NASA CONTRACTOR REPORT 166138

A Study to Define the Research and Technology Requirements for Advanced Turbo/Propfan Transport Aircraft

I. M. Goldsmith

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A Study to Define the Research and Technology Requirements for Advanced Turbo/Propfan Transport Aircraft

I. M. Goldsmith
McDonnell Douglas Corporation
Douglas Aircraft Company
Long Beach, California 90846

Prepared for
Ames Research Center
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NASA
National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

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FOREWORD

This document presents the results of a contract study (NAS2-10178) for the National Aeronautics and Space Administration (NASA) by Douglas Aircraft Company, McDonnell Douglas Corporation. This work is part of the Propfan program in the overall Aircraft Energy Efficiency (ACEE) program of which Max Klotzsche is the Douglas Program Manager. The Douglas Project Manager of the Advanced Turbofan Projects is Irene M. Goldsmith. The NASA technical monitor for the contract is Jeffrey Bowles of the V/STOL Systems Technology Branch, NASA Ames Research Center. The overall direction and coordination of the Advanced Turboprop Program (ACEE) is provided by NASA Lewis.

This broad brush treatment concerns the Douglas DC-9 Super 80 Propfan Feasibility study in which emphasis is placed on practical engineering aspects of the propfan installations. The following Douglas personnel from the key engineering discipline groups have made major contributions to this study.

E. S. Rutowski	Chief Technology Engineer, Special Programs Aerodynamics
H. R. Welge	Unit Chief - Advanced Aircraft Design Aerodynamics
R. W. Hahn	Section Chief - Advanced Aircraft Design Performance
R. E. Adkisson	Section Chief - Design Structural Advanced Design
G. V. Deneff	Section Chief - Analysis Structural Advanced Design
R. E. Pearson	Dynamics/Structural Mechanics
H. L. Leve	Section Chief - Structural Analysis/ Dynamic Response
F. S. La Mar	Project Engineer - Power Plant
D. E. DeLaney	Acoustic Design Requirements
B. W. Kimoto	Advanced Weight Engineering
M. M. Platte	Branch Chief - Technology Systems Analysis
M. T. Eshelman	Maintenance Data Analysis/Product Support
J. A. Stern	Chief Compatibility Engineer - Airlines
R. A. Wright	Unit Chief - Technology Configuration Design

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SECTION 1

SUMMARY AND CONCLUSIONS

The work performed by Douglas Aircraft Company, under contract No. NAS2-10178 with NASA Ames, is summarized herein and concerns the feasibility of the propfan relative to the turbofan using the Douglas DC-9 Super 80 DS-8000 as the actual operational base aircraft. The base case propfan propulsion system assumes an Allison PD370-22A scaled turboshaft engine and an eight-blade, 800-ft/sec (244 m/sec) tip speed propfan as defined in the Hamilton Standard Data Package. This broad brush study considers the 155-passenger economy-class aircraft (31,775-lb [14,413 kg] payload), M_{cruise} at 0.80 at 31,000-ft (9449 m) initial altitude, and an operational capability compatible with 1985.

After a preliminary configuration concept survey, three propfan arrangements are selected as the basic propfan aircraft for comparison with the present DC-9 Super 80 P&WA JT8D-209 turbofan powered aircraft. The propfan arrangements selected are the wing-mount, conventional horizontal tail aft-mount, and aft fuselage pylon-mount configurations.

This study differs from several previous propfan/turbofan "paper airplane" comparisons in that the emphasis of the work performed under contract is placed on practical engineering aspects by (1) using an actual flying aircraft as a base, and (2) investigating the major aircraft engineering discipline areas incurred by a propfan installation.

The technical evaluation considers the configuration feasibility, aerodynamics, propulsion, structural loads, structural dynamics, sonic fatigue, acoustics, weights, maintainability, performance, rough-order-of-magnitude (ROM) economics, and airline coordination. All inputs of the various engineering disciplines are integrated through the configuration, the weights analysis, and the results presented in terms of performance and economics. The propfan aircraft performance results are evaluated in terms of increments or decrements from the base case DC-9 Super 80 turbofan.

In addition to the evaluation of the base case propfan configurations, sensitivity studies considering effects of alternate cruise Mach number, mission stage lengths including a multi-hop mission, and propfan characteristics such as number of blades, tip speed/disc loading, variations in propfan efficiency, and variations of propfan near-field acoustic levels are included. From these overall study results, a promising advanced propfan twin-engine, medium-range, high-subsonic transport configuration is identified.

Recommendations for further study and testing are included. Flight testing is considered essential for verification of a propfan aircraft design.

Conclusions from the study are as follows:

- The propfan configuration is definitely feasible and competitive with the turbofan installation.

- Further study is warranted; analysis, some wind tunnel tests, and particularly flight test are required.

- The propfan aircraft performance advantages over the turbofan DC-9 Super 80 are given in Tables 1 and 2.

- Of the three propfan configurations investigated, the preferred ranking from first to third is as follows from the performance and direct operating costs points of view:

  - Conventional horizontal tail aft mount - Configuration 3

  - Wing mount - Configuration 1

  - Aft fuselage pylon mount - Configuration 2.

  Any differences between the first two configurations are small and not adequate to justify selection of one over the other.

TABLE 1

RANGE COMPARISON

Configuration	Wing Mount No. 1		Horizontal Tail Mount No. 3		Aft Fuselage Pylon Mount No. 2	
Cruise Condition	Opt	M = 0.8	Opt	M = 0.8	Opt	M = 0.8
100 Percent Psgr Load Factor						
Range Change (%)	+25.0	+13.0	+31.2	+18.3	+2.8	-5.7
Avg Specific Range (%)	+38.5	+25.0	+41.7	+27.4	+34.3	+22.8
60 Percent Psgr Load Factor						
Range Change (%)	+43.3	+30.0	+47.8	+34.6	+27.0	+16.0
Avg Specific Range (%)	+37.9	+24.2	+39.9	+26.7	+34.2	+22.0

TABLE 2

FUEL SAVINGS AND DIRECT OPERATING COST COMPARISON*

Configuration	Wing Mount No. 1		Horizontal Tail Mount No. 3		Aft Fuselage Pylon Mount No. 2	
Mission Range	Fuel Savings (%)	DOC Reduction (%)	Fuel Savings (%)	DOC Reduction (%)	Fuel Savings (%)	DOC Reduction (%)
200 n mi (370 km)	24.4	8.5	25.4	9	23.5	8.3
500 n mi (926 km)	23.9	6.2	25	7	22.2	6
800 n mi (1482 km)	23.2	6	24.7	7.8	23.1	5.7
1200 n mi (2222 km)	23.3	6	25	9	23	4.5

*Fuel Price = $1.00/gal (26.4¢/liter)

- The variation in stage length (100 n mi [185 km] to maximum range) does not result in marked changes in the percent advantage for the propfan in fuel burned compared with the turbofan-powered DC-9 Super 80 for constant stage length (approximately 22 to 26 percent fuel savings at 100 percent passenger load factor). However, it should be noted that the aircraft, even though it may be flying a shorter range than the design range missions, still retains the capability and versatility of flying a mission up to its maximum design range.

- For very-short-range missions, the mission ground rule that one-third of the range be at cruise condition dictates a cruise altitude of approximately 15,000 ft (4572 m) and an associated cruise Mach number of approximately 0.65.

- Results of propfan characteristics sensitivity studies on the basic configurations considered are as follows:

    - The 10-blade propfan shows a very slight performance improvement over the 8-blade propfan (0.4 percent fuel savings and 3.7 percent increase in maximum range). This increase is due to the slightly lighter installation weight of the 10-blade propfan.

    - The variation in tip speed to 600 ft/sec (183 m/sec) from 800 ft/sec (244 m/sec) does not incur an anticipated ground clearance problem (propfan diameter change from 14.4 ft [4.4 m] to 17.5 ft [5.3 m]). However, the reduced noise level of the lower tip speed propfan with the associated reduced acoustic treatment does not compensate for the weight of the larger diameter propfan; performance losses relative to the 800-ft/sec (244 m/sec) case on the order of 2 to 3 percent in fuel burned and a 21 percent loss in maximum range are incurred for the 600-ft/sec (183 m/sec) tip speed case.

    - Over the propfan efficiency variation explored (-4 to +1 percent), the range sensitivity is as follows: 1 percent η variation equals 2 percent range variation.

- In the case of the wing-mount configuration, the ±6 dB variation in acoustic level results in a -685 to +875 lb (-311 to +397 kg) change in manufacturer's weight empty, relative to the base case wing mount configuration, which is comparable to range changes in the wing mount configuration of +50 to -90 n mi (+92.6 to -166.7 km) at the maximum takeoff gross weight of 140,000 lb (63,503 kg) and full passenger payload of 31,775 lb (14,413 kg). For this basic wing mount propfan configuration, the total acoustic treatment weight penalty (including the sonic fatigue compensation to the fuselage) is approximately 1200 lb (545 kg), or roughly 1.5 percent of the aircraft operational weight empty.

- The interior noise level of the propfan aircraft is maintained equal to the 82 dBA of the existing DC-9 Super 80. The far-field FAR 36 noise estimations show the propfan to have the following approximate margins below the FAR 36 (Stage 3) noise limits.

Takeoff	- 9.6 EPNdB
Sideline	- 2.2 EPNdB
Approach	- 6 EPNdB

  Also, the propfan configuration noise levels are estimated to be less than those noise levels estimated for the DC-9 Super 80.

- Maintenance costs represent a small part of the overall aircraft operating costs and should not be a deterrent to airline acceptance of the propfan aircraft.

- Sensitivity analysis of propulsion system maintenance costs shows that an 80 percent variation in assumed maintenance costs results in an approximate 2 percent change in overall direct operating cost (DOC).

- The sensitivity trends for the ROM economic analysis follow those shown by the performance analysis.

Comparison of the costs of DC-9 Super 80 propfan aircraft relative to the turbofan aircraft indicates

- Acquisition costs - 6.6 to 12 percent higher for the propfan aircraft.

- Direct operating costs - 8.0 percent less for propfan aircraft at typical operating conditions of 800 n mi (1482 km) stage length and fuel price of $1.00 per gallon (26.4 cents per liter).

Coordination with four airlines, over the elapsed time of the study, results in following general comments by the airlines:

- The interest and enthusiasm for the propfan aircraft have greatly increased; this is primarily due to the doubling of the fuel costs from July 1979 to August 1980.

- The fuel savings associated with the propfan over the turbofan are more than adequate to outweigh the complexities and maintenance costs of the propfan installation.

- The initial propfan airplane should be one of the order of

    - 155 to 165 passenger seats

    - design M_{cruise} of 0.8 and fully compatible with the aircraft currently in the fleet from the points of view of scheduling, route planning, and air traffic control

    - design initial cruise altitude of 31,000 ft (9450 m).

- Passenger acceptance was initially of concern; however, it is no longer considered a stumbling block.

SECTION 2

INTRODUCTION

BASIC STUDY DESCRIPTION

As the need for operational aircraft propulsive systems which are highly energy efficient becomes more and more critical with the steadily decreasing supplies and increasing cost of fossil fuel, the propfan aircraft becomes of greater interest as a possible means of countering the airframe manufacturers' and airline operators' problems related to the fossil fuel shortages. Previous "paper aircraft" conceptual design studies throughout the industry have indicated the potential for significant fuel savings for a propfan powered transport aircraft compared with a comparable turbofan powered aircraft. The study summarized herein addresses the research and technology requirements for an advanced turboprop/propfan transport configuration and presents comparisons of the turboshaft/propfan and the turbofan propulsion systems from the practical points of view of engineering feasibility, performance capability, and ROM economic evaluation, using the DC-9 Super 80 aircraft (Figure 1) as the actual operational base aircraft.

This report summarizes the work performed by Douglas Aircraft Company under Contract No. NAS2-10178 with NASA Ames. After a preliminary configuration concept survey of probable propfan configuration arrangements, the three DC-9-80 propfan configurations shown in Figures 2 through 4 have been selected as the basic propfan aircraft to be compared to the present DC-9 Super 80 P&WA JT8D-209 turbofan powered aircraft.

This study differs from the previous propfan/turbofan paper airplane comparisons done throughout the industry in that the emphasis of the work performed under this contract is placed on the practical engineering aspects by (1) using an actual flying aircraft - the Douglas DC-9 Super 80 - as a base, and (2) investigating the major aircraft engineering discipline problem areas incurred by a propfan installation.

MODEL DC-9 SUPER 80

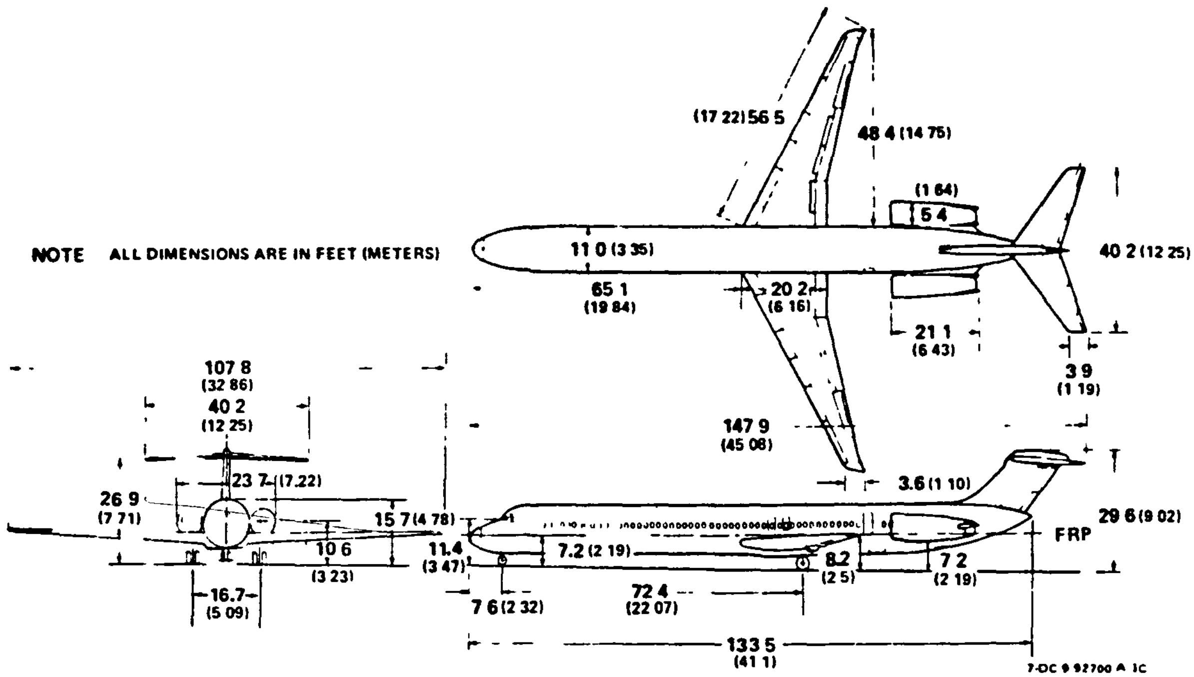

FIGURE 1. GENERAL ARRANGEMENT

DC-9 SUPER 80 PROPFAN

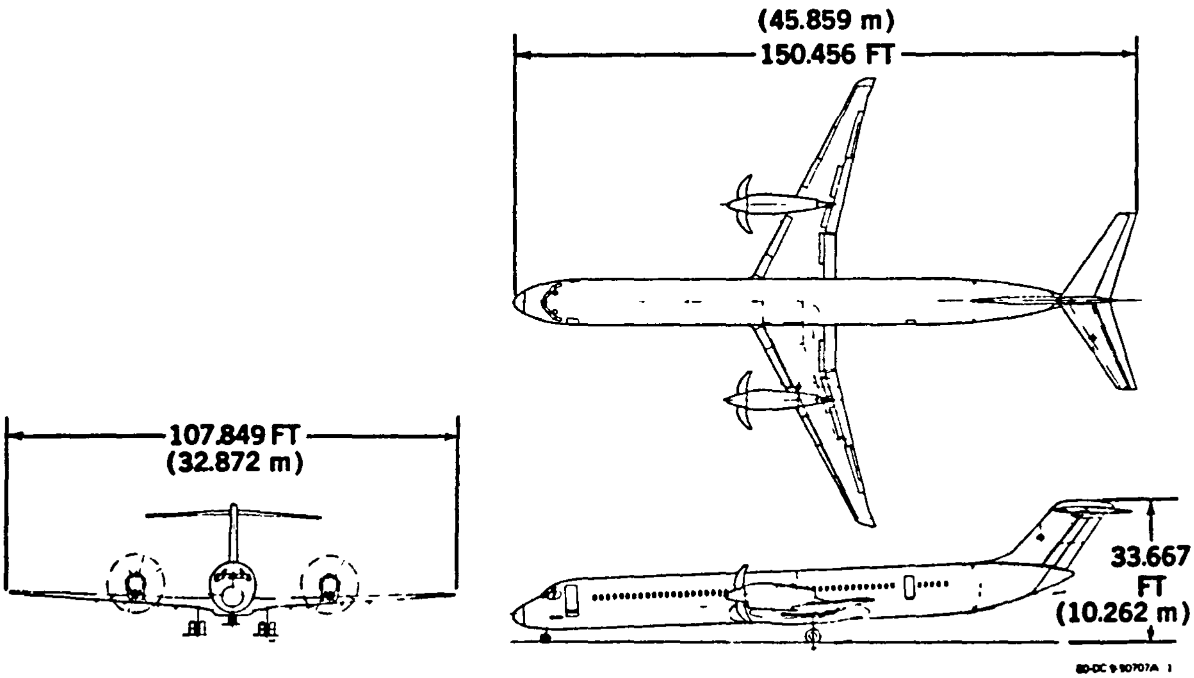

FIGURE 2. GENERAL ARRANGEMENT – WING-MOUNTED PROPFAN, CONFIGURATION 1

DC-9 SUPER 80 PROPFAN

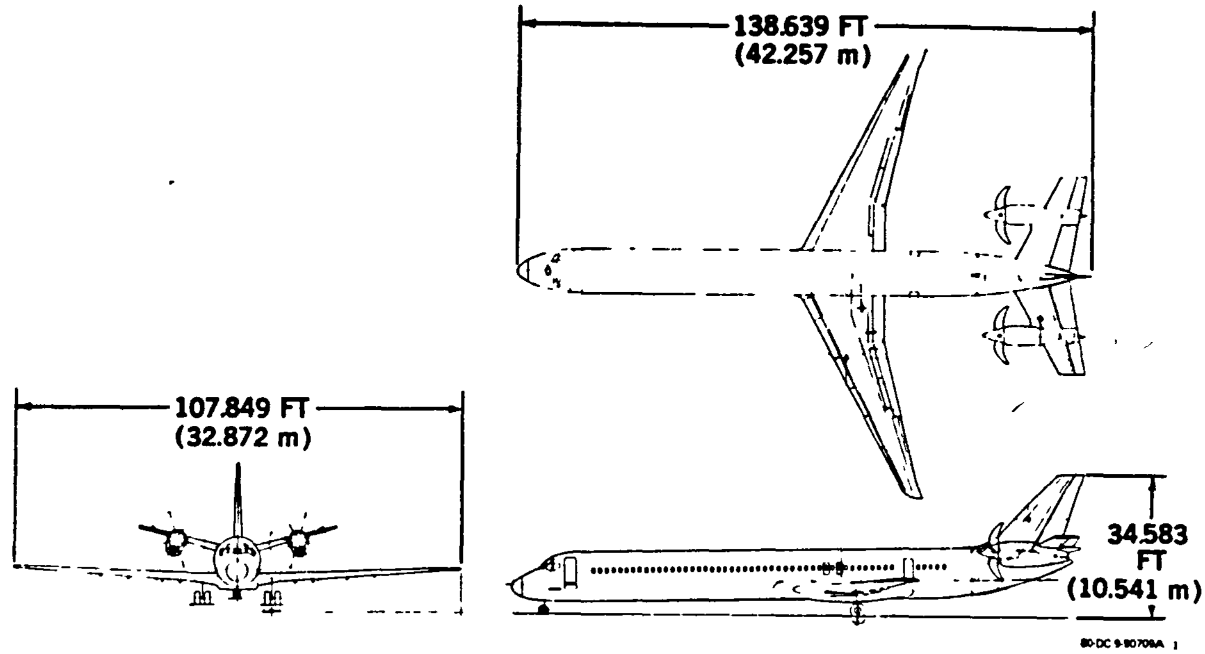

FIGURE 3. GENERAL ARRANGEMENT – HORIZONTAL TAIL MOUNTED PROPFAN, CONFIGURATION 3

DC-9 SUPER 80 PROPFAN

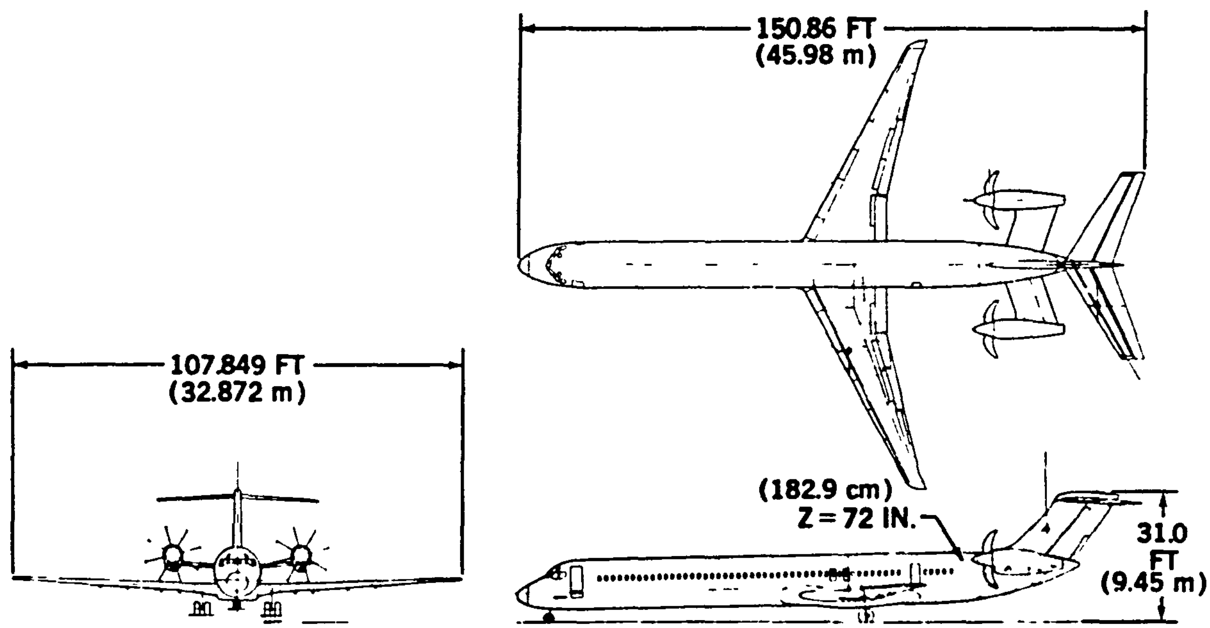

FIGURE 4. GENERAL ARRANGEMENT – AFT FUSELAGE PYLON-MOUNTED PROPFAN, CONFIGURATION 2

The engineering discipline areas for which technical evaluation have been considered are: configuration arrangement, aerodynamics, propulsion, structural loads, structural dynamics, sonic fatigue, acoustics, weights, performance, and economics.

It is to be emphasized that the scope of the study is a broad brush treatment of the major practical engineering aspects to provide a valid direct comparison of a commercial propfan and a JT8D-209 turbofan-powered DC-9 Super 80 aircraft compatible with initial operations in 1985. The propfan aircraft results are evaluated in terms of incremental or decrimental changes (Δ's) from the base case DC-9 Super 80 turbofan. These evaluations include the engineering feasibility, mission performance, ROM economics, maintainability aspects, airline coordination, and evaluation as to the viability of the propfan. From these study results, a promising advanced propfan twin-engine medium-range, high-subsonic transport configuration is identified.

PROPULSION SYSTEM

The turboprop engine characteristics and performance used in the study are those of the Detroit-Diesel Allison (DDA) PD370-22A (Reference 1), an axial flow engine with a free turbine, proposed for service in 1985. It represents an advanced turboprop engine with a 25:1 compressor pressure ratio, and incorporates demonstrated ATEGG technologies with basic shaft and bearing arrangements from the new T701 turboshaft engine.

The engine is scaled to meet the cruise thrust requirements of the various aircraft configurations. At the beginning of the study, it was estimated than an engine with 23 percent more power than the "spec size" PD370-22A would be required for the DC-9 Super 80 application, or a rating of 15,160 shp (11,307 kW). The layouts for all the aircraft configurations show a propulsion system with dimensions based on this scale factor of 1.23, unless otherwise noted. The amount of engine scaling finally required by each configuration is listed in its table of aircraft characteristics.

The engine drives a Hamilton Standard propfan, a new concept in propeller design having swept blades with advanced airfoil sections, and using advanced structural materials and design. The propfan has been designed for high disc loadings and for efficient propulsive operation at free-stream Mach numbers up to 0.8. All propfan data, including design, sizing, installation clearances, weights, performance, and acoustic characteristics, are provided by Hamilton Standard. These data are from the Hamilton Standard Data Packages (References 2 through 8). The base case propfan in an eight blade design which operates at a tip speed of 800 ft/sec (244 m/sec). It is sized to give a disc loading of 37.5 shp/ft^2 (301 kW/m^2) when installed on a PD370-22A engine operating at maximum cruise power at Mach 0.8 and 35,000 ft (10,668 m). For the 1.23 scaled engine, the propfan diameter is 13.85 ft (4.22 m). As the engine is scaled, the propeller is scaled to maintain the same disc loading.

Characteristics of the propulsion system are summarized in Table 3. The base case disc loading, specified in the statement of work, is representative of the results of past studies of the tradeoff between propfan diameter and efficiency. The effects of different tip speeds and disc loadings with a ten blade propfan are investigated in the study.

Table 3
PROPULSION SYSTEM CHARACTERISTICS

Engine:	DDA PD370-22A Pressure ratio = 25:1 Technology = T701 + ATEGG Compressor Base-case scale factor = 1.23 Base-case takeoff rating, SLS, = 15,160 shp (11,307 kW)
Propfan:	Hamilton Standard eight-blade (base case) and ten-blade Design Mach No. = 0.8 Base-case tip speed = 800 ft/sec (244 m/sec) Base-case cruise disc loading = 37.5 shp/ft^2 (301 kW/m^2) Base-case diameter = 13.85 ft (4.22 m)

STUDY GROUND RULES

The study ground rules may be summarized as follows:

- 1985 operational capability - Technologies and/or aircraft components are assumed compatible with a 1985 operational aircraft.

- Basic aircraft is the DC-9 Super 80 DSS 8000 Specification. Takeoff gross weight is 140,000 lb (63,503 kg) with 155 economy class passengers.

- Turboshaft engine selection is the Allison PD370-22A engine scaled, on the basis of the engine manufacturer scaling factors, to match the aircraft thrust requirements.

- Propfan data is from the Hamilton Standard Data Package. The base propfan characteristics for the study are the eight blade, $M_{design} = 0.80$, 800 ft/sec (244 m/sec) tip speed, 37.5 shp/D^2 (301 kW/m^2) disc loading. In all cases, the propfan is scaled to match the aircraft thrust requirements.

- Mission performance assumes $M_{cruise} = 0.8$ with alternate mission M_{cruise} investigated.

- Propfan propulsion system sizing is based on cruise requirements at $M_{cruise} = 0.8$ at 31,000 ft (9450 m) initial cruise altitude.

- Propfan configurations to be considered for the more detailed portion of the study are those selected as most feasible from a preliminary configuration concepts survey. One wing mounted propfan and one aft mounted propfan configuration are selected from this preliminary conceptual survey. In addition to these two propfan configurations, a second aft mounted configuration is included in the study at the request of NASA.

- Structural design criteria of the propfan aircraft are the same as for the base DC-9 Super 80.

- Interior noise of the propfan aircraft is 82 dbA, the same level as for the DC-9 Super 80 baseline passenger aircraft.

- Domestic reserves are assumed on all mission performance.

- Comparative results are measured in terms of Δ's from the DC-9 Super 80.

- ROM costing (acquisition and DOC) assume 1979 dollars.

- From the costing point of view, the propfan aircraft are considered as new aircraft with maximum usage made of the common DC-9 Super 80 components and subsystems.

TRADE STUDIES

In addition to evaluation of the three base case propfan configurations, the following sensitivity studies are included:

- M_{cruise}
  - M = 0.80
  - M - Optimum

- Mission

  Varying stage length (100 n mi [185 km] to maximum range)

  Multi hop legs (200 - 500 - 300 n mi [370 - 926 - 556 m])

  (Total Range - 1000 n mi (1852 m)

- Propfan Characteristics

  Number of blades (8 versus 10)

  Tip speed/disc loading variation on ten-blade propfan

800 ft/sec (244 m/sec), 37.5 shp/D^2 (301 kW/m^2)

700 ft/sec (213 m/sec), 30 shp/D^2 (241 kW/m^2)

600 ft/sec (183 m/sec), 26 shp/D^2 (209 kW/m^2)

Propfan efficiency, η (-4% $\eta \rightarrow$ +1% η from base case)

Noise level (±6 dB from base case)

These sensitivities are measured in terms of Δ aircraft weight, fuel burned, or range.

HAMILTON STANDARD INPUTS

Hamilton Standard has been particularly helpful, not only in the supply of the propfan basic data but also in analyses of the feasibility of the propfan installations from the point of view of structural mounting and the associated estimation of excitation factors for the propfan itself.

REPORT ORGANIZATION

Sections 3 and 4 present discussions of the preliminary configuration concept work, the selection and description of three propfan configurations for the more detailed analyses, and the comparative performance results of the several propfan configurations with the DC-9 Super 80, including results of sensitivity trades. A technical discussion and a cursory evaluation of the pertinent engineering disciplines are included in Section 5. The associated ROM economic evaluations are summarized in Section 6. The results of coordination with the two trunk and two regional air carriers (United, Delta, Republic, and USAir) are summarized in Section 7. As stated previously, the study is a broad brush treatment of a gamut of the design and operational problems associated with the propfan aircraft: many problem areas are noted which need further in-depth analyses including wind tunnel or flight test.. These areas are summarized in Section 8 with recommendations made for further specific study and critical tests. Detail of propfan aircraft sizing and multi hop mission performance, Hamilton Standard comments on propfan installation, and DC-9 Super 80 baseline aircraft characteristics are included in Appendixes A, B and C, respectively.

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SECTION 3
PROPFAN CONFIGURATION CONCEPTS EVALUATION

CONFIGURATION CONCEPTS

The initial phase of the study involves a survey of pertinent propfan configuration concepts, a preliminary evaluation from the engineering disciplines' points of view, and a selection of the most feasible configurations to be included in the further detailed study. One wing mount and two aft mount propfan configurations are selected for the major evaluation effort of the study.

The study ground rules for the selection of feasible propfan concept configurations are essentially the same as noted in Section 2 except that economic evaluation is not included in this preliminary screening. Constant engine/propfan size is assumed for all the preliminary concept layouts and the cursory engineering evaluation is of adequate depth for ranking the several concepts.

The configuration concepts considered in this preliminary survey are selected as those types of propulsion system installations generally representative of the feasible propfan arrangements. The conceptual configurations evaluated are summarized in Figures 5 and 6. Tractor, pusher, and dual rotation propfan installations are considered. The dual rotation propfans are dropped from the study at this early date on the basis that in Hamilton Standard's judgment, they are not compatible with the 1985 operational time period assumed for the study. The seven configuration concepts considered in this conceptual evaluation are presented in the following text. Throughout, the clearances assumed for the propfan installations are those recommended in the Hamilton Standard Data Package.

Configuration 1, the tractor propfan wing mount - This installation involves the relocation of the propulsion systems from the aft fuselage to the wings.

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(2) ALLISON PD370-22A-TYPE ENGINES — 15,160 SHP EACH (11307 kW)
HAMILTON STANDARD 8-BLADE PROPFAN
DC-9 SUPER 80 PROPFAN

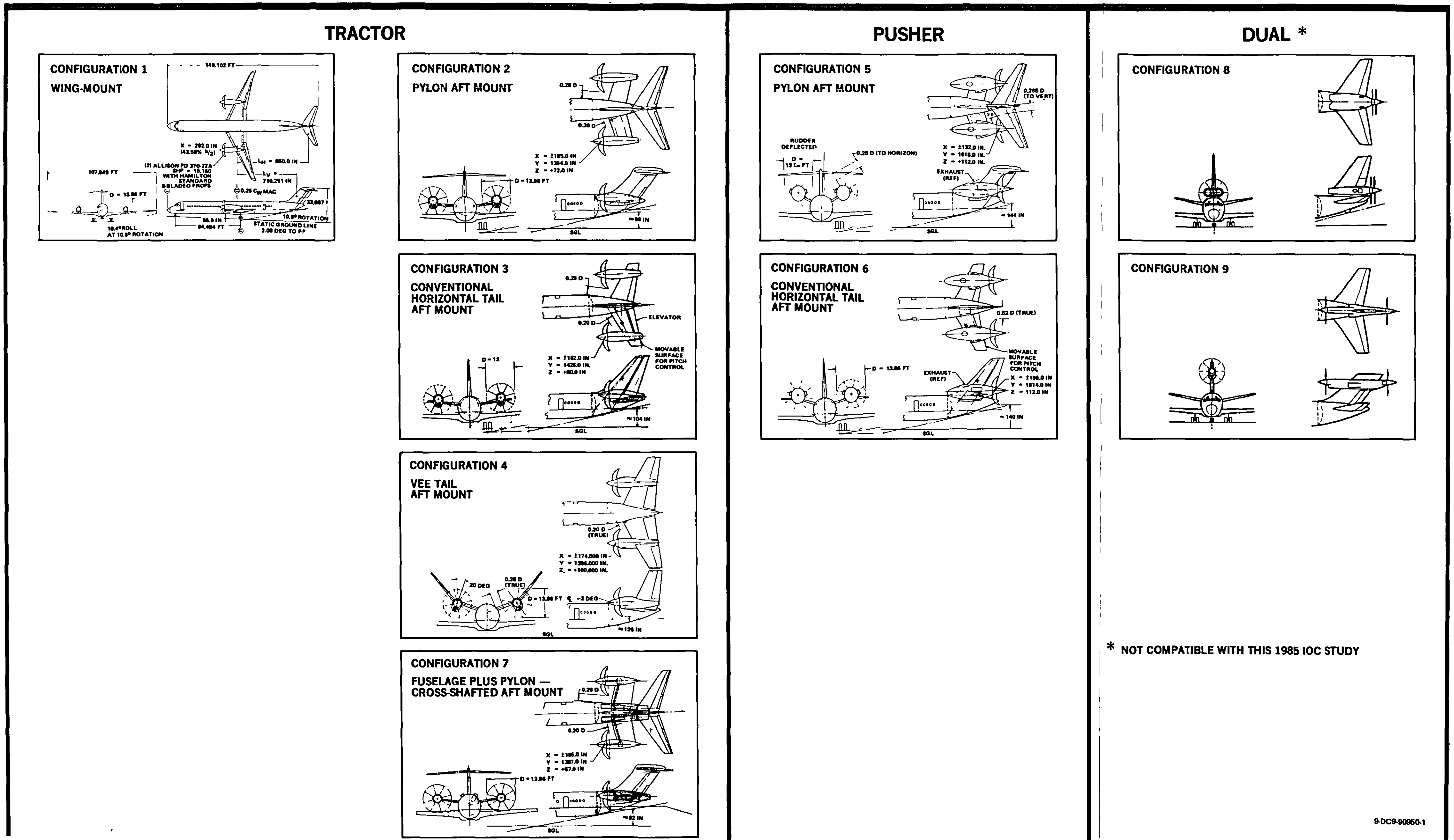

FIGURE 5. CONCEPTUAL CONFIGURATIONS EVALUATED

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(2) ALLISON PD370-22A TYPE ENGINES — 15,160 SHP (11,307 kW)
HAMILTON STANDARD 8-BLADE PROPFANS

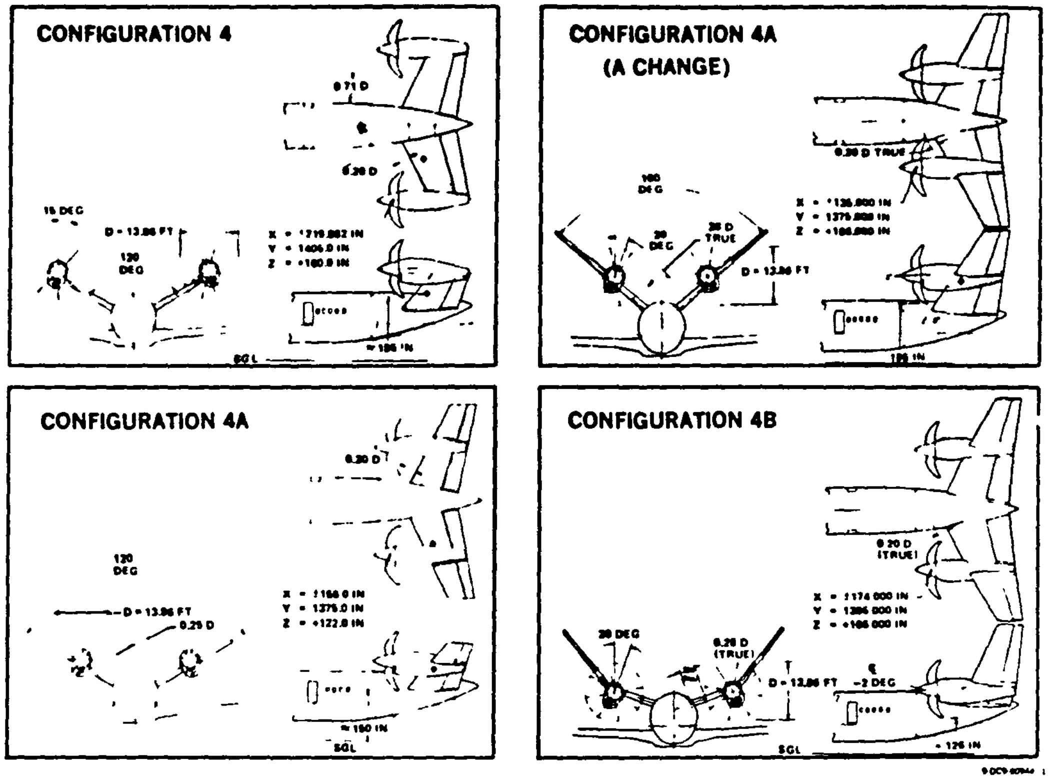


FIGURE 6. AFT-MOUNTED PROPFAN VEE-TAIL CONFIGURATION

As expected, the wing itself must be moved forward to maintain the airplane balance and the horizontal tail increased in size to compensate for the removal of the aft-mounted turbofans which have a stabilizing effect.

Configuration 2, aft fuselage pylon mount tractor propfan - Due to the propfan clearance requirements, the pylons must be quite long and large in area compared to the pylon arrangement of the DC-9 Super 80 turbofan.

Configuration 3, conventional horizontal tail mount tractor propfan - This arrangement encompasses a fixed horizontal tail.

Configuration 4, Vee tail aft mount tractor configuration - This arrangement offers the advantage of providing greater propfan ground clearance. Several versions are considered, as shown in Figure 6.

Configuration 7, aft fuselage pylon mount tractor installation - The arrangement is quite complex with the cross shafted propfans and the two separate gear boxes

Configuration 5, aft fuselage pylon mount pusher propfan - A major interference problem exists since the propfan is operating near the aerodynamic control surfaces and is under the tail surface; in addition, the propfan must operate in an adverse flow field created by the exhaust gas from the engine.

Configuration 6, conventional horizontal tail aft mount pusher propfan - This propfan arrangement must operate in an adverse flow field due to the engine exhaust and aerodynamic effect as in Configuration 5; the propfan blade stresses are sensitive to the horizontal and/or vertical tail interactions.

In both of the pusher propfan configurations, the high thrust line is associated with a high thrust trim change; and the gyroscopic moments are very objectionable.

The preliminary nacelle arrangements used in this first evaluation are shown in Figures 7 through 9. No effort is made at this time to aerodynamically contour the nacelle properly. The tractor propfan nacelle is a high wing mount which provides propfan ground clearance and a large overhang from the wing to allow for a modular propulsion system installation. Two pusher propfan nacelle arrangements are illustrated in Figures 8 and 9. Figure 8, with the plenum inlet and the engine exhaust over the top of the nacelle, is considered preferrable to the installation shown in Figure 9, which has a conventional inlet and the engine exhausts through the propfan. Exhausting through the propfan is particularly undesirable for efficient propfan performance. Therefore, the type of nacelle shown in Figure 8 is used for the pusher propfan installations.

RELATIVE RANKING - TECHNICAL AREAS

The Douglas technical design criteria for the cursory evaluation of the configuration concepts shown in Figures 5 and 6 cover the following discipline areas:

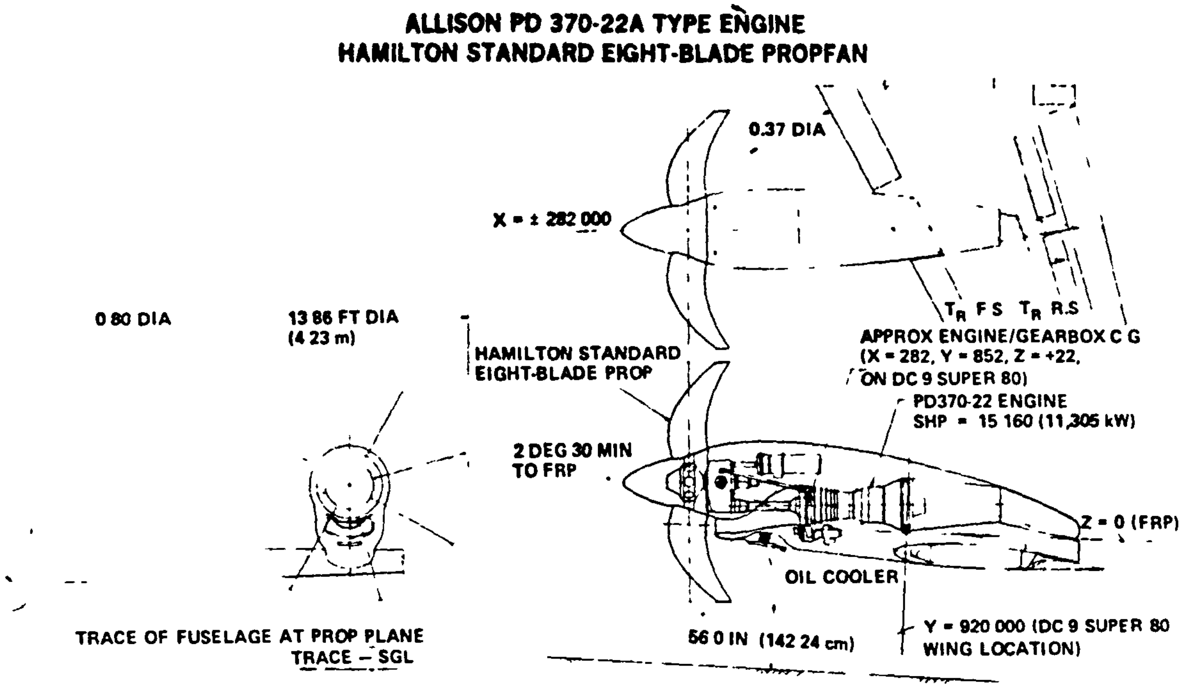


FIGURE 7. TRACTOR PROPFAN NACELLE ARRANGEMENT

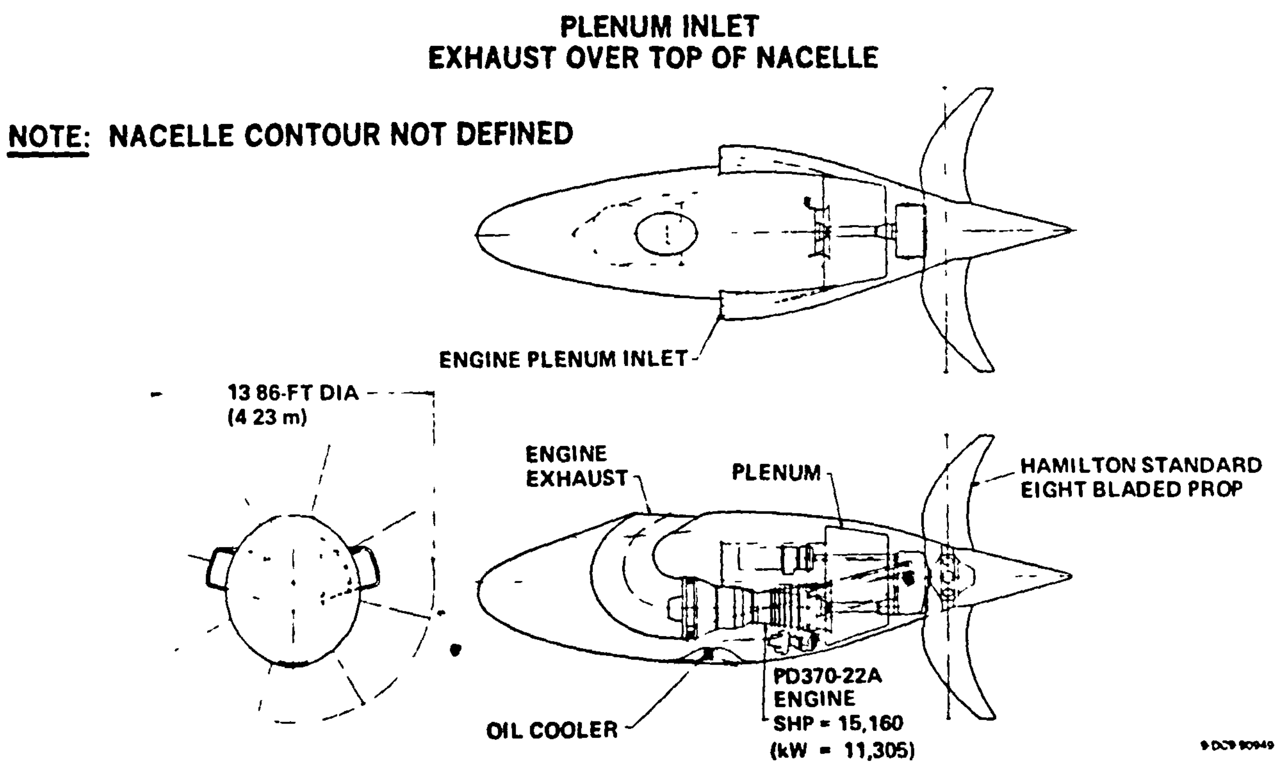


FIGURE 8. PUSHER PROPFAN NACELLE ARRANGEMENT, PLENUM INLET

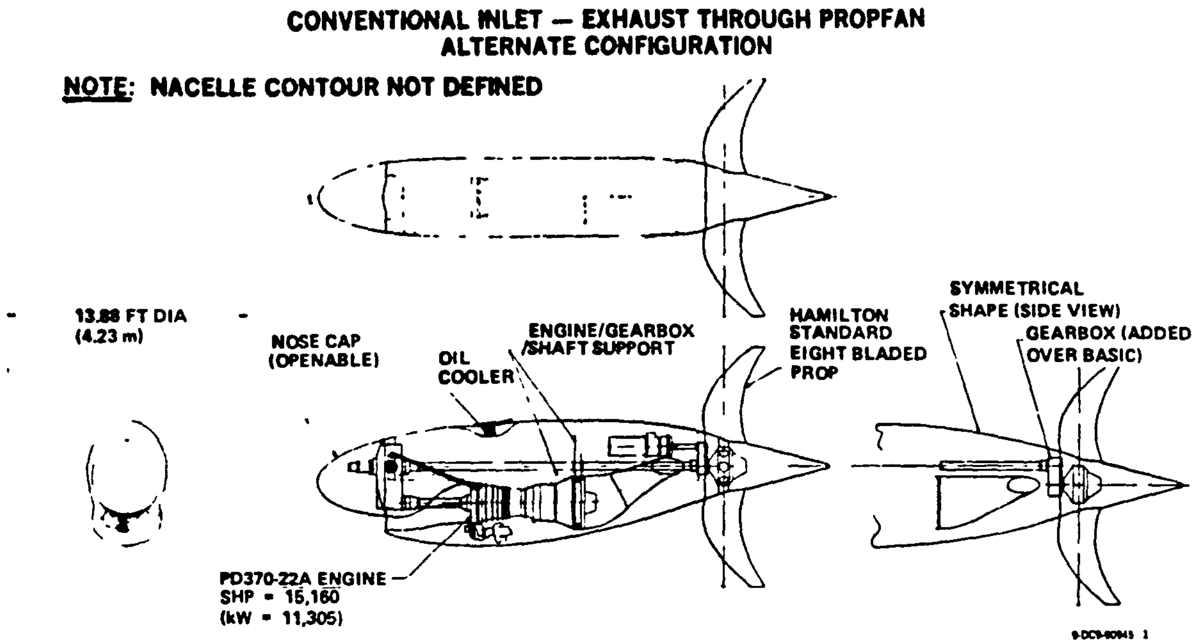


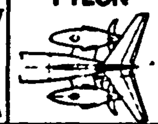
FIGURE 9. PUSHER PROPFAN NACELLE ARRANGEMENT, CONVENTIONAL INLET

configuration arrangement, aerodynamics, performance, structures/dynamics, weights, and acoustics.

Hamilton Standard also made a technical evaluation of the concepts considering the aerodynamic, structures, and acoustics aspects, all from the propfan point of view. Figure 10 summarizes the relative ranking of the aft-mounted configurations. The ratings shown in Figure 10 denote the top ranking as 1 and the less desirable ranked configurations as a higher number such as 5 or 6. The configuration with the most low values (1's and 2's, etc.) on the ranking is considered most feasible. The wing mount propfan, Configuration 1, is not included in this evaluation since it is to be considered in the second phase of the study.

The Hamilton Standard evaluation of Configurations 1 through 4 considers these four configurations acceptable with small differences between the approaches; however, Configurations 5 and 6 are considered unacceptable because of the adverse flow fields due to exhaust gases and the operation of the propfan rotor near the tail. Also, the gyroscopic moments on these

NUMBER 1 DENOTES TOP RANKING

CONFIGURATION NO. MOUNT / TECHNICAL DESIGN AREAS	TRACTOR				PUSHER	
	2 PYLON 	3 H-TAIL 	VEE 4 TAIL 	FUSELAGE/ PYLON 7 	5 PYLON 	6 H-TAIL 
CONFIG ARRANGEMENT	3	1	2	4	5	6
AERODYNAMICS						
S&C	1	2	3	4	5	6
DRAG	5	1	2	4	6	3
PERFORMANCE	2	1	2	6	4	5
STRUCTURES	4	5	1	6	2	3
DYNAMICS	NO PARTICULAR PREFERENCE EXCEPT MOVABLE SURFACES PRESENT SOME PROBLEM					
WEIGHTS	1	2	3	6	4	5
ACOUSTICS	5	3	4	6	1	1
HAMILTON STANDARD						
AERODYNAMICS	3	1	2	*	4	5
STRUCTURES	1	2	3	*	4	5
ACOUSTICS	3	2	1	*	4	5

* NOT AVAILABLE FOR COMMENT

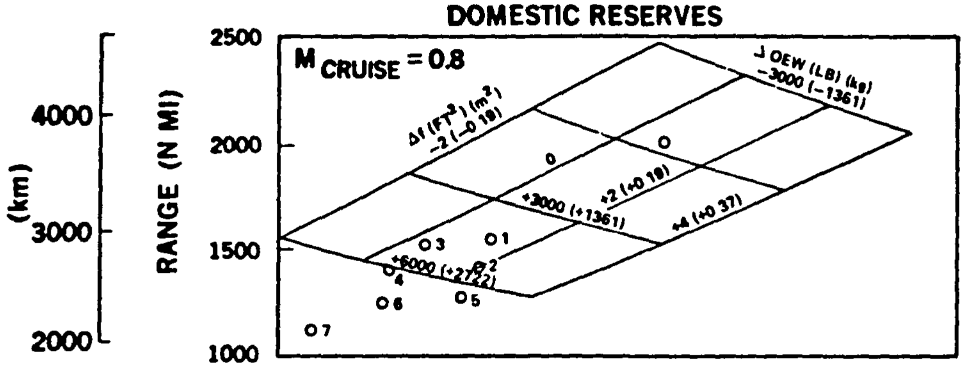
FIGURE 10. RELATIVE RANKING OF AFT-MOUNTED PROPFAN CONCEPTS

latter two configurations are probably bad. In general, the rear mounts are favored over the wing mount since the acoustics and structures carry less penalty.

Rough performance evaluation of the range capability expected from the seven configuration concepts is presented in Figures 11 through 13 in terms of a delta weight and delta drag matrix as measured from the base DC-9 Super 80 performance. A cursory assessment of the impact of cruise sizing requirements on the relative ranking of the various propfan configurations is made by considering three criteria for sizing the engine, based on the following ground rules for cruising the aircraft:

- M_{cruise} = 0.8 and 31,000 ft (9450 m) initial cruise altitude
- M_{cruise} = 0.8 and minimum engine size
- Optimum M_{cruise} and fixed engine size.

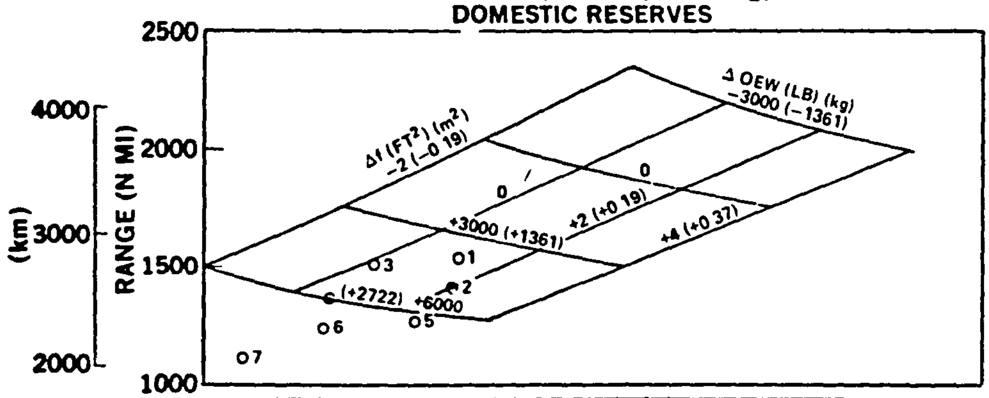
SIZING CRITERIA — 31,000-FOOT (9,450-m) INITIAL CRUISE ALTITUDE
PD370-22A TYPE ENGINE
T.O. GROSS WT = 140,000 LB (63,503 kg) BASE OEW = 78,666 LB (35,682 kg)
PAYLOAD = 31,775 LB (14,413 kg)
DOMESTIC RESERVES



CONFIGURATION	INITIAL CRUISE ALTITUDE, FT (m)	ENGINE SCALE FACTOR
1	31,000 (9450)	1.320
2	31,000 (9450)	1.340
3	31 000 (9450)	1.287
4	31,000 (9450)	1.299
5	31,000 (9450)	1.369
6	31 000 (9450)	1.334
7	31,000 (9450)	1.335

FIGURE 11. RANGE CAPABILITY, 31,000-FOOT INITIAL CRUISE ALTITUDE

PD370-22A TYPE ENGINE
T.O. GROSS WT = 140,000 LB, (63,503 kg) BASE OEW = 78,666 LB (35,682 kg)
PAYLOAD = 31,775 LB (14,413 kg)
DOMESTIC RESERVES



CONFIGURATION	INITIAL CRUISE ALTITUDE FT (m)	ENGINE SCALE FACTOR
1	29 200 (8900)	1.305
2	29 000 (8839)	1.333
3	28 800 (8778)	1.271
4	28 700 (8748)	1.285
5	29 000 (8839)	1.359
6	28,600 (8717)	1.325
7	28 500 (8687)	1.326

FIGURE 12. RANGE CAPABILITY, MINIMUM ENGINE SIZE FOR M_{CRUISE} = 0.8

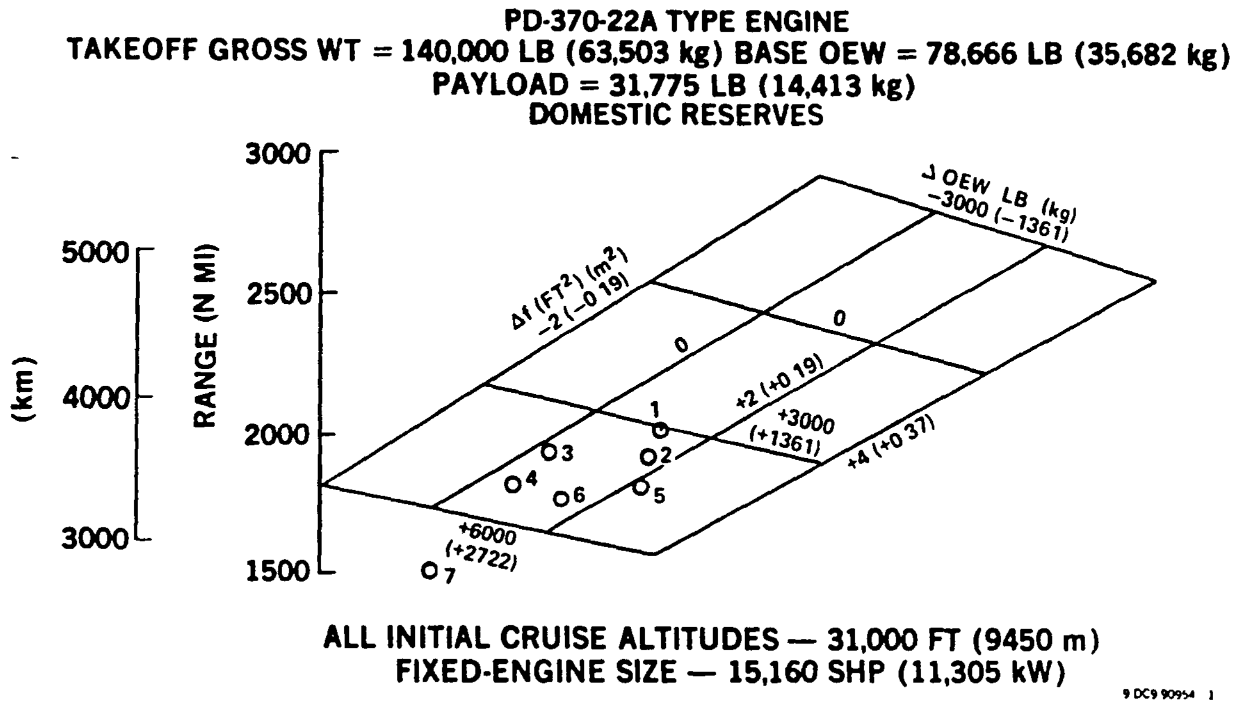


FIGURE 13. RANGE CAPABILITY, OPTIMUM M_{CRUISE} – FIXED ENGINE SIZE

As noted in Figures 11 through 13, the assumptions for engine sizing criteria do not alter the relative ranking of the configuration concepts. Configurations 1, 3, 4, and 2 are the first four preferrable concepts based on the criteria of longest range with low drag increment. Configuration 7, with the heavy weight due to the cross shafting and high drag arrangement, shows particularly low range performance on the matrices (Figures 11 through 13). These matrices also indicate the cruise altitudes and engine sizes to be expected in the more detailed phase of the study.

CONFIGURATION SELECTIONS

The concepts evaluation resulted in the selection of Configuration 3 as the most feasible and competitive of the aft mounted propfan arrangements. Configuration 4B is an alternate selected in case the propfan ground clearance should become a major configuration problem in the trade study involving low propfan tip speeds. The Vee tail arrangement of Configuration

4B is compatible with increased propfan ground clearance; however, the high engine mount and the Vee tail result in increased tail size as well as accessibility problems for maintenance.

Upon a later request from NASA, Configuration 2 is added to the study for further consideration. The aft-fuselage pylon mounted propfans appear on first analysis to be similar to the basic DC-9 Super 80 arrangement and thus worthy of further analysis. However, the propfan clearances required and thus the resulting long, heavy pylons, as well as the propfan wake effects on the empennage are all factors which do not exist on the basic DC-9 Super 80 and which must be taken into account. The aircraft balance problems typical of an aft engine mount are exaggerated in the case of Configuration 2 because of the increased weight in the aft of the aircraft arrangement.

The concept evaluation resulted in the selection of Configuration 1 (wing mount), Configuration 3 (horizontal tail mount), and Configuration 2 (aft-fuselage pylon mount) for the further study of propfan installations. Three-view drawings and the relative performance capabilities of these configurations are presented in Section 4.

SECTION 4

SELECTED CONFIGURATIONS AND ASSOCIATED PERFORMANCE

CONFIGURATIONS

The detailed three-views of the three selected base case propfan configurations are presented in Figures 14 through 16. The detailed general arrangement of the DC-9 Super 80 is included in Figure 17 for the purpose of amplifying the three-views. The basic interior of the DC-9 Super 80, not affected by the propfan installation, is essentially the same as the propfan configurations. These three-views have not been redrawn to account for the small differences in engine thrust size that come from the final performance sizing. These small differences are not considered significant to the overall three-view; however, all performance and weights reflect the final correctly sized engine. The three-views plus the group weight statements shown in Figure 18 summarize the results of the integration of the engineering discipline work described in Section 5.

A few items of interest on the specific configurations are:

- Configuration 1 (Wing Mount)
    - Wing moved forward 95 in. (242 cm) from the DC-9 Super 80 position.
    - Main landing gear strut is extended 10 in. (25.5 cm) to provide the 10.5-degree rotation, but is compressed during retraction.
- Configuration 3 (Horizontal Tail Mount)
    - Wing moved rearward 38 in. (97 cm) from the DC-9 Super 80 position.
    - Main landing gear canted 5 degrees aft relative to the fuselage reference plane (FRP) so that the tipover limit can be satisfied under the loading condition of manufacturer's weight empty.

- Configuration 2 (Aft Fuselage Pylon Mount)

  - Wing moved rearward 38 in. (97 cm) relative to the DC-9 Super 80 position.

  - Main landing gear canted 5 degrees aft relative to the FRP; air-conditioning system relocated in the forward cargo compartment; and a 580-gallon (2195 liter) belly fuel tank located in the forward cargo compartment all of which is required to satisfy the tipover limit requirement under the loading condition of manufacturer's weight empty.

The satisfactory loading capabilities characteristic of the three propfan configurations, considering the maximum payload assumed in this study of 155 passengers (31,775 lb or 14,413 kg), are shown in the cg diagrams presented in Figures 19 through 21.

PERFORMANCE

Mission Ground Rules

Engine Sizing - In all cases, the engines are sized for each configuration to achieve a 31,000-ft (9450 m) initial cruise altitude at optimum (99-percent maximum range) Mach number under the conditions of maximum takeoff gross weight of 140,000 lb (63,503 kg) and climbing to the initial cruise altitude. This engine size is then held fixed for the remainder of the study.

Cruise Methods - Several methods of cruise are investigated, as each has an influence on the performance results. The cruise methods considered are:

- Step-climb cruise (31,000, to 35,000, to 39,000 ft [9450 to 10,660 to 16,890 m]) flown at optimum Mach number is characteristic of commercial aircraft operation, included as a matter of interest. The same cruise method is also flown during this study at M_{cruise} = 0.80 as per the contract SOW.

CHARACTERISTICS DATA			
ITEM	WING (BASIC)	HORIZONTAL TAIL	VERTICAL TAIL
AREA, SQ FT	1209 3	360	198 3
(SQ m)	(112 3)	(33.4)	(18.4)
ASPECT RATIO	9 618	5 0	.82
TAPER RATIO	.1556	35	.80
Λ c/4	24 5°	31.6°	43 5°
DIHEDRAL	+3°	−3°	–
VOL RATIO	–	1.6	090

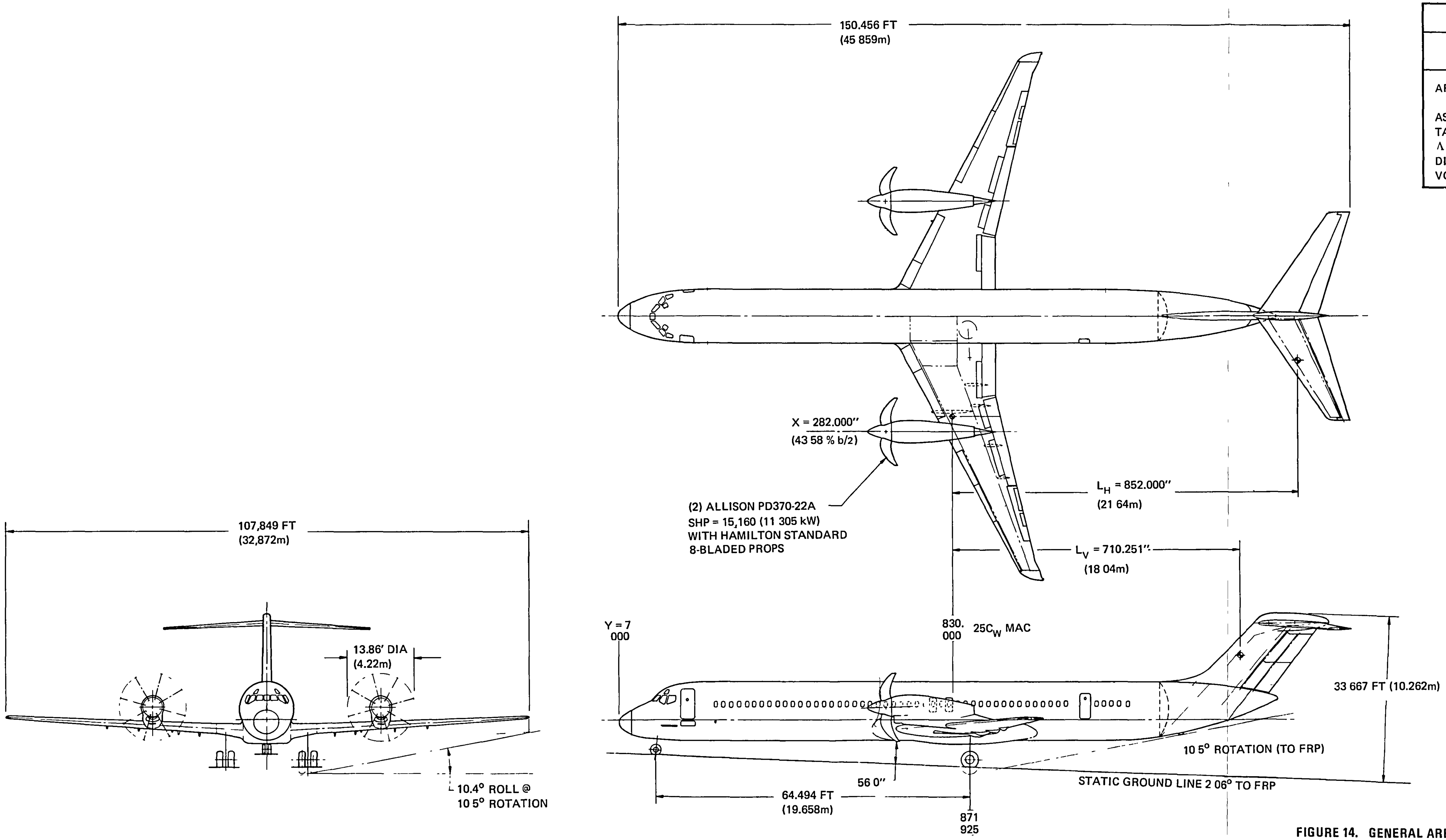


FIGURE 14. GENERAL ARRANGEMENT, WING-MOUNTED TURBOPROP/PROPFAN, CONFIGURATION 1

CHARACTERISTICS DATA			
ITEM	WING (BASIC)	HORIZONTAL TAIL	VERTICAL TAIL
AREA, SQ FT	1209 3	505	225
(SQ m)	(112 3)	(46 9)	(20 9)
ASPECT RATIO	9 618	4 5	1 5
TAPER RATIO	.1556	40	.35
Λ c/4	24 5°	25°	40°
DIHEDRAL	+3°	+15°	–
VOL RATIO	–	1 48	0782

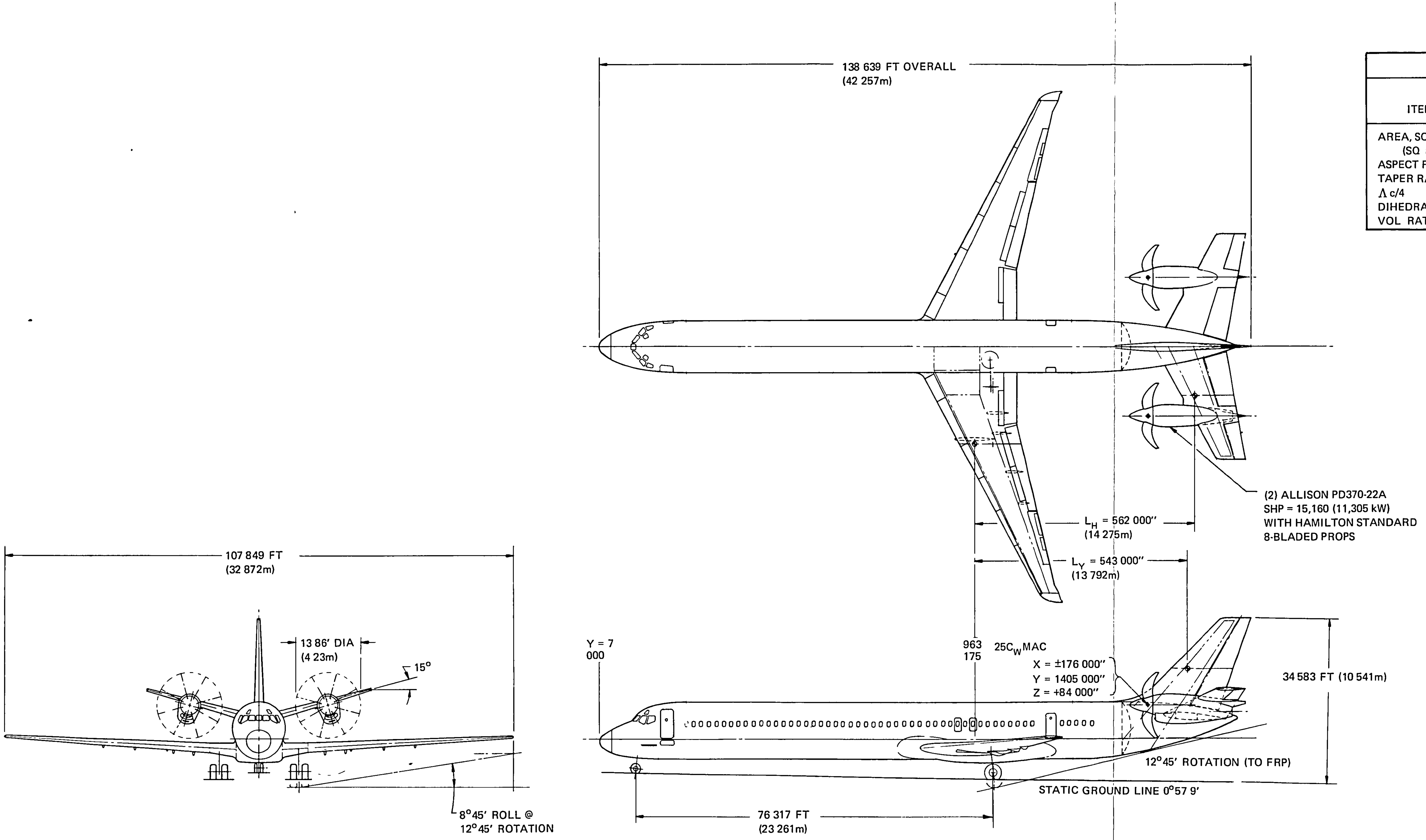


FIGURE 15. GENERAL ARRANGEMENT, AFT-MOUNTED TURBOPROP/PROPFAN, CONFIGURATION 3

ITEM	CHARACTERISTICS DATA WING (BASIC)	HORIZONTAL TAIL	VERTICAL TAIL
AREA, SQ FT (SQ m)	1209.3 (112.3)	386 (35 9)	213 (19.8)
ASPECT RATIO	9 618	5.144	.82
TAPER RATIO	.1556	.450	.80
$\Lambda c/4$	24.5°	30°	43 5°
DIHEDRAL	+3°	−3°	–
VOL. RATIO	–	1.45	0785

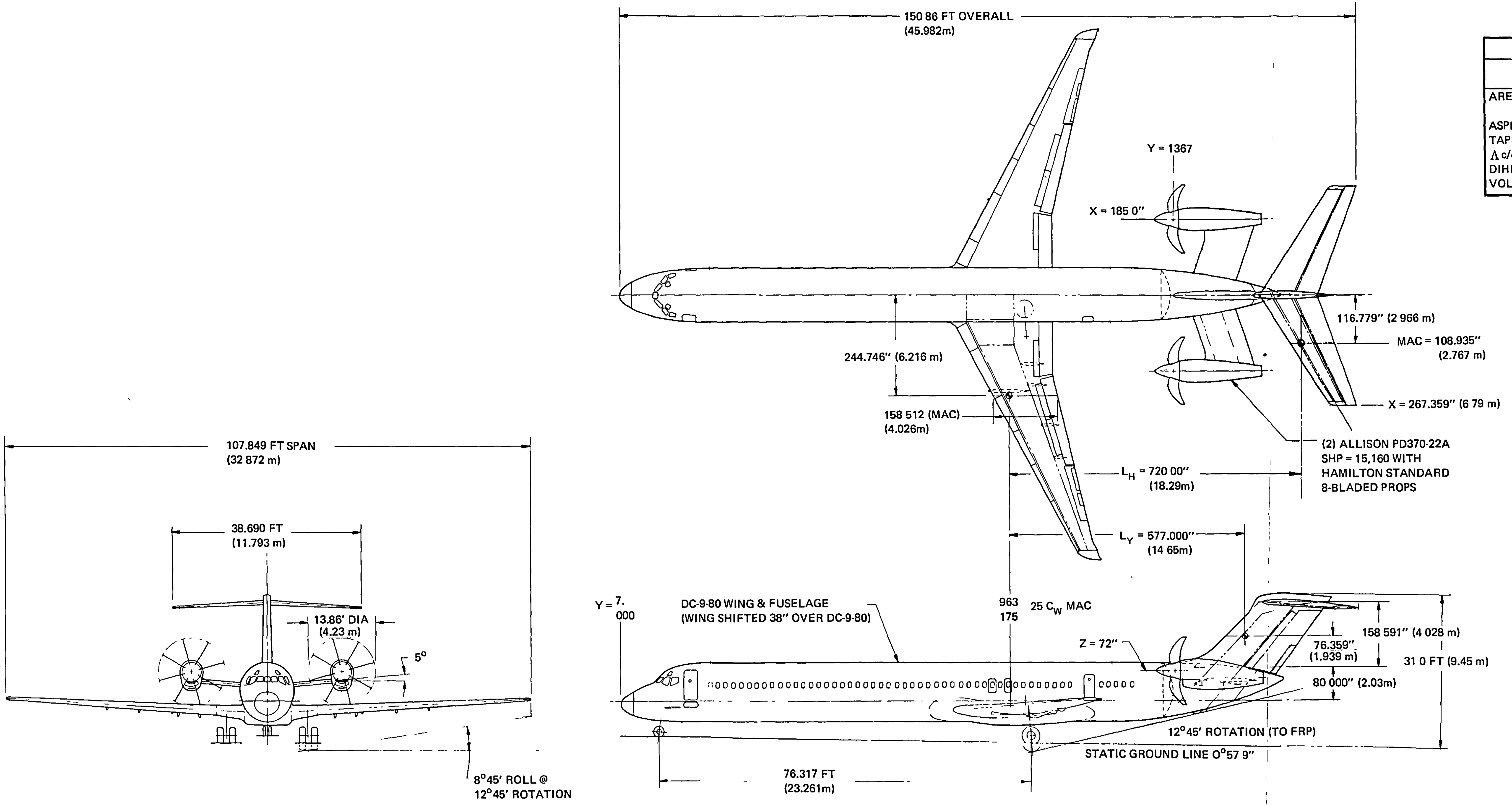


FIGURE 16. GENERAL ARRANGEMENT, AFT-MOUNTED TURBOPROP/PROPFAN, CONFIGURATION 2

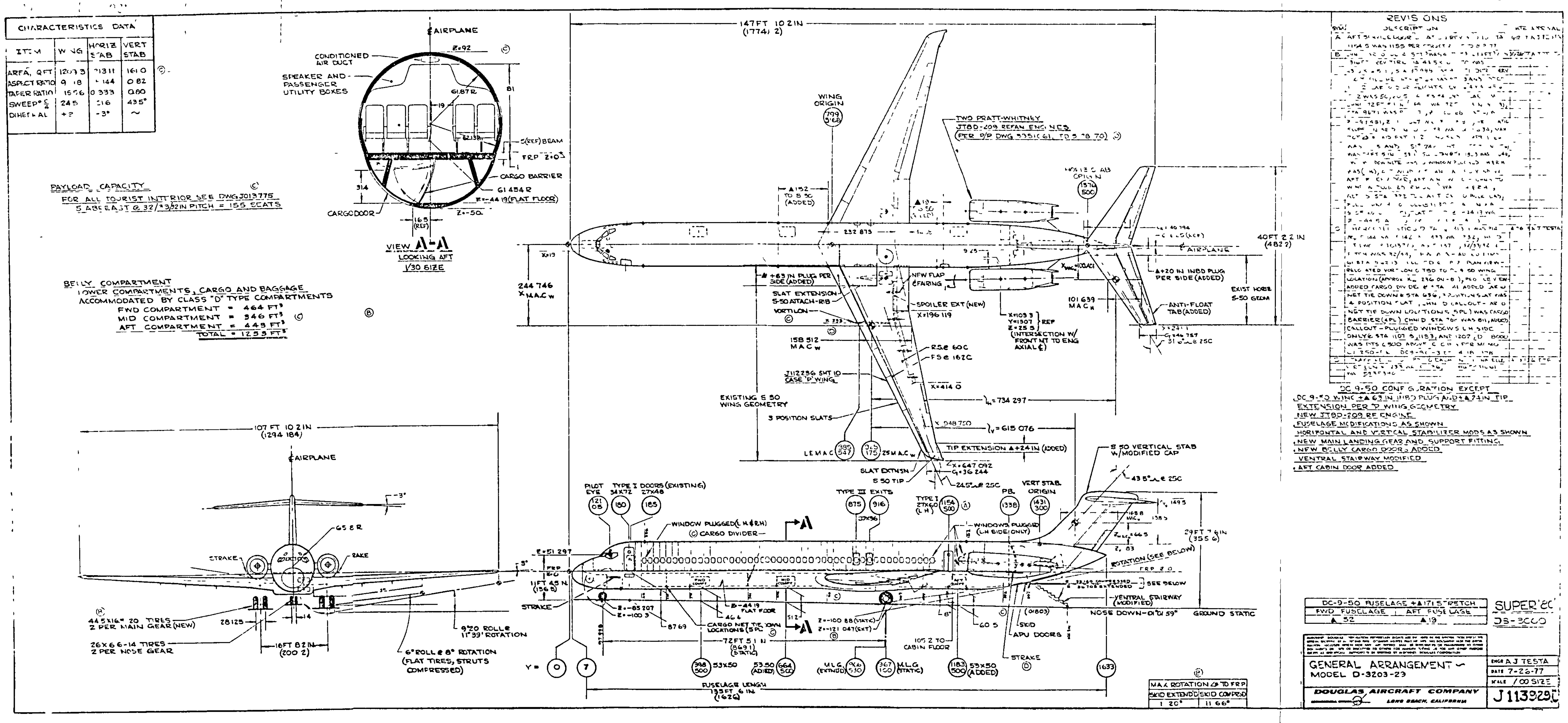


FIGURE 17. GENERAL ARRANGEMENT, MODEL D-3203-29

	DC 9-80	TURBOPROP		
	BASE	CONFIG NO 1	CONFIG NO 3	CONFIG NO 2
GEOMETRY	AFT FUS	WING	HORIZ TAIL	AFT FUS
TAKEOFF GROSS WEIGHT (LB)	140,000	140,000	140,000	140 000
MAX PAYLOAD WEIGHT (LB)	39,334	34,800	36,010	31,732
PAYLOAD WEIGHT – 155 PASSENGERS (LB)	31,775	31,775	31,775	31 775
WING AREA (FT^2)	1,209	1,209	1,209	1,209
HORIZ TAIL AREA/VERTICAL TAIL AREA (FT^2)	313/161	380/198	505/225	390/213
HORIZ TAIL ARM/VERTICAL TAIL ARM (IN)	734/615	852/710	562/543	712/577
RATED SHAFT HORSEPOWER/ENGINE		16,520	16 275	16 515
NO OF BLADES/TIP SPEED (FPS)	0-	8/800	8/800	8/800
PROPELLER DIAMETER (FT)	0-	14 47	14 36	14 47
WEIGHT DATA				
WING	15,318	15 490	15,397	15,373
HORIZONTAL TAIL	1,918	1,941	2,868	2,460
VERTICAL TAIL	1,197	1,546	1,249	1 533
FUSELAGE	16,273	16,483	16,757	16 700
LANDING GEAR	5,345	5,488	5,445	5,445
NACELLE AND MOUNTING STRUCTURE	2,129	2,525	2,276	4 596
PROPULSION AND ENGINE SYSTEM	10,441	12,402	12,175	12,397
FUEL SYSTEM	727	685	788	1,364
FLIGHT CONTROLS AND HYDRAULICS	2,298	2,502	2,947	2,745
AUX POWER UNIT	839	839	839	839
INSTRUMENTS	922	922	922	922
AIR CONDITIONING AND PNEUMATICS	1,938	2,211	2,186	2,498
ELECTRICAL AND LIGHTING SYSTEM	2,535	2,555	2,550	2,545
AVIONICS AND AUTO FLIGHT CONTROLS	1,349	1,349	1,349	1,349
FURNISHINGS	11,113	11,928	11,113	11,213
ANTI ICE	594	604	619	598
AUX GEAR	88	88	88	88
MANUFACTURE EMPTY WEIGHT	75,024	79,558	79,568	82,566
OPERATOR ITEMS WEIGHT	3,642	3,642	3,642	3,642
OPERATIONAL EMPTY WEIGHT	78,666	83,200	83,210	86,208

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	DC 9-80	TURBOPROP		
	BASE	CONFIG NO 1	CONFIG NO 3	CONFIG NO 2
GEOMETRY	AFT FUS	WING	HORIZ TAIL	AFT FUS
TAKEOFF GROSS WEIGHT (kg)	63,503	63,503	63,503	63,503
MAX PAYLOAD WEIGHT (kg)	17,842	18,785	15,880	14,393
PAYLOAD WEIGHT – 155 PASSENGERS (kg)	14,413	14,413	14,413	14,413
WING AREA (m^2)	112	112	112	112
HORIZ TAIL AREA/VERTICAL TAIL AREA (m^2)	29/15	33/18	47/21	36/20
HORIZ TAIL ARM/VERTICAL TAIL ARM (cm)	1,864/1,562	2,164/1,303	1,427/1,379	1 808/1,466
RATED SHAFT HORSEPOWER/ENGINE (kW)		12,319	12 136	12 315
NO OF BLADES/TIP SPEED (m/sec)	-0	8/244	8/244	8/244
PROPELLER DIAMETER (m)	-0	4 41	4 38	4 41
WEIGHT DATA (kg)				
WING	6,948	7,026	6 984	6,973
HORIZONTAL TAIL	870	880	1,301	1116
VERTICAL TAIL	543	701	566	695
FUSELAGE	7,381	7,477	7,601	7,575
LANDING GEAR	2,424	2,489	2,470	2,470
NACELLE AND MOUNTING STRUCTURE	966	1,145	1,032	2,085
PROPULSION AND ENGINE SYSTEM	4,736	5,625	5,522	5,623
FUEL SYSTEM	330	311	357	619
FLIGHT CONTROLS AND HYDRAULICS	1,042	1,135	1,337	1,245
AUX POWER UNIT	381	381	381	381
INSTRUMENTS	418	418	418	418
AIR CONDITIONING AND PNEUMATICS	879	1,003	992	1,133
ELECTRICAL AND LIGHTING SYSTEM	1,150	1,159	1,157	1,154
AVIONICS AND AUTO FLIGHT CONTROLS	612	612	612	612
FURNISHINGS	5,041	5,410	5 041	5,086
ANTI ICE	269	274	281	271
AUX GEAR	40	40	40	40
MANUFACTURE EMPTY WEIGHT	34,030	36,087	36,091	37,451
OPERATOR ITEMS WEIGHT	1,652	1,652	1,652	1 652
OPERATIONAL EMPTY WEIGHT	35,682	37,739	37,743	39 103

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FIGURE 18. SUMMARY OF GROUP WEIGHT STATEMENTS

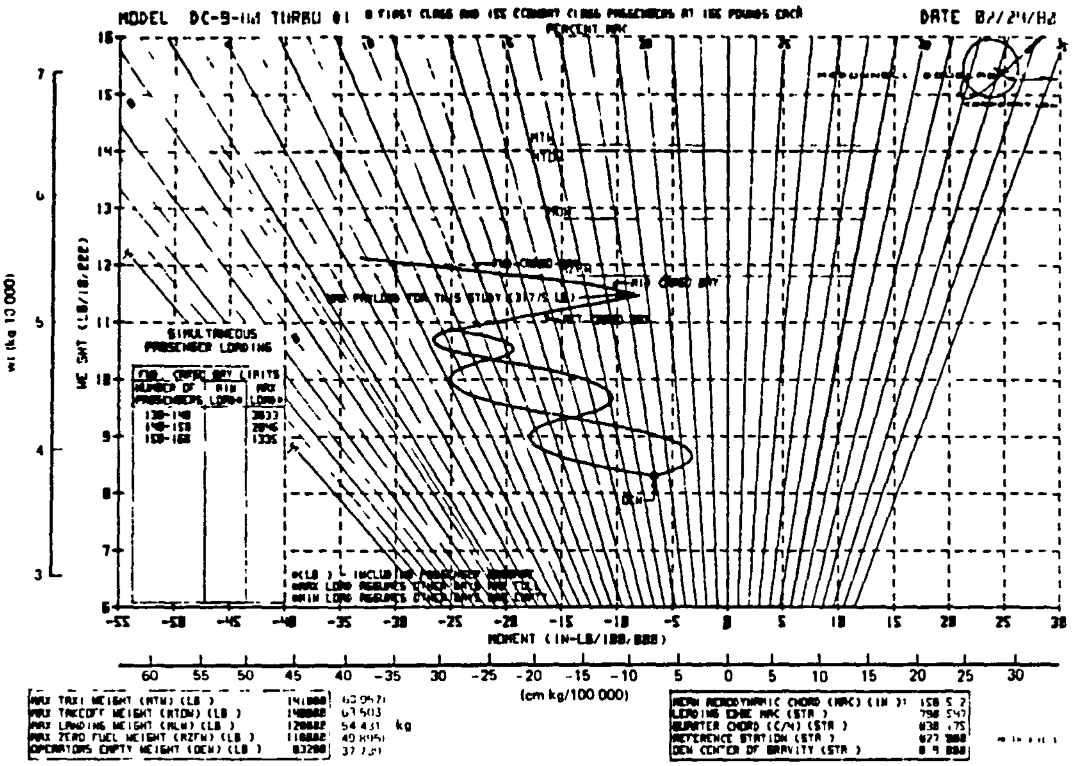

FIGURE 19. CG DIAGRAM, CONFIGURATION 1

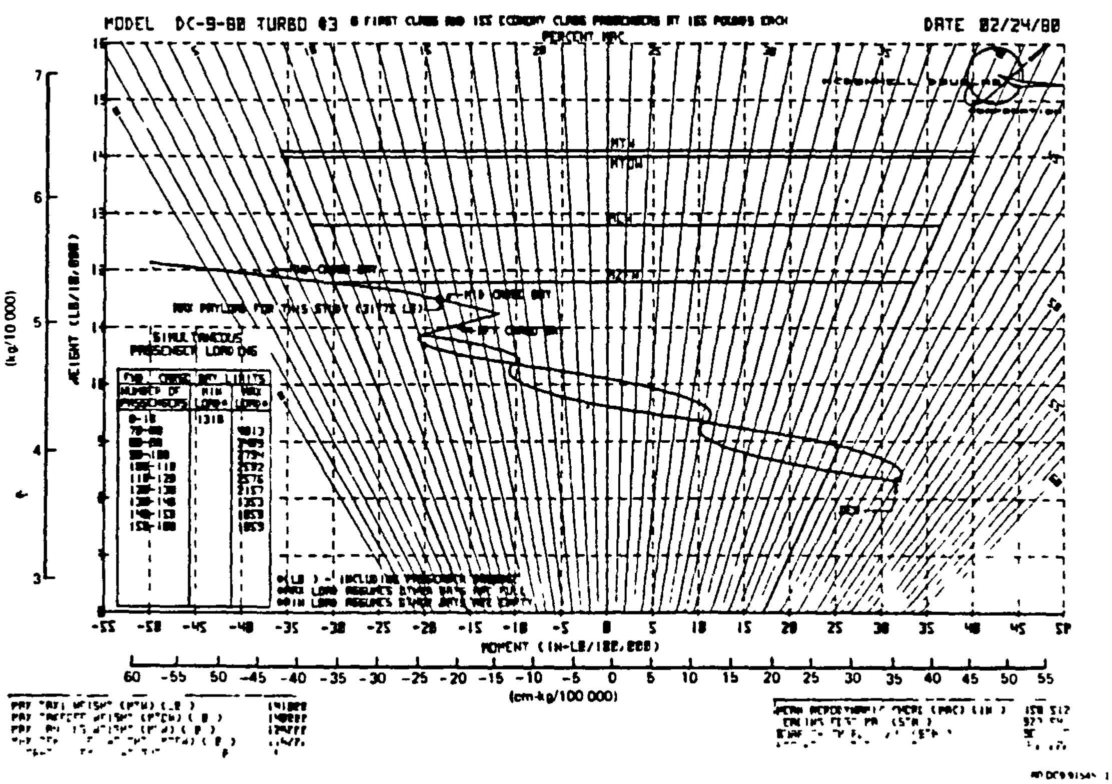

FIGURE 20. CG DIAGRAM, CONFIGURATION 3

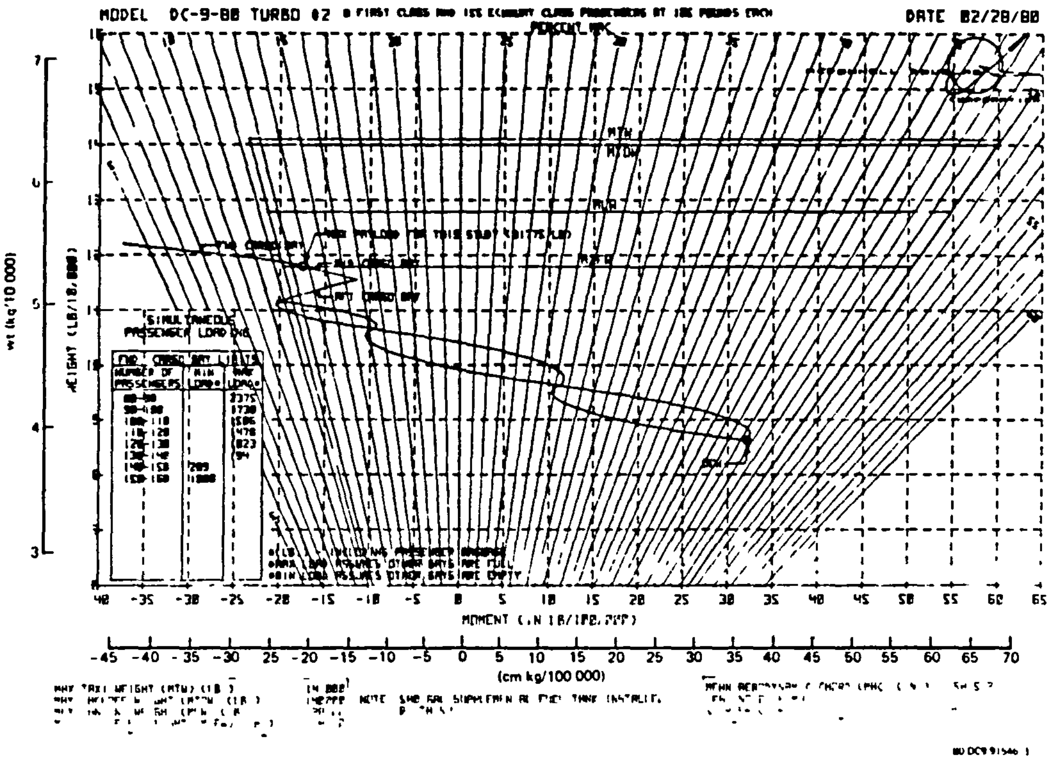

FIGURE 21. CG DIAGRAM, CONFIGURATION 2

- Cruise-climb at optimum altitude at constant Mach number. This cruise method is expedient in making trade studies and the associated comparisons.

- Constant Mach number cruise at optimum initial cruise altitude held constant throughout the mission.

- Throughout, the cruise length is assumed to be at least one-third of the total range. In the case of the very short ranges (such as 100 to 200 n mi or 185 to 370 km), this assumption therefore restricts the cruise altitude to a low 15,000 to 25,000 ft (4570 to 7620 m) and the associated cruise Mach number to the optimum speed for cruise at that resultant altitude; this Mach number is considerably reduced below M = 0.8.

In general, the majority of the sensitivity studies are performed using the M_{cruise} = 0.8 at optimum altitude. To avoid any confusion throughout the performance presentation, the cruise method is noted on each plot.

Reserves - Throughout, standard FAA domestic fuel reserves are assumed. Fuel reserves used for the mission are based on FAR 121.639. The reserves include the fuel necessary to climb from sea level to 30,000 ft (9145 m) using maximum climb thrust and the long-range speed schedule, cruising at 30,000 ft (9145 m) at 99-percent maximum specific range speed and descending to sea level for a total distance to the alternate destination of 200 n mi (370 km). The reserves also include fuel for cruising at the alternate destination for 45 minutes at 30,000 ft (9145 m) at 99 percent of the maximum specific range speed.

Performance Results

Throughout the performance analysis, which included at least eight sensitivity studies, the general conclusion is that the ranking of the configuration is consistent as follows: Configuration 3, first; Configuration 1, second; and Configuration 2, third. There is little difference between Configurations 3 and 1.

The contract statement of work states that the aircraft cruise to be considered is M = 0.8. Since this Mach number is considerable above that for maximum range performance, the effect of cruise Mach number on range performance is investigated. In addition to the base case performance, a number of sensitivity studies are included, as noted:

- M_{cruise}
  - M = 0.80
  - M = optimum
- Mission
  - Stage length
  - Multi hop
- Propfan Characteristics
  - Number of blades
  - Tip speed/disc loading
  - Propfan efficiency
  - Acoustic level

The base case aircraft performance and the sensitivity study results are summarized in Tables 4 through 6. Additional detailed performance including a further explanation of the specific trade study is presented after these summary tables.

Effect of Design Operating Conditions and Number of Propfan Blades - Tables 4 through 6 present a general summary of the relative performance of the basic Configurations 1, 3, and 2 at the mission conditions of varying stage lengths and the propfan configuration effects of number of propfan blades and the effects of propfan tip speed/disc loading. The comparisons are made at the M_{cruise} = 0.80 at constant altitude cruise of 35,000 ft (10,662 m). The small differences in the performance of Configurations 1 and 3 are evident, Configuration 3 showing a slight advantage. Configuration 2, with its heavier weight empty and added pylon drag, shows a performance disadvantage. A range differential of approximately 5 percent exists among the three configurations. The comparison shown in Tables 4 through 6 are at 100 percent passenger load factor and, in general, show approximately 23 to 26 percent improvement in fuel burned at a given range compared to the DC-9 Super 80. Typical variations of fuel burned and takeoff gross weight with range are shown in Figures 22 and 23. Had the comparisons been made at a lower passenger load factor, the comparison of range improvement and average specific range with the DC-9 Super 80 would have shown greater savings. Such is summarized in Table 7.

For the case of the long-range cruise-climb mission, the performance comparable to that of Tables 4 through 6 is presented in Figure 24 for the maximum range condition.

For all the missions except for the very short ranges, the cruise altitudes vary within approximately 1000 ft (305 m) of each other. The DC-9 Super 80 cruise is at the higher altitude. Figure 25 presents this cruise altitude variation, assuming constant cruise altitude, with the range of the aircraft. As noted previously, the short-range performance is compatible with 15,000 ft (4572 m) to 25,000 ft (7620 m) cruise.

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TABLE 4

EFFECTS OF NUMBER OF BLADES AND DESIGN OPERATING CONDITIONS
M = 0.80 Cruise at 35,000 ft (10,668 m) Altitude (or Buffet-Limited Altitude)
Payload - 31,775 Lb (14,413 kg)

Design Condition	Reference DC-9-80 Turbofan				DC-9-80 Propfan Configuration 1															
No. Blades	-				8				10				10				10			
Tip Speed ft/sec (m/sec)	-				800 (244)				800 (244)				700 (213)				600 (183)			
SHP/D² (kW/m²)	-				37.5 (301)				37.5 (301)				30 (241)				26 (209)			
Prop Diameter* ft (m)	-				14.47 (4.41 m)				14.45 (4.40)				16.1 (4.9)				17.50 (5.33)			
Stage Length n mi (km)	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max
Takeoff Gross Weight lb (kg)	121,600 (55,157)	124,420 (56,436)	132,180 (59,956)	140,000 (63,503)	123,000 (55,792)	125,100 (56,744)	131,060 (59,448)	140,000 (63,503)	121,664 (55,186)	123,770 (56,141)	129,620 (58,795)	140,000 (63,503)	123,290 (55,923)	125,400 (56,880)	131,330 (59,570)	140,000 (63,503)	125,215 (56,797)	127,550 (57,856)	133,700 (60,645)	140,000 (63,503)
Fuel Burned lb (kg)	3,200 (1451)	6,060 (2749)	13,830 (6273)	21,640 (9816)	2,390 (1084)	4,655 (2111)	10,610 (4813)	19,550 (8868)	2,365 (1073)	4,600 (2086)	10,460 (4745)	20,840 (9453)	2,370 (1075)	4,620 (2096)	10,540 (4781)	19,220 (8718)	2,440 (1107)	4,775 (2166)	10,930 (4958)	17,230 (7815)
Max Range n mi (km)				1,270 (2352)				1,450 (2685)				1,570 (2908)				1,440 (2667)				1,250 (2315)
OWE lb (kg)	78,665 (35,682)				83,200 (37,739)				82,135 (37,256)				83,750 (37,979)				85,550 (38,805)			
Percent Difference Relative to DC-9-80 Turbofan																				
Takeoff Gross Weight					+1.15	+.55	-0.84		-	-0.52	-1.93		+1.39	+0.77	-0.64		+2.97	+2.52	+1.16	
Fuel Burned					-25.3	-23.2	-23.3		-26.0	-23.7	-24.4		-25.9	-23.8	-23.8		-23.8	-21.2	-21.0	
Range at Max TOGW								+14.2				+23.6				+13.4				-1.6

*Basic aircraft configuration not redrawn after performance sizing.

TABLE 5

EFFECTS OF NUMBER OF BLADES AND DESIGN OPERATING CONDITIONS
M = 0.80 Cruise at 35,000 ft (10,668 m) Altitude (or Buffet-Limited Altitude)
Payload - 31,775 Lb (14,413 kg)

Design Condition	Reference DC-9-80 Turbofan				DC-9-80 Propfan Configuration 3															
No. Blades	-				8				10				10				10			
Tip Speed ft/sec (m/sec)	-				800 (244)				800 (244)				700 (213)				600 (183)			
SHP/D^2 (kW/m^2)	-				37.5 (301)				37.5 (301)				30 (241)				26 (209)			
Prop Diameter* ft (m)	-				14.35 (4.374)				14.33 (4.368)				15.98 (4.87)				17.37 (5.29)			
Stage Length n mi (km)	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max
Takeoff Gross Weight lb (kg)	121,600 (55,157)	124,420 (56,436)	132,180 (59,956)	140,000 (63,503)	122,270 (55,461)	124,490 (56,468)	130,325 (59,114)	140,000 (63,503)	121,750 (55,225)	123,960 (56,227)	129.740 (58,849)	140,000 (63,503)	123,320 (55,937)	125,543 (56,945)	131,380 (59,593)	140,000 (63,503)	125,500 (56,926)	127,815 (57,976)	133,890 (60,731)	140,000 (63,503)
Fuel Burned lb (kg)	3,200 (1451)	6,060 (2749)	13,830 (6273)	21,640 (9816)	2,355 (1068)	4,580 (2077)	10,415 (4724)	20,095 (9115)	2,345 (1064)	4,550 (2064)	10,335 (4688)	20,600 (9344)	2,395 (1086)	4,565 (2071)	10,405 (4720)	19.030 (8632)	2,415 (1095)	4,725 (2143)	10,805 (4901)	16,915 (7673)
Max Range n mi (km)				1,270 (2352)				1,525 (2824)				1,570 (2908)				1,445 (2676)				1,240 (2296)
OWE lb (kg)	78,665 (35,682)				82,755 (37,537)				82,289 (37,326)				83,835 (38,027)				85,775 (38,907)			
Percent Difference Relative to DC-9-80 Turbofan																				
Takeoff Gross Weight					+0.5	+0.1	-1.4		+0.1	-0.4	-1.9		+1.4	+0.90	-0.60		+3.2	+2.7	+1.3	
Fuel Burned					-26.4	-24.4	-24.7		-26.8	-25.0	-25.3		-26.8	-24.6	-24.8		-24.6	-22.1	-21.9	
Range at Max TOGW								+20.0				+23.7				+13.9				-2.4

*Basic aircraft configuration not redrawn after performance sizing.

TABLE 6

EFFECTS OF NUMBER OF BLADES AND DESIGN OPERATING CONDITIONS
M = 0.80 Cruise at 35,000 ft (10,668 m) Altitude (or Buffet-Limited Altitude)
Payload - 31,775 Lb (14,413 kg)

Design Condition	Reference DC-9-80 Turbofan				DC-9-80 Propfan Configuration 2															
No. Blades	-				8				10				10				10			
Tip Speed ft/sec (m/sec)	-				800 (244)				800 (244)				700 (213)				600 (183)			
SHP/D^2 (kW/m^2)	-				37.5 (301)				37.5 (301)				30 (241)				26 (209)			
Prop Diameter* ft (m)	-				14.46 (4.41)				14.57 (4.44)				16.22 (4.94)				17.50 (5.33)			
Stage Length n mi (km)	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max	100 (185)	300 (556)	800 (1482)	Max
Takeoff Gross Weight lb (kg)	121,600 (55,157)	124,420 (56,436)	132,180 (59,956)	140,000 (63,503)	125,800 (57,062)	128,090 (58,101)	134,020 (60,790)	140,000 (63,503)	125,550 (56,949)	127,840 (57,987)	134,070 (60,813)	140,000 (63,503)	127,350 (57,765)	129,660 (58,813)	135,930 (61,657)	140,000 (63,503)	129,320 (58,659)	131,710 (59,743)	138,170 (62,673)	140,000 (63,503)
Fuel Burned lb (kg)	3,200 (1451)	6,060 (2749)	13,830 (6273)	21,640 (9816)	2,410 (1093)	4,700 (2132)	10,640 (4826)	16,620 (7539)	2,480 (1125)	4,730 (2145)	10,960 (4971)	16,890 (7661)	2,430 (1102)	4,740 (2150)	11,020 (4999)	15,090 (6845)	2,480 (1125)	4,860 (2204)	11,330 (5139)	13,160 (5969)
Max Range n mi (km)				1,270 (2352)				1,214 (2248)				1,215 (2250)				1,080 (2000)				919 (1702)
OWE lb (kg)	78,665 (35,682)				86,208 (39,103)				85,887 (38,958)				87,679 (39,770)				89,482 (40,588)			
Percent Difference Relative to DC-9-80 Turbofan																				
Takeoff Gross Weight					+3.5	+2.9	+1.4		+3.2	+2.7	+1.4		+4.7	+4.2	+2.2		+6.3	+5.9	+4.5	
Fuel Burned					-24.7	-22.4	-23.1		-23.8	-21.9	-20.8		-24.1	-21.8	-20.3		-22.5	-19.8	-18.1	
Range at Max TOGW								-4.4				-4.3				-15.0				-27.6

*Basic aircraft configuration not redrawn after performance sizing.

