NASA CR-137923

(NASA-CR-137923) COST/BENEFIT TRADEOFFS FOR REDUCING THE ENERGY CONSUMPTION OF THE COMMERCIAL AIR TRANSPORTATION SYSTEM. VOLUME 1: TECHNICAL ANALYSIS Final Report (Douglas Aircraft Co., Inc.) 289 p

N77-23072

HC A13/MF A01

Unclas

G3/03 30480

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

FINAL REPORT

VOLUME I: TECHNICAL ANALYSIS

JUNE 1976

Prepared Under Contract NAS2-8618
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER

DOUGLAS AIRCRAFT COMPANY
MCDONNELL DOUGLAS CORPORATION
Long Beach, California

PREFACE

This report was prepared by the Douglas Aircraft Company, McDonnell Douglas Corporation, under NASA Contract NAS2-8618 for a study of the "Cost/Benefit Tradeoffs for Reducing the Energy Consumption of the Commercial Air Transportation System." The study, hereafter referred to as the RECAT Study (Reduced Energy for Commercial Air Transportation), was performed from November 5, 1974 to June 30, 1976.

The NASA Technical Monitor for the RECAT Study was Louis J. Williams, Research Aircraft Technology Office, Ames Research Center, Moffett Field, California.

The Douglas Study Team consisted of Emmett F. Kraus, responsible for Technical Analyses, assisted by Melvin A. Sousa, responsible for Turboprop Aircraft Analysis; and June C. Van Abkoude, responsible for Market and Economic Analyses, assisted by Clayton R. Sturdevant.

Appreciation for their cooperation and contribution is extended to the RECAT Study co-contractors: Lockheed-California Company, United Airlines and United Technologies Research Center. Appreciation is also extended to the Hamilton Standard Division of United Technologies Corporation for assistance in preparation of propfan propulsion data.

TABLE OF CONTENTS

	Page
PREFACE	ii
LIST OF FIGURES	vii
LIST OF TABLES	xiii
SYMBOLS AND ABBREVIATIONS	xviii
SUMMARY	1
INTRODUCTION	5
1.0 DOMESTIC FLEET BASELINE AIRCRAFT	7
1.1 Baseline Aircraft	7
2.0 ALTERNATIVE OPERATING PROCEDURES	38
2.1 Flight Operations	38
2.1.1 Climb and Descent Profiles	38
2.1.2 Cruise Altitude	39
2.1.3 Cruise Speed	40
2.1.4 Navigation	42
2.1.5 Holding	43
2.1.6 Reserves, Contingencies, and Tankering	43
2.2 Airline Operations	44
2.2.1 Seating Density and Load Factor	44
2.2.2 Maintenance	44
2.2.3 Loading	44
2.2.4 Flight Planning	45
2.2.5 Ground Maneuver and Delays	45
2.2.6 Takeoff and Landing	46
2.3 Operating Procedures Selected for Study	46

Page

3.0 TECHNOLOGY 53

3.1 Advanced Technology 53

3.1.1 Improved Transonic Airfoils 53

3.1.2 Winglet Drag Reduction 55

3.1.3 Active Controls 57

3.1.4 Advanced Material Applications 58

3.1.5 Carbon Brakes 61

3.1.6 Propulsive Noise Reduction 61

3.2 State-of-the-Art Technology 61

3.2.1 Fairings, Gaps, Steps 62

3.2.2 Extended Wing Tips 62

3.2.3 Cutback Pylons 64

3.2.4 General Weight Reduction 64

4.0 MODIFICATION AND DERIVATIVE STUDIES 66

4.1 Sensitivity Studies 66

4.2 Modification and Derivative Configurations 66

5.0 NEW NEAR-TERM AIRCRAFT 125

5.1 Design Specifications and Ground Rules 126

5.1.1 Interior Arrangements 126

5.2 Design Procedures 134

5.3 N80-2.15 Series Aircraft 139

5.3.1 Configuration Trade Studies 139

5.3.2 Optimum Design Characteristics 139

5.3.3 Optimum Geometry 140

5.3.4 Energy Efficiency 140

5.4 N80-2.30 Series Aircraft 156

5.4.1 Configuration Trade Studies 156

5.4.2 Optimum Design Characteristics and Geometry . . 156

5.4.3 Energy Efficiency 157

		Page
5.5	N80-2.55 Series Aircraft	173
	5.5.1 Configuration Trade Studies	173
	5.5.2 Optimum Design Characteristics	173
	5.5.3 Energy Efficiency	173
5.6	N80-4.30 Series Aircraft	182
	5.6.1 Configuration Trade Studies	182
	5.6.2 Optimum Design Characteristics	182
	5.6.3 Energy Efficiency	182
5.7	N80-4.55 Series Aircraft	192
	5.7.1 Configuration Trade Studies	192
	5.7.2 Optimum Design Characteristics	192
	5.7.3 Energy Efficiency	192
5.8	Comparison of New Near-Term Aircraft	201
	5.8.1 Fuel Savings Comparison	201
	5.8.2 Effect of Fuel Price on N80 Designs	202
	5.8.3 Payload-Range Capability	203
5.9	Acoustical Analysis	215
	5.9.1 Nacelle Configuration Definition	215
	5.9.2 Noise Analysis Procedure	215
	5.9.3 FAR Part 36 Noise Level Estimates	216
	5.9.4 EPNL vs Distance and Noise Contours	216
6.0	TURBOPROP CONFIGURATION STUDIES	232
6.1	Advanced Turboprop Propulsion	232
6.2	Configuration Studies	235
6.3	Aircraft Weights	238
6.4	Mission Profile and Performance Assumptions	244
6.5	Payload-Range Comparisons	246
6.6	Block Fuel Comparisons	246
6.7	Effect of Improved Propulsive Efficiency	251

Page

7.0 CONCLUSIONS AND RECOMMENDATIONS 257
7.1 Technology Conclusions 257
7.2 Research and Technology Recommendations 262

8.0 REFERENCES 264

LIST OF FIGURES

Figure		Page
1	DC-8 Genealogy	9
2	DC-9 Genealogy	10
3	DC-10 Genealogy	11
4	Baseline Mission Profile - Domestic	15
5	DC-8-20 and DC-8-50 General Airplane Dimensions	16
6	DC-8-61 General Airplane Dimensions	17
7	DC-9-10 General Airplane Dimensions	18
8	DC-9-30 General Airplane Dimensions	19
9	DC-10-10 General Airplane Dimensions	20
10	DC-10-40 General Airplane Dimensions	21
11	DC-8-20 and DC-8-50 Baseline Interior Arrangement	22
12	DC-8-61 Baseline Interior Arrangement	23
13	DC-9-10 Baseline Interior Arrangement	24
14	DC-9-30 Baseline Interior Arrangement	25
15	DC-10-10 Baseline Interior Arrangement	26
16	DC-10-40 Baseline Interior Arrangement	27
17	Baseline Aircraft Payload-Range Comparison	29
18	Baseline Aircraft Fuel Efficiency Comparison	37
19	Long-Range and High-Speed Climb and Descent Schedules	39
20	Range Increment due to Slowdown from 0.85M	41
21	Fuel Saved by Fuel-Conservative Operations	52
22	Drag Divergence Mach Number Variation with Airfoil Thickness Ratio	54
23	Comparison of 2-D Airfoil Section Characteristics	56

LIST OF FIGURES (cont'd)

Figure		Page
24	Local Mach Number on Upper Surface at Cruise Conditions	56
25	Representative Winglet Performance Summary for DC-10-30 Airplane	59
26	Structural Arrangement for Graphite-Epoxy Rudder . . .	59
27	DC-10 Isogrid Window Belt	60
28	Tail Fillets	63
29	Wing Leading Edge Fillet	63
30	Spoiler Trailing Edge Step	65
31	Comparison of Original and Cutback DC-8 Pylons	65
32	Average Modification Sensitivity Factors	71
33	Fuel-Conservative DC-8 Retrofit Study Items	73
34	Fuel-Conservative DC-9 Study Items	74
35	Fuel-Conservative DC-10 Study Items	75
36	Payload-Range Comparison for DC-8-20 Models	89
37	Payload-Range Comparison for DC-8-50 Models	90
38	Payload-Range Comparison for DC-8-61 Models	91
39	Payload-Range Comparison for DC-9-10 Models	92
40	Payload-Range Comparison for DC-9-30 Models	93
41	Payload-Range Comparison for DC-10-10 Models	94
42	Payload-Range Comparison for DC-10-40 Models	95
43	Block Fuel vs. Range for Modified DC-8 Aircraft	116
44	Block Fuel vs. Range for Modified DC-9-10 Aircraft . .	117
45	Block Fuel vs. Range for Modified and Derivative DC-9-30 Aircraft	118

LIST OF FIGURES (cont'd)

Figure		Page
46	Block Fuel vs. Range for Modified and Derivative DC-10-10 Aircraft	119
47	Block Fuel vs. Range for Modified and Derivative DC-10-40 Aircraft	120
48	Modified Aircraft Fuel Savings	123
49	Derivative Aircraft Fuel Savings	124
50	New Near-Term Aircraft Designator Code	125
51	Mission Profile for New Near-Term Aircraft	129
52	Advanced Technologies for New Near-Term Aircraft	130
53	Interior Arrangement for N80-2.15, N80-2.30, and N80-2.55	131
54	Interior Arrangement for N80-4.30 and N80-4.55	132
55	PASAP Sizing Grid	136
56	Sizing Procedure	138
57	N80-2.15$_{15}$ Optimum Aircraft Geometry and Relative DOC vs. Cruise Mach Number	141
58	N80-2.15$_{30}$ Optimum Aircraft Geometry and Relative DOC vs. Cruise Mach Number	142
59	N80-2.15$_{60}$ Optimum Aircraft Geometry and Relative DOC vs. Cruise Mach Number	143
60	Relative DOC vs. Cruise Mach Number and Fuel Price for Optimum Geometry N80-2.15 Aircraft	144
61	N80-2.15$_{MF}$ Optimum Aircraft Geometry and Relative Fuel Use vs. Cruise Mach Number	145
62	Effect of Wing Aspect Ratio on N80-2.15$_{MF}$ Block Fuel . .	146
63	Plan Views of Optimized N80-2.15 Aircraft	147
64	Effect of Fuel Price on N80-2.15 Optimum Aircraft Geometry and Cruise Mach Number	151

LIST OF FIGURES (cont'd)

Figure		Page
65	Block Time and Block Fuel vs. Range - Optimum N80-2.15 Aircraft	152
66	Energy Efficiency Parameters vs. Range - Optimum N80-2.15 Aircraft	153
67	N80-2.30$_{15}$ Optimum Aircraft Geometry and Relative DOC vs. Cruise Mach Number	158
68	N80-2.30$_{30}$ Optimum Aircraft Geometry and Relative DOC vs. Cruise Mach Number	159
69	N80-2.30$_{60}$ Optimum Aircraft Geometry and Relative DOC vs. Cruise Mach Number	160
70	Relative DOC vs. Cruise Mach Number and Fuel Price for Optimum Geometry N80-2.30 Aircraft	161
71	Effect of Design Cruise Mach Number on DOC	162
72	N80-2.30$_{MF}$ Optimum Aircraft Geometry and Relative Fuel Use vs. Cruise Mach Number	163
73	Plan Views of Optimized N80-2.30 Aircraft	164
74	Effect of Fuel Price on N80-2.30 Optimum Aircraft Geometry and Cruise Mach Number	168
75	Block Time and Block Fuel vs. Range - Optimum N80-2.30 Aircraft	169
76	Energy Efficiency Parameters vs. Range - Optimum N80-2.30 Aircraft	170
77	Plan Views of Optimized N80-2.55 Aircraft	174
78	Block Time and Block Fuel vs. Range - Optimum N80-2.55 Aircraft	178
79	Energy Efficiency Parameters vs. Range - Optimum N80-2.55 Aircraft	179
80	Effect of Fuel Price on N80-4.30 Optimum Aircraft Geometry and Cruise Mach Number	183
81	Plan Views of Optimized N80-4.30 Aircraft	184

LIST OF FIGURES (cont'd)

Figure		Page
82	Block Time and Block Fuel vs. Range - Optimum N80-4.30 Aircraft	188
83	Energy Efficiency Parameters vs. Range - Optimum N80-4.30 Aircraft	189
84	Plan Views of Optimized N80-4.55 Aircraft	193
85	Block Time and Block Fuel vs. Range - Optimum N80-4.55 Aircraft	197
86	Energy Efficiency Parameters vs. Range - Optimum N80-4.55 Aircraft	198
87	Energy Efficiency Parameters at Design Range for Optimum N80 Aircraft	204
88	Effect of Design Fuel Price on Fuel Use	205
89	Effect of Design Cruise Mach Number and Design Fuel Price on Fuel Use	206
90	N80 Block Fuel vs. Design Range	207
91	New Near-Term Aircraft Fuel Savings	208
92	New Near-Term Aircraft Cruise Mach Number Comparison	209
93	New Near-Term Aircraft Aspect Ratio Comparison	210
94	New Near-Term Aircraft Wing Span Comparison	211
95	Effect of Wing Aspect Ratio on DOC	212
96	Payload-Range Envelopes for Domestic Range N80 Aircraft	213
97	Payload-Range Envelopes for International Range N80 Aircraft	214
98	EPNL Map for $N80\text{-}2.15_{15}$ Aircraft	219
99	EPNL Map for $N80\text{-}2.15_{MF}$ Aircraft	220
100	EPNL Map for $N80\text{-}2.30_{15}$ Aircraft	221
101	EPNL Map for $N80\text{-}2.30_{MF}$ Aircraft	222
102	EPNL Map for $N80\text{-}4.30_{15}$ Aircraft	223

LIST OF FIGURES (cont'd)

Figure		Page
103	EPNL Map for N80-4.30$_{MF}$ Aircraft	224
104	Estimated Noise Contours for N80-2.15$_{15}$ Aircraft	225
105	Estimated Noise Contours for N80-2.15$_{MF}$ Aircraft	226
106	Estimated Noise Contours for N80-2.30$_{15}$ Aircraft	227
107	Estimated Noise Contours for N80-2.30$_{MF}$ Aircraft	228
108	Estimated Noise Contours for N80-4.30$_{15}$ Aircraft	229
109	Estimated Noise Contours for N80-4.30$_{MF}$ Aircraft	230
110	EPNL Contour Area Comparison for Aircraft Configurations with Optimization Parameters of Minimum DOC @ 15¢/Gallon and Minimum Fuel	231
111	Thrust vs. Mach Number for Propfans and Turbofans	234
112	General Configuration, DC-9-30D5 Propfan	236
113	DC-9-30D6 Propfan, Wing and Tail Configurations	237
114	Interior Arrangement, DC-9-30D5 and DC-9-30D6 Propfans . .	239
115	Alternate DC-9-30 Propfan Nacelle Configurations with Main Gear Stowed in Nacelle	240
116	DC-9-30 Propfan Nacelle Configuration with Main Gear Stowed in Fuselage	241
117	Turboshaft Engine Power-to-Weight Ratio vs. Shaft Horsepower	245
118	Propfan Payload-Range Comparisons	247
119	Block Fuel Comparison of DC-9-30 Turbofan, Propfan and SCW Derivatives - 30,000 ft Cruise Altitude	248
120	Block Fuel Comparison of DC-9-30 Turbofan, Propfan and SCW Derivatives - 15,000 ft Cruise Altitude	249
121	Comparison of Block Fuel Savings	250
122	Effect of TSFC on Propfan Payload - Range Envelope	254
123	Effect of TSFC on Propfan Fuel Savings	255

LIST OF TABLES

Table No.		Page
1	Units Conversion Table	6
2	DC Jets in U.S. Domestic Passenger Service	12
3	Baseline Aircraft Characteristics	13
4	Direct Operating Cost Assumptions	14
5	Technical Ground Rules	14
6	Passenger Convenience Data	28
7	DC-8-20 Baseline Flight Profile Data - Fuel Use vs. Distance	30
8	DC-8-50 Baseline Flight Profile Data Fuel Use vs. Distance	31
9	DC-8-61 Baseline Flight Profile Data - Fuel Use vs. Distance	32
10	DC-9-10 Baseline Flight Profile Data - Fuel Use vs. Distance	33
11	DC-9-30 Baseline Flight Profile Data - Fuel Use vs. Distance	34
12	DC-10-10 Baseline Flight Profile Data - Fuel Use vs. Distance	35
13	DC-10-40 Baseline Flight Profile Data - Fuel Use vs. Distance	36
14	Operational Variations	47
15	Effect of Fuel-Conservative Flight Operations on Block Fuel and DOC at 1973 CAB Average Stage Length	48
16	Baseline and High Density Seating Capacities	49
17	Effect of Fuel-Conservative Airline Operations on Block Fuel and DOC at 1973 CAB Average Stage Length	50
18	Modification Sensitivities	70

LIST OF TABLES (cont'd)

Table No.		Page
19	Design Changes for Retrofit, Production Modified, and Derivative Aircraft	72
20	Weight Change Summary - DC-8-20 and DC-8-50 Retrofit Aircraft	76
21	Weight Change Summary - DC-8-61 Retrofit Aircraft	77
22	Weight Change Summary - DC-9 and DC-10 Retrofit Aircraft	78
23	Weight Change Summary - DC-10-10 and DC-10-40 Production Modifications	79
24	Weight Change Summary - DC-9 Derivatives	80
25	General Weight Reduction Summary for DC-9 Derivatives	81
26	Composite Secondary Structure Weight Reduction Summary for DC-9 Derivatives	81
27	Weight Change Summary - DC-10 Derivatives	82
28	Low-Risk Composite Secondary Structure Weight Savings	83
29	Composite Secondary Structure Weight Savings	84
30a	Modified and Derivative Aircraft Characteristics	85
30b	Modified and Derivative Aircraft Characteristics	86
30c	Modified and Derivative Aircraft Characteristics	87
30d	Modified and Derivative Aircraft Characteristics	88
31	DC-8-20R - Fuel Use vs. Distance	96
32	DC-8-20DR - Fuel Use vs. Distance	97
33	DC-8-20ER - Fuel Use vs. Distance	98
34	DC-8-50R - Fuel Use vs. Distance	99
35	DC-8-50DR - Fuel Use vs. Distance	100
36	DC-8-50ER - Fuel Use vs. Distance	101

LIST OF TABLES (cont'd)

Table No.		Page
37	DC-8-61R - Fuel Use vs. Distance	102
38	DC-8-61DR - Fuel Use vs. Distance	103
39	DC-8-61ER - Fuel Use vs. Distance	104
40	DC-9-10R - Fuel Use vs. Distance	105
41	DC-9-30R - Fuel Use vs. Distance	106
42	DC-10-10R - Fuel Use vs. Distance	107
43	DC-10-40R - Fuel Use vs. Distance	108
44	DC-10-10M - Fuel Use vs. Distance	109
45	DC-10-40M - Fuel Use vs. Distance	110
46	DC-9-30D1 - Fuel Use vs. Distance	111
47	DC-9-30D2 - Fuel Use vs. Distance	112
48	DC-9-30D3 - Fuel Use vs. Distance	113
49	DC-10-10D - Fuel Use vs. Distance	114
50	DC-10-40D - Fuel Use vs. Distance	115
51	Effect of Modifications and Derivative Designs on Block Fuel and DOC at 1973 CAB Average Stage Length	121
52	Effect of Individual Modification Items on Block Fuel at 1973 CAB Average State Length	122
53	NASA Design Study Ground Rules	127
54	New Airplane Specifications	128
55	Passenger Convenience Data	133
56	Sizing Constraints	137
57	Optimum N80-2.15 Aircraft Characteristics	148
58	N80-2.15 Design Data	149
59	N80-2.15 Weight Data	150

LIST OF TABLES (cont'd)

Table No.		Page
60	Block Time and Block Fuel vs. Distance - Optimum N80-2.15 Aircraft	154
61	Energy Efficiency Parameters vs. Distance - Optimum N80-2.15 Aircraft	155
62	Optimum N80-2.30 Aircraft Characteristics	165
63	N80-2.30 Design Data	166
64	N80-2.30 Weight Data	167
65	Block Time and Block Fuel vs. Distance - Optimum N80-2.30 Aircraft	171
66	Energy Efficiency Parameters vs. Distance - Optimum N80-2.30 Aircraft	172
67	Optimum N80-2.55 Aircraft Characteristics	175
68	N80-2.55 Design Data	176
69	N80-2.55 Weight Data	177
70	Block Time and Block Fuel vs. Distance - Optimum N80-2.55 Aircraft	180
71	Energy Efficiency Parameters vs. Distance - Optimum N80-2.55 Aircraft	181
72	Optimum N80-4.30 Aircraft Characteristics	185
73	N80-4.30 Design Data	186
74	N80-4.30 Weight Data	187
75	Block Time and Block Fuel vs. Distance - Optimum N80-4.30 Aircraft	190
76	Energy Efficiency Parameters vs. Distance - Optimum N80-4.30 Aircraft	191
77	Optimum N80-4.55 Aircraft Characteristics	194
78	N80-4.55 Design Data	195
79	N80-4.55 Weight Data	196

LIST OF TABLES (cont'd)

Table No.		Page
80	Block Time and Block Fuel vs. Distance - Optimum N80-4.55 Aircraft	199
81	Energy Efficiency Parameters vs. Distance - Optimum N80-4.55 Aircraft	200
82	Noise Levels of Optimized N80 Aircraft	218
83	Geometric and Weight Data	242
84	Specific Range for Flight with 15,000 Ft Cruise Altitude	252
85	Specific Range for Flight with 30,000 Ft Cruise Altitude	253
86	Fuel Savings Summary - U.S. Domestic Fleet	258

SYMBOLS AND ABBREVIATIONS

Alt	Altitude
APPROX	Approximately
ASNM	Available Seat-Nautical Miles
Assy	Assembly
ATA	Air Transport Association
ATC	Air Traffic Control
BTU	British Thermal Unit
c	Chord Length
CAB	Civil Aeronautics Board
c/4	Quarter Chord Location
Δc_d	Compressibility Drag Coefficient
CG	Center of Gravity
c_ℓ	Two-Dimensional Lift Coefficient
cm	Centimeters
c_p	Pressure Coefficient
Coeff	Coefficient
CW	Conventional Wing
D	Diameter
DAC	Douglas Aircraft Company
db	Decibels
Deg	Degrees
DOC	Direct Operating Cost
DOC_1	Level 1 of Constant DOC

DOC_2	Level 2 of Constant DOC
DOC_3	Level 3 of Constant DOC
DOC_{15}	Optimization Parameter: Minimum DOC @ 15 Cents per Gallon Fuel
DOC_{30}	Optimization Parameter: Minimum DOC @ 30 Cents per Gallon Fuel
DOC_{60}	Optimization Parameter: Minimum DOC @ 60 Cents per Gallon Fuel
DSMA	Douglas Santa Monica Airfoil
δ	Pressure Ratio
Δ	Incremental Parameter Change
Elev	Elevator
EMER	Emergency
Eng	Engine
EPNdB	Unit of Effective Perceived Noise Level
EPNL	Effective Perceived Noise Level, EPNdB
ESHP	Equivalent Shaft Horsepower
FAA	Federal Aviation Administration
FAR	Federal Air Regulation
FB_1	Level 1 of Constant Fuel Burned
FB_2	Level 2 of Constant Fuel Burned
FB_3	Level 3 of Constant Fuel Burned
F_N	Net Thrust per Engine
fps	Feet per Second
ft	Feet
4-D RNAV	Four-Dimensional Area Navigation

GAL	Gallons
GAW	General Aviation Wing
GE	General Electric Company
GLA	Gust Load Alleviation
Horiz	Horizontal
HP	Horsepower
hr	Hour
in	Inches
JFK	Kennedy International Airport (New York)
KEAS	Knots Equivalent Air Speed
kg	Kilograms
kt	Knots
LAV	Lavatory
lb	Pounds
LBM	Mass in Pounds
L/D	Lift-to-Drag Ratio
LDW	Landing Weight
L.F.	Load Factor
LH	Left Hand
m	Meters
M	Mach Number
M_{DIV}	Drag Divergence Mach Number
M_{LOCAL}	Local Mach Number
MAX	Maximum

MF	Optimization Parameter: Minimum Fuel
Mi	Statute Miles
MIN	Minimum
min	Minutes
MLA	Maneuver Load Alleviation
MLG	Main Landing Gear
NASA	National Aeronautics and Space Administration
NM	Nautical Miles
No.	Number
N80	New Near-Term Aircraft: NASA Specification, 1980 Introduction Date
OASPL	Overall Sound Pressure Level
OEW	Operational Empty Weight
PASAP	Passenger Aircraft Sizing and Performance Program
PSGR	Passengers
PNL	Perceived Noise Level
PNLM	Peak Perceived Noise Level
PROP	Propeller
psf	Pounds per Square Foot
P&WA	Pratt and Whitney Aircraft
rad	Radians
RECAT	Reduced Energy for Commercial Air Transportation
RH	Right Hand
RNAV	Area Navigation
RPNM	Revenue Passenger Nautical Miles
RSS	Reduced Static Stability

SCW	Supercritical Wing
SFC	Specific Fuel Consumption
SHP	Shaft Horsepower
SL	Sea Level
SLS	Sea Level Static
Sq	Square
Stab	Stabilizer
STD	Standard
S_W	Wing Area
T	Thrust
TAS	True Air Speed
TF	Turbofan
TOGW	Takeoff Gross Weight
TP	Turboprop
TSFC	Thrust Specific Fuel Consumption
USTEDLEC	Study of Unconventional Aircraft Engines Designed for Low Energy Consumption
V_E	Equivalent Air Speed
Vert	Vertical
VOR	Very High Frequency Omni-Directional Radio
VOR-DME	VOR with Distance Measuring Equipment
X	Distance along Chord from Airfoil Leading Edge

SUMMARY

The purpose of this study was to examine and compare the effectiveness and associated costs of operational and technical options for reducing the fuel consumption of the U.S. commercial airline fleet. The study examined the time period from 1973 to 1990, and was divided into three parts.

Part I, the primary study, investigated the means for reducing the jet fuel consumption of the U.S. scheduled airlines in domestic passenger operations. Part II concentrated on the design and examination of two turboprop aircraft as possible fuel conserving derivatives of the DC-9-30. Part III extended the primary study in Part I to include the international operations of the U.S. scheduled carriers.

The Part I domestic fleet study began with the selection of representative Douglas jet transports in the domestic fleet. For these baseline aircraft, consistent fuel use and cost statistics were determined for standard, high speed flight profiles. Next the effects of operational variations from the baseline flight profile were considered for each aircraft. These variations included alternative flight operations, involving both navigational and aircraft management procedures, as well as alternative ground operations. The operational procedures were further divided into those that could be implemented without a significant change in the current air traffic control (ATC) system, and those that would require ATC changes.

Following the study of operational procedures, possible aircraft retrofit modifications for existing fleet aircraft were examined, including new engines, winglets, and general drag reduction items. More extensive production modifications for the DC-10 were also examined. These included winglets, general drag reduction items, and general weight reduction items including composite secondary structure.

Next, derivative versions of in-production Douglas airplanes were considered. These included a DC-9 with an all new supercritical wing, stretched versions of the DC-9 and DC-10, and a shortened, twin-engine derivative of the DC-10.

Finally, three families of new near-term domestic range aircraft were designed, based on 1976 technology with a 1980 target introduction date.

The families were defined by their range and payload capability: 1,500 nautical miles with 200 passengers; 3,000 nautical miles with 200 passengers; and 3,000 nautical miles with 400 passengers. Within each family, the airplanes were optimized for minimum direct operating cost (DOC) at three fuel prices of 15, 30, and 60 cents per gallon and for minimum fuel consumption.

Examination of the possibilities for reducing fuel consumption by means of operational changes, retrofit and production modifications, derivative aircraft, and new near-term aircraft led to the specification of 46 aircraft operational and design options for consideration in the domestic market.

The Part II turboprop study involved the examination of new Hamilton Standard propfans for the DC-9-30. Conventional wing-mounted engine locations were considered. Both the existing wing and an all new, high aspect ratio, supercritical wing were examined in conjunction with the turboprop.

In Part III, the domestic study results were extended to the aircraft in the international fleets of U.S. air carriers. A total of 13 baseline aircraft were examined, including Douglas, Lockheed, and Boeing airplanes in the international fleet. Fuel characteristics for derivative versions of several in-production aircraft were estimated.

Two families of new near-term international range aircraft were designed, again based on 1976 technology with a 1980 target introduction date. The payload-range requirements were 200 passengers at 5,500 nautical miles and 400 passengers at 5,500 nautical miles. Optimum aircraft were derived in both families for minimum DOC at 30 and 60 cents per gallon and for minimum fuel use.

In the domestic fleet, individual operational improvements offer seat-mile fuel savings of 4 to 13 percent over the baseline operation. Combinations of fuel-saving operations are possible in the far term which together give fuel savings as high as 30.5 percent. This high figure requires an advanced ATC system, an increase in average load factor from 58 to 65 percent, and high seating density. The near-term potential for fuel savings through operational improvements is approximately 6 percent, relative to the baseline operation, primarily due to reductions in cruise speed.

The fuel savings that result from study retrofit and production modifications range from 4 percent for DC-9 retrofits with aerodynamic improvements, to 28 percent for the DC-8-20 Retrofit with a new turbofan engine and aerodynamic improvements. However, considering the limited number of DC-8 aircraft remaining in the fleet, aerodynamic modifications show more fleetwide potential for fuel savings than engine modifications. The overall near-term potential for fuel savings in the domestic fleet through design modifications is approximately 6 percent.

The derivative aircraft designs studied in Part I and Part III use from 3 to 28 percent less fuel per seat-mile than their baseline aircraft. The shortened DC-10-10 uses 3 percent less fuel per seat-mile than the baseline DC-10-10 and 19 percent less fuel per seat-mile than the baseline DC-8-61. The stretched DC-10-40 with aerodynamic and structural improvements uses 28 percent less fuel per seat-mile than the baseline DC-10-40.

The new near-term aircraft substantially reduce seat-mile fuel use, due to the incorporation of current technologies, higher design fuel prices, and larger seating capacities. The new aircraft are approximately 20 percent more fuel efficient than current narrow-body aircraft and 10 percent more fuel efficient than current wide-body aircraft.

The DC-9-30 derivative turboprops use 27 to 33 percent less fuel than the baseline DC-9-30 at the average stage length of 290 nautical miles. At 58 percent load factor, the maximum range capability is increased up to 73 percent.

INTRODUCTION

In Autumn 1973, when jet fuel prices began to increase rapidly and fuel availability was restricted, attention was focused on the air transport industry's need to increase efficiency and conserve fuel. In response, the airlines made immediate adjustments in schedules and operations, and government and industrial organizations pursued efforts to identify the most effective means to reduce present and future transport fuel requirements.

Preliminary studies indicated that changes in aircraft schedules and operations, together with the application of new technologies, could lead to possible fuel savings of over 50 percent (References 1-10). However, the solutions presented were often a mixture of near-term and far-term improvements, and the real costs and effectiveness of these fuel saving possibilities over time were unclear.

In November 1974, the NASA Ames Research Center contracted with the Douglas Aircraft Company (DAC), Lockheed-California Company, United Airlines, and United Technologies Research Center to study the relative costs and benefits associated with near-term solutions for Reducing the Energy consumed by domestic Commercial Air Transportation (RECAT Study). The study was structured to provide interaction between the contractors in order to determine realistic bounds for the domestic demand for jet fuel through 1990, as well as the costs associated with the operation of the alternative aircraft fleets leading to these bounds.

During the course of the study, interest also developed in a specific examination of advanced turboprop aircraft and also in the particular problems associated with fuel conservation in the international market. In November 1975, the Douglas Aircraft Company was authorized to study DC-9 derivative turboprop-powered aircraft, and to conduct a preliminary investigation of fuel conservation for passenger aircraft on the international routes of U.S. carriers.

Volume 1, Sections 1 through 5, of this report describes the results of the technical analysis of the Douglas Aircraft Company domestic and international fleet study. Technical information on the DC-9 derivative turboprop designs

PRECEDING PAGE BLANK NOT FILMED

is presented in Volume 1, Section 6. The economic and market analyses for the domestic and international fleet studies and for the advanced turboprop aircraft are discussed in Volume II.

This report contains U.S. Customary Units. Table 1 gives conversions to International System (SI) Units.

TABLE 1

UNITS CONVERSION TABLE

TO CONVERT	MULTIPLY BY
LINEAR:	
INCHES TO CENTIMETERS	2.54
FEET TO METERS	0.3048
NAUTICAL MILES TO KILOMETERS	1.852
AREA:	
$INCHES^2$ TO $CENTIMETERS^2$	6.452
$FEET^2$ TO $METERS^2$	0.0929
NAUTICAL $MILES^2$ TO $KILOMETERS^2$	3.430
VOLUME:	
$INCHES^3$ TO $CENTIMETERS^3$	16.39
$FEET^3$ TO $METERS^3$	0.0283
GALLONS TO LITERS	3.785
GALLONS TO $METERS^3$	3.785×10^{-3}
WEIGHT:	
POUNDS TO KILOGRAMS	0.4536

SECTION 1.0

DOMESTIC FLEET BASELINE AIRCRAFT

The domestic fleet study baseline year of 1973 was selected as representative of conditions before the energy crisis and the subsequent rapid rise of fuel prices. The study covers the period from 1973 to 1990. In the Douglas part of the RECAT Study, the domestic fleet of Douglas jet transports and the routes and passengers flown by Douglas jets were used to form the model for the overall U.S. fleet.

1.1 Baseline Aircraft

Passenger versions of Douglas turbojet and turbofan commercial transports used in the domestic fleet were chosen as baseline aircraft. These include aircraft from the following families: DC-8-20, DC-8-50, DC-8-60, DC-9-10, DC-9-30, DC-10-10, and DC-10-40. Figures 1 through 3 trace the genealogy of the DC-8, DC-9 and DC-10 aircraft. The total number of these aircraft in the fleets of domestic trunk and local service carriers, as of June 1974, is shown in Table 2 along with their average flight time and annual fuel use. Each aircraft family is comprised of several models. The most common model in domestic passenger service was chosen as the baseline aircraft for each family. The study baseline models and their characteristics are given in Table 3. The general characteristics of the airplanes are based on actual delivered aircraft. Weight adjustments were included to reflect both changes after delivery, as well as the new baseline interiors. The assumptions made in determining the baseline direct operating costs are given in Table 4. A more complete presentation of costs is presented in Volume II.

The technical ground rules and baseline flight operations profile for the study are given in Table 5 and Figure 4, respectively. These baseline operations were selected as representative of minimum DOC operations used by domestic carriers prior to the 1973 fuel price increases. Figures 5 through 10 show overall airplane dimensions; and interior arrangements are shown in Figures 11 through 16. The interiors shown do not directly correspond to current domestic airline interiors because of the seating density ground rules. The study interior arrangements are dual class interiors with approximately 10 percent first class seating and 90 percent coach seating.

Seat pitch is 38 inches for first class and 34 inches for coach. The aircraft in domestic commercial passenger service actually have fewer seats because of larger first class sections and/or larger seat pitch distances.

The 10/90 split between first class and coach seats and the 38/34-inch seat pitch standard were intended to allow comparison of aircraft using consistent cabin seating densities. Even so, exact comparisons between aircraft families are clouded because different seat widths and passenger conveniences, as shown in Table 6, imply different utilization of aircraft interior space. Consequently, the effects of scale and technology differences between aircraft families still remain slightly obscured.

Payload-range capabilities for the baseline airplanes, flying the baseline domestic flight profiles, are given in Figure 17. Tables 7 through 13 present fuel use parameters for the baseline airplanes at several ranges. Figure 18 shows the comparison of available seat-nautical miles per gallon for the baseline airplanes.

Tables 7 through 13 and the curves of Figure 18 are based on engineering handbook performance data. Consequently, they are representative of new aircraft on the idealized flight profile of Figure 4 in zero wind conditions. In practice, airlines actually experience greater air hold and ground delay times, clearances to non-optimum altitudes, winds, high temperatures, engine and airframe performance deterioration, and excess fuel loads. These factors, together with lower seating densities, lead to lower actual seat-mile fuel efficiency than indicated by handbook data. Fuel consumption reported by the airlines to the Civil Aeronautics Board (CAB), and published in Reference 11, is given for comparison in Figure 18 at the 1973 CAB average stage length for each aircraft. Actual aircraft fuel efficiency, in terms of seat-nautical miles per gallon, is a weighted average of 30.2 percent below the values derived for ideal conditions at the CAB average stage lengths. The weighted average is based on the CAB efficiency levels relative to ideal, given in Figure 18, and the annual fuel consumption for each aircraft, given in Table 2.

