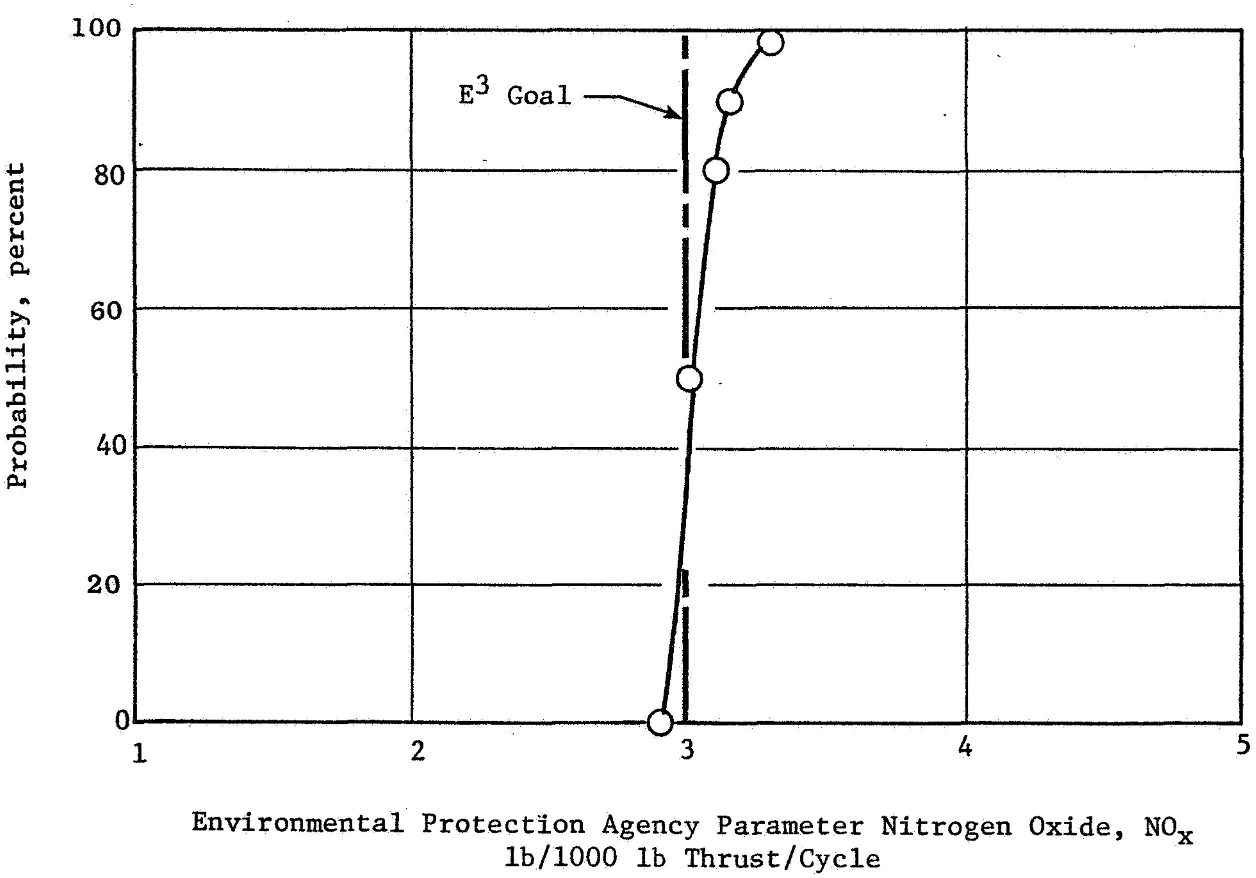


Figure 39. Probability of Meeting NO$_x$ Goal.

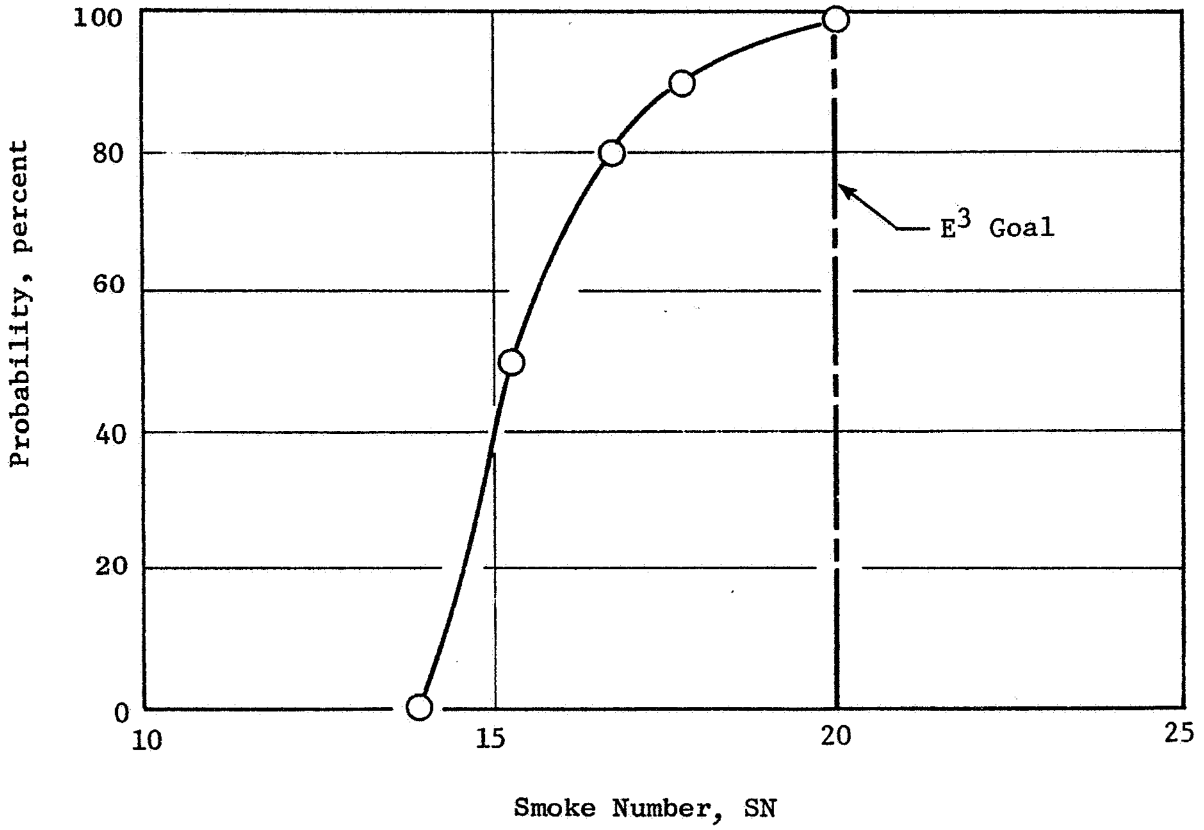


Figure 40. Probability of Meeting Smoke Goal.

The above standard deviations were derived from available engine and component test data and include engine-to-engine variations and measurement variations.

The results of the study indicate (Figure 37) that the probability of meeting the CO goal is 90% for a 4% ground idle requirement and 100% for a 6% ground idle requirement. The HC and smoke goals are expected to be met with 100% probability as shown in Figures 38 and 40. The probability of meeting the NO_x goal, however, is estimated to be 50% (Figure 39).

9.0 CONCLUSIONS

Preliminary design of the E^3 Flight Propulsion System has indicated that all NASA program goals will be met or exceeded. However, the noise level margin on the Boeing twin jet was 2.6 EPNdB instead of the desired 3, and the NO_x margin for the double annular combustor is slightly less than desired for production variability. An item-by-item discussion follows.

9.1 INSTALLED SFC

The installed sfc of the FPS, without customer bleed or power extraction, was projected to be 14.2% better than the baseline CF6-50C versus the NASA goal of 12%. In addition, with customer bleed extraction, the use of a regenerative fuel heater was projected to provide an additional net 0.4% improvement relative to the baseline engine, for a total potential benefit of 14.6%.

The improvement in sfc translated into improvements in mission fuel burned of 15.5 to 21.7% over the range of study aircraft and missions.

9.2 DETERIORATION

The NASA goal is a 50% reduction in performance deterioration rate in service relative to the CF6-50C. It was projected this goal will be met. This translated into an equivalent 1% improvement in average, in-service sfc over the usage life of the engine. Credit for this improvement raised the mission fuel savings to 16.3 to 22.9% over the range of study aircraft and missions.

9.3 DIRECT OPERATING COST

The NASA goal was a 5% improvement in DOC. The improvements shown were 5 to 12.3% depending on the study aircraft, mission, and whether credit was given for improved performance retention.

9.4 NOISE

The NASA goal was to meet FAR 36 (1978) standards. Acoustic evaluations showed the E^3 engine in the advanced study aircraft has at least 3 EPNdB margin relative to the standard, except for the Boeing twin jet which has 2.6 EPNdB margin.

9.5 EMISSIONS

The NASA goal was to meet the EPA-proposed 1981 Standard. The E^3 engine was projected to meet CO, HC, and Smoke requirements with margin and NO_x with less margin than is needed for production engine variation.

9.6 COMMERCIAL ENGINE PRACTICES

The NASA goal was that the design had to meet commercial operating requirements. The E^3 Flight Propulsion System was designed according to General Electric commercial design practices to meet this goal.

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SYMBOLS AND ABBREVIATIONS

A/F	Airframe
AMAC	Advanced Multistage Axial Flow Compressor
BPR	Bypass Ratio
CD&I	Component Development and Integration
cm	Centimeter
CO	Carbon Monoxide
D_{HL}	Nacelle Highlight Diameter
D_{max}	Nacelle Maximum Diameter
DOC	Direct Operating Cost
DS	Directionally Solidified
E^3	Energy Efficient Engine
ECCP	Experimental Clean Combustor Program
ECS	Environmental Control System
EPA	Environmental Protection Agency
EPAP	EPA Parameter (measure of emissions)
EPNdB	Effective Perceived Noise in Decibels
EPNL	Effective Perceived Noise Level (in Decibels)
FADEC	Full Authority Digital Electronic Control
FAR	Federal Airworthiness Regulations
FOD	Foreign Object Damage
FPR	Fan Pressure Ratio
FPS	Flight Propulsion System
fps	Feet per Second
ft.	Feet

SYMBOLS AND ABBREVIATIONS (Continued)

gal.	Gallon
HC	Hydrocarbon
HPC	High Pressure Compressor
HPT	High Pressure Turbine
hr	Hour
ICLS	Integrated Core - Low Spool Vehicle
in.	Inch
IOC	Indirect Operating Cost
kg	Kilogram
km	Kilometer
kn	Knots
K $	Thousands of Dollars
ℓ	Liter
lb	Pound
LPT	Low Pressure Turbine
m	Meter
MCL	Maximum Climb
M	Mach Number
N	Newton
NO_x	Oxides of Nitrogen
nmi	Nautical Mile
OEW	Operating Weight Empty
O_{WE}	Operating Weight Empty
PDR	Preliminary Design Review

SYMBOLS AND ABBREVIATIONS (Concluded)

PD&I	Preliminary Design and Integration
QCSEE	Quiet Clean Short-haul Experimental Engine
ROI	Return on Investment
sfc	Specific Fuel Consumption
SLS	Sea Level Static
SLTO	Sea-Level-Takeoff
SN	Smoke Number
STEDLEC	Study of Turbofan Engine Designed for Low Energy Consumption
St Mi.	Statute Mile
TO	Takeoff
TOGW	Takeoff Gross Weight
T/R	Thrust Reverser
USTEDLEC	Unconventional STEDLEC
VSCF	Variable Speed Constant Frequency (Generator)
W_{AF}	Airframe Weight
W_f	Fuel Weight
η	Efficiency
Δ	Change in

APPENDIX A

Appendix A is a reproduction of report D6-48069 supplied by Boeing Aircraft Company as their contribution to aircraft integration. The format and printing have been altered to coordinate with this publication.

BOEING COMMERCIAL AIRPLANE COMPANY
A DIVISION OF THE BOEING COMPANY
SEATTLE, WASHINGTON

ENERGY EFFICIENT ENGINE AND AIRPLANE INTEGRATION STUDY

PURCHASE ORDER 200-4XX-14N43049
UNDER
NASA CONTRACT NAS3-10643

C-2

FOR

GENERAL ELECTRIC COMPANY
AIRCRAFT ENGINE GROUP
EVENDALE, OHIO

APPENDIX A

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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 first to help determine if the GE Advanced Technology Engine (ATE) met NASA performance goals and secondly to ensure that E^3 nacelle met airplane requirements and objectives, aircraft manufacturer's design practice, and FAA certification requirements. 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 ATE and CF6-50C engine data supplied by GE were cycled with the airplane to achieve the most fuel-efficient and economical airplane for each engine installation. Table A-I shows the airplane design point performance and characteristics. The design-mission fuel burned for the ATE was 18.3% lower than for the CF6-50C engine. Based on GE supplied maintenance cost and engine price data, the ATE also had 6% lower design-mission DOC than the CF6-50C-powered airplane.

Table A-II shows that noise levels for the ATE-powered airplane meet FAR 36 - Amendment 8 requirements for a twin-engine airplane. A 3 EPNdB margin between nominal noise estimates and the FAR 36 - Amendment 8 require ments is achieved except at approach where the margin is 2 EPNdB. Since no attempt was made in this preliminary estimate to refine the nacelle treatment to the lowest noise levels, it was concluded that refinement of noise treatment could attain the 3 EPNdB margin Boeing generally considers acceptable to assure certifiable noise levels.

The fuel burned, economics, and noise results based on engine data supplied by GE for the ATE show that the NASA goals for the GE 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.

- Boeing preliminary evaluation of the ATE nacelle weights indicated the nacelle to be over 1000 lb heavier than the GE estimated weight. Boeing's weight estimate was based on methods reflecting low technical risk for commercial operation. A 1000 lb weight increase reduces fuel burned savings from 18.3% to about 17% and reduces the design-mission DOC advantage from 6 to 5.8%.

- The ATE engine price supplied by GE is too high according to Boeing projections. Boeing's assessment indicated an engine price 22% less than the GE estimate. The Boeing estimated price increased the Design Mission DOC advantage of the ATE from 6% to 7.5%.

Table A-I. Airplane Characteristics and Performance

	MODEL 768-869 (CF6-50C ENGINE)	MODEL 768-868 (ATE)		
DESIGN RANGE, N.MI.	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		
ENGINE PERFORMANCE AND WEIGHT DATA	REF 3	REF 3	PDR STATUS NOV. 20, 21, 1978	
ENGINE PERFORMANCE RETENSION ALLOWANCE, % TSFC	BASE	0	-1.0	0
TAKEOFF THRUST/ENGINE, LB (SEA LEVEL WITHOUT BLEED OR HPX)	37,970	37,710	37,840	37,930
TOGW, LB	257,350	243,560	244,460	245,090
OPERATING WEIGHT EMPTY, LB	160,940	156,930	158,260	158,480
MANUFACTURER EMPTY WEIGHT, LB	149,540	145,530	146,820	147,030
MAXIMUM LANDING WEIGHT, LB	230,650	218,290	219,090	219,660
BLOCK FUEL, LB				
-AT DESIGN RANGE AND PAYLOAD	41,730	34,400	34,090	34,400
-AT 1000 N.MI. RANGE, 108 PASSENGERS	19,130	16,040	15,890	16,040
-AT 665 N.MI. RANGE, 108 PASSENGERS	13,260	11,205	11,100	11,205

NOTE: ABOVE DATA BASED ON G.E. SUPPLIED ENGINE PERFORMACE, ENGINE WEIGHT, AND NACELLE WEIGHT.

- Nacelle assessment and evaluation requires continual review as the design evolves to ensure that the nacelle design meets airplane requirements and objectives, aircraft manufacturer's design practice, and airline and FAA certification requirements. During the Boeing assessment, several versions of the ATE nacelle design were reviewed. In GE'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 GE. Some nacelle design problems were identified. Much additional effort would be required to ensure a flight-acceptable nacelle installation.

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.

Table A-II. Nominal Noise Estimate

	ATE EPNdB	FAR 36 (1978) Requirement EPNdB	Margin EPNdB
Takeoff	90.0	93.8	-3.8
Sideline	90.0	98.2	-8.2
Approach	100.0	102.0	-2.0

2.0 INTRODUCTION

The NASA Aircraft Energy program (ACEE) has the objective of improving the energy efficiency of future U.S. aircraft so that substantial fuel savings and economics 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 the General Electric Company (GE) under subcontract No. P.O. 200-4X X 14K 40096 in support of the GE prime contract NAS3-20627. Objective of the GE prime contract 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:

Task 1 -	Aircraft and Mission Definition. Under this task an advanced technology transport aircraft was defined with a design range, performance passenger capacity, and mission appropriately for domestic use.
Task 2-	Aircraft Performance and Sensitivity. This task evaluated a current technology reference engine, the CF6-50C (Ref.3) scaled to the airplane requirements and a similarly scaled advanced technology engine, the ATE (Ref.3) 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 power with the advanced engine.
Task 3 - Subtask A	Aircraft and Engine Integration. Under this task a GE nacelle was evaluated for nacelle construction, nacelle aerodynamics airframe accessory requirements and location, maintinability, accessibility and safety requirements. Results of the aerodynamic study were reported in Reference 5.
Task 3 - Subtask B	Long Duct Wind Tunnel Study. It was intended that Boeing assess and comment on wind tunnel tests of a GE-designed nacelle simulator test model. Because of delay in model

fabrication the tests could not be completed in the contract schedule. Boeing therefore expects to complete this task on a contract extension and report on this task in a later report.

Task 4 - Reports

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 ft. 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 CF6-50C and ATE-powered airplanes and compares the resulting performance, noise, and economics of the two airplanes. These studies were based on the GE-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 22% lower than GE's estimate.

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

3.0 ABBREVIATIONS AND SYMBOLS

A/P	airplane
AR	aspect ratio
ATE	advanced technology engine
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, °F
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
PDR	preliminary design review
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
Λ 0.26C	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 and considerations of potential fuel saving. 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.

Statistics of airplane fuel consumption for various stage lengths have shown that over 85% of total domestic passenger-jet fuel consumption occurs at stage lengths at or below 2000 statute miles. Furthermore as Figure A-1 shows, the shorter ranges account for the bulk of the fuel used.

Considering the potential market and the opportunity or fuel saving at shorter ranges 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

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

	Domestic Airplane	
Range, nmi	665	1000
Payload, passengers (15/85% mix)	108	108
Cruise Mach number	0.8	0.8

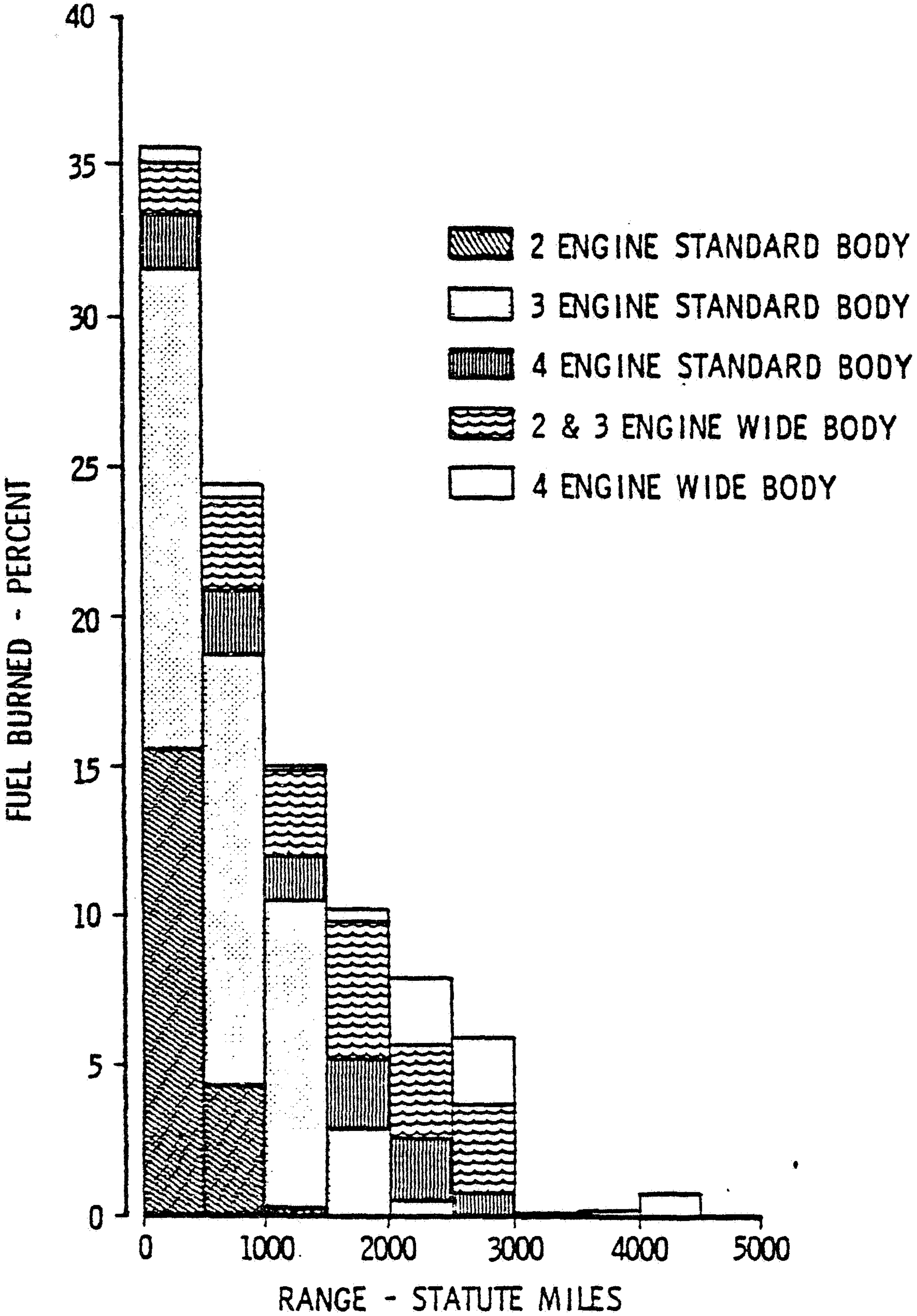


Figure A-1. Domestic Passenger Jet Fuel Consumption as a Function of Range

A typical mission profile is shown in Figure A-2.

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 aiplane configurations drawings (Fig. A-3).

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.

4.2.2 Weight and Structures

Possible application of advanced aluminum alloys and advanced composite structures on airframe conponents is shown with potential weight savings on Table A-III.

4.3 AIRPLANE GEOMETRY GUIDELINES

The airplane geometry guidelines shown in Figure A-4 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. P.O. 200-4XX-14K40096.

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. A-5 and A-6) provided balance between interference drag and flutter weight penalty. Figure A-7 compares the ATE and CF6-50C installations using these guidelines.

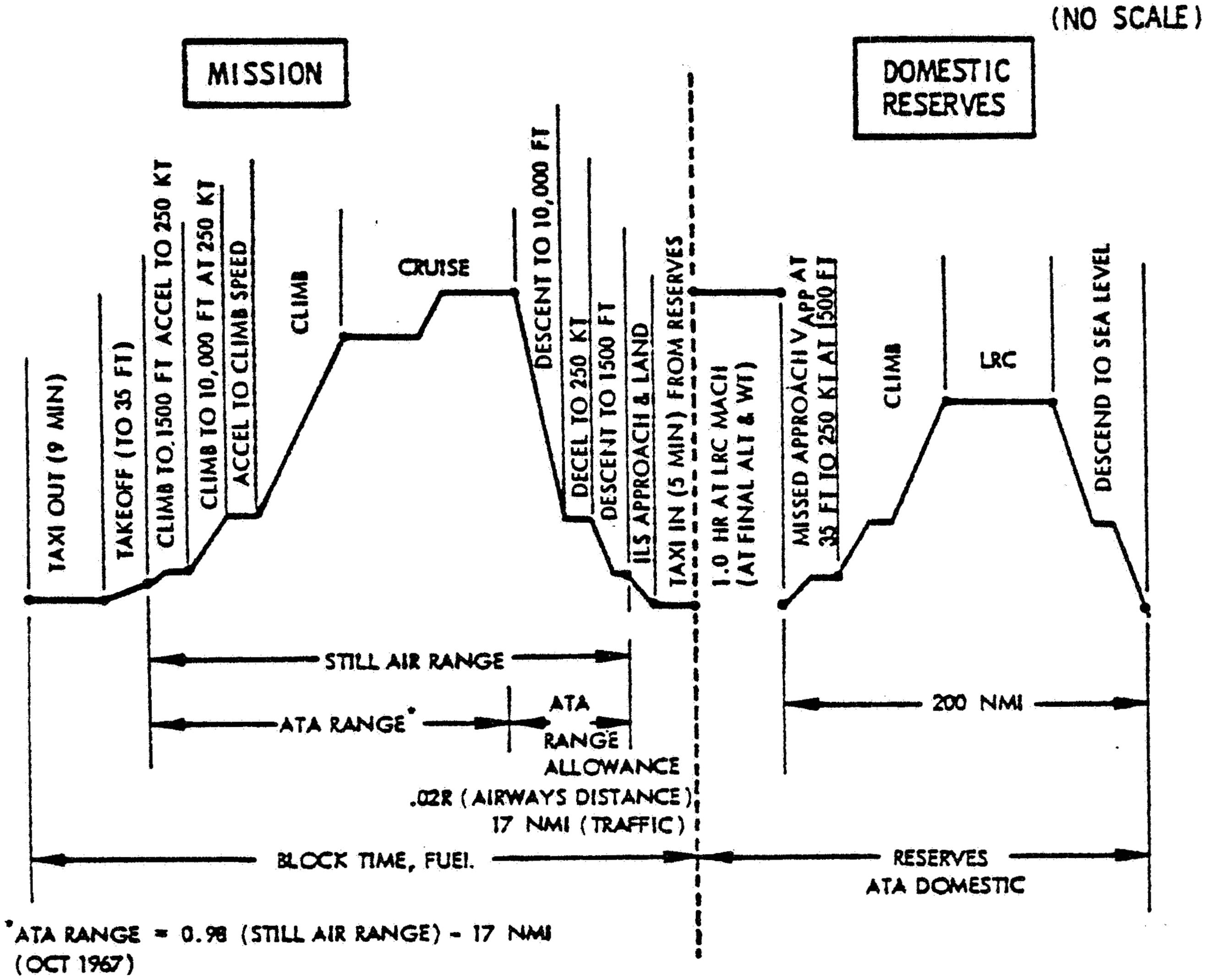


Figure A-2. Typical Mission Profile

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

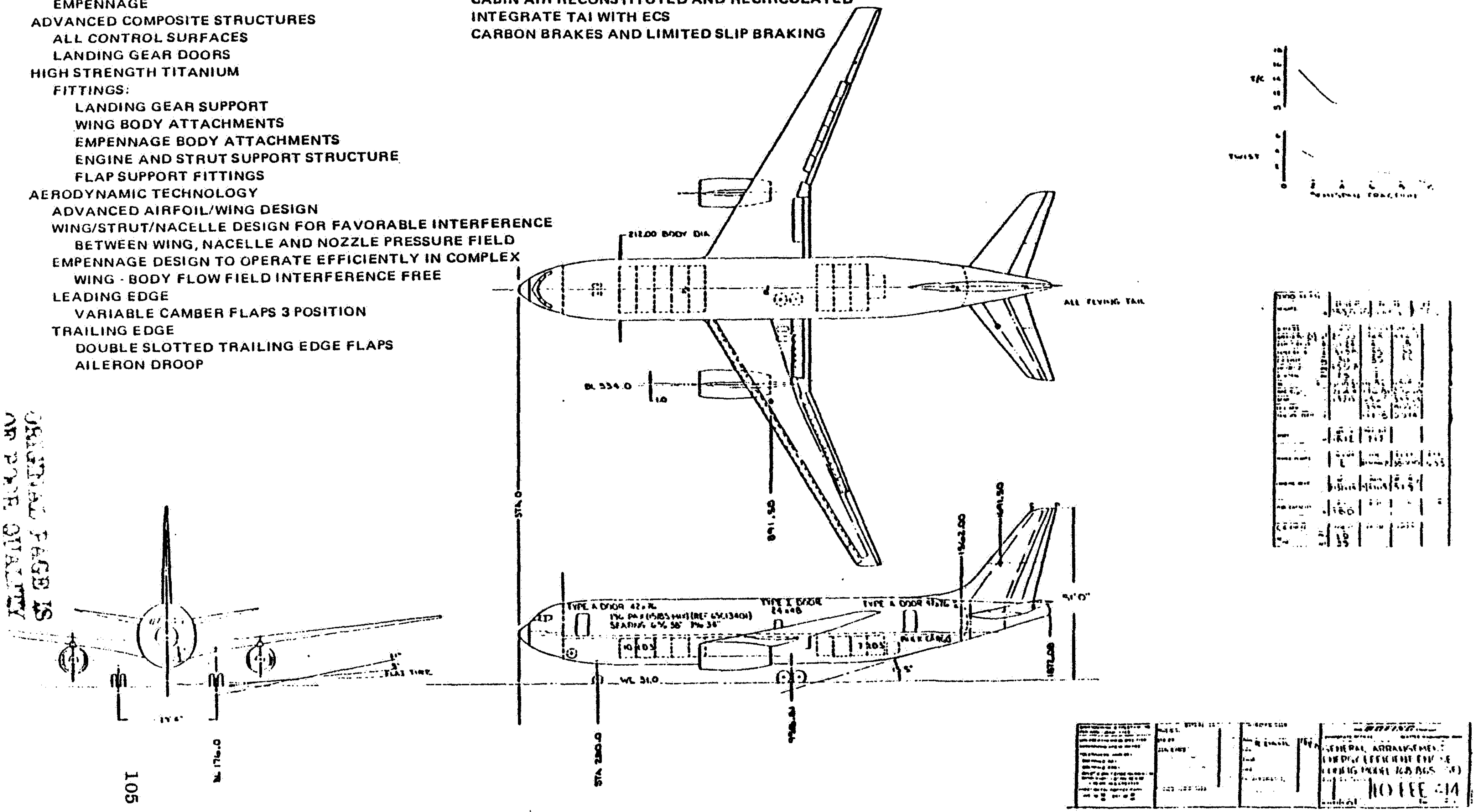
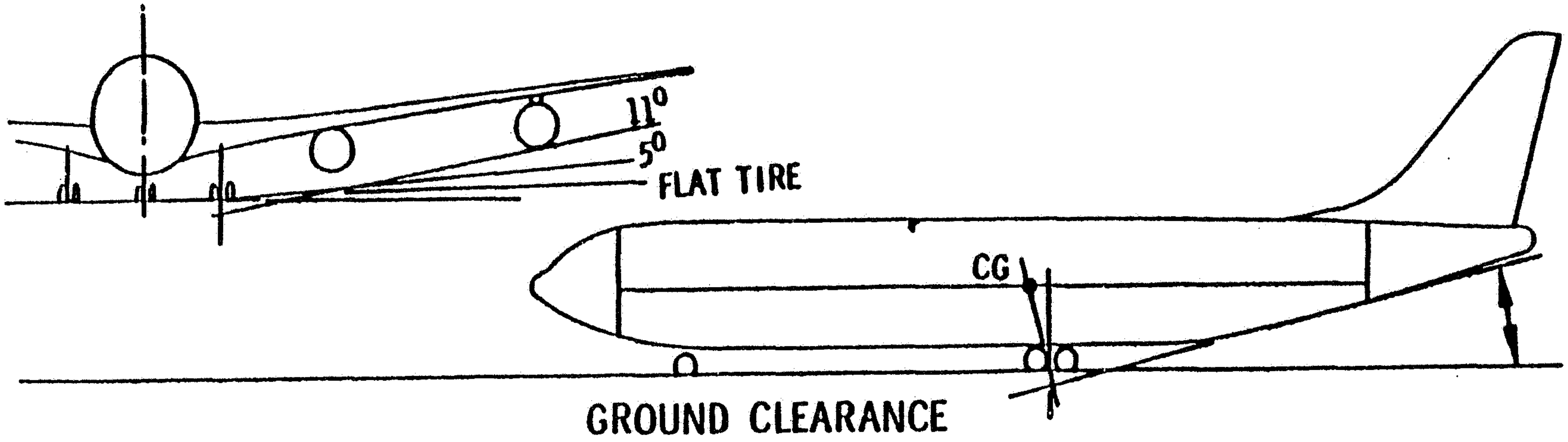


Figure A-3. Energy Efficient Engine Configuration (General Arrangement) - Model 768-865

Table A-III. Advanced Airframe Structure for E^3 Studies

CURRENT TECHNOLOGY	NEW TECHNOLOGY		
MATERIAL	MATERIAL	STRUCTURAL COMPONENT	WEIGHT SAVING % OF COMPONENT WEIGHT
STANDARD ALUMINUM ALLOYS (CURRENT 747)	ADVANCED ALUMINUM ALLOYS	WING BOX	6%
		FUSELAGE	4%
		EMPENNAGE BOX	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%



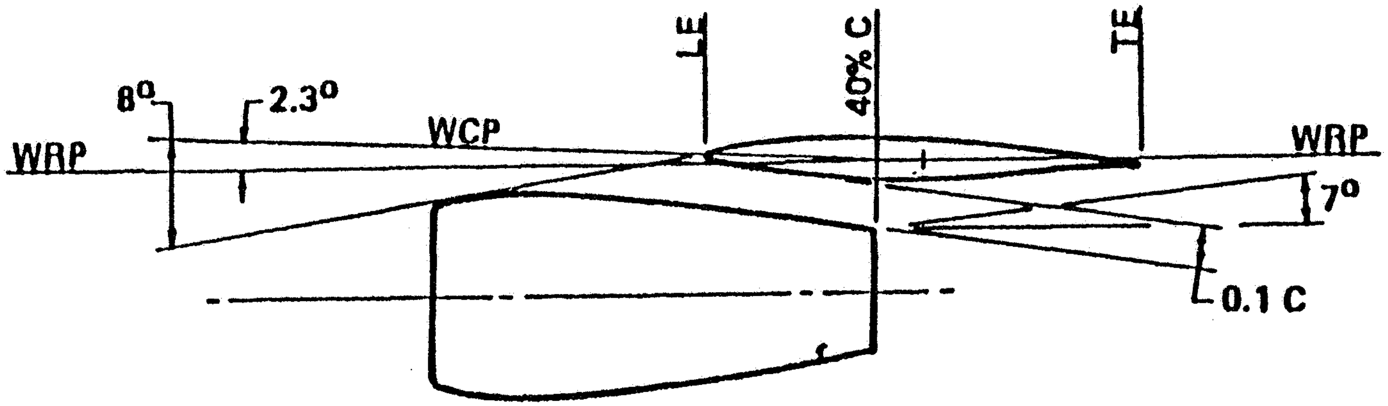
- TAKE OFF ROTATION

  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 A-4. Airplane Geometry Guidelines



- NACELLE PLACEMENT

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

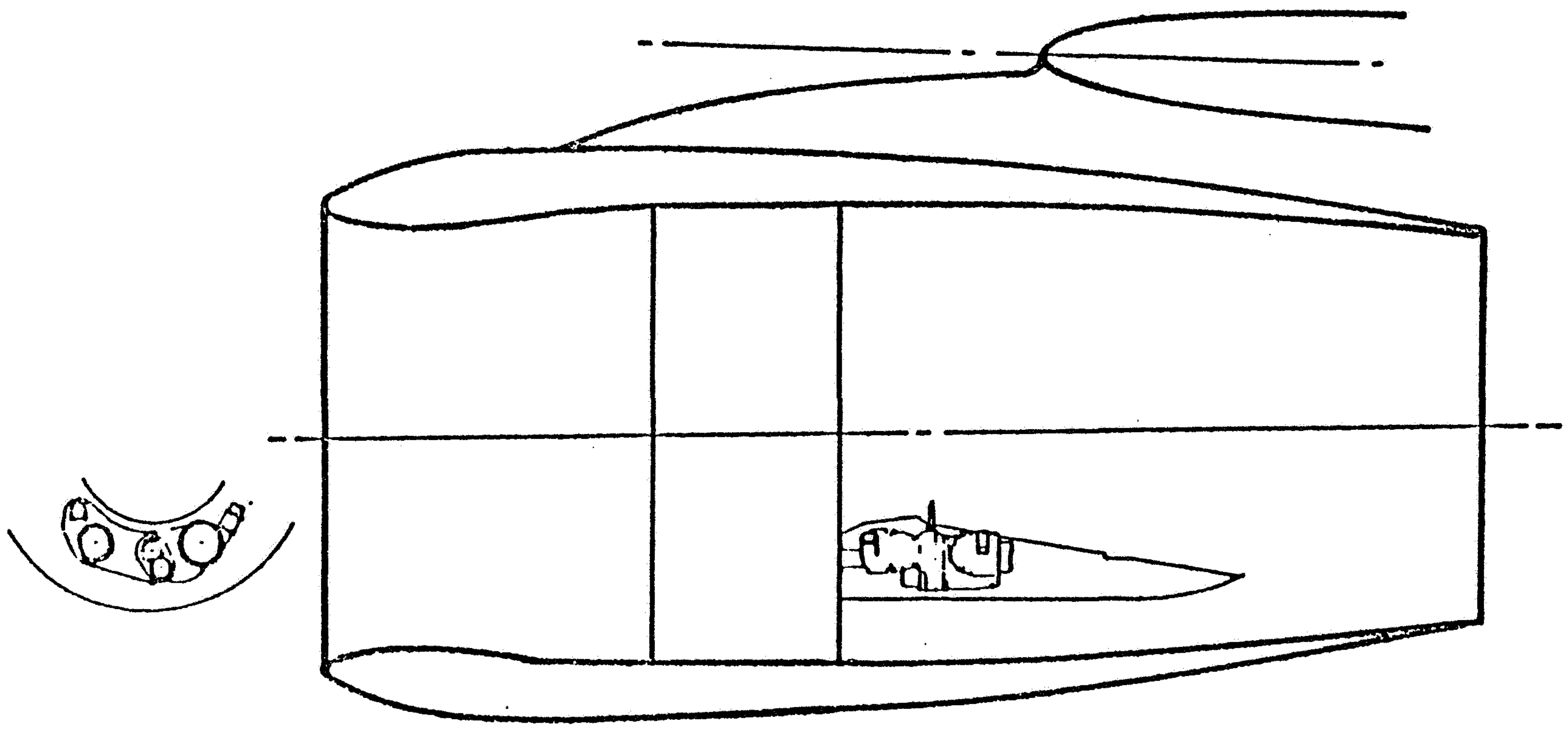
- NO VORTEX SHEDDING OVER WING

  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 A-5. 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 A-6. Engine Placement Ground Rules

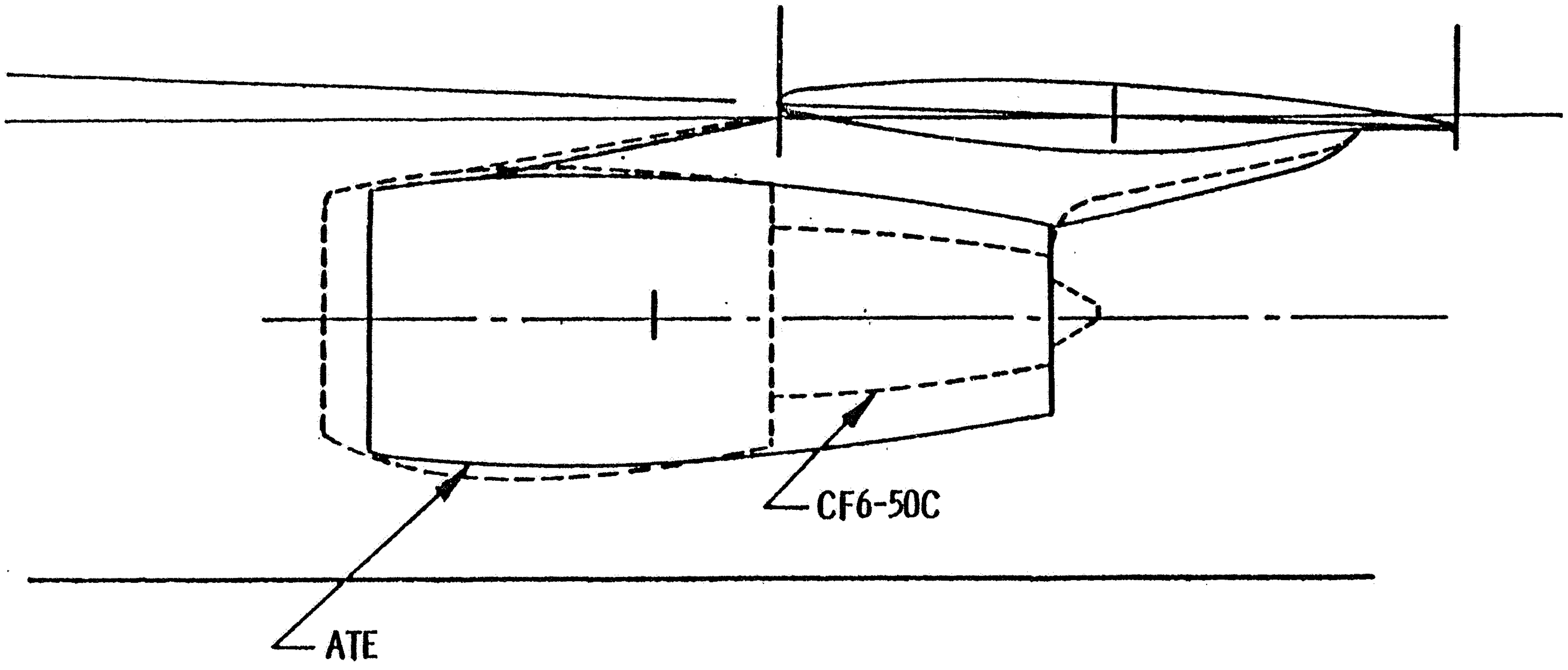


Figure A-7. Installation Comparison

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

4.4.2 Nacelle Design

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 A-8.

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.

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

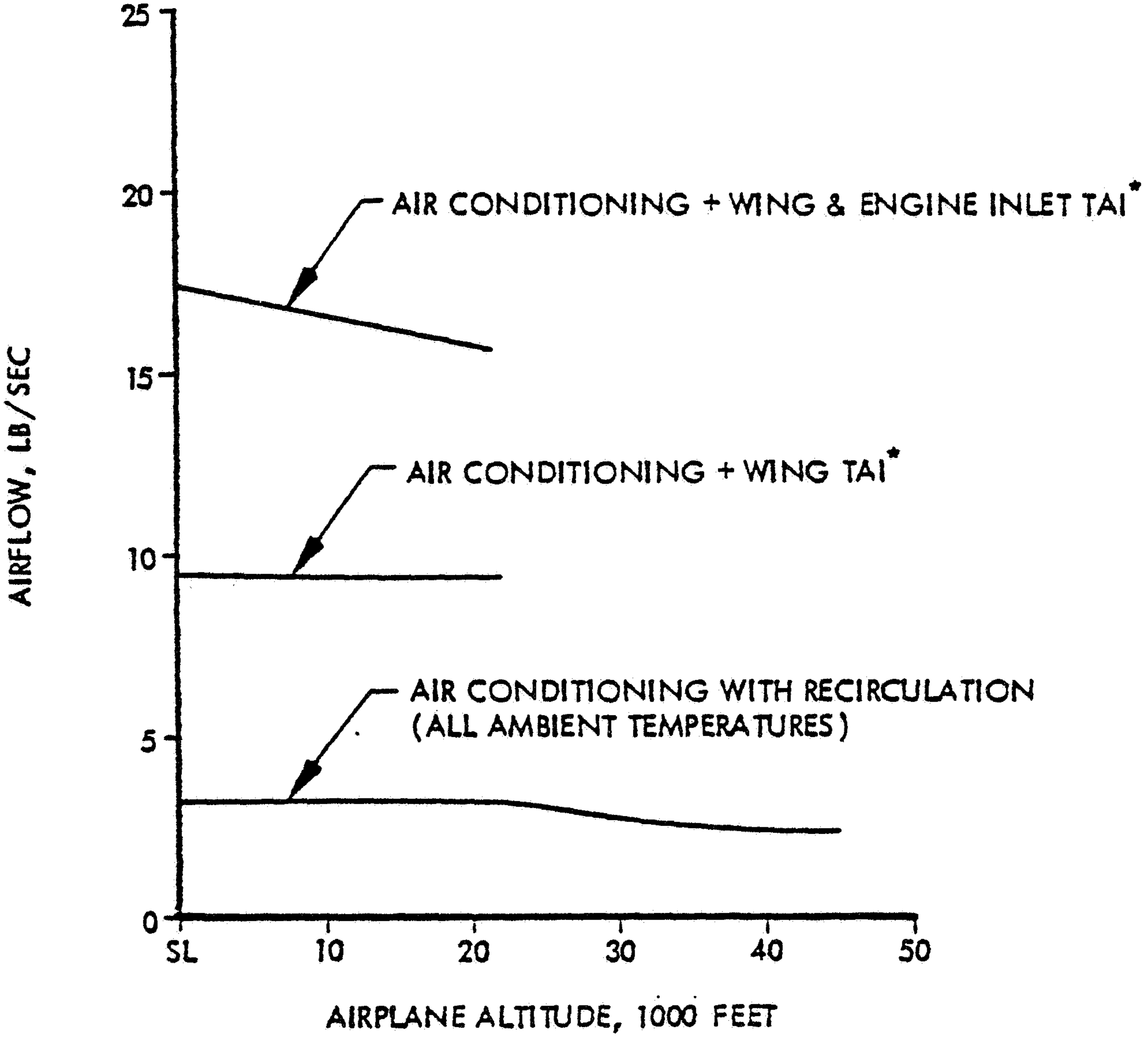
For the preliminary airplane, this study selected a twin-engine wide-body configuration with double-aisle seven-abreast seating. Wing geometry (AR = 10, $\Lambda_{0.25C}$ = 30 deg) was consistent with the cruise speed and takeoff and landing characteristics. The lower lobe cargo space was configured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

A prelimnary drawing of the baseline airplane is shown in Figure A-3.

4.5.2 Engine Description

Scalable CF6-50C and ATE turbofan engines (Ref. 3) 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 CF6-50C engine was installed in a short-fan-duct nacelle similar to the Boeing model 747 engine installation; the ATE was installed in a long-duct nacelle that included a forced mixer.

Main characteristics of the two engines at maximum climb thrust, 0.8 Mach, and an altitude of 35 000 ft are:



* ICING CONDITIONS DEFINED BY FAR 25.1419

Figure A-8. Airplane Bleed Airflow Requirement

	ATE	CF6-50C
Bypass ratio	6.8	4.2
Installed SFC	0.546	0.629
Fan pressure ratio	1.65	1.76
Overall pressure ratio	38	32
Maximum turbine rotor inlet temp. (SLS hot-day takeoff)	2340°F	--

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

The following method was used for determining the DOC and ROI of the airplane powered by the CF6-50C and the ATE 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 A-IV, A-V, and A-VI and in Figures A-9 and A-10.

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 investments. 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 A-VII.

Table A-IV. DOC Elements

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 A-V. Basic Characteristics of Boeing 1977 Coefficients

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 expenses	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 A-VI. Domestic Direct Operating Cost Formulas

	BOEING 1977
CREW PAY ($/BLK-HR) 2-MAN CREW 1 3-MAN CREW 1	 $(29.67F_w + 2.838)\ F_u + 19.80$ $(33.54F_w + 3.483)\ F_u + 29.70$
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 ENGINE	 0.06 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)

Definitions of terms and units

TOGW	Maximum takeoff gross weight-lb
Ca	Airframe price-$
Ca	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)

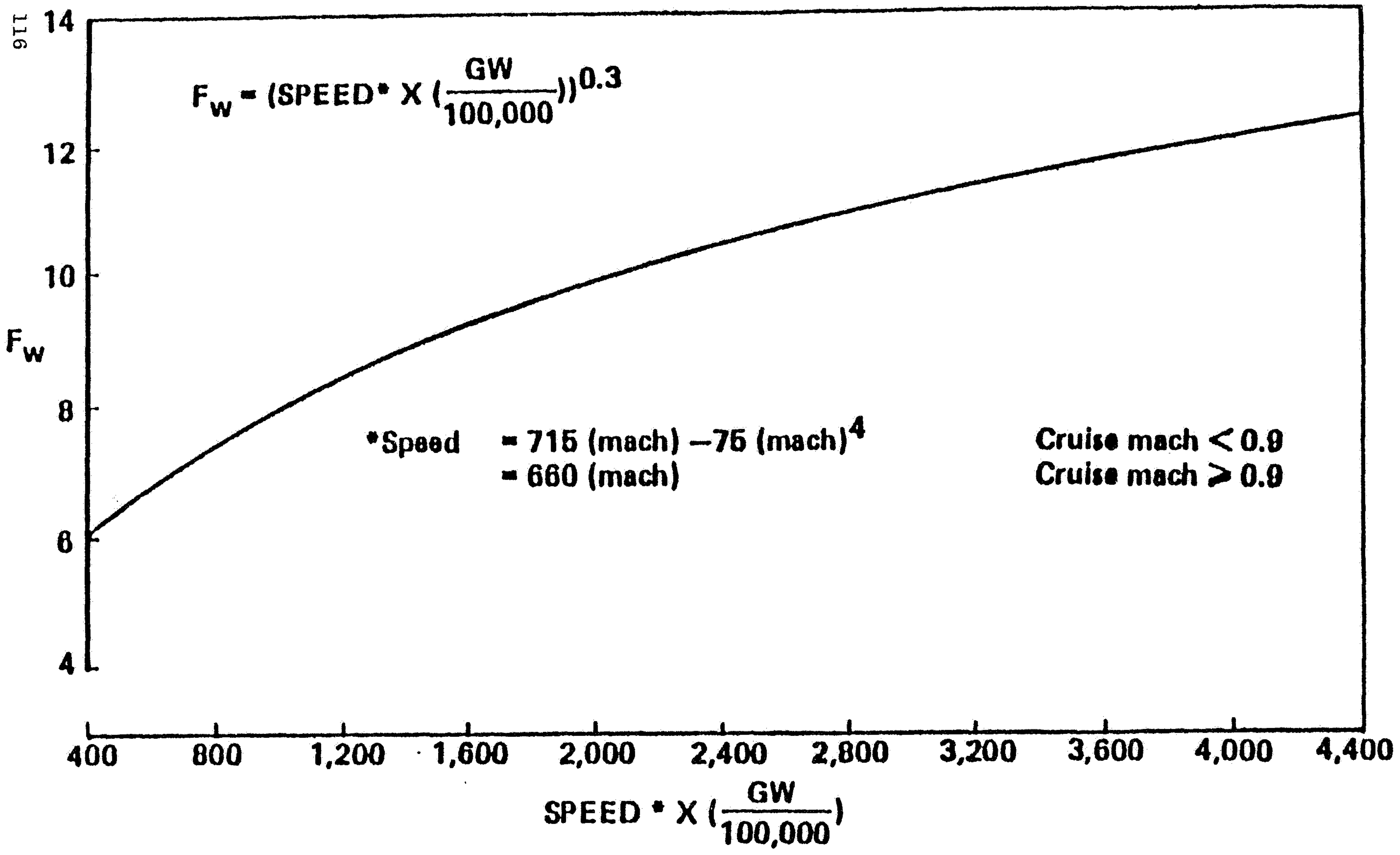


Figure A-9. F_W Factor for Crew Pay

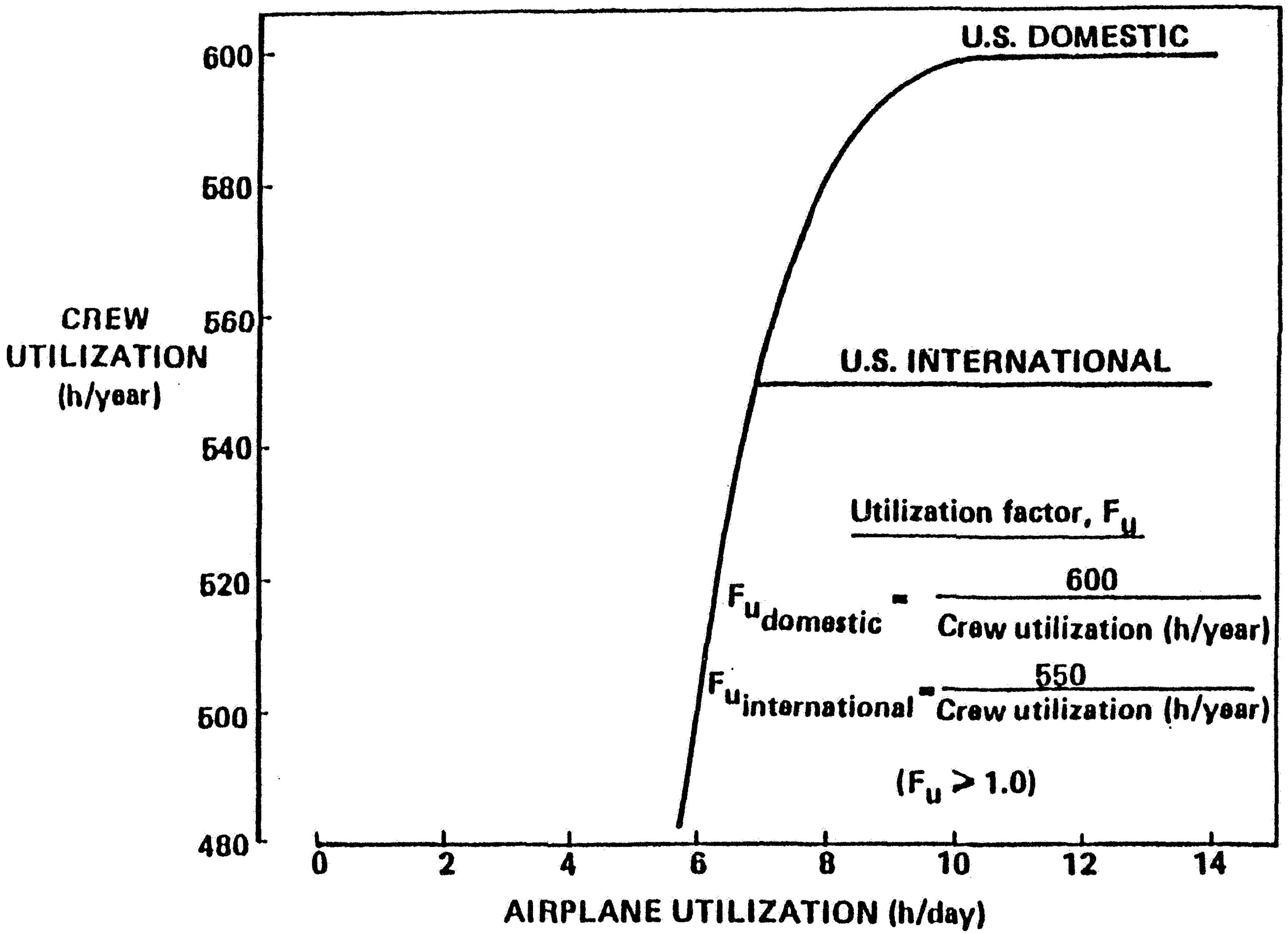


Figure A-10. Crew Utilization

Table A-VII. Return on Investment Method

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)

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

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)

5.0 AIRPLANE PERFORMANCE AND SECURITY

5.1 AIRPLANE SIZING

Both the CF6-50C and the ATE powered airplanes were sized to meet the same design mission. The effect of engine technology on airplane size and performance is shown in Figure A-11. The wing loading for these airplanes was chosen for minimum block fuel (BLKF) and takeoff gross weight (TOGW), but with an 84°F day sea-level takeoff field length (TOFL) constraint of 6000 ft determining the thrust loading. Selected wing loadings (w/s) were 100 lb/sq.ft. for the ATE-powered airplane and 105 lb/sq.ft. for the CF6-50C-powered airplane. Engine thrust to weight (T/W) difference at given wing loading shown in Figure A-11 were due to difference in BPR between the two engines.