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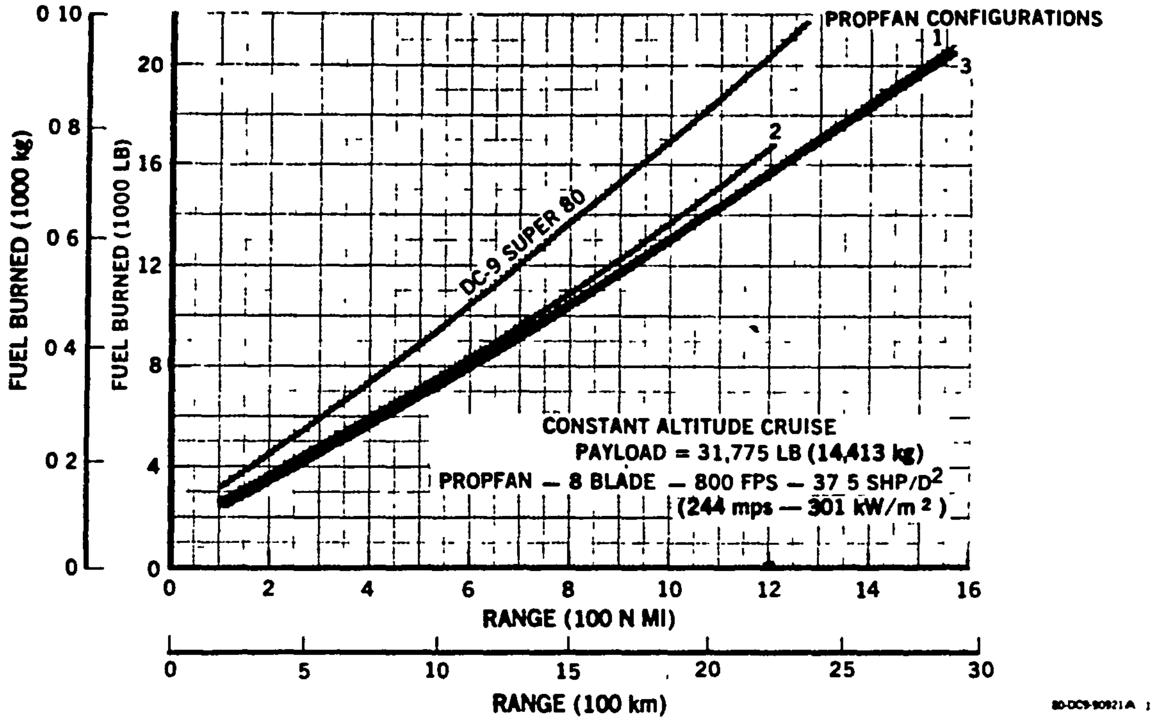

FIGURE 22. VARIATION OF FUEL BURNED WITH RANGE

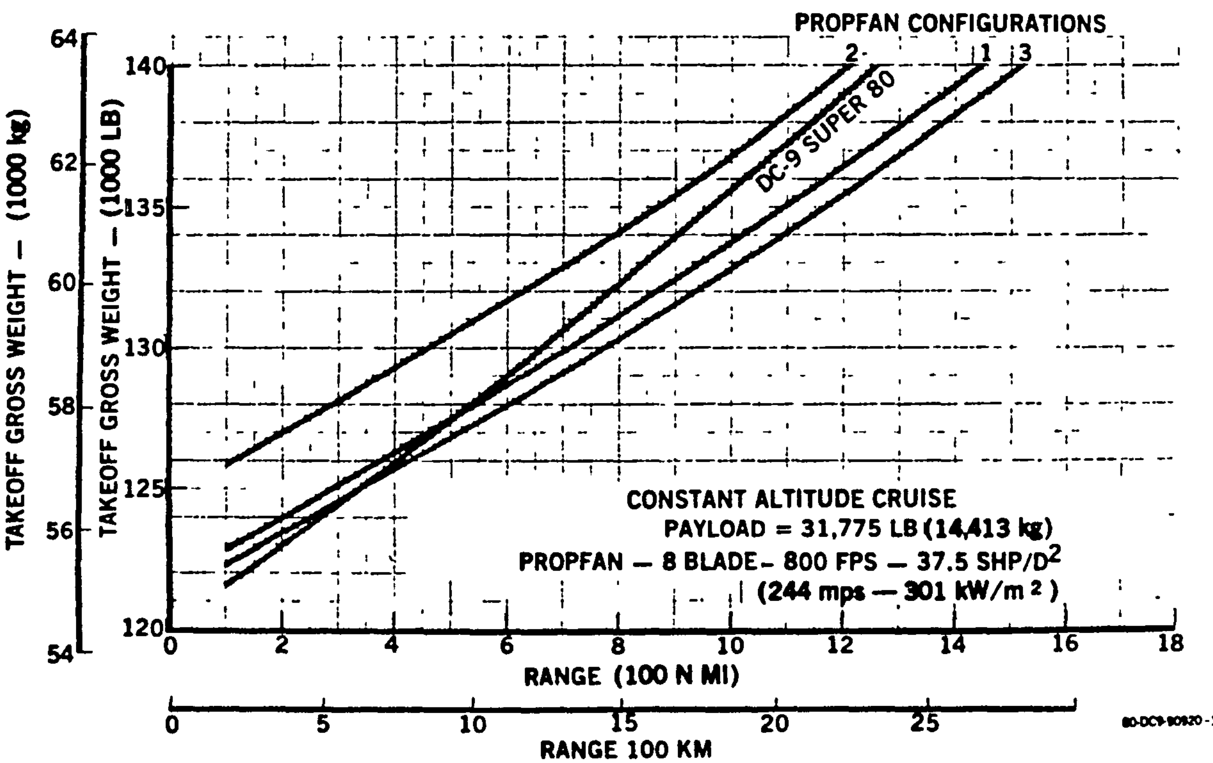

FIGURE 23. VARIATION OF TAKEOFF GROSS WEIGHT WITH RANGE

TABLE 7

EFFECT OF PERCENT LOAD FACTOR ON RANGE
AND AVERAGE SPECIFIC RANGE IMPROVEMENTS RELATIVE TO
THE DC-9 SUPER 80

Configuration 3

Step-Climb Cruise 31,000-35,000 ft
(9,450-10,668 m)

(Reference: Figures 26 and 27)

		Percent Range Improvement		Percent Average Specific Range Improvement	
Takeoff Design Weight-Lb (kg)	Design Payload (%)	M_{cruise} = 0.80	Long-Range Cruise M	M_{cruise} = 0.80	Long-Range Cruise
140,000 (63,503)	100	18.3	31.2	27.4	41.7
140,000 (63,503)	60	34.6	47.8	26.7	39.9
121,930 (55,307)	0	36.1	51.3	29.9	44.0

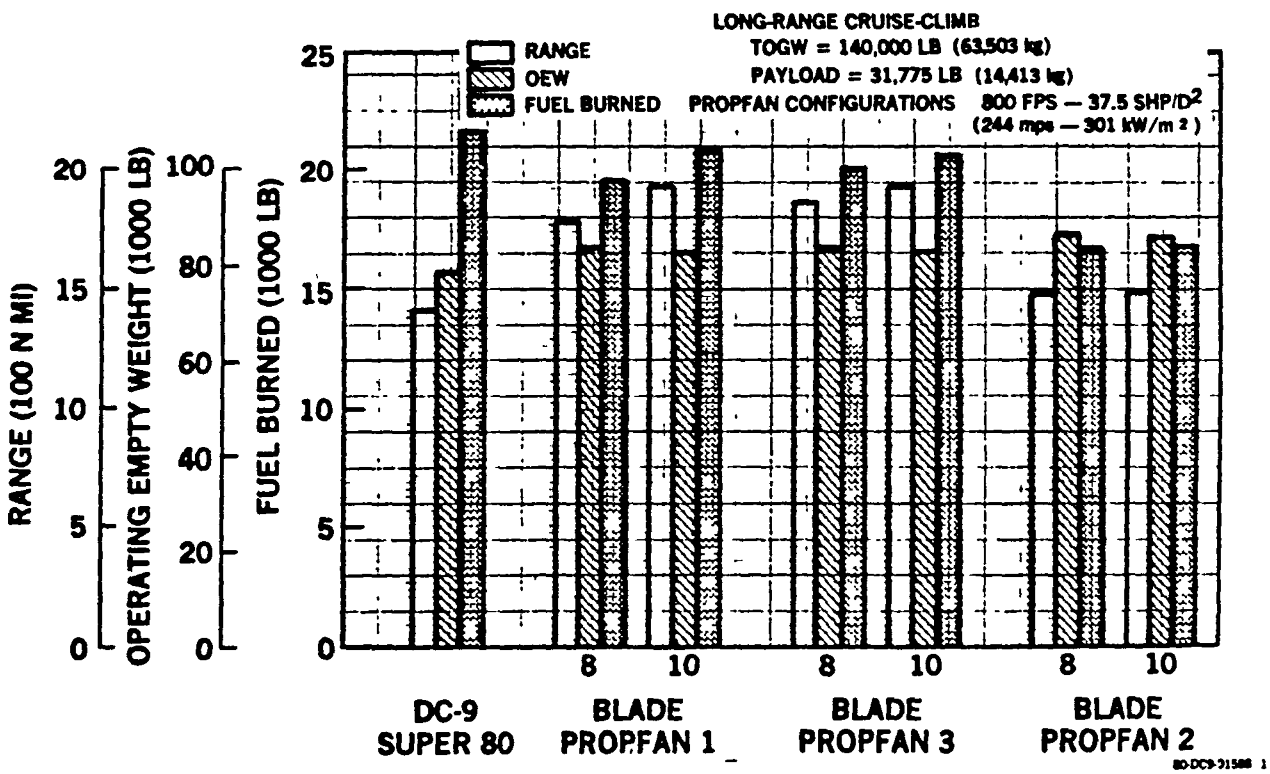

FIGURE 24. MAXIMUM RANGE CAPABILITY SUMMARY

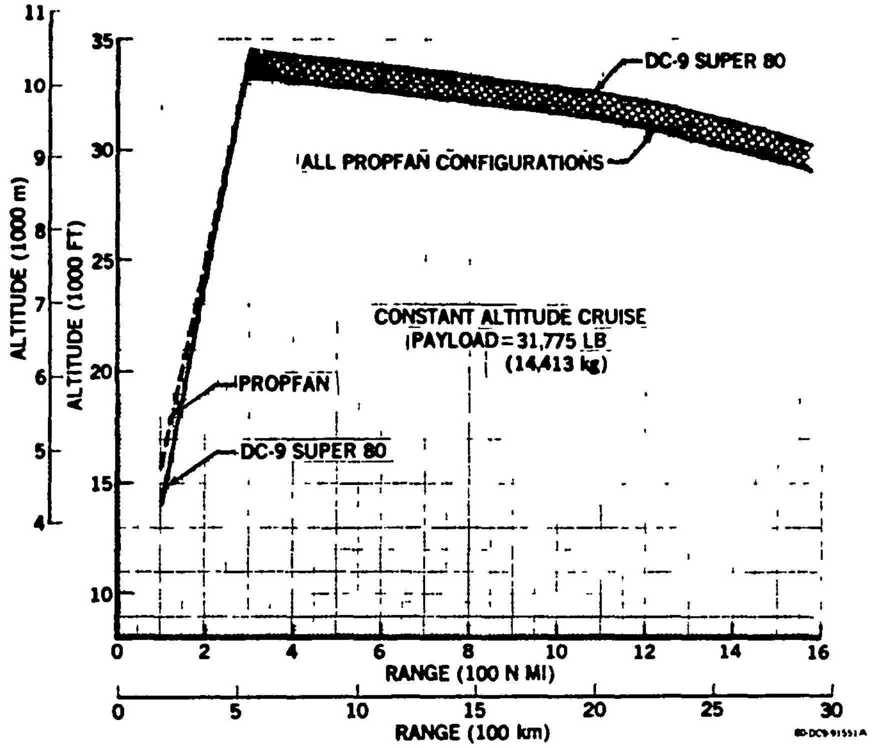

FIGURE 25. MISSION CRUISE ALTITUDE VARIATION WITH RANGE

Payload/Range Comparison - The comparative capability of the propfan configuration and the DC-9 Super 80 is shown in Figures 26 and 27. These payload ranges represent the M_{cruise} = 0.80 and the optimum M_{cruise} for the step-climb cruise characteristic of airline operation. The performance of the DC-9 Super 80 and the propfan configurations is determined with the same ground rules. The relative comparisons of the range and average specific range, as a function of the mission cruise Mach number, are shown in Figures 28 and 29.

The effect of cruise Mach number on range, assuming constant takeoff gross weight, is shown in Figure 30 and Table 8. The effect of cruise Mach number on fuel burned at constant range (equal to that obtained at M = 0.80) is shown in Figure 31 and Table 9.

The M_{cruise} = 0.76 results in approximately an 11 percent range improvement for the DC-9 Super 80, while the propfan configurations show a 14+ percent increase in range over the M_{cruise} = 0.80.

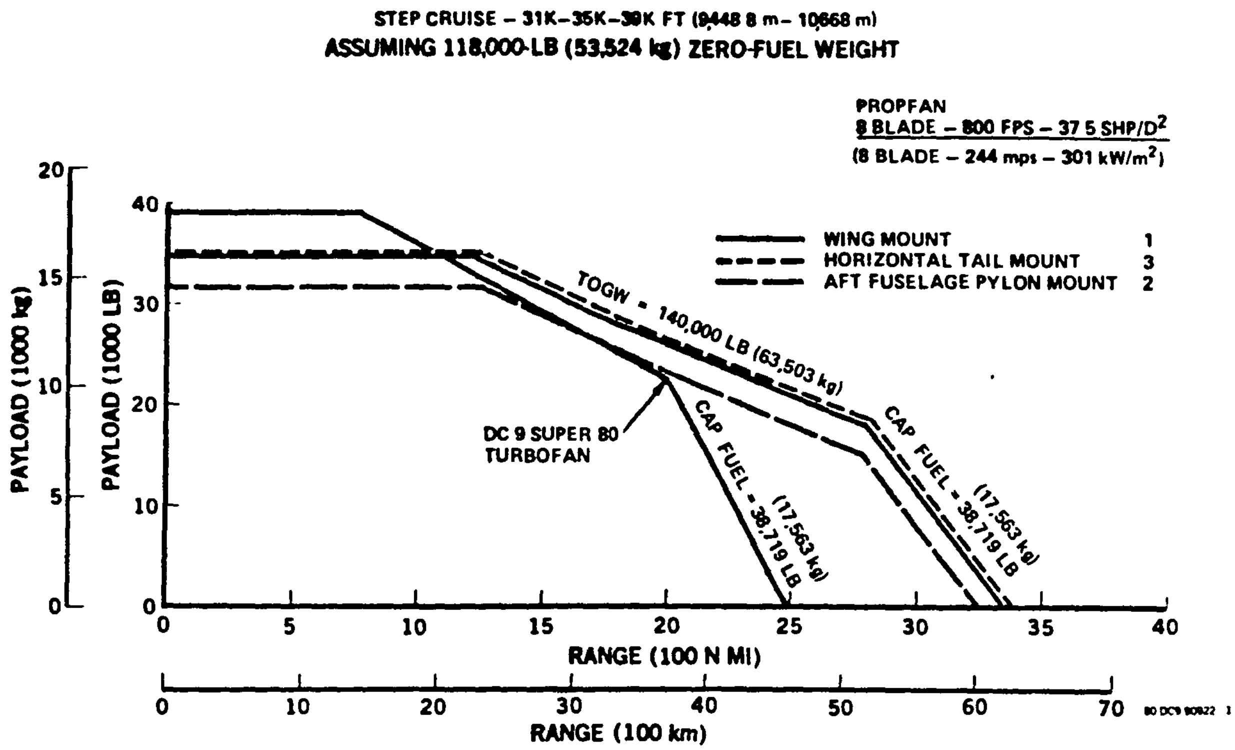

FIGURE 26. PAYLOAD RANGE, CRUISE M = 0.8

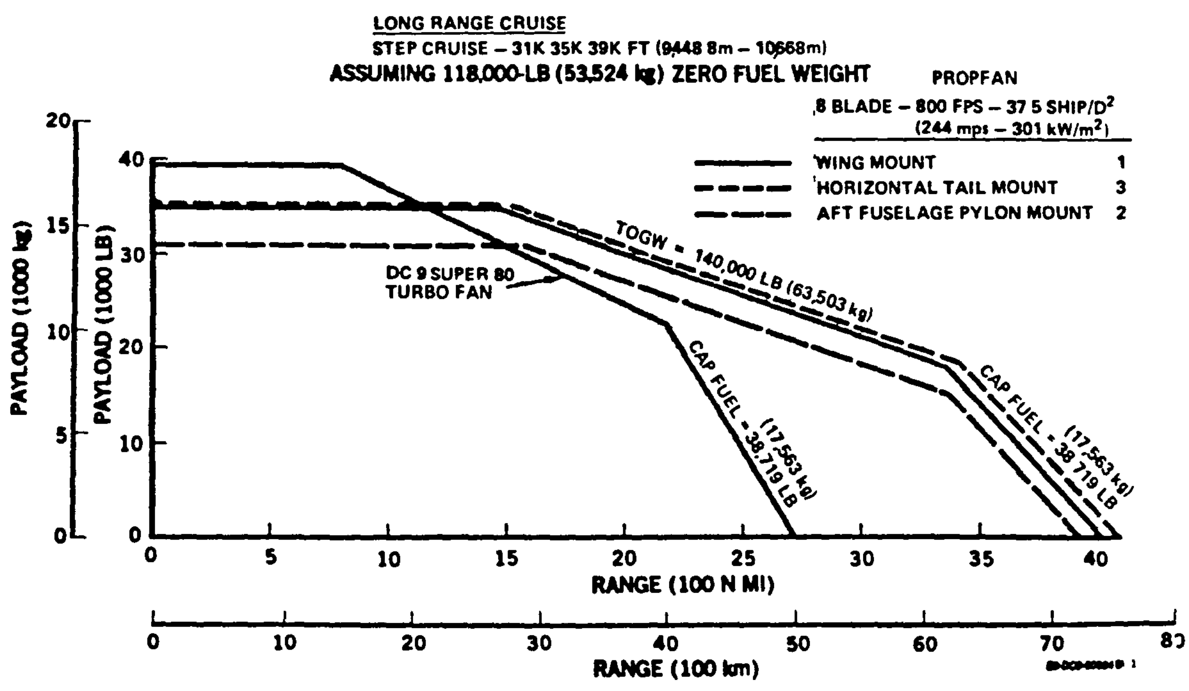

FIGURE 27. PAYLOAD RANGE, LONG-RANGE CRUISE

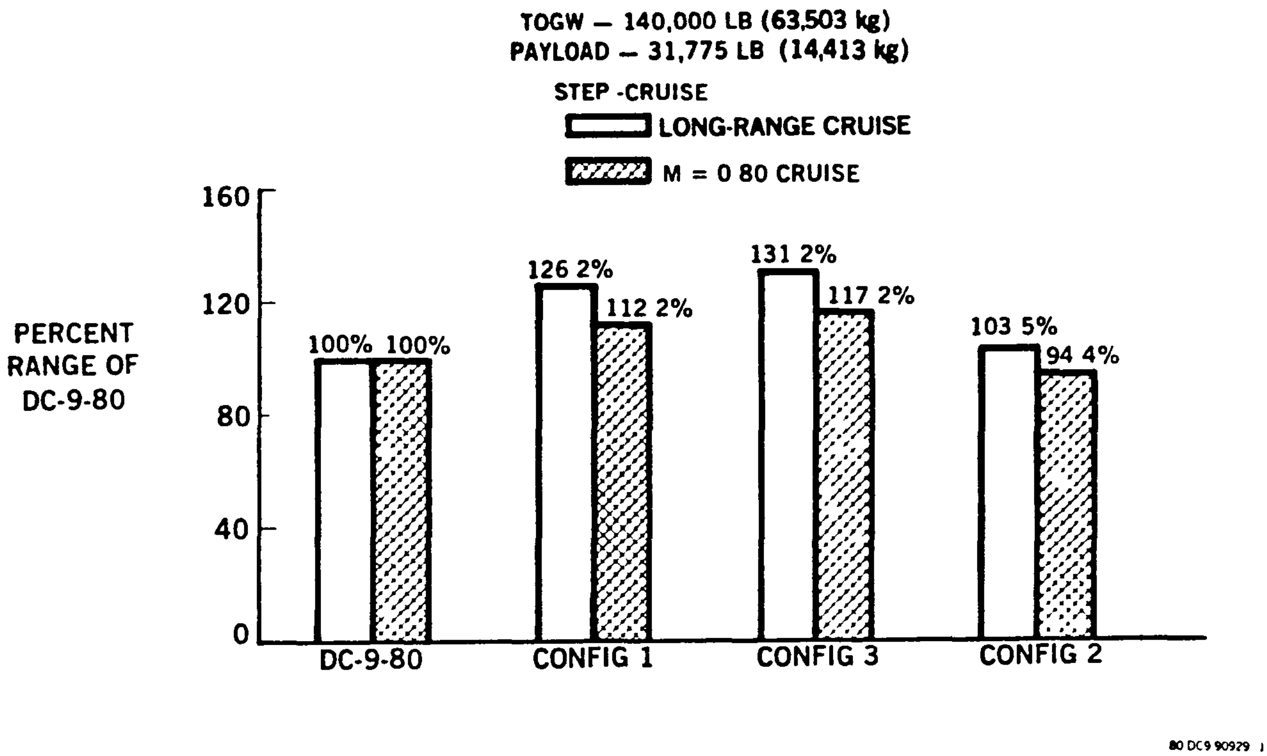

FIGURE 28. RANGE COMPARISON OF BASE CONFIGURATIONS

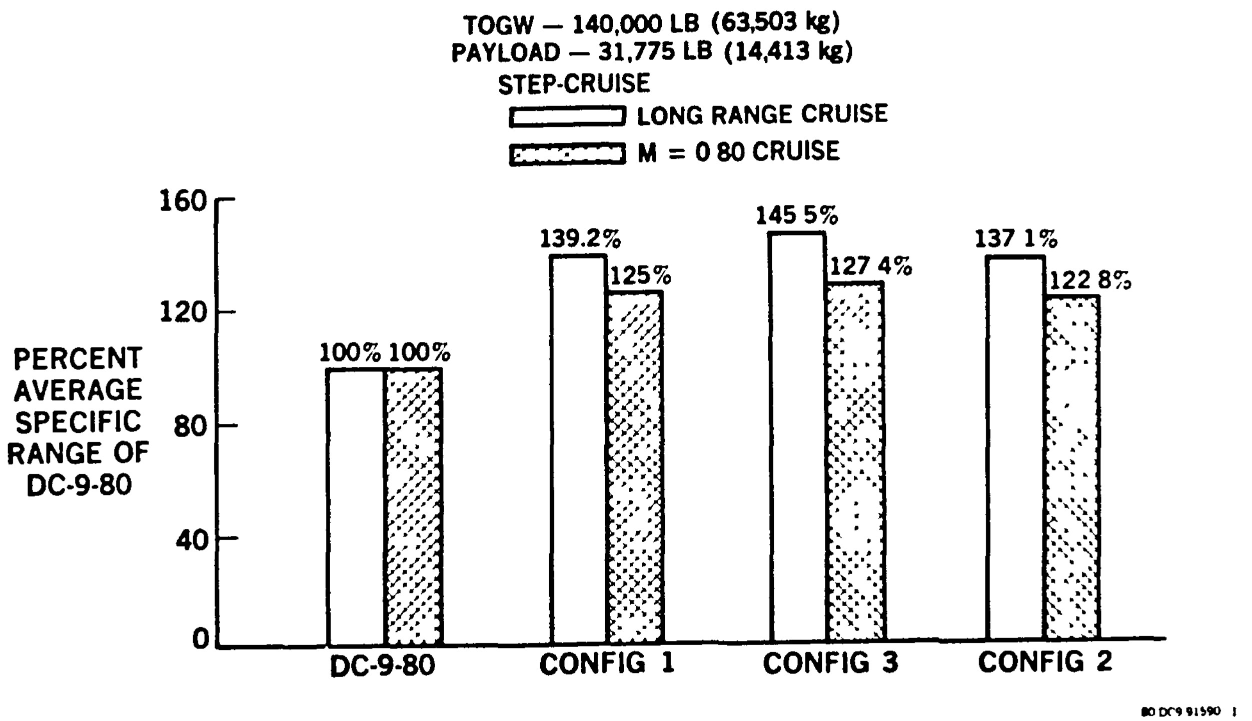

FIGURE 29. SPECIFIC RANGE COMPARISON OF BASE CONFIGURATIONS

TOGW = 140,000 LB (63,503 kg)
PAYLOAD = 31,775 LB (14,413 kg)
CRUISE CLIMB
PROPFAN – 8 BLADE – 800 FPS – 37.5 SHP/D² (244 m/sec – 301 kW/m²)

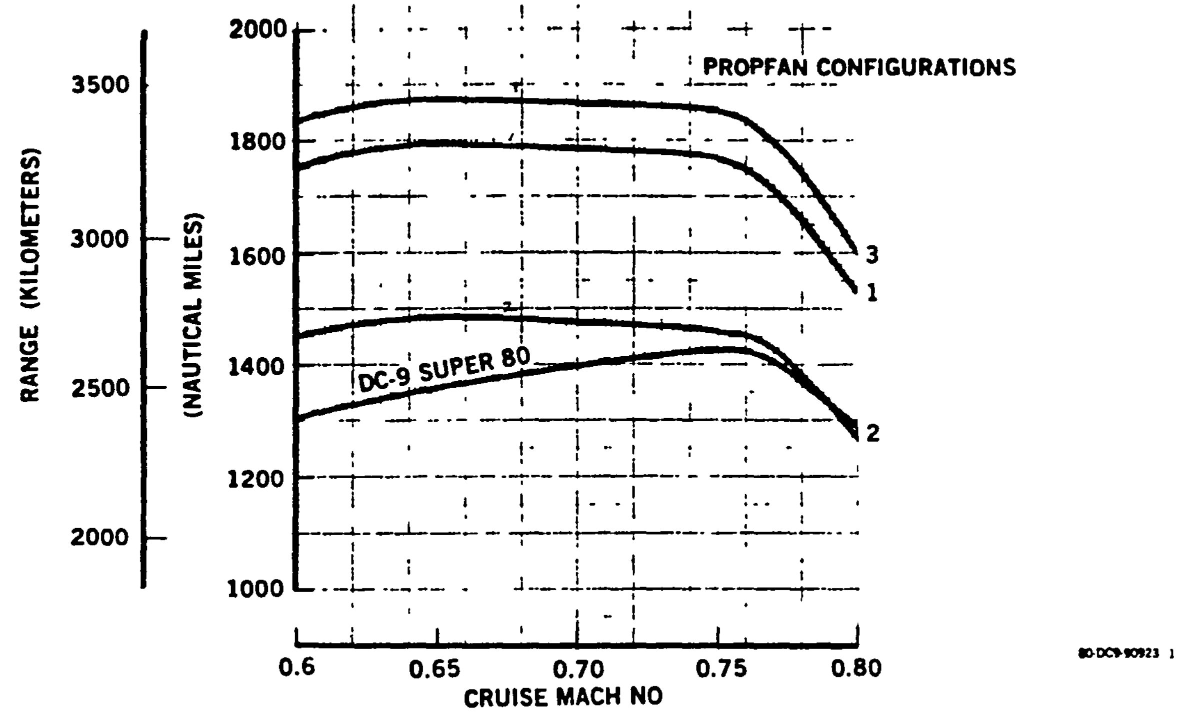

FIGURE 30. EFFECT OF CRUISE MACH NO. ON RANGE

CONSTANT RANGE (EQUAL TO REFERENCE RANGE
OBTAINABLE AT M_{CRUISE} = 0.80 FOR EACH CONFIGURATION)
PAYLOAD = 31,775 LB (14,413 kg)
CRUISE CLIMB
PROPFAN — 8 BLADE — 800 FPS — 37.5 SHP/D² (244 m/sec — 301 kW/m²)

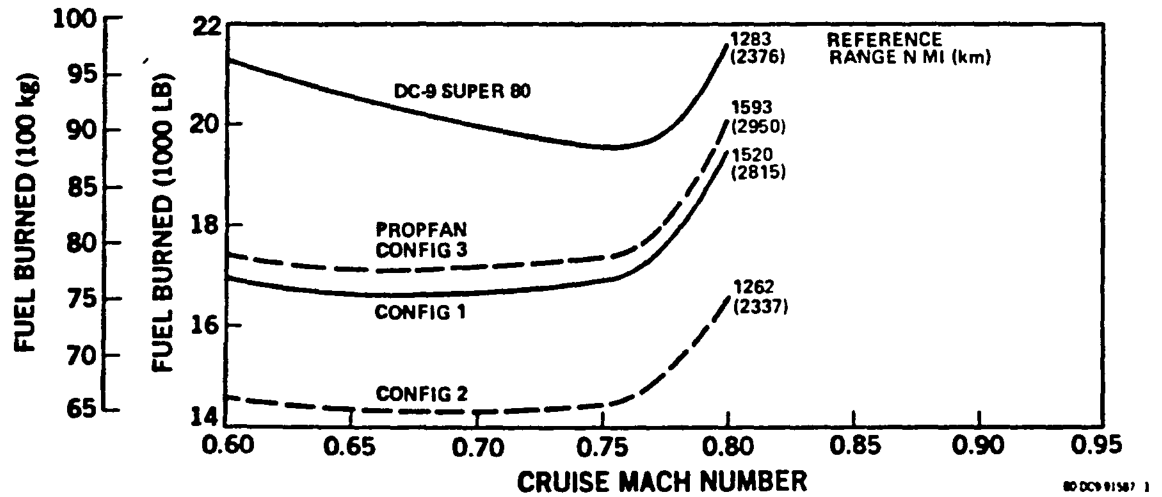

FIGURE 31. EFFECT OF CRUISE MACH NO. ON FUEL BURNED

TABLE 8

EFFECT OF CRUISE MACH NUMBER ON RANGE
Constant Takeoff Gross Weight

	M = 0.80	M = 0.76	M = 0.65
DC-9-80 Turbofan Range n mi (km)	1280 (2371)	1420 (2630)	1350 (2500)
DC-9-80 Propfan			
Configuration 1 Range	1530 (2833)	1745 (3232)	1790 (3315)
Configuration 3 Range	1600 (2963)	1835 (3398)	1875 (3473)
Configuration 2 Range	1270 (2352)	1450 (2685)	1490 (2759)

Percent increase in range for M = 0.76 cruise (near-optimum M) over M = 0.80 cruise

DC-9-80 Turbofan	+ 11 %
DC-9-80 Propfan	
Configuration 1	+ 14.1 %
Configuration 3	+ 14.7 %
Configuration 2	+ 14.2 %

Stage Length Variation - The effect of stage lengths of the propfan configurations, varying from 100, 300, 800 ft (185, 556, 1482 km), and maximum range, compared to the DC-9 Super 80 is shown in Tables 4 through 6. It should be noted that the stage length variation is determined with the same basic aircraft but with fuel off-loaded to be compatible with the desired shortened stage length. In order words, the aircraft at all stage lengths has the capability of performing missions up to its maximum design capability. Such an aircraft parametric variation is expected to show less advantage at the short range for the propfan than if the aircraft were specifically designed for a given short range. As the aircraft are compared herein, the size and operating weight empty of the basic aircraft are retained;

TABLE 9

EFFECT OF CRUISE MACH NUMBER ON FUEL BURNED
Constant Range (equal to M_{cruise} = 0.80 Range) for each Configuration*

	Cruise Mach Number 0.80	0.76	0.65
	Fuel burned per configuration lb (kg)		
DC-9-80 Turbofan	21,645 (9818)	19,571 (8877)	20,486 (9292)
DC-9-80 Propfan			
Configuration 1	19,552 (8869)	17,003 (7712)	16,664 (7559)
Configuration 3	20,100 (9117)	17,473 (7926)	17,134 (7772)
Configuration 2	16,618 (7539)	14,555 (6602)	14,279 (6477)

*Reference Ranges	
DC-9-80 Turbofan	1283 n mi (2376 km)
DC-9-80 Propfan Config 1	1520 n mi (2815 km)
Config 3	1593 n mi (2950 km)
Config 2	1262 n mi (2337 km)

Percent decrease in fuel burned for M = 0.76 cruise (near-optimum M) from M = 0.80 cruise (reference range obtainable at M_{cruise} = 0.80)

DC-9-80 Turbofan	-9.6%
DC-9-80 Propfan	
Config 1	-13.0%
Config 3	-13.1%
Config 2	-12.4%

however, the resultant aircraft retains its versatility and potential for alternate missions if the using airline should so desire.

As noted previously, the mission ground rules are such that at least one-third of the distance covered should be at cruise. This is in accordance with a general rule of thumb from the airline operations. Consequently, on the very short range cases such as 100 or 200 n mi (185 or 370 km), this cruise restriction determines the altitude (15,000 to 25,000 ft [4570 to 7620]) and optimum cruise speed (M ∿ 0.55 - 0.65) compatible with these lower altitudes. For all other of the stage length variation cases, the cruise is performed at M = 0.8 at a constant altitude equal to the optimum initial cruise altitude.

A summary of the performance comparison of the propfan configurations and the DC-9 Super 80 is presented in Figure 32.

Multi Hop Mission - The relative efficiency of the propfan compared to the turbofan on multi hop mission performance is presented in Figure 33. An assumed multi hop mission having legs of 200, 500, and 300 n mi (370, 926, and 556 km) is compared to a single hop mission of 1000 n mi (1852 km). In the case of the multi hop mission, no refueling is done at the intermediate stops; and of course, landing and takeoff allowances are taken into account at these intermediate stages. Reserves for the total 1000 n mi (1852 km) distance are carried onboard throughout the trip. As noted in Figure 33,

M = 0 80 CRUISE (OR AS NOTED FOR THE 100 N MI (185 m) STAGE LENGTH)
PAYLOAD = 31,775 LB (14,413 kg)

STAGE LENGTH N MI (km)	100 (185)	300 (556)	800 (1482)	MAX
PERCENT FUEL BURNED RELATIVE TO DC-9-80				
CONFIG 1	−25	−23	−23	
CONFIG 3	−26	−24	−25	
CONFIG 2	−25	−22	−23	
PERCENT MAX RANGE RELATIVE TO DC-9-80				
CONFIG 1				+14
CONFIG 3				+20
CONFIG 2				−4

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FIGURE 32. EFFECT OF STAGE LENGTH ON FUEL BURNED COMPARISON

PAYLOAD = 31,775 LB (14,413 kg)
8 BLADE — 800 FT/SEC (244 m/SEC) TIP SPEED PROPFAN

MULTI-HOP MISSION LEGS	**200 N MI (370 km)** **500 N MI (926 km)** **300 N MI (556 km)**
SINGLE-HOP MISSION LEGS	**1000 N MI (1852 km)**

CONFIGURATION		T.O GROSS WT/% PENALTY*	FUEL BURNED/% PENALTY*
DC 9 80 TURBOFAN			
MULTI HOP		139,200/+3 1 (63,140 kg/+3 1)	20,690/+26 2 (9385 kg/+26 2)
SINGLE HOP		135,000 (61,235 kg)	16,400 (7439 kg)
DC 9-80 PROPFAN			
CONFIGURATION 1	MULTI-HOP	136,270/+2 0 (61,811 kg/+2 0)	15,690/+18 9 (7117 kg/+18 9)
	SINGLE HOP	133,600 (60,600 kg)	13,200 (5987 kg)
CONFIGURATION 3	MULTI-HOP	135,515/+2 1 (61,468 kg/+2 1)	15,475/+19 0 (7019 kg/+19 0)
	SINGLE-HOP	132,900 (60,282 kg)	13,000 (5897 kg)
CONFIGURATION 2	MULTI-HOP	139,320/+1 9 (63,194 kg/+1.9)	15,810/+17 1 (7171 kg/+17 1)
	SINGLE-HOP	136,700 (62,006 kg)	13,500 (6123 kg)

*% PENALTY FOR MULTI-HOP MISSION OVER THE SINGLE-HOP MISSION

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FIGURE 33. MULTI-HOP PERFORMANCE COMPARISON

the propfan configurations show an approximate 7 to 9 percent less penalty for the multi hop mission compared to the DC-9 Super 80, and this at a slightly lower takeoff gross weight.

Propfan Characteristics - The sensitivity of several propfan characteristics, such as number of blades, tip speed/disc loading, propfan efficiency, and noise, is included in this investigation.

Figures 34 through 36 present the propfan configurations which reflect the 10-blade propfan and the tip speed variation (with the associated disc loading variation) from 800, 700, to 600 ft/sec (244, 213, to 183 m/sec). Throughout, the propfan locations reflect the Hamilton Standard recommended clearances from the fuselage side wall, the wing leading edge, and adequate ground clearances.

As previously noted, the basic performance for these propfan variations are presented in Tables 4 through 6 for the three basic aircraft Configurations 1, 3, and 2 compared to the DC-9 Super 80.

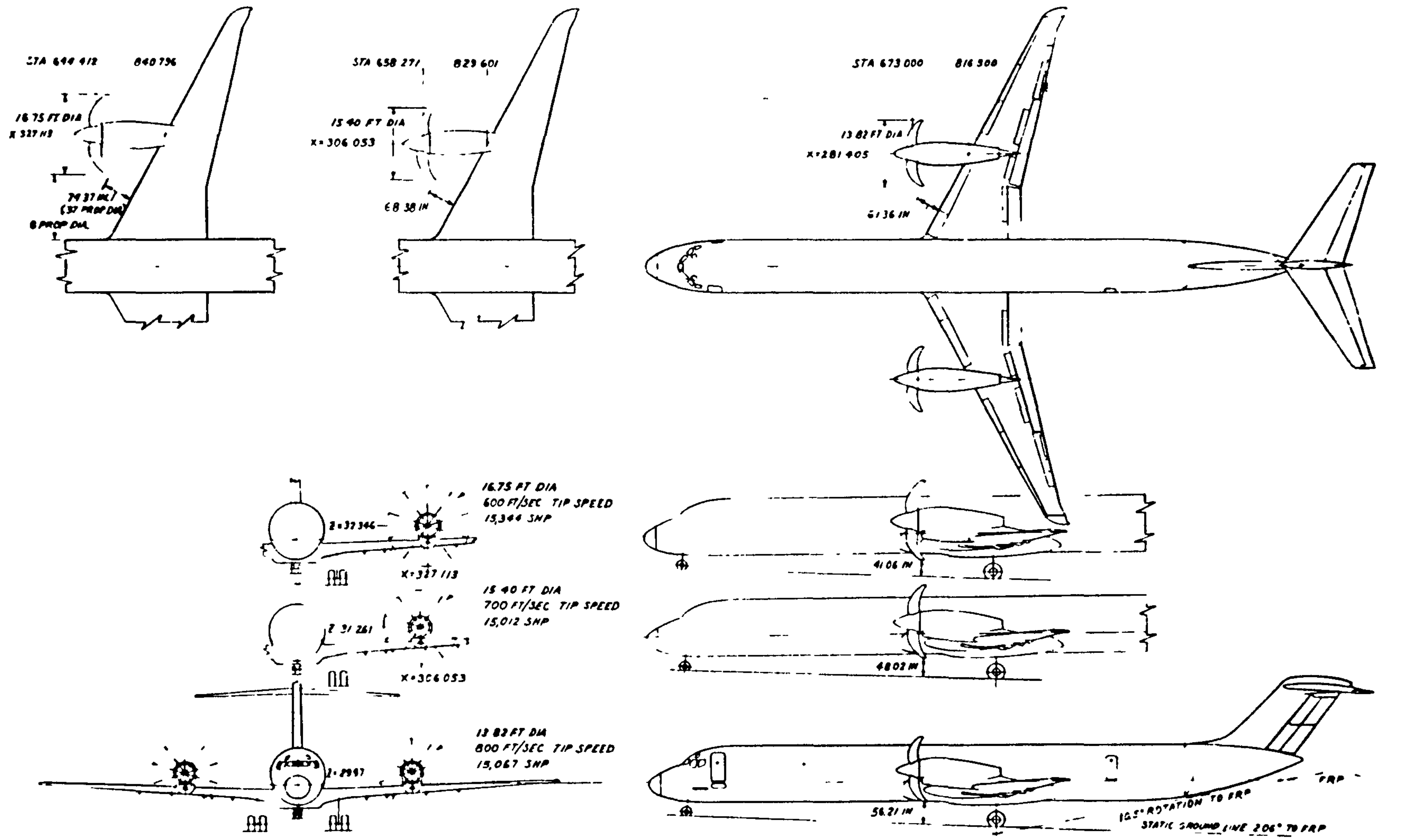

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FIGURE 34. WING MOUNT PROPFAN INSTALLATION

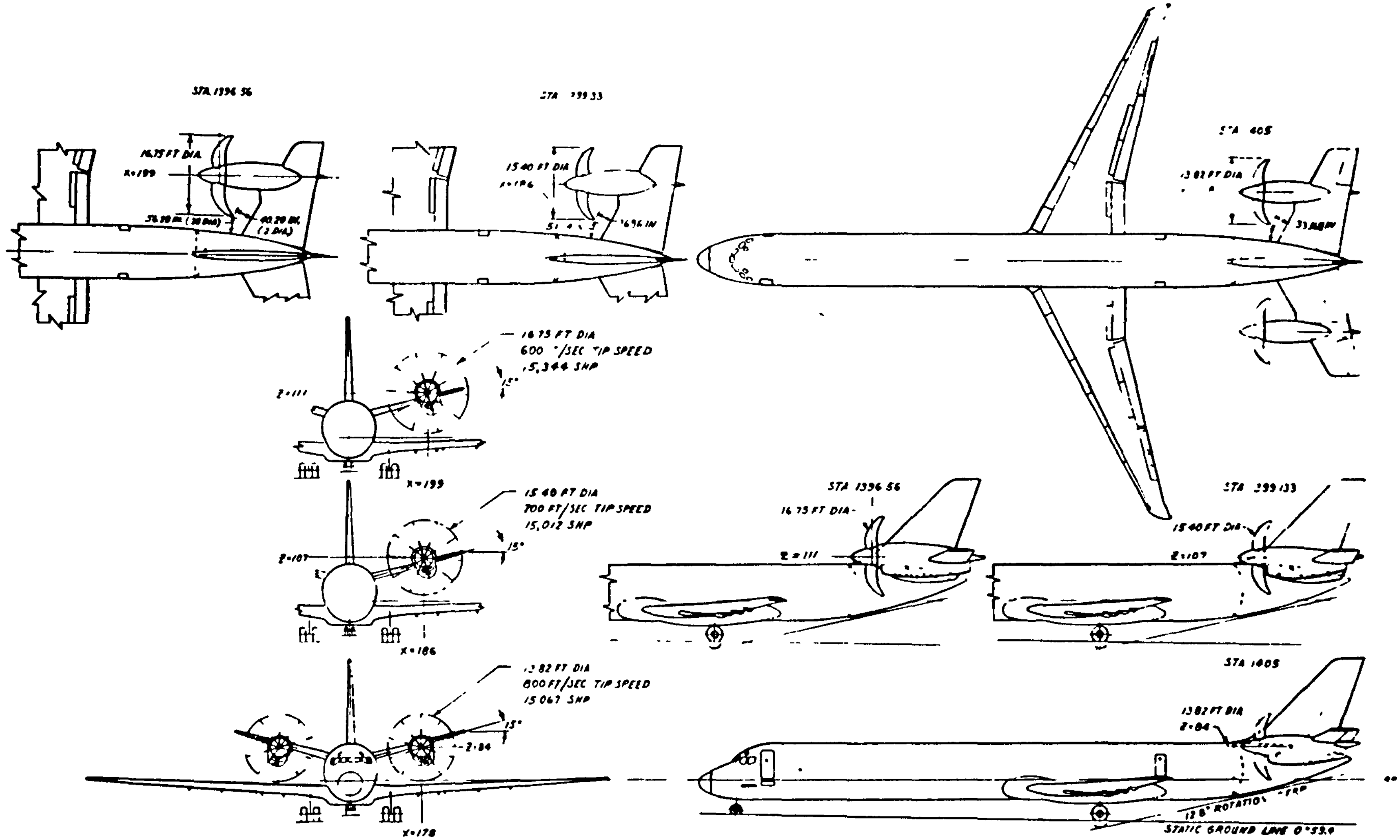

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FIGURE 35. HORIZONTAL TAIL MOUNT PROPFAN INSTALLATION

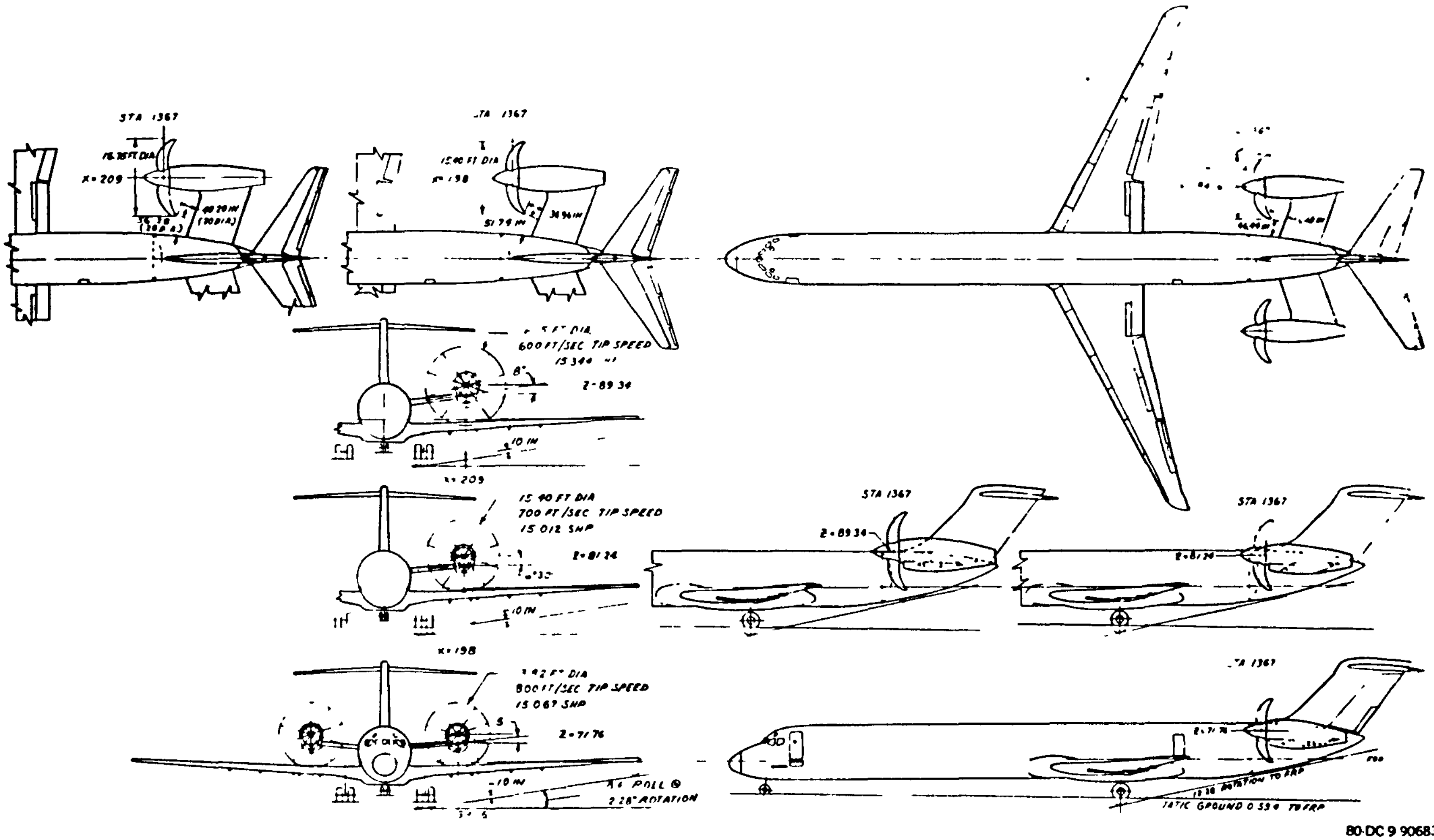

FIGURE 36. PYLON AFT MOUNT PROPFAN INSTALLATION

Effect of Number of Blades - The effect of the number of propfan blades, 8 versus 10, is shown in Figure 37. For simplification, Configuration 3 is cited as the example. The 10-blade propfan is slightly smaller in diameter than the 8-blade, as would be expected; however, the 10-blade propfan also has a very slightly better aircraft performance due to the lighter weight propfan installation. This difference in propfan weight is explained in Section 5.

M_{CRUISE} = 0 80
PAYLOAD = 31,775 LB (14,413 kg)

DESIGN CONDITION		REFERENCE DC 9-80 TURBOFAN				DC 9 80 PROPFAN CONFIGURATION 3							
NO BLADES		–				8				10			
TIP SPEED	FT/SEC (m/SEC)	–				800 (244)				800 (244)			
SHP/D²	(kW/m²)	–				37 5 (301)				37 5 (301)			
PROP DIAMETER*	FT (m)	–				14 35 (4.37)				14 33			
STAGE LENGTH	N MI (km)	100 (185)	300 (556)	800 (1,482)	MAX	100 (185)	300 (556)	800 (1,482)	MAX	100 (185)	300 (556)	800 (1,482)	MAX
TAKEOFF GROSS WEIGHT	LB (kg)	121,600 (55,157)	124,420 (56,436)	132,180 (59,956)	140,000 (63 503)	122,270 (55,461)	124,490 (56,468)	130 325 (59,114)	140 000 (63 503)	121,750 (55,225)	123,960 (56,227)	129 740 (58,849)	140 000 (63 503)
FUEL BURNED	LB (kg)	3,200 (1,451)	6,060 (2,749)	13,830 (6,273)	21,640 (9,816)	2,355 (1,068)	4,580 (2,077)	10 415 (4,724)	20,095 (9,115)	2 345 (1,064)	4 550 (2 064)	10,335 (4,688)	20 600 (9,344)
MAX RANGE	N MI (km)				1,270 (2,352)				1,525 (2,824)				1,570 (2,908)
OWE	LB (kg)	78,665 (35,682)				82,755 (37,537)				82,289 (37,326)			
% DIFFERENCE RELATIVE TO DC 9-80 TURBOFAN													
TAKE OFF GROSS WT						+0 5	+0 1	–1 4		+0 1	–0 4	–1 9	
FUEL BURNED						–26 4	–24 4	–24 7		–26 8	–25 0	–25 3	
RANGE AT MAX TOGW									+20 0				+23 7

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FIGURE 37. EFFECT OF NUMBER OF BLADES

Effect of Tip Speed/Disc Loading - The effects of tip speed/disc loading are summarized in Figure 38 for the 10-blade propfan for the design conditions of

800 ft/sec - 37.5 shp/D^2 (244 m/sec - 301 kW/m^2)
700 ft/sec - 30 shp/D^2 (213 m/sec - 241 kW/m^2)
600 ft/sec - 26 shp/D^2 (183 m/sec - 209 kW/m^2).

For convenience, Configuration 3 is again cited for the comparison. As the tip speed/disc loading decreased to 600 ft/sec - 26 shp/D^2 (183 m/sec - 209 kW/m^2, the propfan diameters increased from approximately 14.4 to 17.5 ft (4.4 to 5.3 m). This larger propfan diameter does not lead to the anticipated ground clearance problems; therefore, Configuration 4B is not required. However, this high-diameter propfan lends itself to a less

$M_{CRUISE} = 0.80$

PAYLOAD = 31,775 LB (14,413 kg)

DESIGN CONDITION		DC 9 80 PROPFAN CONFIGURATION 3											
NO BLADES		10				10				10			
TIP SPEED	FT/SEC (m/SEC)	800 (244)				700 (213)				600 (183)			
SHP/D²	(kW/m²)	37 5 (301)				30 (241)				26 (209)			
PROP DIAMETER	FT (m)	14 33 (4 37)					15 98 (4 87)				17 37 (5 29)		
STAGE LENGTH	N MI (km)	100 (185)	300 (556)	800 (1,482)	MAX	100 (185)	300 (556)	800 (1,482)	MAX	100 (185)	300 (556)	800 (1,482)	MAX
TAKEOFF GROSS WEIGHT	LB (kg)	121 750 (55,225)	123,960 (56,227)	129 740 (58 849)	140 000 (63 503)	123 320 (55,937)	125 543 (56 945)	131,380 (59 593)	140 000 (63,503)	125 500 (59 926)	127 815 (57,976)	133 890 (60,731)	140 000 (63,503)
FUEL BURNED	LB (kg)	2,345 (1 064)	4,550 (2,064)	10,335 (4,688)	20,600 (9,344)	2,395 (1,086)	4,565 (2,071)	10,405 (4,720)	19 030 (8 632)	2 415 (1,095)	4 725 (2 143)	10 805 (4 901)	16 915 (7 673)
MAX RANGE	N MI (km)				1,570 (2 908)				1,445 (2 676)				1,240 (2 296)
OWE	LB (kg)	82,289 (37,326)				83,835 (38,027)				85,775 (38,907)			
% DIFFERENCE RELATIVE TO DC 9-80 TURBOFAN													
TAKEOFF GROSS WEIGHT		+0 1	−0 40	−1 9		+1 4	+0 90	−0 60		+3 2	+2 7	+1 3	
FUEL BURNED		−26 8	−25 0	−25 3		−26 8	−24 6	−24 8		−24 6	−22 1	−21 9	
RANGE AT MAX TOGW					+23 7				+13 9				−2 4

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FIGURE 38. EFFECT OF TIP SPEED/DISC LOADING

feasible configuration arrangement (Figures 34 through 36) and also to a decrease in performance. The reduced noise level of the lower tip speed propfan with the associated reduced acoustic treatment (Configuration 1 only) is not adequate to compensate for the weight of the larger diameter propfan; therefore, the lower tip speed propfan results in the reduced performance and a less feasible configuration arrangement.

Effect of Propfan Efficiency - The sensitivity of the propfan aircraft range performance to propfan efficiency is checked over a variation of -4 to +1 percent efficiency. This trade is prompted by the possible efficiency variation in the propfan during its development. This effect of propfan efficiency is shown in Figures 39 and 40. All three propfan configurations followed essentially the same trend. Over the propfan efficiency variation explored (-4 to +1 percent), the range sensitivity is as follows: 1 percent efficiency variation equals 2 percent range variation.

This variation of range with change in propfan efficiency is definitely related to the fact that the engine-propfan systems of these base case

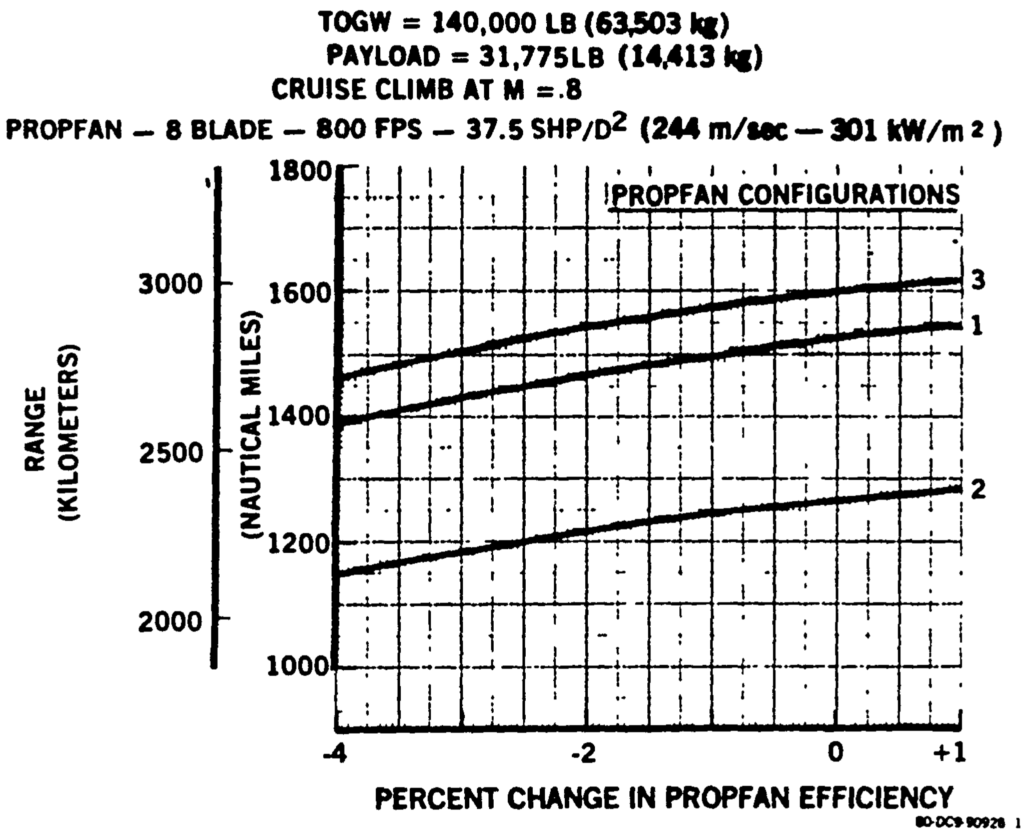

FIGURE 39. EFFECT OF PROPFAN EFFICIENCY ON RANGE

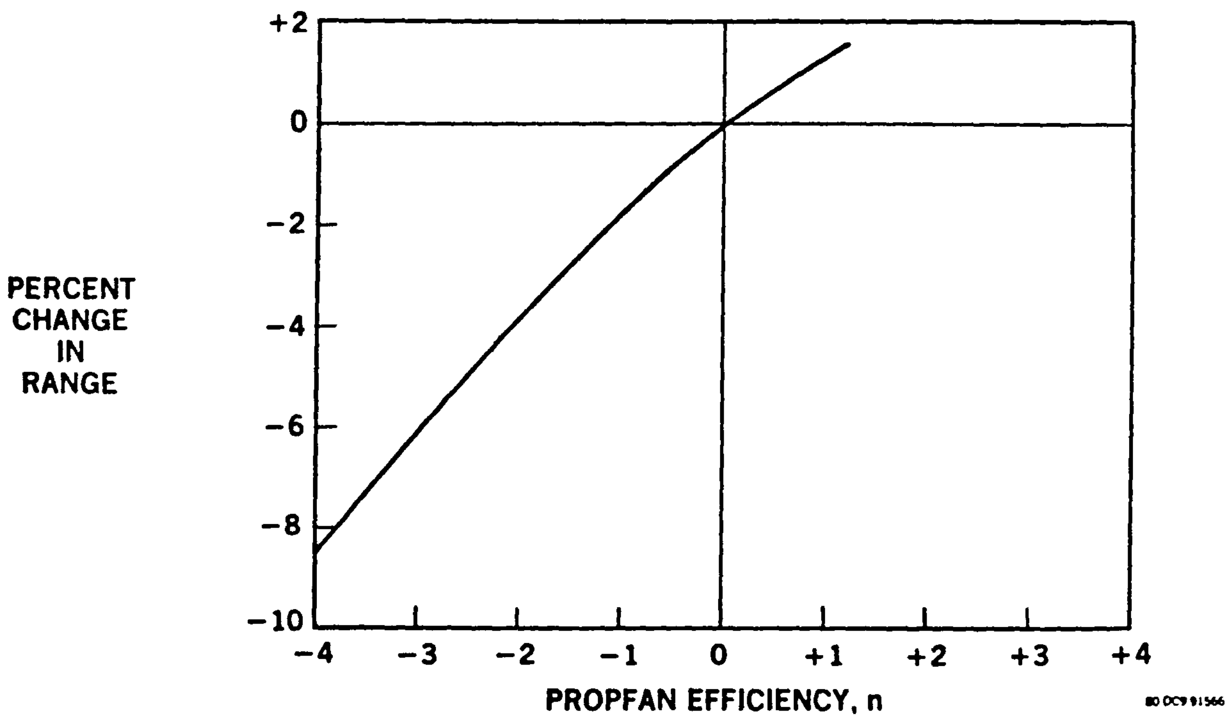

FIGURE 40. RANGE SENSITIVITY TO PROPFAN EFFICIENCY

aircraft configurations are sized for cruise at 31,000 ft; thus, the ranges of all three configurations are extremely sensitive to thrust variations and therefore to propfan efficiency. A loss of only 1 percent in thrust, or propfan efficiency, decreases the initial cruise altitude approximately 2500 ft, with a resulting range loss of approximately 2 percent. A gain of 1 percent in thrust, or propfan efficiency, increases the altitude approximately 1000 ft, at which point the configurations become buffet limited with a subsequent range increase of approximately 1.4 percent. Any further increase in thrust will have no benefit on range unless the maximum takeoff gross weight of the configurations can be increased to take advantage of additional fuel. Further losses in thrust, greater than 1 percent, will show range losses greater than 2 percent because of the rapid altitude loss with thrust loss and the subsequent increase of engine specific fuel consumption (SFC).

Effect of Propfan Acoustic Level - The acoustic levels assumed throughout this study are those predicted in the Hamilton Standard Data Package. To give an indication of the weight penalties, and consequent penalties in the aircraft fuel burned, a variation of ±6 dB from the basic acoustic levels is considered on Configuration 1. This wing mount propfan configuration is the one arrangement of the three which is subject to major changes in acoustic or structural treatment due to a change in decibel level. Table 10 summarizes the estimated weight changes due to the ±6-dB acoustic level variation. As noted in Table 10, the total acoustic treatment for the basic case is 1195 lb (542 kg), or roughly 1.5 percent of the aircraft operating empty weight.

The weight differentials of -685 and +875 lb (-311 and +397 kg) in manufacturer's weight empty due to the +6 dB are comparable to range changes in Configuration 1 equal to +50 to -90 n mi (+93 to 167 km) at the maximum takeoff gross weight of 140,000 lb (63,503 kg) and full passenger payload of 31,775 lb (14,413 kg). Since the aircraft is operated at the maximum takeoff gross weight of 140,000 lb (63,503 kg), the Δ weight attributed to the ±6-dB variation also represents the corresponding fuel savings or penalty due to the ±6-dB noise variations.

TABLE 10

WEIGHT DIFFERENTIALS ASSOCIATED WITH ±6-dB ACOUSTIC LOAD VARIATION

Propfan Configuration 1 (Wing Mount)

Conditions:

Acoustic Trim Panel Mass Weight Penalty over DC-9-80

Minimum Required Trim Panel Mass for 82-dB Interior

Trim Panel Mass Penalty for Above-Floor Only

8-Blade Propfan, 800-fps Tip Speed (244 m/sec), 13.86-ft (4.22 m) Diameter

dB Load Variation dB Level	Normal (Basic) 138 dB at BPF	-6 dB 132 dB at BPF	+6 dB 144 dB at BPF
Acoustic Penalty - Trim Panel Mass	+ 815 lb (370 kg)	+ 340 lb (+ 154 kg)	+ 1515 lb (687 kg)
Sonic Fatigue Penalty	+ 380 lb (172 kg)	+ 170 lb (+ 77 kg)	+ 555 lb (+ 252 kg)
Total Delta Weight Over DC-9-80	+ 1195 lb (542 kg)	+ 510 lb (+ 231 kg)	+ 2070 lb (+ 939 kg)
Weight Differential from Basic Acoustic Treatment	0	- 685 lb (- 311 kg)	+ 875 lb (+397 kg)

SECTION 5
ENGINEERING DISCIPLINES TECHNICAL DISCUSSION

The preceding configuration and performance evaluation of the three propfan configurations summarizes the integration of pertinent results from the several engineering discipline areas. It should again be noted that this contract study is a broad brush treatment of the feasibility of propfan installations on a medium-range transport such as the DC-9 Super 80. The depth of detail to which the engineering discipline work is considered is consistent with this broad brush treatment. Areas requiring further study are noted, and recommendations for specific analysis and tests are summarized in Section 8.

The pertinent investigations in the several disciplines are discussed in the following paragraphs. Much of the results of these analyses is summarized in the weight inputs to the aircraft performance.

AERODYNAMICS

Drag

Drag increments to the baseline DC-9 Super 80 drag levels are calculated for each propfan configuration. These increments are estimated by finding the drag differences between the drag reduction resulting from the removal of the DC-9 Super 80 engine installation and the drag increase due to the installation of each propfan plus the empennage area changes.

Zero-Lift Drag - The skin friction drag due to the wetted area of the nacelle, pylon, horizontal tail, and vertical tail is calculated to find the zero-lift drag increment. Skin friction coefficients and a form factor appropriate to each component are used. Scrubbing drag is included for those surfaces washed by the propfan flow. A tabulation of the zero-lift drag increments in terms of Δf for each component of the base case eight blade propfan installations follows in Table 11. The total Δf values for the 10 blade, tip speed/disc loading trade study are summarized in Table 12.

TABLE 11

ZERO-LIFT DRAG INCREMENTS FOR PROPFAN
BASE CASE CONFIGURATIONS
(No Interferences)

Eight-Blade, 800-ft/sec (244 m/sec) tip speed, 37.5 shp/D^2 (301 kW/m^2)

Configuration	1	3	2
Component	Wing Mount Δf ft^2 (m^2)	Horizontal Tail Mount Δf ft^2 (m^2)	Aft Fuselage Pylon Mount Δf ft^2 (m^2)
Nacelle and Pylon	-0.58 (-0.054)	-0.54 (-0.050)	+1.28 (+0.119)
Wing Scrubbing	+0.39 (+0.036)	–	–
Horizontal Tail	+0.50 (+0.046)	+1.17 (+0.109)	+0.80 (+0.074)
Vertical Tail	+0.30 (+0.028)	+.55 (+0.051)	+0.44 (+0.041)
Total	0.61 (0.057)	1.18 (0.110)	2.52 (0.234)

The drag is nearly constant for Configurations 1 and 3 with decreasing tip speed because, as the tip speed goes down, the q in the prop-wash is decreased more than the washed area is increased, thereby producing a net drag reduction. To offset this effect, the lower tip speed propfans are larger and farther from the center-of-gravity. To maintain lateral control, the vertical tail size increases which in turn increases the drag. For Configurations 1 and 3, these effects are offsetting. For Configuration 2, the pylon which supports the nacelle must also increase in size as the propfan size increases. This added effect causes the drag of Configuration 2 to increase continuously with decreasing tip speed.

Interference Drag and Swirl Thrust Recovery - For the wing mounted engine installations, the drag is increased by 3 percent of basic airplane drag [Δf = 1.04 ft^2 (0.097 m^2)] to account for distortions in the spanload (induced drag), excess profile drag (interference drag), and swirl thrust recovery due to the propfan wash flowing over the wing. This increment is based on test results obtained from a high speed simulated propfan test run at NASA Ames during a joint NASA-MDC program (Reference 9).

The above 3 percent penalty is appropriate for the six degree swirl condition present behind all of the propfans studied, and implies a certain amount of thrust recovery from the swirl.

For the tail and pylon mounted configurations, it is assumed that the pylon support or tail surface can be tailored in some way so as to recover more swirl energy and eliminate the 3 percent penalty assumed above. These surfaces can be more easily tailored to the propfan flow field since the lift forces on these surfaces are considerably smaller than on the wing.

A summary of the total zero-lift drag including the above-mentioned interferences is presented in Table 13.

If future development activities can be conducted to study the benefits achievable due to wing modifications to recover more of the swirl energy, then this swirl penalty can be reduced. A suggested study program is outlined in Section 8.

Drag Due to Lift - The drag due to lift of the basic DC-9 Super 80 is not changed for the various propfan installations. The aft mounted installation does not affect the wing flow, and should have a negligible effect on the drag due to lift. The wing mounted installation does not influence the drag due to lift over the limited C_L range of interest, based on the test results obtained in Reference 9. Therefore, the "e" factor used in the standard $C_L^2/\pi ARe$ calculation of induced drag is assumed the same for all propfan configurations.

Stability and Control

Propeller Normal Force Coefficient Change With Angle of Attack - Propellers, both at idle and full power, are known to be significant contributors to the stability of an aircraft. A positive change in angle of attack of the propeller rotational axis will produce a normal force which is proportional to at least the number of blades and propeller side area. Since both the number of blades and the side area of the present propfans are significantly different from that of previously analyzed propellers, a detailed analysis is required.

TABLE 12

ZERO-LIFT DRAG INCREMENTS FOR TE BLADE PROPFAN TRADE STUDY (No Interferences)

Ten-Blade, Tip Speed/Disc Loading Trade

Configuration	1 Wing Mount			3 Horizontal Tail Mount			2 Aft Fuselage Pylon Mount		
Tip Speed/Disc Loading, ft/sec/shp/D^2 (m/sec/kW/m^2)	800/37.5 (244/301)	700/30 (213/241)	600/26 (183/209)	800/37.5 (244/301)	700/30 (213/241)	600/26 (183/209)	800/37.5 (244/301)	700/30 (213/241)	600/26 (183/209)
q_{prop}/q_o	1.126	1.103	1.083	1.126	1.103	1.083	1.126	1.103	1.083
Δf, ft^2 (m^2)	+0.63 (+0.058)	+0.69 (+0.064)	+0.63 (0.058)	+1.16 (+0.108)	+1.19 (+0.111)	+1.16 (0.108)	+2.55 (+0.237)	+3.03 (+0.281)	+3.11 (+0.289)

TABLE 13

TOTAL ZERO-LIFT DRAG INCREMENTS FOR PROPFAN CONFIGURATIONS Including Interferences

Swirl Angle, ϕ, = 6°

Configuration	1 Wing Mount				3 Horizontal Tail Mount				2 Aft Fuselage Pylon Mount			
Number of Blades	8	10			8	10			8	10		
Tip Speed/Disc Loading - ft/sec/SHP/D^2 (m/sec/kW/m^2)	800/37.5 (244/301)	800/37.5 (244/301)	700/30 (213/241)	600/26 (183/209)	800/37.5 (244/301)	800/37.5 (244/301)	700/30 (213/241)	600/26 (183/209)	800/37.5 (244/301)	800/37.5 (244/301)	700/30 (213/241)	600/26 (183/209)
q_{prop}/q_o	1.126	1.126	1.103	1.083	1.126	1.126	1.103	1.083	1.126	1.126	1.103	1.083
Δf, ft^2 (m^2)	1.65 (0.153)	1.67 (0.155)	1.73 (0.161)	1.67 (0.155)	1.18 (0.110)	1.16 (0.108)	1.19 (0.111)	1.16 (0.108)	2.52 (0.234)	2.55 (0.237)	3.03 (0.281)	3.11 (0.289)

The method of H. S. Ribner (Reference 10) was used to estimate the side force contribution of first a conventional six bladed propeller (World War II type) (so that use of the dual rotation data could be avoided) and then the present propfan. Figure 41 illustrates the results. Previous data from Perkins and Hage (Reference II) (also Ribner's analysis) along with the above-mentioned present six blade estimate, form a reasonable variation for single rotation conventional propellers. The propfan however, with its large side area, produces approximately twice the normal force for a given number of blades.

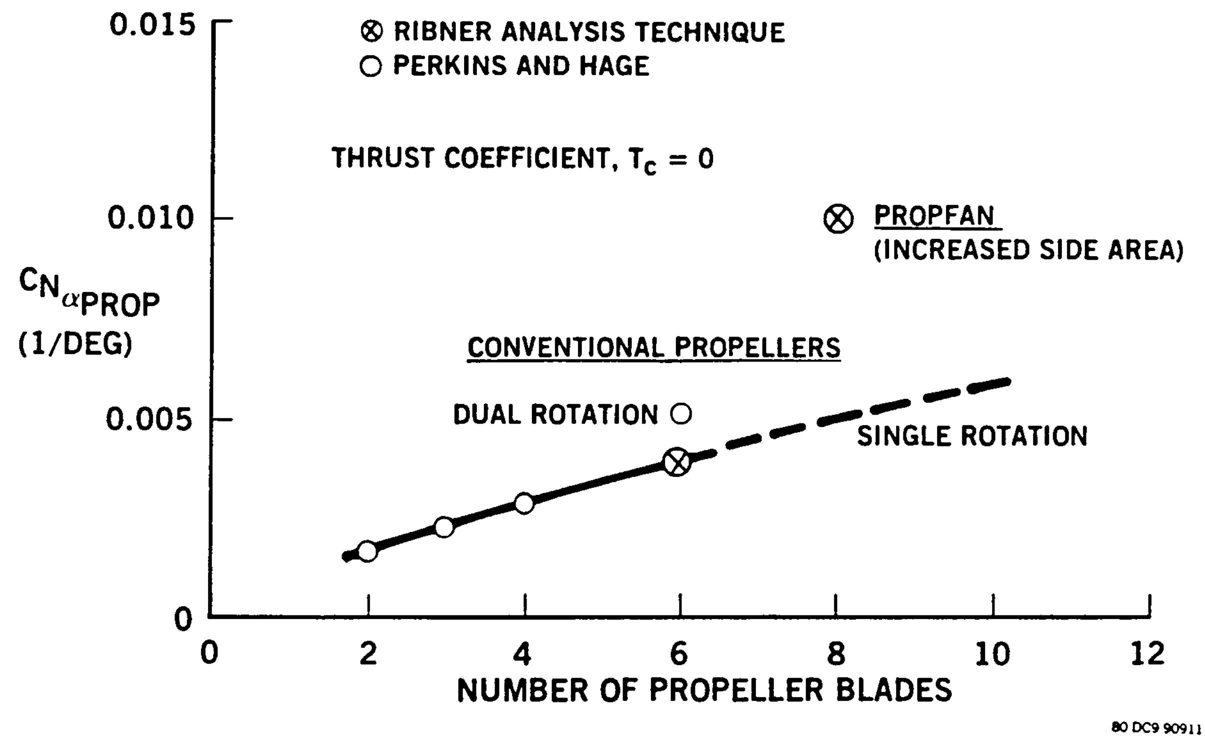

FIGURE 41. PROPELLER NORMAL FORCE COEFFICIENT CHANGE WITH ANGLE OF ATTACK

While there is no basic reason to doubt the present analysis, the predicted changes in stability level (relative to conventional propellers) are sufficiently large to require experimental verification. It is therefore recommended that the present propfan design be wind tunnel-tested at the earliest convenience to determine its normal force contribution.

Horizontal Tail Sizing - Horizontal tail sizing is presented in Figures 42 through 44 for all three base configurations analyzed, in terms of tail

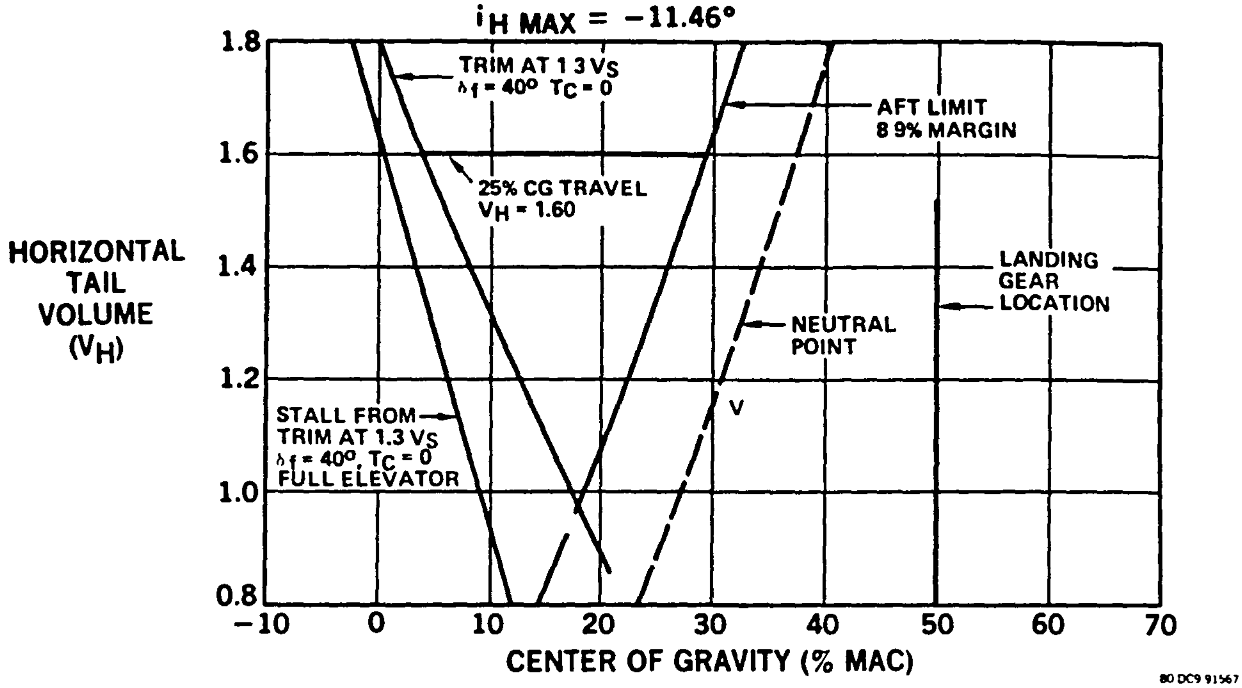

FIGURE 42. ESTIMATED CENTER OF GRAVITY LIMITS, CONFIGURATION 1

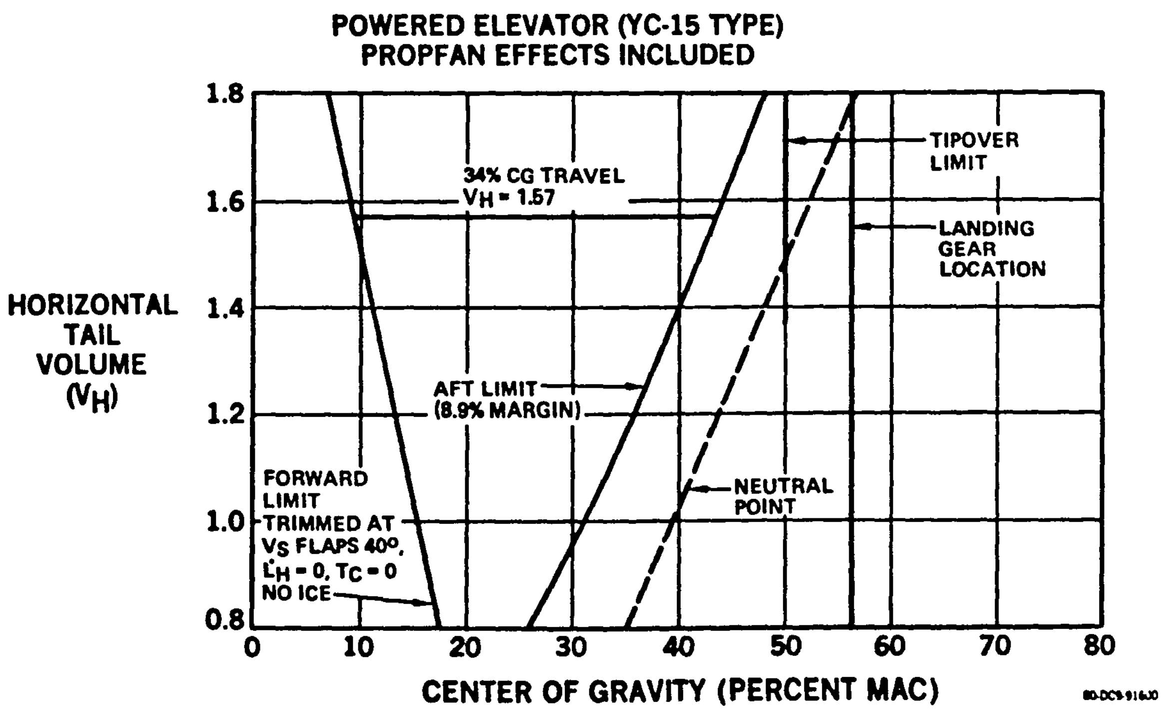

FIGURE 43. ESTIMATED CENTER OF GRAVITY LIMITS, CONFIGURATION 3

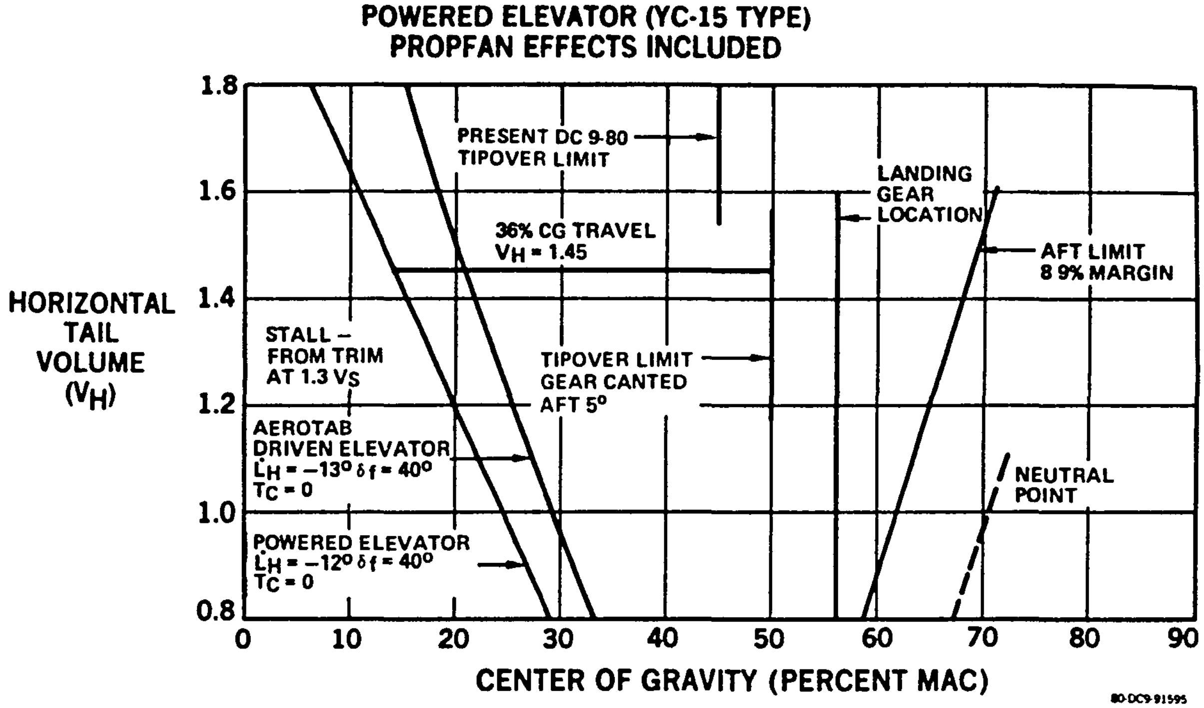

FIGURE 44. ESTIMATED CENTER OF GRAVITY LIMITS, CONFIGURATION 2

volume versus center-of-gravity. The most critical forward center-of-gravity limit together with the aft stability limit with margin are shown so that the effect of required center-of-gravity travel on tail volume can be readily seen. A summary of the pertinent data from these three figures is given in Table 14.

Although Configuration 1 is a relatively conventional layout, its stability is quite different from that of the DC-9 Super 80. Removal of the aft nacelle pylons, the addition of long wing mounted nacelles, and the addition of large propfans – all unstable contributions – have caused the neutral point and forward center-of-gravity limit to move forward relative to that of the DC-9 Super 80. The forward center-of-gravity of the aircraft is limited by the ability to trim at $1.3V_{s_{min}}$ with full flaps and zero thrust coefficient. When combined with the neutral point and a static margin of 8.9 percent mean aerodynamic chord (MAC), a horizontal tail volume of 1.60 is produced.

Configuration 3 and the DC-9 Super 80 differ not only in layout but in basic design of the longitudinal control system. Mounting engines on the horizontal

TABLE 14

HORIZONTAL TAIL SIZING

Configuration	DC-9-80	1	3	2
Static Margin (% MAC)	8.9	8.9	8.9	8.9
CG Range (% MAC)	34	25	34	36
Forward Limit Criterion	$1.3V_s$ Trim*	$1.3V_s$ Trim*	Stall*	Stall*
Aft Limit Criterion	Static Margin	Static Margin	Static Margin	Tipover Limit
Tail Volume (V_H)	1.20	1.60	1.57	1.45

*Full Flaps, T_C = 0 (FAA Requirement)

tail requires the rather stiff rigid structure of a fixed horizontal tail. To compensate for the loss in trim incidence setting, a powerful elevator of the YC-15 type is chosen. This elevator is a single-slot type with a 35-percent chord and a 35-degree maximum deflection. Figure 43 illustrates the center-of-gravity limits of this design. It should be noted that the forward limit is now set by the ability to stall the aircraft with full flaps.

The layout of Configuration 2 is very similar to that of the DC-9 Super 80 with one exception. In order to mount the propfans with proper clearance, it has been necessary to greatly increase the aspect ratio of the nacelle pylon unit. As a result, the nacelle pylon now acts as a relatively efficient horizontal tail. Figure 44 shows that the stabilizing contribution of the propfans, combined with the increased stabilizing efficiency of the nacelle pylons, has driven the neutral point aft. The increased stability of the nacelle pylon has also caused the forward limit to be set by the ability to fly to stall from trim at 1.3 $V_{S_{min}}$ rather than the ability to trim at 1.3 $V_{S_{min}}$ alone. Unfortunately, gear location problems prevent the far aft aerodynamic limit from being of practical use. In order to avoid the resulting extremely large horizontal tail sizes, two modifications have been made to the original design. The main gear is canted aft, and a full-powered elevator is added. The resulting horizontal tail volume is relatively small even though the full aerodynamic aft limit is not used. It might be possible to reduce the size of the horizontal tail by installing a controllable elevator on the engine pylon. This possibility would require a complete analysis, including wind tunnel tests, and has not been considered in this study.

Vertical Tail Sizes - Vertical tails for all three configurations are sized for single engine out minimum control speeds. Configuration 1, with wing mounted engines and associated long thrust moment arms, is particularly critical in this respect. In order to provide sufficient control, it is necessary to increase the tail volume on this design by 50 percent and to use a more powerful double hinge rudder. Stability of this design is decreased by the large unstable side force contribution of the propfans. The increased vertical tail volume is, however, more than suffucient to compensate for the instability of the propfans. Configurations 2 and 3, both having aft mounted engines, have relatively short thrust moment arms. These designs suffer from low directional stability problems typical of long fuselage, short tail arm aircraft. As a result, it is necessary to increase the tail size by approximately 25 percent and to limit the rudder deflection slightly. As rudder power is not a problem here, a single hinge rudder is used. Since the propfans are aft of the center-of-gravity, the side force contribution of the propfans in yaw is stabilizing and no problem.

Propfan Tip Speed/Disc Loading Effects on Tail Sizing - A study has been performed to assess the effects of propfan tip speed/disc loading on vertical tail size. Disc loading is varied while maintaining consistent clearance between the propfan tip and the fuselage side. As propfan loadings decrease, propfan diameter and associated thrust moment arms increase.

The resulting thrust moments require larger tail sizes in order to handle the single engine out condition. The study results are listed in Table 15. Note that the baseline aircraft does not match due to very small differences in the original vertical tail sizing.

Relaxed Static Stability - All three configurations have been analyzed without relaxed static stability so that they may be directly compared with the DC-9 Super 80. The Super 80 itself shows no gain from relaxed static stability

TABLE 15

EFFECT OF PROPFAN TIP SPEED/DISC LOADING VARIATION ON VERTICAL TAIL VOLUME

Configuration		1 Wing-Mount	3 Horizontal Tail-Mount	2 Aft Fuselage Pylon Mount
Propfan Diameter	Vertical Tail Volume			
13.85 ft (Base) (4.22 m)	8 blade 800 ft/sec (244 m/sec), tip speed 37.5 SHP/D^2 (301 kW/m^2)	0.090	0.078	0.078
13.82 ft (4.21 m)	10 blade 800 ft/sec (244 m/sec), tip speed 37.5 SHP/D^2 (301 kW/m^2)	0.091	0.077	0.079
15.40 ft (4.69 m)	10 blade 700 ft/sec (213 m/sec), tip speed 30 SHP/D^2 (241 kW/m^2)	0.099	0.081	0.084
16.75 (5.10 m)	10 blade 600 ft/sec (183 m/sec), tip speed 26 SHP/D^2 (209 kW/m^2)	0.101	0.083	0.086

since its aft limit and horizontal tail size are set by deep stall considerations. However, two of the three propfan configurations analyzed show a considerable reduction in horizontal tail size when relaxed static stability is employed. Configuration 1, whose center-of-gravity travel is the most forward, shows the largest tail volume reduction. Using the most aft static margin presently considered practical for transport aircraft, -4.5 percent MAC, the tail volume for Configuration 1 may be reduced from V_H = 1.60 to V_H = 1.27. The amount of relaxed static stability usable on Configuration 3 is also the full -4.5 percent MAC. The horizontal tail volume may then be reduced from V_H = 1.57 to V_H = 1.18. This reduction in tail volume ignores the fact that the engine will blanket a larger percentage of the horizontal tail as the tail volume is reduced. Further analysis is required to arrive at a satisfactory tail volume for Configuration 3 for the relaxed stability case. Configuration 2 cannot gain from relaxed static stability since its aft limit is set by airplane tipover. Even if tipover did not limit aft center-of-gravity travel on Configuration 2, deep stall considerations might prevent the use of relaxed static stability.

DC-9 Wing Body Flow Fields

The flow field entering the propfan is obtained analytically using a surface panel method (Reference 12). This method accounts for the effects of compressibility by applying the Goethert rule. The DC-9 wing and a body similar to the DC-9 are analyzed separately and the results combined assuming linear superposition. The results are obtained at $M_0 = 0.8$ and $C_L = 0.5$.

The results for the wing mounted configuration are shown in Figures 45 and 46 for two vertical positions relative to the wing plane. Within this flow field the propfan for the current study has been superimposed. The vertical, or upwash, velocity component is roughly constant at about 5 percent of the free stream velocity across the propfan disc. However, variations of about 5 percent in the axial velocity component occur at the inboard side of the propfan which comes closest to the wing leading edge. The sidewash velocity variation is within 2 percent.

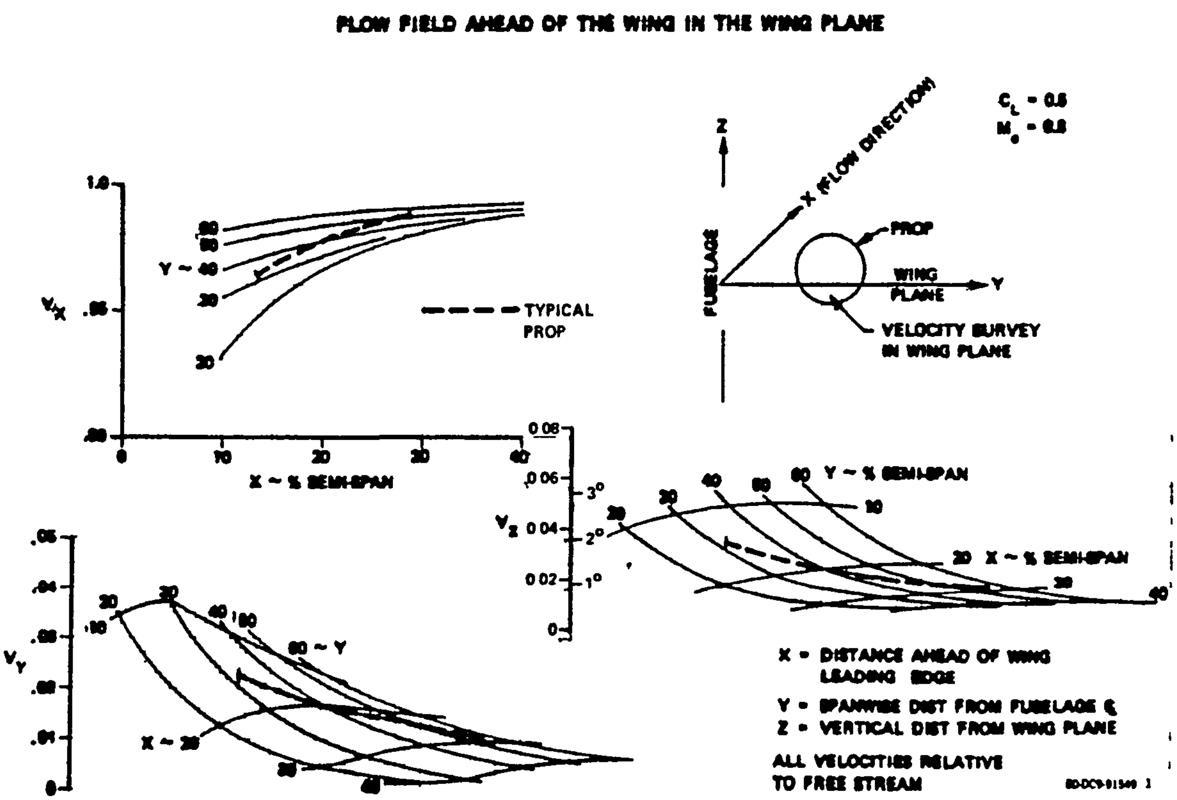

FIGURE 45. FLOW FIELD AHEAD OF THE WING IN THE WING PLANE

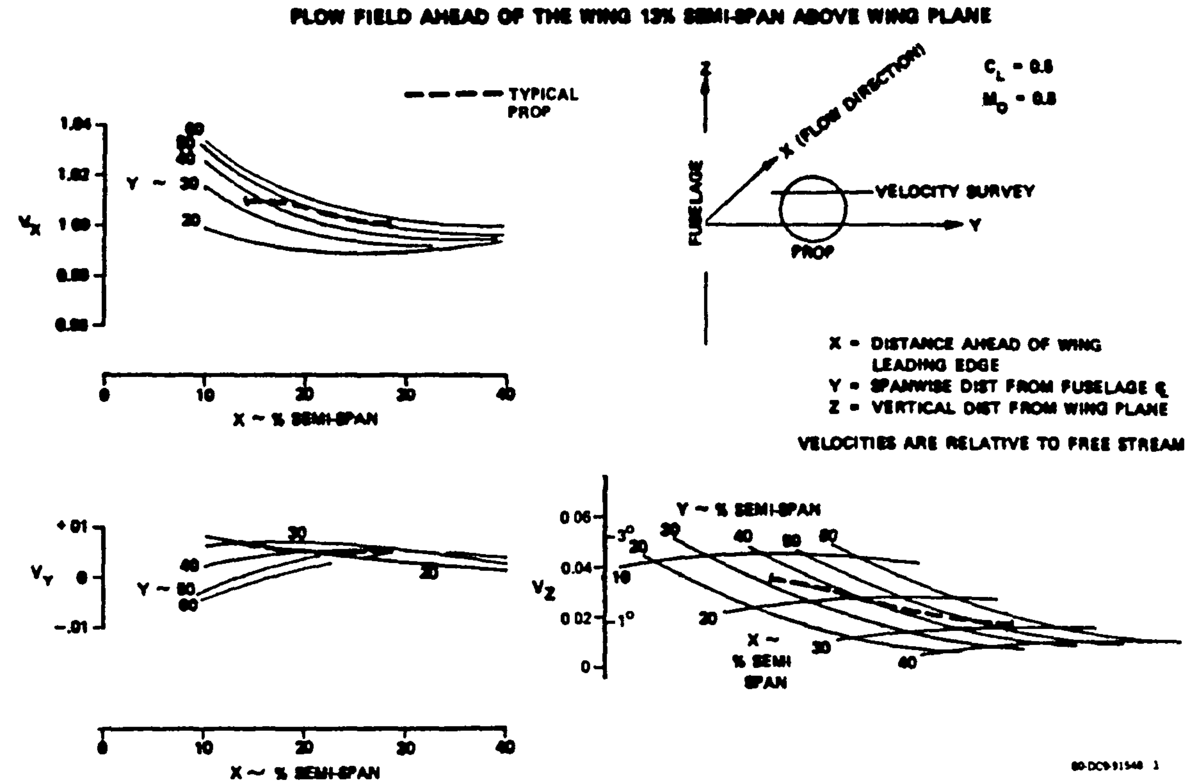

FIGURE 46. FLOW FIELD AHEAD OF THE WING 13-PERCENT SEMISPAN ABOVE WING PLANE

The flow field for the aft mounted installation is shown in Figure 47. The axial location selected [$X/b/2$ = -1.0, or 50 percent span] closely approximates the position of the propfan for Configurations 2 and 3 of the current study. The approximate positions of the aft-mounted propfan in the flow field are also shown. Sidewash velocities range from 3 to 6 percent of the free stream velocity, and downwash velocities range between 2 and 3 percent.

Since the propfan is above the wing, the viscous wake from the wing should go below the propfan, and thus the axial velocity increments are negligible.

Over or Under Wing Propfan Installations

A brief survey of available NASA test data* was made to determine some general guidelines for nacelle placement on the wing. The conclusions from this survey are summarized as follows:

*The survey covered NACA TN 2776, NACA TR 415, 436, 462, 564, and 569.

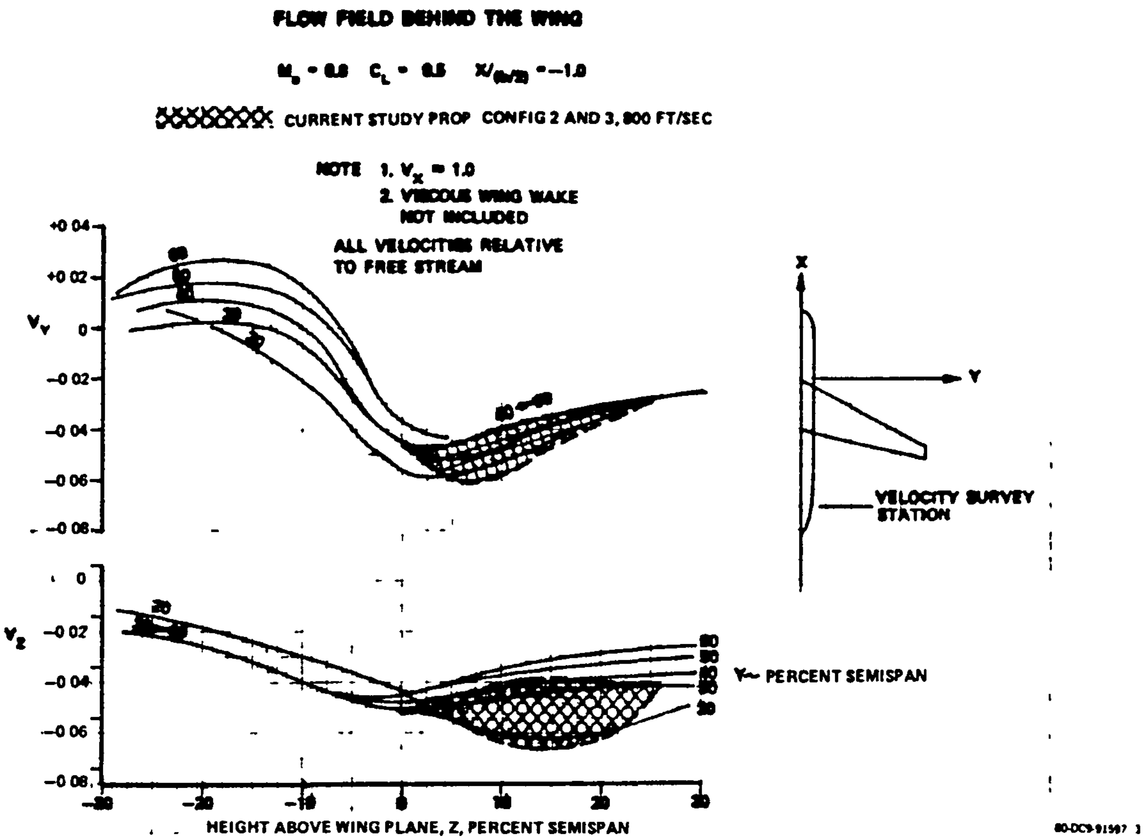

FIGURE 47. FLOW FIELD BEHIND THE WING

- Primary aerodynamic factors dictating the choice of vertical location are:

  - Propulsive efficiency
  - Lift effects
  - Interference drag

  These factors are all mutually interactive.

- Propulsive efficiency is best away from the wing where slipstream is above or below wing.

- Lift characteristics are best when slipstream is above the wing rather than below the wing so that the slipstream induces flow about the wing in the direction of circulation.

- Interference drag is lowest for installation below the wing where the local velocities are lowest.

- The best compromise location is centrally mounted on the wing as the best compromise between lift effects and interference.

The practical aspects of nacelle placement are discussed in the following paragraphs.

The Douglas turboprop powered C-133 military airplane is a high wing aircraft with the engine nacelle located below the wing. The design criterion used for this location was that the wing upper surface be kept as aerodynamically clean as possible.* The underwing location also minimized the distance between the engine thrust line and center-of-gravity, which made maintenance easier.

The high wing configuration of the C-133 permitted the nacelles to be located under the wing while still maintaining adequate propeller ground clearance. Low wing installations, typical of commercial aircraft, may well have a propeller ground clearance problem that may require placing the nacelle above the wing or having an excessively long landing gear. To get adequate propfan ground clearance in the case of the DC-9, propfan nacelles are mounted on the wing upper surface even though, from an aerodynamic point of view, this installation may have the risk of high interference drag.

STRUCTURES

Structural design and analysis studies are performed in support of configuration development and evaluation. These tasks include weight change analyses, engine installation design, sonic fatigue analyses, and flutter analyses.

Weight Change Analyses

The selected propfan configurations are analyzed in support of the overall structural weight evaluation. Analysis items are selected on the basis of potential for significant weight change from the baseline or where an empirical approach is not adequate. Fundamental preliminary design methods are applied to determine incremental weight changes. The DC-9 Super 80 serves

*"Heavy Cargo Transport Symposium," Douglas Long Beach Report LB25142, 1956.

as the baseline configuration. With the exception of center of gravity and design speed, the propfan configurations are subjected to the baseline design criteria, as indicated in Table 16. Design speeds for the full range of altitudes are shown in Figure 48.

Configuration change factors which are considered to qualify for this broad brush analysis include tail length, engine placement, propfan effects, and wing movement. These result in changes to the wing, fuselage, and tail structure which (with amplifying remarks) are summarized in Table 17. Except where otherwise noted, the weight penalties are associated with ultimate mode conditions. Additional details on weight penalties associated with sonic fatigue and flutter are provided in subsequent discussions.

The propfan slipstream effect on span load distributions is of initial concern and therefore considered. The span load with the propfan wash is obtained by incrementing available DC-9 Super 80 span load data at the cri-

TABLE 16
DESIGN CRITERIA

	DC-9-80 Baseline	DC-9-80 Propfan
Max Ramp Weight - 1000 lb (1000 kg)	141 (63.96)	141 (63.96)
Max Takeoff Weight - 1000 lb (1000 kg)	140 (63.50)	140 (63.50)
Max Landing Weight - 1000 lb (1000 kg)	130 (58.97)	130 (58.97)
Max Zero Fuel Weight - 1000 lb (1000 kg)	120 (54.43)	120 (54.43)
Engines	JT8D-209 (Turbofan)	PD370-22A (Propfan)
CG Limits at Max Ramp Weight	2.4 to 27.5	3.5 to 27.5
(% MAC) at Max Takeoff Weight	1.4 to 27.7	3.2 to 27.7
at Max Zero Fuel Weight	-3.5 to 25.5	-0.8 to 25.5
Max Maneuver Load Factor	2.5	2.5
Max Level Flight Speed (M/KIAS) (km/hr)	0.84/340 (630)	0.80/325 (603)
Max Dive Speeds (M/KIAS) (km/hr)	0.895/395 (732)	0.85/380 (704)

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TABLE 17

DC-9 SUPER 80 PROPFAN CONFIGURATIONS STRUCTURAL MODIFICATIONS AND WEIGHTS

	BASIC DATA/UNITS		CONFIGURATION: DC 9 SUPER 80 TURBOFAN (BASELINE)	DC 9 SUPER 80 PROPFAN (WING MOUNTED)	DC-9 SUPER 80 PROPFAN (FUSELAGE MOUNTED)	DC 9 SUPER 80 PROPFAN (TAIL MOUNTED)	REMARKS
COMPONENT	MAX RAMP WEIGHT – W_R	1000 LB (1000 kg)	141 (63 96)	141 (63.96)	141 (63 96)	141 (63 96)	
	MAX TAKEOFF WEIGHT – W_{TO}	1000 LB (1000 kg)	140 (63 50)	140 (63 50)	140 (63 50)	140 (63.50)	
	MAX LANDING WEIGHT – W_L	1000 LB (1000 kg)	130 (58 97)	130 (58.97)	130 (58 97)	130 (58 97)	
	MAX ZERO FUEL WEIGHT – W_{ZF}	1000 LB (1000 kg)	120 (54 43)	120 (54 43)	120 (54 43)	120 (54 43)	
	ENGINES		JT8D-209	PD370 22A	PD370 22A	PD370 22A	
	CG LIMITS – GROUND	PERCENT MAC	2 4 27 5	3 5 27 5	3 5 27 5	3 5 27 5	AT MAXIMUM RAMP WEIGHT
	CG LIMITS – FLIGHT	PERCENT MAC	1 4 27 7	3 2 27 7	3 2 27 7	3 2 27 7	AT MAXIMUM TAKEOFF WEIGHT
	CG LIMITS – FLIGHT	PERCENT MAC	–3 5 25 5	–0 8 25 5	–0 8 25 5	–0 8 25 5	AT MAXIMUM ZERO FUEL WEIGHT
	TAIL LENGTH, β(1)	IN (m)	780 (19 81)	896 (22 76)	756 (19 20)	562 (14 27)	(1) DISTANCE BETWEEN WING (0 25 C_W AND HORIZONTAL TAIL (0 45 C_H)
	MANEUVER LOAD FACTOR, n	LIMIT	2 5	2 5	2 5	2 5	
	ENGINE/POD/PYLON WEIGHT	LB/ACFT (kg/ACFT)	13 300 (6033)	14 000 (6350)	14 000 (6350)	14 000 (6350)	
	ENGINE LOCATION		AFT FUSELAGE	WING	AFT FUSELAGE	HORIZONTAL TAIL	
	WING MOVEMENT	IN (cm)	0	95 (241 3) FWD	38 (96 5) AFT	38 (96 5) AFT	
	PROPELLER		NO	YES (8 BLADE)	YES (8-BLA DE)	YES (8 BLADE)	
	MODIFICATIONS		ΔW LB/ACFT (kg/ACFT)	ΔW LB/ACFT (kg/ACFT)	ΔW LB/ACFT (kg/ACFT)	ΔW LB/ACFT (kg/ACFT)	
WING	MODIFY WING COVER PANELS – TAIL LENGTH ' EFFECT(2)		0 (0)	–32 (–14 5)	10 (4 5)	59 (26.8)	(2) MOVEMENT OF THE WING AND RESIZING OF THE HORIZONTAL TAIL CHANGE TAIL LENGTH AND HENCE HING LOADS T_H = HORIZONTAL TAIL LOAD = $(\alpha/\beta)_n W_{TO}$ L_W = WING AIR LOAD = $nW_{TO} - T_H$ = $(1 - \alpha/\beta)n W_{TO}$ ΔW = $K_1 (L_W/L_{W_{B/L}} - 1) W_{ST}$ K_1 = INERTIA LOAD EFFECT = 1 25 W_{ST} = STRUCTURAL WEIGHT AFFECTED = $K_2 W_o$ K_2 = MANEUVER SENSITIVE FRACTION = 0 64 W_o = COVER PANEL WEIGHT = 6500 LB (2948 kg) PER AIRPLANE
	– FWD CG EFFECT(3)		0 (0)	–13 (–5 9)	–9 (–4 1)	–19 (–8 6)	(3) AFT MOVEMENT OF THE FWD CG REDUCES WING LOADS SEE NOTE (2) FOR BASIC RELATIONSHIPS
	– 'ENGINE EFFECT		0 (0)	–510(4) (–231 3)	0 (0)	0 (0)	(4) PLACEMENT OF ENGINE (AND ENGINE SUPPORTS) ON THE WING PROVIDES ADDITIONAL INERTIA RELIEF AND HENCE LOWER NET SECTION LOADS
	– ' PROPELLER ' EFFECT		0 (0)	0(5) (0)	–	–	(5) THE SPAN LOADING CP MOVES INBD FOR "POWER ON" CONDITIONS (SEE FIGURE 50, 51) THIS RESULTS IN LOWER SECTION LOADS HOWEVER WING DESIGN IS BASED ON THE MORE CRITICAL OF "POWER ON" OR "POWER OFF CONDITIONS, HENCE, WEIGHT SAVING IS NOT FEASIBLE
	MODIFY FLAPS SPOILERS SLATS AND FIXED LEADING EDGES – ' PROPELLER ' EFFECT		0	1023(6) (464 0)	–	–	(6) INCREASE WEIGHT OF THESE ITEMS IN PROPELLER DISC AREA BY 80 PERCENT TO ACCOUNT FOR 80 PERCENT HIGHER LOCAL DYNAMIC PRESSURE, i e Δq/q = 0 80 (BASED ON HAMILTON STANDARD PROPFAN DATA FOR FULL POWER AT 195 KEAS AT SEA LEVEL) THIS ASSUMES NO CHANGE IN DEPLOYMENT SPEEDS OR SETTINGS
FUSELAGE	MODIFY FUSELAGE – ' ENGINE ' EFFECT(7)		0	–260 (–117 9)	180 (81 6)	350 (158 8)	(7) ENGINE LOCATION OR WEIGHT CHANGE AFFECTS AFT FUSELAGE SECTIONS SHEARS AND MOMENTS SHEAR AND BENDING MATE RIAL CHANGED PROPORTIONATELY
	– WING MOVEMENT" EFFECT(8)		0 (0)	0 (0)	0 (0)	0 (0)	(8) MOVEMENT OF THE WING FWD OR AFT PRODUCES OFFSETTING CHANGES IN LOAD AT THE FRONT AND REAR SPAR (AS ILLUS TRATED BY FIGURE 49 IN A FIRST ORDER APPROXIMATION) ALTHOUGH THE DISTRIBU TION OF MATERIAL WILL BE DIFFERENT, THE NET WEIGHT CHANGE IS JUDGED TO BE SMALL
	– "PROPELLER ' EFFECT(9)		0 (0)	380 (172 4)	240 (108 9)	175 (79 4)	(9) THE PROXIMITY OF THE PROPELLER TO THE FUSELAGE REQUIRES REINFORCEMENT OF THE SHELL FOR ACOUSTIC FATIGUE REFER TO THE TEXT AND SUPPORTING FIGURES FOR ADDITIONAL DETAILS
PYLON	NEW PYLON – BENDING MATERIAL		–	–	1064(10) (482 6)	–	(10) TOTAL WEIGHT RELATIVE TO A ' NO PYLON BASIS ALSO, GUST LOAD FACTOR = 8 ULT (DOWN), t/c = 12 5 PERCENT, INSTALLED ENGINE WEIGHT = 7000 LB (3175 kg)/SIDE, PYLON CHORD (C) = 110 IN (279 4 cm) STRUCTURAL CHORD = 66 IN (167 6 cm)
HORIZONTAL TAIL	NEW TAIL – BENDING MATERIAL		0	–	–	320(11) (145 2)	(11) PLACEMENT OF ENGINES ON THE TAIL ADD ADDITIONAL INERTIA LOADS WHICH RESULT IN HIGHER SECTION LOADS AND HENCE HIGHER WEIGHT DIFFERENCES IN AREA PLANFORM THICKNESS, ETC ALSO ACCOUNTED FOR CRITICAL CONDITION IS 2 5 g (LIMIT) BALANCED MANEUVER AT W_{ZF} + 4000 LB (1814 kg) 19 000 FT (5791 m), M = 0 796
	– "PROPELLER ' EFFECT		0	–	–	0(12) (0)	(12) THE SPAN LOADING CP MOVES INBD FOR ' POWER ON ' CONDITIONS (SEE FIGURE 49) WHICH RESULTS IN LOWER SECTION LOADS HENCE, TAIL DESIGN IS BASED ON THE MORE CRITICAL POWER OFF CONDITIONS AND WEIGHT REDUCTION FOR THIS EFFECT IS NOT POSSIBLE
AIRPLANE	MODIFY COMPONENTS – STIFFNESS, MASS, GEOMETRY" EFFECTS(13)		0 (0)	0 (0)	0 (0)	0 (0)	(13) BASED ON PRELIMINARY ANALYSES NO FLUTTER PENALTIES WERE REQUIRED REFER TO TEXT AND SUPPORTING FIGURES FOR ADDITIONAL DETAIL AND QUALIFICATION

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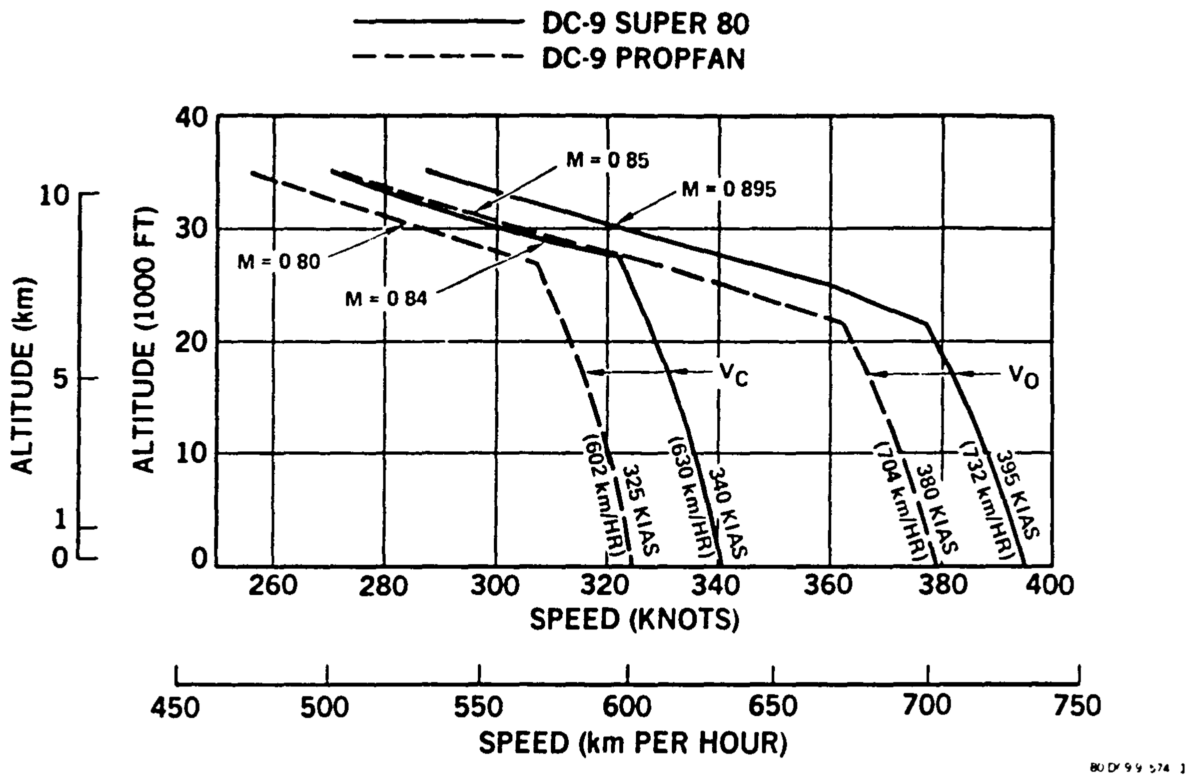


FIGURE 48. DESIGN SPEEDS

tical design load conditions. The increments to the span load of the wing mounted and tail mounted configurations due to the propfan wash are calculated using the method shown:

$$\Delta c_\ell = \left[\frac{\Delta c_\ell / c_\ell}{\Delta q/q}\right]_{\text{TEST DATA}} \cdot \frac{\Delta q}{q} c_{\ell_{DC-9}} + \left[\frac{\Delta c_\ell}{\phi}\right]_{\text{TEST DATA}} \cdot \phi$$

Figure 49 indicates the wing moment effect on fuselage bending.