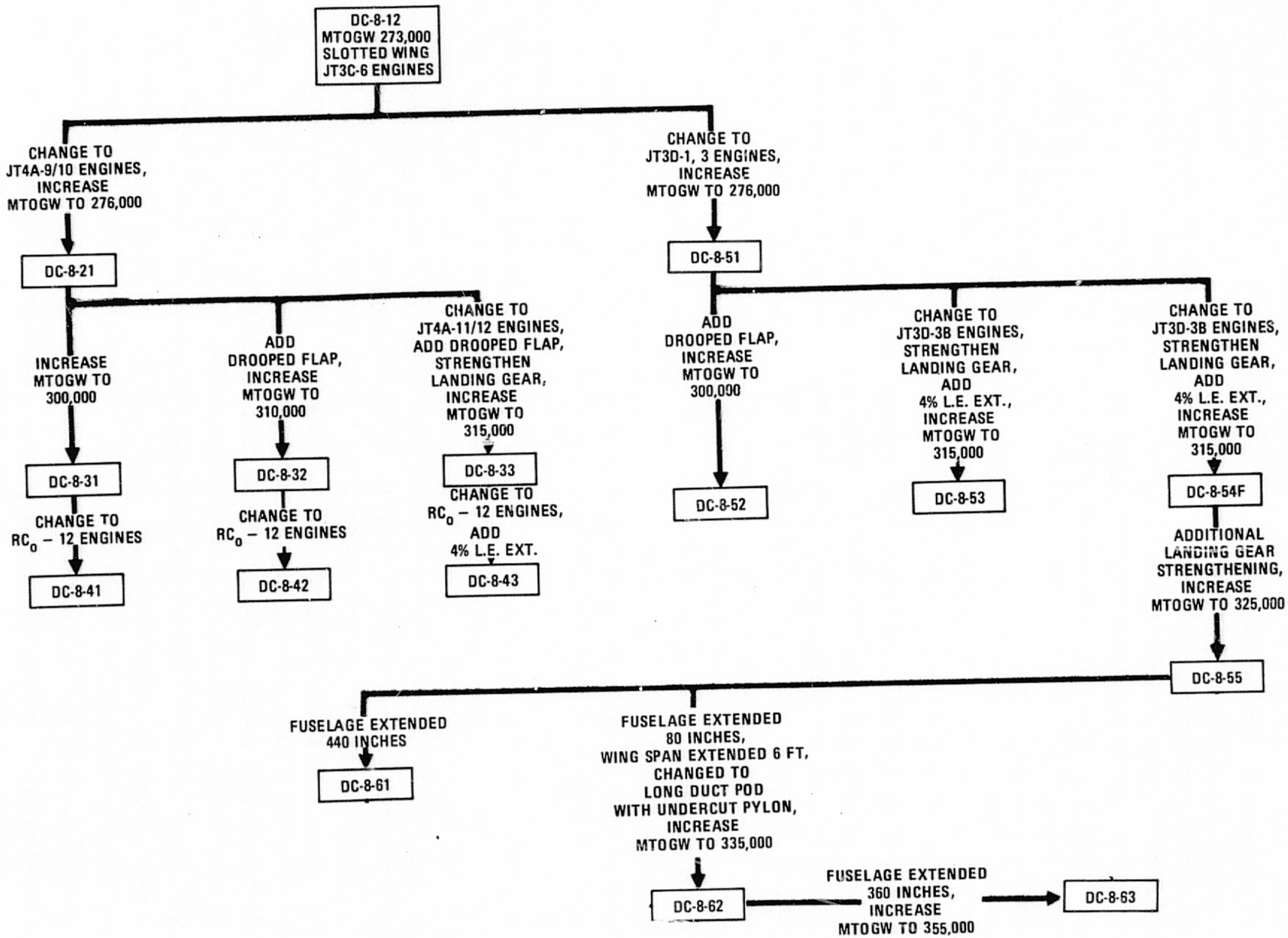


FIGURE 1. DC-8 GENEALOGY

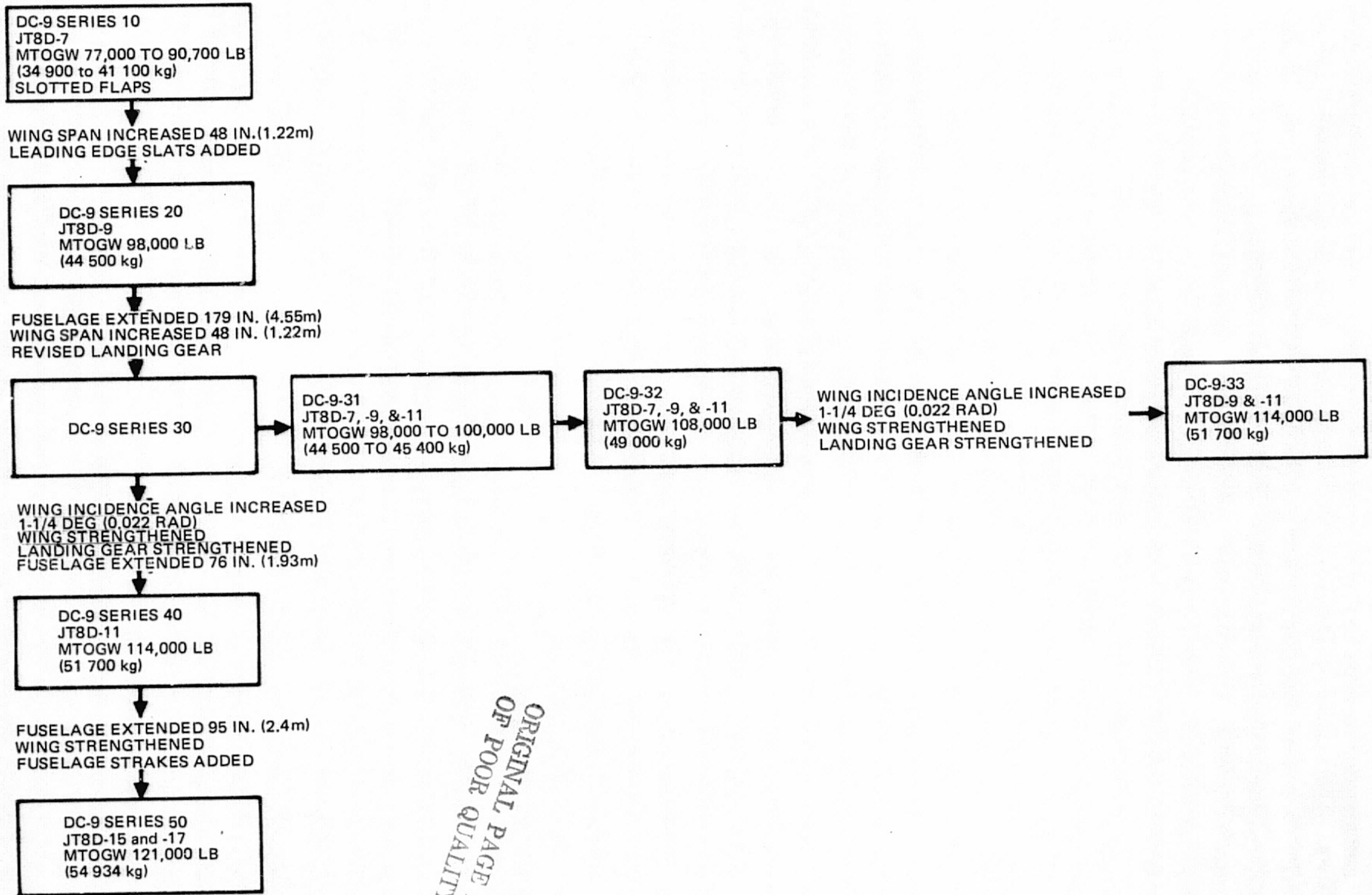


FIGURE 2. DC-9 GENEALOGY

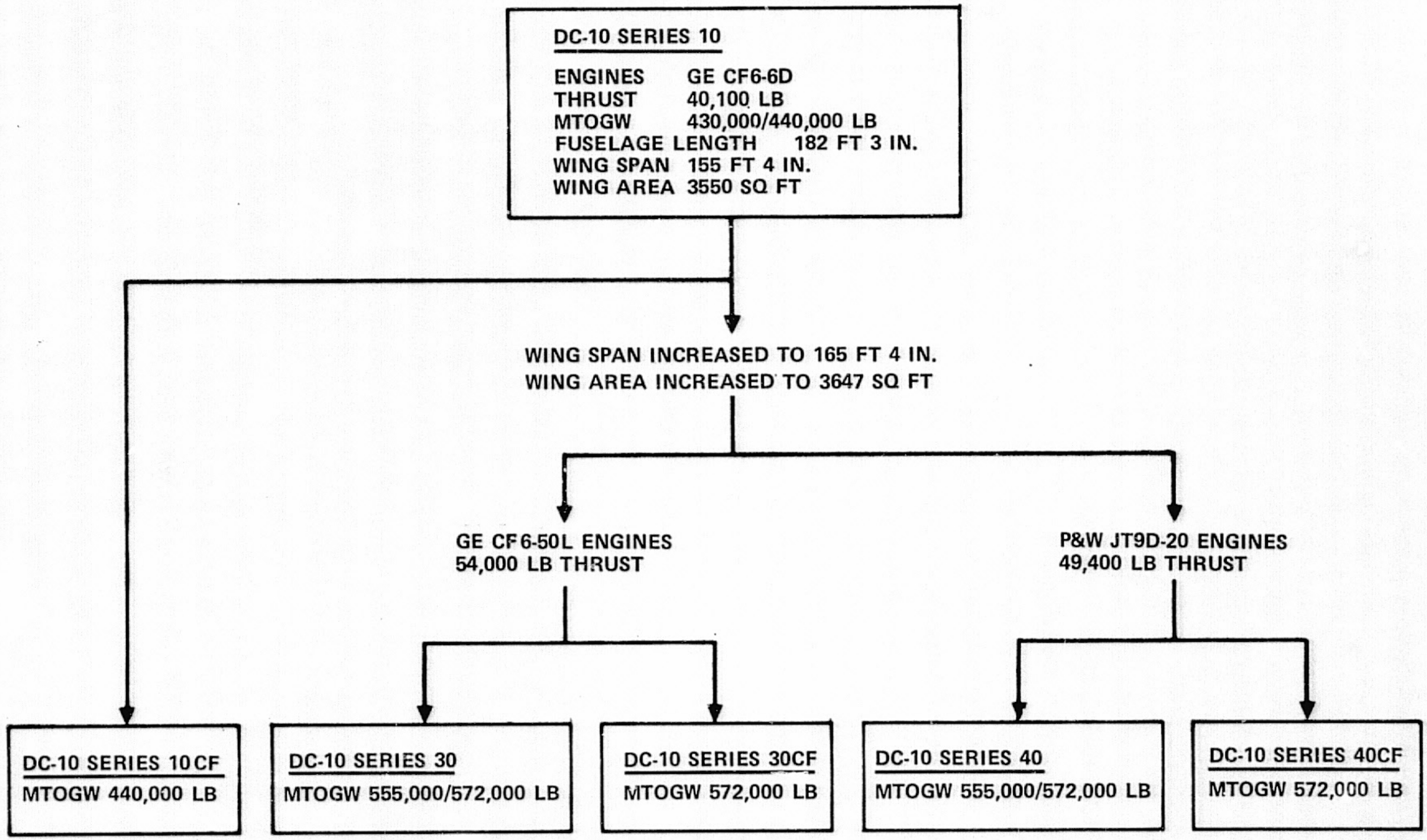


FIGURE 3. DC-10 GENEALOGY

TABLE 2

DC JETS IN U.S. DOMESTIC PASSENGER SERVICE

JUNE 1974

AIRPLANE	NUMBER IN SERVICE	AVERAGE FLIGHT TIME (HR)	YEARLY FUEL USE* (GAL)
DC-8-20	29	50,000	164,210,000
DC-8-50	41	32,000	232,200,000
DC-8-61	45	20,000	268,750,000
DC-9-10	84	18,000	182,040,000
DC-9-30	240	15,000	637,230,000
DC-10-10	81	6,000	522,160,000
DC-10-30	2	4,000	13,030,000
DC-10-40	22	3,000	143,280,000
TOTAL	544		2,162,900,000

*Estimated from Reference 11, using number of aircraft for June 1974.

TABLE 3

BASELINE AIRCRAFT CHARACTERISTICS

AIRCRAFT MODEL		DC-8-21	DC-8-52	DC-8-61	DC-9-15	DC-9-32	DC-10-10	DC-10-40
ENGINES: NUMBER		4	4	4	2	2	3	3
TYPE		JT4A-9	JT3D-3B	JT3D-3B	JT8D-7	JT8D-7	CF6-6D	JT9D-20
SLS THRUST/ENGINE	(LB)	16,800	18,000	18,000	14,000	14,000	40,100	49,400
NUMBER OF PSGRS., 10/90% SPLIT, 38/34" PITCH		146	146	203	70	92	277*	252
HIGH SPEED CRUISE MACH NUMBER		.83	.82	.82	.80	.80	.85	.85
MAXIMUM RANGE: @ 100% LOAD FACTOR, HIGH SPEED CRUISE	(NM)	2,670	4,200	3,260	1,360	1,220	3,410	5,020
@ 58% LOAD FACTOR, HIGH SPEED CRUISE	(NM)	3,060	4,800	3,560	1,420	1,310	3,880	5,560
1973 CAB AVERAGE STAGE LENGTH	(NM)	862	731	800	300	290	870	670
MAXIMUM TAKEOFF DISTANCE, SL, STD DAY	(FT)	8,050	8,940	10,480	6,480	5,530	8,840	12,340
APPROACH SPEED AT STUDY LANDING WEIGHT, STD DAY	(KT)	121	120	128	116	111	121	132
WING AREA	(FT^2)	2,773	2,881	2,884	934	1,001	3,550	3,647
WING SPAN	(FT)	142.4	142.4	142.4	89.4	93.4	155.3	165.3
MAXIMUM TAKEOFF WEIGHT	(LB)	276,000	300,000	325,000	90,700	108,000	430,000	555,000
MAXIMUM LANDING WEIGHT	(LB)	193,000	202,000	240,000	81,700	99,000	363,500	403,000
STUDY LANDING WEIGHT	(LB)	171,300	167,830	192,230	63,390	74,090	285,870	319,770
OPERATORS EMPTY WEIGHT	(LB)	137,900	138,430	156,100	49,840	57,900	237,240	270,910
STUDY PAYLOAD, 58% LOAD FACTOR @ 200 LB/PSGR AND BAG	(LB)	17,000	17,000	23,600	8,200	10,600	32,200	29,200
FUEL CAPACITY	(GAL)	17,550	17,900	17,900	3,679	3,679	21,763	36,522
FUEL USE WITH STUDY PAYLOAD AT 1973 CAB AVERAGE STAGE LENGTH	($\frac{LB}{ASNM}$)	0.224	0.185	0.144	0.225	0.184	0.125	0.161
1973 DOC AT 1973 CAB AVERAGE STAGE LENGTH, 30¢/GAL FUEL PRICE	($\frac{¢}{ASNM}$)	2.029	1.961	1.495	2.803	2.309	1.403	1.846

*Lower Galley

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 3

BASELINE AIRCRAFT CHARACTERISTICS

AIRCRAFT MODEL		DC-8-21	DC-8-52	DC-8-61	DC-9-15	DC-9-32	DC-10-10	DC-10-40
ENGINES: NUMBER		4	4	4	2	2	3	3
TYPE		JT4A-9	JT3D-3B	JT3D-3B	JT8D-7	JT8D-7	CF6-6D	JT9D-20
SLS THRUST/ENGINE	(LB)	16,800	18,000	18,000	14,000	14,000	40,100	49,400
NUMBER OF PSGRS., 10/90% SPLIT, 38/34" PITCH		146	146	203	70	92	277*	252
HIGH SPEED CRUISE MACH NUMBER		.83	.82	.82	.80	.80	.85	.85
MAXIMUM RANGE: @ 100% LOAD FACTOR, HIGH SPEED CRUISE	(NM)	2,670	4,200	3,260	1,360	1,220	3,410	5,020
@ 58% LOAD FACTOR, HIGH SPEED CRUISE	(NM)	3,060	4,800	3,560	1,420	1,310	3,880	5,560
1973 CAB AVERAGE STAGE LENGTH	(NM)	862	731	800	300	290	870	670
MAXIMUM TAKEOFF DISTANCE, SL, STD DAY	(FT)	8,050	8,940	10,480	6,480	5,530	8,840	12,340
APPROACH SPEED AT STUDY LANDING WEIGHT, STD DAY	(KT)	121	120	128	116	111	121	132
WING AREA	(FT^2)	2,773	2,881	2,884	934	1,001	3,550	3,647
WING SPAN	(FT)	142.4	142.4	142.4	89.4	93.4	155.3	165.3
MAXIMUM TAKEOFF WEIGHT	(LB)	276,000	300,000	325,000	90,700	108,000	430,000	555,000
MAXIMUM LANDING WEIGHT	(LB)	193,000	202,000	240,000	81,700	99,000	363,500	403,000
STUDY LANDING WEIGHT	(LB)	171,300	167,830	192,230	63,390	74,090	285,870	319,770
OPERATORS EMPTY WEIGHT	(LB)	137,900	138,430	156,100	49,840	57,900	237,240	270,910
STUDY PAYLOAD, 58% LOAD FACTOR @ 200 LB/PSGR AND BAG	(LB)	17,000	17,000	23,600	8,200	10,600	32,200	29,200
FUEL CAPACITY	(GAL)	17,550	17,900	17,900	3,679	3,679	21,763	36,522
FUEL USE WITH STUDY PAYLOAD AT 1973 CAB AVERAGE STAGE LENGTH	($\frac{LB}{ASNM}$)	0.224	0.185	0.144	0.225	0.184	0.125	0.161
1973 DOC AT 1973 CAB AVERAGE STAGE LENGTH, 30¢/GAL FUEL PRICE	($\frac{¢}{ASNM}$)	2.029	1.961	1.495	2.803	2.309	1.403	1.846

*Lower Galley

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4

DIRECT OPERATING COST ASSUMPTIONS

- ALL COSTS AND PRICES IN 1973 DOLLARS
- MODIFIED 1967 ATA DOC EQUATIONS
- CREW COSTS - 1967 ATA EQUATION ESCALATED AT 6% PER YEAR
- FUEL PRICES - 15¢, 30¢, AND 60¢ PER GALLON
- INSURANCE RATE - 1%
- DEPRECIATION - 16 YEARS, 10% RESIDUAL
- SPARES - 15% TOTAL FLYAWAY COST
- LABOR RATE - $6.10 PER HOUR
- DAC LATEST MAINTENANCE DATA
- MAINTENANCE BURDEN - 1.8 x DIRECT AIRFRAME AND ENGINE LABOR COST

TABLE 5

TECHNICAL GROUND RULES

SEATING DENSITY:	10/90 SPLIT WITH 38"/34" PITCH 8 ABREAST ON BASELINE DC-10
LOAD FACTOR:	58% FOR FUEL USE COMPARISONS 100% FOR NEW AIRPLANE SIZING
PAYLOAD:	NO CARGO CARRIED IN FUEL USE COMPARISONS 200 LB/(PSGR & BAGS) IN FUEL USE COMPARISONS
GALLEY LOCATION:	LOWER DECK, WHERE FEASIBLE
TOTAL MANEUVER TIME:	15 MINUTES
FUEL ONBOARD:	MISSION FUEL ONLY (INCLUDES RESERVES) DENSITY = 6.8 LBM/GALLON HEAT CONTENT = 18,600 BTU/LBM

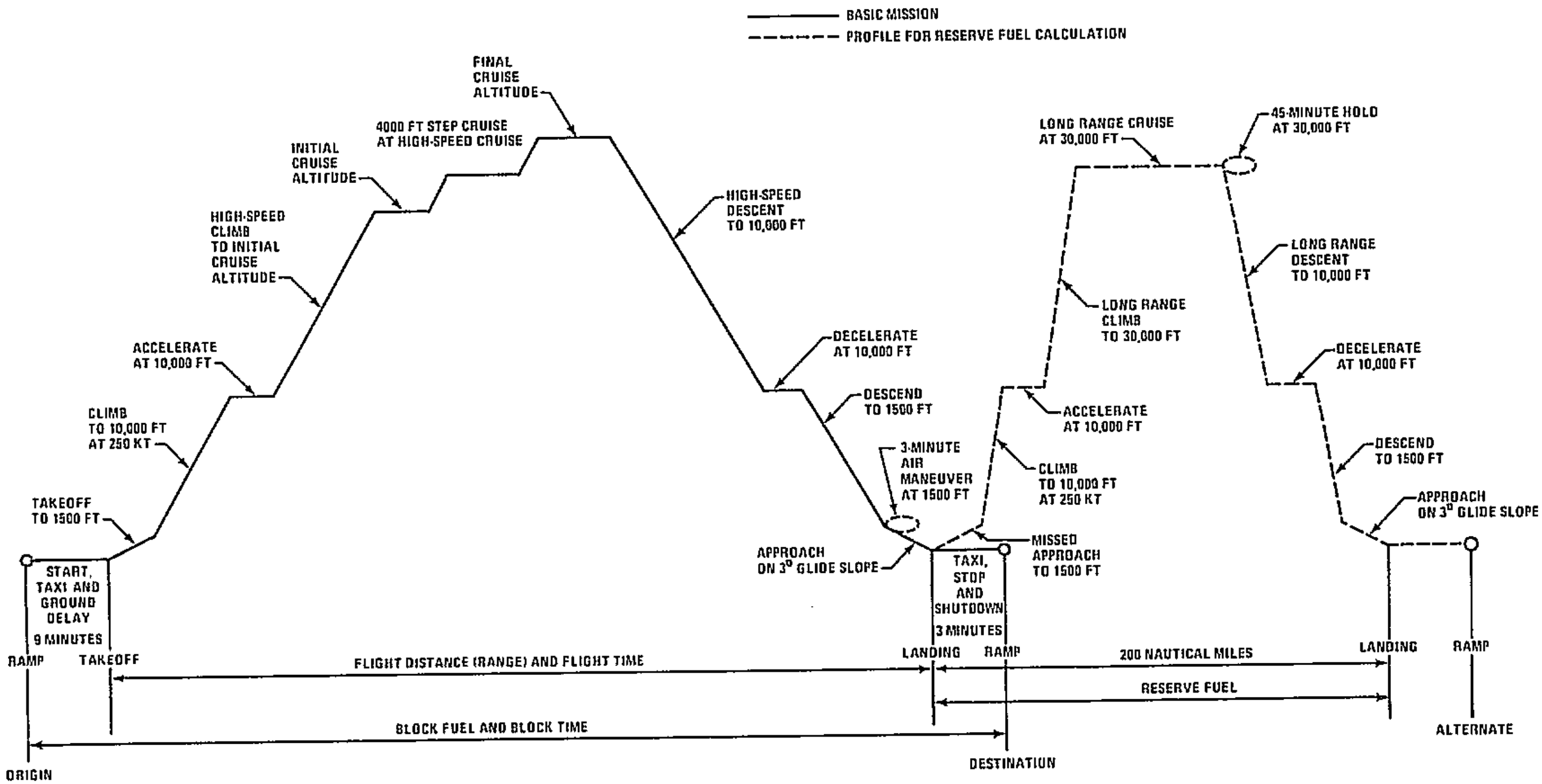


FIGURE 4. BASELINE MISSION PROFILE - DOMESTIC

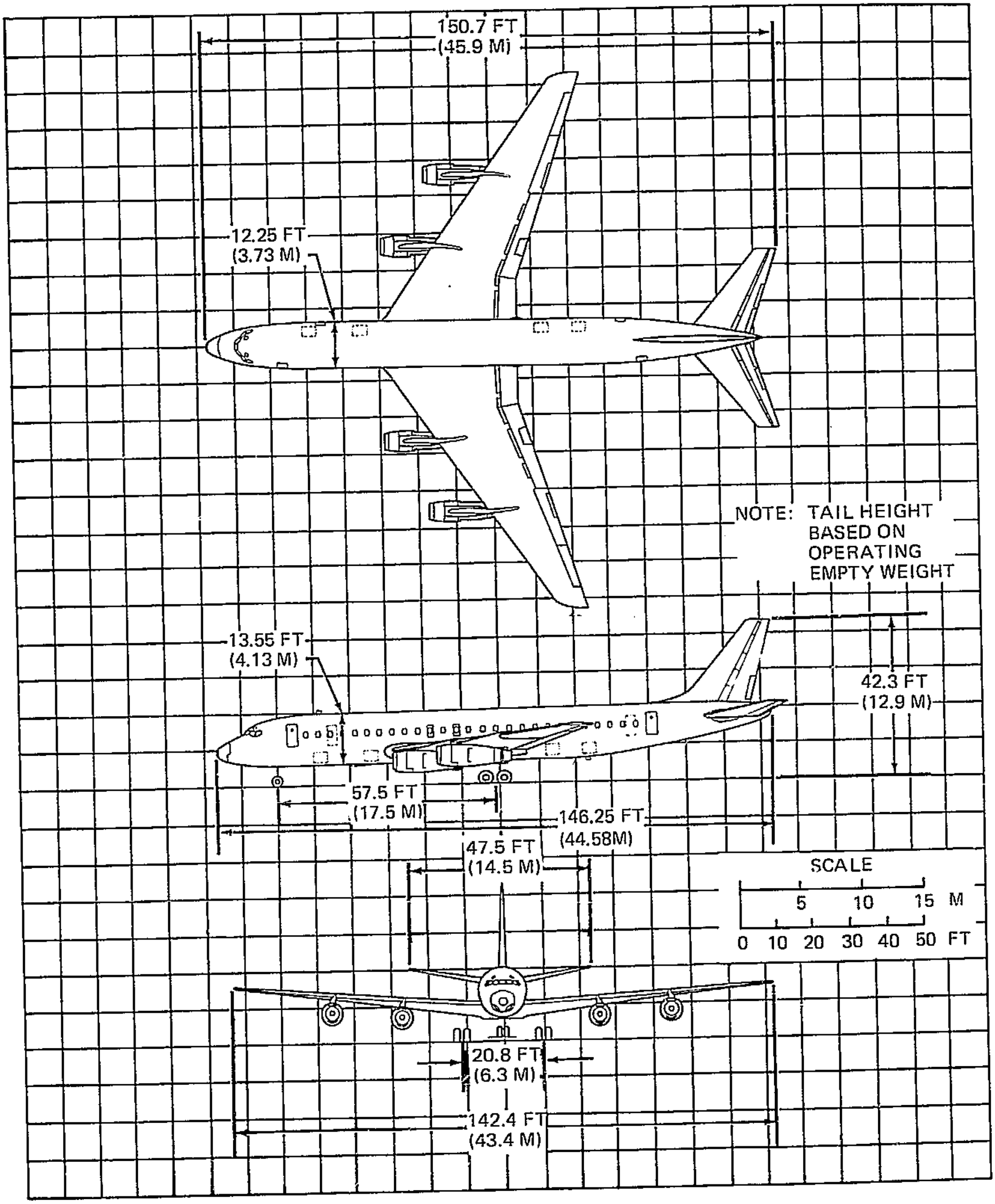


FIGURE 5. DC-8-20 AND DC-8-50 GENERAL AIRPLANE DIMENSIONS

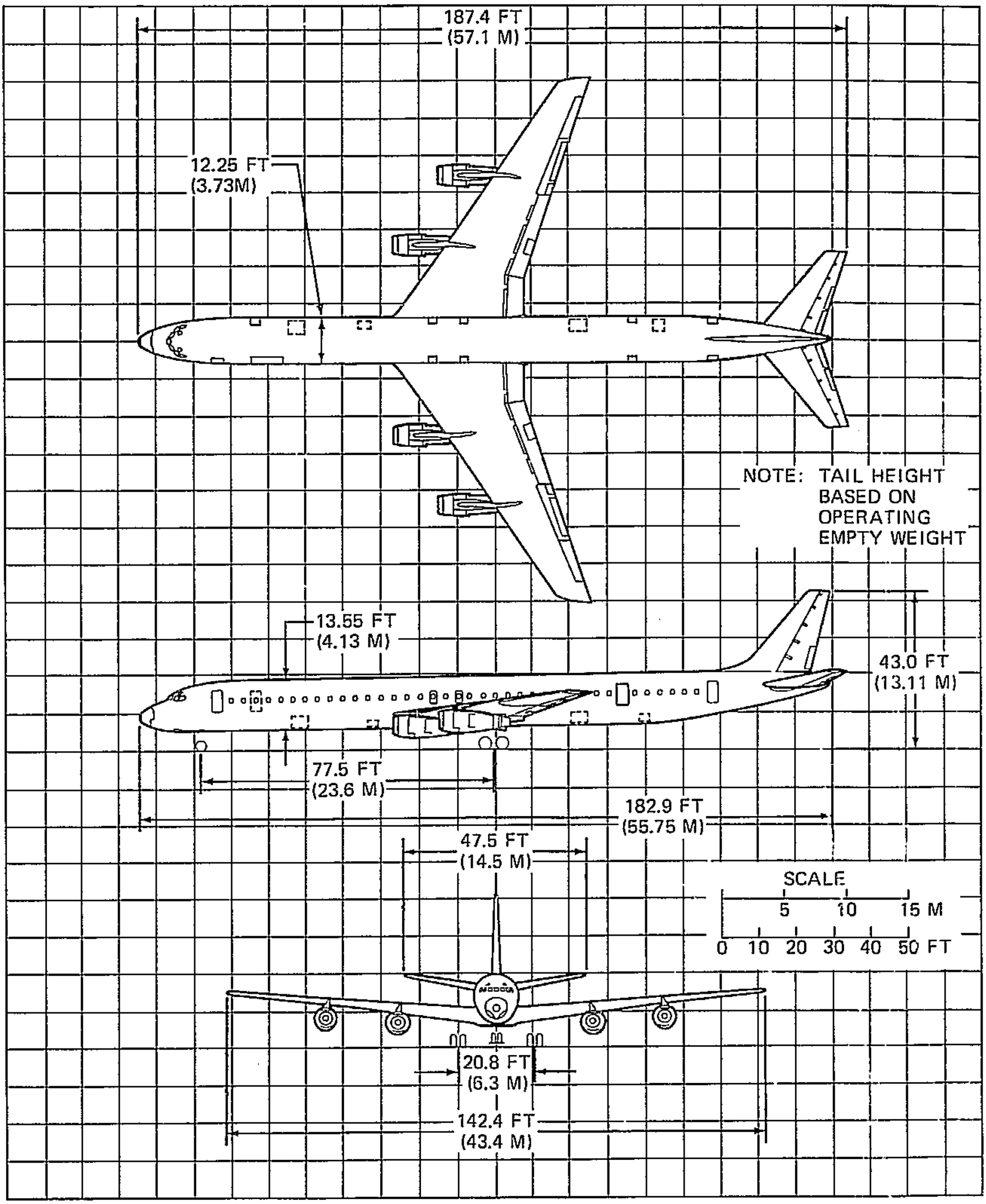


FIGURE 6. DC-8-61 GENERAL AIRPLANE DIMENSIONS .