5.1.1 Airplane Performance and Characteristics

Characteristics and performance of the CF6-50C and the ATE-powered airplanes are compared in Table A-VIII. Each airplane was designed to meet airplane and mission requirements (Sec. 4.1). The BLKF and TOGW shown in Table A-VIII are based on an airplane sizing program.

5.1.2 Airplane Weight

Table A-IX shows results of a weight analysis on domestic E^3 airplanes with the ATE and CF6-50C engines. These weights reflect the advanced technology features discussed in Section 4.2. The nacelle weights were supplied by GE and scaled to the appropriate thrust level. A preliminary balance analysis indicated acceptable loadability for both airplanes.

5.1.3 Airframe Noise and FAR 36 Flight Conditions

The airframe noise prediction method applied is part of the Boeing standard aircraft-community noise prediction procedure. This method was based on airframe noise being predominantly generated by turbulent flow at the edges of airfoils, cavities, and landing gear members. Quantitative values contained in the method were determined from flight tests of in-service Boeing aircraft. All methods are under continual review to maintain a technology level consistent with their status as validated Boeing standards.

Noise was predicted as 1/3 octave band sound pressure levels having directively defined by a 150-ft polar arc from 10 to 170 deg at 10 deg intervals. The spectra were extrapolated for the required flight condition in order to generate airplane flyover time histories of sound pressure level and weighted noise values (SPL, dB(A)). The perceived noise level (PNL) time history was calculated and converted to effective perceived noise level (EPNL).

In normal use, the predicted airframe noise component is added to other noise components at the spectral level for extrapolation and derivation of total airplane EPNL. In addition, as used here, airframe noise can be predicted and extrapolated separately.

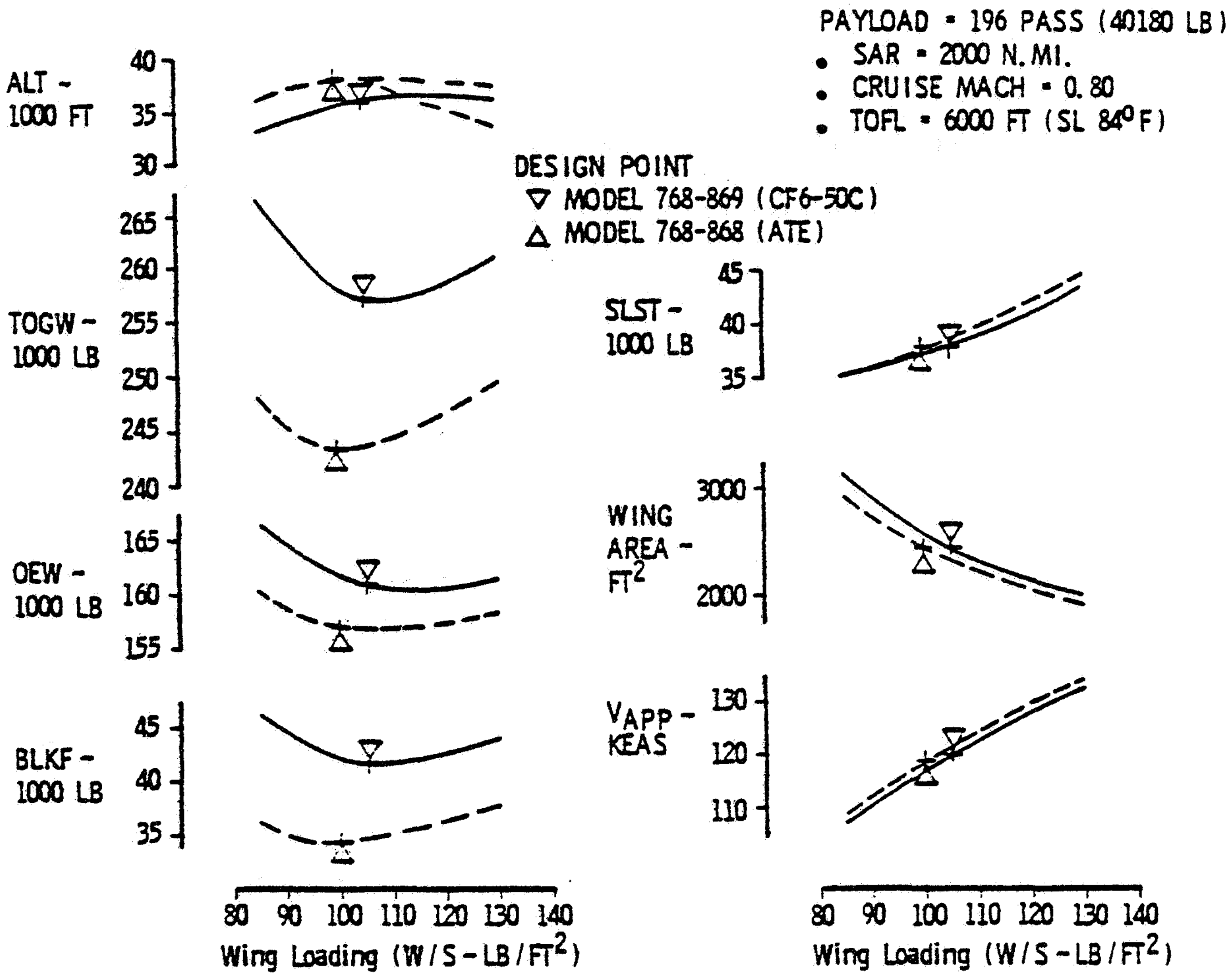


Figure A-11. Airplane Performance Trades

Table A-VIII. Airplane Characteristics and Performance

	MODEL 768-869 (CF6-50C ENGINE)	MODEL 768-868 (ATE)		
DESIGN RANGE, N.MI.	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		
ENGINE PERFORMANCE AND WEIGHT DATA	REF 3	REF 3	PDR STATUS NOV. 20, 21, 1978	
ENGINE PERFORMANCE RETENSION ALLOWANCE, % TSFC	BASE	0	-1.0	0
TAKEOFF THRUST/ENGINE, LB (SEA LEVEL WITHOUT BLEED OR HPX)	37,970	37,710	37,840	37,930
TOGW, LB	257,350	243,560	244,460	245,090
OPERATING WEIGHT EMPTY, LB	160,940	156,930	158,260	158,480
MANUFACTURER EMPTY WEIGHT, LB	149,540	145,530	146,820	147,030
MAXIMUM LANDING WEIGHT, LB	230,650	218,290	219,090	219,660
BLOCK FUEL, LB				
-AT DESIGN RANGE AND PAYLOAD	41,730	34,400	34,090	34,400
-AT 1000 N.MI. RANGE, 108 PASSENGERS	19,130	16,040	15,890	16,040
-AT 665 N.MI. RANGE, 108 PASSENGERS	13,260	11,205	11,100	11,205
BLOCK TIME, HRS				
-AT DESIGN RANGE AND PAYLOAD	4.70	4.70	4.70	4.70
-AT 1000 N.MI. RANGE, 108 PASSENGERS	2.51	2.51	2.51	2.51
-AT 665 N.MI. RANGE, 108 PASSENGERS	1.80	1.80	1.80	1.80

NOTE: ABOVE DATA BASED ON G.E. SUPPLIED ENGINE PERFORMACE, ENGINE WEIGHT, AND NACELLE WEIGHT.

Table A-IX. Weight Statement for GE E^3 Airplanes

	Weight (LB)	
	Model 768-868 (ATE)	Model 768-869 (CF6-50C)
Wing	30,280	31,820
Empennage	4,440	4,470
Body	33,430	33,710
Nacelle*	6,870	9,060
Gear	12,700	12,630
Total structure	(87,630)	(91,690)
Propulsion system	(15,600)	(15,280)
Fixed equipment and options	(42,300)	(42,570)
Standard and operational items	(11,400)	(11.400)
OEW	156,930	160,940

*GE provided nacelle weight plus Boeing estimated pylon and mount weight.

Table A-X gives flight conditions at FAR 36 measuring points for the CF6-50C and ATE-powered airplanes. This table also shows nominal airframe noise component EPNL values. For a study engine, it is standard Boeing practice to add an uncertainty margin of 3 EPNdB to the total predicted noise level. This ensures that airplane noise will fall within certifiable limits.

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 ATE (Table A-XI) were based on a nominal acoustic treatment to the engine and nacelle, not on a fully iterated lining design study. It was concluded that with further refinement the approach noise could attain the 3 EPNdB margin generally considered acceptable for assuring certificable noise levels.

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.

5.1.5 Airplane Drawings of Sized Airplanes

Figures A-12 and A-13 show drawings of the CF6-50C and ATE-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 Table A-XII and A-XIII. 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 A-14 shows BLKF and BLKT versus range for both CF6-50C and ATE-powered airplanes. For the domestic airplane on the average mission, the airplane with ATE engines uses 15.5% less fuel than the CF6-50C airplane. For the design mission without performance retention, the saving for the ATE-powered airplane is 17.6%. These savings represent about 3% improvement

Table A-X. Flight Conditions for FAR-36 Noise Calculations--77°F

Domestic Airplane	Takeoff	Sideline	Approach
Model 768-868 (ATE Engine)	(1)	(2)	(3)
% of takeoff thrust at flight condition	100	100	100
Speed, knots	153	153	134
Altitude, feet	2,200	900	394
Bleed (lb/sec)/HPX (per engine)	(0.0/160)	(0.0/160)	(0.0/160)
Engine angle relative to flight path, degrees	7.7	7.7	5.5
Climb angle, degrees	7.3	7.3	-3
Airframe noise, EPNdB*	72.5	72.6	93.0

(1) 6500m from brake release at maximum takeoff weight

(2) 2000m from touchdown at design mission landing weight

(3) 450m sideline distance

* Nominal noise estimate shown -- appropriate design/demonstration tolerances are required for certifiable/guarantee levels.

Table A-XI. Nominal Noise Estimates

	ATE *	FAR 36-8 Requirement	Notes
Takeoff	90.0	93.8 dB	No cutback 6500m point
Sideline	90.0	98.2 dB	Sideline distance 450m point
Approach	100.0	102.0 dB	2000m from threshold (two extended flap segments, 3 deg glide slope)

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

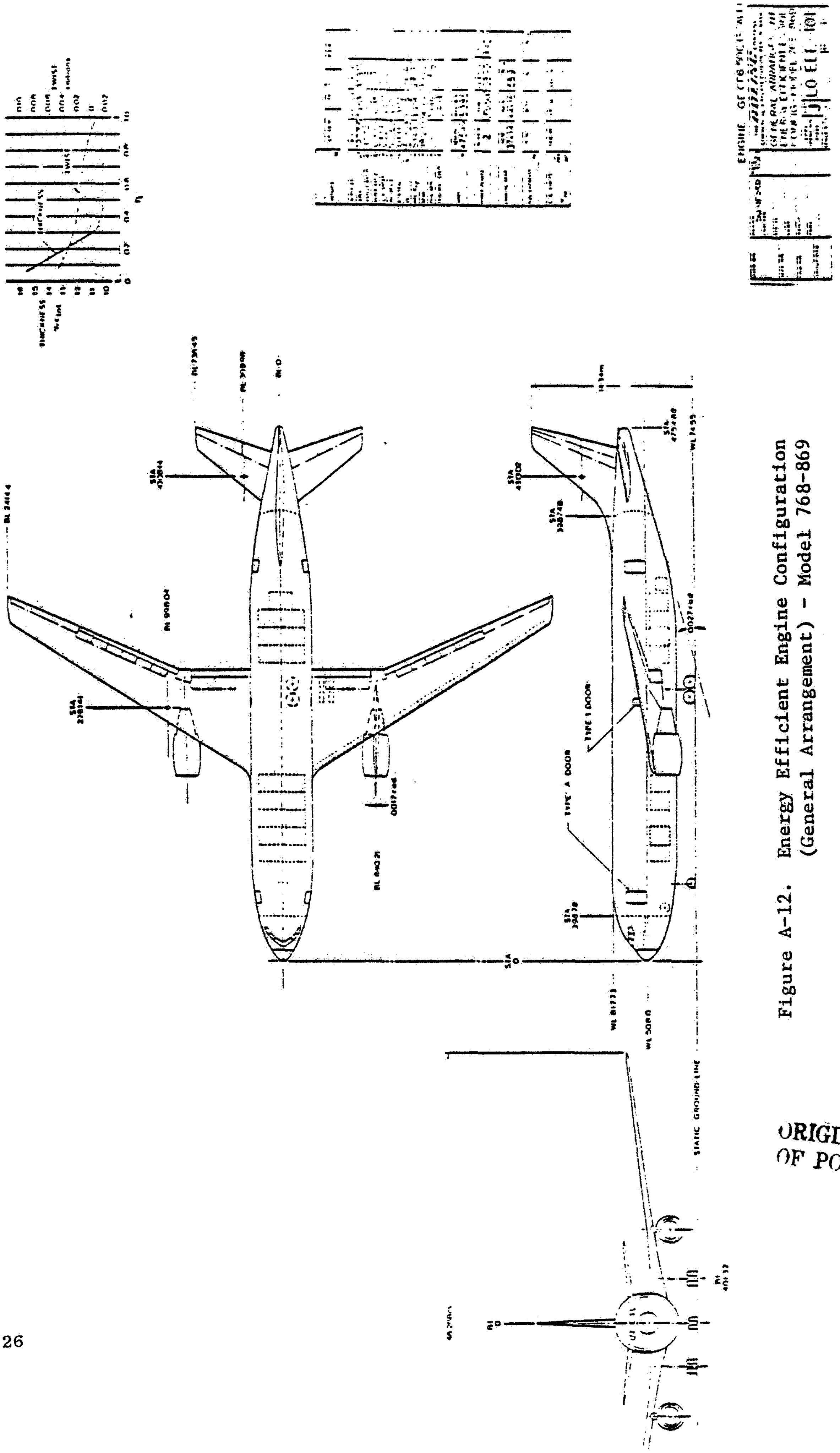


Figure A-12. Energy Efficient Engine Configuration (General Arrangement) - Model 768-869

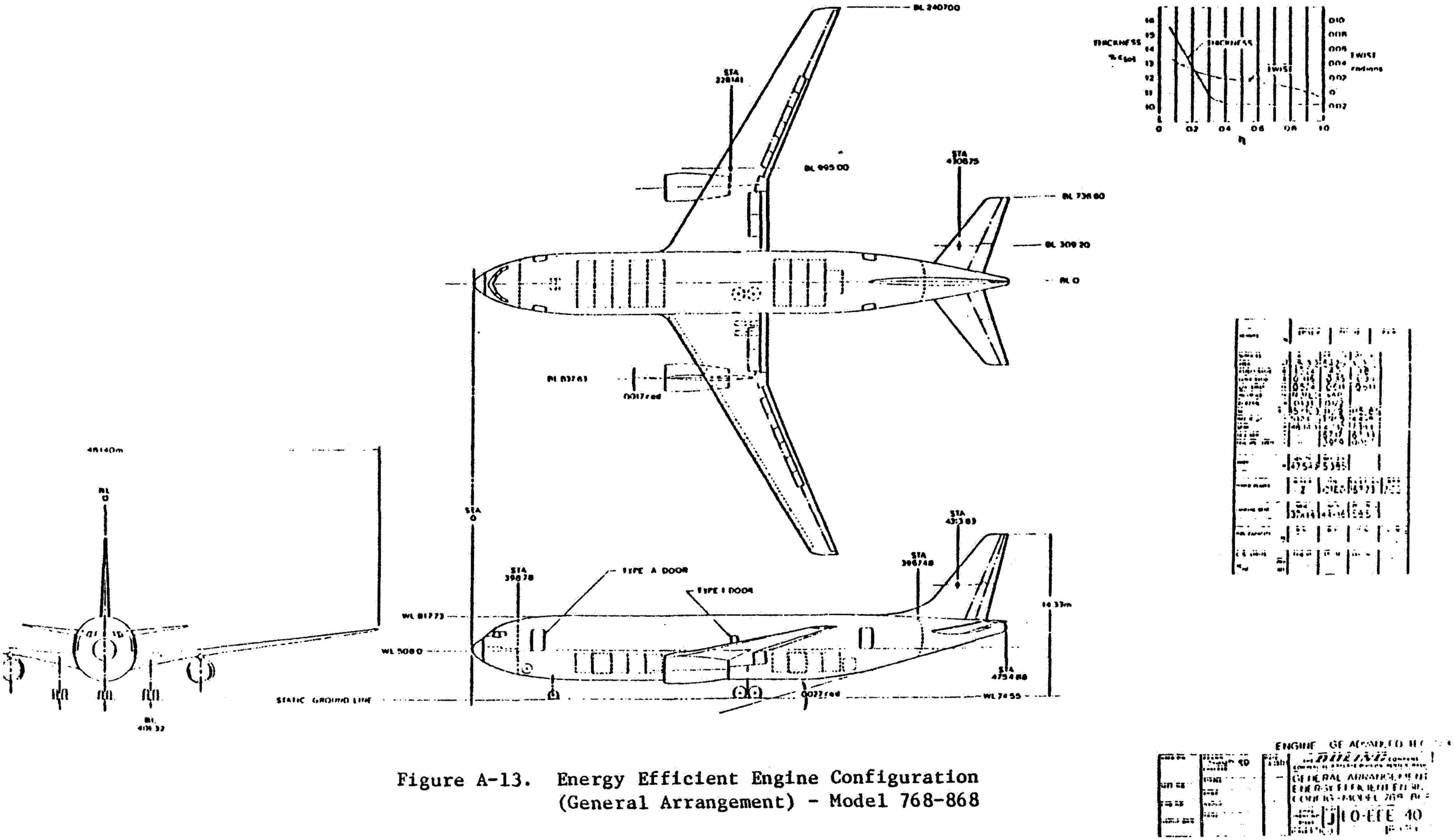


Figure A-13. Energy Efficient Engine Configuration (General Arrangement) - Model 768-868

Table A-XII. Domestic Airplane Sensitivity Factors - Model 768-869

MODEL 769-869
(CF6-50C ENGINES)
5% CHANGE

	BASED CYCLE	5% F_{NCR} +/-	5% SFC +/-	5% CR DRAG +/-	5% OEW +/-	5% F_{FNTO} +/-
TOGW	257350	-0.3/+0.4	+1.2/-1.5	+2.0/-1.9	+6.1/-5.7	-0.5/+0.8
OEW	160940	-0.2/+0.2	+1.6/-0.8	+1.1/-1.0	+8.5/-7.9	-1.0/+1.3
MEW	149540	-0.2/+0.2	+0.9/-0.9	+1.2/-1.1	+8.7/-8.1	-1.0/+1.4
BLKF	41730	-1.2/+1.8	+4.7/-4.6	+6.4/-5.8	+3.9/-3.5	-0.3/+1.1
SLST	37970	-0.3/+0.4	+1.1/-1.4	+2.2/-2.1	+5.6/-5.2	-5.2/+6.2

196 PASSENGERS
2000 N.MI. RANGE
TOFL = 6000 FT
WING LOADING = 105 LB/SQ FT

Table A-XIII. Domestic Airplane Sensitivity Factors - Model 768-868

MODEL 768-868
(G.E. ADVANCED TECHNOLOGY ENGINES)
5% CHANGE

	BASED CYCLE	5% F_{NCR} +/-	5% SFC +/-	5% CR DRAG +/-	5% OEW +/-	5% F_{FNTO} +/-
TOGW	243600	-0.1/+0.3	+1/4/-1.4	+1.7/-1.5	+6.3/-5.8	-0.7/+1.1
OEW	156930	-0.1/+0.1	+0.7/-0.7	+0.9/-0.8	+8.5/-7.9	-1.0/+1.5
MEW	145530	-0.1/+0.2	+0.8/-0.7	+1.0/-0.9	+8.8/-8.1	-1.1/+1.6
BLKF	34400	-0.6/+1.3	+4.6/-4.5	+5.8/-5.1	+4.3/-3.8	+0.4/+0.8
SLST	37710	-0.1/+0.2	+1.3/-1.2	+1.9/-1.7	+5.8/-5.3	-5.4/+6.4

196 PASSENGERS
2000 N.MI. RANGE
TOFL = 6000 FT
WING LOADING = 100 LB/SQ FT

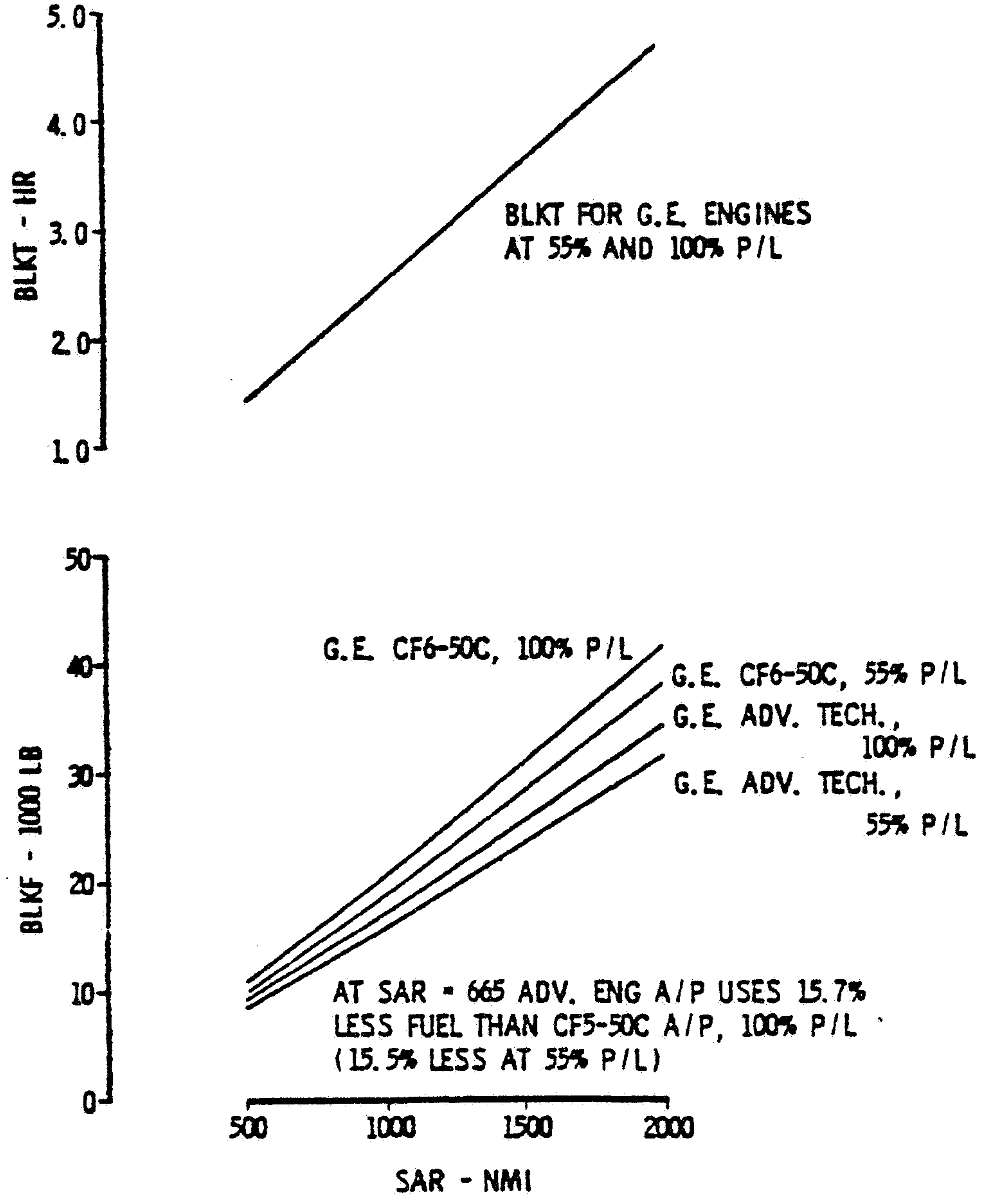


Figure A-14. Block Fuel Comparison

over the earlier study. This improvement is explained by a more accurate accounting of specific fuel consumption (SFC) reduction for the ATE engine during climb and descent mission segments. Allowing a 1% TSFC improvement over the lifetime of the engine for performance retention improves these savings by about 0.9% as shown in Figure A-15.

A breakdown in fuel used during various mission segments is shown in Figure A-16. The large percentage of fuel burned during climb for typical stage lengths shows the importance of maintaining the advance-engine SFC improvement at climb power setting.

Overall fuel burned improvement for the ATE-powered airplane 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 GE E^3 program are presented in Tables A-XIV, A-XV, and A-XVI. The initial economic analysis (Table A-XIV) was based on the May 8, 1978 engine data of Reference 3. This analysis considered three fuel prices of 35, 40 and 45 /gal and used a typical range of 665 nmi. GE updated the engine data prior to the November 20-21, 1978 preliminary design review (PDR). This later data was used to update the economic analysis summarized in Table A-XV. This updated analysis was for 40 /gal fuel and mission stage lengths of 665, 1000, and 2000 nmi. Also considered in this analysis was the effect of a 1% TSFC improvement allowance for performance retention over the engine life.

In comparison with current high bypass ratio engine prices GE's ATE engine price appeared higher than could be supported by a competitve market. Based on this consideration Boeing projected an engine price approximately 22% lower than the GE-estimated price. The effect of this lower price on DOC and ROI is shown in Table A-XV.

A summary of DOC improvement for the November 20-21, 1978 PDR status is shown in Figure A-17. At the design mission the NASA 5% DOC improvement goal is exceeded for all ranges when the lower Boeing estimated engine price is used; however, when the GE price is used only the design-mission DOC exceeds the goal.

The DOC and ROI calculations were based on methods discussed in section 4.6. In addition the following assumptions were used in the airplane ROI calculations:

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

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

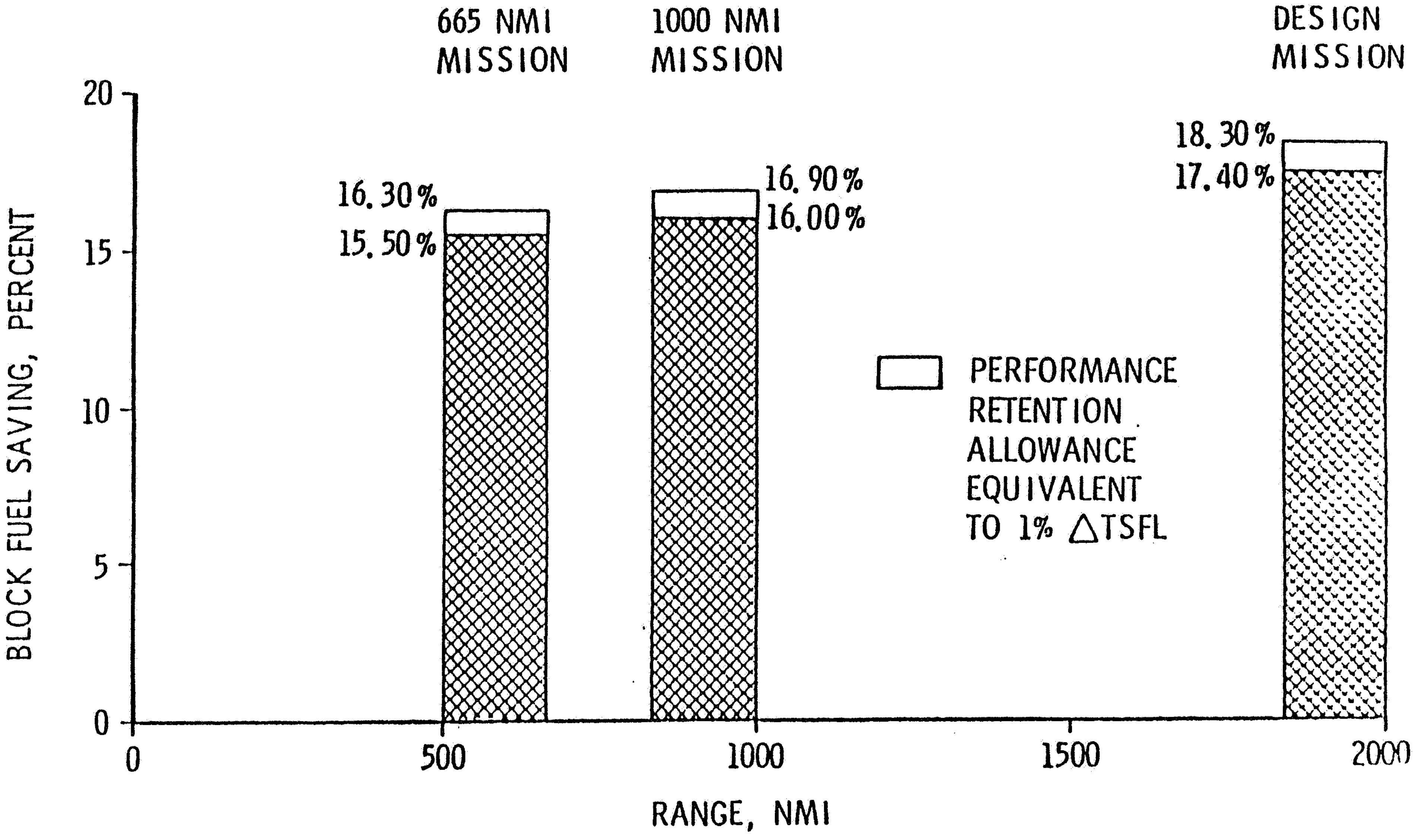


Figure A-15. November 1978 PDR Status Fuel Saving

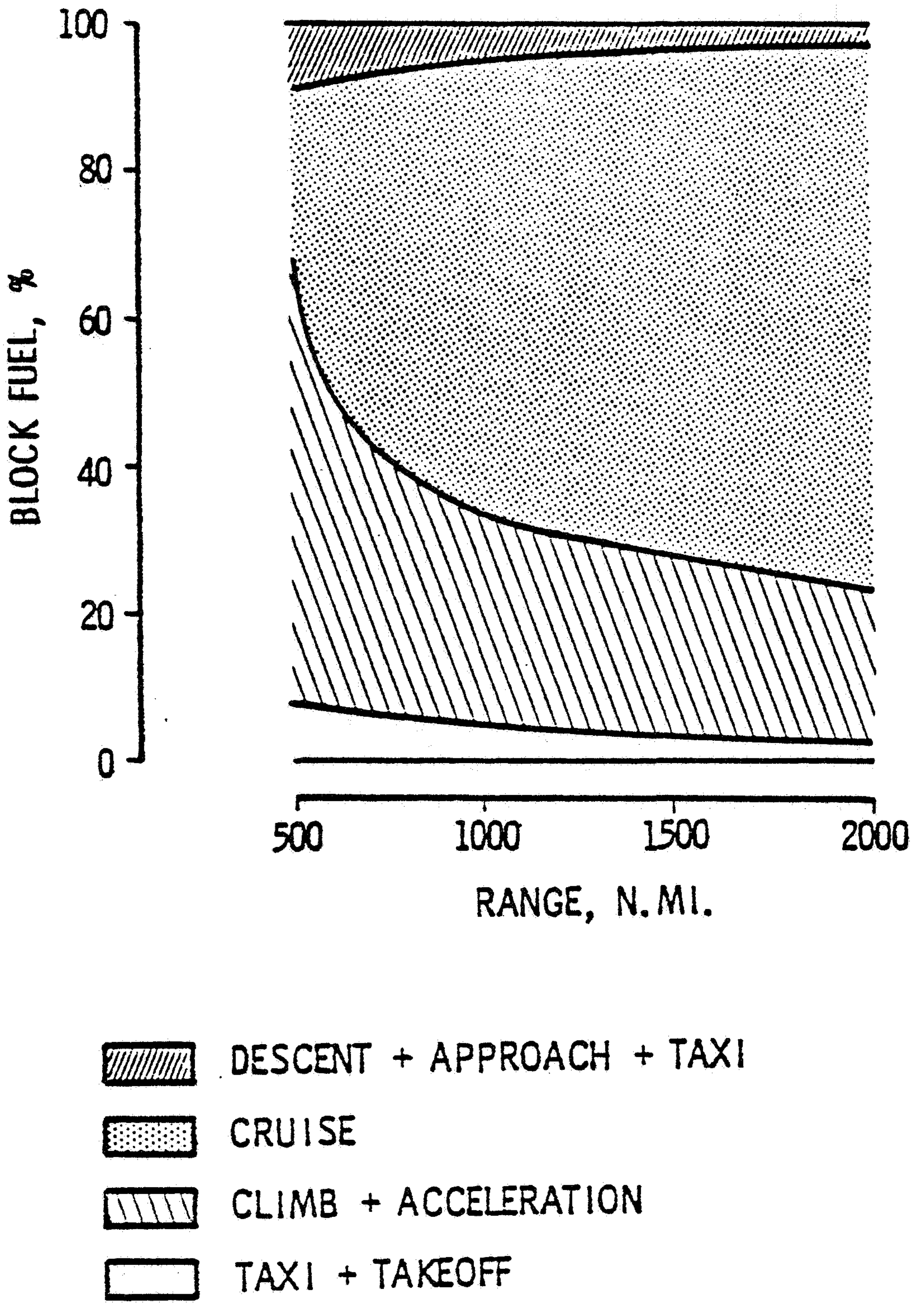


Figure A-16. Percent Block Fuel by Mission Profile Segment

Table A-XIV. Initial Economic Analysis

- MAY 1978 ENGINE DATA
- 665 N.MI. TYPICAL MISSION

ENGINE	CF6-50C			G.E. - E^3 ENGINE		
FUEL /GAL	35	40	45	35	40	45
DOC: ($ MILLIONS/YEAR)	5.072	5.253	5.435	4.935	5.089	5.242
FUEL	1.273	1.455	1.637	1.076	1.230	1.383
CREW	1.092	--	--	1.076	--	--
INSURANCE	0.111	--	--	0.114	--	--
BURDEN	0.500	--	--	0.494	--	--
ENGINE LABOR	0.084	--	--	0.081	--	--
ENGINE MATERIAL	0.273	--	--	0.233	--	--
AIRFRAME LABOR	0.166	--	--	0.166	--	--
AIRFRAME MATERIAL	0.123	--	--	0.123	--	--
DEPRECIATION	1.449	--	--	1.568	--	--
AIRPLANE AFTER TAX ROI (%)	11.55	11.0	10.4	11.53	11.1	10.7
INCREMENTAL AFTER TAX ROI (%)				4.2	5.5	6.8

Table A-XV. November 1978 PDR Status Economic Analysis

55% PAYLOAD

ENGINE	CF6-50C			GE - E^3 ENGINE PERFORMANCE RETENTION = 1% TSFC			G.E.-E^3 ENGINE		
RANGE N.MI.	665	1000	2000	655	1000	2000	665	1000	2000
DOC: ($ MILLIONS/YEAR)	5.253	5.431	6.107	5.021	5.163	5.716	5.033	5.176	5.732
FUEL ($ 0.40/GALLON)	1.455	1.599	2.118	1.218	1.328	1.730	1.230	1.341	1.746
CREW	1.092	1.154	1.308	1.076	1.137	1.289	1.076	1.137	1.289
INSURANCE	0.111	0.111	0.111	0.118	0.118	0.118	0.118	0.118	0.118
BURDEN	0.500	0.489	0.492	0.494	0.480	0.483	0.494	0.480	0.483
ENGINE LABOR	0.084	0.082	0.079	0.081	0.078	0.074	0.081	0.078	0.074
ENGINE MATERIAL	0.273	0.264	0.259	0.177	0.170	0.163	0.177	0.170	0.163
AIRFRAME LABOR	0.166	0.163	0.167	0.166	0.163	0.167	0.166	0.163	0.167
AIRFRAME MATERIAL	0.123	0.120	0.124	0.123	0.121	0.124	0.123	0.121	0.124
DEPRECIATION	1.4	1.4	1.4	1.568	1.568	1.568	1.568	1.568	1.568
AIRPLANE AFTER TAX									
ROI:	11.0	13.1	15.7	11.3	13.3	16.0	11.3	13.3	16.0
INCREMENTAL AFTER TAX									
ROI:				7.7	9.2	13.8	7.2	8.7	13.2

Table A-XVI. November 1978 PDR Status Economic Analysis (Boeing Engine Price)

- NOVEMBER 1978 PDR STATUS, 1% TSFC PERFORMANCE RETENTION ALLOWANCE
- BOEING E^3 ENGINE PRICE
- 55% PAYLOAD

ENGINE	CF6-50C			G.E. - E^3 ENGINE		
RANGE, N.MI.	665	1000	2000	665	1000	2000
DOC: ($ MILLIONS/YEAR)	5.253	5.431	6.107	4.951	5.093	5.646
FUEL ($0.40/GALLON)	1.455	1.599	2.118	1.218	1.328	1.730
CREW	1.092	1.154	1.308	1.076	1.137	1.289
INSURANCE	0.111	0.111	0.111	0.114	0.114	0.114
BURDEN	0.500	0.489	0.492	0.494	0.480	0.483
ENGINE LABOR	0.084	0.082	0.079	0.081	0.078	0.074
ENGINE MATERIAL	0.273	0.264	0.259	0.177	0.170	0.163
AIRFRAME LABOR	0.166	0.163	0.167	0.166	0.163	0.167
AIRFRAME MATERIAL	0.123	0.120	0.124	0.123	0.121	0.124
DEPRECIATION	1.449	1.449	1.449	1.502	1.502	1.502
AIRPLANE AFTER TAX						
ROI (%)	11.0	13.1	15.7	11.8	13.9	16.6
INCREMENTAL AFTER TAX						
ROI (%)				21.4	23.9	31.9

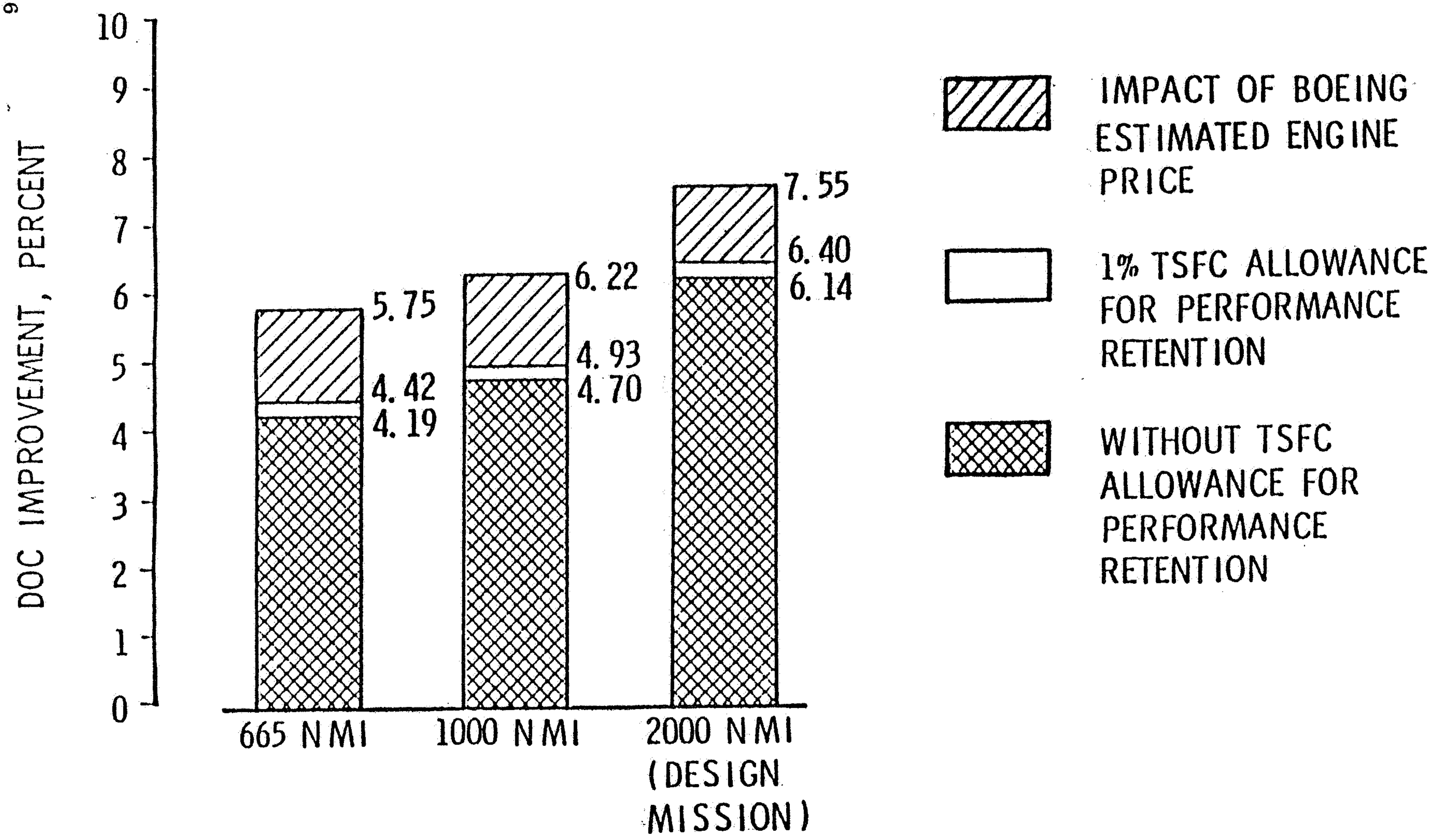


Figure A-17. November 1978 PDR Status Direct Operating Cost Comparison

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

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

Since airplane ROI is based on airplane profitabiltiy compared to total airplane costs, it measures the value of investing in the total airplane system. On the other hand, incremental ROI, as shown in Tables A-XIV, A-XV, and A-XVI, was based on savings realized by using the ATE compared to its increased price. Incremental ROI thus shows return on only the money invested in the engine. Because the airplane performance and cost differences between the CF6-50C and ATE-powered airplanes are minimal, the improved economics are generated primarily by engine improvements. It is therefore more realistic to use incremental ROI for deciding the economic value of the new engine.

6.0 ENGINE/AIRPLANE INTEGRATION

This section describes the Boeing assessment and evaluation of the GE designed ATE engine/nacelle installation defined by GE drawings, References 6, 7, 8 and 9. 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. Aerodynamic lines for a nacelle simulator model were evaluated, and results in Reference 5.

Being preliminary, the GE drawings lacked numerous construction details, and in-depth critique of detail construction was not possible. Comments were provide on areas where some detail was shown. Figure A-18 represents the GE designed nacelle.

a. Inlet

Apparently the attachment between inlet and cowl/engine structure is provided by means of bolts installed in a clevis with the bolt installed in a radial direction. To maintain internal and external contour control, the clevis surfaces must be machined very accurately, otherwise the contours will be subject to steps and gaps which are not aerodynamically acceptable. The potential for bolt to hole misalignment is also very high. Access to the bolt heads is not apparent. The load path between the inlet and engine/cowl structure appears to be very soft and subject to deflection, which will also increase the gaps on both inner and outer flow surfaces. The inlet bulkhead form is not conducive to attachment of bulkhead connectors for electrical, pneumatic, or hydraulic lines, so passing services through the bulkhead will be difficult.

b. Fan Case and Cowl

Due to the integrated nature of the fan case and fan cowl it is important to examine the interface details to ensure compatibility. Comments have already been made relative to the inlet attachment. The interface at the forward tongue and groove joint must pass radially upward to gain access to the core mounted accessories, but it is not clear where the break in the outer shell is located. The section of honeycomb forward of the reverser seal appears to be an extension of the outer fan case/cowl, yet the inner wall of the reverser illustrates seals and means for opening the ducts. More clarification in this area is needed.

In the absence of a primary reverser the diffusing primary gas will tend to flow forward when the fan flow is being reversed. For this reason the materials in the fan duct/cowl must be chosen carefully to prevent inadvertent structural damage from hot gases or provide some controlled leakage through the blocker door array.

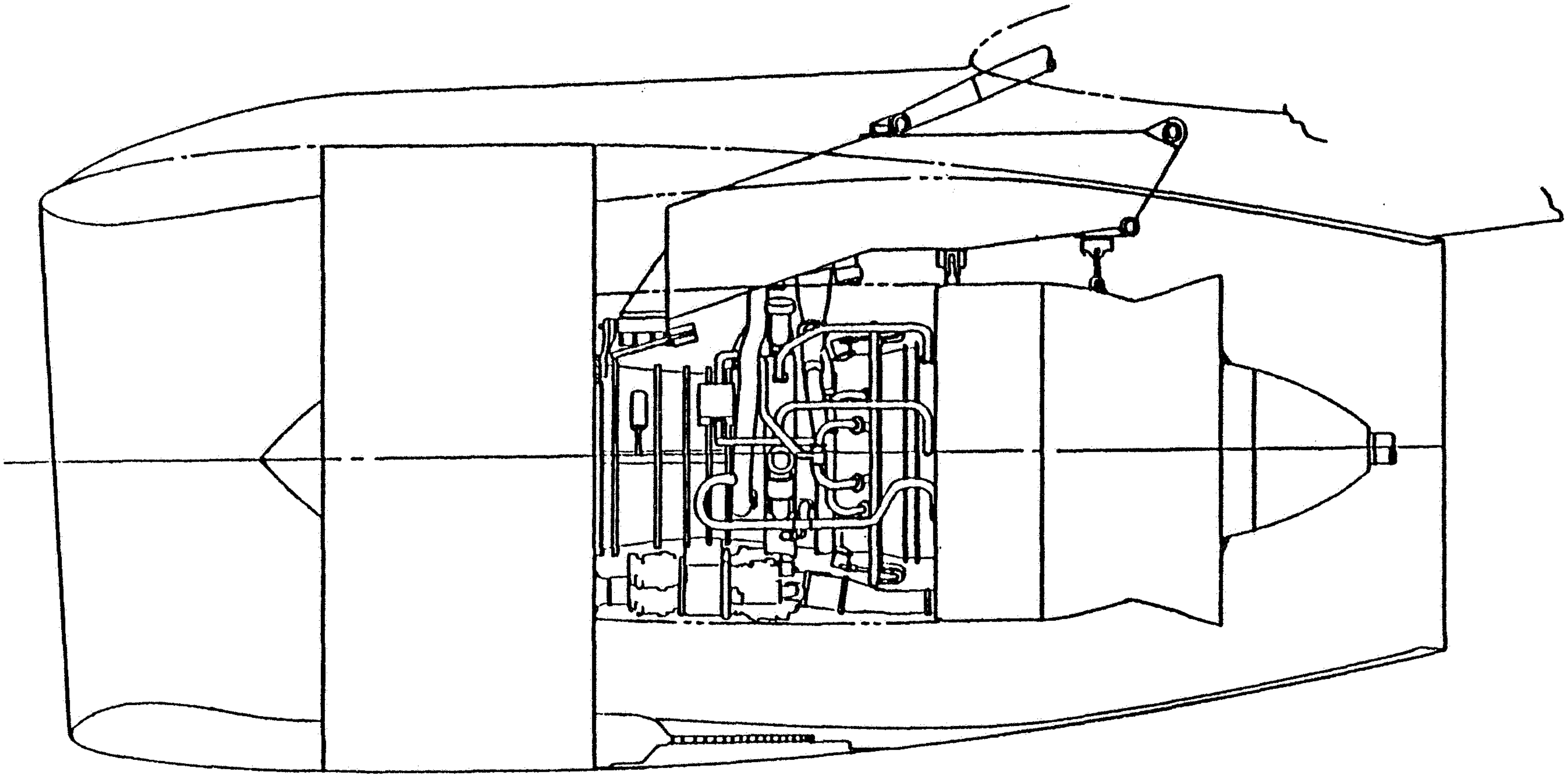


Figure A-18. General Electric Energy Efficient Nacelle

The controlled leakage concept must be evaluated very carefully because for each pound of forward thrust generated the system is penalized 3 pounds of reverse thrust.

The seal and V groove between the fan duct/cowl and the tailpipe is not continuous at the top and thus hoop loads must be carried around the slot made by the strut penetration. This can cause serious stress concentrations at the aft end of the slot, as well as problems with supporting the pressure load on the flat sides of the strut and nozzle.

The duct inner wall contour shown does not provide room for a longeron or latches at the bottom centerline. Minimum acceptable clearance between accessory items and cowl structure is 0.375 inches. This contour also is too tight for installation of an accessory drain system, or cowl venting provisions.

The air seal (garlock type) at the forward end of the fan duct inner wall appears to be backwards, unless the accessory compartment is pressurized to a level greater than fan duct pressure. If the compartment pressure is higher than fan duct pressure, drainage and venting of the compartment will be difficult if exterior aerodynamic losses are to be avoided. Since no lower bifurcation is shown clarification of the vent and drain system is needed.

At the aft end of the fan duct outer wall of the V groove joint should be inverted to facilitate opening the main cowl for access to the accessories. The configuration as shown has no lower bifurcation, and thus the system requires the following sequence of operation to gain access to the accessories.

1. Unlatch and remove the tailpipe.
2. Unlatch and remove or hinge outer fan duct wall and reverser up and out of the way.
3. Remove the inner fan duct wall by unlatching and removing.

This is necessary to gain access each time a mechanic wishes to check the oil or any other routine maintenance task. This would not be acceptable to most airlines.

c. Fan Thrust Reverser

Location of the actuation mechanism for the reverser is not apparent. The space between inner and outer fan case walls appears marginal for installation of an actuation system for the reverser. The logical place for actuation is occupied by the cascades and the structural thickness of the fan cowl limits putting the actuator in the line with the sleeve. The axial length provided in the outer fan duct ahead of the cascades and aft of the sweep plane for duct opening is not adequate for installation of an actuator with 29-inch stroke.

Further concerns relative to the thrust reverser include the method of providing positive longitudinal sealing in the stowed position, the interference of the door leading edge with duct structure during translation, and the blockage door angle in the deployed position.

These concerns are illustrated by Figure A-19. With regard to the door angle, Boeing data show a 90 degree door angle (i.e., perpendicular to the duct wall) to give the most effective thrust reversing and highest effective area.

d. Mixer

Details of the mixer attachment are lacking. It appears that the engine plug is attached and supported from the outer engine exhaust case.

The purpose of the link between the plug and lobe valley is not clear. It appears to be for support of the lobe of the mixer, but as drawn it could impose loads on the mixer and change the primary/secondary area relationship. Since the plug is always bathed in primary flow up to the link and the lobe is bathed by both fan and primary flow, the plug will grow thermally more than the mixer. When this happens the link will move aft at the plug attached end and thus pull the lobe inward. To be neutral in its motion the link should be more nearly perpendicular to the plug contour. The link must also be positioned such that it does not change the area ratio.

c. Tailpipe

The joint between the tailpipe and the fan duct should be inverted to allow for the simplest and lightest construction of the tailpipe.

6.2 AIRFRAME ACCESSSORY REQUIREMENTS AND LOCATION

Hydraulic and electric loads are shown in Figures A-20 and A-21. 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 the chin-mounted accessories.