The ratios from test data are obtained as a function of span position from joint NASA-MDC high-speed simulated propeller test (Reference 9) where the effects of the slipstream ($\Delta q/q$) and the effects of swirl (ϕ) are measured separately. The $\Delta q/q$ and ϕ values that are multiplied by these ratios are obtained using Hamilton Standard data at the flight conditions corresponding to critical load conditions for the DC-9. The resulting span loads are shown in Figures 50 and 51.

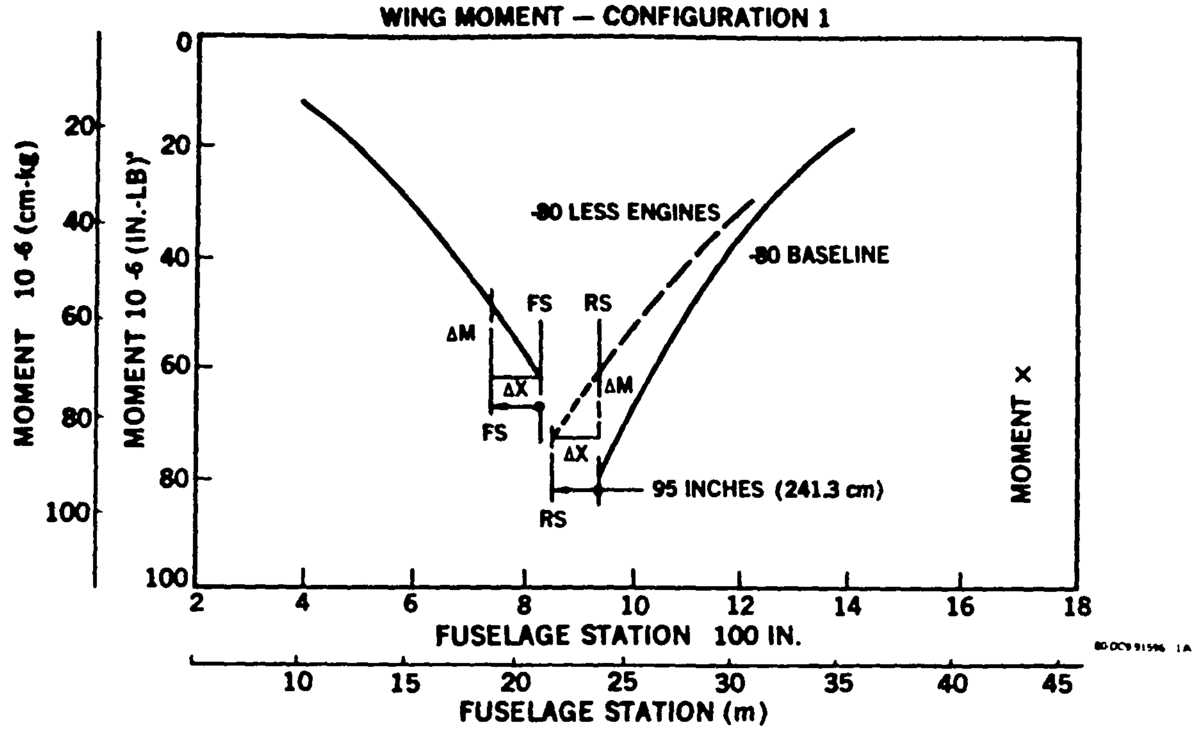


FIGURE 49. WING MOVEMENT EFFECT ON FUSELAGE BENDING

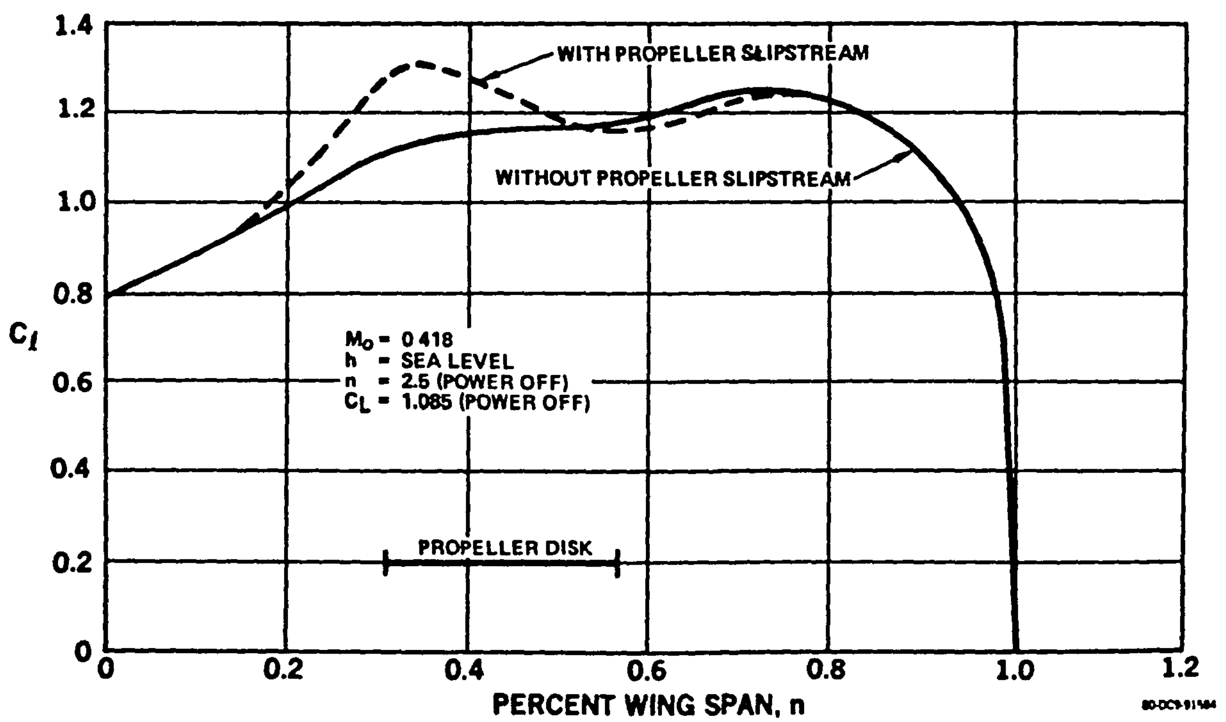


FIGURE 50. DC-9 SUPER 80 SPANWISE LOADS WITH AND WITHOUT PROPELLER SLIPSTREAM

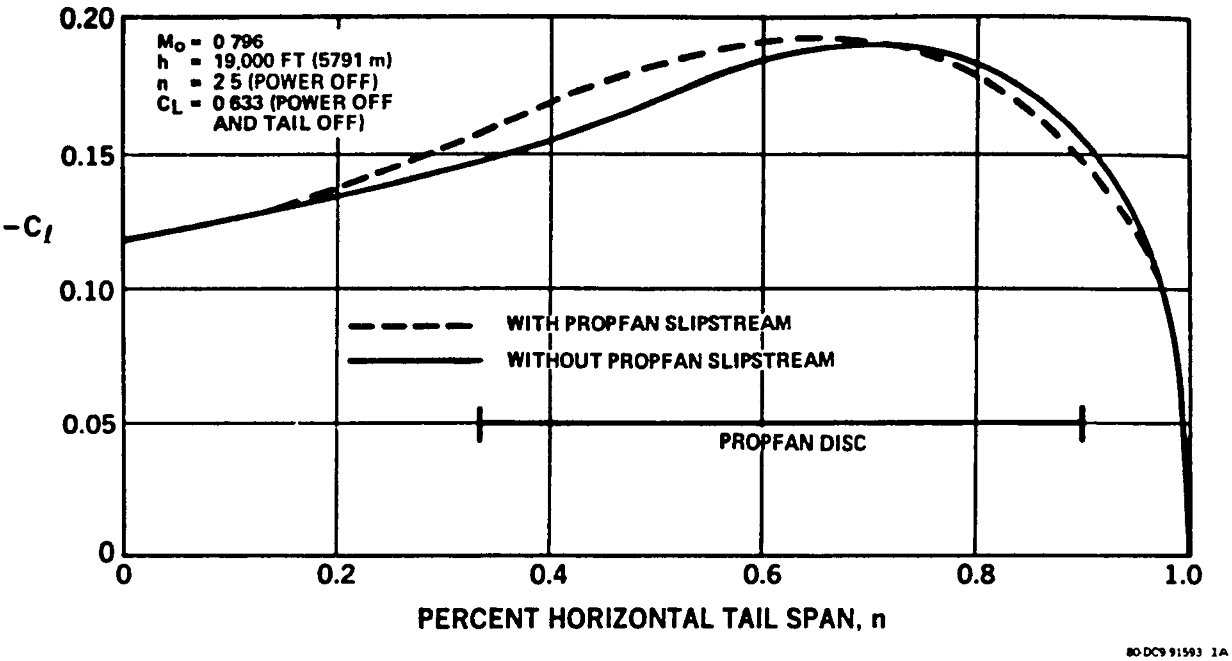


FIGURE 51. DC-9 SUPER 80 HORIZONTAL TAIL SPANWISE LOADS WITH AND WITHOUT PROPFAN SLIPSTREAM

Engine/Propfan Structural Installation

The engine gearbox propfan configuration is located forward of primary wing structure so the engine may be lowered for removal and replacement. The engine-nacelle arrangement is attached to the wing upper surface through two machined frames, one at the front spar and one at the rear spar. The thrust loads are transferred at the nacelle-wing interface. The nacelle may be removed from the wing box without disturbing the seal integrity of the wing fuel tank. Advantages of such a nacelle concept are summarized in Figure 52.

Nacelle Design Concept - The basic structural arrangement is a semi-monocoque horseshoe shaped configuration, as shown in Figure 53. The lower segment is a single door hinged on the outboard side for access for engine maintenance and removal. The nacelle structure has longerons, vertical frames, and aluminum skin panels. The longitudinal door sill frames are deep members to stabilize the structure under compressive loads. The monocoque arrangement was selected to provide a direct structural path for the support of the engine and gearbox. The tubular structural arrangement of previous propeller

SIMPLE, STRAIGHT-FORWARD MOUNT

STIFF MOUNT EFFECTIVE IN FLUTTER AND/OR WHIRL FLUTTER REDUCTION

EASE OF MAINTENANCE

- **ENGINE REMOVAL FREE OF WING INTERFERENCE**
- **ACCESS TO NACELLE**
- **MODULAR ENGINE/PROPFAN/GEARBOX/ACCESSORY MAINTENANCE**

80-DC9-80933A

FIGURE 52. ENGINE/PROPFAN STRUCTURAL MOUNTING CONCEPT ADVANTAGES

aircraft would be massive to support the engine so far forward of the wing as needed for a propfan installation, and would still require nacelle structure to streamline the system. Consequently, the approach taken here is to use the nacelle as the load carrying structure.

The engine gearbox assembly is attached to the nacelle at two places: (1) aft engine mount plane, and (2) gearbox centerline. The assumption is the gearbox and engine are connected together in such a manner as to transfer all loads between them. Other arrangements should be examined to ensure the optimum configuration is obtained to reduce propfan vibration and prevent whirl mode. The support arrangement of the engine/gearbox to the nacelle must be designed to eliminate as much of the propeller vibration effects as possible so that passenger comfort will be at a maximum. The approach taken by deHavilland Aircraft of Canada on the DHC-7 small transport appears to be an excellent guide, as noted in Reference 13.

Hamilton Standard's comments on a possible gearbox mounting arrangement to the nacelle are provided in Reference 14. Their concept attaches the gearbox in four places to resist all possible loads. The rear set of attach points also furnishes a support aft of the engine forward mount plane. The engine is supported at the aft mount plane by structure in the nacelle. The engine/gearbox support configuration will be selected and "optimized" during follow-on work.

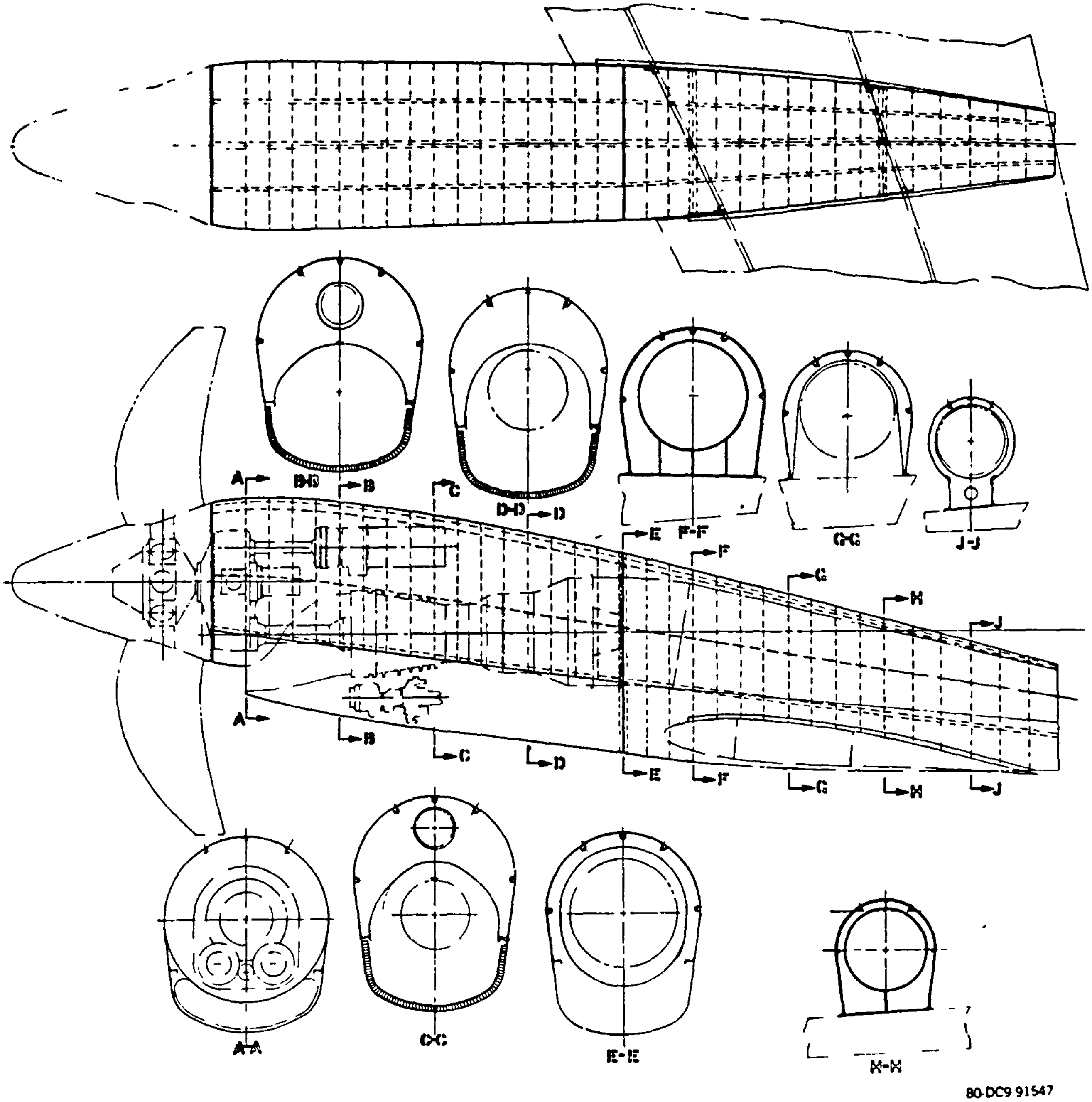


FIGURE 53. PROPFAN NACELLE CONFIGURATION

The extreme forward position of the propfan plane has an added advantage due to the reduction in the propfan excitation factor, as reported by Hamilton Standard in Reference 15. Therefore, the design to provide for excellent maintenance has a two-fold purpose. The gearbox is arranged to the compound idler configuration as sketched in Figure 54, taken from Reference 16. The shape for the gearbox housing fits into the space required for the propeller spinner size.

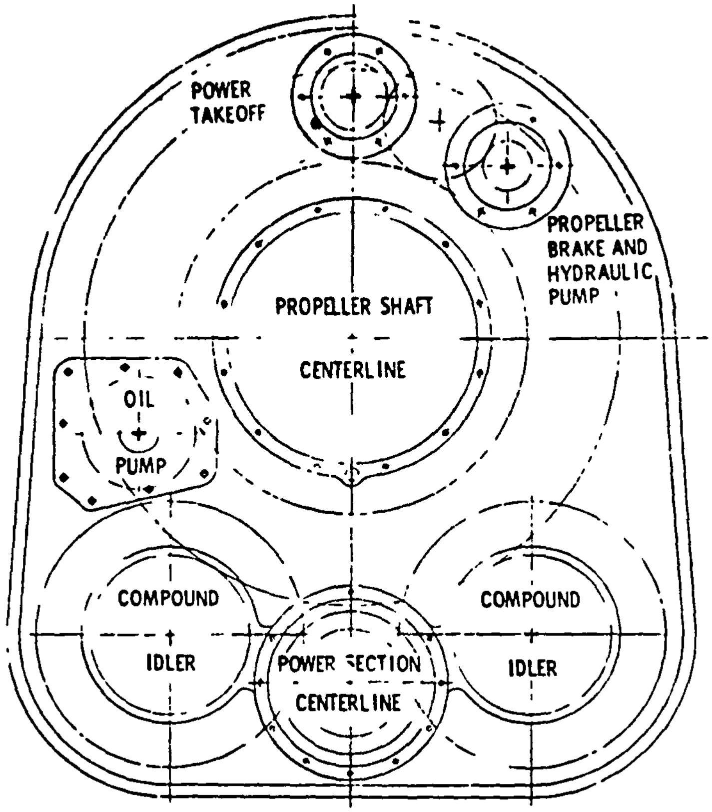


FIGURE 54. COMPOUND IDLER

The ratio of the nacelle diameter to the propeller diameter is larger than recommended by Hamilton Standard, as noted in Reference 17. The ratio is 0.418 versus 0.35. The large dimension is the result of having to set the propeller axis so high above the wing in order that it may clear the ground by the recommended dimensions. The nacelle length is 13 percent larger than the minimum, as suggested in the Hamilton Standard's guidelines (Reference 17).

The nacelle stiffnes factor K_T data have been replotted as a carpet plot in Figure 55. This will be the guide to ensure flutter and whirl mode free operation. These data came from the guidelines in Reference 17.

The multiroller traction drive patented by Dr. Algirdis L. Nasvytis, shown in Figure 56, has possibilities as a feasible gearbox for the propfan system. The system should run smoother and quieter and require less maintenance than the toothed gear type of arrangement. However, this probably would not be ready for service in 1985.

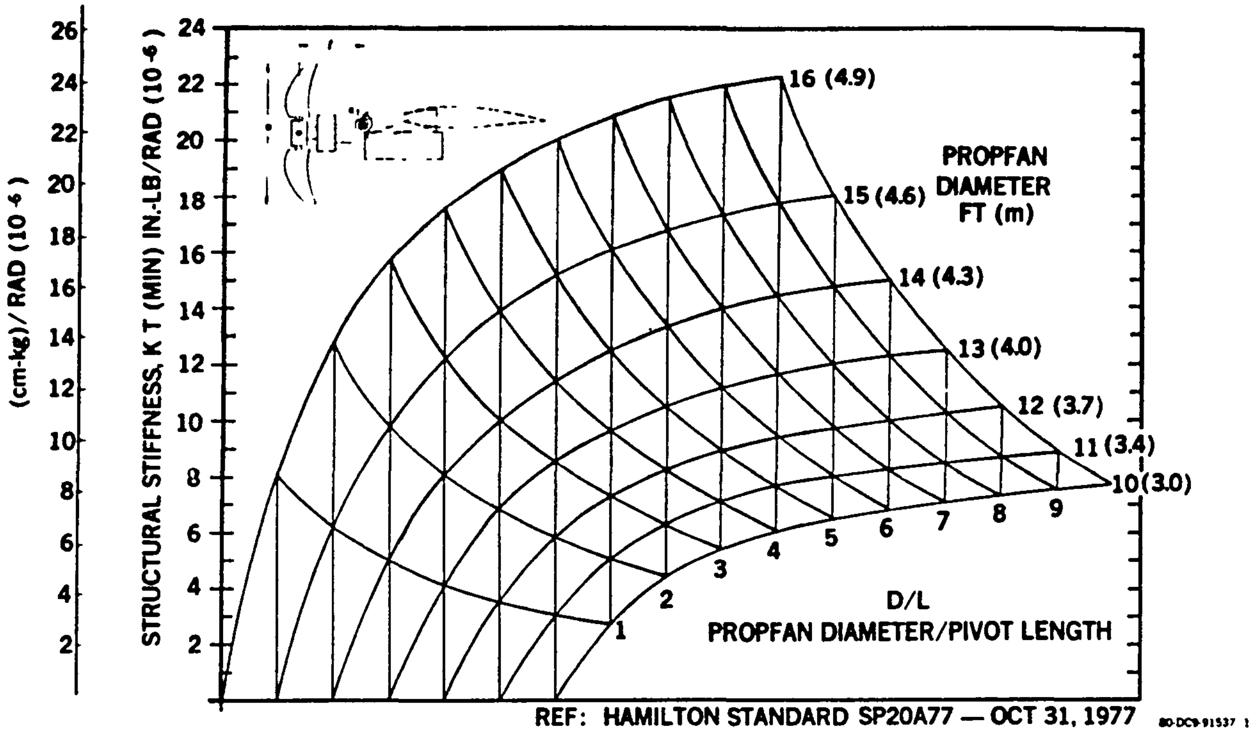


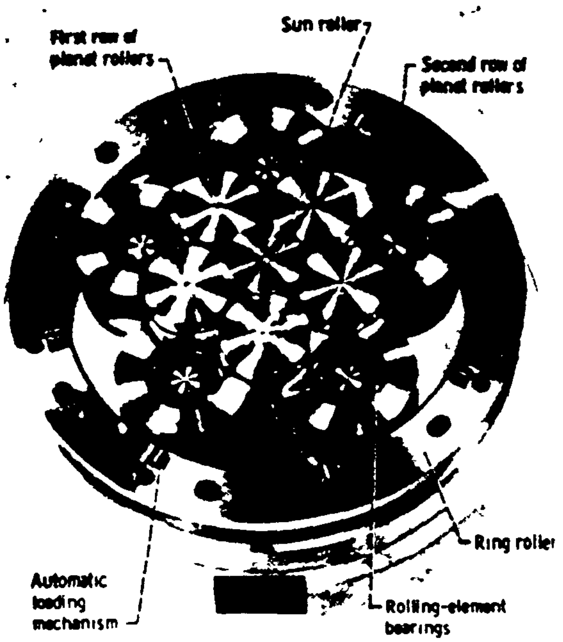
FIGURE 55. STIFFNESS REQUIRED TO PREVENT WHIRL FLUTTER VERSUS PROP DIAMETER/PIVOT LENGTH

The lower door is a full depth honeycomb sandwich structure. This may be designed for either aluminum or composite material, preferably with composites to reduce weight. Small preflight access doors can be added as required in the nacelles or door structure.

Propfan Configuration Sonic Fatigue Analysis

The potential for sonic fatigue has tended to diminish the later jet engine designs with the advent of high bypass flows and the use of acoustic linings. The possibility of sonic fatigue in the DC-9 Super 80 is even more remote because of the extreme aft positions of the engines. The use of propfan engines on an airplane can significantly increase sonic fatigue problems. This is particularly the case in the presently considered application on the DC-9 Super 80 in which the blade tips are close to the fuselage wall and the helical tip speed during cruise flight exceeds M = 1.0.

Acoustic Environment - The assessment of sonic fatigue in the present study involves turboprop/propfan engines placed in three different configurations;



Multiroller traction drive uses two or three rows of variable-diameter planet rollers

Cleveland OH—A multiroller traction drive that is able to transmit high-power loads at high speed ratios without the use of toothed gears is proving to be a major advance in the area of power transmission

The development is called the "Nasvytis" multiroller traction drive after a 1966 invention by Dr Algirdis L Nasvytis who is still associated with the project It will probably find immediate application in the machine tool industry where ultrahigh speeds for grinders and millers can be achieved, improving product quality and production rates

It may also replace gas turbines that power high-speed drive systems In this case it would act as a speed increaser married to a conventional ac motor, accomplishing the same results in a simpler and cheaper manner As a replacement for both geared drives and conventional traction drives, the 'Nasvytis could also be used in applications such as automotive gas turbine engine drive trains, helicopter main rotor transmission, aircraft drive systems rocket engine turbopump drive systems, wind turbines and high-speed turbomachinery

The traction idea is not new About 34 patents were issued between 1879 and 1971 to cover various fixed-ratio traction drive concepts Of those, eight were issued to Dr Nasvytis Earlier versions used a single-row format that restricted hp capacity and limited the speed-ratio capability to about 7 1 The solution came in 1966 when Dr Nasvytis added two or three rows of variable-diameter planet rollers to the system, creating a revolution in traction drive theory and freeing the concept for expanded power loads and speed ratio ranges

The 'Nasvytis' drive is composed of a planetary cluster of smooth rollers bearing directly against one another This configuration includes a "sun" roller in the center, two rows or more of "planet" rollers surrounding the sun roller and a "ring" roller enclosing the total complex at the perimeter By introducing power to the outer ring, a speed increaser is created By introducing power to the central sun roller a speed reducer is created

According to Stuart H Loewenthal lead engineer for NASA's Lewis Research Center team, "We are just beginning to find out exactly what these drive systems can and cannot do " A number of advantages were cited

•For many applications the drives would be simpler and cheaper to manufacture because they do not require gear tooth design or cutting The tolerances for the roller components are well within normal machine grinding limits

•The drive is much quieter than conventional toothed drives and could contribute to a reduction in noise pollution

•The Nasvytis is lighter and smaller than conventional gear boxes and tooth changers

•It is as efficient as gear systems In a recent NASA test it performed at a measured efficiency greater than 95% at speeds to 73,000 rpm for 15 1 ratio

•It is less susceptible to breakdown and wear because special traction fluids provide a miniscule separation between rollers and damp out drive line vibrations

The multiroller traction drive could conceivably be used even where heavy loads, high speeds and high ratios are not the prime requirement, because it is cheaper to build quieter smaller and a possible energy saver □

•REF: DESIGN NEWS – 9/24/79

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FIGURE 56. MULTIROLLER TRACTION DRIVE TRANSMITS LOADS WITHOUT GEARS

namely, wing mounted (Configuration 1), horizontal stabilizer mounted (Configuration 3), and aft fuselage pylon mounted just forward of the horizontal stabilizer (Configuration 2). The acoustic pressures imposed on the fuselage wall for each configuration are given in Figure 57. This discussion, unless otherwise noted, considers the base case propfan of eight blades, 800 ft/sec (244 m/sec) tip speed, and 37.5 shp/D^2 (301 kW/m^2). The displayed curves define the contribution from the blade passage frequency (BPF). (At each indicated fuselage station, the ordinate of the curve gives the root mean square (RMS) level of the pressure in decibels.) Also noted in the figure is the reduction in pressure levels to be attributed to the multiples of the blade passage frequency. The data presented in the figure are based on free field data supplied by Hamilton Standard (Reference 7). The data shown include an increment of 4 dB to account for wall reflection. For estimating the effects of sonic fatigue, it is conservatively assumed that the pressure designated at any station applies uniformly over the circumference.

Analytical Approach - The approach used in arriving at the sonic fatigue needs of the fuselage structure is similar for all three configurations. This

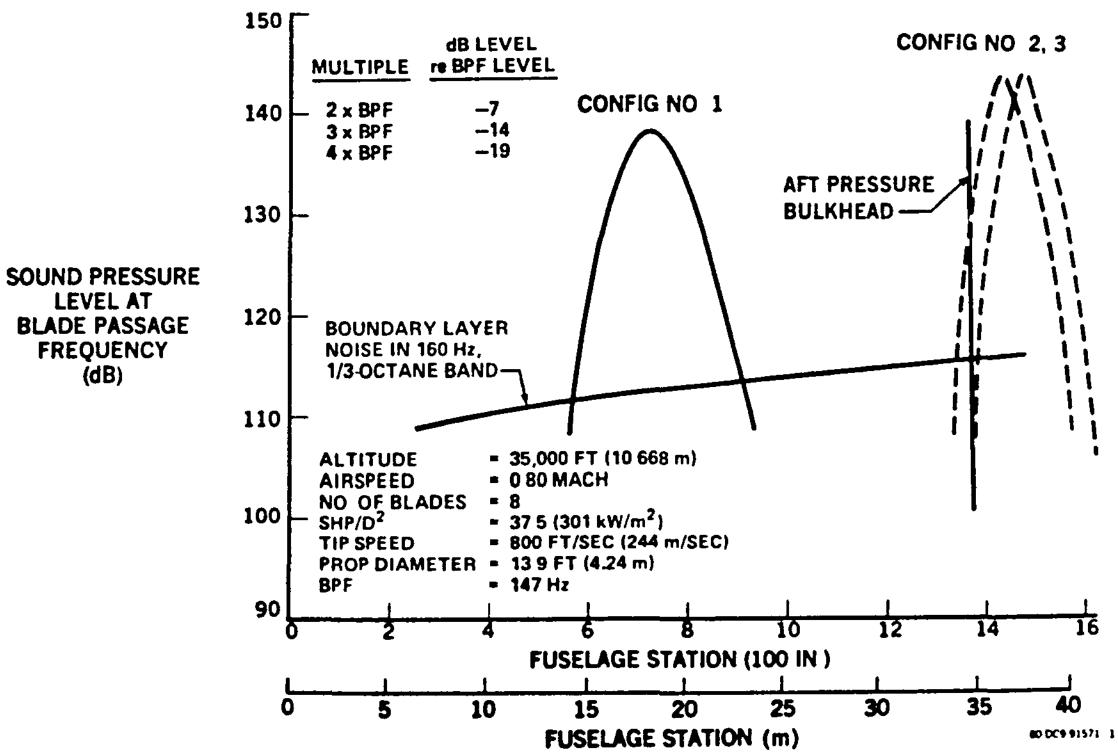


FIGURE 57. DC-9 SUPER 80 PROPFAN FUSELAGE EXTERIOR ACOUSTIC LOADING AT BLADE PASSAGE FREQUENCY

approach will now be described with reference to Configuration 1. The DC-9 Super 80 fuselage wall in the region exposed to the acoustic pressures from the propfan has, on the average, the following characteristics: (1) 0.063 in. (1.6 mm) skin thickness, (2) 19 in. (48 cm) ring frame spacing, and (3) 7.5 in. (19 cm) longeron spacing. The natural frequency of the fundamental mode of the 7.5 by 19 in. (19 by 48 cm) skin panel is estimated at 250 Hz considering clamped edge conditions and ignoring pressurization effects.

Next to be considered is the mission profile for the airplane. The mission used for the study has 55,000 flights for fail safe design with an average of 1 hour per flight. The portion of the flight attributed to cruise is taken at 62.4 percent. For each skin panel in the fuselage wall, this means approximately 34,000 hours of exposure to the acoustic pressure conditions defined in Figure 57.

It is presumed in the sonic fatigue analysis that the panel resonance will coincide with one of the multiples of the blade passage frequency, i.e., a multiple of 147 Hz. Since the estimated resonance frequency of a fuselage wall panel is close to the first multiple (i.e., 294 Hz), the frequency is taken to be that of the fundamental resonance mode of the panel. This means that the panel must withstand an exposure of 3.6×10^{10} ($34{,}000 \times 3{,}600 \times 294$) cycles. This number of cycles is beyond that attained in any test program and requires considerable extrapolation to estimate the associated allowable fatigue strength. To be conservative, the lower 95 percent confidence limit is extrapolated on the fatigue curve given in Figure 5.3.1-2 of Reference 18. At $N = 3.6 \times 10^{10}$, the allowable RMS stress is estimated at 600 psi (415 N/cm^2).

The peak of the pressure curve for Configuration 1 in Figure 57 is at 138 dB. At the first multiple, the peak value is 131 dB (138 - 7). Using this value, the maximum RMS stress induced in the panel can be obtained from a modification of Equation 5.3.1-1 in Reference 18. The modification is required to convert a formula based on broad-band random pressure to one appropriate for discrete frequency pressures. From the modified formula, a maximum RMS stress of approximately 930 psi (640 N/cm^2) is found.

The scope of the study limited the investigation to conventional means of structural changes for sonic fatigue improvement. These changes involve an increase in skin thickness and a reduction in panel size. Only modifying the skin gage necessitates a skin thickness of at least 0.08 in. (2 mm) in order to meet the allowable. It is deemed more effective to reduce the ring frame spacing with lesser possible change to the skin thickness. This latter approach does not substantially affect the weight increment, but provides benefits for interior noise. These benefits include: (1) lesser acoustic radiation to the interior from the smaller, stiffer panels and (2) greater absorption of the radiated noise by acoustic treatment due to the higher resonant frequency of the panels.

Results of Analysis - The natural frequency of the reduced size panel 7.5 by 9.5 in. (19 by 24 cm) is approximately 320 Hz, ignoring the effects of pressurization. In this case, it is still appropriate to consider that the panel resonance will coincide with the first multiple of the BPF (i.e., 294 Hz). Using the modified prediction formula with the pressure and cycles of exposure given above, it is found that the 0.063-in. (1.6 mm) skin was inadequate. The skin thickness is set to 0.07 in. (1.8 mm). The changes for Configuration 1 to attain an adequate sonic fatigue design are as follows from an extension of the above analysis to all affected stations along the fuselage:

1. Increase skin thickness from 0.063 in. (1.6 mm) to 0.07 in. (1.8 mm) between fuselage stations 650 and 800.

2. Reduce ring frame spacing from 19 in. (48 cm) to 9.5 in. (24 cm) between fuselage stations 600 and 850.

The analyses conducted for Configurations 3 and 2 are similar to those for Configuration 1. The changes made to these configurations for sonic fatigue purposes are summarized in Figures 58 and 59. Again, a tightening of ring frame spacing and an increase in skin thickness are used to attain the necessary integrity.

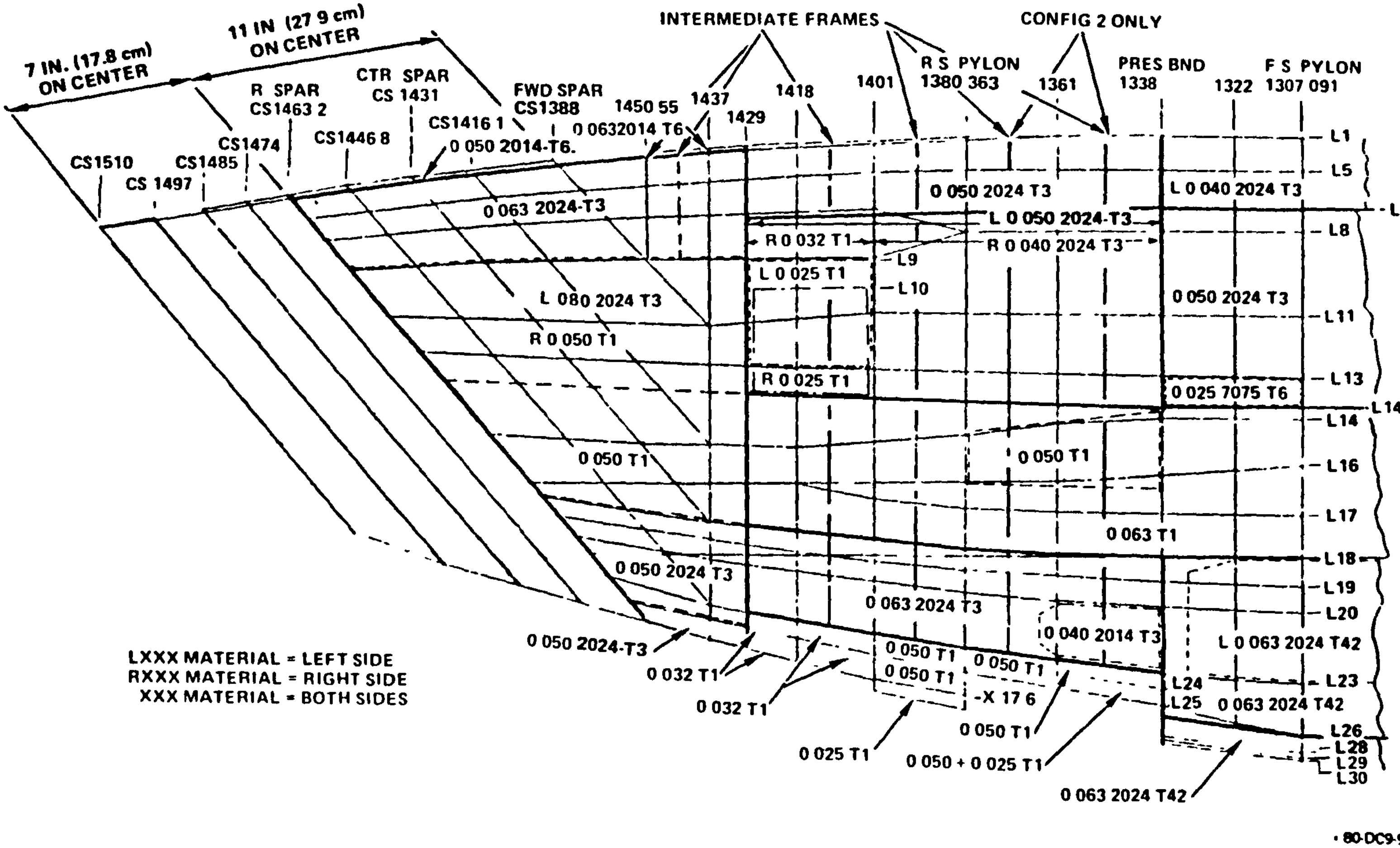


FIGURE 58. SONIC FATIGUE REQUIREMENTS FOR DC-9 SUPER 80 PROPFAN CONFIGURATIONS, CONFIGURATIONS 2 AND 3 FRAME SPACING

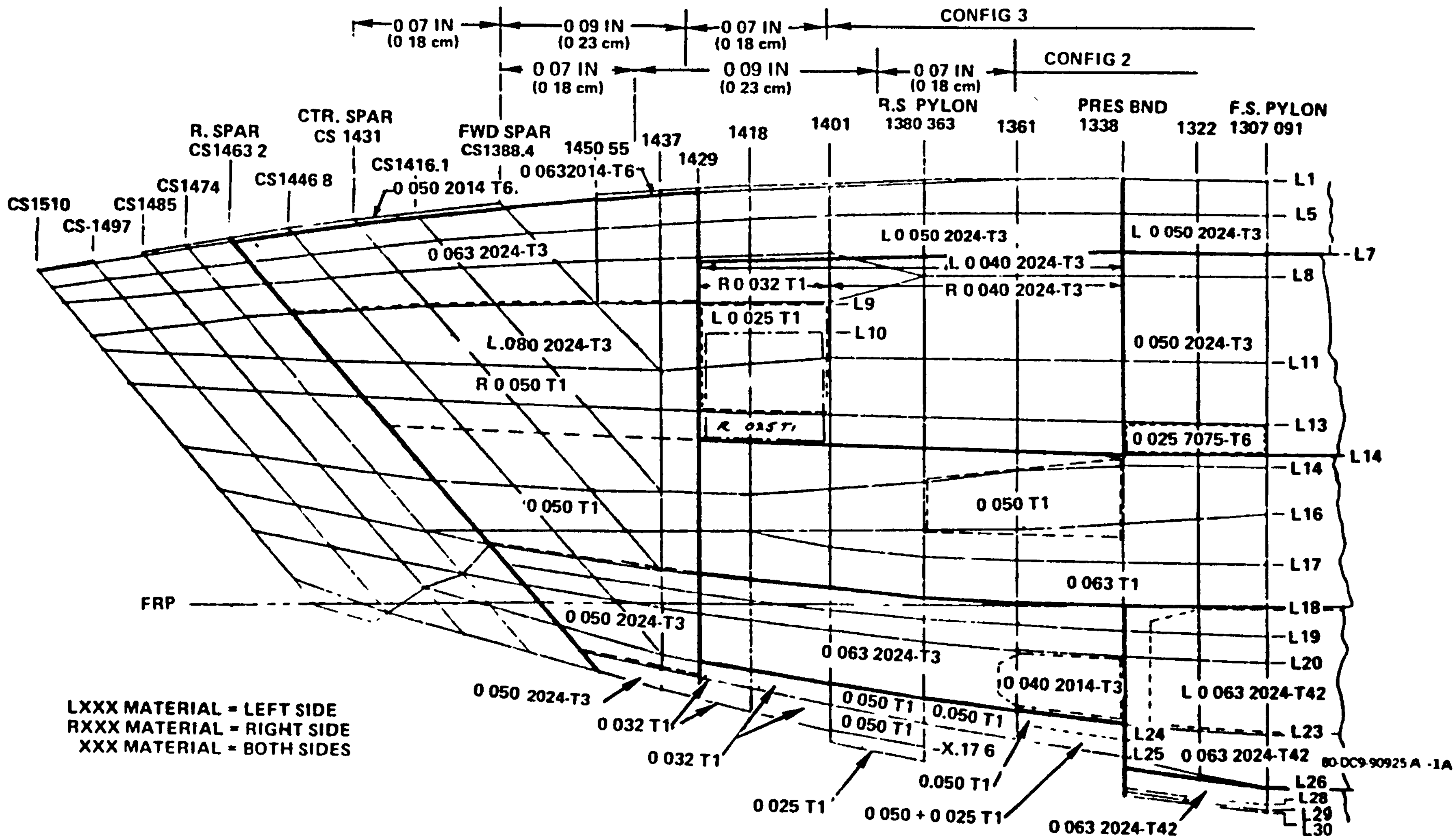


FIGURE 59. SONIC FATIGUE REQUIREMENTS FOR DC-9 SUPER 80 PROPFAN CONFIGURATIONS, CONFIGURATIONS 2 AND 3 SKIN THICKNESSES

An alternate design that would also be adequate for Configurations 3 and 2, with a possible associated weight reduction, is to use a composite sandwich for the skin aft of fuselage station 1437. In this approach, there would be no change in the DC-9 Super 80 ring frame spacing and one-half of the longerons could be removed. The composite sandwich would have a weight (not including attachments) of about 0.51 lb/ft^2 (2.5 kg/m^2).

Requirements for Further Substantiating Analyses and Test Data - The exposure of 3.6 x 10^{10} cycles will require fatigue testing to establish allowable strengths since S-N data do not exist at this number of cycles. The testing would have to be conducted on an accelerated basis in a Progressive Wave Tube (PWT) using a discrete noise generator. The maximum pressure applied on the fuselage panels for Configurations 3 and 2 is 136 decibels (143 - 7). The Douglas PWT can provide 155 dB of discrete frequency pressure. Applying all this pressure at the fundamental resonance of the panel will require about 10 hours of testing per panel.

The panels exposed to a significant sonic environment in Configurations 3 and 2 are in a nonpressurized portion of the fuselage. The methodology for predicting the sonic fatigue requirements of structures is based on data from panel tests free of steady loads (for instance, the data summarized in Reference 18). In airplanes using turbofan engines, the primary sonic fatigue problem occurs during takeoff in which the pressurization effect is inconsequential. Because of this, there is no sonic fatigue data on panels that are simultaneously subjected to steady in-plane loads as would be caused by pressurization. Therefore, although the fatigue predictions have a satisfactory basis for Configurations 3 and 2 and can be reasonably verified in the PWT, the predictions for the panels of Configuration 1 have a significant uncertainty due to pressurization effects.

To remove the existing uncertainty, sonic fatigue testing will have to be done on in-plane loaded panels. A technique for doing this type of testing will require further investigation. The net pressure acting on the fuselage is near 7.5 psi (52,000 Pa). The membrane loads induced in the panel by this pressure will cause the fundamental resonance to increase on the order of 100 Hz. The consequences of this are (1) an increased number of applied cycles, and (2) a reduction of 7 dB in applied pressure due to the second multiple of the BPF (i.e., 441 Hz) being most likely to coincide with the panel resonant frequency. The improved situation from the latter more than compensates for the detrimental effect of the former. Even with the benefit from the latter, the consequences of having high in-plane loads simultaneously with the acoustically imposed environment are still of concern.

Additional information supporting the sonic fatigue analysis will have to come from a flight test program. It is not expected that any panel will have a fatigue failure during the limited duration of the flight program. What will be determined is the manner in which the fuselage wall responds to the acoustic pressures. The data obtained will then lead to improved structural models and response formulations and thereby provide a more substantive basis for sonic fatigue life prediction.

Sensitivity Studies - Two facets of the propfan sensitivity trades considered in this overall study are influenced considerably by the results of the sonic fatigue analysis. These two facets are discussed below.

<u>Ten-Blade Propfan with Tip Speed/Disc Loading Variation</u> - The first of these sensitivity studies involves variations to the fuselage walls for the base case Configurations 1, 3, and 2 which are necessary for the 10 blade propfan with varying tip speed and disc loading. The base case Configuration 1, 2, and 3 involved an eight-bladed propfan. A 10-bladed propfan is now evaluated for the same three configurations. For each configuration, the following 10-bladed propfan variations are considered:

1. Propfan diameter - 13.8 ft (4.21 m) with tip speed of 800 ft/sec (244 m/sec) in M = 0.8 cruise flight.

2. Propfan diameter = 15.4 ft (4.69 m) with tip speed of 700 ft/sec (213 m/sec) in M = 0.8 cruise flight.

3. Propfan diameter = 16.8 ft (5.12 m) with tip speed of 600 ft/sec (183 m/sec) in M = 0.8 cruise flight.

The associated blade passage frequencies are 184.5, 144.7, and 114.0 Hz, respectively. In Configuration 1, the tip clearance is 0.8 diameter while in Configurations 3 and 2, it is 0.28 diameter.

The peak wall pressures at blade passage frequencies for variations 1, 2, and 3 pertinent to Configuration 1 are 136, 133, and 128 dB, respectively. The distribution of the wall pressures along the fuselage is similar to that shown in Figure 57. The peak pressures for Configurations 3 and 2 at blade passage frequencies are approximately 6 dB greater than those for Configuration 1. The pressure distributions for these last two configurations are as shown in Figure 57. The reductions of the peak pressures at multiples of the blade passage frequency are as follows for the three variations:

	dB re Blade Passage Frequency Level		
Frequency	Variation 1	Variation 2	Variation 3
2 x BPF	-7	-11	-15
3 x BPF	-14	-21	-30
4 x BPF	-19	-31	-43

Configuration 1 Results - It is presumed that the resonance of the panel coincides with the first multiple of the blade passage frequency. To assure its adequacy for variation 1, a skin thickness increase to 0.075 in. (1.9 mm) is made in conjunction with intermediate frames. Variation 2 has a blade passage frequency near the eight bladed case and imposes significantly lower pressures. Only intermediate frames are needed with no skin change from the original DC-9 Super 80 design. The extremely low pressures of variation 3 necessitate only minor modification to the original DC-9 Super 80 design. In summary, the following changes are made in the baseline DC-9 Super 80 design for Configuration 1 sonic fatigue integrity:

Variation	Change
1	Increase skin thickness to 0.075 in. (1.9 mm) between fuselage stations 650 and 800. Reduce ring frame spacing to 9.5 in. (24 cm) between fuselage stations 600 and 850.

2	Reduce ring frame spacing to 9.5 in. (24 cm) between fuselage stations 680 and 780.
3	Add intermediate ring frames between fuselage stations 710 and 740.

Configurations 3 and 2 Results - The results for Configurations 3 and 2 can best be described in terms of those previously given in Figures 58 and 59. The basis of the results for these two configurations is similar to that for Configuration 1. The following constitutes a summary of the changes required to the baseline DC-9 Super 80 design for sonic fatigue integrity in Configurations 3 and 2:

Variation	Change
1	Increase skin thickness to 0.095 in. (2.4 mm) in 0.09 in. (2.3 mm) zones of Figure 59. Increase skin thickness to 0.075 in. (1.9 mm) in 0.07 in. (1.8 mm) zones of Figure 59. Tighten ring frame spacing as indicated in Figure 58.
2	Apply skin thickness of 0.07 in. (1.8 mm) in 0.09 in. (2.3 mm) zones of Figure 59 (no other skin change). Tighten ring frame spacing as indicated in Figure 58.
3	Apply skin thickness of 0.063 in. (1.54 mm) and intermediate ring frames in 0.09 in. (2.3 mm) zones of Figure 59 (no other change).

Effects of External Sound Pressure Level Variations - The second sensitivity study concerns the uncertainty of the acoustic pressure levels produced on the fuselage surface from the propfan. This trade study described in the following paragraph pertains to the eight blade propfan, wing mount Configuration 1. The results presented give the sonic fatigue requirements for variation of ±6 dB in the sound pressure levels acting on the fuselage wall.

Figure 57 gives the external sound-pressure level distribution at blade passage frequency for the eight bladed propfan in Configuration 1. Also specified in Figure 57 are the pressure level reductions at multiples of the blade passage frequency. Effects on sonic fatigue requirements due to ±6 dB increments in the sound pressure levels are evaluated. Changes required in the DC-9 Super 80 fuselage wall design for adequate sonic fatigue capability are found to be the following for the indicated increments:

Increment	Change
+6 dB	Add intermediate frames between fuselage stations 580 and 870. Increase skin thicknesses to 0.09 in. (2.3 mm) between fuselage stations 680 and 770. 0.08 in. (2.03 mm) between fuselage stations 650 and 680 and between 770 and 800. 0.07 in. (1.8 mm) between fuselage stations 600 and 650 and between 800 and 850.
-6 dB	Add intermediate frames between fuselage stations 670 and 780.

Flutter Evaluation

Selective preliminary flutter analyses are performed in support of the configuration development and associated weight definition. A summary of these flutter analyses results is as follows:

- Preliminary bending/torsion flutter analyses, which ignore gyroscopic coupling and propeller aerodynamics, of the wing mounted Configuration 1 show that the wing strength design also meets the required flutter criteria.

- Preliminary propeller/nacelle whirl flutter analysis is based on the method of NASA TN D-659. This simplified method generates a stability boundary in terms of required yaw and pitch frequencies for the engine fundamental mode shapes. Based upon inspection, the strength design of the wing mounted configuration probably meets the required whirl flutter criteria. The horizontal stabilizer mounted configuration and the aft fuselage mounted configuration are marginal; the structural box inboard of the engine may have to be stiffened. A more rigorous analysis is required to assess the actual required weight penalty, if any.

- No failure whirl analyses are done. Whirl flutter analysis and whirl flutter model tests of failure configurations will be an important part of any future design or certification dynamics program.

Further detailed discussion of these several aspects of the flutter analysis follows.

Bending/Torsion Flutter Analysis

Bending/torsion flutter analyses are carried out for the wing mounted configuration. Mass, inertia, rigidity, and aerodynamic data used in this wing installation flutter analysis are the same as used in the basic DC-9 Super 80 flutter analyses except for the engine installation. Data for the engine installation are provided by the Weights subdivision. Gyroscopic coupling and propeller aerodynamics are ignored. Both heavy and light fuel configurations are analyzed. Engine support flexibility is varied over a wide range since the precise values are not currently known. Both symmetric and antisymmetric cases are analyzed, although from previous experience, the symmetric case is expected to be most critical. The vehicle is found to be flutter free at all speeds up to 1.2 V_D. The flutter analysis is based upon the normal modes of vibration of the vehicle. Figure 60 shows the two most important wing/mode shapes. Note that in this potentially critical symmetric case, the mode involving inner panel wing torsion and engine pitch is at a lower frequency than the first wing bending mode. Since the wing bending mode climbs in frequency with airspeed while the inner panel torsion mode does not, there is no tendency for these two modes to coalesce. Hence, no flutter involving the lower frequency wing/engine vibration modes occurs. Flutter speeds involving higher frequency modes are above 1.2 V_D. Figure 61 shows typical plots of frequency versus velocity and damping versus velocity for the heavy fuel symmetric case.

Propeller/Nacelle Whirl Flutter

A preliminary whirl analysis of the engine/propeller system is conducted. The analysis is based upon an idealization which includes the flexibility of the engine support structure, but which assumes the wing box itself to be rigid. Wing aerodynamics are also ignored. The stability boundary is sensitive to the mode line location in the pitch and yaw modes, and for this analysis a conservative forward location is used.

Figure 62 shows the calculated stability boundary and the minimum expected design values for pitch and yaw frequencies. An adequate margin is seen to exist. As noted above, this result is for the engine flexibly mounted to a rigid backup point. A more rigorous analysis would include the mass, inertia, rigidity, and aerodynamic data for the parent surface to which the engine is mounted. These analyses have not been completed, but it is possible to draw some tentative judgments based on the work that has been done.

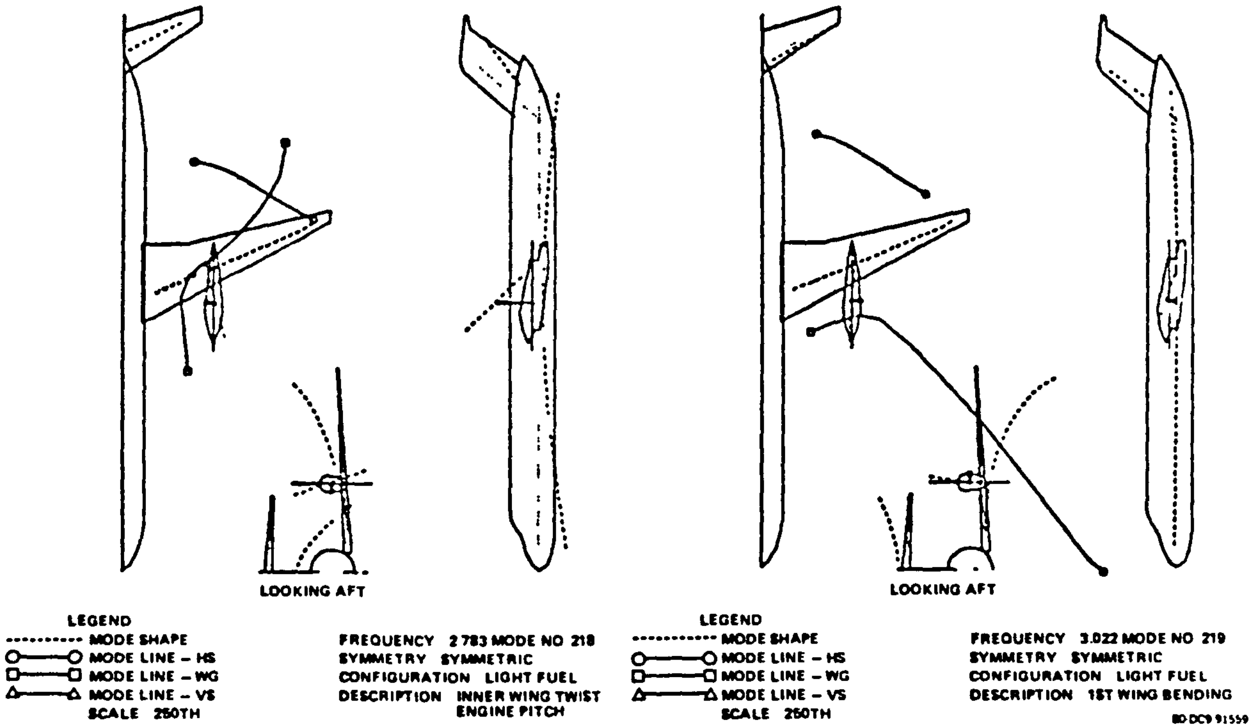


FIGURE 60. DC-9 SUPER 80 PROPFAN MODE SHAPES

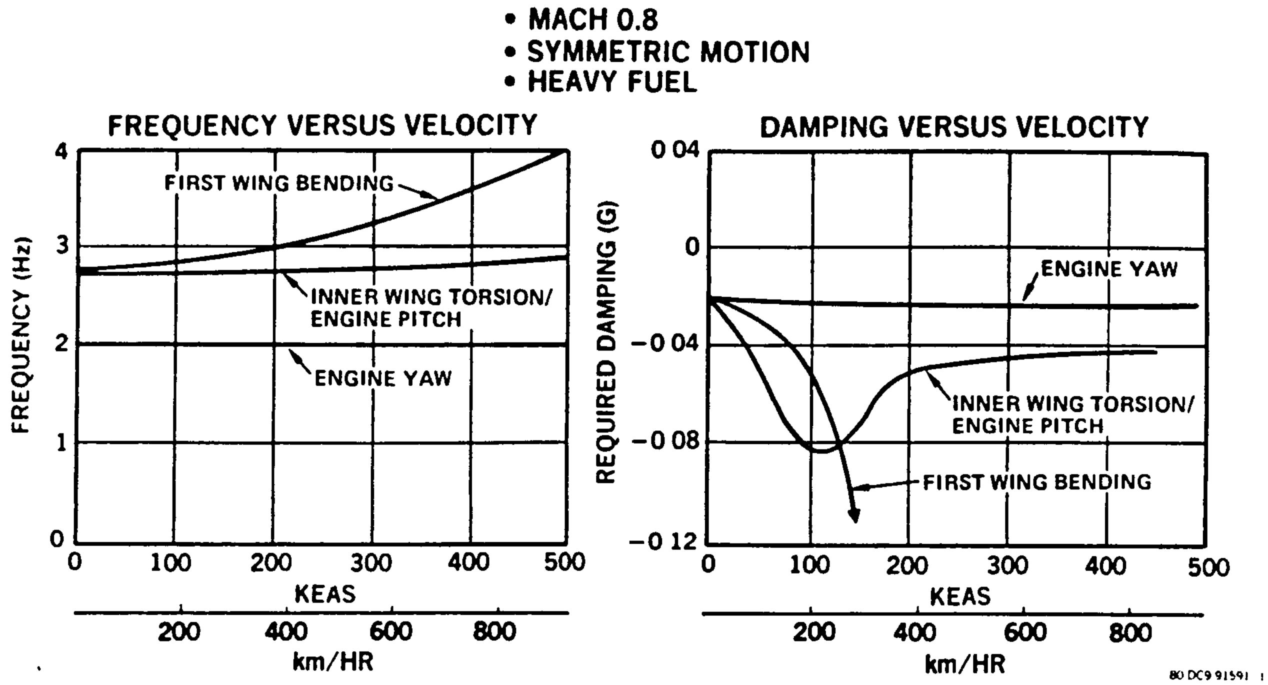


FIGURE 61. DC-9 SUPER 80 PROPFAN FREQUENCY VERSUS VELOCITY AND DAMPING VERSUS VELOCITY

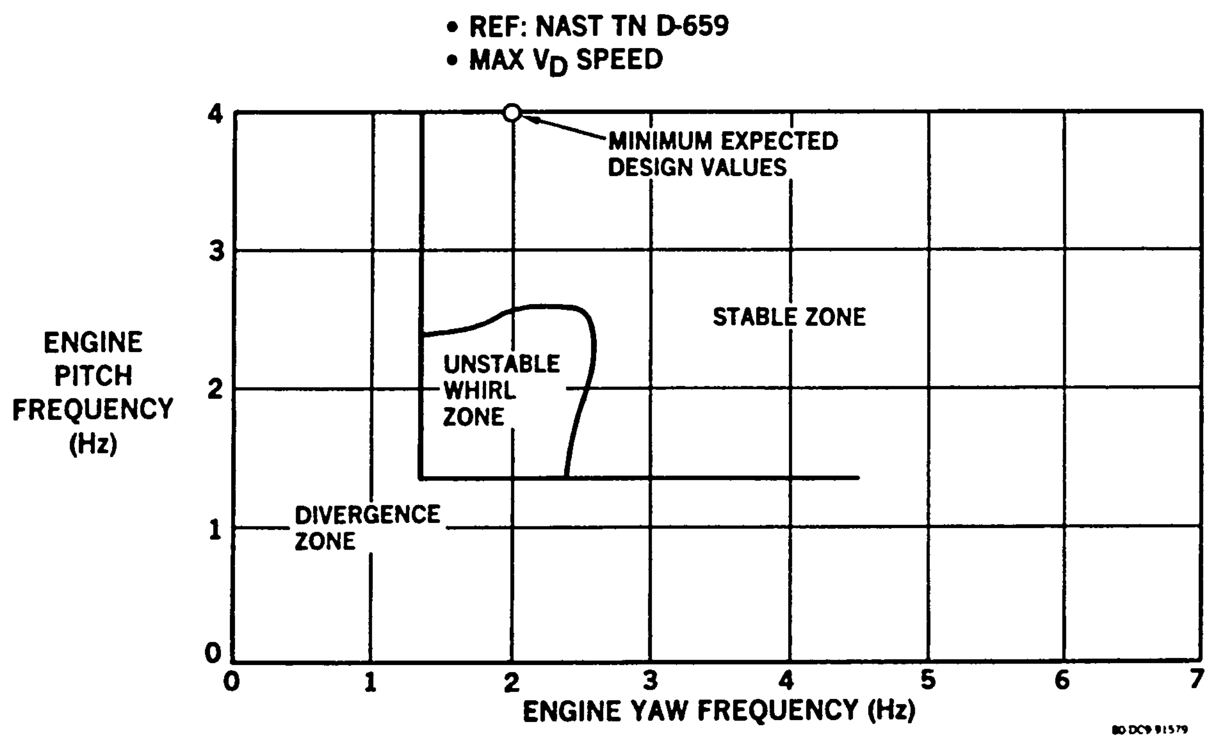


FIGURE 62. DC-9 SUPER 80 PROPFAN WHIRL FLUTTER BOUNDARY

- <u>Wing Mounted Installations</u>

  For the wing mounted installation, the engine yaw frequency remains approximately 2.0 Hz. Figure 60 shows a wing/engine mode with significant engine pitch at 2.78 Hz. In Figure 62, this combination of frequencies shows a much smaller margin from the unstable zone. However, the node line shown in Figure 60 for this mode is in the beneficial aft direction relative to the assumed node point. Furthermore, the mode contains outer wing bending, which adds a significant amount of aerodynamic damping to the modes and thus alleviates the problem. Based on these considerations, it is concluded that the wing engine installation is probably free from whirl flutter problems at all speeds up to 1.2 V_D.

- <u>Horizontal Stabilizer Installation</u>

  Since the horizontal stabilizer torque box is significantly smaller than the wing torque box, it is expected that the horizontal stabilizer torsion/engine pitch mode will be at a lower frequency than the corresponding mode on the wing installation, putting it very near to or into the unstable zone of Figure 62. It is still true that the actual node line relative to that assumed is beneficial, but the additional damping due to the horizontal stabilizer bending motion would be considerably less than for the wing since the stabilizer is much smaller than the wing. Therefore, the strength designed horizontal stabilizer installation appears to be marginal for whirl flutter. The fix, if required, would be to stiffen the torque box between the fuselage and engine.

- <u>Aft Fuselage Mounted Configuration</u>

  The pylon torque box is wider than the horizontal stabilizer torque box and its length is about the same. Therefore, the engine frequencies should be somewhat higher than for the horizontal stabilizer case.

  However, there is no outer surface to generate aerodynamic damping in this configuration. On balance, the aft mounted configuration also appears to be marginal. Again, the fix, if required, is to stiffen the pylon.

Whirl Flutter of Failure Configurations

No failure conditions have been analyzed. Failure conditions cannot be analyzed by simply assuming a lower frequency in the preliminary design analysis reported above because actual failures cause significant changes in the mode shape, i.e., the effective node line position. The structural idealization for future analyses will require a finite element model for the prediction of mode shapes and frequencies for any probable single failure.

PROPULSION SYSTEM

Engine

At the beginning of the study, it was estimated that an engine with a rated power of approximately 15,000 shp (11,000 kW) would be required for a two-engine DC-9 Super 80 application. Availability of the aircraft for service in 1985 was noted as one of the study ground rules. Detroit-Diesel Allison (DDA) has prepared estimates of performance, weight, and dimensions of several advanced engines based on the T701, a turboshaft engine with 8000 shp (6000 kW) developed for the Army HLH Program. These advanced engines incorporate demonstrated ATEGG technologies, a new compressor providing a higher pressure ratio and greater power, with basic shaft and bearing arrangements of the T701. They can be scaled to the required power range, and are compatible with the 1985 time period. Performance estimates have been used in previous Douglas propfan studies. Designated PD370-22, PD370-40, etc., the engines differ in turbine match, exhaust area, and gearbox design. The PD370-22A was selected as a representative engine for the DC-9 Super 80 propfan installation study. This version of the PD370 series has the following characteristics designed for a DC-9 Super 80 type of operation:

1. Rematched for 0.8 Mach No. at 35,000-ft (10,668 m) altitude.
2. Exhaust nozzle area for minimum thrust SFC at this altitude.
3. New, simplified gearbox design.

For reference, other advanced turboshaft engines studied by engine manufacturers are listed in Table 18.

The performance, weight, and dimensions of the PD370-22A used in the study are from Reference 1. The engine characteristics are compared with those of the T701 in Table 19. The core size of the unscaled PD370-22A is the same as that of T701.

Initially, the DC-9 Super 80 application was estimated to require 23 percent more power than the "spec size" PD370-22A. The three-view drawings of all the aircraft configurations show a propulsion system based on this scale factor, which gives a rated power of 15,160 shp (11,300 kW).

The engine is sized at cruise at 31,000 ft (9450 m) altitude at optimum cruise Mach number, following takeoff at maximum gross weight. Since the aircraft drag varies for the different configurations, the engine size varies accordingly. The scale factors vary from approximately 1.3 to 1.36; the engine ratings are from 16,000 shp (12,000 kW) to 16,800 shp (12,500 kW).

Although the scaling slightly exceeds the upper shaft horsepower limit recommended in Reference 1, weights and dimensions have been extrapolated by using the scaling exponents provided.

TABLE 18

TURBOSHAFT/TURBOPROP STUDY ENGINES

Mfg	Engine	Rating SHP (kW)	Scaling SHP (kW)	Pressure Ratio	Core
DDA	PD370-22A	12,328 (9,193)	7,500 to 15,000 (5,600 to 11,000)	25	T701
	PD370-42	9,610 (7,166)	6,000 to 12,000 (4,500 to 9,000)	30	New
P&WA (Fla)	STS538A	14,150 (10,550)	N.A.	15.5	JT10D
	STS539	16,820 (12,540)	N.A.	21.3	F100
	STS5[illegible]1	12,490 (13,790)	N.A.	25	New
P&WA (Conn.)	STS487	20,830 (15,600)	12,000 to 29,000 (9,000 to 22,000)	40	New
GE (Mass.)	F404/T1A1	12,500 (9,320)	N.A.	18.7	F404

TABLE 19

CHARACTERISTICS OF DDA TURBOPROP ENGINES

	T701 Turboshaft	PD370-22A Turboprop
Rated Power	8079 shp (6025 kW)	12,328 shp (9193 kW)
Scaling Range	-	7,000 to 15,000 shp (5,200 to 11,200 kW)
Free Turbine	Yes	Yes
Compression Ratio	12.8:1	25:1
Burner-out Temp	2300°F (1260°C)	2360°F (1293°C)
Length (flange to fl)	63.9 in. (1.62 m)	74.3 in. (1.89 m)*
Inlet Diameter	20.4 in. (0.52 m)	25.8 in. (0.66 m)
Weight	1179 lb (535 kg)	1566 lb (710 kg)*
Status	Completed PPFRT. Industrial version in production.	Proposed. (T701 + ATEGG technology) OK for 1985 IOC

*without gearbox

Gearbox

The PD370-22A is offered with a reduction gearbox having an overall gear ratio of 7.52. Factors are provided for adjusting gearbox dimensions and weights for other gear ratios. The gear ratio for the base case propulsion system study is 7.80.

Upward rotation of the propfan at the fuselage results in lower excitation loads and cabin noise (Reference 19), so provision for opposite rotation is assumed to be included in the gearbox design.

Propfan

The engine drives a Hamilton Standard propfan, a new concept in propeller design having blades with advanced airfoil sections and using advanced structural materials and design. The propfan design is the result of several years of development and testing of an advanced propeller concept that will operate efficiently at Mach 0.8, and have a relatively smaller diameter (higher disc loading) than conventional propellers. (References 20 and 21 are representative of the literature available containing descriptions of propfan designs, their development and potential.) For the base case propulsion system for this study, the 8 blade propfan has been used, and the 10 blade design has been investigated as part of the sensitivity studies. Performance estimates are from Reference 2 for the 8 blade and from Reference 3 for the 10 blade propfan.

Propfan performance can be conveniently expressed in terms of propfan efficiency, η_p, where

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{thrust x free-stream velocity}}{\text{shaft power}}$$

Thus, propfan thrust = $\eta_p \dfrac{\text{shaft power}}{\text{free stream velocity}}$

in consistent units.

The principal variables in propfan performance at a given flight condition are propfan tip speeds and disc (or power) loading, which is the shaft power divided by the square of the propfan diameter. (The disc loading changes with speed, altitude, and power setting, so these must always be specified when referring to an absolute value of disc loading. The tip speed is normally held constant for all flight conditions.) Figure 63 shows a typical relationship of propfan efficiency to disc loading and tip speed at cruise. The efficiency increases with propfan diameter (decreasing disc loading), but weight, clearance, and other installation problems become more severe. Higher tip speeds are efficient at higher power loadings, but result in increased noise levels, as noted in the discussion of acoustics.

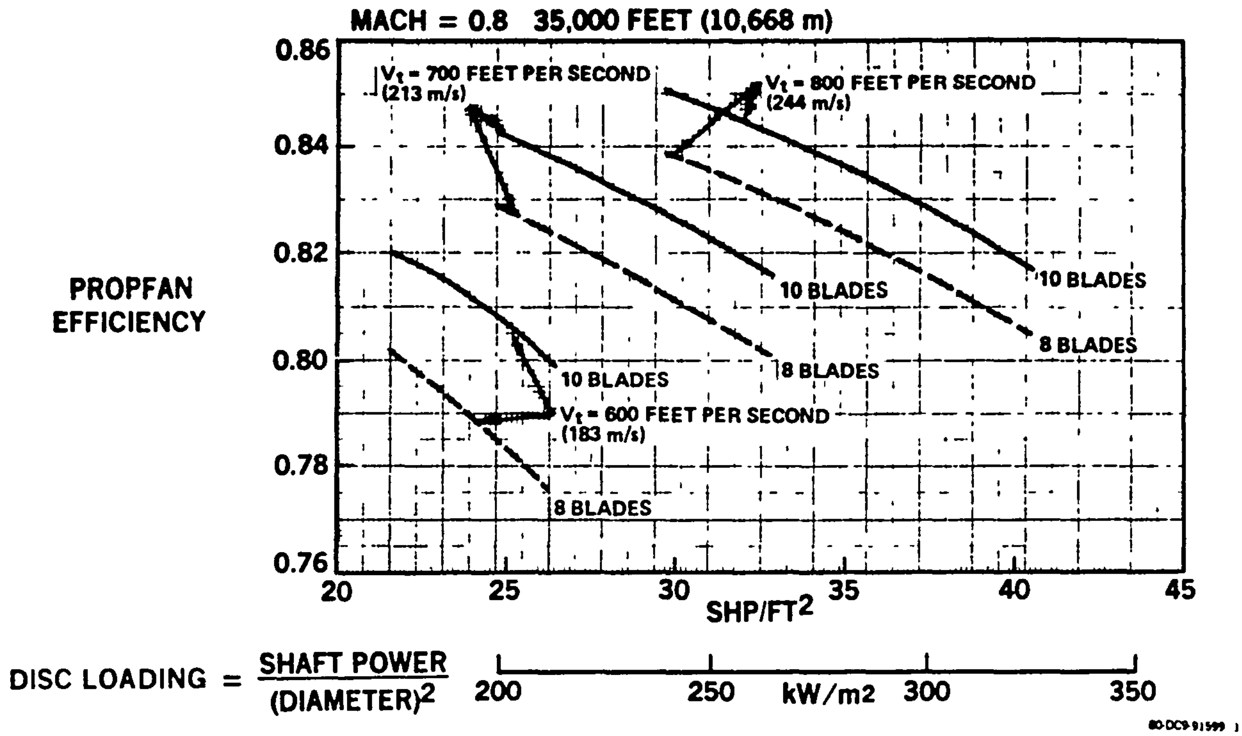


FIGURE 63. CRUISE EFFICIENCY FOR EIGHT AND TEN BLADE PROPFANS

Previous studies have indicated that a cruise disc loading of 37.5 shp/ft^2 (301 kW/m^2) at 35,000 ft (10,668 m), and a tip speed of 800 ft/sec (244 m/sec) are a reasonable combination for a Mach 0.8 aircraft, and these conditions were specified in the statement of work for the base case propulsion system. The effects of lower tip speeds and disc loadings on the aircraft have been investigated and are reported in Section 4 and in the sonic fatigue and acoustics discussions of Section 5.

For the base case propulsion system, with a 1.23-scale PD370-22A engine, the propfan diameter is 13.85 ft (4.22 m). The propfan is scaled as the engine is scaled, to maintain the design disc loading. The propfan diameter therefore varies as the square root of the engine scale factor.

Installed Performance

For calculation of aircraft performance, propulsion system installed thrust and fuel flow are required at all flight conditions. The "bookkeeping" in this study includes the external drag of the nacelle package in the airplane drag. Assumptions for the installed engine performance include an inlet pressure recovery of 1.00 and 200 shp (150 kW) power extraction. A gearbox loss of 1 percent is included in the engine performance of Reference 1. The propfan efficiency is calculated using the power input to the propfan and the Hamilton Standard parametric relationships in References 2 and 3. The thrust available to the aircraft is the sum of the propeller thrust and the net thrust of the jet exhaust.

The scaling instructions of Reference 1 show a slightly nonlinear effect on power and specific fuel consumption for scaling factors from 1.0 to 1.2. As the study scale factors are greater than 1.2, and the installation losses are not accurately known, the assumption was made that thrust and fuel flow vary directly with scale factor.

Performance Effect of Blade Number, Disc Loading, and Tip Speed

A study has been made to estimate the effect of changes in propfan parameters: 10 blades rather than the 8 of the base case, at the base case tip speed and disc loading; at 700 ft/sec (213 m/sec) tip speed and 30 shp/ft^2 (241 kW/m^2); and at 600 ft/sec (183 m/sec) tip speed with disc loading of 25 shp/ft^2 (209 kW/m^2). The installed performance for each propulsion system configuration has been estimated and compared with the baseline performance, and thrust multipliers calculated to use on the computer performance to approximate the thrust of the new configuration. These factors are shown in Figure 64 for a range of flight Mach numbers. The effects of changes in the propfan design parameters on propfan and engine size, presented in Table 20, result in a small change in engine size for a constant thrust, but in a large increase in propfan diameter for lower loadings and tip speeds. The effects on aircraft performance resulting from these propsan variations are covered in Section 4.

Propulsion System Weights

Propulsion system weights are expressed as a function of engine scale factor, to be compatible with the computerized aircraft performance calculation program. Engine weight is based on the relationships in Reference 1. Gearbox weight is calculated from information in the same reference, and increased 10 percent to account for provision of counterrotation capability (Reference 22). Propfan weights are from equations derived to fit the weight estimation curves of References 4 and 5.

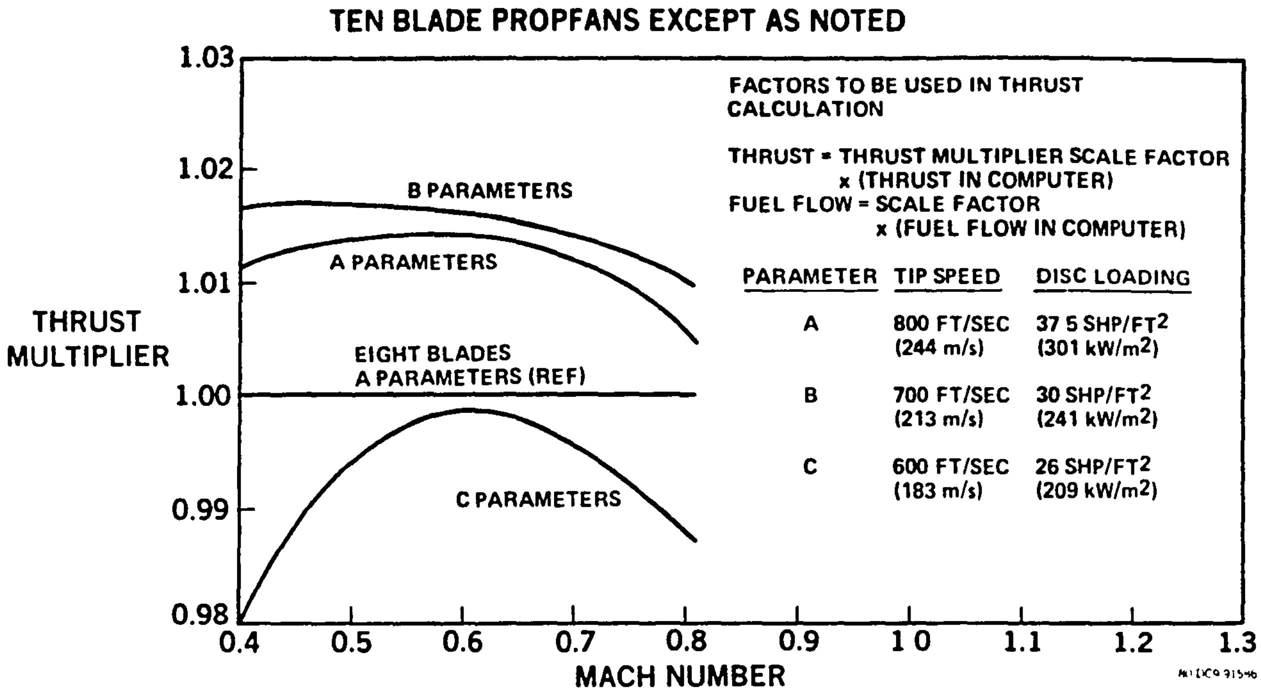


FIGURE 64. ESTIMATED PROPFAN PERFORMANCE THRUST FACTORS

TABLE 20

EFFECT OF PROPFAN PARAMETERS ON PROPULSION SYSTEM SIZE
FOR EQUAL THRUST AT MACH 0.8, 35,000 FT (10,668 m)

No. of Blades	8	10	10	10
Tip Speed, ft/sec (m/sec)	800 (244)	800 (244)	700 (213)	600 (183)
Disc Loading, shp/ft^2 (kW/m^2)	37.5 (301)	37.5 (301)	30 (241)	26 (209)
Engine Scale Factor	1.23	1.22	1.22	1.25
Propfan Diameter, ft (m)	13.85 (4.22)	13.8 (4.21)	15.4 (4.69)	16.8 (5.12)
Gear Ratio	7.8	7.8	10.0	12.5
Blade Passage Frequency, hz	147	184	145	114

The effect of blade number, tip speed, and disc loading on propulsion system weights* is shown in Figure 65. (The figure is intended to show trends, and may differ a percent or two from other weight tabulations because of differences in installation losses.) The high disc loadings give lighter weight, but, as was shown previously, have lower efficiencies, resulting in higher thrust specific fuel consumption.

Figure 65 also indicates that the 10 blade propulsion system has less weight than the 8 blade. For the same diameter, loading, and tip speed, the 8 blade propfan weight has been estimated to be about 15 percent greater than that of the 10 blade propfan (References 4 and 5). This apparent anomaly results from both designs having the same total activity factor (TAF). The conventional propeller weight equation developed by Hamilton Standard from historical data (Reference 23) relates weight to blade number (N) and activity factor per blade (AF) by:

$$\text{Weight} \propto AF \times (N)^{0.65}$$

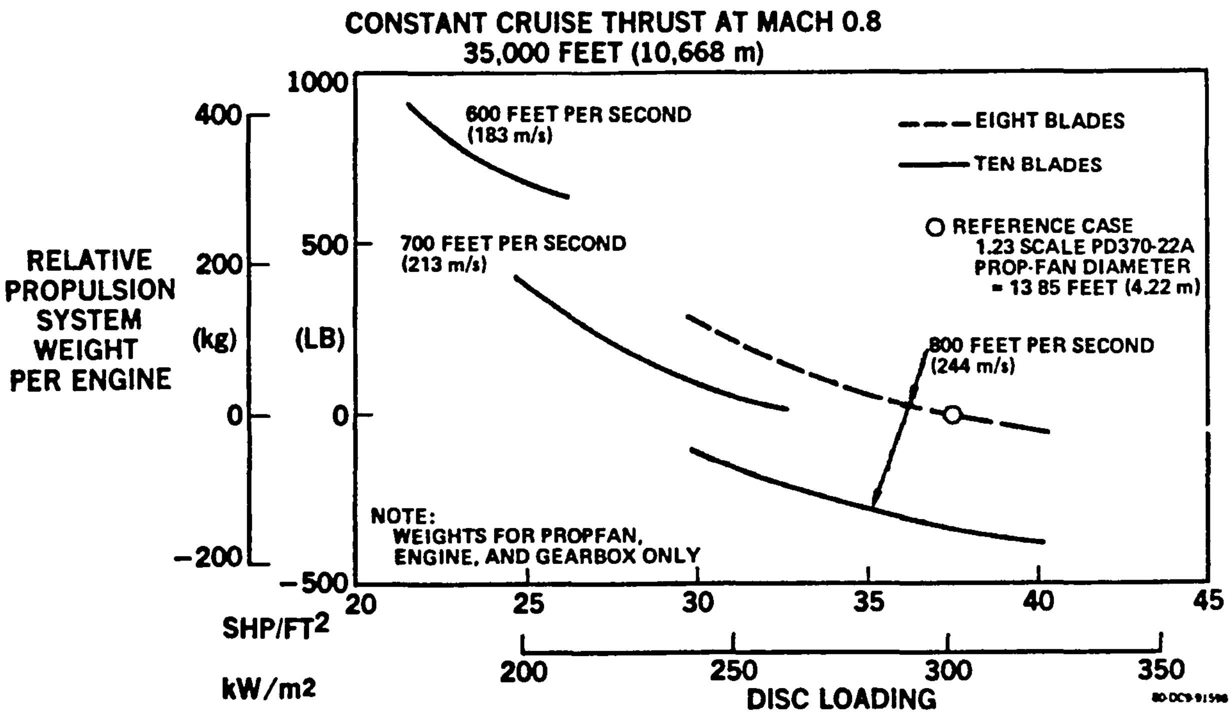


FIGURE 65. EFFECT OF PROPFAN VARIABLES ON PROPULSION SYSTEM WEIGHT

*Engine gearbox and propfan weights only.

or $\text{Weight} \propto (\text{TAF}) \times (N)^{-0.35}$

This relationship accounts for 8 percent of the difference in 8 and 10 blade weights. Another factor is the narrower chord blade of the 10 blade design. This results in a lower centrifugal twisting moment, so the pitch-change system is lighter weight.

*The activity factor of a blade expresses the distribution of blade area along the radius.

$$AF = \frac{100{,}000}{16} \int_{x = 0.15}^{x = 1.0} \frac{b}{D} x^3 dx$$

where b is the local blade section width and x is the fraction of the tip radius.

The total activity factor is the number of blades multiplied by the activity factor per blade.

ACOUSTICS

The economic benefits of operating turboprop aircraft can be realized only if an acceptable level of passenger comfort can be achieved. In addition to the acceptable cabin vibration levels, an environmental factor critical to passenger comfort on all turboprop aircraft is the cabin acoustic noise level in the vicinity of the propeller plane. An acceptable cabin acoustic environment for the DC-9 Super 80 propfan has been defined as equivalent to the acoustic environment of the production DC-9 Super 80 turbofan, using the A-weighting system. Since the DC-9 Super 80 turbofan is a very new aircraft, no interior noise surveys have yet been conducted on it. However, estimates of the noise levels inside the DC-9 Super 80 are based upon data measured during cruise flight of the DC-9-50. The average of the maximum levels measured in several DC-9-50 aircraft is 82 dBA. This is therefore the maximum allowable level and will correspond to the loudest point in the DC-9 Super 80 propfan.

External Acoustic Environment

The factors that determine the interior noise environment in any aircraft (excluding the effects of on-board and structure-borne noise sources) are the external noise environment, the sound transmission characteristics of the fuselage/sidewall structure, and the acoustic absorption characteristics of the passenger cabin. First, the external environment must be defined. The external noise environment on propfan aircraft consists of shock-like pressure pulses from the propellers in addition to the normal boundary layer noise. The propeller blade pulses are periodic, and can be expressed in the frequency domain as a series of discrete sound pressure levels at integer multiples of the propeller blade passage frequency. The boundary layer noise is aperiodic and translates into the frequency domain as broadband noise. In this study, the external noise due to the propellers is predicted using the method contained in Reference 24, and the boundary layer noise is predicted using a technique based on methods contained in Reference 25.

External acoustic load predictions are required in the preliminary portion of this study for 10 aircraft engine mounting configurations using 8 blade propfans. These configurations are ranked by Acoustics according to minimum acoustic load from the propfans impinging on the passenger cabin portion of the fuselage. After an elimination process, the three configurations that are studied include a wing mounted case (Configuration No. 1) and two aft mounted configurations; a stabilizer mounted design (Configuration No. 3), and a pylon mounted case (Configuration No. 2). The external acoustic loading for the first harmonic is shown as a function of fuselage station for these three configurations in Figures 66 through 68.

In addition to the three 8 blade propfan configurations, three variations using 10 blade propfans were required for each of the three engine mounting locations, for a total of 12 possible combinations. The external acoustic loads for the first harmonic for the 10 blade propfan cases are shown in Figures 69 through 71. The 8 and 10 blade variations all have different blade passage frequencies, as shown in each figure. The levels of the higher harmonics are shown relative to the first harmonic level in Table 21. These harmonic roll-offs apply to both 8 blade and 10 blade propfans.

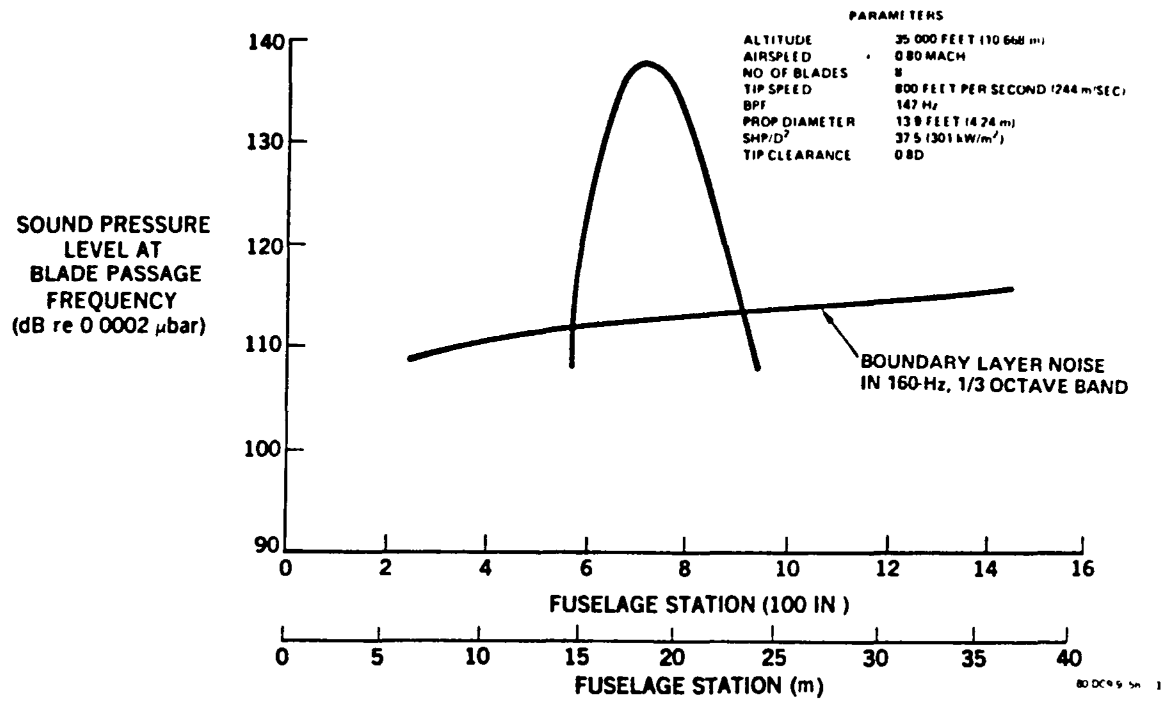


FIGURE 66. DC-9 SUPER 80 PROPFAN ACOUSTIC LOADING CONFIGURATION 1, EIGHT-BLADED PROPS

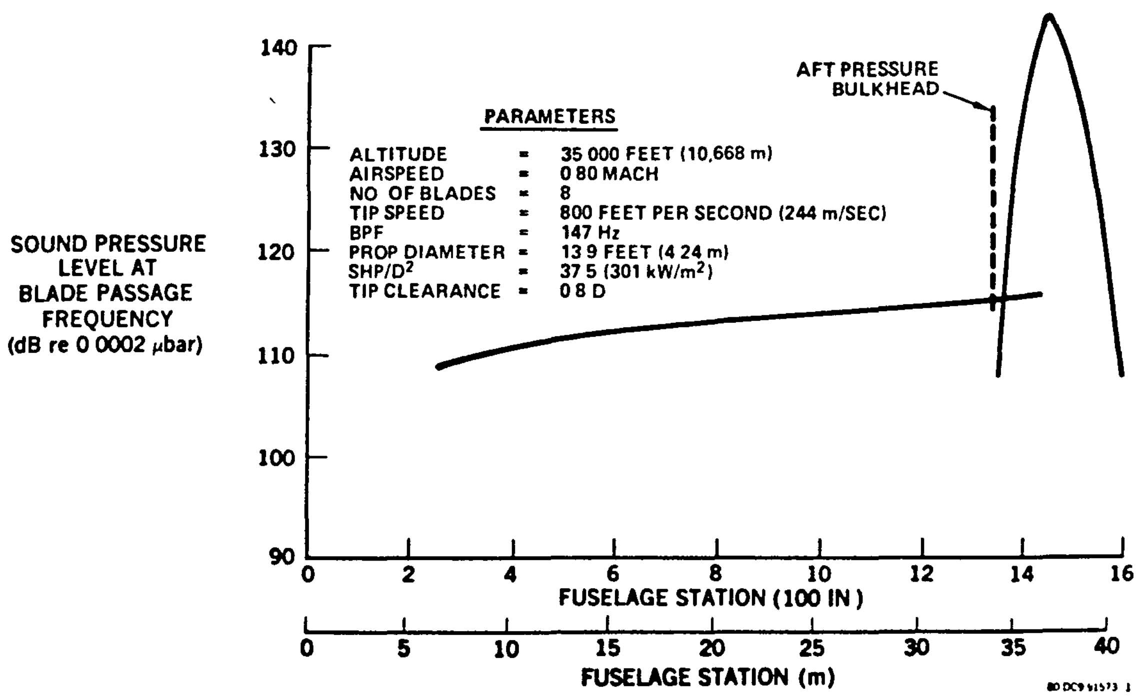


FIGURE 67. DC-9 SUPER 80 PROPFAN ACOUSTIC LOADINGS CONFIGURATION 3, EIGHT-BLADED PROPS

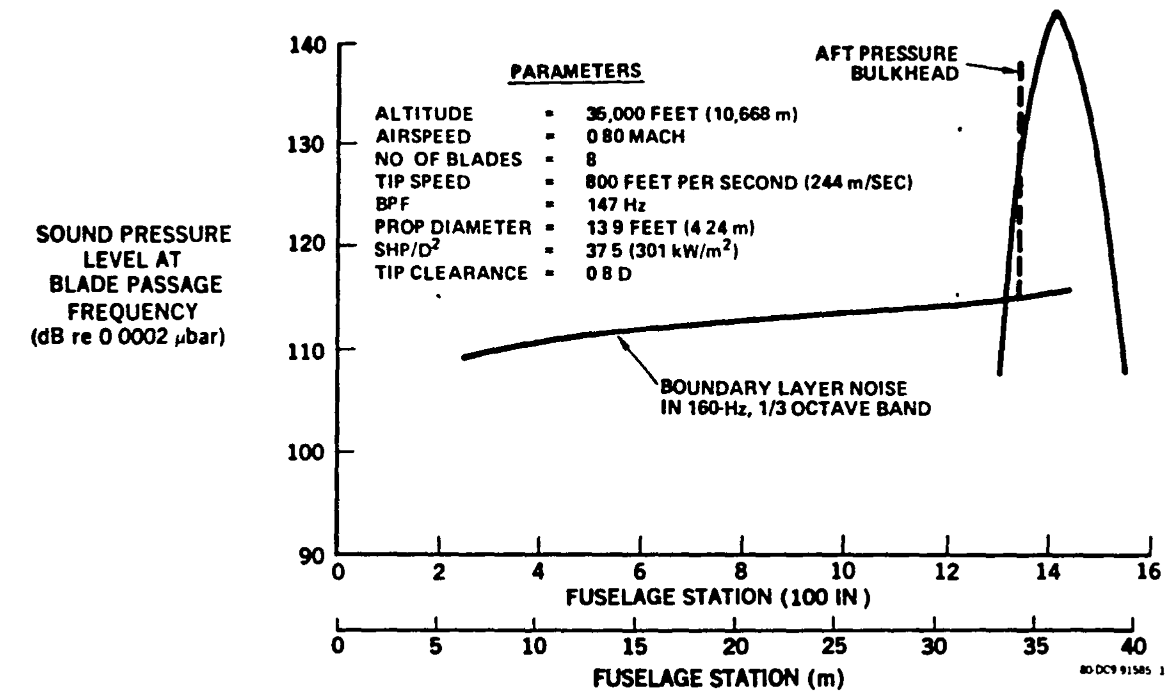
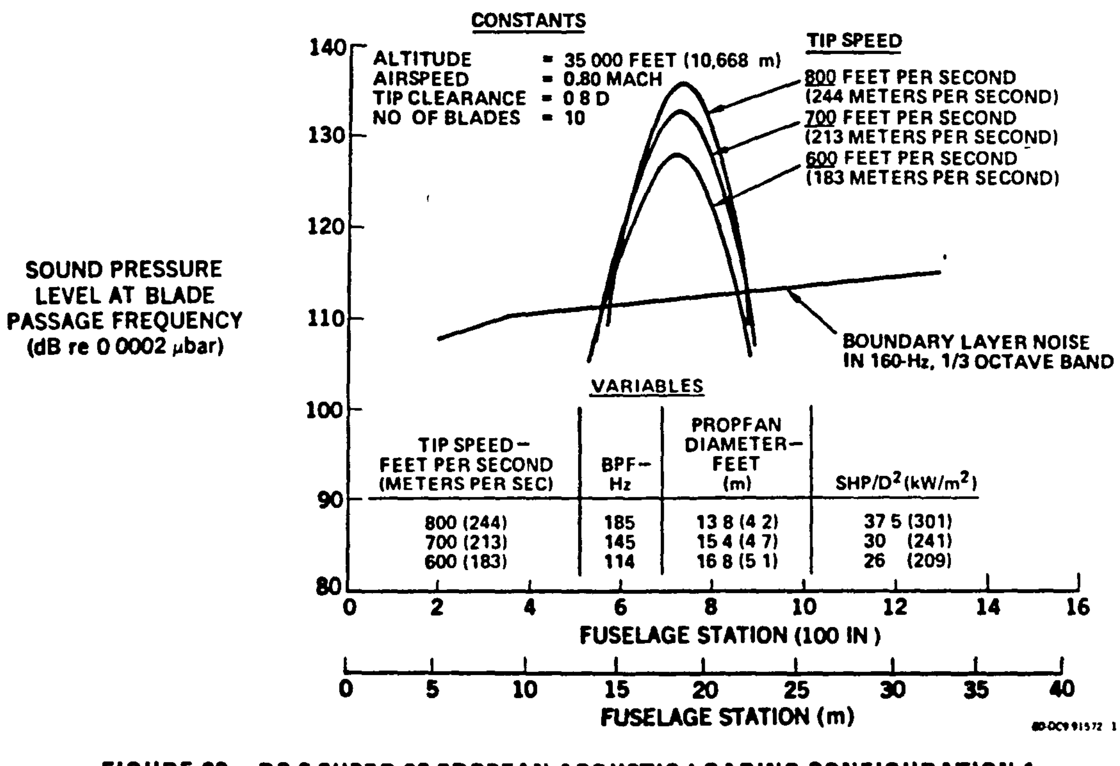


FIGURE 68. DC-9 SUPER 80 PROPFAN ACOUSTIC LOADING CONFIGURATION 2, EIGHT-BLADED PROPS



TIP SPEED—FEET PER SECOND (METERS PER SEC)	BPF—Hz	PROPFAN DIAMETER—FEET (m)	SHP/D2 (kW/m2)
800 (244)	185	13 8 (4 2)	37 5 (301)
700 (213)	145	15 4 (4 7)	30 (241)
600 (183)	114	16 8 (5 1)	26 (209)

FIGURE 69. DC-9 SUPER 80 PROPFAN ACOUSTIC LOADING CONFIGURATION 1, TEN-BLADED PROPS

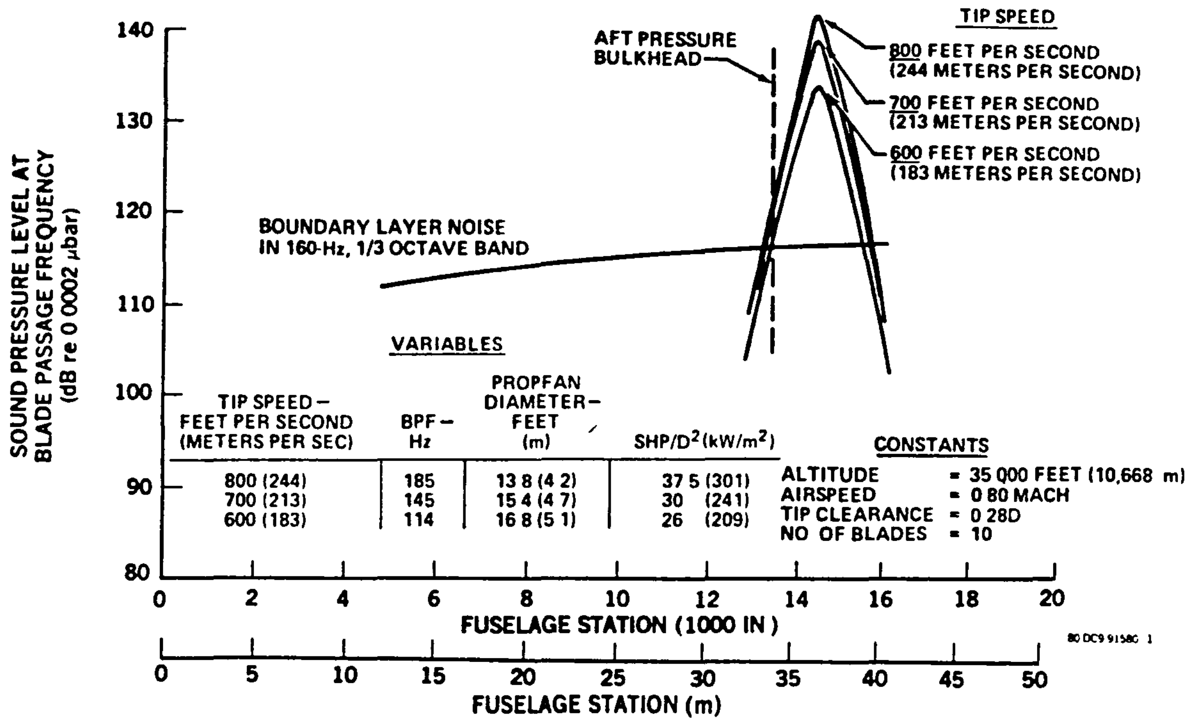


FIGURE 70. DC-9 SUPER 80 PROPFAN ACOUSTIC LOADING CONFIGURATION 3, TEN-BLADED PROPS

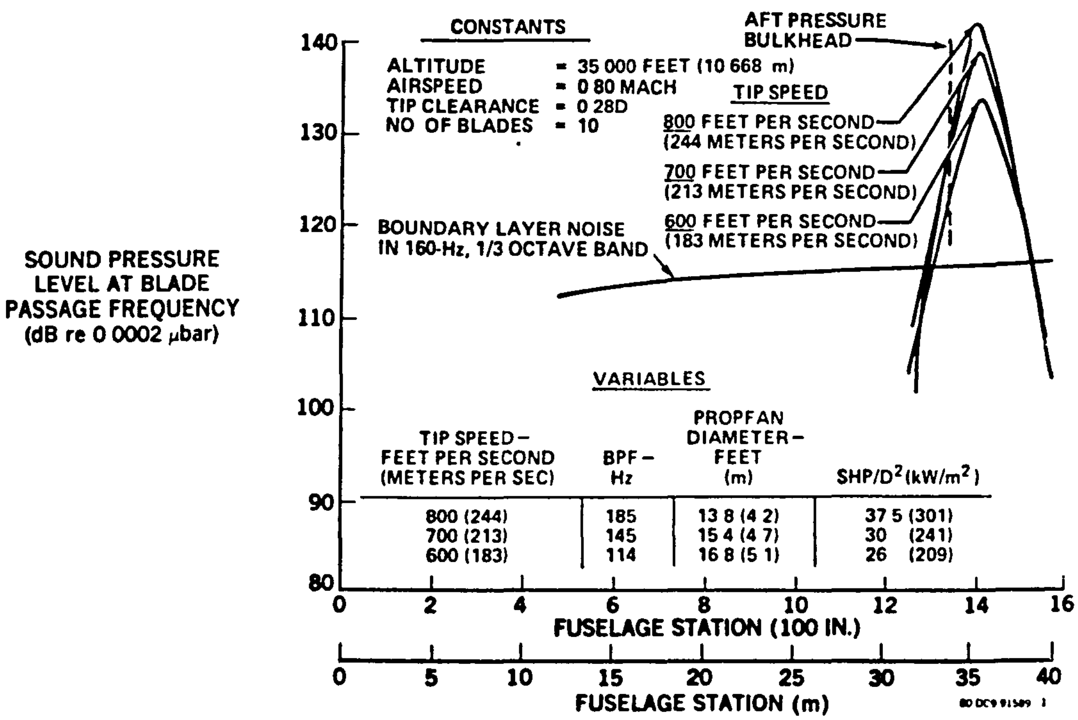


FIGURE 71. DC-9 SUPER 80 PROPFAN ACOUSTIC LOADING CONFIGURATION 2, TEN-BLADED PROPS

TABLE 21

HARMONIC LEVELS re SOUND PRESSURE LEVEL AT BLADE PASSAGE FREQUENCY*

	TIP SPEED — FT/SEC (METERS/SEC)		
HARMONIC	800 (244)	700 (213)	600 (183)
2 x BPF	-7 dB	-11 dB	-15 dB
3 x BPF	-14 dB	-21 dB	-30 dB
4 x BPF	-19 dB	-31 dB	-43 dB

NOTE THE HARMONIC ROLL-OFF RATES APPLY TO BOTH EIGHT-BLADED AND TEN-BLADED PROPFANS

*DATA FROM REFERENCE 24

80-DC9 91541 1

Interior Noise Prediction Model

The interior noise prediction model for this study is adapted from models developed during the course of previous IRAD and CRAD propfan studies performed by Douglas Aircraft Company. A flow chart of the model is shown in Figure 72. It is based on a double-wall transmission loss technique contained in Reference 26. The low frequency effects of fuselage curvature and stiffness are not included in this technique, but these effects are accounted for in the Douglas model by using in-flight fuselage transmission loss data obtained on the YC-15 (References 27 and 28). These data are corrected for fuselage radius and structural differences in order to apply them to the DC-9 Super 80 propfan fuselage.