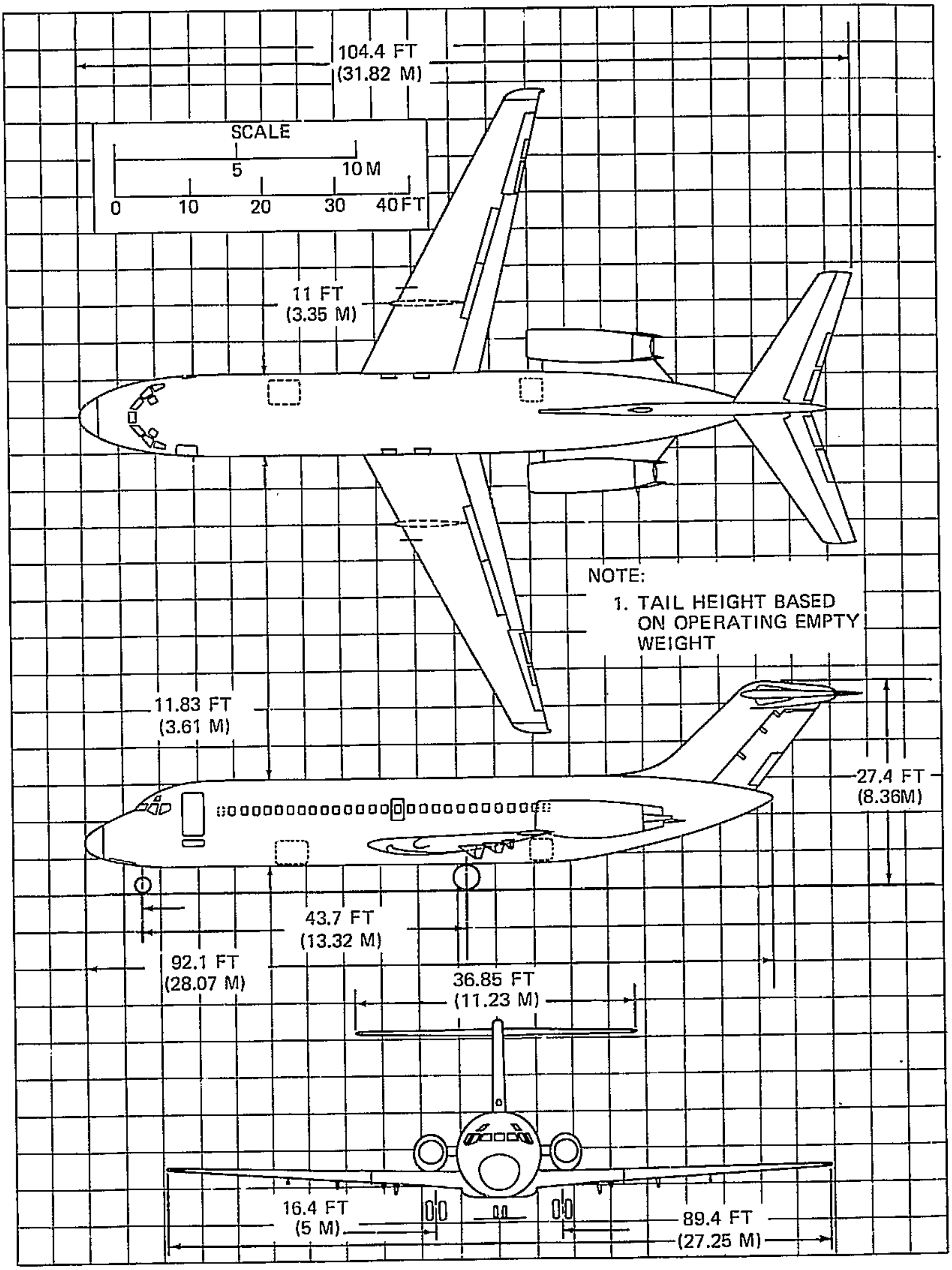


FIGURE 7. DC-9-10 GENERAL AIRPLANE DIMENSIONS

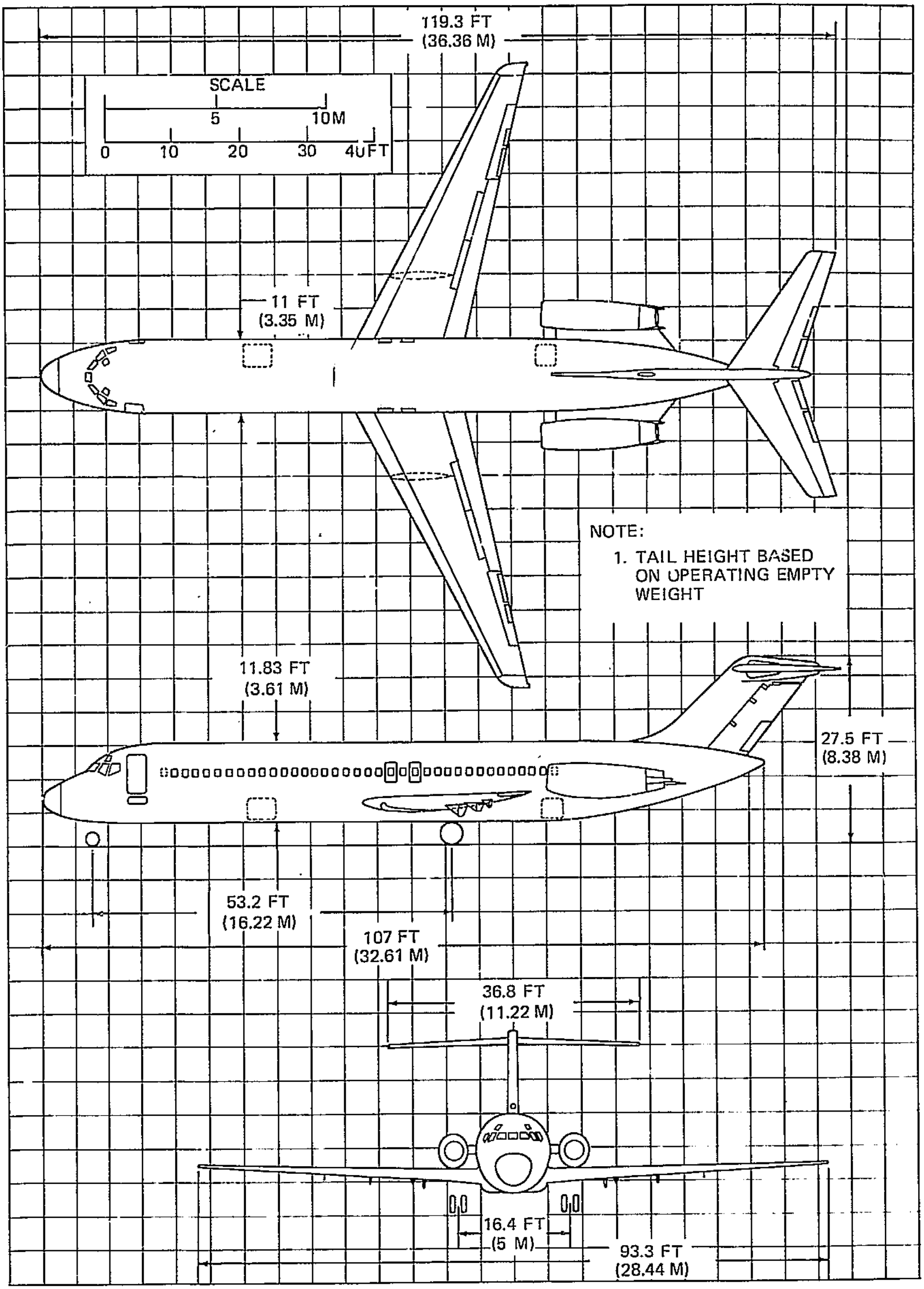


FIGURE 8. DC-9-30 GENERAL AIRPLANE DIMENSIONS

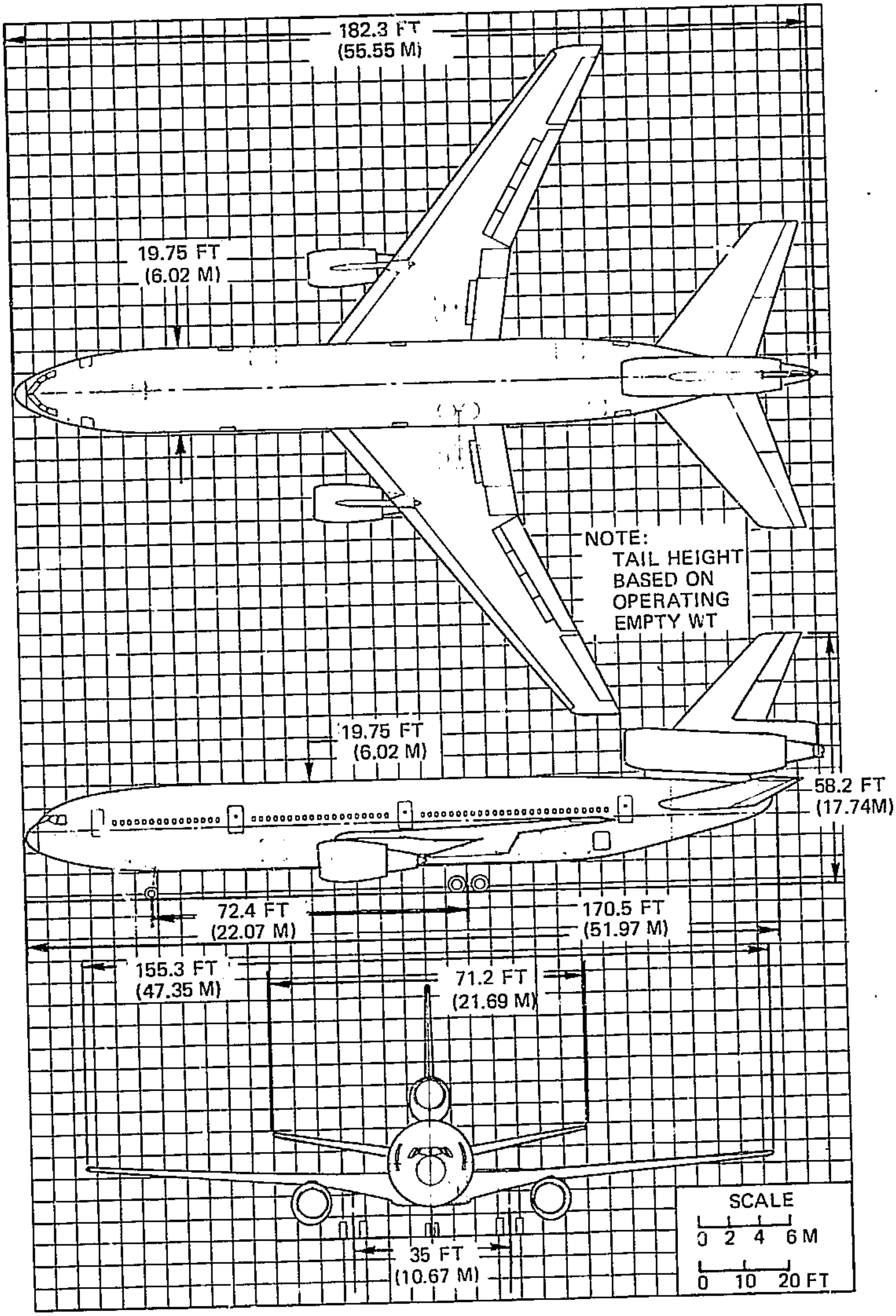


FIGURE 9. DC-10-10 GENERAL AIRPLANE DIMENSIONS

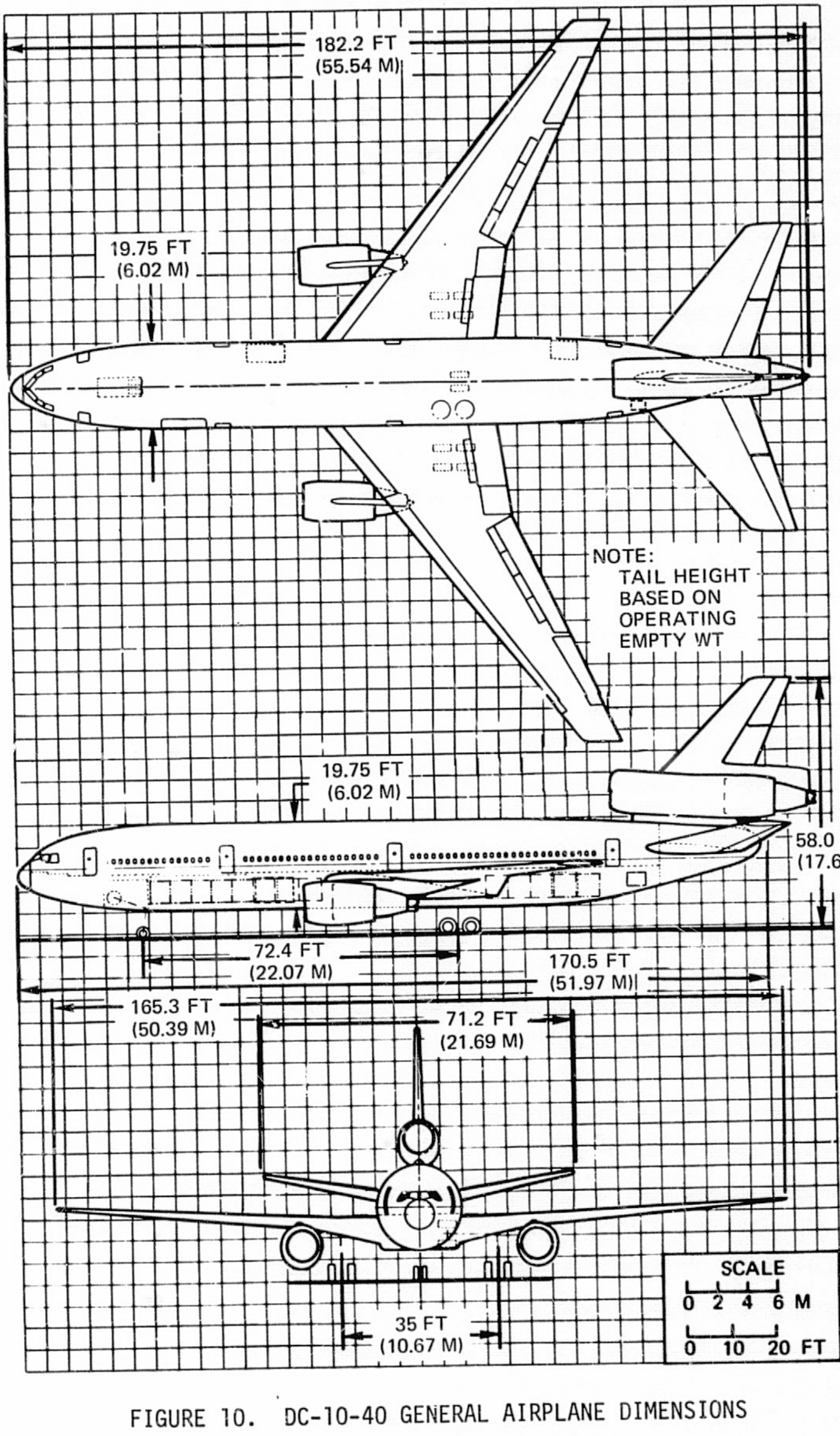


FIGURE 10. DC-10-40 GENERAL AIRPLANE DIMENSIONS

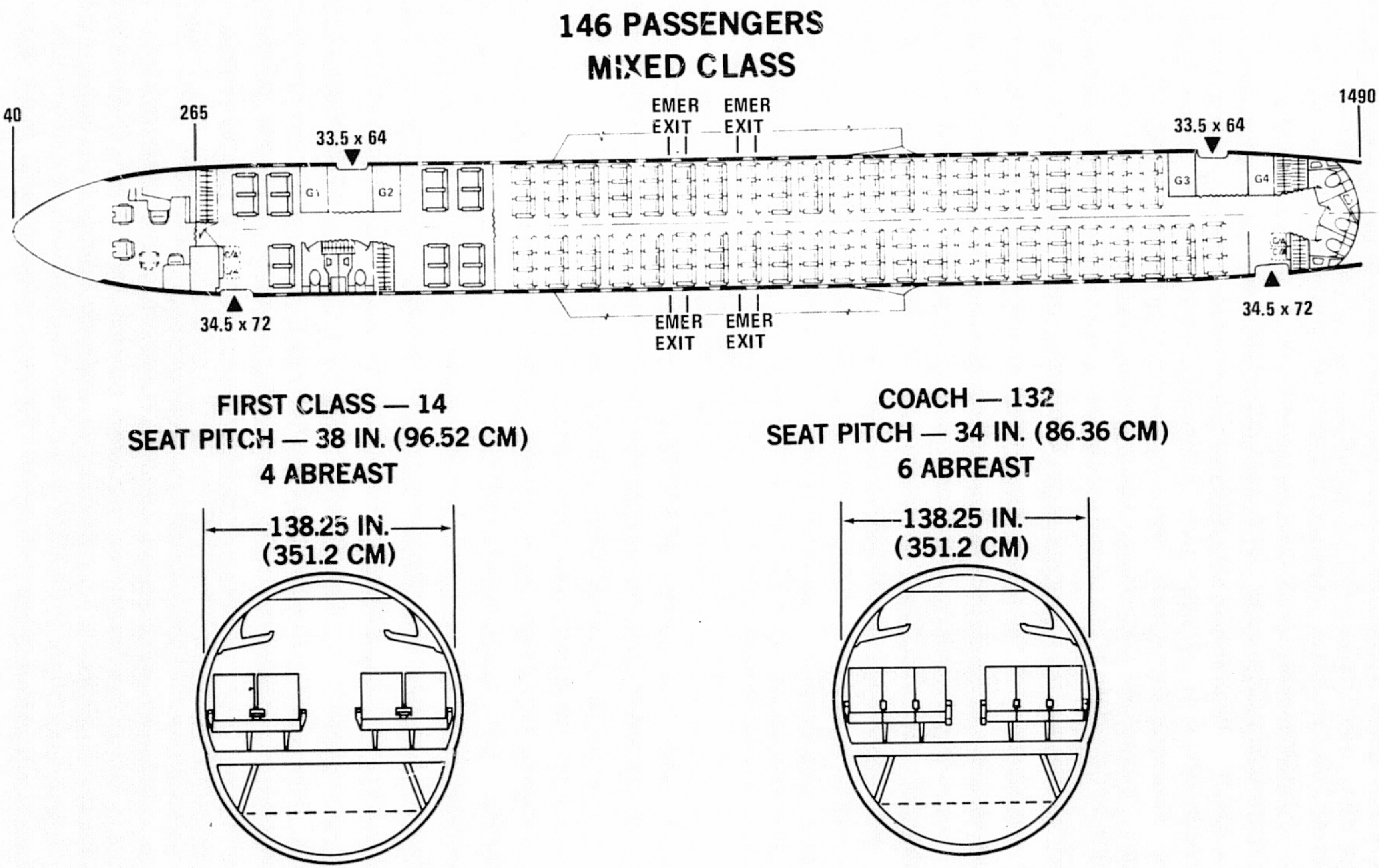


FIGURE 11. DC-8-20 AND DC-8-50 BASELINE INTERIOR ARRANGEMENT

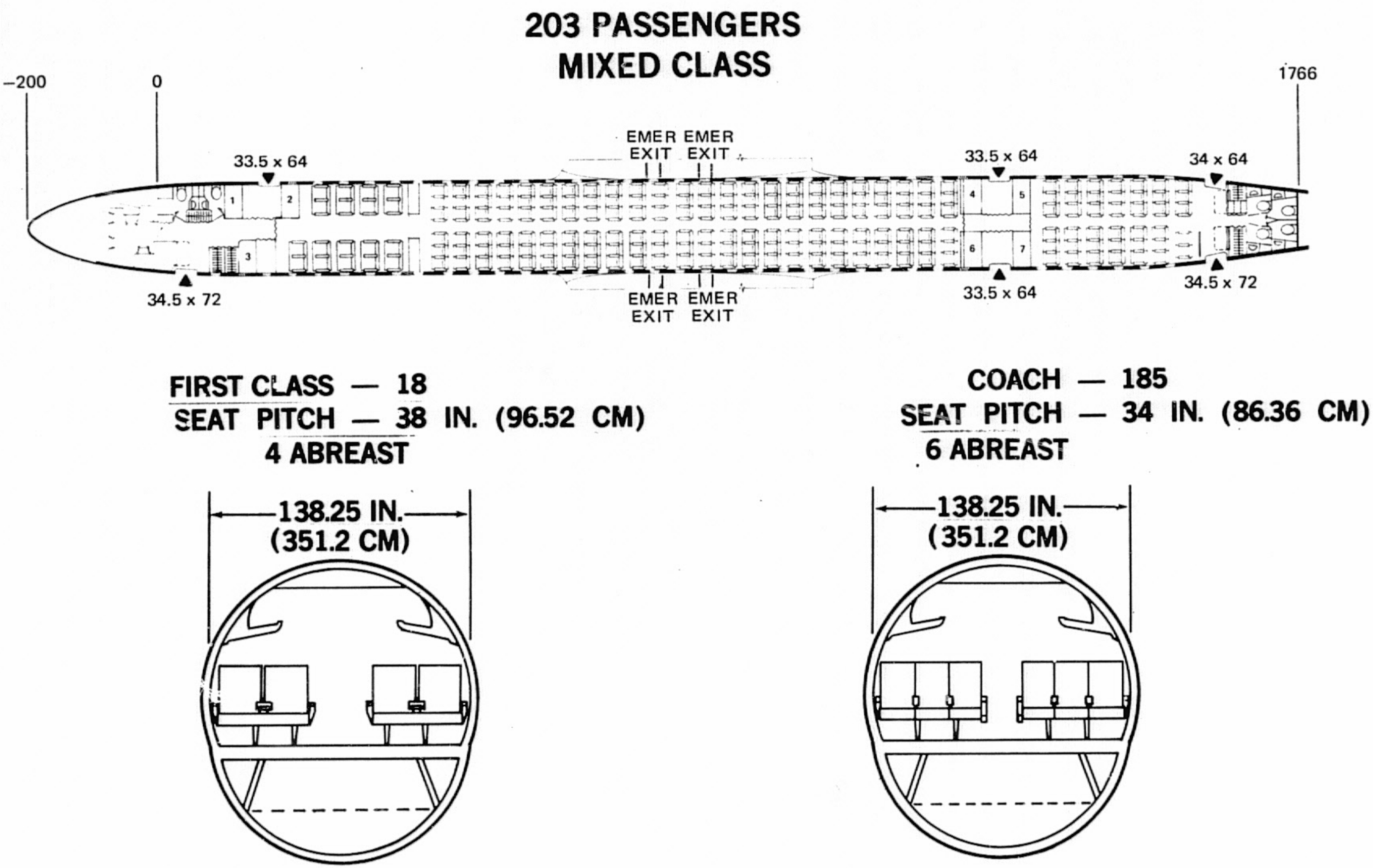


FIGURE 12. DC-8-61 BASELINE INTERIOR ARRANGEMENT

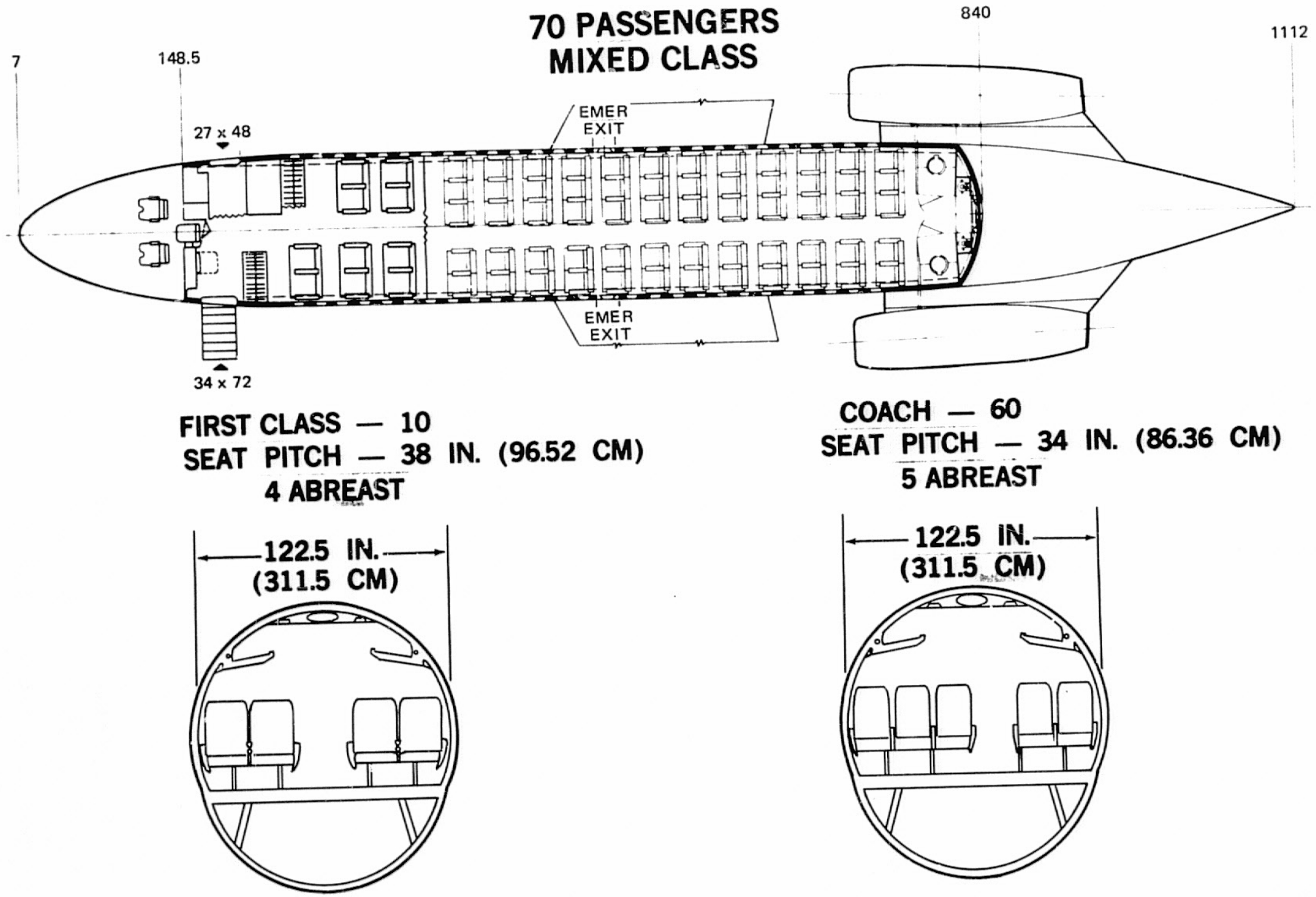


FIGURE 13. DC-9-10 BASELINE INTERIOR ARRANGEMENT

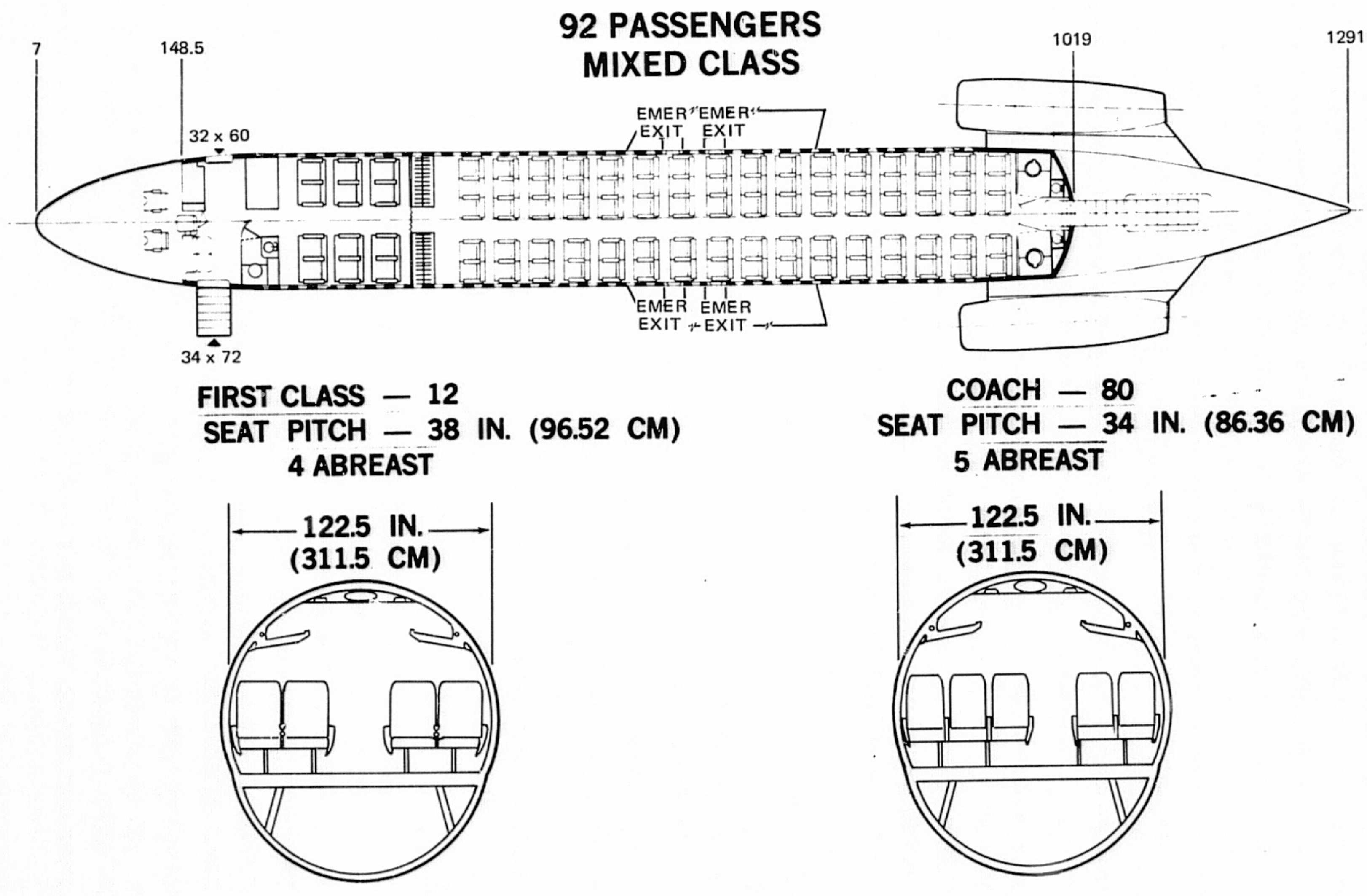


FIGURE 14. DC-9-30 BASELINE INTERIOR ARRANGEMENT

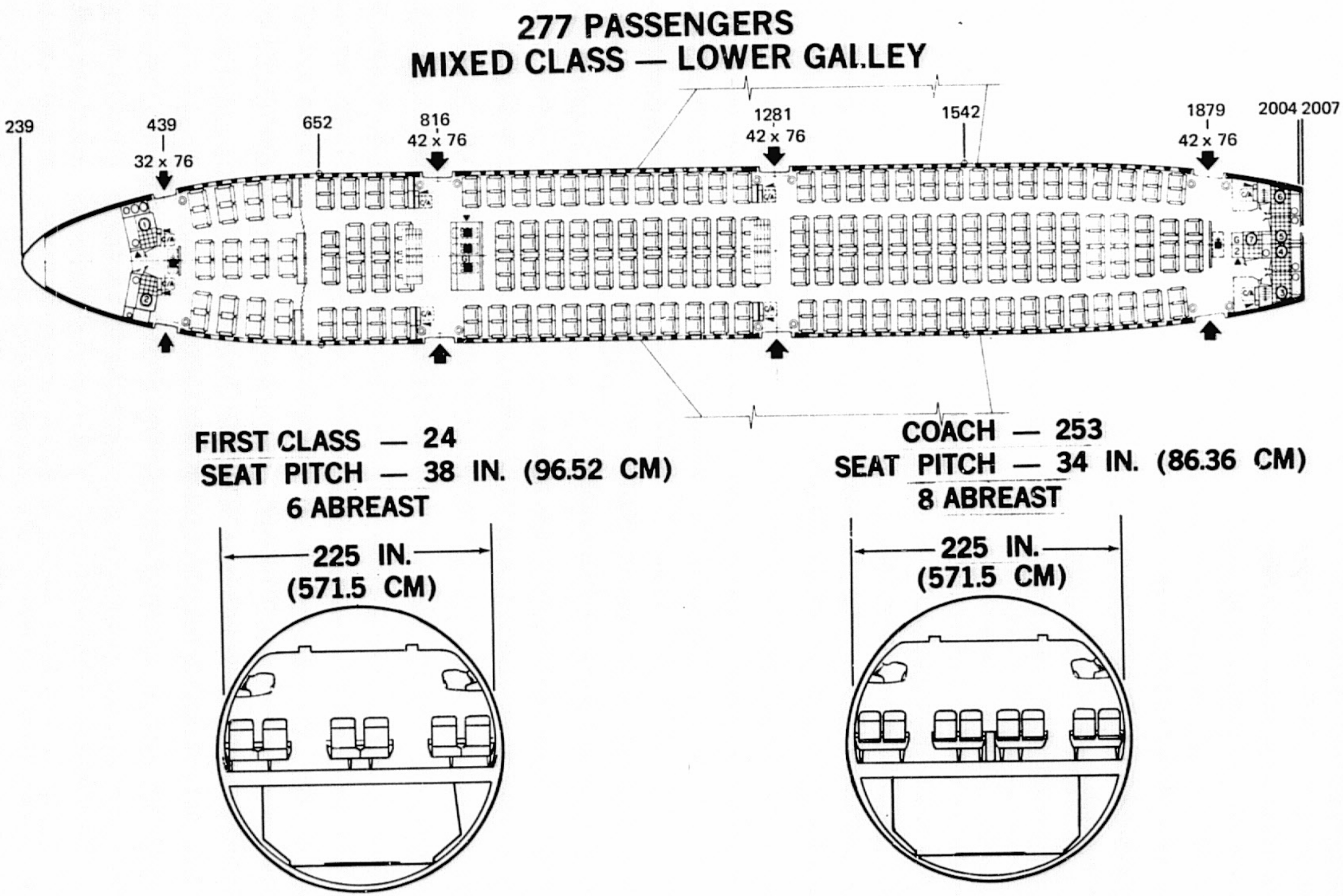


FIGURE 15. DC-10-10 BASELINE INTERIOR ARRANGEMENT

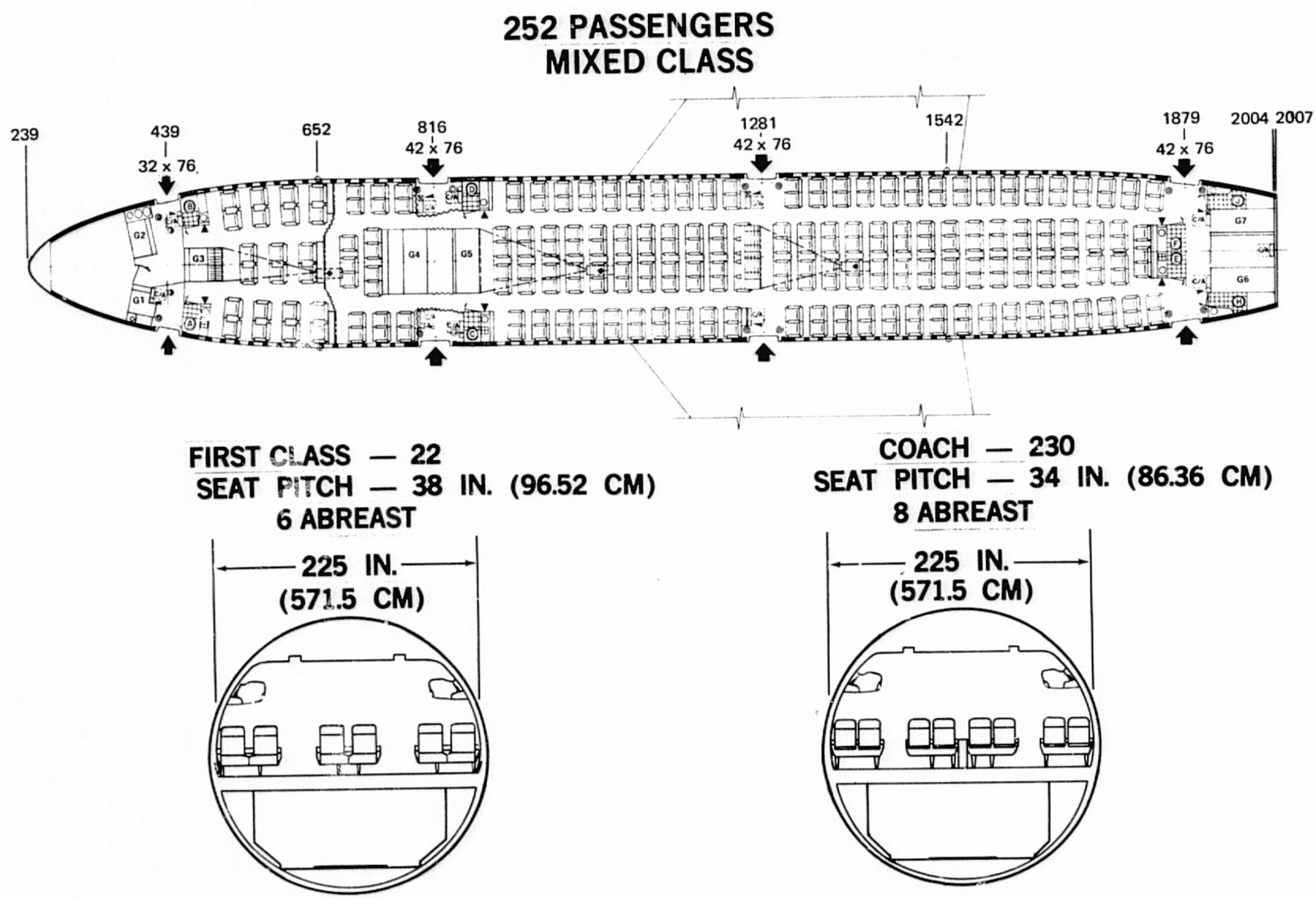


FIGURE 16. DC-10-40 BASELINE INTERIOR ARRANGEMENT

TABLE 6

PASSENGER CONVENIENCE DATA

Baseline Aircraft

10/90 Split, 38"/34" Seat Pitch

AIRCRAFT	NUMBER OF SEATS	COACH SEAT WIDTH (in)	GALLEYS		CLOSET SPACE		LAVATORIES	
			Area (in^2)	Area/Psgr (in^2)	Total Length (in)	Length/Psgr (in)	Number	Psgr/Lav
DC-8-20	146	16.5	5,670	38.8	199	1.36	5	29.2
DC-8-50	146	16.5	5,670	38.8	199	1.36	5	29.2
DC-8-61	203	16.5	10,700	52.7	210	1.03	6	33.8
DC-9-10	70	17.5	2,400	34.3	80	1.14	2	35.0
DC-9-30	92	17.5	2,500	27.2	80	.87	3	30.7
DC-10-10*	277	18.5	31,856	115.0	200	.72	7	39.6
DC-10-40	252	18.5	16,710	66.3	120	.48	8	31.5

* With lower galley, lower galley area (excluding walkway) = 23,856 in^2, upper galley area = 8,000 in^2

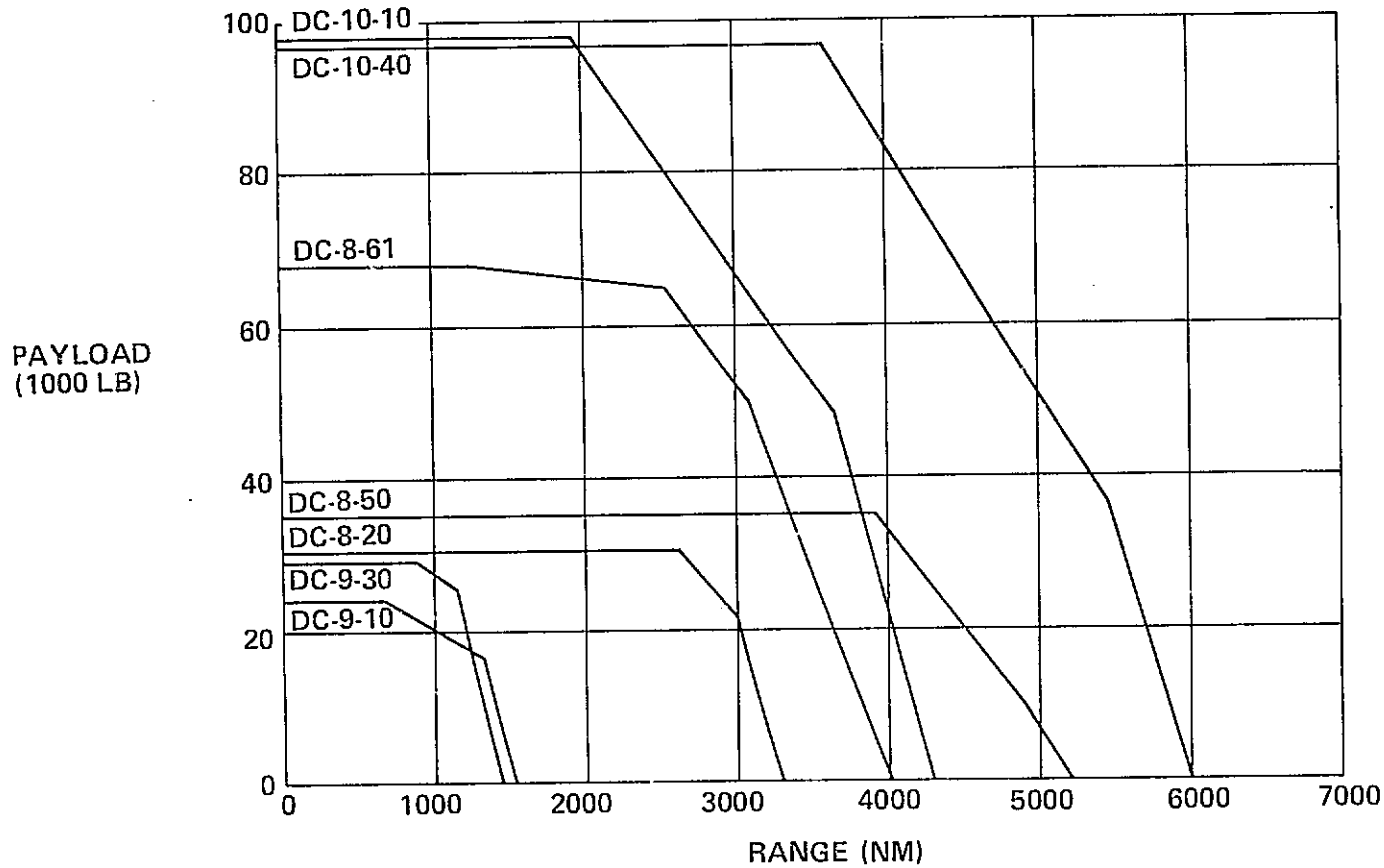


FIGURE 17. BASELINE AIRCRAFT PAYLOAD-RANGE COMPARISON

TABLE 7

DC-8-20 BASELINE FLIGHT PROFILE DATA

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	$\frac{\text{BTU}}{\text{Nautical Mile}}$	$\frac{\text{Available Seat - NM}}{\text{Gallon}}$ (2)	$\frac{\text{BTU}}{\text{Available Seat - NM}}$
100	5,600	1,041,600	17.73	7,134
250	9,200	684,500	26.98	4,688
500	16,980	631,700	29.23	4,326
750	24,760	614,000	30.07	4,206
1,000	32,550	605,400	30.50	4,147
2,000	63,680	592,200	31.18	4,056
3,000	94,820	587,900	31.41	4,027
3,060	96,690	587,700	31.42	4,026

(1) FROM DAC PERFORMANCE DATA FOR BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 146 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 8

DC-8-50 BASELINE FLIGHT PROFILE DATA

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	5,200	967,200	19.09	6,625
250	8,900	662,200	27.89	4,535
500	14,560	541,600	34.09	3,710
750	20,220	501,500	36.82	3,435
1,000	25,890	481,600	38.35	3,298
2,000	48,540	451,400	40.91	3,092
3,000	71,190	441,400	41.84	3,023
3,500	82,510	438,500	42.11	3,003

(1) FROM DAC PERFORMANCE DATA FOR BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 146, FUEL DENSITY = 6.8 LB/GALLON

TABLE 9

DC-8-61 BASELINE FLIGHT PROFILE DATA

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	$\frac{\text{BTU}}{\text{Nautical Mile}}$	$\frac{\text{Available Seat - NM}}{\text{Gallon}}$ (2)	$\frac{\text{BTU}}{\text{Available Seat - NM}}$
100	6,720	1,249,900	20.54	6,157
250	10,240	761,900	33.70	3,753
500	16,000	595,200	43.14	2,932
750	22,000	545,600	47.06	2,688
1,000	28,300	526,400	48.78	2,593
2,000	55,170	513,100	50.04	2,527
3,000	84,000	520,800	49.30	2,566
3,500	101,420	539,000	47.64	2,655

(1) FROM DAC PERFORMANCE DATA FOR BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 203 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 10

DC-9-10 BASELINE FLIGHT PROFILE DATA

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM / Gallon (2)	BTU / Available Seat - NM
100	2,400	446,400	19.83	6,377
250	4,200	312,500	28.33	4,464
500	7,000	260,400	34.00	3,720
750	9,700	240,600	36.80	3,437
1,000	12,550	233,400	37.93	3,335
1,250	15,700	233,600	37.90	3,337
1,420	17,930	234,900	37.70	3,355

(1) FROM DAC PERFORMANCE DATA FOR BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 70, FUEL DENSITY = 6.8 LB/GALLON

TABLE 11

DC-9-30 BASELINE FLIGHT PROFILE DATA

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	2,510	466,900	24.92	5,075
250	4,400	327,400	35.55	3,558
500	7,350	273,400	42.56	2,972
750	10,250	254,200	45.78	2,763
1,000	13,200	245,500	47.39	2,669
1,250	16,250	241,800	48.12	2,628
1,310	17,020	241,700	48.15	2,627

(1) FROM DAC PERFORMANCE DATA FOR BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 92 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 12

DC-10-10 BASELINE FLIGHT PROFILE DATA

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	8,310	1,545,700	22.67	5,580
250	12,400	922,600	37.98	3,331
500	19,200	714,200	49.05	2,578
750	26,700	662,200	52.91	2,390
1,000	34,000	632,400	55.40	2,283
2,000	64,770	602,400	58.16	2,175
3,000	98,000	607,600	57.66	2,194
3,500	116,600	619,600	56.54	2,237

(1) FROM DAC PERFORMANCE DATA FOR BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 277, FUEL DENSITY = 6.8 LB/GALLON

TABLE 13

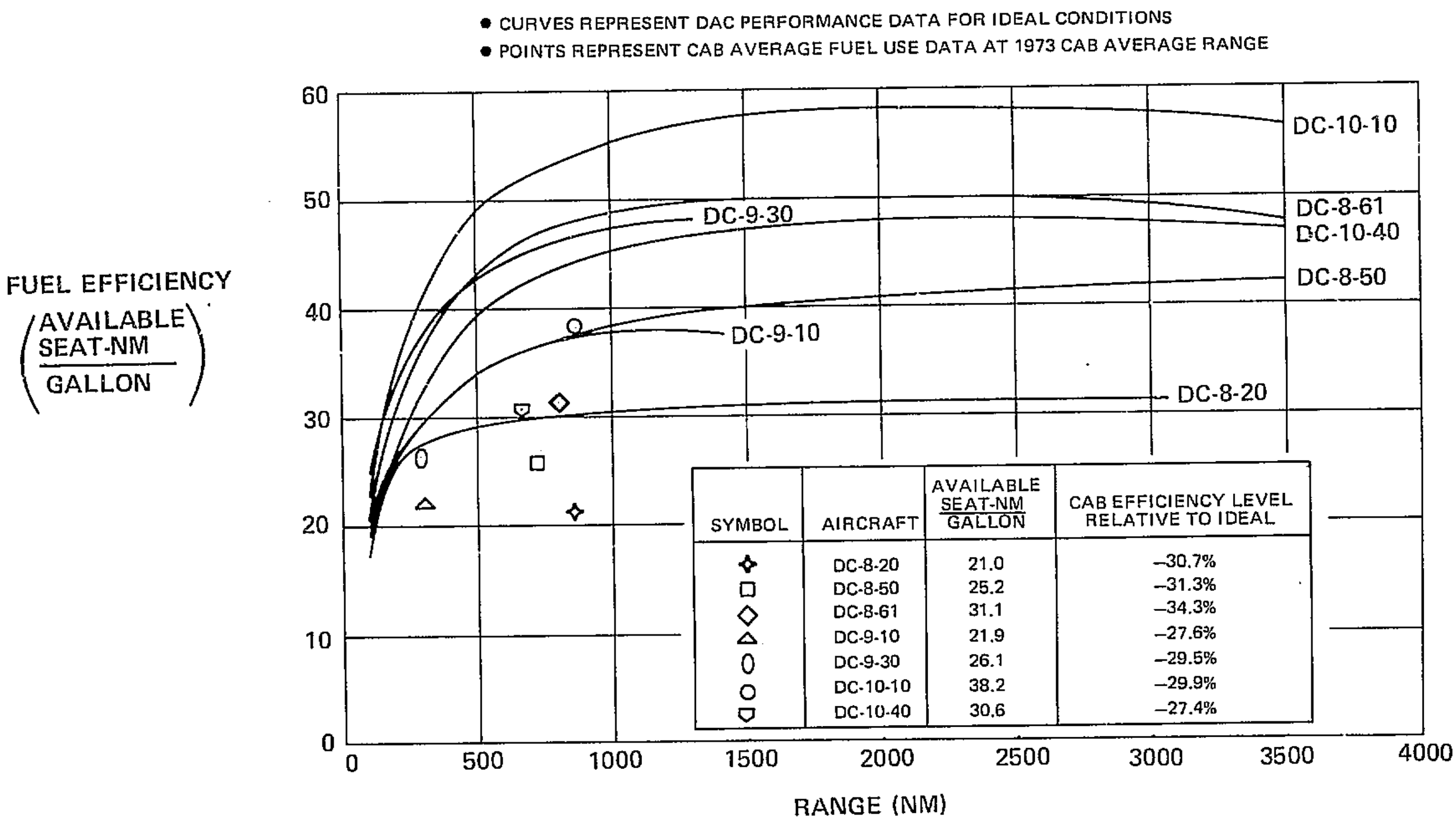
DC-10-40 BASELINE FLIGHT PROFILE DATA

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	9,890	1,839,500	17.33	7,300
250	14,340	1,066,900	29.87	4,234
500	21,750	809,100	39.39	3,211
750	30,000	744,000	42.84	2,952
1,000	37,750	702,200	45.39	2,786
2,000	71,500	665,000	47.93	2,639
3,000	108,000	669,600	47.60	2,657
3,500	128,240	681,500	46.77	2,704

(1) FROM DAC PERFORMANCE DATA FOR BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 252 , FUEL DENSITY = 6.8 LB/GALLON



SYMBOL	AIRCRAFT	AVAILABLE SEAT-NM / GALLON	CAB EFFICIENCY LEVEL RELATIVE TO IDEAL
✧	DC-8-20	21.0	–30.7%
□	DC-8-50	25.2	–31.3%
◇	DC-8-61	31.1	–34.3%
△	DC-9-10	21.9	–27.6%
0	DC-9-30	26.1	–29.5%
○	DC-10-10	38.2	–29.9%
▽	DC-10-40	30.6	–27.4%

FIGURE 18. BASELINE AIRCRAFT FUEL EFFICIENCY COMPARISON

SECTION 2.0

ALTERNATIVE OPERATING PROCEDURES

Fuel-conservative operating procedures are the most effective means of immediately saving fuel. In this report, operations cover the total range of activity from the preliminary flight planning to the engine shutdown at the destination, and even include airline policy items such as average load factor and seating density. These operational variations were divided into two categories, flight operations and airline operations. Flight operations include aircraft climb and descent profiles, cruise profiles, navigational procedures, and maneuvers and delays. Airline operations include control over load factor, seating density, maintenance standards, and center of gravity location.

2.1 Flight Operations

2.1.1 Climb and Descent Profiles

The relationships between high-speed and long-range climb and descent profiles are shown in Figure 19. Long-range climb refers to a climb profile that gets to cruise altitude sooner (in terms of both time and distance), thereby allowing the longest cruise distance at the chosen cruise altitude. The long-range climb profile will result in an overall longer range flight for a given fuel weight than the high-speed climb, even though the long-range climb covers less distance during the climb itself (90 nautical miles versus 100 nautical miles). This result is due to the fact that an aircraft following the high-speed climb profile spends a greater amount of time at lower altitudes where aircraft fuel efficiency deteriorates rapidly.

For shortest overall flight time, the high-speed climb and descent profiles are used. This may again appear anomalous, since the actual time-to climb is greater for the high-speed climb. However, the greater ground distance travelled in climb results in a net time saving. The descent times in this case are equal for the two profiles due to the cabin descent rate limit of 300 feet per minute. With this single exception, the concepts explained for the climb profiles apply equally to descent profiles.

When cabin descent rate limits permit, use of flight idle during descent saves fuel, but may result in high fuselage angles for some aircraft types at high altitudes.