Table A-XVII 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

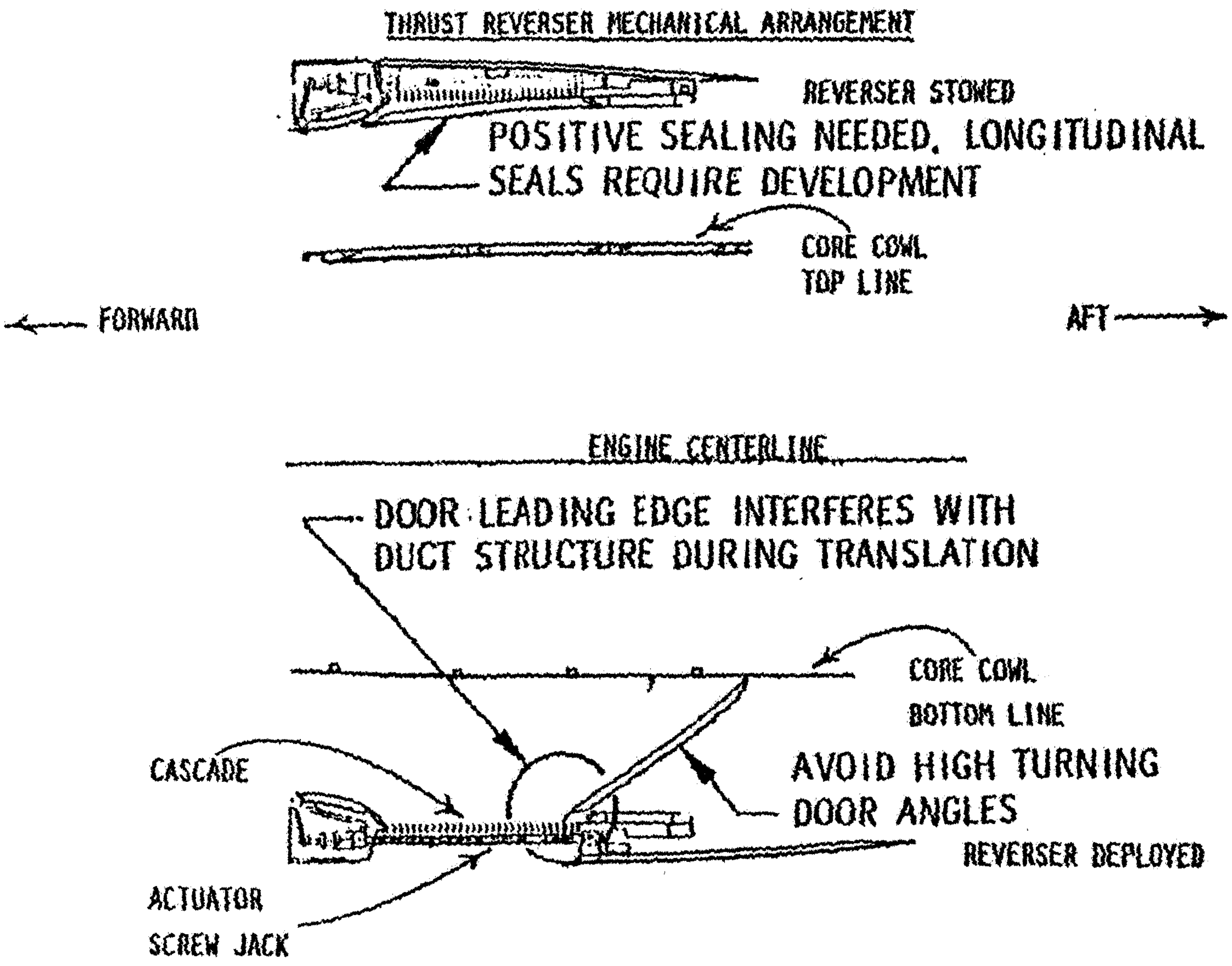


Figure A-19. Thrust Reverser Concerns

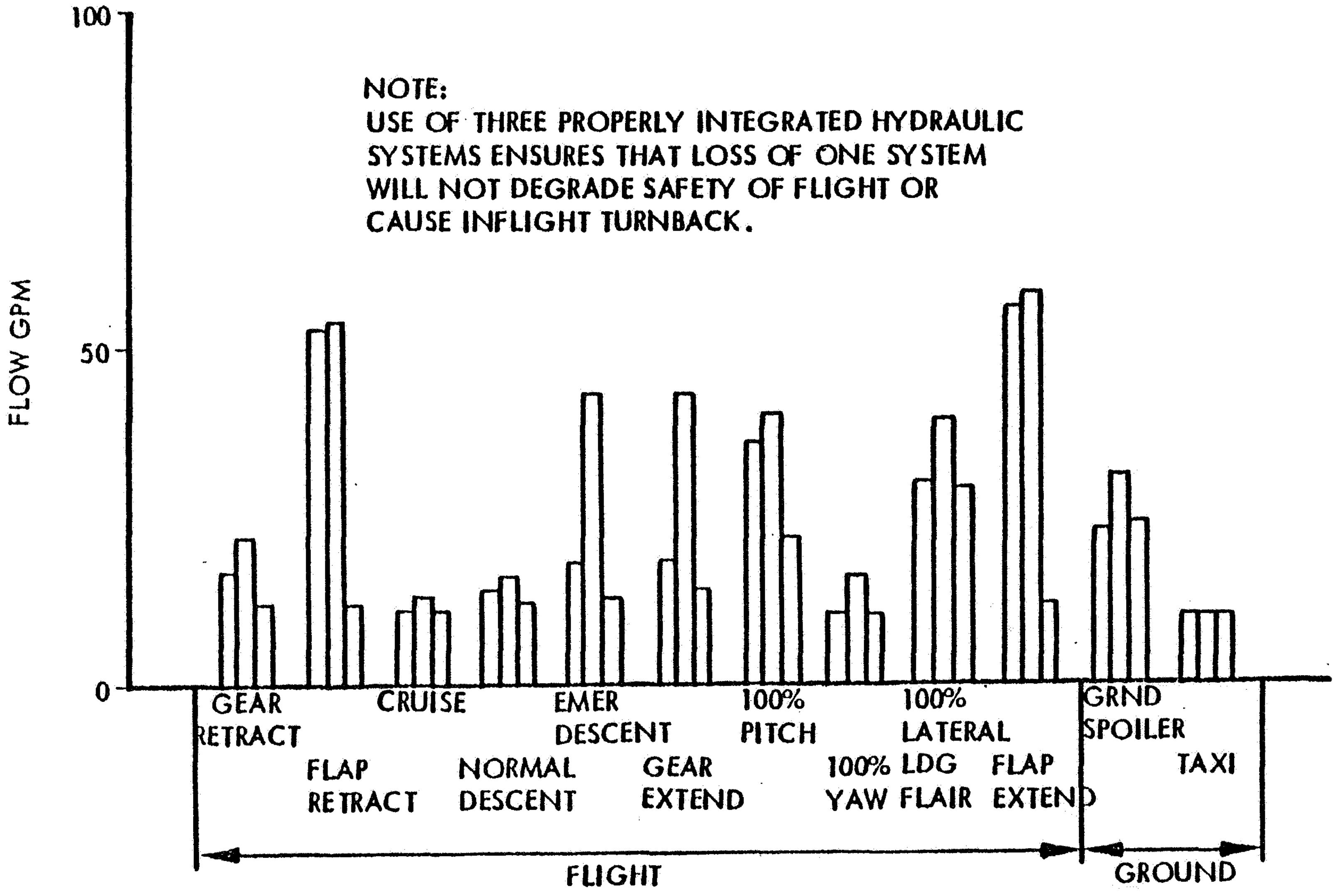


Figure A-20. Hydraulic Loads

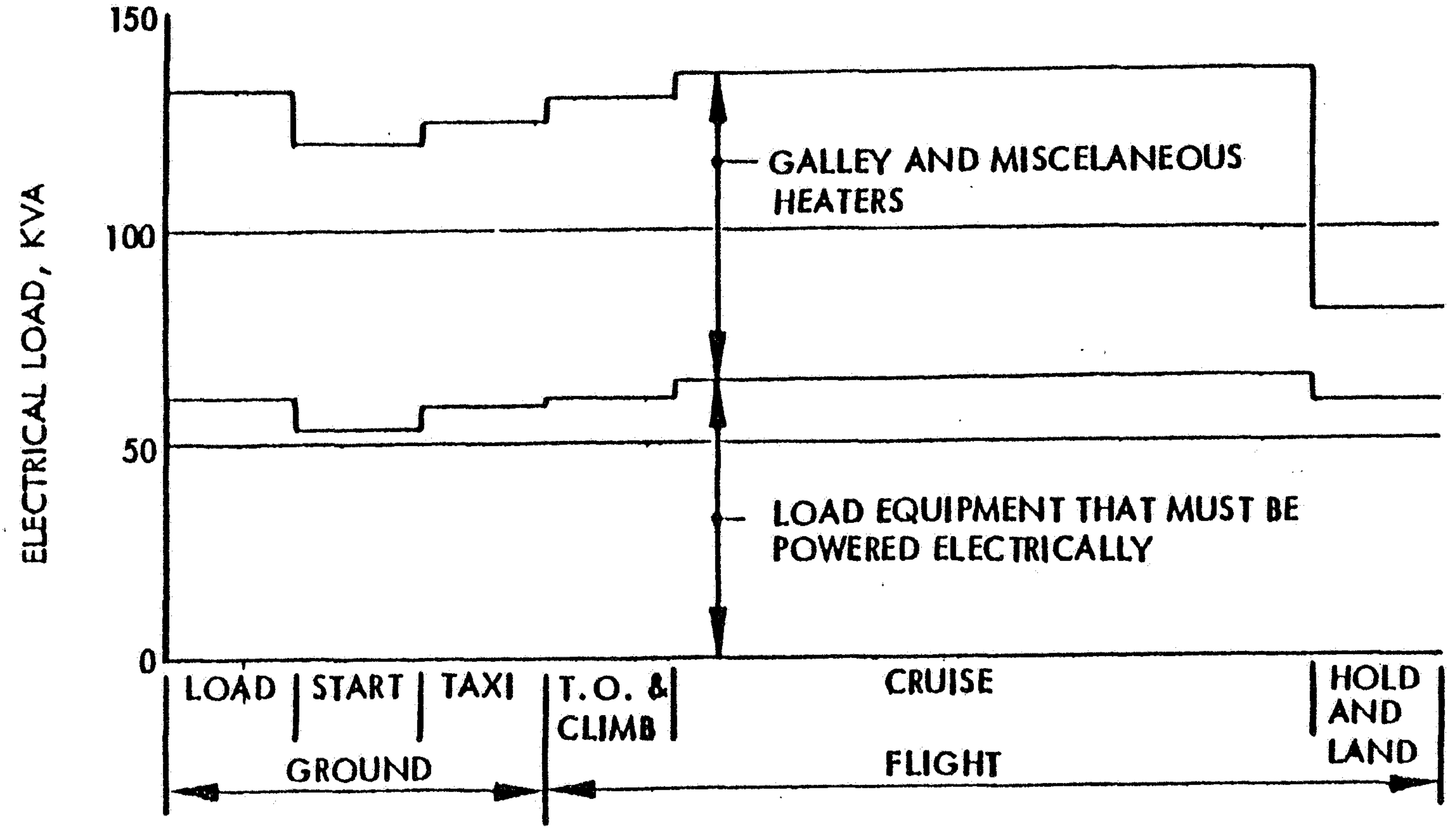


Figure A-21. Electric Loads

Table A-XVII. 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	Top Only
Fuel Spill per DOT/FAA order 8110.19	5	5	0	5	0	5
Accessibility to accessories	4	3	3	5	5	1
Heat rejection	2	5	5	5	5	5
Accessibility to variable IGV	2	5	5	5	5	5
Compatibility with load reduction	5	5	5	5	5	5
Compatibility with zero moment mount	2	5	5	5	5	5
Customer Acceptance	4	0	0	0	5	0
	24	28/0	23/0	35/0	30/0	26/0

Note: Rating 0 to 5, with 5 most acceptable and 0 not acceptable specified that no fuel may be spilled during a wheels-up landing. The chin-mounted gearbox and engine fuel pump would be difficult to certify this requirement.

Table A-XVII reflects these considerations and shows the core-mounted gearbox to be the most acceptable location.

6.3 MAINTAINABILITY, ACCESSIBILITY, AND SAFETY

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

6.4 FUEL HEATER SYSTEM

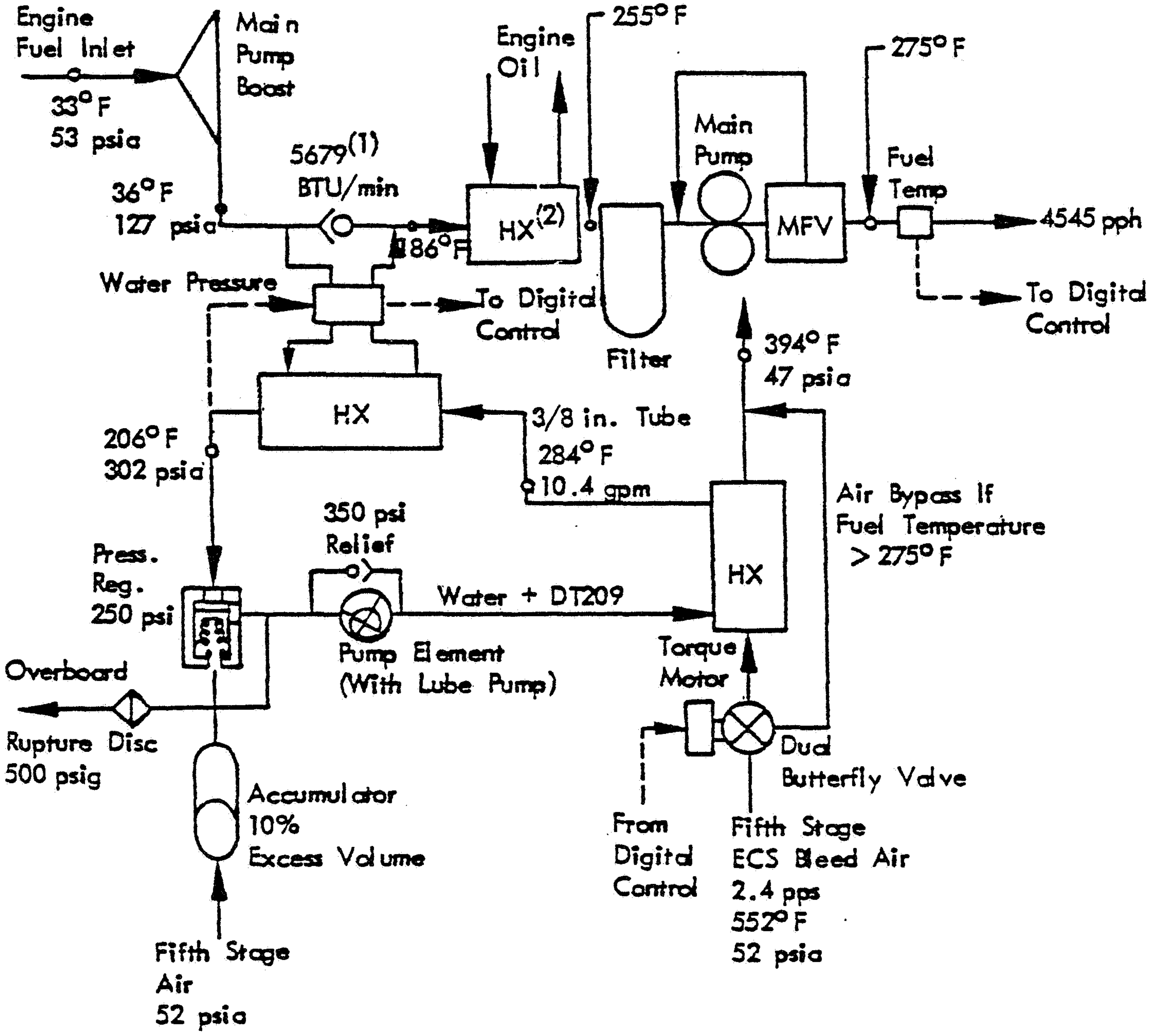
GE has proposed that engine fuel be used as a heat sink for cooling the ECS bleed air. This system will improve engine TSFC by retaining thermal energy in the engine cycle rather than dumping heat overboard by the conventional use of fan air for ECS air cooling. GE estimates a net TSFC improvement as high as 0.8% when both retained heat and elimination of fan-air bleed are considered. In the proposed system heat is transferred from the ECS air-to-water precooler to a water-to-fuel heat exchanger located in the fuel system between the boost-and high-pressure fuel-pump elements. The GE fuel-heater system is shown in Figure A-22.

As proposed the fuel-heater system becomes inadequate as a heat sink during maximum anti-icing operation. For such a condition one engine is considered inoperative, and using the heat sink from the remaining engine, the precooler is required to have sufficient capacity to provide cooled air for one airconditioning pack and thermal anti-icing air for one inlet cowl and both wings. The required capacity was provided by modifying the GE fuel-heater system as shown in Figure A-23 to include an air-to-air heat exchanger to supplement the fuel heat sink. In the Boeing modification, a control valve opens to permit fan airflow through the cool side of the supplemental heat exchanger as the fuel temperature approaches its upper limit of 275°F. During the maximum anti-icing condition the heat rejection rate of the bleed air icreases to 26000 BTU/min compared to 3900 BTU/min during maximum cruise at 35000 ft. For safety the maximum temperature of the bleed air circulated through the airplane is 450°F and for operational reasons the minimum is 300°F.

The fuel-heater system has potential for fuel saving and should be further investigated. Wtih additional study consideration could be given to elimination of the intermediate fluid between the fuel and air and to recirculation of fuel to the fuel tanks during anti-icing operation when a larger heat sink is required.

6.5 NACELLE MOUNT SYSTEM

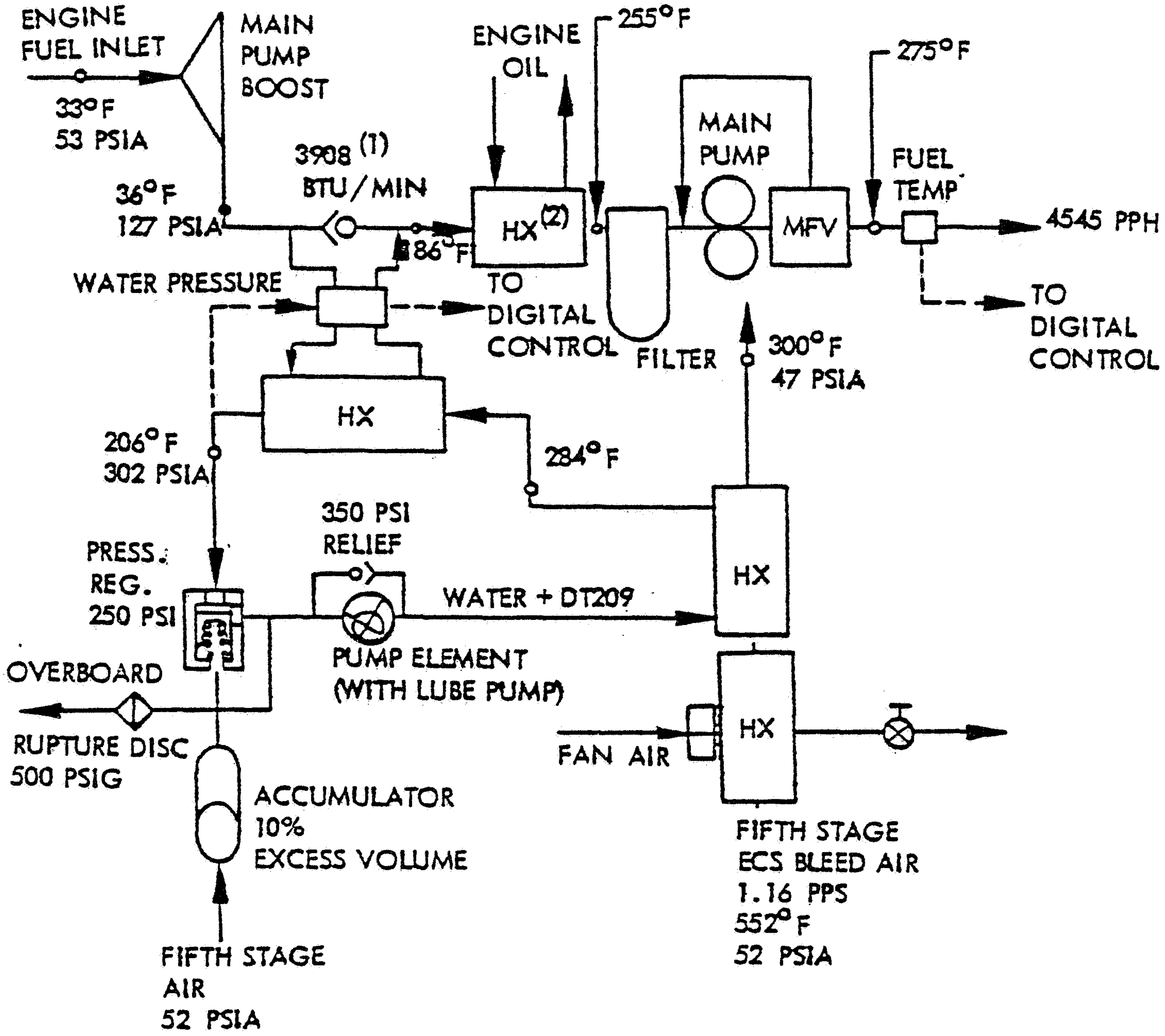
The GE nacelle design and mount systems were continuously reviewed during the course of the current E^3 study to ensure that the GE design



(1) Values shown for 35,000 maximum cruise with 2.4 pps ECS Bleed.

(2) Lube oil/fuel HX would be downstream of main pump when ECS heat provides all fuel anti-ice heating.

Figure A-22. E^3 - Fuel Heater System (GE)



(1) Values shown for 35,000 maximum cruise with 1.16 PPS ECS Bleed.

(2) Lube oil/fuel HX would be downstream of main pump when ECS heat provides all fuel anti-ice heating.

Figure A-23. E^3 - Fuel Heater System (Boeing Modification) would meet Boeing criteria and design practices. The mount system illustrated in Figure A-18 reflects GE's attempt at resolving the issues that were raised during Boeing's review. Figure A-24 shows the GE mount system adapted to a Boeing-designed pylon structure.

The GE mount system departs from Boeing practice by using a four-point rather than a three-point support. This type of support must be designed to accommodate tolerance buildup and to avoid preloading and indeterminant load paths. Because of the preliminary nature of the mount design Boeing did not attempt a detail structural assessment.

Boeing would prefer a three-point support system; however, the four-point system with proper design considerations will meet Boeing criteria. A definite advantage of the four point support system is that it has a potential for reducing engine bending, one of the causes of performance deterioration in current engines. The GE mount system may thus aid in meeting performance retention goals of the E^3 program.

The loads shown on Table A-XVIII give Boeing engine mount design criteria. Table A-XIX summarizes resultant airloads that occur once per flight. Figures A-25, A-26, A-27, and A-28 illustrate the airloads on the nacelle from which the resultants of Table XIX 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.

6.6 NACELLE MATERIAL

Boeing was in general agreement with the type of nacelle materials selected by GE. Boeing had good results with Kevlar/aluminum containment structures in laboratory experiments, and based on this experience the fan containment concept shown appears 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 vulnerable to lightning strikes; however the GE materials list shows consideration of a lightning protection system. Use of aluminum brazed titanium honeycomb for the core cowl structure would be 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.

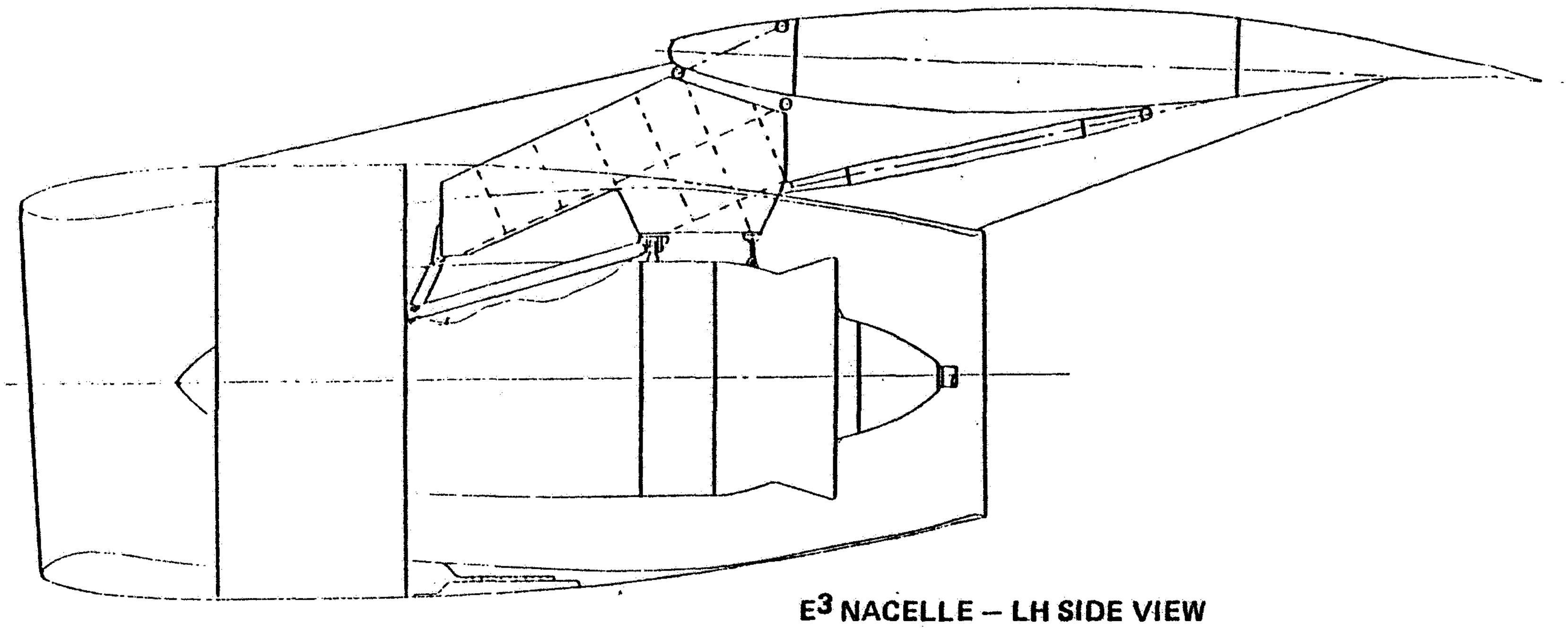


Figure A-24. Long Duct Nacelle Mount

Table A-XVIII. 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 critical)

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.

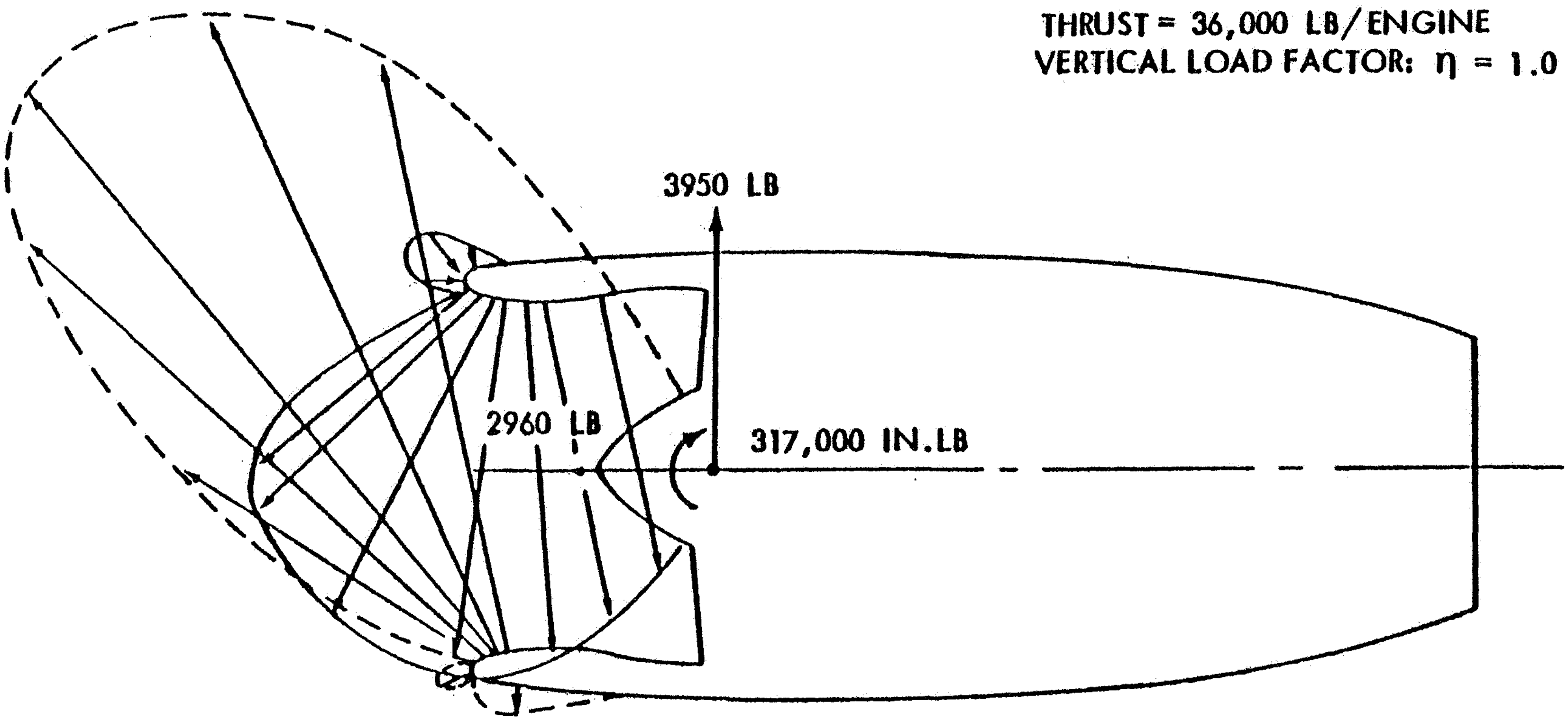
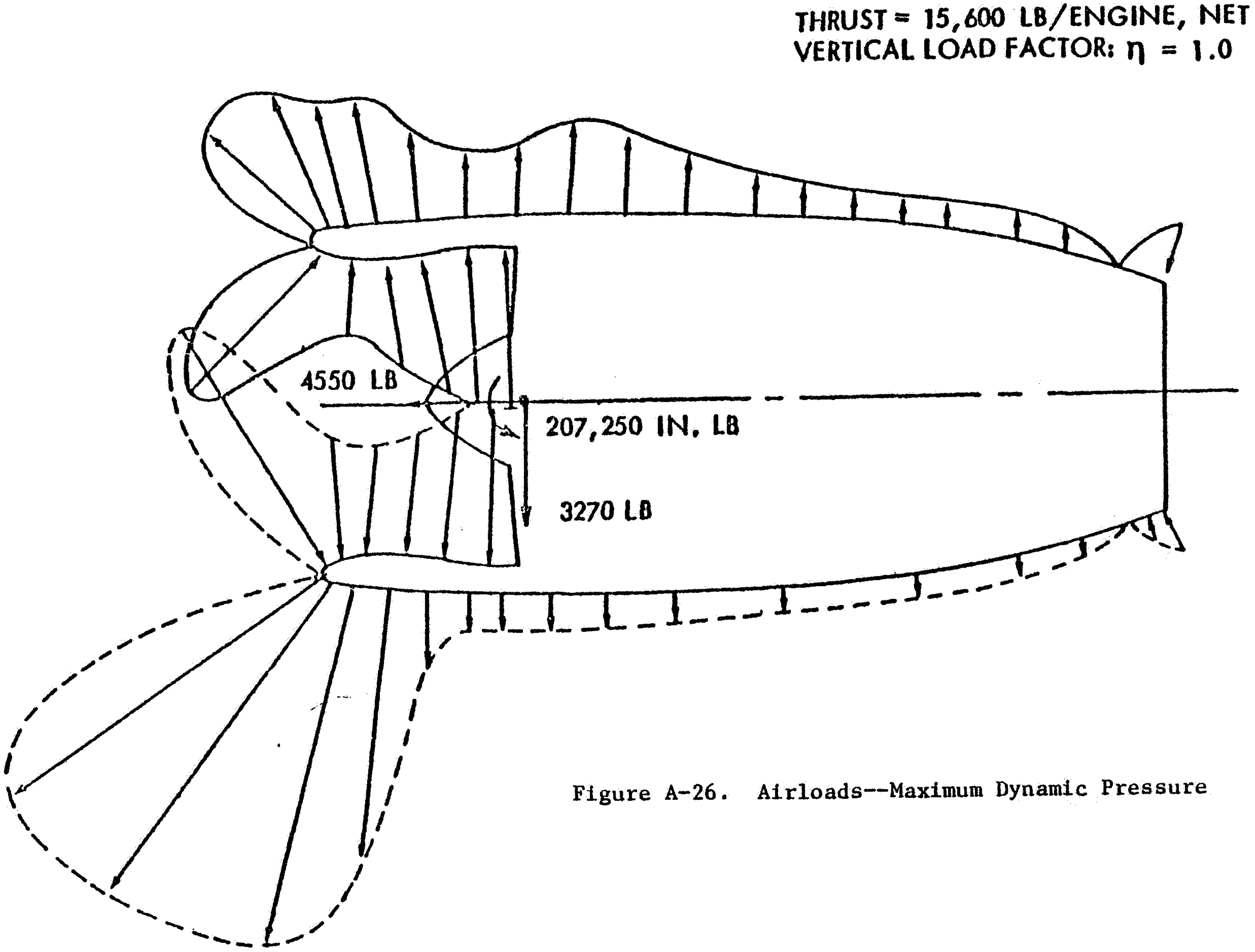


Figure A-25. Airloads--Maximum Takeoff



THRUST = 15,600 LB/ENGINE, NET
VERTICAL LOAD FACTOR: η = 1.0

Figure A-26. Airloads--Maximum Dynamic Pressure

THRUST = 18,500 LB/ENGINE, NET
VERTICAL LOAD FACTOR: $\eta = 1.0$

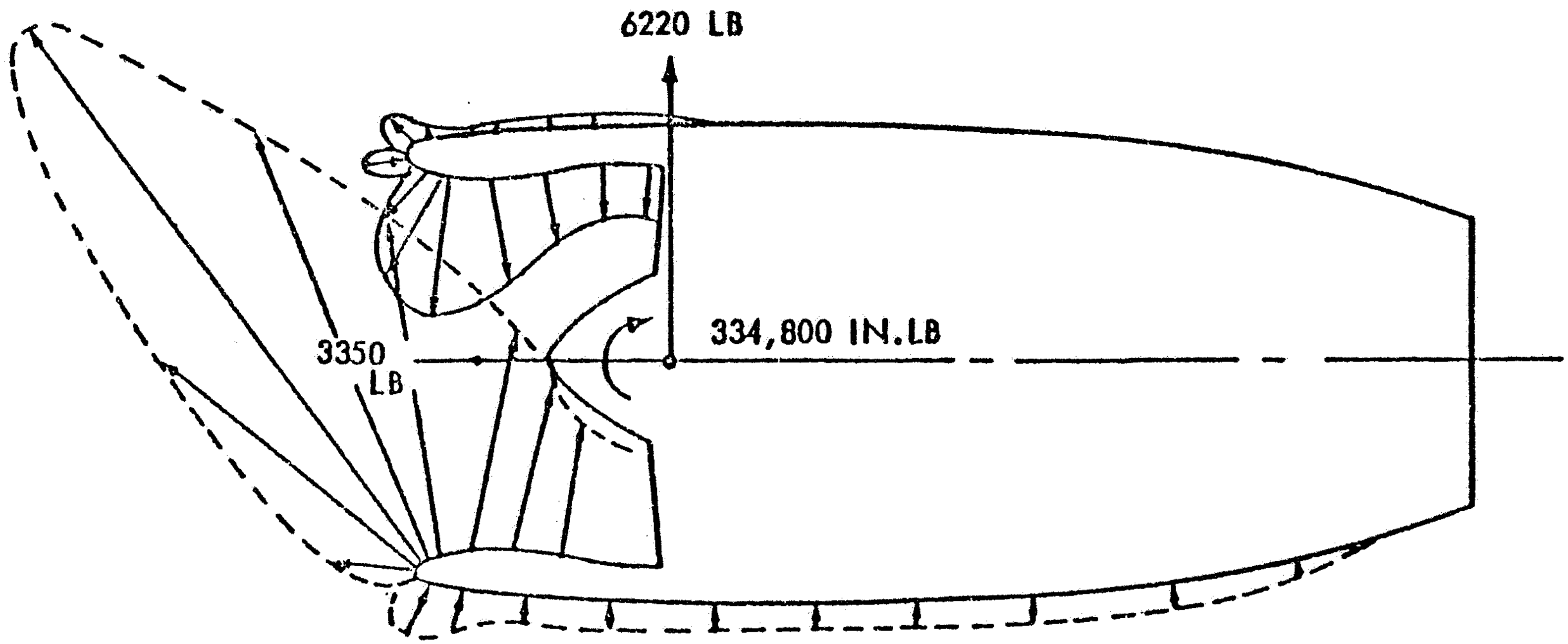


Figure A-27. Airloads--0-deg Flap, $1.3V_{stall}$

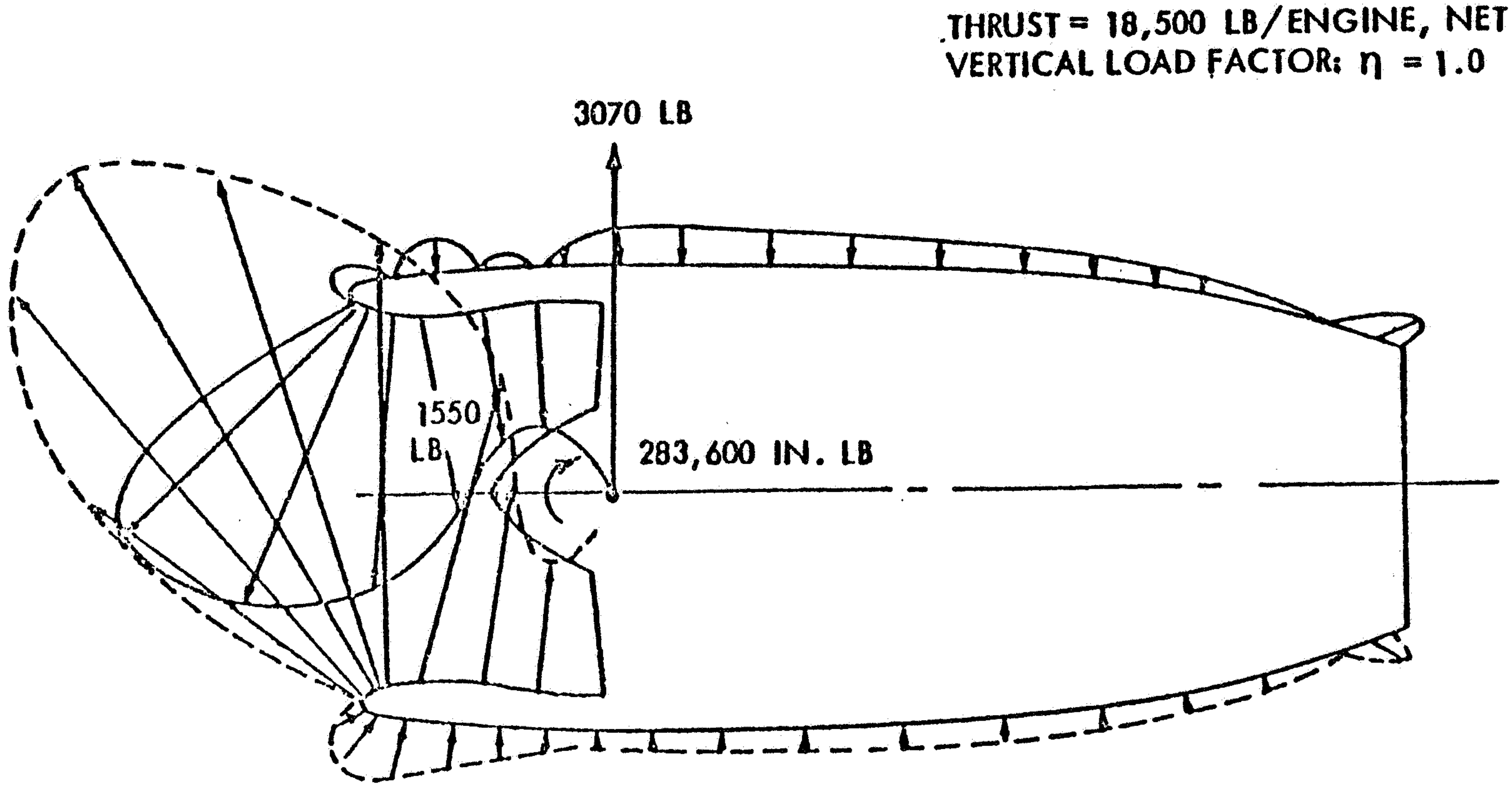
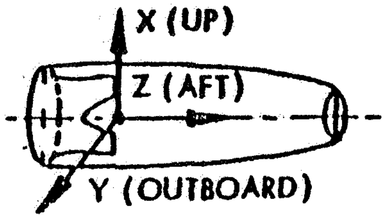


Figure A-28. Airloads--10-deg Flap, $1.3V_{stall}$

Table A-XIX. Engine Nacelle Airloads

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

SIGN CONVENTION



RIGHT HAND RULE FOR MOMENTS

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

[1] $\alpha_W = 16$ DEG. AND $\alpha_{INLET} + 12$ DEG.

BASED ON SLS THRUST F = 45,500 LBS

SCALE: LOADS BY F

MOMENTS BY $(F)^{1/4}$

6.7 NACELLE WEIGHT EVALUATION

Table A-XX compares Boeing and GE weight estimates of selected components of the E^3 long-duct mixed-flow nacelle. Due to differences in the method by which the various nacelle components were functionally accounted for by Boeing and GE, it was not possible to provide a weight comparison for all items. Consequently, comparisons were made for only those components on which GE provided weight data. Table A-XXI presents the weight data received from GE.

Differences in Boeing and GE estimated weight levels were primarily due to differences in assumptions. An in-depth weight evaluation of the GE composite nacelle required more detailed design and structural sizing than could be accomplished within the airframer's funded activity; therefore, Boeing used existing nacelles and advanced designs as a basis for estimating nacelle weight and potential benefits due to use of composites. The weight differences between Boeing and GE represent differences in nacelle design and levels of technical risk. Table A-XXII summarizes the advanced technology weight reduction factors used in the Boeing analysis. These factors were based on advanced technology application. Weight analysis details can be found in Table A-XXIII.

For the November 1978 PDR GE revised the nacelle weight downward and increased the ATE engine weight. The net result was a weight decrease of over about 495 lb./nacelle compared to Reference 3 data for a sized nacelle and engine.

Table A-XX. GE Advanced Nacelle Evaluation

Nacelle Component	Nacelle Weight (lb/pod) SLST = 46900 lb		Weight Difference (GE minus Boeing)	
	Boeing Estimate	GE Estimate	lb	%
Inlet	770*	510	-260	-33.8
Fan Cowl	180	Included in Fan Module	---	
Fan Duct, Reverser And Core Cowl	2188	1469	-719	-32.9
Mixer	118	Included In LPT Module	---	
Plug	96			
Tail Pipe	549	191	-358	-65.2
	(3901)	**	**	**

* Includes 90 lb burst containment allowance.

** Total not computed due to weight distribution differences between Boeing and GE.

Table A-XXI. General Electric Energy Efficient Engine Estimated Weights

E^3 ENGINE ESTIMATED WEIGHTS

ESTIMATED ENGINE WEIGHT		46,900 LBS. T.O. THRUST	36,500 LBS. T.O. THRUST
FAN MODULE	Engine 8750 lb	3322 LBS	2316 LBS.
LPT MODULE*		1950 LBS	1360 LBS.
CORE		2503 LBS	1745 LBS.
C&A, SUMPS & DRIVES		975 LBS	680 LBS.
INLET	Nacelle 2825 lb	510 LBS	385 LBS.
FAN REVERSER & DUCT**		1265 LBS	958 LBS.
CORE COWL		204 LBS	154 LBS.
TAILPIPE		191 LBS	145 LBS.
ENGINE BUILD-UP		655 LBS	495 LBS.

*INCLUDES REAR FRAME, MIXER AND EXHAUST CENTERBODY.

**INCLUDES PYLON WALLS INTERNAL TO THE BYPASS DUCT.

Table A-XXII. Weight Reduction Factors for Advanced Technology Application

Nacelle Component	Weight Reduction Factor(%)
Inlet	5
Fan Cowl	20
Fan duct, reverser, core cowl	4.6
Mixer	0
Plug	0
Tailpipe	0

Table A-XXIII. Boeing Weight Analysis Summary

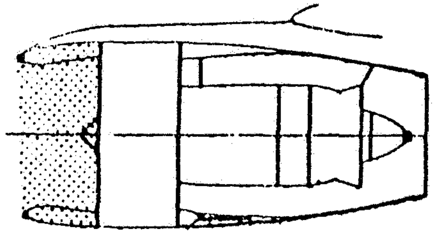
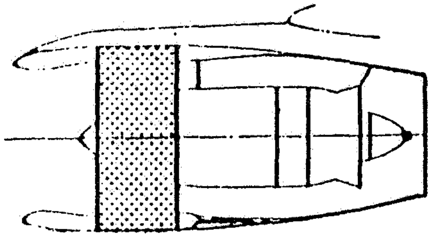
Nacelle Component	Assumed Substructure and Material	Remarks
Inlet Cowl 	Lip: spun or explosion formed aluminum sheet. Bulkhead: built-up aluminum webs, chords and stiffener. Cowling: Graphite/Kevlar fabric outer skin, nonmetallic heat resistant phenolic (HRP) core, Dyna-Rohr Inner face structural acoustic panels Attach ring: machined aluminum Anti-icing components: aluminum spray tube, aluminum and Inconel 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 CF6-50C nacelles, hence no potential for weight saving.
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.

Table A-XXIII. Boeing Weight Analysis Summary (continued)

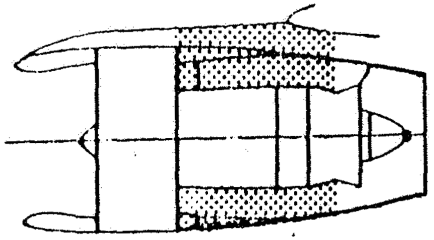
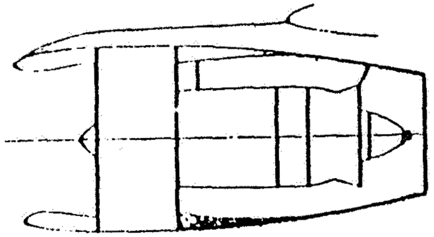
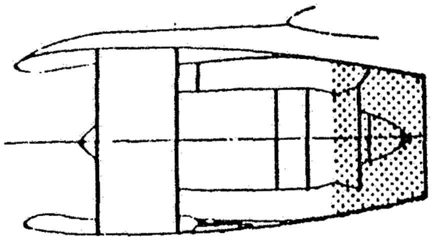
Nacelle Component	Assumed Substructure and Material	Remarks
Fan duct and core cowl (D-duct construction assumed) 	Outer fairing: Graphite/Kevlar with nonmetallic HRP core Outer fan duct walls and bifurcations: aluminum sandwich Dyna-Rohr panels Inner fan duct walls: titanium sandwich Bumper blocks, rings 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. 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	GE 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 A-XXIII. Boeing Weight Analysis Summary (Concluded)

Nacelle Component	Assumed Substructure and Material	Remarks
Mixer, plug and tailpipe 	Mixer lobes: single-thickness titanium Lobe support struts and ring: Inconel Lobe fairing: aluminum Plug: Inconel, thickness as required by minimum welding gage criteria. Tailpipe: Inconel	Data base for mixer includes experimental work on daisy-lobe mixers and previous Boeing analytical studies. GE 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 ATE as installed in the Boeing Model 768-868 would surpass the design mission fuel consumption goal by over 6% if it could be developed as assumed.

2. Boeing's evaluation being more conservative than GE's indicated the ATE nacelle to be over 1000 lb. heavier than the GE weight estimate. A weight increase of 1000 lb/nacelle (i.e., 2000 lb. total) increases fuel burned by about 1%; however, DOC increases only 0.3%.

3. The NASA goal of 5% DOC reduction is bettered by 1% using GE supplied engine performance, weight, and economic data. However, Boeing considers the engine price quoted by GE unrealistically high for E^3 technology levels. When the 20% lower Boeing price estimate is applied, the DOC improvement increases from 6.4 to 7.5%. The DOC improvement with the higher Boeing weight and lower price is about 7.2%.

4. Engine noise estimates based on a preliminary engine noise treatment show that FAR 36 amendment 8 could met. Since 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 the 3 EPNdB margin Boeing generallly considers acceptable for assuring certificable 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, General Electric Purchase Order No. 200-4XX-14N43049.

2. EEE Component Development and Integration Program, General Electric Purchase Order No. 200-4XX-14K40096.

3. Study data for Advanced Technology and Reference engines. NASA Energy Efficient Engine Program, General Electric Co. Aircraft Engine Group, May 5, 1978.

4. Energy Efficient Engine and Integration Studies for General Electric Company, D6-44690, December 6, 1977.

5. Aerodynamic Analysis of GE E^3 Model Scale Nacelle Simulator (Unnumbered report submitted to GE by letter August 9, 1978).

6. General Electric Drawing No. 4013237-857.

7. General Electric Drawing No. 4013267-002.

8. General Electric Drawing No. 4013267-810.

9. General Electric Presentation "E^3 Mount Configuration".

APPENDIX B

Appendix B is a reproduction of report LR 28933 supplied by Lockhead-California Company as their contribution to aircraft integration. The format and printing have been altered to coordinate with this publication.

FINAL REPORT

ENERGY EFFICIENT ENGINE COMPONENT DEVELOPMENT AND INTEGRATION STUDY

Purchase Order 200-4XX-14N43062

Prepared for: GENERAL ELECTRIC COMPANY
AIRCRAFT ENGINE GROUP
Cincinnatti, Ohio

LOCKHEED-CALIFORNIA COMPANY • BURBANK
A DIVISION OF LOCKHEED CORPORATION

APPENDIX B

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1.0 INTRODUCTION AND SUMMARY

This study was accomplished by the Commercial Advanced Design Division of the Lockheed-California Company for the General Electric Company in support of their "Energy Efficient Engine component Development and Integration" Program with NASA-Lewis Research Center. The effort required was in accordance with General Electric Company Purchase Order 200-4XX-14N43062 and consisted of the following Tasks:

- TASK 1 - Aircraft and Mission Definition
- TASK 2 - Aircraft Performance and Mission Sensitivity
- TASK 3 - Aircraft/Engine Integration
- TASK 4 - Reporting

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", General Electric Purchase Order number 200-4XX-14K43170, which included:

- Definition of airplane 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 28377, two aircraft configurations were developed; one for a domestic mission and one for an intercontinental mission. These domestic and intercontinental aircraft, using the CF6-50C turbofan 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 (n.mi.)	1,400	3,000
Configuration	3 Engine Wide Body	4 Engine Wide Body

At the start of this study effort, a re-evaluation of aircraft technology features and mission criteria was accomplished. This resulted in retention of the previously selected criteria, except that the payload capacity of 100,000 pounds (500 passengers) was incorporated in liew of 80,000 pounds (400 passengers) previously used. This change resulted from 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 B-I. 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 General Electric for installation on the domestic and intercontinental aircraft is a mixed flow, direct drive high-bypass turbofan with the following characteristics, as compared to the current CF6-50C engine:

	CF6-50C	E^3
Technology Level	Current	1990's
Fan Drive	Direct	Direct
Exhaust	Separate	Mixed
Bypass Ratio	4.2	6.8
Overall Ratio	32	38
Turbine Inlet Temp.	2445°F	2450°F

Table B-II is a tabulation of the aircraft design and performance characteristics of the domestic and intercontinental aircraft with the E^3 engine. Comparison of this data with the reference aircraft (CF6-50C engine) indicates mission fuel and direct operating cost (DOC) savings with the E^3 engine as follows:

	Fuel Savings		DOC Savings	
	Design	Typical	Design	Typical
Domestic	18.3%	17.3%	8%	6.8%
Intercontinental	22.9%	21.2%	12%	10.5%

General arrangement drawings, depicting the domestic and intercontinental aircraft, with the E^3 engine, are included as Figures B-I and B-2. The size of the E^3 engine, as supplied by General Electric, is well matched (thrust-both takeoff and cruise, reverse thrust level, and power extraction) with the Lockheed specified mission/payload characteristics for the 1990's aircraft.

Installation layout drawings of the E^3 engine on the domestic aircraft (wing and center mounted engine) are included as Figures B-3 through B-5, and depict location of the aircraft accessories in the engine core as well as placement of the nacelle with respect to the wing consistent with minimization of interference drag penalties.

The results of this study are as follows:

- The NASA defined goals for minimum fuel and DOC savings of 12% and 5%, respectively, are attained with the E^3 engine
- Nacelle aerodynamic and mechanical characteristics (inlet, nacelle contour, and mount systems) are acceptable for aircraft installation

Table B-I. Reference Aircraft Design and Performance Characteristics

	Domestic	Intercontinental
Mission Characteristics		
Design Range (n.mi.)	3000	6500
Typical Range (n.mi.)	1400	3000
Cruise Speed	M0.8	M0.8
No. Passengers	500	500
Init. Cruise Altitude (ft)	37,000	32,000
Field Length (ft)	6837	9369
Approach Speed (kt)	135	133
Design Characteristics		
Configuration	3 Engine-Trijet	4 Engine-Quadjet
Power Plant	CF6-50C	CF6-50C
Sweep (.25C)	30°	30°
W/S (lb/ft^2)	118	145
T/W	0.274	0.248
AR	10	10
t/c (%)	13	13
TOGW (lb)	478,622	709,664
OEW (lb)	261,795	303,963
Wing Span (ft)	201.4	221.2
Body Length (ft)	228.3	229.5
Body Diameter (ft)	19.6	19.6
Performance Characteristics		
Thrust/Eng. (SLS,lb)	43,714	43,999
Block Fuel - Design (lb)	98,116	266,136
Block Fuel - Typ. (lb)	42,629	103,425
DOC - Design (¢/ASM)	1.262	1.449
DOC - Typ. (¢/ASM)	1.360	1.435

Table B-II. E^3 AIRCRAFT AND PERFORMANCE CHARACTERISTICS

	Domestic	Intercontinental
Mission Characteristics		
Design Range (n.mi.)	3000	6500
Typical Range (n.mi.)	1400	3000
Cruise Speed	M0.8	M0.8
No. Passengers	500	500
Init. Cruise Altitude (ft)	37,000	32,000
Field Length (ft)	6837	9369
Approach Speed (kt)	135	133
Design Characteristics		
Configuration	3 Engine-Trijet	4 Engine-Quadjet
Power Plant	E^3	E^3
Sweep (.25C)	30°	30°
W/S (lb/ft^2)	113	135
T/W	0.270	0.241
AR	10	10
t/c (%)	13	13
TOGW (lb)	453,652	624,577
OEW (lb)	256,767	283,672
Wing Span (ft)	200.2	215.6
Body Length (ft)	228.3	229.5
Body Diameter (ft)	19.6	19.6
Performance Characteristics		
Thrust/Eng. (SLS,lb)	40,832	37,631
Block Fuel - Design (lb)	80,158	205,221
Block Fuel - Typ. (lb)	35,254	81,504
DOC - Design (¢/ASM)	1.161	1.290
DOC - Typ. (¢/ASM)	1.269	1.299

CHARACTERISTICS	WING	HORIZONTAL TAIL	VERTICAL TAIL
AREA - SQ M.(SQ FT)	372.32 (4007.61)	80.13 (862.50)	50.38 (542.27)
ASPECT RATIO	10	5	1.6
SPAN - M.(FT)	61.02 (200.19)	19.95 (65.45)	8.98 (29.46)
ROOT CHORD - M.(IN)	9.38 (369.59)	6.15 (242.30)	8.63 (339.96)
TIP CHORD - M.(IN)	2.82 (110.89)	1.85 (72.68)	2.59 (101.99)
TAPER RATIO	0.30	0.30	0.30
MAC ~ M.(IN)	6.69 (263.40)	4.39 (172.70)	6.08 (239.55)
SWEEP ~ RAD .(DEG)	0.524 (30)	0.524 (30)	0.611 (35)
T/C ROOT ~ %	13.5	10	10
T/C TIP ~ %	10.5	10	10

GROSS WEIGHT - 205416 KG. (452857 LB.)