Once the fuselage/sidewall transmission loss (TL) is computed, it is converted to noise reduction (NR) by applying an adjustment for estimated cabin sound absorption. The noise reduction can then be combined with the external acoustic loads from the propfans and boundary layer noise to arrive at noise levels inside the cabin. The levels are then log summed using the A-weighting

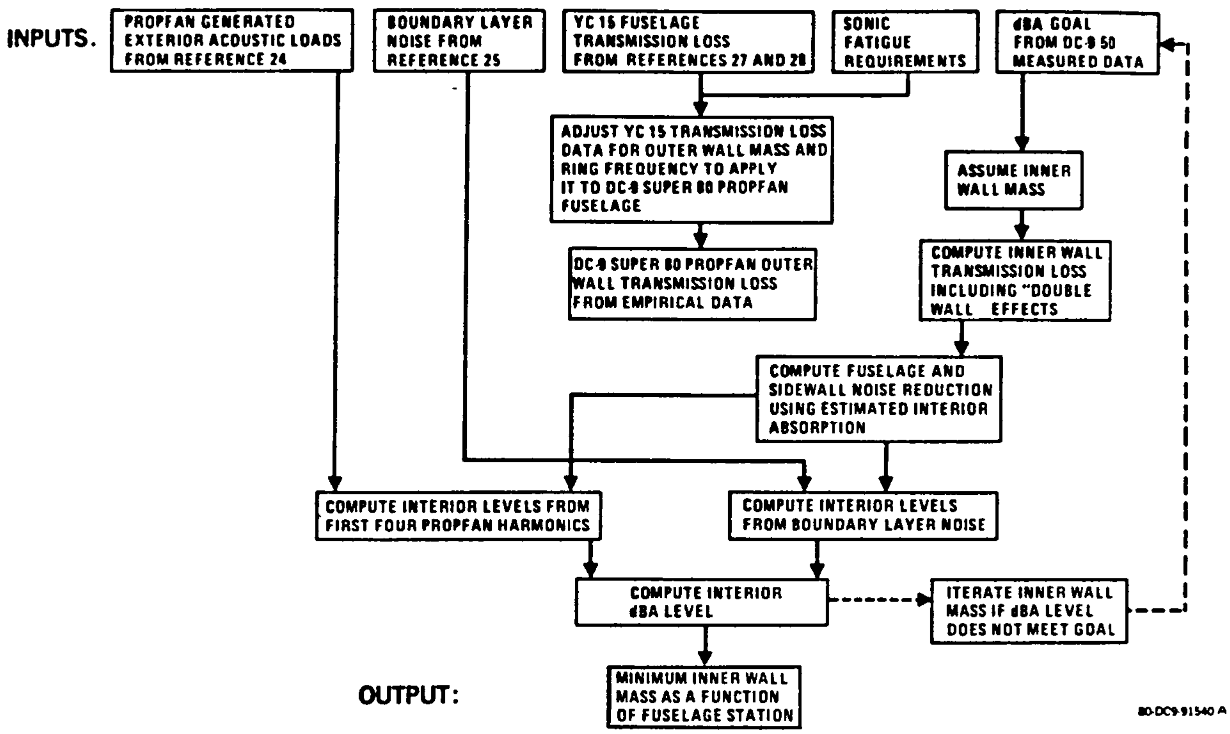


FIGURE 72. FLOW CHART OF INTERIOR NOISE PREDICTION MODEL

scale to arrive at a single-number dBA level. By iterating and varying the trim panel mass, an interior level of 82 dBA can be achieved.

This procedure also provides a means of evaluating alternative acoustic treatments, both in the fuselage structure and aircraft sidewall. Changes in fuselage construction can be accounted for by changing the estimated fuselage shell transmission loss. Changes in trim panel or cavity (between the fuselage and trim panel) constructions are handled in a different manner. The model assumes that the trim panel behaves according to the mass law principle. For a panel with other than mass law behavior such as a honeycomb panel, an equivalent mass is determined at the blade passage frequency, which is the frequency that controls the interior dBA level in the area of high propfan acoustic loading. If this equivalent mass is equal to or greater than the computed minimum required trim panel mass, then the panel will provide adequate attenuation to achieve the 82-dBA interior noise goal.

Evaluation of Acoustic Treatment Designs

This interior noise prediction model provides a means of evaluating various acoustic treatment designs for the DC-9 Super 80 propfan. All treatment designs were evaluated initially for Configuration 1 with an eight blade propfan. A list of the acoustic treatment designs that were evaluated for this configuration is shown in Table 22. These designs address three possible types of treatment: (1) changes to the fuselage structure, (2) changes to the trim panel, and (3) changes in cavity depth. Discussions with personnel in other discipline areas reveal that increasing the depth of the cavity is not feasible because of interior space limitations, so this possibility is

TABLE 22
DC-9 SUPER 80 PROPFAN FEASIBILITY STUDY
ACOUSTIC TREATMENT DESIGNS CONSIDERED FOR CONFIGURATION 1
8 BLADE PROPFAN

Fuselaoe	Trim Panel	Cavity*
Standard DC-9-80 construction except frames 9.5 in. (24.1 cm) on center stations 600 to 850, 0.071 in. skin stations 650 to 800	Standard trim panel with added mass	Standard DC-9-80 cavity depth 3 in. (7.6 cm)
Aluminum honeycomb construction	Honeycomb trim panel	Increased cavity depth up to 6 in. (15.2 cm)
Isogrid structure with frames 19 in. (48.3 cm) on center and no longerons from stations 650 to 800	Honeycomb trim panel with added mass	
Standard construction with added mass		
Standard construction with added stiffness		
Standard construction with added structural damping		

*NOTE: Increasing the depth of the wall cavity on the DC-9-80 turboprop is not considered a viable alternative because of interior space limitations.

dropped from the study. Transmission loss characteristics of the various treatment designs are determined from measured data (Reference 29).

Results of the preliminary investigation of the remaining treatment designs are shown in Table 23. Each combination in the matrix is examined for acoustic treatment attenuation and efficiency (i.e., noise reduction at blade passage frequency per pound of surface weight). Most designs using honeycomb trim panels simply do not provide the necessary attenuation. Others such as aluminum honeycomb fuselage structure do not offer any acoustic advantages over standard construction, and are therefore eliminated from further consideration. The addition of mass to the fuselage structure is also considered to be an inefficient use of mass for the amount of attenuation gained. Other techniques such as adding stiffness or damping to fuselage structural components are considered to be effective only under certain con-

TABLE 23

DC-9 SUPER 80 PROPFAN FEASIBILITY STUDY

RESULTS OF PRELIMINARY INVESTIGATION OF ACOUSTIC TREATMENT DESIGNS CONSIDERED FOR CONFIGURATION 1 8-BLADE PROPFAN

	Trim Panel Designs		
Fuselage Designs	Standard Trim Panel with Added Mass	Honeycomb Trim Panel	Honeycomb Trim Panel with Added Mass
Standard DC-9-80 except frames 9 5 in (24 1 cm) on center stations 600 to 850 and 0 071 in skin stations 650 to 800	Warrants further consideration	Not enough attenuation	Warrants further consideration
Aluminum honeycomb construction	No advantages over standard construction	Not enough attenuation	No advantage over standard construction
Isogrid structure with frames frames 19 in. (48.3 cm) on center and no longerons from from stations 650 to 800	Warrants further consideration	Not enough attenuation	Warrants further consideration
Standard construction with added mass to fuselage	Inefficient use of mass	Inefficient use of mass	Inefficient use of mass
Standard construction with added stiffness to fuselage	No benefit because of high modal density	Not enough attenuation	No benefit because of high modal density
Standard construction with added damping to structural components	Need more detailed study of modal frequencies	Not enough attenuation	Need more detailed study of modal frequencies

ditions which will be discussed later. By process of elimination, the matrix is reduced to four promising treatment designs:

1. Standard frame-stringer fuselage construction sized by sonic fatigue requirements with additional mass added to the production trim panel or blanket system. This is known as "add-on" acoustic treatment. A sketch of the production DC-9 Super 80 turbofan sidewall structure is shown in Figure 73.

2. Standard frame-stringer fuselage construction sized by sonic fatigue requirements with a fiberglass-filled honeycomb trim panel. This system also requires additional mass in the trim panel or blanket system. The extra mass could either be in the form of an impervious septum such as leaded vinyl in the blanket system or in the form of a heavier back sheet on the honeycomb panel.

3. Isogrid fuselage construction with mass added to the production trim panel or blanket system. Isogrid is a half-inch thick integrally-stiffened panel machined from a solid piece of aluminum. It has low and mid-frequency noise attenuation which is superior to that of standard fuselage construction. Isogrid structure is shown in Figures 74 and 75.

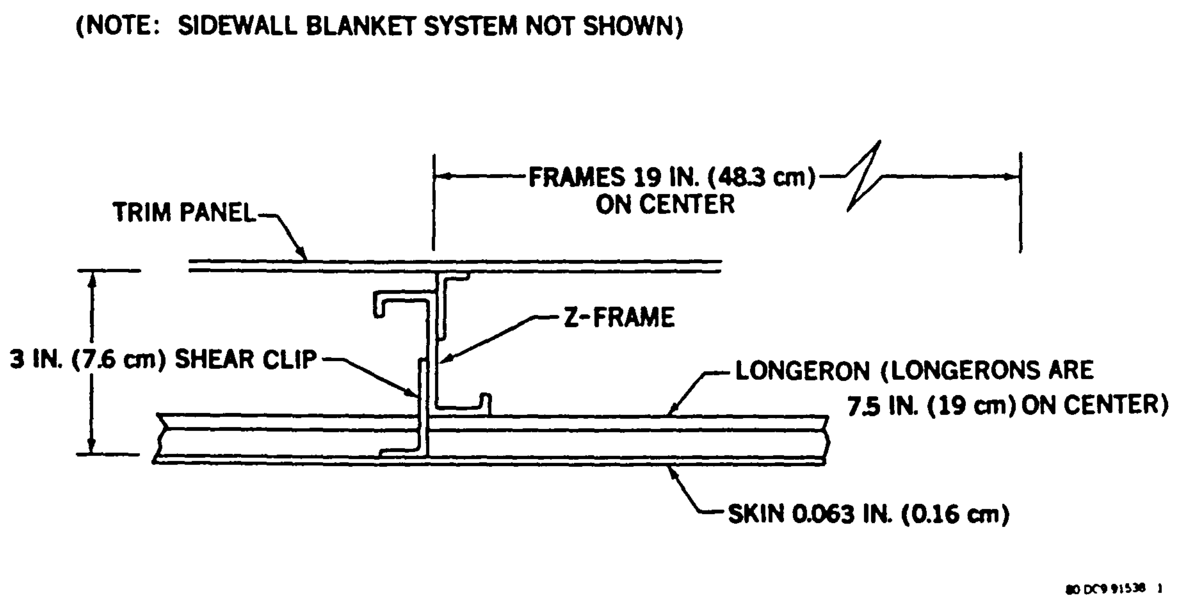


FIGURE 73. STANDARD DC-9 SUPER 80 CONSTRUCTION

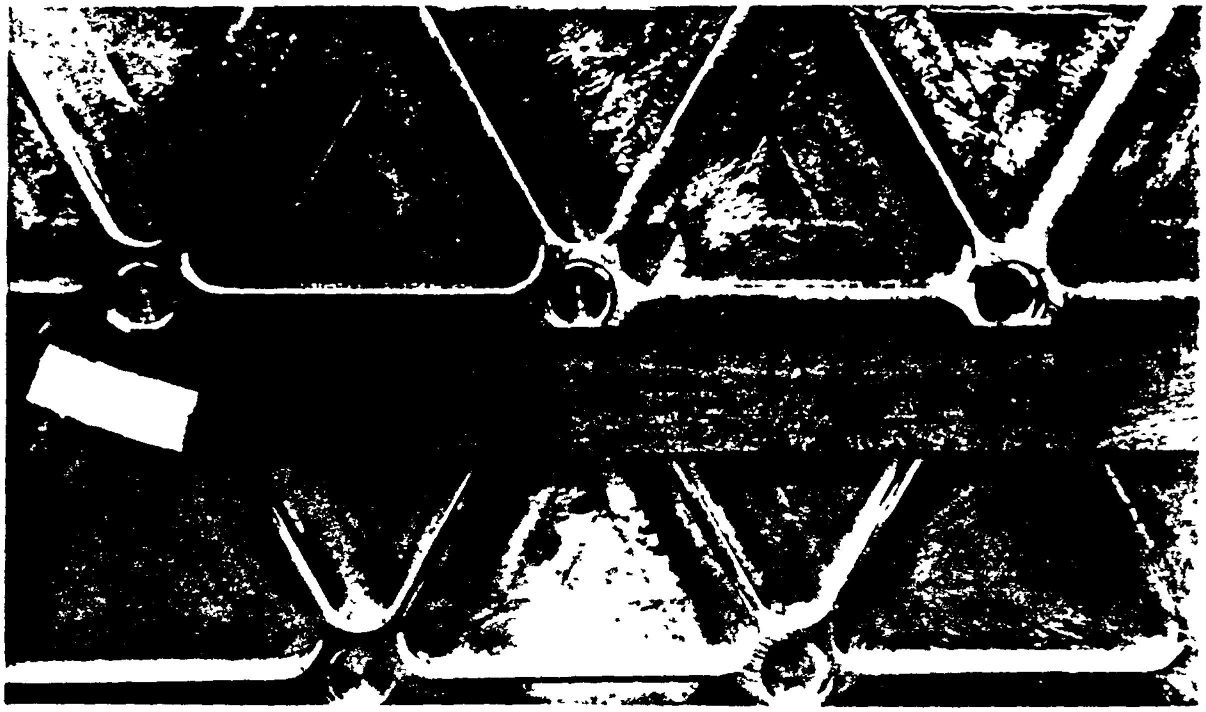


FIGURE 74. ISOGRID STRUCTURE

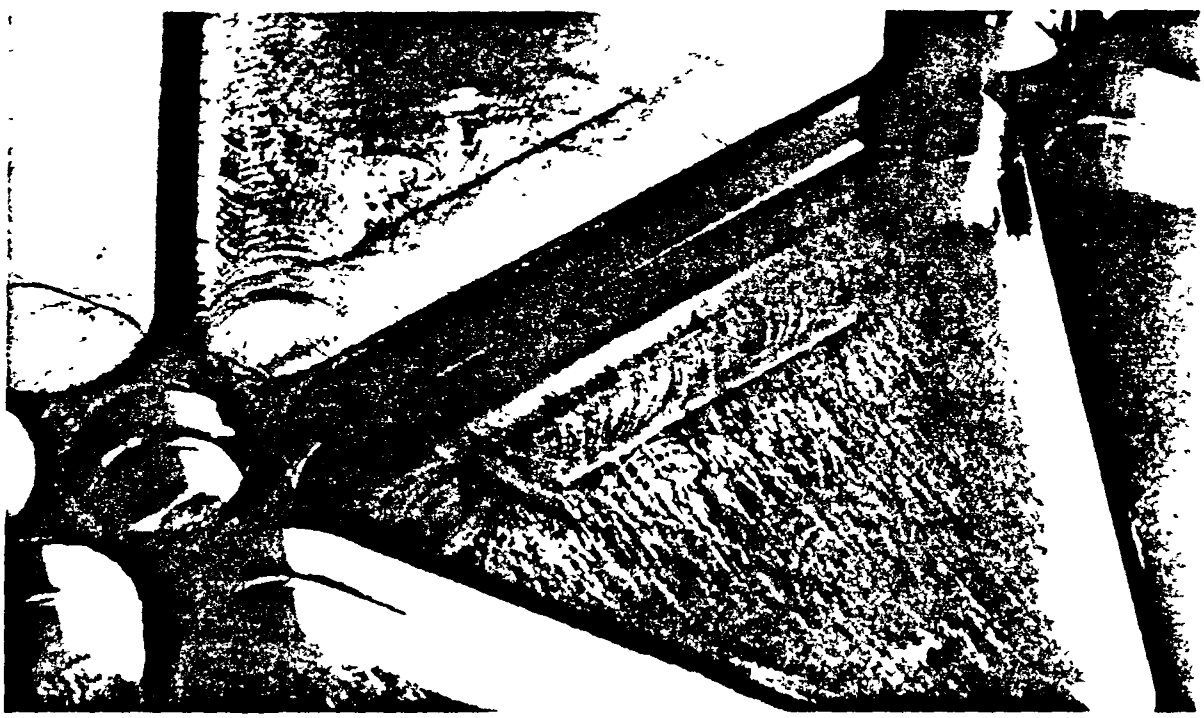


FIGURE 75. ISOGRID STRUCTURE

4. Isogrid fuselage structure with a fiberglass-filled honeycomb trim panel. This design requires the addition of mass to the trim panel back sheet or blanket system in the same manner as design No. 2. A sketch of design No. 4 is shown in Figure 76.

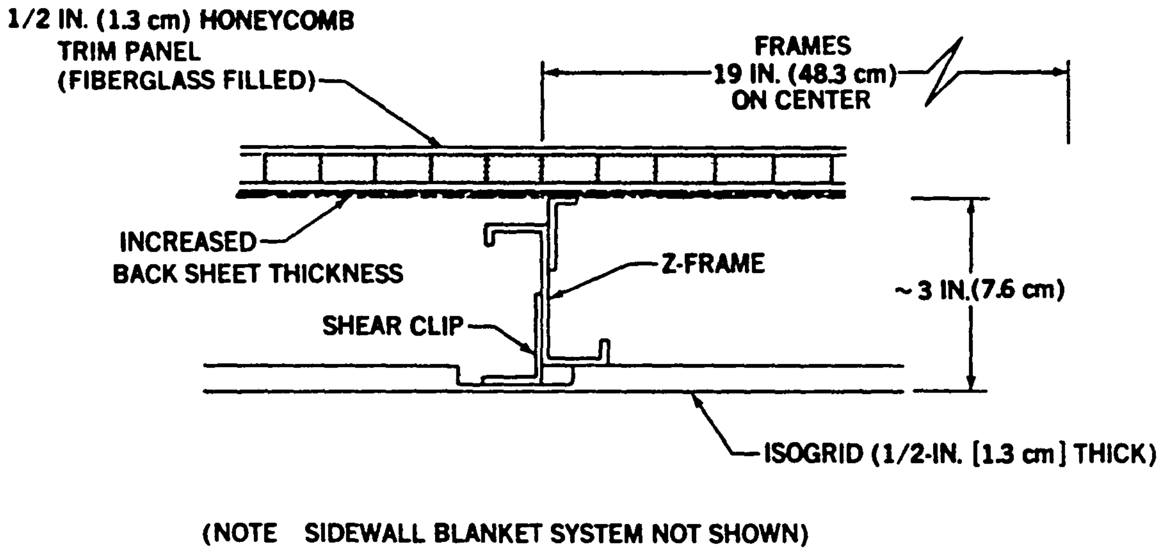


FIGURE 76. ISOGRID STRUCTURE/HONEYCOMB TRIM PANEL CONSTRUCTION

Determination of Acoustic Treatment Weights

Configuration 1, Eight Blade Propfans – The acoustic treatment designs have been evaluated using the interior noise prediction model described previously. For the eight blade version of Configuration 1, the minimum required trim panel mass (for 82 dBA interior) versus fuselage station is shown in Figure 77. The upper solid line on the plot corresponds to treatment design No. 1, the upper broken line corresponds to treatment design No. 3, the lower solid line represents design No. 4, and the lower broken line represents the production DC-9 Super 80 turbofan design with standard trim panel. Treatment design No. 2 is omitted from this figure for clarity, but it falls between the lines representing designs No. 1 and No. 3. Acoustic modifications to the aircraft are assumed to be above the passenger floor only and uniform circumferentially. As shown in Figure 77, isogrid structure shows good promise for reducing the required trim panel weight. Honeycomb trim panels with additional cavity treatment also appear to be an effective means of obtaining the necessary noise reduction.

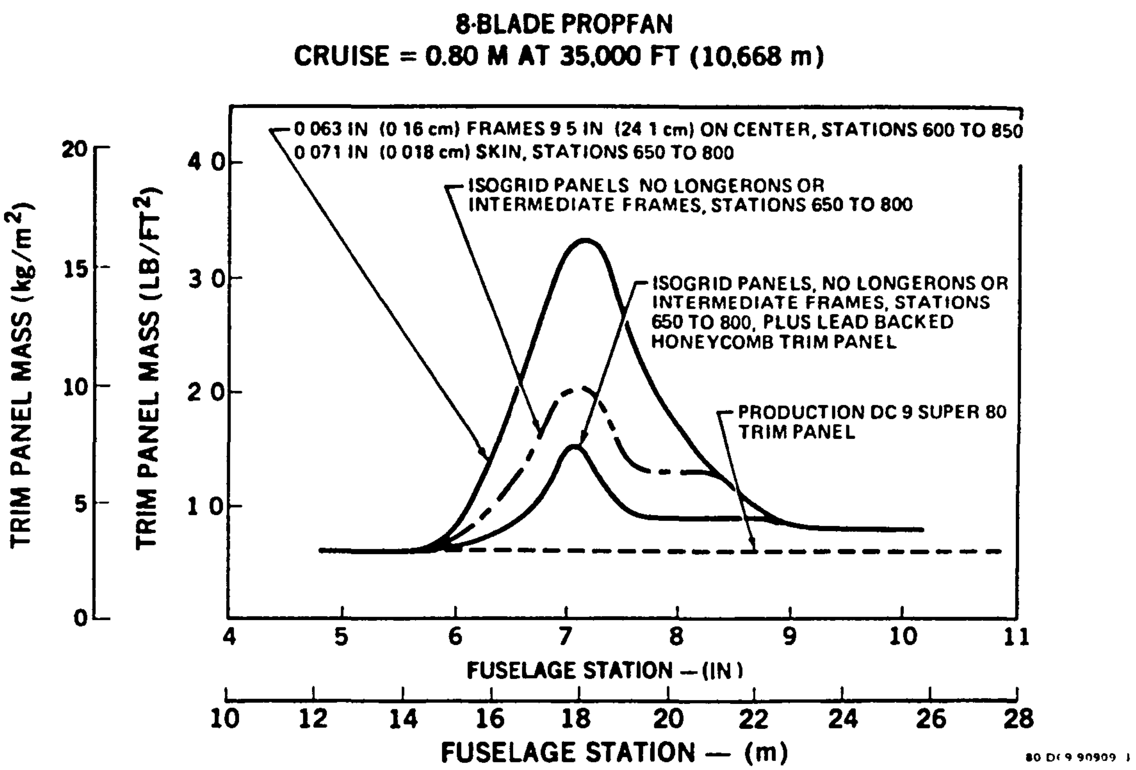


FIGURE 77. TRIM PANEL MASS FOR 82-dBA INTERIOR ON PROPFAN – CONFIGURATION 1

Configurations 2 and 3, Eight Blade Propfans - The remaining configurations have all been evaluated using treatment design No. 1 as the basis for comparison. Acoustic treatment requirements are presented in the form of minimum required trim panel mass (for 82 dBA interior) versus cabin station number. For the aft mounted configurations, it has been assumed that the aft pressure bulkhead at station 1338 would act as an adequate acoustic barrier to reduce propfan noise coming through the tail cone. Therefore, all acoustic treatment for the aft mounted configurations is applied to attenuate propeller noise impinging on the fuselage exterior forward of the aft pressure bulkhead. The eight blade version of Configuration 3 has no propfan acoustic loading forward of the aft pressure bulkhead in excess of the boundary layer noise, and therefore no additional acoustic treatment above the DC-9 Super 80 turbofan baseline requirement is needed.

The required trim panel weights for the eight blade versions of Configurations 2 and 3 using treatment design No. 1 are given in Figure 78. The figure shows that no additional acoustic treatment is required for the eight blade version of Configuration 3. However, treatment is required for

8-BLADE PROPFAN
TREATMENT DESIGN NO. 1

	STATION 1307 TO 1338	STATION 1269 TO 1307
CONFIGURATION 2 PYLON MOUNT	2.1 LB/FT 2 (10.25 kg/m 2)	1.0 LB/FT 2 (4.88 kg/m 2)
CONFIGURATION 3 TAIL MOUNT	PRODUCTION*	PRODUCTION

*THERE ARE NO ADDITIONAL ACOUSTIC REQUIREMENTS FOR CONFIGURATION 3 THE PRODUCTION DC-9 SUPER 80 TURBOFAN TRIM PANEL WILL MEET THE 82-dBA INTERIOR REQUIREMENT

80-DC9-90904A 1

FIGURE 78. TRIM PANEL MASS REQUIRED FOR 82-dBA INTERIOR ON PROPFAN CONFIGURATIONS 3 AND 2

Configuration 2. The required trim panel weight for the two structural bays immediately forward of the aft pressure bulkhead (stations 1307 to 1338) is 2.1 lb/ft^2 (10.25 kg/m^2); for the two bays forward of station 1307 (stations 1259 to 1307), the required trim panel weight is 1.0 lb/ft^2 (4.88 kg/m^2)

Total acoustic treatment insight penalties are presented in the Weights section of this report.

Configuration 1, 10-Blade Propfan - Figure 79 is a plot of the required trim panel weights, using treatment No. 1, for the three 10 blade versions of Configuration 1. Structural modifications for acoustic fatigue reasons are listed on the plot as are the tip speeds and disc loadings for each of the three cases. Each case has a different blade passage frequency, as noted in Figure 79. Required trim panel weights in the figure are not only a result of reduced sound pressure levels on the fuselage exterior, but the different blade passage frequencies also affect other factors such as double wall response, dBA weighting, and interior absorption. These factors contribute to make the required trim panel weight for the 800 ft/sec (244 m/sec) tip speed case of Figure 79 lower than the corresponding eight blade version of Figure 78. The 700 ft/sec (213 m/sec) and 600 ft/sec (183 m/sec) cases of Figure 79 benefit mainly from lower propeller noise levels impinging on the fuselage.

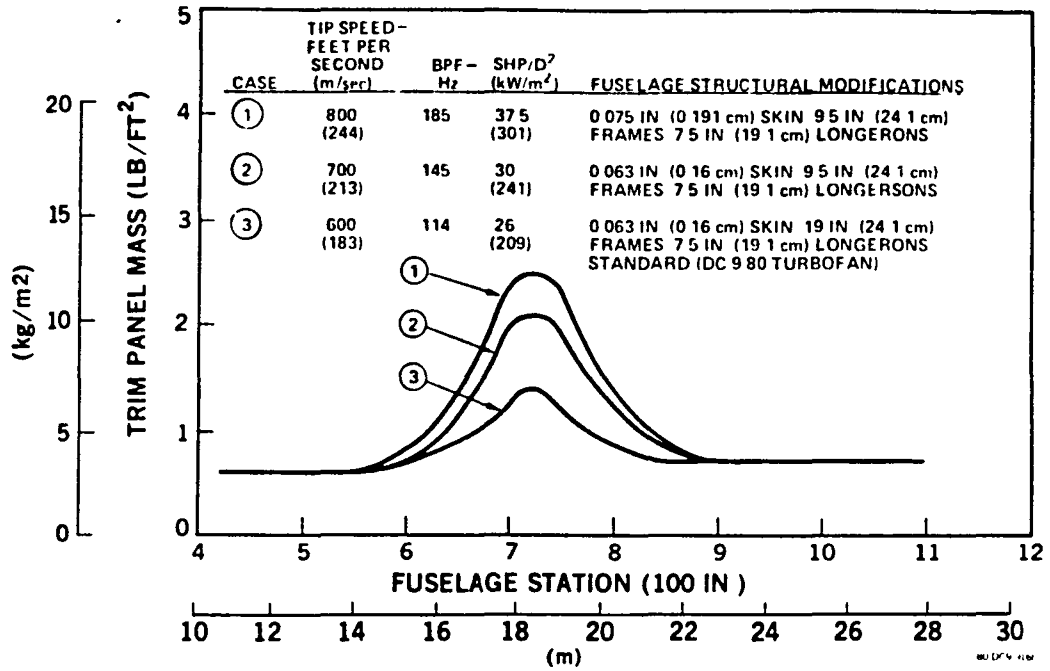


FIGURE 79. DC-9 SUPER 80 PROPFAN CONFIGURATION 1, TEN-BLADED PROPS TRIM PANEL MASS REQUIRED FOR 82-dBA INTERIOR

Configurations 2 and 3, 10 Blade Propfans - The required trim panel weights using treatment design No. 1 for the 10 blade version of Configurations 2 and 3 are given in Table 24. Unlike the 8 blade aft mounted configurations, acoustic treatment will be required for all of the 10 blade aft mounted versions because the directivities predicted for the 10 blade configurations all show propfan loads occurring forward of the aft pressure bulkhead. Acoustic treatment is specified in Table 24 for two segments of fuselage: the section from station 1307 to station 1338, and the section from station 1269 to station 1307. The acoustic treatment specified runs above the passenger floor only (for all versions). For Configuration 3, no additional acoustic treatment in excess of DC-9 Super 80 turbofan requirements is needed forward of station 1307.

Modal Response

In the discussion of possible acoustic treatment designs, it was stated that adding stiffness or damping to the fuselage structure was considered to be an effective means of noise control only under certain conditions. This con-

TABLE 24

CONFIGURATIONS 2 AND 3, 10 BLADED PROPFANS

TRIM PANEL MASS REQUIRED FOR 82-dBA INTERIOR
USING TREATMENT DESIGN NO. 1

ALL TREATMENT IS ABOVE PASSENGER FLOOR

Configuration	Tip Speed ft/sec (m/sec)	Trim Panel Weight Sta 1307 to Sta 1338 lb/ft^2 (kg/m^2)	Trim Panel Weight Sta 1269 to Sta 1307 lb/ft^2 (kg/m^2)
2	800 (244)	1.8 (8.79)	1.1 (5.37)
2	700 (213)	1.6 (7.81)	1.0 (4.88)
2	600 (183)	1.1 (5.37)	1.0 (4.88)
3	800 (244)	1.1 (5.37)	Production
3	700 (213)	1.1 (5.37)	Production
3	600 (183)	1.0 (4.88)	Production

clusion resulted from a study of fuselage modal response conducted to examine the possibility of a resonance condition. Resonance occurs when the propeller blade passage frequency falls at the same frequency as a fuselage vibrational mode. In order to study the possibility of a resonance condition occurring, a modal response model was developed using an approach developed at Douglas (unpublished). The fuselage shell is modeled as a cylinder with stiffeners and damping. Stiffness is provided in the circumferential direction by ring frames with Z-shaped cross sections and in the axial direction by hat-section longerons. The model does not include the passenger floor. The model predicts the frequencies of selected fuselage vibration modes and the intensity of acoustic radiation of each mode to the cabin interior, permitting calculation of fuselage shell transmission loss. Shell transmission loss can be predicted for each mode individually or for a selected combination of modes.

Due to the complexity involved in accurately modeling the fuselage, several simplifications have been incorporated in the model so that it does not become unwieldy or expensive to examine many different aircraft configurations. These simplifications lead to uncertainty as to the exact natural frequency or transmission loss characteristic that a particular mode will have. Instead of being used to predict absolute values of natural frequency and transmission loss for the modes, this model is used to examine modal density and relative changes in transmission loss.

Adding stiffness or damping to fuselage structure will not automatically increase shell transmission loss. These treatment concepts are to be used primarily for avoiding resonance conditions. In fact, when used improperly, they can do more harm than good. Adding stiffness to the fuselage is useful if one wants to raise the natural modal frequencies of the structure in order to get them above the excitation frequency, thereby avoiding resonance. However, if there are structural modes below the excitation frequency, these will also be raised by increasing the stiffness, and a new resonance condition may be created.

If one cannot avoid a resonance condition, then the addition of structural damping may be considered to reduce structural response. Structural damping effectively decreases the magnitude of the response if the modal frequency is at or near the excitation frequency, but has a lesser effect on the response of a mode that has a frequency located some distance from the excitation frequency. In order to be most effective, structural damping should be introduced some distance away from the skin. A good location would be in the web of the Z-section ring frames. This would be expensive to do, but it may become necessary if a resonance condition exists.

The interior dBA level is primarily controlled by the tone at blade passage frequency. It is hoped that since this low frequency tone falls in an area of low modal density, a resonance condition can be avoided by attaining a sufficient mismatch between the modal and blade passage frequencies. Figure 80 is a plot of the modal frequencies calculated from the fuselage response model for the fuselage shell of the eight bladed version of Configuration 1. The figure shows that there are several modes in the vicinity of the blade passage

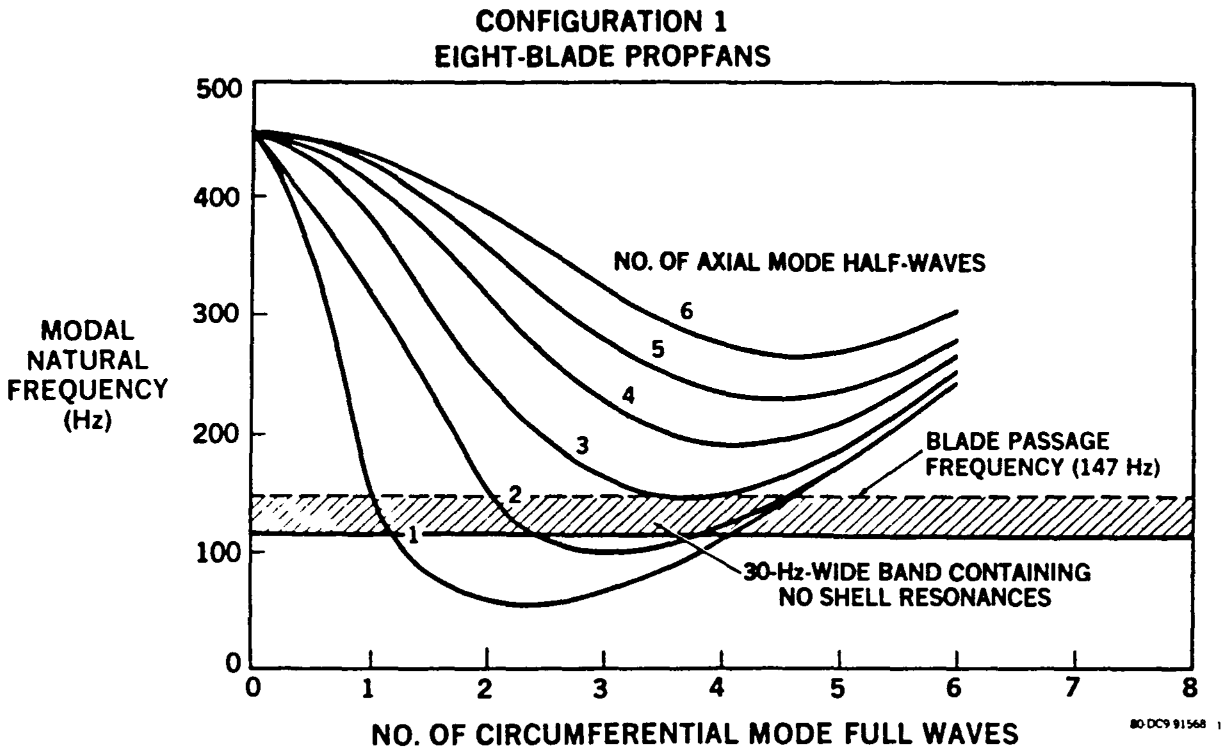


FIGURE 80. MODAL NATURAL FREQUENCIES, CONFIGURATION 1, EIGHT-BLADED PROPFANS

frequency (147 Hz), both above and below. Although the existence of these modes can be determined analytically, some of them will probably not respond on the aircraft. Which modes will actually respond well cannot easily be determined analytically because of complicated phase relationships between external pressures at different spatial locations.

As indicated in Figure 80, it is difficult to attain a large frequency mismatch between modal and blade passage frequencies, but it may be possible to attain a mismatch of approximately 10 Hz. The amount of benefit that one would gain from a 10 Hz mismatch is shown in Figure 81. This figure is a plot of change in fuselage transmission loss predicted from the response model, versus modal natural frequency. The dip in the curves at blade passage frequency corresponds to a resonance match. In this case, 1.5 percent critical damping is assumed. It is also assumed that all modes responded equally well. The curves show that a mismatch of 10 Hz results in a shell transmission loss benefit of approximately 10 to 15 dB.

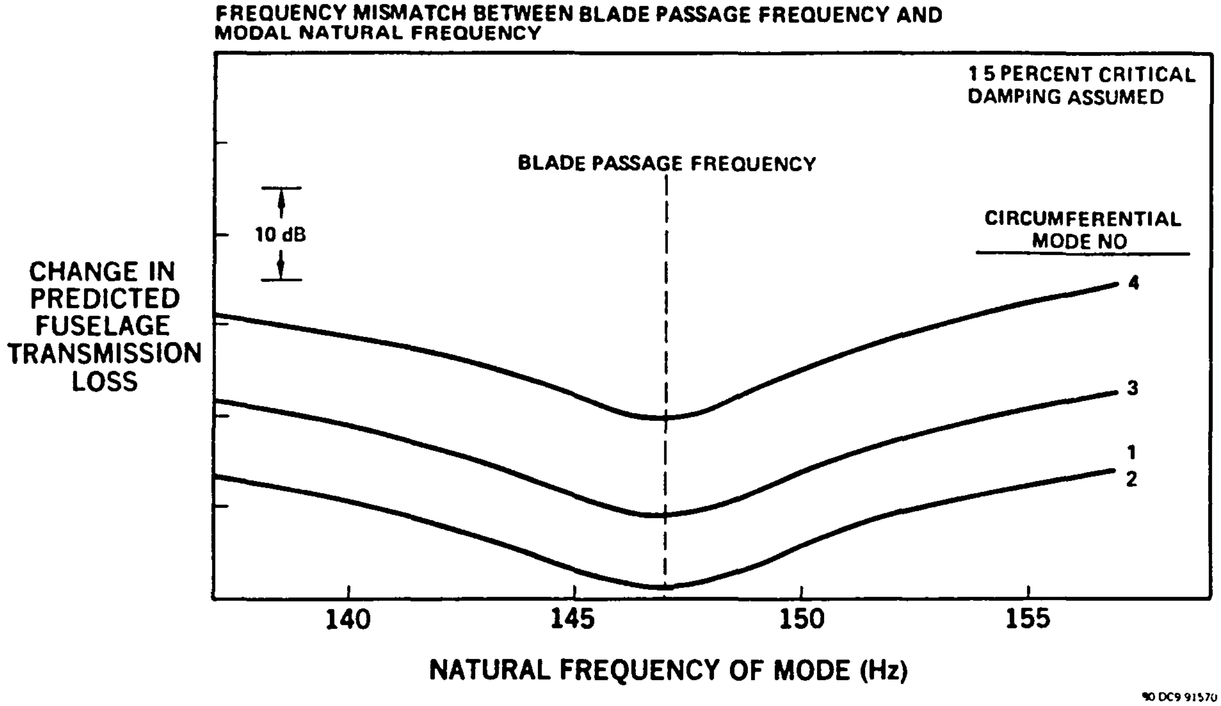


FIGURE 81. CHANGE IN PREDICTED FUSELAGE TRANSMISSION LOSS

Increasing the amount of structural damping can have a beneficial effect on the effective transmission loss for modes near blade passage frequency. Figure 82 shows the change in calculated transmission loss for several modes versus amount of structural damping. As the modal frequency nears blade passage frequency, the damping becomes more effective.

Further detailed study using a more complex model (such as a finite element approach) is necessary to identify actual modal frequencies and responses. This is, however, beyond the scope of the present study. Perhaps the best approach to avoid a resonance condition is to maintain some degree of flexibility in adjusting the blade passage frequency by altering engine rpm. Using this approach, the aircraft structure can be designed to avoid resonance using the best information available; then, when the aircraft is built, it can be fine-tuned for maximum noise reduction by making a slight adjustment in engine rpm.

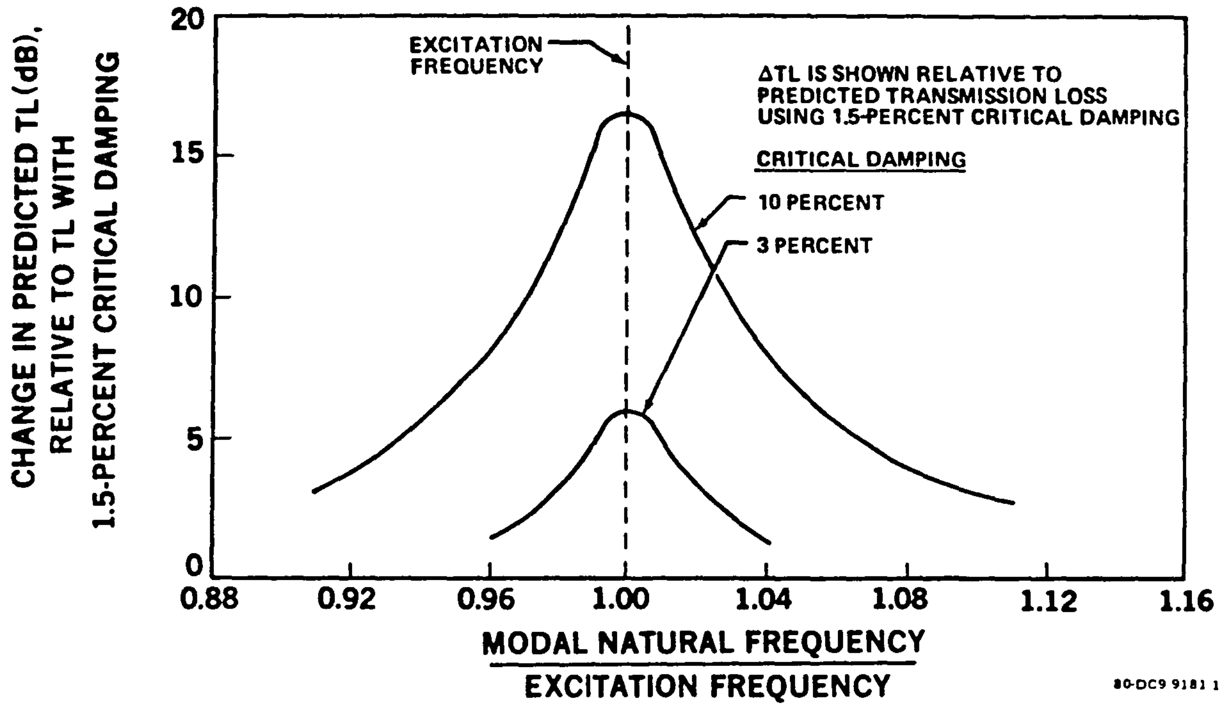


FIGURE 82. CHANGE IN PREDICTED FUSELAGE TRANSMISSION LOSS DUE TO INCREASED STRUCTURAL DAMPING

±6-dB Load Variation

As part of this study, the sensitivity of acoustic treatment weight to variations of ±6 dB in predicted exterior propeller noise levels is examined. The configuration used for this examination is the eight blade version of Configuration 1. Acoustic treatment weights are determined using treatment design No. 1 ("add-on" trim panel mass). The results are shown in Figure 83. The figure shows a very large variation in required trim panel weight. This is consistent with the general mass law concept which states that for a constant interior noise level, acoustic treatment weight must be doubled for every 6 dB increase in acoustic load.

Flyover Noise

Estimates of DC-9 Super 80 propfan flyover noise are generated using the procedure contained in Reference 30. The procedure is used to make noise estimates at the FAR Part 36 measurement locations for representative aircraft weights and flight profiles. The DC-9 Super 80 propfan noise estimates include the benefits of cutback on takeoff, and the approach number represents

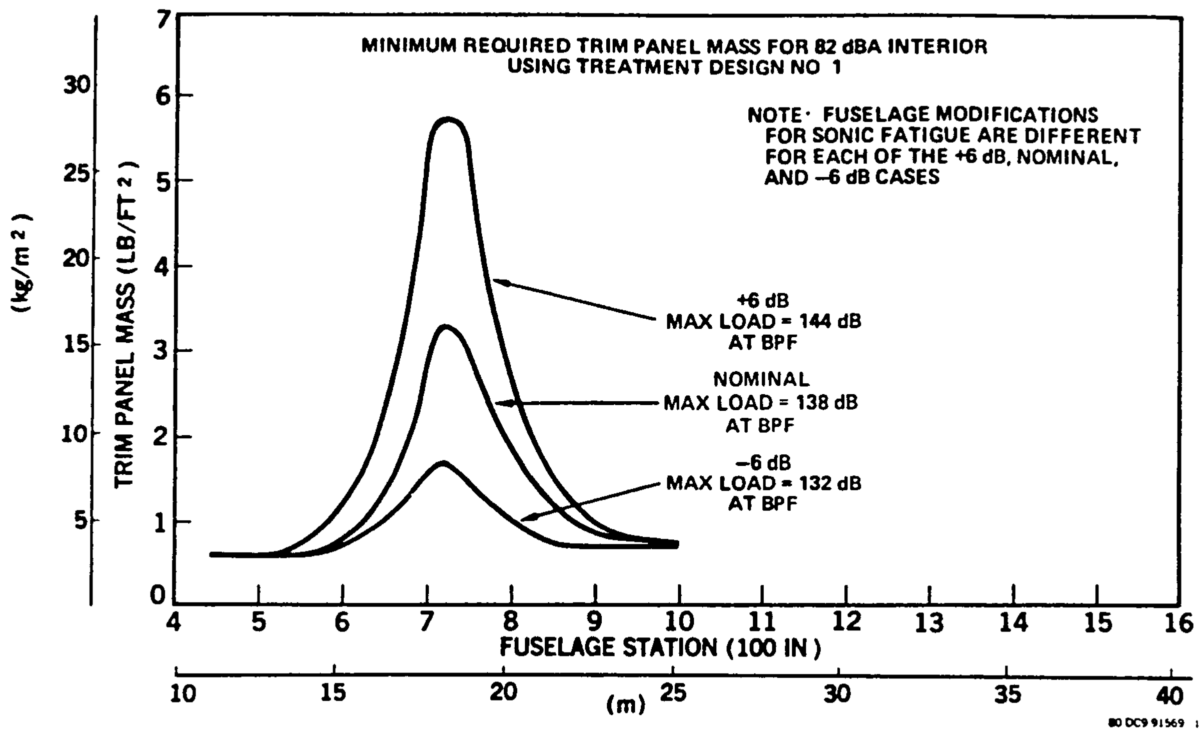


FIGURE 83. EFFECT OF ±6-dB ACOUSTIC LOAD VARIATION
CONFIGURATION 1, EIGHT-BLADED PROPS

a 40-degree flap condition. Effective perceived noise levels (EPNdB) estimated for the DC-9 Super 80 propfan are shown in Figure 84 at the three FAR Part 36 locations. Also shown are the applicable FAR Part 36 Stage 3 noise limits. The DC-9 Super 80 propfan is below the Stage 3 noise limit at all locations, according to the prediction procedure.

Representative FAR Part 36 certification noise levels for the DC-9 Super 80 turbofan with JT8D-209 engines have also been included in Figure 84 for purposes of comparison with the DC-9 Super 80 propfan estimates. The DC-9 Super 80 turbofan noise levels include cutback on takeoff and 40-degree flaps on approach. A comparison with the propfan estimates shows that the propfan appears to be very quiet at the takeoff measurement point. This is mainly a result of the steep climb gradient that enables the propfan to achieve a much greater altitude than the turbofan at the takeoff measurement point. At the sideline and approach measurement points, the turbofan and propfan levels are approximately equal.

TOGW = 140,000 LB (63,503 kg)
LGW = 128,000 LB (58,060 kg)

	TAKEOFF (WITH CUTBACK) (EPNdB)	SIDELINE (EPNdB)	APPROACH (40-DEG FLAPS) (EPNdB)
DC-9 SUPER 80 PROPFAN*	81	94	94
FAR 36 NOISE LIMITS (STAGE 3)	90.6	96.2	100.0
CERTIFICATION NOISE LEVELS FOR SUPER 80 TURBOFAN (JT8D-209)	90.4	94.6	93.3

*DATA ESTIMATED FROM REFERENCE 30

80-DC9-90903A

FIGURE 84. DC-9 SUPER 80 PROPFAN FAR FIELD NOISE ESTIMATES AT FAR 36 MEASUREMENT LOCATIONS

WEIGHTS

The base airplane chosen for the study is the DC-9 Super 80 (Detail Specification No. DS8000). The aircraft characteristics and general features of this base aircraft are as follows:

Design ramp gross weight, lb (kg)	=	141,000	(63,945)
Design maximum takeoff gross weight, lb (kg)	=	140,000	(63,492)
Design maximum landing gross weight, lb (kg)	=	128,000	(58,050)
Design maximum zero-fuel gross weight, lb (kg)	=	118,000	(53,515)
Operational empty weight, lb (kg)	=	78,666	(35,676)
Manufacturer's empty weight, lb (kg)	=	75,024	(34,024)

Trapezoidal wing area (planform area) ft^2 (m^2)	=	1209.3	(112.3)
Theoretical horizontal tail area, ft^2 (m^2)	=	313.1	(29.1)
Theoretical vertical tail area, ft^2 (m^2)	=	161.0	(14.9)
Total fuselage length, ft (m)	=	135.5	(41.3)
Total number of economy class passengers	=	155	

Aft fuselage side mounted JT8D-209 (2)

Propfan Configurations

Using the DC-9 Super 80 weights and geometry as the base, three propfan installation concepts have been evaluated. The three selected locations are wing mount, horizontal tail mount, and aft fuselage pylon mount, shown in Figures 14, 15, and 16, respectively.

The engine/propfan/gearbox configuration for all three concepts are kept consistent. The turboshaft engine, gearbox, shaft, interconnecting struts, and torquemeter weights are based on the PD370-22A and derived by using tne scaling formulas given in Reference 1. A 10 percent weight penalty has been applied to the gearbox to account for opposite rotation. The base case eight blade propfan weight is calculated by using a weight equation derived from Reference 4, with a design takeoff propfan disc loading of 78.92 shp/D^2 (633 kW/m^2) (cruise disc loading of 37.5 [301 kW/m^2] at Mach 0.8 and 35,000 ft [10,668 m] altitude) and propfan tip speed at 800 ft/sec (244 m/sec).

A summary group weight statement of the basic DC-9 Super 80 and the three propfan configurations is presented in Figure 18 (Section 4). The integration of the configuration changes attributable to the propfan installations is all summarized in these weight estimates. As shown in the group weight statements, a considerable number of the subsystems is common with the DC-9 Super 80. However, the major components of the configurations are subject to some change due to the engine/propfan locations and the associated stability and control, structural rearrangement, sonic fatigue, and acoustic assessments. To simplify the reading of these variations, those subsystems or components for all three configurations which remain the same are denoted with an asterisk in the following description of the Configuration 1, 3, and 2 weight derivations. Center-of-gravity diagrams for the three configurations are presented in Figures 19 through 21.

Configuration 1 (Wing Mounted Propfan) - The wing mounted propfan configurations, shown in Figure 14, utilizes the same wing and fuselage geometry as the DC-9 Super 80. Due to the relocation of the engines from the aft fuselage to the wing and retention of the airplane balance for best loadability, the wing and main landing gear are shifted forward 95 in. (2.4 m) relative to the DC-9 Super 80.

The DC-9 Super 80 wing weight is modified to reflect a reduction in bending material weight due to the placement of the engines on the wing which provides bending load relief, and also a reduction in tail loads due to additional tail arm length attributed to the forward wing shift. The wing weight is also modified to reflect local weight penalties associated with the fixed leading edge, leading-edge slat, spoilers, and trailing-edge flap structure affected by the propeller wash. The weight penalties account for higher dynamic loads due to higher dynamic pressure.

The horizontal stabilizer design is assumed to be similar to the DC-9 Super 80. The weight increase over the DC-9 Super 80 reflects the larger tail area with a slight reduction in bending material unit weight due to the longer tail arm caused by the wing shift.

The vertical stabilizer geometrics are identical to the DC-9 Super 80 except for the increase in area. The increase in weight reflects the larger tail size, split rudder design, and an increase in bending material unit weight (lb/ft^2) due to higher tail loads relative to the DC-9 Super 80.

The DC-9 Super 80 fuselage weight is modified to reflect a reduction in bending moment on the aft fuselage due to removal of the aft engines and an increase in aft fuselage bending moment due to the larger tail and longer tail arm. The fuselage sonic fatigue weight penalty associated with the wing mounted propfan includes 9.5 in. (24.13 cm) on the center frame spacing between fuselage frame station 600 and 850. (The average DC-9 Super 80 frame spacing is 19 in. (48.3 cm) on center.) The weight penalty also includes a minimum skin gage of 0.070 in. (18 cm) between fuselage frame station 650 and 800.

The DC-9 Super 80 main landing gear installation weight is revised to reflect an increase in strut length required to maintain the 10.5 degree rotation angle. The rolling assembly weights and nose gear assembly weight are assumed to be the same as on the DC-9 Super 80.

The nacelle and mounting structure weights are assumed to reflect Figure 53. The weight includes the nacelle skin, stringers, frames, and bulkheads; keel box structure for the lower door support; door, doublers, and hinges; engine and nacelle mounting frames and machined bulkheads; fire shields; and engine inlet installation. The weights were estimated from preliminary structural sizing calculations and are based on metal-type fabrication.

The propulsion and related systems weight includes the dry engine, gearbox, strut and shafts, propfan and controls, tailpipe and exhaust system, and engine-related systems. The engine weight represents a 16,520 rated shaft horsepower Allison PD370-22A turboshaft engine. The propfan weight represents a 14.47 ft (4.41 m) diameter, 8 blade 800 ft/sec (244 m/sec) tip speed Hamilton Standard propfan. The weights for the engine, gearbox, and interconnecting struts and shaft are determined by utilizing Allison's weight scaling equations.

The propeller and control weight is calculated by using the Hamilton Standard propeller weight equation. The tailpipe and exhaust system and engine related systems weight are based on preliminary structural sizing calculation and empirical weight equations.

The fuel system weight is assumed to be similar to the DC-9 Super 80 except for plumbing differences in the fuselage resulting from the engine relocation. The fuel system weight represents the removal of the base DC-9 Super 80 aft fuselage engine fuel plumbing weight and installation of plumbing required for a wing-mounted engine installation. Weight is added for the fuel line for the auxiliary power system due to the longer line run.

The flight control and hydraulic system is assumed to be similar in design to the DC-9 Super 80 except for plumbing changes due to engine relocation, location and resizing of components, and plumbing required for the heavier gear and larger tail surfaces.

The auxiliary power unit location requirements and design are assumed to be kept intact with no changes required relative to the DC-9 Super 80.

The instruments weight is assumed to be similar to that of the DC-9 Super 80 because of similar aircraft system and requirements. Recalibration or replacement of the engine instruments is assumed with no difference in weight.

The air conditioning system component weights and locations are assumed to be similar to the DC-9 Super 80. The lower cargo compartment heating system ducting is revised to reflect the difference in forward and aft component volumes due to the forward wing shift. The delta weight change for the revision is assumed to be negligible.

The DC-9 Super 80 pneumatic system weight is modified to reflect a power extraction source compatible with the turboshaft engine. The high- and low-bleed air pressure valves, controls, and manifolds of the DC-9 Super 80 are replaced with engine driven air compressor and gearbox installations. Ducting is added from the engine driven air compressors to the air conditioning turbomachinery located aft of the fuselage aft pressure bulkhead.

The electrical power system weight assumes the use of DC-9 Super 80 components. The power cable weight is modified to reflect a shorter power cable length from the engine driven generators to the electrical power center. The interior and exterior lighting weight is assumed to be similar to the DC-9 Super 80.

The avionics and autoflight control system weight is assumed to be similar to the DC-9 Super 80.

The furnishings group weight is assumed to be similar to the DC-9 Super 80 except that additional acoustic treatment weight penalty is added to the interior sidewall paneling to achieve an 82 dBA interior noise level. The acoustically treated area is assumed to be the fuselage periphery above the cabin floor and between fuselage station 600 and 1020. For the 8 blade propfan design, the acoustic treatment trim panel weight penalty is 815 lb (370 kg), which is approximately 1 percent of the operating weight empty. For the 10 blade propfan design, the acoustic penalty weight is less. Total acoustic treatment weights, including sonic fatigue penalty, are approximately 1.5 percent of operating weight empty. The lower cargo compartment lining weight is revised to reflect the changes in forward and aft compartment volumes due to the forward wing shift. The delta weight change for the revision is assumed to be negligible.

The anti-ice system weight change accounts for the longer horizontal stabilizer leading edge de-ice ducting required by the slightly larger tail. The remaining anti-ice system weight is assumed similar to the DC-9 Super 80.

Configuration 3 (Horizontal Tail Mounted Propfan) - Configuration 3, with the propfan mounted on the horizontal stabilizer, shown in Figure 15, has the same wing and fuselage geometry as the DC-9 Super 80. The horizontal and vertical stabilizers reflect a conventional tail design. With the engines on the horizontal stabilizer, the wing and main landing gear are shifted aft 38 in. (0.965 m) relative to the DC-9 Super 80 in order to retain the airplane balance for best loadability.

The wing weight reflects a slight increase in skin weight caused by an increase in wing load. The increase in wing load is attributed to the aft movement of the wing, resulting in an increase in down tail load. The remaining wing structure and weight is assumed to be similar to the DC-9 Super 80.

The horizontal stabilizer is considered to be of all new design relative to the DC-9 Super 80. The horizontal stabilizer weight is derived by utilizing MAPES (Reference 31). The engine support bulkhead weight penalty is part of the nacelle and mounting system weight and not part of the stabilizer weight.

The vertical stabilizer is considered to be of all new design relative to the DC-9 Super 80. The weight is derived by utilizing MAPES.

The DC-9 Super 80 fuselage weight is modified to show an increase in the aft fuselage bending material and the additional sonic fatigue weight penalty. The bending material weight penalty results from an increase in bending moment due to (1) the movement of the engines from the aft fuselage to the horizontal tail, and (2) an increase in engine installation weight. The sonic fatigue weight penalty consists of additional intermediate frames at fuselage stations 1391, 1410, 1444, and 1460. Frame spacing between fuselage cant station 1388.4 and 1463.2 is modified to reflect 11 in. (28 cm) on center, and frames between fuselage cant station 1463.2 and 1510 are modified to reflect 6 in. (15.24 cm) on center. The sonic fatigue weight penalty also includes an increase in fuselage skin thickness to 0.090 in. (0.229 cm) between fuselage station 1429 and 1480; 0.070 in. (0.178 cm) between fuselage station 1401 and 1429, and 1480 to 1510; and a minimum skin thickness of 0.050 in. (0.127 cm) between fuselage station 1338 and 1401, and aft of fuselage station 1510. The tail cone is assumed to be identical to the DC-9 Super 80.

The main landing gear installation weight is revised to reflect a 5-degree aft cant of the wheel centerline relative to the DC-9 Super 80. Repositioning of the wheels is required due to a tipover condition existing during ground operations at weight levels less than the operational empty weight. The rolling assembly weights and the nose gear installation weight are assumed to be similar to the DC-9 Super 80.

The nacelle and mounting structure weights are derived to reflect Figure 53. The weight includes the nacelle skin, stringers, and bulkheads; keel box structure for the lower door support; doors, doublers, and hinge; engine and nacelle mounting frames, and machined bulkheads; fire shields, and engine inlet. The weights are estimated from preliminary structural sizing calculations and are based on metal type fabrication.

The propulsion and related systems weight includes the dry engine, gearbox, strut and shafts, propeller and controls, tailpipe and exhaust system, and engine related systems. The engine weight represents a 16,275 rated shaft horsepower (12,141 kW) Allison PD370-22A turboshaft engine. The propfan weight represents a 14.36 ft (4.38 m)-diameter, eight bladed, 800-ft/sec (244 m/sec) tip speed Hamilton Standard propfan. The weights for the engine, gearbox, and interconnecting struts and shafts are determined by utilizing Allison's weight scaling equations. The propfan and control weight is calculated by using the Hamilton Standard propfan weight equation. The weights of the tailpipe and exhaust system and engine related systems are based on preliminary structural sizing calculation and empirical weight equations.

The fuel system weight is assumed to be similar to the DC-9 Super 80 except for plumbing differences in the aft fuselage resulting from the horizontal stabilizer-mounted engines.

The flight controls and hydraulic system weights are assumed to be similar in design to the DC-9 Super 80 except for plumbing changes due to the engine relocation and the redesign of the elevator rudder and outboard horizontal stabilizer trim controls to fully powered control surfaces due to the all new tail design. The weight also reflects the resizing of the component and plumbing required for the heavier landing gear and larger tail control surfaces.

The auxiliary power unit location requirements and design are assumed to be kept intact with no changes required from the DC-9 Super 80.

The instruments are assumed to be similar in weight to the DC-9 Super 80 because of similar aircraft systems and requirements. Recalibration or replacement of the engine instruments is assumed to be done with no difference in weight.

The air conditioning system component weights and geographic locations are assumed to be similar to the DC-9 Super 80. The lower cargo compartment heating system ducting is revised to reflect the difference in forward and aft compartment volumes due to the aft wing shift. The delta weight change for the revision is assumed to be negligible.

The DC-9 Super 80 pneumatic system weight is modified to reflect a power extraction source compatible with the turboshaft engine. The high and low bleed air pressure valves, controls, and manifolds of the DC-9 Super 80 are replaced with engine driven air compressor and gearbox installations. Additional ducting is added from the engine driven air compressors to the air conditioning turbomachinery, located aft of the fuselage aft pressure bulkhead.

The electrical power system weight assumes the use of DC-9 Super 80 components. The power cable weight is modified to reflect a longer power cable length from the engine driven generators to the electrical power center. The weight of the interior and exterior lighting is assumed to be similar to the DC-9 Super 80.

The avionics and autoflight control system weight is assumed to be similar to the DC-9 Super 80.

The furnishings group weight is assumed to be identical to the DC-9 Super 80. The acoustic study shows that the DC-9 Super 80 production trim panel design will achieve an 82 dBA interior noise level.

The anti-ice system weight change accounts for the longer horizontal stabilizer leading edge de-ice ducting required by the larger tail. The remaining anti-ice system weight is assumed to be similar to the DC-9 Super 80.

Configuration 2 (Aft Fuselage Pylon Mounted Propfan - The configuration with the aft fuselage mounted propfan, shown in Figure 16, has the same wing and fuselage geometry as the DC-9 Super 80. With the propfan plane line aft of the fuselage aft pressure bulkhead, the wing and main landing gear are shifted aft 38 in. (96.5 cm) from the DC-9 Super 80 to retain the airplane balance for best loadability.

The wing weight reflects a slight increase in skin weight caused by an increase in wing load. The increase in wing load is attributed to the aft movement of the wing, resulting in an increase in down-tail load. The remaining wing structure and weight is assumed to be similar to the DC-9 Super 80.

The horizontal tail geometry and construction are assumed to be similar to the DC-9 Super 80 except for an increase in tail area. The weight increase from the DC-9 Super 80 horizontal tail weight reflects the larger tail area.

The vertical tail is similar in geometry and construction to the DC-9 Super 80 except for a larger tail area. The increase in vertical tail weight reflects the larger tail area.

The DC-9 Super 80 fuselage weight is modified to show an increase in aft fuselage bending material and sonic fatigue weight penalty. The bending material weight penalty results from an increase in bending moment due to the aft movement of the engines and an increase in engine installation weight. The sonic fatigue weight penalty consists of 9.5 in. (24.1 cm) on center frame spacing from fuselage frame station 1338 to vertical stabilizer front spar (aft fuselage station 1388 cant). Frame spacing between the front and rear spar of the vertical stabilizer is assumed to be 11.0 in. (27.9 cm) on center and 6.0 in. (15.2 cm) on center between the vertical tail rear spar and aft fuselage station 1510 cant. The sonic fatigue weight penalty also includes increasing the skin thickness to 0.090 in. (0.229 cm) between fuselage station 1391 and 1444, increasing the skin thickness to 0.070 in. (0.178 cm) between fuselage station 1361 and 1391 and between station 1444 and 1473, and increasing the skin thickness to a minimum of 0.050 in. (0.127 cm) between fuselage station 1307 and 1361 and between station 1473 and 1525. The remaining fuselage is assumed to be common to the DC-9 Super 80.

The main landing gear installation weight is revised to reflect a 5 degree aft cant of the wheel center line relative to the DC-9-80. Repositioning of the wheels is required due to a tipover condition existing during ground operations at weight levels less than the operational empty weight. The rolling assembly weights and the nose gear installation weight are assumed to be similar to the DC-9 Super 80.

The nacelle and mounting structure weights are derived to reflect Figure 53. The weight includes the nacelle skin, stringers, and bulkheads; keel box structure for the lower door support; doors, doublers, and hinge; engine and nacelle mounting frames and machined bulkheads; fire shields, engine inlet, and the pylon/strut installation. The weights are estimated from preliminary structural sizing calculations and are based on metal type fabrication.

The propulsion and related systems weight includes the dry engine, gearbox, strut and shafts, propeller and controls, tailpipe and exhaust system, and engine related systems. The engine weight represents a 16,515 rated shaft horsepower (12,310 kW) Allison PD370-22A turboshaft engine. The propfan weight reflects a 14.47 ft (4.41 m)-diameter, eight bladed, 800 ft/sec (244 m/sec) tip speed Hamilton Standard propfan. The propfan and control weight is calculated by using the Hamilton Standard propfan weight equation. The tailpipe and exhaust system and engine related systems weights are based on preliminary structural sizing calculation and empirical weight equations.

The fuel system is assumed to be similar to the DC-9 Super 80 except for the addition of a production 580 gallon (2195 liter) belly fuel tank installation placed in the forward cargo compartment at fuselage station 540. The belly fuel tank installation weight is required to help alleviate the MEW tipover condition. The fuel system weight also reflects modifications to the aft fuselage plumbing resulting from the engines being located further aft and further outboard relative to the DC-9-80.

The flight controls and hydraulic system weight is assumed to be similar in design to the DC-9 Super 80 except for plumbing changes due to the engine relocation, and the redesign of the elevator controls to a fully powered control surface. The weight also reflects the resizing of the component and plumbing required for the heavier landing gear and larger tail control surfaces.

The auxiliary power unit location requirement and design are assumed to be kept intact with no changes required relative to the DC-9 Super 80.

The instruments weight is assumed to be similar to the DC-9 Super 80 because of the similarity in the aircraft system and requirement. Recalibration or replacement of the engine instruments is assumed to be done with no difference in weight.

The air conditioning system component weights are assumed to be similar to the DC-9 Super 80. The refrigeration system components are relocated between fuselage station 218 and 275 to alleviate the MEW tipover condition. A new ram air and exhaust system, located under the forward fuselage, is added due to the relocation of the refrigeration units. Conditioned air riser duct weights from the relocated equipment to the cabin overhead distribution system are also part of the increase in weight over the DC-9 Super 80. The lower cargo compartment heating system ducting is revised to reflect the difference in the forward and aft compartment volumes due to the relocation of the air conditioning refrigeration units, 58C gallon (2195 liter) belly fuel tank, and aft wing shift.

The DC-9 Super 80 pneumatic system weight is modified to reflect a power extraction source compatible with the turboshaft engine. The high and low bleed air pressure valves, controls, and manifolds on each engine of the DC-9 Super 80 are replaced with engine-driven air compressor and gearbox installations. Additional pneumatic ducting is added from the engine driven air compressors to the air conditioning turbomachinery, located aft of the fuselage aft pressure bulkhead.

The electrical power system weight assumes the use of DC-9 Super 80 components. The power cable weight is modified to reflect a longer cable length from the engine driven generators to the electrical power center. The interior and exterior lighting weight is assumed to be similar to the DC-9 Super 80.

The avionics and autoflight control system weight is assumed to be similar to the DC-9 Super 80.

The furnishings group weight is assumed to be similar to the DC-9 Super 80 except that an additional acoustic treatment weight penalty is added to the interior sidewall paneling to achieve an 82 dBA interior noise level. The acoustically treated area is assumed to be the fuselage periphery above the cabin floor and between fuselage station 1269 and station 1338. The lower cargo compartment lining weight is revised to reflect the changes in forward and aft compartment volumes due to the aft wing shift. The delta weight change for the revision is assumed to be negligible.

The anti-ice system weight change accounts for the longer horizontal stabilizer leading-edge de-ice ducting required by the larger tail. The remaining anti-ice system weight is assumed to be similar to the DC-9 Super 80.

Propfan Sensitivity Study

A propeller weight sensitivity study has been conducted: the results are shown in Tables 25 through 27. Three propfan mount locations are investigated, each

TABLE 25

WEIGHT BREAKDOWN SUMMARY OF 8 BLADE VS 10 BLADE PROPFAN TRADE STUDY

CONFIGURATION 1 — WING MOUNTED PROPFAN

A. ENGLISH UNITS

Propfan Configuration	8 Blades	10 Blades		
PROPELLER TIP SPEED (FPS)/DIAMETER (FT)	800/13.86	800/13.82	700/15.40	600/16.75
VERTICAL TAIL AREA (FT^2)	198.3	200.5	218.2	222.6
WEIGHT DATA (lb):				
Wing	(15,490)	(15,482)	(15,452)	(15,423)
Horizontal Tail	(1,941)	(1,941)	(1,941)	(1,941)
Vertical Tail	(1,546)	(1,561)	(1,688)	(1,719)
Fuselage	(16,483)	(16,507)	(16,302)	(16,221)
Tail Supt & Bending Matl Penalty	767	773	821	833
Frames, Splices & Att, Wing/Gear Supt	2,746	2,744	2,750	2,756
Remaining Fuselage Structure	12,590	12,590	12,590	12,590
Sonic Fatigue Penalty	380	400	141	42
Flight Controls & Hydraulics	(2,502)	(2,506)	(2,538)	(2,546)
Propulsion & Nacelle	(13,407)	(12,676)	(14,282)	(16,192)
Dry Engine	3,860	3,836	3,822	3,908
Propeller, Gearbox & Shaft	6,150	5.646	6,446	7.284
Engine System & Exhaust System	1,130	1,126	1,122	1,140
Nacelle & Mounting Structure	2,267	2,068	2,892	3,860
Furnishings	(11,928)	(11,630)	(11,499)	(11,289)
Acoustic Trim Panel Penalty	815	517	386	176
Remaining Furnishings	11,113	11,113	11,113	11,113
Remaining Systems	(14,741)	(14,741)	(14,741)	(14,741)
Manufacturer's Empty Weight	78,038	77,044	78,443	80,072
Operator Items Weight	3,642	3,642	3,642	3,642
Operational Empty Weight	81,680	80,686	82,085	83,714
Delta OEW - Pounds/Airplane	-0-	- 994	+ 405	+2,034
GEOMETRY AND WEIGHTS				
Takeoff Gross Weight (lb)	140,000	140,000	140,000	140,000
S_W (ft^2)	1,209	1,209	1,209	1,209
S_H (ft^2)	360	360	360	360
Rated SHP/Engine	15,160	15,067	15,012	15,334
Max Payload Weight (lb)	39,334	39,334	39,334	39,334

TABLE 25

WEIGHT BREAKDOWN SUMMARY OF 8 BLADE VS 10 BLADE PROPFAN TRADE STUDY

CONFIGURATION 1 -- WINC MOUNTED PROPFAN

B. METRIC UNITS

Propfan Configuration	8 Blades	10 Blades		
PROPELLER TIP SPEED (mps)/ DIAMETER (m)	244/4.23	244/4.21	213/4.69	183/5.11
VERTICAL TAIL AREA (m^2)	60.4	61.1	66.5	67.8
WEIGHT DATA (kg):				
Wing	(7,026)	(7,023)	(7,009)	(6,996)
Horizontal Tail	(880)	(880)	(880)	(880)
Vertical Tail	(701)	(708)	(766)	(780)
Fuselage	(7,477)	(7,487)	(7,394)	(7,358)
Tail Supt & Bending Matl Penalty	348	350	372	378
Frames, Splices & Att, Wing/Gear Supt	1,246	1,245	1,247	1,250
Remaining Fuselage Structure	5,711	5,711	5,711	5,711
Sonic Fatigue Penalty	172	181	64	19
Flight Controls & Hydraulics	(1,135)	(1,137)	(1,151)	(1,155)
Propulsion & Nacelle	(6,081)	(5,750)	(6,478)	(7,345)
Dry Engine	1,751	1,740	1,733	1,773
Propeller, Gearbox & Shaft	2,790	2,561	2,924	3,304
Engine System & Exhaust System	512	511	509	517
Nacelle & Mounting Structure	1,028	938	1,312	1,751
Furnishings	(5,410)	(5,275)	(5,216)	(5,121)
Acoustic Trip Panel Penalty	369	234	175	80
Remaining Furnishings	5,041	5,041	5,041	5,041
Remaining Systems	(6,686)	(6,686)	(6,686)	(6,686)
Manufacturer's Empty Weight	35,397	34,947	35,581	36,320
Operator Items Weight	1,652	1,652	1,652	1,652
Operational Empty Weight	37,049	36,599	37,233	37,972
Delta OEW - kg/Airplane	-0-	-451	+184	+923
GEOMETRY AND WEIGHTS				
Takeoff Gross Weight (kg)	63,503	63,503	63,503	63,503
S_W (m^2)	112	112	112	112
S_H (m^2)	47	47	47	47
kW/Engine	11,305	11,235	11,194	11,434
Max Payload Weight (kg)	17,842	17,842	17,842	17,842

TABLE 26

WEIGHT BREAKDOWN SUMMARY OF 8 BLADE VS 10 BLADE PROPFAN TRADE STUDY

CONFIGURATION 3 — HORIZONTAL TAIL MOUNTED PROPFAN

A. ENGLISH UNITS

Propfan Configuration	8 Blades	10 Blades		
PROPELLER TIP SPEED (FPS)/DIAMETER (FT)	800/13.86	800/13.82	700/15.40	600/16.75
VERTICAL TAIL AREA (FT^2)	225	222	234	239
WEIGHT DATA (lb):				
Wing	(15,397)	(15,396)	(15,400)	(15,403)
Horizontal Tail	(2,868)	(2,862)	(2,880)	(2,912)
Vertical Tail	(1,249)	(1,231)	(1,301)	(1,330)
Fuselage	(16,757)	(16,731)	(16,731)	(16,775)
Tail Supt & Bending Matl Penalty	1,115	1,082	1,169	1,254
Frames, Splice & Att & Wing Support	2,877	2,873	2,875	2,875
Remaining Fuselage Structure	12,590	12,590	12,590	12,590
Sonic Fatigue Penalty	175	186	97	56
Flight Controls & Hydraulics	(2,947)	(2,941)	(2,965)	(2,974)
Propulsion & Nacelle	(13,220)	(12,594)	(13,904)	(15,580)
Dry Engine	3,860	3,836	3,822	3,908
Propeller, Gearbox & Shaft	6.150	5,646	6,446	7,284
Engine Systems & Exhaust	1,130	1,126	1,122	1,140
Nacelle & Mounting Structure	2,080	1,986	2,514	3,248
Furnishings	(11,113)	(11,135)	(11,135)	(11,129)
Acoustic Trim Panel Penalty	-0-	22	22	16
Remaining Furnishings	11,113	11,113	11,113	11,113
Remaining Systems	(14,786)	(14,786)	(14,786)	(14,786)
Manufacturer's Empty Weight	78,237	77,576	79,002	80,789
Operator Items Weight	3,642	3,642	3,642	3,642
Operational Empty Weight	81,979	81,318	82,744	84,531
Delta OEW - Pounds/Airplane	-0-	- 661	+ 765	+2,552
GEOMETRY & WEIGHTS				
Takeoff Gross Weight (lb)	140,000	140,000	140,000	140,000
S_W (ft^2)	1,209	1,209	1,209	1,209
S_H (ft^2)	505	505	505	505
Rated SHP/Engine	15,160	15,067	15,012	15,344
Max Payload Weight (lb)	39,334	39,334	39,334	39,334

TABLE 26

WEIGHT BREAKDOWN SUMMARY OF 8 BLADE VS 10 BLADE PROPFAN TRADE STUDY

CONFIGURATION 3 — HORIZONTAL TAIL MOUNTED PROPFAN

B. METRIC UNITS

Propfan Configuration	8 Blades	10 Blades		
PROPELLER TIP SPEED (mps)/DIAMETER (m)	244/4.23	244/4.21	213/4.69	183/5.11
VERTICAL TAIL AREA (m^2)	20.9	20.6	21.7	22.2
WEIGHT DATA (kg):				
Wing	(6,984)	(6,983)	(6,985)	(6,987)
Horizontal Tail	(1,301)	(1,298)	(1,306)	(1,321)
Vertical Tail	(567)	(558)	(590)	(603)
Fuselage	(7,601)	(7,589)	(7,589)	(7,609)
Tail Sup't & Bending Matl Penalty	506	491	530	569
Frames, Splice & Att & Wing Support	1,305	1,303	1,304	1,304
Remaining Fuselage Structure	5,711	5,711	5,711	5,711
Sonic Fatigue Penalty	79	84	44	25
Flight Controls & Hydraulics	(1,337)	(1,334)	(1,345)	(1,349)
Propulsion & Nacelle	(5,996)	(5,713)	(6,307)	(7,067)
Dry Engine	1,751	1,740	1,734	1,773
Propeller, Gearbox & Shaft	2,789	2,561	2,924	3,304
Engine Systems & Exhaust	513	511	509	517
Nacelle & Mounting Structure	943	901	1,140	1,473
Furnishings	(5,041)	(5,051)	(5,051)	(5,048)
Acoustic Trim Panel Penalty	-0-	10	10	7
Remaining Furnishings	5,041	5,041	5,041	5,041
Remaining Systems	(6,707)	(6,707)	(6,707)	(6,707)
Manufacturer's Empty Weight	35,488	35,188	35,835	36,645
Operator Items Weight	1,652	1,652	1,652	1,652
Operational Empty Weight	37,185	36,885	37,532	38,343
Delta OEW - kg/Airplane	-0-	-300	+347	+1,158
GEOMETRY AND WEIGHTS				
Takeoff Gross Weight (kg)	63,503	63,503	63,503	63,503
S_W (m^2)	112	112	112	112
S_H (m^2)	47	47	47	47
kW/Engine	11,305	11,235	11,194	11,442
Max Payload Weight (kg)	17,842	17,842	17,842	17,842

TABLE 27

WEIGHT BREAKDOWN SUMMARY OF 8 BLADE VS 10 BLADE PROPFAN TRADE STUDY

CONFIGURATION 2 – FUSELAGE MOUNTED PROPFAN

A. ENGLISH UNITS

Propfan Configuration	8 Blades	10 Blades		
PROPELLER TIP SPEED (FPS)/DIAMETER (FT)	800/13.86	800/13.82	700/15.40	600/16.75
VERTICAL TAIL AREA (FT^2)	213	214	228	233
WEIGHT DATA (lb):				
Wing	(15,373)	(15,373)	(15,378)	(15,380)
Horizontal Tail	(2,460)	(2,460)	(2,460)	(2 460)
Vertical Tail	(1,533)	(1,539)	(1,629)	(1,662)
Fuselage	(16,700)	(16,712)	(16,676)	(16,618)
Tail Sup't & Bending Material	1,020	1,012	1,071	1,110
Unpenalized Frames & Wing Support	2,850	2,850	2,851	2,852
Sonic Fatique Penalty	240	260	164	66
Remaining Fuselage Structure	12,590	12,590	12,590	12,590
Flight Controls & Hydraulics	(2,646)	(2,646)	(2,646)	(2,646)
Propulsion & Nacelle	(15,314)	(14,600)	(16,178)	(18,118)
Dry Engine	3,960	3,836	3,822	3,908
Propeller, Gearbox & Shaft	6,150	5,646	6,446	7,284
Engine Systems & Exhaust	1,130	1,126	1,122	1,140
Nacelle & Mounting Structure	4,174	3,992	4,788	5,786
Furnishings	(11,213)	(11,199)	(11,182)	(11,155)
Acoustic Trim Panel Penalty	100	86	69	42
Remaining Furnishings	11,113	11,113	11,113	11,113
Remaining Systems	(15,648)	(15,648)	(15,648)	(15,648)
Manufacturer's Empty Weight	78,865	78,157	79,801	81,700
Operator Items Weight	3,642	3,642	3,642	3,642
Operational Empty Weight	84,529	83,821	85,465	87,364
Delta OEW - Pounds/Airplane	-0-	- 708	+ 936	+2,835
GEOMETRY & WEIGHTS				
Takeoff Gross Weight (lb)	140,000	140,000	140,000	140,000
S_W (ft^2)	1,209	1,209	1,209	1,209
S_H (ft^2)	389	389	389	389
Rated SHP/Engine	15,160	15,067	15,012	15,344
Max Payload Weight (lb)	39,334	39,334	39,334	39,334

TABLE 27

WEIGHT BREAKDOWN SUMMARY OF 8 BLADE VS 10 BLADE PROPFAN TRADE STUDY

CONFIGURATION 2 — FUSELAGE MOUNTED PROPFAN

B. METRIC UNITS

Propfan Configuration	8 Blades	10 Blades		
PROPELLER TIP SPEED (mps)/DIAMETER (m)	244/4.23	244/4.21	213/4.69	183/5.11
VERTICAL TAIL AREA (m^2)	19.8	19.9	21.2	21.6
WEIGHT DATA (kg):				
Wing	(6,973)	(6,973)	(6,975)	(6,976)
Horizontal Tail	(1,116)	(1,116)	(1,116)	(1,116)
Vertical Tail	(695)	(698)	(739)	(754)
Fuselage	(7,575)	(7,580)	(7,564)	(7,538)
Tail Support & Bending Material	462	459	486	503
Unpenalized Frames & Wing Support	1,293	1,293	1,293	1,294
Sonic Fatigue Penalty	109	117	74	30
Remaining Fuselage Structure	5,711	5,711	5,711	5,711
Flight Controls & Hydraulics	(1,200)	(1,200)	(1,200)	(1,200)
Propulsion & Nacelle	(6,946)	(6,622)	(7,338)	(8,218)
Dry Engine	1,796	1,740	1,733	1,773
Propeller, Gearbox & Shaft	2,790	2,561	2,924	3,304
Engine Systems & Exhaust	513	510	509	517
Nacelle & Mounting Structure	1,893	1,811	2,172	2,624
Furnishings	(5,086)	(5,080)	(5,072)	(5,060)
Acoustic Trim Panel Penalty	45	39	31	19
Remaining Furnishings	5,041	5,041	5,041	5,041
Remaining Systems	(7,098)	(7,098)	(7,098)	(7,098)
Manufacturer's Empty Weight	35,773	35,451	36,197	37,058
Operator Items Weight	1,652	1,652	1,652	1,652
Operational Empty Weight	38,342	38,021	38,766	39,628
Delta OEW - kg/Airplane	-0-	-321	+424	+1,286
GEOMETRY AND WEIGHTS				
Takeoff Gross Weight (kg)	63,503	63,503	63,503	63,503
S_W (m^2)	112	112	112	112
S_H (m^2)	36	36	36	36
kW/Engine	11,305	11,235	11,194	11,442
Max Payload Weight (kg)	17,842	17,842	17,842	17,842

utilizing 10 blade propfan configurations. The three 10 blade propfan configurations are: (1) 800 ft/sec (244 m/sec) tip speed with a design takeoff propfan disc loading of 78.89 (633 kW/m^2); (2) 700 ft/sec (213 m/sec) tip speed with a design takeoff propeller disc loading of 63.3 (508 kW/m^2), and (3) a 600 ft/sec (183 m/sec) tip speed with a design takeoff propfan disc loading of 54.69 (439 kW/m^2). The three propfan configurations are shown in Figures 34, 35, and 36, respectively.

The propulsion system weight for each of the propfan configurations has been determined by utilizing Allison's scaling equations for the engine, gearbox, and interconnecting struts and shaft. The propeller weights have been calculated by the Hamilton Standard weight equation. The nacelle structure weight is derived by ratioing nacelle geometry changes shown in Figures 14 through 16.

Supporting data from the design disciplines for such items as vertical tail size due to engine spanwise location, structural, acoustics, sonic fatigue, and propulsion system weight penalties for each of the three 10 blade propfan configurations were integrated into the computerized MAPES system to produce the individual operational empty weights. Parameters such as takeoff gross weight, trapezoidal wing area, and horizontal tail area for each engine mount location concept are kept constant.

All propfan weights have been taken from References 4 and 5. The 10 blade propfan weighs 1850 lb (839 kg), while the 8 blade propfan weighs 2100 lb (952.5 kg). The reasons for this have been discussed in Sections 4 and 5. The installation of this lighter weight propfan is the basic reason for the 944-lb (451 kg) difference between the 8 and the 10 blade aircraft configurations.

A detailed breakdown of the weight differentials between the 8 and 10 blade installations is presented in Table 28. Here the 10 blade program is compared to the 8 blade program.

TABLE 28

WEIGHT DIFFERENTIALS

	10 Blade vs 8 Blade	
	Δ Wt lb (kg)	Δ WT lb (kg)
Wing		-8 (-3.6)
Vertical Tail	+15 (+6.8)	
Tail Support and Bending Material Penalty	+6 (+2.7)	
Frames, Splices, and Attachments, Wing/Gear Support		-2 (-0.9)
Sonic Fatigue Penalty	+20 (+9.1)	
Flight Controls and Hydraulics	+4 (+1.8)	
Dry Engine		-24 (-10.9)
Propfan, Gearbox, and Shaft		-504 (-228.6)
Engine System and Exhaust System		-4 (-1.8)
Nacelle and Mounting Structure		-199 (-90.3)
Acoustic Trim Panel Penalty		-298 (-135.2)
Net Δ Weight		-994 (-450.9)

MAINTENANCE COST EFFECTS

This preliminary maintenance survey is conducted to project the magnitude of maintenance cost penalties or advantages associated with wing mounted and aft mounted DC-9 Super 80 propfan configurations as compared to the baseline DC-9 Super 80/JT8D-209 aircraft. Data reported by Hamilton Standard and Detroit Diesel Allison in Reference 16 on the estimated maintenance and reliability of the advanced core, gearbox, and propfan are used for the advanced turboprop engine.

The considerations of this analysis are

- To critique the advanced turboprop engine maintenance cost estimate and conclusions reported in Reference 16.
- Develop direct maintenance cost baselines representing the man-hour and material rates which would be expended for maintenance of the DC-9 Super 80 propfan configurations for use in comparison to the DC-9 Super 80/JT8D-209 configuration.
- Assess, to the extent possible, the tire and brake and the foreign object damage (FOD) cost differential between the DC-9 Super 80 propfan and DC-9 Super 80/JT8D-209 aircraft.

Critique of Allison Estimate

The methodology used by Allison in its study was to collect maintenance data on the 501-D13 engine and gearbox used in the Electra L188 and Convair CV580 aircraft and on the Hamilton Standard 54H60 propeller used in the Saturn Airways L-382 Hercules during the 1960s. The 501-D13 engine and gearbox together with the 54H60 propeller were then scaled up in size to produce a thrust equivalent to the JT8D-7 engine (0.8 M, 35,000 ft [10,668m]). The scale factors derived were then applied to the maintenance data gathered on the 501-D13/54H60 turboprop for use in comparison with maintenance data on the JT8D-7 engine in the B737 aircraft. Allison also used these data as a baseline for development of reliability and maintenance estimates for an advanced turboprop engine having equivalent capabilities. A summary of the maintenance cost data collected or derived by Allison using this process is presented in Table 29.

As shown in Table 29, the total maintenance cost per engine flight hour (EFH) for the advanced turboprop engine was estimated by Allison in 1976 dollars at $16.39 as compared to $29.32 for the scaled-up version of the 501-D13/54H60 turboprop. Maintenance cost reduction sources to achieve the $16.39/EFH are presented in Figures 85 through 87. The important features shown in the figures are:

TABLE 29
*DOLLARS/ENGINE FLIGHT HOUR (EFH)
(unburdened)

	Core	Grbx	Prop	Fan	Rev	Total
501-D13/54H60	17.66	1.94	2.11			21.71
Scaled 501-D13/54H60	25.03	2.11	2.18			29.32
JT8D-7 (B737)	17.81			0.91	1.19	19.91
Advanced Turboprop	15.66	0.12	0.61			16.39
Advanced Turbofan	15.31			1.31	1.69	17.71

*1976 Dollars, 0.8 Hour Flight Length

- Elimination of scheduled overhauls which were characteristic of the 501-D13/54H60 turboprop and accounted for 40 percent of maintenance costs,
- Incorporation of on-condition maintenance philosophy only,
- Use of on-line diagnostics to reduce removals,
- Incorporation of modular design in the advanced turboprop to make it possible to gain access to a failed unit without removing a major unit such as the propeller or gearbox,
- Incorporation of accessory gearbox separate from the main drive gearbox,
- Use of high reliability latest state-of-the-art components and parts,
- Reduction of number of parts.

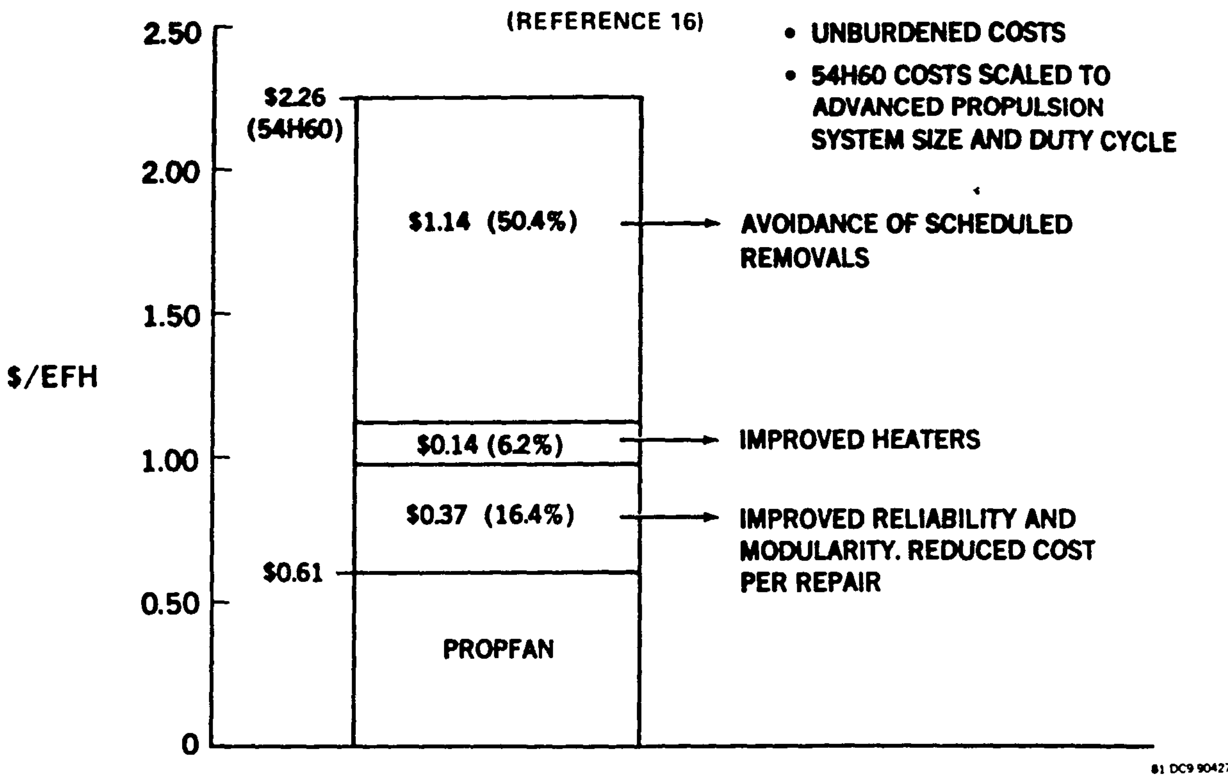


FIGURE 85. MAINTENANCE COST REDUCTION SOURCES FOR PROPFAN

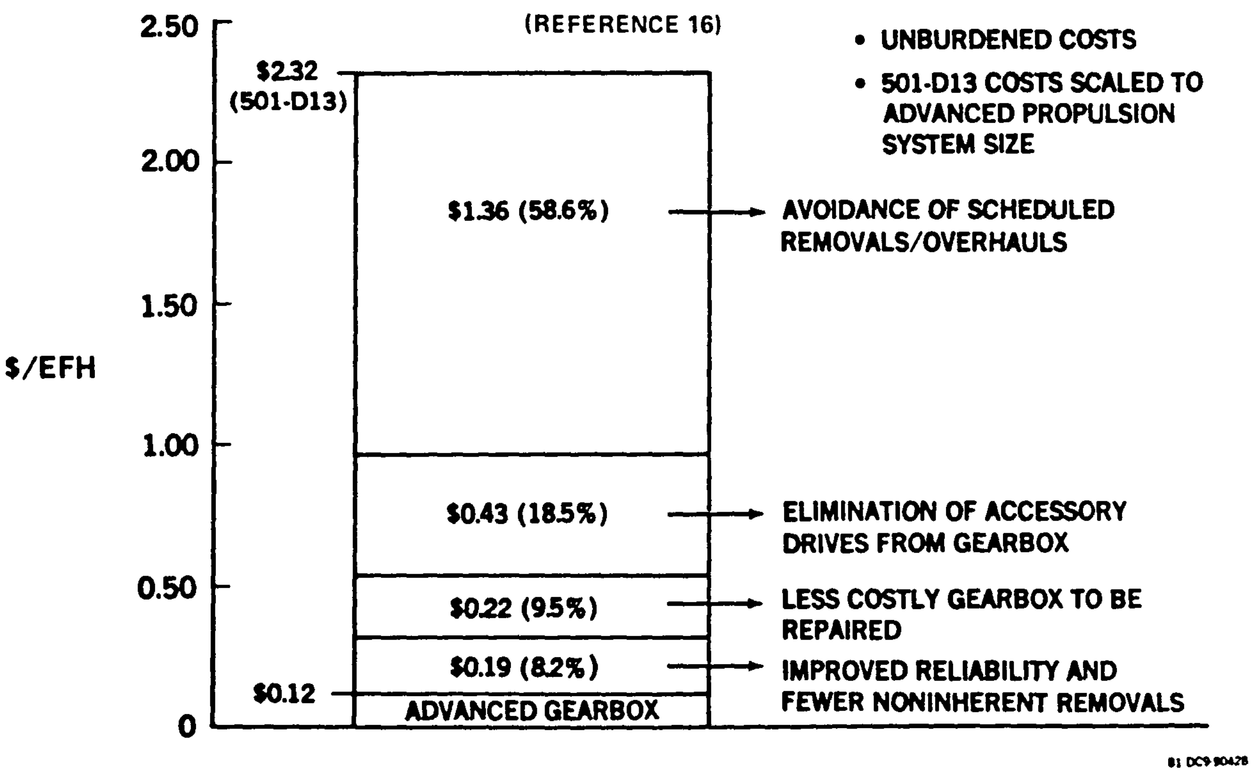


FIGURE 86. MAINTENANCE COST REDUCTION SOURCES FOR ADVANCED REDUCTION GEARBOX

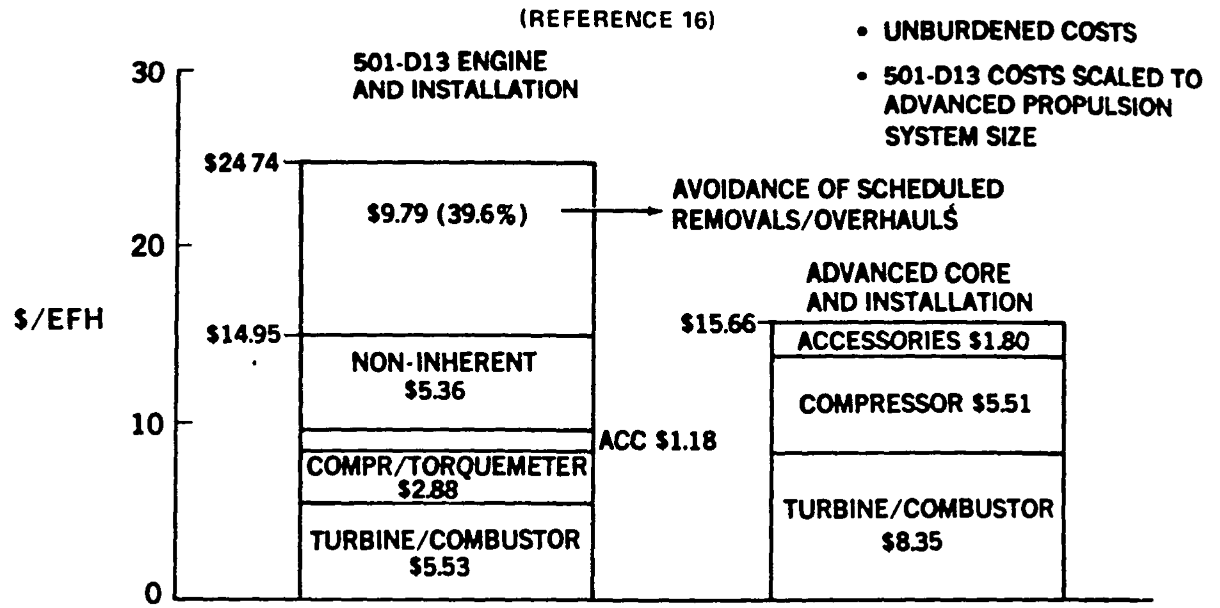


FIGURE 87. MAINTENANCE COST REDUCTION SOURCES FOR AND COMPARISON WITH ADVANCED CORE

Allison's conclusions as a result of their study are as follows:

- The maintenance costs are higher on the 501-D13 turboprop than on the JT8D primarily because of higher core engine costs.

- The core costs are comparable for equivalent technology advanced turboprop and turbofan engines. Improvements to the propeller and gearbox will make their maintenance costs comparable to the fan and thrust reverser.

- Maintenance cost does not appear to be a valid barrier against possible airline use of future turboprops.

To evaluate and compare the estimates and conclusions reached by Allison, known direct maintenance costs were obtained for the JT8D-7, -9, and -11 engines used in DC-9 aircraft. Factors used to compute baseline direct maintenance costs for a single JT8D-7, -9, and -11 engine at 0.8 engine cycle are as follows:

Labor		Material (1977$)	
MH/EH	MH/Eng Cycle	$/FH	$/Eng Cycle
0.4488	0.282	9.772	5.748

Direct maintenance costs in 1976 dollars (to compare with Allison's estimates quoted in 1976 dollars) are computed as follows:

Labor	=	0.4488 + 0.282 = 0.7308		
		0.7308 x 9.00 =		$ 6.577
Material	=	9.772 + 5.748 =15.52		
		15.52 x 0.92 =		$ 14.278
			Total	$ 20.855

These direct maintenance costs for the JT8D-7, -9, and -11 engines are based on reiterative maintenance analyses and experience over the 11 years that the JT8D engine has been in service. By contrast, the Allison estimate of $16.39/EFH for the advanced turboprop is the result of reliability assessments of predicted maintenance actions and maintenance man-hour estimates using the scaled 501-D13/54H60 turboprop as the baseline. The Allison assertion that the advanced turboprop can be maintained at a rate of $16.39/EFH -- or less than the JT8D-7, -9, and -11 engines -- is considered very optimistic by McDonnell Douglas power plant and maintenance cost analysis experts when the known baseline cost for the JT8D-7, -9, and -11 engines is $20.86/EFH.

Moreover, newer technology engines have shown maintenance costs four to five times greater than the JT8-D engines, as indicated by the following table:

Total Engine	DMC Per Engine Flight Hour at 0.8 Duty Cycle*
JT8D-9	$ 19.516
CF6-50C2	103.045
RB211-524B	99.936
JT9D-59H	81.540
CFM-56-2	42.468

*Based on data from various engine manufacturers

Newer technology engines are designed to achieve lower fuel consumption (as is the propfan engine). However, the different types of materials, construction, and weight savings used to gain lower fuel consumption result in engines that are less tolerant of damage, and therefore have higher maintenance costs.

Comparative Analysis of DC-9 Super 80 Turboprop vs Turbofan Direct Maintenance Cost Curves

When a new aircraft model is first conceived by McDonnell Douglas, maintenance costs are estimated by a gross methodology which considers size, weight, payload, speed, engine thrust, and cost as compared to Douglas produced aircraft whose direct maintenance costs are known. The initial baseline or direct maintenance cost levels are established by a system by system comparison which considers reliability and maintenance design improvements, differences in functional requirements, and the number, size, and capacity of maintenance significant components within each system. Since time and funding are not available for such a detailed system analysis of the advanced turboprop engine, a gross methodology based on experience and expertise in maintenance cost estimating has been applied to the factors listed in Table 4.4-I of Reference 16 to establish an MDC estimate of what it will probably cost to maintain the advanced turboprop engine. This methodology is based on the following assumptions:

- As stated previously, Allison's estimate of maintenance costs for the engine are extremely optimistic. McDonnell Douglas takes a more conservative or pessimistic posture which establishes a projected upper limit of maintenance costs. The actual costs will probably be somewhere in between.

- Reliability (maintenance action rates) listed in Table 4.4-I of Reference 16 are understated by 30 percent.

- Power section major repair maintenance action (MA) rates from newer technology engines range from 0.09 to 0.10 MA/1000 flight hours based on duty cycles of 3.5 to 5 hours. These MA rates would be even higher for shorter duty cycles projected for the DC-9 Super 80 propfan aircraft. It is therefore believed that application of a factor of 10 (0.060) to the 0.006 MA rate estimated by Allison is justified.

- Line man-hours are understated by 50 to 200 percent. Some of the Allison estimates for line man-hours are fractions of an hour (0.2, 0.3, and 0.5). The minimum MH per repair should not be less than 1 man-hour per repair.

Table 30 represents a reformatting of Table 4.4-I of Reference 16 to show a comparison of the Allison estimate and the McDonnell Douglas estimate derived by application of the above assumptions. Allison and McDonnell Douglas data shown in Table 30 are expressed in 1977 dollars so that the estimates can be accurately compared to the DC-9 Super 80/JT8D-209 baseline expressed in 1977 dollars. A comparison of the MMH/EH and total cost/EH from each estimate for the advanced turboprop engine and from the JT8D-209 engine in the DC-9 Super 80 aircraft is as follows:

	Advanced Turboprop		JT8D-209
	Allison Est	MDC Est	Baseline
MMH/EH	0.263	0.552	0.468
$/EH	17.64	38.04	21.03

Having established the McDonnell Douglas estimate for the advanced turboprop engine, both the Allison and McDonnell Douglas engine estimates are integrated into the DC-9 Super 80 direct maintenance cost baseline in order to develop curves for various flight lengths. The input data for these curves are shown in Tables 31 and 32. These tables represent the DC-9 Super 80 baseline with certain adjustments to allow for the propfan engine. The maintenance costs called for in Chapter 32, Landing Gear*, are reduced 5 percent to allow for an expected decrease in tire and brake costs as a result of the increased landing deceleration capabilities of the reverse pitch propellers on the

*All chapter references in this paragraph are to ATA Specification 100 (Specification for Manufactured Technical Data, Air Transport Association of America, June 1, 1956, Rev. Dec. 30, 1977).