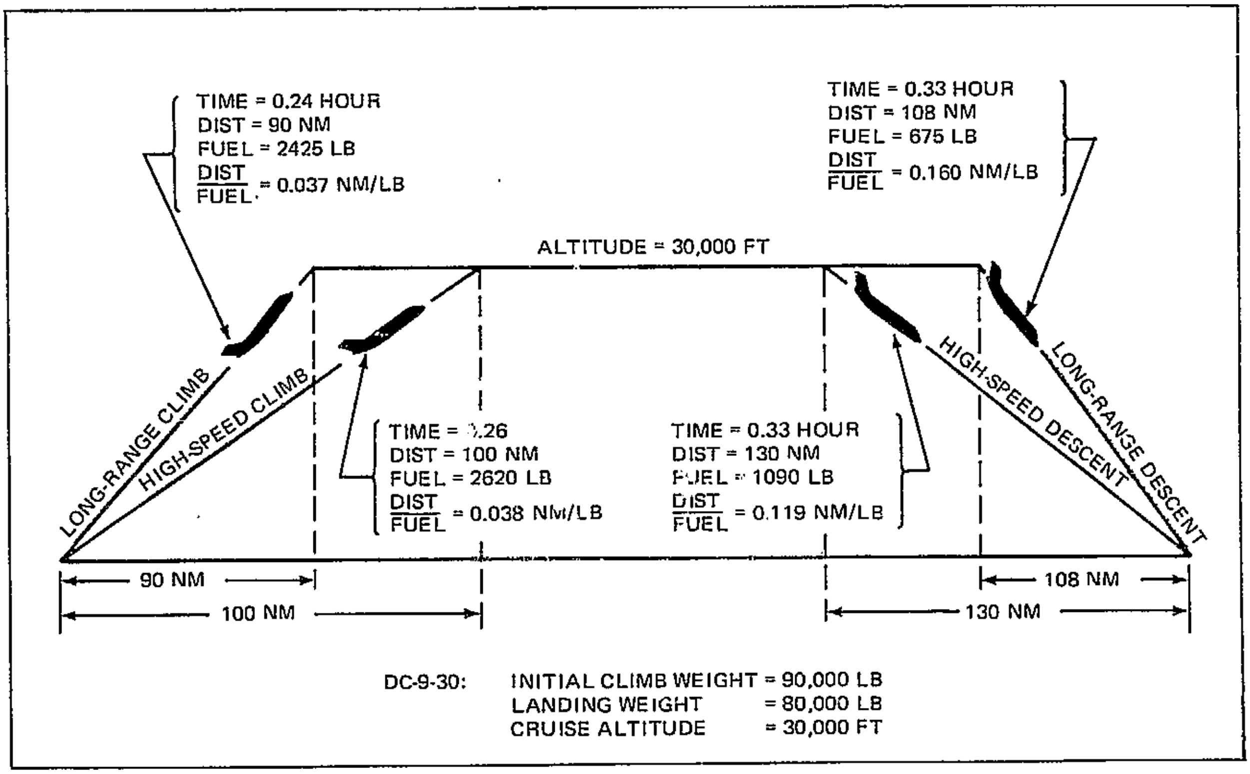


Figure 19. LONG-RANGE AND HIGH-SPEED CLIMB AND DESCENT SCHEDULES

2.1.2 Cruise Altitude

Cruise at optimum flight altitude is essential for maximum fuel economy. The optimum altitude increases as the aircraft becomes lighter, which means that to maintain optimum altitude the aircraft must climb as it cruises. Current ATC procedures do not permit cruise climb, therefore a step climb is used. Depending on the aircraft, flight weight, and Mach number, flying at an altitude 4,000 feet below the optimum (as well as above in the case of the DC-8 or DC-10) results in an increase of approximately 2 to 8 percent in the fuel required for a given range. Under current ATC procedures climb steps of 4,000 feet in cruise altitude are used to stay as close to the optimum cruise altitude as possible. Airway congestion may limit this, particularly in international operations, where flight level flexibility is extremely limited. If closer flight level spacing were available, steps of 2,000 feet could be used. These smaller steps very closely approximate cruise climb in fuel efficiency.

For the DC-9, the highest attainable altitude results in the minimum fuel use. However, the altitude could be limited by any of three factors: short stage lengths where climb and descent comprise the total trip distance, cruise thrust limitations, or the 35,000 foot operational altitude limit. Furthermore, operators prefer to avoid flight levels for which the maximum rate of climb is less than 500 feet per minute. A typical short range operation for the DC-9 involves high speed climb to 15,000 feet, high-speed cruise at constant altitude, and high speed descent. The best efficiency profile for short range is the "spike" profile, where the aircraft climbs and descends at long range speeds with no cruise portion. At 290 nautical miles, the spike profile saves 20 percent of the fuel used by the high speed 15,000 foot profile. The cost in time is only 4 minutes.

2.1.3 Cruise Speed

Cruise Mach number has a significant effect on cruise fuel efficiency. Maximum fuel mileage is attained at the peak of the published specific range curves. This maximum efficiency point frequently occurs at very low Mach numbers (0.72 M for a DC10-10 at 25,000 feet and 400,000 pounds flight weight). Long-range cruise is defined at any altitude and flight weight as the speed corresponding to 99 percent maximum nautical miles per pound. This definition is used because at slower speeds, jet transports become speed unstable due to engine-airframe matching characteristics. The large throttle adjustments, required at lower Mach numbers to maintain steady speed, largely offset any potential gains in fuel economy.

Two other drawbacks of slower speeds are increased operating costs due to longer block times and increased penalties due to headwinds. The effect of headwinds on a DC-10-10 operating at 320,000 pounds average flight weight on a 2,000 nautical mile cruise leg at 30,000 feet is shown in Figure 20.

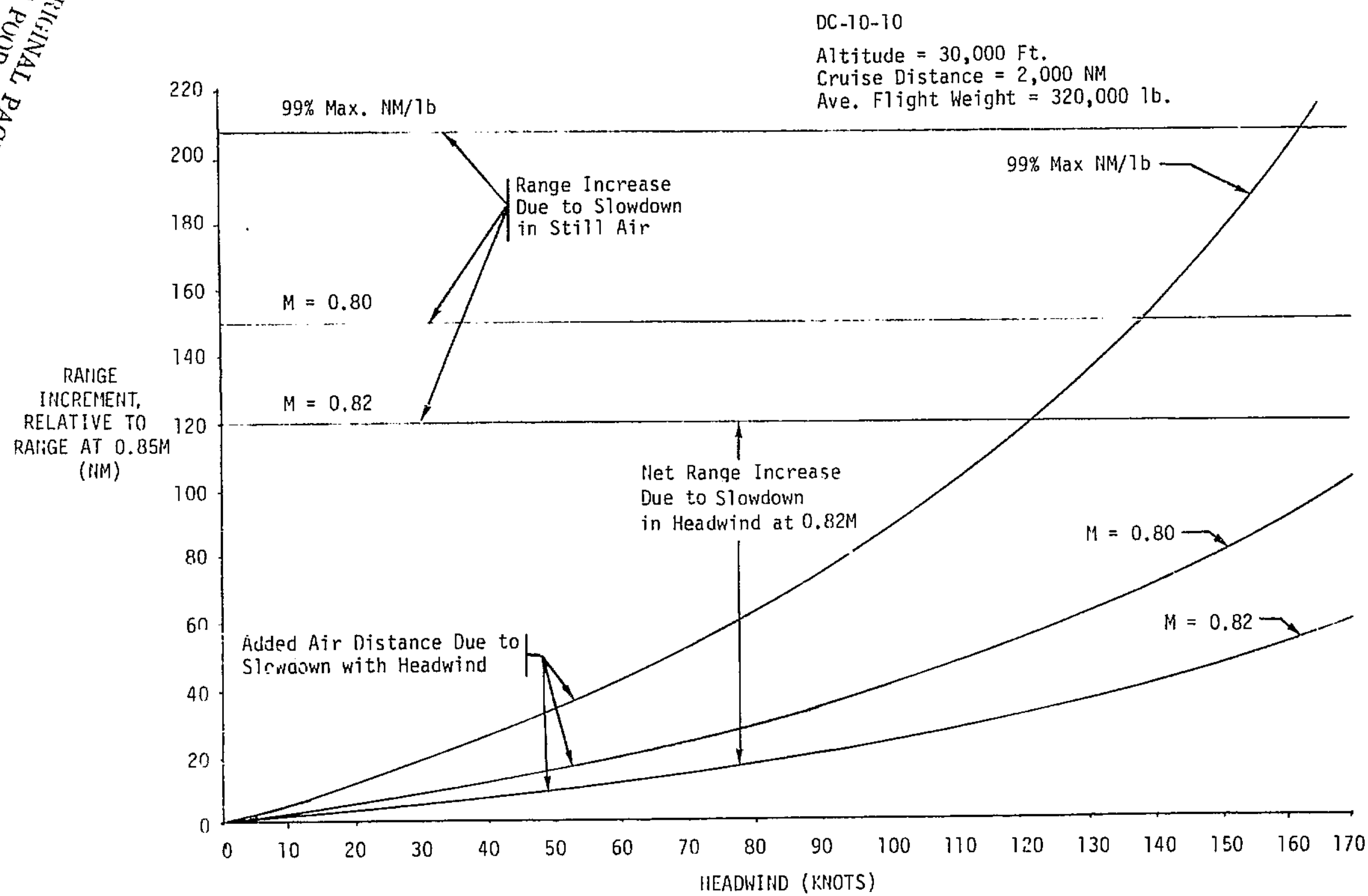


FIGURE 20. RANGE INCREMENT DUE TO SLOWDOWN FROM 0.85M

Horizontal lines represent the additional range capability gained by slowing from 0.85M to the noted Mach number. The curved lines show the additional miles that must be flown as a result of the effect of the headwind at each Mach number. The difference between the curves and the horizontal lines represents the actual benefit of the speed reduction. For very high headwinds, it is more economical to increase cruise speed in order to reduce the time of exposure to the headwind.

Tailwinds do not balance the headwind effect. At 0.82M at 30,000 feet a 40 knot tailwind gives back only about 85 percent as much fuel for a given cruise distance as a 40 knot headwind takes, because tailwind exposure time is less than headwind exposure time. Furthermore, not all winds are pure headwind or tailwind, and only quartering or pure tailwinds provide a net cruise benefit. Thus, only about 25 percent of the winds provide any fuel benefit at all in a random wind environment. In this study, still air was assumed. Consequently, the fuel-saving benefits shown in this study for reduced speed will be decreased in practice by the effect of the wind.

2.1.4 Navigation

Aircraft generally navigate along prescribed routes derived from ground based navigation stations such as VOR stations. Due to the locations of these stations, an aircraft may fly a nondirect route from origin to destination. Area navigation (RNAV) has been proposed as a means to reduce this nondirect routing in an advanced ATC system.

Area navigation is an onboard sensing and calculation system that operates upon radio signals from VOR-DME stations or other ground based navigational equipment. From these signals the current position of the aircraft is determined and further calculations allow the aircraft to fly along a direct route between two city pairs. Three-dimensional RNAV offers the increased possibility for direct vertical guidance during climb and descent maneuvers. Four-dimensional RNAV (4-D RNAV) adds the capability of scheduling the aircraft location precisely with time. This would permit timing the entire flight, from engine startup to shutdown, in order to schedule departure and arrival times to minimize delays.

2.1.5 Holding

Whenever possible, holding should be carried out with the aircraft in a clean configuration and at the highest possible altitude. When terminal delays are expected at the destination, the linear hold technique can be used if ATC permits. This involves reducing the cruise speed to absorb as much of the delay as possible enroute. One benefit of linear holding is that cruise speeds can be reduced to closely approximate long-range cruise. Another benefit results from eliminating or reducing time spent in a racetrack hold pattern. Maneuver requirements in the racetrack pattern increase fuel flow about 4 percent.

If significant congestion is anticipated at the destination airport, delays can be minimized by holding aircraft at the departure gate. The Federal Aviation Agency (FAA) has estimated that 658,000 gallons of jet fuel were saved on January 7, 1976 by holding aircraft at the originating airport until they could be assured of being accepted at Chicago's O'Hare International Airport. High winds at O'Hare had seriously reduced the airport's traffic-handling capacity that day. As a result of the success of this one-day test, this procedure is being refined for regular operational use.

2.1.6 Reserves, Contingencies, and Tankering

Airlines carry more fuel than required for the basic mission for several reasons. Fuel reserves are carried to assure that there is enough fuel to reach an alternate airport in the event that the destination airport is closed. Aside from a careful choice of alternates, and possibly adopting the technique of planning to reclear to the alternate enroute, regulations make it difficult to reduce fuel reserves. Airlines also carry contingency fuel, at the discretion of the pilot, in cases where extremely poor weather or other problems are anticipated. Fuel is tankered whenever local prices make this advantageous or when availability is a problem at certain locations.

Minimizing the amount of excess fuel carried is one of the most important items for overall fuel savings. Carrying extra fuel increases aircraft weight, which requires higher engine thrust and, hence, increases fuel use. For example, a DC-10 on a 2,000 nautical mile trip at 30,000 feet and 0.82M will consume 10 percent of any surplus fuel carried to the destination. At 5,000 nautical miles, 34 percent of the surplus fuel is consumed.

2.2 Airline Operations

2.2.1 Seating Density and Load Factor

Seat-mile fuel economy can be improved by adding more seats and by filling more seats. However, airlines must watch their competitive position. Smaller, closer seats are less comfortable; and higher average load factors imply fewer available flights, sometimes resulting in the turning away of potential passengers at peak times. Both effects can seriously reduce passenger appeal if taken to an extreme.

2.2.2 Maintenance

Engine, airframe, and instrument maintenance standards can affect overall aircraft efficiency. Recent studies show that more intensive engine maintenance procedures can reduce the deterioration that causes SFC to rise with time, and additional work in this area has been recommended (References 12 and 13). In the RECAT study it was estimated that maintaining closer tolerances on engine performance could lead to a 0.3 percent improvement in SFC for narrow-body aircraft and a 1 percent improvement for wide-body aircraft.

Aircraft skin damage increases drag. In a recent audit of aircraft condition, one aircraft was found to have 170 dents caused by ground vehicles. Improperly rigged spoilers, ailerons and flaps can increase drag 5 to 10 percent. Machmeter, altimeter, and fuel flow instrument errors can adversely affect fuel economy. They can also improve economy, depending on direction of error. Consequently, in this study the overall fleetwide effect of instrument error was assumed to be negligible.

2.2.3 Loading

Aircraft center of gravity (CG) location has a small but noticeable effect on drag. From a fuel efficiency standpoint, it is better to load the airplane toward the aft CG limit because the down force required on the horizontal stabilizer to maintain trim is reduced, which reduces the overall airplane drag. Most airlines have a target CG location as far aft as possible. However, tight scheduling of passenger and baggage loading often makes it difficult to meet the target CG. It is uneconomical to delay the flight or to rearrange baggage in order to achieve the target CG. The RECAT study airline contractor felt that the target CG could be moved aft another 1/2 to 1 percent if stricter discipline were used in loading. This could result in an average 0.1 percent reduction in fuel use.

2.2.4 Flight Planning

By careful selection of alternate airports closer to the destination, reserve fuel carried can be reduced. On long distance flights, another useful technique is reclearing to the alternate destination while enroute. Many airlines use computer-assisted flight planning techniques which permit examination of alternate routes and altitudes to take advantage of wind and temperature conditions.

2.2.5 Ground Maneuver and Delays

Large amounts of fuel can be consumed by extended ground circuits and delays at the takeoff point due to congestion. One airline has reported that one of its wide-body aircraft was number 46 in line for takeoff on a congested day at JFK Airport and burned 2,800 pounds of fuel from startup to start of takeoff.

Some airlines have experimented with shutting down one or several engines during taxi operations, but fuel savings were insignificant in most cases. Also, several operational problems were encountered, including increased jet blast and increased foreign body ingestion caused by the higher thrust of the engines in use, interruption of starting drills, additional pilot work-load, need for fire protection during startup, increased problems if an engine fails to start, and the need for engine warm-up.

Tugs and powered wheels have been studied as fuel saving possibilities (References 14 and 15); but these solutions are cumbersome, add complexity, and are uneconomical because of the very slow ground movement speeds that result.

Careful scheduling and flight planning can minimize ground maneuver and delay time. The most effective way to reduce fuel consumed by departure delays is to hold the aircraft at the gate until a departure can be made without waiting at the takeoff point. Ground delays at the destination can be reduced by some of the holding methods described in Section 2.1.5.

2.2.6 Takeoff and Landing

Use of reduced flap settings and thrust settings can reduce takeoff fuel. When noise abatement is not a factor, flaps and slats should be retracted as soon as possible after passing 800 feet and clear of obstacles. On approach, the maneuvering configuration should be maintained until intercepting the glidepath. By delaying application of landing flap to 1,000 feet instead of 1,500 feet, additional fuel can be saved. Where runway and weather conditions permit, it is better to use reduced flap settings for fuel economy.

2.3 Operating Procedures Selected for Study

The study flight and airline operational variations are compared to the baseline operations in Table 14. Some alternative flight operations, such as cruise climb and 4-D RNAV require an advanced ATC system for their implementation.

The effect of 4-D RNAV in an advanced ATC environment is twofold: 1) it permits an average 1/2 percent reduction in flight distance due to direct routing, and 2) it allows precise departure and enroute scheduling, which is credited with an average 5 minute reduction in delay and maneuver time.

The effect of fuel-conservative flight profiles, relative to the baseline flight profile, is given in Table 15. The fuel-conservative profile in the current ATC system includes long-range operations in climb, cruise and descent. For an advanced ATC system, the fuel-conservative profile also includes cruise climb or 2,000 foot steps and use of 4-D RNAV.

Fuel-conservative operations in the current ATC system reduce fuel use by about 4 to 8 percent, depending on the aircraft. Block fuel savings are substantially improved by upgrading the ATC system, becoming 8 to 11 percent. An additional benefit of advanced ATC is the reduction in DOC's. With the current ATC system, fuel-saving flight profiles result in lower speeds which increase block time and DOC's. The assumed delay time reduction in the advanced ATC system reduces overall block time and, together with fuel savings, decreases DOC's.

In order to assess the possibility of additional fuel savings beyond those shown in Table 15 for fuel-conservative flight profiles with advanced ATC,

TABLE 14

OPERATIONAL VARIATIONS

	OPERATIONAL ITEM	BASELINE OPERATION	FUEL - CONSERVATIVE OPERATION	
			CURRENT ATC	ADVANCED ATC
FLIGHT OPERATIONS	CLIMB AND DESCENT PROFILES	HIGH SPEED PROFILES	LONG RANGE PROFILES	LONG RANGE PROFILES
	CRUISE ALTITUDE	4000' STEP ALTITUDE WHEN APPROPRIATE	4000' STEP ALTITUDE WHEN APPROPRIATE	2000' STEP ALTITUDE WHEN APPROPRIATE, OR CRUISE CLIMB
	CRUISE SPEED	HIGH SPEED CRUISE MACH NUMBER (A)	LONG RANGE CRUISE @ 99% MAX NM/LB	LONG RANGE CRUISE @ 99% MAX NM/LB
	NAVIGATION	VOR	VOR	4-D RNAV
	MANEUVER & DELAY TIME	15 MINUTES	15 MINUTES	10 MINUTES
AIRLINE OPERATIONS	LOAD FACTOR	58%	65%	65%
	SEATING DENSITY	10/90 SPLIT, 38"/34" PITCH	ALL COACH, 34" PITCH	ALL COACH, 34" PITCH
	MAINTENANCE STANDARDS	MAINTAIN SAFETY, RELIABILITY, AND APPEARANCE (B)	ALSO MAINTAIN CLOSER TOLERANCES ON ENGINE AND AERODYNAMIC PERFORMANCE	ALSO MAINTAIN CLOSER TOLERANCES ON ENGINE AND AERODYNAMIC PERFORMANCE
	C.G. LOCATION	TARGET C.G. APPROXIMATELY 1-3% FORWARD OF MOST AFT C.G. LOCATION POSSIBLE (B)	MOVE C.G. AFT 1%	MOVE C.G. AFT 1%

A SEE TABLE 1

B IN-SERVICE OPERATION, NOT STUDY BASELINE

TABLE 15

EFFECT OF FUEL-CONSERVATIVE FLIGHT OPERATIONS
ON BLOCK FUEL AND DOC
AT 1973 CAB AVERAGE STAGE LENGTH

AIRCRAFT	FUEL-CONSERVATIVE FLIGHT PROFILE (1) CURRENT ATC				FUEL-CONSERVATIVE FLIGHT PROFILE (2) ADVANCED ATC			
	ΔBLOCK FUEL $\left(\% \frac{BTU}{ASNM}\right)$	ΔDOC $\left(\% \frac{¢}{ASNM}\right)$			ΔBLOCK FUEL $\left(\% \frac{BTU}{ASNM}\right)$	ΔDOC $\left(\% \frac{¢}{ASNM}\right)$		
		@ 15¢/GAL	@ 30¢/GAL	@ 60¢/GAL		@ 15¢/GAL	@ 30¢/GAL	@ 60¢/GAL
DC-8-20	-4.96	4.70	2.30	-0.10	-9.57	-0.28	-2.58	-4.89
DC-8-50	-4.44	5.54	3.42	1.08	-8.42	0.57	-1.34	-3.44
DC-8-61	-4.84	5.40	3.20	0.78	-9.11	0.38	-1.65	-3.90
DC-9-10	-8.19	5.04	2.71	-0.13	-10.98	0.57	-1.46	-3.99
DC-9-30	-7.86	3.53	1.56	-0.83	-9.85	-0.63	-2.30	-4.28
DC-10-10	-6.42	2.94	1.07	-0.97	-10.30	0.18	-1.92	-4.28
DC-10-40	-6.90	2.68	0.81	-1.35	-11.10	-0.42	-2.51	-4.92

(1) INCLUDES LONG RANGE CLIMB AND DESCENT, 4000' STEP ALTITUDE CRUISE @ 99% MAX NM/LB

(2) INCLUDES LONG RANGE CLIMB AND DESCENT, CRUISE CLIMB @ 99% MAX NM/LB, 33% (5 MIN.) REDUCTION IN DELAY AND MANEUVER TIME, 4-D RNAV.

an idealized mission profile was studied for the DC-10. The idealized profile involved calculation of the energy required to lift the aircraft to altitude, accelerate it to long-range cruise speed, cruise climb, and descend at flight idle. Power plant efficiency and aircraft drag were taken into consideration. The fuel use for the idealized profile was only 2 percent less than for the fuel-conservative operations with advanced ATC shown in Table 15. It is clear, then, that fuel-conservative flight profiles with advanced ATC permit nearly optimum fuel efficiency, and that the ATC system should be upgraded to take advantage of the existing aircraft capability to conserve fuel.

Seating density changes were made by removing the first class sections of the baseline configurations and converting to all coach interiors at 34-inch seat pitch. To show the effect of even higher density seating arrangements, the DC-10-40 interior was also changed from 8 to 9 abreast. Table 16 shows the baseline and high density seating capacities for the study baseline airplanes.

The effects of increased seating density are given in Table 17 at the 1973 CAB average stage length for each aircraft. Fuel use per seat-mile is reduced 7 to 13 percent, depending on the aircraft. The large difference between the DC-10-10 and DC-10-40 effects is due to the differences in both baseline and high density interiors.

TABLE 16
BASELINE AND HIGH DENSITY SEATING CAPACITIES

Aircraft	Baseline (10/90 split)	High Density (all coach)
DC-8-20	146	159
DC-8-50	146	159
DC-8-61	203	218
DC-9-10	70	77
DC-9-30	92	105
DC-10-10(1)	277	293
DC-10-40	252	295(2)

(1) lower galley, (2) 9-abreast

TABLE 17

EFFECT OF FUEL-CONSERVATIVE AIRLINE OPERATIONS
ON BLOCK FUEL AND DOC
AT 1973 CAB AVERAGE STAGE LENGTH

AIRCRAFT	INCREASED SEATING DENSITY (1)				INCREASED LOAD FACTOR (2)			
	Δ BLOCK FUEL $\left(\% \frac{BTU}{ASNM}\right)$	Δ DOC $\left(\% \frac{¢}{ASNM}\right)$			Δ BLOCK FUEL $\left(\% \frac{BTU}{RPNM}\right)$	Δ DOC $\left(\% \frac{¢}{RPNM}\right)$		
		@ 15¢/GAL	@ 30¢/GAL	@ 60¢/GAL		@ 15¢/GAL	@ 30¢/GAL	@ 60¢/GAL
DC-8-20	-7.31	-7.86	-7.74	-7.61	-9.33	-10.11	-9.96	-9.73
DC-8-50	-7.33	-7.96	-7.80	-7.70	-9.36	-10.21	-10.04	-9.86
DC-8-61	-6.14	-6.73	-6.56	-6.45	-9.38	-10.30	-10.07	-9.87
DC-9-10	-8.63	-9.00	-8.92	-8.84	-10.29	-10.77	-10.66	-10.57
DC-9-30	-11.47	-12.17	-12.04	-11.91	-10.94	-12.20	-12.08	-11.97
DC-10-10	-4.87	-5.34	-5.27	-5.15	-9.49	-11.28	-11.14	-10.94
DC-10-40	-13.06	-14.06	-13.87	-13.63	-10.06	-11.50	-11.36	-11.26

(1) CHANGE 10/90 SPLIT TO ALL TOURIST @ 34" PITCH (ON DC-10-40, ALSO CHANGE SEATS FROM 8 TO 9 ABREAST)

(2) INCREASE LOAD FACTOR FROM 58% TO 65%

The increased load factor of 65 percent, shown for fuel-conservative airline operations in Table 14, is close to the maximum average value that can be maintained on a fleetwide basis without leaving a significant number of passengers behind in peak travel periods. The effects of increasing load factor from 58 to 65 percent are shown in Table 17. The energy per passenger carried is reduced approximately 9 to 11 percent. The variation between aircraft is due mostly to differences in baseline configurations. Operating costs on a passenger-mile basis are improved about 10 to 12 percent.

Since improvements in both maintenance standards and CG location result in fuel savings, these items were included in Table 14. The objective of improved maintenance standards is to maintain aircraft efficiency closer to new aircraft levels. No fuel saving benefit for improved maintenance is taken relative to baseline levels in this study, however, because the baseline fuel consumption levels are representative of aircraft in new condition. In addition, due to the difficulty in achieving a more stringent target aft CG location, and the small potential benefits (Section 2.2.3), no fuel saving credit is taken in this study for more aft loading.

Figure 21 summarizes the results of the fuel-conservative operations study. Fuel-saving operational options could be combined to give even greater savings. For example, relative to the baseline operation, the DC-10-40 shows an 11.1 percent improvement in fuel consumption for fuel-conservative flight profiles in an advanced ATC system and a 13.1 percent improvement for 9-abreast, all coach seating. Together, these options would give a fuel saving of 22.7 percent. The percentages combine as follows: $1-(1-.111)(1-.131) = .227$. If these improvements are combined with the 10.1 percent fuel reduction for increased load factor, the overall fuel saving is 30.5 percent. However, high seating density and high load factors together lead to reduced passenger appeal.

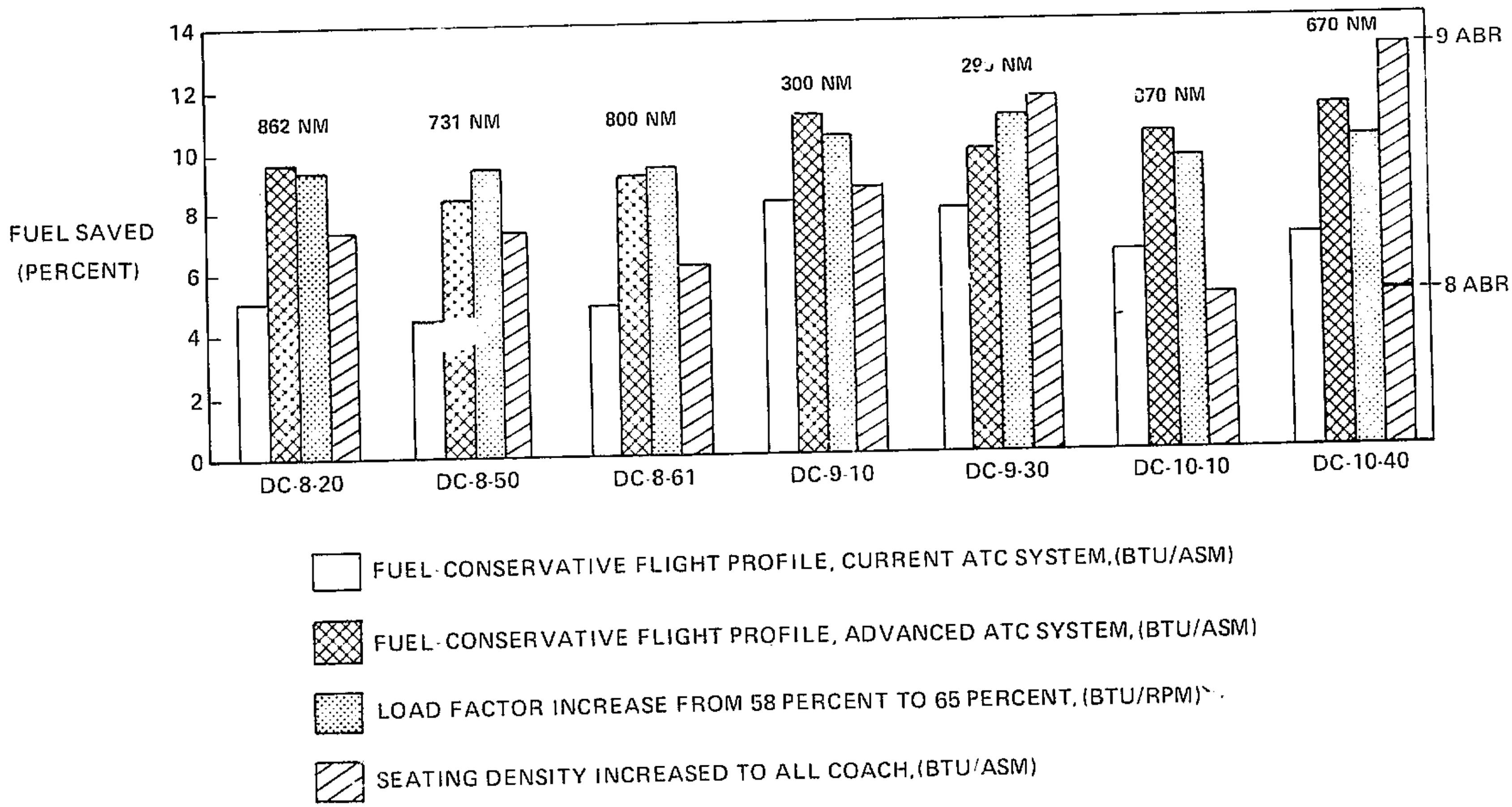


FIGURE 21. FUEL SAVED BY FUEL-CONSERVATIVE OPERATIONS

SECTION 3.0
TECHNOLOGY

3.1 Advanced Technology

Technology, as applied to commercial aircraft, tends to be more of an evolutionary process than revolutionary. Aircraft designed in a particular time period contain the proven technology of that period, with derivative aircraft incorporating new technology as it becomes available and is cost-effective. In recent years dramatic developments have been made in systems technology, transonic aerodynamics and new materials. A brief description of the technology advances considered viable for retrofit of existing aircraft, for derivatives of in-production aircraft, or for new aircraft available in the 1980 time period are given in this section.

3.1.1 Improved Transonic Airfoils

Improved transonic, or supercritical, airfoils have been in development for several years. This class of airfoil was originally developed by Dr. Richard T. Whitcomb of the NASA Langley Research Center. Extensive wind tunnel and theoretical research has been conducted in many countries in universities, industry, and national laboratories, and several aircraft have been flown using supercritical airfoils. Figure 22 shows that supercritical airfoils can offer a substantially higher drag divergence Mach number for a given airfoil thickness, an excellent structural shape, and high maximum lift coefficient.

Figure 23 compares the pressure distribution of a supercritical airfoil with that of an airfoil in use on a modern transport. Relative shapes are also shown. An important characteristic of supercritical airfoils is the higher loading towards the trailing edge due to aft camber. With greater load carried over the aft portion, the pressure coefficient is reduced at and aft of the airfoil crest. The crest is the point on the upper surface tangent to the freestream. Lowering the negative pressure coefficient at and aft of the crest raises the drag divergence Mach number.

Another significant characteristic of the airfoil, from which it derives its name "supercritical", is its flat upper surface which allows the shock to move back rapidly on the chord resulting in a larger chordwise extent of

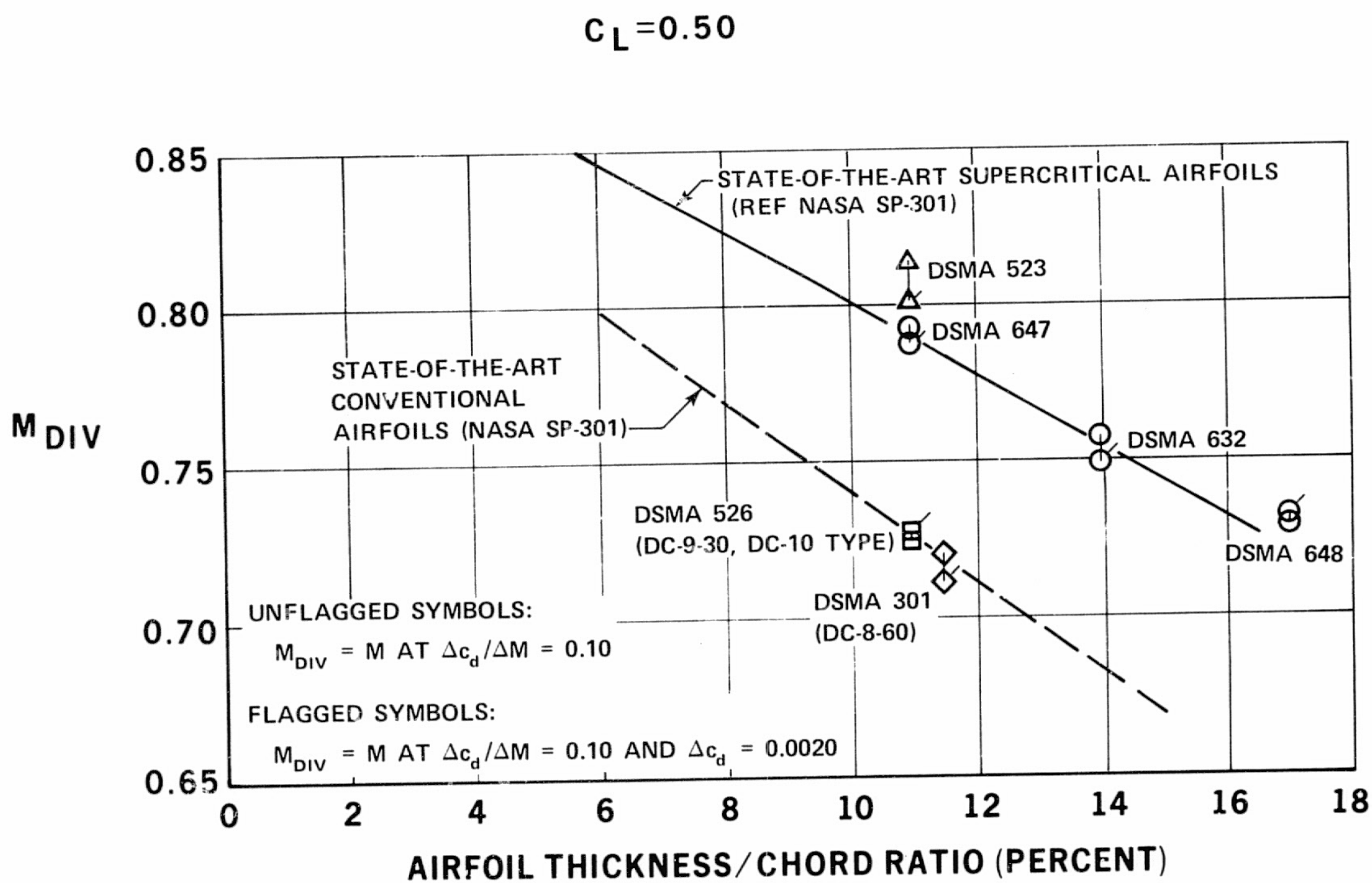


FIGURE 22. DRAG DIVERGENCE MACH NUMBER VARIATION WITH AIRFOIL THICKNESS RATIO

supercritical flow than that exhibited on present-day airfoils (Figure 24). It is important to note that the maximum velocities on this type of airfoil are no higher than those of conventional airfoils; only the extent of the supercritical region differs. This large supercritical region results in a significantly improved L/D since much more lift is generated for a given shock loss. The third characteristic of the transonic airfoil is the tangency of the upper and lower surfaces at the trailing edge, which eliminates the large pressure increase normally found on an airfoil and permits the higher adverse pressure gradient required by the aft loading, without causing separation on the upper surface of the wing. The upper surface is relatively flat through the midsection of the airfoil and the lower surface is cusped just ahead of the trailing edge. This shape gives slightly greater front spar depth and somewhat lower rear spar depth for a given overall airfoil thickness.

A disadvantage of the airfoil is the difficulty of constructing a section with a tangent upper and lower surface at the trailing edge. This requires a very thin section. It appears, however, that modern structural technology can handle this problem with honeycomb techniques.

Although the characteristics of the supercritical airfoil can be used to increase either speed or lift capability, these characteristics can also be used to increase thickness and aspect ratio, and reduce sweep. The optimum configuration for any wing design is determined by analyzing various combinations of thickness and sweep. Important benefits can be obtained by using supercritical airfoils. The DC-9-30D3 aircraft, described in Section 4.0, derives nearly a 5 percent fuel saving from its supercritical wing, and a small reduction in operating costs is obtained at higher fuel prices.

3.1.2 Winglet Drag Reduction

Recent NASA research and wind tunnel work has shown potential aerodynamic performance improvements for specially tailored and cambered wing end plates, commonly referred to as winglets. Winglets are capable of providing induced drag reductions, and corresponding airplane performance improvements, which

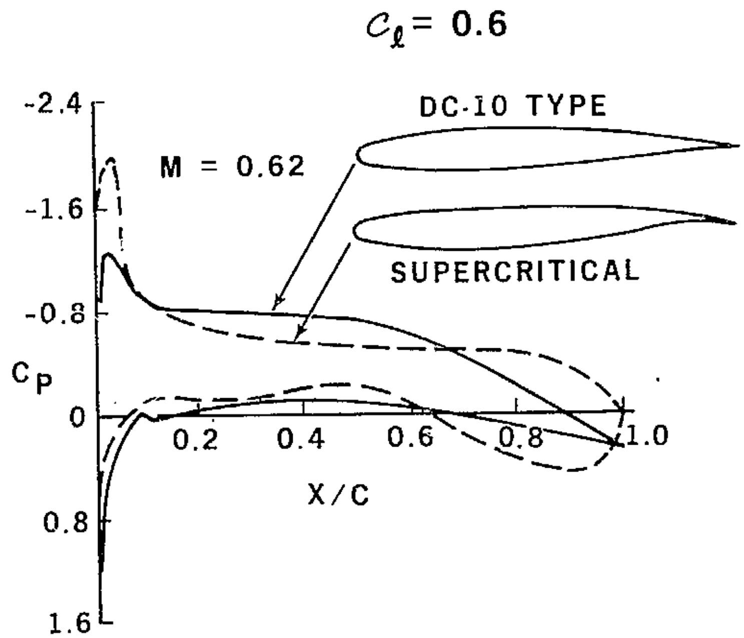


FIGURE 23. COMPARISON OF 2-D AIRFOIL SECTION CHARACTERISTICS

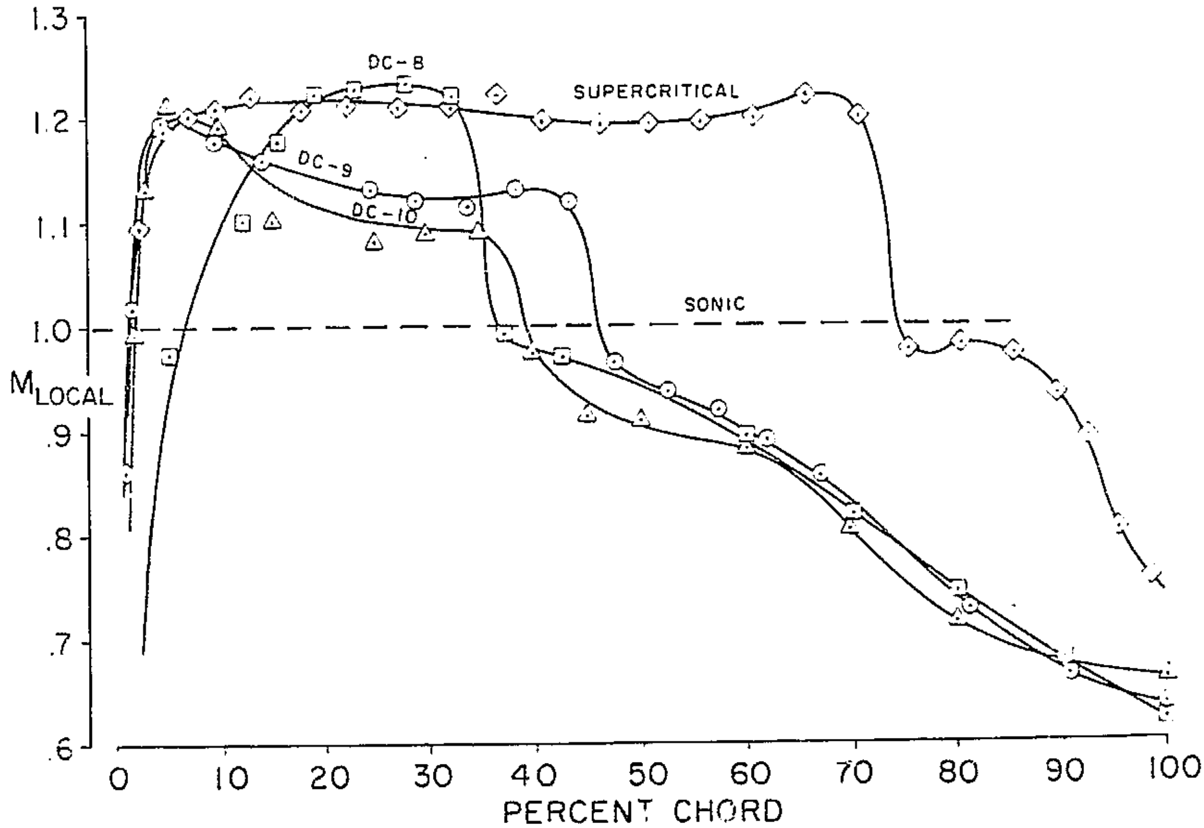


FIGURE 24. LOCAL MACH NUMBER ON UPPER SURFACE AT CRUISE CONDITIONS

are greater than the performance penalties resulting from weight and parasite drag increases.