POWER PLANT (3) G.E. E^3 TURBOFAN

INSTALLED THRUST - 181287 N (40757 LB.)

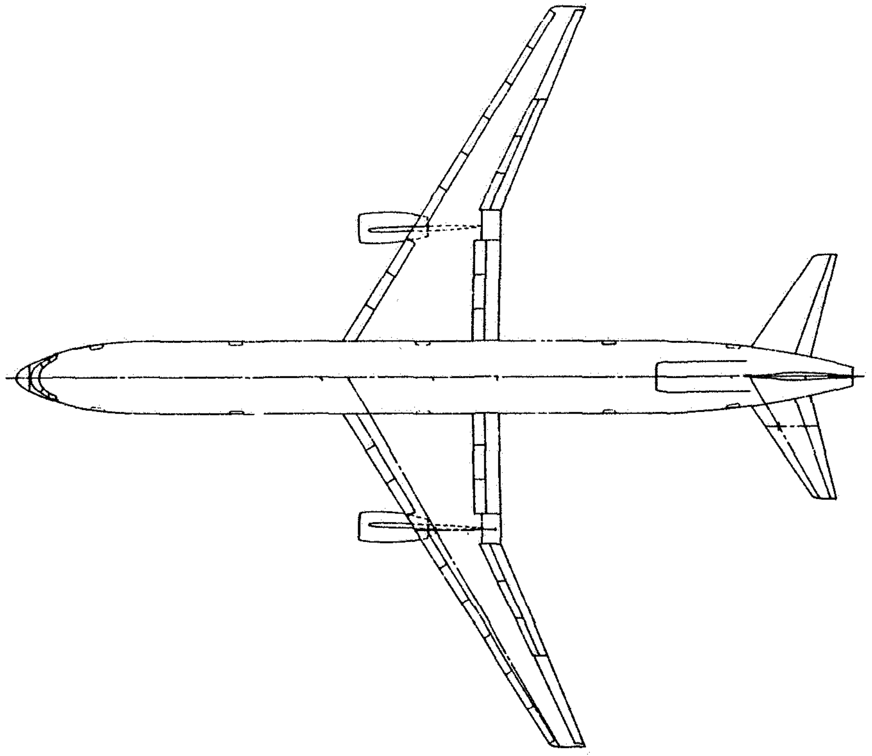
PASSENGERS - 469

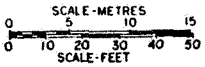
RANGE - 3,000 N.M.

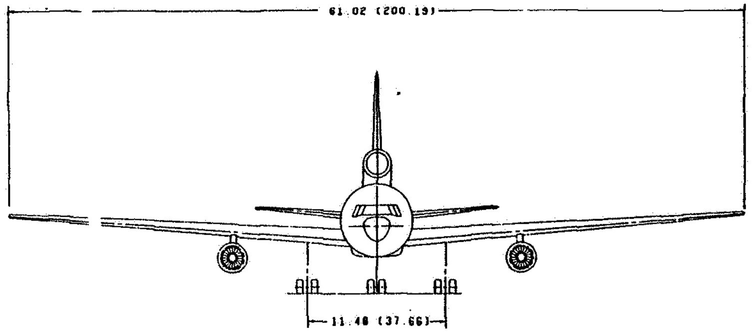
2. DIMENSIONS IN METRES (FEET), OR NOTED

1. CADAM REF. DWG. CL1333-11-1.1.2.3

NOTES:







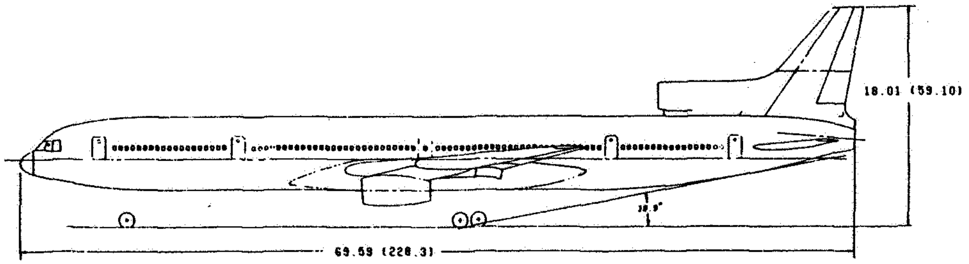


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Figure B-1. Three-View Drawing of Domestic Aircraft with E^3 Engine.

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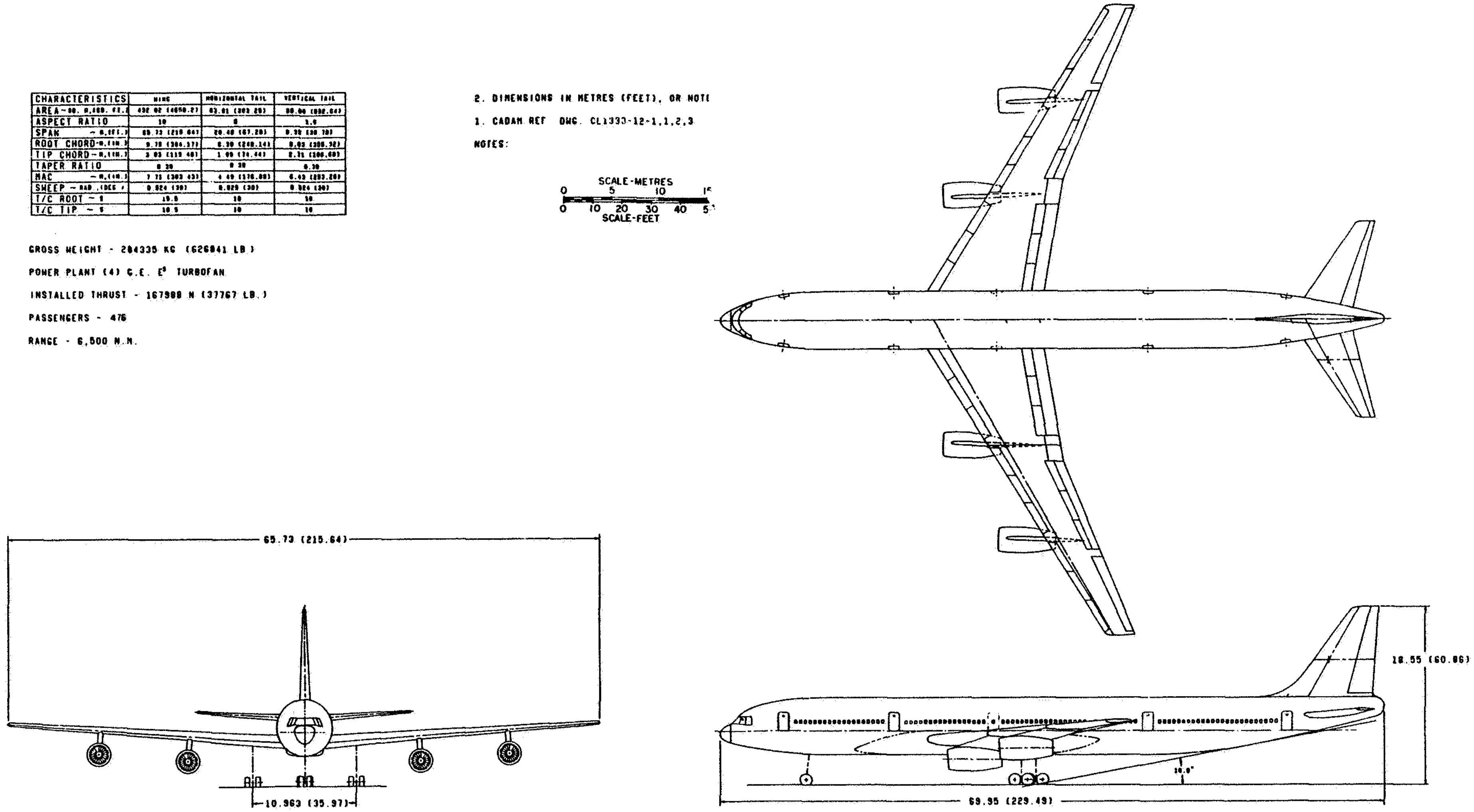

CHARACTERISTICS	WING	HORIZONTAL TAIL	VERTICAL TAIL
AREA ~ SQ. M.(SQ. FT.)	432.02 (4650.2)	83.81 (902.25)	58.84 (632.64)
ASPECT RATIO	10	5	1.6
SPAN ~ M.(FT.)	65.73 (215.64)	20.48 (67.20)	9.35 (30.70)
ROOT CHORD ~ M.(IN.)	9.78 (384.17)	6.30 (248.14)	8.03 (288.32)
TIP CHORD ~ M.(IN.)	2.93 (115.40)	1.89 (74.44)	2.31 (100.60)
TAPER RATIO	0.30	0.30	0.30
MAC ~ M.(IN.)	7.71 (303.43)	4.49 (176.80)	6.43 (253.20)
SWEEP ~ RAD.(DEG.)	0.524 (30)	0.529 (30)	0.524 (30)
T/C ROOT ~ %	15.5	10	10
T/C TIP ~ %	10.5	10	10

GROSS WEIGHT - 284335 KG (626841 LB.)

POWER PLANT (4) G.E. E^3 TURBOFAN

INSTALLED THRUST - 167988 N (37767 LB.)

PASSENGERS - 476

RANGE - 6,500 N.M.

NOTES:

1. CADAM REF DWG. CL1330-12-1,1,2,3

2. DIMENSIONS IN METRES (FEET), OR NOTE

Figure B-2. Three-View Drawing of Intercontinental Aircraft with E^3 Engine.

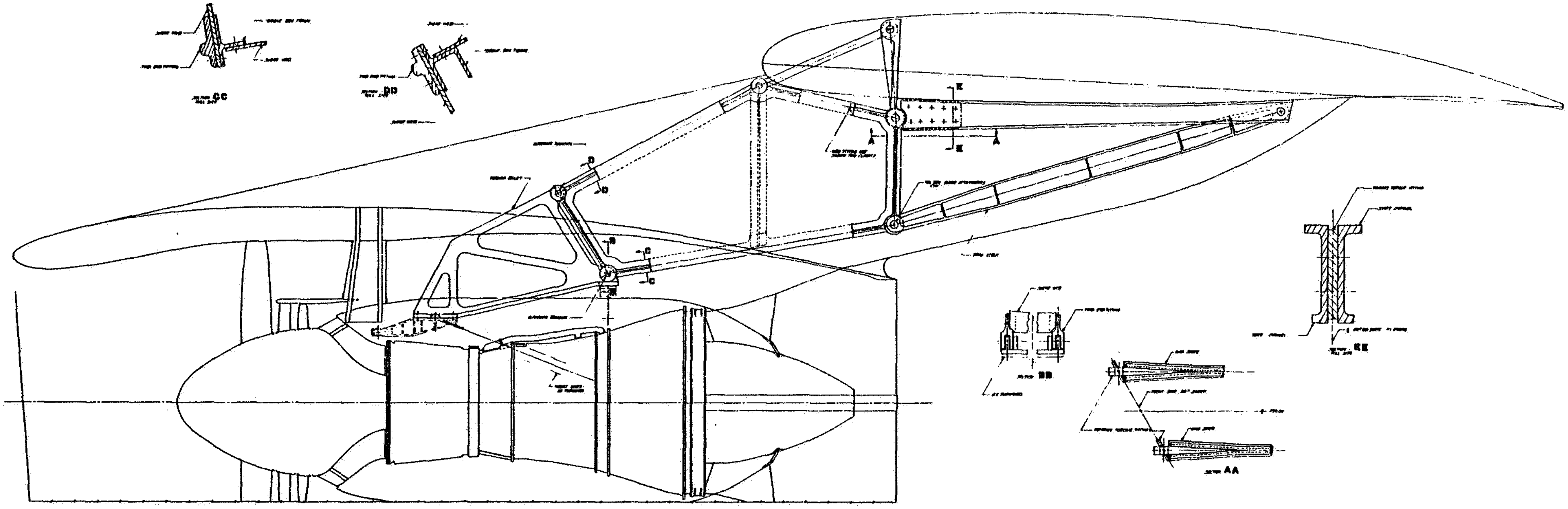

Figure B-3. Wing Engine Installation Layout with E^3 Engine.

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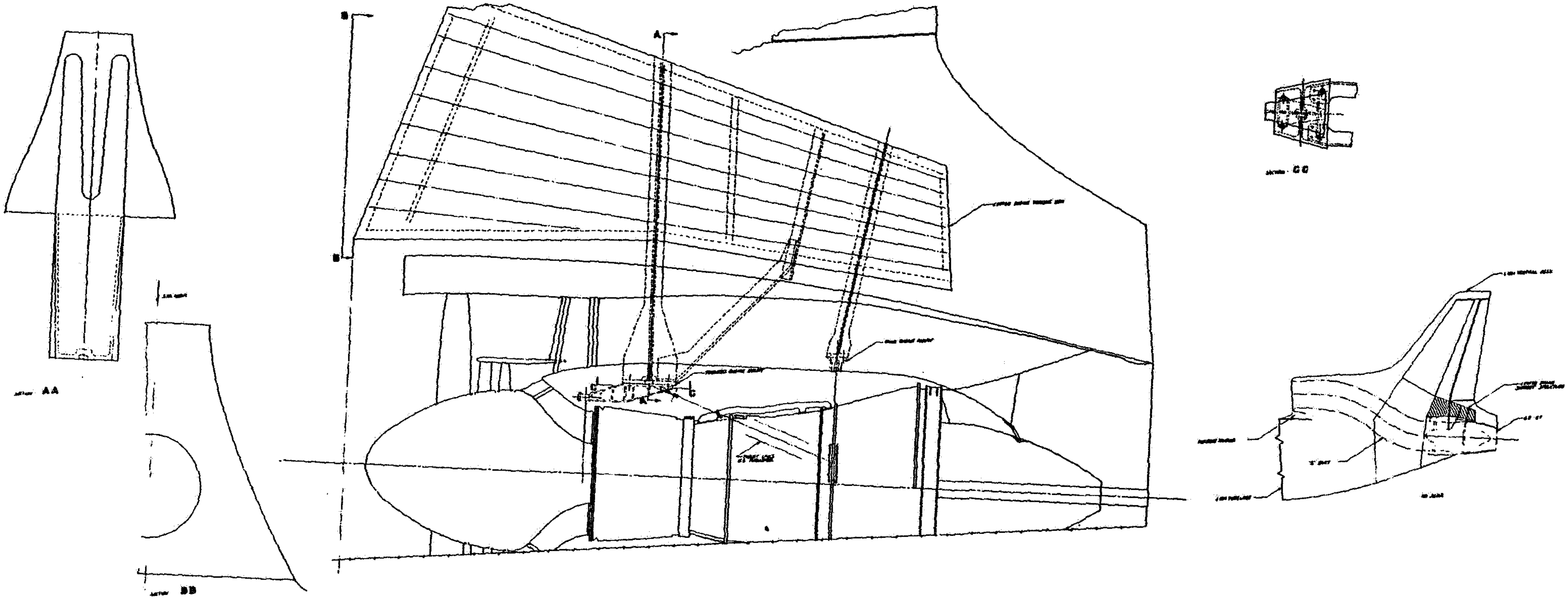

Figure B-4. Center Engine Installation Layout with E^3 Engine.

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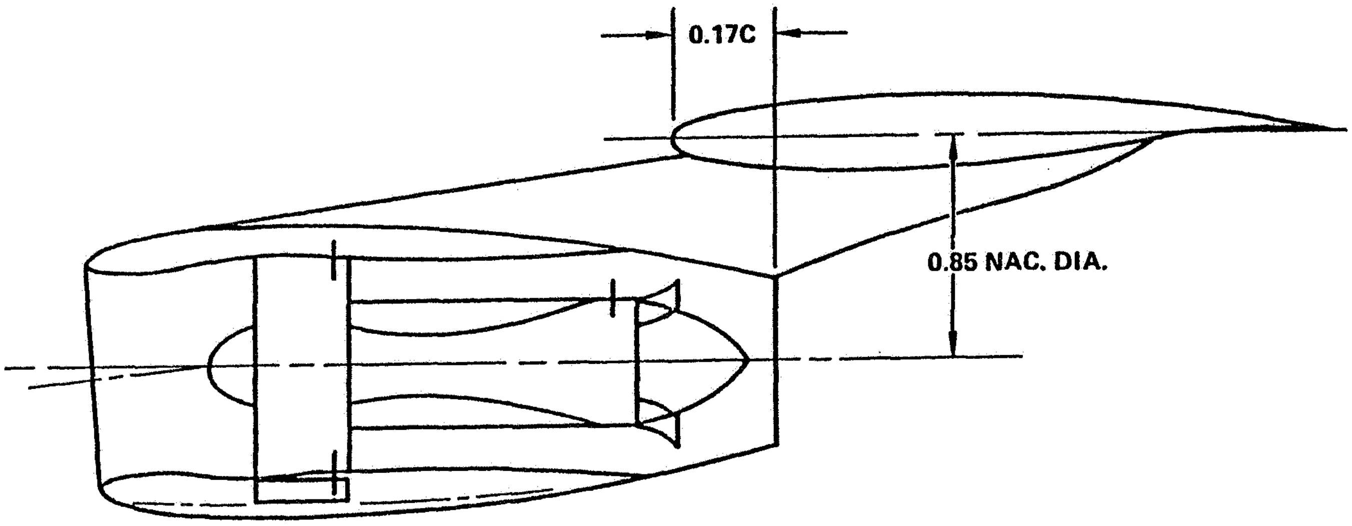

Figure B-5. Wing Engine Location - E^3 Engine

- Installation of the E^3 engine with mixed exhaust appears feasible without a penalty for interference drag
- The thrust characteristics of the E^3 engine, supplied by General Electric, are compatible with 1990's commercial aircraft.
- Incorporation of the E^3 engine results in aircraft configuration, sized for long range and large payload capacity, which are compatible with existing airport facilities (field length, wing span, body length, and gross weight).

2.0 STUDY EFFORT

The study effort accomplished by Lockheed in support of General Electric companys Energy Efficient Engine Component Development and Integration program consisted of the following major tasks:

- Task 1 - Aircraft and Mission Definition
- Task 2 - Aircraft Performance and Mission Sensitivity
- Task 3 - Aircraft/Engine Integration

2.1 AIRCRAFT AND MISSION 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 28377). 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 mission characteristics and technology levels is included as Table B-III. General arrangement drawings are included as Figures B-6 and B-7, and the procedures for calculating DOC are included as Supplement B.

2.2 AIRCRAFT PERFORMANCE AND MISSION SENSITIVITY

Performance, weight, and pertinent installation data for both the current CF6-50C engine and the advanced technology E^3 engine was supplied by General Electric for incorporation into the reference aircraft. Each aircraft was sized for minimum mission fuel and DOC using the Lockheed Parametric Analysis (ASSET) program, depicted in Figure B-8. The ASSET Analysis Program is a Lockheed Proprietary synthesis model to size parametrically and determine the weight, performance, and cost of aircraft sized to meet given mission profiles, payload capacity, and structural criteria using a pre-selected optimization criteria. Aircraft fuel usage, and DOC for both the design and average missions, along with estimates of the airframe noise for the FAR 36 measuring points is included in Tables B-IV and B-V. Supplement A includes the computer printouts for the domestic and intercontinental aircraft with the E^3 engine.

2.2.1 Sensitivity Analysis

Sensitivity factors were calculated for each aircraft (domestic and intercontinental) with the E^3 engine to assess the effects of changes in SFC, engine weight, engine intial price, and engine maintenance cost on aircraft performance (TOGW, fuel usage, and DOC). The following sensitivity factors were calculated:

	±5% SFC	±1000 lb	±*250K	±20%
TOGW	X	X		
Fuel Wt	X	X		
DOC	X	X	X	X

Table B-III. DESIGN AND TECHNOLOGY FEATURES-1990's TRANSPORT AIRCRAFT

	Domestic	Intercontinental
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
<u>Advanced Technology</u>		
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	-5.5% wing wt.	-5.5% wing wt.
• Load Relief	-1% body wt.	-1% body wt.
• Relaxed Stability	-28% tail size	-28% tail size
Advanced Composites	-8.7% M.E.W.	-9.2% M.E.W.
• Primary Struct.		
• Secondary Struct.		

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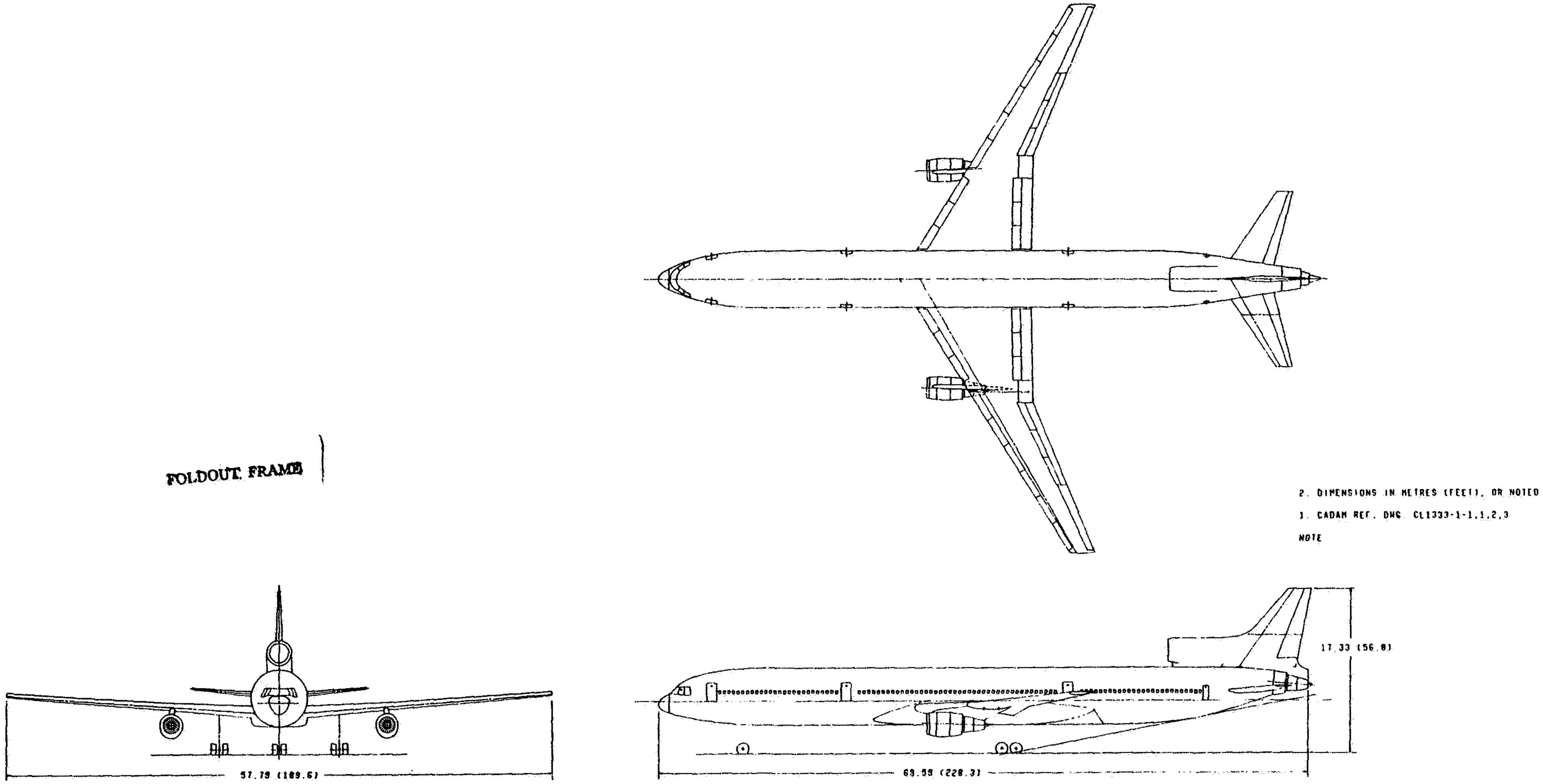

Figure B-6. Three-View Drawing of Domestic Aircraft with CF6-50C Engine.

C-3

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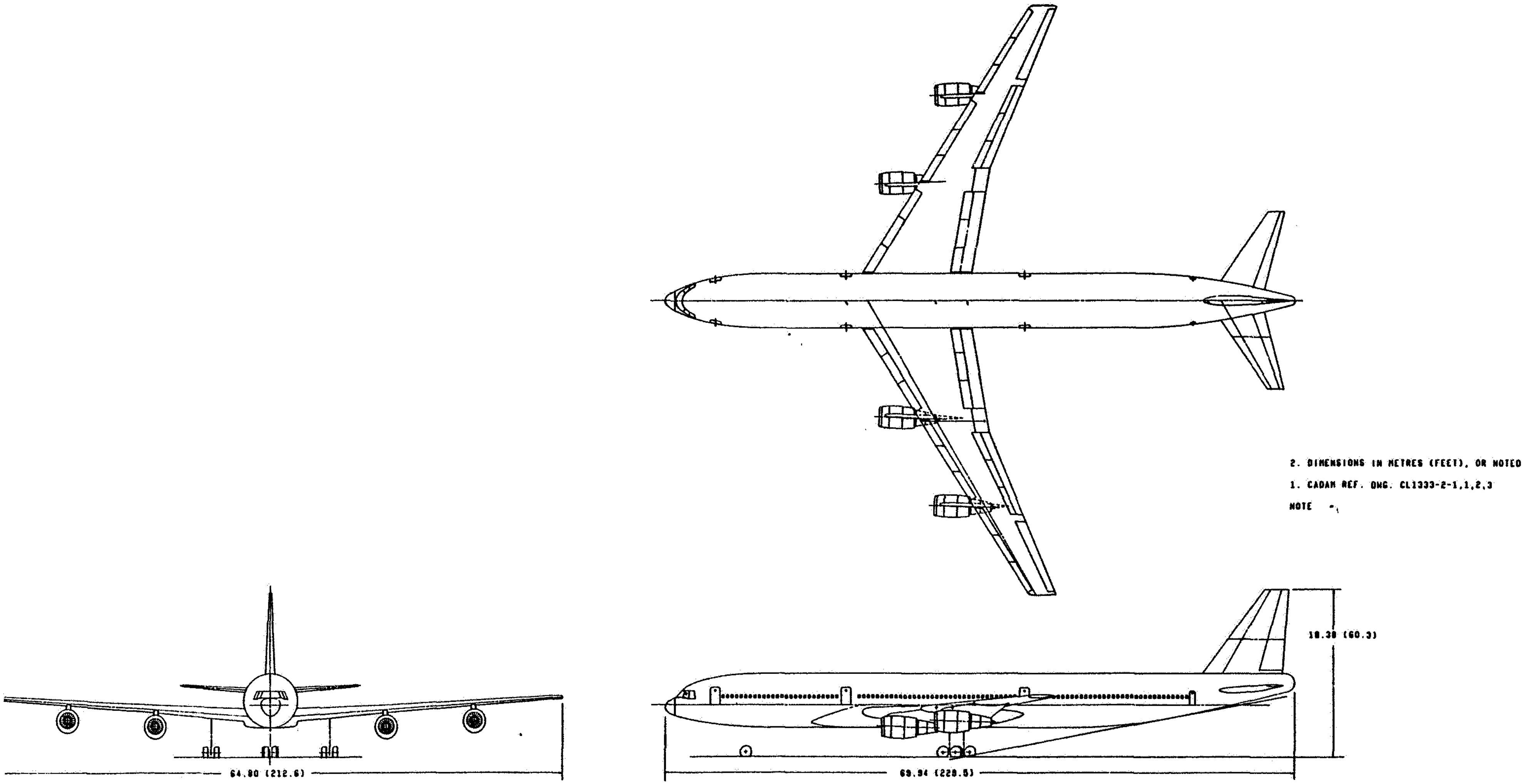

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Figure B-7. Three-View Drawing of Intercontinental Aircraft with CF6-50C Engine.

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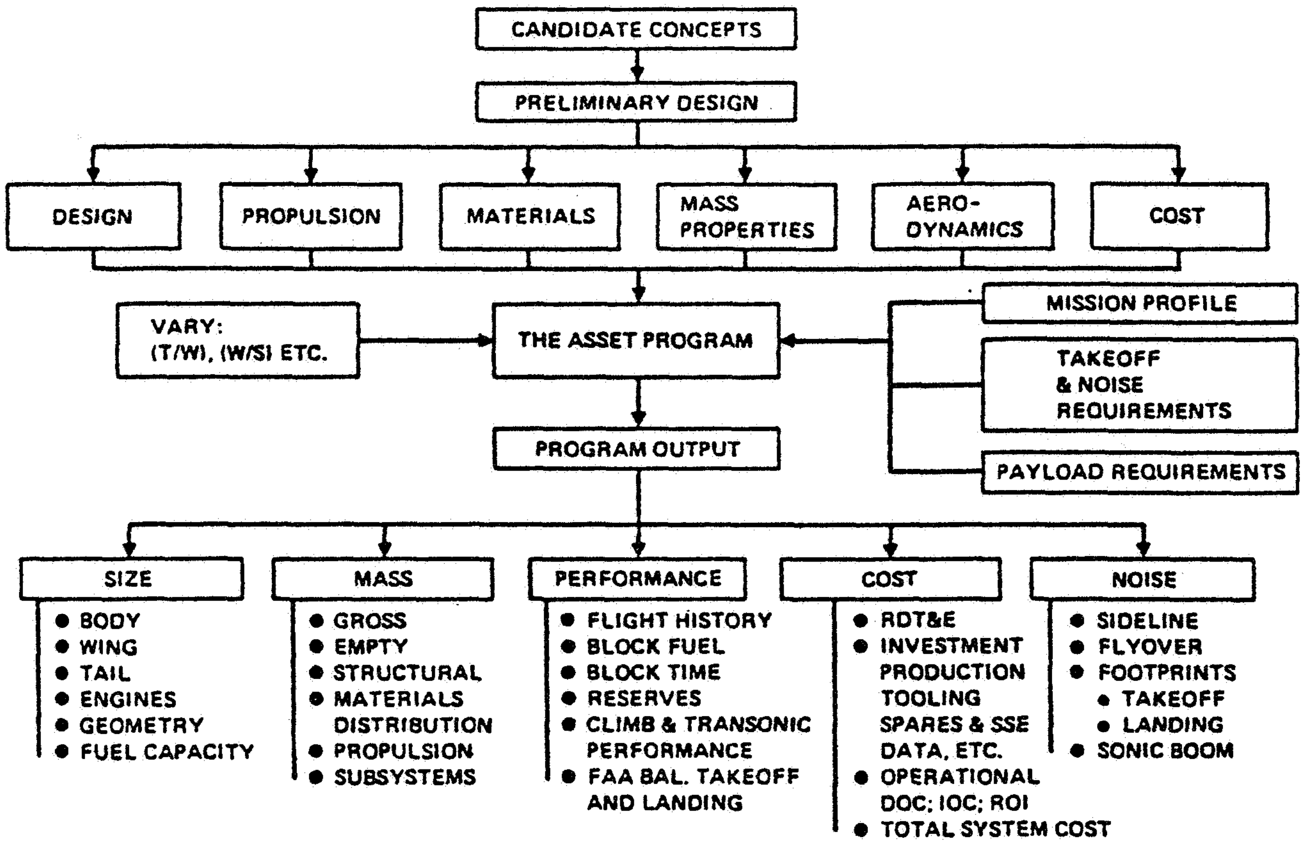

Figure B-8. ASSET Synthesis Cycle

Table B-IV. Aircraft Block Fuel and DOC

Fuel - Design Range (100% L.F.)

Segment	Domestic CF6-50C	 E^3	Intercontinental CF6-50C	 E^3
Takeoff	1089	776	1462	959
Climb	14520	11417	19185	15514
Cruise	81228	66610	243746	186963
Decent	675	845	917	1055
Land	600	510	825	730
Total	98112	80158	266135	204221

Fuel - Typical Range (55% L.F.)

Segment	Domestic CF6-50C	 E^3	Intercontinental CF6-50C	 E^3
Takeoff	1089	776	1462	959
Climb	10818	8350	11709	9529
Cruise	29529	24886	88584	69315
Decent	651	801	879	1001
Land	540	441	791	700
Total	42627	35254	103425	81504

Aircraft D.O.C. (/ASM)

	Domestic CF6-50C	 E^3	Intercontinental CF6-50C	 E^3
DOC - Design	1.262	1.161	1.449	1.290
DOC - Typical	1.360	1.269	1.435	1.299

Table B-V. AIRFRAME NOISE ESTIMATES (E^3 ENGINE)

Condition	Domestic	Intercontinental
Approach (42° Flap, Geardown, 3° Glide)		
Landing Weight (lb)	371,635	418,209
Approach Speed (knots)	135	133
Altitude (ft)	394	394
Airframe Noise (EPNdB)	95.9	96
Takeoff (25° Flap, Gear up)		
Climb Angle	5.96°	4.66°
TOGW (lb)	452,857	626,841
Altitude (ft)	1668	1128
Distance (n.mi.)	3.5	3.5
Speed (knots)	150.55	160.6
Airframe Noise (EPNdB)	84.1	89.6
Sideline Point		
Airframe Noise (EPNdB)	80.0	83.2

Table B-VI and B-VII depict the sensitivity factors for the E^3 aircraft (with advanced technology engine).

2.2.2 Performance Retention

As specified by NASA, one of the major goals for the E^3 program is to incorporate those design features into the advanced technology engine which will ensure that deterioration of SFC characteristics with time (engine cycles) will be less than 50 percent of that currently experienced on the CF6-50C engine. This improvement was assessed to provide an additional 1% in SFC reduction, effectively over the service life of the engine.

An assessment of the impact on aircraft performance characteristics of the E^3 engine, with and without credit for improved performance retention characteristics, was accomplished using the engine SFC and weight characteristics supplied by General Electric. Table B-VIII and B-IX depict the results of this assessment. These results indicate an additional increase in aircraft fuel savings of approximately 1% is attained with performance retention incorporated. The fuel savings included in this report are those values obtained with performance retention incorporated into the E^3 engine.

2.3 AIRCRAFT/ENGINE INTEGRATION

2.3.1 Nacelle Configuration

The nacelle dimensions and weight for the E^3 engine were supplied by General Electric. The E^3 engine uses a mixed flow exhaust which requires a full length nacelle.

Use of the full length nacelle requires consideration of the following installation items:

- Potential of interference drag penalty particularly for wing mounted engine.
- Increased in wetted area of the nacelle and subsequent increase in drag.
- Potential of increased nacelle weight due to full length cowl.
- Access to engine hot section and to engine and aircraft accessories.

As part of this study effort, an assessment was made of the nacelle design, supplied by General Electric, for acceptability of aerodynamic and mechanical characteistics. This assessment included nacelle contour and envelope dimensions (both interior and exterior), inlet geometry, engine mount system, nacelle structural arrangement and materials, and nacelle weight. The results of this evaluation were supplied to General Electric for consideration during their preliminary design phase of the E^3 flight propulsion system. Assessment of the flight propulsion system design used as the baseline for the NASA/GE Preliminary Design Review (PDR), November 1978, results in the following conclusions:

- Nacelle contours provide acceptable aerodynamic characteristics for incorporation into the E^3 aircraft.

Table B-VI. Sensitivity Factors - Domestic Aircraft - E^3 Engine.

Base	1.161/1.269	453,652	80,158/35,254	
	ΔDOC (¢/ASM)	ΔTOGW (lb)	ΔFuel (lb)	
ΔSFC				
+5%	+0.021/+0.0181%	+ 8526	+ 5114	6.38%
0	0	0	0	---
-5%	-0.021/-0.0181%	- 8337	- 4994	6.23%
ΔEngine Weight at 40,000 lb/F_N				
+1000 lb	+0.006/+0.052%	+ 5677	+ 876	---
0	0	0	0	---
-1000 lb	-0.006/-0.052%	- 5514	- 851	---
ΔEngine Cost				
+ $250K	+0.021/+0.0181%	NA	NA	
0	0			
- $250K	-0.021/-0.0181%			
ΔEngine Maint.				
+20%	+0.023/+0.0190%			
0	0			
-20%	-0.024/-0.0207%			

Table B-VII. Sensitivity Factors - Intercontinental Aircraft - E^3 Engine.

Base	1.290/1.299	624,577	205,221/81,504	
	ΔDOC (¢/ASM)	ΔTOGW (lb)	ΔFuel (lb)	
ΔSFC				
+5%	+0.042/+0.033%	+25419	+16505	8.04%
0	0	0	0	---
-5%	-0.042/-0.033%	-24321	-15732	7.67%
ΔEngine Weight at 37,600 lb/F_N				
+1000 lb	+0.009/+0.007%	+ 8952	+ 2643	---
0	0	0	0	---
-1000 lb	-0.009/-0.007%	- 8395	- 2476	---
ΔEngine Cost				
+ $250K	+0.024	NA	NA	
0	0			
- $250K	-0.025			
ΔEngine Maint.				
+20%	+0.027			
0	0			
-20%	-0.028			

Table B-VIII. INTERCONTINENTAL AIRCRAFT PERFORMANCE CHARACTERISTICS

	CF6-50C Engine	E^3 Engine Without Improved Performance Retention	E3 Engine With Improved Performance Retention
No. Pax	500	500	500
Design Range (n.mi.)	6,500	6,500	6,500
Gross Wt. (lb)	709,664	629,443	624,577
Empty Wt. (lb)	303,963	285,767	283,672
Engine Thrust (lb)	43,999	37,925	37,631
Design Fuel (lb)	266,136	208,378	205,221
Typical Fuel (lb)	103,425	82,731	81,504
Des. Fuel Savings	-	21.7%	22.9%
Typ. Fuel Savings	-	20.1%	21.2%

Table B-IX. DOMESTIC AIRCRAFT PERFORMANCE CHARACTERISTICS

	CF6-50C Engine	E3 Engine Without Improved Performance Retention	E^3 Engine With Improved Performance Retention
No. Pax	500	500	500
Design Range (n.mi.)	3,000	3,000	3,000
Gross Wt. (lb)	478,622	455,319	453,652
Empty Wt. (lb)	261,796	257,710	256,767
Engine Thrust (lb)	43,714	40,978	40,832
Design Fuel (lb)	98,113	81,157	80,158
Typical Fuel (lb)	42,629	35,684	35,254
Des. Fuel Savings	-	17.3%	18.3%
Typ. Fuel Savings	-	16.3%	17.3%

- Inlet geometry is acceptable and is consistent with our previous experience with this size of engine on the L-1011 commercial aircraft
- The engine mount system is structurally adequate and compatible with pylon mounting to the aircraft. Evaluation of the mount system, with respect to fail-safe capabilities, and the design approach necessary, are included in Figure B-9
- Nacelle structural arrangement, structural materials, and weight estimates made by General Electric appear to be reasonable and acceptable.

Use of composite materials in the nacelle results in a weight savings of aproximately 15 percent as compared to an all metal nacelle. This estimate, supplied by General Electric, is consistent with Lockheed's efforts for Advanced Acoustic Composite Nacelles, NASA Report CR 132649.

2.3.2 Nacelle - Wing Interference

Figure B-5 depicts installation of the E^3 engine to the wing of the domestic aircraft. Placement of the engine with respect to the wing is consistent with Lockheed experience on the L-1011 for elimination or minimization of interference drag penalties. Aerodynamic assessments of this installation indicate no drag penalty imposed by wing/nacelle interference. Development testing (wind tunnel tests) and tailoring will be required prior to actual installation of the E^3 mixed flow engine on the 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

During this study, various aircraft accessory locations were considered. Table B-X presents a qualitative asessment of the advantages and disadvantages of each location. Figure B-10 depicts location of aircraft accessories for the wing mounted engines in the pylon. Locating the aircraft accessories in the engine pylon is desirable for minimization of nacelle drag and improved maintainability/reliability due to the improved environment (lower temperature). Attempts to pylon mount all accessories (both engine and aircraft), for best nacelle aerodynamic shape, requires an increase in pylon size and probable adverse effect on interference drag. Figure B-11 depicts the other accessory locations subjected to design layouts during this study. These design layouts show that accessories located in the engine core or external to the fan case are practical for the E^3 engine. Since location of engine and aircraft accessories will ultimately depend on the desires of the E^3 engine user, it is important to provide an engine/nacelle configuration which is adaptable to the user requirements. The E^3 engines, as configured, accomplishes this goal. Accessories can be core mounted, fan case mounted, or pylon mounted without requiring changes to the basic engine design.

2.3.4 Access Provisions

The E^3 engine/nacelle configuration selected as the baseline for the flight propulsion system PDR uses core mounted accessories (both engine and aircraft). This configuration requires access to the engine core which will be provided by hinging the thrust reverser and interior (core) cowl. In the event that pylon mounted aircraft accessories are incorporated in future

Table B-X. 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 • Enhance accessibility to components • Small pylon	• Large nacelle • Revision to nacelle structure and thrust reverser
Core Mount	Core Mount	• Utiliize 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

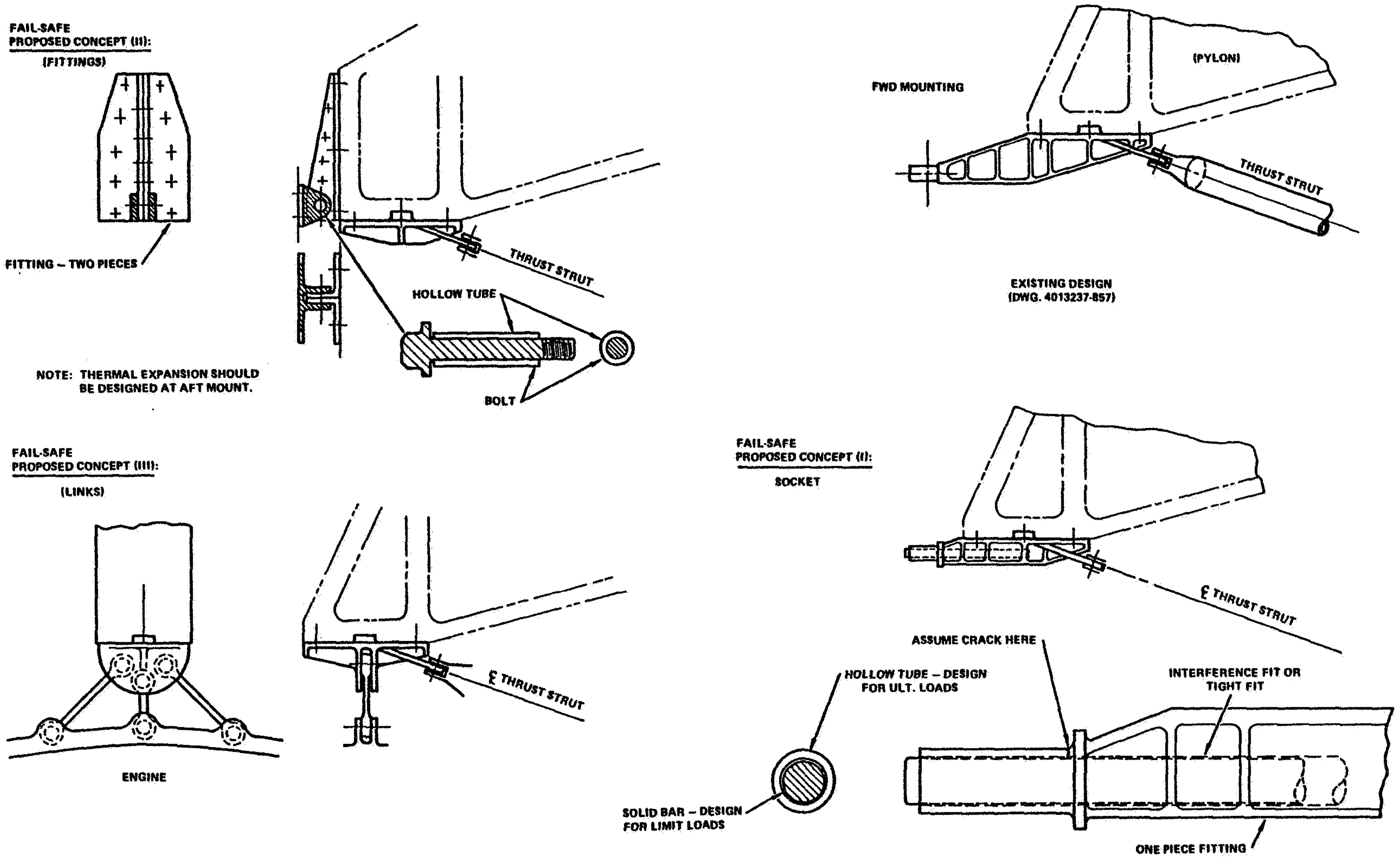

Figure B-9. Fail-Safe Design Concepts E^3 Engine Mount System.

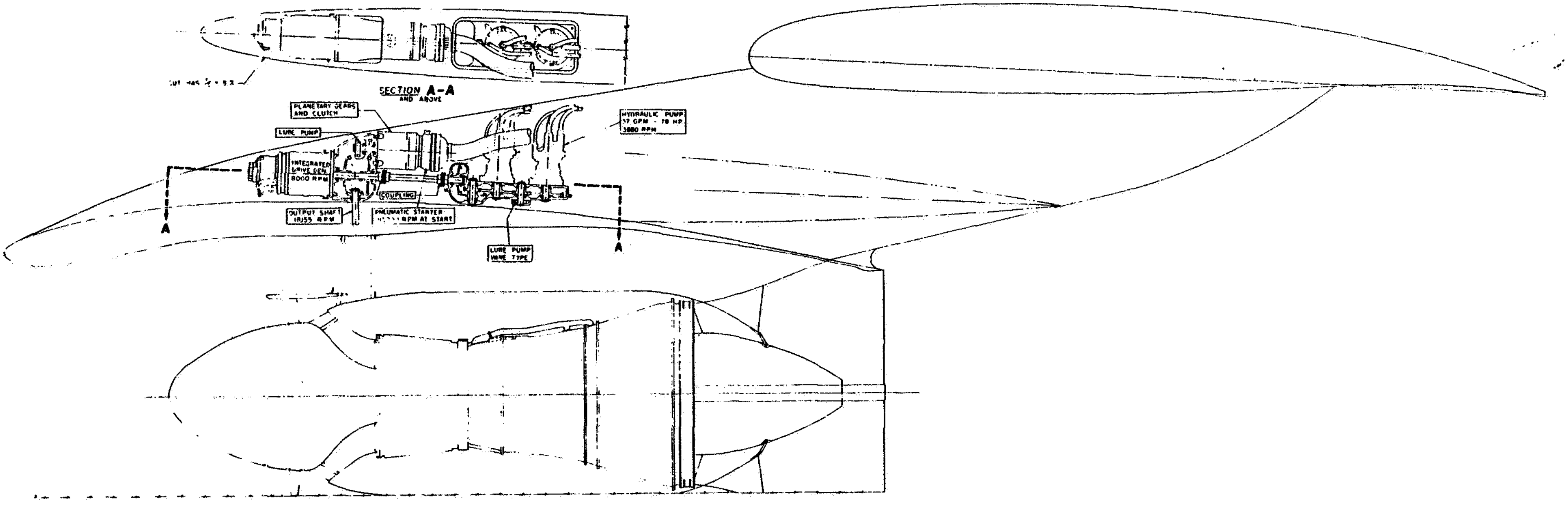

Figure B-10. Pylon-Mounted Aircraft Accessories - E^3 Wing Engine Installation.

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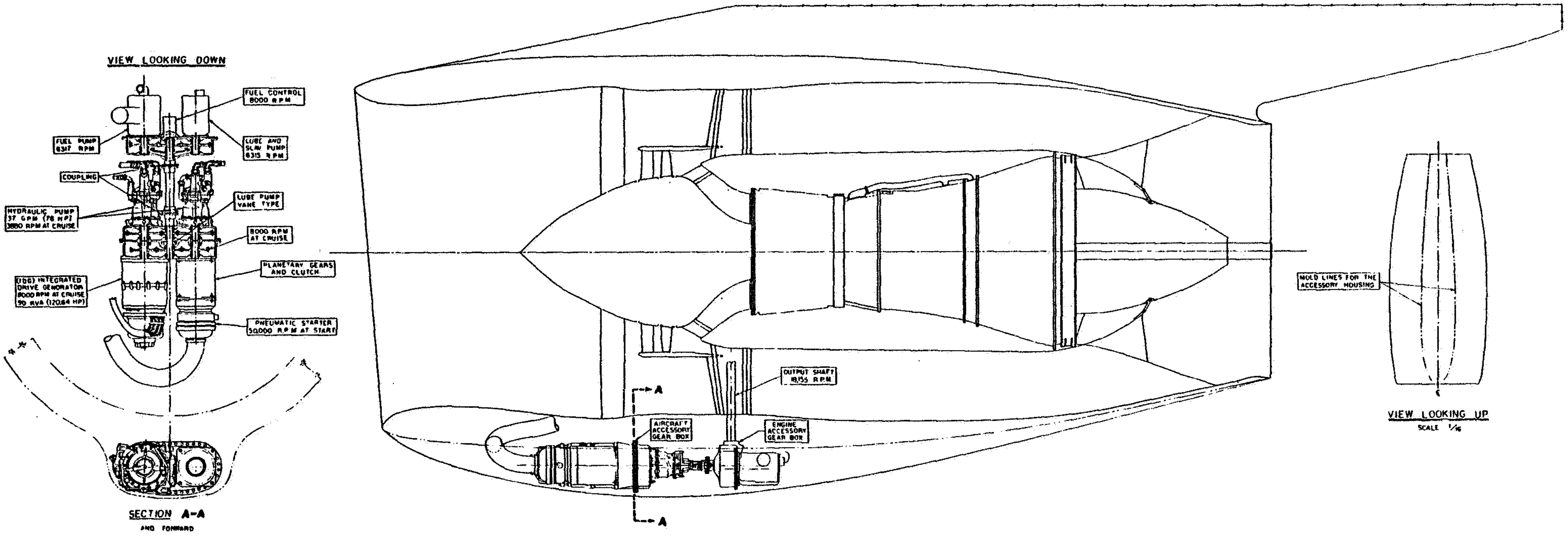


Figure B-11. E^3 Engine with Fan Case-Mounted Accessories.

engines, access would be provided by removing the top of the pylon to provide ready access to components. Since the pylon skin is subjected to aerodynamic loads only, with the pylon structural arrangement shown in Figure B-10, removal of panels for access can be accomplished with non-structural, quick turn type of fasteners. An additional work stand similar to that currently required for the center engine on the L-1011 will also be required for pylon mounted accessories.

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. Required levels of reverse thrust for the E^3 aircraft are approximately 35 percent of engine forward thrust. As currently sized, the E^3 engine will provide reverse thrust static effectiveness of 34 percent of forward thrust, which is slightly less than the CF6-50C with both the fan and turbine reverser. The level of reverse thrust estimated for the E^3 engine is considered acceptable for both the domestic and intercontinental aircraft designs. Flow directivity of the thrust reverser 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 B-12.

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 E^3 center engine was located such that ground clearance of the 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. As is the case with the wing engine installation, future aerodynamic development testing and possible tailoring will be required to minimize interference effects. For this study effort, zero interference drag penalty, which is consistent with L-1011 experience, was used for the center engine installation.