TABLE 30

SUMMARY OF DETROIT DIESEL ALLISON AND MDC PROPFAN ENGINE COST PER FLIGHT HOUR

ITEM & MAINTENANCE ACTION	MAINTENANCE ACTIONS PER 1000 FLT HR		SHOP MANHOURS PER REPAIR		LINE MANHOURS PER REPAIR		PARTS COST PER REPAIR (1977 DOLLARS)		MAINTENANCE MANHOURS PER 1000 FLT HR		LABOR PER 1000 FLT HR (@9 50/HR)		PARTS COST PER 1000 FLT HR (1977 DOLLARS)		TOTAL COST PER 1000 FLT HR	
	DDA	MDC	DDA	MDC	DDA	MDC	DDA	MDC	DDA	MDC	DDA	MDC	DDA	MDC	DDA	MDC
POWER SECTION & ACCESSORIES																
POWER SECTION MAJOR REPAIR	0.006	0.060	1689.5	2252.7	10.5	15.8	216756	216756	10.200	136 110	96.90	1293.05	1300 54	13005.36	1397.44	14298.41
COMPRESSOR REPAIR	0.097	0.139	789.8	1053.1	10.2	15.3	41904	41904	77.600	148.508	737.20	1410.83	4064.69	5824.66	4801.89	7235.49
HPT/COMBUSTOR BLADE-SCHED RPLC	0.050	0.071	39.8	53.1	10.2	15.3	79434	79434	2.500	4.856	23 75	46.13	3971.70	5639.81	3995.45	5685.94
HPT/COMBUSTOR BLADE REPAIR	0.097	0.139	64 8	86.4	10.2	15.3	31563	31363	7.275	14.136	68.88	134.29	3061.61	4387.26	3130.49	4521.55
POWER TURBINE REPAIR	0.020	0.029	134.0	178.7	6.0	9.0	25639	25639	2.800	5.449	26.60	51.77	512.78	743.53	539.38	795.30
ENGINE ACCESSORY GRBX REPAIR	0.025	0.036	99.7	132.9	0.3	1.0	648	648	2.500	4.820	23.75	45.79	16.20	23.33	39.95	69.12
ENGINE ACCESSORIES REPAIR	0.036	0.051	24.7	32.9	0.3	1.0	837	837	0.900	1.729	8.55	16.43	30.13	42.69	38.68	59.12
ENG MINOR COMPONENTS REPAIR	0.200	0.286	7.8	10.4	0.2	1.0	462	462	1.600	3.260	15.20	30.97	92.40	132.13	107.60	163.10
STARTING SYSTEM REPAIR	0.333	0.476	19.7	26.3	0.3	1.0	3046	3046	6.660	13.042	63.27	123.90	1014.32	1449.90	1077.59	1573.80
ELECTRONICS & CONTROLS REPAIR	0.500	0.714	23.5	31.3	0.5	1.0	847	847	12.000	23.062	114.00	219.09	423.50	604.76	537.50	823.85
LINE INSPECTIONS									125.600	169.900	1193.00	1614.00			1193.00	1614.00
SUBTOTAL POWER SECTION									249.635	524.872	2371.10	4986.25	14487.87	31853.43	16858.97	36839.68
ADVANCED PROPELLERS																
SPINNER REPAIR	0.0086	0.012	25.0	33.3	0.2	1.0	540	540	0.217	0.412	2.062	3.914	4.644	6.480	6.706	10.394
DISC & AFT FAIRING REPAIR	0.0029	0.004	8.0	10.7	4.0	6.0	1890	1890	0.035	0.067	0.333	0.637	5.481	7.560	5.814	8.197
PITCH CHANGE ACTUATOR REPAIR	0 0332	0.047	22.4	32.0	4.4	6.6	1755	1755	0.890	1.814	8.455	17.233	58.266	82.485	66.721	99.718
BLADES REPAIR	0.0459	0.066	45.4	64.9	2.3	3.5	7619	7619	2.189	4.514	20.796	42.883	349.712	502.854	370.508	545 737
FWD COVER & FAIRING REPAIR	0.0055	0.008	7.5	10.0	1.3	2.0	270	270	0.048	0.096	0.456	0.912	1.485	2.160	1.941	3.072
PITCH CHG REGULATOR REPAIR	0.0912	0.130	48.9	69.9	2.8	4.2	1080	1080	4.715	9.633	44.793	91.514	98.496	140.400	143.289	231.914
COMPONENTS REPAIR	0.1756	0.251	8.0	10.7	1.0	1.5	270	270	1.580	3.062	15.010	29.089	47.412	67.770	62.422	96.859
SUBTOTAL PROPELLER									9.674	19 598	91.905	186.182	565.496	809.709	657.401	995.891
MAIN DRIVE GEARBOX																
MAJOR REPAIR	0.004	0.006	168.0	224.0	12.0	18.0	10130	10130	0.720	1.452	6.840	13.79	40.52	60.78	47.36	74.57
MINOR REPAIR	0.036	0.051	78.0	104.0	12.0	18.0	1285	1285	3.240	6.222	30.78	59.11	46.26	65.54	46.26	124.65
SUBTOTAL GEARBOX									3.960	7.674	37.62	72.90	86.78	126.32	124.40	199.22

TABLE 30

SUMMARY OF DETROIT DIESEL ALLISON AND MDC PROPFAN ENGINE COST PER FLIGHT HOUR (Continued)

TOTALS

Item	Maintenance Manhours Per 1000 Flt Hr		Labor Per 1000 Flt Hr		Parts Cost per 1000 Flt Hr (1977 Dollars)		Total Cost Per 1000 Flt Hr (1977 Dollars)	
	DDA	MDC	DDA	MDC	DDA	MDC	DDA	MDC
Advanced Propeller	9.674	19.598	91.905	186.182	565.496	809.709	657.401	995.891
Main Gearbox	3.960	7.674	37.62	72.90	86.78	126.32	124.40	199.22
Power Section,								
Accessories, Line Inspections	249,635	524.872	2371.10	4986.25	14,487.87	31,853.43	16,858.97	36.839.68
Grand Total	263.269	552.144	2500.625	5245.332	15,140.146	32,789.459	17,640.711	38,034.791

TABLE 31

DC-9-80 TURBOPROP DIRECT MAINTENANCE
COST BASELINE USING DETROIT DIESEL
ALLISON ESTIMATES (1977 DOLLARS)

	LABOR		MATERIAL	
ATA SPEC 100 SYSTEM	MMH/FH	MMH/FLT	$/FH	$/FLT
0 GENERAL	1.3148	0.4436	0.8560	0.1440
21 AIR CONDITIONING	0.0589	0.0000	1.8570	0.0000
22 AUTO FLIGHT	0.1532	0.0000	0.4060	0.0000
23 COMMUNICATIONS	0.0671	0.0000	0.5890	0.0000
24 ELECTRICAL POWER	0.1316	0.0000	0.9660	0.0000
25 EQUIP/FURNISHINGS	0.0093	0.1979	0.6000	2.2700
26 FIRE PROTECTION	0.0016	0.0000	0.1920	0.0000
27 FLIGHT CONTROLS	0.0180	0.0000	1.1960	0.0000
28 FUEL	0.0348	0.0000	0.8050	0.0000
29 HYDRAULIC POWER	0.0301	0.0000	1.1500	0.0000
30 ICE & RAIN PROT	0.0079	0.0000	0.0960	0.0000
31 INSTRUMENTS	0.0246	0.0000	0.0000	0.0000
32 LANDING GEAR	0.0000	0.2800	0.0000	9.1680
33 LIGHT	0.0035	0.0000	0.2110	0.0000
34 NAVIGATION	0.2042	0.0000	1.1110	0.0000
35 OXYGEN	0.0280	0.0000	0.5720	0.0000
36 PNEUMATIC	0.0183	0.0000	0.5610	0.0000
38 WATER/WASTE	0.0079	0.0000	0.2160	0.0000
49 ABRN AUX POWER	0.0000	0.0424	0.0000	1.5420
52 DOORS	0.0000	0.0456	0.0000	0.1210
53 FUSELAGE	0.0000	0.0023	0.0000	0.0280
54 NACELLES/PYLONS	0.0000	0.0092	0.0000	0.0750
55 STABILIZERS	0.0000	0.0192	0.0000	0.0720
56 WINDOWS	0.0000	0.0104	0.0000	0.8780
57 WINGS	0.0000	0.0836	0.0000	0.1530
61 PROPELLERS	0.0140	0.0060	0.7180	0.3440
AIRFRAME SUBTOTAL	**2.1278	**1.1402	*12.102	*14.795
72 POWER PLANT (ENG)	**0.326	**0.162	*18.524	* 8.878
AIRCRAFT TOTAL	2.4538	1.3022	30.626	23.673

*CONVERTED TO 1978 DOLLARS =

AIRFRAME SUBTOTAL	**13.07	**15.97
72 POWER PLANT	**20.006	** 9.588

**USED AS INPUTS TO COMPUTER PROGRAM

TABLE 32

DC-9-80 TURBOPROP DIRECT MAINTENANCE COST ESTIMATE USING DOUGLAS AIRCRAFT ESTIMATES (1977 DOLLARS)

	LABOR		MATERIAL	
ATA SPEC 100 SYSTEM	MMH/FH	MMH/FLT	$/FH	$/FLT
0 GENERAL	1.3148	0.4436	0.8560	0.1440
21 AIR CONDITIONING	0.0589	0.0000	1.8570	0.0000
22 AUTO FLIGHT	0.1532	0.0000	0.4060	0.0000
23 COMMUNICATIONS	0.0671	0.0000	0.5890	0.0000
24 ELECTRICAL POWER	0.1316	0.0000	0.9660	0.0000
25 EQUIP/FURNISHINGS	0.0093	0.1979	0.6000	2.2700
26 FIRE PROTECTION	0.0016	0.0000	0.1920	0.0000
27 FLIGHT CONTROLS	0.0180	0.0000	1.1960	0.0000
28 FUEL	0.0348	0.0000	0.8050	0.0000
29 HYDRAULIC POWER	0.0301	0.0000	1.1500	0.0000
30 ICE & RAIN PROT	0.0079	0.0000	0.0960	0.0000
31 INSTRUMENTS	0.0246	0.0000	0.0000	0.0000
32 LANDING GEAR	0.0000	0.2800	0.0000	9.1680
33 LIGHT	0.0035	0.0000	0.2110	0.0000
34 NAVIGATION	0.2042	0.0000	1.1110	0.0000
35 OXYGEN	0.0280	0.0000	0.5720	0.0000
36 PNEUMATIC	0.0183	0.0000	0.5610	0.0000
38 WATER/WASTE	0.0079	0.0000	0.2160	0.0000
49 ABRN AUX POWER	0.0000	0.0424	0.0000	1.5420
52 DOORS	0.0000	0.0456	0.0000	0.1210
53 FUSELAGE	0.0000	0.0023	0.0000	0.0280
54 NACELLES/PYLONS	0.0000	0.0092	0.0000	0.0750
55 STABILIZERS	0.0000	0.0192	0.0000	0.0720
56 WINDOWS	0.0000	0.0104	0.0000	0.8780
57 WINGS	0.0000	0.0836	0.0000	0.1530
61 PROPELLERS	0.0260	0.0120	1.0300	0.4940
AIRFRAME SUBTOTAL	**2.1398	**1.1462	*12.414	*14.992
72 POWER PLANT (ENG)	**0.682	**0.340	*40.642	*19.480
AIRCRAFT TOTAL	2.8263	1.4826	53.056	34.472

*CONVERTED TO 1978 DOLLARS =

AIRFRAME SUBTOTAL	**13.407	**16.191
72 POWER PLANT	**43.893	**21.038

* *INPUTS TO COMPUTER PROGRAM

propfan aircraft as compared to the thrust reverser on the DC-9 Super 80/JT8D-209 configuration. Data from Chapter 70, Power Plant (Airframe), representing the cost of the thrust reverser on the turbofan, are deleted and those from Chapter 61, Propellers are added. Chapter 72, Power Plant, includes cost factors for the turboprop engine and gearbox. Cost factors shown in Tables 31 and 32 as well as those shown in Table 33 for the DC-9 Super 80/JT8D-209 configuration are input to a computer program which calculates labor and material costs for different flight lengths. All costs are expressed in 1978 dollars. The results of the computer runs shown in Tables 34 through 36 are plotted on the curves of Figures 88 through 90. It should be noted that the engine maintenance costs shown in these data cover two engines, while engine maintenance costs previously discussed in this report covered only one engine.

From Figures 88 and 90, there is considerable variance between the cost estimates of Allison and McDonnell Douglas to maintain the turboprop engines and the total aircraft. This variance is primarily due to the difference between Allison's and McDonnell Douglas' estimates to maintain the propfan core engine. Since Allison's estimate is considered optimistic and the McDonnell Douglas estimate conservative or pessimistic, the two curves provided a band of costs, with the probable real cost falling somewhere in between. From Figure 89, the curves for the DC-9 Super 80/JT8D-209 airframe including the thrust reverser and for the DC-9 Super 80 turboprop including the propellers are fairly close. (Note: gearbox maintenance costs are included in Figure 88.)

It is estimated that tire and brake costs would be reduced by 5 percent due to the increased deceleration capability of the reversed pitch on the propellers of the DC-9 Super 80 turboprop. This would reduce the landing gear costs (Chapter 32) by $0.642/FH for a one hour flight length.

It is assumed that when Allison made their reliability assessment of the advanced turboprop engine, the probability of foreign object damage (FOD) was included in their statistical analysis. The maintenance action rates that

TABLE 33

DC-9-80/JT8D-209 DIRECT MAINTENANCE COST BASELINE (1977 DOLLARS)

ATA SPEC 100 SYSTEM	LABOR MMH/FH	LABOR MMH/FLT	MATERIAL $/FH	MATERIAL $/FLT
0 GENERAL	1.3148	0.4436	0.8560	0.1440
21 AIR CONDITIONING	0.0589	0.0000	1.8570	0.0000
22 AUTO FLIGHT	0.1532	0.0000	0.4060	0.0000
23 COMMUNICATIONS	0.0671	0.0000	0.5890	0.0000
24 ELECTRICAL POWER	0.1316	0.0000	0.9660	0.0000
25 EQUIP/FURNISHINGS	0.0093	0.1979	0.6000	2.2700
26 FIRE PROTECTION	0.0016	0.0000	0.1920	0.0000
27 FLIGHT CONTROLS	0.0180	0.0000	1.1960	0.0000
28 FUEL	0.0348	0.0000	0.8050	0.0000
29 HYDRAULIC POWER	0.0301	0.0000	1.1500	0.0000
30 ICE & RAIN PROT	0.0079	0.0000	0.0960	0.0000
31 INSTRUMENTS	0.0246	0.0000	0.0000	0.0000
32 LANDING GEAR	0.0000	0.2948	0.0000	9.6500
33 LIGHT	0.0035	0.0000	0.2110	0.0000
34 NAVIGATION	0.2042	0.0000	1.1110	0.0000
35 OXYGEN	0.0280	0.0000	0.5720	0.0000
36 PNEUMATIC	0.0183	0.0000	0.5610	0.0000
38 WATER/WASTE	0.0079	0.0000	0.2160	0.0000
49 ABRN AUX POWER	0.0000	0.0424	0.0000	1.5420
52 DOORS	0.0000	0.0456	0.0000	0.1210
53 FUSELAGE	0.0000	0.0023	0.0000	0.0280
54 NACELLES/PYLONS	0.0000	0.0092	0.0000	0.0750
55 STABILIZERS	0.0000	0.0192	0.0000	0.0720
56 WINDOWS	0.0000	0.0104	0.0000	0.8780
57 WINGS	0.0000	0.0836	0.0000	0.1530
70 POWER PLANT (A/F)	0.2947	0.0642	2.6990	0.6080
AIRFRAME SUBTOTAL	**2.4085	**1.2132	*14.0830	*15.5410
72 POWER PLANT (ENG) JT8D-209	**0.9350	**0.4674	*21.4120	*10.2640
AIRCRAFT TOTAL	3.3435	1.6806	35.4950	25.8050

*CONVERTED TO 1978 DOLLARS =

AIRFRAME SUBTOTAL	**15.210	**16.789
72 POWER PLANT (ENG)	**23.125	**11.085

**USED AS INPUTS TO COMPUTER PROGRAM

TABLE 34

DC-9-80 TURBOPROP DIRECT MAINTENANCE COST ESTIMATES FOR VARIOUS FLIGHT LENGTHS USING DETROIT DIESEL ALLISON ESTIMATES OF ENGINE MAINTENANCE COSTS

AIRCRAFT TYPE DC-9-80
ENGINE TYPE PROPFAN
BASELINE 100
YEAR-DOLLARS 1978
LABOR RATE 10.90

	LABOR		MATERIALS		AIRCRAFT	
	MH/FH	MH/FLT	$/FH	$/FLT	$/FH	$/FLT
AIRFRAME	2.1278	1.1402	13.0700	15.9790	36.2630	28.4072
ENGINE	0.3260	0.1620	20.0060	9.5880	23.5594	11.3538
AIRCRAFT	2.4538	1.3022	33.0760	25.5670	59.8224	39.7610

FLIGHT LENGTH	AIRFRAME LABOR	AIRFRAME MATERIAL	AIRFRAME TOTAL	ENGINE LABOR	ENGINE MATERIAL	ENGINE TOTAL	AIRCRAFT LABOR	AIRCRAFT MATERIAL	AIRCRAFT TOTAL
.25	72.91	76.99	149.89	10.62	58.36	69.97	83.52	135.34	218.87
.50	48.05	45.03	93.08	7.08	39.18	46.27	55.13	94.21	139.34
.75	39.76	34.38	74.14	5.91	32.79	38.70	45.67	67.17	112.84
1.00	35.62	29.05	64.67	5.32	29.59	34.91	40.94	58.64	99.59
1.25	33.14	25.85	58.99	4.97	27.69	32.64	38.10	53.53	91.63
1.50	31.48	23.72	55.20	4.73	26.40	31.13	36.21	50.12	86.33
1.75	30.29	22.20	52.50	4.56	25.48	30.05	34.86	47.69	82.54
2.00	29.41	21.06	50.47	4.44	24.80	29.24	33.84	45.86	79.70
2.25	28.72	20.17	48.89	4.34	24.27	28.61	33.05	44.44	77.49
2.50	28.16	19.46	47.63	4.26	23.84	28.10	32.42	43.30	75.73
2.75	27.71	18.88	46.59	4.20	23.49	27.69	31.91	42.37	74.28
3.00	27.34	18.40	45.73	4.14	23.20	27.34	31.48	41.60	73.08
3.25	27.02	17.99	45.00	4.10	22.96	27.05	31.11	40.94	72.06
3.50	26.74	17.64	44.38	4.06	22.75	26.80	30.80	40.38	71.18
3.75	26.51	17.33	43.84	4.02	22.56	26.59	30.53	39.89	70.43
4.00	26.30	17.06	43.36	3.99	22.40	26.40	30.29	39.47	69.75
4.25	26.12	16.83	42.95	3.97	22.26	26.23	30.09	39.09	69.18
4.50	25.95	16.62	42.58	3.95	22.14	26.08	29.90	38.76	68.65
4.75	25.81	16.43	42.24	3.93	22.02	25.95	29.73	38.46	68.19
5.00	25.68	16.27	41.94	3.91	21.92	25.83	29.59	38.19	67.77
5.25	25.56	16.11	41.67	3.89	21.83	25.72	29.45	37.95	67.40
5.50	25.45	15.98	41.43	3.87	21.75	25.62	29.33	37.72	67.05
5.75	25.35	15.85	41.20	3.86	21.67	25.53	29.21	37.52	66.74
6.00	25.26	15.73	41.00	3.85	21.60	25.45	29.11	37.34	66.45
6.25	25.18	15.63	40.81	3.84	21.54	25.38	29.02	37.17	66.18
6.50	25.11	15.53	40.63	3.83	21.48	25.31	28.93	37.01	65.94
6.75	25.03	15.44	40.47	3.81	21.43	25.24	28.85	36.86	65.71
7.00	24.97	15.35	40.32	3.81	21.38	25.18	28.77	36.73	65.50
7.25	24.91	15.27	40.18	3.80	21.33	25.13	28.70	36.60	65.31
7.50	24.85	15.20	40.05	3.79	21.28	25.07	28.64	36.48	65.12
7.75	24.80	15.13	39.93	3.78	21.24	25.02	28.58	36.37	64.95
8.00	24.75	15.07	39.81	3.77	21.20	24.98	28.52	36.27	64.79
MRU=	1.421								

TABLE 35

DC-9-80 TURBOPROP DIRECT MAINTENANCE COST ESTIMATES FOR VARIOUS FLIGHT LENGTHS USING DETROIT DIESEL ALLISON ESTIMATES OF ENGINE MAINTENANCE COSTS

AIRCRAFT TYPE DC-9-80
ENGINE TYPE PROPFAN
BASELINE L7X980
YEAR-DOLLARS 1978
LABOR RATE 10.90

	LABOR MH/FH	LABOR MH/FLT	MATERIALS $/FH	MATERIALS $/FLT	AIRCRAFT $/FH	AIRCRAFT $/FLT
AIRFRAME	2.1398	1.1462	13.4070	16.1910	36.7308	28.6846
ENGINE	0.6820	0.3400	43.8930	21.0380	51.3268	24.7440
AIRCRAFT	2.8218	1.4862	57.3000	37.2290	88.0576	53.4286

FLIGHT LENGTH	AIRFRAME LABOR	AIRFRAME MATERIAL	AIRFRAME TOTAL	ENGINE LABOR	ENGINE MATERIAL	ENGINE TOTAL	AIRCRAFT LABOR	AIRCRAFT MATERIAL	AIRCRAFT TOTAL
.25	73.30	78.17	151.47	22.26	128.04	150.30	95.56	206.22	301.77
.50	48.31	45.79	94.10	14.95	85.97	100.81	63.16	131.76	194.91
.75	39.98	34.99	74.98	12.38	71.94	84.32	52.36	106.94	159.30
1.00	35.92	29.60	65.42	11.14	64.93	76.07	46.96	94.53	141.49
1.25	33.32	26.35	59.68	10.40	60.72	71.12	43.72	87.08	130.80
1.50	31.65	24.20	55.95	9.90	57.92	67.82	41.55	82.12	123.69
1.75	30.46	22.66	53.12	9.55	55.91	65.47	40.01	78.57	118.59
2.00	29.57	21.50	51.07	9.29	54.41	63.70	38.86	75.91	114.77
2.25	28.88	20.60	49.48	9.08	53.24	62.32	37.96	73.85	111.80
2.50	28.32	19.88	48.20	8.92	52.31	61.22	37.24	72.19	109.43
2.75	27.87	19.29	47.16	8.78	51.54	60.32	36.65	70.84	107.49
3.00	27.49	18.80	46.29	8.67	50.91	59.57	36.16	69.71	105.87
3.25	27.17	18.39	45.56	8.57	50.37	58.94	35.74	68.76	104.50
3.50	26.89	18.03	44.93	8.49	49.90	58.40	35.39	67.94	103.32
3.75	26.66	17.72	44.38	8.42	49.50	57.93	35.08	67.23	102.31
4.00	26.45	17.45	43.90	8.36	49.15	57.51	34.81	66.61	101.41
4.25	26.26	17.22	43.49	8.31	48.84	57.15	34.57	66.06	100.63
4.50	26.10	17.00	43.11	8.26	48.57	56.83	34.35	65.57	99.93
4.75	25.95	16.92	42.77	8.21	48.32	56.54	34.17	65.14	99.31
5.00	25.82	16.65	42.47	8.17	48.10	56.27	34.00	64.75	98.74
5.25	25.70	16.49	42.19	8.14	47.90	56.04	33.84	64.39	98.23
5.50	25.60	16.35	41.95	8.11	47.72	55.83	33.70	64.07	97.77
5.75	25.50	16.22	41.72	8.08	47.55	55.63	33.57	63.77	97.35
6.00	25.41	16.11	41.51	8.05	47.40	55.45	33.46	63.50	96.96
6.25	25.32	16.00	41.32	8.03	47.26	55.29	33.35	63.25	96.61
6.50	25.25	15.90	41.14	8.00	47.13	55.13	33.25	63.03	96.28
6.75	25.17	15.81	40.98	7.98	47.01	54.99	33.16	62.82	95.97
7.00	25.11	15.72	40.83	7.96	46.90	54.86	33.07	62.62	95.69
7.25	25.05	15.64	40.69	7.94	46.79	54.74	32.99	62.44	95.43
7.50	24.99	15.57	40.56	7.93	46.70	54.63	32.92	62.26	95.18
7.75	24.94	15.50	40.43	7.91	46.61	54.52	32.85	62.10	94.95
8.00	24.89	15.43	40.32	7.90	46.52	54.42	32.78	61.95	94.74
FRU=	1.390								

TABLE 36

DC-9-80/JT8D-209 BASELINE DIRECT MAINTENANCE COST ESTIMATES FOR VARIOUS FLIGHT LENGTHS

AIRCRAFT TYPE DC-9-80
ENGINE TYPE JT8D-209
BASELINE L7X980
YEAR-DOLLARS 1978
LABOR RATE 10.90

	LABOR MH/FH	LABOR MH/FLT	MATERIALS $/FH	MATERIALS $/FLT	AIRCRAFT $/FH	AIRCRAFT $/FLT
AIRFRAME	2.4085	1.2132	15.2100	16.7840	41.4626	30.0079
ENGINE	0.9340	0.4674	23.1250	11.0850	33.3056	16.1797
AIRCRAFT	3.3425	1.6806	38.3350	27.8690	74.7682	46.1875

FLIGHT LENGTH	AIRFRAME LABOR	AIRFRAME MATERIAL	AIRFRAME TOTAL	ENGINE LABOR	ENGINE MATERIAL	ENGINE TOTAL	AIRCRAFT LABOR	AIRCRAFT MATERIAL	AIRCRAFT TOTAL
.25	79.15	52.35	131.49	30.56	67.46	98.02	109.71	149.81	259.52
.50	52.70	48.78	101.48	20.37	45.29	65.66	73.07	94.07	167.14
.75	43.88	37.59	81.47	16.97	37.91	54.88	60.86	75.49	136.35
1.00	39.48	31.99	71.47	15.28	34.21	49.49	54.75	66.20	120.96
1.25	36.83	28.64	65.47	14.26	31.99	46.25	51.09	60.63	111.72
1.50	35.07	26.40	61.47	13.58	30.52	44.09	48.65	56.91	105.56
1.75	33.81	24.80	58.61	13.09	29.45	42.55	46.90	54.25	101.16
2.00	32.86	23.60	56.47	12.73	28.67	41.40	45.59	52.27	97.86
2.25	32.13	22.67	54.80	12.44	28.05	40.59	44.57	50.72	95.30
2.50	31.54	21.92	53.47	12.22	27.55	39.78	43.76	49.48	93.24
2.75	31.06	21.31	52.37	12.03	27.15	39.19	43.09	48.47	91.56
3.00	30.66	20.80	51.47	11.88	26.82	38.70	42.54	47.62	90.16
3.25	30.32	20.37	50.70	11.75	26.54	38.28	42.07	46.91	88.98
3.50	30.03	20.01	50.04	11.64	26.29	37.93	41.67	46.30	87.96
3.75	29.78	19.69	49.46	11.54	26.08	37.62	41.32	45.77	87.08
4.00	29.56	19.41	48.96	11.45	25.90	37.35	41.01	45.30	86.32
4.25	29.36	19.16	48.52	11.38	25.73	37.11	40.74	44.89	85.64
4.50	29.19	18.94	48.13	11.31	25.59	36.90	40.50	44.53	85.03
4.75	29.04	18.74	47.78	11.25	25.46	36.71	40.29	44.20	84.49
5.00	28.90	18.57	47.46	11.20	25.34	36.54	40.10	43.91	84.01
5.25	28.77	18.41	47.18	11.15	25.24	36.39	39.92	43.64	83.57
5.50	28.66	18.26	46.92	11.11	25.14	36.25	39.76	43.40	83.17
5.75	28.55	18.13	46.68	11.07	25.05	36.12	39.62	43.18	82.80
6.00	28.46	18.01	46.46	11.03	24.97	36.00	39.49	42.98	82.47
6.25	28.37	17.90	46.26	11.00	24.90	35.89	39.36	42.79	82.15
6.50	28.29	17.79	46.08	10.96	24.83	35.79	39.25	42.62	81.87
6.75	28.21	17.70	45.91	10.94	24.77	35.70	39.15	42.46	81.61
7.00	28.14	17.61	45.75	10.91	24.71	35.62	39.05	42.32	81.37
7.25	28.08	17.53	45.60	10.88	24.65	35.54	38.96	42.18	81.14
7.50	28.02	17.45	45.46	10.86	24.60	35.46	38.88	42.05	80.93
7.75	27.95	17.38	45.33	10.84	24.55	35.39	[illegible]	41.93	80.73
8.00	27.91	17.31	45.21	10.82	24.51	35.33	38.72	41.82	80.54
BRU=	1.412								

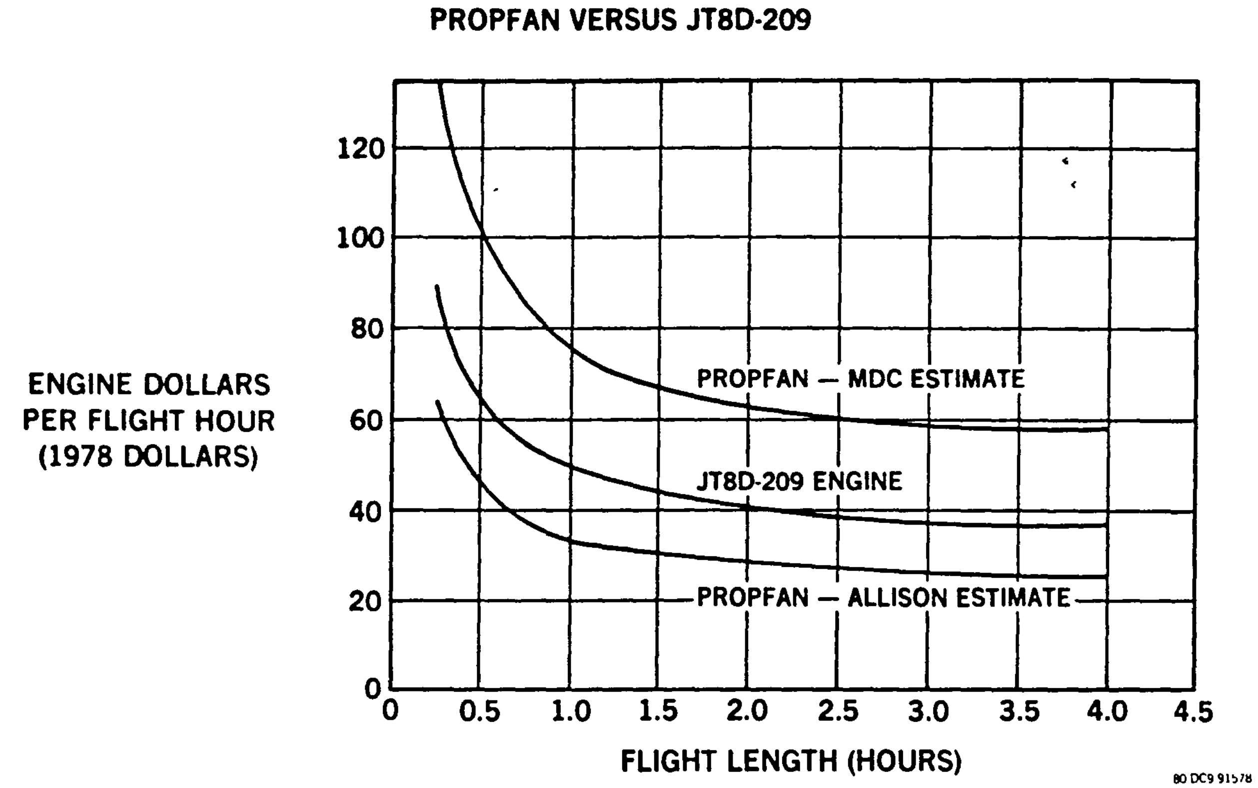


FIGURE 88. ENGINE DIRECT MAINTENANCE COST (PROPFAN VERSUS JT8D-209)

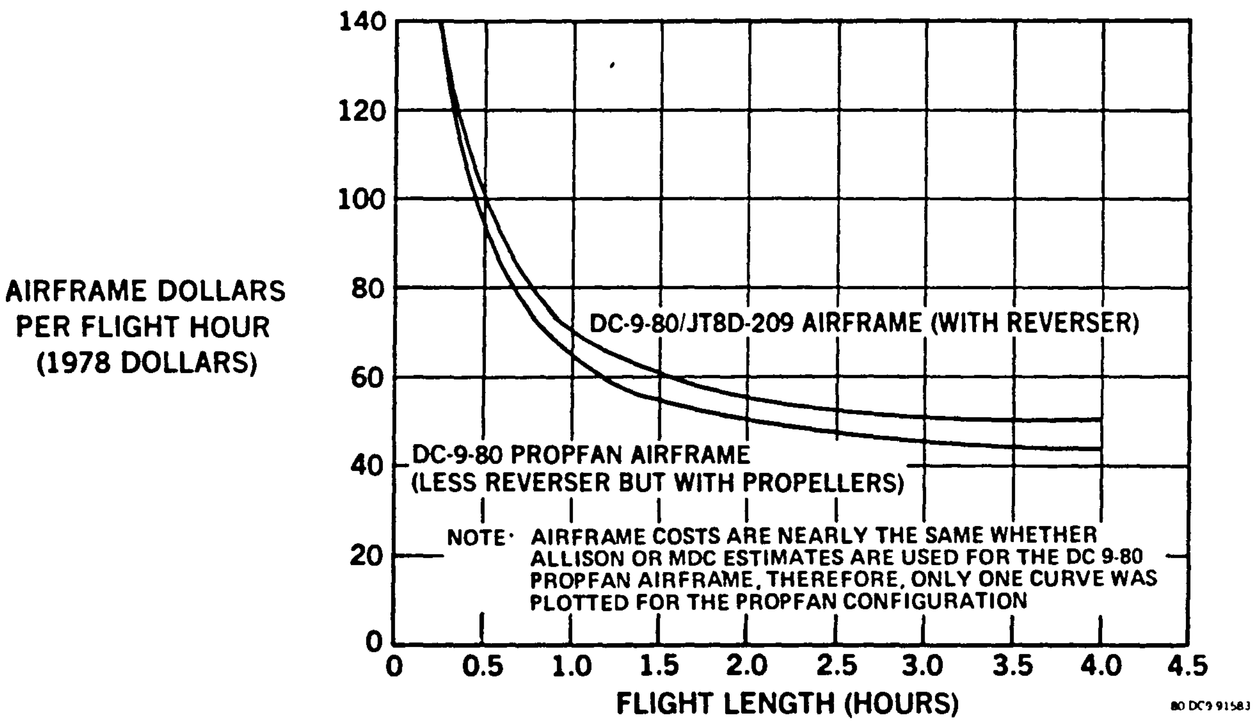


FIGURE 89. AIRFRAME DIRECT MAINTENANCE COST (DC-9 SUPER 80 TURBOPROP VERSUS DC-9 SUPER 80/JT8D-209)

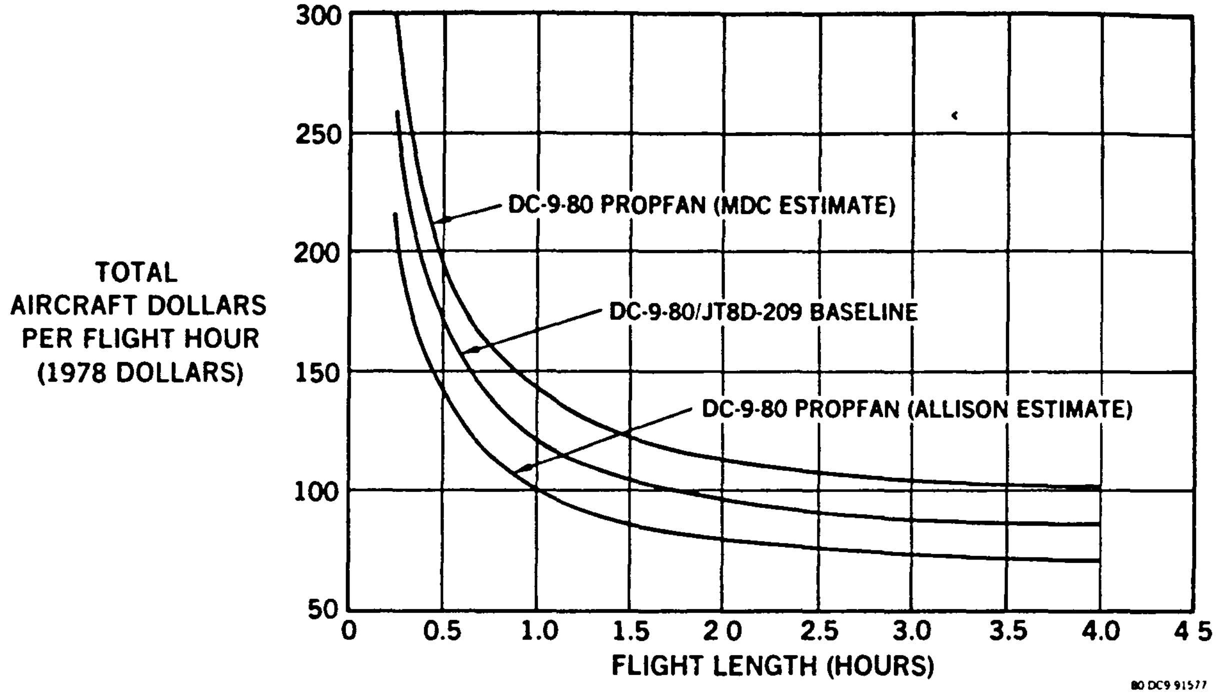


FIGURE 90. TOTAL AIRCRAFT DIRECT MAINTENANCE COST (DC-9 SUPER 80 TURBOPROP VERSUS DC-9 SUPER 80/JT8D-209)

Allison used to establish their direct maintenance cost estimates would therefore already include FOD as would the McDonnell Douglas estimate since the McDonnell Douglas estimate is an adjustment of the Allison estimate. Following this assumption, the direct maintenance cost curves in Figures 88 through 90 already include FOD.

Foreign Object Damage Data

Data from United Airlines indicate the maintenance cost attributed to FOD accounts for a small percentage of United's total engine maintenance costs, as shown in Table 37.

In an effort to more directly assess the difference in projected FOD maintenance requirements between wing mounted and aft mounted DC-9 Super 80 propfan configurations, historical FOD unplanned engine removal data on the DC-8, DC-9, DC-10, B727, B737, B747, and L-1011 are taken from Pratt & Whitney Aircraft Engine Removal Data Reports, General Electric Engine Operational Reports, and data submitted by United and Delta Airlines. From these data,

TABLE 37

UNITED AIRLINES FLEET
ENGINE FOREIGN OBJECT DAMAGE COST DATA
FOR THE YEAR 1977

AIRPLANE TYPE	ENGINE[2] FLIGHT HOURS	TOTAL ENGINE[1] DMC* (DOLLARS)	TOTAL ENGINE FOD[2] DMC (DOLLARS)	FOD COST AS % OF TOTAL DMC
B747	248,800	16,699,000	443,054	2.65
DC-10	330,000	29,960,000	865,400	2.89
DC-8	950,518	21,115,050	123,684	0.59
B727	1,035,036	28,558,746	290,815	1.02
B737	206,328	9,794,000	66,780	0.68
TOTAL	2,770,682	106,126,796	1,789,733	1.69

Data Source: 1. CAB Form 41 Uniform System of Account and Reports.
2. United Airlines.

*Direct Maintenance Cost

FOD rates per 1000 engine hours and per 1000 engine cycles for each type of aircraft are tabulated and plotted against the position of the engines with respect to the main landing gear and the height of the engines above the ground. These data are shown in Tables 38 and 39 and in Figures 91 through 94.

Of the two FOD rates considered, FOD per 1000 engine cycles is probably the more meaningful statistic since FOD is associated more with landing, takeoff and other ground operations than flight operations. Although examination of Tables 37 and 38 and Figures 91 through 94 does not lead to any firm conclusions as to whether wing or aft mounted engines are more or less susceptible to FOD, the following inferences can be drawn:

- The FOD rate of 0.060/1000 cycles shown in Table 38 for the aft fuselage mounted engines on the DC-9 covering 4,604,200 cycles is considerably lower than the 0.118 rate covering 1,876,912 cycles for aft fuselage side mounted engines cited in Delta Airlines letter 1200-1, dated 7-31-79.

TABLE 38

FOD/1000 ENGINE CYCLES BY TYPE AIRCRAFT AND ENGINE MOUNTING

Acft Type	Period Reported	Eng Type	FOD Unplanned Removals	Eng Cycles	FOD Per 1000 Eng Cycles	Sample Size	How Mounted	Distance From Main LG (in. [cm] +Fwd, - Aft +[cm])	Height Above Ground in. (cm)
DC-8	1973-1977	JT3D	55	1,824,773	0.030	UAL	Wing	INBD + 336 (853) OTBD + 192 (488)	INBD 37 (94) OTBD 57 (145)
B747	9/78 - 8/79	JT9D	49	1,269,900	0.039	Fleet	Wing	INBD + 370 (940) OTBD + 30 (76)	INBD 104 (264) OTBD 128 (325)
B727	7/78 - 6/79	JT8D	353	8,229,000	0.043	Fleet	Aft Fus Side & Ctr	SIDE - 372 (-945) CNTR - 260 (-660)	SIDE 154 (391) CNTR 250 (635)
B737	7/78 - 6/79	JT8D	119	2,712,900	0.044	Fleet	Wing	WING + 150 (381)	WING 62 (157)
DC-10-10	CUM THRU 8/79	CF6-6	123	2,162,318	0.057	Fleet	Wing & Center	WING + 400 (1016) CNTR - 440 (-1118)	WING 96 (244) CNTR 400 (1016)
DC-9	7/78 - 6/79	JT8D	278	4,604,200	0.060	Fleet	Aft Fus Side	SIDE - 178 (-450)	SIDE 78 (198)
L-1011	7/77 - 6/79	RB211	6	93,563	0.064	Delta	Wing & Center	WING + 285 (724) CNTR - 340 (-864)	WING 96 (244) CNTR 388 (986)
DC-10-30	CUM THRU 8/79	CF6-50	153	2,351,631	0.065	Fleet	Wing & Center	WING + 400 (1016) CNTR - 440 (-1118)	WING 96 (244) CNTR 400 (1016)

Source:

1. Pratt & Whitney JT9D Engine Removal Data Report, September 1979.
2. UAL letter C-00-72-05, dated 8-9-79.
3. GE CF6-6 Bi-Monthly Operational Report - July/August 1979.
4. GE CF6-50 Bi-Monthly Operational Report - July/August 1979.
5. Delta letter 1200-1, dated 7-31-79.
6. Pratt & Whitney JT8D Engine Removal Data Report - July 1979.

TABLE 39

FOD/1000 ENGINE HOURS BY TYPE AIRCRAFT AND ENGINE MOUNTING

Acft Type	Period Reported	Eng Type	FOD Unplanned Removals	Eng Hours	FOD Per 1000 hr	Sample Size	How Mounted	Position With Respect To Main Lg in. (cm) +Fwd, - Aft	Height Above Ground in. (cm)
B747	9/78 - 8/79	JT9D	49	4,663,300	0.011	Fleet	Wing	INBD + 370 (940) OTBD + 30 (76)	INBD 104 (264) OTBD 128 (325)
DC-8	1973 - 1977	JT3D	55	4,616,678	0.012	UAL	Wing	INBD + 336 (853) OTBD + 192 (488)	INBD 37 (94) OTBD 57 (145)
DC-10-10	CUM THRU 8/79	CF6-6	123	5,903,129	0.021	Fleet	Wing & Center	WING + 400 (1016) CNTR - 400 (-1118)	WING 96 (244) CNTR 400 (1016)
DC-10-30	CUM THRU 8/79	CF6-50	153	7,360,604	0.021	Fleet	Wing & Center	WING + 400 (1016) CNTR - 440 (-1118)	WING 96 (244) CNTR 400 (1016)
L-1011	7/77 - 6/79	RB211	6	238,837	0.025	Delta	Wing & Center	WING + 285 (724) CNTR - 340 (-864)	WING 96 (244) CNTR 388 (986)
B727	7/78 - 6/79	JT8D	353	10,991,200	0.037	Fleet	Aft Fus Side & Ctr	SIDE - 272 (-691) CNTR - 260 (-660)	SIDE 154 (391) CNTR 250 (635)
B737	7/78 - 6/79	JT8D	119	2,488,700	0.048	Fleet	Wing	WING + 150 (381)	WING 62 (157)
DC-9	7/78 - 6/79	JT8D	278	3,936,000	0.071	Fleet	Aft Fus Side	SIDE - 178 (-452)	SIDE 78 (198)

Source:

1. Pratt & Whitney JT9D Engine Removal Data Report, September 1979.
2. UAL letter C-00-72-05, dated 8-9-79.
3. GE CF6-6 Bi-Monthly Operational Report - July/August 1979.
4. GE CF6-50 Bi-Monthly Operational Report - July/August 1979.
5. Delta letter 1200-1, dated 7-31-79.
6. Pratt & Whitney JT8D Engine Removal Data Report - July 1979.

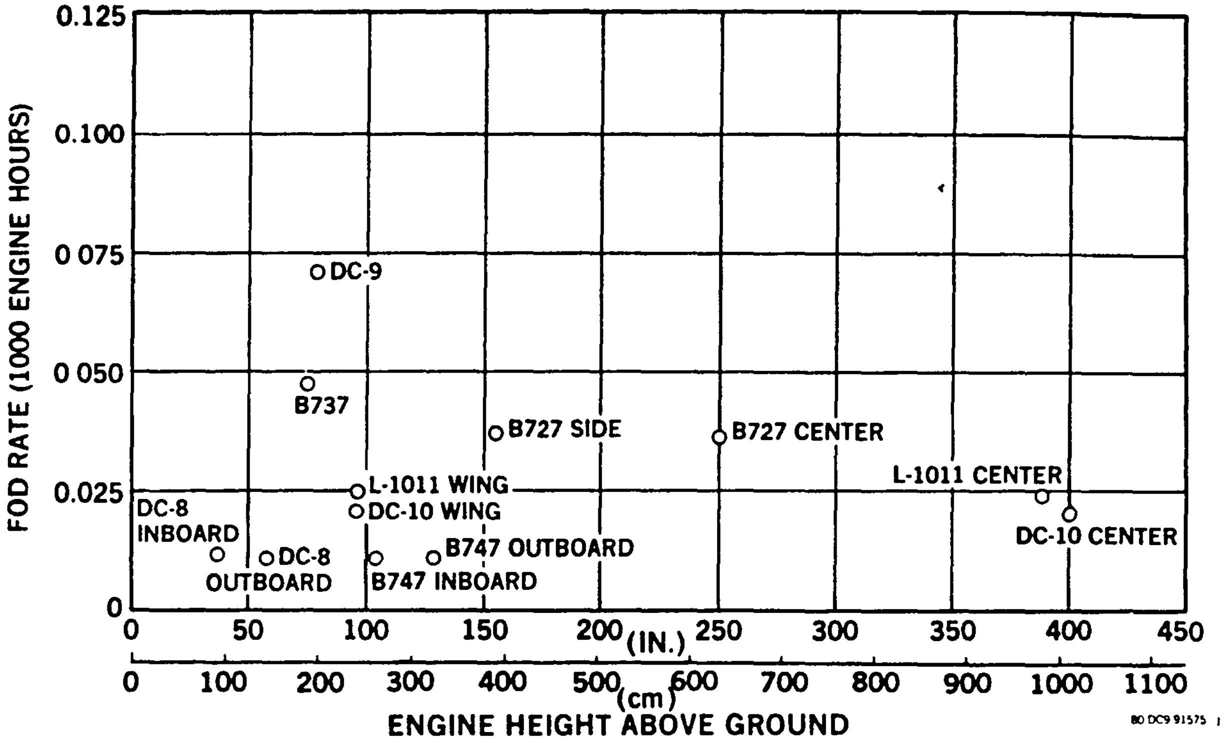


FIGURE 91. FOD/1000 ENGINE HOURS VERSUS ENGINE HEIGHT ABOVE GROUND

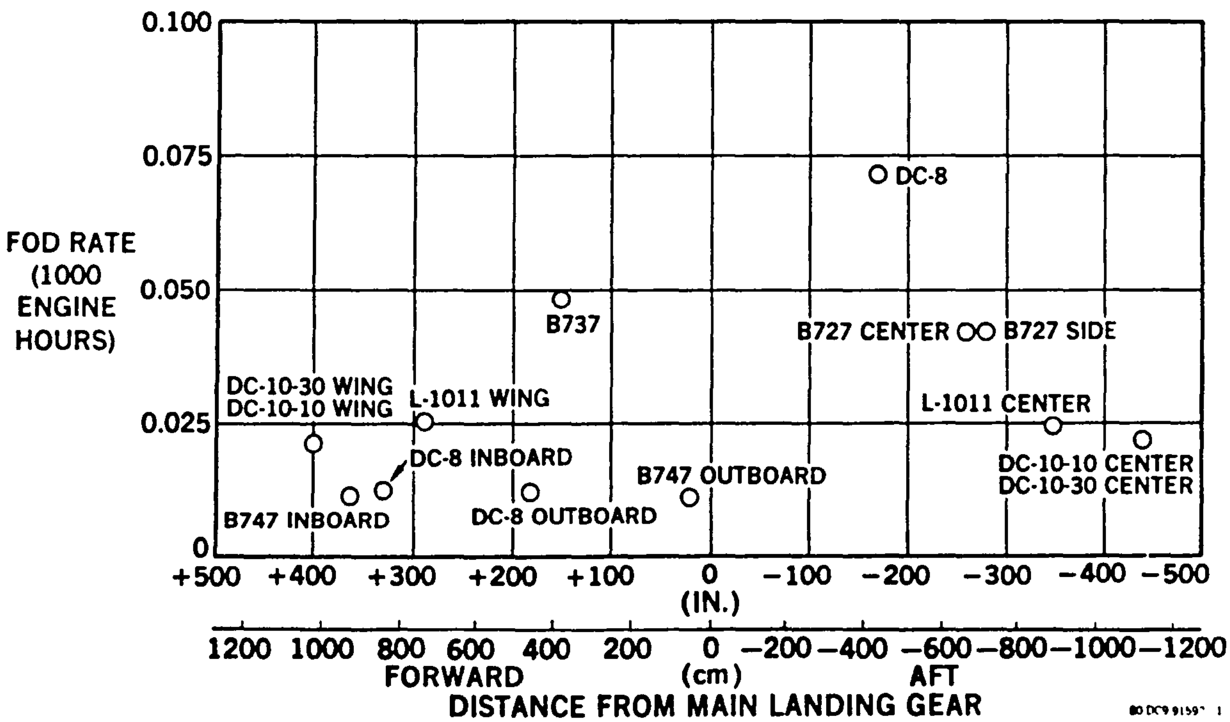


FIGURE 92. FOD/1000 ENGINE HOURS VERSUS DISTANCE OF ENGINE FROM MLG

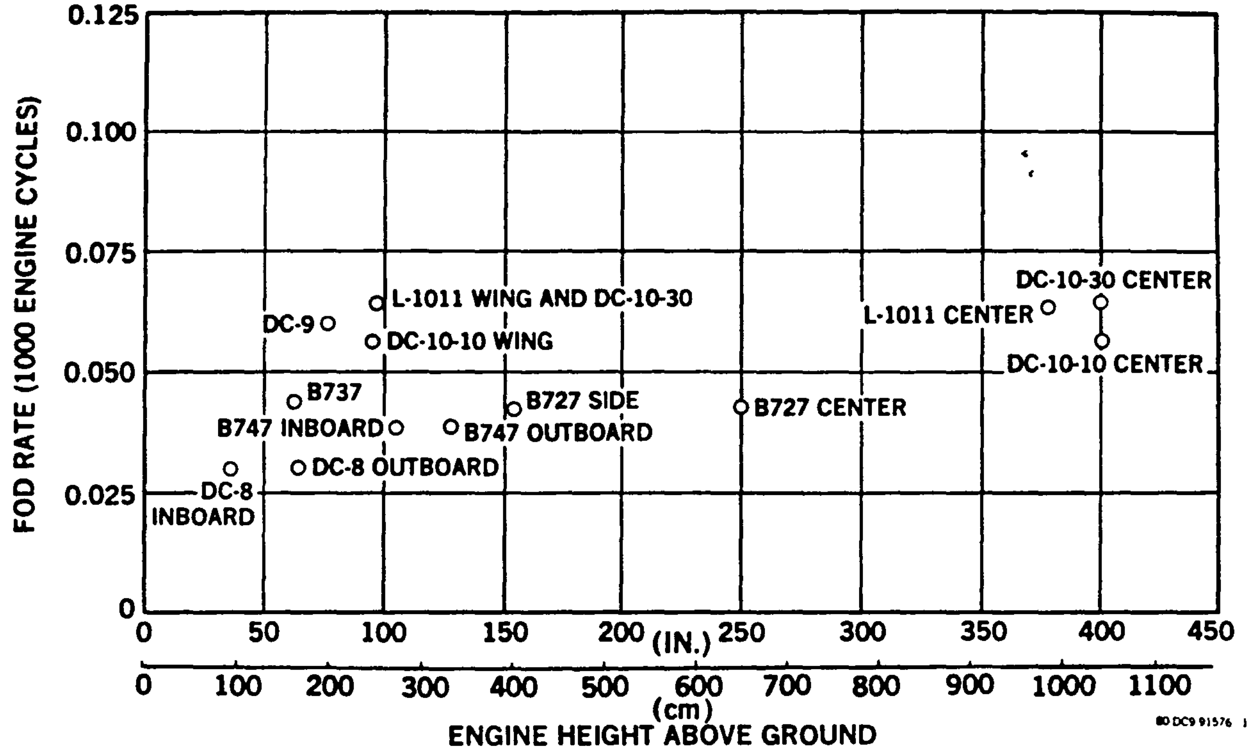


FIGURE 93. FOD/1000 ENGINE CYCLES VERSUS ENGINE HEIGHT ABOVE GROUND

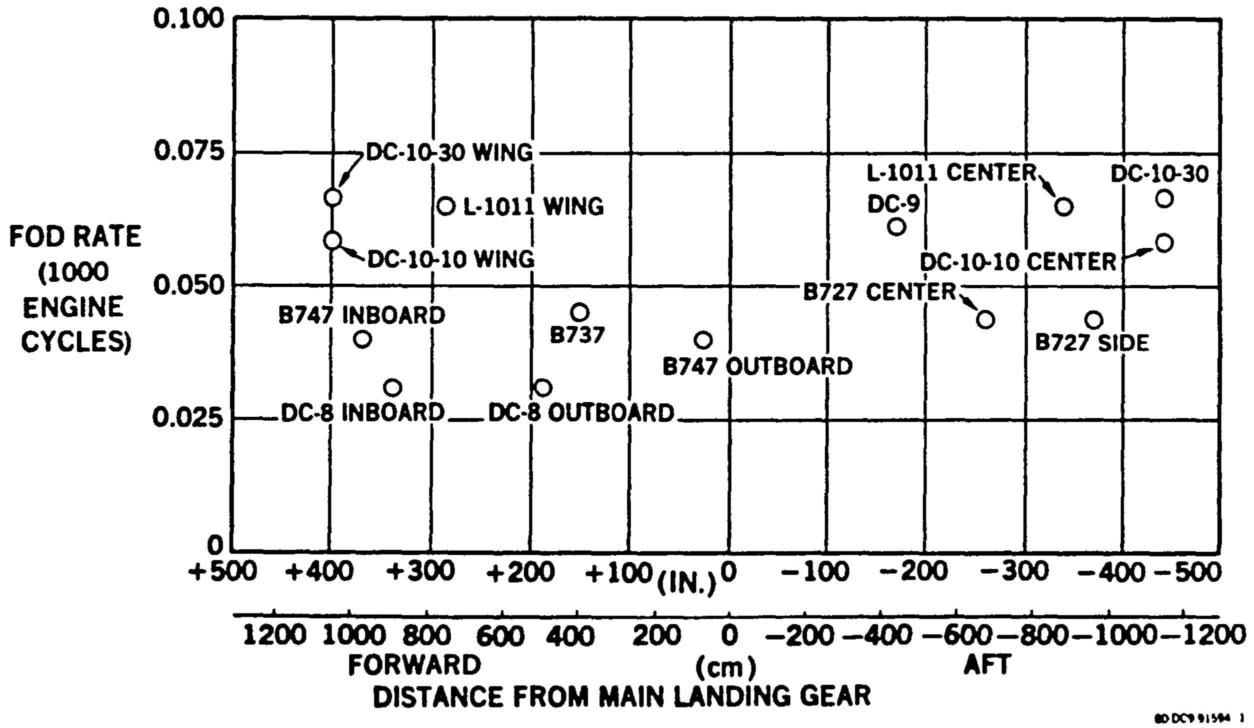


FIGURE 94. FOD/1000 ENGINE CYCLES VERSUS DISTANCE OF ENGINE FROM MLG

- From the FOD per 1000 engine hours data, wing mounted engines appear to be less susceptible to FOD then aft side mounted engines. However, this is not necessarily supported by the FOD per 1000 engine cycles data. For example, the FOD per 1000 cycles on the DC-9 aft fuselage side mounted engines (0.060) is less than the L-1011 (0.064) and DC-10-30 (0.065) which have two wing mounted engines.

- The B727 aft fuselage side mounted engines experienced one of the lowest FOD per 1000 cycle rates. The B727 aft side mounted engines are mounted 154 in. (391 cm) off the ground as compared to 78 in. (198 cm) on the DC-9. This suggests that height above the ground, out of the direct path of debris thrown up by the main landing gear, is an important consideration in FOD rates on aft fuselage mounted engines. High mounting off the ground could minimize FOD and lend support to other tradeoff considerations favoring aft mounted propfan engines on the DC-9 Super 80.

- FOD per 1000 engine cycles was lowest on aircraft engines equipped with JT3D, JT8D, and JT9D engines which suggests that some engines may be more resistant to FOD than others. The air inlet of the advanced turboprop engine is smaller than the turbofan and is protected by the propeller; therefore, it is the consensus that the core of the turboprop would receive less FOD than the core of the turbofan. The propellers would be susceptible to FOD; however, the fact that the propfans are of modular design and blades can be removed in pairs without removing the entire propeller could result in less propeller maintenance attributable to FOD than would be expected on the older turboprop engines.

- FOD per 1000 engine cycles was 0.065 in the DC-10-30 aircraft as compared to 0.057 in the DC-10-10 aircraft. These FOD rates together with the fact that nearly all DC-10-30 aircraft are operated by foreign airlines indicate that differences in operational environment are significant factors in FOD.

In summary, there are numerous variables associated with FOD, making it difficult to predict whether maintenance costs resulting from FOD would be higher or lower on wing or aft-mounted engines. The United Airlines cost data of Table 37 suggests that FOD is not a major consideration in terms of overall maintenance costs. The FOD per 1000 engine cycles data show a band of 0.035 between the lowest FOD rate on the DC-8 and the highest on the DC-10-30, which is equivalent to 3.5 cases of FOD per 10,000 cycles of aircraft operation. This could be considered a predicted maximum difference in FOD regardless of whether the propfan engines are wing or aft mounted.

MAINTAINABILITY CONCLUSIONS

This study appears to corroborate Allison's conclusion that comparative maintainability between an advanced turboprop and a turboprop engine does not appear to be a valid barrier against airline use of future turboprops. However, the engine maintenance costs will probably be considerably higher than quoted by Allison and somewhat higher than the JT8D-209 engine. Discounting the difference in engine maintenance costs, the effect of maintenance costs on the DC-9 Super 80 airframe would be minimal.

SECTION 6
ROM ECONOMIC ANALYSIS

The three selected propfan configurations are analyzed to establish their economic attributes compared to the baseline DC-9 Super 80 turbofan. The three propfan configurations evaluated the propulsion system installed on the wing (Configuration 1), the horizontal stabilizer (Configuration 3), or on the aft fuselage (Configuration 2). In this section, data are provided by which the plausible range of candidate configurations can be evaluated. The primary measure derived from the economic data is the direct operating cost; however, considerable emphasis is also placed on generation and determination of the input data used in computing the direct operating costs.

This section contains (1) the methodology by which the significant elements of the measure are derived, (2) the quantitative results based on the ground rules for the conduct of the study, (3) a comparison of the proposed propfan configurations and the turbofan baseline, and (4) the impact of cruise efficiency.

In order to accomplish the economics task, it is necessary to both generate and attain cost data from the internal Douglas organization of the airframe and from the industry in propulsion and propeller subsystems. Sensitivity analyses are accomplished with propulsion subsystem because of the uncertainties associated with the maintenance estimates received from industry sources.

ESTIMATING METHODOLOGY

Direct Operating Costs

Direct operating costs (DOCs) are derived by use of the Douglas Advanced Engineering Method, which represents a continuum of updating the 1967 ATA Method. In the main, the modifications made for updating include 1980 price levels, current operating practices, profiles and performance, and system attributes. There are no indirect cost elements included except those which have been traditionally considered in the DOC computation; i.e., cabin attendants and maintenance burden. The basic constituents of the DOC follow:

- Crew Cost - Computed as a function of block time, number of crew in cockpit, and maximum takeoff gross weight. A two-man crew is assumed.

- Cabin Attendants - Computed as a function of block time and the number of seats in the aircraft.

- Airframe Depreciation - Computed as a function of airframe price, block distance, productivity, and the period of depreciation. Productivity is assumed at 1,000,000 n mi per year and the depreciation period is 14 years (straight line method). A 10 percent residual value is assumed. Spares are included in the depreciation computation.

- Engine Depreciation - Computed as a function of the engine price and the same elements included for the airframe. A 10 percent residual value is assumed. Spares are included in the depreciation computation.

- Insurance - Computed as a function of aircraft cost, block distance, and productivity. Annual rate of 1 percent is assumed.

- Landing Fees - Computed as a function of maximum takeoff gross weight.

- Airframe Maintenance - Composed of hourly maintenance labor and material and cyclic maintenance labor and material. Labor is derived as a function of maintenance man hours per flight hour and per cycle (MMH/flight). Material is also derived on the same basis. Labor is assumed at $13.00 an hour, with a burden addition of 200 percent.

- Engine Maintenance - Composed of hourly maintenance labor and material and cyclic maintenance labor and material. Labor is derived as a function of maintenance man hours per flight hour per engine and the cyclic cost of maintenance man hours per flight per engine. Labor rates are as shown above for the airframe.

- Fuel - Computed as a function of block fuel and the price of fuel. The base price per gallon is assumed at $1.00; but, sensitivities are accomplished at $0.40, $0.80, $1.20, and $1.80 per gallon in accordance with predetermined ground rules. These price levels are based on the point in time that the statement of work was generated.

Airframe maintenance labor and material inputs to the DOC equations, provided by the Douglas Product Support department, are based upon historical experience with actual airline data. Propulsion maintenance labor and material cost inputs for the baseline turbofan are generated in the same manner.

Propulsion system maintenance estimates for the propfan configurations are generated as a band of values using industry inputs for the engine, gearbox, and propeller (in each case) as a base. Examination of the base industry values indicates them to be on the optimistic side. This conclusion is drawn from a considerable study effort by Douglas on the USN Marine Patrol Aircraft program and an evaluation of P3C and C-130 historical maintenance data. These data show that the P3C yields values approximately four times those offered by industry. It is recognized that a large proportion of the discrepancy is due to differences in utilization, bookkeeping, and efficiency between the military and the private sector. Therefore, the Douglas Product Support department prepared an independent estimate which resulted in a value about 2.1 times the industry base. At this point, a band was generated ranging between 1.16 and 2.1 times the base with a third point at 1.743 times the base. This latter value is an independent estimate developed by the advanced estimating group in Systems Analysis and appears to be acceptable to the individuals involved with the analysis of the data. However, it will be shown in a subsequent section that engine maintenance is a small fraction of the DOC and relatively insensitive to these perturbations.

Aircraft Price

The aircraft prices of the proposed candidates are derived on a discrete basis which involves the use of industrial engineering techniques. This means that proposed modifications to the baseline aircraft such as structures, configuration, engine installation, and rerouting of fuel lines are all viewed as separate issues for each proposed configuration. This involves in-depth technical inputs describing the changes and their impact on the weight statement. However, the estimates are not based on dollars per pound, but rather on man hours required to accomplish tasks associated with the changes. The weight data provide insight in to the material requirements and their costs. The airframe is estimated apart from the propulsion and propeller subsystems, but the final price includes the integration and assembly of these subsystems.

Since depreciation and other price-influenced elements represent a sizable portion of the DOC, it is deemed prudent to avoid parametric estimating techniques in order to attempt to achieve as much confidence in the airframe estimate as possible. Therefore, a representative study price is developed for a DC-9 Super 80 having a delivery date that would warrant pricing in 1980 dollars. Utilizing the costs of the precursor models, estimates are developed for the modifications required to achieve a baseline DC-8 Super 80. The difference between the representative study price and the newly developed estimate is only +1.97 percent (the new estimate is higher). This established the case for providing credible estimates of modifications and model changes and enhanced the DOC values as a measure.

The cost elements which are considered in developing the pricing estimates for the baseline and the proposed configurations are tabulated below:

- Design Engineering
- Fabrication
- Assembly
- Inspection
- Tooling
- Raw Materials/Purchased Parts
- Instruments and Special Equipment
- Product Support
- Sustaining Engineering
- Sustaining Tooling
- Manufacturing Development
- Planning
- Flight Test
- Laboratories
- Engines/Propellers/Gearboxes
- Miscellaneous

Propulsion subsystem cost data are obtained from documentation provided by industry sources.

The study does not attempt to conduct a market analysis, structure an airline operation, or study its economics. A conservative assumption is made for one manufacturer producing 200 aircraft with a peak rate of five per month and a predetermined but reasonable return on investment. It is further assumed that commonality would exist with the baseline aircraft with respect to tooling and hardware. The baseline also contains the same assumption regarding return on investment.

In deriving the in-house labor estimates, several other key assumptions are made. They are:

- Labor costs include a direct base labor rate, overhead, and G&A.
- Direct base labor rates are varied by organization functions.
- Technologies are assumed available and off-the-shelf.
- All peculiar elements of the proposed configurations are assumed to start at unit T_1.

In the process of deriving the estimates, it became apparent that all functional elements did not follow the same trend. This implies that tooling, for example, could increase while production labor for fabrication and assembly could decrease, which reflects primarily the design concept.

RESULTS

Aircraft Prices

It should be noted that the prices used in generating DOCs are considered to be study prices with consistency and propriety as the primary objectives of the estimates. Pricing strategy, market analyses, and airline economics are intentionally deleted. In the event that a comparison would be made of study prices versus quoted baseline prices, then a reduction in DOC on the order of 3 percent would be required. This implies that a higher study price is assumed. Therefore, comparisons should be made only among the configurations and with the estimated baseline aircraft. Price data have been normalized and are shown in Table 40.

In all these propfan configurations, the price exceeds that of the turbofan baseline, with the horizontal tail-mounted Configuration 3 being the least expensive. Configurations 1 and 2 are almost identical in price, but the individual constituents do vary; and decisions regarding choice are affected by the nature of these constituents.

The wing mounted case (Configuration No. 1) ranks the most expensive with respect to manufacturing because of the major changes. This configuration includes a new and larger horizontal stabilizer; a new and larger vertical stabilizer; the installation of new wing pylons; and plug additions to the fuselage. The addition of the new pylons represents a high cost area. but also involves a new wing leading edge. Also, all services which involve relocation from the existing aft position to a forward position, such as electrical, hydraulics, and air conditioning, require redevelopment and manufacturing costs at new positions on the progress curve. Changes to the tail section also involve new control surfaces.

TABLE 40

NORMALIZED COMPARATIVE PRICE MATRIX

Baseline Selection	DC-9-80	Configuration 1 (Wing Mount)	Config 3 (Horiz Stab. Mount)	Config 2 (Fuselage Mount)
*DC-9-80	1.00	1.120	1.067	1.123
Configuration 1 (Wing Mount)	0.893	1.00	0.952	1.003
Configuration 3 (Horiz Stab. Mount)	0.937	1.050	1.00	1.053
Configuration 2 (Fuselage Mount)	0.890	0.997	0.949	1.00

*Based on the estimated value

In Configuration No. 3 (horizontal stabilizer mount), the changes include a new and larger horizontal stabilizer; a new and larger vertical stabilizer; new control surfaces; the addition of a fuselage plug; minor landing gear modification to permit a 5 degree aft cant; and minor changes to the systems are made to locate the installation. This configuration permits the consolidation of certain tasks and developments because the new engine installation will occur in the new horizontal stabilizer.

The fuselage/pylon mounted case (Configuration No. 2) involves a new but smaller horizontal stabilizer; a new and larger vertical stabilizer; the addition of a fuselage plug; and new pods and pylons; as well as small modification to the aft landing gear to provide a 5 degree aft cant. When these are coupled to the fuselage/pylon concept, this configuration generates the highest tooling cost of the three configurations which is mainly due to the fuselage/pylon arrangement. Systems do not require major revisions as experienced with Configuration 1 because of the same general location of the engines. Manufacturing labor is ranked between the two other concepts.

Regardless of the configuration, the flight test and laboratory programs are considered to be of the same magnitude for each.

The DC-9 Super 80 turbofan enjoys the cost advantages of commonality with the many previous DC-9 versions and the quantity production which is expected to continue into the mid-1980s. Similarly, the propfan configurations would also share in the cost benefits of this long production run, as well as the benefits of the fuselage stretch and wing tip extensions provided by the DC-9 Super 80 turbofan configuration. Therefore, the propfan configurations only are charged with the unique changes from the turbofan configuration together with the learning curve advantages of commonality, extending in various amounts back to the earliest DC-9s.

Direct Operating Costs

Direct operating costs are developed for a series of conditions in order to explore their impact. In this process, over 800 DOCs are derived and are presented in several ways to expedite the comparisons. The DOCs are developed for the following purposes and are presented in Figures 95 through 142.

Throughout, the cruise conditions are as stated in Section 4 of this report, and are described as follows:

> As noted previously, the mission ground rules are such that at least one-third of the distance covered should be at cruise. This is in accordance with a general airline practice. Consequently, on the very short range cases such as 100 or 200 n mi (185 or 370 km), this cruise restriction determines the altitude (15,000 to 25,000 ft [4570 to 7620 m]) and optimum cruise speed (M = 0.55-0.65) compatible with these lower altitudes. For all other of the stage length variation cases, the cruise is performed at M = 0.8 at a constant altitude equal to the optimum initial cruise altitude.

Figure 95 compares the DOCs of the configurations and the baseline for the case of the $1.00 per gallon (26.49 cents/liter) fuel at various stage lengths and for the nominal engine maintenance assumption. The results show that the propfan configurations possess significant potential DOC advantages (approximately 7.2 to 9 percent), and in particular at the lower stage lengths where these aircraft may normally and regularly operate; e.g., 400 n mi (741 km). This reduction in propfan DOCs is magnified at the higher fuel prices, where this trend is the reality.

Figures 96 through 98 consider the base case propfan (8 blade, 800 ft/sec [244 m/sec]) tip speed and disc loading of 37.5 shp/ft^2) [301 kW/m^2] at M_{cruise} = 0.80 and show the breakdown of the DOC elements at a constant fuel price but with variable engine maintenance assumptions. These data are presented graphically to emphasize the cost element distribution. In each case, Configuration 3 (tail mounted) exhibits the lowest DOC relative to the baseline. This lower DOC ranges from 7 to 9 percent below the turbofan base line. The largest cost drivers, however, are fuel, depreciation, and the combined elements of the crew. Of minor importance is the engine maintenance

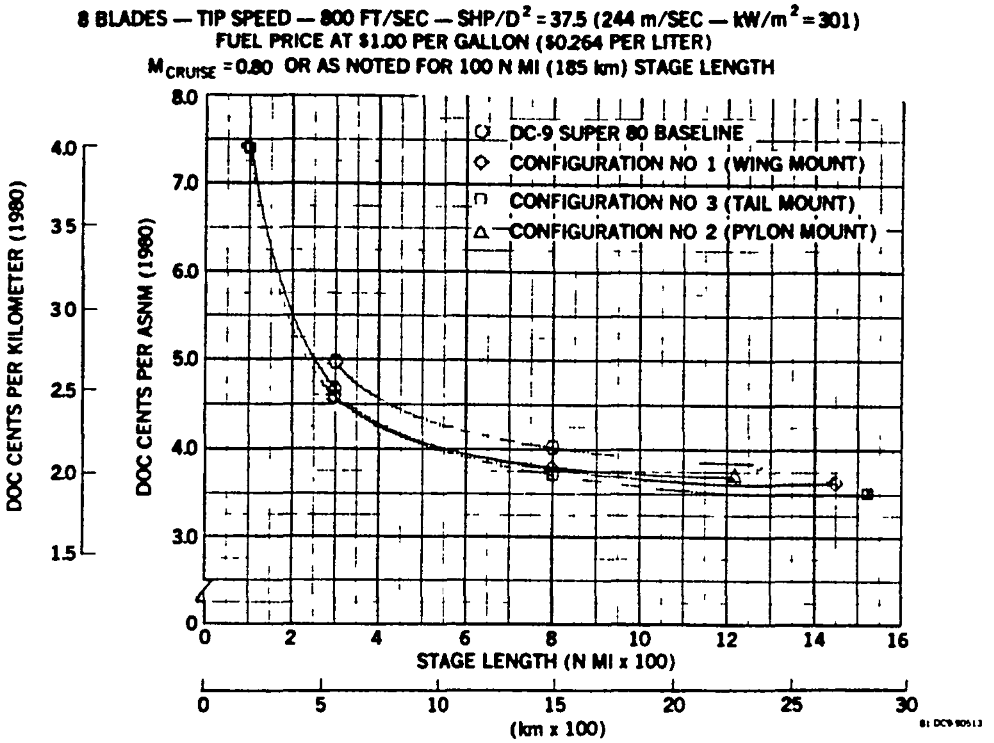


FIGURE 95. DIRECT OPERATING COST VERSUS STAGE LENGTH – ENGINE MAINTENANCE AT 1.743 TIMES MINIMUM BASE ESTIMATE

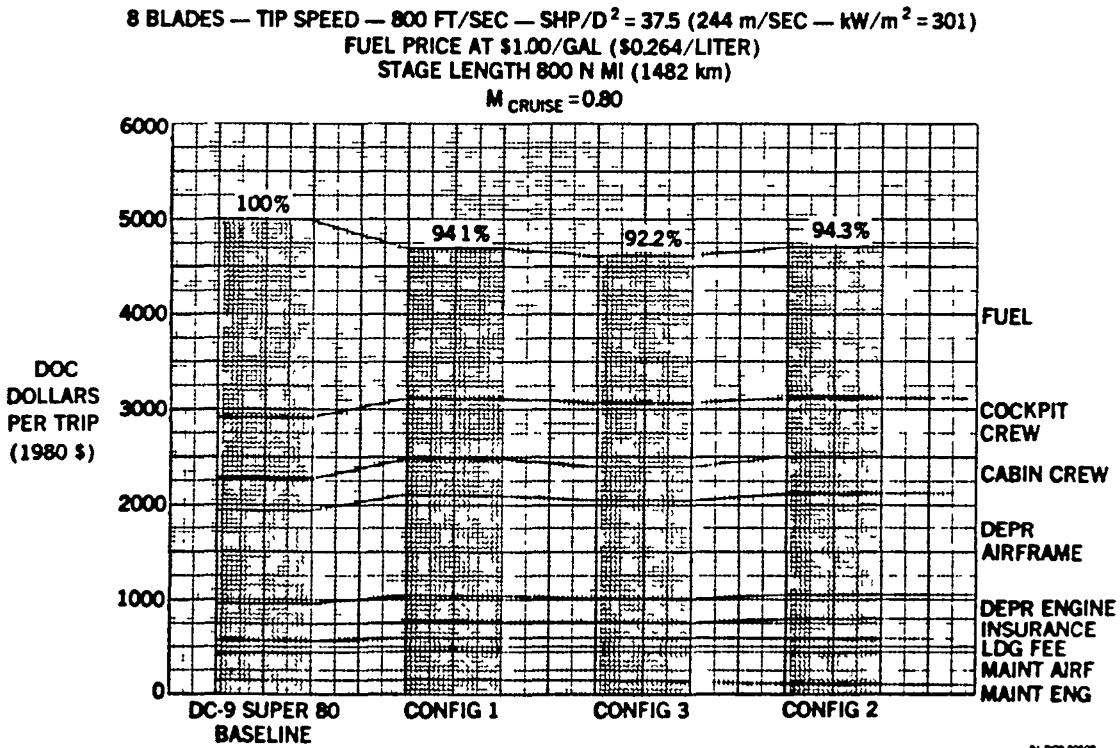


FIGURE 96. DIRECT OPERATING COST COMPARISON BY MAJOR ELEMENT – ENGINE MAINT AT 1.743 TIMES BASE ESTIMATE

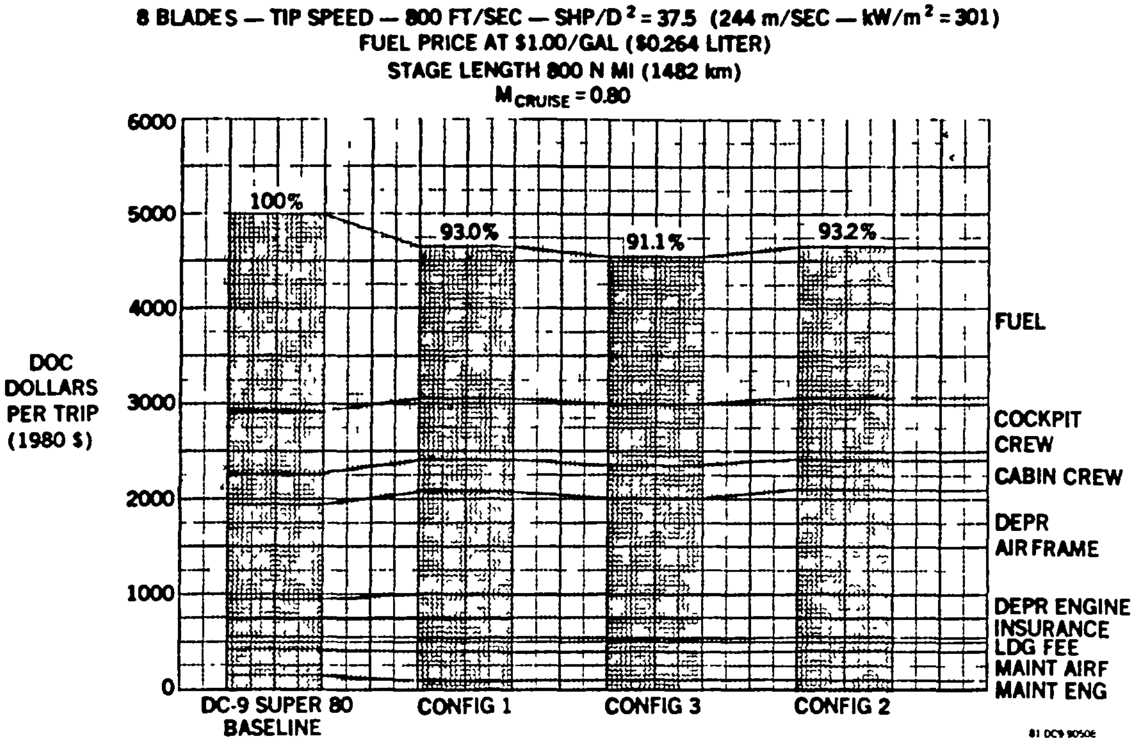


FIGURE 97. DIRECT OPERATING COST COMPARISON BY MAJOR ELEMENT – ENGINE MAINT AT 1.16 TIMES BASE ESTIMATE

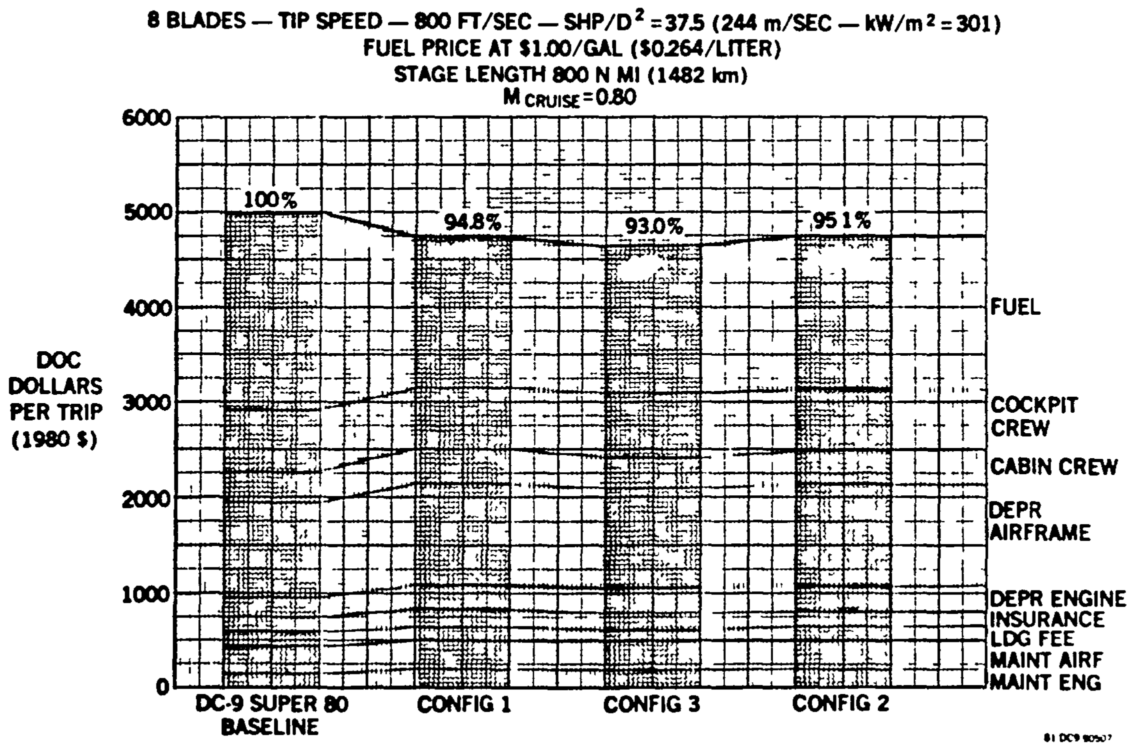


FIGURE 98. DIRECT OPERATING COST COMPARISON BY MAJOR ELEMENT – ENGINE MAINT AT 2.1 TIMES BASE ESTIMATE

upon which the sensitivities are performed. The impact of the driving cost elements of DOC and the minor impact of engine maintenance are again noted in Tables 41 through 43 which show the tabulated percentage values of the sensitivity studies. In all cases, engine maintenance represents only 2.3 to 4.4 percent of the total DOC which means that engine maintenance is relatively insensitive to the wide variation of maintenance assumptions made in this study (e.g., 1.16 to 2.12 times the base estimate by industry). This same type of percentage breakdown of DOC elements of the DC-9 Super 80 turbofan baseline is shown in Table 44.

For clarity, tabulated values of DOC for Configurations 1 and 3, as a function of stage length and engine maintenance assumptions, are summarized in Tables 45 and 46.

TABLE 41

COMPARATIVE IMPACT ON DIRECT OPERATING COST AS A FUNCTION OF ENGINE MAINTENANCE ASSUMPTIONS

Configuration 1 - Wing Mount

8 Blade - Tip Speed - 800 ft/sec - SHP/D^2 = 37.5 (244 m/sec - kW/m^2 = 301

800 n mi Stage Length (1482 km)

M_{cruise} = 0.80

DOC Element	Case 1 Engine Maint at 1 16 x Base Value (%)	Case 2 Engine Maint at 1.743 x Base Value (%)	Case 3 Engine Maint at 2 1 x Base Value (%)
Cockpit Crew	14.1	13.9	13 8
Cabin Crew	7 1	7.0	6 9
Airframe Depreciation	23.6	23.3	23.1
Engine Depreciation	5.2	5.1	5 1
Insurance	4.0	4.0	4.0
Landing Fees	3.0	3.0	3.0
Airframe Maintenance	6 6	6.5	6 4
Engine Maintenance	2.3	3 5	4.3
*Fuel	34.1	33.7	33.4
Total	100.0	100 0	100 0
Percent of DOC Baseline	93.0	94 1	94.9

*Base Case· $1.00/Gal (26.4¢/Liter)

TABLE 42

COMPARATIVE IMPACT ON DIRECT OPERATING COST AS A FUNCTION OF ENGINE MAINTENANCE ASSUMPTIONS

Configuration 3 - Horizontal Stab. Mount

8-Blades - Tip Speed - 800 ft/sec - SHP/D^2 = 37.5 (244 m/sec - kW/m^2 = 301)

800 n mi Stage Length (1482 km)

$M_{cruise} = 0.80$

DOC Element	Case 1 Engine Maint at 1 16 x Base Value (%)	Case 2 Engine Maint at 1.743 x Base Value (%)	Case 3 Engine Maint at 2 1 x Base Value (%)
Cockpit Crew	14 4	14.2	14.1
Cabin Crew	7.2	7.1	7.1
Airframe Depreciation	22.7	22.5	22.3
Engine Depreciation	5 3	5 2	5 1
Insurance	3 9	3.9	3.9
Landing Fees	3.1	3.0	3.0
Airframe Maintenance	6 9	6.8	6 7
Engine Maintenance	2.4	3.6	4 4
*Fuel	34.1	33.7	33.4
Total	100.0	100 0	100.0
Percent of Baseline DOC	91 1	92.2	93.0

*Base Case $1.00/Gal (26 4¢/Liter)

Sensitivity Studies

The results of these sensitivity studies are presented in tables as well as in plot form since in many cases the results are quite close and these differences are difficult to distinguish in the plotted results. However, the plots are useful for quickly noting trends or interpolating results between the selected data points.

Mach Number Variation - The sensitivity of the DOCs at the design range to cruise Mach number for the baseline DC-9 Super 80 and Configurations 1 and 3 is presented in Table 47 and Figures 99 through 101. The optimum M_{cruise} is shown from these ROM DOC plots to be approximately 0.76, which is consistent with the performance range and fuel burned results (Figures 30 and 31). As noted from these costing data, the optimum cruise Mach number increases slightly with decreasing fuel price. In general, this DOC trend with cruise

TABLE 43

COMPARATIVE IMPACT ON DIRECT OPERATING COST AS A FUNCTION OF ENGINE MAINTENANCE ASSUMPTIONS

Configuration 2 - Fuselage Mount

8 Blades - Tip Speed - 800 ft/sec - SHP/D^2 = 37.5 (244 m/set - kW/m^2 = 301)

800 n mi length (1482 km)

M_{cruise} = 0.80

Doc Element	Case 1 Engine Maint at 1.16 x Base Value (%)	Case 2 Engine Maint at 1.743 x Base Value (%)	Case 3 Engine Maint at 2.1 x Base Value (%)
Cockpit Crew	14 1	13 9	13.8
Cabin Crew	7.1	7.0	6 9
Airframe Depreciation	23.6	23.3	23.1
Engine Depreciation	5 2	5.1	5.1
Insurance	4.0	4.0	4.0
Landing Fees	3.0	3.0	3 0
Airframe Maintenance	6.6	6 5	6.4
Engine Maintenance	2.3	3.5	4.3
*Fuel	34.1	33 7	33 4
Total	100.0	100 0	100 0
Percent of Baseline Doc	93.2	94.3	95.1

*Base Case $1.00/gal (26 4¢/liter)

Mach number is relatively flat and shows the propfan DOCs to be consistently lower than those of the turbofan.

Stage Length Variation - A summary tabulation of the base case propfan (tip speed of 800 ft/sec (244 m/sec) and disc loading of 37.5 shp/ft^2 [301 kW/m^2]) showing the DOC variation for the three propfan configuration concepts at several stage lengths is presented in Table 48. These data are plotted in Figure 95. Carpet plots showing the variation of DOCs with propfan configuration, stage length, fuel price, and engine maintenance assumptions are all presented in Figures 102 through 138 in the following sequence:

Figures 102 through 111

Config DC-9 Super 80 Config 1, 3, 2	8 blade - 800 ft/sec (244 m/sec) tip speed, 37.5 shp/D^2 (301 kW/m^2)

TABLE 44

DISTRIBUTION OF DIRECT OPERATING COST ELEMENTS
DC-9 SUPER 80 TURBOFAN BASELINE

$M_{cruise} = 0.80$

800 n mi Stage Length (1482 km)

	%
Cockpit Crew	13.3
Cabin Crew	6.6
Airframe Depreciation	19.7
Engine Depreciation	4.2
Insurance	3.3
Landing Fees	2.8
Airframe Maintenance	5.9
Engine Maintenance	2.9
*Fuel	41.3
Total	100.0

*Base Case: $1.00/Gal (26.4¢/Liter)

<u>Figures 112 through 120</u>

Config 1, 3, 2 — 10 blade - 800 ft/sec (244 m/sec) tip speed, 37.5 shp/D^2 (301 kW/m^2)

<u>Figures 121 through 129</u>

Config 1, 3, 2 — 10 blade - 700 ft/sec (213 m/sec) tip speed, 30 shp/D^2 (241 kW/m^2)

<u>Figures 130 through 138</u>

Config 1, 3, 2 — 10 blade - 600 ft/sec (183 m/sec) tip speed, 26 shp/D^2 (209 kW/m^2)

TABLE 45

EFFECT OF ENGINE MAINTENANCE ASSUMPTIONS ON OVERALL DIRECT OPERATING COSTS

Configuration 1

8 Blade - Tip Speed 800 ft/sec - SHP/D^2 = 37.5 (244 m/sec - kW/m^2 = 301)

M_{cruise} = 0.80 (or as noted) for the 100 n mi [185 km] stage length)

Engine Maintenance Assumption	Stage Length n mi (km)	Direct Operating Costs - ¢/ASNM (¢/km)				
		Fuel Price $0.40 ($0.106/liter)	$0.80 ($0.211/liter)	$1.00 ($0.264/liter)	$1.20 ($0.317/liter)	$1.80/gal ($0.475/liter)
1.16 base estimate	100 (185)	5.930 (3.202)	6.851 (3.699)	7.311 (3.948)	7.772 (4.197)	9.152 (4.942)
	300 (556)	3.698 (1.997)	4.296 (2.320)	4.595 (2.481)	4.894 (2.643)	5.790 (3.126)
	800 (1482)	2.981 (1.610)	3.492 (1.886)	3.747 (2.023)	4.003 (2.161)	4.769 (2.575)
	1453* (2691)	2.809 (1.517)	3.327 (1.796)	3.586 (1.936)	3.845 (2.076)	4.623 (2.496)
1.743 base estimate	100 (185)	6.069 (3.277)	6.990 (3.774)	7.450 (4.023)	7.910 (4.271)	9.291 (5.017)
	300 (556)	3.766 (2.034)	4.364 (2.356)	4.662 (2.517)	4.961 (2.679)	5.858 (3.163)
	800 (1482)	3.025 (1.633)	3.536 (1.909)	3.792 (2.048)	4.047 (2.185)	4.813 (2.599)
	1453* (2691)	2.846 (1.537)	3.365 (1.817)	3.624 (1.957)	3.883 (2.097)	4.661 (2.517)
2.13 base estimate	100 (185)	6.168 (3.331)	7.089 (3.828)	7.549 (4.076)	8.009 (4.325)	9.390 (5.070)
	300 (556)	3.814 (2.059)	4.412 (2.382)	4.711 (2.544)	5.010 (2.705)	5.906 (3.189)
	800 (1482)	3.057 (1.651)	3.568 (1.927)	3.825 (2.065)	4.079 (2.203)	4.845 (2.616)
	1453* (2691)	2.813 (1.519)	3.392 (1.831)	3.651 (1.971)	3.910 (2.111)	4.688 (2.531)

*Max Range

TABLE 46

EFFECT OF ENGINE MAINTENANCE ASSUMPTIONS ON OVERALL DIRECT OPERATING COSTS

Configuration 3

8 Blade - Tip Speed 800 ft/sec - SHP/D^2 = 37.5 (244 m/sec - kW/m^2 = 301)

M_{cruise} = 0.80 (or as noted for the 100 n mi [185 km] stage length)

Engine Maintenance Assumption	Stage Length n mi (km)	Direct Operating Costs - ¢/ASNM (¢/km)				
		Fuel Price $0.40 ($0.106/liter)	$0.80 ($0.211/liter)	$1.00 ($0.264/liter)	$1.20 ($0.317/liter)	$1.80/gal ($0.475/liter)
1.16 base estimate	100 (185)	5.914 (3.193)	6.922 (3.738)	7.276 (3.929)	7.729 (4.173)	9.090 (4.908)
	300 (556)	3.652 (1.972)	4.240 (2.289)	4.534 (2.448)	4.827 (2.606)	5.709 (3.083)
	800 (1482)	2.922 (1.578)	3.423 (1.848)	3.674 (1.984)	3.924 (2.119)	4.696 (2.536)
	1524* (2822)	2.691 (1.453)	3.199 (1.727)	3.453 (1.865)	3.907 (2.110)	4.469 (2.413)
1.743 base estimate	100 (185)	6.058 (3.271)	6.980 (3.769)	7.414 (4.003)	7.868 (4.248)	9.229 (4.983)
	300 (556)	3.719 (2.008)	4.307 (2.326)	4.601 (2.484)	4.895 (2.643)	5.797 (3.130)
	800 (1482)	2.966 (1.602)	3.467 (1.872)	3.718 (2.008)	3.969 (2.143)	4.721 (2.549)
	1524* (2822)	2.772 (1.497)	3.280 (1.771)	3.534 (1.908)	3.788 (2.045)	4.550 (2.457)
2.13 base estimate	100 (185)	6.152 (3.322)	7.060 (3.812)	7.513 (4.057)	7.967 (4.302)	9.389 (5.070)
	300 (556)	3.768 (2.035)	4.356 (2.352)	4.650 (2.511)	4.944 (2.670)	5.826 (3.146)
	800 (1482)	2.998 (1.619)	3.499 (1.889)	3.950 (2.133)	4.000 (2.160)	4.753 (2.566)
	1524* (2822)	2.799 (1.511)	3.307 (1.786)	3.561 (1.923)	3.814 (2.059)	4.596 (2.482)

*Max Range

TABLE 47

EFFECT OF MACH NUMBER ON DIRECT OPERATING COST

8 Blades - Tip Speed 800 ft/sec - $SHP/D^2 = 37.5$

(244 m/sec - $kW/m^2 = 301$)

M_{cruise}	Aircraft	Design Range* n mi (km)	Direct Operating Costs = ¢/ASNM (¢/km)				
			$0 40 ($0 106/liter)	$0 80 ($0 211/liter)	$1 00 ($0.264/liter)	$1 20 ($0 317/liter)	$1 80/gal ($0 475/liter)
0 8	DC-9-80	1283 (2376)	2 460 (1 328)	3.109 (1 679)	3 434 (1 854)	3 759 (2 030)	4 734 (2.556)
	Config 1	1520 (2815)	2 209 (1 193)	2 704 (1 460)	2 952 (1 594)	3 200 (1 728)	3 943 (2 129)
	Config 3	1593 (2950)	2 248 (1 214)	2 734 (1 476)	2 977 (1 608)	3 220 (1 739)	3 950 (2 133)
0 76	DC-9-80	1283 (2376)	2 464 (1 331)	3 052 (1 648)	3 346 (1 807)	3 640 (1 965)	4 521 (2 441)
	Config 1	1520 (2815)	2 230 (1 204)	2 727 (1 473)	2 943 (1 589)	3 158 (1 705)	3 805 (2 055)
	Config 3	1593 (2950)	2 274 (1 228)	2 696 (1 456)	2 908 (1 570)	3 119 (1 684)	3 753 (2 027)
0 65	DC-9-80	1283 (2376)	2 592 (1 400)	3 206 (1 731)	3 514 (1 897)	3 822 (2 064)	4 744 (2 562)
	Config 1	1520 (2815)	2 431 (1 313)	2 853 (1 5[illegible]1)	3 064 (1 654)	3 275 (1 768)	3 909 (2 111)
	Config 3	1593 (2950)	2 383 (1 287)	2 797 (1 510)	3 004 (1 622)	3 211 (1 734)	3 833 (2 070)

*See reference range for M = 0 8 cruise - Figure 3, and Table 9

DESIGN RANGE OF 1,283 N MI (2,376 km)

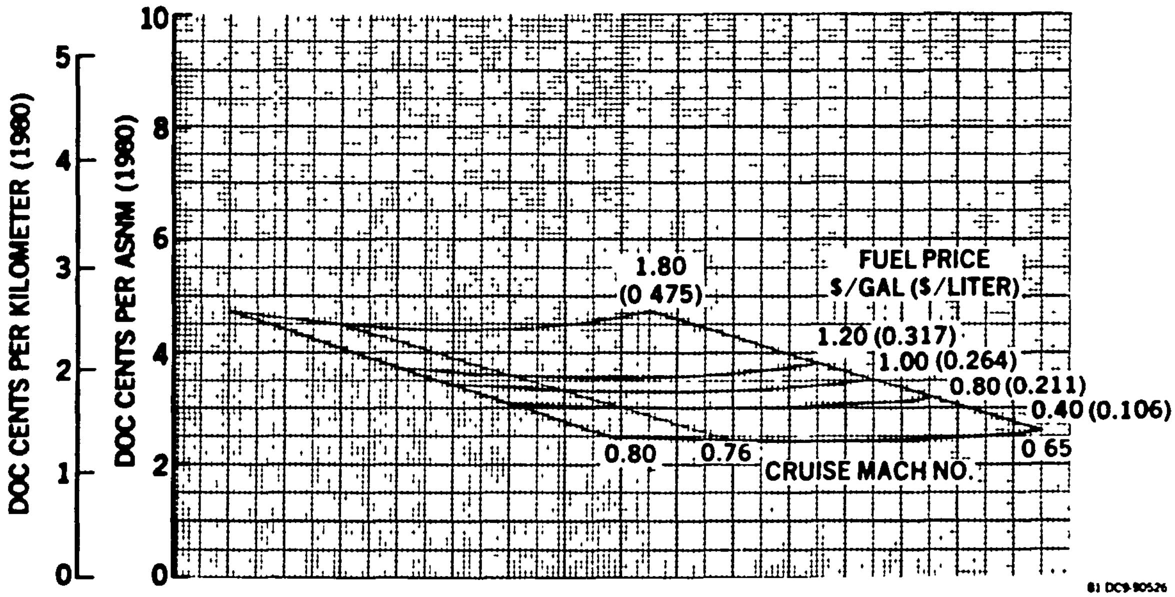


FIGURE 99. DC-9 SUPER 80 BASE CASE – IMPACT OF MACH NUMBER ON DIRECT OPERATING COST

8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D² = 37.5 (244 m/SEC — kW/m² = 301)
(DESIGN RANGE OF 1,520 N MI (2,815 km)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

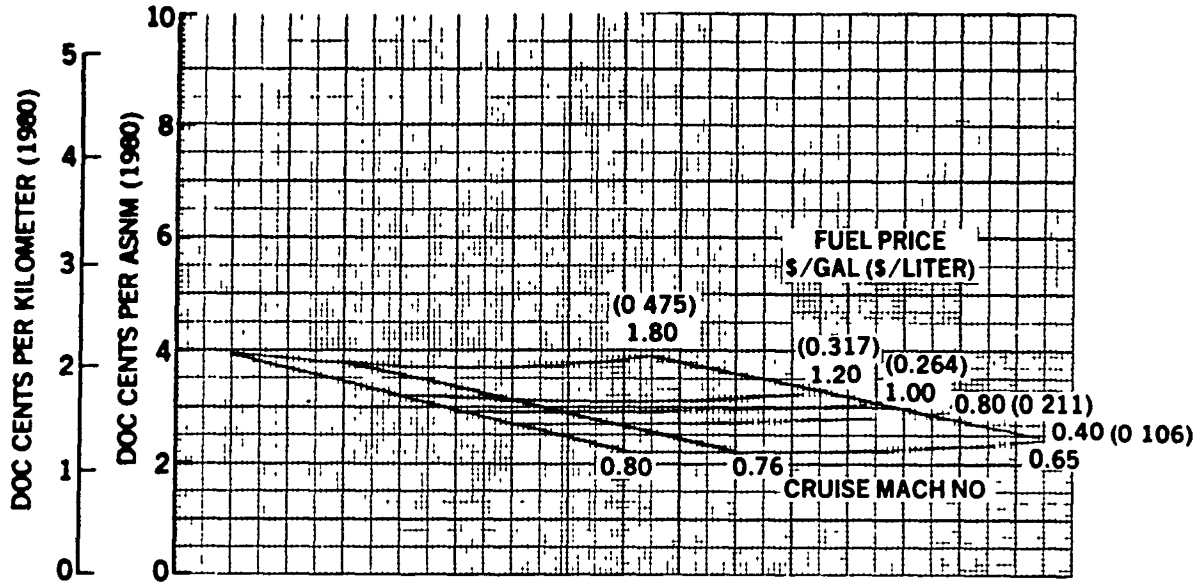
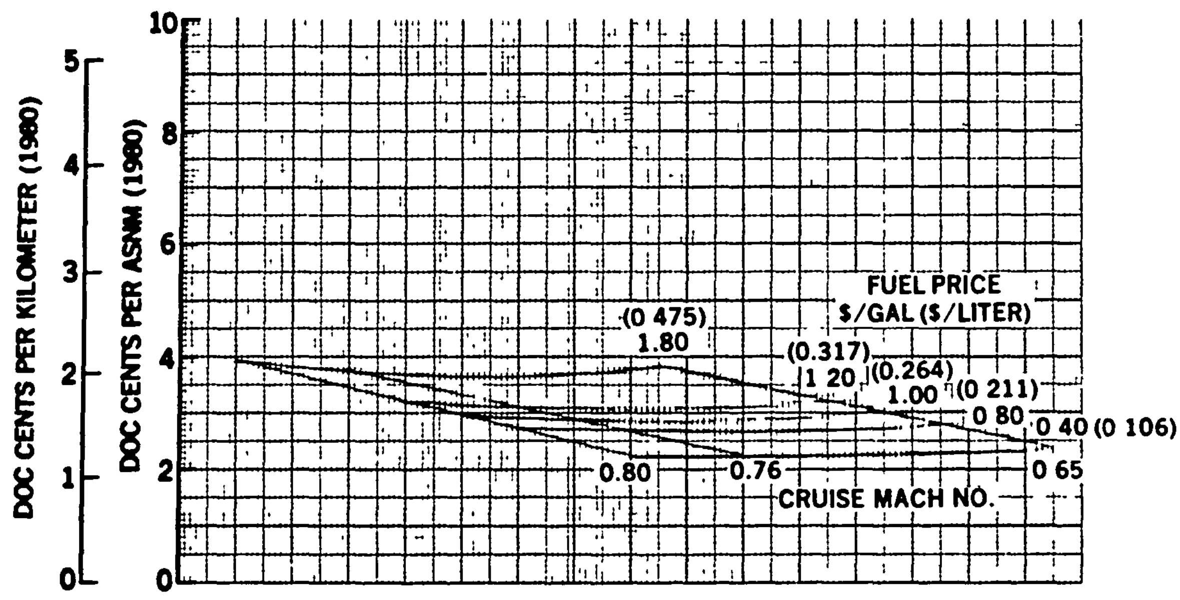


FIGURE 100. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT) IMPACT OF MACH NUMBER ON DIRECT OPERATING COST

81 DC9-90525

8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D² = 37.5 (244 m/SEC — kW/m² = 301)
DESIGN RANGE OF 1,503 N MI (2950 km)
(ENGINE MAINT AT 1 743 TIMES MINIMUM BASE ESTIMATE)



81 DC9 90524

FIGURE 101. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT) IMPACT OF MACH NUMBER ON DIRECT OPERATING COST

TABLE 48

EFFECT OF CONFIGURATION ON DIRECT OPERATING COSTS

8 Blade - Tip Speed 800 ft/sec - SHP/D^2 = 37.5 (244 m/sec - kW/m^2 = 301)

M_{cruise} = 0.80 (or as noted for the 100 n mi [185 km] stage length)

Configuration	Stage Length n mi (km)	Direct Operating Costs - ¢/ASNM (¢/km) Fuel Price $0.40 ($0.106/liter)	$0.80 ($0.211/liter)	$1.00 ($0.264/liter)	$1.20 ($0.317/liter)	$1.80/gal ($0.475/liter)
DC-9 Super 80	100 (185)					
	300 (556)	3.792 (2.048)	4.570 (2.468)	4.959 (2.678)	5.348 (2.888)	6.514 (3.517)
	800 (1482)	3.032 (1.637)	3.698 (1.997)	4.031 (2.177)	4.364 (2.356)	5.363 (2.896)
	1267* (2346)	2.877 (1.553)	3.535 (1.909)	3.864 (2.086)	4.193 (2.264)	5.180 (2.797)
Configuration 1	100 (185)	6.069 (3.277)	6.990 (3.774)	7.450 (4.023)	7.910 (4.271)	9.291 (5.017)
	300 (556)	3.766 (2.033)	4.364 (2.356)	4.662 (2.517)	4.961 (2.679)	5.858 (3.163)
	800 (1482)	3.025 (1.633)	3.536 (1.909)	3.792 (2.048)	4.047 (2.185)	4.813 (2.599)
	1453* (2691)	2.846 (1.537)	3.365 (1.817)	3.624 (1.957)	3.883 (2.097)	4.661 (2.517)
Configuration 3	100 (185)	6.058 (3.271)	6.980 (3.769)	7.414 (4.003)	7.868 (4.248)	9.229 (4.983)
	300 (556)	3.719 (2.008)	4.307 (2.326)	4.601 (2.484)	4.895 (2.643)	5.797 (3.130)
	800 (1482)	2.966 (1.602)	3.467 (1.872)	3.718 (2.008)	3.969 (2.143)	4.721 (2.549)
	1524* (2822)	2.772 (1.497)	3.280 (1.771)	3.534 (1.908)	3.788 (2.045)	4.550 (2.457)
Configuration 2	100 (185)	6.076 (3.281)	7.005 (3.782)	7.469 (4.033)	7.934 (4.284)	9.327 (5.036)
	300 (556)	3.778 (2.040)	4.382 (2.366)	4.684 (2.529)	4.986 (2.692)	5.892 (3.181)
	800 (1482)	3.035 (1.639)	3.547 (1.915)	3.803 (2.053)	4.059 (2.192)	4.827 (2.606)
	1214* (2248)	2.901 (1.566)	3.428 (1.851)	3.692 (1.994)	3.956 (2.136)	4.746 (2.563)

*Max Range

$M_{CRUISE} = 0.80$

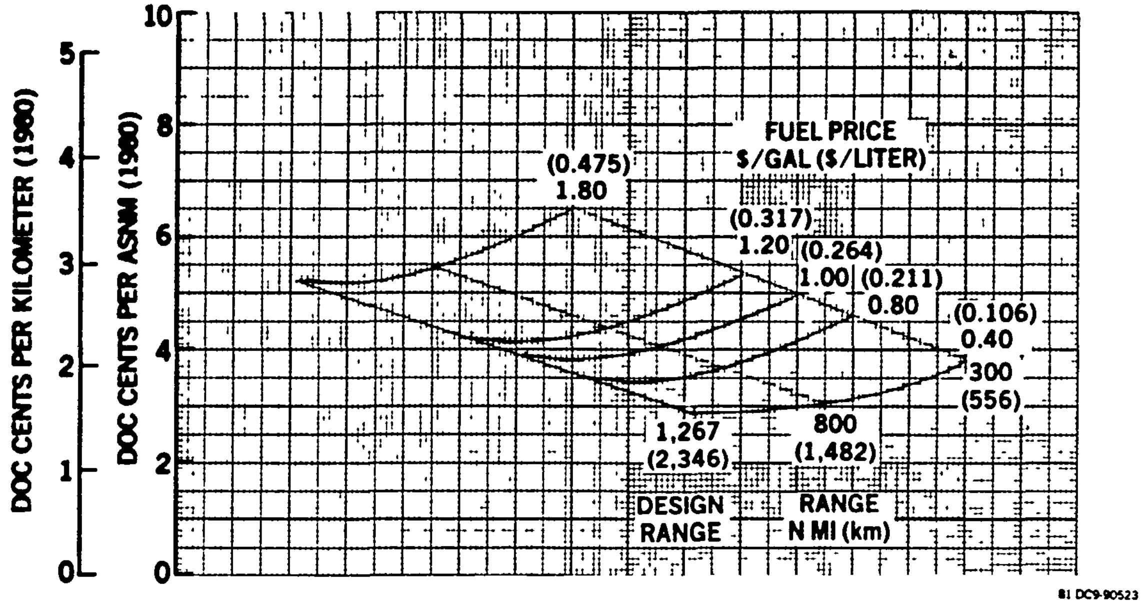
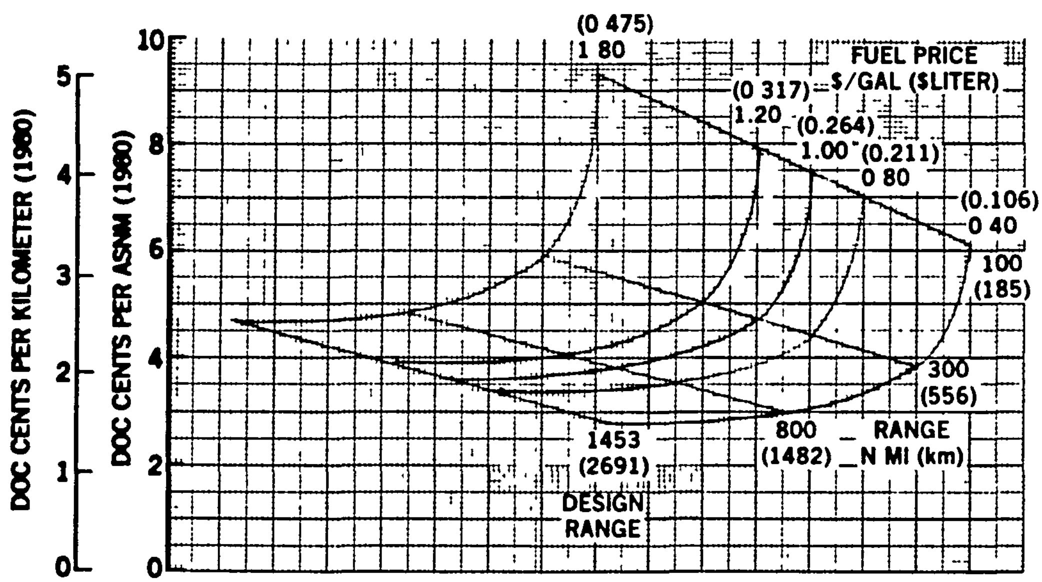