NASA and Douglas work to date indicates that the induced drag improvement is a function of winglet root loading. Primary design parameters controlling winglet loading include winglet span and winglet spanwise airfoil distribution, incidence angle, dihedral angle, chord and sweep. Of secondary importance are winglet taper ratio and geometric twist.

Since the maximum induced drag improvement for a winglet occurs when the winglet root is highly loaded, winglet geometry optimization requires a tradeoff between winglet loading and structural considerations for a given level of induced drag reduction. A measure of the additional wing bending material required to accommodate winglets (i.e., a "weight index") can be obtained from an integration of a weight parameter that is a function of both wing bending moment and airfoil thickness. A typical winglet performance summary is presented in Figure 25, which shows induced drag reduction and weight as a function of airplane lift coefficient and winglet incidence, for a given winglet dihedral. The root normal force coefficient on the winglet, which is indicative of the extent to which the winglet will maintain attached flow, is also shown. A summary of this type provides a measure of the weight penalty imposed for a given induced drag reduction at a specified level of winglet root loading.

3.1.3 Active Controls

Reductions in tail size and in gust and maneuver loads, and gains in the control of flutter have become possible by using active control systems. Reduced static stability (RSS) systems sense flight path perturbations and quickly actuate the proper control surface correction; and the smaller tails used with RSS result in lower drag, weight, fuel consumed and cost. Gust and maneuver load alleviation (GLA and MLA) extend fatigue life and decrease structural design loads and structural weight. Flutter control reduces wing stiffness requirements, and thus weight, to a level consistent with that required by strength.

3.1.4 Advanced Material Applications

Aircraft design improvements are rapidly evolving within structures technology through the application of high-modulus fibrous composites and advanced metallic materials.

Composite structure studies conducted by Douglas and other aircraft manufacturers have made it possible to apply composite technologies in the fabrication of commercial aircraft. The studies show that the use of high-modulus, low density fibrous composites, such as boron-epoxy, boron-aluminum, and graphite-epoxy, provides the flexibility to tailor the structural design more efficiently than with conventional materials, resulting in a substantial reduction in airplane weight, manufacturing cost, and airplane fuel consumption.

Recently, NASA contracted with Douglas to fabricate, and place into service, graphite-epoxy rudders for the DC-10. The structural arrangement is shown in Figure 26. Utilizing the technology gained from previous Douglas and NASA studies, Douglas has initiated additional DC-9 and DC-10 composite secondary structure weight reduction studies. These studies include composite wing and tail control surfaces and trailing edges, fuselage floors and floor beams, and doors. Preliminary results, on a wide variety of secondary structural components, have shown that weight savings of 15 to 30 percent can be achieved with the use of composites.

Previous advanced metallic structure studies have shown that the application of advanced metallics to future aircraft will require a minimum deviation from normal design procedures. The greatest difference will be due to the new fabrication techniques required for the new metallics systems. Douglas has studied many structural weight reduction concepts, including such items as integrally machined wing skin panels, honeycomb sandwich tail skin panels, and an isogrid fuselage shell. These have shown substantial potential weight savings over conventional structural fabrication methods.

An aluminum alloy isogrid window belt structure for the DC-10 is shown in Figure 27. Isogrid refers to frames or integrally stiffened plates with multiple triangular pockets. The gridwork behaves as an isotropic sheet,

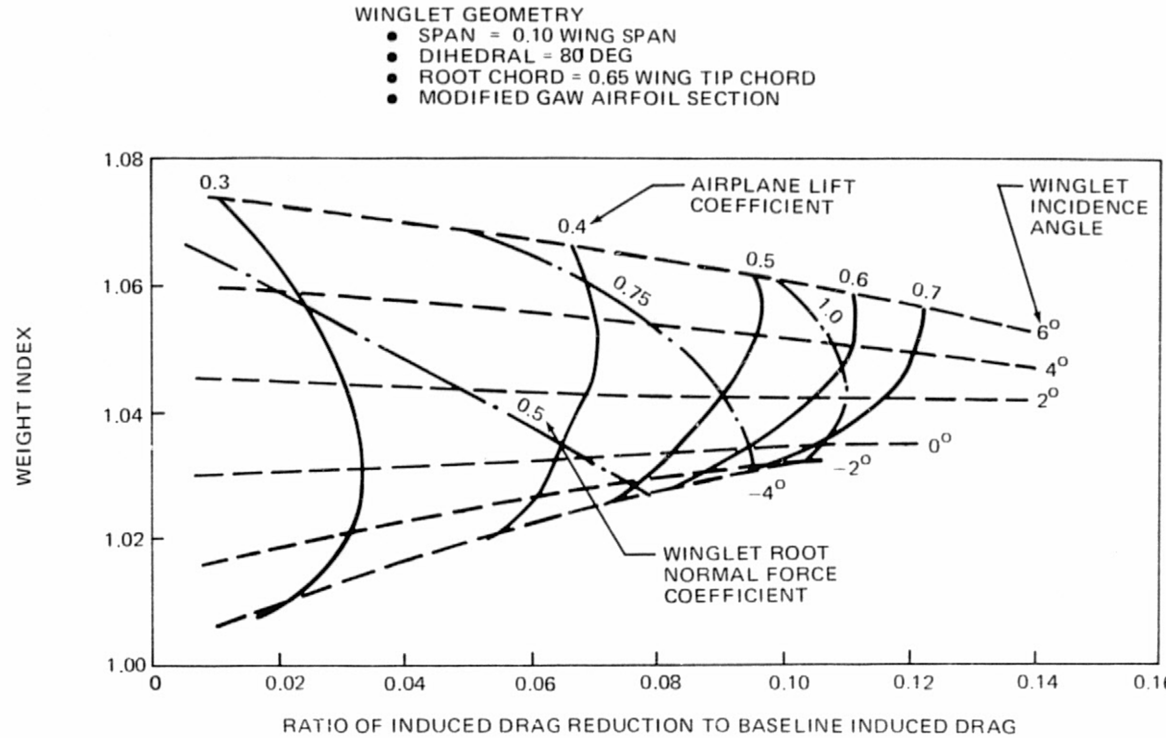


FIGURE 25. REPRESENTATIVE WINGLET PERFORMANCE SUMMARY FOR DC-10-30 AIRPLANE

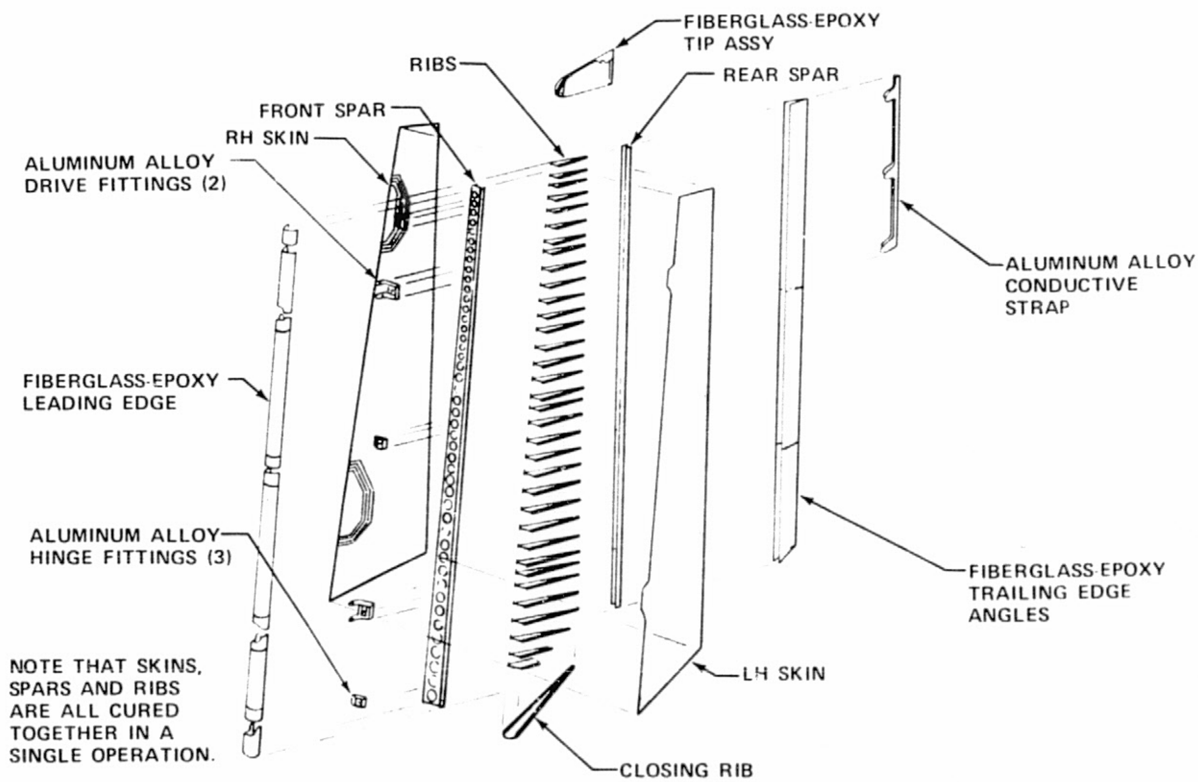


FIGURE 26. STRUCTURAL ARRANGEMENT FOR GRAPHITE-EPOXY RUDDER

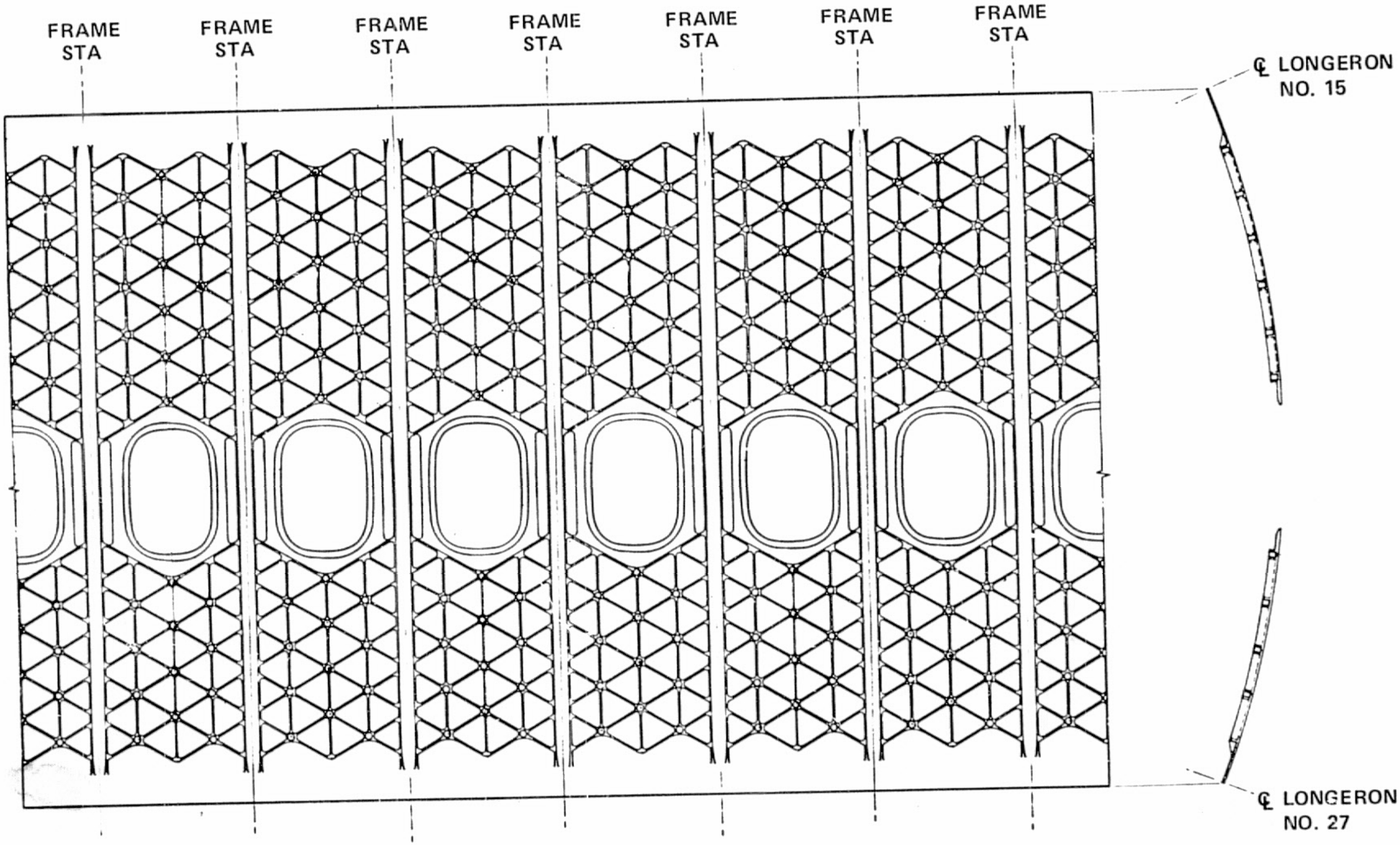


FIGURE 27. DC-10 ISOGRID WINDOW BELT

hence, "isogrid". Both aluminum and composite panels of isogrid have been built and tested by DAC. Aluminum isogrid can be machined from flat plate on a numerically controlled mill. The simple repeating pattern is economical to design and build. The nodes provide numerous natural attachment points, and discontinuities can be handled by local adjustments in pocket size and/or web and skin width. Isogrid fuselage sections have a wall thickness nearly 4 inches thinner than conventional stiffened skin sections. If circumferential frames are used, as when isogrid is installed as a modification to an existing fuselage, the frames can be narrowed about 1.5 inch. The properties of isogrid make it a natural candidate for the window belt region. Extra cabin width is achieved along with design and construction simplicity. Weight savings are also achieved because the isogrid geometry can be tailored to local loads. On the DC-10-40D derivative presented in Section 4.0, the isogrid window belt saves 1,515 pounds relative to the built-up structure currently used. Isogrid window belts are also included in the study DC-10 production modifications and in the new near-term aircraft.

3.1.5 Carbon Brakes

The Douglas Aircraft Company, in conjunction with aircraft brake manufacturers, has initiated a program to develop the technology required for replacing the DC-10 steel brake assemblies with carbon brakes. Current carbon brake development studies and tests show that, due to a significant reduction in heat sink weight on the DC-10-40, there is a weight savings of 1,100 pounds. The benefit for the DC-10-10, which has no center main gear, is 890 pounds.

3.1.6 Propulsive Noise Reduction

Current production engines have single degree of freedom acoustically absorptive liners in the fan inlet, fan exhaust duct and turbine exhaust. For the new near-term aircraft study, multiple degree of freedom absorptive liners were assumed for the fan inlet and fan exhaust duct acoustic treatment, in order to provide noise reductions over a wider frequency range.

3.2 State-of-the-Art Technology

In addition to new technology that could be applied to commercial transports, a number of state-of-the-art modifications could be made to improve the performance of these aircraft. A brief description of the drag and weight improvement concepts considered in this study follows.

3.2.1 Fairings, Gaps, Steps

An examination of the existing fleet indicates that a general drag cleanup program involving fillets, fairings, gaps, seals, etc. can give a potential cruise drag improvement of 5 to 10 percent, depending on the airplane and extent of cleanup. High on the list of cleanup items for the DC-8 and DC-9 are the aerodynamically-balanced control surfaces which have inherently large gaps. Due to the low fuel price prevalent when the DC-8 and DC-9 were designed, the 4 to 5 percent drag penalty for these gaps was offset by the complexity and cost of a powered control system. Even with today's high fuel prices, the cost of modifying the DC-8 or DC-9 to use powered controls is too high. However, the DC-10 and most other recent commercial aircraft have powered controls.

Filleting at the tail/fuselage and the wing/fuselage intersections, as shown in Figures 28 and 29, can eliminate small areas of flow separation, giving up to a 3 percent cruise drag improvement. Elimination of production steps (e.g., slat-to-wing, spoiler-to-wing), as shown in Figure 30, can give a measurable drag improvement depending on the size of the step eliminated. Other items such as lights, antennas, drain masts, rain gutters, rivet heads, etc. have a potential for as much as 4 percent drag improvement if completely eliminated. However, it is very difficult and expensive to remove or otherwise house many of these items since they are required for commercial operation.

3.2.2 Extended Wing Tips

Traditionally wing tip extensions have been added primarily for takeoff performance improvement. However, a cruise drag improvement may also be obtained with a tip extension. A tip extension increases the parasite drag, while lowering the induced drag. Thus, the cruise lift coefficient is important in the evaluation of wing tip extensions. At low lift coefficients, the parasite drag penalty can exceed the induced drag improvement for a net drag increase. However, at the higher cruise lift coefficients typical of "growth" airplanes, the wing tip extensions can offer a significant improvement.

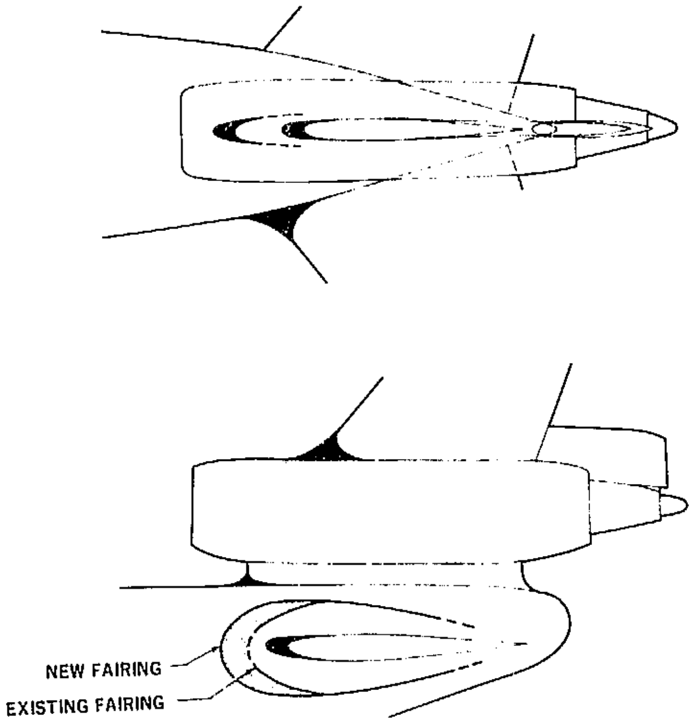


FIGURE 28. TAIL FILLETS

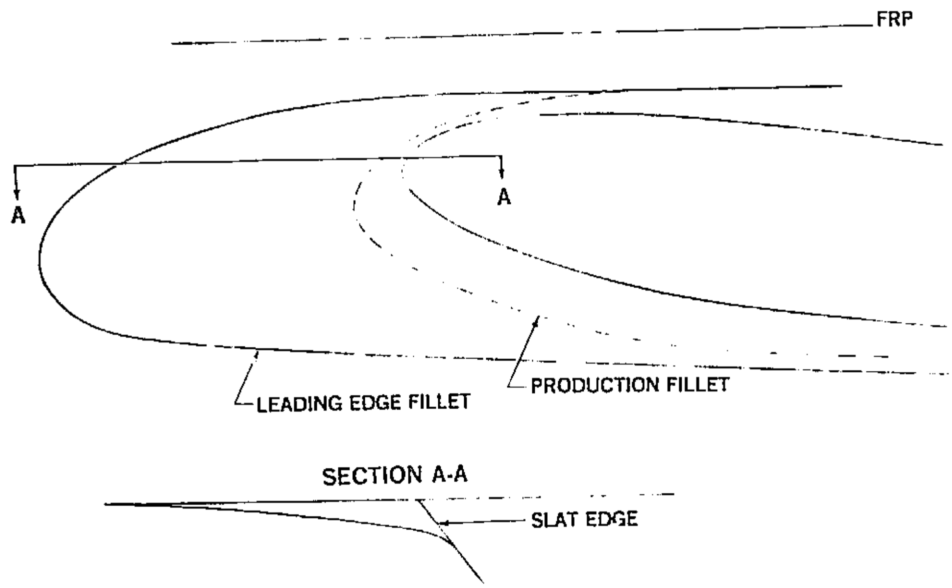


FIGURE 29. WING LEADING EDGE FILLET

3.2.3 Cutback Pylons

The cutback, or undercut, pylon was developed to minimize aerodynamic interference effects between the wing and the pylon. While the early models of the DC-8 did not use this approach, the DC-8-62 and DC-8-63 models (Figure 31) and all DC-10 models have this feature. Minimizing the interference effects requires the consideration of the curvature of the streamlines that exist on a swept wing. Since this curvature is most pronounced near the wing leading edge, pylons are now designed so that the pylon leading edge intersects the wing lower surface aft of this critical region. Typical improvements that could be applied to aircraft which do not currently have cutback pylons would be on the order of 0.5 percent of total airplane drag for short range missions and as much as two percent for long range missions.

3.2.4 General Weight Reduction

General weight reduction items include numerous changes, each of which provides a small weight improvement, and which together provide a sizeable weight savings. General weight reduction programs are ongoing throughout the production life of an aircraft, taking advantage of both new technology and service experience with the aircraft. Changes are incorporated on the production line as they are approved. These changes are typically not cost-effective as retrofit items. Some of the general weight saving items considered in this study are:

- reducing cabin interior side-wall lining thickness
- replacing current insulation blankets with lightweight blankets
- removing acoustic insulation from forward cabin floor
- deleting individual air outlets
- reducing cargo compartment liner to a thinner gage
- replacing steel door hinges with titanium hinges
- replacing steel fasteners with titanium fasteners
- removing clad from all aluminum bonded surfaces
- replacing current wires with equivalent lightweight wire
- reducing main gear trim cylinder diameter
- increasing main landing gear strut material allowables

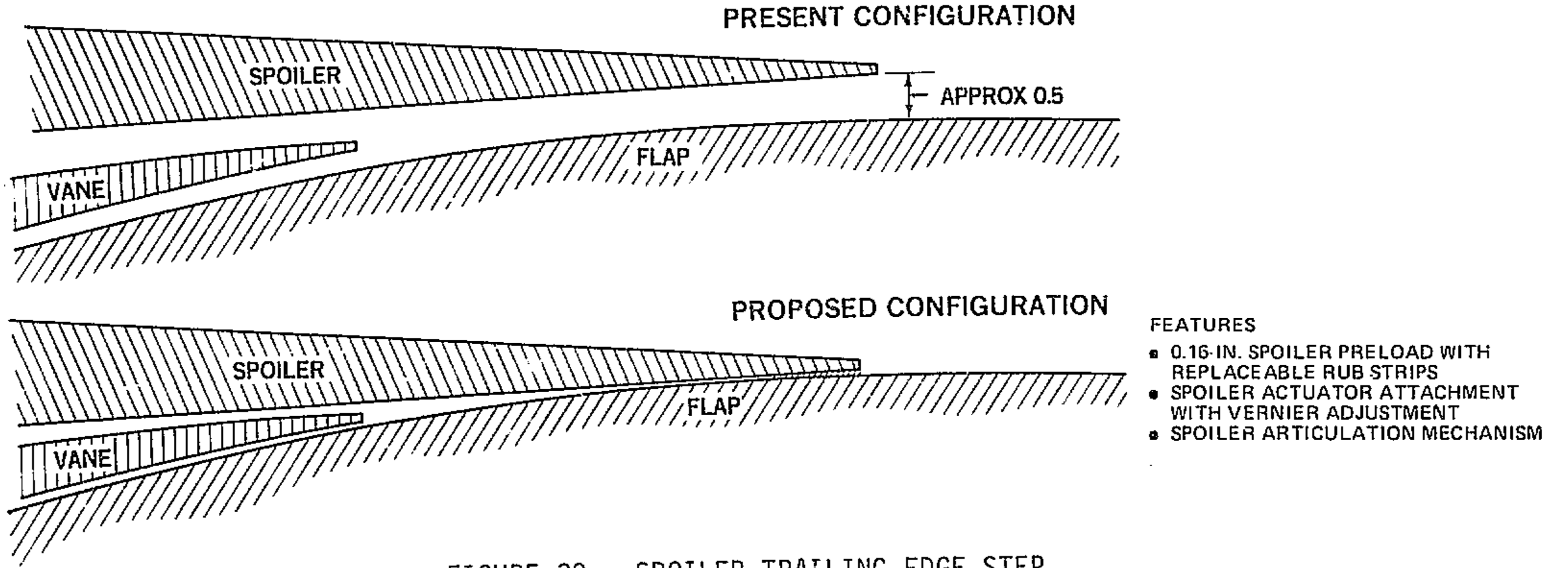


FIGURE 30. SPOILER TRAILING EDGE STEP

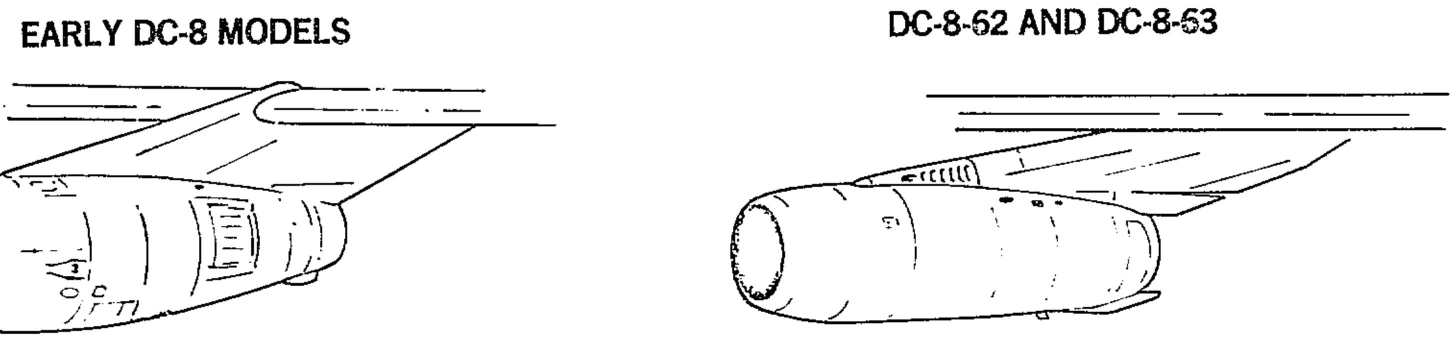


FIGURE 31. COMPARISON OF ORIGINAL AND CUTBACK DC-8 PYLONS

SECTION 4.0

MODIFICATION AND DERIVATIVE STUDIES

Aircraft design changes were studied in order to identify the fuel-saving potential of retrofit modifications, production modifications, and derivative airplanes. Following a sensitivity study to determine the relative value of drag, SFC, and weight improvements on each baseline airplane, a total of twenty reconfigured aircraft were proposed and analyzed.

4.1 Sensitivity Studies

In order to assess the relative value of reductions in drag, SFC, and weight, a study was made of relative fuel use and DOC changes when these items are improved 10 percent. Table 18 presents the results at the 1973 CAB average stage length for each aircraft. Drag and SFC changes are equivalent. The effect on DOC of a 10 percent increase in aircraft cost is also presented. It can be observed that, on a percentage basis, drag and SFC changes are approximately twice as effective as weight changes in improving fuel consumption. The effect of fuel price on DOC sensitivities is also shown. A doubling of fuel price from 30 cents to 60 cents per gallon increases the effect of the drag, SFC, and weight reductions on DOC, and reduces the effect of increasing aircraft price. Figure 32 shows the average sensitivity factors for each of the DC-8, DC-9, and DC-10 aircraft families.

4.2 Modification and Derivative Configurations

Table 19 presents the design changes which were combined to create twenty reconfigured study airplanes. Nomenclature for these study airplanes is also given in Table 19. The areas affected by design changes are indicated in Figures 33, 34, and 35. General drag reduction items include aerodynamic improvements such as rerigged controls, new fairings, reduced gaps and steps, and other items described in Section 3.2.1. General weight reduction items are summarized in Section 3.2.4.

Retrofit modifications were limited to engine changes and drag reduction items, including winglets. Engine retrofits were considered only for the DC-8 airplanes because properly sized replacement engines offering substantial SFC reductions are not available for the DC-9 and DC-10. The DC-8 retrofit packages were broken down into separate engine retrofit and drag retrofit packages in order to show th relative effects of these items.

Modification of production aircraft offers the possibility of structural redesign, using advanced metallics and composites to save weight. Only the DC-10 aircraft were studied for production modifications because only the DC-10-10 and DC-10-40 baseline aircraft have sufficient remaining production life to warrant substantial changes. Production has stopped on all DC-8 models and the DC-9-10 series. Production of the DC-9-30 is expected to continue for only about two years. It is being superseded by the DC-9-50 (Figure 2).

Derivatives involve extensive changes to the baseline aircraft, such as a new wing or fuselage. Derivatives of the DC-9-30, DC-10-10, and DC-10-40 were studied, as shown in Table 19. Three derivatives are stretched airplanes, one has an unchanged fuselage length, and one is shortened. Two have new supercritical wings. Four require new engines to meet thrust requirements. Weight and/or drag reduction items are also included in the derivative designs. The DC-9-30D2 has extended wing tips, a recontoured leading edge, and an improved high lift system, in addition to the items shown in Table 19. These features improve takeoff and landing performance and reduce airplane drag.

Weight adjustments were determined for each design change and are itemized in Tables 20 through 29. The weight tables also serve to define each modification and derivative design in more detail. It will be noticed that winglets on retrofit modifications involve a lower weight penalty than winglets on production modifications or derivative designs. Winglets change the wing spanload distribution and wing strengthening is required to maintain the same payload capability and service life. Wing box strengthening is straightforward on production aircraft, but is not practical as a retrofit item. Therefore, aircraft with retrofit winglets must be operated at a lower maximum takeoff gross weight in order to keep the maximum wing loads within the capacity of the original structure.

Table 25 details the items included in the general weight reduction program for DC-9 derivatives. Table 26 lists the DC-9 composite secondary structure weight savings. Composites are also used in modified and derivative versions of the DC-10-10 and DC-10-40. Table 28 lists low-risk composite weight savings for DC-10 models and Table 29 lists state-of-the-art composite items which entail moderate risk.

General characteristics of these aircraft are given in Tables 30a through 30d. The average stage lengths and high speed cruise Mach numbers for the modified and derivative models are the same as for their respective baselines. Maximum takeoff weights and seating capacities for modified aircraft are also the same as their baselines. The fuel savings for the modified aircraft result in increased range capability. The payload-range profiles of the modified and derivative aircraft are compared to the profiles of the baseline airplanes in Figures 36 through 42. All payload-range plots were generated using the baseline flight profile, Figure 4. Fuel use parameters are given in Tables 31 to 50, and comparative fuel use plots are given in Figures 43 to 47.

The effects of the modification and derivative options on fuel use and DOC are summarized in Table 51 at the CAB average stage length. Modification options produce significant fuel use reductions but generally appear to be uneconomical at the study fuel prices. Substantial fuel benefits accrue from refan engine (JT8D-209) retrofits on the DC-8 models; but the economics of the refan retrofits are unfavorable, except for the DC-8-20R and DC-8-20ER at a fuel price of 60 cents per gallon. Although the cost of the engine modification on the DC-8-20 is as expensive as those for the DC-8-50 and DC-8-61, the used aircraft value assumed for the DC-8-20 in 1976 was very low. This fact, plus the substantial fuel savings achieved with the refan engines on the DC-8-20, in contrast to the savings on the DC-8-50 and DC-8-61, contributed to making the DC-8-20R and DC-8-20ER models economically viable relative to the baseline DC-8-20 at 60 cents per gallon.

Most modifications were expensive, and DOC penalties generally resulted even at a 60 cent per gallon fuel price, despite significant fuel savings. The drag retrofit modification is the least expensive redesign item and, due to the very low used DC-8-20 price, the DC-8-20DR DOC's were very good relative to the baseline DC-8-20. It should be noted, however, that the DOC's of each modification are strongly dependent on the ground rules assumed in calculating them. For instance, the baseline airplanes were priced as new aircraft in 1973 dollars. Aircraft out of production were priced on the basis of the latest known sale price escalated to 1973 dollars. The modification prices were based on the 1976 used aircraft value de-escalated to 1973 dollars, plus the cost of the modification and any applicable airframe and engine refurbishment. Also, depreciation periods for the baseline airplanes were 16 years, while for the DC-8 retrofit models they were 5 years. A complete discussion of the aircraft prices and DOC's is presented in Section 2.0 of Volume II.

The stretched derivative airplanes show substantial seat-mile fuel use reductions, ranging from 19.8 percent for the DC-9-30D1 to 27.9 percent for the DC-10-40D; and much improved DOC's due to the increased number of seats. The DC-9-30D3 involves only a new supercritical wing, but fuel use is still reduced by 4.94 percent, with a small reduction in operating costs at 30 cents and 60 cents per gallon. The 2.76 percent reduction in fuel for the DC-10-10D is remarkable because this is a shortened aircraft with fewer seats than its baseline.

The fuel-saving effects of individual modification items are given in Table 52 and Figure 48. As a convenience, the percentages in Table 52 were combined by simple addition, rather than by the method of Section 2.3. This permits straightforward chart comparisons of the data, as in Figure 48. The retrofit winglet modifications are shown to give a slightly greater fuel-saving benefit than the production winglet modifications in Table 52, because the added weight of the wing box strengthening as part of the production winglet modification slightly reduces the amount of fuel saved.

Figure 49 shows derivative aircraft fuel savings compared to the baseline models. The DC-10-10D is also compared to the similar-capacity DC-8-61, and shows a 19 percent seat-mile fuel use improvement relative to this narrow-body aircraft.

TABLE 18

MODIFICATION SENSITIVITIES

CHANGE IN BLOCK FUEL AND DOC

RESULTING FROM A 10% CHANGE IN PARAMETER

FOR BASELINE OPERATION AT 1973 CAB AVERAGE RANGE

AIRPLANE	1973 CAB AVERAGE RANGE (NM)	10% REDUCTION IN DRAG OR SFC			10% REDUCTION IN OEW			10% INCREASE IN 1973 AIRCRAFT TOTAL NEW PRICE	
		% Δ FUEL	% Δ DOC @ $\frac{30¢}{GAL}$	% Δ DOC @ $\frac{60¢}{GAL}$	% Δ FUEL	% Δ DOC @ $\frac{30¢}{GAL}$	% Δ DOC @ $\frac{60¢}{GAL}$	% Δ DOC @ $\frac{30¢}{GAL}$	% Δ DOC @ $\frac{60¢}{GAL}$
DC-8-20	862	-9.60	-4.76	-6.36	-4.38	-2.17	-2.90	2.15	1.44
DC-8-50	731	-9.51	-4.03	-5.66	-4.47	-1.90	-2.66	2.61	1.83
DC-8-61	800	-9.56	-4.11	-5.75	-4.43	-1.90	-2.67	2.67	1.87
DC-9-10	300	-7.05	-2.53	-3.73	-2.72	-0.98	-1.45	2.75	2.02
DC-9-30	290	-6.94	-2.47	-3.64	-2.89	-1.03	-1.51	2.83	2.09
DC-10-10	870	-10.32	-4.11	-5.88	-4.37	-1.75	-2.49	3.45	2.47
DC-10-40	670	-10.17	-3.97	-5.71	-4.52	-1.76	-2.54	3.63	2.61

NOTE: DOC values based on 1973 aircraft new price

FUEL SAVED AND DOC CHANGE DUE TO INDEPENDENT 10 PERCENT CHANGE IN DRAG, SFC, OEW, OR PRICE AT 1973 CAB AVERAGE STAGE LENGTH.