2.3.7 Engine Bleed Requirements and Power Extraction

For this study effort, engine bleed and power extraction requirements were included in the engine performance data supplied by General Electric. Estimates of the bleed and power extraction requirements for a 500 passenger aircraft for the early 1990's are:

- Bleed air - 9 lb/sec for ECS and anti-icing (Total for all engines)
- Power extraction - 370 hp for hydraulic pumps and generator (Total for all engines)

2.3.8 Engine Fire Protection

Figure B-13 depicts the applicable fire zones established by Lockheed for the E^3 engine. The following criteria was used to establish the E^3 engine fire protection criteria:

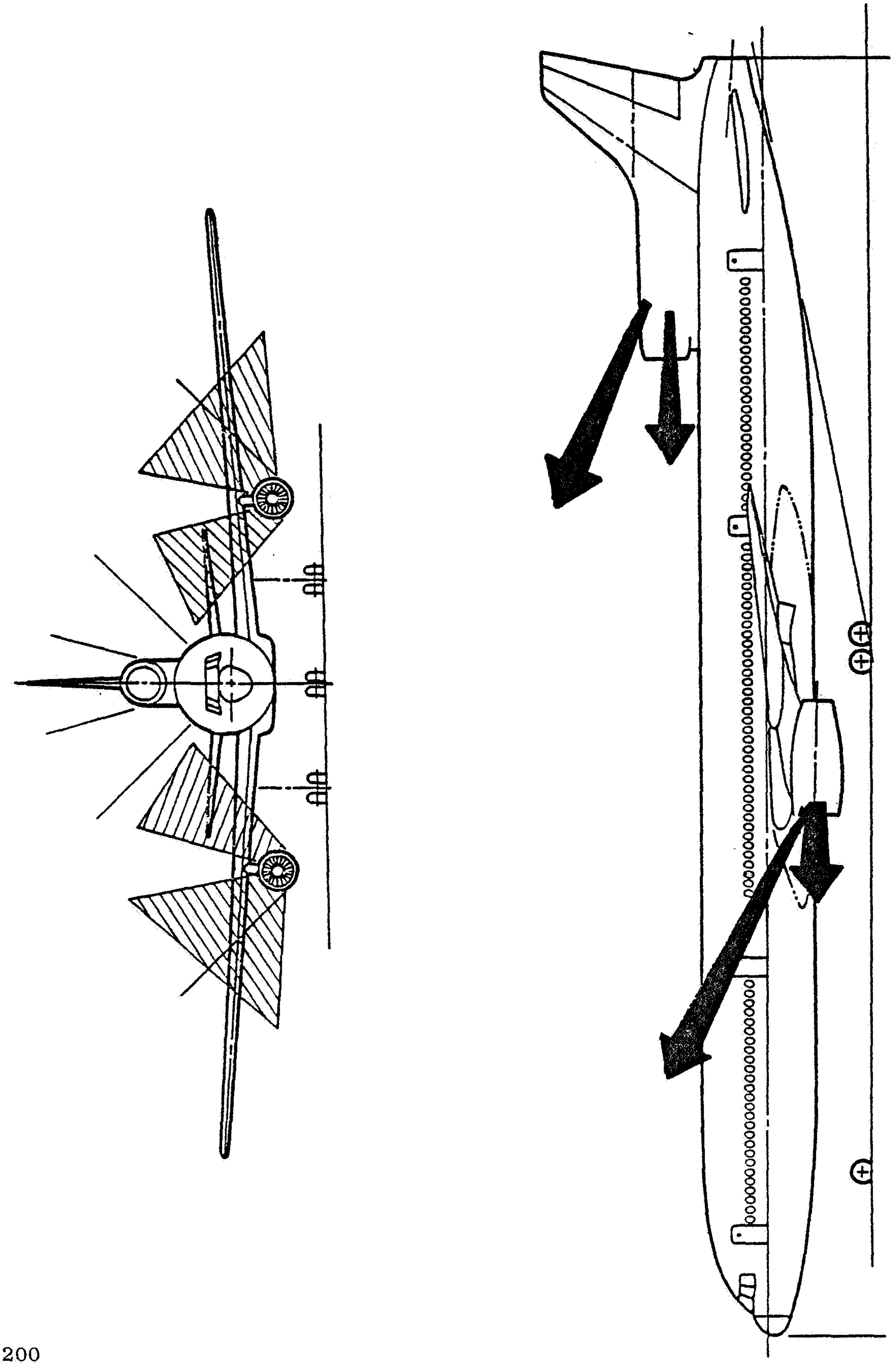
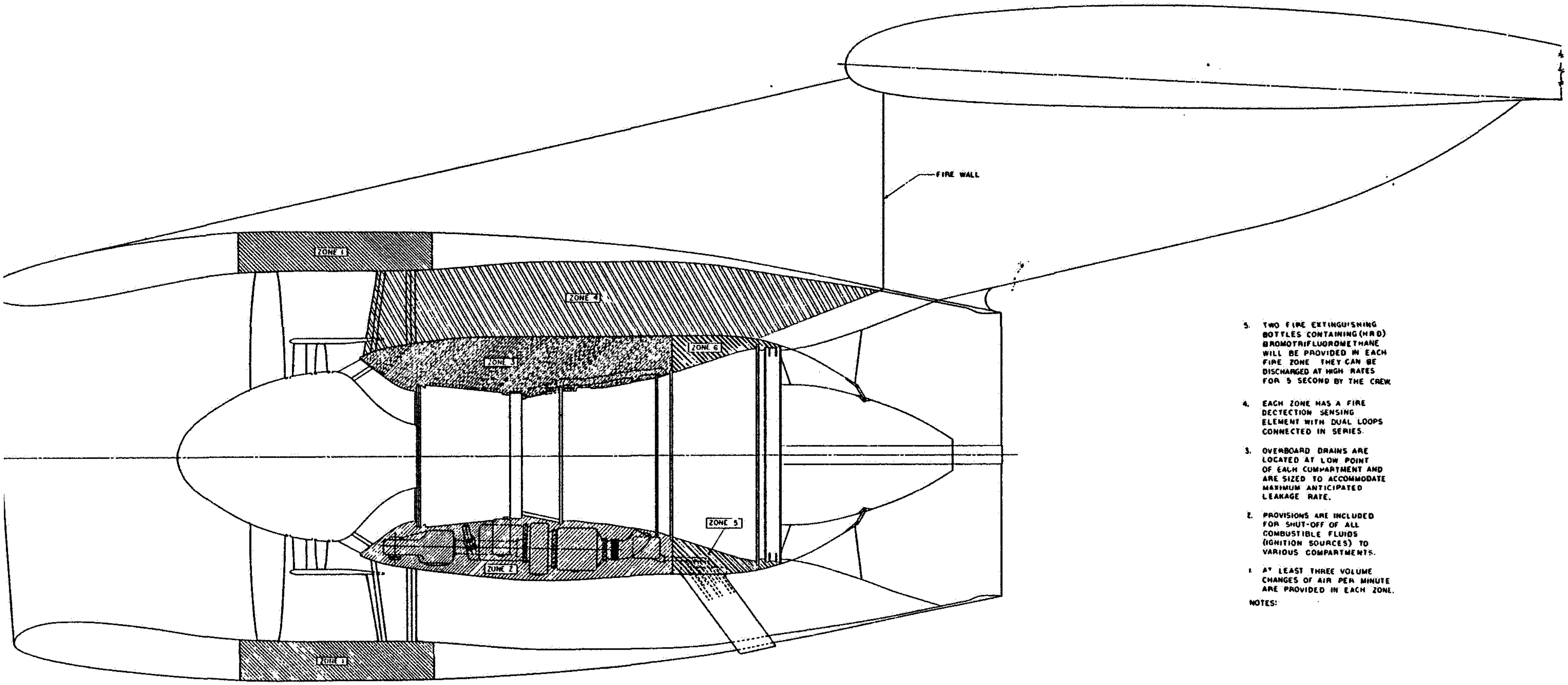


Figure B-12. Thrust Reverser Flow Directivity



5. TWO FIRE EXTINGUISHING BOTTLES CONTAINING (HRD) BROMOTRIFLUOROMETHANE WILL BE PROVIDED IN EACH FIRE ZONE THEY CAN BE DISCHARGED AT HIGH RATES FOR 5 SECOND BY THE CREW.

4. EACH ZONE HAS A FIRE DECTECTION SENSING ELEMENT WITH DUAL LOOPS CONNECTED IN SERIES.

3. OVERBOARD DRAINS ARE LOCATED AT LOW POINT OF EACH COMPARTMENT AND ARE SIZED TO ACCOMMODATE MAXIMUM ANTICIPATED LEAKAGE RATE.

2. PROVISIONS ARE INCLUDED FOR SHUT-OFF OF ALL COMBUSTIBLE FLUIDS (IGNITION SOURCES) TO VARIOUS COMPARTMENTS.

1. AT LEAST THREE VOLUME CHANGES OF AIR PER MINUTE ARE PROVIDED IN EACH ZONE.

NOTES:

Figure B-13. Layout of Fire Zones for E^3 Engine.

- Fire Prevention: Compartmentation used for containment and to provide maximum separation between combustibles and ignition sources. Fireproof bulkheads should be provided in the more critical areas. Flameproof bulkheads should be provided in the more critical areas Flameproof barriers are required to protect primary structure and engine support structure. Fire zones will require ventilation and overboard drains located at low points. Ventilation of the compartments should be a minimum of three volume changes per minute and can be provided by fan air or ram air during in-flight conditions.
- Fire Detection: Fire detection is provided by audio and visual indication at the flight station for engine compartments as well as the APU and main wheel wells. Thermistor type, continuous sensing elements are used as the sensors to activate appropriate warning indicators on flight station control panels. Each fire zone contains its own sensors and control loops.
- Fire Extinguishing System: High rate of discharge (HRD) system is normally provided for engine accessory compartment and APU compartment. On the L-1011 aircraft, the fire extinguishing material is Bromo-trifluoromethane and two fire extinguisher bottles are provided for each engine fire zone. Bottles are operated (discharged) from controls located in the flight station.

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 B-14 and B-15 show the savings in block fuel and DOC, of the domestic and intercontinental aircraft with the E^3 engine when compared to the reference aircraft (CF6-50C engine). The results show significant savings for the E^3 engine as follows:

	Domestic		Intercontinental	
	Des. Range	Typ. Range	Des. Range	Typ. Range
Block Fuel	18.3%	17.3%	22.9%	21.2%
DOC	8.0%	6.8%	12.0%	10.5%

Figure B-16 depicts the advantages in aircraft size when the E^3 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.

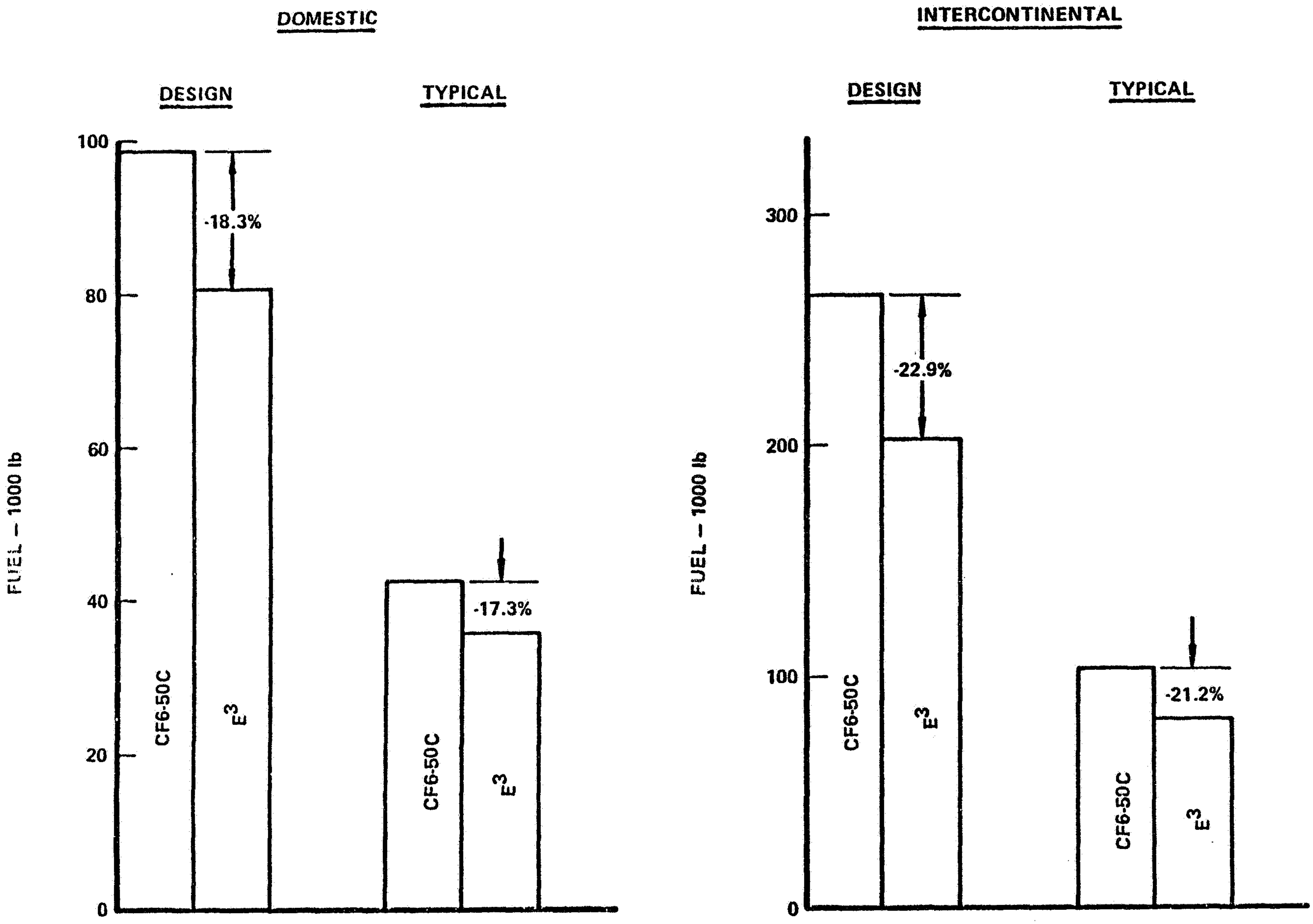


Figure B-14. Block Fuel Savings with E^3 Engine

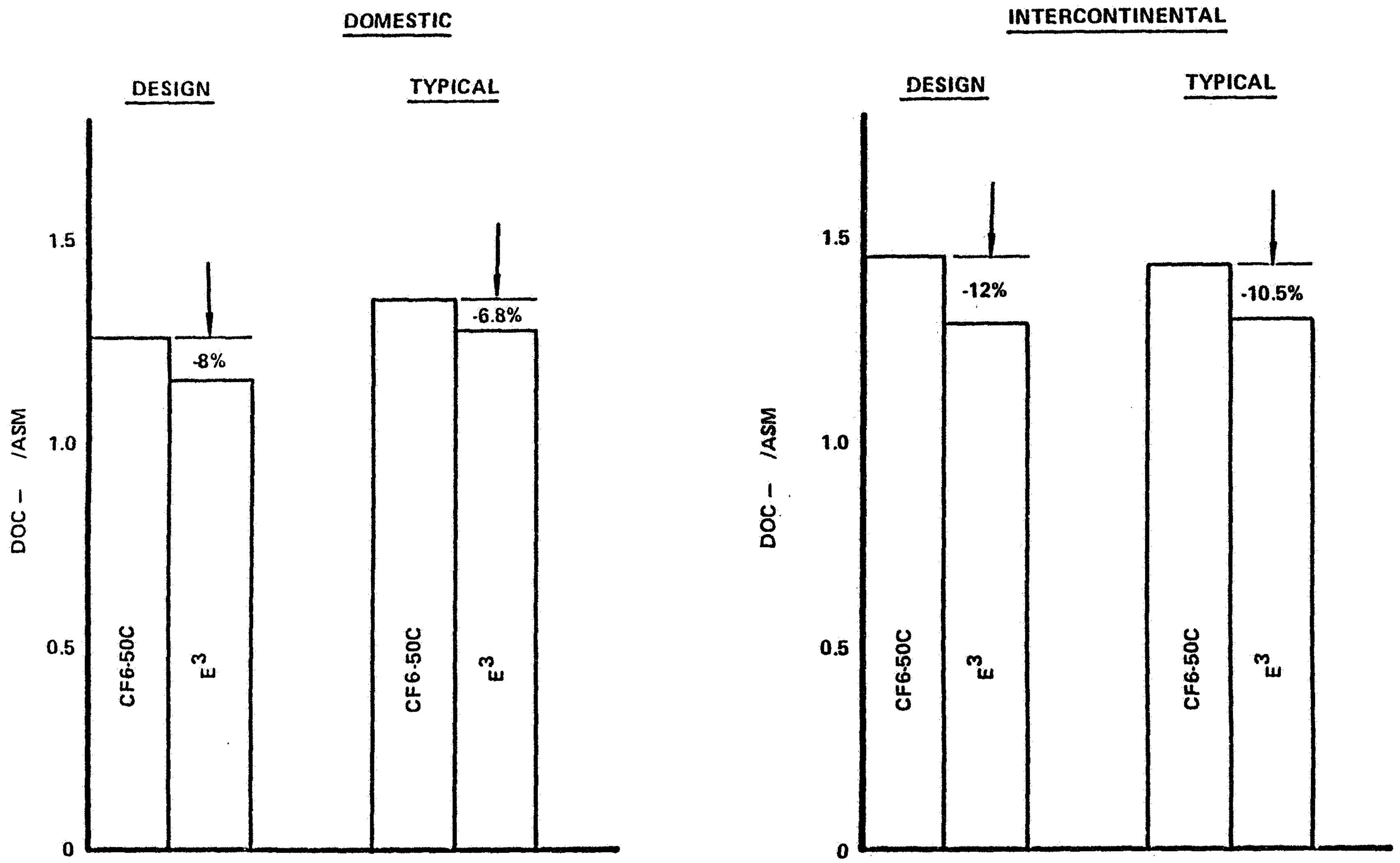


Figure B-15. DOC Savings with E^3 Engine

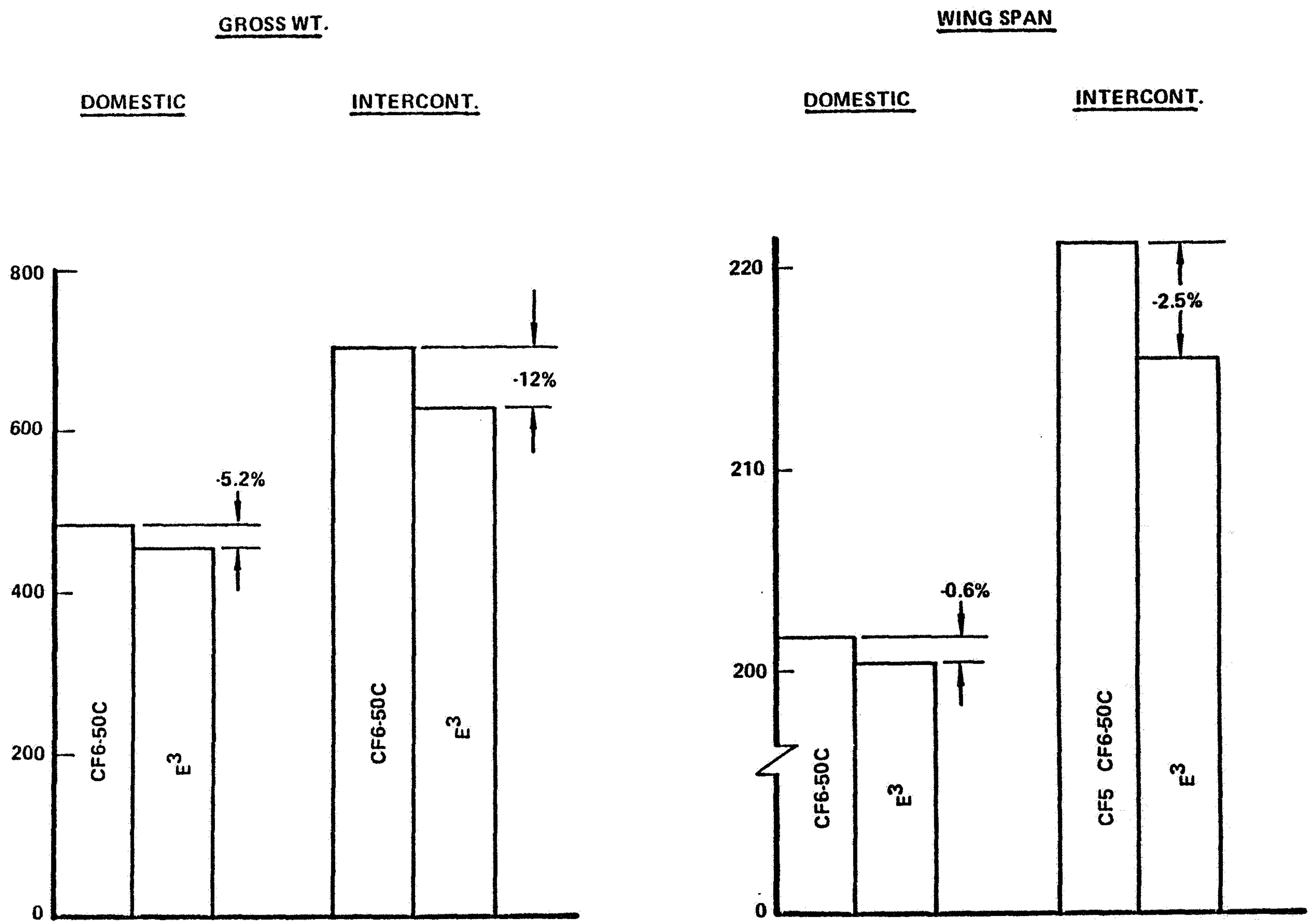


Figure B-16. Aircraft Size Advantage with E^3 Engine

3.0 CONCLUSIONS AND RECOMMENDATIONS

The results of this study, accomplished with the advanced technology, direct drive, mixed flow E^3 engine, with the design and performance characteristics supplied by General Electric, show that:

- The NASA specified goals for minimum fuel and DOC savings are exceeded with the E^3 engine
- Nacelle aerodynamic and mechanical characteristics are acceptable for aircraft installation
- Installation of the mixed exhaust E^3 engine on both the domestic and intercontinental aircraft appears feasible without a penalty for interference drag
- Thrust characteristics of the E^3 engine are compatible with the 1990's commercial aircraft selected by Lockheed
- Incorporation of the E^3 engine results in aircraft configurations, sized for long range and large payload capacity, which are compatible with existing airport facilities.

SUPPLEMENT A

- Asset Computer Printout - Domestic Aircraft with E^3 Engine
- Asset Computer Printout - Intercontinental Aircraft with E^3 Engine

```
  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              AUGUST 17 1978

 AIRCRAFT MODEL --CL 1332-9                         ENGINE I.D. -- 429000               WING QUARTER CHORD SWEEP = 30.00 DEG
 I.O.C. DATE    --1985                              SLS SCALE 1.0 =  46900              WING TAPER RATIO = 0.300
 DESIGN SPEED   --SUBSONIC                          NUMBER OF ENGINES = 3.

  1 W/S              113.0    0.0    0.0    0.0    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              0.270 0.0    0.0    0.0    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    452857      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
 13 FUEL WEIGHT      97270      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
 14 OP. WT. EMPTY   255587      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
 15 ZERO FUEL WT.   355587      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
 16 THRUST/ENGINE    40757      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
 17 ENGINE SCALE     0.869 0.0    0.0    0.0    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        4008.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
 19 WING SPAN        200.2    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
 20 H. TAIL AREA     927.8    0.0    0.0    0.0    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     577.9    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      11.37  0.0    0.0    0.0    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     7.38  0.0    0.0    0.0    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 3.087 0.0    0.0    0.0    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.      2.463 0.0    0.0    0.0    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.   50.19  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
 28 INVESTMNT-BIL.   1.142 0.0    0.0    0.0    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       1.161 0.0    0.0    0.0    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       1.029 0.0    0.0    0.0    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. - 0/0   35.65  0.0    0.0    0.0    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)     81222      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)     35002      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
CONSTRAINT OUTPUT
 36 TAKEOFF DST(1)    6958      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
 37 CLIMB GRAD(1)   0.1109 0.0    0.0    0.0    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)    6592      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
 39 CLIMB GRAD(2)   0.0395 0.0    0.0    0.0    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)    6054      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
 41 AP SPEED-KT(1)   135.2    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        8      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
 43 SEP( 2) - FPS        5      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
```

DOMESTIC AIRCRAFT (E^3 ENGINE)

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

                        T/C     AR    W/S     T/W

                      13.00 10.00 113.0    0.270

                 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)
                      4007.6        200.19       0.300       30.000     32.260        21.95

WING PANELS--       AREA(SQ FT)    EXP. AREA    AVG T/C    L.E. SWEEP  SFLE(SQ FT)  REF L(FT)
                      2562.0        1815.2       13.00      32.260       0.0          29.52
                      1838.8        1838.8       13.00      32.260       0.0          16.46

TOTAL WING--        AREA(SQ FT)     EFF AR      AVG T/C     CR(FT)      CT(FT)        MAC(FT)       L(FT)
                      4400.8         9.11        13.00      40.32        9.24         25.53         72.42

FUSELAGE--          LENGTH(FT)   S WET(SQ FT)   BWW(FT)   EQUIV D(FT)  SPI(SQ FT)
                      228.33       12707.9       19.58      19.58       300.95

                       BW(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
                      927.92        702.90      13.40        87.11     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
                      577.94        577.94      20.84        91.66     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)
                       11.37         7.38       19.67        7.83       967.12         2.          30.08

FUEL TANKS--        WING(CU FT)  BOX(CU FT)   FUS(CU FT)
                      4662.21      1340.69     9999.00

WETTED VOLUMES-- BODY             WING         TAILS       PODS        PYLONS       PONTOONS      TOTAL
                   53501.06       5449.88      1085.65     1892.19       0.0          0.0       61928.78
```

DOMESTIC AIRCRAFT (E^3 ENGINE)

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

                         T/C    AR    W/S    T/W

                        12.00 10.00 113.0   0.270

                         W E I G H T   S T A T E M E N T

                         WEIGHT(POUNDS)                           WEIGHT FRACTION        (PERCENT)

CROSS WEIGHT                     (    452857.)
FUEL AVAILABLE                         97270.                     FUEL                     21.48
   EXTERNAL                                0.
   INTERNAL                      97266.
ZERO FUEL WEIGHT                      355587.
PAYLOAD                               100000.                     PAYLOAD                  22.08
   PASSENGERS                    85000.
   BAGGAGE                             0.
   CARGO                         15000.
   STORES                              0.
OPERATIONAL EMPTY WEIGHT              255587.
   OPERATIONAL ITEMS             16193.                           OPERATIONAL ITEMS         4.77
   STANDARD ITEMS                 5406.
EMPTY WEIGHT                          233988.
   STRUCTURE                        135192.                       STRUCTURE                29.85
      WING                       48514.
      ROTOR                            0.
      TAIL                        5876.
      BODY                       56519.
      ALIGHTING GEAR             18781.
      ENGINE SECTION AND NACELLE  5503.
   PROPULSION                         29119.                      PROPULSION                6.43
      CRUISE ENGINES             22180.
      LIFT ENGINES                     0.
      THRUST REVERSER             4709.
      EXHAUST SYSTEM                   0.
      ENGINE CONTROL               208.
      STARTING SYSTEM              532.
      PROPELLERS                       0.
      LUBRICATING SYSTEM               0.
      FUEL SYSTEM                 1491.
      DRIVE SYSTEM (POWER TRANS)       0.
   SYSTEMS                            69677.
      FLIGHT CONTROLS             4407.
      AUXILIARY POWER PLANT       1116.
      INSTRUMENTS                  923.
      HYDRAULIC AND PNEUMATIC     2673.
      ELECTRICAL                  5967.
      AVIONICS                    2200.                           SYSTEMS                  15.39
      ARMAMENT                         0.
      FURNISHINGS AND EQUIPMENT  44293.
      AIR CONDITIONING            7682.
      ANTI-ICING                   416.
      PHOTOGRAPHIC                     0.
      LOAD AND HANDLING                0.
                                                                  TOTAL             (       100.)
```

DOMESTIC AIRCRAFT (E^3 ENGINE)

```
                                          M I S S I O N   S U M M A R Y

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

SEGMENT       INIT     INIT     INIT     SEGMT   TOTAL   SEGMT   TOTAL   SEGMT   TOTAL    EXTERN   ENGINE  EXTERN    AVG     AVG      MAX
            ALTITUDE   MACH    WEIGHT    FUEL    FUEL    DIST    DIST    TIME    TIME     STORE    THRUST  F TANK    L/D     SFC      OVER
              (FT)      NO      (LB)     (LB)    (LB)   (N MI)  (N MI)   (MIN)   (MIN)    TAB ID   TAB ID  TAB ID   RATIO  (FF/T)     PRES


TAKEOFF
  POWER 1       0.   0.0     452857.       0.      0.      0.      0.     0.0     0.0         0.  429501.      0.    0.0    0.297    0.09

  POWER 2       0.   0.0     452857.     776.    776.      0.      0.     1.3     1.3         0.  429501.      0.    0.0    0.297    0.09

CLIMB           0.   0.378   452081.    7614.   8390.    109.    109.    19.5    20.9         0.  429201.      0.   19.97   0.500    0.09

ACCEL       30000.   0.692   444467.     827.   9217.     20.    130.     2.8    23.7         0.  429201.      0.   19.16   0.557    0.09

CLIMB       30000.   0.800   443640.    2976.  12193.     85.    215.    11.0    34.7         0.  429201.      0.   19.29   0.568    0.09

CRUISE      37000.   0.800   440664.   64687.  76880.   2535.   2750.   331.5   366.2         0. -429101.      0.   19.72   0.567    0.0

DESCENT     40000.   0.800   375977.      70.  76950.     25.   2774.     3.2   369.4         0.  203301.      0.   18.41  -0.393    0.09

DECEL       30000.   0.800   375907.      21.  76971.      6.   2781.     0.9   370.2         0.  203301.      0.   17.99  -0.405    0.09

DESCENT     30000.   0.692   375885.     754.  77726.     94.   2874.    17.8   388.0         0.  203301.      0.   19.35  -1.118    0.0

CRUISE      40000.   0.800   375131.    2986.  80712.    126.   3000.    16.4   404.4         0. -429101.      0.   19.56   0.571    0.09

LOITER       1500.   0.315   372145.     510.  81222.      0.   3000.     3.0   407.4         0. -429101.      0.   19.01   0.523    0.09

RESET           0.   0.0     371635.       0.  81222.  -3000.      0.     0.0   407.4         0.        0.      0.    0.0    0.0      0.09

RESET           0.   0.0     371635.       0.  81222.      0.      0.     0.0   407.4         0.        0.      0.    0.0    0.0      0.09

CLIMB           0.   0.378   371635.    1658.  82880.     15.     15.     3.3   410.7         0.  429201.      0.   19.26   0.468    0.09

ACCEL       10000.   0.456   369977.       0.  82880.      0.     15.     0.0   410.7         0.  429201.      0.   19.27   0.477    0.09

CLIMB       10000.   0.456   369977.    3821.  86701.     62.     77.    10.6   421.3         0.  429201.      0.   19.18   0.508    0.09

CRUISE      30000.   0.725   366155.     350.  87051.     13.     90.     1.8   423.1         0. -429101.      0.   18.24   0.579    0.09

DESCENT     30000.   0.692   365806.     397.  87448.     64.    154.    11.3   434.4         0.  203301.      0.   19.15  -0.727    0.09

DECEL       10000.   0.456   365408.     -0.   87448.      0.    154.     0.0   434.4         0.  203301.      0.   19.19  -1.183    0.09

DESCENT     10000.   0.456   365408.     325.  87773.     27.    181.     5.9   440.3         0.  203301.      0.   19.19  -1.762    0.09

CRUISE      30000.   0.725   365084.     518.  88290.     19.    200.     2.7   443.0         0. -429101.      0.   18.22   0.579    0.09

CRUISE       1500.   0.378   364566.     388.  88679.      0.    200.     2.0   445.0         0. -429101.      0.   19.47   0.623    0.09

CRUISE      30000.   0.725   364177.    8587.  97266.      0.    200.    45.0   490.0         0. -429101.      0.   18.21   0.579    0.09

WTO   =  452857.1      FUEL A= 97270.3     FUEL R= 97265.6
```

DOMESTIC AIRCRAFT (E^3 ENGINE)

ALTERNATE MISSION NO. 1 SUMMARY

F**3 AIRCRAFT / 551 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)	CAB OVER PRES
TAKFOFF POWER 1	0.	0.0	360359.	0.	0.	0.	0.	0.0	0.0	0.	429501.	0.	0.0	0.297	0.09
POWER 2	0.	0.0	360359.	776.	776.	0.	0.	1.3	1.3	0.	429501.	0.	0.0	0.297	0.09
CLIMB	0.	0.379	359583.	5224.	6000.	73.	73.	13.3	14.6	0.	429201.	0.	18.96	0.498	0.09
ACCEL	30000.	0.692	354359.	504.	6504.	12.	86.	1.7	16.3	0.	429201.	0.	17.37	0.557	0.09
CLIMB	30000.	0.800	353855.	2622.	9126.	81.	167.	10.5	26.8	0.	429201.	0.	18.10	0.569	0.09
CRUISE	41000.	0.800	351233.	21813.	30939.	983.	1150.	128.6	155.4	0.	-429101.	0.	19.29	0.577	0.0
DESCENT	41000.	0.800	329420.	72.	31011.	25.	1175.	3.3	158.7	0.	203301.	0.	17.48	-0.399	0.09
DECEL	30000.	0.800	329348.	20.	31031.	6.	1181.	0.8	159.5	0.	203301.	0.	16.82	-0.406	0.09
DESCENT	30000.	0.692	329328.	709.	31740.	88.	1269.	16.7	176.2	0.	203301.	0.	18.36	-1.120	0.09
CRUISE	41000.	0.800	328619.	2821.	34561.	131.	1400.	17.1	193.3	0.	-429101.	0.	19.09	0.577	0.09
LOITER	1500.	0.290	325798.	441.	35002.	0.	1400.	3.0	196.3	0.	-429101.	0.	18.66	0.507	0.09
RESET	0.	0.0	325357.	0.	35002.	-1400.	0.	0.0	196.3	0.	0.	0.	0.0	0.0	0.09
RESET	0.	0.0	325357.	0.	35002.	0.	0.	0.0	196.3	0.	0.	0.	0.0	0.0	0.09
CLIMB	0.	0.378	325357.	1405.	36408.	13.	13.	2.8	199.1	0.	429201.	0.	18.21	0.468	0.09
ACCEL	10000.	0.456	323951.	0.	36408.	0.	13.	0.0	199.1	0.	429201.	0.	18.26	0.477	0.0
CLIMB	10000.	0.456	323951.	3146.	39553.	51.	64.	8.7	207.8	0.	429201.	0.	18.15	0.507	0.0
CRUISE	30000.	0.705	320806.	674.	40227.	26.	90.	3.8	211.6	0.	-429101.	0.	17.63	0.583	0.09
DESCENT	20000.	0.692	320131.	372.	40599.	60.	150.	10.5	222.1	0.	203301.	0.	18.11	-0.728	0.09
DECEL	10000.	0.456	319759.	0.	40599.	0.	150.	0.0	222.1	0.	203301.	0.	18.15	-1.183	0.09
DESCENT	10000.	0.456	319759.	305.	40904.	25.	175.	5.5	227.7	0.	203301.	0.	18.15	-1.763	0.0
CRUISE	20000.	0.705	319455.	633.	41537.	25.	200.	3.6	231.3	0.	-429101.	0.	17.59	0.584	0.09
CRUISE	1500.	0.379	318821.	371.	41908.	0.	200.	2.0	233.3	0.	-429101.	0.	18.51	0.646	0.09
CRUISE	20000.	0.705	318451.	7900.	49808.	0.	200.	45.0	278.3	0.	-429101.	0.	17.46	0.585	0.09

DOMESTIC AIRCRAFT (E^3 ENGINE)

COST SUMMARY

RDT AND E

	TOTAL *
DEVELOPMENT - NONRECURRING	
ENGINEERING	942.18
TOOLING	536.96
TEST ARTICLES	72.51
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	1551.65
INTEGR LOGISTICS SUPPORT	
PLANNING	10.03
TRAINING	3.41
HANDBOOKS	19.18
SSE	4.91
TOTAL ILS	37.53
TOTAL DVLPMNT-NONREC	1589.18
DEVELOPMENT - RECUR(PROTOTYPES)	
AIR VEHICLE	694.39
SPARES	179.22
TOTAL DVLPMNT-RECUR	873.61
GOVMNT DVLPMNT COST	0.0
TOTAL DVLPMNT COST	2462.80

PRODUCTION

	MATERIAL	LABOR	TOTAL PER PROD A/C**
STRUCTURE	4142.50	13208.30	17350.78
WING	1880.62	2750.84	4631.46
ROTOR	0.0	0.0	0.0
TAIL	189.10	432.73	621.83
BODY	1248.92	9176.08	10425.00
ALIGHTING GEAR	612.11	31.58	643.69
ENG SECT + NACELLE	211.76	817.07	1028.82
ENG SECTION	0.0	0.0	0.0
NACELLE	148.65	722.04	870.69
AIR INDUCTION	63.10	95.03	158.13
PROPULSION	118.05	123.24	241.30
ENGINE INSTALL	0.0	28.95	28.95
THRUST REVERSER	0.0	6.15	6.15
EXHAUST SYSTEM	0.0	0.0	0.0
ENGINE CONTROLS	3.58	5.73	9.31
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	61.16	72.37	133.53
DRIVE SYS(PWR TRN)	0.0	0.0	0.0
SYSTEMS	2733.85	7565.96	10299.82
FLIGHT CONTROLS	478.15	360.39	838.54
AUX POWER PLANT	125.23	22.78	148.01
INSTRUMENTS	66.51	64.86	131.37
HYDRAULIC + PNEUM	132.91	360.26	493.17
ELECTRICAL	410.11	1168.01	1578.12
AVIONIC INSTALL	29.45	329.67	359.11
ARMAMENT	0.0	0.0	0.0
FURN AND EQUIP	1067.18	4694.86	5762.04
AIR CONDITIONING	402.51	536.08	938.60
ANTI-ICING	21.81	29.05	50.86
PHOTOGRAPHIC	0.0	0.0	0.0
LOAD AND HANDLING	0.0	0.0	0.0
SYSTEMS INTEGR	505.12	588.96	1094.08
TOTAL COST	7499.52	21486.40	28985.92
TOTAL HRS **		769.20	769.20
ENG CHANGE ORDERS			953.37
SUSTAINING ENG COST			1786.19
PROD TOOLING COST			1559.78
QUALITY ASSURANCE			2894.43
MISCELLANEOUS ***			1000.32
TOTAL AIRFRAME COST			37179.96
ENGINE COST			4107.86
AVIONICS COST			267.19
TOTAL MANUFACTURING COST			41555.01
WARRANTY			224.13
TOTAL PRODUCTION COST			41779.12

PROCUREMENT

	PER PROD A/C**
TOTAL PRODUCTION	41779.12
INTEGR LOGISTICS SUPPORT	
PLANNING	30.65
TRAINING	10.42
TRAINERS	360.68
HANDBOOKS	40.93
FACILITIES	0.0
SSE - CFE	20.89
SSE - GFE	751.07
TOTAL ILS	1214.64
INITIAL SPARES COST	5682.21
PRODUCTION DEVELOPMENT	
ENGINEERING	317.56
TOOLING	-120.76
ENGINES	0.0
TOTAL PROD DEV	196.80
TOTAL PROCUREMENT	48872.75

* - MILLIONS OF DOLLARS

** -1000 OF DOLLARS OR HOURS PER PROD A/C

*** - INCLUDES PROD DATA, SYSTEMS ENGR AND OTHER SYSTEMS

DOMESTIC AIRCRAFT (E^3 ENGINE)

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                                              OPERATIONAL COSTS

 DIRECT OPERATIONAL COST (DOC)           INDIRECT OPERATIONAL COST (IOC)                             MISC. DATA

                 C/SM***   PERCENT                                 C/SM***   PERCENT

FLIGHT CREW      0.18986  16.35699   SYSTEM                        0.02131   2.07120   RANGE (N. MI.)                2999.96

FUEL AND OIL     0.32060  21.26840   LOCAL                         0.05896   5.72997   BLOCK SPEED (MPH)              418.21

INSURANCE        0.02007   1.72878   AIRCRAFT CONTROL              0.00159   0.15439   BLOCK TIME (HRS)                 7.17

DEPRECIATION     0.44088  37.98386   CABIN ATTENDANT               0.21039  20.44603   FLIGHT TIME (HRS)                7.17

MAINTENANCE      0.26304  22.66199   FOOD AND BEVERAGE             0.13520  13.13899   AVG STAGE LENGTH (N. MI.)     1144.00

                                     PASSENGER HANDLING            0.12880  12.51637   AVG CARGO PER FLIGHT         17413.00
TOTAL DOC        1.23440  100.000
                                     CARGO HANDLING                0.05700   5.53917   UTILIZATION (HRS PER YR)      3636.00

                                     OTHER PASSENGER EXPENSE       0.32984  32.05363   FLIGHTS PER A/C PER YEAR       506.88

                                     OTHER CARGO EXPENSE           0.00583   0.56622   FARE ($)                       268.80

                                     GENERAL + ADMINISTRATION      0.08010   7.78404

                                     TOTAL IOC                     1.02902   100.000        *** - CENTS PER SEAT N. MILE
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

                                          RATE OF RETURN ON INVESTMENT

YEAR   AVG NO    AIRCRAFT    AVERAGE    CUMULATIVE    AVERAGE    REVENUE   INTEREST   OPERATING    CASH      ROI
      AIRCRAFT    ADDED    INVESTMENT  DEPRECIATION    BOOK                EXPENSE    EXPENSE      FLOW
       DURING    DURING      DURING                  VALUE OF
        YEAR      YEAR        YEAR                    FLEET

                              $M           $M          $M          $M        $M          $M         $M      PERCENT

  1      6.3      10.0      356.76        21.41      335.36      261.70     34.25      104.05     -76.73     28.61
  2     16.3      10.0      927.58        77.06      850.52      680.42     83.57      270.54      13.32     29.01
  3     20.0       0.0     1141.64       145.56      996.08      837.44     93.16      332.97     182.82     30.00
  4     20.0       0.0     1141.64       214.06      927.58      837.44     82.20      332.97     188.30     31.62
  5     20.0       0.0     1141.64       282.56      859.09      837.44     71.24      332.97     193.78     33.51
  6     20.0       0.0     1141.64       351.05      790.59      837.44     60.28      332.97     199.26     35.72
  7     20.0       0.0     1141.64       419.55      722.09      837.44     49.32      332.97     204.74     38.35
  8     20.0       0.0     1141.64       488.05      653.59      837.44     38.36      332.97     210.22     41.53
  9     20.0       0.0     1141.64       556.55      585.09      837.44     27.40      332.97     215.70     45.45
 10     20.0       0.0     1141.64       625.05      516.59      837.44     16.44      332.97     221.18     50.42

                      AVG ROI OVER THE 10 YEAR PERIOD =  35.65 PERCENT
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DOMESTIC AIRCRAFT (E^3 ENGINE)

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                                                     OPERATIONAL COSTS

  DIRECT OPERATIONAL COST (DOC)              INDIRECT OPERATIONAL COST (IOC)                              MISC. DATA

                    C/SM***    PERCENT                                     C/SM***    PERCENT

FLIGHT CREW         0.20727   16.32909   SYSTEM                            0.02688    1.96712   RANGE (N. MI.)                1399.95

FUEL AND OIL        0.29610   17.96275   LOCAL                             0.12635    9.24694   BLOCK SPEED (MPH)              383.08

INSURANCE           0.02191    1.72583   AIRCRAFT CONTROL                  0.00340    0.24915   BLOCK TIME (HRS)                 3.65

DEPRECIATION        0.48131   37.91907   CABIN ATTENDANT                   0.22969   16.80977   FLIGHT TIME (HRS)                3.65

MAINTENANCE         0.33082   26.06329   FOOD AND BEVERAGE                 0.14760   10.80227   AVG STAGE LENGTH (N. MI.)     1144.00

                                         PASSENGER HANDLING                0.27600   20.19872   AVG CARGO PER FLIGHT         17413.00
TOTAL DOC           1.33790   100.000
                                         CARGO HANDLING                    0.12214    8.93902   UTILIZATION (HRS PER YR)      3636.00

                                         OTHER PASSENGER EXPENSE           0.32984   24.13913   FLIGHTS PER A/C PER YEAR       994.95

                                         OTHER CARGO EXPENSE               0.00583    0.42641   FARE ($)                       125.44

                                         GENERAL + ADMINISTRATION          0.09868    7.22150


                                         TOTAL IOC                         1.36641   100.000          *** - CENTS PER SEAT N. MILE

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                                               RATE OF RETURN ON INVESTMENT

YEAR     AVG NO     AIRCRAFT     AVERAGE     CUMULATIVE     AVERAGE     REVENUE     INTEREST     OPERATING     CASH       ROI
        AIRCRAFT     ADDED     INVESTMENT   DEPRECIATION     BOOK                   EXPENSE       EXPENSE      FLOW
         DURING      DURING      DURING                    VALUE OF
          YEAR        YEAR        YEAR                       FLEET

                                   $M            $M           $M          $M          $M            $M          $M       PERCENT

  1        6.3        10.0       356.76        21.41        335.36      239.72       34.25        114.73      -93.05      23.74
  2       16.3        10.0       927.58        77.06        850.52      623.26       83.57        298.29      -29.14      24.02
  3       20.0         0.0      1141.64       145.56        996.08      767.09       93.16        367.12      130.57      24.75
  4       20.0         0.0      1141.64       214.06        927.58      767.09       82.20        367.12      136.05      25.99
  5       20.0         0.0      1141.64       282.56        859.09      767.09       71.24        367.12      141.53      27.42
  6       20.0         0.0      1141.64       351.05        790.59      767.09       60.28        367.12      147.01      29.11
  7       20.0         0.0      1141.64       419.55        722.09      767.09       49.32        367.12      152.49      31.11
  8       20.0         0.0      1141.64       488.05        653.59      767.09       38.36        367.12      157.97      33.53
  9       20.0         0.0      1141.64       556.55        585.09      767.09       27.40        367.12      163.45      36.52
 10       20.0         0.0      1141.64       625.05        516.59      767.09       16.44        367.12      168.93      40.30

                          AVG ROI OVER THE 10 YEAR PERIOD =  29.06 PERCENT
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DOMESTIC AIRCRAFT (E^3 ENGINE)

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  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                    AUGUST 17 1978

AIRCRAFT MODEL --CL 1332-10                              ENGINE I.D. -- 429000                   WING QUARTER CHORD SWEEP = 30.00 DEG
I.O.C. DATE    --1985                                    SLS SCALE 1.0 =  46900                  WING TAPER RATIO = 0.300
DESIGN SPEED   --SUBSONIC                                NUMBER OF ENGINES-= 4.

  1 W/S              134.8    0.0   0.0   0.0   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              0.241    0.0   0.0   0.0   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      6500      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

 12 GROSS WEIGHT    626841      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 13 FUEL WEIGHT     241436      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 14 OP. WT. EMPTY   285405      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 15 ZERO FUEL WT.   385405      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 16 THRUST/ENGINE    37767      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 17 ENGINE SCALE     0.805    0.0   0.0   0.0   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        4650.     0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
 19 WING SPAN        215.6    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     449.3    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
 21 V. TAIL AREA     625.2    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
 22 ENG. LENGTH      10.99    0.0   0.0   0.0   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     7.11    0.0   0.0   0.0   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      229.5    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  1.568    0.0   0.0   0.0   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.      2.757    0.0   0.0   0.0   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.   55.50    0.0   0.0   0.0   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       1.290    0.0   0.0   0.0   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       1.223    0.0   0.0   0.0   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   24.11    0.0   0.0   0.0   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)     34000      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 33 MISN V2(1,1)    208632      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 34 MISN V1(2,1)     40000      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 35 MISN V2(2,1)     81386      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
CONSTRAINT OUTPUT
 36 TAKFOFF DST(1)    9459      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 37 CLIMB GRAD(1)   0.0653    0.0   0.0   0.0   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)    8819      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 39 CLIMB GRAD(2)   0.0370    0.0   0.0   0.0   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)    5919      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 41 AP SPEED-KT(1)   133.1    0.0   0.0   0.0   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        7      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 43 SEP( 2) - FPS        2      0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
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INTERCONTINENTAL AIRCRAFT (E^3 ENGINE)

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                       E**3 AIRCRAFT                / 500 PASS / 6500 N MI / M = .80 MISS

                                           T/C     AR    W/S     T/W

                                          13.00  10.00  134.8   0.241

                               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)
                      4650.2        215.04       0.300       30.000     32.260         23.65

WING PANELS--      AREA(SQ FT)     EXP. AREA     AVG T/C    L.E. SWEEP  SFLE(SQ FT)  REF L(FT)
                      2480.3        2169.6       13.00       32.260       0.0          32.06
                      2133.7        2133.7       13.00       32.260       0.0          17.73

TOTAL WING--       AREA(SQ FT)      EFF AR       AVG T/C      CR(FT)      CT(FT)      MAC(FT)        L(FT)
                      5113.9         9.09        13.00        43.61        9.95        27.57         78.01

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
                      944.26        717.11       13.54       106.52      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
                      625.16        624.15       21.68       105.96      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)
                      10.99          7.11        19.00         7.53      1799.18         4.          0.0

FUEL TANKS--       WING(CU FT)   BOX(CU FT)   FUS(CU FT)
                     5974.55       1593.37      9999.00

WETTED VOLUMES-- BODY             WING         TAILS        PODS        PYLONS       PONTOONS      TOTAL
                    51825.04       6980.34      1178.14      3388.57       0.0          0.0        63372.09
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INTERCONTINENTAL AIRCRAFT (E^3 ENGINE)

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1995 AIRCRAFT                  / 500 PASS / 6500 N MI / M = .80 MISS

                          T/C     AR    W/S     T/W

                          15.00  10.00  134.8   0.241

                        W E I G H T    S T A T E M E N T

                          WEIGHT(POUNDS)                        WEIGHT FRACTION       (PERCENT)

GROSS WEIGHT                  (   626841.)
FUEL AVAILABLE                    241436.                       FUEL                     38.52
   EXTERNAL                          0.
   INTERNAL                   241436.
ZERO FUEL WEIGHT                  385405.
PAYLOAD                           100000.                       PAYLOAD                  15.95
   PASSENGERS                 85000.
   BAGGAGE                           0.
   CARGO                      15000.
   STORES                            0.
OPERATIONAL EMPTY WEIGHT          285405.
   OPERATIONAL ITEMS          16222.                            OPERATIONAL ITEMS         3.99
   STANDARD ITEMS              8785.
EMPTY WEIGHT                      260398.
   STRUCTURE                    151947.                         STRUCTURE                24.24
      WING                    59651.
      ROTOR                          0.
      TAIL                     6111.
      BODY                    55119.
      ALIGHTING GEAR          24363.
      ENGINE SECTION AND NACELLE  6704.
   PROPULSION                    35641.                         PROPULSION                5.69
      CRUISE ENGINES          26990.
      LIFT ENGINES                   0.
      THRUST REVERSER          5964.
      EXHAUST SYSTEM                 0.
      ENGINE CONTROL            257.
      STARTING SYSTEM           709.
      PROPELLERS                     0.
      LUBRICATING SYSTEM             0.
      FUEL SYSTEM              1722.
      DRIVE SYSTEM (POWER TRANS)     0.
   SYSTEMS                       72838.
      FLIGHT CONTROLS          4852.
      AUXILIARY POWER PLANT    1115.
      INSTRUMENTS              1137.
      HYDRAULIC AND PNEUMATIC  3592.
      ELECTRICAL               5815.
      AVIONICS                 2900.                            SYSTEMS                  11.62
      ARMAMENT                       0.
      FURNISHINGS AND EQUIPMENT 44293.
      AIR CONDITIONING         7682.
      ANTI-ICING                427.
      PHOTOGRAPHIC                   0.
      LOAD AND HANDLING              0.
                                                                TOTAL              (     100.)
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INTERCONTINENTAL AIRCRAFT (E^3 ENGINE)

MISSION SUMMARY

[illegible] 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	626841.	0.	0.	0.	0.	0.0	0.0	0.	429501.	0.	0.0	0.297	0.0
POWER 2	0.	0.0	626841.	959.	959.	0.	0.	1.3	1.3	0.	429501.	0.	0.0	0.297	0.0
CLIMB	0.	0.379	625882.	11913.	12872.	141.	141.	25.1	26.4	0.	429201.	0.	20.10	0.501	0.0
ACCEL	30000.	0.692	613969.	1323.	14195.	26.	167.	3.5	29.9	0.	429201.	0.	20.42	0.557	0.0
CLIMB	30000.	0.800	612645.	2278.	16474.	50.	217.	6.4	36.4	0.	429201.	0.	20.52	0.571	0.0
CRUISE	34000.	0.800	610367.	187086.	203560.	6033.	6250.	787.5	823.9	0.	-429101.	0.	20.39	0.568	0.0
DESCENT	43000.	0.800	423281.	84.	203644.	25.	6275.	3.2	827.1	0.	203301.	0.	18.80	-0.393	0.0
DECEL	35000.	0.800	423197.	27.	203671.	6.	6281.	0.9	827.9	0.	203301.	0.	18.38	-0.405	0.0
DESCENT	35000.	0.692	423170.	941.	204614.	94.	6375.	17.9	845.8	0.	203301.	0.	19.80	-1.120	0.0
CRUISE	40000.	0.630	422229.	3288.	207902.	125.	6500.	16.3	862.1	0.	-429101.	0.	20.11	0.578	0.0
LOITER	1500.	0.400	418939.	730.	208632.	0.	6500.	3.0	865.1	0.	-429101.	0.	19.41	0.677	0.0
RESET	0.	0.0	418209.	0.	208632.	-6500.	0.	0.0	865.1	0.	0.	0.	0.0	0.0	0.0
RESET	0.	0.0	418209.	0.	208632.	0.	0.	0.0	865.1	0.	0.	0.	0.0	0.0	0.0
CRUISE	41000.	0.800	418209.	17103.	225735.	0.	0.	86.5	951.6	0.	-429101.	0.	20.03	0.580	0.0
TAKEOFF POWER 1	0.	0.0	401106.	0.	225735.	0.	0.	0.0	951.6	0.	429501.	0.	0.0	0.297	0.0
POWER 2	0.	0.0	401106.	959.	226694.	0.	0.	1.3	953.0	0.	429501.	0.	0.0	0.297	0.0
CLIMB	0.	0.378	400147.	1649.	228343.	12.	12.	2.7	955.7	0.	429201.	0.	19.35	0.469	0.0
ACCEL	10000.	0.456	398498.	48.	228391.	0.	12.	0.0	955.7	0.	429201.	0.	19.40	0.477	0.0
CLIMB	10000.	0.456	398450.	3701.	232083.	49.	61.	8.3	964.0	0.	429201.	0.	19.29	0.508	0.0
CRUISE	30000.	0.730	394749.	891.	232974.	29.	90.	4.1	968.1	0.	-429101.	0.	18.15	0.602	0.0
DESCENT	30000.	0.692	393858.	484.	233458.	63.	153.	11.1	979.2	0.	203301.	0.	19.26	-0.728	0.0
DECEL	10000.	0.456	393374.	0.	233458.	0.	153.	0.0	979.2	0.	203301.	0.	19.30	-1.183	0.0
DESCENT	10000.	0.456	393374.	398.	233856.	27.	180.	5.9	985.1	0.	203301.	0.	19.30	-1.763	0.0
CRUISE	36000.	0.733	392976.	615.	234471.	20.	200.	2.8	987.9	0.	-429101.	0.	18.11	0.602	0.0
CRUISE	1500.	0.378	392361.	6682.	241153.	0.	200.	30.0	1017.9	0.	-429101.	0.	19.56	0.667	0.0

INTERCONTINENTAL AIRCRAFT (E^3 ENGINE)

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                                    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   / 3000 N MI / M = .80 MISS

SEGMENT          INIT    INIT     INIT     SEGMT   TOTAL   SEGMT    TOTAL   SEGMT  TOTAL    EXTERN   ENGINE   EXTERN   AVG     AVG     MAX
               ALTITUDE  MACH     WEIGHT   FUEL    FUEL    DIST     DIST    TIME   TIME     STORE    THRUST   F TANK   L/D     SFC     OVER
                 (FT)    NO       (LB)     (LB)    (LB)    (N MI)  (N MI)  (MIN)  (MIN)    TAB ID   TAB ID   TAB ID   RATIO   (FF/T)  PRES


TAKEOFF
  POWER 1          0.   0.0    444199.       0.       0.      0.      0.    0.0    0.0       0.   429501.      0.    0.0    0.297   0.0

  POWER 2          0.   0.0    444199.     959.     959.      0.      0.    1.3    1.3       0.   429501.      0.    0.0    0.297   0.0

CLIMB              0.   0.378  443239.    6208.    7167.     70.     70.   12.7   14.1       0.   429201.      0.   20.03   0.498   0.0

ACCEL          30000.   0.692  437032.     557.    7720.     11.     81.    1.5   15.6       0.   429201.      0.   18.56   0.557   0.0

CLIMB          30000.   0.800  436475.    2764.   10488.     69.    150.    8.9   24.5       0.   429201.      0.   19.19   0.569   0.0

CRUISE         40000.   0.800  433710.   66136.   76624.   2600.   2750.  340.0  364.5       0.  -429101.      0.   19.96   0.583   0.0

DESCENT        42000.   0.800  367574.      97.   76722.     28.   2778.    3.7  368.1       0.   203301.      0.   17.92  -0.404   0.0