FIGURE 102. DC-9-80 TURBOFAN BASELINE – DIRECT OPERATING COSTS

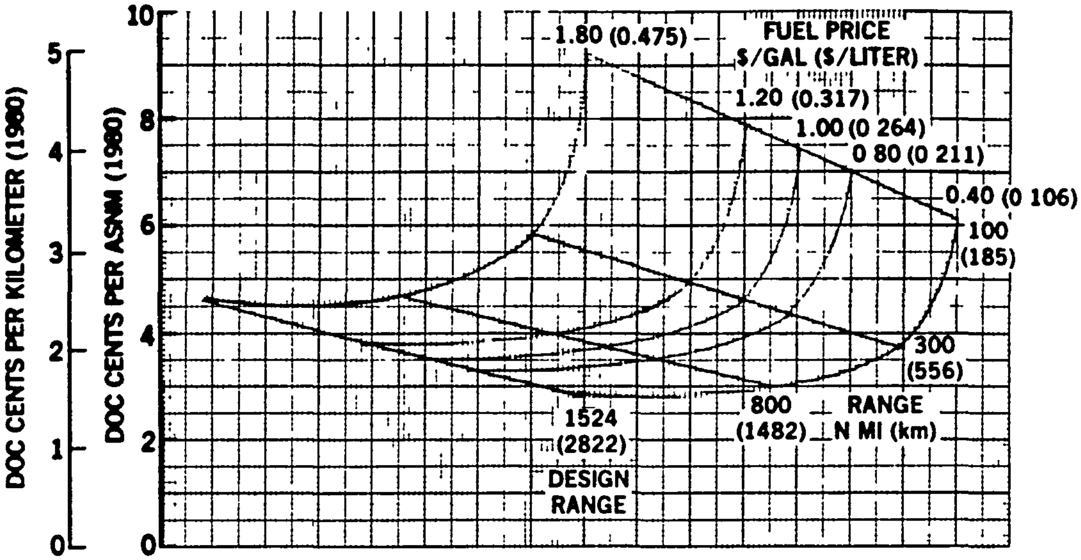
8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC · kW/m^2 = 301)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)
M_{CRUISE} = 0.80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81 DC9-90518

FIGURE 103. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT)

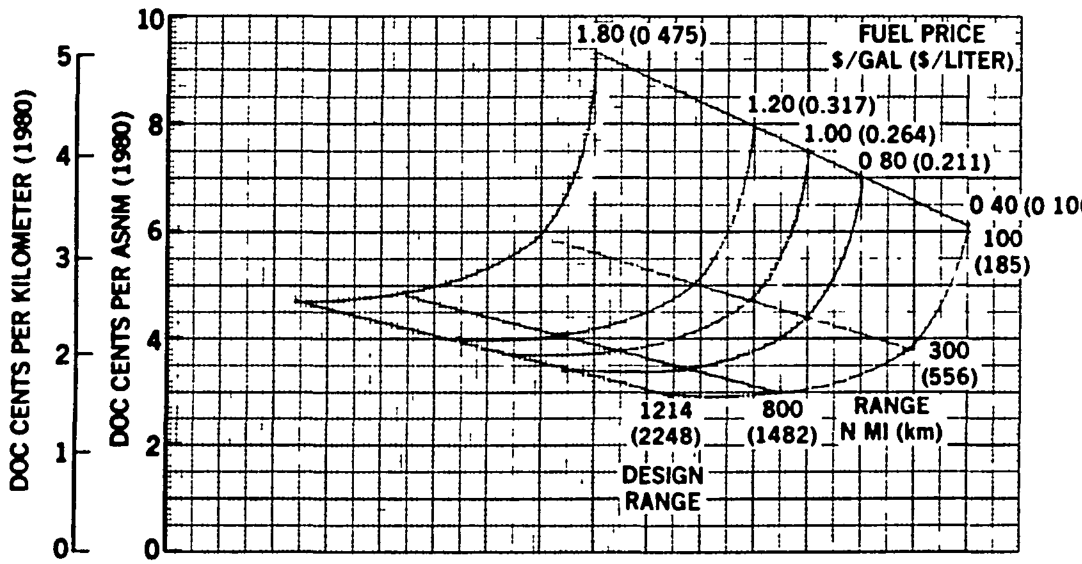
8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D² = 37.5 (244 m/SEC - kW/m² = 301)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)
M_{CRUISE} = 0.80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81 DC9-90522

FIGURE 104. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT)

8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D² = 37.5 (244 m/SEC - kW/m² = 301)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)
M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81 DC9-90519

FIGURE 105. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT)

8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC - kW/m^2 = 301)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)
M_{CRUISE} = 0 80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

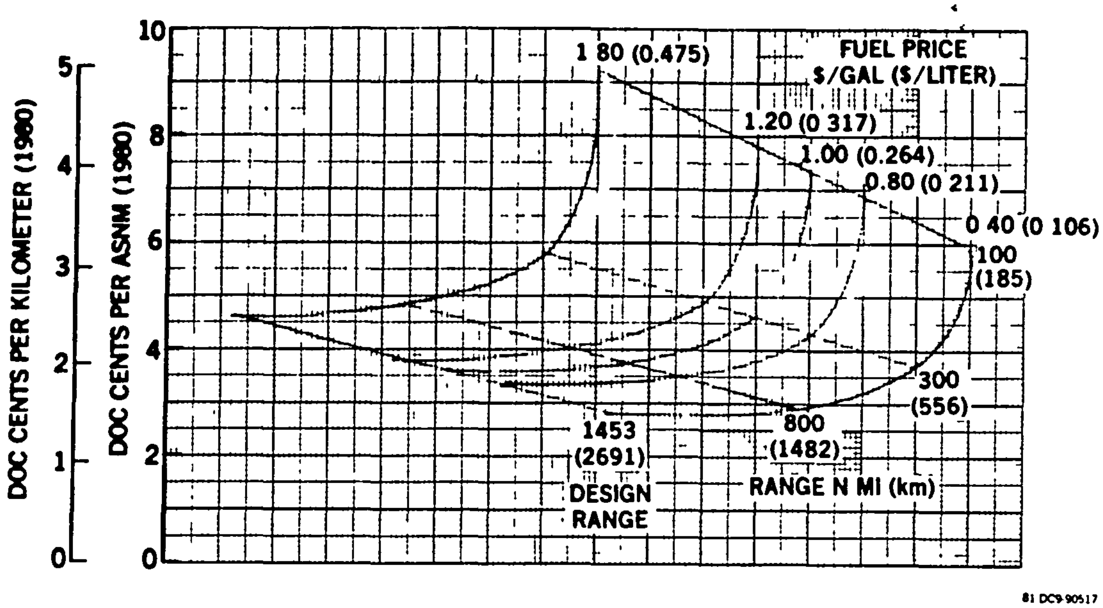


FIGURE 106. DC-9-80 PROPFAN CONFIGURATION NO.1 (WING MOUNT)
DIRECT OPERATING COSTS

8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC - kW/m^2 = 301)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)
M_{CRUISE} = 0 80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

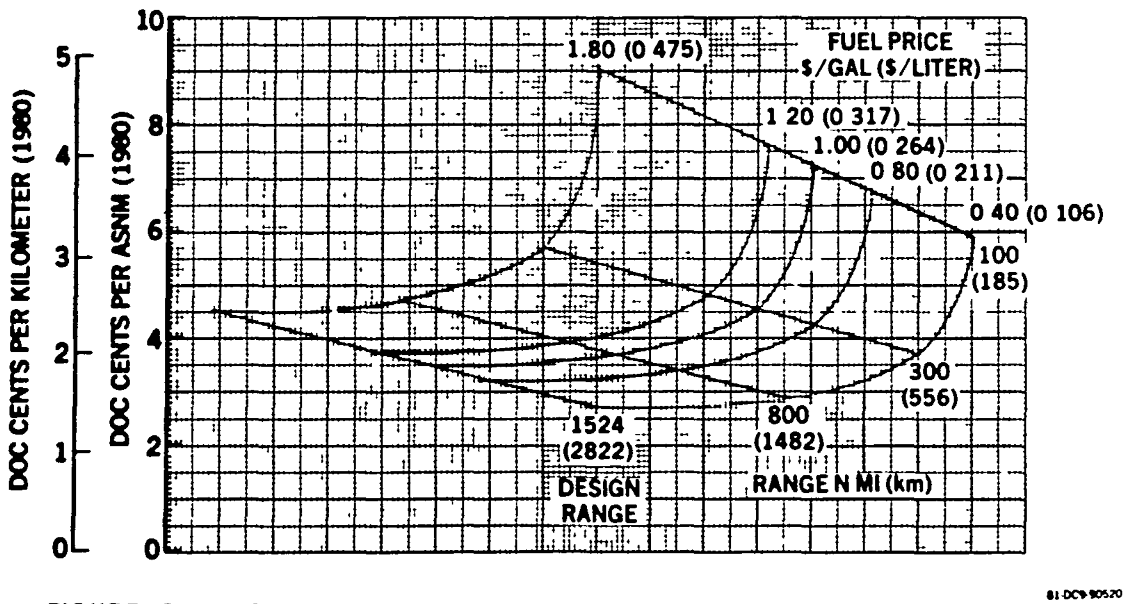


FIGURE 107. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ STAB. MOUNT)
DIRECT OPERATING COSTS

8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC — kW/m^2 = 301)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)
M_{CRUISE} = 0 80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

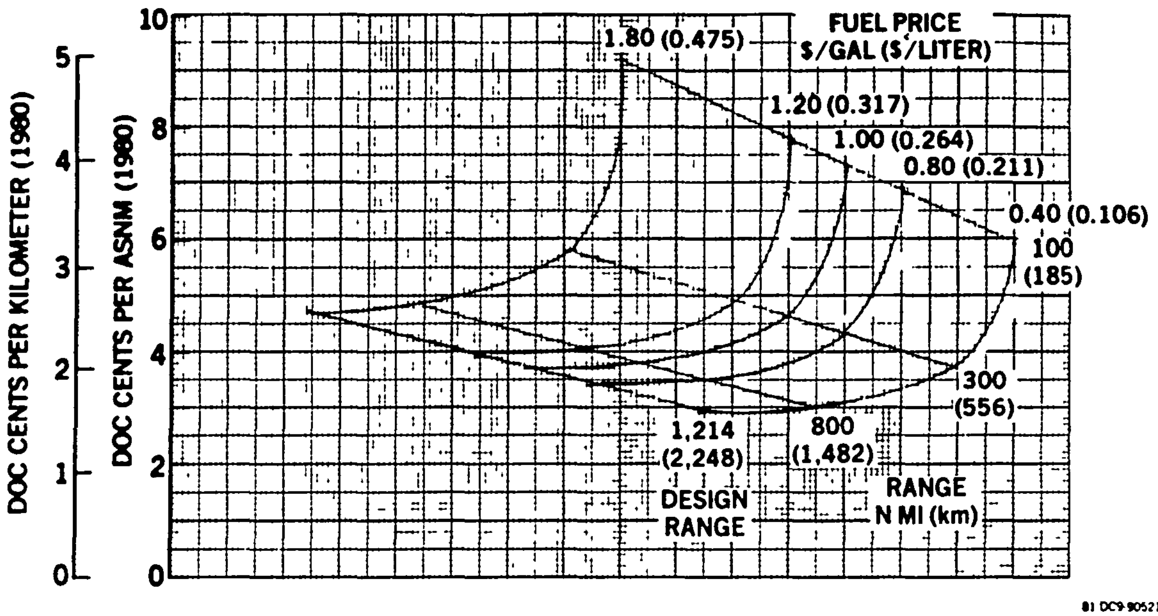


FIGURE 108. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT) DIRECT OPERATING COSTS

8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37 5 (244 m/SEC — kW/m^2 = 301)

M_{CRUISE} = 0 80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

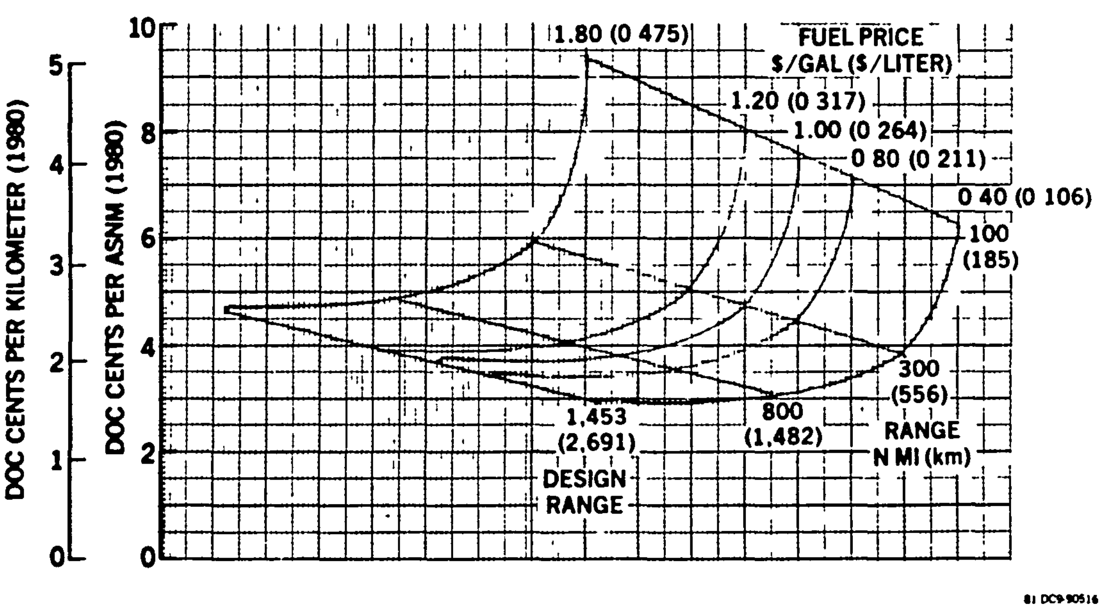
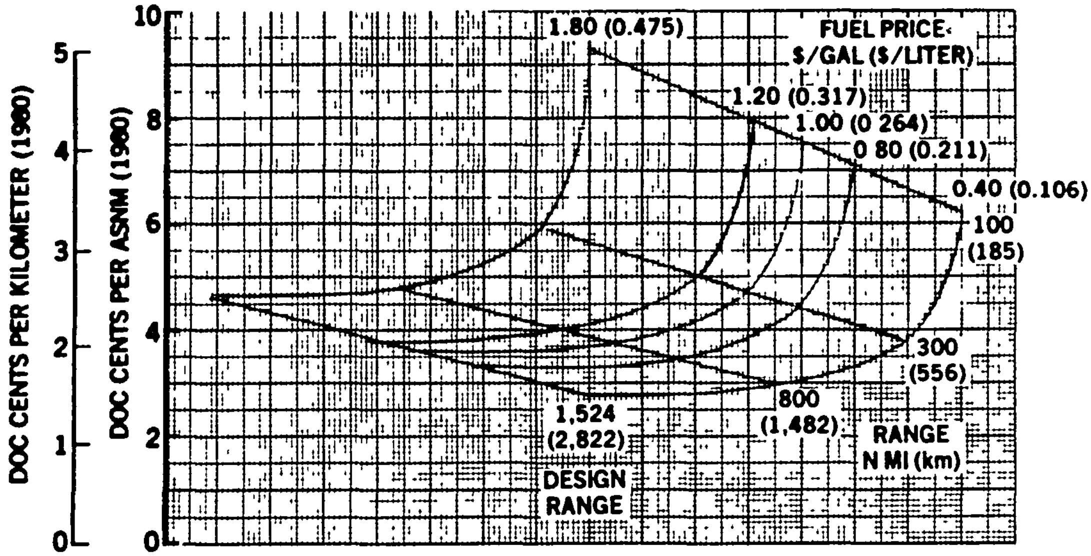


FIGURE 109. DC-9-80 PROPFAN CONFIGURATION NO.1 (ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D² = 37.5 (244 m/SEC — kW/m² = 301)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81 DC9-90515

FIGURE 110. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT) (ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

8 BLADES — TIP SPEED — 800 FT/SEC — SHP/D² = 37.5 (244 m/SEC — kW/m² = 301)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

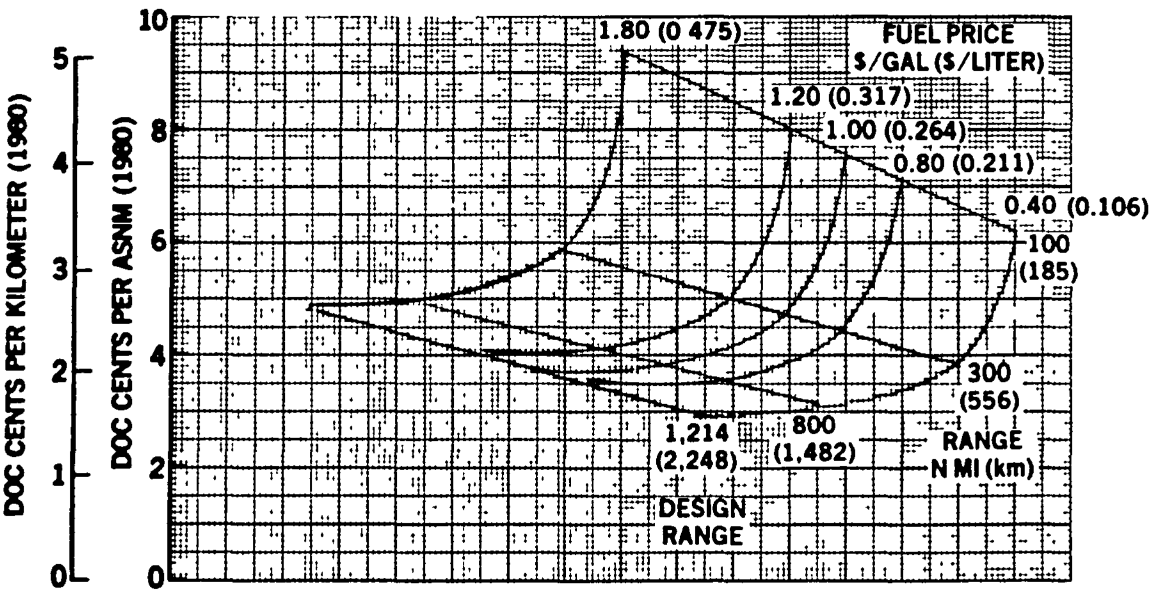


FIGURE 111. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT) (ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

81-DC9-90447

10 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC · kW/m^2 = 301)

M_{CRUISE} = 0.80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

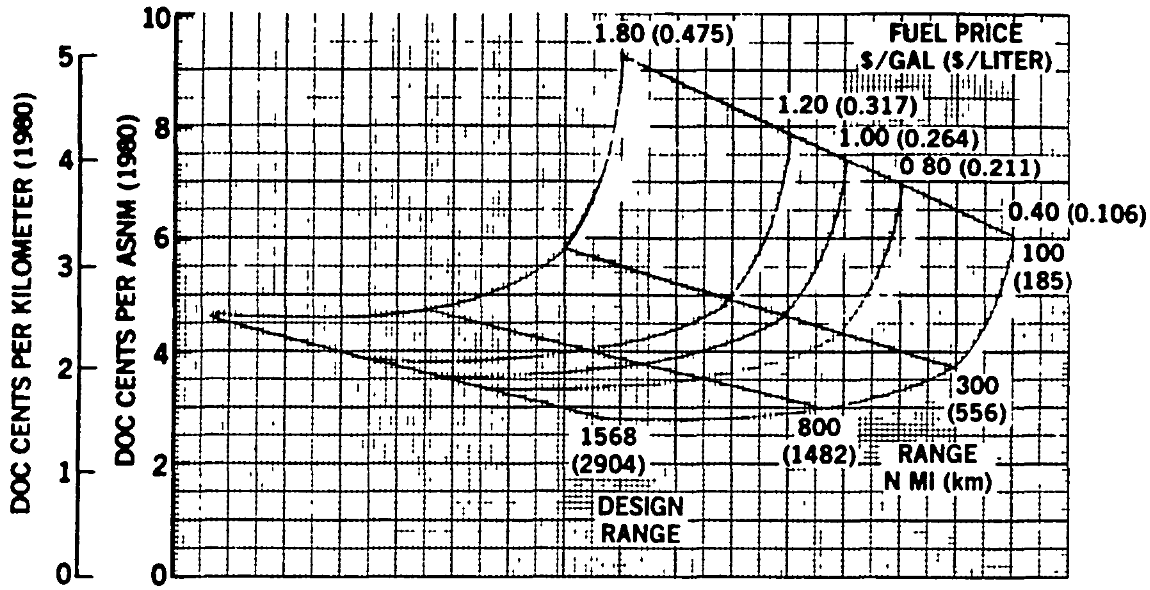
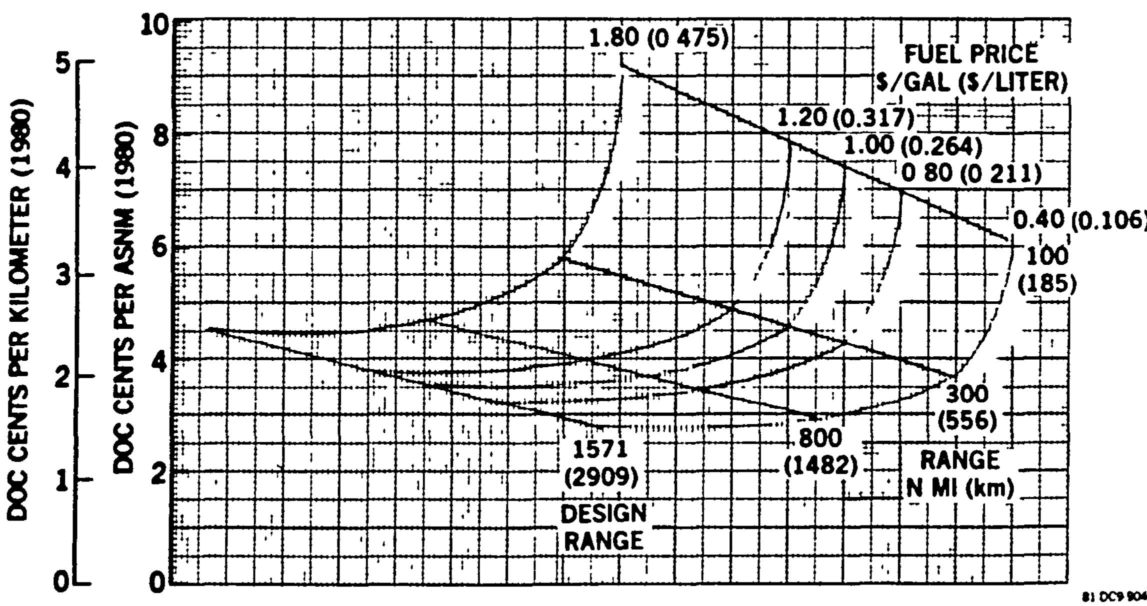


FIGURE 112. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

81 DC9 90446

10 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC · kW/m^2 = 301)

M_{CRUISE} = 0.80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81 DC9 90446

FIGURE 113. DC-9-80 PROPFAN CONFIGURATION NO 3 (HORIZ STAB. MOUNT)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC — kW/m^2 = 301)

M_{CRUISE} = 0.80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

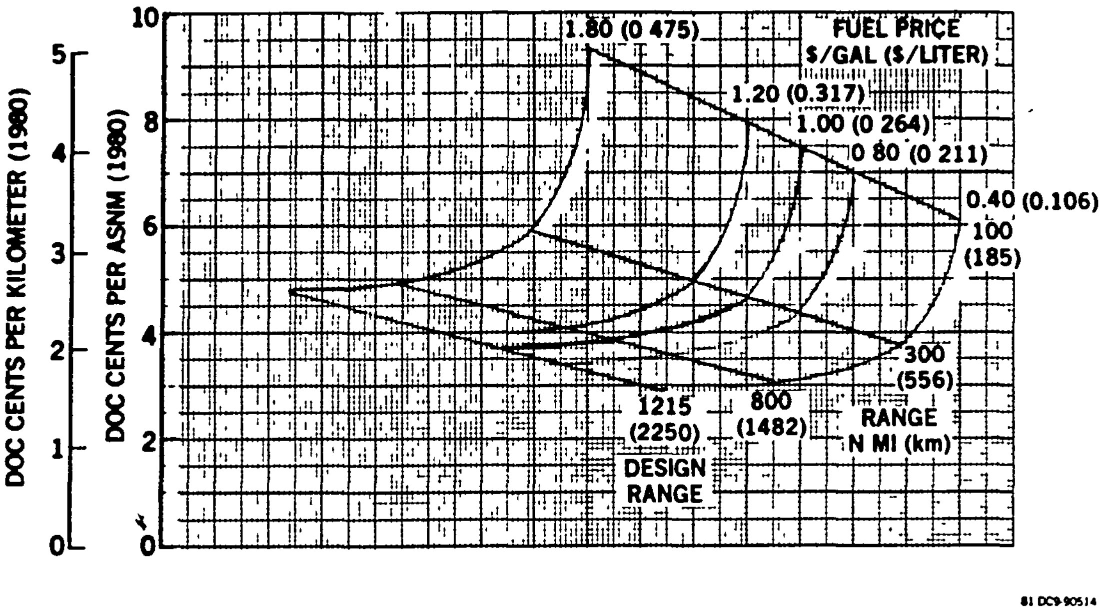


FIGURE 114. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC — kW/m^2 = 301)

M_{CRUISE} = 0.80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

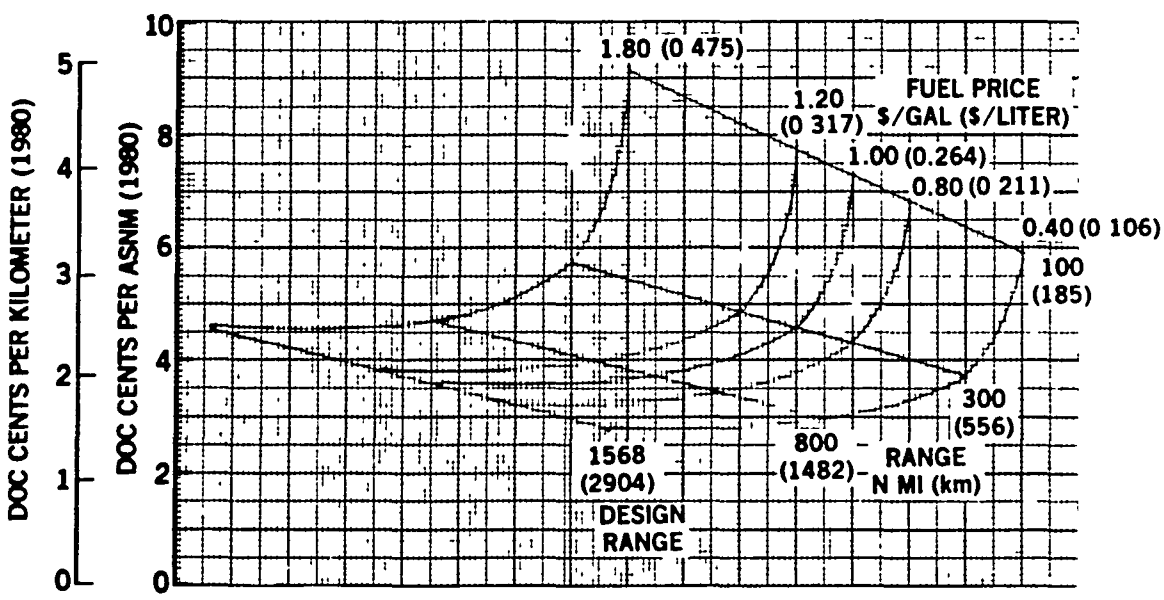


FIGURE 115. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC · kW/m^2 = 301)

M_{CRUISE} = 0.80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

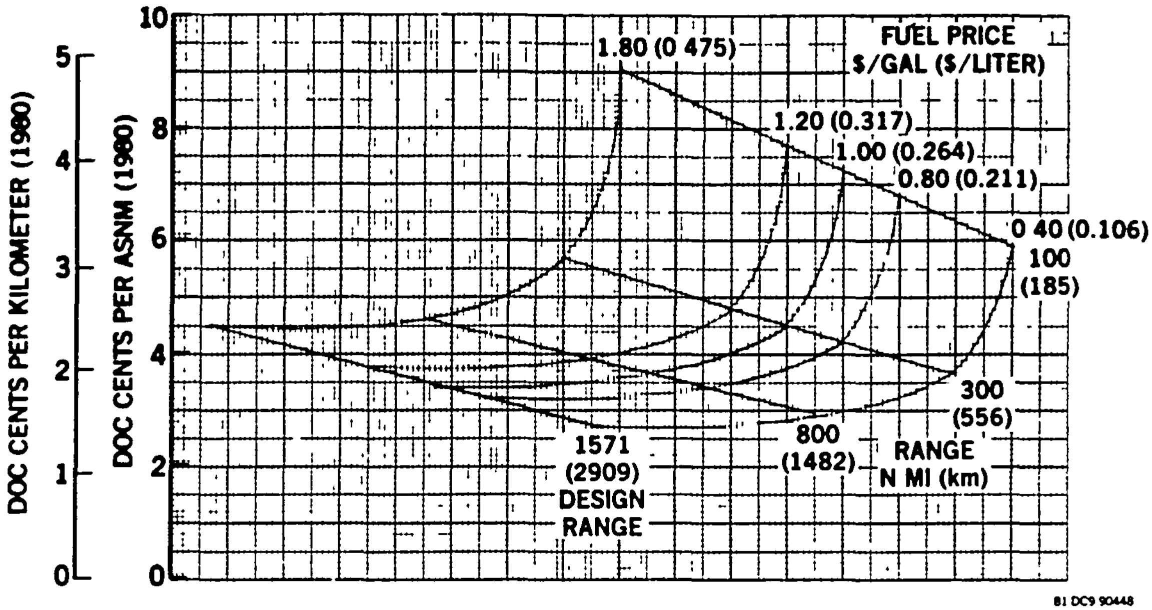


FIGURE 116. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC-kW/m^2 = 301)

M_{CRUISE} = 0.80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

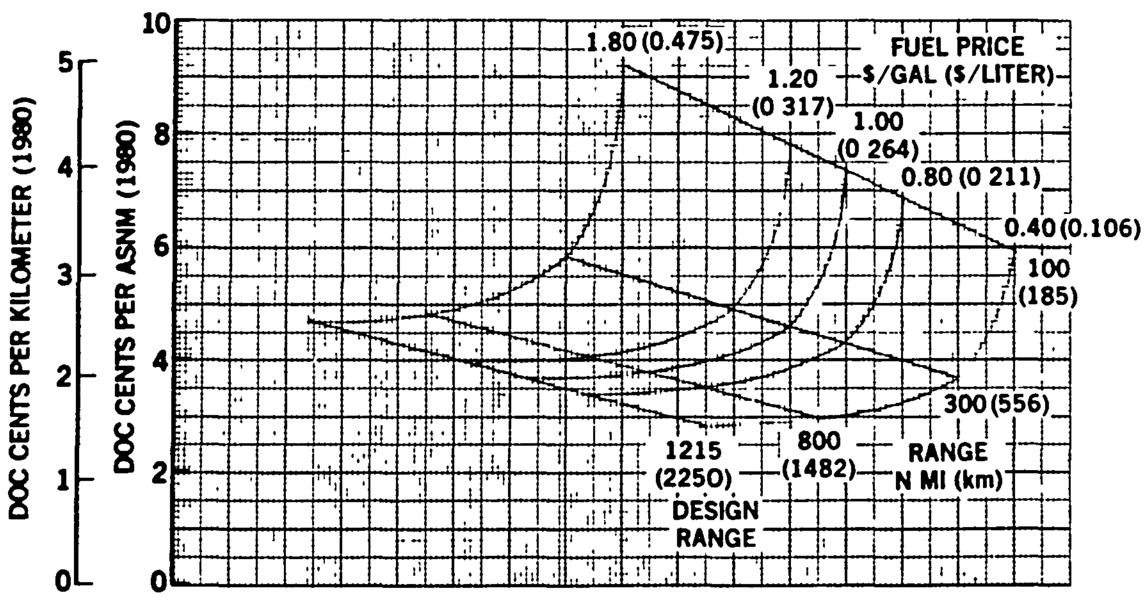
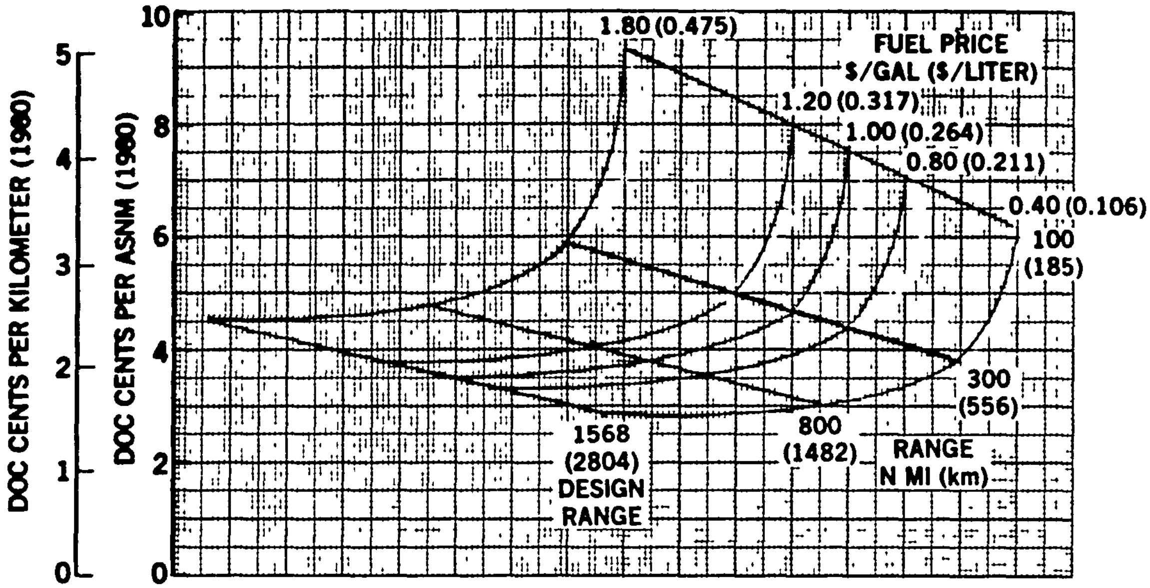


FIGURE 117. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT) 81 DC9 90444
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 800 FT/SEC — SHP/D² = 37.5 (244 m/SEC — kW/m² = 301)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

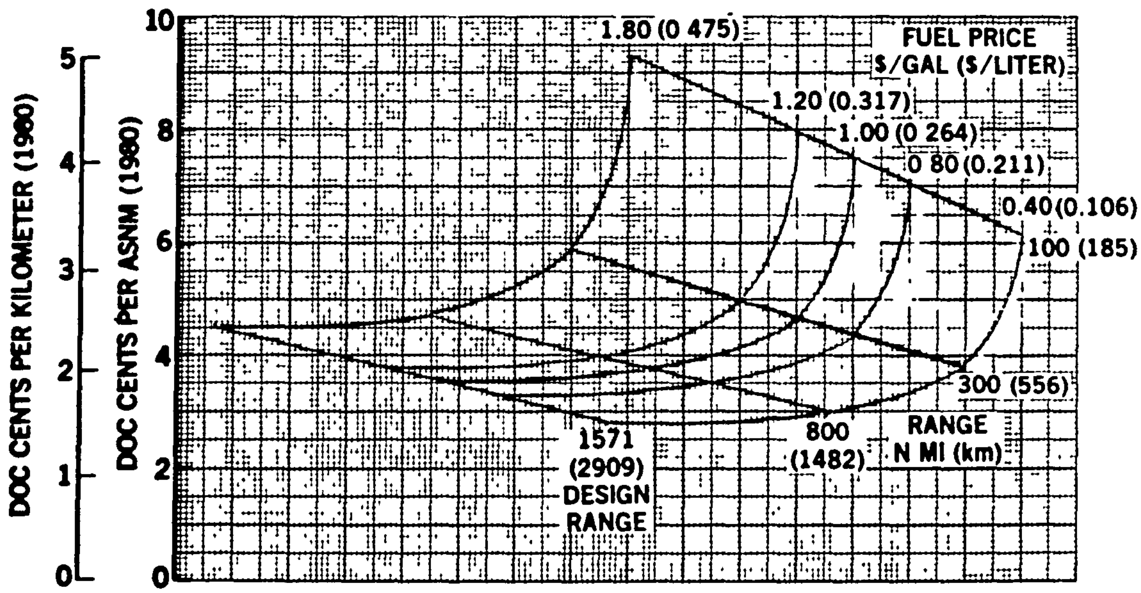


81-DC9-90449

FIGURE 118. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT)
(ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 800 FT/SEC — SHP/D² = 37.5 (244 m/SEC — kW/m² = 301)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81-DC9-90445

FIGURE 119. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT)
(ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 800 FT/SEC — SHP/D^2 = 37.5 (244 m/SEC — kW/m^2 = 301)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

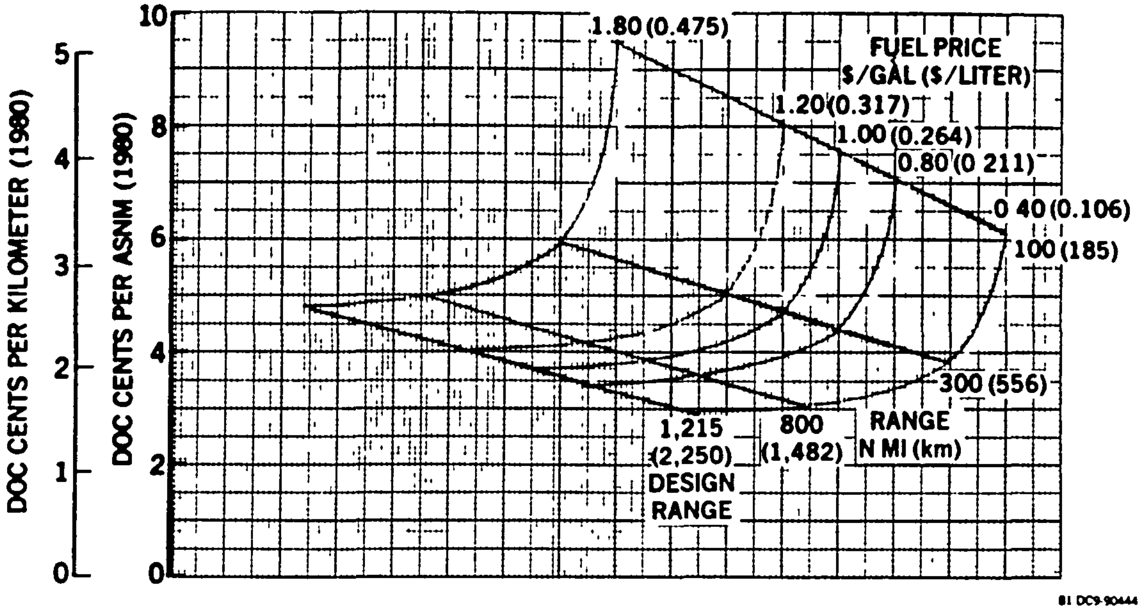


FIGURE 120. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT)
(ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 700 FT/SEC — SHP/D^2 = 30 (213 m/SEC — kW/m^2 = 241)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

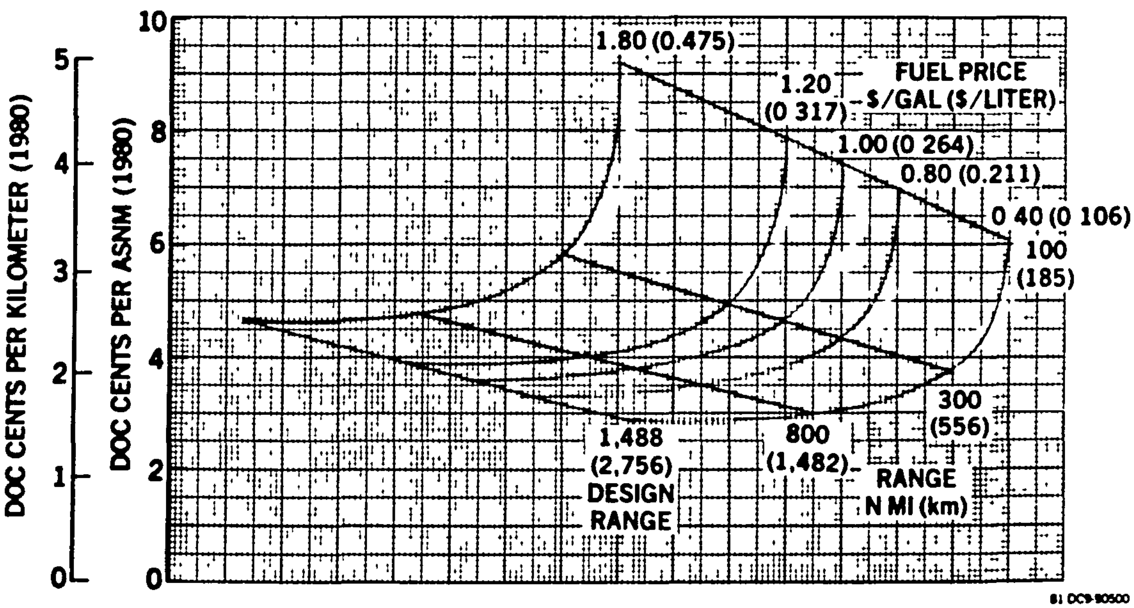
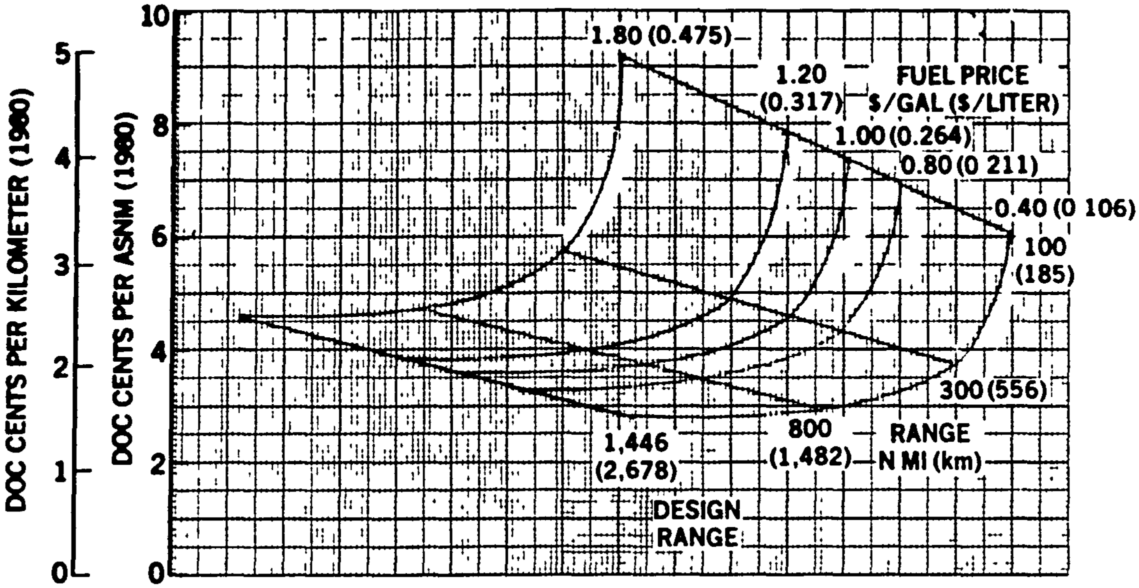


FIGURE 121. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 700 FT/SEC — SHP/D^2 = 30 (213 m/SEC — kW/m^2 = 241)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81 DC9 90445

FIGURE 122. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT) (ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 700 FT/SEC — SHP/D^2 = 30 (213 m/SEC — kW/m^2 = 241)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

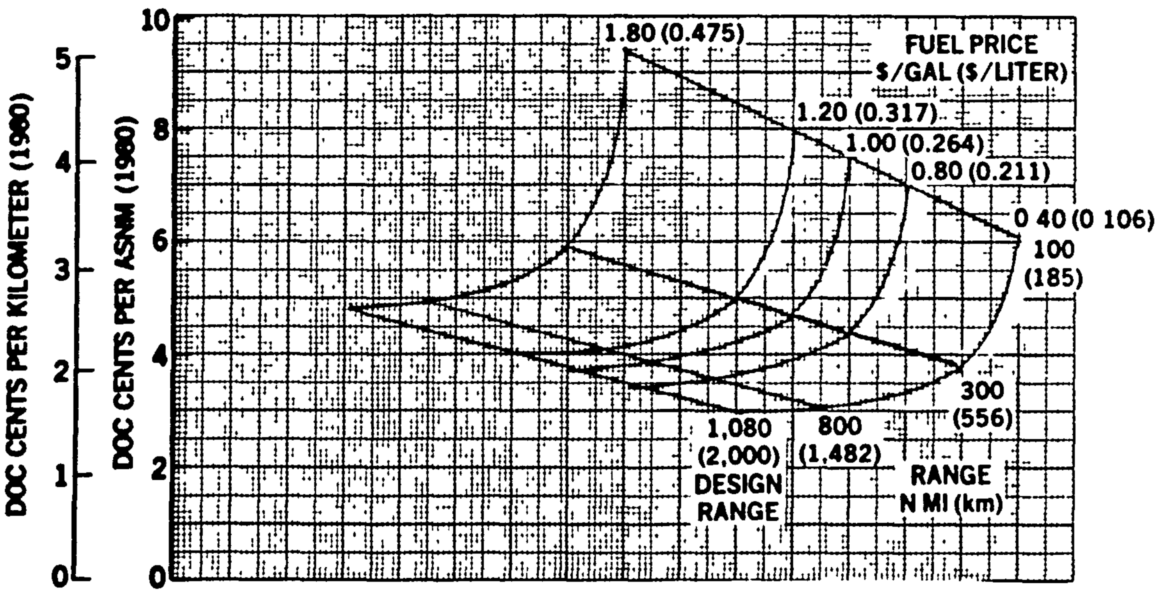
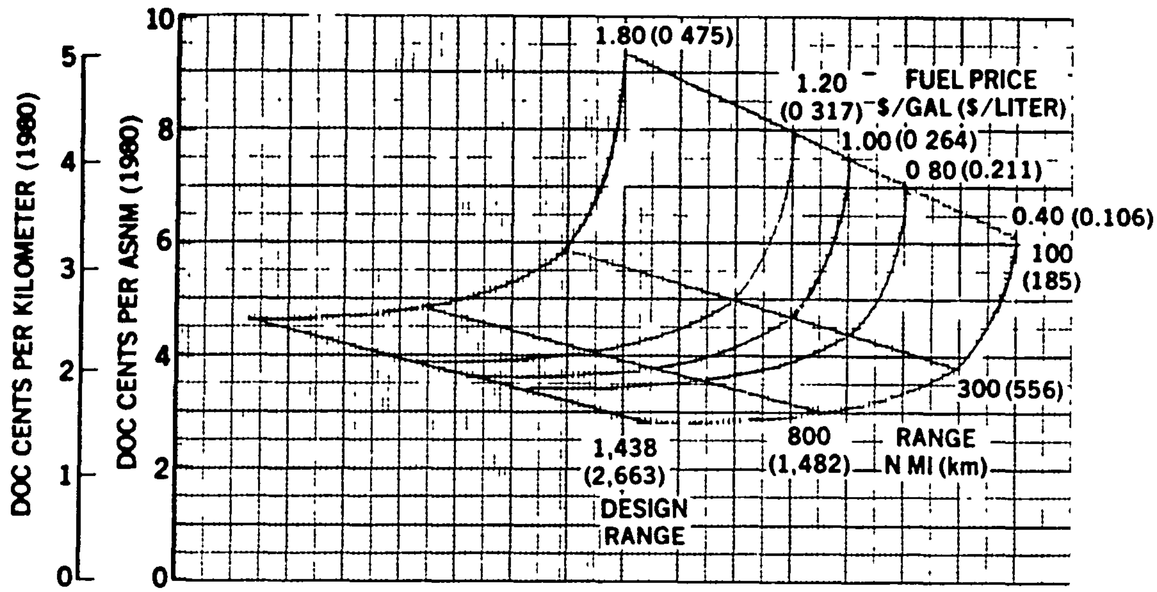


FIGURE 123. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT) (ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

81-DC9-90501

10 BLADES — TIP SPEED — 700 FT/SEC — SHP/D^2 = 30 (213 m/SEC — kW/m^2 = 241)

M_{CRUISE} = 0 80, OR AS NOTED FOR THE 100 N MI (185) STAGE LENGTH



81 DC9 90441

FIGURE 124. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT)
(ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 700 FT/SEC — SHP/D^2 = 30 (213 m/SEC — kW/m^2 = 241)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

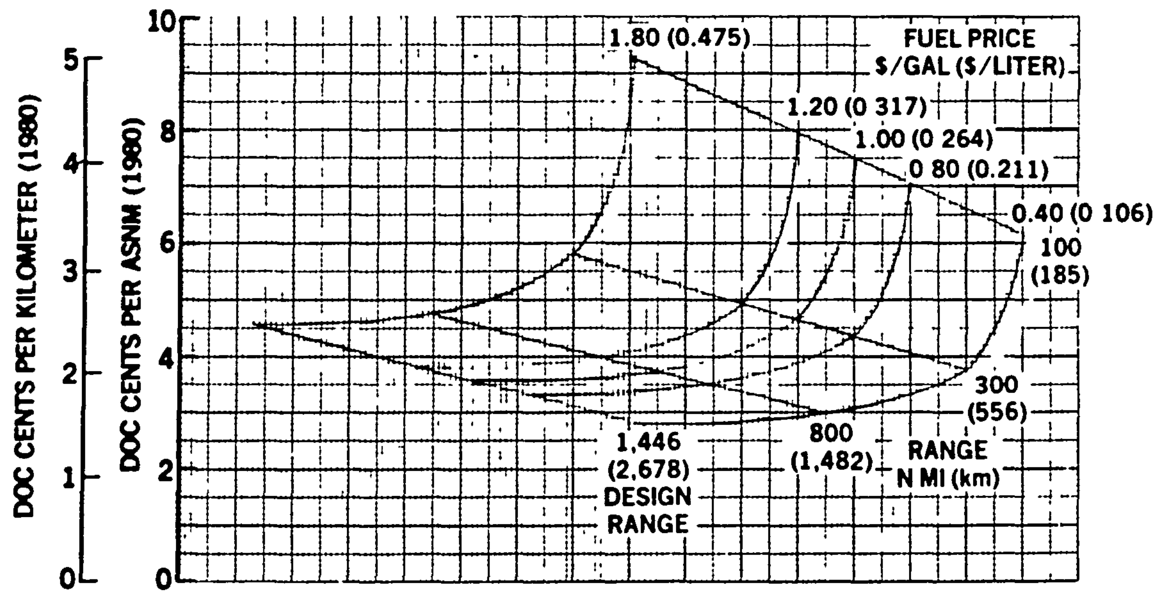
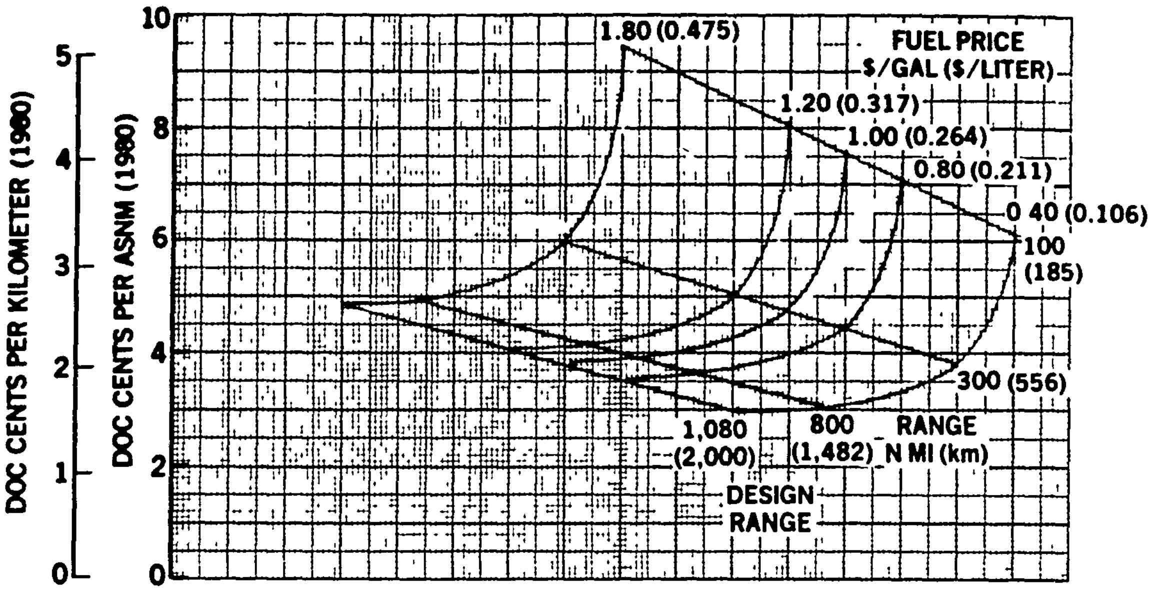


FIGURE 125. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT)
(ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

81 DC9 90502

10 BLADES — TIP SPEED — 700 FT/SEC — SHP/D² = 30 (213 m/SEC — kW/m² = 241)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81 DC9-90440

FIGURE 126. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT) (ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 700 FT/SEC — SHP/D² = 30 (213 m/SEC — kW/m² = 241)

M_{CRUISE} = 0 80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

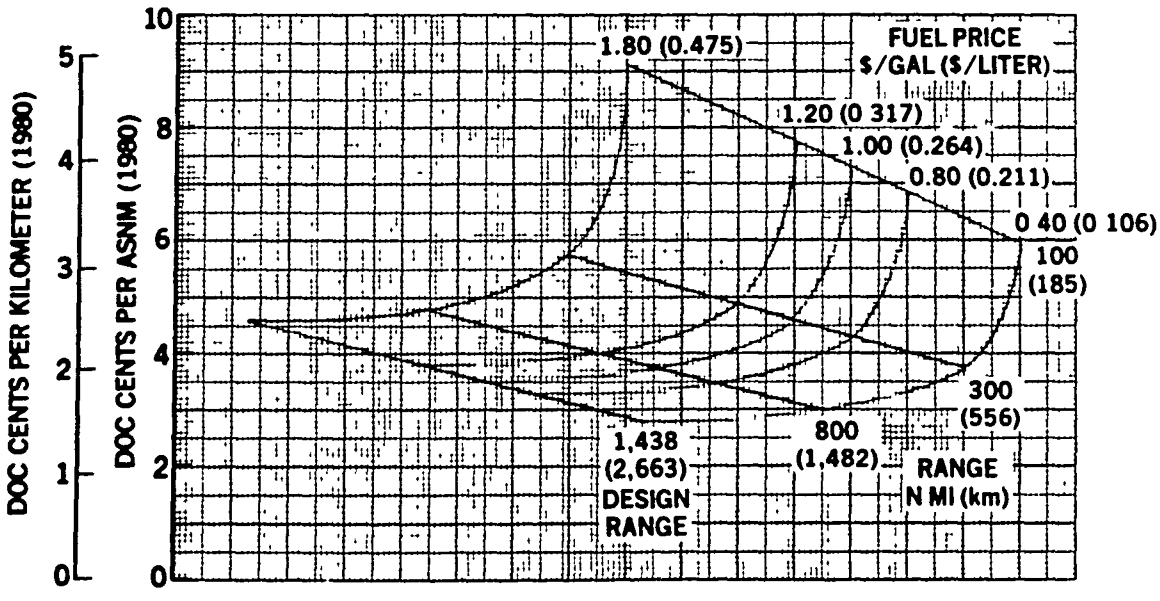


FIGURE 127. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT) (ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)

81 DC9-90503

10 BLADES — TIP SPEED — 700 FT/SEC — SHP/D^2 = 30 (213 m/SEC — kW/m^2 = 241)

M_{CRUISE} = 0 80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

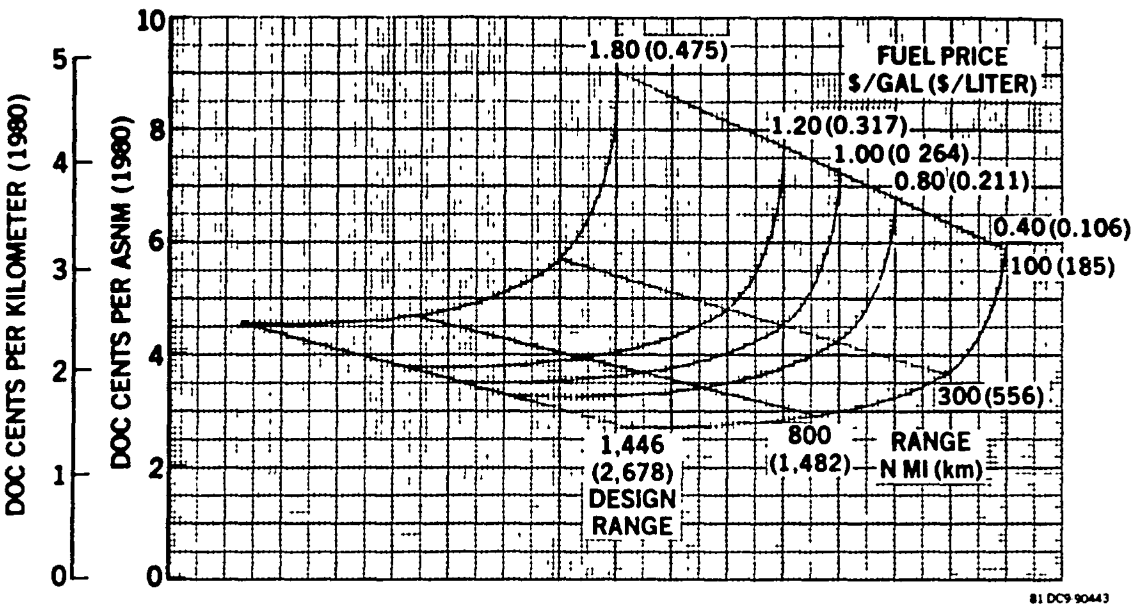


FIGURE 128 DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ STAB. MOUNT)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 700 FT/SEC — SHP/D^2 = 30 (213 m/SEC — kW/m^2 = 241)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

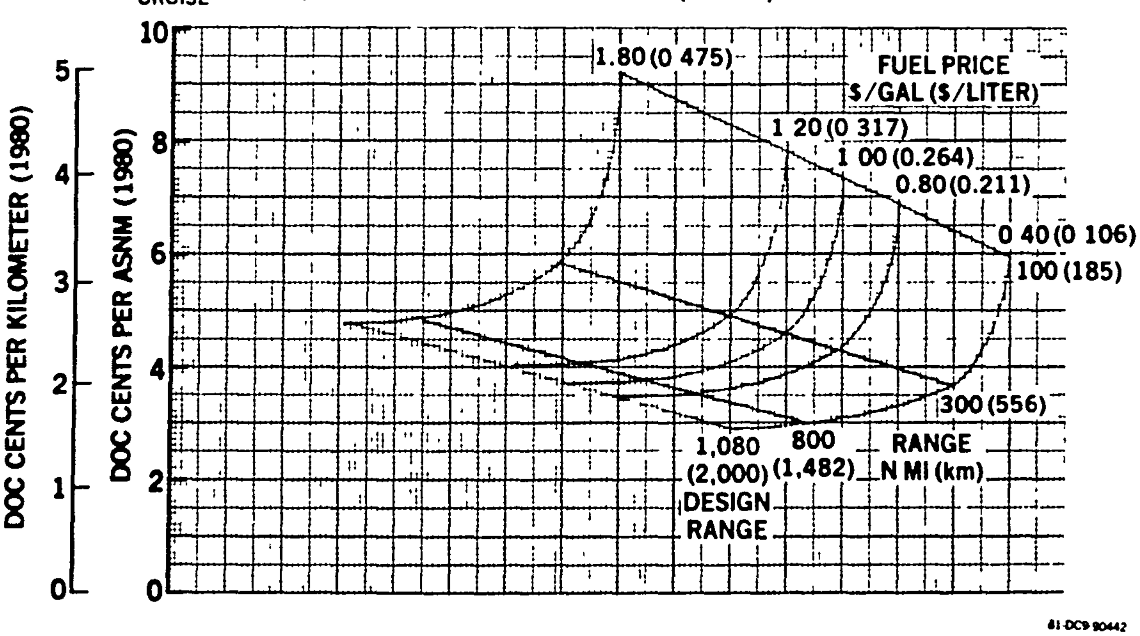
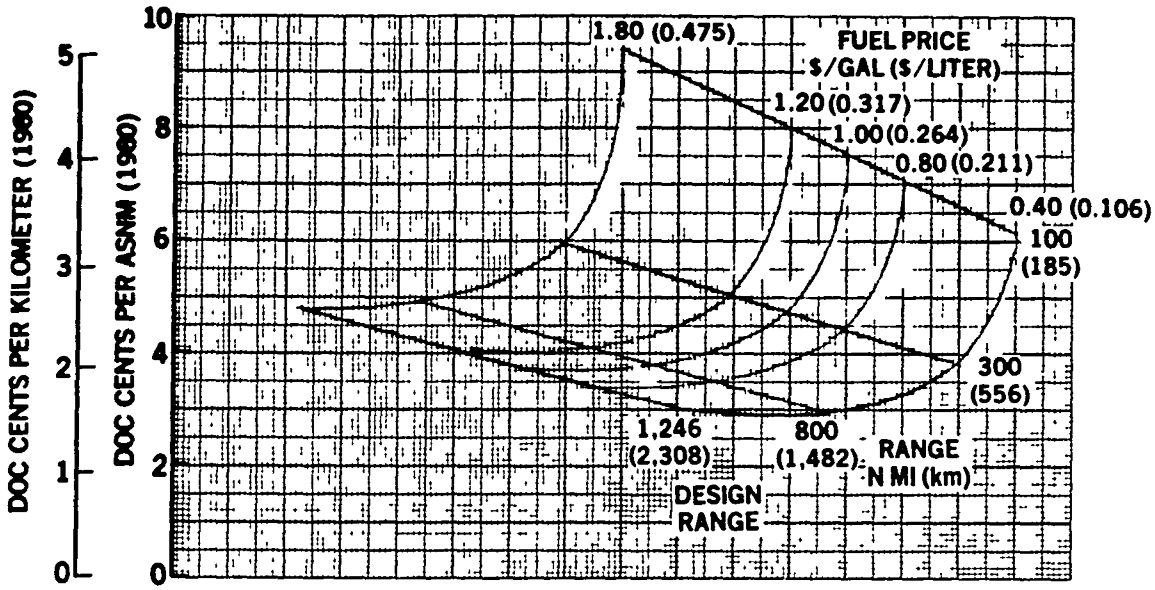


FIGURE 129 DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 600 FT/SEC — SHP/D^2 = 26 (183 m/SEC — kW/m^2 = 209)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81 DC9-90449

FIGURE 130. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 600 FT/SEC — SHP/D^2 = 26 (183 m/SEC — kW/m^2 = 209)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

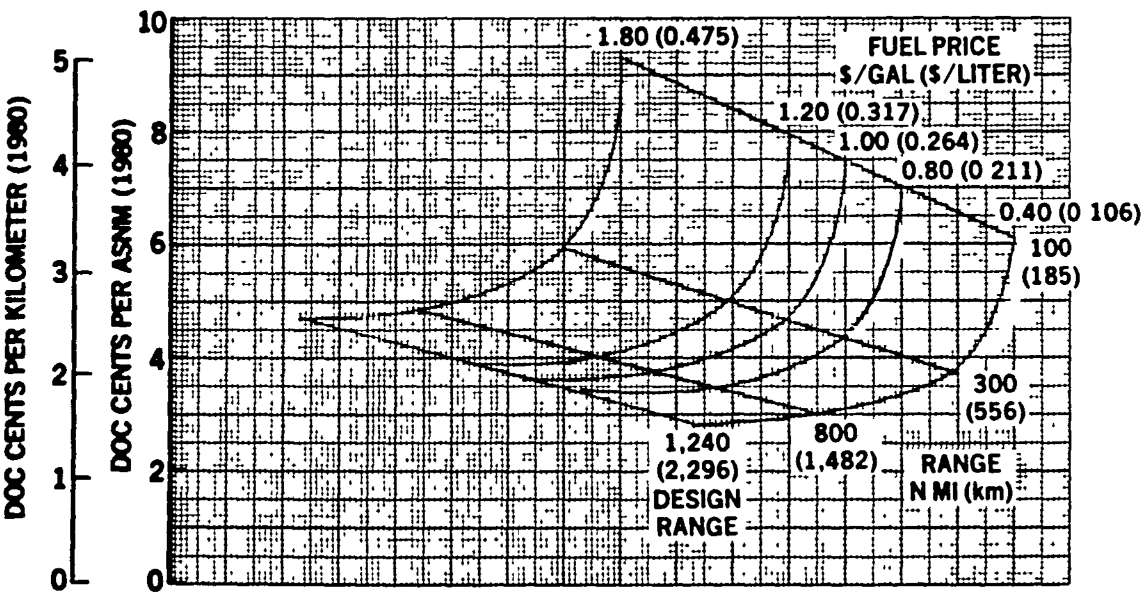
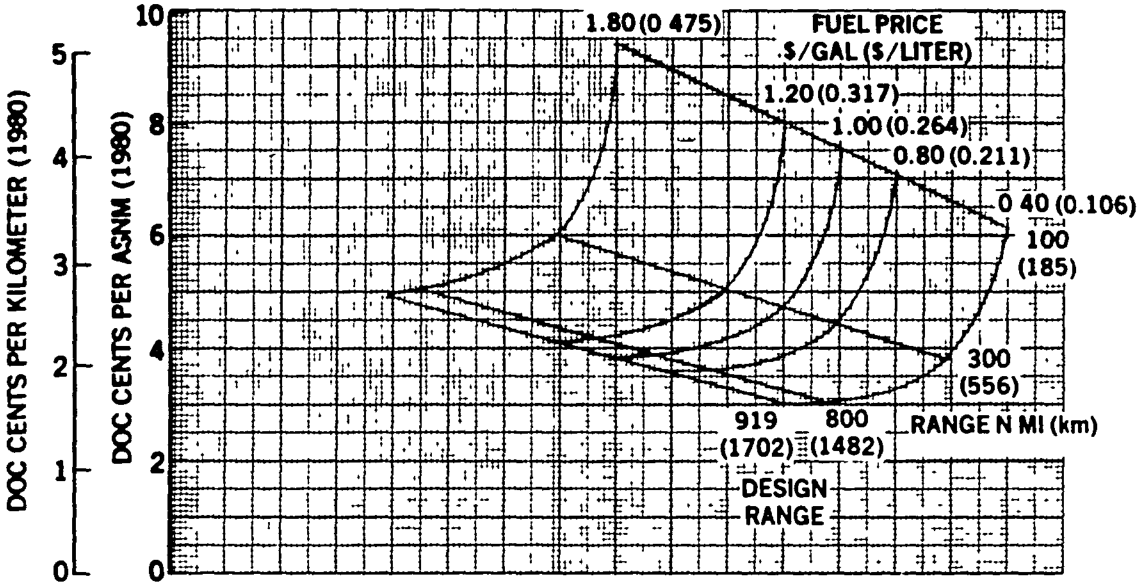


FIGURE 131. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

81 DC9-90504

10 BLADES — TIP SPEED — 600 FT/SEC — SHP/D^2 = 26 (183 m/SEC · kW/m^2 = 209)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH



81-DC9-90448

FIGURE 132. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT)
(ENGINE MAINT AT 1.743 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 600 FT/SEC — SHP/D^2 = 26 (183 m/SEC · kW/m^2 = 209)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

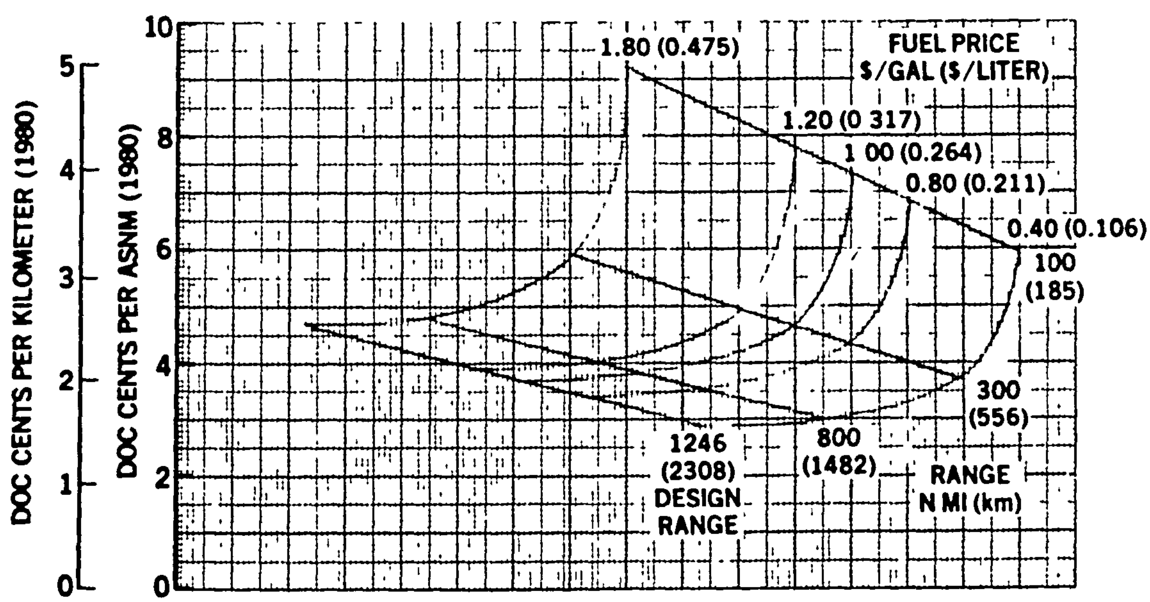


FIGURE 133. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)

81-DC9-90505

10 BLADES — TIP SPEED — 600 FT/SEC — SHP/D^2=26 (183 m/sec — kW/m^2 = 209)

M_{CRUISE} = 0.80 OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

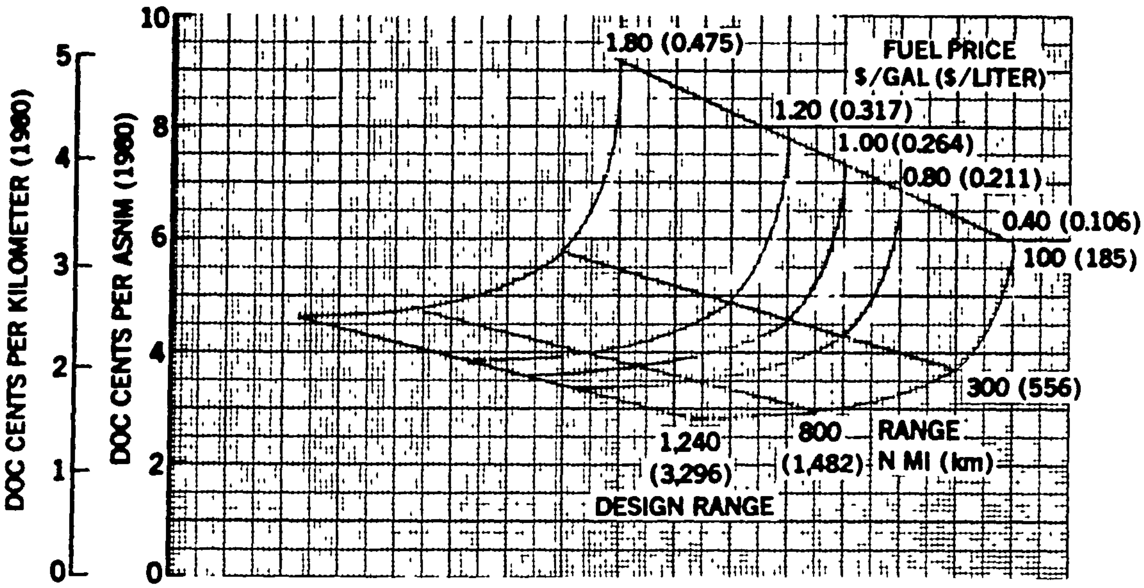


FIGURE 134. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 600 FT/SEC — SHP/D^2 = 26 (183 m/SEC — kW/m^2 = 209)

M_{CRUISE} = 0.80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

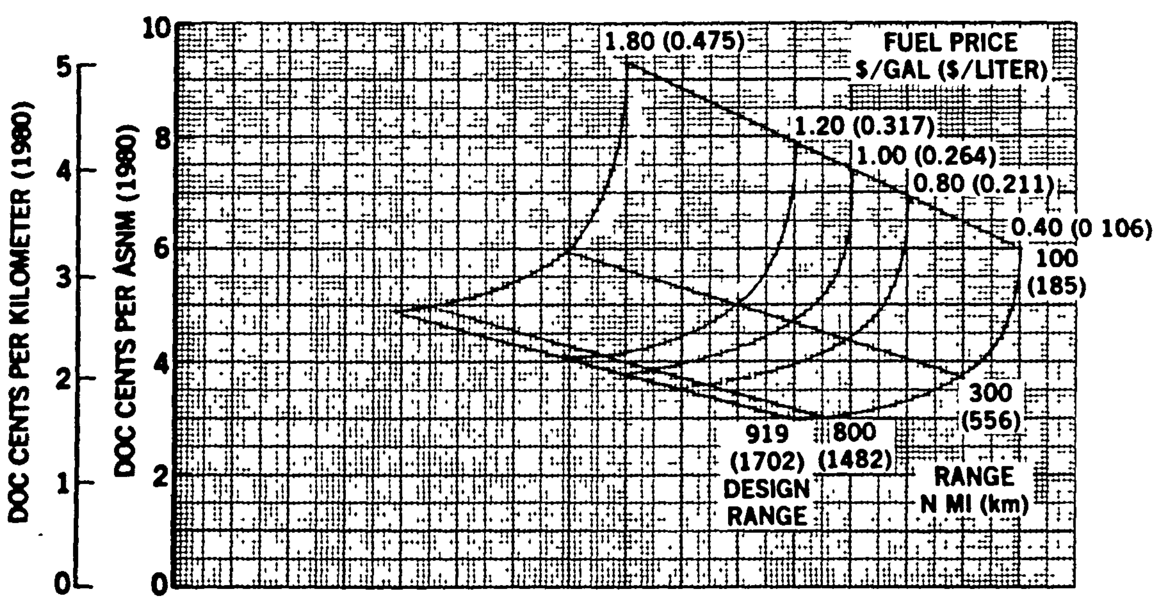


FIGURE 135. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT)
(ENGINE MAINT AT 1.16 TIMES MINIMUM BASE ESTIMATE)

10 BLADES — TIP SPEED — 600 FT/SEC — SHP/D² = 26 (183 m/SEC — kW/m² = 209)

M_{CRUISE} = 0 80,OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

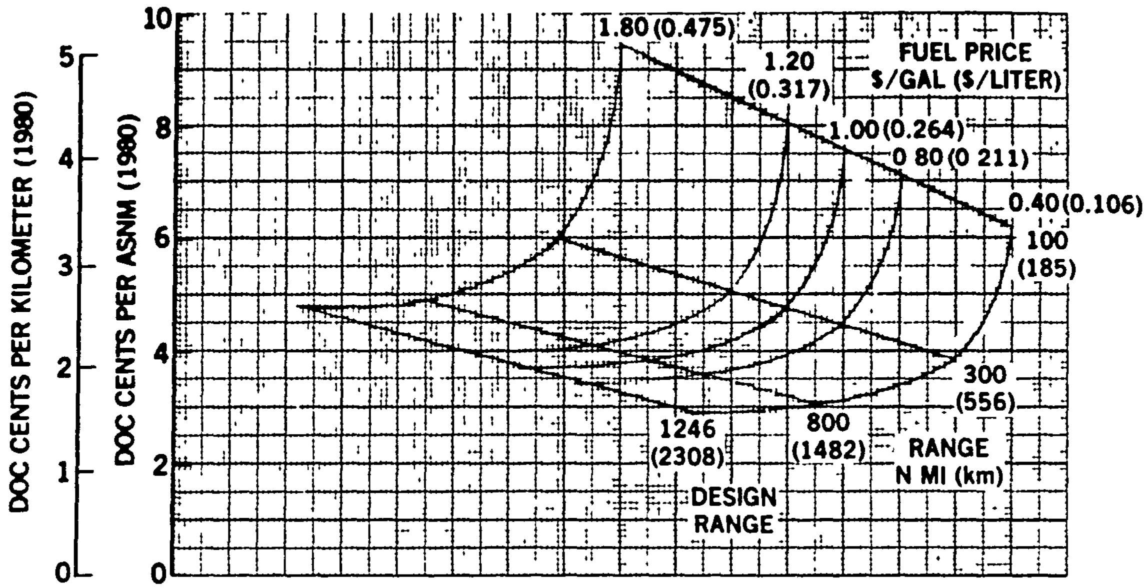


FIGURE 136. DC-9-80 PROPFAN CONFIGURATION NO. 1 (WING MOUNT)
(ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

81 DC9 90447

10 BLADES — TIP SPEED — 600 FT/SEC — SHP/D² =26 (183 m/sec — kW/m²=209)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

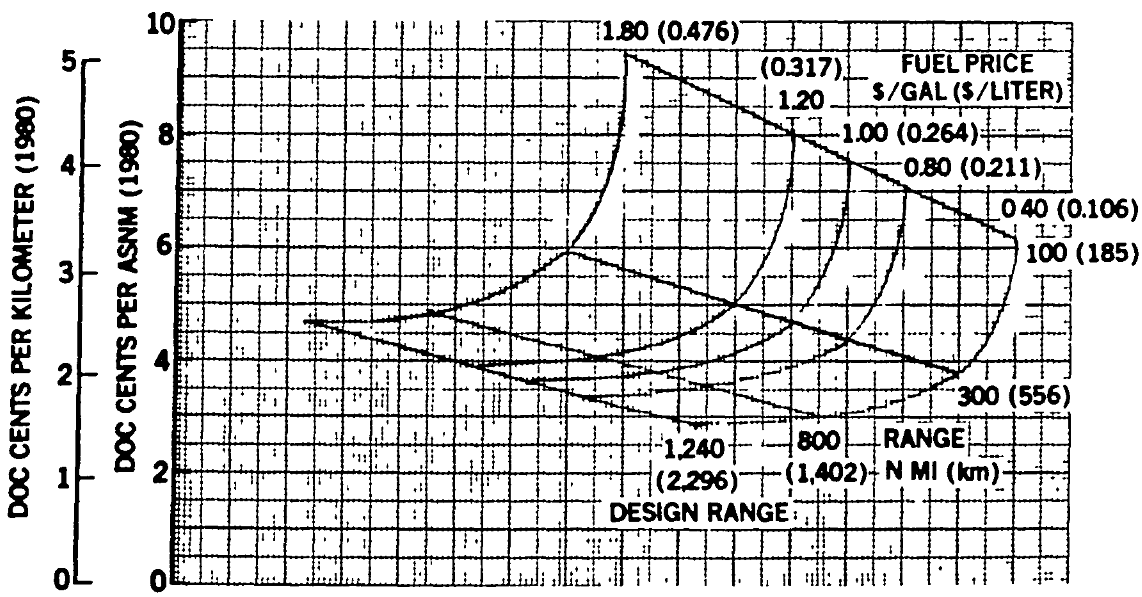


FIGURE 137. DC-9-80 PROPFAN CONFIGURATION NO. 3 (HORIZ. STAB. MOUNT)
(ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

81-DC9-90528

10 BLADES — TIP SPEED — 600 FT/SEC — SHP/D² = 26 (183 m/sec — kW/m² = 209)

M_{CRUISE} = 0.80, OR AS NOTED FOR THE 100 N MI (185 km) STAGE LENGTH

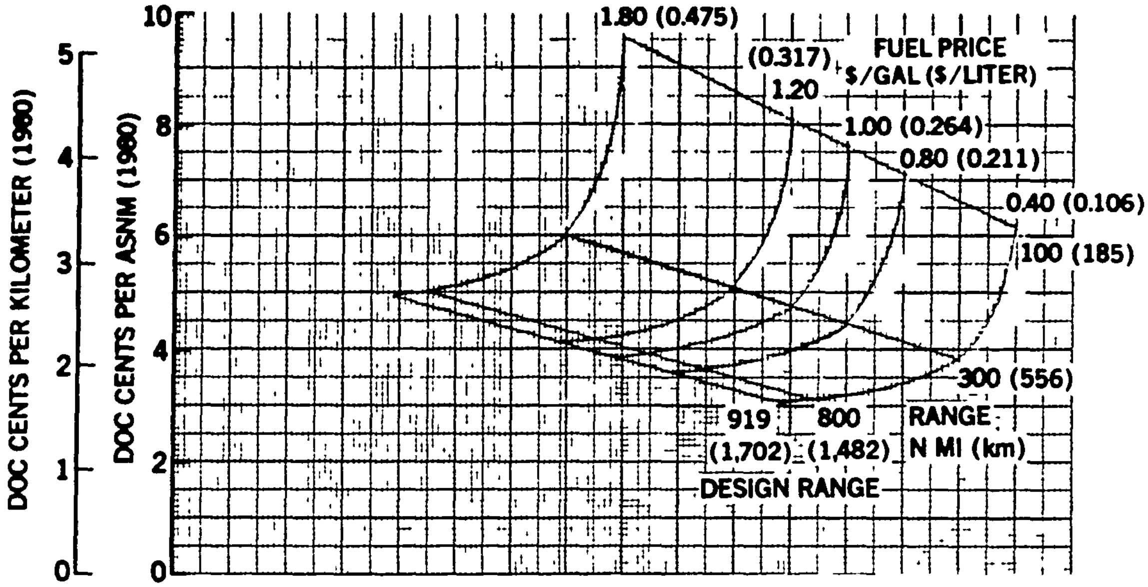


FIGURE 138. DC-9-80 PROPFAN CONFIGURATION NO. 2 (FUSELAGE MOUNT) (ENGINE MAINT AT 2.12 TIMES MINIMUM BASE ESTIMATE)

81 DC9 90527

Multi Hop Versus Single Mission - Table 49 and Figures 139 and 140 summarize the effects of the multi hop versus single hop mission on the DOCs. The multi hop flights with sequential route segments of 200, 500, 300 n mi (370, 926, and 556 km) are compared to a single hop mission at 1000 n mi (1852 km). Figure 139 presents the comparison of Configurations 1 and 3 with the baseline DC-9 Super 80 for the single and multiple hop conditions at a constant range of 1000 n mi (1852 km), 100 percent load factor, the engine maintenance assumption used throughout the study of 1.743 times the minimum base estimate, and the base case propfan configuration. As fuel prices increase, the propfan configurations continue to show sizable DOC reductions from the turbofan baseline. Reductions on the order of 4.3 to 6.1 percent for the single hop case and 6.6 percent to 7.9 percent for the multi hop case still prevail at the nomimal price of $1.00 per gallon (26.4¢/liter).

The effect of reduced passanger load factor (60 percent) on the DOCs for the multi hop mission is presented in Figure 140. The DOCs for this multi hop case present the same general results of diverging differences at the higher fuel prices between the turbofan and the propfan configurations. At the

TABLE 49

EFFECT OF MULTI HOP VS SINGLE HOP MISSION ON DIRECT OPERATING COST

M_{cruise} = 0.80 (or as noted for the 200 n mi [370 km] stage length)

8 Blades - Tip Speed 800 ft/sec - SHP/D^2 = 37.5 (244 m/sec - kW/m^2 = 301)

Multi Hop Mission - 200 , 500 , 300 n mi legs (370, 926, 556 km legs)
Single Hop Mission- 1000 n mi leg (1852 km)

			Direct Operating Cost ¢/ASNM (¢/km)				
Configuration	Mission Type	% Passenger Load Factor	Fuel Price $0 40 ($0 106/liter)	$0 80 ($0 211/liter)	$1 00 ($0 264/liter)	$1 20 ($0 317/liter)	$1 80/gal ($0 475/liter)
DC-9-Super 80	1000 n mi (1852 km)						
	Multi Hop	100	3 686 (1 990)	4 483 (2 421)	4 882 (2 636)	5 280 (2 851)	6.476 (3 497)
	Single-Hop	100	2 919 (1 576)	3 550 (1 917)	3 866 (2 088)	4.182 (2 258)	5 129 (2 769)
	Multi Hop	60	3 488 (1 883)	4 237 (2 288)	4 612 (2 490)	4.987 (2 692)	6 112 (3 300)
Configuration 1	Multi-Hop	100	3 651 (1 971)	4 256 (2 298)	4 558 (2 461)	4 860 (2 624)	5 767 (3.114)
	Single Hop	100	2 937 (1 586)	3 445 (1 860)	3 699 (1 997)	3 953 (2 134)	4 716 (2 546)
	Multi Hop	60	3 480 (1 879)	4 060 (2 192)	4 351 (2 349)	4 640 (2 505)	5 511 (2 975)
Configuration 3	Multi Hop	100	3 609 (1 949)	4 199 (2 267)	4 497 (2 428)	4 795 (2 589)	5 690 (3 072)
	Single Hop	100	2.881 (1 556)	3 381 (1 826)	3 632 (1 421)	3 882 (2 096)	4 633 (2.502)
	Multi Hop	60	3 431 (1 852)	4 062 (2 193)	4 288 (2 315)	4 574 (2 469)	5 431 (2.932)

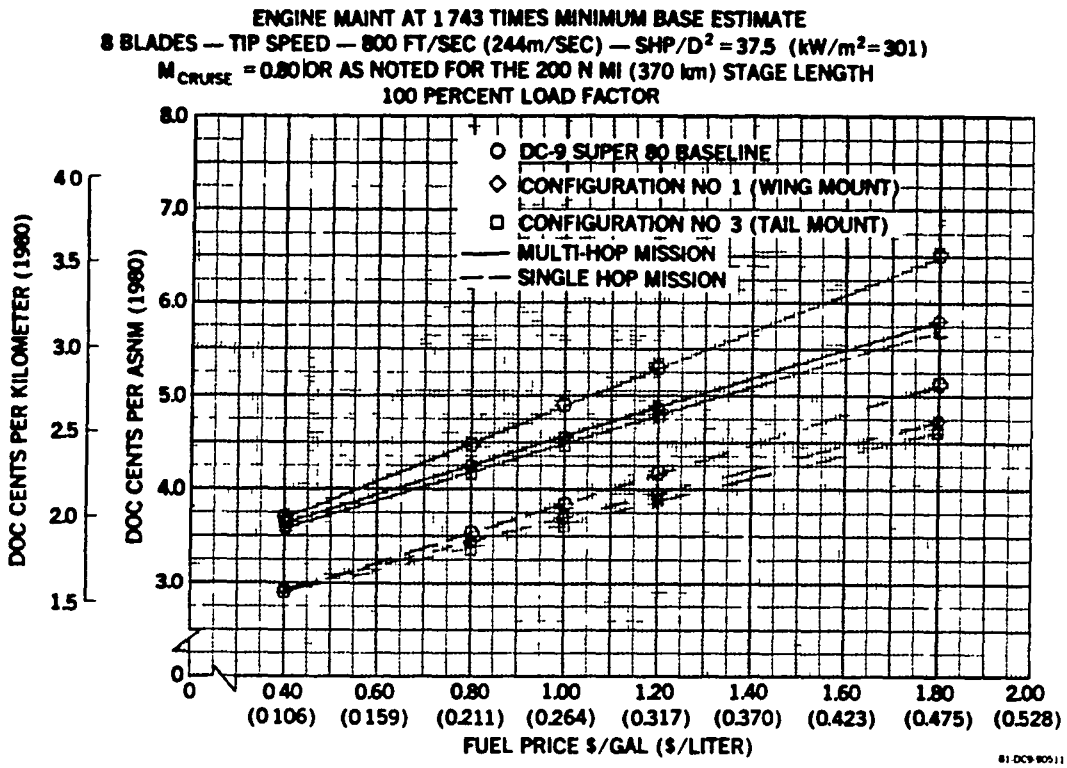


FIGURE 139 EFFECT OF SINGLE AND MULTI HOP ON DIRECT OPERATING COST AT A CONSTANT RANGE OF 1000 NM AND VARIABLE FUEL PRICES

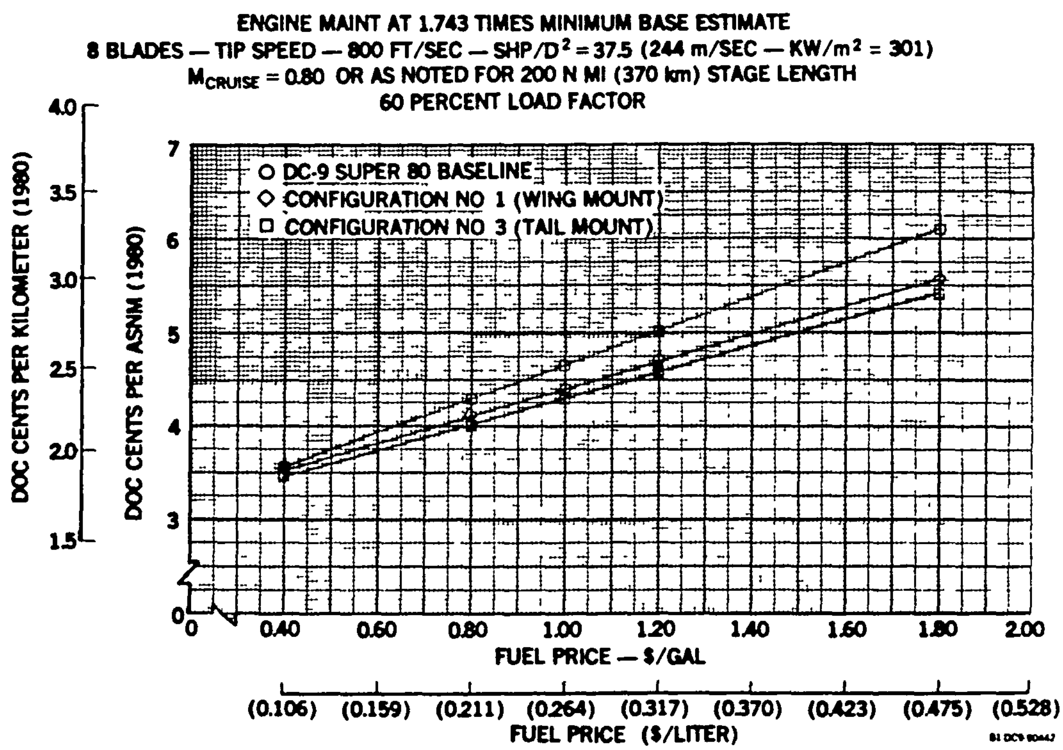


FIGURE 140 EFFECT OF MULTI HOP ON DIRECT OPERATING COST AT A CONSTANT RANGE OF 1000 N MI AND VARIABLE FUEL PRICES

current assumed base price of $1.00 per gallon, the delta DOC between the baseline and Configuration 3 (tail mount) is lower for the propfan. As can be noted in the comparison of the 100 percent and the 60 percent passenger load factor, the reduction to 60 percent load factor incurs an approximate 4.4 to 5.6 percent reduction in DOC over the 100 percent load factor case.

Effect of Number of Propfan Blades - As in the case of the performance results, Figure 37, DOC differences between the 8 and 10-blade propfan configurations are negligible (Table 50 and Figure 141). The slightly lower DOCs for Configurations 1 and 3 shown for the 10 blade over the 8-blade propfan (Table 50) are consistent with the very small performance advantages shown. As noted in Figure 141, these DOC differences are not distinguishable on the plot.

Effect of Tip Speed/Disc Loading - The effects of propfan tip speed/disc loading on DOC are shown in Tables 51 through 53 and Figure 142. As noted from Figure 142, the DOC appears to be relatively insensitive to changes in tip speed/disc loading with a very slight increase at the 600 ft/sec/26 shp/D^2

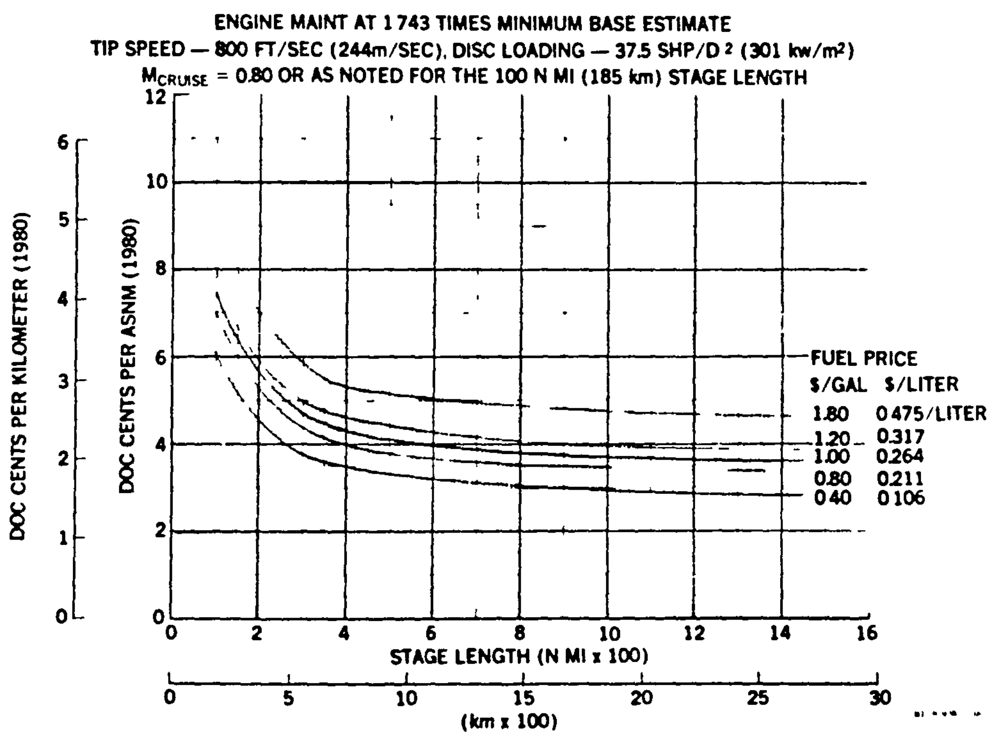


FIGURE 141. DIRECT OPERATING COST COMPARISON OF 8 AND 10 BLADE PROPFANS CONFIGURATION NO. 1

TABLE 50

EFFECT OF NUMBER OF PROPFAN BLADES ON DIRECT OPERATING COSTS

Tip Speed/Disc Loading 800 ft/sec/37.5 SHP/D^2 (244 m/sec/301 kW/m^2)

M_{cruise} = 0.80 (or as noted for the 100 n mi [185 km] stage length)

	Stage Length n-mi (km)	Direct Operating Costs c/ASNM (c/km) Fuel Price $0.40 ($0.106/liter)	$0.80 ($0.211/liter)	$1.00 ($0.264/liter)	$1.20 ($0.317 liter)	$1.80/gal ($0.475/liter)
Configuration 1						
8 Blade	100 (185)	6.069 (3.277)	6.990 (3.774)	7.450 (4.023)	7.910 (4.271)	9.291 (5.017)
	300 (556)	3.766 (2.033)	4.364 (2.356)	4.662 (2.517)	4.961 (2.679)	5.858 (3.163)
	800 (1482)	3.025 (1.633)	3.536 (1.909)	3.792 (2.048)	4.047 (2.185)	4.813 (2.599)
	1453* (2691)	2.846 (1.537)	3.365 (1.817)	3.624 (1.957)	3.883 (2.097)	4.661 (2.517)
10 Blade	100 (185)	6.060 (3.272)	6.792 (3.667)	7.428 (4.011)	7.884 (4.257)	9.251 (4.995)
	300 (556)	3.757 (2.029)	4.348 (2.348)	4.643 (2.507)	4.938 (2.666)	5.824 (3.145)
	800 (1482)	3.018 (1.630)	3.522 (1.902)	3.774 (2.038)	4.025 (2.173)	4.780 (2.581)
	1568* (2904)	2.824 (1.525)	3.335 (1.801)	2.591 (1.399)	3.847 (2.077)	4.615 (2.492)
Configuration 3						
8 Blade	100 (185)	6.058 (3.271)	6.980 (3.769)	7.414 (4.003)	7.868 (4.248)	9.229 (4.983)
	300 (556)	3.719 (2.008)	4.307 (2.326)	4.601 (2.484)	4.895 (2.643)	5.777 (3.119)
	800 (1482)	2.966 (1.602)	3.467 (1.872)	3.718 (2.008)	3.969 (2.143)	4.721 (2.549)
	1524* (2822)	2.772 (1.497)	3.280 (1.771)	3.534 (1.908)	3.788 (2.045)	4.550 (2.457)
10 Blade	100 (185)	6.048 (3.266)	6.950 (3.753)	7.401 (3.996)	7.853 (4.240)	9.207 (4.971)
	300 (556)	3.714 (2.005)	4.298 (2.321)	4.590 (2.478)	4.882 (2.636)	5.758 (3.109)
	800 (1482)	2.962 (1.599)	3.460 (1.868)	3.708 (2.002)	3.957 (2.137)	4.704 (2.540)
	1571* (2909)	2.763 (1.492)	3.268 (1.765)	3.520 (1.901)	3.773 (2.037)	4.530 (2.446)
Configuration 2						
8 Blade	100 (185)	6.076 (3.281)	7.005 (3.782)	7.469 (4.033)	7.934 (4.284)	9.327 (5.036)
	300 (556)	3.778 (2.040)	4.382 (2.366)	4.684 (2.529)	4.986 (2.692)	5.892 (3.181)
	800 (1482)	3.035 (1.639)	3.547 (1.915)	3.803 (2.053)	4.059 (2.192)	4.827 (2.606)
	1214* (2248)	2.901 (1.566)	3.428 (1.851)	3.692 (1.994)	3.956 (2.136)	4.746 (2.563)
10 Blade	100 (185)	6.086 (3.286)	7.024 (3.793)	7.493 (4.046)	7.962 (4.299)	9.370 (5.059)
	300 (556)	3.781 (2.042)	4.388 (2.369)	4.692 (2.533)	4.995 (2.697)	5.906 (3.189)
	800 (1482)	3.044 (1.644)	3.571 (1.928)	3.835 (2.071)	4.099 (2.213)	4.891 (2.641)
	1215* (2250)	2.908 (1.570)	3.443 (1.859)	3.711 (2.004)	3.979 (2.148)	4.782 (2.582)

*Max Range

TABLE 51

EFFECT OF TIP SPEED/DISC LOADING ON DIRECT OPERATING COST

Configuration 1
10 Blade Propfan
M_{cruise} = 0.80 (or as noted for the 100 n mi [185 km] stage length)

Tip Speed/Disc Loading	Stage Length n mi (km)	Direct Operating Costs ¢/ASNM (c/km)				
		Fuel Price $0.40 ($0.106/liter)	$0.80 ($0.211/liter)	$1.00 ($0.264/liter)	$1.20 ($0.317/liter)	$1.80/gal ($0.475/liter)
800 ft/sec/37.5 SHP/D^2 (244 m/sec/301 kW/m^2)	100 (185)	6.060 (3.272)	6.972 (3.765)	7.428 (4.011)	7.884 (4.257)	9.251 (4.995)
	300 (556)	3.757 (2.029)	4.348 (2.348)	4.643 (2.507)	4.938 (2.666)	5.824 (3.145)
	800 (1482)	3.018 (1.630)	3.522 (1.902)	3.774 (2.038)	4.025 (2.173)	4.780 (2.581)
	1568* (2904)	2.824 (1.525)	3.335 (1.801)	3.591 (1.939)	3.847 (2.077)	4.615 (2.492)
700 ft/sec/30 SHP/D^2 (213 m/sec/241 kW/m^2)	100 (185)	6.058 (3.271)	6.971 (3.764)	7.427 (4.010)	7.884 (4.257)	9.254 (4.997)
	300 (556)	3.762 (2.031)	4.355 (2.352)	4.652 (2.512)	4.949 (2.672)	5.839 (3.153)
	800 (1482)	3.082 (1.664)	3.529 (1.906)	3.783 (2.043)	4.037 (2.180)	4.798 (2.591)
	1438* (2663)	2.845 (1.536)	3.360 (1.814)	3.617 (1.953)	3.874 (2.092)	4.646 (2.509)
600 ft/sec/26 SHP/D^2 (183 m/sec/209 kW/m^2)	100 (185)	6.102 (3.295)	7.041 (3.802)	7.510 (4.055)	7.980 (4.309)	9.389 (5.070)
	300 (556)	3.786 (2.044)	4.399 (2.375)	4.705 (2.541)	5.012 (2.706)	5.931 (3.203)
	800 (1482)	3.040 (1.642)	3.566 (1.926)	3.829 (2.068)	4.092 (2.210)	4.882 (2.636)
	1246* (2308)	2.896 (1.564)	3.428 (1.851)	3.695 (1.995)	3.961 (2.139)	4.760 (2.570)

*Max Range

TABLE 52

EFFECT OF TIP SPEED/DISC LOADING

Configuration 3
10 Blade Propfan
M_{cruise} = 0.80 (or as noted for the 100 n mi [185 km] stage length)

Tip Speed/Disc Loading	Stage Length n mi (km)	Direct Operating Costs ¢/ASNM (¢/km) Fuel Price $0.40 ($0.106/liter)	$0.80 ($0.211/liter)	$1.00 ($0.264/liter)	$1.20 ($0.317/liter)	$1.80/gal ($0.475/liter)
800 ft/sec/37.5 SHP/D^2 (244 m/sec/301 kW/m^2)	100 (185)	6.048 (3.266)	6.950 (3.753)	7.401 (3.996)	7.853 (4.240)	9.207 (4.971)
	300 (556)	3.714 (2.005)	4.298 (2.321)	4.590 (2.478)	4.882 (2.636)	5.758 (3.109)
	800 (1482)	2.962 (1.599)	3.460 (1.868)	3.708 (2.002)	3.957 (2.137)	4.704 (2.540)
	1571* (2909)	2.763 (1.492)	3.268 (1.765)	3.520 (1.901)	3.793 (2.048)	4.530 (2.446)
700 ft/sec/30 SHP/D^2 (213 m/sec/241 kW/m^2)	100 (185)	6.048 (3.266)	6.951 (3.753)	7.403 (3.997)	7.854 (4.241)	9.208 (4.972)
	300 (556)	3.718 (2.008)	4.304 (2.324)	4.597 (2.482)	4.891 (2.641)	5.770 (3.116)
	800 (1482)	2.966 (1.602)	3.466 (1.872)	3.717 (2.007)	3.967 (2.142)	4.709 (2.543)
	1446* (2678)	2.782 (1.502)	3.289 (1.776)	3.542 (1.913)	3.796 (2.050)	4.556 (2.460)
600 ft/sec/26 SHP/D^2 (183 m/sec/209 kW/m^2)	100 (185)	6.074 (3.280)	7.004 (3.782)	7.469 (4.033)	7.934 (4.284)	9.328 (5.037)
	300 (556)	3.738 (2.018)	4.344 (2.346)	4.647 (2.509)	4.951 (2.673)	5.860 (3.164)
	800 (1482)	2.984 (1.611)	3.504 (1.892)	3.764 (2.032)	4.084 (2.205)	4.804 (2.594)
	1240* (2296)	2.838 (1.532)	3.363 (1.816)	3.686 (1.990)	3.889 (2.100)	4.677 (2.525)

*Max Range

TABLE 53

EFFECT OF TIP SPEED/DISC LOADING

Configuration 2
10 Blade Propfan
M_{cruise} = 0.80 (or as noted for the 100 n mi [185 km] stage length)

Tip Speed/Disc Loading	Stage Length n mi (km)	Direct Operating Costs ¢/ASNM (¢/km)				
		Fuel Price $0.40 ($0.106/liter)	$0.80 ($0.211/liter)	$1 00 ($0.264/liter)	$1.20 ($0.317/liter)	$1.80/gal $0.475/liter)
800 ft/sec/37.5 SHP/D^2 (244 m/sec/301 kW/m^2)	100 (185)	6.086 (3.286)	7.024 (3.793)	7.493 (4.046)	7.962 (4.299)	9.370 (5.059)
	300 (556)	3.781 (2.042)	4.388 (2.369)	4.692 (2.533)	4.995 (2.697)	5.906 (3.139)
	800 (1482)	3.044 (1.644)	3.571 (1.928)	3.835 (2.071)	4.099 (2.213)	4.891 (2.641)
	1215* (2250)	2.908 (1.570)	3.443 (1.859)	3.711 (2.004)	3.979 (2.148)	4.782 (2.582)
700 ft/sec/30 SHP/D^2 (213 m/sec/241 kW/m^2)	100 (185)	6.085 (3.286)	7.022 (3.792)	7.490 (4.044)	7.959 (4.298)	9.365 (5.057)
	300 (556)	3.784 (2.043)	4.393 (2.372)	4.697 (2.536)	5.002 (2.701)	5.915 (3.194)
	800 (1482)	3.046 (1.645)	3.576 (1.931)	3.842 (2.075)	4.107 (2.218)	4.903 (2.647)
	1080* (2000)	2.943 (1.589)	3.481 (1.880)	3.750 (2.025)	4.019 (2.170)	4.327 (2.606)
600 ft/sec/26 SHP/D^2 (185 m/sec/209 kW/m^2)	100 (185)	6.101 (3.294)	7.054 (3.809)	7.531 (4.066)	8.008 (4.324)	9.439 (5.097)
	300 (556)	3.800 (2.052)	4.424 (2.389)	4.736 (2.557)	5.048 (2.726)	5.984 (3.231)
	800 (1482)	3.060 (1.652)	3.605 (1.947)	3.878 (2.094)	4.151 (2.241)	4.969 (2.683)
	919* (1702)	3.009 (1.625)	3.561 (1.923)	3.836 (2.071)	4.112 (2.220)	4 939 (2.667)

*Max Range

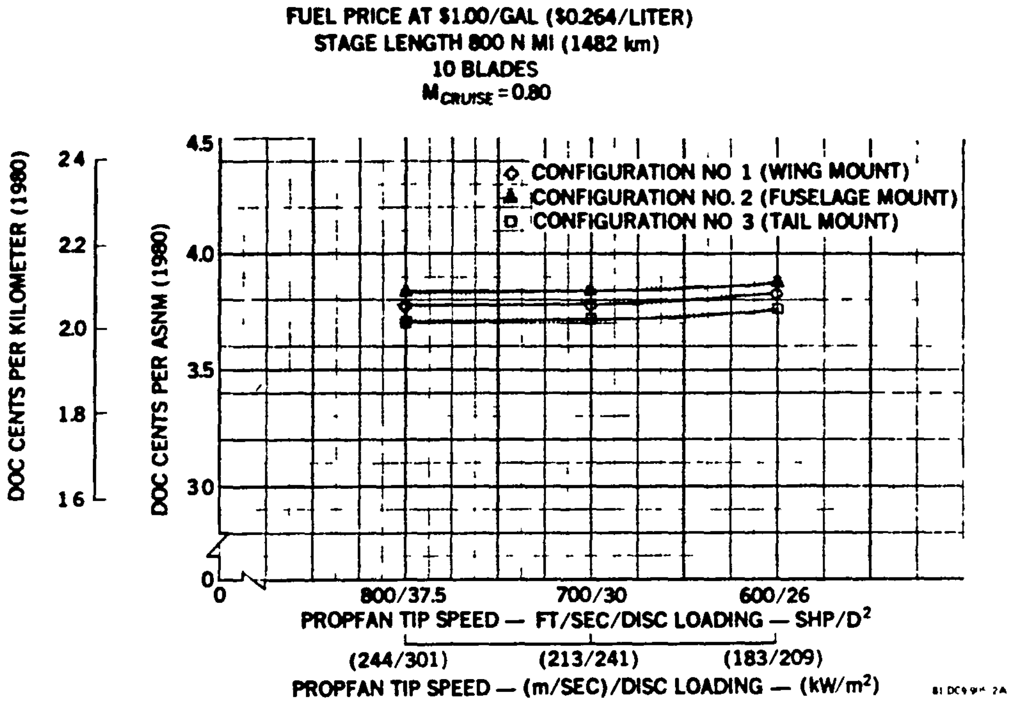


FIGURE 142. DIRECT OPERATING COST VERSUS TIP SPEED – ENGINE MAINT AT 1.743 TIMES BASE ESTIMATE

(183 m/sec/209 kW/m^2) case. The trend is essentially the same for the three propfan configurations.