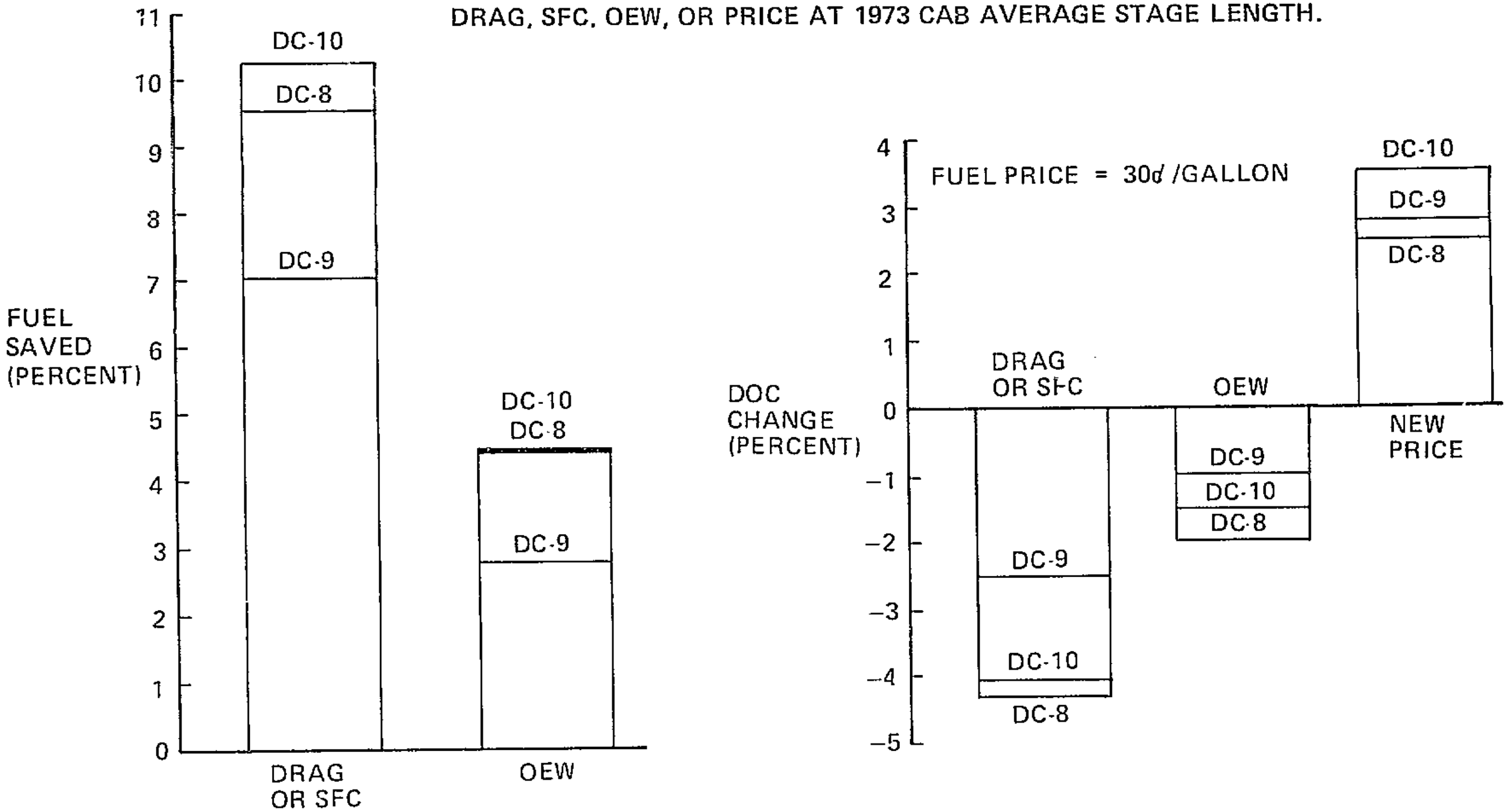


FIGURE 32. AVERAGE MODIFICATION SENSITIVITY FACTORS

TABLE 19

DESIGN CHANGES FOR RETROFIT, PRODUCTION MODIFIED, AND DERIVATIVE AIRCRAFT

AIRCRAFT(1)	EARLIEST INTRODUCTION DATE	DESIGN CHANGE ITEM: NEW ENGINE	GENERAL DRAG REDUCTION PROGRAM	WINGLET	GENERAL WEIGHT REDUCTION PROGRAM	COMPOSITE SECONDARY STRUCTURE	STRETCH/ SHRINK	NEW SUPERCRITICAL WING
DC-8-20R	79	JT8D-209	X	X				
DC-8-20DR	78	-	X	X				
DC-8-20ER	79	JT8D-209	-	-				
DC-8-50R	79	JT8D-209(2)	X	X				
DC-8-50DR	78	-	X	X				
DC-8-50ER	79	JT8D-209(2)	-	-				
DC-8-61R	79	JT8D-209(2)	X	X				
DC-8-61DR	78	-	X	X				
DC-8-61ER	79	JT8D-209(2)	-	-				
DC-9-10R	78	-	X	X				
DC-9-30R	78	-	X	X				
DC-10-10R	78	-	X	X				
DC-10-40R	78	-	X	X				
DC-10-10M	78	-	X	X	X	X		
DC-10-40M	78	-	X	X	X	X		
DC-9-30D1	79	JT8D-17	-	X	X	X	+171"	-
DC-9-30D2	79	JT8D-209	X	-	X	X	+209"	-
DC-9-30D3	80	-	-	-	-	-	-	X
DC-10-10D	80	CF6-50	X	-	X	X	-360"	X
DC-10-40D	80	CF6-50A	X	X	X	X	+360"	-

(1) AIRCRAFT DESIGNATORS:

R = RETROFIT
DR = DRAG (AERODYNAMIC) RETROFIT
ER = ENGINE RETROFIT
M = PRODUCTION MODIFICATION
D = DERIVATIVE

(2) INCLUDES CUTBACK PYLON

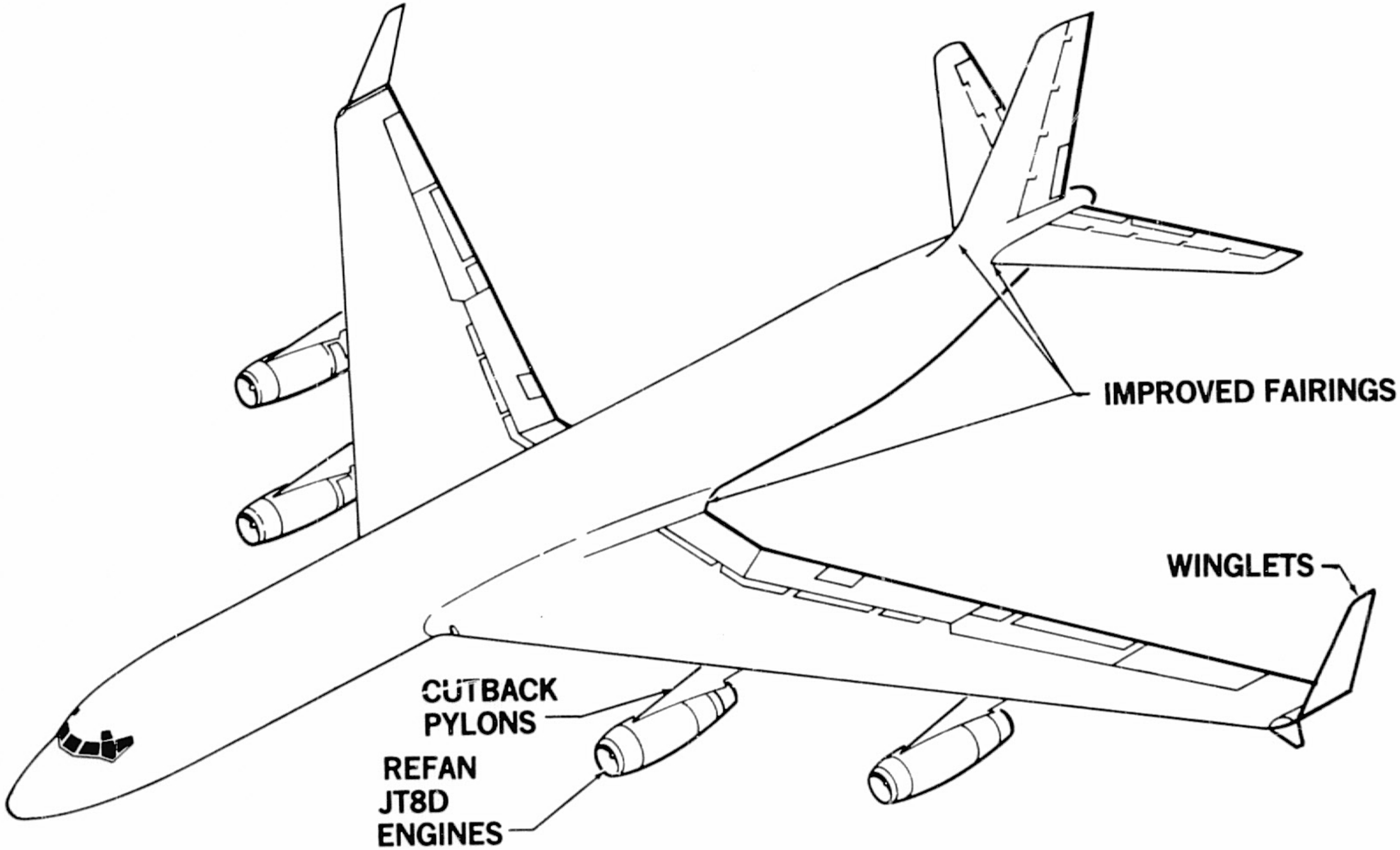
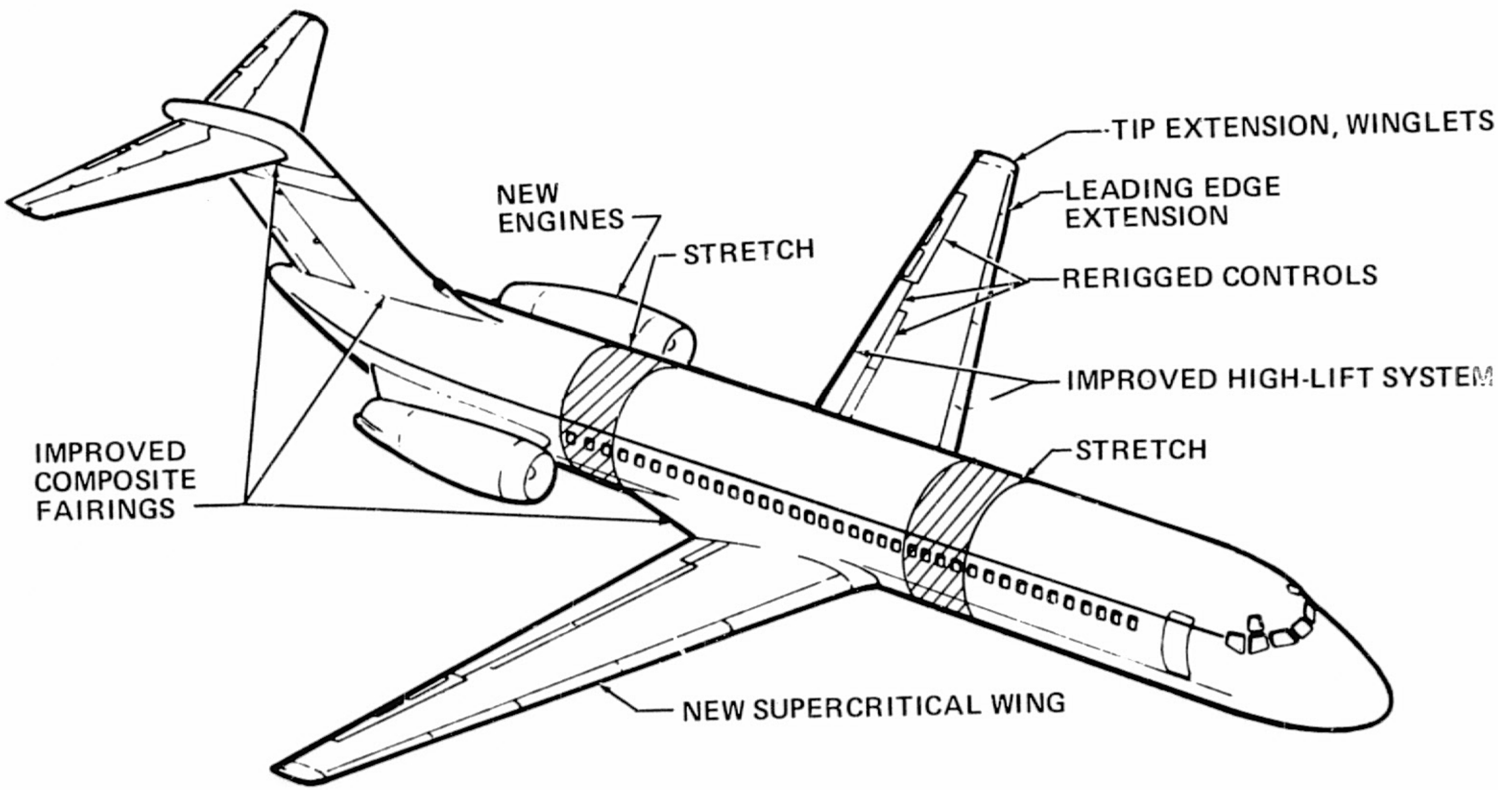
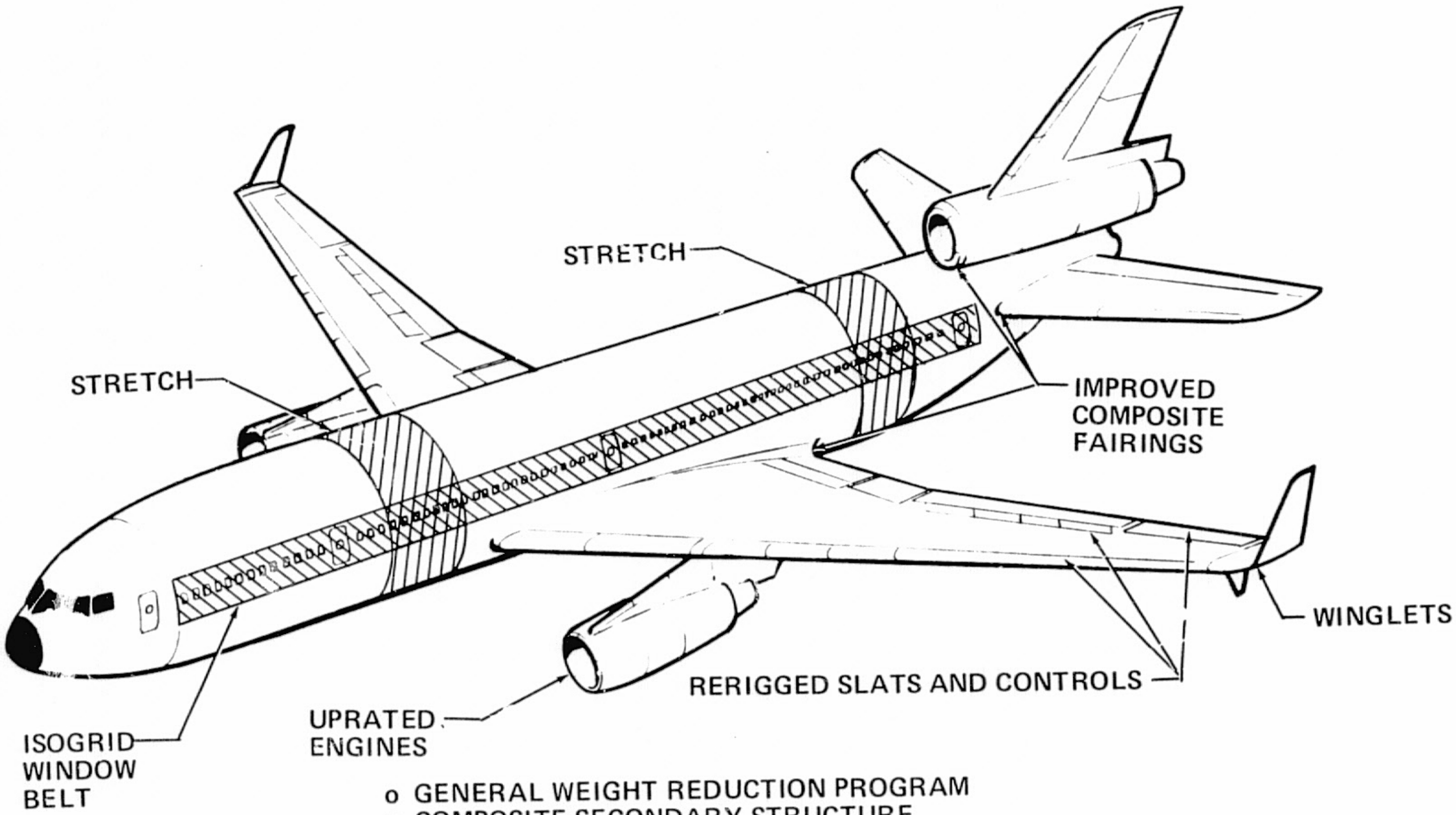


FIGURE 33. FUEL-CONSERVATIVE DC-8 RETROFIT STUDY ITEMS



- o GENERAL WEIGHT REDUCTION PROGRAM
- o COMPOSITE SECONDARY STRUCTURE
  - FAIRINGS
  - WING AND TAIL TRAILING EDGES
  - FLOOR
  - DOORS

FIGURE 34. FUEL-CONSERVATIVE DC-9 STUDY ITEMS



- o GENERAL WEIGHT REDUCTION PROGRAM
- o COMPOSITE SECONDARY STRUCTURE
  - – FAIRINGS
  - – TIPS
  - – WING AND TAIL TRAILING EDGES
  - – CONTROL SURFACES
  - – FLOOR
  - – GEAR DOORS

FIGURE 35. FUEL-CONSERVATIVE DC-10 STUDY ITEMS

TABLE 20

WEIGHT CHANGE SUMMARY - DC-8-20 AND DC-8-50 RETROFIT AIRCRAFT

AIRCRAFT MODEL	DC-8-20R	DC-8-20DR	DC-8-20ER	DC-8-50R	DC-8-50DR	DC-8-50ER
BASELINE OPERATIONAL EMPTY WEIGHT	137,900	137,900	137,900	138,430	138,430	138,430
WEIGHT CHANGE ITEMS:						
• Winglet Structure Retrofit Penalty	(+617)	(+617)	(0)	(+617)	(+617)	(0)
• Drag Reduction Penalty	(+265)	(+265)	(0)	(+265)	(+265)	(0)
- Wing Fillet Redesign	+175	+175		+175	+175	
- Horiz. and Vert. Tail Fillet Redesign	+90	+90		+90	+90	
• Propulsion System Modification	(-2,732)	(0)	(-2,732)	(-1,605)	(0)	(-1,605)
- Replace Engine with JT8D-209						
Dry Engine (JT4A-9 to JT8D-209)	-3,400		-3,400	--		--
Thrust Reverser	-236		-236	-1,488		-1,488
Nacelle and Systems	+904		+904	+65		+65
Dry Engine (JT3D-3B to JT8D-209)	--		--	-616		-616
Pylon Installation	--		--	+434		+434
TOTAL WEIGHT CHANGE	-1,850	+882	-2,732	-723	+882	-1,605
RETROFIT OPERATIONAL EMPTY WEIGHT	136,050	138,782	135,168	137,707	139,312	136,825

TABLE 21

WEIGHT CHANGE SUMMARY - DC-8-61 RETROFIT AIRCRAFT

AIRCRAFT MODEL	DC-8-61R	DC-8-61DR	DC-8-61ER
BASELINE OPERATIONAL EMPTY WEIGHT	156,100	156,100	156,100
WEIGHT CHANGE ITEMS:			
• Winglet Structure Retrofit Penalty	(+617)	(+617)	(0)
• Drag Reduction Penalty	(+265)	(+265)	(0)
– Wing Fillet Redesign	+175	+175	
– Horiz. and Vert. Tail Fillet Redesign	+90	+90	
• Propulsion System Modification	(-1,605)	(0)	(-1,605)
– Replace JT3D-3B with JT8D-209			
Dry Engine	-616		-616
Thrust Reverser	-1,488		-1,488
Nacelle and Systems	+65		+65
Pylon Installation	+434		+434
TOTAL WEIGHT CHANGE	-723	+882	-1,605
RETROFIT OPERATIONAL EMPTY WEIGHT	155,377	156,982	154,495

C.2

TABLE 22

WEIGHT CHANGE SUMMARY - DC-9 AND DC-10 RETROFIT AIRCRAFT

AIRCRAFT MODEL	DC-9-10R	DC-9-30R	DC-10-10R	DC-10-40R
BASELINE OPERATIONAL EMPTY WEIGHT	49,840	57,900	237,240	270,910
WEIGHT CHANGE ITEMS				
• Winglet Structure Retrofit Penalty	(+214)	(+214)	(+760)	(+760)
• Drag Reduction Penalty	(+135)	(+135)	(+425)	(+425)
- Wing Fillet Redesign	+89	+89	+280	+280
- Horiz. and Vertical Tail Fillet Redesign	+46	+46	+145	+145
TOTAL WEIGHT CHANGE	+349	+349	+1,185	+1,185
RETROFIT OPERATIONAL EMPTY WEIGHT	50,189	58,249	238,425	272,095

TABLE 23

WEIGHT CHANGE SUMMARY - DC-10-10 AND DC-10-40 PRODUCTION MODIFICATIONS

AIRCRAFT MODEL	DC-10-10M	DC-10-40M
BASELINE OPERATIONAL EMPTY WEIGHT	237,240	270,910
WEIGHT CHANGE ITEMS:		
• Winglet Installation Penalty	(+ 1,494)	(+ 1,494)
Bending Material	+ 734	+ 734
Winglet Structure	+ 760	+ 760
• Drag Reduction Penalty	(+ 425)	(+ 425)
Wing Fillet Redesign	+ 280	+ 280
Horizontal and Vertical Tail Fillet Redesign	+ 145	+ 145
• General Weight Reduction	(- 3,285)	(- 5,546)
Carbon Brakes	- 890	- 1,100
Landing Gear Structure Technology Improvement	- 200	- 525
Integrally Machined Window Belt Structure	- 1,210	- 1,210
Miscellaneous Weight Savings	- 985	- 1,265
Sculptured Wing Skins	0	- 525
Delete Center Section Fuel Tanks	0	- 921
• Composite Secondary Structure*	(- 3,065)	(- 3,226)
Total Weight Change	- 4,431	- 6,853
MODIFICATION OPERATIONAL EMPTY WEIGHT	232,809	264,057

*See Table 29

TABLE 24

WEIGHT CHANGE SUMMARY - DC-9 DERIVATIVES

AIRCRAFT MODEL	DC-9-30D1	DC-9-30D2	DC-9-30D3
BASELINE OPERATIONAL EMPTY WEIGHT	57,900	57,900	57,900
WEIGHT CHANGE ITEMS:			
• Basic Derivative Weight Changes	(+6,710)	(+11,745)	(0)
- Fuselage, Furnishings, Systems, & Operator Items	5,072	6,492	
- Wing and Tail	216	749	
- Landing Gear	577	591	
- Propulsion System	845	3,533	
- Others		380	
• Technology Weight Changes			
- Winglet Installation Penalty	(+ 400)	(0)	(0)
Bending Material	186		
Winglet Structure	214		
- Drag Reduction Penalty	(0)	(+135)	(0)
Wing Fillet Redesign		89	
Horiz. and Vert. Tail Fillet Redesign		46	
- General Weight Reduction*	(-1,400)	(-1,400)	(0)
- Composite Secondary Structure Weight Reduction**	(-1,000)	(-1,000)	(0)
- Supercritical Airfoil Wing Penalty	(0)	(0)	(+ 180)
Wing Structure			280
Control and Hydraulic Systems			-100
TOTAL WEIGHT CHANGE	+4,710	+9,480	+ 180
DERIVATIVE OPERATIONAL EMPTY WEIGHT	62,610	67,380	58,080

* See Table 25

** See Table 26

TABLE 25

GENERAL WEIGHT REDUCTION SUMMARY
FOR DC-9 DERIVATIVES

ITEM DESCRIPTION	WEIGHT SAVINGS (LB)
Wing Skins	190
Fuselage Skins	179
Bolt Material	93
Windows	53
Bonded Metallics	19
Thrust Reversers	12
APU Gear Box	13
Cabin Insulation	218
Cabin Sidewall Panels	92
Cargo Compartment Ceiling	26
Electric Wiring	166
Electric Relays	20
Circuit Breakers	18
Hydraulic Fittings	219
Oxygen System	13
Miscellaneous Items	69
TOTAL WEIGHT REDUCTION	1,400

TABLE 26

COMPOSITE SECONDARY STRUCTURE WEIGHT REDUCTION
SUMMARY FOR DC-9 DERIVATIVES

ITEM DESCRIPTION	WEIGHT SAVINGS (LB)
WING:	(359)
Trailing Edge Structure	43
Aileron Structure	74
Trailing Edge Flap Structure	194
Spoiler Structure	20
Fairings and Tips	28
TAIL:	(209)
Horiz. Stab. & Elev. Structure	124
Rudder Structure	85
FUSELAGE:	(432)
Floor Panels	100
Floor Beams & Supports	145
Main Landing Gear Doors	20
Emergency Exit Doors	24
Belly Cargo Doors	38
Passenger Entrance Door	30
Galley Service Door	16
Air Stair Structure	59
TOTAL WEIGHT REDUCTION	1,000

TABLE 27

WEIGHT CHANGE SUMMARY - DC-10 DERIVATIVES		
AIRCRAFT MODEL	DC-10-10D	DC-10-40D
BASELINE OPERATIONAL EMPTY WEIGHT	237,240	270,910
WEIGHT CHANGE ITEMS:		
• Basic Derivative Weight Changes	(-75,383)	(+12,721)
- Fuselage, Furnishings, Systems, Operator Items	-28,269	14,905
- Wing and Tail	-30,455	1,886
- Landing Gear	- 6,257	154
- Propulsion System	-10,402	- 4,224
• Technology Weight Changes	(-1,087)	(-7,911)
- Winglet Installation Penalty	(0)	(+1,560)
Bending Material		+ 766
Winglet Structure		+ 794
- Drag Reduction Penalty	(0)*	(+ 425)
Wing Fillet Redesign		+ 280
Horiz. and Vert. Tail Fillet Redesign		+ 145
- General Weight Reduction	(0)*	(-6,670)
Carbon Brakes		-1,100
Landing Gear Structural Technology Improvements		- 600
Integral Machined Window Belt Structure		-1,515
Miscellaneous Weight Savings		-1,265
Sculptured Wing Skins		- 525
Delete Center Section Wing Fuel Tank		-1,665
- Composite Secondary Structure Weight Reduction**	(-1,087)	(-3,226)
TOTAL WEIGHT CHANGE	(-76,470)	(+4,810)
DERIVATIVE OPERATIONAL EMPTY WEIGHT	160,770	275,720

* Included in Basic Derivative Weight Changes
** See Table 29

TABLE 28

LOW-RISK COMPOSITE SECONDARY STRUCTURE WEIGHT SAVINGS

ITEM DESCRIPTION	WEIGHT SAVINGS (LB)		
	DC-10-10M	DC-10-10D	DC-10-40M and DC-10-40D
LOW-RISK ITEMS:			
WING:	(582)	(160)	(676)
Outer Trailing Edge Structure	64	117	66
Spoiler Structure	76	43	76
Slat Structure	190		201
Fairings and Tips	252		333
TAIL:	(131)	(52)	(134)
Vertical Stabilizer Trailing Edge Structure	12	10	12
Horizontal Stabilizer Trailing Edge Structure	44	42	48
Fairing and Tips	75		74
FUSELAGE FLOOR PANELS	(174)	(0)	(199)
ENGINE PYLON DOORS	(53)	(0)	(43)
TOTAL LOW-RISK WEIGHT REDUCTION	940	212	1,052

TABLE 29

COMPOSITE SECONDARY STRUCTURE WEIGHT SAVINGS

ITEM DESCRIPTION	WEIGHT SAVINGS (LB)		
	DC-10-10M	DC-10-10D	DC-10-40M and DC-10-40D
STATE OF THE ART ITEMS:			
WING:	(566)	(367)	(579)
Inner Trailing Edge Structure	119	188	123
Aileron Structure	272	179	281
Trailing Edge Flap Vanes	175		175
TAIL:	(489)	(508)	(493)
Elevator Structure	193	198	196
Rudder Structure	276	310	279
Lower Vertical Diverter	20		18
FUSELAGE:	(995)	(0)	(1,027)
Floor Supports	814		816
Movable Tailcone	146		159
Main Landing Gear Doors	35		52
ENGINE NACELLE DOOR PANELS	(75)	(0)	(75)
TOTAL STATE OF THE ART WEIGHT REDUCTION	2,125	875	2,174
TOTAL LOW-RISK WEIGHT REDUCTION (TABLE 28)	940	212	1,052
TOTAL COMPOSITE SECONDARY STRUCTURE WEIGHT REDUCTION	3,065	1,087	3,226

TABLE 30a

MODIFIED AND DERIVATIVE AIRCRAFT CHARACTERISTICS

AIRCRAFT		DC-8-20R	DC-8-20DR	DC-8-20ER	DC-8-50R	DC-8-50DR
Maximum Takeoff Weight	(LB)	270,000	270,000	276,000	294,000	294,000
Engines: Number		4	4	4	4	4
Type		JT8D-209	JT4A-9	JT8D-209	JT8D-209	JT3D-3B
SLS Rated Thrust/Engine	(LB)	18,000	16,800	18,000	18,000	18,000
High Speed Cruise Mach Number		.83	.83	.83	.82	.82
Number of Mixed Class Passengers		146	146	146	146	146
Design Range:* @ 100% Load Factor	(NM)	3,910	2,820	3,770	5,000	4,380
@ 58% Load Factor	(NM)	4,360	3,250	4,170	5,690	5,000
Average Stage Length	(NM)	862	862	862	731	731
Fuel Use at Average Stage Length, 58% Load Factor	$(\frac{LB}{ASNM})$	0.161	0.214	0.171	0.158	0.177
1973 DOC at Average Stage Length, 30¢/Gal Fuel Price	$(\frac{¢}{ASNM})$	2.200	1.853	2.231	2.485	2.014

*At High Speed Cruise Mach Number

TABLE 30b

MODIFIED AND DERIVATIVE AIRCRAFT CHARACTERISTICS

AIRCRAFT		DC-8-50ER	DC-8-61R	DC-8-61DR	DC-8-61ER	DC-9-10R
Maximum Takeoff Weight	(LB)	300,000	318,000	318,000	325,000	88,900
Engines: Number		4	4	4	4	2
Type		JT8D-209	JT8D-209	JT3D-3B	JT8D-209	JT8D-7
SLS Rated Thrust/Engine	(LB)	18,000	18,000	18,000	18,000	14,000
High Speed Cruise Mach Number		.82	.82	.82	.82	.80
Number of Mixed Class Passengers		146	203	203	203	70
Design Range:* @ 100% Load Factor	(NM)	4,820	3,850	3,420	3,700	1,440
@ 58% Load Factor	(NM)	5,480	4,200	3,750	4,050	1,520
Average Stage Length	(NM)	731	800	800	800	300
Fuel Use at Average Stage Length, 58% Load Factor	$(\frac{LB}{ASNM})$	0.166	0.122	0.137	0.129	0.216
1973 DOC at Average Stage Length, 30¢/Gal Fuel Price	$(\frac{¢}{ASNM})$	2.507	2.007	1.652	2.026	3.197

*At High Speed Cruise Mach Number

TABLE 30c

MODIFIED AND DERIVATIVE AIRCRAFT CHARACTERISTICS

AIRCRAFT		DC-9-30R	DC-10-10R	DC-10-40R	DC-10-10M	DC-10-40M
Maximum Takeoff Weight	(LB)	106,000	418,000	535,000	430,000	555,000
Engines: Number		2	3	3	3	3
Type		JT8D-7	CF6-6D	JT9D-20	CF6-6D	JT9D-20
SLS Rated Thrust/Engine	(LB)	14,000	40,100	49,400	40,100	49,400
High Speed Cruise Mach Number		.80	.85	.85	.85	.85
Number of Mixed Class Passengers		92	277	252	277	252
Design Range:* @ 100% Load Factor	(NM)	1,300	3,830	5,460	4,120	5,820
@ 58% Load Factor	(NM)	1,390	4,390	6,080	4,540	6,300
Average Stage Length	(NM)	290	870	670	870	670
Fuel Use at Average Stage Length, 58% Load Factor	$(\frac{LB}{ASNM})$	0.177	0.113	0.146	0.112	0.144
1973 DOC at Average Stage Length, 30¢/Gal Fuel Price	$(\frac{¢}{ASNM})$	2.691	1.418	1.825	1.503	1.976

*At High Speed Cruise Mach Number

TABLE 30d

MODIFIED AND DERIVATIVE AIRCRAFT CHARACTERISTICS

AIRCRAFT		DC-9-30D1	DC-9-30D2	DC-9-30D3	DC-10-10D	DC-10-40D
Maximum Takeoff Weight	(LB)	121,000	127,000	108,000	283,000	530,000
Engines: Number		2	2	2	2	3
Type		JT8D-17	JT8D-209	JT8D-7	CF6-50	CF6-50A
SLS Rated Thrust/Engine	(LB)	16,000	18,000	14,000	46,600	49,000
High Speed Cruise Mach Number		.80	.80	.80	.85	.85
Number of Mixed Class Passengers		117	122	92	199	327
Design Range:* @ 100% Load Factor	(NM)	1,350	1,810	1,350	2,900	4,870
@ 58% Load Factor	(NM)	1,460	1,940	1,440	3,680	5,620
Average Stage Length	(NM)	290	290	290	870	670
Fuel Use at Average Stage Length, 58% Load Factor	$(\frac{LB}{ASNM})$	0.147	0.138	0.175	0.121	0.116
1973 DOC at Average Stage Length, 30¢/Gal Fuel Price	$(\frac{¢}{ASNM})$	2.075	2.116	2.302	1.607	1.634