DECEL          30000.   0.800  367477.      24.   76746.      6.   2784.    0.8  368.9       0.   203301.      0.   17.08  -0.406   0.0

DESCENT        30000.   0.692  367453.     880.   77626.     88.   2872.   16.7  385.6       0.   203301.      0.   18.70  -1.121   0.0

CRUISE         41000.   0.800  366573.    6060.   83686.    128.   3000.   16.7  402.4       0.  -429101.      0.   19.46   0.585   0.0

LOITER         15000.   0.400  360513.     700.   84386.      0.   3000.    3.0  405.4       0.  -429101.      0.   18.22   0.703   0.0

RESET              0.   0.0    359813.       0.   84386.  -3000.      0.    0.0  405.4       0.        0.      0.    0.0    0.0     0.0

RESET              0.   0.0    359813.       0.   84386.      0.      0.    0.0  405.4       0.        0.      0.    0.0    0.0     0.0

CRUISE         41000.   0.800  359813.    4343.   88729.      0.      0.   40.5  445.9       0.  -429101.      0.   19.35   0.586   0.0

TAKEOFF
  POWER 1          0.   0.0    355469.       0.   88729.      0.      0.    0.0  445.9       0.   429501.      0.    0.0    0.297   0.0

  POWER 2          0.   0.0    355469.     959.   89688.      0.      0.    1.3  447.3       0.   429501.      0.    0.0    0.297   0.0

CLIMB              0.   0.378  354510.    1463.   91151.     10.     10.    2.4  449.6       0.   429201.      0.   18.31   0.468   0.0

ACCEL          10000.   0.456  353047.       0.   91151.      0.     10.    0.0  449.6       0.   429201.      0.   18.39   0.477   0.0

CLIMB          10000.   0.456  353047.    3145.   94296.     41.     52.    7.0  456.7       0.   429201.      0.   18.27   0.507   0.0

CRUISE         30000.   0.705  349902.    1109.   95405.     38.     90.    5.5  462.2       0.  -429101.      0.   17.74   0.612   0.0

DESCENT        30000.   0.692  348793.     454.   95859.     59.    149.   10.4  472.6       0.   203301.      0.   18.23  -0.728   0.0

DECEL          10000.   0.456  348339.       0.   95859.      0.    149.    0.0  472.6       0.   203301.      0.   18.27  -1.183   0.0

DESCENT        10000.   0.456  348339.     374.   96233.     25.    174.    5.5  478.1       0.   203301.      0.   18.28  -1.763   0.0

CRUISE         30000.   0.705  347965.     750.   96983.     26.    200.    3.7  481.8       0.  -429101.      0.   17.70   0.612   0.0

CRUISE         15000.   0.373  347215. [illegible] [illegible]  0.   200.   30.0  511.8       0.  -429101.      0.   18.58   0.690   0.0
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INTERCONTINENTAL AIRCRAFT (E^3 ENGINE)

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                                                    C O S T   S U M M A R Y

            RDT AND E                                   PRODUCTION                                              PROCUREMENT
                                                                                 TOTAL PER
                            TOTAL *                     MATERIAL       LABOR     PROD A/C**                          PER PROD A/C**

DEVELOPMENT - NONRECURRING              STRUCTURE        4790.13    13946.31   18736.43      TOTAL PRODUCTION       46117.74
                                        WING             2309.19     3361.71    5670.90
 ENGINEERING               1104.32      ROTOR               0.0         0.0        0.0       INTEGR LOGISTICS SUPPORT
 TOOLING                    582.84      TAIL              196.36      447.23     643.59       PLANNING                 33.40
 TEST ARTICLES               77.09      BODY             1215.91     8891.26   10107.18
 DATA                         0.0       ALIGHTING GEAR    792.70       40.70     833.40       TRAINING                 11.38
 SYSTEMS ENG/MNGMT            0.0       ENG SECT + NACELLE 275.96    1205.40    1481.36
 CRUISE ENGINE                0.0        ENG SECTION        0.0         0.0        0.0        TRAINERS                360.68
 LIFT ENGINE                  0.0        NACELLE          237.39     1147.60    1384.99
 FAN                          0.0        AIR INDUCTION     38.57       57.81      96.37       HANDBOOKS                50.16
 AVIONICS                     0.0
 OTHER SYSTEMS                0.0         PROPULSION      145.94      146.17     292.11       FACILITIES                0.0
 FACILITIES                   0.0       ENGINE INSTALL      0.0        35.00      35.00
  TOTAL AIR VEHICLE        1764.24      THRUST REVERSER     0.0         7.73       7.73       SSE - CFE                23.06
                                        EXHAUST SYSTEM      0.0         0.0        0.0
INTEGR LOGISTICS SUPPORT                ENGINE CONTROLS     4.42        7.04      11.45       SSE - GFE               751.07
 PLANNING                    11.23      STARTING SYSTEM    70.98       13.31      84.29           TOTAL ILS          1229.03
 TRAINING                     3.82      PROPELLER INSTALL   0.0         0.0        0.0
 HANDBOOKS                   27.23      LUBRICATING SYSTEM  0.0         0.0        0.0
 SSE                          5.50      FUEL SYSTEM        70.54       83.08     153.62      INITIAL SPARES COST     6385.54
         TOTAL ILS           47.78      DRIVE SYS(PWR TRN)  0.0         0.0        0.0
                                                                                             PRODUCTION DEVELOPMENT
TOTAL DVLPMNT-NONREC       1812.02        SYSTEMS        2906.69     7962.44   10869.13       ENGINEERING             350.19
                                        FLIGHT CONTROLS   525.64      394.31     919.96
                                        AUX POWER PLANT   125.03       22.64     147.68       TOOLING                -159.85
DEVELOPMENT - RECUR(PROTOTYPES)         INSTRUMENTS        81.42       79.02     160.45
                                        HYDRAULIC + PNEUM 178.35      481.13     659.48       ENGINES                   0.0
 AIR VEHICLE                750.38      ELECTRICAL        467.71     1325.75    1793.46         TOTAL PROD DEV        190.34
 SPARES                     194.23      AVIONIC INSTALL    38.75      431.83     470.59
                                        ARMAMENT            0.0         0.0        0.0
TOTAL DVLPMNT-RECUR         944.61      FURN AND EQUIP   1265.52     4465.39    5730.91
                                        AIR CONDITIONING  401.89      532.72     934.61      TOTAL PROCUREMENT      53923.45
GOVMNT DVLPMNT COST           0.0       ANTI-ICING         22.37       29.65      52.01
                                        PHOTOGRAPHIC        0.0         0.0        0.0
                                        LOAD AND HANDLING   0.0         0.0        0.0

TOTAL DVLPMNT COST         2756.63      SYSTEMS INTEGR    561.26      651.32    1212.58

                                            TOTAL COST   8404.00    22706.19   31110.19
                                            TOTAL HRS **               812.87     812.87

                                        ENG CHANGE ORDERS                      1021.86
                                        SUSTAINING ENG COST                    2005.61
                                        PROD TOOLING COST                      1648.32
                                        QUALITY ASSURANCE                      3058.75           * - MILLIONS OF DOLLARS
                                        MISCELLANEOUS ***                      1057.11
                                                TOTAL AIRFRAME COST           39899.82          ** -1000 OF DOLLARS OR
                                                                                                     HOURS PER PROD A/C
                                        ENGINE COST                            5224.60
                                        AVIONICS COST                           751.60         *** - INCLUDES PROD DATA,
                                                TOTAL MANUFACTURING COST      45875.41                 SYSTEMS ENGR AND
                                                                                                       OTHER SYSTEMS
                                        WARRANTY                                242.30

                                                TOTAL PRODUCTION COST         46117.74
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INTERCONTINENTAL AIRCRAFT (E^3 ENGINE)

OPERATIONAL COSTS

DIRECT OPERATIONAL COST (DOC)

	C/SM***	PERCENT
FLIGHT CREW	0.21679	16.81765
FUEL AND OIL	0.43100	28.74396
INSURANCE	0.01859	1.44175
DEPRECIATION	0.40916	31.72406
MAINTENANCE	0.27431	21.27258
TOTAL DOC	1.34990	100.000

INDIRECT OPERATIONAL COST (IOC)

	C/SM***	PERCENT
SYSTEM	0.02323	1.89938
LOCAL	0.09343	7.64021
AIRCRAFT CONTROL	0.00208	0.17039
CABIN ATTENDANT	0.25277	20.67020
FOOD AND BEVERAGE	0.07891	6.45245
PASSENGER HANDLING	0.13403	10.96017
CARGO HANDLING	0.04262	3.48555
OTHER PASSENGER EXPENSE	0.48400	39.57838
OTHER CARGO EXPENSE	0.00595	0.48663
GENERAL + ADMINISTRATION	0.10586	8.65665
TOTAL IOC	1.22289	100.000

MISC. DATA

RANGE (N. MI.)	6500.00
BLOCK SPEED (MPH)	439.13
BLOCK TIME (HRS)	14.80
FLIGHT TIME (HRS)	14.80
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	279.22
FARE ($)	504.46

*** - 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	394.45	23.67	370.78	253.58	37.87	142.49	-116.44	20.09
2	16.3	10.0	1025.57	85.23	940.37	659.32	92.40	370.48	-67.45	20.27
3	20.0	0.0	1262.24	160.94	1101.31	811.47	103.00	455.98	101.00	20.82
4	20.0	0.0	1262.24	236.67	1025.57	811.47	90.88	455.98	107.06	21.76
5	20.0	0.0	1262.24	312.41	949.84	811.47	78.76	455.98	113.12	22.86
6	20.0	0.0	1262.24	388.14	874.10	811.47	66.65	455.98	119.18	24.15
7	20.0	0.0	1262.24	463.87	798.37	811.47	54.53	455.98	125.23	25.68
8	20.0	0.0	1262.24	539.61	722.64	811.47	42.41	455.98	131.29	27.53
9	20.0	0.0	1262.24	615.34	646.90	811.47	30.29	455.98	137.35	29.82
10	20.0	0.0	1262.24	691.08	571.17	811.47	18.18	455.98	143.41	32.71

AVG ROI OVER THE 10 YEAR PERIOD = 24.11 PERCENT

INTERCONTINENTAL AIRCRAFT (E^3 ENGINE)

OPERATIONAL COSTS

DIRECT OPERATIONAL COST (DOC)

	C/SM***	PERCENT
FLIGHT CREW	0.22657	17.44775
FUEL AND OIL	0.36439	24.12915
INSURANCE	0.01943	1.49627
DEPRECIATION	0.42761	32.92953
MAINTENANCE	0.31162	23.99727
TOTAL DOC	1.34960	100.000

INDIRECT OPERATIONAL COST (IOC)

	C/SM***	PERCENT
SYSTEM	0.02644	1.67800
LOCAL	0.20243	12.84574
AIRCRAFT CONTROL	0.00451	0.28648
CABIN ATTENDANT	0.26417	16.76337
FOOD AND BEVERAGE	0.08246	5.23288
PASSENGER HANDLING	0.29040	18.42770
CARGO HANDLING	0.09235	5.86037
OTHER PASSENGER EXPENSE	0.48400	30.71284
OTHER CARGO EXPENSE	0.00595	0.37762
GENERAL + ADMINISTRATION	0.12315	7.81496
TOTAL IOC	1.57589	100.000

MISC. DATA

RANGE (N. MI.)	3000.00
BLOCK SPEED (MPH)	420.18
BLOCK TIME (HRS)	7.14
FLIGHT TIME (HRS)	7.14
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	578.87
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	394.45	23.67	370.78	242.64	37.87	155.99	-128.66	16.79
2	16.3	10.0	1025.57	85.20	940.37	630.87	92.40	405.58	-99.22	16.89
3	20.0	0.0	1262.24	160.94	1101.31	776.46	103.00	499.18	61.89	17.26
4	20.0	0.0	1262.24	236.67	1025.57	776.46	90.88	499.18	67.95	17.95
5	20.0	0.0	1262.24	312.41	949.84	776.46	78.76	499.18	74.01	18.74
6	20.0	0.0	1262.24	388.14	874.10	776.46	66.65	499.18	80.07	19.67
7	20.0	0.0	1262.24	463.87	798.37	776.46	54.53	499.18	86.13	20.78
8	20.0	0.0	1262.24	539.61	722.64	776.46	42.41	499.18	92.19	22.12
9	20.0	0.0	1262.24	615.34	646.90	776.46	30.29	499.18	98.25	23.77
10	20.0	0.0	1262.24	691.08	571.17	776.46	18.18	499.18	104.31	25.86

AVG ROI OVER THE 10 YEAR PERIOD = 19.65 PERCENT

INTERCONTINENTAL AIRCRAFT (E^3 ENGINE)

SUPPLEMENT B

DIRECT OPERATING COST (COD) 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 + Avonics + 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 + 0.27 x T) x LR x FT x ELH

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

APPENDIX C

Appendix C is a reproduction of report ACEE-15-FR-9735 A supplied by Douglas Aircraft Company as their contribution to aircraft integration. The format and printing have been altered to coordinate with this publication. A preliminary report was the instrument used by General Eletric Company for aircraft integration analysis. The preliminary report extended through Section 4.3, the final complete report is presented here.

SEPTEMBER 1979

FINAL REPORT ON STUDY TRANSPORTS
POWERED BY G.E. ENERGY EFFICIENT ENGINES

GENERAL ELECTRIC PURCHASE ORDER 200-4XX-14N44386

DOUGLAS AIRCRAFT COMPANY
MCDONNELL DOUGLAS CORPORATION

FINAL REPORT ON
STUDY TRANSPORTS POWERED
BY G.E. ENERGY EFFICIENT ENGINES

This final report summarizes work done under General Electric Purchase Order 200-4XX-14N44386 as part of General Electric's prime contract Energy Efficient Engine (E^3) Component Development and Integration Program with the NASA Lewis Research Center.

This report completes submittal of final report inputs for Task 1, 2 and 3 in compliance with the Task 4 Reporting requirements.

PREFACE

This report presents results of a study conducted by the Douglas Aircraft Company as a subcontractor to General Electric to investigate applications of engines based on use of NASA supported Energy Efficient Engine (E^3) Technology. This work was done under Purchase Order 200-4XX-14N44386 as a part of the General Electric prime contract from the NASA Lewis Research Center on Energy Efficient Engine Component Development and Integration program.

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.

The study results presented herein were conducted from May 1978 through August 1979.

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1.0 INTRODUCTION

This study is based on an airplane which is an advanced technology derivative of the DC-10 as illustrated in Figure C-1. This selection was arrived at from a solicitation of the views of Douglas marketing and engineering personnel on a logical and likely new airframe.

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 version incorporating a 65-foot fuselage stretch with a wing area compatible with an international version was configured. This aircraft growth would follow an initial stretch in the early 1980's as indicated in Figure C-2.

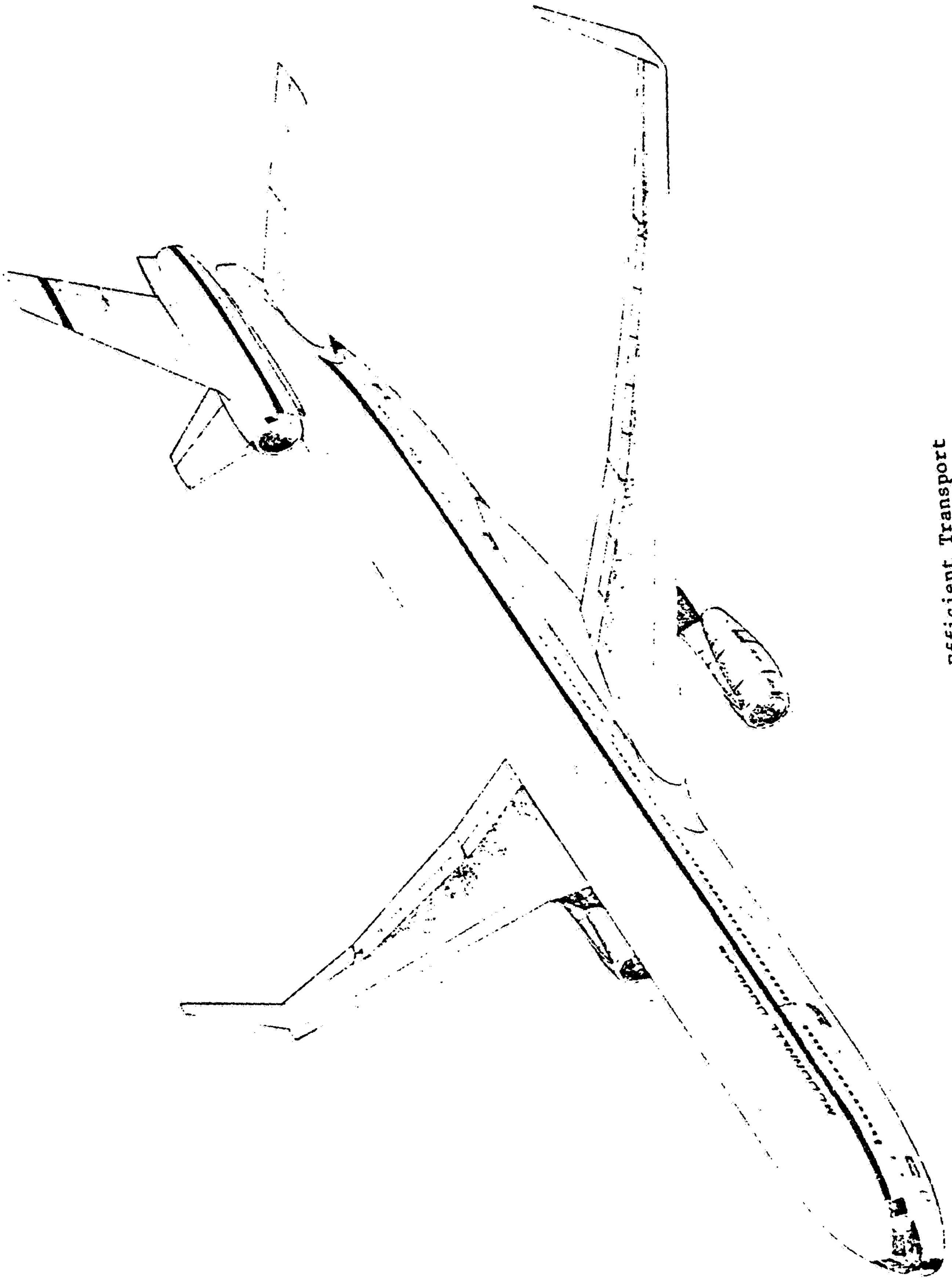

Figure C-1 Energy-Efficient Transport

- COMBINE COST-EFFECTIVE ADVANCED TECHNOLOGY AND DC-10 COMMONALITY TO PRODUCE AIRCRAFT WITH BEST OPERATING ECONOMICS
- SELECT COMMON WING SIZE TO PROVIDE BOTH DOMESTIC TRANSCONTINENTAL RANGE AND INTERCONTINENTAL RANGE VERSIONS TO CAPTURE LARGE MARKET BASE

Figure C-2 Aircraft Design Concept

2.0 ADVANCED TECHNOLOGY FEATURES

The selection of advanced technology features was based on results from recent studies and on-going technology development programs including the NASA Aircraft Energy Efficiency program activities on Composites and the Energy Efficient Transport.

2.1 AERODYNAMICS

Advancements in aerodynamics provide a major improvement in aircraft efficiency. Figure C-3 lists the major elements.

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 cross 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 Douglas/EET wind tunnel programs have substantiated that these advanced airfoils will provide the desired characteristics for a high aspect ratio wing application.

WING

- SUPERCRITICAL AIRFOILS - REDUCED WEIGHT AND DRAG, INCREASED LIFT CAPABILITY
- HIGH ASPECT RATIO - REDUCED INDUCED DRAG DECREASES BOTH FUEL BURNED AND THRUST REQUIRED
- WINGLETS - REDUCED INDUCED DRAG DECREASES FUEL BURNED WHILE MINIMIZING SPAN AND WEIGHT INCREASE

HIGH-LIFT SYSTEM

- VARIABLE CAMBER KRUEGER - HIGH MAXIMUM LIFT CAPABILITY WITH MODEST FLAP DEFLECTIONS
- TWO-SEGMENT FLAP - HIGH LIFT-TO DRAG WITH LIMITED FLAP DEFLECTION MINIMIZES THRUST REQUIRED AND APPROACH NOISE

Figure C-3 Advanced Features - Aerodynamics

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 recently completed Douglas/EET task generated an optimized high aspect ratio supercritical wing which considered the winglet as part of the original design. 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 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 Keueger leading edge. 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 progress in across the span.

This high-lift system design will provide excellent C_{Lmax} capability and very high lift-to-drag ratios allowing the use of 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. An extensive wind tunnel program which as part of the Douglas/EET effort was recently completed using a full span high aspect ratio supercritical wing with several combinations of high lift system.

2.2 MATERIALS

Material improvements expected are shown in Figure C-4. Improvements in metal alloys and structure fabrication techniques as well as the major use of advanced composites are visualized. The application of advanced composites to primary structure is dependent on major technology development sponsored by NASA.

COMPOSITES

- WING AND EMPENNAGE PRIMARY AND SECONDARY STRUCTURE
- CONTROL SURFACES
- FLOOR BEAMS
- LANDING GEAR DOORS
- FAIRINGS
- ENGINE NACELLES
- CARBON BRAKES

LESS WEIGHT

METALS

- BONDED STRUCTURE
- IMPROVED ALLOYS

LESS WEIGHT

Figure C-4 Advanced Features - Materials

2.2.1 Advanced Composites

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 structues 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.

2.2.2 Metals

Improved alloys are expected as well as the use of bonded structures resulting from the PABST program presently being conducted under Air Force sponsorship.

The forward fuselage section of a C-15 airframe has been fabricated using bonded structure and testing has been underway.

2.3 SYSTEMS

2.3.1 Longitudinal 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 aerodnamic 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 feel for control column motions and forces required for manuevering 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. This study was expanded in 1978 to include the effect of control system characteristics including failure cases and transient phenomena.

2.3.2 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 manuever 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 is 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 Lockhead 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 pursured in combination with the ACEE program.

2.3.3 Other

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

- Digital avionics - reduced weight and improved reliability and capability.
- Flight performance management - reduced aircraft operational fuel consumption.
- Air conditioning - reduced engine bleed requirements.
- APU - reduced weight and fuel consumption.
- 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 to be utilized in the E^3 aircraft.

3.0 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 aircraft include the selection of a common wing size to satisfy the needs of both a domestic transcontinental and intercontinental range version. The requirements shown on Table C-I are based to a great extent on the DC-10-10 transcontinental and the DC-10-30 intercontinental range aircraft. Design cruise Mach number was reduced from the DC-10 levels to reduce fuel consumption. The domestic aircraft is shown in Figure C-5. An intercontinental range version would require additional thrust and a four-wheel centerline main landing gear assembly to accommodate the higher gross weight.

3.1 AIRCRAFT CHARACTERISTICS

The aircraft characteristics are shown in Table C-II compared to those which would result from the use of scaled CF6 engines. The aircraft incorporates a DC-10 fuselage stretched 65 feet, a new high aspect ratio wing with supercritical 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. 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 DC-10-30. The flight crew consists of a three man cockpit crew and 15 cabin attendants.

The wing area was set by the requirement for a 31,000 foot initial cruise altitude capability for an intercontinental range version. 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 tail utilize composites in primary and secondary structures to minimize weight.

The scaled thrust size of the G.E. study engine was set by the thrust limited initial cruise altitude requirement of 33,000 ft. The resulting takeoff field length is 7400 ft. compared to the requirement of not to exceed 8000 ft., indicating a reasonable match between airframe and engine characteristics.

3.2 DIRECT OPERATING COST

The direct operating cost for the advanced airplane was determined using engine costs supplied by G.E. For comparative purposes, the direct operating cost was also determined for the same airframe technology but

Table C-I. 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

Table C-II. GE E^3 Aircraft Characteristics

Domestic Transcontinental Range

Engine	Scaled CF6-50C	Advanced
Mixed Class Seats	458	458
Design Range (Nautical Miles)	3,000	3,000
Engine Thrust Size (LB/Engine)	44,630	41,360
Adjusted Wing Area (SQ FT)	5,190	4,680
Weights:		
Maximum Takeoff (LB)	539,000	499,000
Maximum Landing (LB)	475,000	459,000
Operator's Empty (LB)	303,240	289,950
Performance:		
Cruise Mach Number	0.80	0.80
Takeoff Field Length, MTOGW, SL 84°F (FT)	6,900	7,400
Approach Speeds, Passengers, Bags, Reserves (KEAS)	120	124
Thrust Limited Initial Cruise Altitude (FT)	33,000	33,000
Buffet Limited Initial Cruise Altitude (FT)	37,100	36,500
Fuel Burned At Design Range (LB) (100% Passenger Load Factor)	123,060	98,650
Typical Stage Length (Nautical Miles)	2,000	1,000
Fuel Burned At Typical Range (LB)	39,940	32,630

(60% Passenger } Load Factors)
(30% Cargo }

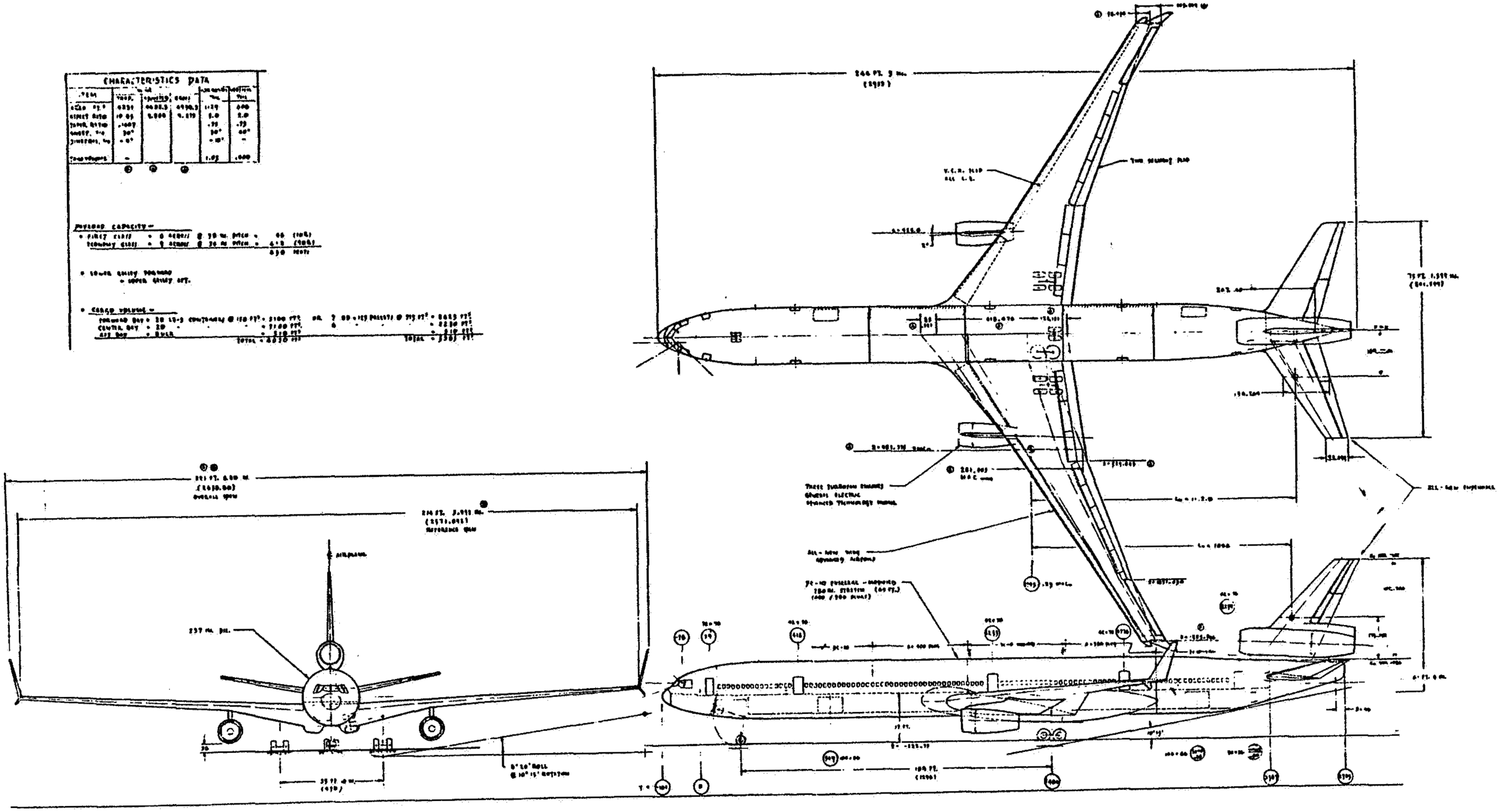

Figure C-5. Domestic Aircraft.

scaled CF6 engines. The comparison is shown in Table C-III and the DOC calculation method in Table C-IV.

3.3 DRAG

The airplane parasite and induced drag are shown in Table C-V. Nacelle drag is included in the engine data. The compressibility drag increment is shown in Figure C-6. The takeoff and landing drag polars are presented in Figure C-7.

3.4 WEIGHT

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

3.5 SENSITIVITY FACTORS

Sensitivity factors were generated and are shown in Table C-VII. 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.

3.6 NOISE

The airframe or non-propulsive noise with flight conditions and engine power settings at the FAR noise measuring points are shown in Table C-VIII. Sound pressure levels by frequency band and direction at these conditions are shown in Table C-IX.

3.7 SECONDARY POWER

The secondary power requirements have been estimated and the mechanical power requirements are shown in Table C-X. 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 C-8.

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 bleed with a temperature greater than 500°F plus 5 pounds/second

Table C-III. Direct Operating Costs Transcontinental Range Domestic Trijets

	Scaled CF6-50C		Advanced Engine	
Aircraft Study Price (1978 $M)	46.43		47.44	
Stage Length (n mi)	1000	3000	1000	3000
Block Fuel (lb)	38300	123060	32630	98650
Block Time (hr)	2.54	6.84	2.55	6.87
DOC (1978 $/trip)				
Cockpit Crew	1126	3032	1100	2962
Depreciation	2385	7154	2455	7366
Insurance	290	871	297	890
Landing Fees	404	404	374	374
Airframe Maintenance	802	1520	786	1486
Engine Maintenance	582	1635	426	1199
Fuel	2980	9184	2435	7362
TOTAL DOC	8569	23800	7873	21639
Relative DOC	0	0	-8.1%	-9.1%

Table C-IV. DAC DOC Method For GE E^3 Study

Direct operating costs for the GE domestic E^3 aircraft are in 1978 dollars and consist of the following components:

Cockpit Crew (3 man crew)

$$\$/\text{flight} = t_b \times (280 + 30.3 \times \frac{TOW}{100000})$$

where: t_b = block time (hours)

TOW = maximum takeoff weight (lb)

Airframe Depreciation

$$\$/\text{flight} = (1-R) \times C_A \times (1 + S_A) \times D/D_A/P$$

where: R = residual value ratio = 0.10

C_A = aircraft price less bare engine price (1978 \$)

S_A = airframe spares ratio = 0.08

D = trip distance (nautical miles)

D_A = depreciation period = 16 years

P = annual productivity = 1200000 nautical miles/year

Engine Depreciation

$$\$/\text{flight} = (1-R) \times C_e \times N_e \times (1 + S_E) \times D/D_A/P$$

where: C_e = price of one bare engine (1978 \$)

N_e = number of engines = 3

S_e = engine spares ration = 0.25

Insurance

$$\$/\text{flight} = I \times (C_A + N_e \times C_e) \times D/P$$

where: I = annual insurance rate = 0.0075

Landing Fees

$$\$/\text{flight} = L \times TOW/1000$$

where: L = landing fee rate per 1000 lb of maximum takeoff weight = 0.75 \$/1000 lb

Table C-IV. DAC DOC Method For GE E^3 Study (Concluded).

Fuel

$/flight = $C_f \times F_B / 6.7$

where: C_f = fuel price = 0.50 $/gallon

F_B = block fuel

Airframe Maintenance

$/flight = $t_F \times [162 \times 334 \times 10^{-6} \times (W_A - 240000.)]$

$+ 400 + 40 \times 10^{-5} \times (W_A - 240000.)$

where: t_F = flight time (hr) = $t_B - 0.167$

W_A = airframe weight (lb)

= manufacturer's empty weight - bare engine weight

Engine Maintenance

$/flight = $223 \times t_F \times \sqrt{E_x}$ for advanced engine

= $260 \times t_F \times \sqrt{E_x}$ for CF6-50C

where: E_x = engine thrust scale factor

Table C-V. Aircraft Drag

Aircraft With Advanced Engines

Reference Area:	Trapezoidal Wing Area = 4,231 ft^2
Parasite Drag:	$f = 67.86\ ft^2$ (excludes nacelles)
Induced Drag:	$AR_{trapezoidal} = 10.85$ $e = 0.953$ (includes winglet effects)

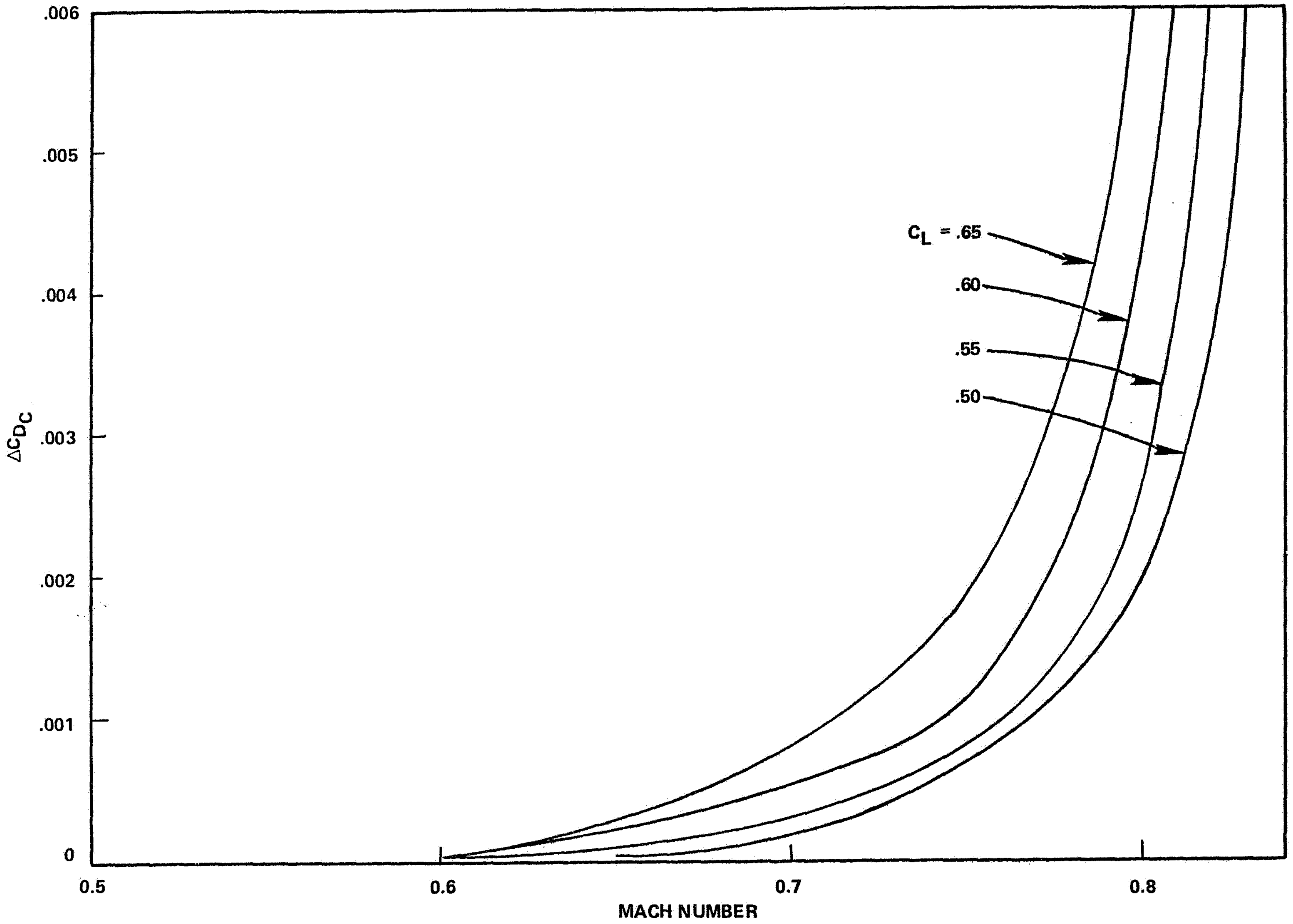

Figure C-6. Compressibility Drag Rise Characteristics

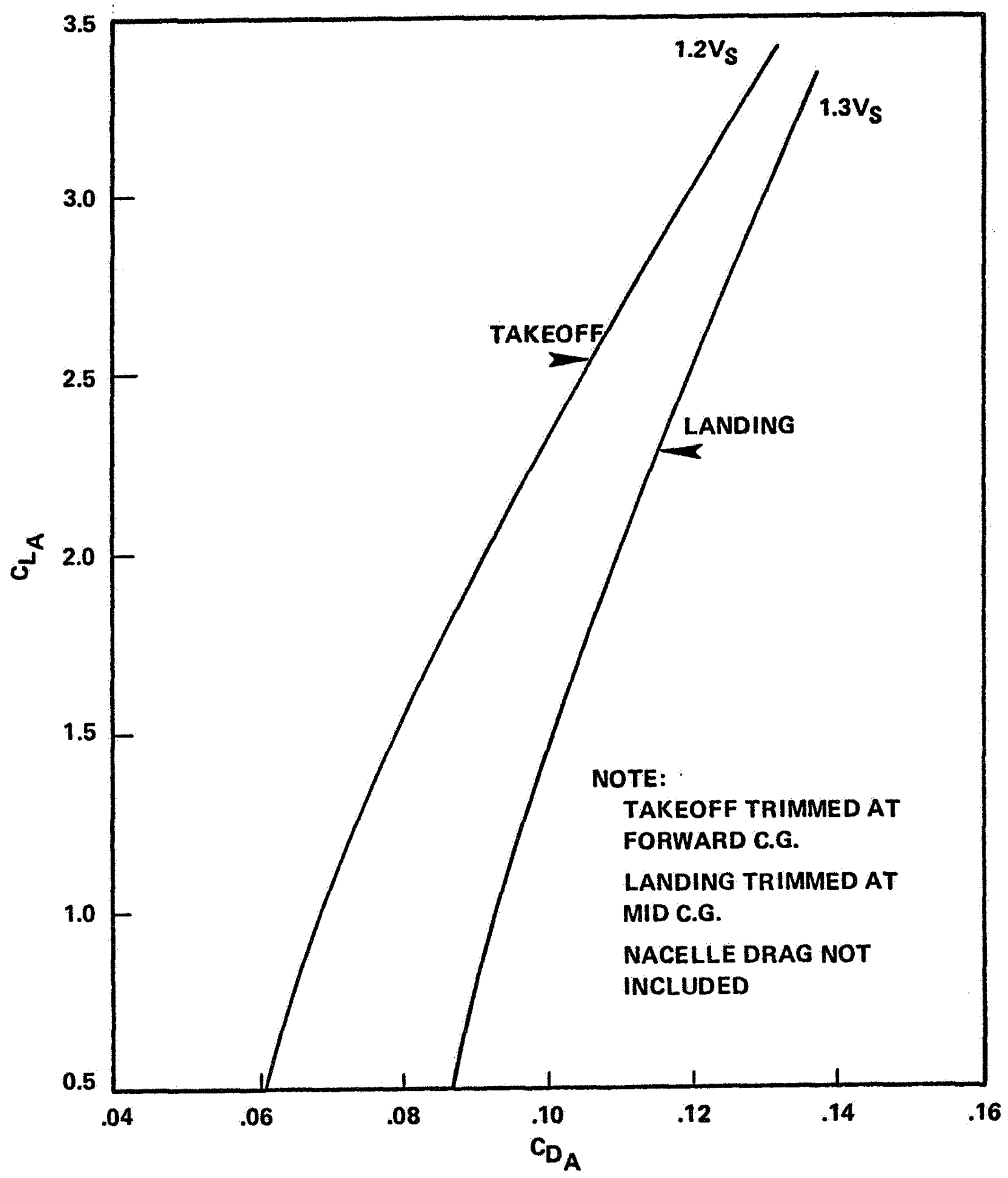

Figure C-7. High-Lift Polars Gear-Up

Table C-VI. Aircraft Weight Breakdowns

Domestic Transcontinental Range Trijets

Weights (lb)	Scaled CF6-50 Engines	Advanced Engines
Wing	61,260	55,250
Horizontal Tail	4,980	4,250
Vertical Tail	2,320	1,990
Fuselage	62,720	61,950
Landing Gear	22,120	20,360
Propulsion*	38,640	36,480
APU	1,435	1,435
Fuel System	2,240	2,130
Flight Controls and Hydraulic System	11,880	10,540
Instruments	1,750	1,750
Air Conditioning and Pneumatics	4,965	4,965
Electrical	6,460	6,460
Avionics	2,700	2,700
Furnishings	53,290	53,290
Ice Protection	730	650
Handling Gear	60	60
Manufacturer's Empty Weight	277,550	264,260
Operator's Items	25,690	25,690
Operator's Empty Weight	303,240	289,950

*Includes lower vertical tail

Table C-VII. Sensitivity Factors

Domestic Trijet With GE Advanced Engines

A CHANGE IN	SFC	Engine Weight	Engine Price	Engine Maintenance
OF	+5%	+1000 lb each	+10%	+10%
WILL CAUSE				
Δ Maximum Takeoff Weight	+2.5%	+1.2%	0	0
Δ Operator's Empty Weight	+1.7%	+1.7%	0	0
Δ Adjusted Wing Area	+4.6%	+1.6%	0	0
Δ Engine Thrust Size	2.1%	+0.9%	0	0
Δ Fuel Burned at Design Range	+6.8%	+0.9%	0	0
Δ Fuel Burned at 1000 n mi	+6.3%	+0.9%	0	0
Δ DOC at Design Range	+3.0%	+0.9%	+0.6	+0.6
Δ DOC at 100 n mi	+2.7%	+0.9%	+0.6	+0.5

Table C-VIII. Airframe Generated Noise at FAR-36 Measuring Points

Trijet With GE Advanced Engines

Condition	Sideline	Takeoff	Cutback	Approach
Aircraft Weight (LB)	497000	497000	497000	457000
Geometric Altitude (FT)	850	1638	1545	394
Aircraft Pitch Angle (Deg)	+15	+15	+12	+3
Climb Gradient (%)	10.9	10.6	5.2	-5.2
Installed Thrust Per Engine				
- (LB)	30190	29690	20340	5430
- (% Of Takeoff)	100	100	68	18
True Airspeed (Knots)	147	148	148	146
Flap Deflection (Degrees)	20	20	20	30
Airframe Noise (EPNdB)	76.6	77.2	77.7	92.3

NOTE: Thrust Size = 41230 LB/Engine

Table C-IX. Nonpropulsive Noise Study.

NONPROPULSIVE NOISE STUDY E3   DOMESTIC ADVANCED G.E. VERSION   H5TI   DATE 02/15/79

NON-PROPULSIVE

SIDELINE CANS DOM   MACH NO. = 0.219

PHYS N1 = 5000.0 RPM   FLAP AREA = 255.2 SQ FT   FLAP POS = 20.0 DEG

850. FOOT ALTITUDE * 1477. FOOT SIDELINE DISTANCE SOUND PRESSURE LEVELS, DB

BAND CENTER FREQUENCY, HERTZ	ANGLE FROM INLET CENTERLINE (DEGREES) 20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0	150.0	160.0
50	48.1	52.0	54.3	55.8	56.8	57.2	57.3	57.0	56.4	55.4	54.1	52.5	50.3	47.6	43.8
63	48.5	52.2	54.4	55.9	56.8	57.3	57.4	57.2	56.7	55.8	54.6	53.1	51.1	48.4	44.7
80	48.5	52.0	54.0	55.4	56.4	57.1	57.5	57.5	57.3	56.7	55.7	54.2	52.3	49.7	45.9
100	49.5	52.6	54.2	55.4	56.4	57.2	57.8	58.1	58.1	57.7	56.9	55.6	53.8	51.3	47.5
125	49.6	52.7	54.5	55.8	57.1	58.1	58.8	59.1	59.1	58.6	57.8	56.5	54.6	52.0	48.0
160	47.9	51.3	53.4	55.1	56.4	57.5	58.2	58.5	58.4	57.9	56.9	55.5	53.5	50.7	46.6
200	46.8	51.1	54.0	56.2	57.7	58.7	59.2	59.3	58.9	58.1	56.9	55.2	52.9	49.8	45.4
250	44.5	50.5	54.6	57.4	59.2	60.3	60.8	60.7	60.2	59.2	57.7	55.7	53.0	49.2	44.0
315	45.1	51.1	55.2	58.0	59.9	61.0	61.5	61.5	61.0	60.0	58.6	56.6	53.9	50.2	44.9
400	44.0	49.6	53.7	55.7	58.8	60.2	60.8	61.0	60.6	59.8	58.5	56.6	54.0	50.4	45.1
500	44.0	48.8	52.1	54.7	56.7	58.1	58.9	59.3	59.1	58.5	57.3	55.6	53.3	49.9	44.7
630	44.8	49.6	52.1	53.8	55.2	56.3	57.1	57.5	57.4	57.0	56.1	54.6	52.4	49.3	44.2
800	43.6	49.5	52.5	54.3	55.5	56.3	56.7	56.8	56.6	55.9	54.9	53.3	51.0	47.6	42.3
1000	40.6	47.4	51.0	53.2	54.7	55.5	56.0	56.0	55.6	54.8	53.5	51.7	49.1	45.4	39.6
1250	37.9	45.4	49.0	51.2	52.7	53.6	54.2	54.3	54.0	53.4	52.2	50.5	47.9	44.0	37.7
1600	33.5	42.2	46.6	49.2	50.9	52.1	52.7	52.9	52.7	51.9	50.7	48.7	45.9	41.6	34.3
2000	30.2	40.3	45.0	47.7	49.4	50.6	51.4	51.7	51.5	50.8	49.6	47.7	44.7	40.0	32.0
2500	25.2	37.0	42.2	45.0	46.7	47.9	48.8	49.2	49.2	48.7	47.5	45.6	42.4	37.3	28.1
3150	13.4	29.3	36.3	39.0	42.1	43.6	44.7	45.4	45.5	44.9	43.6	41.2	37.4	31.0	19.2
4000	0.0	17.4	26.6	31.9	35.8	38.8	40.8	41.9	42.1	41.4	39.7	36.6	31.6	23.2	7.5
5000	0.0	8.7	18.9	24.7	29.4	33.4	36.1	37.7	38.2	37.5	35.6	32.2	26.5	16.9	0.0
6300	0.0	0.0	9.1	16.4	21.9	25.7	28.1	29.3	29.3	28.1	25.6	21.3	14.2	2.3	0.0
8000	0.0	0.0	0.0	4.2	11.2	15.7	18.4	19.6	19.5	17.9	14.7	9.3	0.4	0.0	0.0
10000	0.0	0.0	0.0	0.0	0.0	0.5	4.3	6.1	6.1	4.2	0.2	0.0	0.0	0.0	0.0
PNL	59.4	65.5	69.4	72.1	74.1	75.4	76.1	76.4	76.1	75.4	74.1	72.1	69.3	65.4	59.4
PNLT	59.4	65.5	69.4	72.1	74.1	75.4	76.1	76.4	76.1	75.4	74.1	72.1	69.3	65.4	59.4
A WTD	50.2	55.1	59.6	61.5	63.6	64.7	65.3	65.5	65.2	64.5	63.3	61.5	59.0	55.4	49.9
OASPL	58.3	62.6	65.4	67.5	68.9	70.0	70.5	70.6	70.3	69.6	68.4	66.8	64.5	61.3	56.8
ACO RNG	5428	3460	2599	2139	1972	1713	1639	1618	1648	1730	1875	2108	2483	3127	4409

Table C-IX. Nonpropulsive Noise Study (Continued).

NONPROPULSIVE NOISE STUDY E3 DOMESTIC ADVANCED G.E. VERSION H5TI DATE 02/15/79

NON-PROPULSIVE

TAKEOFF CAN5 DOM MACH NO. = 0.222

PHYS N1 = 5000.0 RPM FLAP AREA = 255.2 SQ FT FLAP POS = 20.0 DEG

1638. FOOT ALTITUDE * 0. FOOT SIDELINE DISTANCE SOUND PRESSURE LEVELS, DB

BAND CENTER FREQUENCY, HERTZ	ANGLE FROM INLET CENTEPLINE (DEGREES)														
	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0	150.0	160.0
50	47.4	51.7	54.3	56.0	57.1	57.7	57.9	57.6	57.1	56.1	54.8	53.2	51.1	48.4	45.0
63	47.8	52.0	54.5	56.1	57.2	57.7	58.0	57.8	57.3	56.5	55.3	53.8	51.8	49.2	45.8
80	47.7	51.6	54.0	55.6	56.8	57.6	58.1	58.2	57.9	57.3	56.3	54.9	53.0	50.5	47.0
100	48.7	52.2	54.1	55.5	56.6	57.6	58.3	58.7	58.7	58.3	57.6	56.3	54.6	52.1	48.6
125	48.9	52.5	54.5	56.1	57.5	58.6	59.4	59.8	59.8	59.4	58.6	57.3	55.5	52.9	49.3
160	47.2	51.0	53.3	55.2	56.7	57.9	58.7	59.1	59.1	58.6	57.7	56.3	54.4	51.7	48.0
200	46.0	50.8	54.0	56.3	58.0	59.1	59.7	59.9	59.6	58.8	57.7	56.0	53.8	50.8	46.7
250	43.4	50.0	54.4	57.4	59.5	60.7	61.3	61.3	60.8	59.9	58.4	56.4	53.7	50.2	45.3
315	44.1	50.8	55.2	58.3	60.3	61.6	62.2	62.2	61.8	60.8	59.4	57.4	54.7	51.1	46.2
400	42.8	49.2	53.7	57.0	59.3	60.7	61.5	61.7	61.4	60.6	59.3	57.4	54.9	51.4	46.6
500	42.6	48.3	52.0	54.9	57.1	58.7	59.6	60.0	59.9	59.3	58.1	56.5	54.1	50.9	46.2
630	43.3	49.0	51.9	53.9	55.5	56.8	57.7	58.2	58.3	57.9	57.0	55.5	53.4	50.4	45.9
800	42.0	48.9	52.3	54.4	55.8	56.8	57.4	57.6	57.4	56.8	55.8	54.2	52.0	48.8	44.1
1000	38.7	46.7	50.7	53.3	55.0	56.0	56.6	56.7	56.4	55.6	54.4	52.6	50.1	46.6	41.4
1250	35.7	44.6	48.9	51.4	53.1	54.2	54.9	55.1	54.9	54.3	53.1	51.4	49.0	45.4	39.8
1600	30.7	41.2	46.2	49.2	51.2	52.6	53.4	53.7	53.5	52.9	51.6	49.7	47.0	43.0	36.6
2000	26.9	38.9	44.5	47.7	49.8	51.2	52.1	52.5	52.4	51.8	50.6	48.7	45.9	41.6	34.5
2500	21.3	35.4	41.6	45.0	47.1	48.6	49.6	50.2	50.3	49.8	48.7	46.8	43.8	39.1	31.2
3150	8.0	27.3	35.5	39.8	42.4	44.2	45.5	46.3	46.5	46.1	44.8	42.6	39.0	33.2	23.0
4000	0.0	14.5	25.4	31.7	36.2	39.5	41.8	43.1	43.5	42.9	41.2	38.3	33.5	25.9	12.5
5000	0.0	5.3	17.5	24.3	29.7	34.1	37.3	39.1	39.8	39.2	37.5	34.3	28.9	20.2	4.6
6300	0.0	0.0	5.1	15.8	22.1	26.5	29.3	30.8	31.0	30.1	27.7	23.6	17.0	6.2	0.0
8000	0.0	0.0	0.0	3.5	11.5	16.7	19.9	21.5	21.6	20.3	17.2	12.1	3.8	0.0	0.0
10000	0.0	0.0	0.0	0.0	0.0	1.6	6.1	8.3	8.6	7.0	3.3	0.0	0.0	0.0	0.0
PNL	57.9	64.8	69.2	72.3	74.4	75.9	76.8	77.2	77.0	76.3	75.0	73.1	70.4	66.6	61.1
PNLT	57.9	64.8	69.2	72.3	74.4	75.9	76.8	77.2	77.0	76.3	75.0	73.1	70.4	66.6	61.1
A WTD	48.7	55.5	59.4	62.1	63.9	65.2	66.0	66.2	66.0	65.4	64.2	62.5	60.0	56.5	51.5
OASPL	57.4	62.2	65.3	67.6	69.2	70.4	71.1	71.3	71.0	70.4	69.2	67.6	65.3	62.3	58.1
ACO RNG	6171	2774	2772	2246	1943	1765	1670	1636	1655	1726	1857	2069	2408	2974	4035

Table C-IX. Nonpropulsive Noise Study (Continued).