SUMMARY

Throughout this ROM economic analysis, the relative trends of these costing results for the propfan configuration are consistent with those of the associated performance analysis. The propfan configurations show a definite DOC advantage over the base case turbofan powered DC-9 Super 80, even with a fairly small market size of only 200 aircraft assumed as the capture rate by one manufacturer.

SECTION 7
AIRLINE COORDINATION AND COMMENTS

GENERAL SUMMARY

As part of this contract, visits to representative airlines are required in order to coordinate the results of this propfan study with the airlines' comments and general recommendations as to the feasibility of and desirability of future incorporation of propfan aircraft into the airline operational fleets. Douglas selected two major trunk airlines, United and Delta, and two regional airlines, USAir and Republic. Two visits were made to each of these airlines, one during the early formulation of the study in July 1979 and the other in August 1980 at the conclusion of the study. Several aspects of particular interest, forthcoming from these airlines comments, are noted as follows:

- Throughout the survey, all the airlines expressed definite interest in propfan aircraft as a means of eliminating the possible fuel supply and growing cost problems. However, compared to the first visit (July 1979), this interest, enthusiasm for, and consideration of the propfan as an economically feasible and a very viable concept for future replacement aircraft has definitely increased and become a matter of substantial concern by the time of the second visit (August, 1980). However, it should be noted that United Airlines has been enthusiastic about the propfan throughout the study.

  This increased interest in the propfan is definitely associated with the more than doubtling of fuel costs during this time period. United is currently conservatively estimating mid-1980 fuel prices at $1.60 to $1.75/gallon ($0.423/litter to $0.455/liter).

- The response as to the approximate size and M_{cruise} of the first propfan aircraft put into the fleet was consistent from all four airlines.

- A design passenger payload of approximately 155 to 165 was thought the most desirable. Delta noted that no airline considers less than 120 passengers for a replacement aircraft nowadays. Unanimously, these airlines felt that considering a size smaller than the DC-9 would be a mistake.

- The cruise speed of the propfan must be equal to that of the generic aircraft it is replacing; otherwise, all kinds of scheduling and route structure problems arise. In general, this requirement implies that a cruise Mach number of 0.8 is desirable. USAir in particular is not happy with the current M_{cruise} at less than 0.76. In any case, the propfan aircraft must be compatible with Air Traffic Control which again points to $M_{cruise} \sim 0.8$.

- The twin engine is an acceptable design for the introductory propfan aircraft. Also, the twin engine aircraft is more nearly compatible with the required initial costs to the airlines.

- The question of passenger acceptance of the propfan was initially a matter of concern to the airlines, but currently it is not generally considered a stumbling block.

- The propfan installation has more complexities than the turbofan; however, three out of the four airlines considered that the desirable fuel savings more than outweighed the importance of any of these complexities and attendant maintenance problems.

- In the cases of very short stage lengths on the order of 100 to 200 nmi (185 to 370 km), the airlines generally prefer to fly the mission utilizing a near maximum optimum trajectory defined for the specific weather, terrain, and altitude conditions. However, for the comparative analyses used in this study, the assumption that at least one third of the range should be at cruise condition is considered reasonable by the airlines.

- The areas of major concern to the airlines for the propfan aircraft were:
  - The structural integrity of the propfan blades - what is the construction - what is its structural reliability how will the blade icing problem be handled.
  - The capability of the propfan and gearbox to absorb the level of shaft horsepower necessary for a two engine aircraft design. (The concern stems from the fact that the shaft horsepower/engine considered now is more than twice that used in other turboprop installations).
  - The reliability and maintenance of the gearbox and propfan.

All airlines felt that a flying testbed would do much to alleviate many of the qualms that exist in their minds relative to the overall acceptability of the propfan aircraft.

Within the year between the two Douglas visits to the airlines, a very definite increase in interest in the propfan aircraft is exhibited. Typical airline comments during this last visit are paraphrased as follows:

USAir - USAir could be one of the first buyers of the propfan aircraft. Don't cross USAir off the list or put the airline way down on the list as a propfan user.

Delta - When the program started a year ago, it was felt the program had no chance of survival; now it is felt that the propfan has a very good chance.

Republic - There has been a definite change in attitude; there is no question that propfans will be accepted for their fuel savings.

United - United has been interested in the propfan from the beginning of the program and the interest increases as the program progresses.

As is to be expected, most of the airlines are not doing immediate planning of fleet revision on the basis of fuel efficiency. The actual propfan aircraft is too far down the road to be considered in such fleet revision. However, United noted that the percent fuel savings forthcoming from the propfan over the turbofan is much greater than that used as a criteria by American Airlines in their recent efforts of fleet revisions directed toward improved fuel efficiency.

SPECIFIC COMMENTS

Further details of the discussions with the individual airlines are presented in the following paragraphs which are extracted from the trip reports associated with the two visits.

VISITS TO AIRLINES, JULY 18-21, 1979

As part of the Douglas-NASA Super 80 Propfan Feasibility Study, four airlines were visited during July 18-21, 1979: Allegheny (since changed to USAir), Delta, United, and Republic. Discussions can be classified into several general areas: (1) configuration selection, (2) energy, (3) actions necessary to provide confidence in propfan aircraft, and (4) propfan versus laminar flow control (LFC) as a means of future fuel conservation.

The general airline comments in these areas are outlined:

- All airlines favored the wing mounted engine configuration and objected to the aft engine configuration. The objection to the aft mounted engine was due to the airlines' opinion that there would be increased foreign object damage. Another factor was that safety would be reduced as the aft surfaces would be subject to damage in case of a propeller failure.

- The main energy problem has been cost. The availability problem has been and will continue to be solved by purchases in the spot market.

- All the airlines believed that wind tunnel testing would not be sufficient to provide the confidence necessary to seriously consider a propfan powered airplane. Some form of technology flight demonstration will be necessary.

- The majority of the airlines believe that propfan technology has more potential for energy savings, from the operational point of view, than does laminar flow control.

The specific comments of each airline regarding the major topics of discussions are presented in the following text.

Allegheny Airlines - July 19, 1979 (the airline name was changed from Alleghney to USAir during 1979)

William G. Peppler - Staff Director, Development Engineering

Configuration Selection - No real interest existed in a propfan. Allegheny has recently been through the complete propulsion cycle: piston-prop, turbo-prop, fan jet. There are significant negative factors as far as a propfan is concerned: (1) noise, (2) vibration, (3) operational factors - in flight and on the ground - chiefly loading and unloading on the ground, and (4) the impression of being out of date. While the fuel savings from a propfan are important, other factors are also of importance, such as public acceptance, maintainability, and total system economics. The aft propfan configurations were not well received.

Energy - Fuel is expensive and getting more so. Fuel saving through conservation is very effective, but there is still a long way to go. Procedures such as slowing down aircraft, education of the flight crew, improved operations such as taxiing on one engine, more aircraft towing, improved navigation such as use of the Omega system being studied, and consideration given to use of flight management systems. To balance fuel availability, some use of "fuel tankering" is being made.

Actions Necessary to Provide Confidence in Propfan Aircraft - Wind tunnel tests will not provide sufficient confidence for serious consideration of propfans. A technology demonstrator airplane would be required to prove the reliability, cabin noise levels, and system economics. A cargo demonstrator operated in an airline environment would be better yet; Allegheny would consider operating such an airplane under the proper conditions.

Allegheny would be very interested in participating in a thorough propfan systems study similar to the NASA-funded STOL Systems Study. The criteria for Allegheny management to recommend consideration of a propfan airplane include: (1) attractive system economics, and (2) airplane speed not compromised.

Propfan versus Laminar Flow Control - Allegheny is interested in laminar flow control as a potential fuel savings technology.

Delta Airlines - July 20, 1979

C. K. Bautz - Performance & Analysis Engineering Superintendent
Burt Terrell - Structures Project Engineer
Don Collier - Chief Aircraft Engineer
C. C. Davis - Propulsion Project Engineer
Jim Goodrum - Chief Power Plant Engineer
Tom Newton - Project Engineer - Reliability

Configuration Selection - Delta favors a wing mounted engine configuration; a tail mounted engine configuration was thought questionable for the following reasons:

- Structural vibration and aerodynamic circulation problems are of concern.

- Delta has data that show that fuselage mounted engines on the DC-9 and B727 have over four times more foreign object damage than the wing mounted engines on its DC-8 and L-1011 airplanes. Delta has provided a year's data to substantiate this position. Blowback over the runways from B747s and DC-10s is a factor in the FOD problem.

- There was also objection to a tail mounted configuration from a safety standpoint. A propeller failure could damage the elevators and rudder.

- Propfan installation would probably require a synchronization system - another system and more complexity.

- From a maintenance standpoint, wing mounted engines are better than aft engines.

Energy - Commencing July 1, 1979, Delta started serious aircraft fuel conservation. Before that, it was a token effort. At present, the main efforts are being directed toward cruise speed reduction. There is concern over both fuel cost and availability. Considerable fuel is being purchased on the spot market.

Delta is not opposed to "fuel tankering"; it is not a planned operation. No penalty should be incorporated in aircraft to provide such a capability.

Delta's acceptance of a propfan aircraft fleet would only be as a means of survival.

Action Necessary to Provide Confidence in Propfan Aircraft - A technology demonstrator will be needed; wind tunnel testing is not sufficient. There must also be proof of passenger acceptance; in general, Delta did not believe that passenger acceptance would be a real problem.

Propfan versus Laminar Flow Control - Delta sees no way in which an airline can operate an airplane efficiently with laminar flow control. Delta's management has instructed that no further effort be devoted to studying this concept. This airline was a subcontractor to Lockheed in their NASA funded laminar flow control study. Delta believes that a propfan has more potential.

United Airlines - July 23, 1979

Paul Beard - Staff Engineer - Power Plant
R. E. Coykendall - Aircraft Development Manager
D. L. Davis - Manager - Power Plant Installation
A. E. Domke - Staff Engineer - Operational Engineering

NASA Personnel Attending Meeting:

Jeff Bowles - NASA Ames
Lou Williams - NASA Ames

Configuration Selection - United did not favor the tail mounted engine configurations. Foreign object damage is greater and is a major objection. The need for chine tires on both the DC-9 and B-727 was cited. United will provide premature engine removal data to substantiate this position.

There is also the potential for the rudder and, more importantly, the elevator to be damaged due to either an engine or propeller failure. Further, maintenance is more difficult as the engines are higher from the ground, and their distance from the airplane's center-of-gravity results in considerable movement.

The question was raised why no wing mounted pusher installation was considered in the study.

Passenger appeal of a propfan will be a very important consideration in the success of its commercial application. (A previous survey by United of passenger acceptance showed that passengers were not adverse to the propfan with significant fare reduction.)

Energy - Up to now, very little emphasis has been placed on fuel availability; the prime emphasis has been upon cost. For planning purposes, United is using 60 cents a gallon (15.85 cents/liter) as their third quarter 1979 fuel cost. Using procedures incorporating aspects of the Douglas model, United has done some fuel tankering and will probably do more in the future as it solves local fuel problems. In general, it is not cost-effective for United.

Actions Necessary to Provide Confidence in Propfan - Wind tunnel testing alone will not provide sufficient confidence for United to be serious about a propfan. Flight demonstration which affords long time exposure in an airline environment may be necessary. Evaluation of the concept on a cargo plane will be helpful.

Propfan versus Laminar Flow Control - United has more faith in propfan technology than it does in laminar flow control. The airline believes that propfan aircraft will have more reliability and lower maintenance cost than an airplane with laminar flow control.

Republic Airlines - July 24, 1979

Charles B. Vesper - Assistant Vice President

Configuration Selection - Under present conditions, it may be difficult to market a propfan to the traveling public, but this could change with time. Republic favors the wing mounted configuration, but for unquantifiable reasons.

Energy - All the fuel desired is available if one wishes to pay for it. Republic is currently getting about 20 percent of its fuel on the spot market. Their average fuel price, contract and spot fuel, is 62 cents a gallon (16.4 cents/liter), with spot fuel ranging from 85 cents to 92 cents/gallon (22.5 cents/liter to 24.3 cents/liter). The spot fuel must be purchased in $1 million minimum quantities.

Republic's fares have increased 15.1 percent so far in 1979 due chiefly to fuel costs and will probably continue to increase every two months to counterbalance the rising fuel costs.

Fuel ferrying in general is not very effective for the Republic routes.

Actions Necessary to Provide Confidence in Propfan Aircraft - Wind tunnel tests alone will not provide enough confidence for Republic to seriously consider a propfan powered airplane. A demonstrator will be necessary as a minimum. In the past, Republic has only purchased aircraft that have already been fully certified and are in airline service.

Propfan versus Laminar Flow Control - Republic Airlines believes the propfan has more potential than laminar flow control as an airline fuel saving technology.

VISITS TO AIRLINES, AUGUST 19-22, 1980

The same four airlines visted in July 1979 were also visited again August 19-22, 1980. Representatives of NASA accompanied Douglas on the

1980 visits. Discussions can be classified into three general areas — operational considerations, configuration and sizing, and passenger acceptance.

The general airline comments in these areas are summarized:

- Since the July 1979 visits, there was considerably more interest in propfan aircraft. This is primarily due to the doubling of fuel costs in the July 1979-August 1980 time frame.

- The reliability of the propfan gearbox is an area of airline concern. They require a major development effort to build their confidence.

- Cabin noise and vibration must be minimized.

- The size (155-165 passengers), range, and configuration of the study airplane are proper for the initial propfan airplane.

- The fuel savings associated with the propfan over the turbofan are more than adequate to make the propfan a strong competitor for the future aircraft.

The specific comments of each airline regarding the major topics of discussion are presented in the following text.

USAir - August 19, 1980

Chuck Faust - Staff Engineer - Structures
Stan Fickes - Flight Operations Manager
William Peppler - Staff Director - Development Engineering

NASA Personnel Attending Meeting:

Dave Sagerser - NASA Lewis
Lou Williams - NASA Ames

Operational Considerations - Since the cost of fuel has more than doubled since July 1979, USAir has become considerably more interested in propfan development.

On short flights, less than 300 nmi (556 km), it is not realistic to have one third of the flight in cruise. However, for ease of analysis, in the present study there was no objection to using this criterion.

Airplanes are currently refueled at each stop. This could change as a function of either fuel cost or availability.

Low propfan direct operating costs are not the only consideration; high levels of reliability are equally important. The propfan concept adds systems, and there are concerns that can only be resolved by a major development effort.

In the past, all propeller systems have had problems. The reversing and feathering systems have been far from trouble free. The very large amount of power that must be handled by the gearbox may be a source of trouble. A demonstrator airplane will be required to allay these concerns; a testbed airplane will not suffice.

Mr. Peppler commented that USAir should not be "crossed off" relative to using the propfan as they may well be among the first to use the propfan aircraft.

Configuration and Sizing - The wing mounted engines will delay passenger loading and unloading since the propellers must be stopped before these operations can commence.

The size, range, and speed of the study airplane are good. Airplanes smaller than the DC-9-30/-50 will not be needed by USAir in the 1990s and are thought to be a mistake for the initial propfan aircraft. The minimum design passenger payload considered should be less than 110 in any case.

A takeoff field length of 5280 ft (1610 m at altitude) with a full passenger payload on the 84°F (23°C) day is compatible with USAir mission requirements.

Passenger Acceptance - To help achieve passenger acceptance of propfan aircraft, the economic advantages of the airplane over turbofan powered aircraft must be widely communicated to the traveling public. The cabin noise and vibration should not exceed that of turbofan powered aircraft.

USAir was not aware of the propfan acceptability study prepared by United Airlines for NASA Ames. Offhand, USAir was somewhat skeptical of the study conclusions.

It is very important that the propfan concept be proven by service experience since, on the surface, it looks like going backward in technology.

Delta Airlines - August 20, 1980

C. K. Bautz - Performance and Analysis, Engineering Manager
Jim Goodrum - Chief Power Plant Engineer
Tom Newton - Project Engineer - Reliability

NASA Personnel Attending Meeting:

Dave Sagerser - NASA Lewis
Lou Williams - NASA Ames

Operational Considerations - The fuel problem has gotten worse. Delta is cruising its DC-9s at 0.76 Mach; this is about as slow as they want to cruise the airplanes. The trades of fuel burned versus flight times are getting serious attention.

A propfan aircraft now has a good chance, while a year ago Delta thought the concept had no chance. The approximate 30 percent potential fuel savings from propfans are attracting attention. However, the maintenance economics should be the same as or less than for the DC-9 Super 80.

On segments shorter than 300 nmi (556 km), there is often no time in cruise; it is all climb and descent. On segments longer than 300 nmi (556 km), one third cruise or greater is a good assumption. Delta is not currently planning on giving up many of their short routes or flights to small cities.

There is definite interest in the propfan testbed program. However, there are concerns regarding a propfan commercial transport, such as: (1) cabin vibration; (2) a new propulsion system will require five to six years to mature and in the interim, there are many problems; and (3) major costs will be incurred for ramp modifications as well as for additional propfan shop and overhaul facilities.

Configuration and Sizing - The overwing configuration "looks" best. A 1200 nmi (2222 km), range is satisfactory. A capacity of 155 passengers or larger, using 32-in. (81.3 cm) coach seat pitch, is desired. The DC-9 Super 80 capability is "excellent." No one is talking about an airplane with 120 seats or less.

The twin engine aircraft is not a matter of concern for the initial propfan aircraft.

Passenger Acceptance - There will be a passenger mind set to be overcome in marketing a propfan powered airplane, but this can be done by an effective marketing program.

Republic Airlines - August 21, 1980

Harvey Armstrong - Director of Engineering
Brian Chapman - Performance Weight and Balance Engineer
Milton Ellyson - Director - Airport Requirements
Wayne Miller - Manager - Flight Standards
Mark Thelen - Aircraft Performance Engineer
Charles Vesper - Assistant Vice President - Schedules and Tariffs

NASA Personnel Attending Meeting:

Dave Sagerser - NASA Lewis
Jeff Bowles - NASA Ames

Operational Considerations - Republic anticipates not only rapidly increasing fuel costs, but also fuel availability problems. Fuel is conservatively estimated at $1.50 per gallon ($0.396 per liter) by the mid-1980s. The fuel savings of the propfan over the turbofan aircraft will outweigh maintenance costs and complexities of the propfan installation. There is no question that propfans will be acceptable because of the fuel savings.

Republic's aim is to operate through as many stations as possible without refueling.

More safeguards will be needed on a propfan powered airplane as there will be more systems and complexities than there are on a turbofan powered airplane. Foreign object damage may be a problem, especially for aft mounted engine configurations. Slush into the aft-mounted propfans is a problem of concern.

The manufacturers must be conservative in the use of composites.

The minimization of interior noise and vibration is very important. The turboprop Convairs were subject to a great deal of sonic fatigue.

Configuration and Sizing - A cruise speed of 0.80 Mach is necessary to assure compatibility with the Air Traffic Control system.

A passenger capacity of 155 to 165 is about right; the capacity should not be less for efficient use in the 1990s.

Passenger Acceptance - The very high price of fuel in the future will result in passengers accepting propfan powered aircraft. The passenger acceptance of propfans will be a parallel to the acceptance of small cars.

United Airlines - August 22, 1980

Paul M. Beard - Staff Engineer - Propulsion Engineering
Robert C. Collins - Vice President - Engineering
Richard C. Coykendall - Aircraft Development Manager

John K. Curry - Staff Engineer - Analysis
James K. Goodwine - Manager - New Aircraft and Operational Engineering
Lester W. Olson - Director - Avionics Engineering
Mel B. Schwartz - Staff Engineer - Performance

NASA Personnel Attending Meeting:

Jeff Bowles - NASA Ames
Tom Galloway - NASA Ames

Operational Considerations - It is anticipated that fuel will cost $1.60 to $1.75 per gallon ($0.423 to $0.455 per liter) by the mid-1980s.

The block speeds of a propfan airplane must be compatible with those for the B767. The cruise speed need not be same; however, in order to meet the ATC requirements and to avoid a complete revision of the schedule and route structure with the replacement aircraft (propfan, for instance), a speed of $M_{cruise} \sim 0.8$ is desired.

United has supported the propfan since the program began, and this interest is definitely increasing and solidifying as the propfan program progresses.

Relative total fleet fuel efficiency is important to United; however, the individual aircraft in the fleet must be matched to the specific route and capacity requirements. For instance, B727-222 airplanes will probably be in its fleet beyond 2000.

Configuration and Sizing - The size of the airplane will be determined by engine availability. The gearbox is the area of greatest concern. Since there have been no new fundamental gearbox efforts in many years, this is the area requiring the greatest amount of attention. A 500 hour gearbox environmental service test should be a minimum requirement.

Passenger Acceptance - A propfan airplane should have no problems as far as passenger acceptance is concerned, provided a high level of airplane reliability is achieved.

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SECTION 8

RECOMMENDATIONS FOR FURTHER STUDY AND TEST

The results of this broad brush study of the propfan versus the turbofan, using an actual airplane (the DC-9 Super 80) as a base and taking into account the practical design changes necessitated by the change from a turbofan to a propfan propulsion system installation, have all been positive for the propfan installation. The propfan configurations are feasible; their performance capability - that is, cruise Mach number and altitude - are very competitive; savings in fuel burned, over the comparable turbofan, vary from approximately 25 percent at a full passenger payload and at M_{cruise} 0.8 to approximately 40 percent at a practical passenger load factor of 60 percent and at Mach number for long range cruise; range is improved by at least 5 percent, along with the above-mentioned fuel savings, over that of the turbofan. Throughout all of these positive comparative results of the propfan over the turbofan, the interior noise level of the propfan aircraft is maintained equal to the 82 dBA of the existing DC-9 Super 80. In addition, the far field FAR Part 36 noise estimations show the propfan to have the following approximate advantages over the FAR Part 36 (Stage 3) noise limits:

Takeoff	- 9.6 EPNdB
Sideline	- 2.2 EPNdB
Approach	- 6 EPNdB

Also, the propfan configurations noise levels are estimated to be less than those noise levels approximated for the DC-9 Super 80.

Throughout, the propfan configurations have been shown to be feasible. The performance results have been very worthwhile, particularly in terms of fuel savings over current fossil fuel operations; and further study of the propfan concepts is certainly warranted, with proper emphasis on an early introduction of the propfan aircraft into the operational fleet.

These study results bring to light specific areas where further research and development are required to provide the necessary verification for acceptance by the airlines of the propfan aircraft into the airline fleets. The areas recommended for further study and test are discussed in the following paragraphs in terms of the specific discipline to which the problem area is related.

CONFIGURATION

Propfan Installation Parameters

Continued coordination with the engineering disciplines, Hamilton Standard, and the engine manufacturers is necessary for a well developed, well integrated propfan aircraft. Installation problems such as the following all require concentrated effort:

- The engine/propfan/nacelle aircraft integration;
- Necessary subsystems and their installation for the overall propulsion system;
- Propulsive efficiency as a function of propfan/nacelle installation;
- Propfan-gearbox integration;
- Feasibility of modularized installation for efficient maintenance;
- Innovative landing gear installations for aft mounted propfan.

Innovative design solutions to the problem areas noted are desired.

AERODYNAMICS

Unsteady Flow on Aircraft Components Induced by Propfan Flow

The current state of the art does not include an acceptable analytical or empirical method of predicting the unsteady flow characterisitcs induced on aircraft components by propeller or propfan flow. This capability is essential for proper propfan aircraft design. To obtain the desired technical results, a preliminary analytical analysis of the installed propfan time-harmonic problem must be conducted with special emphasis on aspects that are peculiar to the aircraft application, including such as far field pressures, very thin propeller blades, and complex mountings. Confirmation of these analytical results with test data is then required.

Configuration Integration

Technical areas included in this particular wing mount problem are: (1) effects of propwash on wing stall and $C_{L_{max}}$; (2) pitch-up at stall; (3) span load distortions (induced drag), (4) wing/nacelle profile drag, and (5) distortions to the wing streamline pattern at transonic speeds and consequent drag increases.

In the case of the aft mount installation, the major aerodynamic impact is on the stability and control characteristics of the aircraft. The propfan with its large side area produces approximately twice the normal force of the older conventional propellers for a given number of blades. It is recommended that the present propfan be wind tunnel tested to determine its normal force contribution. Such confirmation of the analytical estimate is needed badly to provide verification of tail sizing. Other areas of uncertainty with the aft mounted propfan include: (1) stall characteristics, (2) control authority at stall, (3) stall recovery, (4) integration of the propfan/nacelle with the horizontal tail, (5) integration of the strut/nacelle/propfan with the aft body of fuselage, and (6) propfan effects on the wing flow--velocity accelerations ahead of the propfan will influence wing flow at cruise.

Nacelle/Wing Contouring in Presence of Propfan

The existing capability of nacelle/wing contouring for turbofan installations needs to be extended and made applicable to the propfan/nacelle/wing installation. The presence of the propfan has a substantial influence on the resultant streamlines and contouring. This capability is not currently in hand, although it is critical to an accurate lift and drag analysis of propfan aircraft configurations.

Improvement in design procedures should include development of a prediction method for nacelle/wing contouring in the presence of a propfan and prediction of propfan slipstream effects as a function of distance from the propfan. Analyses should evaluate the effects on aerodynamic control surfaces such as flap and leading-edge device lift and drag at low speed, second-segment climb conditions, and leading-edge design at low speed, high lift conditions in the strong upwash/downwash flow produced by the propfan.

Swirl Thrust Loss Recovery

The energy lost in the swirl, or angular rotation, of the propfan slipstream is estimated to be equivalent to an 8 percent decrease in efficiency. Since the total loss is only about 20 percent, this swirl energy constitutes a significant percentage of the propeller efficiency loss. Recovery of this swirl energy will produce a significant gain in performance and fuel saving.

Basic technical issues are:

- How much swirl is recovered by a wing designed using conventional design principles?
- For a strut mounted configuration, how much swirl energy can be recovered since the strut only spans one-half of the propfan wash?
- Can the elevators on the horizontal tail be differentially deflected to maximize swirl recovery?
- What is the optimum wing span load in the presence of the prop wash?
- What is the preferred direction of propeller rotation (opposite rotation)?

It is recommended that swirl measurements be made downstream of the wing in the upcoming NASA Ames active propfan test. The amount of residual swirl still remaining will then indicate whether any further improvements are available through wing modification.

Analytical studies should be conducted to find the optimum desirable span loading condition with the propfan wash in the wing flow field. This activity should include propfan efficiency/thrust recovery trade studies.

STRUCTURES

Engine Propfan Structural Installation

Further detailed development of a primary structure load carrying nacelle that is compatible with low excitation propfan installation is required, which is suitable for modular propulsion system arrangement.

Sonic Fatigue Testing

As the sonic fatigue problems increase with a propfan installation over those of the turbofan, it is considered necessary to

- Require fatigue testing in the areas above those number of cycles available in existing data to establish allowable strengths;
- Establish sonic fatigue data on panels subjected to steady in-plane loads such as those caused by pressurization;
- Flight test to determine the manner in which the fuselage wall responds to the acoustic pressures. The flight test data are essential to provide a more substantive basis for sonic fatigue life prediction.

DYNAMICS

Multiblade Propfan Whirl Flutter

Whirl flutter will be an important area of investigation on currently proposed propfan designs. Past application of whirl analysis procedures was to 3 and 4 blade (unswept) propellers, whereas the newly proposed designs feature 8 or 10 highly swept blades.

Therefore, a study should be implemented to assess the current state of the art of whirl flutter analysis procedures, conduct analyses of modern propeller designs, and possibly, perform a simplified whirl flutter model test program to verify the analysis procedures.

PROPULSION

Critical technical problem areas in the propulsion system include the propfan, engines, gearbox controls, and the propulsion system installation.

Propfan

Risk areas involving the propfans are generally recognized and have been discussed in the Hamilton Standard work (References 2 through 8).

Engines

Although turboprop engines benefit from the component improvements of ATEGG and progress in turbofan development, they have not been subjected to the exhaustive cycle analysis concentrated on turbofans in recent years. Engine studies of number of spools, pressure ratios, numbers of turbine stages, and other factors will be required before an all-new turboprop/turboshaft engine design can be defined.

Gearbox

Present day turboprop engines provide about one third the power required by an aircraft the size of the DC-9 Super 80, and have gearboxes with about twice the gear ratio that would be required for a propfan drive. Because of past problems with gearboxes and the lack of developed high power gearboxes, demonstration of flight-weight, 15,000 shp (11,300 kW) gearbox subjected to flight loads is required. Efficiency, low wear, and reliability need to be demonstrated.

Controls

The problems peculiar to the propfan control are not known and will not necessarily be identified without an in-depth study. For example,

- What is the best parameter for setting power, such as maximum climb power?
- What is the sensitivity of low spool rpm to pitch change at cruise?
- With a free turbine, what means can provide acceptable reversing times without overspeeding when the blades are unloaded?

The propfan propulsion controls should reflect a state of the art equal to those of turbofans. By the time a new aircraft is introduced, digital electronics with cathode ray-tube displays and a single lever with command settings are expected. A digital control needs to be developed and flight demonstrated.

Propulsion System Installation

As problems with turboprop systems have frequently been associated with their installation, this is a critical problem area that must be addressed for a successful propfan program.

Inlet - What is effect of propfan flow field, constant low spool rpm, high hub/tip ratio on the best inlet design Mach numbers, diffusion angles, etc.? In addition, with the high-velocity propfan wash, treatment of secondary inlets and exits normally required may have special requirements which are not currently known.

Mounting - The mounting must be designed to prevent whirl flutter as well as to take thrust and g loads. Vibration isolation is critical to provide acceptable passenger comfort levels. These requirements need to be incorporated in a design that permits easy access to the propulsion system components for inspection and service.

Since an advanced turboprop using E^3 technology is required to realize maximum fuel savings, a detailed study is needed to understand its ramifications. For example, E^3 requires reduced tip clearances with active clearance controls. Deflection from flight loads must be very small to preserve performance gains. This type of problem might possibly occur on a propfan installation in terms of shaft flexing from excessive flight loads.

Secondary Power - Power extraction from the main propulsion system has become more costly as bypass ratios have increased and engines become more sensitive to these losses; and the propfan/turboprop is, of course, a very, very high bypass-ratio engine. The amount of bleed air such as currently extracted on the DC-9 Super 80 would greatly reduce the fuel advantage of the propfan if the identical environmental control, pressurization system were used on the propfan aircraft. An integrated systems approach to the entire secondary power problem has a large potential for reducing the penalties now associated with power extraction. The turboprop system, with its relatively high heat rejection, is a particularly good candidate for a study exploring the possibilities of combining all the secondary power requirements and secondary energy sources to achieve an overall efficiency and weight superior to the present day arrangements.

FLIGHT TEST

A large scale flight test program is essential before a prototype propfan aircraft can be designed. Information on the individual critical problem areas cited above can be obtained from flight testing a propfan installation that is not the primary power source of the aircraft. Most important, the interaction of the entire propulsion system and the aircraft can be observed. Cabin noise, vibration, actual propfan loads, and flow field interactions on the aircraft components may all be measured or defined in the flight environment. A flight test program also provides opportunities to try "fixes" for problems that arise during the testing. It is strongly urged that flight tests be conducted to permit evaluation in flight of this promising new propulsion system.

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APPENDIX A

DETAIL OF DC-9 SUPER 80 PROPFAN AIRCRAFT SIZING AND MULTI-HOP MISSION PERFORMANCE

Tables A-1 and A-2 summarize the pertinent detail performance for the DC-9 Super 80 and the propfan Configurations 1, 3, and 2. Table A-1 presents the mission characteristics corresponding to the step-cruise (long range) M_{cruise} = 0.80 performance for the basic propfan. Table A-2 summarizes the effects of stage length, number of propfan blades, and propfan tip speed/disc loading on the mission performance characteristics.

Table A-3 presents the IBM printout for the multi hop mission under conditions of 100 percent and 60 percent passenger load factors. The basic DC-9 Super 80 and Configurations 1, 3, and 2 are considered.

TABLE A-1

PERFORMANCE CHARACTERISTICS OF THE M_{CRUISE} = 0.80 MISSION

Step-Cruise Corresponding to Payload/Range Plot (Figure 26)
Design Takeoff Gross Weight = 140,000 lb (63,503 kg)
100 Percent Passenger Payload = 31,775 lb (14,413 kg)
Propfan - 8 blade, 800 ft/sec, 37.5 SHP/D^2 (244 m/sec, 301 kW/m^2)

Configuration	No. Blades	Tip Speed ft/sec (m/s)	Range n mi (km)	Payload lb (kg)	Engine Size SHP (kW)	Climb Fuel lb (kg)	Climb Time hr	Total Fuel Burned lb (kg)	Reserve Fuel lb (kg)
Basic Turbofan									
DC-9-80	-	-	1309 (2424)	31,775 (14,413)	-	3913 (1775)	0.358	21,641 (9,816)	8077 (3664)
DC-9-80	-	-	1895 (3510)	24,000 (10,886)	-	3913 (1775)	0.358	29,835 (13,533)	7660 (3475)
DC-9-80	-	-	1990 (3685)	22,774 (10,330)	-	3913 (1775)	0.358	31,127 (14,119)	7591 (3443)
Wing Mount Propfan									
Config 1	8	800 (244)	1479 (2739)	31,775 (14,413)	16,517 (12,317)	2201 (998)	0.265	19,552 (8,869)	5452 (2473)
Config 1	8	800 (244)	2191 (4058)	24,000 (10,886)	16,517 (12,317)	2201 (998)	0.265	27,556 (12,499)	5223 (2369)
Config 1	8	800 (244)	2779 (5147)	18,060 (8,192)	16,517 (12,317)	2201 (998)	0.265	33,671 (15,273)	5049 (2290)
Horizontal Tail Aft Mount Propfan									
Config 3	8	800 (244)	1549 (2869)	31,775 (14,413)	16,273 (12,135)	2197 (997)	0.268	20,093 (9,114)	5374 (2438)
Config 3	8	800 (244)	2278 (4219)	24,000 (10,886)	16,273 (12,135)	2197 (997)	0.268	28,097 (12,745)	5146 (2334)
Config 3	8	800 (244)	2829 (5239)	18,523 (8,402)	16,273 (12,135)	2197 (997)	0.268	33,732 (15,301)	4987 (2262)
Aft Fuselage Pylon Mount Propfan									
Config 2	8	800 (244)	1239 (2295)	31,775 (14,413)	16,511 (12,312)	2201 (998)	0.266	16,618 (7,538)	5533 (2510)
Config 2	8	800 (244)	1917 (3550)	24,000 (10,886)	16,511 (12,312)	2201 (998)	0.266	24,625 (11,170)	5305 (2406)
Config 2	8	800 (244)	2780 (5149)	15,207 (6,898)	16,511 (12,312)	2201 (998)	0.266	33,672 (15,273)	5047 (2289)

TABLE A-2

EFFECT OF STAGE LENGTH, PROPFAN NUMBER OF BLADES, AND TIP SPEED ON PERFORMANCE CHARACTERISTICS OF M_{CRUISE} = 0.80 MISSION*

Constant Initial Cruise Altitude

Configuration	No Blades	Tip Speed ft/sec (m/sec)	Range n mi (km)	TOGW lb (kg)	Engine Size SHP (kW)	Climb Fuel lb (kg)	Climb Time hr	Total Fuel Burned (kg)	Reserve Fuel (kg)
Basic Turbofan									
DC-9-80	-	-	100 (185)						
DC-9-80	-	-	300 (556)	124,416 (56,434)	-	3582 (1625)	0.343	6,057 (2747)	8077 (3664)
DC-9-80	-	-	800 (1482)	132,187 (59,959)	-	3816 (1731)	0.359	13,829 (6273)	8077 (3664)
DC-9-80	-	-	1267 (2346)	140,000 (63,503)	-	4068 (1845)	0.377	21,641 (9816)	8077 (3664)
Propfan 8 Blade 800 ft/sec (244 m/sec) Tip Speed									
Wing Mount									
Config 1	8	800 (244)	100 (185)	122,840 (55,719)	16,517 (12,317)	750 (340)	0.075	2,390 (1084)	5452 (2473)
Config 1	8	800 (244)	300 (556)	125,105 (56,747)	16,517 (12,317)	2060 (934)	0.259	4,655 (2111)	5452 (2473)
Config 1	8	800 (244)	800 (1482)	131,058 (59,447)	16,517 (12,317)	2142 (972)	0.265	10,610 (4813)	5452 (2473)
Config 1	8	800 (244)	1453 (2691)	140,000 (63,503)	16,517 (12,317)	2201 (998)	0.266	19,555 (8870)	5452 (2473)
Horizontal Tail Aft Mount									
Config 3	8	800 (244)	100 (185)	122,268 (55,460)	16,273 (12,135)	735 (333)	0.075	2,356 (1069)	5376 (2438)
Config 3	8	800 (244)	300 (556)	124,490 (56,468)	16,273 (12,135)	2048 (929)	0.261	4,579 (2077)	5376 (2438)
Config 3	8	800 (244)	800 (1482)	130,323 (59,113)	16,273 (12,135)	2128 (965)	0.267	10,414 (4724)	5376 (2438)
Config 3	8	800 (244)	1524 (2822)	140,000 (63,503)	16,273 (12,135)	2198 (997)	0.268	20,095 (9115)	5376 (2438)
Aft Fuselage Pylon Mount									
Config 2	8	800 (244)	100 (185)	125,795 (57,060)	16,511 (12,312)	762 (346)	0.076	2,411 (1094)	5533 (2510)
Config 2	8	800 (244)	300 (556)	128,087 (58,099)	16,511 (12,312)	2134 (968)	0.268	4,703 (2133)	5533 (2510)
Config 2	8	800 (244)	800 (1482)	134,018 (60,790)	16,511 (12,312)	2265 (1027)	0.282	10,636 (4824)	5533 (2510)
Config 2	8	800 (244)	1214 (2248)	140,000 (63,503)	16,511 (12,312)	2201 (998)	0.266	16,618 (7538)	5533 (2510)

*Cruise M Less Than 0.8 for 100-n mi Range Cases

TABLE A-2

EFFECT OF STAGE LENGTH, PROPFAN NUMBER OF BLADES, AND TIP SPEED ON PERFORMANCE CHARACTERISTICS OF M_{CRUISE} = 0.80 MISSION* (CONTINUED)

Constant Initial Cruise Altitude

Configuration	No Blades	Tip Speed ft/sec (m/sec)	Range n mi (km)	TOGW lb (kg)	Engine Size SHP (kW)	Climb Fuel lb (kg)	Climb Time hr	Total Fuel Burned (kg)	Reserve Fuel (kg)
Propfan 10 Blade, Configuration 1									
800 ft/sec (244 m/sec)									
Config 1	10	800 (244)	100 (185)	121,534 (55,127)	16,430 (12,252)	741 (336)	0.074	2,367 (1074)	5387 (2443)
Config 1	10	800 (244)	300 (556)	123,765 (56,139)	16,430 (12,252)	2031 (921)	0.257	4,599 (2086)	5387 (2443)
Config 1	10	800 (244)	800 (1482)	129,621 (58,795)	16,430 (12,252)	2110 (957)	0.263	10,456 (4743)	5387 (2443)
Config 1	10	800 (244)	1568 (2904)	140,000 (63,503)	16,430 (12,252)	2189 (993)	0.265	20,837 (9451)	5387 (2443)
700 ft/sec (213 m/sec)									
Config 1	10	700 (213)	100 (185)	123,160 (55,864)	16,379 (12,214)	744 (337)	0.075	2,371 (1075)	5412 (2455)
Config 1	10	700 (213)	300 (556)	125,411 (56,885)	16,379 (12,214)	2044 (927)	0.259	4,623 (2097)	5412 (2455)
Config 1	10	700 (213)	800 (1482)	131,328 (59,569)	16,379 (12,214)	2123 (963)	0.265	10,541 (4781)	5412 (2455)
Config 1	10	700 (213)	1438 (2663)	140,000 (63,503)	16,379 (12,214)	2178 (988)	0.265	19,216 (8716)	5412 (2455)
Propfan 10 Blade, Configuration 1 (Cont)									
600 ft/sec (183 m/sec)									
Config 1	10	600 (183)	100 (185)	125,215 (56,797)	16,726 (12,473)	768 (348)	0.076	2,438 (1106)	5585 (2533)
Config 1	10	600 (183)	300 (556)	127,551 (57,856)	16,726 (12,473)	2119 (961)	0.262	4,774 (2165)	5585 (2533)
Config 1	10	600 (183)	800 (1482)	133,702 (60,646)	16,726 (12,473)	2205 (1000)	0.268	10,927 (4956)	5585 (2533)
Config 1	10	600 (183)	1246 (2308)	140,000 (63,503)	16,726 (12,473)	2230 (1011)	0.266	17,226 (7814)	5585 (2533)

*Cruise M Less Than 0.8 for 100-n mi Range Cases

TABLE A-2

EFFECT OF STAGE LENGTH, PROPFAN NUMBER OF BLADES, AND TIP SPEED ON PERFORMANCE CHARACTERISTICS OF M_{CRUISE} = 0.80 MISSION* (CONTINUED)

Constant Initial Cruise Altitude

Configuration	No Blades	Tip Speed ft/sec (m/sec)	Range n mi (km)	TOGW lb (kg)	Engine Size SHP (kW)	Climb Fuel lb (kg)	Climb Time hr	Total Fuel Burned (kg)	Reserve Fuel (kg)
Propfan 10 Blade, Configuration 3									
800 ft/sec (244 m/sec)									
Config 3	10	800 (244)	100 (185)	121,752 (55,226)	16,209 (12,087)	731 (332)	0.074	2,343 (1063)	5339 (2422)
Config 3	10	800 (244)	300 (556)	123,958 (56,226)	16,209 (12,087)	2029 (920)	0.261	4,548 (2063)	5339 (2422)
Config 3	10	800 (244)	800 (1482)	129,742 (58,850)	16,209 (12,087)	2108 (956)	0.266	10,334 (4687)	5339 (2422)
Config 3	10	800 (244)	1571 (2909)	140,000 (63,503)	16,209 (12,087)	2185 (991)	0.268	20,597 (9343)	5339 (2422)
700 ft/sec (213 m/sec)									
Config 3	10	700 (213)	100 (185)	123,320 (55,937)	16,143 (12,038)	733 (332)	0.076	2,344 (1063)	5360 (2431)
Config 3	10	700 (213)	300 (556)	125,543 (56,945)	16,143 (12,038)	2042 (926)	0.261	4,567 (2072)	5360 (2431)
Config 3	10	700 (213)	800 (1482)	131,379 (59,593)	16,143 (12,038)	2121 (962)	0.268	10,405 (4720)	5360 (2431)
Config 3	10	700 (213)	1446 (2678)	140,000 (63,503)	16,143 (12,038)	2174 (986)	0.268	19,030 (8632)	5360 (2431)
600 ft/sec (183 m/sec)									
Config 3	10	600 (183)	100 (185)	125,503 (56,927)	16,500 (12,304)	758 (344)	0.076	2,413 (1094)	5539 (2512)
Config 3	10	600 (183)	300 (556)	127,813 (57,975)	16,500 (12,304)	2119 (961)	0.264	4,723 (2142)	5539 (2512)
Config 3	10	600 (183)	800 (1482)	133,892 (60,732)	16,500 (12,304)	2204 (1000)	0.271	10,804 (4901)	5539 (2512)
Config 3	10	600 (183)	1240 (2296)	140,000 (63,503)	16,500 (12,304)	2226 (1010)	0.268	16,913 (7672)	5539 (2512)

TABLE A-2

EFFECT OF STAGE LENGTH, PROPFAN NUMBER OF BLADES, AND TIP SPEED ON PERFORMANCE CHARACTERISTICS OF M_{CRUISE} = 0.80 MISSION* (CONCLUDED)

Constant Initial Cruise Altitude

Configuration	No Blades	Tip Speed ft/sec (m/sec)	Range n mi (km)	TOGW lb (kg)	Engine Size SHP (kW)	Climb Fuel lb (kg)	Climb Time hr	Total Fuel Burned (kg)	Reserve Fuel (kg)
Propfan 10 Blade, Configuration 2									
800 ft/sec (244 m/sec)									
Config 2	10	800 (244)	100 (185)	125,548 (56,948)	16,754 (12,493)	771 (350)	0.076	2,436 (1105)	5583 (2532)
Config 2	10	800 (244)	300 (556)	127,840 (57,987)	16,754 (12,493)	2158 (979)	0.269	4,727 (2144)	558[illegible] (2533)
Config 2	10	800 (244)	800 (1482)	134,072 (60,814)	16,754 (12,493)	2177 (987)	0.263	10,962 (4972)	5582 (2532)
Config 2	10	800 (244)	1215 (2250)	140,000 (63,503)	16,754 (12,493)	2194 (995)	0.260	16,890 (7661)	5584 (2533)
700 ft/sec (213 m/sec									
Config 2	10	700 (213)	100 (185)	127,348 (57,764)	16,636 (12,405)	772 (350)	0.077	2,433 (1104)	5594 (2537)
Config 2	10	700 (213)	300 (556)	129,659 (58,812)	16,636 (12,405)	2169 (984)	0.271	4,744 (2152)	5594 (2537)
Config 2	10	700 (213)	800 (1482)	135,931 (61,657)	16,636 (12,405)	2191 (994)	0.266	11,019 (4998)	5592 (2536)
Config 2	10	700 (213)	1080 (2000)	140,000 (63,503)	16,636 (12,405)	2181 (989)	0.260	15,088 (6844)	5593 (2537)
600 ft/sec (183 m/sec)									
Config 2	10	600 (183)	100 (185)	129,320 (58,659)	16,770 (12,505)	786 (357)	0.077	2,475 (1123)	5722 (2595)
Config 2	10	600 (183)	300 (556)	131,706 (59,741)	16,770 (12,505)	2215 (1005)	0.271	4,861 (2205)	5722 (2595)
Config 2	10	600 (183)	800 (1482)	138,173 (62,674)	16,770 (12,505)	2262 (1026)	0.271	11,331 (5140)	5721 (2595)
Config 2	10	600 (183)	919 (1702)	140,000 (63,503)	16,770 (12,505)	2230 (1011)	0.265	13,158 (5968)	5721 (2595)

TABLE A-3

MULTI HOP MISSION - 3 LEGS

DC-9 SUPER 80

Payload - 100 Percent Passenger Load Factor (155)

High Speed Cruise at Constant Initial Cruise Altitude or 35,000 ft

K5JA MISSION ANALYSIS CASE 4 MCDONNELL DOUGLAS CORPORATION JANUARY 8, 1980

RAMP WT = 139237.		TOTAL TIME= 4.680	BLOCK TIME= 3.343	(T-MP) TIME= 0.0
T.O.G.W. = 139237.	FN/ENG = 18000.	TOTAL FUEL= 28767.	BLOCK FUEL= 20669.	(T-MP) FUEL= 0.
WING AREA= [illegible]	NE = 2.0000	TOTAL DIST= 1200.	BLOCK DIST= 1000.	(T-MP) DIST= 0.
PAYLOAD = 32775.	ENG SIZE = 1.0000	F = 24.000	(T-B) TIME= 1.337	MP WT/SW = 0.0
O.E.W. = 78650.	WF MULT = 1.0000	AR = 9.618	(T-B) FUEL= 8077.	MP FN/WT = 0.0
WT/SW = 115.11	FN MULT = 1.0000	E = 0.799	(T-B) DIST= 200.	MP FUEL/WT = 0.0
FN/WT = 0.2586	FUEL/WT = 0.2066			

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE	139048.	0.083	159.	0.0	0.0					
ALLOWANCE	138756.	0.033	291.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	137472.	0.063	885.	17.2	17.2	1500.	10000.	0.388	0.452	
ACCELERATION	137753.	0.039	119.	2.8	20.0	10000.	10000.	0.452	0.523	
CLIMB	136232.	0.129	1472.	47.3	67.4	10000.	22021.	0.523	0.655	
CRUISE	134452.	0.137	1329.	66.7	134.1	22021.	22021.	0.800	0.800	
DESCENT	134740.	0.119	212.	37.4	171.5	22021.	10000.	0.569	0.452	
DESCENT	134536.	0.106	204.	28.5	200.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	133975.	0.067	561.	0.0	200.0					V APP= 131.022
ALLOWANCE	133880.	0.050	95.	0.0	200.0					
ALLOWANCE	133721.	0.033	159.	0.0	200.0					
ALLOWANCE	133430.	0.033	291.	0.0	200.0					
STAGE POINT										
CLIMB	132596.	0.060	834.	16.2	216.2	1500.	10000.	0.358	0.452	
ACCELERATION	132484.	0.039	112.	2.7	218.8	10000.	10000.	0.452	0.523	
CLIMB	129165.	0.349	3319.	140.3	359.1	10000.	35000.	0.523	0.720	
CRUISE	125847.	0.515	3318.	232.3	591.5	35000.	35000.	0.779	0.786	
DESCENT	125461.	0.231	357.	80.6	672.0	35000.	10000.	0.741	0.452	
DESCENT	125260.	0.104	200.	28.0	700.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	124737.	0.067	524.	0.0	700.0					V APP= 126.425
ALLOWANCE	124642.	0.050	95.	0.0	700.0					
ALLOWANCE	124483.	0.033	159.	0.0	700.0					
ALLOWANCE	124192.	0.033	291.	0.0	700.0					
STAGE POINT										
CLIMB	123441.	0.054	751.	14.5	714.6	1500.	10000.	0.398	0.452	
ACCELERATION	123340.	0.038	101.	2.4	717.0	10000.	10000.	0.452	0.523	
CLIMB	120517.	0.244	2[illegible].	117.6	834.6	10000.	35000.	0.523	0.720	
CRUISE	119690.	0.127	829.	53.4	892.9	35000.	35000.	0.795	0.797	
DESCENT	119112.	0.330	578.	107.1	1000.0	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	118612.	0.067	500.	0.0	1000.0					V APP= 123.243
ALLOWANCE	118517.	0.050	95.	0.0	1000.0					
BLOCK POINT										
STAGE POINT										
CLIMB	117637.	0.059	880.	15.7	15.7	0.	10000.	0.378	0.452	
ACCELERATION	117543.	0.037	94.	2.3	18.0	10000.	10000.	0.452	0.523	
CLIMB	116032.	0.135	1491.	51.2	69.1	10000.	25000.	0.523	0.694	
CRUISE	115218.	0.145	384.	58.6	127.8	25000.	25000.	0.675	0.673	
DESCENT	114779.	0.241	439.	72.2	200.0	25000.	0.	0.604	0.378	
HOLD	110443.	0.750	4333.	0.0	200.0	30000.	30000.	0.739	0.731	
STAGE POINT										

TABLE A-3

MULTI HOP MISSION - 3 LEGS (Continued)
DC-9 SUPER 80
Payload - 60 Percent Passenger Load Factor (93)
High Speed Cruise at Constant Initial Cruise Altitude or 35,000 ft

K5JA MISSION ANALYSIS [illegible] MCDONNELL DOUGLAS CORPORATION JANUARY [illegible], 1980

RAMP WT	= 124602.										
T.O.G.W.	= 124[illegible].	FN/ENG	= 1[illegible]000.	TOTAL TIME=	4.530	BLOCK TIME=	3.294	(T-MP) TIME=	0.0		
WING AREA	= 12[illegible].3	NE	= 2.0000	TOTAL FUEL=	26871.	BLOCK FUEL=	19464.	(T-MP) FUEL=	0.		
PAYLOAD	= 19[illegible].	ENG SIZE	= 1.0000	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-MP) DIST=	0.		
C.F.W.	= 7[illegible].	WF MULT	= 1.0000	F =	24.300	(T-B) TIME=	1.336	MP WT/SW =	0.0		
WT/SW	= 10[illegible].04	FN MULT	= 1.0000	AR =	9.618	(T-B) FUEL=	7407.	MP FN/WT =	0.0		
FN/WT	= 0.2[illegible]9	FUEL/WT	= 0.2157	E =	0.799	(T-B) DIST=	200.	MP FUEL/WT =	0.0		

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE [illegible]	124443.	0.083	159.	0.0	0.0					
ALLOWANCE [illegible]	124152.	0.033	291.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	123401.	0.054	751.	14.5	14.5	1500.	10000.	0.388	0.452	
ACCELERATION	123301.	0.013	101.	2.4	17.0	10000.	10000.	0.452	0.523	
CLIMB	121876.	0.127	1425.	47.4	64.3	10000.	23606.	0.523	0.676	
CRUISE	120649.	0.133	1227.	66.6	131.0	23605.	23606.	0.800	0.800	
DESCENT	120419.	0.130	230.	41.5	172.4	23606.	10000.	0.587	0.452	
DESCENT	120222.	0.103	197.	27.5	200.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	119718.	0.057	504.	0.0	200.0					V APP= 123.356
ALLOWANCE	119623.	0.050	95.	0.0	200.0					
[illegible]	119464.	0.083	159.	0.0	200.0					
ALLOWANCE	119173.	0.033	291.	0.0	200.0					
STAGE POINT										
CLIMB	118463.	0.051	710.	13.7	213.7	1500.	10000.	0.388	0.452	
ACCELERATION	118363.	0.007	[illegible]	2.3	216.0	10000.	10000.	0.452	0.523	
CLIMB	115700.	0.273	2663.	107.8	323.8	10000.	35000.	0.523	0.723	
CRUISE	112002.	0.533	3706.	271.5	595.3	35000.	35000.	0.800	0.800	
DESCENT	[illegible]	0.223	374.	78.0	673.3	35000.	10000.	0.741	0.452	
DESCENT	111437.	[illegible]	191.	26.7	700.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	110966.	0.067	472.	0.0	700.0					V APP= 119.245
ALLOWANCE	110871.	0.050	95.	0.0	700.0					
[illegible]	110712.	0.083	159.	0.0	700.0					
ALLOWANCE	110421.	0.033	291.	0.0	700.0					
STAGE POINT										
CLIMB	109779.	0.046	642.	12.4	712.4	1500.	10000.	0.338	0.452	
ACCELERATION	109693.	0.007	86.	2.1	714.4	10000.	10000.	0.452	0.523	
CLIMB	107424.	0.234	2269.	93.3	807.7	10000.	35000.	0.523	0.720	
CRUISE	106285.	[illegible]	1139.	89.8	897.5	35000.	35000.	0.800	0.800	
DESCENT	[illegible]	0.315	[illegible]	102.5	1000.0	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	[illegible]	0.067	451.	0.0	1000.0					V APP= 116.126
ALLOWANCE	[illegible]	[illegible]	95.	0.0	1000.0					
BLOCK POINT										
STAGE POINT										
CLIMB	[illegible]	0.050	711.	13.4	13.4	0.	10000.	0.378	0.452	
ACCELERATION	[illegible]	[illegible]	80.	1.9	15.3	10000.	10000.	0.452	0.523	
CLIMB	[illegible]	0.114	1254.	42.9	53.3	10000.	25000.	0.523	0.694	
CRUISE	[illegible]	[illegible]	[illegible]	[illegible]	131.6	25000.	25000.	0.650	0.648	
DESCENT	[illegible]	[illegible]	216.	68.4	200.0	25000.	0.	0.604	0.378	
[illegible]	97750.	0.750	3353.	0.0	200.0	30000.	30000.	0.705	0.697	
STAGE POINT										

TABLE A-3
MULTI HOP MISSION - 3 LEGS (Continued)
DC-9 SUPER 80
Payload - 100 Percent Passenger Load Factor (155)
Long Range Cruise

ASJA MISSI[illegible] [illegible] [illegible] [illegible]ONNELL DOUGLAS CORPORATION [illegible] 198?

RAMP WT = [illegible]										
T.O. [illegible] = [illegible]	FN/[illegible]	= 1[illegible]	TOTAL TIME=	4.721	BLOCK TIME=	[illegible]	(T-R) TIME =	0.0		
W[illegible] = [illegible]	[illegible]	= [illegible]	TOTAL FUEL=	2?[illegible]	BLOCK FUEL=	202?7.	(T-R) FUEL =	0.		
PAYLOAD = [illegible]	ENG SIZE	= 1.[illegible]	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-R) DIST=	0.		
[illegible] = [illegible]	[illegible]	= 1.0000	[illegible] =	24.300	(T-R) TIME=	1.3?7	[illegible] WT/S =	0.0		
WT/S = [illegible]	FN MULT	= 1.0000	AR =	9.618	(T-R) FUEL=	8077.	[illegible] FN/WT =	0.0		
FN/WT = [illegible]	FUEL/WT	= 0.2042	[illegible] =	0.799	(T-R) DIST=	200.	[illegible] FUEL/WT =	0.0		

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOW[illegible]	1386?5.	0.07?	159.	0.0	0.0					
ALLOW[illegible]	1?8336.	0.0??	241.	0.0	0.0					
STAGE [illegible]										
STAGE [illegible]										
CLIMB	137455.	0.063	351.	17.1	17.1	1500.	10000.	0.388	[illegible]	
ACCELERATION	137337.	0.004	118.	2.8	19.9	10000.	10000.	0.452	0.523	
CLIMB	13??66.	0.129	1?71.	47.3	67.2	10000.	22062.	0.523	[illegible]	
CRUISE	134711.	0.150	1154.	66.7	133.9	22062.	22062.	0.634	[illegible]	
DESCENT	134?79.	0.11?	212.	37.5	171.5	22062.	10000.	0.569	[illegible]	
DESCENT	134??5.	0.126	204.	28.5	200.0	10000.	0.	0.452	0.378	
STAGE [illegible]										
LANDING	13?735.	0.237	560.	0.0	200.0					V APP= 130.92?
ALLOW[illegible]	13??40.	0.050	95.	0.0	200.0					
ALLOW[illegible]	13?431.	0.083	15?.	0.0	200.0					
ALLOW[illegible]	133190.	0.033	241.	0.0	200.0					
STAGE [illegible]										
CLIMB	13235?.	0.159	352.	16.1	216.1	1500.	10000.	0.388	[illegible]	
ACCELERATION	132?47.	0.009	111.	2.7	218.8	10000.	10000.	0.452	0.523	
CLIMB	129?43.	[illegible]	3??4.	137.6	35?.?	10000.	35000.	0.523	0.720	
CRUISE	1??770.	[illegible]	3173.	233.1	591.5	35000.	35000.	0.704	0.70?	
DESCENT	[illegible]	0.2?1	387.	80.?	672.0	35000.	10000.	0.7?1	[illegible]	
DESCENT	[illegible]	[illegible]	200.	28.?	700.0	10000.	0.	0.452	[illegible]	
STAGE [illegible]										
[illegible]	[illegible]	[illegible]	[illegible]	0.0	700.0					V APP= 12?.33?
ALL[illegible]	[illegible]	[illegible]	95.	0.0	700.0					
ALL[illegible]	[illegible]	0.0?3	159.	0.0	700.0					
ALL[illegible]	12?1?5.	[illegible]	241.	0.0	700.0					
ST[illegible]										
[illegible]	[illegible]	0.0??	351.	14.5	714.5	1500.	10000.	0.3?8	[illegible]	
ACCELERATION	[illegible]	[illegible]	11?.	[illegible]	716.9	10000.	10000.	0.452	[illegible]	
[illegible]	1???7.	[illegible]	2?17.	117.?	834.4	10000.	35000.	[illegible]	0.72?	
[illegible]	[illegible]	[illegible]	7??.	3?.5	89?.9	35000.	35000.	0.7??	0.76?	
[illegible]	11?112.	[illegible]	378.	107.1	1000.0	35000.	0.	0.7?1	[illegible]	
S[illegible]										
L[illegible]	[illegible]	[illegible]	560.	0.0	1000.0					V APP= 123.293
ALL[illegible]	11??27.	[illegible]	95.	0.0	1000.0					
[illegible]										
S[illegible]										
CL[illegible]	[illegible]	[illegible]	3?0.	15.7	1?.7	[illegible]	10000.	0.378	0.45?	
ACCELERATI[illegible]	[illegible]	0.037	94.	2.3	[illegible]	10000.	10000.	0.45?	[illegible]	
CL[illegible]	[illegible]	[illegible]	1??2.	51.?	6?.1	10000.	25000.	[illegible]	0.604	
[illegible]	[illegible]	0.1?5	[illegible]	[illegible]	1?7.3	25000.	25000.	0.67?	0.673	
[illegible]	[illegible]	[illegible]	4??.	72.?	200.0	25000.	0.	0.604	0.378	
[illegible]	11??43.	.7?	4?3?.	0.0	200.0	35000.	35000.	0.739	0.731	
C[illegible]										

TABLE A-3
MULTI HOP MISSION - 3 LEGS (Continued)
CONFIGURATION 1
Payload - 100 Percent Passenger Load Factor (155)
High Speed Cruise at Constant Initial Cruise Altitude or 35,000 ft

RSJA MISSION ANALYSIS CASE 1 MCDONNELL DOUGLAS CORPORATION JANUARY 9, 1980

RAMP WT = 136272.							
T.O.G.W. = 136272.	FN/ENG = 16517.	TOTAL TIME=	4.635	BLOCK TIME=	3.293	(T-MP) TIME=	0.0
WING AREA = 1209.[illegible]	NE = 2.00000	TOTAL FUEL=	21142.	BLOCK FUEL=	15691.	(T-MP) FUEL=	0.
PAYLOAD = 31775.	ENG SIZE = 1.3401	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-MP) DIST=	0.
O.E.W. = [illegible]	WT MULT = 1.00000	F =	26.750	(T-B) TIME=	1.342	MP WT/SW =	0.0
WT/SW = 112.69	FN MULT = 1.00000	AR =	9.618	(T-B) FUEL=	5451.	MP FN/WT =	0.0
FN/WT = [illegible]	FUEL/WT = 0.1551	L =	0.799	(T-B) DIST=	200.	MP FUEL/WT =	0.0

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE	136113.	0.083	159.	0.0	0.0					
ALLOWANCE	135724.	0.033	390.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	135287.	0.041	436.	11.1	11.1	1500.	10000.	0.388	0.452	
ACCELERATION	135226.	0.006	62.	2.0	13.1	10000.	10000.	0.452	0.523	
CLIMB	134161.	0.126	1065.	47.8	60.9	10000.	25076.	0.523	0.695	
CRUISE	133202.	0.159	959.	66.7	127.5	25076.	25076.	0.800	0.800	
DESCENT	132939.	0.138	263.	44.5	172.0	25076.	10000.	0.695	0.452	
DESCENT	132649.	0.164	290.	28.0	200.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	132350.	0.007	299.	0.0	200.0					V APP= 130.100
ALLOWANCE	132255.	0.050	95.	0.0	200.0					
ALLOWANCE	132096.	0.083	159.	0.0	200.0					
ALLOWANCE	131707.	0.033	390.	0.0	200.0					
STAGE POINT										
CLIMB	131288.	0.059	419.	10.7	210.7	1500.	10000.	0.388	0.452	
ACCELERATION	131229.	0.006	59.	1.9	212.5	10000.	10000.	0.452	0.523	
CLIMB	129331.	0.200	1898.	104.5	317.1	10000.	35000.	0.523	0.720	
CRUISE	126313.	0.325	3017.	280.6	597.7	35000.	35000.	0.779	0.785	
DESCENT	125964.	0.214	349.	74.8	672.5	35000.	10000.	0.741	0.452	
DESCENT	125678.	0.163	286.	27.5	700.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	125391.	0.007	287.	0.0	700.0					V APP= 126.630
ALLOWANCE	125296.	0.050	95.	0.0	700.0					
ALLOWANCE	125137.	0.083	159.	0.0	700.0					
ALLOWANCE	124747.	0.033	390.	0.0	700.0					
STAGE POINT										
CLIMB	124357.	0.037	390.	9.9	709.9	1500.	10000.	0.388	0.452	
ACCELERATION	124302.	0.006	55.	1.7	711.7	10000.	10000.	0.452	0.523	
CLIMB	122601.	0.232	1701.	92.9	804.5	10000.	35000.	0.523	0.720	
CRUISE	121563.	0.200	1038.	94.3	898.9	35000.	35000.	0.792	0.794	
DESCENT	120935.	0.313	627.	101.1	1000.0	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	120375.	0.007	280.	0.0	1000.0					V APP= 124.233
ALLOWANCE	120281.	0.050	95.	0.0	1000.0					
BLOCK POINT										
STAGE POINT										
CLIMB	[illegible]	0.041	439.	10.9	10.9	0.	10000.	0.378	0.452	
ACCELERATION	120053.	0.005	53.	1.7	12.5	10000.	10000.	0.452	0.523	
CLIMB	119202.	0.105	837.	39.5	52.1	10000.	25000.	0.523	0.694	
CRUISE	118374.	0.209	828.	78.3	130.4	25000.	25000.	0.625	0.625	
DESCENT	117842.	0.233	531.	69.6	200.0	25000.	0.	0.604	0.378	
HOLD	115129.	0.750	2713.	0.0	200.0	30000.	30000.	0.650	0.649	
STAGE POINT										

TABLE A-3
MULTI-HOP MISSION - 3 LEGS (Continued)
CONFIGURATION 1
Payload - 60 Percent Passenger Load Factor (93)
High-Speed Cruise at Constant Initial Cruise Altitude or 35,000 ft

R5JA MISSION ANALYSIS   CASE 1   MCDONNELL DOUGLAS CORPORATION   JANUARY 9, 1980

RAMP WT	= 122505.										
T.O.G.W.	= 122505.	FN/ENG	= 16517.	TOTAL TIME=	4.599	BLOCK TIME=	3.250	(T-MP) TIME=	0.0		
WING AREA=	1209.3	NE	= 2.0000	TOTAL FUEL=	20144.	BLOCK FUEL=	15066.	(T-MP) FUEL=	0.		
PAYLOAD	= 19065.	ENG SIZE	= 1.3401	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-MP) DIST=	0.		
O.E.W.	= 63355.	WF MULT	= 1.0000	F =	26.750	(T-B) TIME=	1.350	MP WT/SW =	0.0		
WT/SW	= 101.35	FN MULT	= 1.0000	AR =	9.618	(T-B) FUEL=	5078.	MP FN/WT =	0.0		
FN/WT	= 0.2695	FUEL/WT	= 0.1644	E =	0.799	(T-B) DIST=	200.	MP FUEL/WT =	0.0		

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE	122406.	0.003	159.	0.0	0.0					
ALLOWANCE	122016.	0.033	390.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	121637.	0.036	379.	9.6	9.6	1500.	10000.	0.388	0.452	
ACCELERATION	121583.	0.005	55.	1.7	11.3	10000.	10000.	0.452	0.523	
CLIMB	120557.	0.124	1026.	47.5	58.8	10000.	26512.	0.523	0.715	
CRUISE	119673.	0.159	884.	66.7	125.5	26512.	26512.	0.800	0.800	
DESCENT	119403.	0.145	270.	47.4	172.9	26512.	10000.	0.622	0.452	
DESCENT	119123.	0.101	280.	27.0	199.9	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	118846.	0.007	277.	0.0	199.9					V APP= 123.209
ALLOWANCE	118751.	0.050	95.	0.0	199.9					
ALLOWANCE	118592.	0.003	159.	0.0	199.9					
ALLOWANCE	118203.	0.033	390.	0.0	199.9					
STAGE POINT										
CLIMB	117838.	0.034	365.	9.2	209.2	1500.	10000.	0.388	0.452	
ACCELERATION	117788.	0.005	51.	1.6	210.8	10000.	10000.	0.452	0.523	
CLIMB	116244.	0.209	1543.	83.7	294.5	10000.	35000.	0.523	0.720	
CRUISE	112970.	0.666	3273.	307.0	601.5	35000.	35000.	0.800	0.800	
DESCENT	112634.	0.207	336.	72.1	673.6	35000.	10000.	0.741	0.452	
DESCENT	112361.	0.078	273.	26.3	699.9	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	112095.	0.007	266.	0.0	699.9					V APP= 119.739
ALLOWANCE	112000.	0.050	95.	0.0	699.9					
ALLOWANCE	111841.	0.003	159.	0.0	699.9					
ALLOWANCE	111451.	0.033	390.	0.0	699.9					
STAGE POINT										
CLIMB	111111.	0.032	340.	8.6	708.5	1500.	10000.	0.388	0.452	
ACCELERATION	111064.	0.005	48.	1.5	710.0	10000.	10000.	0.452	0.523	
CLIMB	109665.	0.189	1399.	75.5	785.5	10000.	35000.	0.523	0.720	
CRUISE	108450.	0.255	1215.	117.6	903.2	35000.	35000.	0.800	0.800	
DESCENT	107855.	0.299	596.	96.7	999.9	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	107593.	0.007	259.	0.0	999.9					V APP= 117.312
ALLOWANCE	107498.	0.050	95.	0.0	999.9					
BLOCK POINT										
STAGE POINT										
CLIMB	107116.	0.035	382.	9.4	9.4	0.	10000.	0.378	0.452	
ACCELERATION	107070.	0.005	46.	1.4	10.9	10000.	10000.	0.452	0.523	
CLIMB	106312.	0.069	758.	33.8	44.6	10000.	25000.	0.523	0.694	
CRUISE	105416.	0.251	896.	89.8	134.4	25000.	25000.	0.596	0.594	
DESCENT	104914.	0.220	502.	65.6	200.0	25000.	0.	0.594	0.378	
HOLD	102420.	0.750	2494.	0.0	200.0	30000.	30000.	0.641	0.637	
STAGE POINT										

TABLE A-3

MULTI HOP MISSION - 3 LEGS (Continued)

CONFIGURATION 1

Payload - 100 Percent Passenger Load Factor (155)

Long Range Cruise

K30A MISSION ANALYSIS CASE 1 MCDONNELL DOUGLAS CORPORATION JANUARY 9, 1980

RAMP WT	= 135603.										
T.O.G.W.	= 135603.	FN/ENG	= 16517.	TOTAL TIME=	4.736	BLOCK TIME=	3.394	(T-MP) TIME=	0.0		
WING AREA=	1209.5	NE	= 2.0000	TOTAL FUEL=	20556.	BLOCK FUEL=	15104.	(T-MP) FUEL=	0.		
PAYLOAD	= 31775.	ENG SIZE	= 1.3404	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-MP) DIST=	0.		
O.E.W.	= 63355.	WF MULT	= 1.0000	F	= 26.750	(T-B) TIME=	1.342	MP WT/SW	= 0.0		
WT/SW	= 112.20	FN MULT	= 1.0000	AR	= 9.618	(T-B) FUEL=	5452.	MP FN/WT	= 0.0		
FN/WT	= 0.2435	FUEL/WT	= 0.1515	E	= 0.799	(T-B) DIST=	200.	MP FUEL/WT	= 0.0		

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE	135524.	0.083	159.	0.0	0.0					
ALLOWANCE	135135.	0.033	390.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	134701.	0.041	434.	11.0	11.0	1500.	10000.	0.388	0.452	
ACCELERATION	134640.	0.006	61.	1.9	13.0	10000.	10000.	0.452	0.523	
CLIMB	133577.	0.120	1063.	47.7	60.7	10000.	25129.	0.523	0.696	
CRUISE	132828.	0.173	749.	66.7	127.4	25129.	25129.	0.642	0.642	
DESCENT	132565.	0.158	263.	44.7	172.1	25129.	10000.	0.605	0.452	
DESCENT	132275.	0.104	290.	27.9	200.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	131977.	0.007	298.	0.0	200.0					V APP= 129.916
ALLOWANCE	131882.	0.050	95.	0.0	200.0					
ALLOWANCE	131723.	0.083	159.	0.0	200.0					
ALLOWANCE	131333.	0.033	390.	0.0	200.0					
STAGE POINT										
CLIMB	130916.	0.039	417.	10.6	210.6	1500.	10000.	0.388	0.452	
ACCELERATION	130857.	0.006	59.	1.9	212.5	10000.	10000.	0.452	0.523	
CLIMB	128971.	0.258	1886.	103.8	316.3	10000.	35000.	0.523	0.720	
CRUISE	126183.	0.666	2788.	281.4	597.7	35000.	35000.	0.738	0.727	
DESCENT	125833.	0.214	349.	74.8	672.5	35000.	10000.	0.741	0.452	
DESCENT	125547.	0.103	286.	27.5	700.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	125260.	0.007	287.	0.0	700.0					V APP= 126.570
ALLOWANCE	125165.	0.050	95.	0.0	700.0					
ALLOWANCE	125006.	0.083	159.	0.0	700.0					
ALLOWANCE	124617.	0.033	390.	0.0	700.0					
STAGE POINT										
CLIMB	124227.	0.037	390.	9.9	709.9	1500.	10000.	0.388	0.452	
ACCELERATION	124172.	0.006	55.	1.7	711.6	10000.	10000.	0.452	0.523	
CLIMB	122475.	0.231	1697.	92.7	804.3	10000.	35000.	0.523	0.720	
CRUISE	121581.	0.232	894.	94.6	898.9	35000.	35000.	0.708	0.704	
DESCENT	120955.	0.315	627.	101.1	1000.0	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	120674.	0.007	280.	0.0	1000.0					V APP= 124.232
ALLOWANCE	120579.	0.050	95.	0.0	1000.0					
BLOCK POINT										
STAGE POINT										
CLIMB	120140.	0.041	439.	10.9	10.9	0.	10000.	0.378	0.452	
ACCELERATION	120087.	0.005	53.	1.7	12.5	10000.	10000.	0.452	0.523	
CLIMB	119200.	0.105	887.	39.6	52.1	10000.	25000.	0.523	0.694	
CRUISE	118572.	0.209	628.	78.3	130.4	25000.	25000.	0.625	0.623	
DESCENT	117040.	0.233	551.	69.6	200.0	25000.	0.	0.604	0.378	
HOLD	115127.	0.750	2714.	0.0	200.0	30000.	30000.	0.650	0.649	
STAGE POINT										

TABLE A-3

MULTI HOP MISSION - 3 LEGS (Continued)

CONFIGURATION 3

Payload - 100 Percent Passenger Load Factor (155)

High Speed Cruise at Constant Initial Cruise Altitude or 35,000 ft

[illegible] MISSION ANALYSIS CASE 3 — MCDONNELL DOUGLAS CORPORATION — JANUARY 9, 1980

RAMP WT	= 135515.								
T.O.G.W.	= 135515.	FN/ENG	= 16273.	TOTAL TIME	= 4.638	BLOCK TIME	= 3.296	(T-MP) TIME	= 0.0
WING AREA	= 1209.5	NL	= 2.0000	TOTAL FUEL	= 20850.	BLOCK FUEL	= 15474.	(T-MP) FUEL	= 0.
PAYLOAD	= 31775.	ENG SIZE	= 1.5203	TOTAL DIST	= 1200.	BLOCK DIST	= 1000.	(T-MP) DIST	= 0.
O.E.W.	= 82890.	WF MULT	= 1.0000	F	= 26.150	(T-B) TIME	= 1.343	MP WT/SW	= 0.0
WT/SW	= 112.06	FN MULT	= 1.0000	AR	= 9.618	(T-B) FUEL	= 5375.	MP FN/WT	= 0.0
FN/WT	= 0.2402	FUEL/WT	= 0.1539	E	= 0.799	(T-B) DIST	= 200.	MP FUEL/WT	= 0.0

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE	135356.	0.003	159.	0.0	0.0					
ALLOWANCE	134972.	0.035	384.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	134539.	0.041	433.	11.2	11.2	1500.	10000.	0.388	0.452	
ACCELERATION	134478.	0.006	61.	2.0	13.2	10000.	10000.	0.452	0.523	
CLIMB	133438.	0.125	1039.	47.1	60.3	10000.	24930.	0.523	0.694	
CRUISE	132494.	0.158	944.	66.7	127.0	24930.	24930.	0.800	0.800	
DESCENT	132234.	0.156	261.	44.7	171.7	24930.	10000.	0.603	0.452	
DESCENT	131944.	0.166	290.	28.4	200.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	131648.	0.007	295.	0.0	200.0					V APP= 129.754
ALLOWANCE	131553.	0.050	95.	0.0	200.0					
ALLOWANCE	131394.	0.003	159.	0.0	200.0					
ALLOWANCE	131010.	0.035	384.	0.0	200.0					
STAGE POINT										
CLIMB	130594.	0.042	416.	10.7	210.7	1500.	10000.	0.388	0.452	
ACCELERATION	130535.	0.006	59.	1.9	212.6	10000.	10000.	0.452	0.523	
CLIMB	128863.	0.263	1673.	104.6	317.3	10000.	35000.	0.523	0.720	
CRUISE	125703.	0.818	2900.	279.0	596.3	35000.	35000.	0.780	0.787	
DESCENT	125354.	0.217	349.	75.8	672.1	35000.	10000.	0.741	0.452	
DESCENT	125069.	0.104	285.	27.9	700.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	124785.	0.007	284.	0.0	700.0					V APP= 126.326
ALLOWANCE	124690.	0.050	95.	0.0	700.0					
ALLOWANCE	124531.	0.003	159.	0.0	700.0					
ALLOWANCE	124147.	0.035	384.	0.0	700.0					
STAGE POINT										
CLIMB	123759.	0.037	388.	10.0	710.0	1500.	10000.	0.388	0.452	
ACCELERATION	123704.	0.006	55.	1.8	711.8	10000.	10000.	0.452	0.523	
CLIMB	122024.	0.232	1680.	93.1	804.9	10000.	35000.	0.523	0.720	
CRUISE	121038.	0.202	985.	92.6	897.4	35000.	35000.	0.795	0.795	
DESCENT	120411.	0.318	627.	102.6	1000.0	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	120135.	0.007	277.	0.0	1000.0					V APP= 123.954
ALLOWANCE	120040.	0.050	95.	0.0	1000.0					
BLOCK POINT										
STAGE POINT										
CLIMB	119603.	0.041	436.	11.0	11.0	0.	10000.	0.378	0.452	
ACCELERATION	119551.	0.005	52.	1.7	12.6	10000.	10000.	0.452	0.523	
CLIMB	118673.	0.105	878.	39.8	52.4	10000.	25000.	0.523	0.694	
CRUISE	117872.	0.203	801.	77.0	129.4	25000.	25000.	0.625	0.624	
DESCENT	117341.	0.256	531.	70.6	200.0	25000.	0.	0.604	0.378	
HOLD	114664.	0.750	2677.	0.0	200.0	30000.	30000.	0.653	0.651	
STAGE POINT										

TABLE A-3

MULTI HOP MISSION - 3 LEGS (Continued)

CONFIGURATION 3

Payload - 60 Percent Passenger Load Factor (93)

High Speed Cruise at Constant Initial Cruise Altitude or 35,000 ft

R53A MISSION ANALYSIS CASE 3 MCDONNELL DOUGLAS CORPORATION JANUARY 9, 1980

RAMP WT	- 121792.									
T.O.G.W.	= 121792.	FN/ENG	= 16273.	TOTAL TIME=	4.603	BLOCK TIME=	3.253	(T-MP) TIME=		0.0
WING AREA=	1209.5	NE	= 2.0000	TOTAL FUEL=	19837.	BLOCK FUEL=	14834.	(T-MP) FUEL=		0.
PAYLOAD	= 19065.	ENG SIZE	= 1.3203	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-MP) DIST=		0.
O.E.W.	= 82890.	WF MULT	= 1.0000	F =	26.150	(T-B) TIME=	1.350	MP WT/SW	=	0.0
WT/SW	= 100.71	FN MULT	= 1.0000	AR =	9.618	(T-B) FUEL=	5003.	MP FN/WT	=	0.0
FN/WT	= 0.2672	FUEL/WT	= 0.1629	E =	0.799	(T-B) DIST=	200.	MP FUEL/WT	=	0.0

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE	121633.	0.005	159.	0.0	0.0					
ALLOWANCE	121249.	0.033	384.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	120873.	0.038	376.	9.7	9.7	1500.	10000.	0.388	0.452	
ACCELERATION	120820.	0.005	53.	1.7	11.4	10000.	10000.	0.452	0.523	
CLIMB	119819.	0.122	1001.	46.8	58.2	10000.	26370.	0.523	0.713	
CRUISE	118949.	0.139	870.	66.7	124.9	26370.	26370.	0.800	0.800	
DESCENT	118686.	0.146	263.	47.7	172.6	26370.	10000.	0.621	0.452	
DESCENT	118401.	0.102	285.	27.3	199.9	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	118127.	0.067	274.	0.0	199.9					V APP= 122.914
ALLOWANCE	118032.	0.050	95.	0.0	199.9					
ALLOWANCE	117873.	0.005	159.	0.0	199.9					
ALLOWANCE	117489.	0.033	384.	0.0	199.9					
STAGE POINT										
CLIMB	117127.	0.035	362.	9.3	209.2	1500.	10000.	0.388	0.452	
ACCELERATION	117076.	0.005	51.	1.6	210.9	10000.	10000.	0.452	0.523	
CLIMB	115555.	0.209	1522.	83.7	294.6	10000.	35000.	0.523	0.720	
CRUISE	112358.	0.883	3196.	305.5	600.2	35000.	35000.	0.800	0.800	
DESCENT	112022.	0.209	336.	73.1	673.3	35000.	10000.	0.741	0.452	
DESCENT	111750.	0.100	272.	26.7	699.9	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	111485.	0.067	265.	0.0	699.9					V APP= 119.412
ALLOWANCE	111391.	0.050	95.	0.0	699.9					
ALLOWANCE	111232.	0.005	159.	0.0	699.9					
ALLOWANCE	110849.	0.033	384.	0.0	699.9					
STAGE POINT										
CLIMB	110511.	0.032	337.	8.7	708.6	1500.	10000.	0.388	0.452	
ACCELERATION	110464.	0.005	47.	1.5	710.1	10000.	10000.	0.452	0.523	
CLIMB	109002.	0.169	1332.	75.6	785.7	10000.	35000.	0.523	0.720	
CRUISE	107906.	0.252	1176.	116.1	901.9	35000.	35000.	0.800	0.800	
DESCENT	107309.	0.304	597.	98.1	999.9	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	107053.	0.067	256.	0.0	999.9					V APP= 117.016
ALLOWANCE	106958.	0.050	95.	0.0	999.9					
BLOCK POINT										
STAGE POINT										
CLIMB	106578.	0.036	379.	9.5	9.5	0.	10000.	0.378	0.452	
ACCELERATION	106533.	0.005	45.	1.5	10.9	10000.	10000.	0.452	0.523	
CLIMB	105783.	0.090	750.	33.9	44.9	10000.	25000.	0.523	0.694	
CRUISE	104914.	0.247	869.	88.5	133.4	25000.	25000.	0.597	0.595	
DESCENT	104411.	0.223	502.	66.6	200.0	25000.	0.	0.595	0.378	
HOLD	101955.	0.750	2457.	0.0	200.0	30000.	30000.	0.642	0.639	
STAGE POINT										

TABLE A-3
MULTI HOP MISSION - 3 LEGS (Continued)
CONFIGURATION 3
Payload - 100 Percent Passenger Load Factor (155)
Long Range Cruise

K50A MISSION ANALYSIS CASE 3 MCDONNELL DOUGLAS CORPORATION JANUARY 9, 1980

RAMP WT = 134929.							
T.O.G.W. = 134929.	FN/ENG = 16273.	TOTAL TIME=	4.735	BLOCK TIME=	3.392	(T-MP) TIME=	0.0
WING AREA= 1209.3	NE = 2.0000	TOTAL FUEL=	20264.	BLOCK FUEL=	14689.	(T-MP) FUEL=	0.
PAYLOAD = 31775.	ENG SIZE = 1.0205	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-MP) DIST=	0.
O.E.W. = 82590.	AF MULT = 1.0000	F =	26.150	(T-B) TIME=	1.343	MP WT/SW =	0.0
WT/SW = 111.58	FN MULT = 1.0000	AR =	9.618	(T-B) FUEL=	5575.	MP FN/WT =	0.0
FN/WT = 0.2412	FUEL/WT = 0.1502	E =	0.799	(T-B) DIST=	200.	MP FUEL/WT =	0.0

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE	134770.	0.083	159.	0.0	0.0					
ALLOWANCE	134366.	0.033	304.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	133955.	0.041	450.	11.1	11.1	1500.	10000.	0.388	0.452	
ACCELERATION	133893.	0.006	62.	2.0	13.1	10000.	10000.	0.452	0.523	
CLIMB	132057.	0.124	1837.	47.1	60.2	10000.	24984.	0.523	0.694	
CRUISE	131320.	0.172	736.	66.7	126.9	24984.	24984.	0.642	0.642	
DESCENT	131056.	0.159	261.	44.8	171.7	24984.	10000.	0.603	0.452	
DESCENT	130769.	0.100	290.	28.3	200.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	130474.	0.087	295.	0.0	200.0					V APP= 129.509
ALLOWANCE	130379.	0.050	95.	0.0	200.0					
ALLOWANCE	130220.	0.083	159.	0.0	200.0					
ALLOWANCE	130035.	0.033	364.	0.0	200.0					
STAGE POINT										
CLIMB	130221.	0.040	414.	10.7	210.7	1500.	10000.	0.388	0.452	
ACCELERATION	130165.	0.006	56.	1.9	212.6	10000.	10000.	0.452	0.523	
CLIMB	128502.	0.259	1661.	103.9	316.5	10000.	35000.	0.523	0.720	
CRUISE	125576.	0.051	2726.	279.8	596.3	35000.	35000.	0.742	0.752	
DESCENT	125227.	0.217	349.	75.8	672.1	35000.	10000.	0.741	0.452	
DESCENT	124942.	0.104	285.	27.9	700.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	124658.	0.087	284.	0.0	700.0					V APP= 126.204
ALLOWANCE	124563.	0.050	95.	0.0	700.0					
ALLOWANCE	124404.	0.083	159.	0.0	700.0					
ALLOWANCE	124020.	0.033	364.	0.0	700.0					
STAGE POINT										
CLIMB	123633.	0.037	387.	10.0	710.0	1500.	10000.	0.388	0.452	
ACCELERATION	123578.	0.006	55.	1.8	711.8	10000.	10000.	0.452	0.523	
CLIMB	121901.	0.252	1677.	92.9	804.7	10000.	35000.	0.523	0.720	
CRUISE	121138.	0.227	763.	92.8	897.4	35000.	35000.	0.715	0.706	
DESCENT	120411.	0.316	327.	102.6	1000.0	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	120134.	0.087	277.	0.0	1000.0					V APP= 123.954
ALLOWANCE	120039.	0.050	95.	0.0	1000.0					
BLOCK POINT										
STAGE POINT										
CLIMB	119605.	0.041	430.	11.0	11.0	0.	10000.	0.378	0.452	
ACCELERATION	119551.	0.005	52.	1.7	12.6	10000.	10000.	0.452	0.525	
CLIMB	118673.	0.105	878.	39.8	52.4	10000.	25000.	0.523	0.694	
CRUISE	117672.	0.205	601.	77.0	129.4	25000.	25000.	0.625	0.624	
DESCENT	117341.	0.236	331.	70.6	200.0	25000.	0.	0.604	0.378	
HOLD	114664.	0.750	2677.	0.0	200.0	30000.	30000.	0.652	0.651	
STAGE POINT										

TABLE A-3

MULTI HOP MISSION - 3 LEGS (Continued)

CONFIGURATION 2

Payload - 60 Percent Passenger Load Factor (93)

High Speed Cruise at Constant Initial Cruise Altitude or 35,000 ft

K5JA MISSION ANALYSIS CASE 2 MCDONNELL DOUGLAS CORPORATION MARCH 4, 1980

RAMP WT = 139323.							
T.O.G.W. = 139323.	FN/ENG = 16511.	TOTAL TIME=	4.646	BLOCK TIME=	3.306	(T-MP) TIME=	0.0
WING AREA= 1209.5	NE = 2.0000	TOTAL FUEL=	21340.	BLOCK FUEL=	15807.	(T-MP) FUEL=	0.
PAYLOAD = 31775.	ENG SIZE = 1.3396	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-MP) DIST=	0.
O.E.W. = 55203.	WF MULT = 1.0000	F =	26.735	(T-B) TIME=	1.340	MP WT/SW =	0.0
WT/SW = 115.21	FN MULT = 1.0000	AR =	9.618	(T-B) FUEL=	5533.	MP FN/WT =	0.0
FN/WT = 0.2570	FUEL/WT = 0.1552	E =	0.799	(T-B) DIST=	200.	MP FUEL/WT =	0.0

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	V APP
ALLOWANCE	139164.	0.083	159.	0.0	0.0					
ALLOWANCE	138774.	0.033	389.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	138325.	0.042	450.	11.4	11.4	1500.	10000.	0.388	0.452	
ACCELERATION	138261.	0.006	63.	2.0	13.5	10000.	10000.	0.452	0.523	
CLIMB	137187.	0.127	1074.	47.9	61.3	10000.	24778.	0.523	0.691	
CRUISE	136212.	0.138	975.	66.7	128.0	24778.	24778.	0.800	0.800	
DESCENT	135952.	0.136	261.	43.9	171.9	24778.	10000.	0.601	0.452	
DESCENT	135659.	0.105	292.	28.1	200.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	135356.	0.067	304.	0.0	200.0					V APP= 131.568
ALLOWANCE	135261.	0.050	95.	0.0	200.0					
ALLOWANCE	135102.	0.083	159.	0.0	200.0					
ALLOWANCE	134713.	0.033	389.	0.0	200.0					
STAGE POINT										
CLIMB	134281.	0.041	432.	11.0	211.0	1500.	10000.	0.388	0.452	
ACCELERATION	134220.	0.006	61.	1.9	213.0	10000.	10000.	0.452	0.523	
CLIMB	132225.	0.274	1995.	110.4	323.4	10000.	35000.	0.523	0.720	
CRUISE	129295.	0.613	2931.	273.7	597.1	35000.	35000.	0.771	0.779	
DESCENT	128943.	0.216	352.	75.2	672.3	35000.	10000.	0.741	0.452	
DESCENT	128655.	0.104	288.	27.7	700.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	128363.	0.067	292.	0.0	700.0					V APP= 128.127
ALLOWANCE	128268.	0.050	95.	0.0	700.0					
ALLOWANCE	128109.	0.083	159.	0.0	700.0					
ALLOWANCE	127720.	0.033	389.	0.0	700.0					
STAGE POINT										
CLIMB	127317.	0.038	402.	10.2	710.3	1500.	10000.	0.388	0.452	
ACCELERATION	127260.	0.006	57.	1.8	712.1	10000.	10000.	0.452	0.523	
CLIMB	125480.	0.243	1780.	97.6	809.7	10000.	35000.	0.523	0.720	
CRUISE	124527.	0.195	953.	88.4	898.1	35000.	35000.	0.787	0.789	
DESCENT	123895.	0.316	632.	101.9	1000.0	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	123610.	0.067	284.	0.0	1000.0					V APP= 125.734
ALLOWANCE	123515.	0.050	95.	0.0	1000.0					
BLOCK POINT										
STAGE POINT										
CLIMB	123063.	0.042	452.	11.2	11.2	0.	10000.	0.378	0.452	
ACCELERATION	123009.	0.006	54.	1.7	12.9	10000.	10000.	0.452	0.523	
CLIMB	122091.	0.108	918.	41.0	53.9	10000.	25000.	0.523	0.694	
CRUISE	121280.	0.201	811.	75.8	129.7	25000.	25000.	0.629	0.628	
DESCENT	120743.	0.235	537.	70.3	200.0	25000.	0.	0.604	0.378	
HOLD	117982.	0.749	2761.	0.0	200.0	30000.	30000.	0.652	0.652	
STAGE POINT										

TABLE A-3
MULTI-HOP MISSION - 3 LEGS (Continued)
CONFIGURATION 2
Payload - 100 Percent Passenger Load Factor (155)
High Speed Cruise at Constant Initial Cruise Altitude or 35,000 ft

K5JA MISSION ANALYSIS CASE 2 MCDONNELL DOUGLAS CORPORATION MARCH 4, 1980

RAMP WT	= 125674.										
T.O.G.W.	= 125674.	FN/ENG	= 16511.	TOTAL TIME=	4.604	BLOCK TIME=	3.257	(T-MP) TIME=	0.0		
WING AREA=	1209.3	NE	= 2.0000	TOTAL FUEL=	20400.	BLOCK FUEL=	15241.	(T-MP) FUEL=	0.		
PAYLOAD	= 19065.	ENG SIZE	= 1.3396	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-MP) DIST=	0.		
O.E.W.	= 68208.	WF MULT	= 1.0000	F	= 26.735	(T-B) TIME=	1.347	MP WT/SW =	0.0		
WT/SW	= 103.92	FN MULT	= 1.0000	AR	= 9.618	(T-B) FUEL=	5159.	MP FN/WT =	0.0		
FN/WT	= 0.2628	FUEL/WT	= 0.1623	E	= 0.799	(T-B) DIST=	200.	MP FUEL/WT =	0.0		

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE	125513.	0.083	159.	0.0	0.0					
ALLOWANCE	125125.	0.035	389.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	124733.	0.037	392.	10.0	10.0	1500.	10000.	0.388	0.452	
ACCELERATION	124678.	0.006	55.	1.8	11.7	10000.	10000.	0.452	0.523	
CLIMB	123644.	0.124	1034.	47.5	59.2	10000.	26159.	0.523	0.710	
CRUISE	122744.	0.139	901.	66.7	125.9	26159.	26159.	0.800	0.800	
DESCENT	122475.	0.144	269.	46.8	172.7	26159.	10000.	0.818	0.452	
DESCENT	122192.	0.132	283.	27.3	199.9	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	121910.	0.067	282.	0.0	199.9					V APP= 124.867
ALLOWANCE	121815.	0.030	95.	0.0	199.9					
ALLOWANCE	121656.	0.083	159.	0.0	199.9					
ALLOWANCE	121266.	0.035	389.	0.0	199.9					
STAGE POINT										
CLIMB	120890.	0.035	377.	9.6	209.5	1500.	10000.	0.388	0.452	
ACCELERATION	120837.	0.005	53.	1.7	211.2	10000.	10000.	0.452	0.523	
CLIMB	119823.	0.219	1014.	87.8	299.0	10000.	35000.	0.523	0.720	
CRUISE	115969.	0.655	3854.	301.5	600.5	35000.	35000.	0.797	0.800	
DESCENT	115629.	0.209	340.	72.8	673.3	35000.	10000.	0.741	0.452	
DESCENT	115353.	0.099	276.	26.6	700.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	115082.	0.067	271.	0.0	700.0					V APP= 121.322
ALLOWANCE	114987.	0.050	95.	0.0	700.0					
ALLOWANCE	114828.	0.083	159.	0.0	700.0					
ALLOWANCE	114439.	0.035	389.	0.0	700.0					
STAGE POINT										
CLIMB	114088.	0.033	351.	8.9	708.8	1500.	10000.	0.388	0.452	
ACCELERATION	114039.	0.005	49.	1.6	710.4	10000.	10000.	0.452	0.523	
CLIMB	112576.	0.197	1463.	79.0	789.4	10000.	35000.	0.523	0.720	
CRUISE	111393.	0.244	1182.	112.7	902.1	35000.	35000.	0.800	0.800	
DESCENT	110791.	0.303	603.	97.8	1000.0	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	110527.	0.067	264.	0.0	1000.0					V APP= 116.699
ALLOWANCE	110432.	0.050	95.	0.0	1000.0					
BLOCK POINT										
STAGE POINT										
CLIMB	110038.	0.037	394.	9.7	9.7	0.	10000.	0.378	0.452	
ACCELERATION	109990.	0.005	47.	1.5	11.2	10000.	10000.	0.452	0.523	
CLIMB	109205.	0.093	786.	35.0	46.3	10000.	25000.	0.523	0.694	
CRUISE	108325.	0.240	879.	87.0	133.2	25000.	25000.	0.604	0.601	
DESCENT	107815.	0.223	510.	66.8	200.0	25000.	0.	0.601	0.378	
HOLD	105272.	0.750	2543.	0.0	200.0	30000.	30000.	0.643	0.641	
STAGE POINT										

TABLE A-3
MULTI HOP MISSION - 3 LEGS (Continued)
CONFIGURATION 2
Payload - 100 Percent Passenger Load Factor (155)
Long Range Cruise

K5JA MISSION ANALYSIS   CASE 2   MCDONNELL DOUGLAS CORPORATION   MARCH 4, 1980

RAMP WT	= 138850.										
T.O.G.W.	= 138850.	FN/ENG	= 16511.	TOTAL TIME=	4.724	BLOCK TIME=	3.384	(T-MP) TIME=	0.0
WING AREA	= 1209.3	NE	= 2.0000	TOTAL FUEL=	20873.	BLOCK FUEL=	15340.	(T-MP) FUEL=	0.
PAYLOAD	= 31775.	ENG SIZE	= 1.3390	TOTAL DIST=	1200.	BLOCK DIST=	1000.	(T-MP) DIST=	0.
O.E.W.	= 88203.	WF MULT	= 1.0000	F =	26.735	(T-B) TIME=	1.340	MP WT/SW =	0.0
WT/SW	= 114.82	FN MULT	= 1.0000	AR =	9.618	(T-B) FUEL=	5533.	MP FN/WT =	0.0
FN/WT	= 0.2378	FUEL/WT	= 0.1503	E =	0.799	(T-B) DIST=	200.	MP FUEL/WT =	0.0

MISSION SEGMENT	FINAL WEIGHT	SEGMENT TIME	SEGMENT FUEL	SEGMENT DIST	ACCUM DIST	INITIAL HP	FINAL HP	INITIAL MACH	FINAL MACH	
ALLOWANCE	138697.	0.083	159.	0.0	0.0					
ALLOWANCE	138307.	0.033	389.	0.0	0.0					
STAGE POINT										
STAGE POINT										
CLIMB	137860.	0.042	446.	11.4	11.4	1500.	10000.	0.388	0.452	
ACCELERATION	137797.	0.006	63.	2.0	13.4	10000.	10000.	0.452	0.523	
CLIMB	136724.	0.127	1072.	47.8	61.2	10000.	24819.	0.523	0.692	
CRUISE	135961.	0.172	763.	66.7	127.9	24819.	24819.	0.642	0.642	
DESCENT	135700.	0.136	261.	44.0	171.9	24819.	10000.	0.602	0.452	
DESCENT	135408.	0.105	292.	28.1	200.0	10000.	0.	0.452	0.376	
STAGE POINT										
LANDING	135105.	0.067	303.	0.0	200.0					V APP= 131.446
ALLOWANCE	135010.	0.050	95.	0.0	200.0					
ALLOWANCE	134851.	0.083	159.	0.0	200.0					
ALLOWANCE	134462.	0.033	389.	0.0	200.0					
STAGE POINT										
CLIMB	134031.	0.041	431.	11.0	211.0	1500.	10000.	0.388	0.452	
ACCELERATION	133970.	0.006	61.	1.9	212.9	10000.	10000.	0.452	0.523	
CLIMB	131984.	0.273	1986.	109.9	322.8	10000.	35000.	0.523	0.720	
CRUISE	129197.	0.640	2787.	274.3	597.1	35000.	35000.	0.747	0.741	
DESCENT	128845.	0.215	351.	75.2	672.3	35000.	10000.	0.741	0.452	
DESCENT	128557.	0.104	288.	27.7	700.0	10000.	0.	0.452	0.378	
STAGE POINT										
LANDING	128265.	0.067	292.	0.0	700.0					V APP= 128.078
ALLOWANCE	128170.	0.050	95.	0.0	700.0					
ALLOWANCE	128011.	0.083	159.	0.0	700.0					
ALLOWANCE	127622.	0.033	389.	0.0	700.0					
STAGE POINT										
CLIMB	127220.	0.038	402.	10.2	710.3	1500.	10000.	0.388	0.452	
ACCELERATION	127163.	0.006	57.	1.8	712.1	10000.	10000.	0.452	0.523	
CLIMB	125385.	0.245	1778.	97.4	809.5	10000.	35000.	0.523	0.720	
CRUISE	124527.	0.215	858.	88.6	898.1	35000.	35000.	0.724	0.720	
DESCENT	123895.	0.310	632.	101.9	1000.0	35000.	0.	0.741	0.378	
STAGE POINT										
LANDING	123610.	0.057	284.	0.0	1000.0					V APP= 125.734
ALLOWANCE	123515.	0.050	95.	0.0	1000.0					
BLOCK POINT										
STAGE POINT										
CLIMB	123063.	0.042	452.	11.2	11.2	0.	10000.	0.378	0.452	
ACCELERATION	123009.	0.006	54.	1.7	12.9	10000.	10000.	0.452	0.523	
CLIMB	122091.	0.108	918.	41.0	53.9	10000.	25000.	0.523	0.694	
CRUISE	121280.	0.201	811.	75.8	129.7	25000.	25000.	0.629	0.628	
DESCENT	120743.	0.235	537.	70.3	200.0	25000.	0.	0.604	0.378	
HOLD	117982.	0.749	2761.	0.0	200.0	30000.	30000.	0.652	0.652	
STAGE POINT										

APPENDIX B

HAMILTON STANDARD COMMENTS ON DC-9 SUPER 80 PROPFAN INSTALLATION

Copies of the Hamilton Standard letters, dated December 13, 1979 and January 21, 1980, which comment on the Douglas DC-9 Super 80 propfan installation are presented in this Appendix B.

HAMILTON STANDARD

Windsor Locks, Connecticut 06096

December 13, 1979

Douglas Aircraft Company
3855 Lakewood Boulevard
Long Beach, California 90846

Attention: Mrs. Irene Goldsmith

Subject: Prop-Fan gearbox mounting

Reference: (a) Douglas letter C1-091-ACEE-574 to HS dated 11-7-79
(b) Prop-Fan Point Design Report to NADC, dated 2-15-78

Dear Irene:

We have reviewed Bob Adkisson's nacelle sketch 04339, which was enclosed with your letter of reference (a). This letter provides our comments on gearbox mounting.

There are several viable techniques for mounting a turboprop or Prop-Fan gearbox. In the past, this method has been redundant side mounts (usually Lord) on the gearbox to transfer vertical, lateral, and thrust loads to hard structure. There were also redundant struts connecting the gearbox to structure in the engine compressor area for handling torque and moment loads. Turboshaft engines generally had adequate structural capacity to handle these loads and there was a rear engine mount to transfer the torque and moment loads to hard structure. We prepared a recommended gearbox mounting scheme for the Navy and reported on it in reference (b). This concept was very similar to that just described except the mounting of the gearbox to the engine was accomplished in a more distributed manner to minimize compressor case distortion. We believe this to be more desireable as engine pressure ratios increase. Perhaps the engine manufacturers can shed more light on this. The text from this report is repeated herein and the two reference sketches are attached. The text is as follows:

"Mounting points are provided on the propulsion assembly to allow for the unit's attachment to the aircraft nacelle structure as shown in Figure 17. This concept provides a support system that incorporates structural redundancy and provisions for vibration isolators.

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INFORMATION FOR:
IRENE GOLDSMITH ORIG. W/E

With this concept, the engine and gearbox are rigidly mounted together through a combined air inlet and engine support structure. The forward mounts provide for straddle mounting the main reduction gearbox to the nacelle structure. These mounts accomodate thrust, transverse, and vertical loads. The aft mounts accomodate vertical and transverse forces. The concept depicted in Figure 17 uses a fail-safe shell structure to transfer forces and moments between the gearbox and the engine compressor section. Thus, this structure provides the dual function of an aerodynamic inlet for the engine and a structural load path. This configuration delivers the load to the compressor front case in a distributed manner and minimizes the distortion on the compressor case.

This mounting scheme is very similar to the propulsion mounting system employed on deHavilland's DHC-7 (See Figure 18) and reported in SAE report 750536, entitled "A Second Generation Turbo-Prop Power Plant," dated April 8-11, 1975. When compared to the older multiple strut mounting approaches, this concept offers a good blend of redundancy, structural simplicity, and hardware accessibility."

We are in the process of designing a gearbox for General Electric's CT-7 engine. This engine was originally developed for helicopter application and does not have a compressor case structure designed to handle turboprop loads. The mounting system schematic for this gearbox is enclosed. It transfers moment and torque loads to hard structure in a manner completely bypassing the engine case. However, this system requires a means to handle engine to gearbox misalignment and a gimbal joint issued.

As you can see from this material, the gearbox is soft mounted rather than hard mounted. The system could be hard mounted but isolation would be negligible and interior comfort may suffer. There needs to be adequate isolation for passenger/crew comfort while maintaining adequate stiffness for controlling whirl flutter.

I hope these comments are of value to you. There are a variety of ways to mount the gearbox and the final solution must consider the stiffness and isolation requirements, the engine load capacity, the accessibility issue, and system weight management. We are presently analyzing Prop-Fan excitations for the three aircraft configurations and will be in touch soon on this subject.