*At High Speed Cruise Mach Number

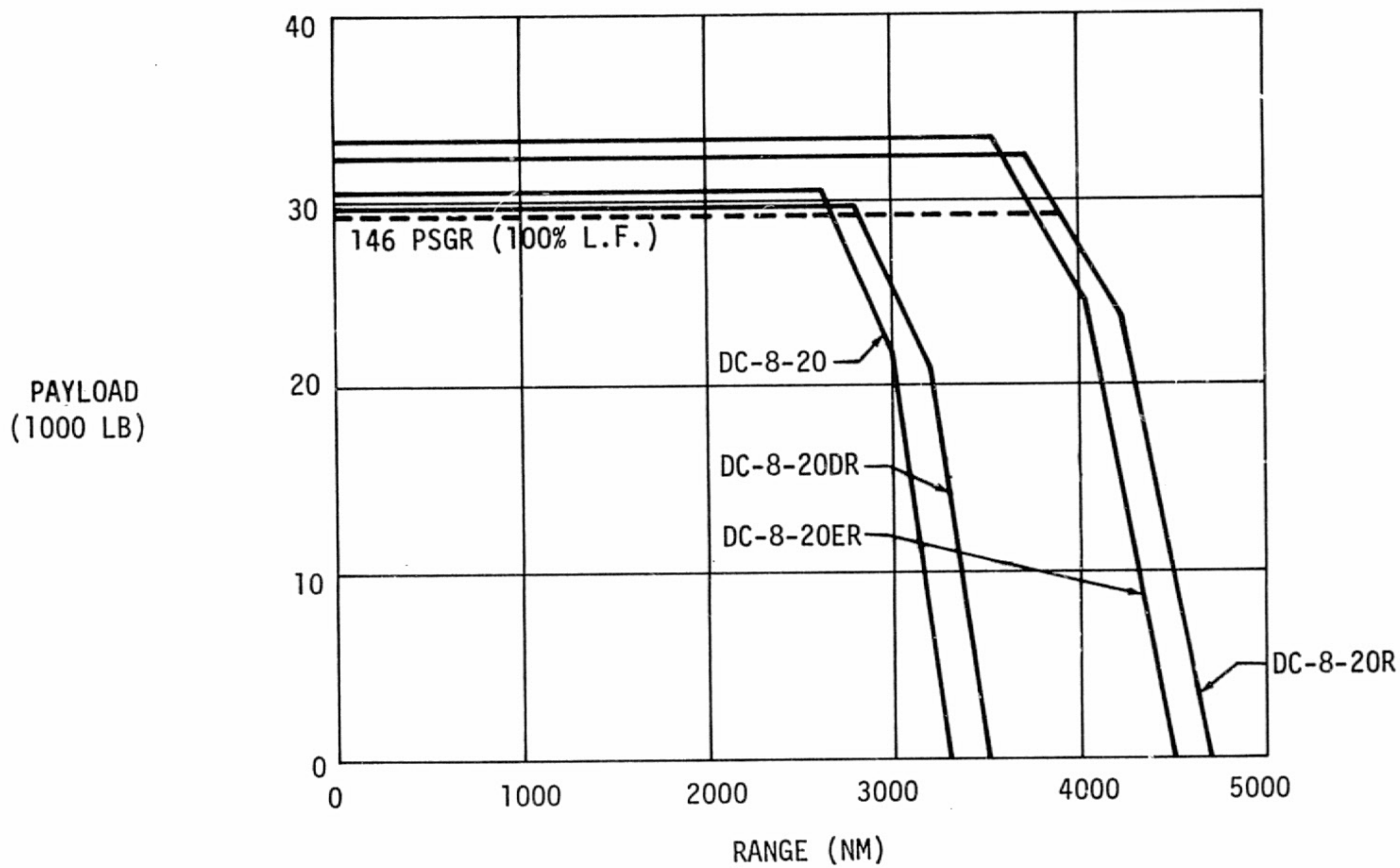


FIGURE 36. PAYLOAD-RANGE COMPARISON FOR DC-8-20 MODELS

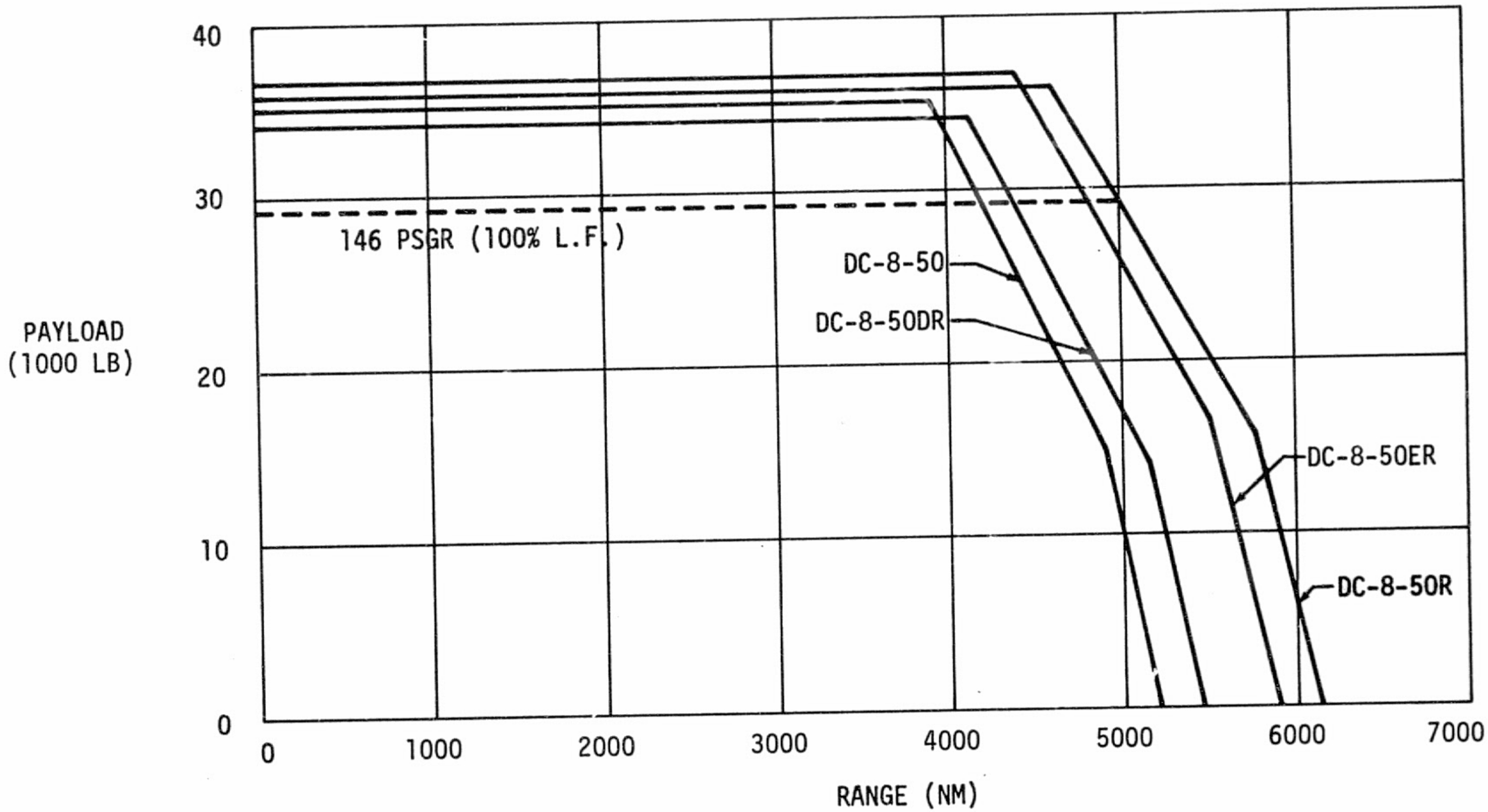


FIGURE 37. PAYLOAD-RANGE COMPARISON FOR DC-8-50 MODELS

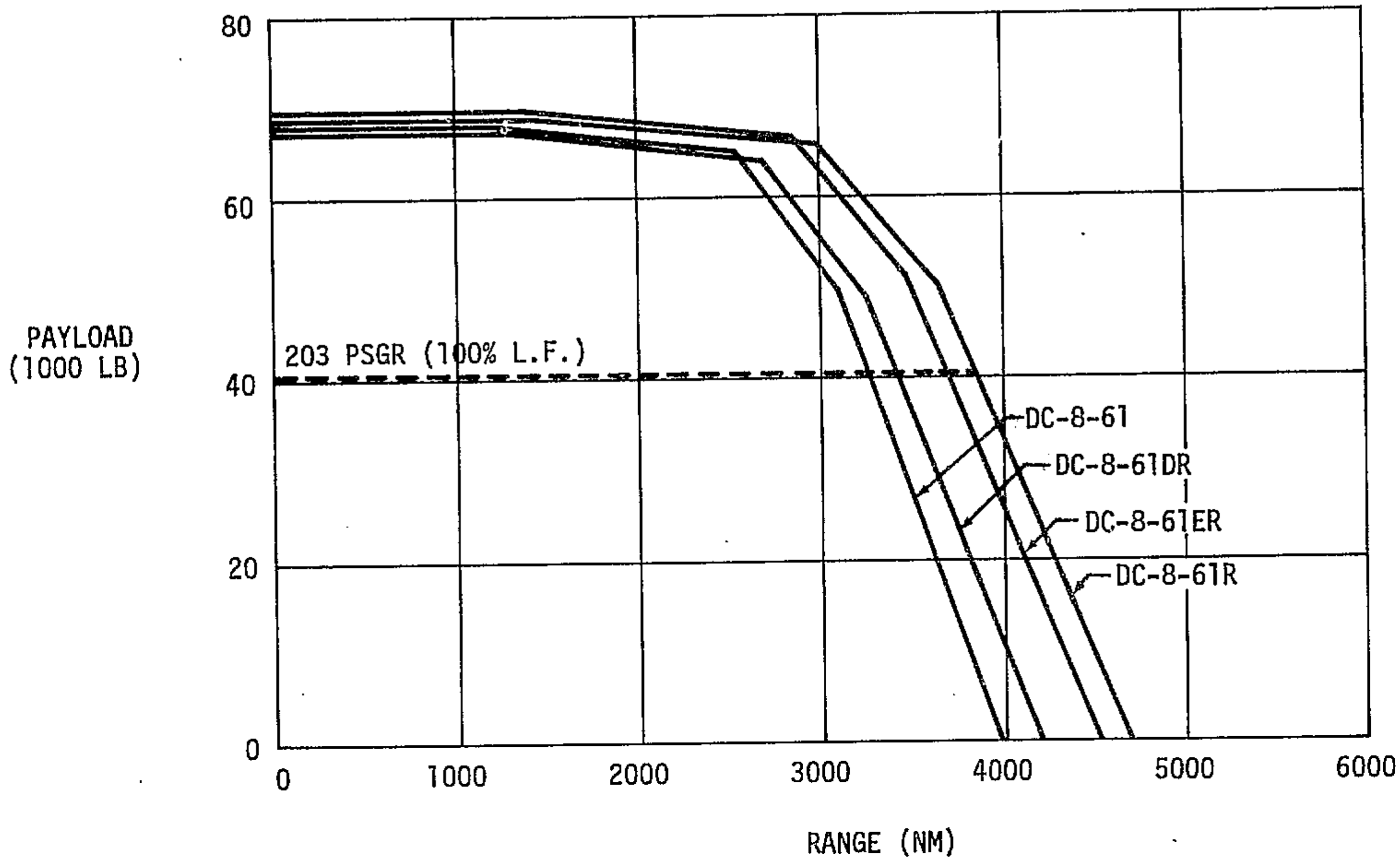


FIGURE 38. PAYLOAD-RANGE COMPARISON FOR DC-8-61 MODELS

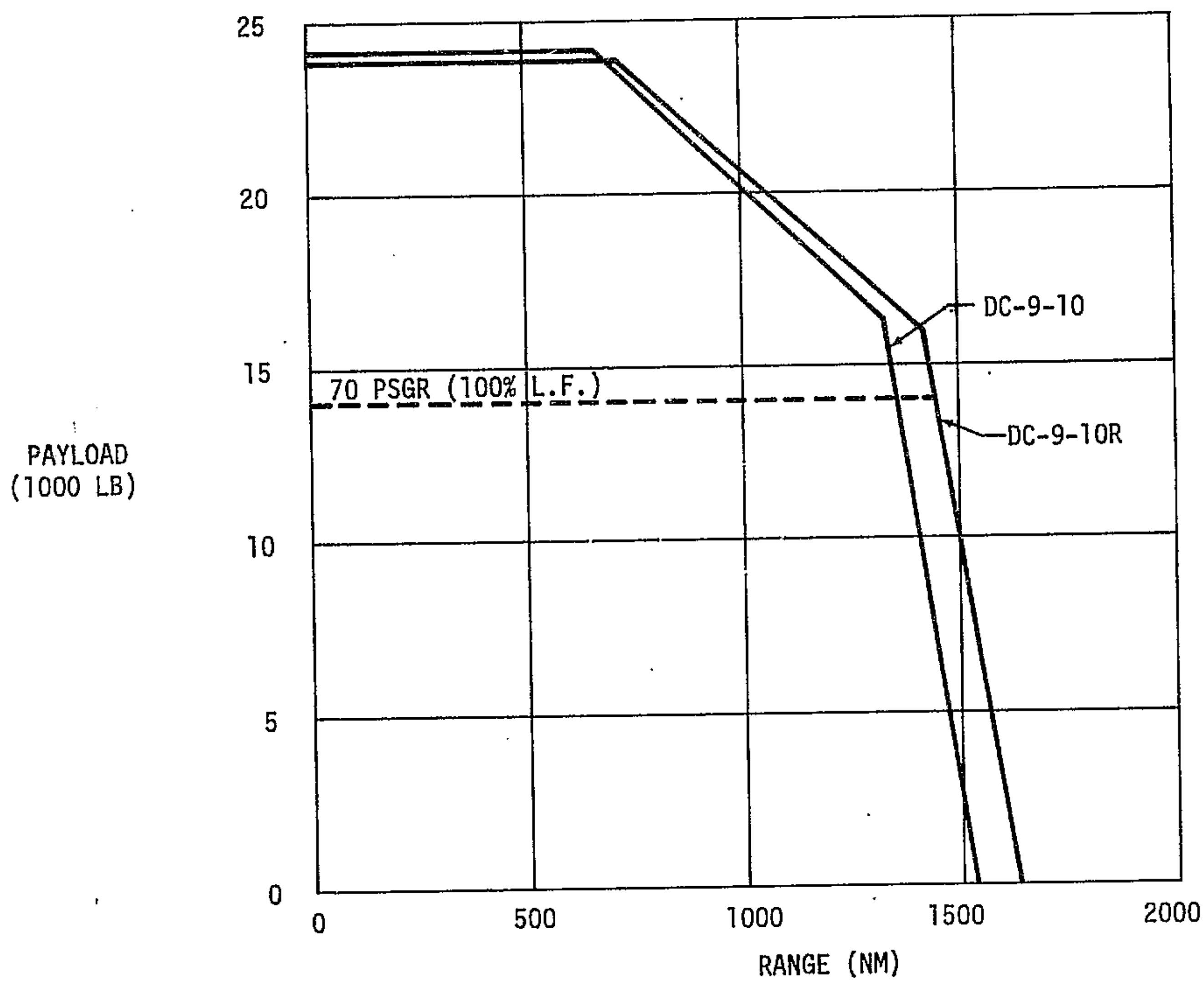


FIGURE 39. PAYLOAD-RANGE COMPARISON FOR DC-9-10 MODELS

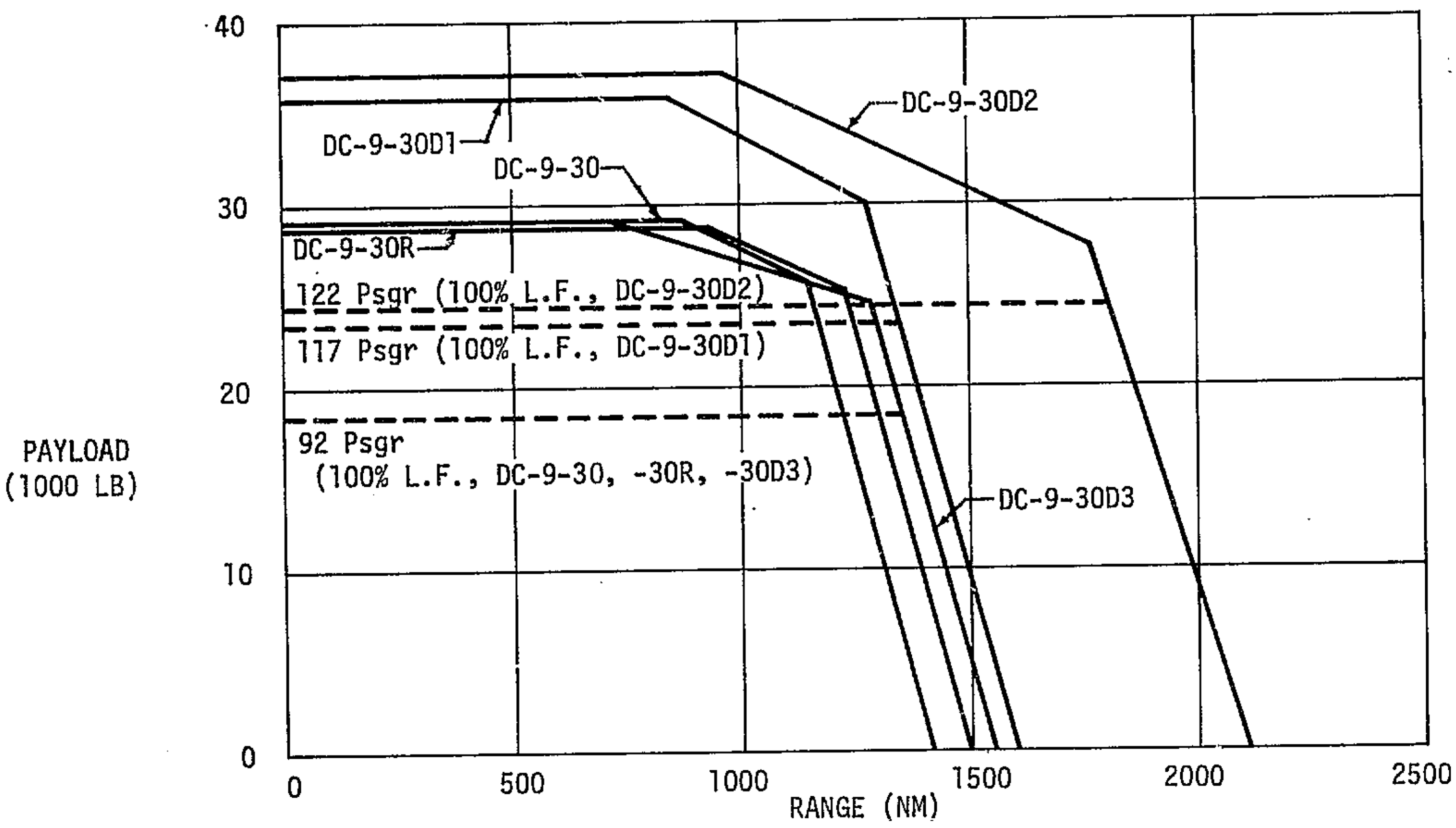


FIGURE 40. PAYLOAD-RANGE COMPARISON FOR DC-9-30 MODELS

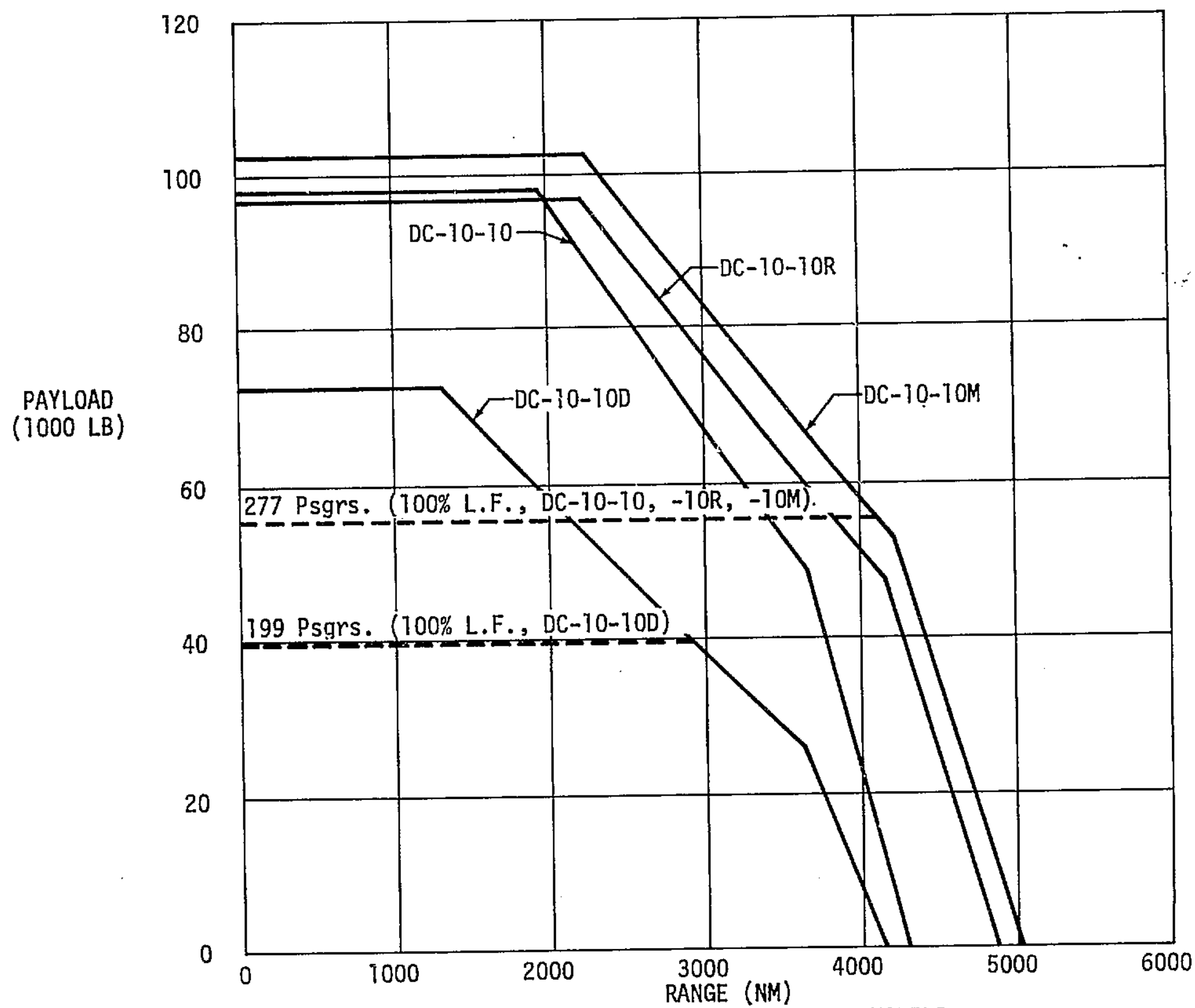


FIGURE 41. PAYLOAD-RANGE COMPARISON FOR DC-10-10 MODELS

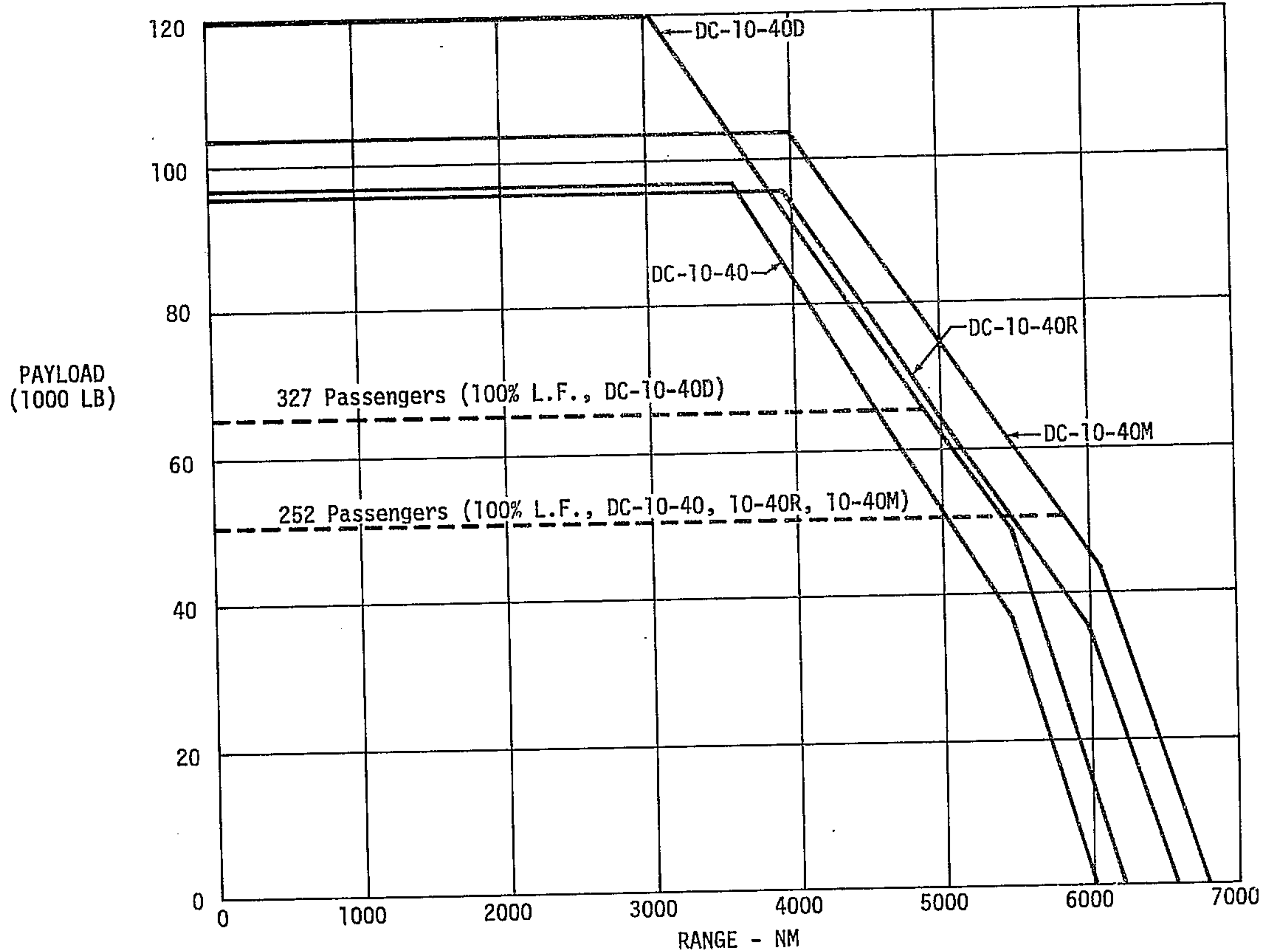


FIGURE 42. PAYLOAD-RANGE COMPARISON FOR DC-10-40 MODELS

TABLE 31

DC-8-20R

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	5,260	978,400	18.87	6,701
250	8,220	611,600	30.19	4,189
500	13,140	488,800	37.78	3,348
750	18,060	447,900	41.23	3,068
1,000	22,990	427,600	43.18	2,929
2,000	42,680	396,900	46.52	2,719
3,000	62,370	386,700	47.75	2,649

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 146, FUEL DENSITY = 6.8 LB/GALLON

TABLE 32

DC-8-20DR

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	5,550	1,032,000	17.89	7,071
250	9,040	672,600	27.46	4,607
500	16,370	609,000	30.32	4,171
750	23,690	587,500	31.43	4,024
1,000	31,020	577,000	32.01	3,952
2,000	60,330	561,100	32.91	3,843
3,000	89,640	555,800	33.23	3,807

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 146 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 33

DC-8-20ER

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	5,320	989,500	18.66	6,778
250	8,380	623,500	29.62	4,270
500	13,760	511,900	36.08	3,506
750	19,140	474,700	38.90	3,251
1,000	24,520	456,100	40.49	3,124
2,000	46,040	428,200	43.13	2,933
3,000	67,570	418,900	44.08	2,869

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 146, FUEL DENSITY = 6.8 LB/GALLON

TABLE 34

DC-8-50R

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM [(2)] / Gallon	BTU / Available Seat - NM
100	5,150	957,900	19.28	6,561
250	7,930	590,000	31.30	4,041
500	12,550	466,900	39.55	3,198
750	17,180	426,100	43.34	2,918
1,000	21,810	405,700	45.52	2,779
2,000	40,320	375,000	49.25	2,568
3,000	58,820	365,000	50.64	2,498

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 146 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 35

DC-9-50DR

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM / Gallon (2)	BTU / Available Seat - NM
100	5,190	965,300	19.13	6,612
250	8,610	640,600	28.83	4,388
500	13,960	519,300	35.56	3,557
750	19,320	479,100	38.54	3,282
1,000	24,670	458,900	40.24	3,143
2,000	46,080	428,600	43.09	2,935
3,000	67,500	418,500	44.12	2,866

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 146 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 36

DC-8-50ER

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE [1]			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM [2] / Gallon	BTU / Available Seat - NM
100	5,170	961,600	19.20	6,586
250	8,220	611,600	30.19	4,189
500	13,150	489,200	37.75	3,351
750	18,090	448,600	41.16	3,073
1,000	23,030	428,400	43.11	2,934
2,000	42,770	397,800	46.43	2,724
3,000	62,520	387,600	47.64	2,655

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 146, FUEL DENSITY = 6.8 LB/GALLON

TABLE 37

DC-8-61R

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	5,810	1,081,000	23.76	5,323
250	8,750	651,000	39.44	3,207
500	13,640	507,400	50.60	2,500
750	18,720	464,300	55.30	2,287
1,000	24,040	447,100	57.42	2,203
2,000	46,350	431,100	59.56	2,123
3,000	69,500	430,900	59.59	2,123

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 203, FUEL DENSITY = 6.8 LB/GALLON

TABLE 38

DC-8-61DR

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM / Gallon (2)	BTU / Available Seat - NM
100	6,450	1,200,000	21.40	5,910
250	9,790	728,400	35.25	3,588
500	15,280	568,400	45.17	2,800
750	21,010	521,000	49.28	2,567
1,000	27,010	502,400	51.11	2,475
2,000	52,490	488,200	52.60	2,405
3,000	79,600	493,500	52.03	2,431

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 203 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 39

DC-8-61ER

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	6,080	1,131,000	22.70	5,571
250	9,200	684,500	37.51	3,372
500	14,360	534,200	48.06	2,631
750	19,720	489,100	52.50	2,409
1,000	25,330	471,100	54.50	2,321
2,000	49,030	456,000	56.31	2,246
3,000	73,900	458,200	56.04	2,257

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 203, FUEL DENSITY = 6.8 LB/GALLON

TABLE 40

DC-9-10R

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	2,320	431,500	20.52	6,165
250	4,030	299,800	29.53	4,283
500	6,690	248,900	35.58	3,555
750	9,230	228,900	38.68	3,270
1,000	11,890	221,200	40.03	3,159
1,250	14,800	220,200	40.20	3,146
1,500	17,820	221,000	40.07	3,157

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 70 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 41

DC-9-30R

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	2,420	450,100	25.85	4,893
250	4,240	315,500	36.89	3,429
500	7,040	261,900	44.43	2,847
750	9,780	242,500	47.98	2,636
1,000	12,540	233,200	49.89	2,535
1,250	15,370	228,700	50.88	2,486
1,390	17,060	228,300	50.97	2,481

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 92, FUEL DENSITY = 6.8 LB/GALLON

TABLE 42

DC-10-10R

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE [(1)]			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM [(2)] / Gallon	BTU / Available Seat - NM
100	7,620	1,417,000	24.72	5,117
250	11,480	854,100	41.02	3,083
500	17,900	665,900	52.61	2,404
750	24,360	604,100	57.99	2,181
1,000	30,810	573,100	61.14	2,069
2,000	57,540	535,100	65.47	1,932
3,000	86,190	534,400	65.56	1,929

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 277 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 43

DC-10-40R

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	9,410	1,750,000	18.21	6,945
250	13,380	995,500	32.02	3,950
500	19,990	743,600	42.86	2,951
750	26,900	667,100	47.78	2,647
1,000	33,820	629,100	50.67	2,496
2,000	62,000	576,600	55.28	2,288
3,000	93,080	577,100	55.23	2,290

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 252, FUEL DENSITY = 6.8 LB/GALLON

TABLE 44

DC-10-10M

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	7,630	1,419,000	24.69	5,123
250	11,370	845,900	41.42	3,054
500	17,600	654,700	53.51	2,364
750	23,900	592,700	59.11	2,140
1,000	30,450	566,400	61.86	2,045
2,000	56,710	527,400	66.43	1,904
3,000	84,840	526,000	66.61	1,899

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 277, FUEL DENSITY = 6.8 LB/GALLON

TABLE 45

DC-10-40M

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	9,330	1,735,000	18.37	6,886
250	13,230	984,300	32.38	3,906
500	19,730	734,000	43.43	2,913
750	26,360	653,700	48.76	2,594
1,000	33,240	618,300	51.55	2,453
2,000	60,600	563,600	56.55	2,236
3,000	90,850	563,300	56.59	2,235

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 252 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 46

DC-9-30D1

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	2,640	491,000	30.14	4,197
250	4,520	336,300	44.00	2,874
500	7,610	283,100	52.27	2,420
750	10,750	266,600	55.51	2,279
1,000	13,850	257,600	57.44	2,202
1,250	17,060	253,900	58.29	2,170
1,460	19,820	252,500	58.61	2,158

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 117 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 47

DC-9-30D2

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	2,570	478,000	32.28	3,918
250	4,490	334,100	46.19	2,738
500	7,440	276,800	55.75	2,269
750	10,380	257,400	59.94	2,110
1,000	13,310	247,600	62.33	2,029
1,250	16,350	243,300	63.43	1,994
1,500	19,440	241,100	64.01	1,976
1,940	25,000	239,700	64.38	1,965

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 122 , FUEL DENSITY = 6.8 LB/GALLON

TABLE 48

DC-9-30D3

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE [1]			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM / Gallon [2]	BTU / Available Seat - NM
100	2,400	446,400	26.07	4,852
250	4,200	312,500	37.24	3,397
500	6,970	259,300	44.88	2,818
750	9,670	239,800	48.52	2,607
1,000	12,390	230,500	50.49	2,505
1,250	15,170	225,700	51.55	2,454
1,440	17,400	224,800	51.77	2,443

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 92, FUEL DENSITY = 6.8 LB/GALLON

TABLE 49

DC-10-10D

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	6,530	1,215,000	20.72	6,103
250	9,270	689,700	36.49	3,466
500	13,830	514,500	48.92	2,585
750	18,580	460,800	54.62	2,315
1,000	23,780	442,300	56.90	2,223
2,000	45,430	422,500	59.57	2,123
3,000	68,870	427,000	58.95	2,146

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 199, FUEL DENSITY = 6.8 LB/GALLON

TABLE 50

DC-10-40D

FUEL USE VS. DISTANCE

Distance (NM)	FUEL USE (1)			
	Block Fuel (LB)	BTU / Nautical Mile	Available Seat - NM (2) / Gallon	BTU / Available Seat - NM
100	8,320	1,548,000	26.73	4,732
250	12,910	960,500	43.06	2,937
500	20,560	764,800	54.08	2,339
750	28,190	699,100	59.16	2,138
1,000	35,720	664,400	62.25	2,032
2,000	66,440	617,900	66.94	1,890
3,000	100,700	624,300	66.24	1,909

(1) BASELINE FLIGHT PROFILES, LOAD FACTOR = 58.0%

(2) TOTAL NUMBER OF SEATS = 327 , FUEL DENSITY = 6.8 LB/GALLON

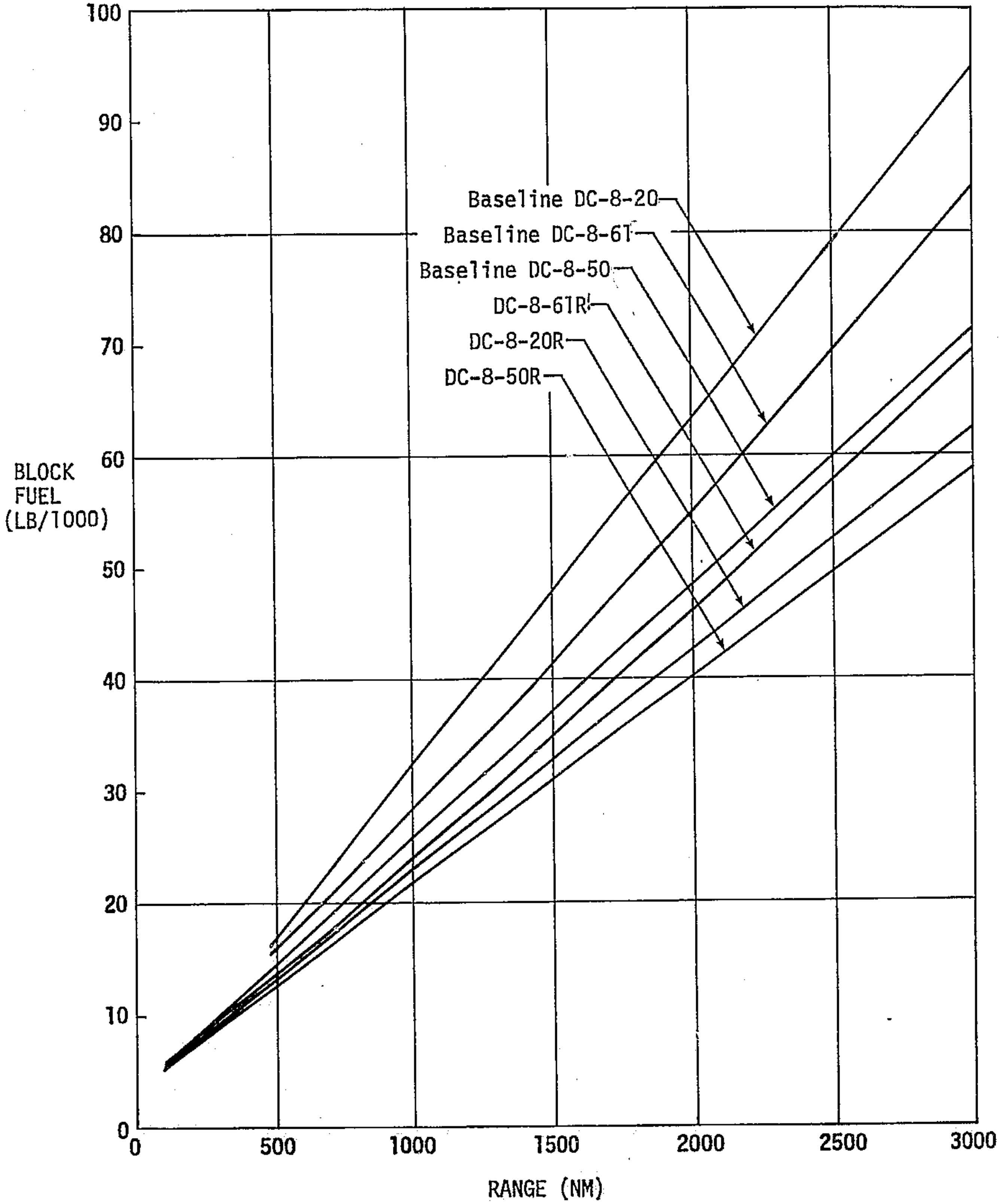


FIGURE 43. BLOCK FUEL VS. RANGE FOR MODIFIED DC-8 AIRCRAFT

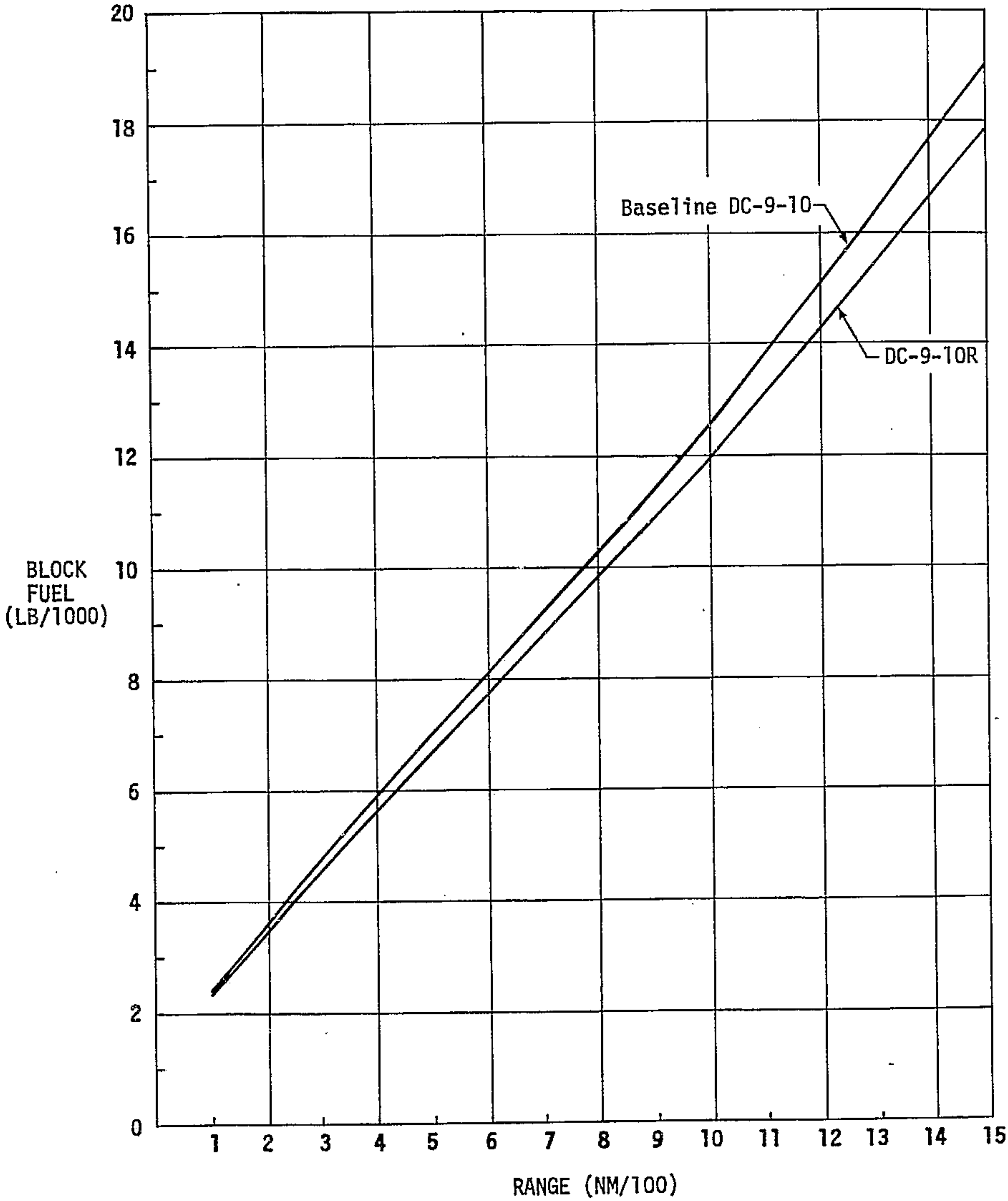


FIGURE 44. BLOCK FUEL VS. RANGE FOR MODIFIED DC-9-10 AIRCRAFT

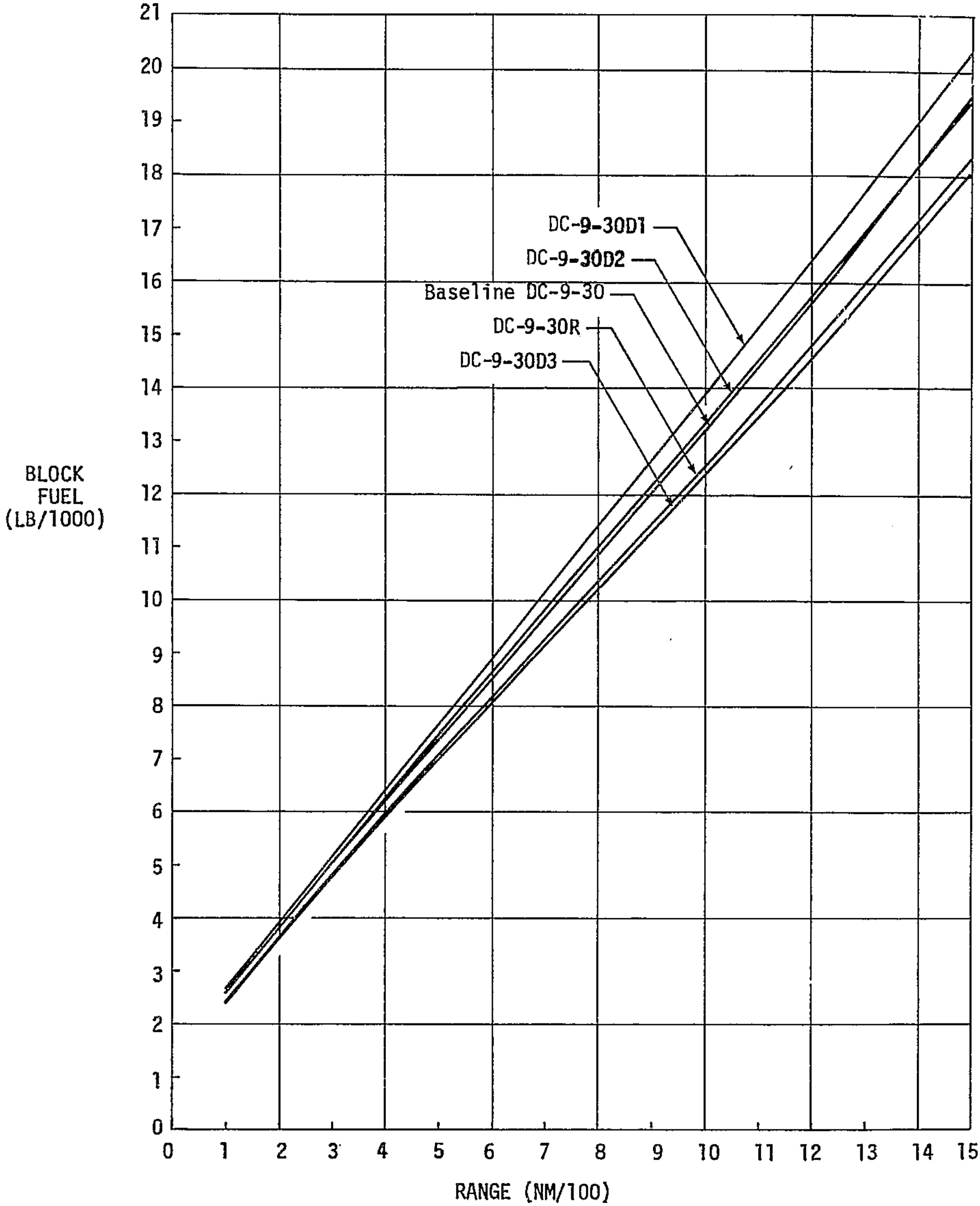


FIGURE 45. BLOCK FUEL VS. RANGE FOR MODIFIED AND DERIVATIVE DC-9-30 AIRCRAFT

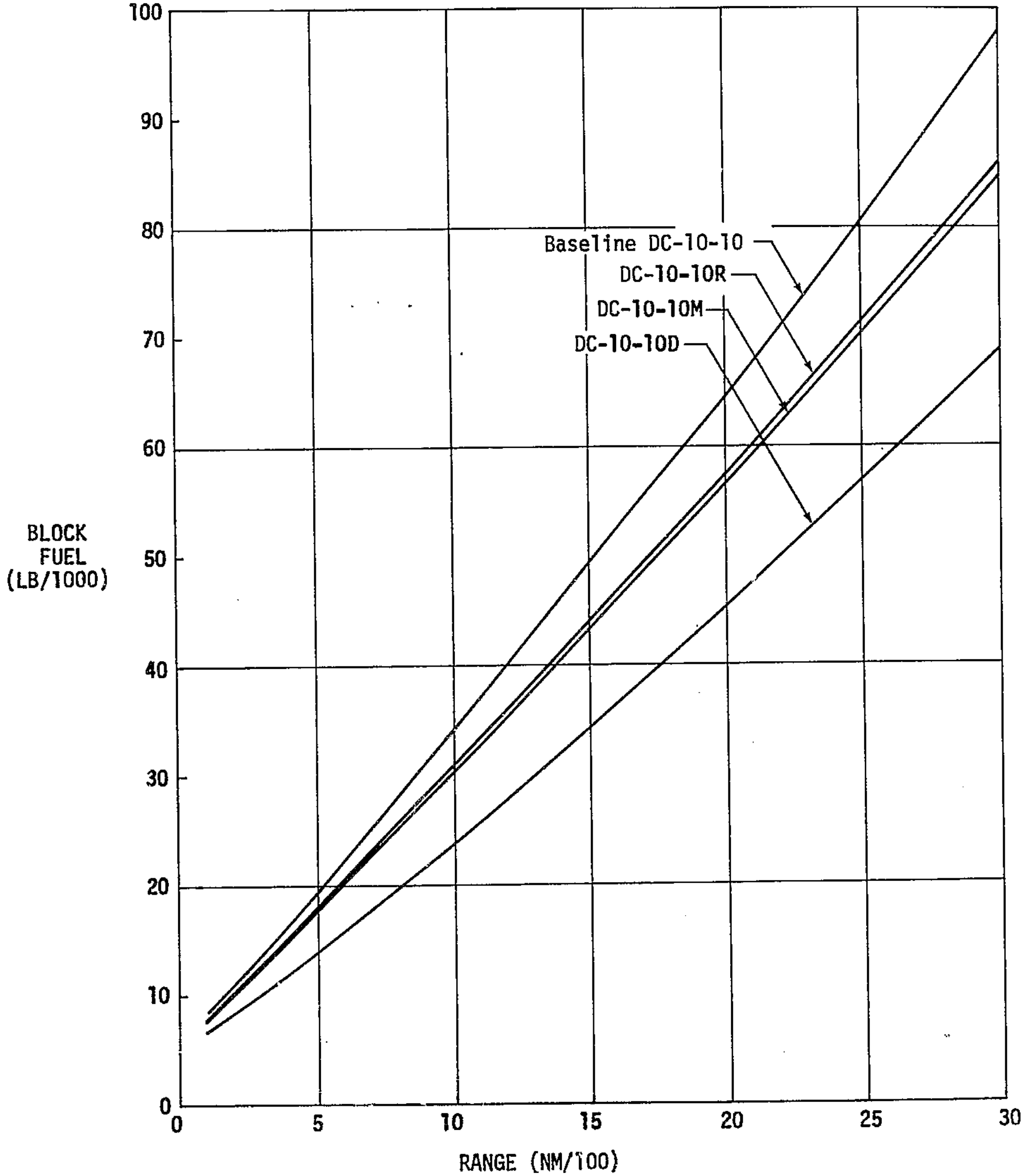


FIGURE 46. BLOCK FUEL VS. RANGE FOR MODIFIED AND DERIVATIVE DC-10-10 AIRCRAFT

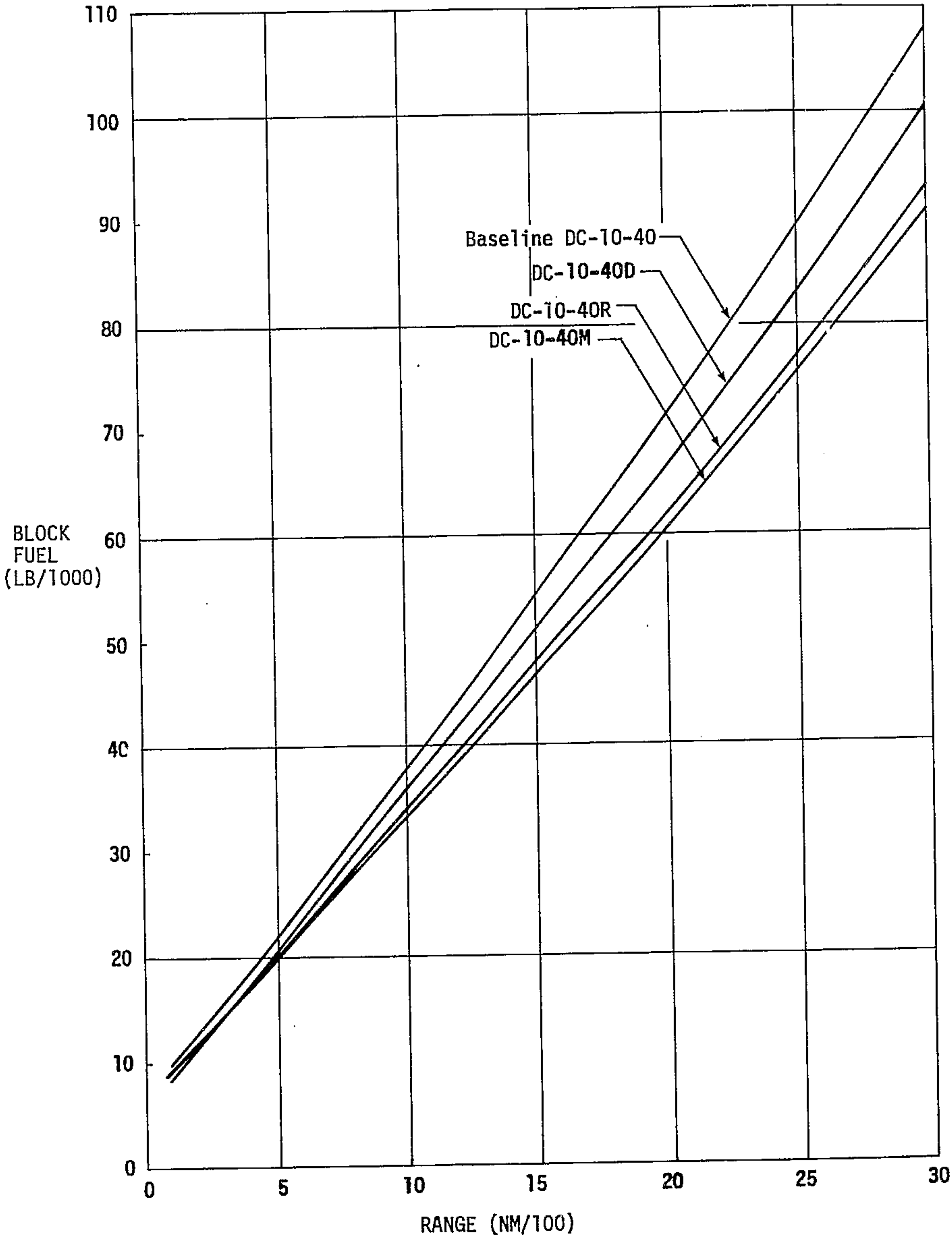


FIGURE 47. BLOCK FUEL VS. RANGE FOR MODIFIED AND DERIVATIVE DC-10-40 AIRCRAFT

TABLE 51

EFFECT OF MODIFICATIONS AND DERIVATIVE DESIGNS
ON BLOCK FUEL AND DOC
AT 1973 CAB AVERAGE STAGE LENGTH
(See Table 30)