NONPROPULSIVE NOISE STUDY E3 DOMESTIC ADVANCED G.E. VERSION H5TI DATE 02/15/79

NON-PROPULSIVE

CUTBACK CAN5 DUM MACH NO. = 0.222

PHYS N1 = 5000.0 RPM FLAP AREA = 255.2 SQ FT FLAP POS = 20.0 DEG

1545. FOOT ALTITUDE * 0. FOOT SIDELINE DISTANCE SOUND PRESSURE LEVELS, DB

BAND CENTER FREQUENCY, HERTZ	ANGLE FROM INLET CENTERLINE (DEGREES) 20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0	150.0	160.0
50	46.8	51.6	54.4	56.2	57.4	58.1	58.3	58.1	57.6	56.7	55.5	53.9	51.9	49.4	46.1
63	47.2	51.9	54.6	56.3	57.5	58.1	58.4	58.3	57.9	57.1	56.0	54.5	52.6	50.2	46.9
80	47.1	51.5	54.1	55.8	57.1	58.0	58.5	58.7	58.5	57.9	57.0	55.6	53.8	51.4	48.1
100	48.1	52.1	54.3	55.7	57.0	59.0	58.8	59.2	59.3	58.9	58.2	57.1	55.4	53.1	49.8
125	48.2	52.4	54.6	56.3	57.8	59.0	59.8	60.3	60.4	60.0	59.3	58.0	56.3	53.9	50.5
160	46.5	50.9	53.5	55.4	57.0	58.3	59.2	59.6	59.6	59.2	58.4	57.1	55.2	52.7	49.2
200	45.3	50.7	54.1	56.5	58.2	59.5	60.2	60.4	60.1	59.4	58.3	56.7	54.6	51.8	48.0
250	42.7	49.9	54.5	57.7	59.8	61.1	61.7	61.8	61.4	60.5	59.1	57.2	54.6	51.2	46.6
315	42.3	50.6	55.3	58.5	60.6	62.0	62.6	62.7	62.3	61.5	60.1	58.2	55.6	52.2	47.5
400	42.0	49.1	53.8	57.2	59.6	61.1	62.0	62.3	62.0	61.3	60.0	58.3	55.8	52.5	48.0
500	41.7	48.1	52.1	55.2	57.5	59.1	60.1	60.6	60.5	59.9	58.9	57.3	55.1	52.0	47.7
630	42.2	48.9	52.0	54.2	55.9	57.3	58.2	58.8	58.9	58.6	57.7	56.4	54.4	51.6	47.5
800	40.8	48.7	52.4	54.7	56.2	57.3	57.9	58.2	58.1	57.5	56.6	55.1	53.1	50.1	45.8
1000	37.3	46.5	50.9	53.6	55.4	56.5	57.2	57.3	57.1	56.4	55.2	53.6	51.3	48.0	43.3
1250	34.2	44.4	49.0	51.8	53.6	54.9	55.5	55.8	55.7	55.1	54.1	52.5	50.2	46.9	41.9
1600	29.0	40.9	46.4	49.6	51.7	53.2	54.1	54.4	54.3	53.7	52.6	50.9	48.3	44.7	39.0
2000	24.8	33.7	44.7	48.1	50.3	51.9	52.8	53.3	53.3	52.8	51.7	50.0	47.4	43.5	37.3
2500	18.8	35.1	41.9	45.5	47.7	49.3	50.4	51.1	51.3	50.9	49.9	48.2	45.5	41.3	34.4
3150	4.5	26.9	35.9	40.5	43.2	45.1	46.5	47.4	47.7	47.4	46.3	44.4	41.1	36.0	27.2
4000	0.0	13.9	25.9	32.5	37.2	40.6	43.0	44.5	44.9	44.5	43.1	40.4	36.2	29.5	17.9
5000	0.0	4.7	18.0	25.2	30.8	35.4	38.6	40.6	41.4	41.1	39.6	36.8	32.0	24.3	11.0
6300	0.0	0.0	6.8	16.9	23.5	28.0	31.0	32.6	33.1	32.3	30.3	26.7	20.8	11.4	0.0
8000	0.0	0.0	0.0	4.9	13.2	18.6	22.0	23.7	24.1	23.0	20.4	15.9	8.6	0.0	0.0
10000	0.0	0.0	0.0	0.0	0.0	4.0	8.7	11.1	11.7	10.5	7.3	1.6	0.0	0.0	0.0
PNL	56.8	64.7	69.4	72.6	74.9	76.5	77.4	77.9	77.8	77.1	76.0	74.2	71.6	68.0	62.9
PNLT	56.8	64.7	69.4	72.6	74.9	76.5	77.4	77.9	77.8	77.1	76.0	74.2	71.6	68.0	62.9
A WTD	47.7	55.3	59.5	62.4	64.3	65.7	66.5	66.9	66.7	66.1	65.1	63.4	61.1	57.9	53.2
OASPL	56.7	62.1	65.5	67.9	69.6	70.9	71.6	71.8	71.6	71.0	70.0	68.4	66.3	63.4	59.4
ACO RNG	6590	3819	2739	2187	1873	1689	1589	1549	1558	1617	1730	1915	2209	2694	3578

Table C-IX. Nonpropulsive Noise Study (Concluded).

NONPROPULSIVE NOISE STUDY E3 DOMESTIC ADVANCED G.E. VERSION H5TI DATE 02/15/79

NON-PROPULSIVE

APPROACH CANS DOM MACH NO. = 0.217

PHYS N1 = 5000.0 RPM FLAP AREA = 255.2 SQ FT FLAP POS = 30.0 DEG

394. FOOT ALTITUDE * 0. FOOT SIDELINE DISTANCE SOUND PRESSURE LEVELS, DB

	ANGLE FROM INLET CENTERLINE (DEGREES)														
BAND CENTER FREQUENCY, HERTZ	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0	150.0	160.0
50	56.3	63.3	66.9	69.4	71.1	72.3	73.0	73.3	73.2	72.7	71.8	70.5	68.6	66.3	63.2
63	57.8	64.5	67.8	70.1	71.7	72.8	73.5	73.9	73.9	73.5	72.8	71.6	70.0	67.8	64.9
80	58.1	64.3	67.2	69.2	70.8	72.1	73.2	73.8	74.1	74.1	73.6	72.6	71.2	69.1	66.2
100	53.6	64.4	66.7	69.4	70.0	71.6	73.0	74.0	74.6	74.8	74.5	73.7	72.3	70.3	67.5
125	58.3	64.2	66.3	68.7	70.5	72.2	73.5	74.5	75.0	75.1	74.7	73.8	72.4	70.3	67.4
160	58.9	65.2	68.0	69.7	71.2	72.5	73.5	74.3	74.7	74.7	74.3	73.4	72.1	70.1	67.3
200	56.4	63.7	67.7	70.5	72.5	74.0	74.9	75.4	75.5	75.1	74.3	72.9	71.1	68.6	65.3
250	55.3	64.0	68.8	72.0	74.1	75.6	76.4	76.7	76.6	75.9	74.8	73.2	70.9	68.0	64.1
315	56.0	64.5	69.1	72.2	74.4	75.8	76.7	77.0	76.9	76.3	75.3	73.7	71.6	68.7	65.1
400	55.3	63.4	67.8	70.9	73.2	74.8	75.9	76.4	76.5	76.1	75.2	73.9	71.9	69.3	65.8
500	56.5	63.9	67.3	69.6	71.5	73.1	74.2	74.9	75.3	75.2	74.6	73.6	72.0	69.8	66.8
630	57.1	65.0	68.3	70.4	71.9	73.0	73.9	74.4	74.7	74.6	74.1	73.2	71.7	69.6	66.7
800	55.9	64.4	68.0	70.2	71.8	73.0	73.9	74.5	74.7	74.5	74.0	73.0	71.4	69.3	66.3
1000	54.9	64.0	67.8	70.2	71.8	73.0	73.9	74.4	74.6	74.4	73.8	72.8	71.3	69.0	65.9
1250	54.2	62.8	67.5	69.6	71.0	72.0	72.8	73.4	73.7	73.7	73.4	72.6	71.2	69.2	66.1
1600	53.0	63.6	67.4	69.4	70.3	70.9	71.5	72.0	72.5	72.8	72.7	72.1	71.0	69.0	66.0
2000	49.7	61.5	65.6	67.8	69.2	70.2	71.2	72.0	72.6	72.9	72.7	72.0	70.7	68.5	65.2
2500	44.9	58.3	63.0	66.0	67.8	69.3	70.5	71.4	71.9	72.1	71.7	70.8	69.2	66.8	63.0
3150	37.5	54.6	60.6	64.3	66.7	68.4	69.8	70.7	71.1	71.1	70.6	69.5	67.7	64.9	60.8
4000	27.8	49.3	56.6	61.2	64.5	67.0	68.9	70.1	70.8	70.8	70.3	69.0	66.9	63.7	58.9
5000	21.0	45.7	53.6	58.5	62.1	64.9	67.0	68.5	69.3	69.5	69.0	67.8	65.6	62.3	57.0
6300	10.9	42.0	51.7	57.1	60.2	62.2	63.6	64.6	65.3	65.5	65.1	63.9	61.9	58.5	52.9
8000	0.0	33.1	45.1	51.9	56.0	58.7	60.6	62.1	62.9	63.2	62.7	61.3	58.8	54.8	48.0
10000	0.0	13.9	34.1	43.3	49.3	53.6	56.7	58.8	60.0	60.3	59.6	57.8	54.6	49.4	40.8
PNL	73.5	84.1	88.5	91.4	93.4	95.0	96.3	97.1	97.5	97.5	97.0	96.0	94.2	91.7	87.9
PNLT	73.5	84.1	88.5	91.4	93.4	95.0	96.3	97.1	97.5	97.5	97.0	96.0	94.2	91.7	87.9
A WTD	63.5	72.8	76.8	79.2	80.9	82.2	83.2	83.9	84.3	84.3	83.8	82.8	81.2	78.9	75.6
OASPL	68.8	76.4	80.1	82.6	84.4	85.7	86.7	87.3	87.6	87.4	86.8	85.7	84.1	81.8	78.6
ACO RNG	2865	1229	783	537	486	435	411	406	414	435	469	516	585	690	864

Table C-X. 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

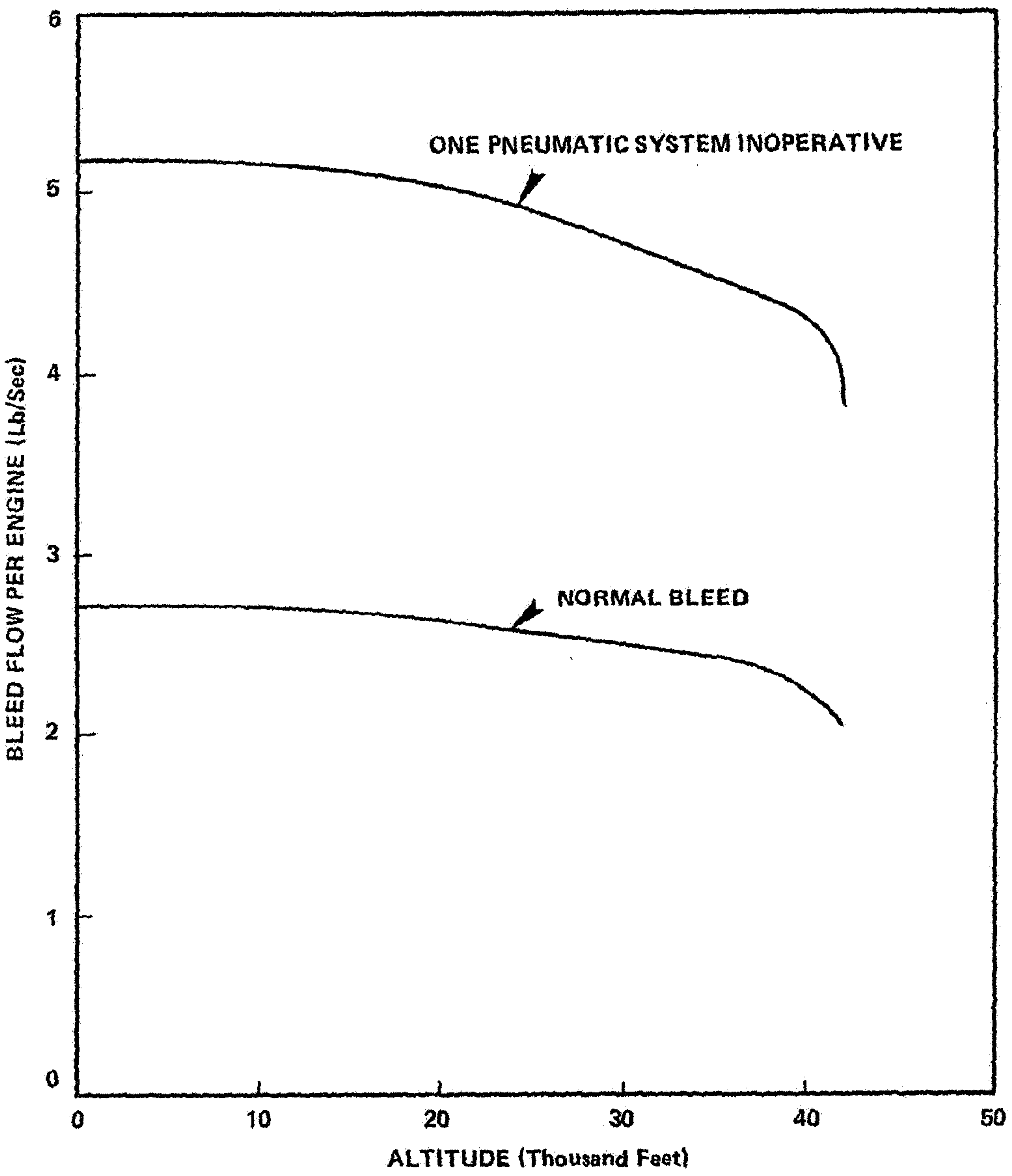

Figure C-8. Aircraft Compressor Bleed Air Required wing anti-ice flow at a temperature greater than 400°F plus 2.7 pounds/second to provide air to drive one air conditioning pack. The sizing case therefore requires a total of 8.4 pounds/second with the engine at 40 to 60% of climb thrust.

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.

4.0 AIRFRAME/PROPULSION SYSTEM INTEGRATION

Preliminary propulsion system integration requirements have been investigated. Study engine installations provided by General Electric have been reviewed; Douglas conducted nacelle/aircraft integration studies and requirements for engine installation in the E^3 study aircraft have been determined. Results of these studies are reported below.

4.1 NACELLE PLACEMENT

The nacelle/pylon/wing relationship must be established to minimize interference drag. Wind tunnel tests are required to establish this relationship. Such tests have been underway as a part of Douglas activities on the NASA Langley Energy Efficient Transport Program. Further development is requried. Figure C-9 shows the current relation between nacelle/ pylon/wing reflecting the best estimate to date. Test results to date indicate a more aft location would have excessive interference drag. Further, studies of the flow efflux pattern during reverse thrust shows a more aft location would have a problem from impingement on the inboard section of the variable camber Kreuger leading edge device on a swept wing.

4.2 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 available from current and derivative versions of CF6, CFM56, JT8D refan, JT9D, JT10D, 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.

4.2.1 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 C-XI.

4.2.2 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.

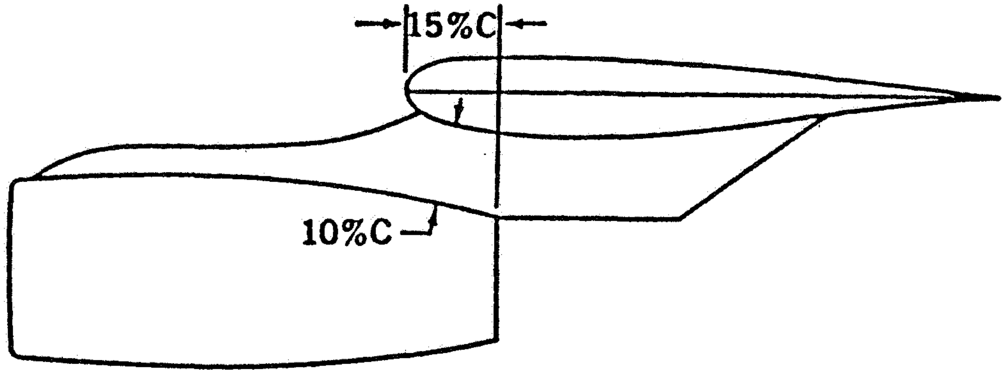

Figure C-9. Nacelle/Wing Relationship

Table C-XI. 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
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

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.

4.2.3 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 conditioning ozone will destroy the ozone, heating and cooling the bleed air may be a viable way to reduce the ozone concentration in the cabin. Cabin air recirculation will reduce ozone contamination.

4.2.4 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.

4.2.5 Bleed Port Locations

Bleed air must be available from the engine at flight idle power to supply the aircraft pneumatic system.

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 at sea level with takeoff thrust would eliminate the need for 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 investiwould have to include a study of the pressure suitability of the next lower stage pressure whenever high stage bleed exceeds 450^{o}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^{o}F at engine idle power with ambient temperatures at the low limit of the FAA icing envelope.

4.2.6 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.

4.3 INSTALLATION STUDIES

Installation studies were made reviewing the G.E. installation for airframe compatability. A listing of the layouts made is shown in Figure C-10 with a brief description. The eight layouts listed in Figure C-10 are shown as Figures C-11 through C-18.

Various fore and aft placement of the nacelle relative to the wing were studied including location on the trailing edge of the wing. The current study location with the nozzle trailing edge at 15% of the wing chord is judged to offer the best promise of attaining a design which has no fan reverser impingement on wing high lift device surfaces without incurring the high risks of nacelle to wing interference drag penalties for aft mounted nacelles or wing flutter penalties which are expected for more forward nacelle positions.

The reference base G.E. installation design utilizes a core mounted accessory arrangement in order to retain a circular nacelle cross section which would produce a minimum frontal and wetted skin area with consequent minimum performance loss due to nacelle external drag. This approach, however, results in reduced accesability to engine mounted components and a more compact and difficult to maintain accessory arrangement. Performance versus maintenance cost trades, including the effects on dispatch delay and cancellation rates are needed. As a part of evaluation/accessory arrangement, three different layout studies were made from which the drag penalties associated with fan case mounted accessories could be assessed relative to equivalent nacelles designed for core mounted accessories. The first two of these studies were made using very preliminary estimates of accessory package configurations and were later found to be very optimistic in regard to accessory package volume requirements. As greater design detail concerning the core mounted accessory package was received from G.E., it was observed that earlier studies pertaining to engine fan case and overall diameters did not provide realistic core compartment volumes to house core mounted accessories without imposing unacceptable flow restrictions in the fan exhaust ducts (DAC layout PP-SK-GEE3-006) shown as Figure C-16. Since this problem did not impact the fan case mounted accessory design, different engine case and nacelle basic diameters are shown in the final study layouts for the core mounted and fan case mounted accessory arrangements (Ref. PP-SK-GEE-007 and PP-SK-GEE3-008 shown as Figures C-17 and C-18 respectively).

DAC LAYOUT NUMBER	G.E. INPUT DATA	LAYOUT DESCRIPTION	LAYOUT PURPOSE	CONCLUSIONS
PP-SK-GEE3-001	G.E. DWG 4013237-857 DTD 5-5-78	WING MOUNTED NACELLE, 46900 LB THRUST, EXHAUST PLANE AT 29%C., CORE MTD. ACCESSORIES	INITIAL DAC ASSESSMENT OF G.E. E^3 FLIGHT INSTALLATION DESIGN	• FAN REVERSER EXHAUST IMPINGES ON WING L.E. HIGH LIFT DEVICES.
PP-SK-GEE3-002 8-25-78	G.E. DWG 4013237-857 DTD 5-5-78	WING MOUNTED NACELLE, 46900 LB THRUST, AFT OF WING NACELLE, CORE MTD. ACCESSORIES	EVALUATE AFT OF WING LOCATION AS MEANS OF AVOIDING REVERSED THRUST EXHAUST INTERFERENCE WITH WING	• HAS MAJOR WING FLUTTER PENALTIES • INCREASES TRIM DRAG • THIS APPROACH WAS ABANDONED FOR E^3 STUDIES.
PP-SK-GEE3-003 9-14-78	G.E. DWG 4013237-857 DTD 5-5-78	WING MOUNTED NACELLE, 46900 LB THRUST, EXHAUST PLANE AT 29%C., FAN CASE MTD. ACCESSORIES WITH THIN METAL FAN CASE.	EVALUATE FAN CASE MOUNTED ACCESSORIES RELATIVE TO DESIGN SHOWN IN PP-SK-GEE3-001	• INCREASES AIRPLANE DRAG (FOR 3 ENGINE A/p) 0.3% RELATIVE REFERENCE BASE CONFIGURATION
PP-SK-GEE3-004A 10-25-78	G.E. DWG 4013267-011 DTD 8-24-78	WING MOUNTED NACELLE, 46900 LB THRUST, EXHAUST PLANE AT 0%C., CORE MTD. ACCESSORIES	UPDATE DAC STUDY CONFIGURATION TO LATEST G.E. DIMENSIONS & DAC ENGINE SIZE REQ'MTS-EVALUATE EXTREME FWD NACELLE TO WING POSITION	• EXCESSIVE PYLON STRUCTURAL WEIGHT & HIGH POTENTIAL FOR WING FLUTTER PROBLEM PREDICTED FOR THIS CONFIGURATION
PP-SK-GEE3-005 10-27-78	G.E. DWG 4013267-011 DTD 8-24-78	WING MOUNTED NACELLE, 40000 LB THRUST, EXHAUST PLANE AT 0%C., FAN CASE MTD ACCESSORIES WITH THICK COMPOSITE FAN CASE	EVALUATE FAN CASE MOUNTED ACCESSORY ARRANGEMENT WITH THICK WALLED COMPOSITE FAN CASE	• INCREASES AIRPLANE DRAG (FOR 3 ENGINE A/p) 0.7% RELATIVE TO PP-SK-GEE3-004 CONFIGURATION
PP-SK-GEE3-006 12-21-78	G.E. DWG 4013267-011 DTD 8-24-78 MODIFIED BY GE/NASA PDR OF NOV. 20 & 21	WING MOUNTED NACELLE, 40000 LB THRUST, EXHAUST PLANE AT 15%C., CORE MTD ACCESSORIES	UPDATE DAC STUDY CONFIGURATION TO LATEST G.E. ENGINE DIMENSIONS AND ACCESSORY CONFIGURATION. INTENDED AS BASELINE FOR MAINTAINABILITY STUDIES.	• BULGE IN FAN DUCT INNER WALL REQUIRED TO CLEAR CORE MOUNTED ACCESSORIES RESULTS IN SEVERE FLOW RESTRICTION IN FAN EXHAUST DUCT
PP-SK-GEE3-007 1-23-79	G.E. DWG 4013267-011 DTD 8-24-78 MODIFIED BY GE/NASA PDR OF NOV 20 & 21	WING MOUNTED NACELLE, 40000 LB THRUST, EXHAUST PLANE AT 15%C., CORE MTD ACCESSORIES, ENLARGED FAN CASE	EVALUATE ENGINE AND NACELLE DIAMETER INCREASE REQUIRED TO PERMIT UNRESTRICTED FAN EXHAUST FLOW PAST CORE MTD ACCESSORY ARRANGEMENT SHOWN ON PP-SK-GEE3-006.	• REQUIRES 3.2% INCREASE IN MAX. NACELLE DIA. (RELATIVE TO PP-SK-GEE3-006) TO ACCOMMODATE DESIRED FAN EXHAUST DUCT AREAS. PRESUMES AVAILABILITY OF COMBINED VSCF/ELECTRIC STARTER-LARGER NACELLE DIA. WILL BE REQUIRED IF THIS PRESUMPTION IS INVALID.
PP-SK-GEE3-008 1-31-79	G.E. DWG 4013267-011 DTD. 8-24-78 MODIFIED BY GE/NASA PDR OF NOV 20 & 21	WING MOUNTED NACELLE, 40000 LB THRUST, EXHAUST PLANE AT 15%C., FAN CASE MTD ACCESSORIES THICK COMPOSITE FAN CASE	EVALUATE FAN CASE MTD ACCESSORY ARRANGEMENT WITH MINIMUM DIAMETER FAN CASE RELATIVE TO INSTL. SHOWN ON PP-SK-GEE3-007	• USES FAN CASE DIA (MAX NACELLE DIA) 3.24% SMALLER THAN PP-SK-GEE3-007. REQUIRES 11.0 INCH BULGE ON BOTTOM & FOR ACCESSORY PACKAGE.

Figure C-10. DAC Layouts For G.E. E^3 Study

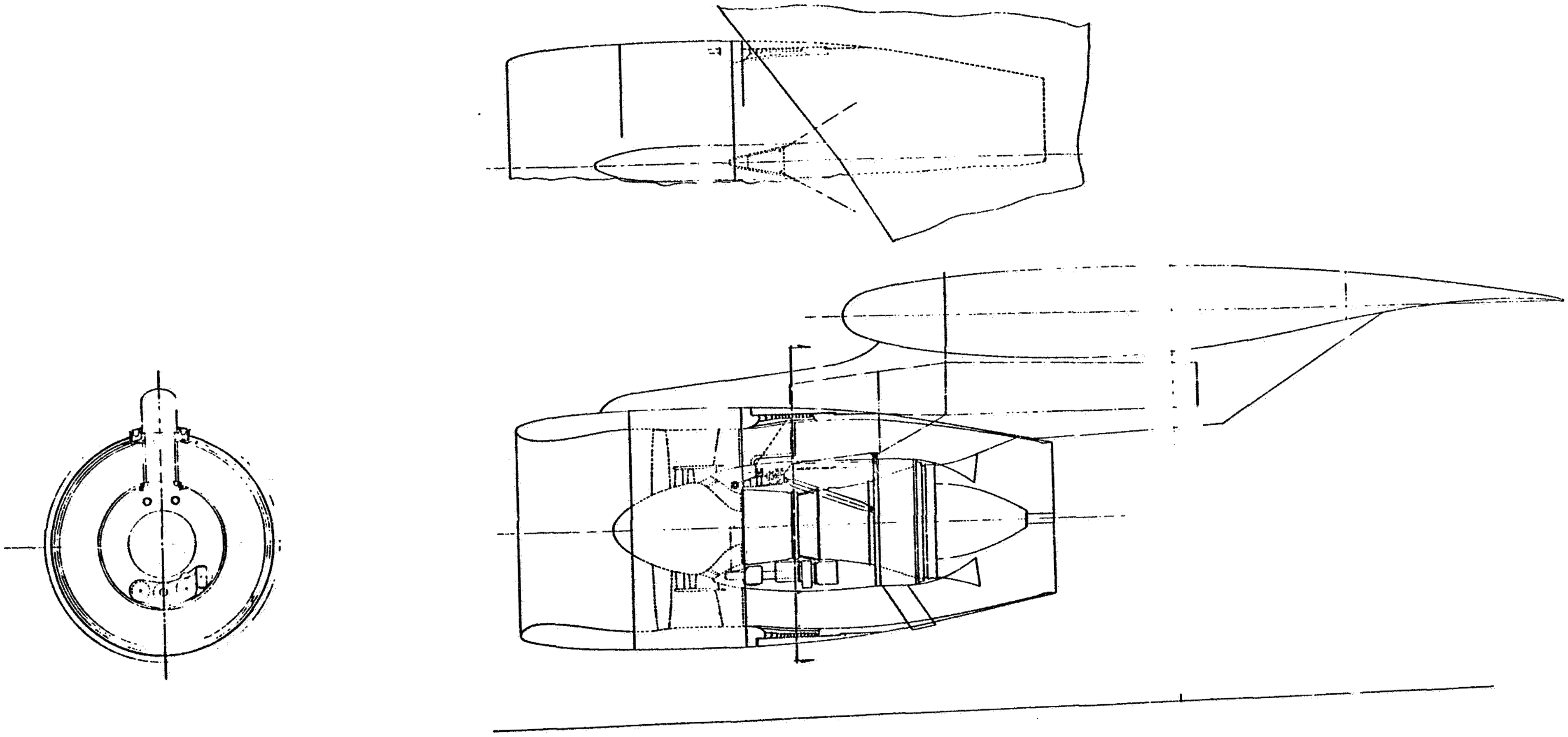

Figure C-11. Study Layout for GE E^3 Engine Wing Installation.

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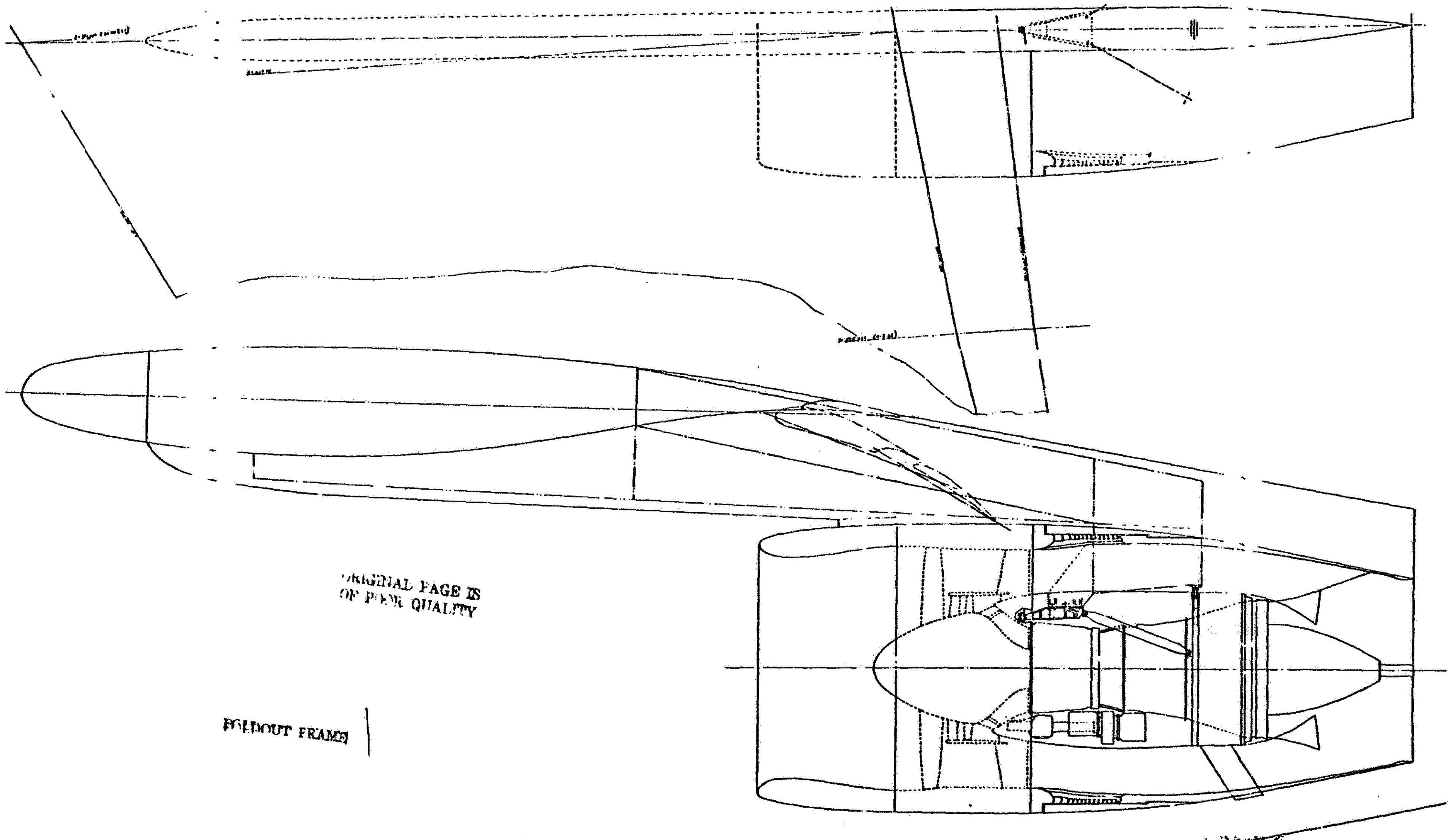

Figure C-12. Study Layout for GE E^3 Engine Installation Aft of Wing Location.

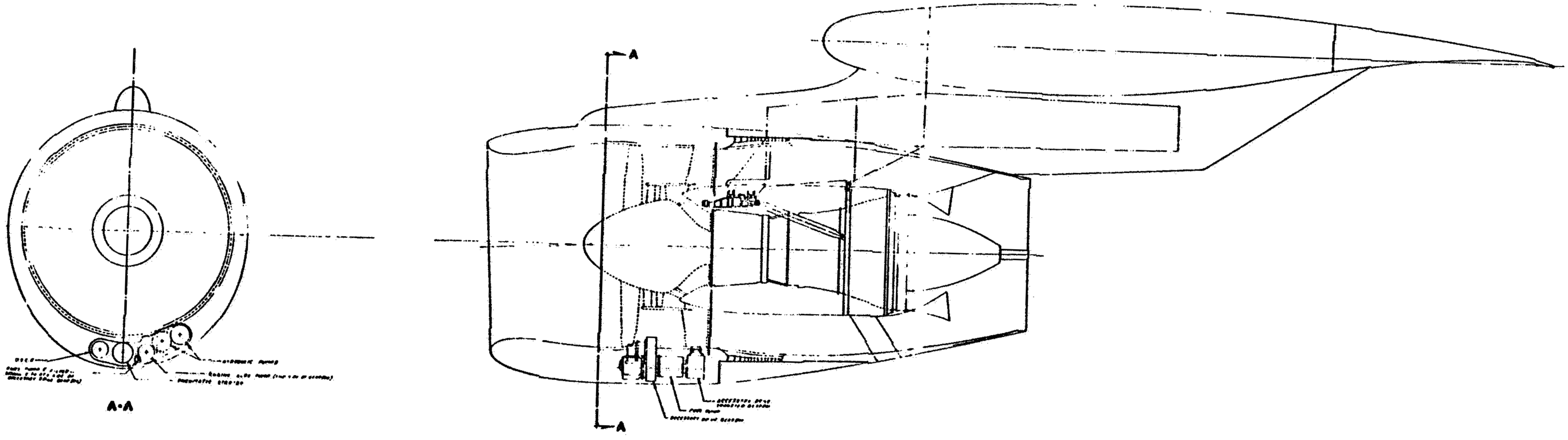

Figure C-13. Study Layout for GE E^3 Engine Installation, Fan Case-Mounted Accessories.

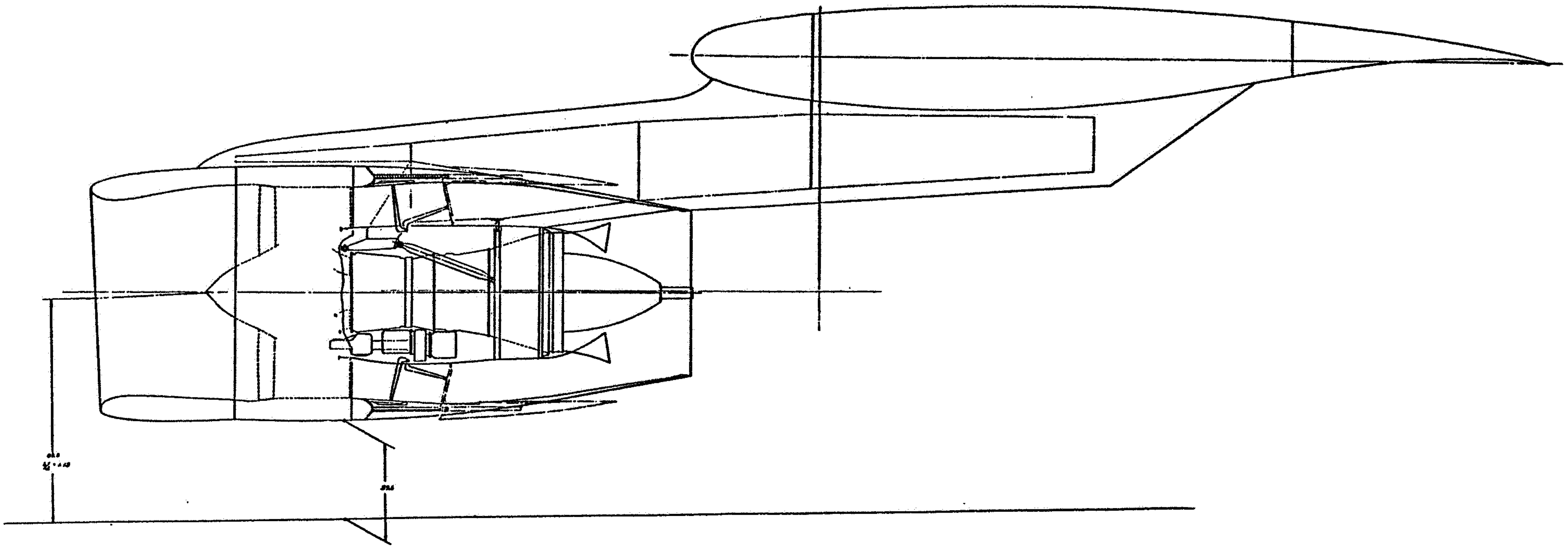

Figure C-14. Study Layout for GE E^3 Engine Installation, Core-Mounted Accessories, 0% Chord Exhaust Position.

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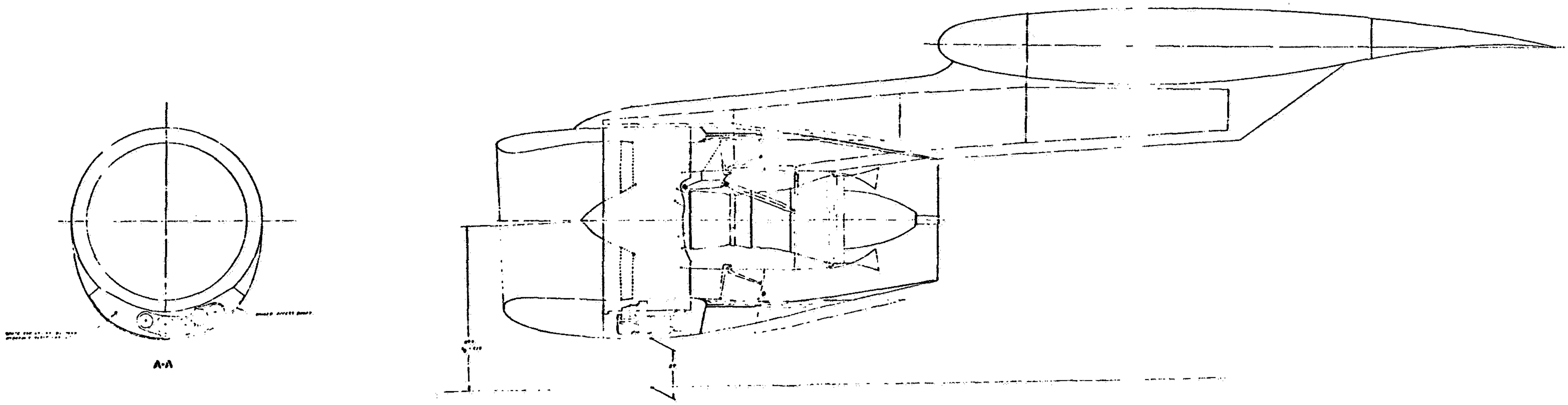

Figure C-15. Study Layout for GE E^3 Engine Installation, Fan Case-Mounted Accessories, 0% Chord Exhaust Position.

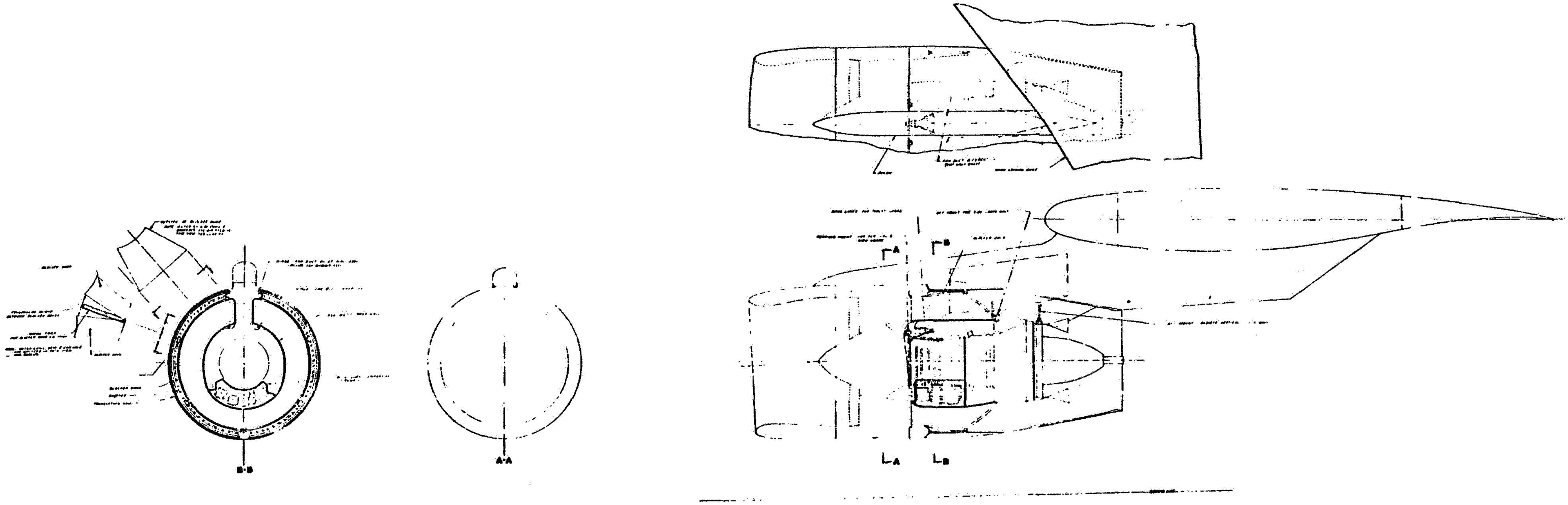

Figure C-16. Study Layout for GE E^3 Engine Installation, Core-Mounted Accessories, 15% Chord Exhaust Position.

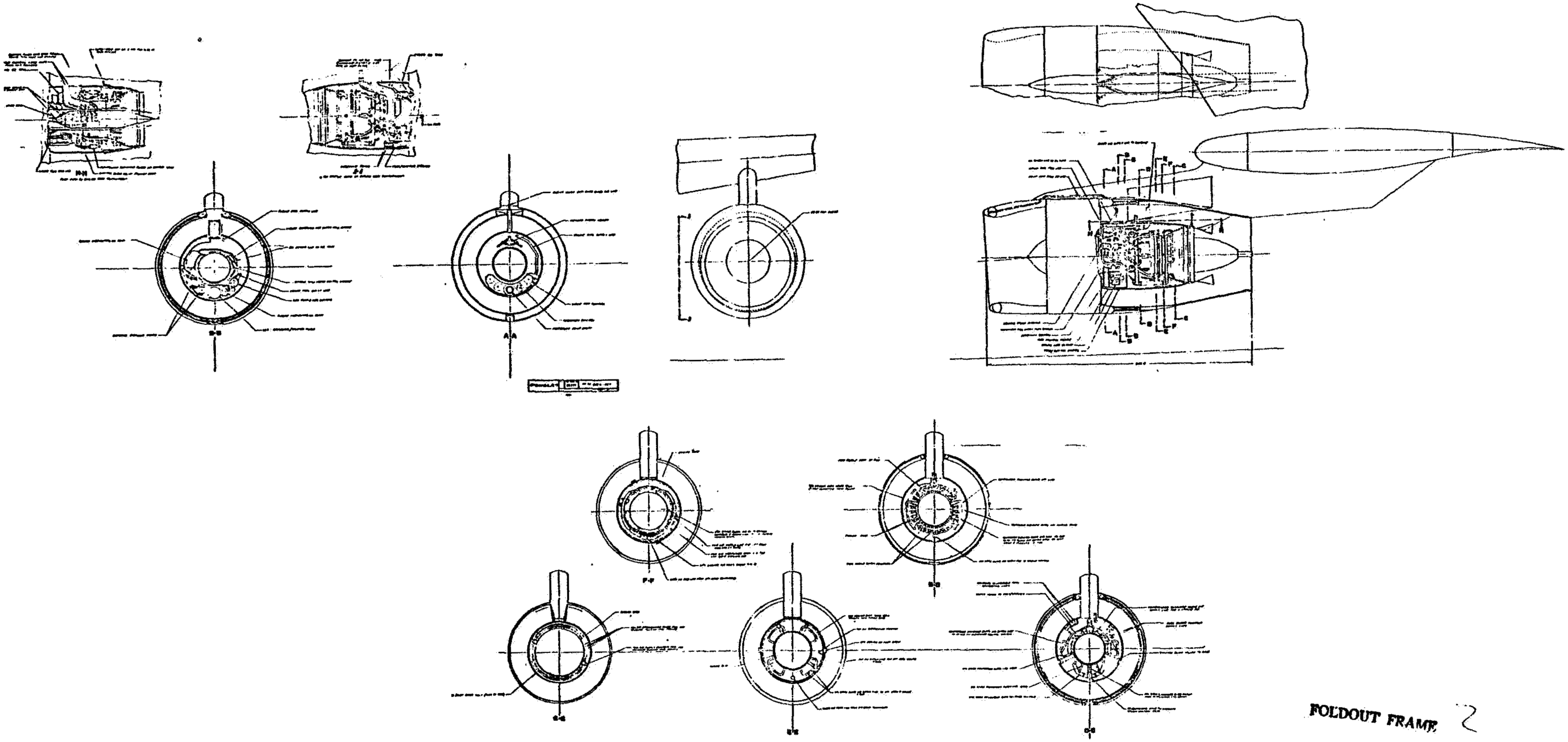

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Figure C-17. Study Layout for GE E^3 Engine Installation, Core-Mounted Accessories, 105-Inch-Diameter Nacelle.

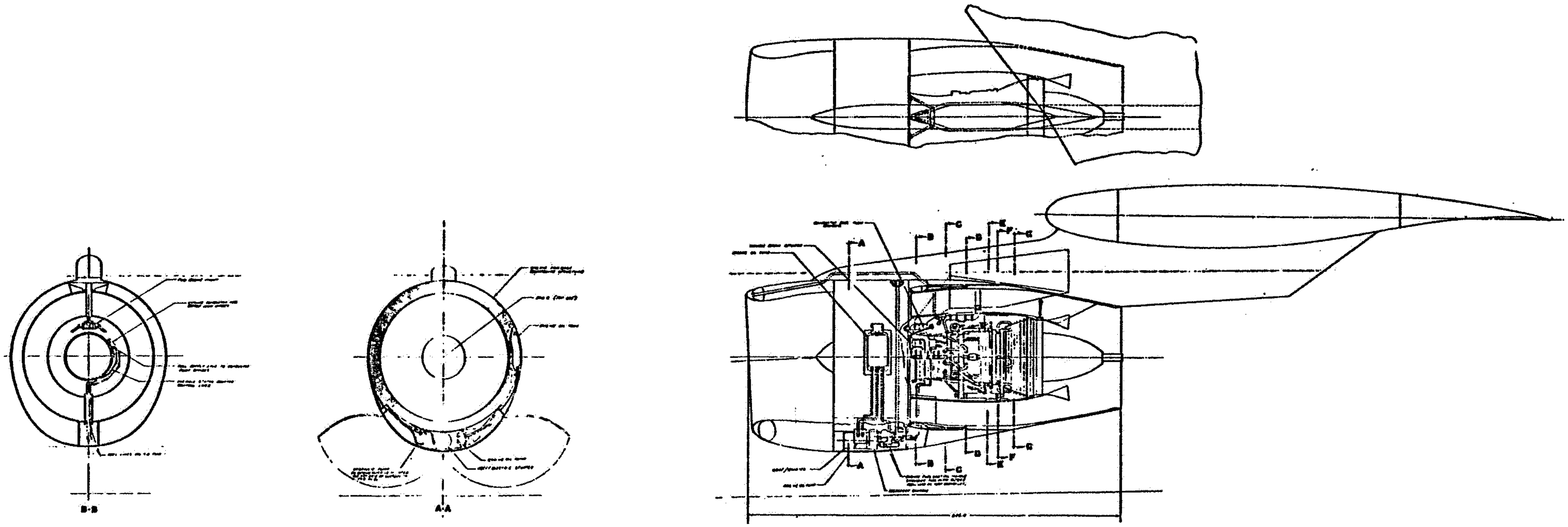

Figure C-18. Study Layout for GE E^3 Engine Installation, Fan Case-Mounted Accessories, 102-Inch-Diameter Nacelle.

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4.3.1 Final Study Configurations

The two final engine installation study layouts (Ref. PP-SK-GEE-007 and PP-SK-GEE-008) were prepared with the primary purpose of comparing the core mounted accessory design with a fan case mounted accessory arrangement. Both layouts were sufficiently detailed in regard to engine accessories and associated plumbing systems so that assessments could be made with respect to nacelle space allocations and maintainability. To serve this purpose, sufficient detail of engine and accessory plumbing and wiring runs has been shown to permit an assessment of the removal-replacement times for those engine installation components which historically have required the most frequent replacements. Since it would be impossible, within the present budget and schedule, to show all such plumbing and wiring, discretion has to be used in deciding which runs were to be shown. The rationale used, has been to show all those large diameter plumbing or cable runs which, because of their size and limited choice of location, could force the use of designs with severe penalties in accessibility to adjacent engine and accessory components. Small diameter piping and wire bundles of approximately one-half inch diameter or less can be designed with a wide latitude concerning their location and so have not been shown on the subject drawings since they should have a relatively small impact on nacelle component maintainability.

The inlet duct flow lines, primary exhaust duct flow lines and engine core configurations on both engine layouts are identical and are based on the configurations shown on G.E. drawing #4013267-011, dtd 8-24-78, scaled to 40,000 lb. thrust. For the core mounted accessory design the fan case exit diameter, the fan exhaust duct diameters and nacelle maximum outer surface diameters are greater than the corresponding values used for the fan case mounted accessory configuration. As outlined in the DAC interim E^3 report (ACEE-15-TR-9735 dtd March 1979) this diametral difference was required to accommodate realistic core compartment volumes to house the accessory package without imposing unaceptable flow restrictions in the fan exhaust ducts. This difference has the net result of both study nacelles having approximately identical wetted surface area values even though the fan case mounted accessory configuration requires an accommodating bulge to the nacelle along the bottom center-line.

The plumbing systems that directly service the engine core (i.e. combustion chamber fuel supply, variable stator servo power and active tip clearance control air supply) are also essentially identical for both study layouts and are derived from information supplied in the GE/NASA PDR of Nov. 1978 and in G.E. drawing #4013270-191 dtd 2-16-79 which depcits the ICLS configuration for customer and engine service bleed air piping.

One 120 KVA electrical generator and two 35 GPM hydraulic pumps are required on each engine on the DAC E^3 transport. In addition to these airframe accessories, the accessory gearbox must provide shaft power interfaces for engine oil pumping, engine fuel controls and engine starting functions. In the case of the core mounted accessory design, reasonable nacelle diameters could be maintained only by combining the airframe electric power generatign and engine starting fuctions into one component in the form of a VSCF/electric starter unit. This is primarily due to the increased bleed air plumbing for the active tip clearance control systems and starter bleed valves which limit the accessory envelope to the core length between the fan case support frame and the 5th stage of the high pressure compressor. With this length restriction the elimination of the air ducting to a pneumatic starter becomes one of the major advantages of the VSCF/electric starter design approach.

4.3.1.1 Core Mounted Accessory Configuration

The accessory gearbox for the core mounted accessory arrangement is shown (on drawing #PP-SK-GEE-007) smile shaped and located just aft of the fan case support bulkhead with all accessories mounted on the aft face of the gearbox. From left to right (looking aft) the accessories are mounted in the following order: fuel control module (including fuel pump and fuel/oil heat exchanger), engine oil pump, VSCF/electric starter (on engine bottom centerline in line with the gearbox input drive shaft), first hydraulic pump and second hydraulic pump. A separate N_3 tach generator is not listed above since a reading of this engine performance parameter is available from the "wild" frequency A.C. output from the VSCF. If an independent indication of N_2 speed is desired a separate Tach generator can be incorporated into the above arrangement without any notable impact on the results of this nacelle design study.

Since information regarding the required operating temperatures and heat rejection rates for the still to be designed fuel control and VSCF/electric starter units were not available, no provisions for accessory temperature controls have been shown on the subject layouts. Compartmentization of the engine accessory zone separate from the rest of the engine core compartment for ventilation purposes would force the design to a choice of either a larger nacelle diameter (with a complete rearrangement of the gearbox and component locations) or a major reduction in accessibility to both the accessories and engine core plumbing components. A more attractive approach, from the viewpoint of maximum accessibility at minimum system weight, would be to use local heat shielding to protect individual accessories from radiant heat from the engine core or bleed air ducts while directing cooling air flow onto these components from air supply ducts mounted to the inner surface of the hinged fan duct assembly. Although a quantitative assessment can not be made for this type of system without specific values for component cooling characteristics, the impact of its employment upon the nacelle lines shown on the subject layout should be minor.

A major access problem disclosed by the subject layout is at the engine core-to-pylon interface where all the engine to airframe system connections are made. Due to the G.E. nacelle concept wherein the aft edge of the hinged portion of the fan duct inner wall is 38 inches forward of the rear flange of the core case, only a 23 inch long portion of the pylon lower bulkhead is common to the engine core compartment. As shown on the layout (drawing #PP-SK-GEE3-007) considerable congestion results in this area due to the presence of the airframe-to-accessory package connections (i.e. fuel feedline, hydraulic supply lines and airframe electrical power lines) as well as the engine bleed air supply ducts to the airframe. With this arrangement, it is anticipated that a significant increase in engine removal and replacement time will result relative to the present DC-10.

4.3.1.2 Fan Case Mounted Accessory Configuration

The accessory gearbox for the fan case mounted accessory arrangement is shown (drawing #PP-SK-GEE3-008) centered below and supported by the bottom of the engine fan case. A two inch deep depression above the accessory compartment has been scalloped out of the 7 inch thick composite fan case shell to minimize the external bulge in the nacelle loft lines required to house the accessory package. Two doors, hinged to the composite fan case at the 3:30 and the 7:30 o-clock positions, and latched together along the bottom centerline form the bulged external nacelle line around the accessory compartment. The accessory gearbox is smile shaped in a manner similar to the design used for the core mounted accessory arrangment but in this case both the forward as well as the aft faces of the gearbox are employed to provide drive pads for the accessories. The engine oil pump, the VSCF/ electric starter and the No. 1 hydraulic pump are mounted to the forward face of the gearbox while the No. 2 hydraulic pump and the engine fuel control module are mounted to the aft side of the gearbox alongside of the gearbox input drive shaft. This arangement is similar to those in use on current commercial transports and provides the minimum bulge to the basic circular nacelle cross section formed by the engine composite fan case. A second scalloped-out well in the composite fan case structure is provided on the horizontal center line on the right hand side of the engine in which is housed the engine oil tank. A metal lined trough between this well and the accessory compartment on the bottom must be provided in order to provide for the oil plumbing between the tank and the engine oil pump. The metal lining would be for the purposes of fire zoning. Similar metal lined troughs must be provided between the engine accessory compartment and the top of the fan case in order to provide fire protected routes from accessory compartment and the pylon for the engine fuel feed line and for airframe hydraulic and electric power supply connections. As shown on the study drawing, the fuel feed line would be routed on the opposite side of the fan case from the other airframe connections.

Except for the absence of the accessory package, the engine core section for this configuration has been kept identical to that for the core mounted accessory configuration. Thus, differences in maintainability costs should be strictly due to the differences in accessory package location.