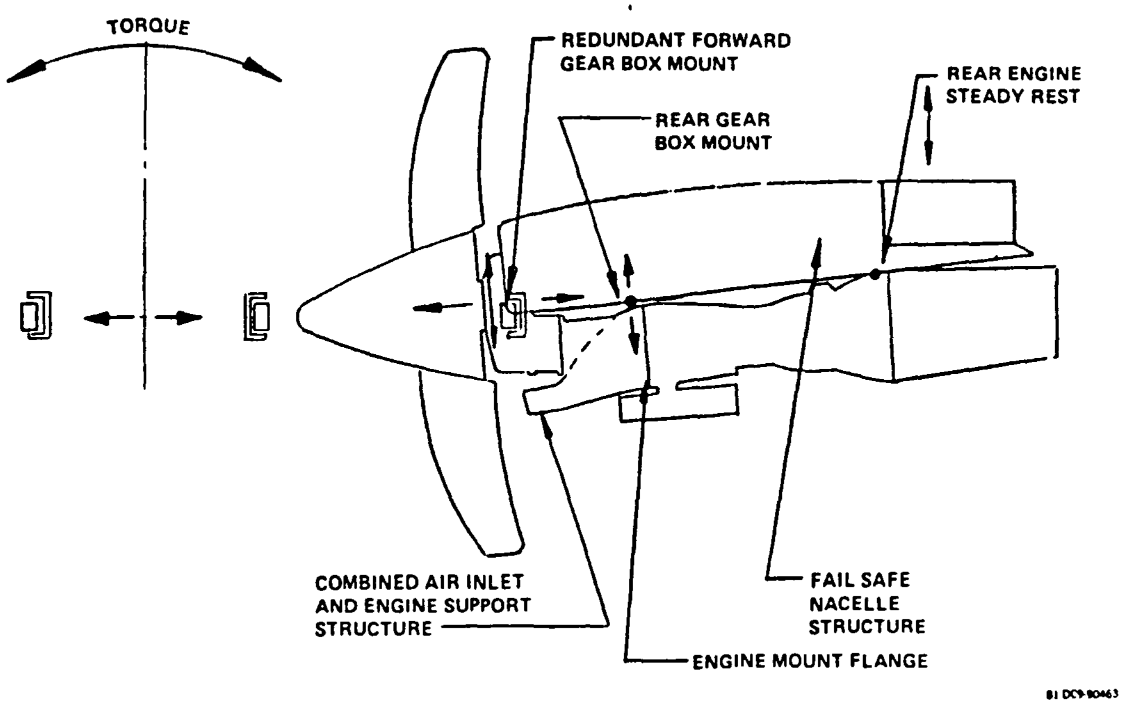
Very truly yours,

HAMILTON STANDARD DIVISION
United Technologies Corporation

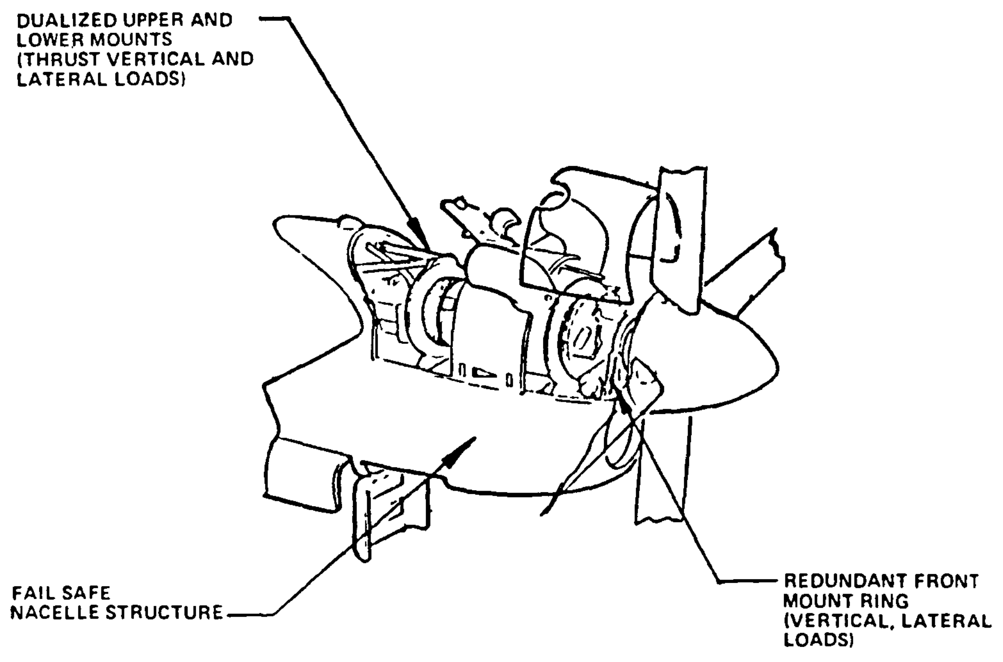
B. S. Gatzen
Prop-Fan Program Manager

Enclosures

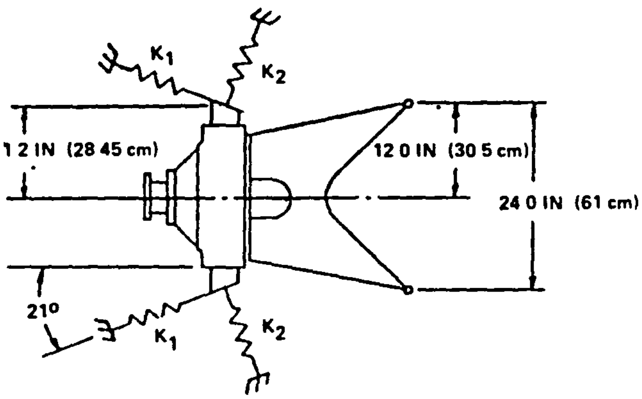
PROPULSION SYSTEM NACELLE MOUNTING

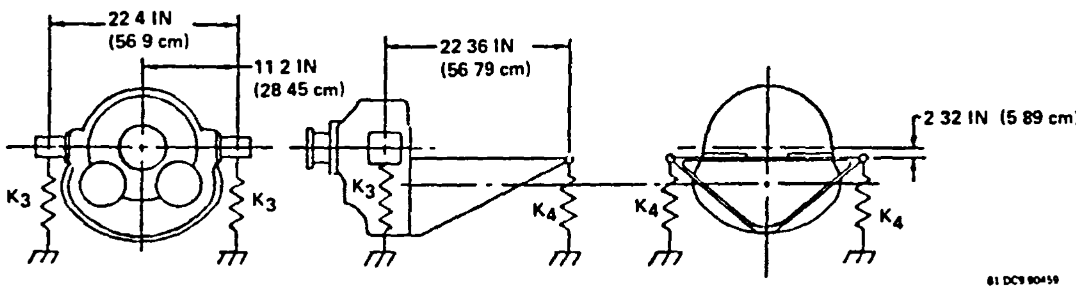


DHC-7 PROPULSION INSTALLATION



MOUNTING SYSTEM SCHEMATIC





HAMILTON STANDARD

Windsor Locks, Connecticut 06096

January 21, 1980

Douglas Aircraft Company
3855 Lakewood Boulevard
Long Beach, California 90846

Attention: Mrs. Irene Goldsmith

Subject: Prop-Fan Excitations on the DC9-80

Reference: Douglas letters C1-091-ACDT-574 and -621 to HS dated 11-7-79 and 12-4-79, respectively

Dear Irene:

We have completed the planned excitation factor analysis of Prop-Fans on the three configurations defined by the reference letter. We have found the excitations to be well under control for all three configurations with design EF's (Excitation Factors) at about 3.0. To put this in prospective, this level is below the design EF for the Lockheed Electra and well below the EF established for the Boeing wing mounted Prop-Fan installation which were studied for Ames in 1976. The Boeing wing mounted configuration had an estimated EF of 4 to 5 and the pylon mounted configuration had an EF of about 3.0. We found your wing mount to yield a more favorable EF because of greater rotor to wing leading edge clearance and a higher thrust axis with respect to the wing zero lift line.

The two aircraft operating conditions considered in the evaluation are at the extreme and opposite corners of the envelope for normal continuous operation. These maximum weight - minimum airspeed and minimum weight - maximum airspeed conditions are listed in Table I. For all three configurations, we have analyzed the two operating conditions with the DAC defined nacelle tilt and then with a tilt which provided a more balanced EF for the two conditions. Balanced means that the EF is about equal at the two conditions. In the wing mounted case, we also evaluated both favorable and unfavorable rotor rotation after setting a tilt for a balanced EF.

Table II shows the results of our analysis on the wing mount configuration. It can be seen that a slight reduction in downtilt brings about a more balanced EF level. In all cases, the higher order excitation levels are very low and do not contribute much to the overall EF. While the unfavorable rotation, which is CW on port side and CCW on starboard side, did increase the higher orders substantially; the rotation effects on overall EF

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were small. These results are attributed to the position of the Prop-Fan rotor with respect to the wing. Moving the rotor nearer to the wing lead edge and dropping the thrust axis would increase the nP levels substantially, raise the overall EF level, and cause the direction of rotation to have a greater influence.

The results of the aft mounted Prop-Fan study are presented in Table III. In general, overall EF levels are satisfactory and higher order components are larger than for the wing mounts. The 1P levels take into account both the wing and pylon or horizontal tail flowfields. The higher nP levels are believed to be associated with, the lesser clearance between the rotor and pylon/tail leading edge and the lesser distance between the thrust axis and pylon/tail zero lift line. Also with the pylon mount, the rotor sees a lift on only one side. The rotation used was unfavorable and it is likely that the nP components would be reduced by using favorable rotation, although this was not studied. For the pylon mount, both nacelle tilt and pylon lift were varied in an effort to balance the EF and lower the nP levels.

This study indicates that Prop-Fans could be successfully installed on a DC9-80. The estimated loads are lower than levels used in Prop-Fan blade preliminary design work conducted by HS to date. The changes we have made to the DAC specified nacelle tilts are not intended to be optimized values but surely are intended to be moving in that direction. The study results also indicate what parameters affect EF; they show that rotor to wing clearances are important in controlling both 1P and nP. Clearly in working out an optimized nacelle tilt and location, it is desireable to study a variety of nacelle positions and their impact on blade vibratory stresses. I call your attention to my saying blade stresses or blade response rather than loads (EF). In optimizing the EF for the initial operating cases, the blade stress sensitivity should be taken into account since stress per EF usually varies with blade angle.

If any questions arise, please feel free to contact me.

Very truly yours,

HAMILTON STANDARD DIVISION
United Technologies Corporation

B. S. Gatzen
Prop-Fan Program Manager

cc: D. Sagerser (NASA - Lewis)
L. Williams (NASA - Ames)

BSG:cw

TABLE I

Douglas DC-9-80/Prop-Fan Operating Conditions

For Excitation Analysis

Condition	Climb	High Speed
Gross Weight, lbs	140,000	90,000
IAS, kts	175	260
TAS, kts	175	454
Mach No.	0.266	0.724
Altitude, ft	S.L.	15,000
Prop RPM	1102	1102
Shaft Power, SHP	14,500	14,000
SHP/D^2	75	73
Slope of Wing Lift, $dC_L/d\alpha$, per deg.	0.86	0.107
Angle between FRL and Wing Zero Lift Line, deg.	3.8	3.0

TABLE II

Aerodynamic Excitation For DC9-80

With Wing Mounted Prop - Fans

Operation	Climb			High Speed		
Thrust Axis Downtilt	DAC	Balanced	Balanced	DAC	Balanced	Balanced
*Downtilt Angle, deg.	6.18	5.38	5.38	5.38	4.58	4.58
Prop Rotation	Favorable	Favorable	Unfavorable	Favorable	Favorable	Unfavorable
1P EF	2.55	2.77	2.77	3.68	2.79	2.73
2P/1P	.036	.031	.072	.025	.043	.079
3P/1P	.005	.003	.008	.016	.021	.019
4P/1P	-	-	.001	.005	.006	.005
5P/1P	-	-	.001	-	-	.002
Equivalent 1P EF	2.60	2.80	2.88	3.92	3.03	2.98
1P Shaft Moment, in-lbs	115,600	125,000	125,400	104,300	78,000	77,500
1P Side Force, lbs	2250	2440	2450	3440	2580	2560

* Downtilt measured from wing zero lift line

TABLE III

Aerodynamic Excitation For DC9-80

With Aft Mounted Prop - Fans

Configuration	Pylon Mount						Horizontal Tail			
Operation	Climb			High Speed			Climb		High Speed	
Thrust Axis Downtilt	DAC	Balanced	Adjusted Lift	DAC	Balanced	Adjusted Lift	DAC	Balanced	DAC	Balanced
Downtilt Angle, deg.	0	-1.0	1.5	0	-1.0	1.5	0	-1.0	1.0	0
Equivalent 1P EF	2.55	3.17	3.12	4.30	2.66	2.58	2.20	2.51	3.82	2.55
2P/1P			.16			.088		.035		.213
3P/1P			.057			.065		.026		.074
4P/1P			.026			.035		.008		.038
5P/1P			.01			.015		.001		.016

Notes:

Downtilt measured from pylon or horizontal tail zero lift line. Higher order ratio with respect to 1P from pylon or horizontal tail. Unfavorable rotation in all cases.

APPENDIX C

DC-9 SUPER 80 BASELINE AIRCRAFT CHARACTERISTICS

This appendix provides detail concerning the new technology and improved systems that separate the Super 80 from its predecessors. The data presented include the following information:

General DC-9 Family Characteristics - Figures C-1 through C-6.

Characteristic Advanced Technology - Figures C-7 through C-10.

DC-9 Super 80 General Arrangement and Characteristics - Figures C-11 and C-12.

DC-9 Super 80 Performance Comparisons - Figures C-13 through C-18.

Alternate Engine Installations Comparisons - JT8D-209 (DC-9 Super 81), JT8D-217 (Super 82), CFM-56, RJ-500, JT10D - Figures C-19 through C-23.

DC-9 Super 80 Subsystem Characteristics - Figures C-24 through C-35.

These data plots are extracted from References C-1, C-2, C-3, and C-4.

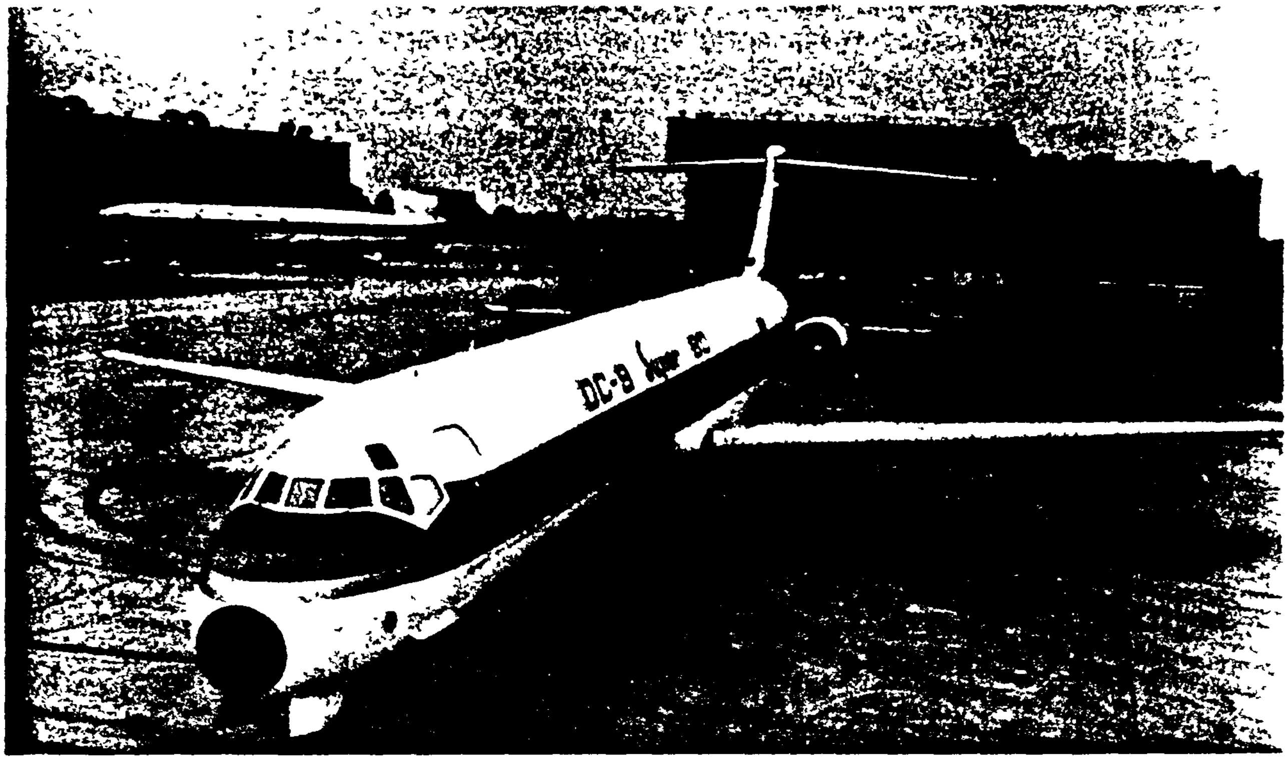


FIGURE C-1. DC-9 SUPER 80

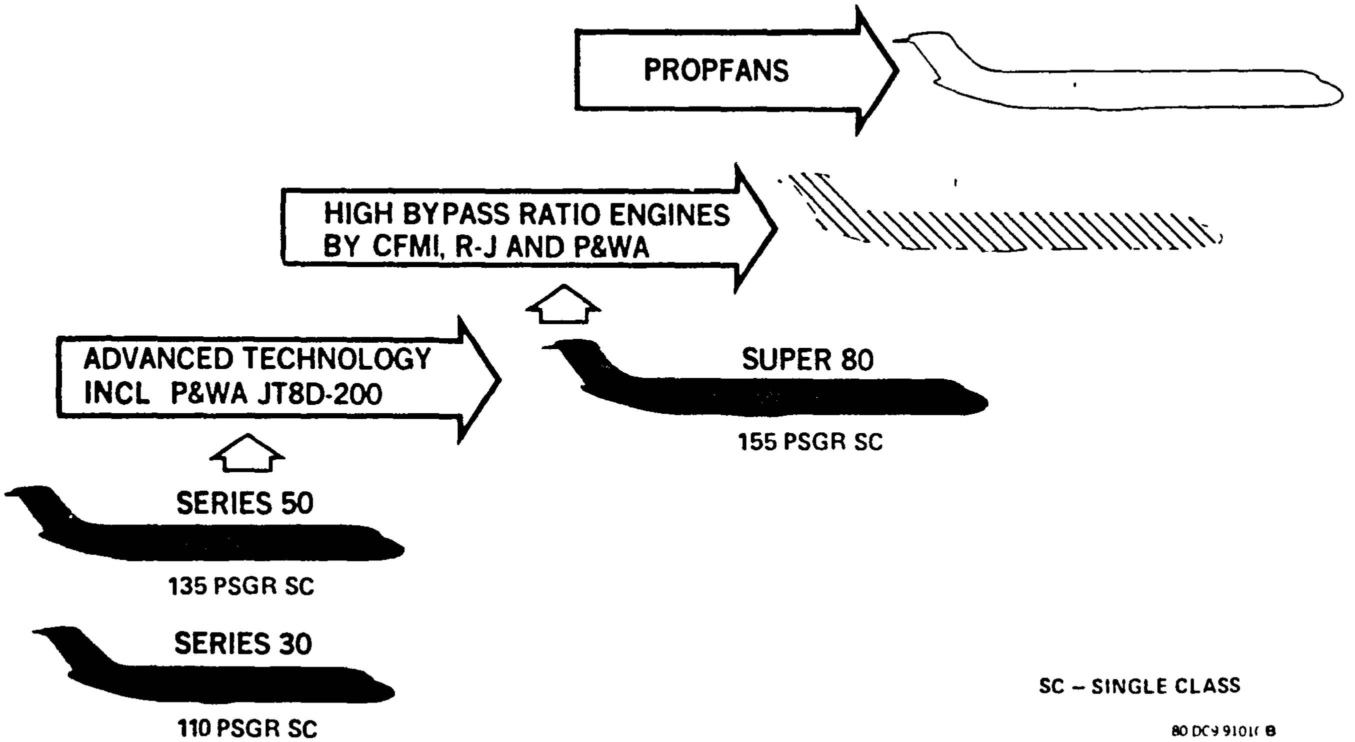


FIGURE C-2. DC-9 FAMILY

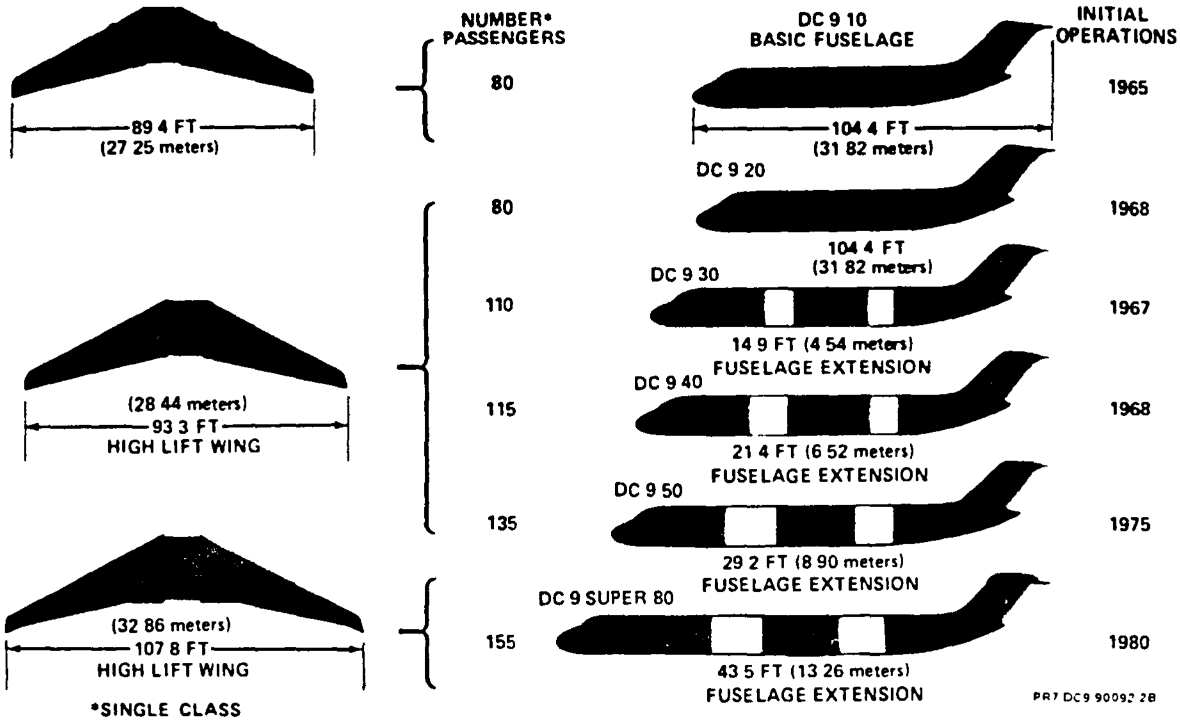


FIGURE C-3. DC-9 FAMILY GROWTH

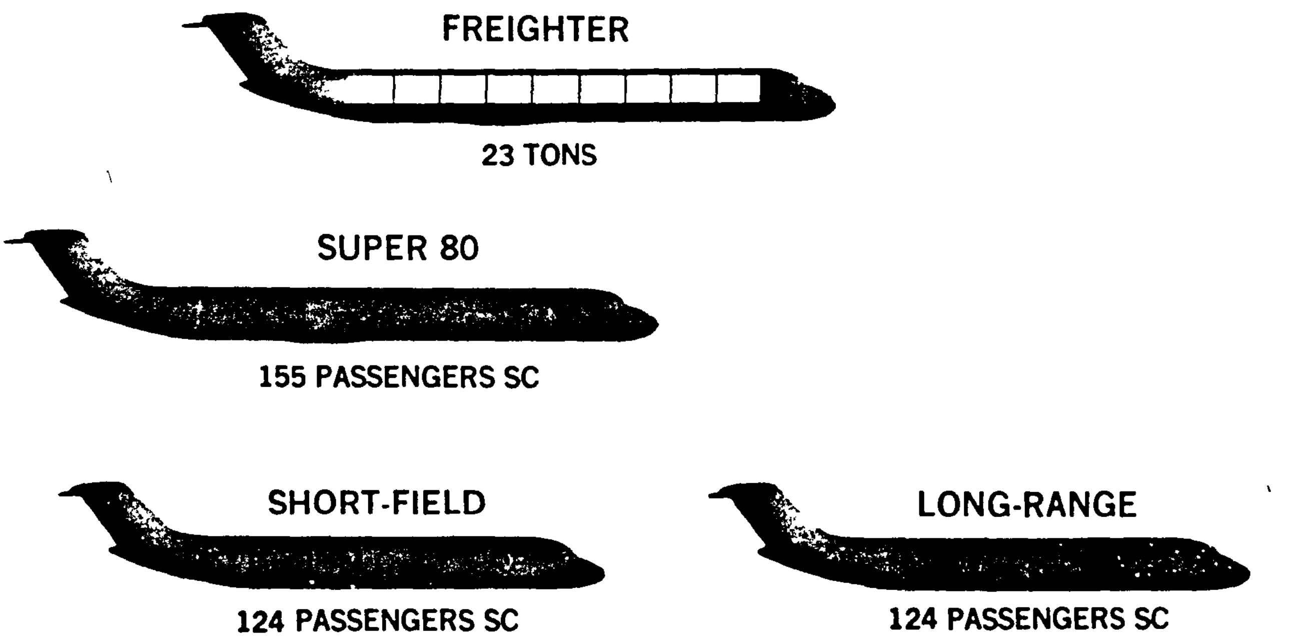
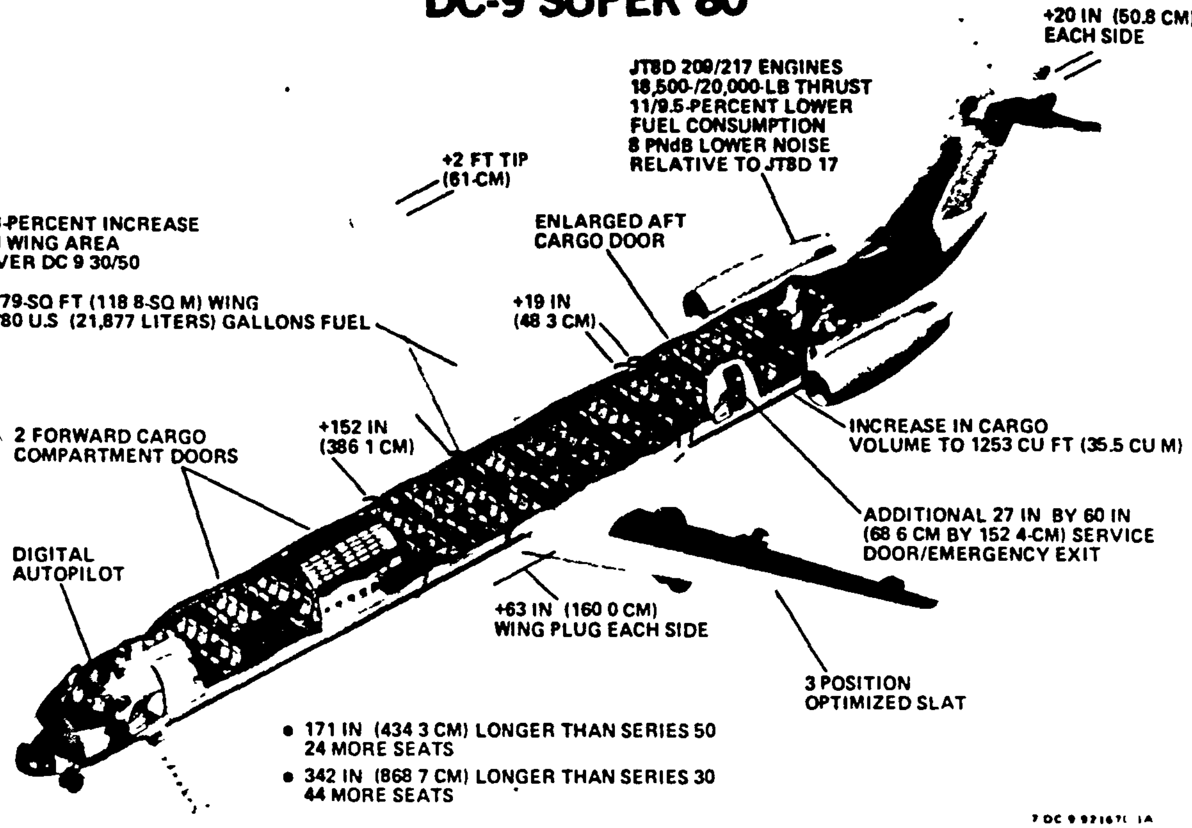
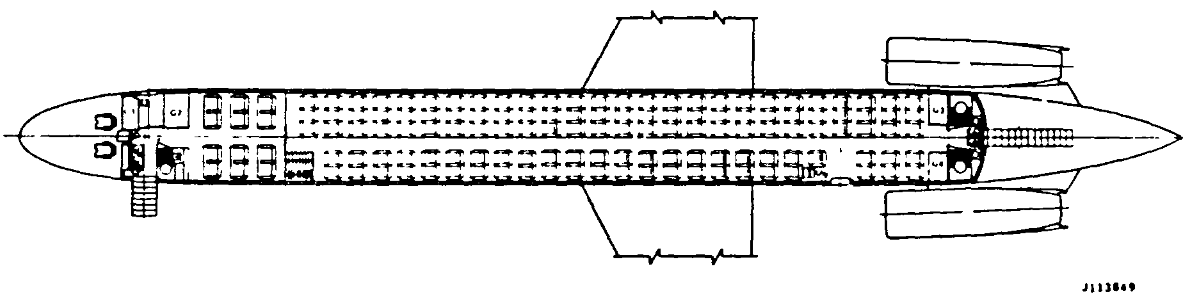


FIGURE C-4. DC-9 SUPER 80 DERIVATIVES

DC-9 SUPER 80





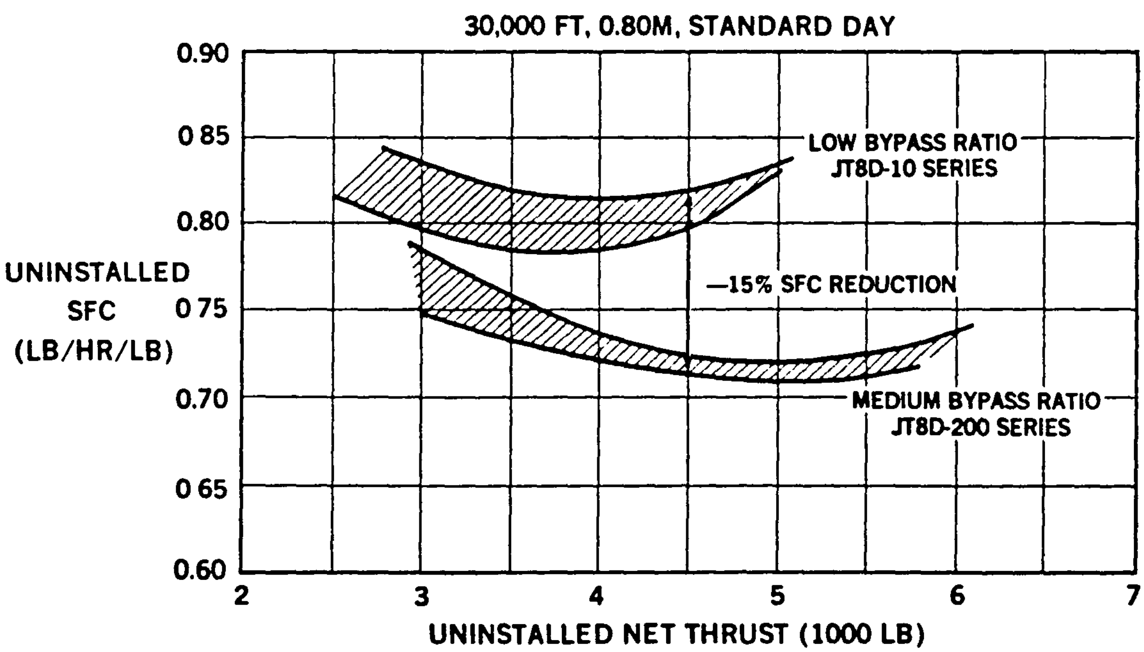
FIRST CLASS 12 [SEAT PITCH — 38-IN.]
ECONOMY CLASS 125 [SEAT PITCH — 34-IN.]
TOTAL 137 SEATS

FIGURE C-6. DC-9 SUPER 80 INTERIOR ARRANGEMENT MIXED CLASS SEATING

- EFFICIENT USE OF ENERGY — MAJOR IMPACT ON COSTS — CRITICAL IN CASE OF FUEL ALLOCATIONS
- REDUCED PILOT WORKLOAD
- IMPROVED ECONOMICS
- IMPROVED RELIABILITY AND REDUCED MAINTENANCE COSTS
- GOOD RELATIONS WITH COMMUNITY — NOISE

80 DC 9 9066

FIGURE C-7. DC-9 SUPER 80 APPROPRIATE ADVANCED TECHNOLOGY



81 DC9 80460

FIGURE C-8. CRUISE PERFORMANCE COMPARISON

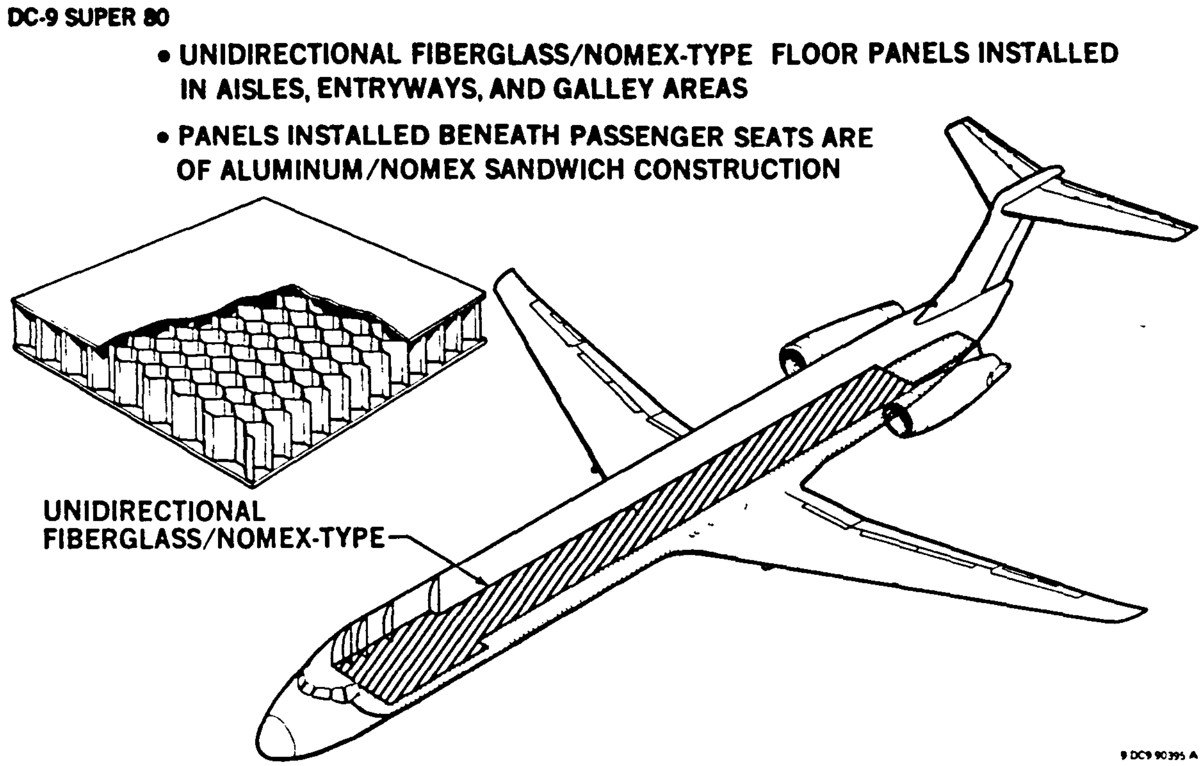


FIGURE C-9. NEW PASSENGER FLOOR DESIGN

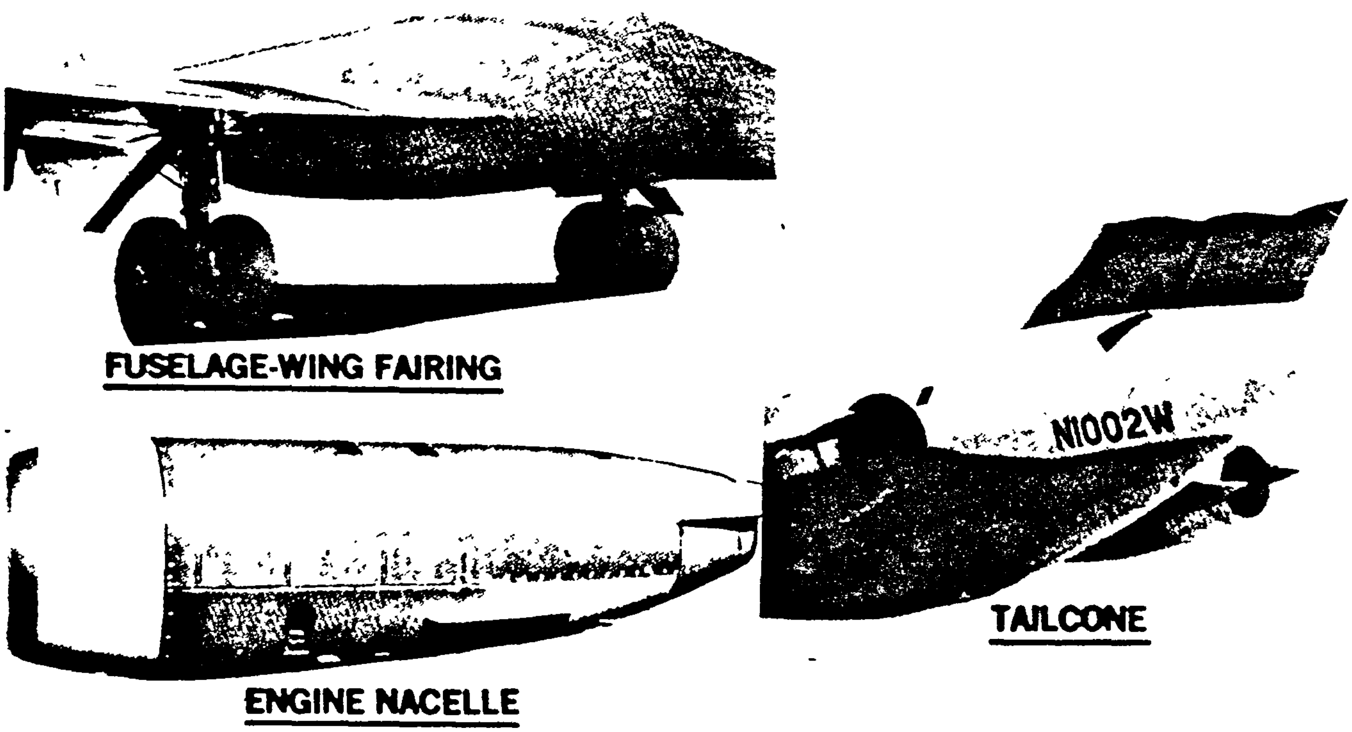


FIGURE C-10. TYPICAL USES OF ADVANCED COMPOSITES

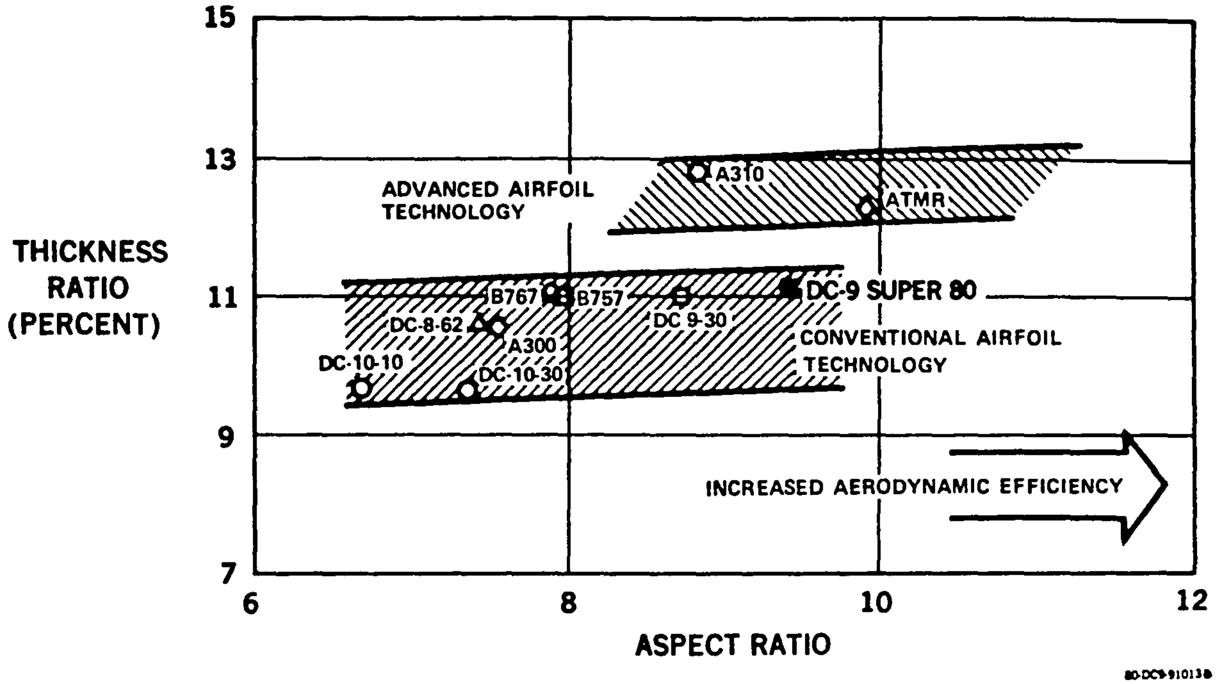


FIGURE C-11. WING TECHNOLOGY

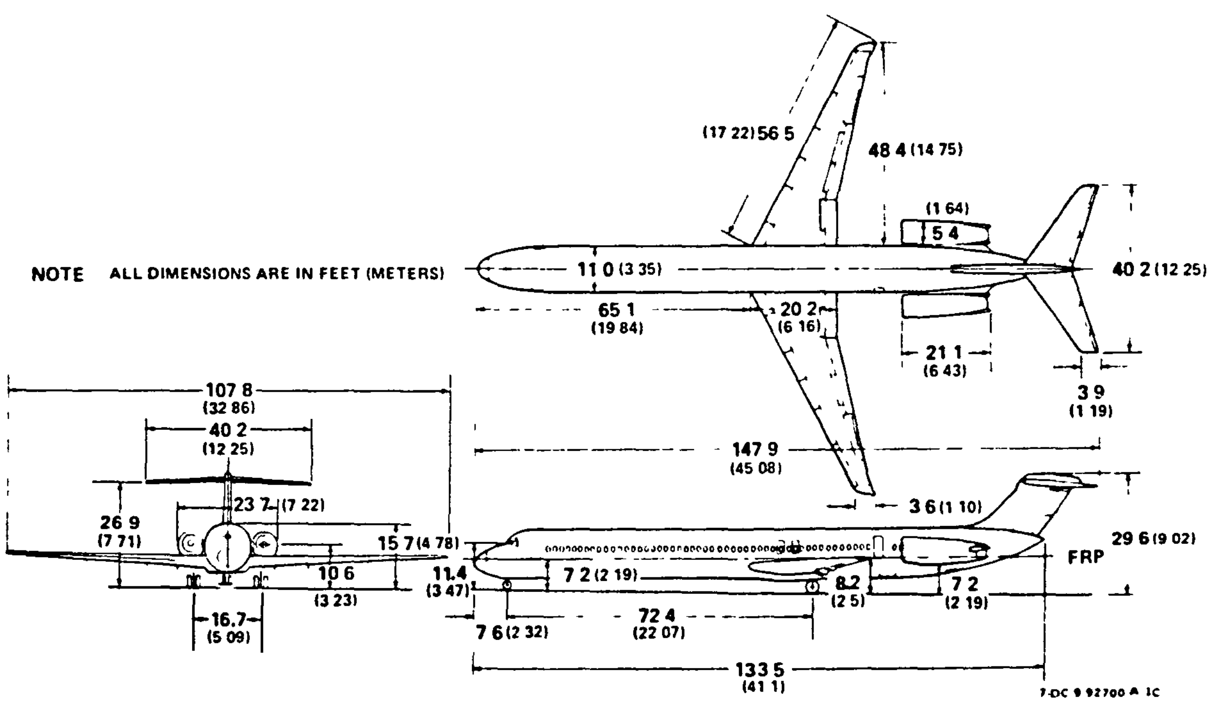


FIGURE C-12. MODEL DC-9 SUPER 80 GENERAL ARRANGEMENT

	DC-9-30	DC-9-50	DC-9 SUPER 80	
ENGINES	JT8D-9A	JT8D-17	JT8D-209	JT8D-217A
THRUST (SLS-LB)	14,500	16,000	18,500 / 19,250	20,000 / 20,850
NO. PASSENGERS — 10/90 MIX	93	114	137	137
NO. PASSENGERS — SINGLE CLASS	110	135	155	155
MAX TAKEOFF WEIGHT (LB)	108,000	121,000	140,000	149,500
MAX LANDING WEIGHT (LB)	99,000	110,000	128,000	130,000
MAX ZERO FUEL WEIGHT (LB)	87,000	98,500	118,000	122,000
FUEL CAPACITY (LB)	24,649/28,535*	33,761**	39,130	39,130

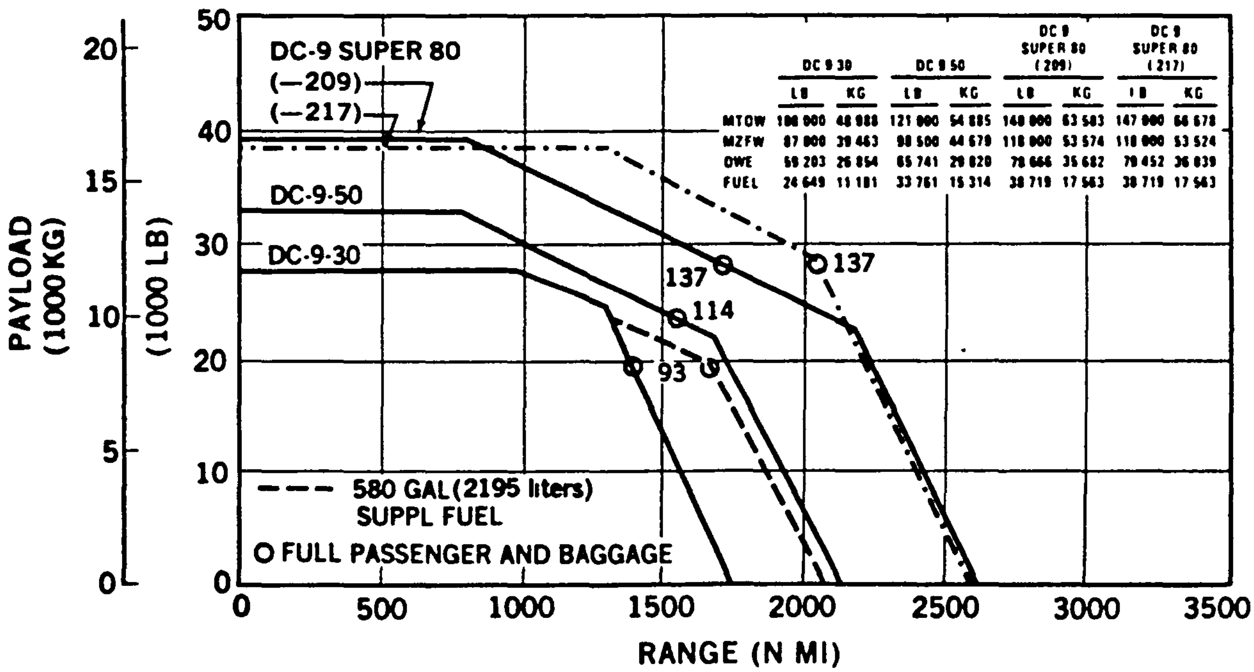
*INCLUDES 580 GALLONS SUPPLEMENTAL FUEL

**INCLUDES 780 GALLONS SUPPLEMENTAL FUEL IN ADDITION TO STANDARD 580 GALLONS

7 DC9 90609L 1

FIGURE C-13. GENERAL CHARACTERISTICS

LONG-RANGE CRUISE AT 31,000/35,000 FT
DOMESTIC RESERVES



7 DC9 90930D 1C

FIGURE C-14. PAYLOAD-RANGE COMPARISON

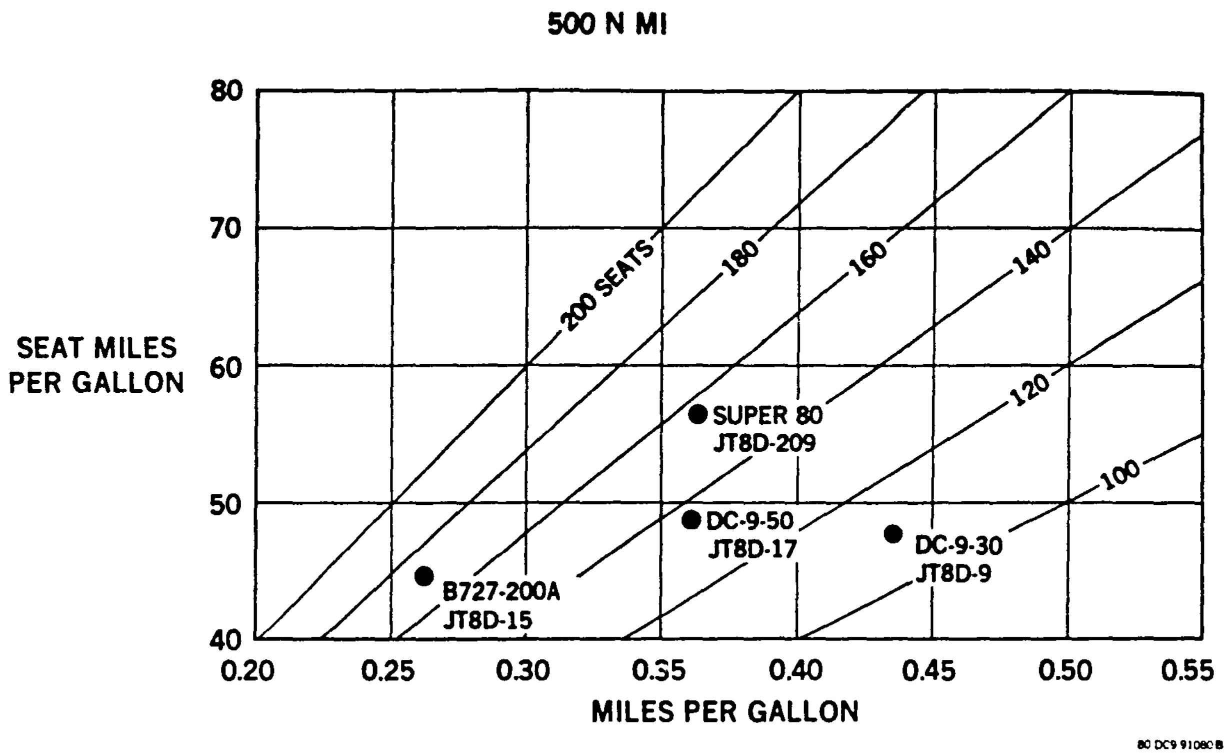


FIGURE C-15. FUEL-BURNED COMPARISON

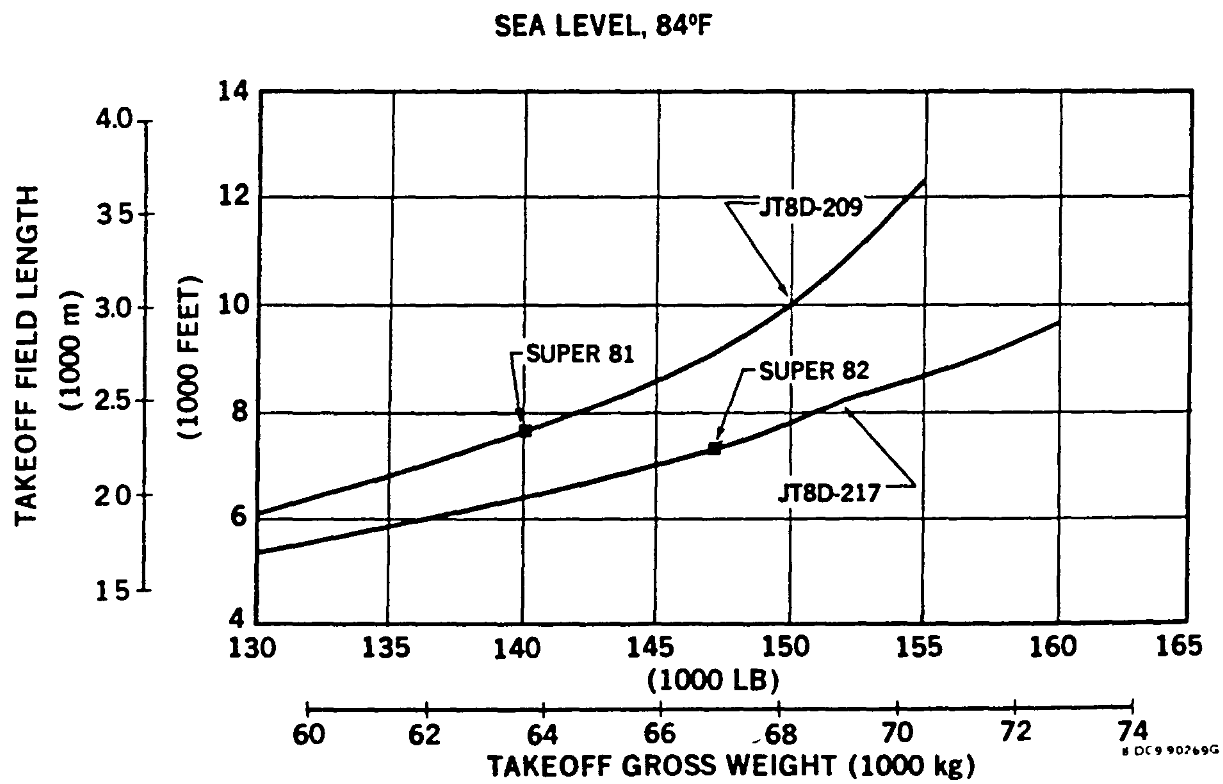


FIGURE C-16. TAKEOFF FIELD LENGTH

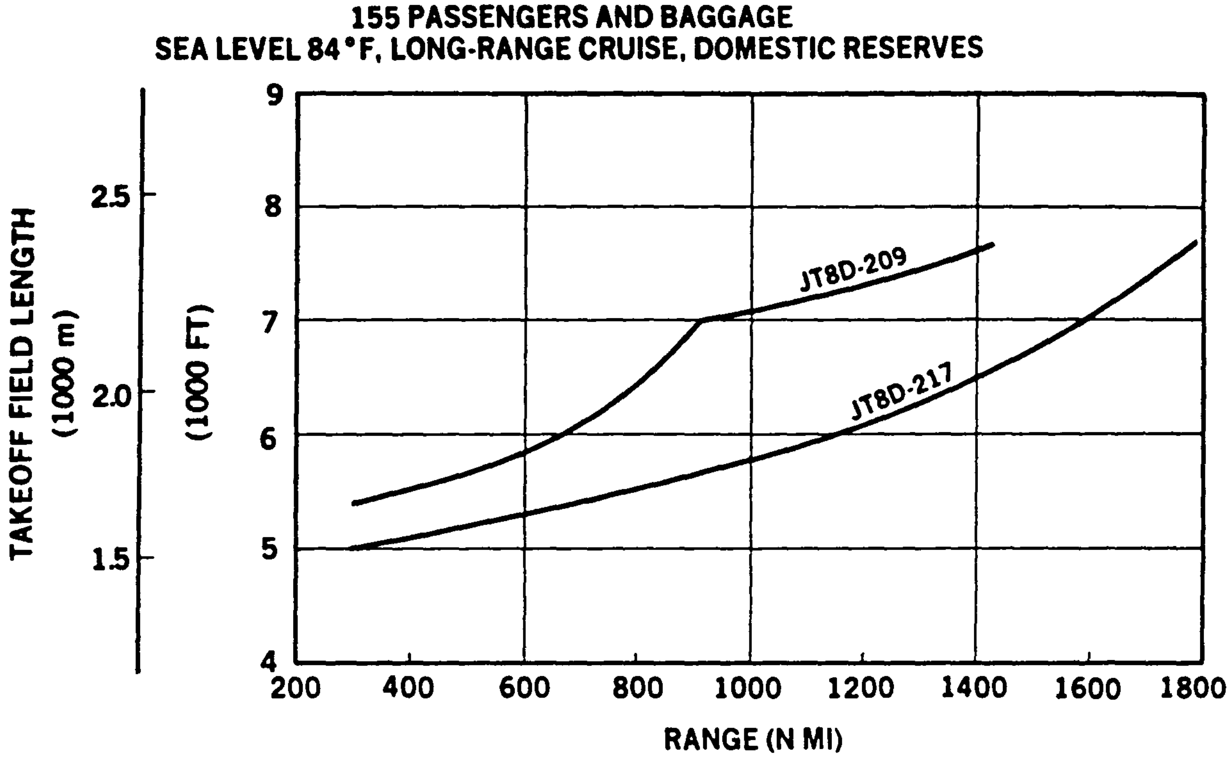


FIGURE C-17. FIELD LENGTH – RANGE COMPARISON

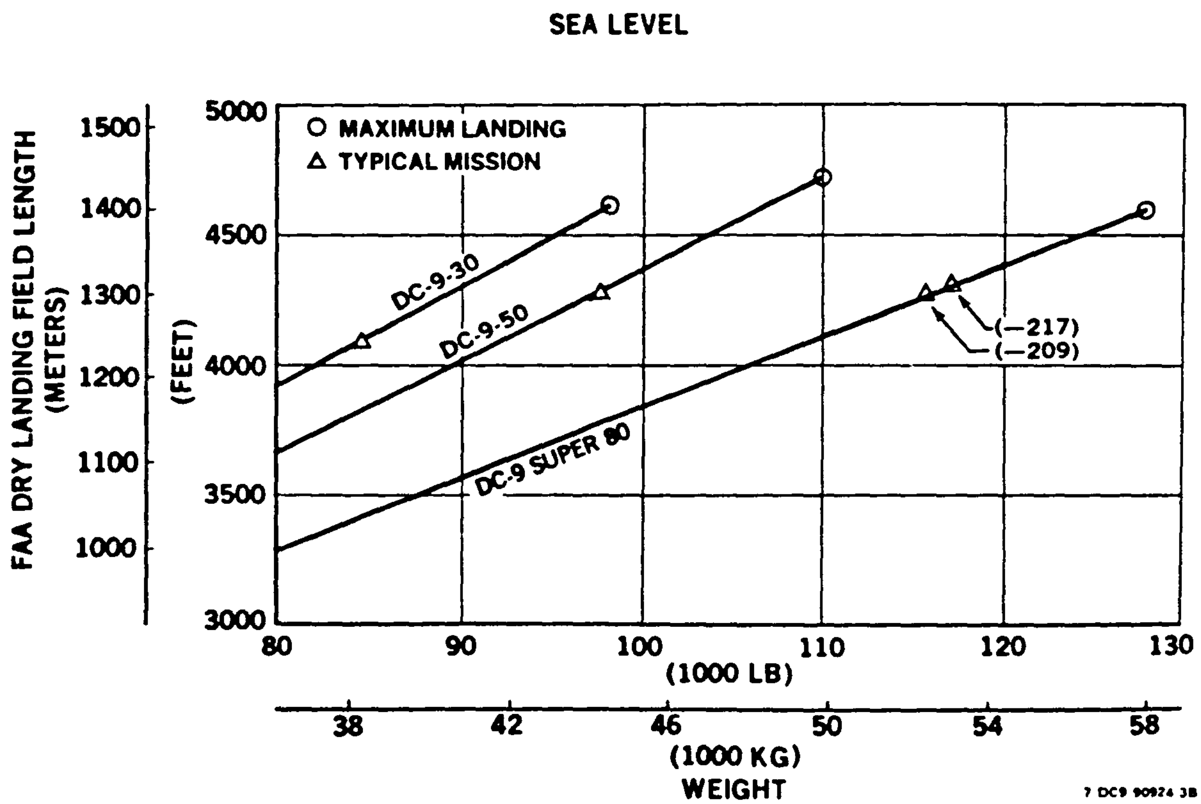


FIGURE C-18. LANDING FIELD LENGTH COMPARISON

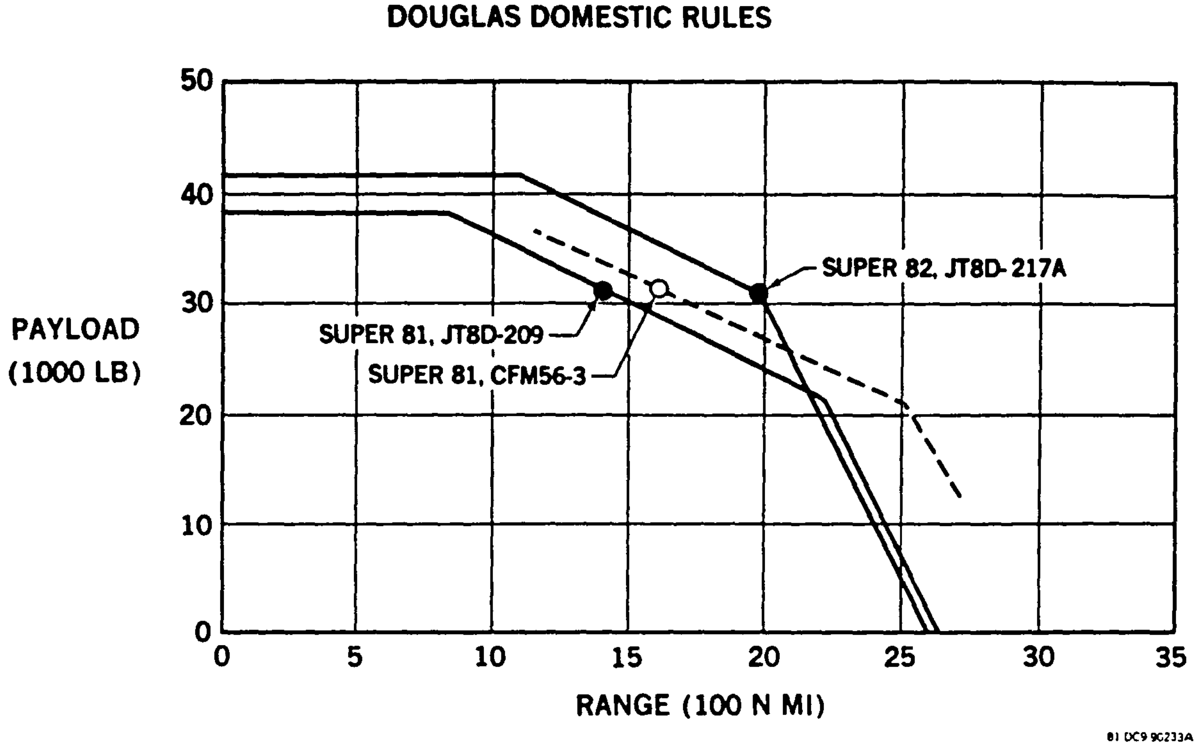


FIGURE C-19. DC-9 PAYLOAD-RANGE COMPARISON

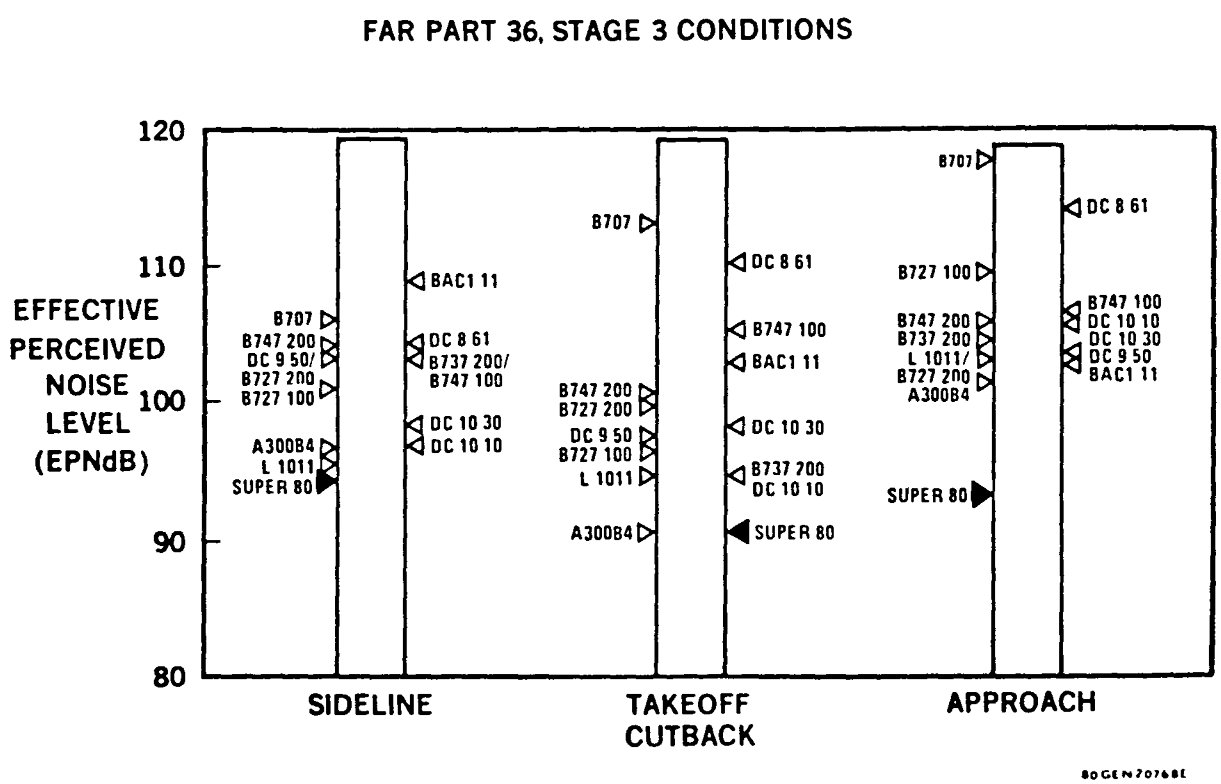


FIGURE C-20. NOISE-LEVEL COMPARISONS

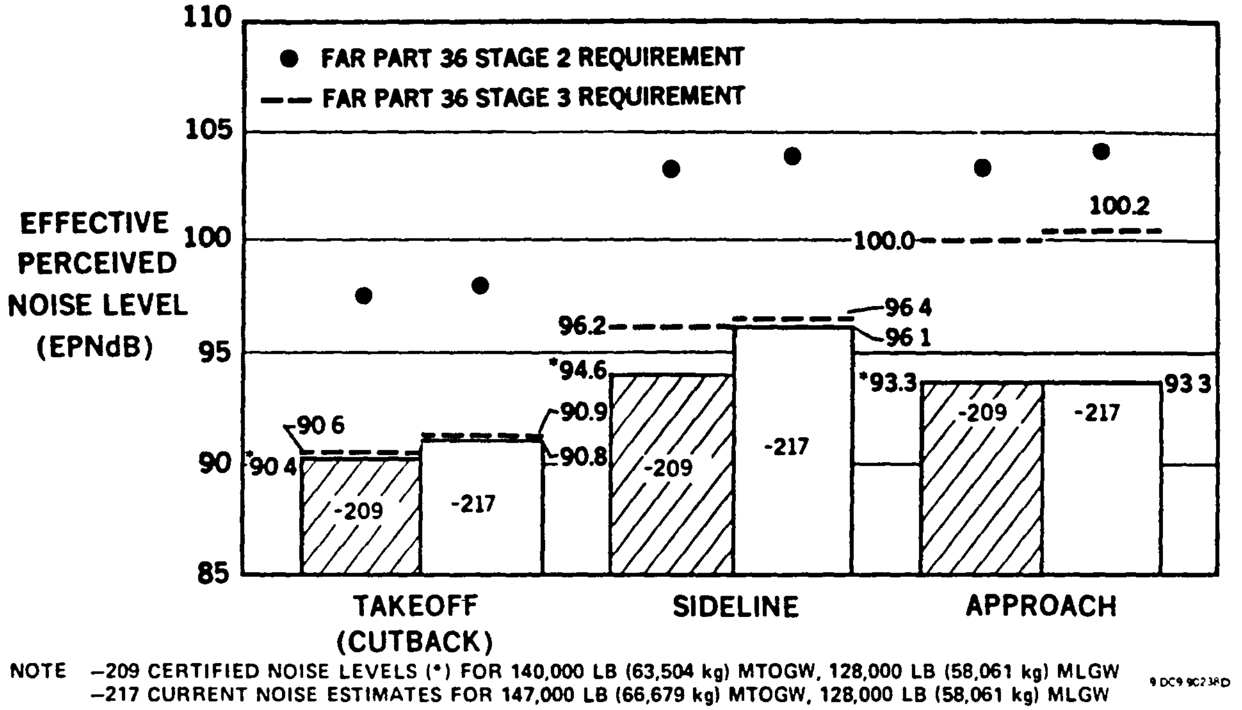


FIGURE C-21. NOISE-LEVEL COMPARISON

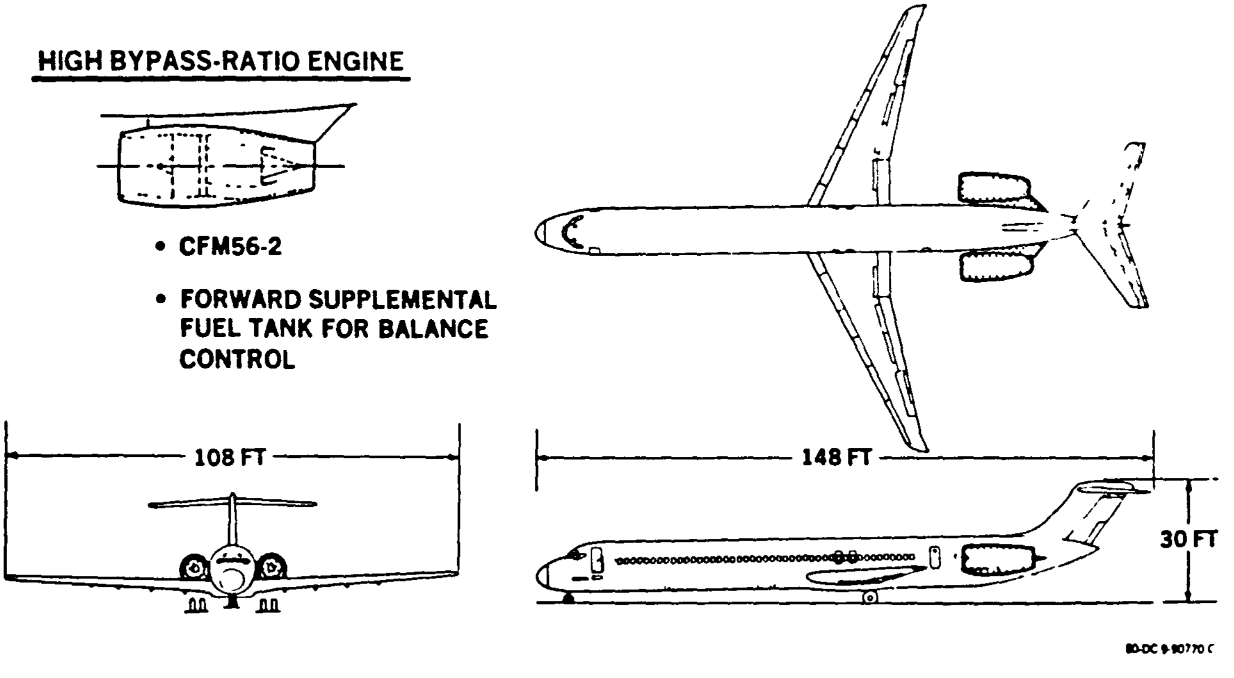


FIGURE C-22. DC-9 SUPER 80 GENERAL ARRANGEMENT

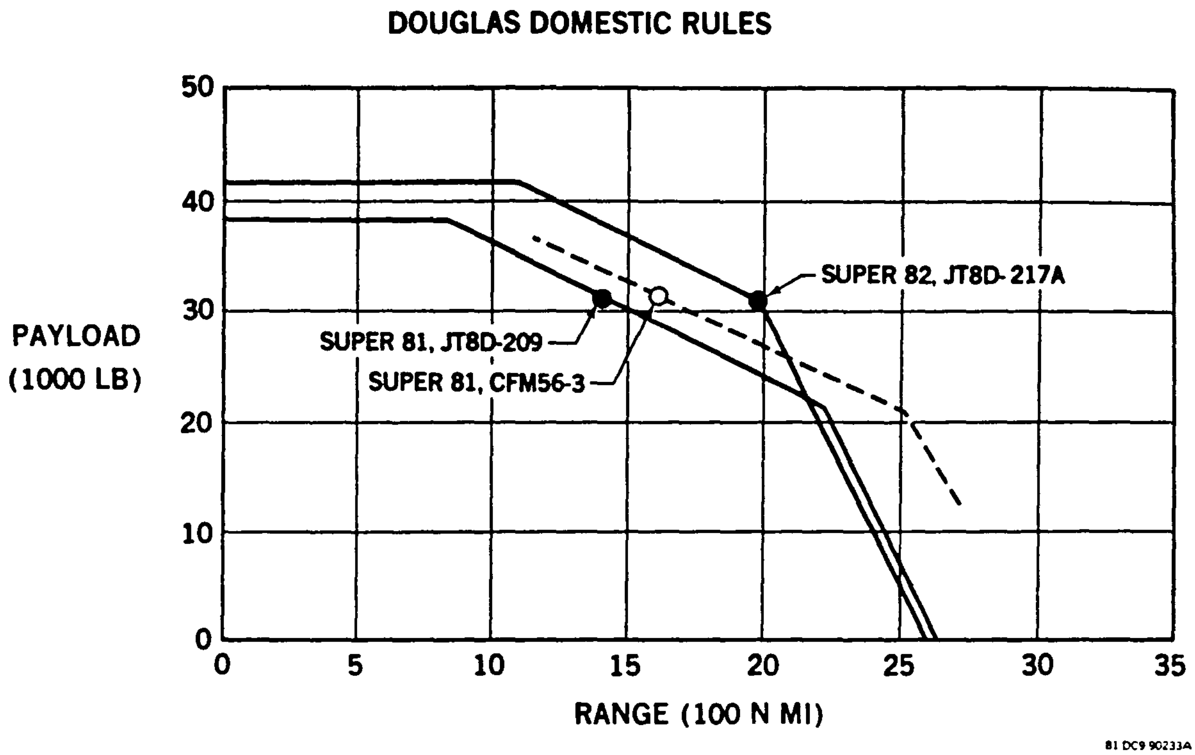


FIGURE C-23. DC-9 PAYLOAD-RANGE COMPARISON

	JT8D 9A	JT8D 17	JT8D 209	JT8D 218	JT8D 217	JT8D 217A	CFM56 2[1]	CFM56 3[3]	RJ500 02
TAKEOFF THRUST (LB) SEA LEVEL STATIC STANDARD DAY	14 500	16 000	18,500 19 250[2]	18 000	20 000 20 850[2]	20 000 20 850[2]	22 000	20 000	20 150
FLAT RATED TEMPERATURE (°F)	84	84	77/84[2]	84	77/84[2]	84	86	86	86
BYPASS RATIO	1 04	1 02	1 78	1 81	1 73	1 73	5 70	5 2	4 72
FAN DIAMETER (IN)	40 2	4 02	49 2	49 2	49 2	49 2	68 3	60 0	59 0
OVERALL PRESS RATIO AT T O	15 9	16 9	17 1	17 1	18 6	18 6	25 6	22 4	19 8
CERTIFICATION DATE	PROD	PROD	PROD	1982	PROD	1982	PROD	1983	1985

NOTES
1 DC 8 70 RE ENGINE
2 AUTOMATIC RESERVE THRUST RATING
3 GROWTH ENGINE UNDER STUDY

81 DC9 90461

FIGURE C-24. DC-9 ENGINE COMPARISON

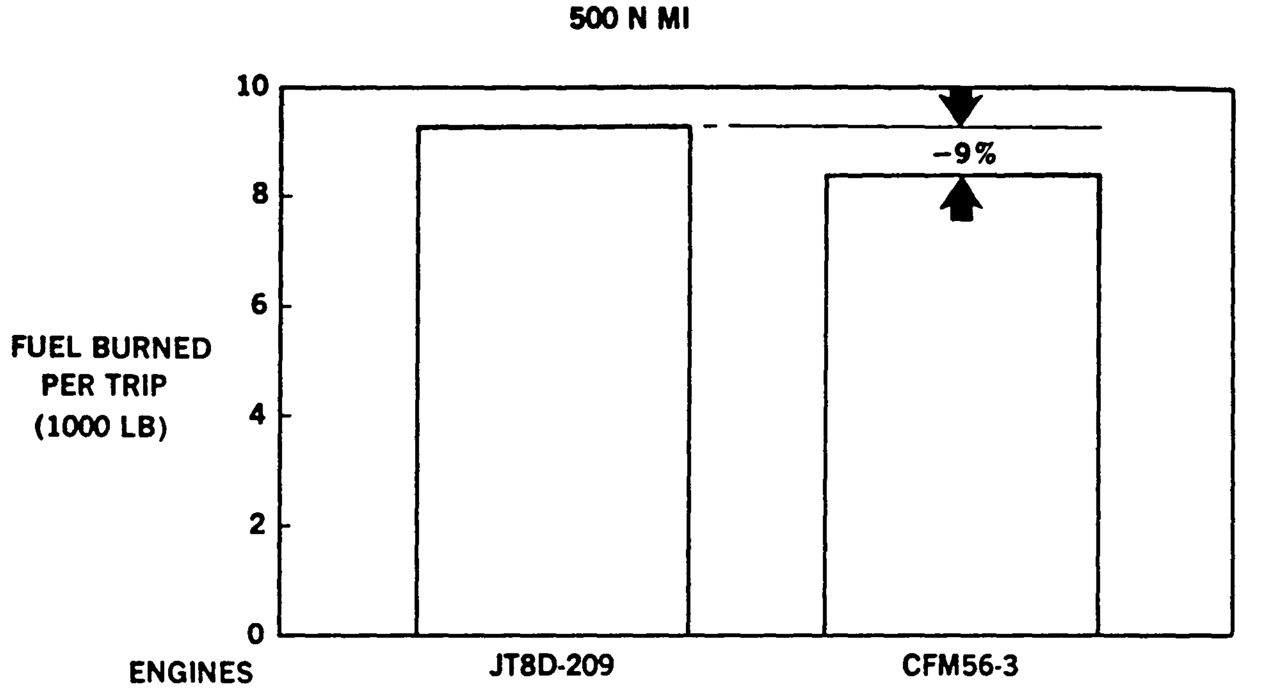


FIGURE C-25. DC-9-81 FUEL-BURNED COMPARISON

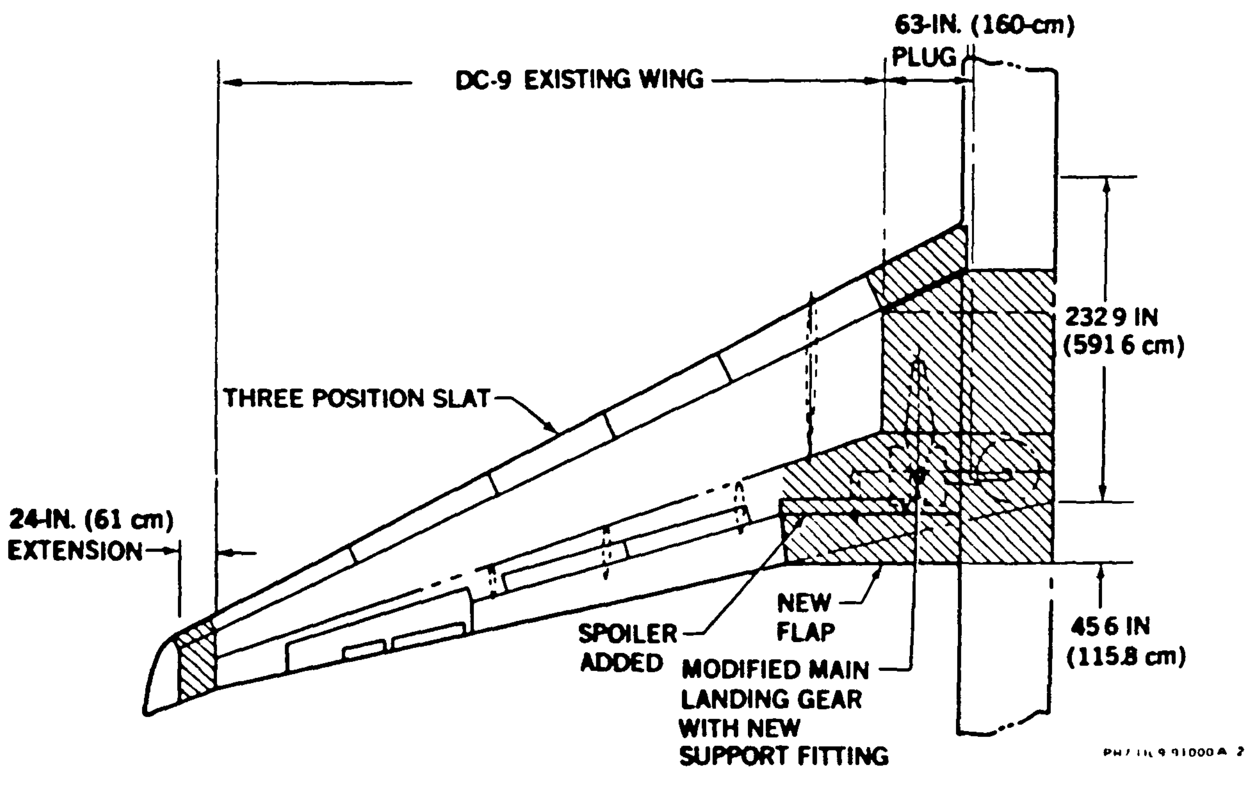
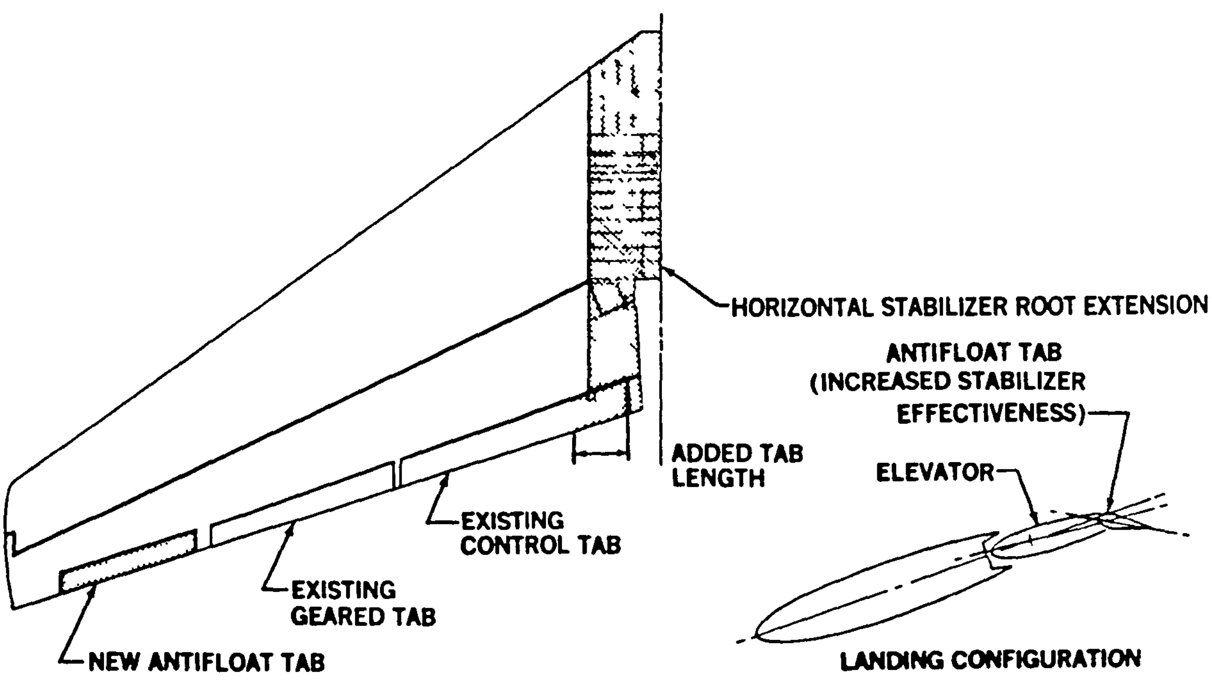


FIGURE C-26. DC-9 SUPER 80 WING

	DC-9-30/50	DC-9 SUPER 80
REF. WING AREA (SQ FT/sq m)	1000.7/93.0	1209.3/112.3
SWEEP C/4	24.5°	24.5°
ASPECT RATIO	8.71	9.62
AVERAGE THICKNESS RATIO	11.0	11.3
FUEL VOLUME (GAL/liters)	3679/13,925	5779/21,874
$C_{L_{MAX}}$	3.0 (δ_f = 50°)	3.039 (δ_f = 40°)

6 DC 9 91079G

FIGURE C-27. WING CHARACTERISTICS



PR/ DC9 90454 1D

FIGURE C-28. HORIZONTAL STABILIZER REVISION

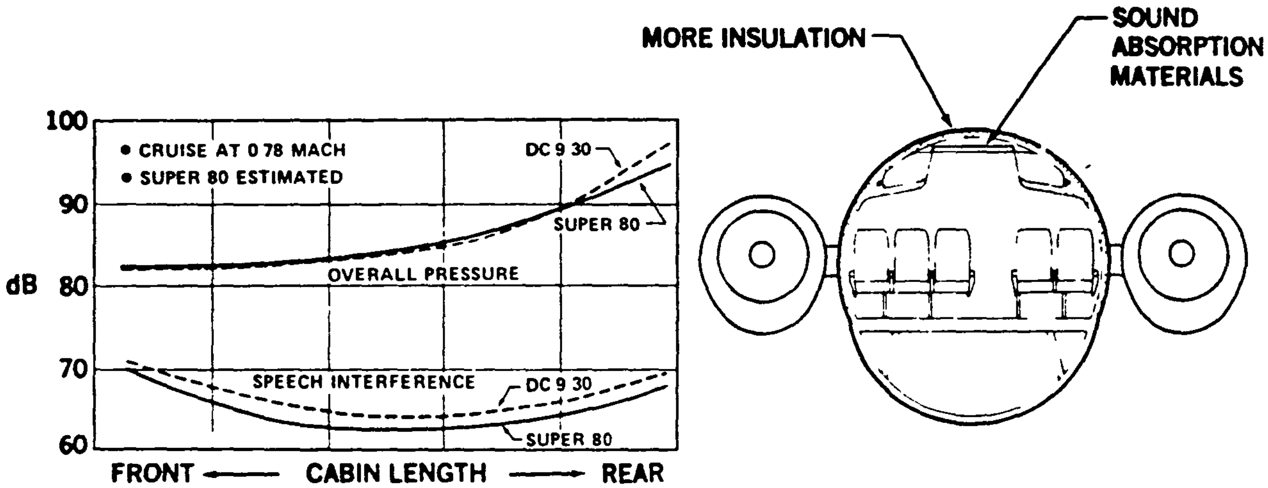


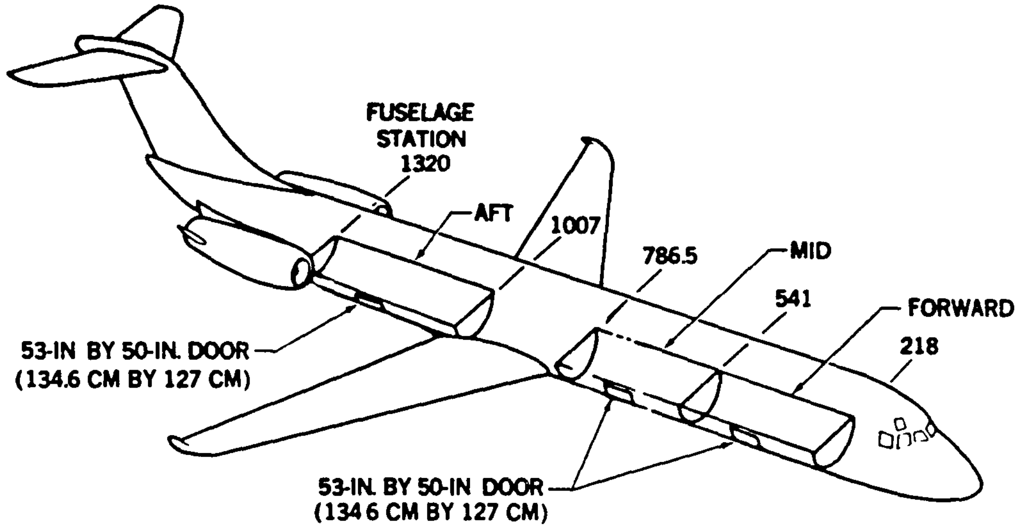
FIGURE C-29. CABIN NOISE LEVEL

• DC9 90444 E

- CARGO CAPACITY INCREASED TO 1253 CU FT (35.48 CU M)
- LOWER CARGO COMPARTMENT FLAT FLOOR
- OPTIONAL PROVISIONS FOR TELESCOPING LOADING SYSTEM (AIR CARGO EQUIPMENT)

• DC9 90227 1C

FIGURE C-30. DC-9 SUPER 80 CARGO COMPARTMENT



COMPARTMENT	CAPACITY (CU FT)	CAPACITY (CU M)
FORWARD	464	13 14
MID	346	9 80
AFT	443	12 55
CABIN OVERHEAD STOWAGE	229	6 49
TOTAL	1482	41 98

FIGURE C-31. DC-9 SUPER 80 BAGGAGE/CARGO COMPARTMENTS

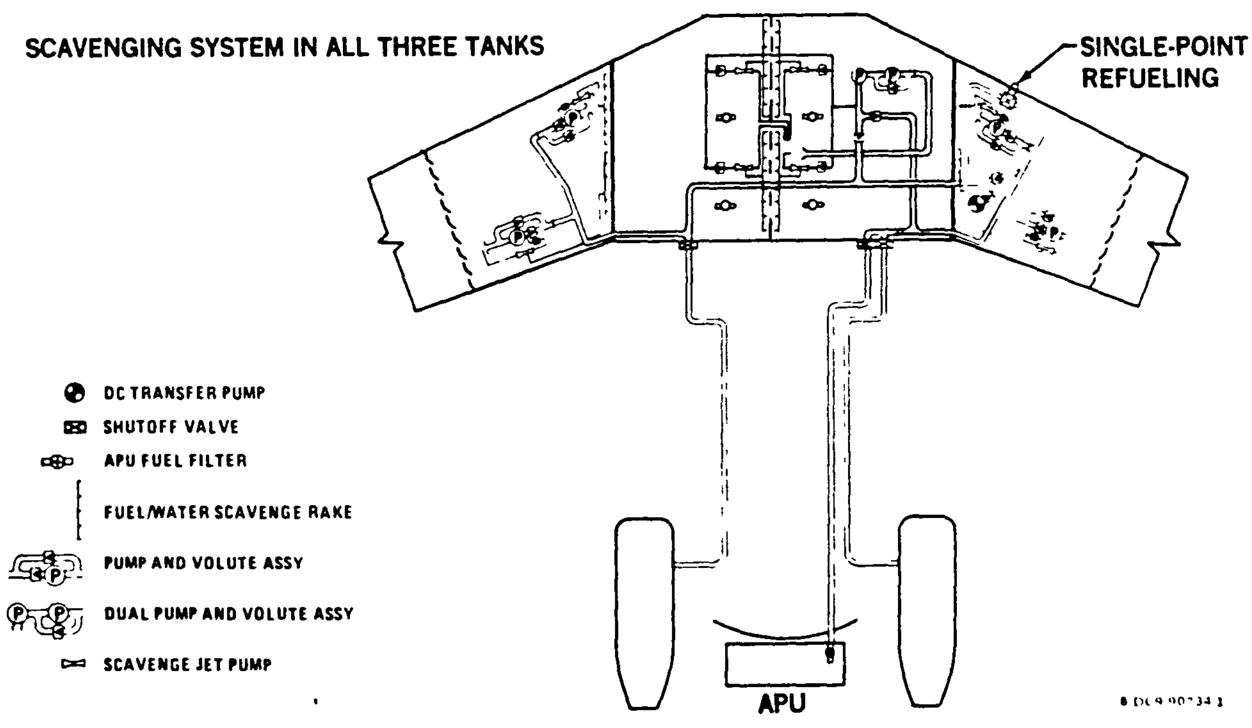


FIGURE C-32. FUEL SYSTEM

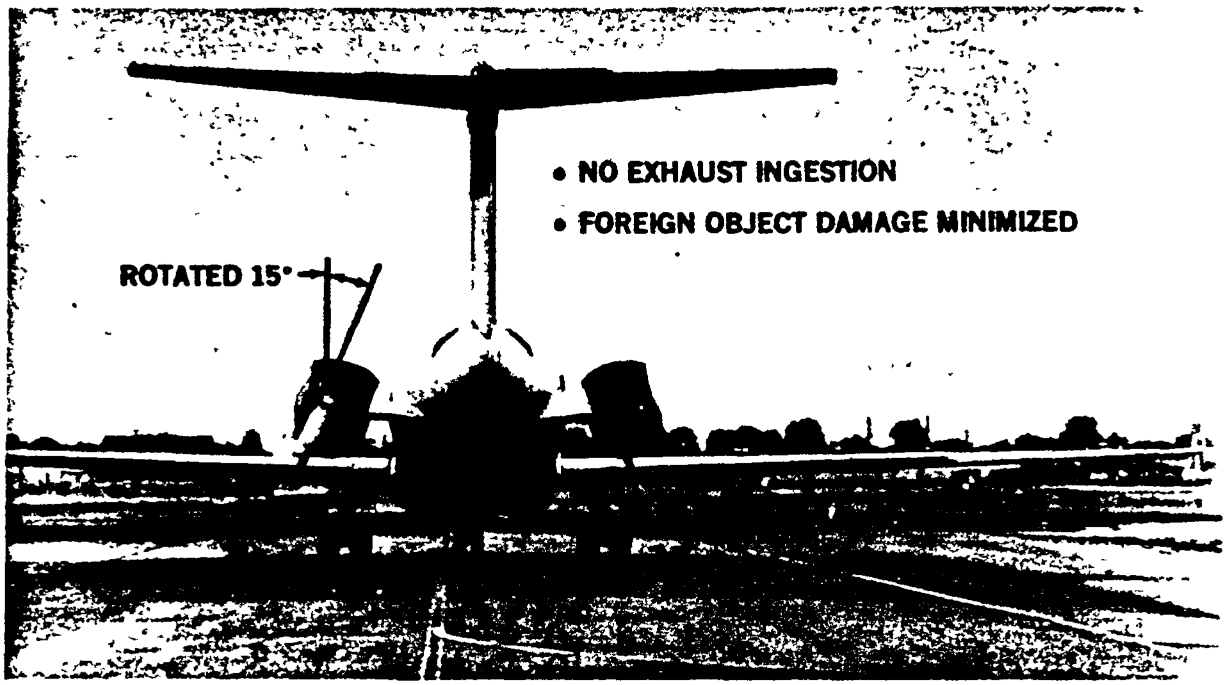


FIGURE C-33. ROTATED THRUST REVERSERS

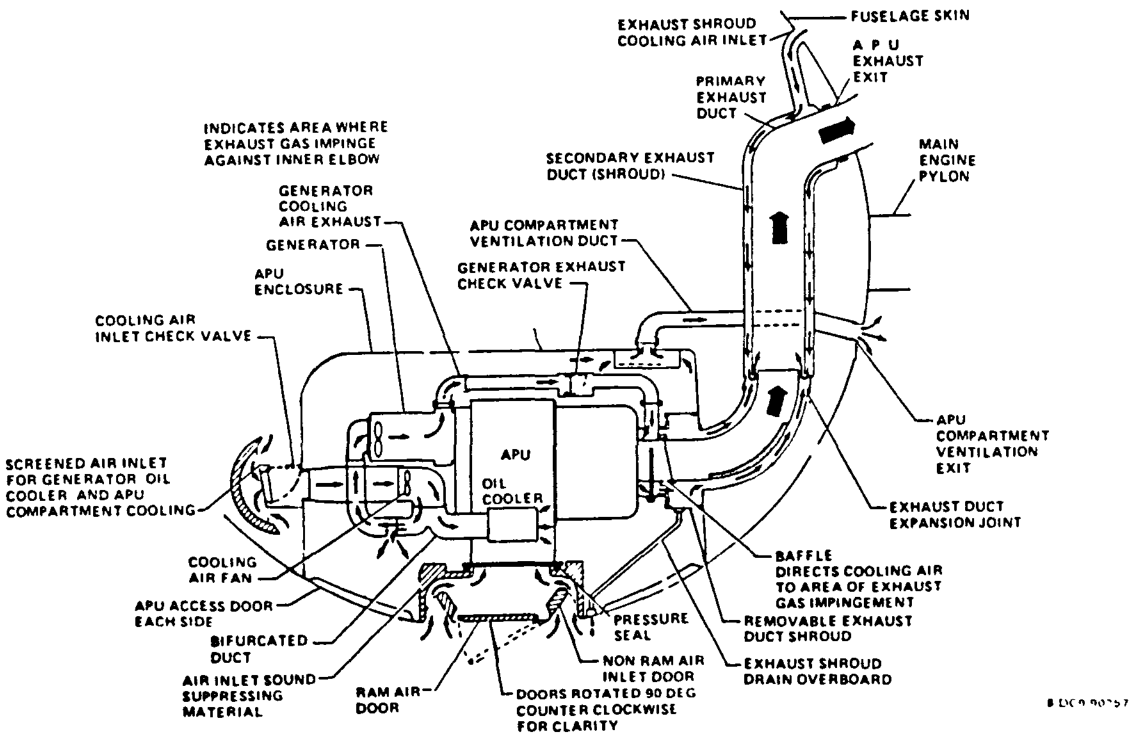


FIGURE C-34. APU AIR FLOW AND EXHAUST SCHEMATIC

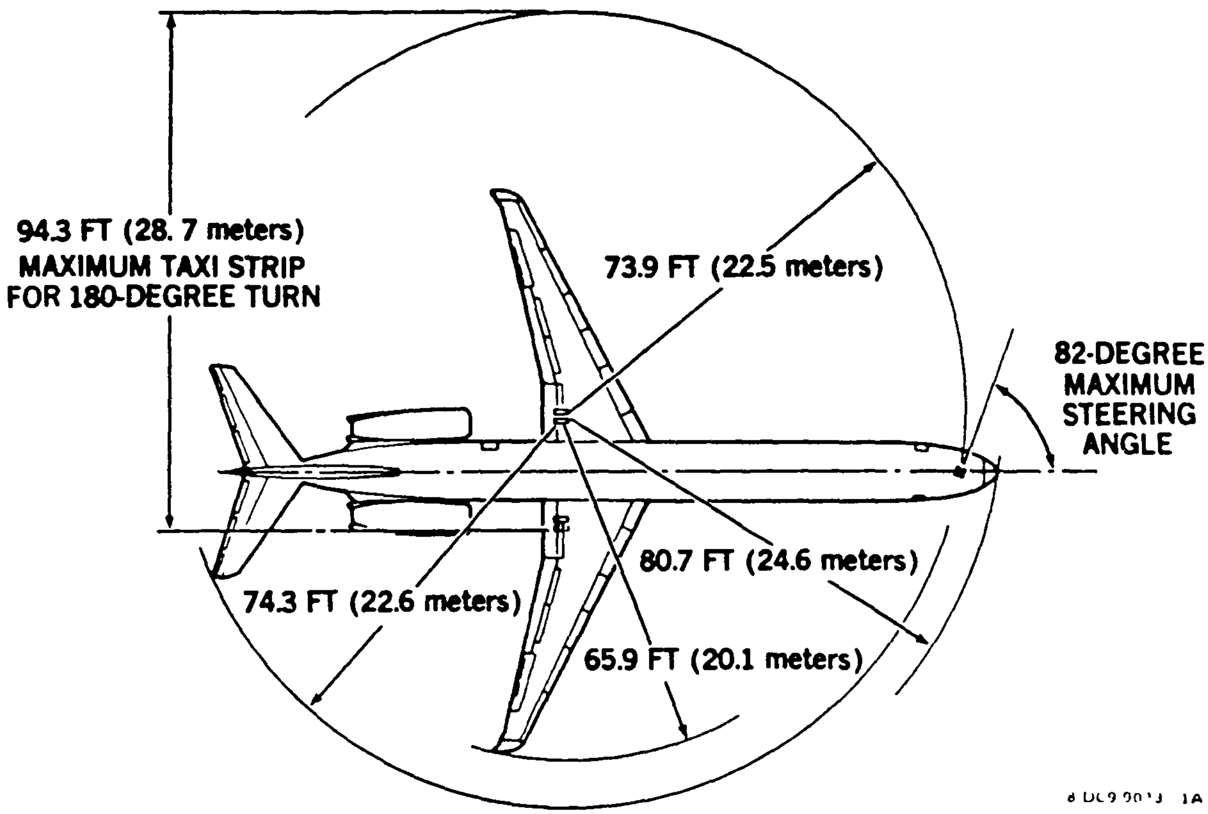


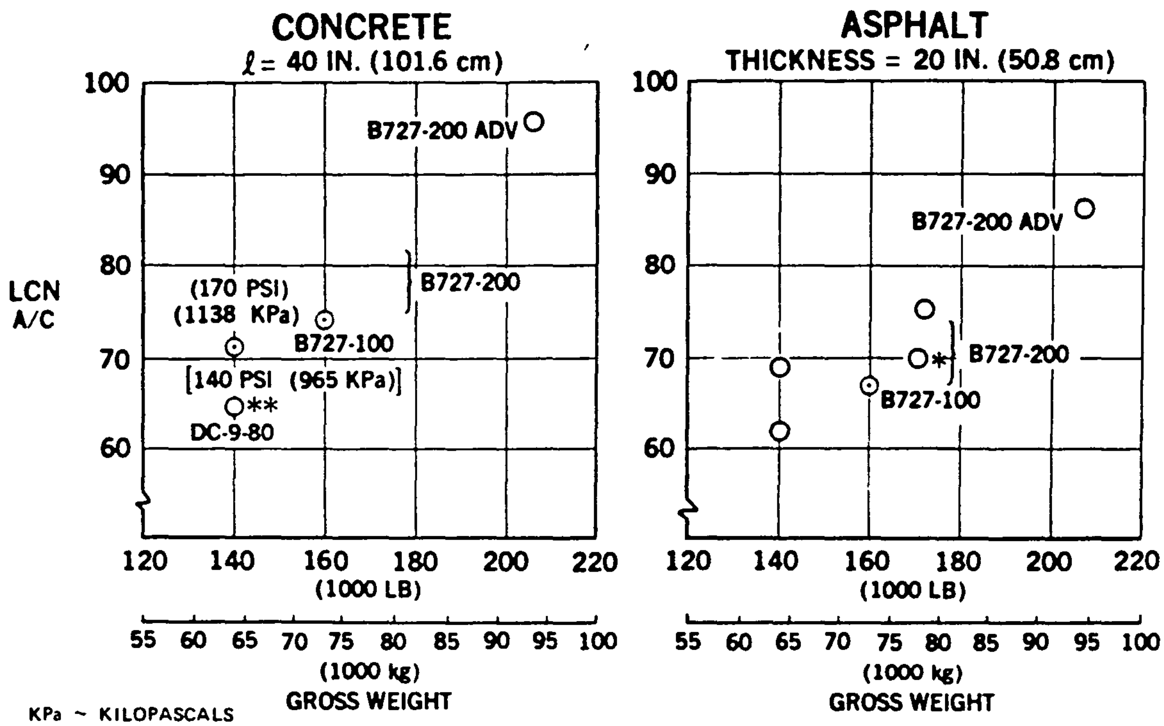
FIGURE C-35. DC-9 SUPER 80 TURNING RADII

DC-9 SUPER 80	DC 9 30	DC 9 50	DC 9 SUPER 80			
MAX TAKEOFF WEIGHT (POUNDS)	108,000	121,000	140,000		147,000	
MAX LANDING WEIGHT (POUNDS)	99,000	110,000	128,000		128,000	
WING LANDING GEAR TIRE SIZE	40x14 16	41x15-18	H44 5x16 5-20		H44 5x16 5 20	
TWIN SPACING (INCHES)	25	26	28 125		28 125	
TIRE PRESSURE (PSI)	154	170	140*	170	150*	180
TIRE CONTACT AREA (SQ IN)	165	164	230	189	188	169
CONCRETE THICKNESS REQUIRED~PCA (INCHES) ~ PDILB (T=400 PSI, K=300 PGI)	9 9	10 6	11 0	11 3	11 6	11 8
RIGID LCN (L = 40 INCHES)	56	65	65	72	78	82
FLEXIBLE LCN (h = 20 INCHES)	52	61	60	67	72	76
FLEXIBLE THICKNESS (INCHES) ~ SEFL 165A						
CBR 10	20 5	21 8	23 2	23 4	24 2	24 2
CBR 15	15 2	16 3	17.2	17.5	18 1	18 3

*OPTIONAL

7 DC 9 92787 1

FIGURE C-36. COMPARATIVE LANDING GEAR CHARACTERISTICS
AND AIRFIELD PAVEMENT REQUIREMENTS



KPa ~ KILOPASCALS
*OPTIONAL TIRE
**OPTIONAL TIRE PRESSURE -

FIGURE C-37. PAVEMENT LOAD CLASSIFICATION NUMBER (LCN) REQUIREMENTS

REFERENCES FOR APPENDIX C

C-1. McDonnell Douglas DC-9 Super 80 Features. Brochure, August 1979

C-2. DC-9 Super 80 Technology. Brochure.

C-3. DC-9 Derivatives and Improvements. Brochure, April 1980.

C-4. McDonnell Douglas DC-9 Super 80 Design Features. Brochure, January 1981.

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NASA CR-166138		
4 Title and Subtitle A Study to Define the Research and Technology Requirements for Advanced Turbo/Propfan Transport Aircraft.		5. Report Date February 1981 6. Performing Organization Code
7. Author(s) I. M. Goldsmith		8. Performing Organization Report No ACEE-16-FR-0016 10. Work Unit No
9 Performing Organization Name and Address Douglas Aircraft Company 3855 Lakewood Blvd. Long Beach, California 90846		11. Contract or Grant No NAS2-10178 13. Type of Report and Period Covered Contractor Final Report
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15. Supplementary Notes
Technical Monitor: Jeffrey V. Bowles/237-11
NASA Research Center
Moffett Field, California 94035 (415) 965-5673 or FTS 448-5673

16 Abstract

This report summarizes the feasibility of the propfan relative to the turbofan using the Douglas DC-9 Super 80 (DS-8000) as the actual operational base aircraft. The propfan propulsion system assumes an Allison PD370-22A scaled turboshaft engine and an eight blade, 800 ft/sec (244 m/sec) tip speed propfan as defined in the Hamilton Standard Data Package. This broad brush study considers the 155 passenger economy class aircraft (31,775 lb [14,413 kg] payload), M_{cruise} at 0.80 at 31,000 ft (8,450 m) initial altitude, and an operational capability in 1985. Three propfan arrangements, wing mounted, conventional horizontal tail aft mounted, and aft fuselage pylon mounted are selected for comparison with the DC-9 Super 80 P&WA JT8D-209 turbofan-powered aircraft.

The technical evaluation considers the configuration feasibility, aerodynamics, propulsion, structural loads, structural dynamics, sonic fatigue, acoustics, weights, maintainability, performance, rough order of magnitude economics, and airline coordination. The propfan performance results, evaluated relative to the base case DC-9 Super 80 turbofan, show the propfan aircraft to be feasible and competitive, as well as providing at least 26 percent savings in cruise fuel, a reduction in far field noise levels, and an 8 percent reduction in direct operating costs.

Sensitivity studies consider the effects of alternate cruise Mach number, mission stage lengths, and propfan design characteristics. Recommendations for further study, ground testing, and flight testing are included.

17 Key Words (Suggested by Author(s))	18. Distribution Statement
DC-9-80 Propfan Aircraft Performance Propfan Parametric Effects Cost; Noise;	Unclassified - Unlimited

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