4.3.2 Maintenance Cost Comparison

To compare the two engine configurations for their relative maintenance costs a review of each configuration was conducted to identify those engine installation components which were uncommon in their method of installation or accessibility. The major components so identified were: the VSCF/electric starter, the two engine driven hydraulic pumps, the engine fuel control module (includes engine fuel pump), the engine oil tank, the engine combustor fuel flow divider and the variable stator actuator. Each of these components was evaluated with respect to the manpower and elapsed time required for a removal/replacement cycle for each of the two engine configurations as shown in Tables C-XII and C-XIII. The labor requirements detailed in Table C-XII and C-XIII are broken down for each component into three categories: the labor involved in gaining access to the nacelle/engine compartment area in which the component is located (see column 2), the labor involved in any

Table C-XII. Replacement Labor Study For Core Mounted Engine Accessories

COMPONENT	ACCESS PROCEDURE	SYSTEM IMPACT DUE TO COMPONENT REMOVAL	ACCESSIBILITY COMPLICATIONS	COMPONENT TO AIRPLANE INTERFACE BREAKDOWN	COMPONENT TO REPLACEMENT LABOR SUMMARY		
					ELAPSED TIME (MIN)	NUMBER OF MEN REQUIRED	MAN HOURS
VSCF/STARTER	REQUIRES OPENING OUTER AND INNER FAN DUCT DOORS (L.H. & R.H. SIDES) LABOR: 2 MEN, 20 MIN, .67 MIN-HR	1) VSCF TO ENGINE GEARBOX OIL LEAK CHECK REQUIRED 2) ELECTRICAL SYSTEM CONTINUITY CHECK REQ'D.	UNIT IS ON BOTTOM & OF ENGINE CORE AND SHOULD BE CAPABLE OF REMOVAL OF ANY OTHER COMPONENTS.	1) VSCF IS SUPPORTED FROM GEARBOX BY QUICK DISCONNECT CLAMP OR EQUIV. 2) 4 TO 7 POWER CABLES ARE ATTACHED TO THREADED TERMINAL POSTS ON VSCF 3) SMALLER WIRE CONNECTIONS FOR HIGH TEMP. WARNING AND N_2 SPEED SENSING ARE BY MEANS OF 1 OR 2 MULTI-PIN CONNECTORS. LABOR: 2 MEN, 12 MIN, .4 MIN-HR	32	2	1.07
NO. 1 HYDRAULIC PUMP	REQUIRES OPENING OUTER AND INNER FAN DUCT DOORS (R.H. SIDE ONLY) LABOR: 2 MEN, 18 MIN, .67 MIN-HR	1) LEAK CHECK AFTER REINSTALLATION	PUMP MODULE CAN BE REMOVED WITHOUT REMOVAL OF OTHER COMPONENTS	1) REMOVEABLE PUMP MODULE IS HELD TO FIXED BASE BY QUICK DISCONNECT CLAMP. FLUID CONNECTIONS TO AIRFRAME ARE MADE TO FIXED PART OF PUMP SO THAT PUMP MODULE MAY BE REPLACED WITHOUT BREAKING FLUID CONNECTIONS LABOR: 1 MAN, 4 MIN, .07 MIN-HR	22	2	0.74
NO. 2 HYDRAULIC PUMP	IDENTICAL TO NO. 1 HYD. PUMP			IDENTICAL TO NO. 1 HYD. PUMP	22	2	0.74
ENGINE FUEL CONTROL MODULE	REQUIRES OPENING OUTER AND INNER FAN DUCT DOORS (L.H. SIDE) LABOR: 2 MEN, 18 MIN, .67 MIN-HR	1) DRAIN FUEL IN LINE FROM PYLON SHUT OFF VALVE TO FUEL CONTROL & LINES FROM ENGINE CORE TO FUEL CONTROL. 2) LEAK CHECK AFTER REPLACEMENT. LABOR: 1 MAN, 5 MIN, .05 MIN-HR	ACCESS IS UNLIMITED BY OTHER ENGINE SYSTEMS. REQUIRES ADJUSTABLE HEIGHT. DOLLY TO SUPPORT COMPONENT WEIGHT DURING REMOVAL.	1) MODULE IS SUPPORTED FROM GEARBOX PAD BY QUICK DISCONNECT CLAMP. 2) APPROX. 6 FUEL LINES MUST BE DISCONNECTED. 3) 2 OIL LINES MUST BE DISCONNECTED FROM FUEL-OIL HEAT EXCHANGER 4) ONE OR MORE ELECTRICAL MULTI-PIN CONNECTORS MUST BE REMOVED LABOR: 2 MEN, 45 MIN, .80 MIN-HR	68	2	1.65

Table C-XII. Replacement Labor Study For Core Mounted Engine Accessories (Cont'd)

COMPONENT	ACCESS PROCEDURE	SYSTEM IMPACT DUE TO COMPONENT REMOVAL	ACCESSIBILITY COMPLICATIONS	COMPONENT TO AIRPLANE INTERFACE BREAKDOWN	COMPONENT REPLACEMENT LABOR SUMMARY		
					ELAPSED TIME (MIN)	NUMBER OF MEN	MAN HOURS
ENGINE OIL PUMP	REQUIRES OPENING OUTER AND INNER FAN DUCT DOORS (L.H. SIDE) LABOR: 2 MEN, 18 MIN, .67 MIN-HR	1) DRAIN OIL LINES TO PUMP 2) LEAK CHECK AFTER PUMP REPLACEMENT LABOR: 1 MAN, 5 MIN, .05 MIN-HR	PUMP CAN BE REMOVED WITHOUT DISTURBING OTHER SYSTEMS. ACCESS TO PUMP PLUMBING CONNECTIONS ARE LIMITED DUE TO PROXIMITY TO FUEL CONTROL AND ITS PLUMBING.	1) PUMP MOUNTS TO GEARBOX BY MEANS OF QUICK DISCONNECT CLAMP 2) 6 EXTERNAL LINES TO PUMP MUST BE DISCONNECTED LABOR: 1 MAN, 18 MIN, .30 MIN-HR	41	2	1.02
FUEL-OIL HEAT	ACCESS REQUIRES OPENING AND INNER FAN DUCT DOORS (BOTH DOORS) LABOR: 2 MEN, 20 MIN, .67 MIN-HR	1) FUEL CONTROL AND FUEL FEED LINE MUST BE DRAINED 2) OIL LINE TO OIL TANK MUST BE DRAINED. 3) INSTL. MUST BE LEAK CHECKED AFTER REINSTALLATION. LABOR: 1 MAN, 5 MIN .08 MIN-HR	ACCESS IS GOOD BUT CLEARANCE WITH 5TH STAGE BLEED DUCT IS LIMITED. ACCESS TO OIL LINE BETWEEN OIL PUMP AND HEAT EXCHANGER IS LIMITED.	1) HEAT EXCHANGER TO FUEL CONTROL IS BOLTED CONNECTION. 2) TWO OIL LINES (4 CONNECTIONS) REQUIRE REMOVAL. LABOR: 1 MAN, 13 MIN, .21 MIN-HR	38	2	.96
OIL TANK	REQUIRES OPENING OUTER AND INNER FAN DUCT DOORS (BOTH SIDES) LABOR: 2 MEN, 20 MIN, .67 MIN-HR	1) DRAIN OIL TANK 2) DRAIN OIL LINES TO TANK 3) LEAK CHECK AFTER REINSTALLATION LABOR: 1 MAN, 6 MIN, 0.1 MIN-HR	WORK STAND REQUIRED AS OIL TANK IS 9 FT ABOVE GROUND ON WING NACELLE. ACCESS IS LIMITED BY PROXIMITY OF HYDRAULIC FEED LINES AND ELECTRIC POWER CABLES.	1) TANK IS SUPPORTED FROM ENGINE CORE AT 4 ANCHOR POINTS (BOLTED CONNECTIONS) 2) 3 FLUID LINES MUST BE DISCONNECTED LABOR: 2 MEN, 10 MIN, .33 MIN-HR	34	2	1.10
COMBUSTOR FUEL SUPPLY FLOW DIVIDER	REQUIRES OPENING OUTER AND INNER FAN DUCT DOORS ON L.H. SIDE OF NACELLE LABOR: 2 MEN, 18 MIN, .60 MIN-HR	1) LEAK CHECK AFTER REINSTALLATION LABOR: 1 MAN, 5 MIN, .08 MIN-HR	REQUIRES LADDER FOR ACCESS (UNIT IS APPROX. 8 FT. ABOVE GROUND ON WING NACELLE). ACCESS TO CONNECTIONS IS MORE LIMITED THAN FOR FAN CASE MOUNTED ACCESSORY CONFIGURATION	1) UNIT IS SUPPORTED BY MOUNTING BRACKET ATTACHED TO CORE WITH THREADED ATTACHMENTS 2) 3 SHROUDED FUEL LINES CONNECTED TO UNIT. 3) ONE (OR MORE) MULTI-PIN ELEC. CONNECTORS MUST DISCONNECT AT UNIT. LABOR: 1 MAN, 18 MIN, .3 MIN-HR	41	2	0.98

Table C-XII. Replacement Labor Study For Core Mounted Engine Accessories (Concluded).

COMPONENT	ACCESS PROCEDURE	SYSTEM IMPACT DUE TO COMPONENT REMOVAL	ACCESSIBILITY COMPLICATIONS	COMPONENT TO AIRPLANE INTERFACE BREAKDOWN	COMPONENT REPLACEMENT LABOR SUMMARY		
					ELAPSED TIME (MIN)	NUMBER OF MEN	MAN HOURS
VARIABLE STATOR ACTUATOR	REQUIRES OPENING OUTER AND INNER FAN DUCT DOORS ON ONE SIDE OF NACELLE LABOR: 2 MEN, 18 MIN, .60 MIN-HR	1) LEAK CHECK AFTER REINSTALLATION	REQUIRES LADDER FOR ACCESS (UNIT IS 8 FT ABOVE GROUND ON WING NACELLE). ACCESS TO FUEL LINE CONNECTIONS IS MORE RESTRICTED THAN FOR FAN MOUNTED ACCESSORY CONFIGURATION.	1) UNIT IS ATTACHED TO MOUNTING BRACKET ON CORE WITH THREADED FASTENERS. 2) TWO SHROUDED FUEL LINES MUST BE DISCONNECTED FROM UNIT. 3) ACTUATOR ROD CONNECTED TO LINK WITH BOLTED ATTACHMENT. LABOR: 1 MAN, 10 MIN, 0.17 MIN-HR	28	2	0.77

NOTE: MAN-HOUR (MN-HR) VALUES SHOWN DO NOT NECESSARILY MATCH THE PRODUCT OF MANPOWER LOAD (NO. OF MEN REQUIRED) AND THE ELAPSED TIME VALUES SINCE MANPOWER LOAD VALUES IN EXCESS OF ONE INDICATE THE MAXIMUM NUMBER OF MEN REQUIRED AT ANY TIME DURING A TASK AND ARE NOT NECESSARILY CONTINUOUS VALUES FOR THE ENTIRE ELAPSED TIME TO ACCOMPLISH A TASK.

Table C-XIII. Replacement Labor Study For Core Mounted Engine Accessories

COMPONENT	ACCESS PROCEDURE	SYSTEM IMPACT DUE TO COMPONENT REMOVAL	ACCESSIBILITY COMPLICATIONS	COMPONENT TO AIRPLANE INTERFACE BREAKDOWN	COMPONENT TO REPLACEMENT LABOR SUMMARY		
					ELAPSED TIME (MIN)	NUMBER OF MEN	MAN HOURS
VSCF/STARTER	OPEN ACCESSORY COMPARTMENT DOORS ON BOTTOM OF FAN COWL LABOR: 2 MEN, 5 MIN, .13 MIN-HR	1) VSCF TO ENGINE GEARBOX OIL LEAK CHECK REQUIRED 2) ELECTRICAL SYSTEM CONTINUITY CHECK	UNIT IS ON BOTTOM & OF ENGINE CORE AND SHOULD BE CAPABLE OF REMOVAL WITH REMOVAL OF ANY OTHER COMPONENTS.	1) VSCF IS SUPPORTED FROM GEARBOX BY QUICK DISCONNECT CLAMP OR EQUIV. 2) 4 TO 7 POWER CABLES ARE ATTACHED TO THREADED TERMINAL POSTS. 3) SMALLER WIRE CONNECTIONS FOR HIGH TEMP. WARNING AND N_2 SPEED SENSING ARE BY MEANS OF 1 OR 2 MULTI-PIN CONNECTORS. LABOR: 2 MEN, 12 MIN, .4 MIN-HR	17	2	0.53
NO. 1 HYDRAULIC PUMP	REQUIRES OPENING ACCESSORY COMPARTMENT DOORS ON BOTTOM OF FAN COWL LABOR: 2 MEN, 5 MIN, .13 MIN-HR	1) LEAK CHECK AFTER REINSTALLATION	PUMP MODULE CAN BE REMOVED WITHOUT REMOVAL OF OTHER COMPONENTS	1) REMOVEABLE PUMP MODULE IS HELD TO FIXED BASE BY QUICK DISCONNECT CLAMP. FLUID CONNECTIONS TO AIRFRAME ARE WITH SELF SEALING QUICK DISCONNECT COUPLINGS THAT ARE INTEGRAL WITH MECHANICAL CONNECTION OF PUMP MODULE LABOR: 1 MAN, 4 MIN, .07 MIN-HR	9	2	0.20
NO. 2 HYDRAULIC PUMP	IDENTICAL TO NO. 1 HYD. PUMP			IDENTICAL TO NO. 1 HYD. PUMP	9	2	0.20
ENGINE FUEL CONTROL MODULE	REQUIRES OPENING ACCESSORY COMPARTMENT DOORS ON BOTTOM OF FAN COWL LABOR: 2 MEN, 5 MIN, .13 MIN-HR	1) DRAIN FUEL IN LINE FROM PYLON SHUT OFF VALVE TO FUEL CONTROL & LINES FROM ENGINE CORE TO FUEL CONTROL. 2) LEAK CHECK AFTER REINSTALLATION LABOR: 1 MAN, 5 MIN, .08 MIN-HR	ACCESS IS UNRESTRICTED. REQUIRES ADJUSTABLE HEIGHT DOLLY TO SUPPORT COMPONENT WEIGHT DURING REMOVAL	1) MODULE IS SUPPORTED FROM GEARBOX BY QUICK DISCONNECT CLAMP. 2) APPROX. 6 FUEL LINES MUST BE DISCONNECTED. 3) 2 OIL LINES MUST BE DISCONNECTED AT FUEL-OIL HEAT EXCHANGER 4) ONE OR MORE MULTI-PIN ELECTRICAL CONNECTORS MUST BE REMOVED LABOR: 2 MEN, 45 MIN, .9 MIN-HR	55	2	1.11

Table C-XIII. Replacement Labor Study For Core Mounted Engine Accessories (Cont'd)

COMPONENT	ACCESS PROCEDURE	SYSTEM IMPACT DUE TO COMPONENT REMOVAL	ACCESSIBILITY COMPLICATIONS	COMPONENT TO AIRPLANE INTERFACE BREAKDOWN	COMPONENT REPLACEMENT LABOR SUMMARY		
					ELAPSED TIME (MIN)	NUMBER OF MEN	MAN HOURS
ENGINE OIL PUMP	REQUIRES OPENING ACCESSORY COMPARTMENT DOORS ON BOTTOM OF FAN COWL LABOR: 2 MEN, 5 MIN, .13 MIN-HR	1) DRAIN OIL LINES TO PUMP 2) LEAK CHECK AFTER PUMP REPLACEMENT LABOR: 1 MAN, 5 MIN, .08 MIN-HR	ACCESS IS UNRESTRICTED	1) PUMP MOUNTS TO GEARBOX BY MEANS OF QUICK DISCONNECT CLAMP 2) 6 EXTERNAL LINES TO PUMP MUST BE DISCONNECTED LABOR: 1 MAN, 15 MIN, .25 MIN-HR	25	2	.46
FUEL-OIL HEAT EXCHANGER	REQUIRES OPENING ACCESSORY COMPARTMENT DOORS ON BOTTOM OF FAN COWL LABOR: 2 MEN, 5 MIN, .13 MIN-HR	1) FUEL FEED LINE MUST BE DRAINED 2) OIL LINE TO OIL TANK MUST BE DRAINED. 3) INSTL. MUST BE CHECKED AFTER REINSTALLATION LABOR: 1 MAN, 5 MIN, .08 MIN-HR	ACCESS IS UNRESTRICTED	1) HEAT EXCHANGER TO FUEL CONTROL IS BOLTED CONNECTION. 2) TWO OIL LINES (4 CONNECTIONS) REQUIRE REMOVAL. LABOR: 1 MAN, 12 MIN, .20 MIN-HR	22	2	.41
OIL TANK	REQUIRES REMOVAL OF BOLTED ON DOOR ON SIDE OF FAN CASE LABOR: 1 MAN, 5 MIN, .08 MIN-HR	1) DRAIN OIL TANK 2) REFILL OIL LINES 3) LEAK CHECK AFTER REINSTALLATION LABOR: 1 MAN, 5 MIN, 0.8 MIN-HR	REQUIRES WORKSTAND OR LADDER FOR ACCESS	1) TANK IS SUPPORTED FROM FAN CASE BY THREADED ATTACHMENTS 2) 3 FLUID LINES MUST BE DISCONNECTED LABOR: 1 MAN, 10 MIN, .16 MIN-HR	19	2	.32
COMBUSTOR FUEL SUPPLY FLOW DIVIDER	REQUIRES OPENING OUTER AND INNER FAN DUCT DOORS ON L.H. SIDE OF NACELLE LABOR: 2 MEN, 18 MIN, .60 MIN-HR	1) LEAK CHECK AFTER REINSTALLATION LABOR: 1 MAN, 5 MIN, .08 MIN-HR	REQUIRES LADDER FOR ACCESS (UNIT IS APPROX. 8 FT. ABOVE GROUND ON WING NACELLE).	1) UNIT IS SUPPORTED BY MOUNTING BRACKET ON ENGINE CORE WITH THREADED FASTENERS 2) 3 SHROUDED FUEL LINES CONNECTED TO UNIT. 3) ONE (OR MORE) MULTIPIN ELEC. CONNECTORS UNIT. LABOR: 1 MAN, 16 MIN, .27 MIN-HR	39	2	0.95

Table C-XIII. Replacement Labor Study For Core Mounted Engine Accessories (Concluded).

COMPONENT	ACCESS PROCEDURE	SYSTEM IMPACT DUE TO COMPONENT REMOVAL	ACCESSIBILITY COMPLICATIONS	COMPONENT TO AIRPLANE INTERFACE BREAKDOWN	COMPONENT REPLACEMENT LABOR SUMMARY		
					ELAPSED TIME (MIN)	NUMBER OF MEN	MAN HOURS
VARIABLE STATOR ACTUATOR	REQUIRES OPENING OUTER AND INNER FAN DUCT DOORS ON ONE SIDE OF NACELLE LABOR: 2 MEN, 18 MIN, .60 MIN-HR	1) LEAK CHECK AFTER REINSTALLATION	REQUIRES LADDER FOR ACCESS (UNIT IS 8 FT ABOVE GROUND ON WING NACELLE).	1) UNIT IS ATTACHED TO MOUNTING BRACKET ON CORE WITH THREADED FASTENERS. 2) TWO SHROUDED FUEL LINES MUST BE DISCONNECTED FROM UNIT. 3) ACTUATOR ROD CONNECTED TO LINK WITH BOLTED ATTACHMENT. LABOR: 1 MAN, 8 MIN, 0.13 MIN-HR	26	2	0.73

NOTE: MAN-HOUR (MN-HR) VALUES SHOWN DO NOT NECESSARILY MATCH THE PRODUCT OF MANPOWER LOAD (NO. OF MEN REQUIRED) AND THE ELAPSED TIME VALUES SINCE MANPOWER LOAD VALUES IN EXCESS OF ONE INDICATE THE MAXIMUM NUMBER OF MEN REQUIRED AT ANY TIME DURING A TASK AND ARE NOT NECESSARILY CONTINUOUS VALUES FOR THE ENTIRE ELAPSED TIME TO ACCOMPLISH A TASK.

system preparation for comonent removal or post replacement system checkouts (see column 3), and the labor involved in physically dismounting/remounting each component to the engine (see column 5). A summary of the column 2, 3 and 5 labor factors for each component is tabulated in column 6 on each table. These totals represent the non-routine maintenance labor performed in replacing a listed component if it is suspected of being failed.

An estimate of the maintenance cost impact of the core located accessories versus the fan case location for unscheduled removals can be obtained by using the labor values in Tables C-XII and C-XIII to calculate estimated costs due to unscheduled component removals as summarized in Table C-XIV.

The labor (man hours) and elapsed time values shown in Table C-XIV are taken from Tables C-I and C-II. The labor costs were calculated by using a labor cost rate of \$11.00 per man hour to which is added a maintenance burden cost equal to 1.8 times the labor cost. The cost due to dispatch delay is taken from the costs shown in NASA Report CR-12113, Vol. II, dtd March 1973 ("An Airline Study of Advanced Technology Requirements For Advanced High Speed Commercial Transport Engines," by G. Phillip Sallee) for the DC-10 and factored by 1.4429 to adjust the amounts for inflationary effects for the 1973 to 1979 time period. This factor is based on the U.S. Department of Commerce Index for government and industry costs. The component unscheduled replacement rates are based on data accumulated by the Douglas Aircraft Company Reliability Engineeering Group for similar engine installed components of the DC 10-30 aircraft for the years of 1976 and 1977. In the cases of the VSCF/electric starter and the engine combustor fuel flow divider in which there were no previous experience to go by, estimates were made on experience with engine components of similar mechanical complexity. For the core mounted accessories that are not uncommon to both engine configurations, two sets of replacement rates are shown; one set which is identical to the set supplied to cost calculations for the fan mounted accessory configuration and a second set which is 10% greater than comparable values in the first set. This second set of unscheduled replacement rates was used along with the first set in order to evaluate sensitivity in costs to the shorter life that could occur due to locating accessories in the more severe temperature environment found in the engine compartment. As shown in Table X-III, a comparison of costs for the fan mounted accessory configuration with the costs (at the accelerated replacement rate) for the core mounted accessory configuration show the later to be \$.045 greater per engine flight hour. This value is only for eight listed components and as such is probably indicative of only half of the resulting cost difference if all the affected components were to be assessed in the choice between accessory package locations. An examination of the Table C-XIV cost breakdown shows that the "cost due to dispatch delay" is the major contributor to the replacement cost total for each component. This cost is an account of increased crew wages and passenger rescheduling expenses, etc. resulting from equipment delays and is not typically counted-in as line maintenance cost in standard DOC calculations. As a result of this study, a \$0.90 per engine flight hour cost difference for the core mounted accessory location relative to the fan case location is indicated as an order of magnitude cost difference estimate for the shop and line maintenance cost due to unscheduled removals only.

Table C-XIV. Cost Comparison of Maintenance Labor Costs for Unscheduled Removals for Fan Case-Mounted Accessories Vs. Core-Mounted Accessories, General Electric E^3 Engine Installation.

COMPONENT	ACCESS'Y CONFIG.	ELAPSED TIME (MINUTES)	MAN-HOURS	LABOR COST (WITH BURDEN)	COST DUE TO DISPATCH DELAY	COST OF COMPONENT REMOVAL	COMPONENT UNSCHEDULED REMOVAL RATE (NO./1000 FT-HRS)	REMOVAL COST PER 1000 FLT-HRS		
								ACCESSORY CONFIGURATION		
								FAN MTD	CORE MTD	CORE MTD ASSEY REMOVED
VSCF	FAN CORE	17 32	0.53 1.07	16.32 32.96	202.01 505.03	218.33 537.99	.1436 .1436 .1596	31.35	77.26	85.86
HYDRAULIC PUMP	FAN CORE	9 22	0.20 0.74	6.16 22.79	202.01 202.01	208.17 224.80	.2755 .2755 .3060	57.35	61.93	68.79
FUEL CONTROL	FAN CORE	55 68	1.11 1.65	34.19 50.82	505.03 2070.63	539.22 2121.45	.1536 .1536 .1707	82.82	325.85	362.13
OIL PUMP	FAN CORE	25 41	0.46 1.02	14.17 31.42	202.01 505.03	216.18 536.45	.1400 .1400 .1556	30.27	75.10	83.47
FUEL/OIL HEAT EXCHANGER	FAN CORE	22 38	0.41 0.96	12.63 29.57	202.01 505.03	214.64 534.60	.0059 .0059 .0066	1.27	3.15	3.53
OIL TANK	FAN CORE	19 34	0.32 1.10	9.86 33.88	202.01 505.03	211.87 538.91	.0801 .0801 .0890	16.97	43.17	47.96
COMBUSTOR FUEL FLOW DIVIDER	FAN CORE	39 41	0.95 0.98	29.26 30.18	505.03 505.03	534.29 535.21	.1500 .1500 .1667	80.14	80.28	89.22
VARIABLE STATOR CONTROL ACTUATOR	FAN CORE	26 28	0.73 0.77	22.48 23.72	202.01 202.01	224.49 225.73	.1500 .1500 .1667	33.67	33.86	37.63
Unscheduled Replacement Cost Total Per 1000 Flt-Hr/Eng.								$333.84	$700.60	$778.59
Unscheduled Replacement Cost Total Per Flt-Hr/Eng.								$ 0.33	$ 0.70	$ 0.78

ΔCost for Core Accessories vs. Fan Case Accessories (Equal Repl. Rate) = $0.37 Per Flt. Hr. Per Engine

ΔCost for Core Accessories (Accelerated Repl. Rate) vs. Fan Case Accessories = $0.45 Per Flt. Hr. Per Engine

In addition to scheduled maintenance cost differences, some other considerations related to accessory location that have not been qualified are:

1: Effect on accessory component life.
2: Higher initial costs when a new nacelle/engine is introduced since the above are based on a mature installation.
3: Effect on engine maintenance cost because of increased teardown and build up costs
4: Installation cost
5: Installation development cost.

It is concluded that an accessory location option should be maintained pending more in depth studies.

4.4 REGENERATIVE FUEL HEAT SYSTEM STUDY

The principle incentive for a regenerative fuel heating system is to transfer unwanted heat from the bleed air supply for the airframe environmental control system to the fuel being supplied to the engine with the prospect of improving (decreasing) the engine SFC values at cruise. In addition, elimination of the fan air bleed that would otherwise be needed at cruise, should also result in an SFC reduction. A study of these potential SFC improvements on the E^3 candidate airplane was conducted using the following design constraints:

1. The heat transfer loop between the bleed air and the fuel system should be through an intermediate, non toxic fluid such as water to minimize the chance of air conditioning contamination with fuel vapor.
2. Fuel temperature should not exceed 275°F.
3. Air pressure loss in water/air heat exchanger <0.5 psi.
4. Engine bleed at entry to the environmental control system (ECS) is not to be less than 300°F. This temperature is called the ECS Set Point (ECSSP).

A schematic of the G.E. candidate system is shown in Figure C-19.

4.4.1 Design Philosophy

Figure C-19 shows an overall system schematic while a preliminary control system logic schematic is shown in Figure C-20. The system is designed to be optional. It has been found that the regenerative system can not be operated at idle descent as fuel temperatures are already close to 275°F with a conventional system due to the heat rejection from the engine oil cooler. The ECS Set Point (ECSSP) temperature is usually 440°F to facilitate hot air wing anti-icing. Without wing anti-icing, the ECSSP temperature has been chosen at 300°F. The lower the ECSSP, the greater the heat available to the regenerative system for heat transfer into the fuel supplied to the engine. The conventional system of switching from the IP bleed to engine HP compressor delivery bleed at low throttle settings is retained since the problem of ECS operation at low bleed pressures and temperatures still exist. The low throttle settings are coincident with high fuel temperatures, therefore, the regenerative system only operates with I.P. bleed air. Bypasses around the bleed/air/water and the fuel/water heat exchangers are included for those operational modes when the regenerative system is not in operation.

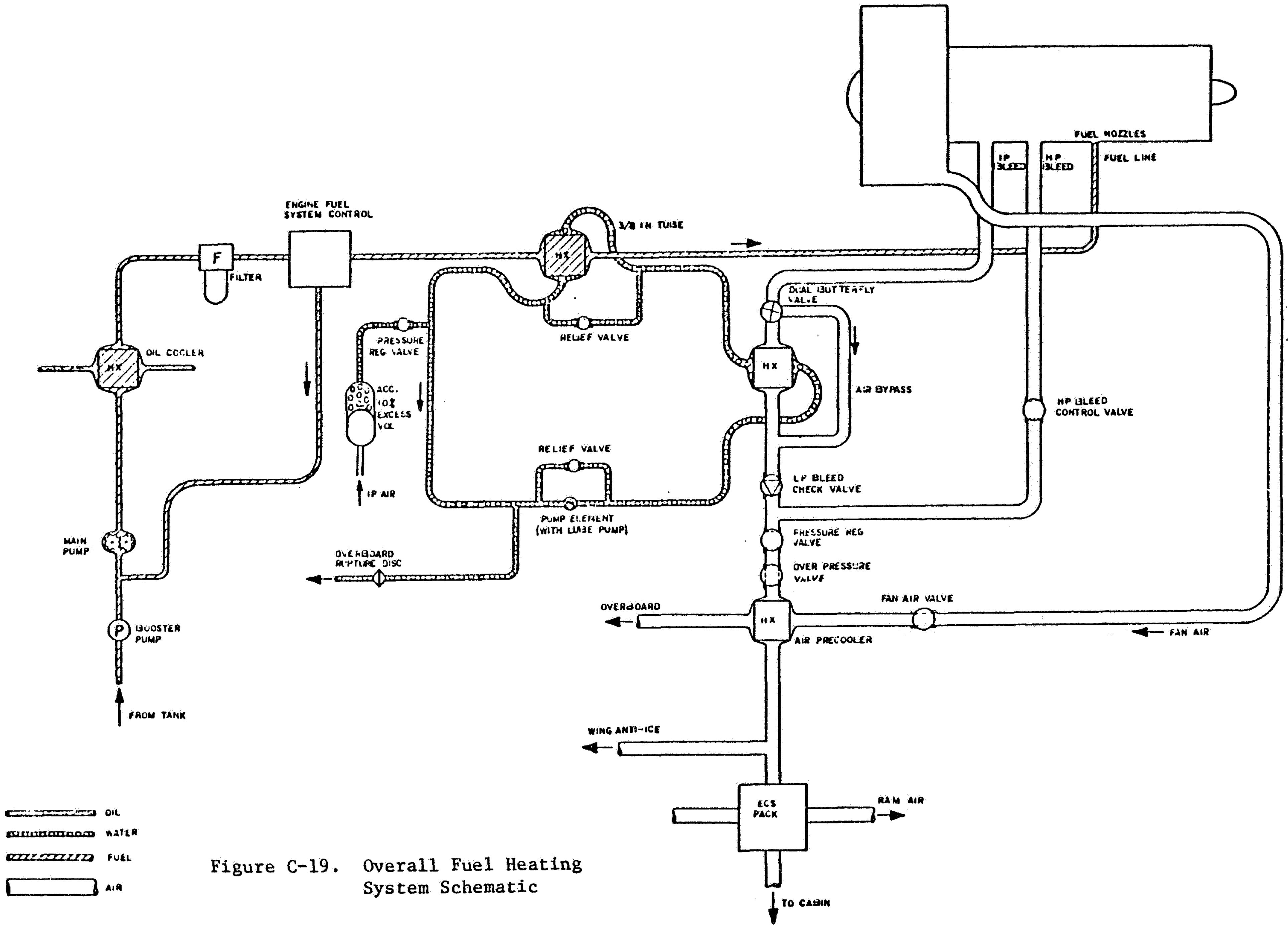


Figure C-19. Overall Fuel Heating System Schematic

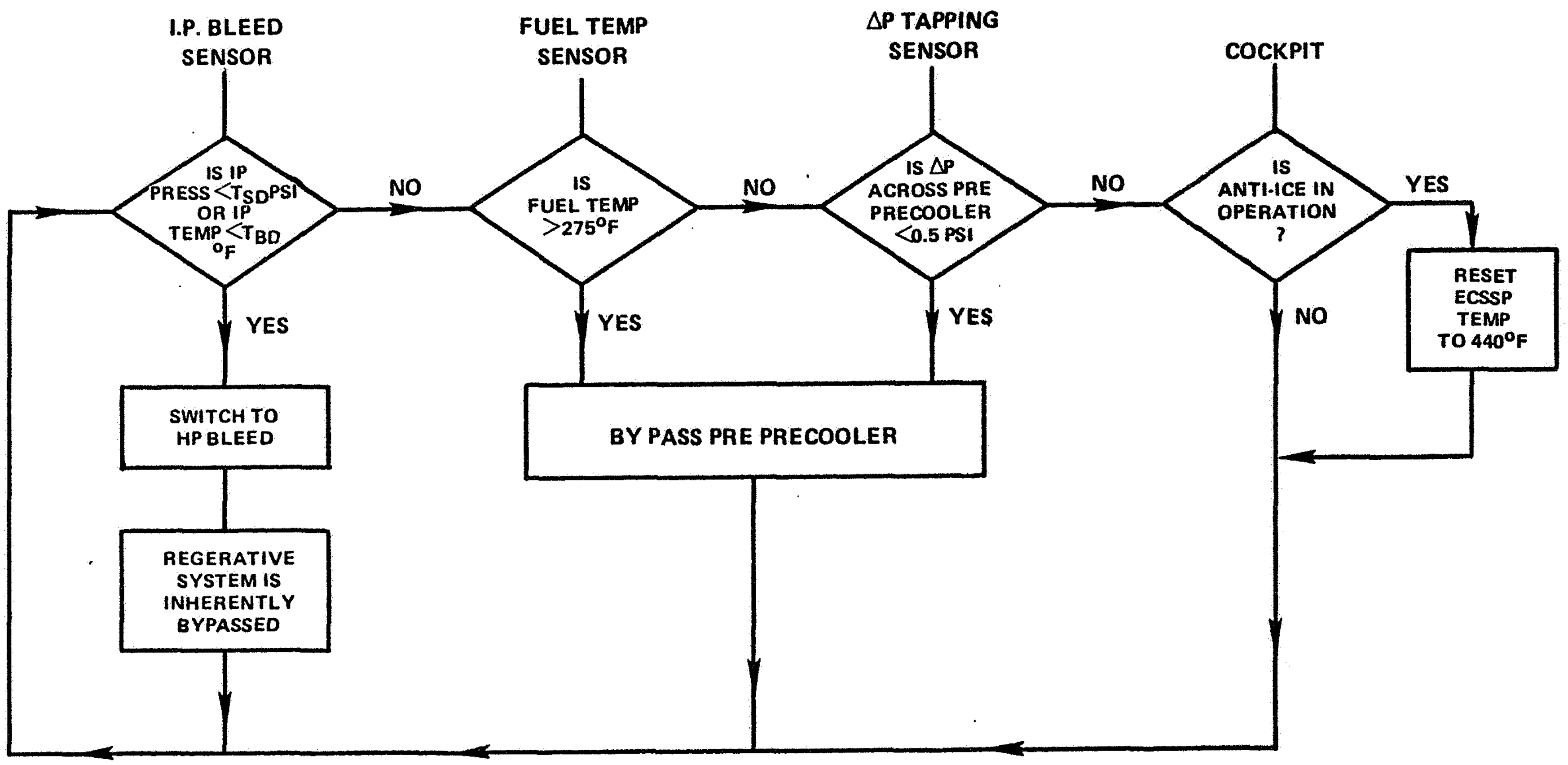


Figure C-20. Preliminary Fuel Heating System Schematic

4.4.2 Aircraft Configuration Studied

The study was concentrated on the E^3 candidate aircraft sized to a minimum takeoff weight of 499,000 lb. which has 3 engines in a DC10-30 arrangement. E^3 bleed quantities were estimated in proportion to the number of passengers with a recirculating ECS system designed for 55% recirculation. It was assumed that cabin bleed flows remained constant throughout a flight, and that the aircraft had one air conditioning pack per engine in operation.

4.4.3 Fuel Temperature Characteristics

Estimates for the E^3 airplane oil cooler fuel outlet temperatures were made from DC10 test data. These temperatures varied according to flight condition, engine power setting, fuel tank temperature and ambient temperature. With the regenerative system operating, the permissible fuel temperature rise would be 275°F minus FOCO, where FOCO is the oil cooler fuel outlet temperature.

4.4.3.1 Descent and Start of Cruise

Engine oil cooler temperature data for a tyical DC10 flight profile for a standard plus 18°F day with an initial fuel tank temperature of 120°F is shown on Figure C-21. According to this data, the oil cooler fuel outlet temperature at cruise initiation would be 218°F, while an Idle Descent condition would produce an oil outlet fuel temperature of 275°F. With this Idle Descent temperature, the regenerative system would have to be shut off to avoid exceeding the maximum fuel temperature limit (275°F). Test data for Standard Day conditions indicate that the FOCO temperature at start of cruise would be 153°F which would allow a 122°F fuel temperature rise due to regenerative system heating.

4.4.3.2 Regenerative System Operation At Cruise

Table C-XV shows the fuel temperature rise for the various options, cruise at M=0.8, 35,000 ft; ISA with a preheat FOCO of 153°F. Where the resultant fuel temperature is less than 275°F, the regenerative system would be operating continuously; to obtain optimum benefit from regenerative heating, the design aim should be to achieve 275°F fuel temperature in the cruise mode since cruise constitutes the greatest proportion of the flight profile. DC10 flight test data indicate that 6°F decrease in FOCO temperature can be expected over the duration of cruise due to cooling of the wing tank fuel temperatures. For the E^3 candidate aircraft with 55% ECS recirculation, the regenerative system could be operated without interruption throughout cruise with a maximum experienced fuel temperature of 271°F.

4.4.3.3 Engine Throttling Effects

As the aircraft gets lighter during prolonged cruise, the engines are throttled back. The effect of partial cruise thrust settings on engine fuel flow and regenerative system heat input is shown in Figure C-22 while Figure C-23 shows the resultant fuel temperature as a function of % max cruise thrust. A reduction of 5% fuel flow corresponds to a 5% reduction of cruise thrust and a 4°F increase in regenerative heating fuel temperature rise will in turn be offset by the lower FOCO temperature due to wing tank cooling

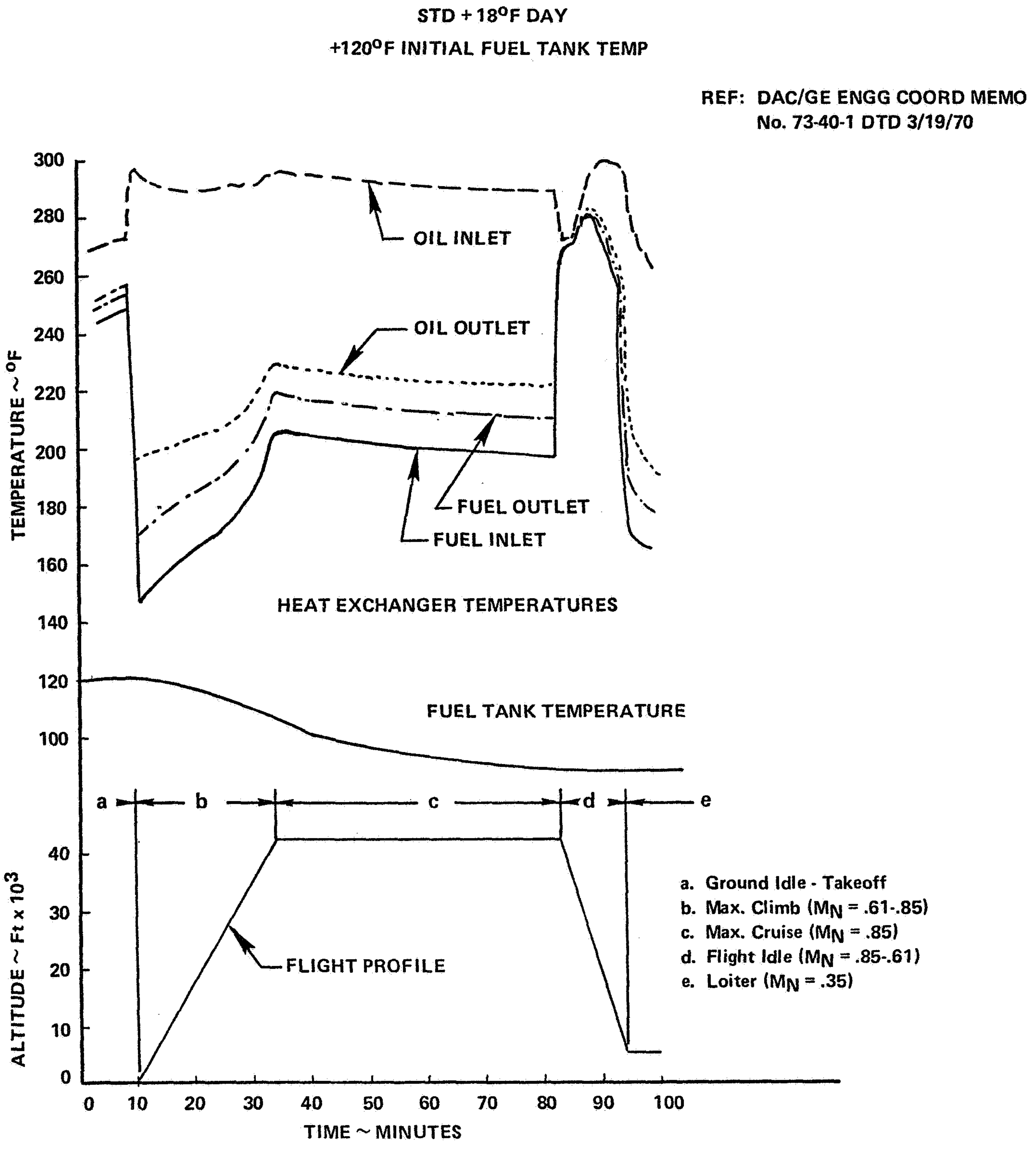


Figure C-21. Fuel/Engine Oil Temperature Profile

Table C-XV. Performance Summary For Regerative Fuel Heating System On DAC Candidate E^3 Engine Transport

RATED TAKEOFF THRUST LB (PER ENGINE)	41360			
MAX. TAKEOFF WEIGHT LB	499000			
MAX. CRUISE FUEL FLOW PER ENG. FOR Mn = 0.8, 35K ALT. LB/HR	4814			
I.P. BLEED TEMP. °F	534			
H.P. BLEED TEMP. °F	860			
H.P. DELIVERY PRESS. PSIA	151			
TYPE OF AIR CONDITIONING	100% NORMAL		55% RE-CIRCULATE	
BLEED AIR FLOW PPS	3.15		1.41	
ENVIRONMENTAL CONTROL SET POINT (ECSSP TEMP) °F	440	300	440	300
FUEL TEMP. RISE DUE TO REGENERATIVE HEATING °F	151	264	68	118
ESTIMATED FUEL TEMP. AFTER PRE-HEATING °F	304	417	221	271

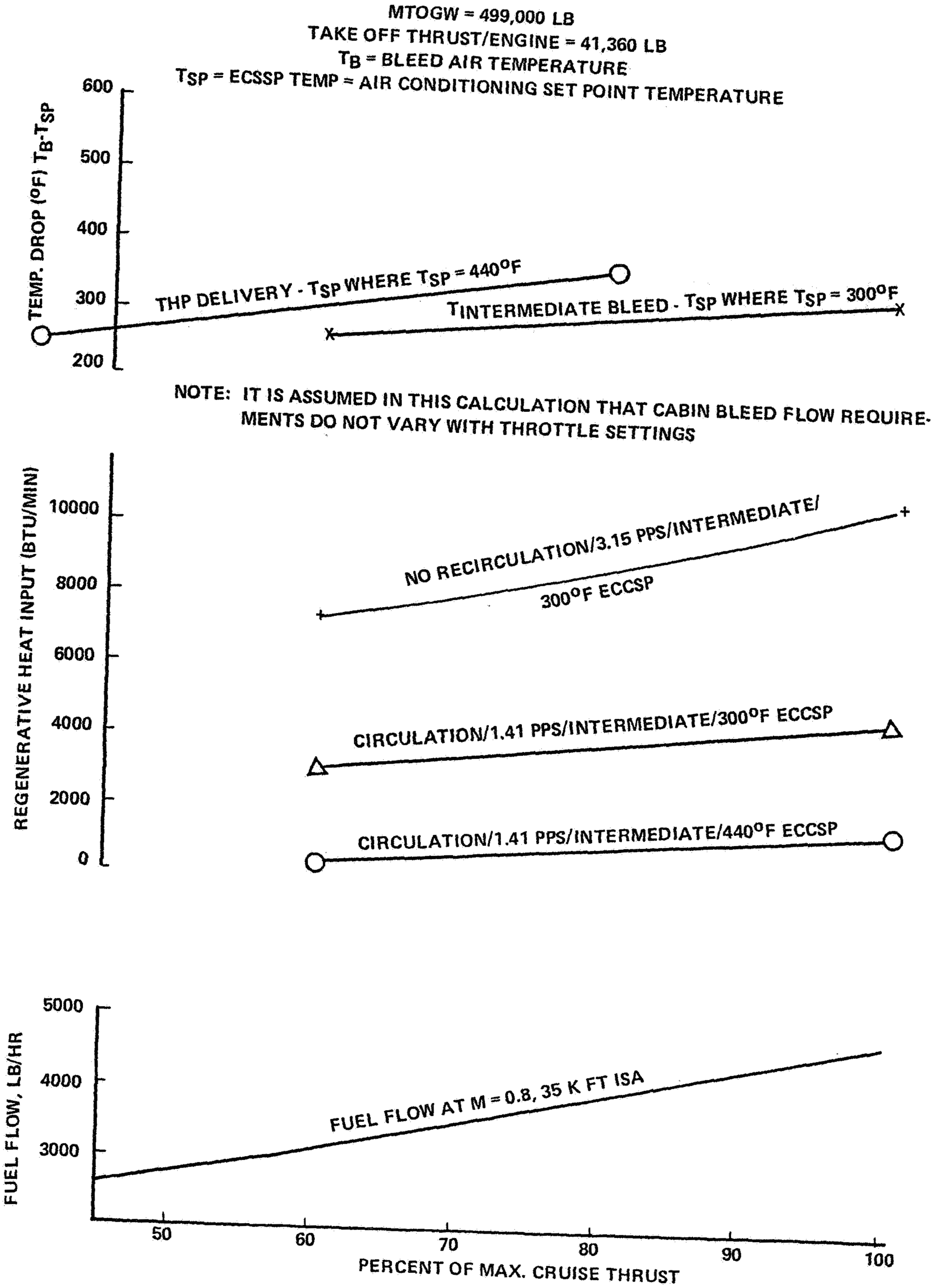
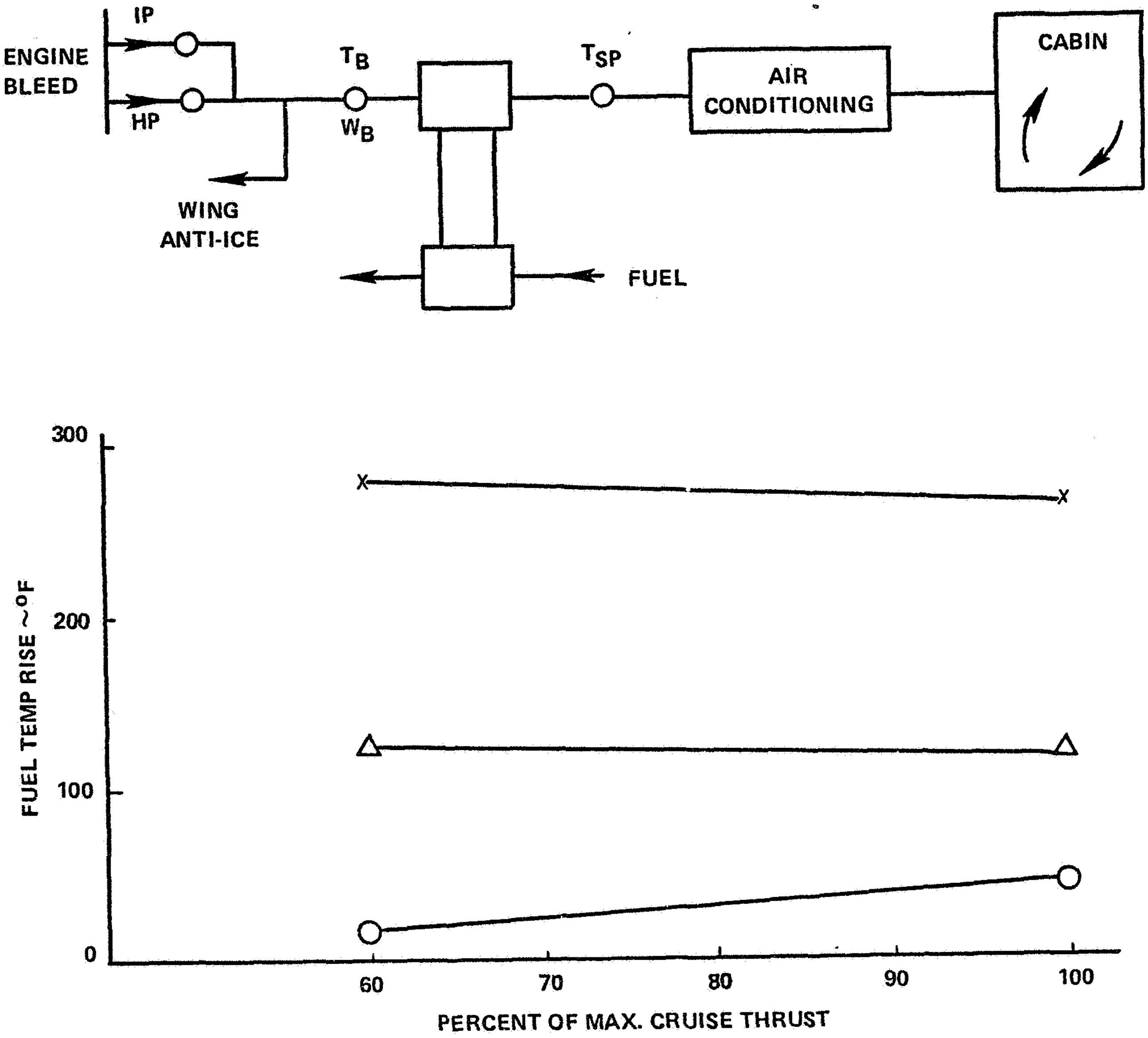


Figure C-22. Effect of Throttling Back on Fuel Flow

MTOGW = 499,000 LB
TAKE OFF THRUST/ENGINE = 41,360 LB
T_B = BLEED AIR TEMPERATURE
T_{SP} = ECSSP TEMP = AIR CONDITIONING SET POINT TEMPERATURE
W_B = ENGINE BLEED NOT INCLUDING ANTI-ICE



$$\text{FUEL TEMP RISE (°F)} = \frac{\text{HEAT INPUT (BTU/MIN)}}{\text{FUEL FLOW (LB/HR)}} \times \frac{60}{0.5}$$

Figure C-23. Effect of Throttling Back on Fuel Temperature (described in Para. 4.4.3.2) so that the absolute value of the fuel temperature at the regenerative heater outlet will substantially remain constant over the entire range of cruise thrust settings with no change in potential SFC savings as cruise progresses.

4.4.4 Cruise SFC Savings Calculations

% SFC Saving purely due to fuel pre-heating

$$\frac{WF \times \Delta TF \times Cpf}{WF \times EHV} = \frac{WB \times (TB - T_{ECSSP}) \times Cpb}{WF \times EHV} \quad - (1)$$

WB	-	Bleed Flow	LB/MIN
WF	-	Fuel Flow	LB/MIN
ΔTF	-	Pre Heat Fuel Temp Rise	Degree F
Cpf	-	Specific Heat of Fuel	BTU/LB/ Degree F
Cph	-	Specific Heat of Bleed Air	BTU/LB/ Degree F
EHV	-	Effective Heating Value of Fuel	BTU/LB
T_B	-	Bleed Temperature	Degree F
T_{ECSSP}	-	Environmental Control System Set Point	Degree F

FROM (1)

$$\Delta T_F = \frac{W_B}{W_F} \times (T_B - T_{ECSSP}) \times \frac{Cpb}{Cpf} \qquad (2)$$

Examining Table 1

It must be remembered that for the E^3 engine, SFC savings are possible due to three reasons:

1) DIRECTLY DUE TO IMPROVED TECHNOLOGY

A basic initial SFC improvement due to a more economical engine.

2) DIRECTLY DUE TO RECIRCULATION

Recirculation reduces cabin bleed by 55% which
(a) reduces SFC due to reduced cabin bleed
(b) reduces SFC due to the associated reduction in fan precooler bleed as a consequence of the reduction in intermediate bleed flow.

3) DIRECTLY DUE TO REGENERATOR

a) the preheating fuel temp rise is greater since the fuel flow to receiver each BTU of bleed heat is reduced.
b) the SFC reduction due to the elimination of fan precooler bleed when the regenerator operates.

This report is concerned only with the savings due to reason 3).

CALCULATION OF SFC SAVINGS

Savings directly due to fuel pre-heating have been estimated by ratioing the pre-heat of the fuel to a fuel effective heating value, thrust is assumed constant and a specific heat of 0.5 for the fuel was assumed, i.e. from (1)

$$\% \text{ SFC saving} = \frac{\Delta T_F \times C_{pf}}{EHV}$$

QUOTED BELOW ARE SFC SAVINGS FOR REASON (3):

(A) WITH CABIN RECIRCULATION ECSSP TEMP = 300 DEGREE F MAX CRUISE RATING

SFC SAVING DIRECTLY DUE TO FUEL PREHEATING	$\frac{118 \times 0.5}{18525} = 0.32\%$
SFC SAVING DUE TO REDUCTION IN PRECOOLER FAN BLEED WITH REGENERATOR	0.06%
IN OPERATION TOTAL SFC REDUCTION DIRECTLY DUE TO REGENERATOR	0.38%

(B) THE MAXIMUM SFC SAVING DIRECTLY DUE TO THE REGENERAOR

Assuming a FOCO of 153 degree F and a fuel temperature after the regenerator of 275 degree F, the maximum SFC saving directly due to the regenerator is:

$$\frac{122 \times 0.5}{18525} = 0.33\%$$

and 1 degree F in fuel temperture rise reduces the SFC by:

$$\frac{0.33}{122} = 0.0027\%$$

4.4.5 Regenerative Fuel Heat Study Conclusions

An SFC improvement can be gained by incorporation of the subject system on the order of 0.3% to 0.5%. The use of such a system would not permit the elimination, or reduction in size, of the bleed air precooler used in current airframe designs to limit bleed air temperatures for environmental control system use. A more detailed definition of Regenerative Fuel Heating System complexity weight and cost, referenced to specific airframe designs, is required before a final conclusion can be made regarding the desirability of such a system.