Aircraft	Δ Block Fuel (% $\frac{BTU}{ASNM}$)	Δ DOC (% ¢/ASNM) @ 15¢/Gal	@ 30¢/Gal	@ 60¢/Gal
DC-8-20R	-28.25	20.50	8.43	- 3.69
DC-8-20DR	- 4.52	-10.09	- 8.67	- 7.28
DC-8-20ER	-23.73	20.96	9.96	- 1.22
DC-8-50R	-14.97	37.90	26.72	14.29
DC-8-50DR	- 4.47	4.66	2.70	0.57
DC-8-50ER	-10.50	38.16	27.84	16.44
DC-8-61R	-14.92	47.70	34.25	19.46
DC-8-61DR	- 4.53	14.57	10.50	5.99
DC-8-61ER	-10.39	48.04	35.52	21.70
DC-9-10R	- 4.06	18.01	14.06	9.27
DC-9-30R	- 3.81	20.97	16.54	11.21
DC-10-10R	- 9.07	3.65	1.07	- 1.78
DC-10-40R	- 9.32	0.81	- 1.14	- 3.47
DC-10-10M	-10.17	11.49	7.13	2.24
DC-10-40M	-10.76	11.37	7.04	2.02
DC-9-30D1	-19.80	- 8.06	-10.13	-12.68
DC-9-30D2	-24.68	- 4.85	- 8.36	-12.68
DC-9-30D3	- 4.94	0.68	- 0.30	- 1.53
DC-10-10D	- 2.76	18.88	14.54	9.64
DC-10-40D	-27.90	- 7.54	-11.48	-16.12

TABLE 52

EFFECT OF INDIVIDUAL MODIFICATION ITEMS ON BLOCK FUEL
AT 1973 CAB AVERAGE STAGE LENGTH
(See Table 30)

Modified Aircraft	Total Δ Block Fuel (1) (%)	Δ Block Fuel for Individual Modification Items (%)			
		JT8D-209 Engine	Winglet	General Drag Reduction	General Weight Reduction (2)
DC-8-20R	-28.25	-23.73	-1.72	-2.80	--
DC-8-20DR	- 4.52	--	-1.72	-2.80	--
DC-8-20ER	-23.73	-23.73	--	--	--
DC-8-50R	-14.97	-10.50 (3)	-1.70	-2.77	--
DC-8-50DR	- 4.47	--	-1.70	-2.77	--
DC-8-50ER	-10.50	-10.50 (3)	--	--	--
DC-8-61R	-14.92	-10.39 (3)	-1.74	-2.79	--
DC-8-61DR	- 4.53	--	-1.74	-2.79	--
DC-8-61ER	-10.39	-10.39 (3)	--	--	--
DC-9-10R	- 4.06	--	-1.31	-2.75	--
DC-9-30R	- 3.81	--	-1.26	-2.55	--
DC-10-10R	- 9.07	--	-3.99	-5.08	--
DC-10-40R	- 9.32	--	-3.94	-5.38	--
DC-10-10M	-10.17	--	-3.87	-5.10	-1.20
DC-10-40M	-10.76	--	-3.84	-5.42	-1.50

(1) Relative to Baseline Aircraft
(2) Includes Composite Secondary Structure
(3) Includes Cutback Pylon

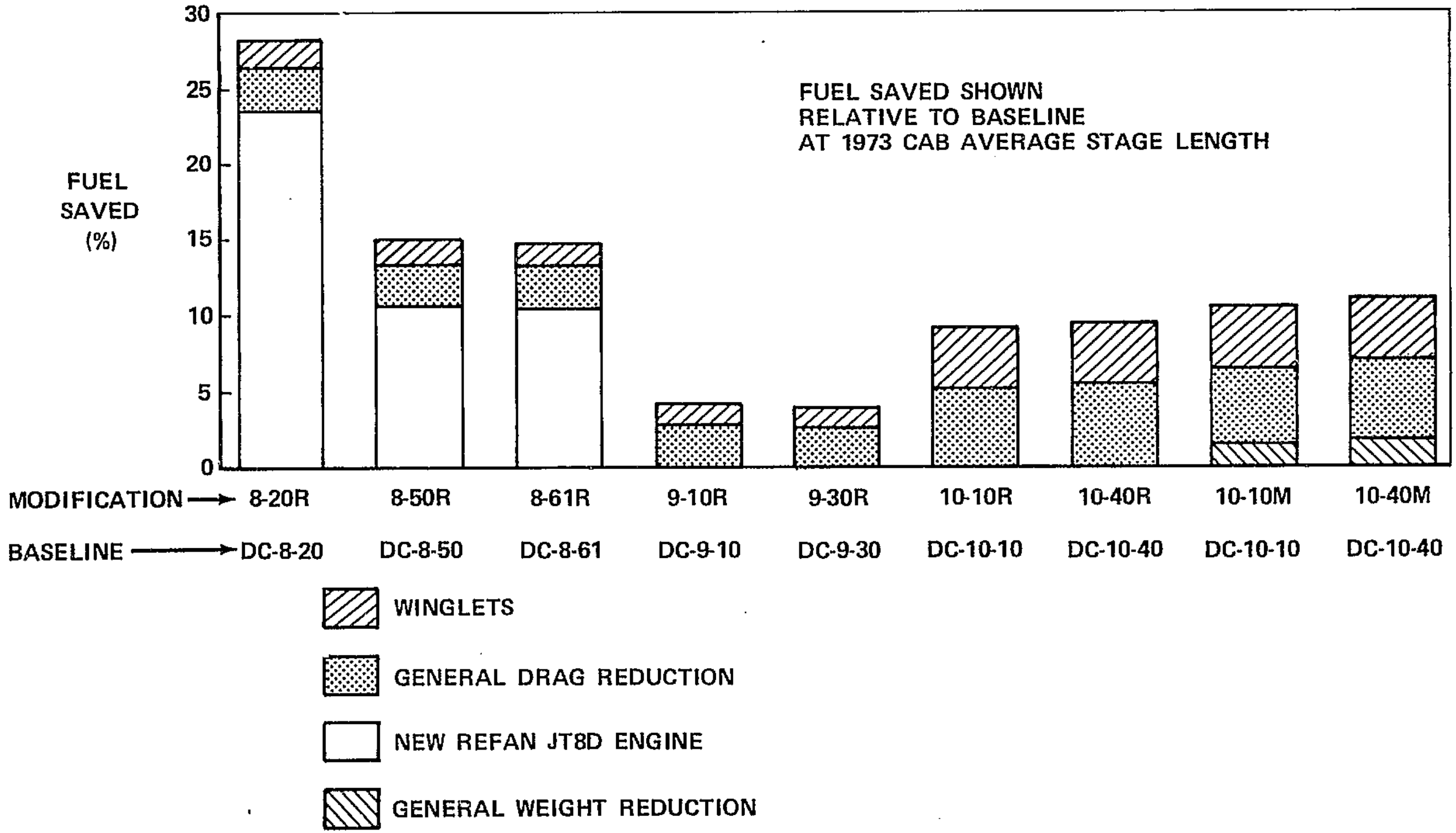


FIGURE 48. MODIFIED AIRCRAFT FUEL SAVINGS

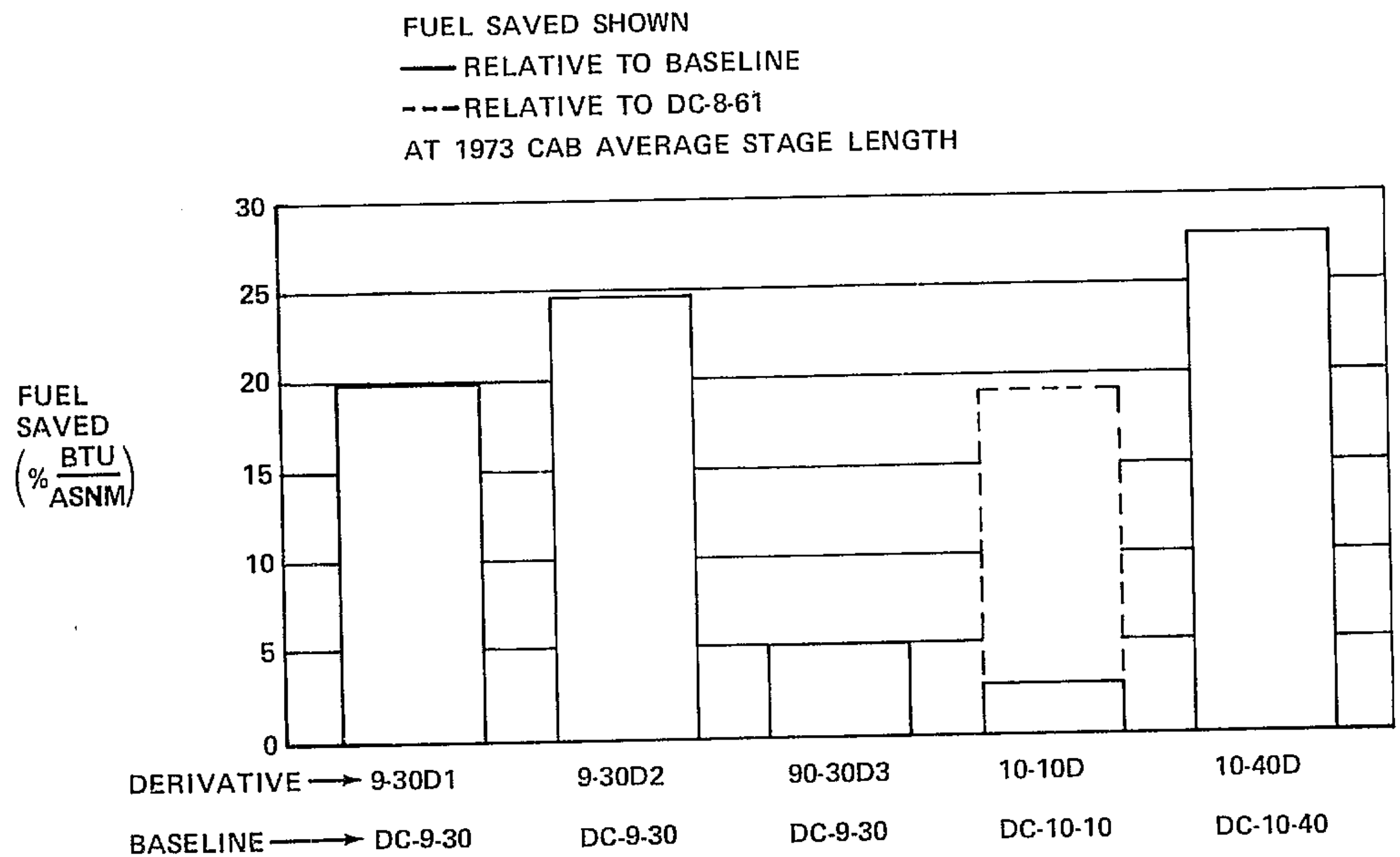


FIGURE 49. DERIVATIVE AIRCRAFT FUEL SAVINGS

SECTION 5.0

NEW NEAR-TERM AIRCRAFT

The impact of rising fuel prices on the design of new aircraft was investigated to determine whether significant improvements in fuel efficiency could be achieved. The new aircraft were designed to NASA specifications and incorporate technology consistent with a 1980 introduction date..

Five families of new aircraft were studied, three domestic range families and two international range families, resulting in eighteen optimized configurations. The domestic range families include aircraft optimized for maximum fuel efficiency and for minimum DOC at three different fuel prices, 15, 30 and 60 cents per gallon. The international range airplanes were optimized for maximum fuel efficiency and for minimum DOC at two fuel prices, 30 and 60 cents per gallon.

As a convenience, a code has been developed to designate the various new near-term airplanes. For example, the 200 passenger, 1,500 nautical mile range aircraft optimized for DOC at a fuel price of 15 cents per gallon, is designated as shown in Figure 50. The subscript indicates the optimization parameter. If an aircraft was optimized for minimum fuel use, the subscript MF is used. When used without a subscript, the designator refers to an entire family of aircraft. The entire group of new near-term airplanes are sometimes referred to as N80 aircraft.

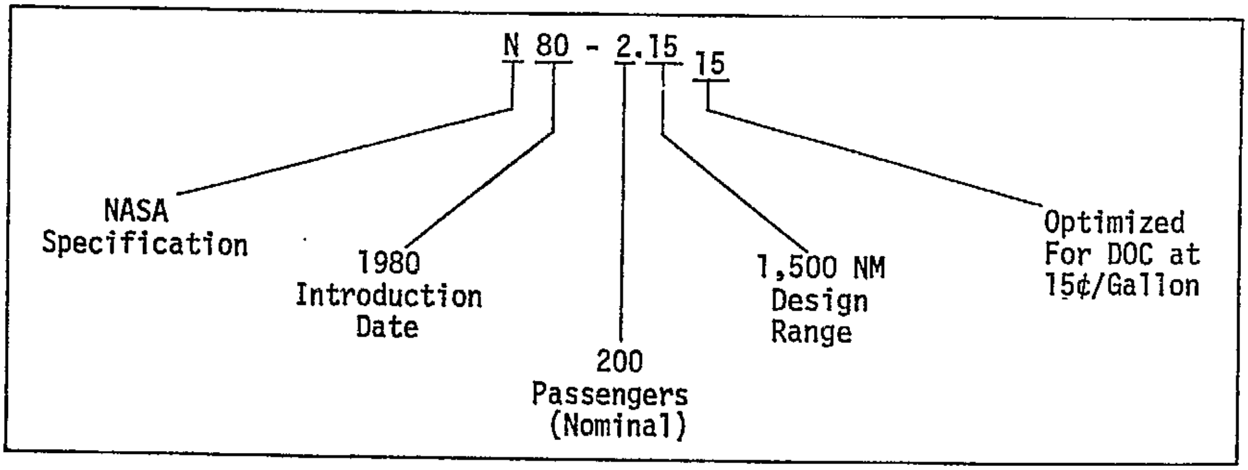


FIGURE 50. NEW NEAR-TERM AIRCRAFT DESIGNATOR CODE

5.1 Design Specifications and Ground Rules

The design ground rules provided by NASA for the five new near-term aircraft families are given in Table 53. Aircraft cruise Mach numbers were optimized in the range 0.70 - 0.90. Within these ground rules, specifications for baseline new near-term airplanes were developed by Douglas and are presented in Table 54. The flight profile used for the study is presented in Figure 51.

Figure 52 lists the advanced technologies incorporated in these airplanes. The use of composite secondary structure for the N80 airplanes was based on current DC-10 composite structure weight saving studies. Composite structure was assumed for the wing and tail control surfaces and trailing edges, and the fuselage floor, floor beams, and door structures. The N80 airplanes also include advanced technology weight saving items such as carbon brakes, thinwall composite nacelles, and isogrid window belts.

Both swept and straight wing designs were considered for minimum DOC as well as minimum fuel airplanes. Recent studies have indicated that the reduced number of parts required for a simpler straight wing could decrease the wing cost up to 15 percent and the overall aircraft cost about 3 percent.

5.1.1 Interior Arrangements

Detailed interior arrangements were prepared for the N80 aircraft and are shown in Figures 53 and 54. Passenger convenience information is provided in Table 55.

For consistency with other study airplanes the interior arrangements are dual class interiors with approximately 10 percent first class seating and 90 percent coach seating. Seat pitch is 38 inches for first class and 34 inches for coach. Actual passenger capacities differ slightly from the nominal 200 and 400 seat ground rules.

All of the 201 seat aircraft share a common interior arrangement (Figure 53). Six abreast seating is provided for first class and seven abreast in coach. The galleys are located on the upper deck.

The 404 seat aircraft also share a common interior arrangement (Figure 54). Six abreast seating is provided for first class and nine abreast in coach. The overall size of this configuration allows room for the forward galley to be located on the lower deck.

TABLE 53

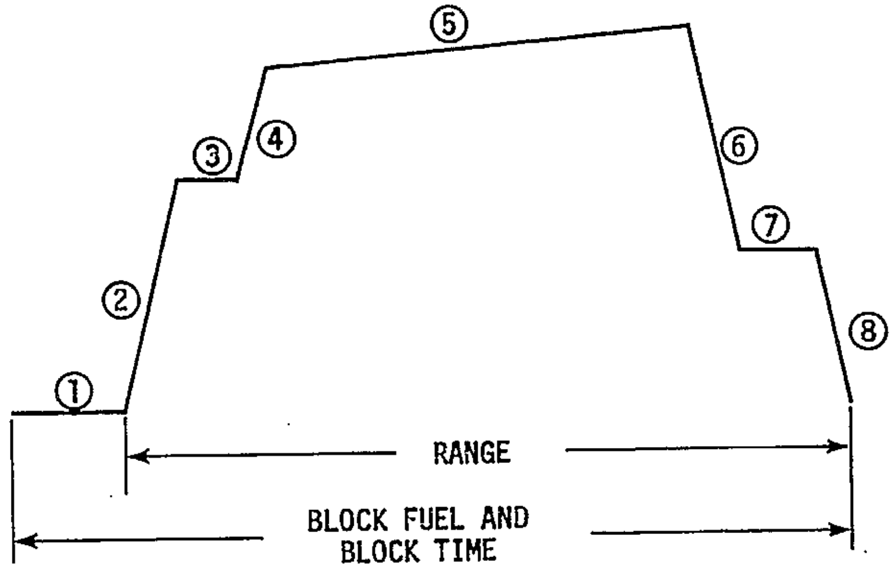
NASA DESIGN STUDY GROUND RULES

NEW AIRPLANE FAMILY	N80-2.15	N80-2.30	N80-2.55	N80-4.30	N80-4.55
Engine	Turbofan	Turbofan	Turbofan	Turbofan	Turbofan
Cruise Mach Number	.70-.90	.70-.90	.70-.90	.70-.90	.70-.90
Passengers	200	200	200	400	400
Range (NM)	1,500	3,000	5,500	3,000	5,500
Target Noise Levels	FAR 36-10	FAR 36-10	FAR 36-10	FAR 36-10	FAR 36-10

TABLE 54

NEW AIRPLANE SPECIFICATIONS

NEW AIRPLANE FAMILY	N80-2.15	N80-2.30	N80-2.55	N80-4.30	N80-4.55
Engines: Number, Location	2, Wing	4, Wing	4, Wing	4, Wing	4, Wing
Type	CF6-6	CFM-56	CFM-56	CF6-6	CF6-6
Number of Crew	3	3	3	3	3
Number of Pax (10/90 Split)	201	201	201	404	404
Seats Abreast	7	7	7	9	9
Galley Location	Upper	Upper	Upper	Lower	Lower
Design Range (NM)	1,500	3,000	5,500	3,000	5,500
Maximum Takeoff Distance (Ft)	7,000	8,000	10,000	9,000	11,000
Maximum Approach Speed (Kt)	120	125	130	130	130
Initial Cruise Altitude (Ft)	31,000	31,000	31,000	31,000	31,000
Airfoil Type	SCW	SCW	SCW	SCW	SCW
Target Noise Levels	FAR 36-10	FAR 36-10	FAR 36-10	FAR 36-10	FAR 36-10



PRIMARY MISSION:

1. Warmup, taxi, takeoff (15 min)
2. Climb to 10,000 ft. at 250 KEAS
3. Accelerate to maximum rate of climb speed
4. Climb to optimum cruise altitude or to ceiling altitude
5. Cruise climb at constant cruise Mach number
6. Descend to 10,000 ft.
7. Decelerate to 250 KEAS
8. Final descent to sea level

RESERVE FUEL MISSION:

- Climb from Sea Level to 30,000 ft.
- Cruise at 30,000 ft. at 99 percent maximum nautical miles per pound
- Descend to Sea Level
- After arriving at alternate, cruise for 45 min. at 99 percent maximum nautical miles per pound at 30,000 ft.

FIGURE 51. MISSION PROFILE FOR NEW NEAR-TERM AIRCRAFT

- WING

  Supercritical Section

  Improved High Lift System - leading edge slats with double slotted, track-motion flap

- POWER PLANTS AND PODS

  CF6-6 with 3/4 length pod (N80-2.15, N80-4.30, and N80-4.55)

  CFM-56 with long duct pod (N80-2.30 and N80-2.55)

- PROPULSIVE NOISE REDUCTION

  Pods to include advanced acoustic composite nacelle technology

- STRUCTURAL IMPROVEMENTS

  Composites: floor beams, doors, nacelles, control surfaces, fairings, wing panels

  Advanced Metallics: isogrid machined window belt

- WEIGHT REDUCTION OF SYSTEMS

  Carbon Brakes

  Environmental Systems

  Auxiliary Power System

  Control System - Longitudinal Stability Augmentation

- COCKPIT

  Reduced Workload

FIGURE 52. ADVANCED TECHNOLOGIES FOR NEW NEAR-TERM AIRCRAFT

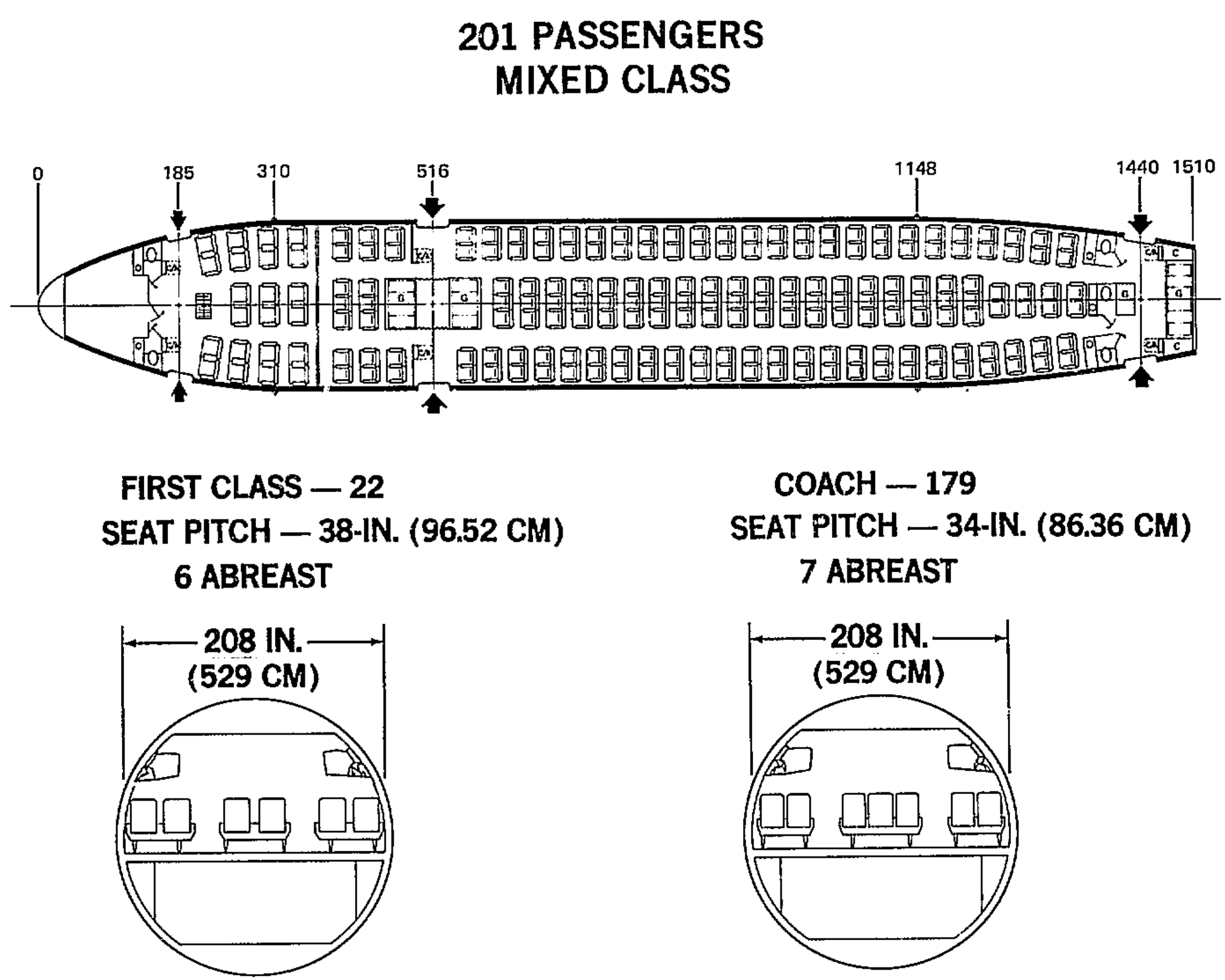


FIGURE 53. INTERIOR ARRANGEMENT FOR N80-2.15, N80-2.30, AND N80-2.55

404 PASSENGERS
MIXED CLASS — LOWER FORWARD GALLEY

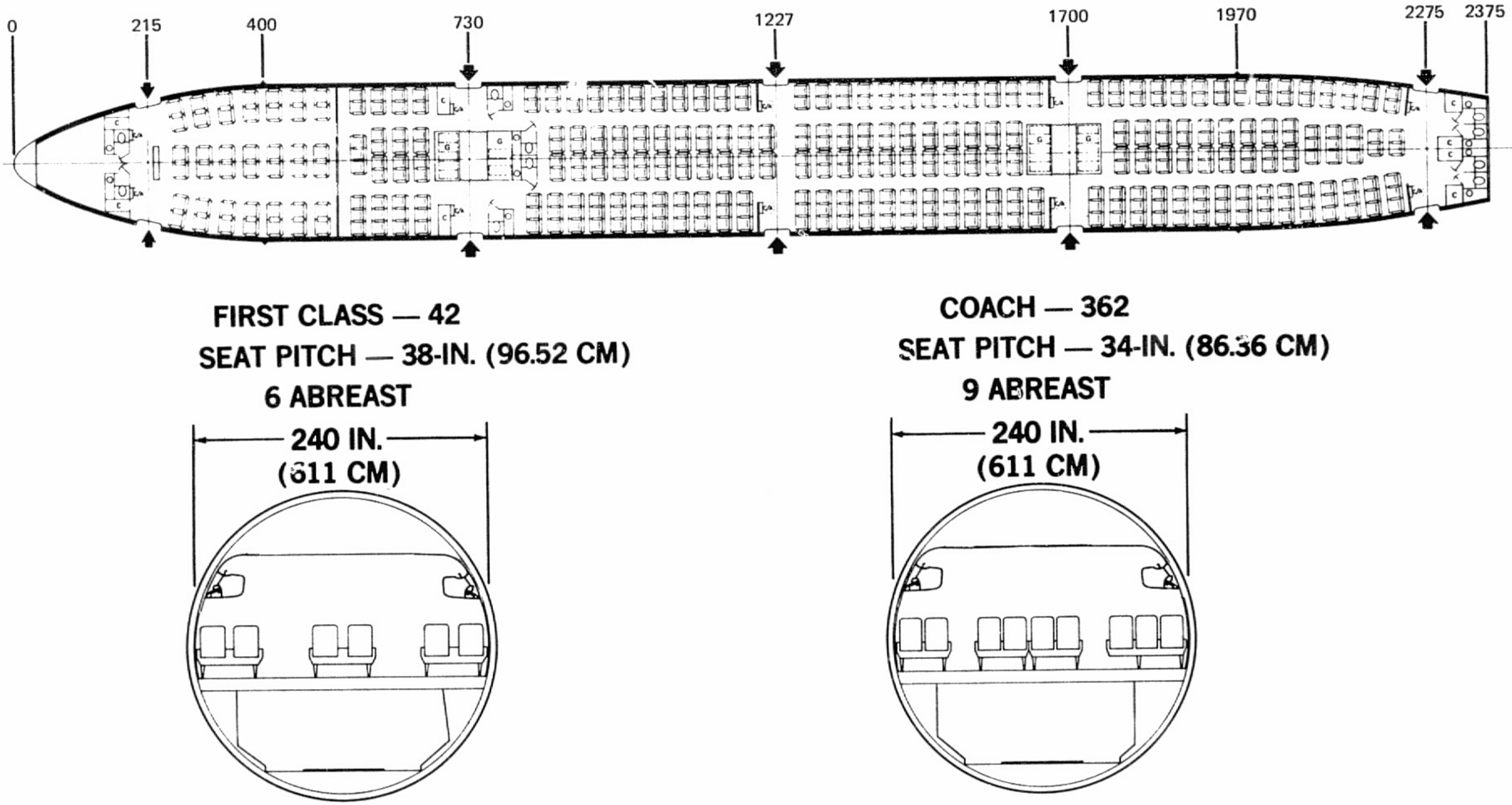


FIGURE 54. INTERIOR ARRANGEMENT FOR N80-4.30 AND N80-4.55

TABLE 55

PASSENGER CONVENIENCE DATA

New Near-Term Aircraft

10/90 Split, 38"/34" Seat Pitch

Aircraft Family	Number of Seats	Galleys		Closet Space		Lavatories	
		Area (In^2)	Area/Psgr (In^2)	Total Length (In)	Length/Psgr (In)	Number	Psgr/Lav
N80-2.15	201	10,200	50.7	130	.65	5	40.2
N80-2.30	201	10,200	50.7	130	.65	5	40.2
N80-2.55	201	10,200	50.7	130	.65	5	40.2
N80-4.30*	404	47,689	118.0	310	.77	10	40.4
N80-4.55*	404	47,689	118.0	310	.77	10	40.4

*With lower galley, lower galley area (excluding walkway) = 34,889 $inch^2$, upper galley area = 12,800 $inch^2$.

5.2 Design Procedures

The final N80 configurations were the result of a systematic sizing study. The Passenger Aircraft Sizing and Analysis Program (PASAP) was used to perform the sizing. PASAP is a multi-disciplinary aircraft design program developed by DAC specifically for rapid analysis of new aircraft configurations. In sizing the N80-2.15 and N80-2.30 aircraft, approximately 140 combinations of thickness, sweep, aspect ratio and Mach number were studied. For each combination, at least five wing areas were considered for each of several thrust levels. The subsequent aircraft were sized using the trends.

A typical sizing grid is presented in Figure 55. The grid intersections represent fixed values of wing area and engine thrust. The left hand scale shows the design takeoff weight associated with grid locations. Design constraints shown include approach speed, takeoff field length and initial cruise altitude capability. The broken lines represent parameter barriers beyond which the constraints are not met. Lines of constant DOC (DOC_1, DOC_2, DOC_3) and constant fuel burned (FB_1, FB_2, FB_3) are overlayed and optimum configurations that meet the design constraints can be chosen. Point A is a minimum DOC design and Point B represents a minimum fuel case. In choosing the final wing area, a solve routine was employed to "ride" a known thrust constraint line, varying wing area until an optimum wing area or a constraint was reached. Thus, Point A is the lowest possible DOC configuration that meets all performance constraints, and Point B is the minimum fuel use configuration that meets all performance constraints.

Table 56 shows the sizing constraints for the N80 family. The optimization parameters at the head of each column correspond to the subscripts used in the aircraft designating code. The performance constraints -- takeoff distance, approach speed, and initial cruise altitude -- were specified in Table 54. Note that initial cruise altitude did not constrain any of the designs. The minimum thrust constraint represents the initial cruise thrust requirement (Reference 16). The fuel volume constraint is based on the assumption that all fuel is carried in the wing, and that the wing must be large enough to carry all of the fuel for the design mission and the reserve fuel mission. The minimum DOC or fuel use constraints are the optimization criteria. Performance and fuel volume constraints materially affect the final sizing of an aircraft optimized for DOC at low fuel prices, such as

10 cents per gallon, because designs at low fuel prices tend toward small wings and high thrust for minimum DOC. As fuel prices increase, or when the minimum fuel use criterion is used, the performance constraints have less of an effect on the wing and engine size. The N80 aircraft were all sized to achieve minimum DOC or minimum fuel use while meeting or exceeding the performance and range requirements.

The geometry optimization procedure is illustrated in Figure 56. At an initial constant cruise Mach number, the baseline N80 aircraft aspect ratio was first optimized for minimum DOC at a given fuel price. The sweep was then optimized, followed by the thickness. The optimum geometry characteristics were then combined, checked, and adjusted to obtain the minimum DOC airplane at the initial cruise Mach number. The Mach number was then incremented, and the optimization procedure repeated until an absolute minimum DOC aircraft was found. The optimization loop was then repeated for the remaining fuel prices, and for minimum block fuel.

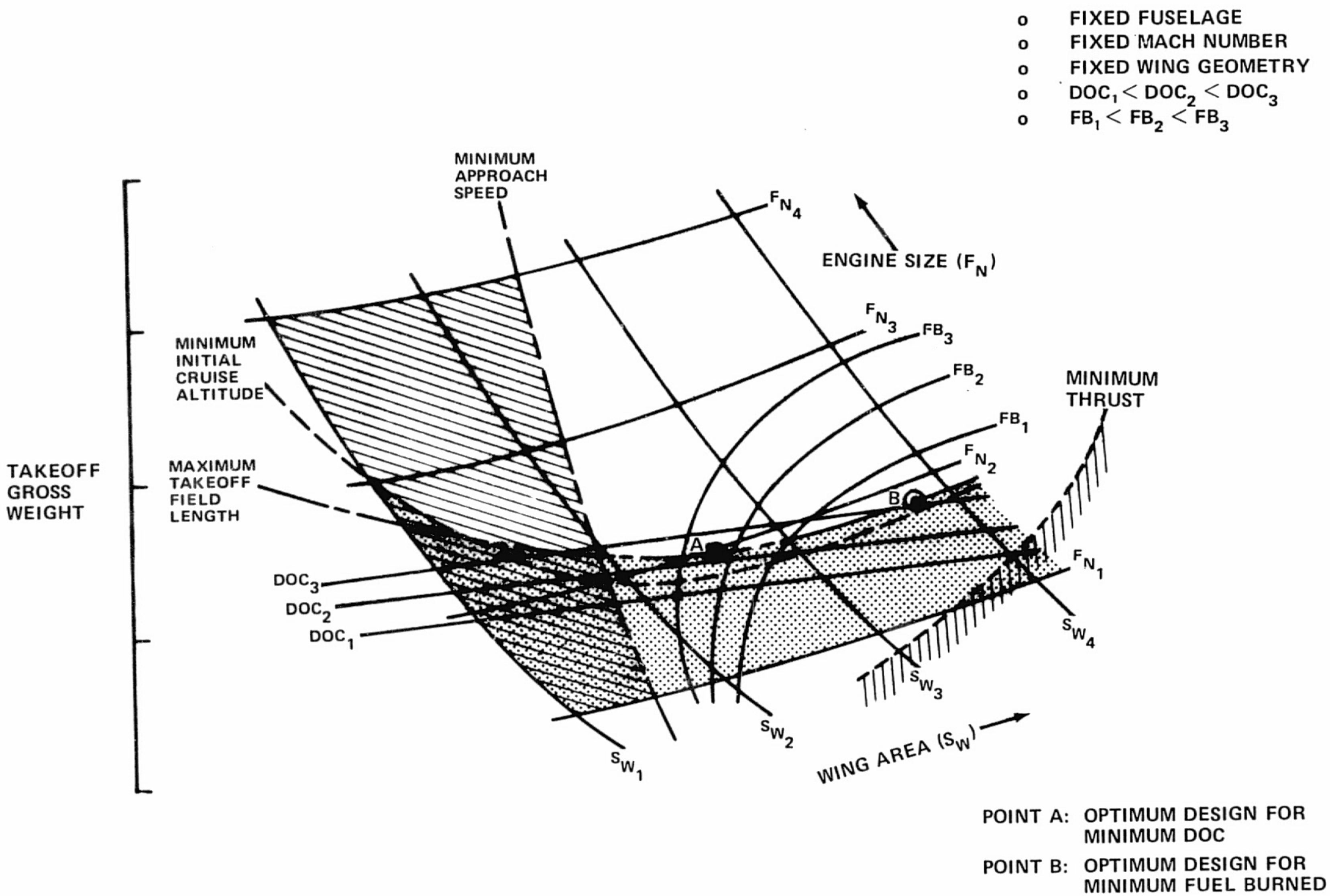


FIGURE 55. PASAP SIZING GRID

TABLE 56

SIZING CONSTRAINTS

NEW AIRCRAFT FAMILY	N80-2.15				N80-2.30				N80-2.55			N80-4.30				N80-4.55		
OPTIMIZATION PARAMETER	15	30	60	MF	15	30	60	MF	30	60	MF	15	30	60	MF	30	60	MF
TAKEOFF DISTANCE	X	X	X	X				X				X	X	X	X	X	X	X
APPROACH SPEED	X	X	X		X	X	X											
INITIAL CRUISE ALT.																		
MINIMUM THRUST					X	X	X		X	X	X							
FUEL VOLUME									X	X	X							
MIN. DOC OR FUEL USE				X				X				X	X	X	X	X	X	X

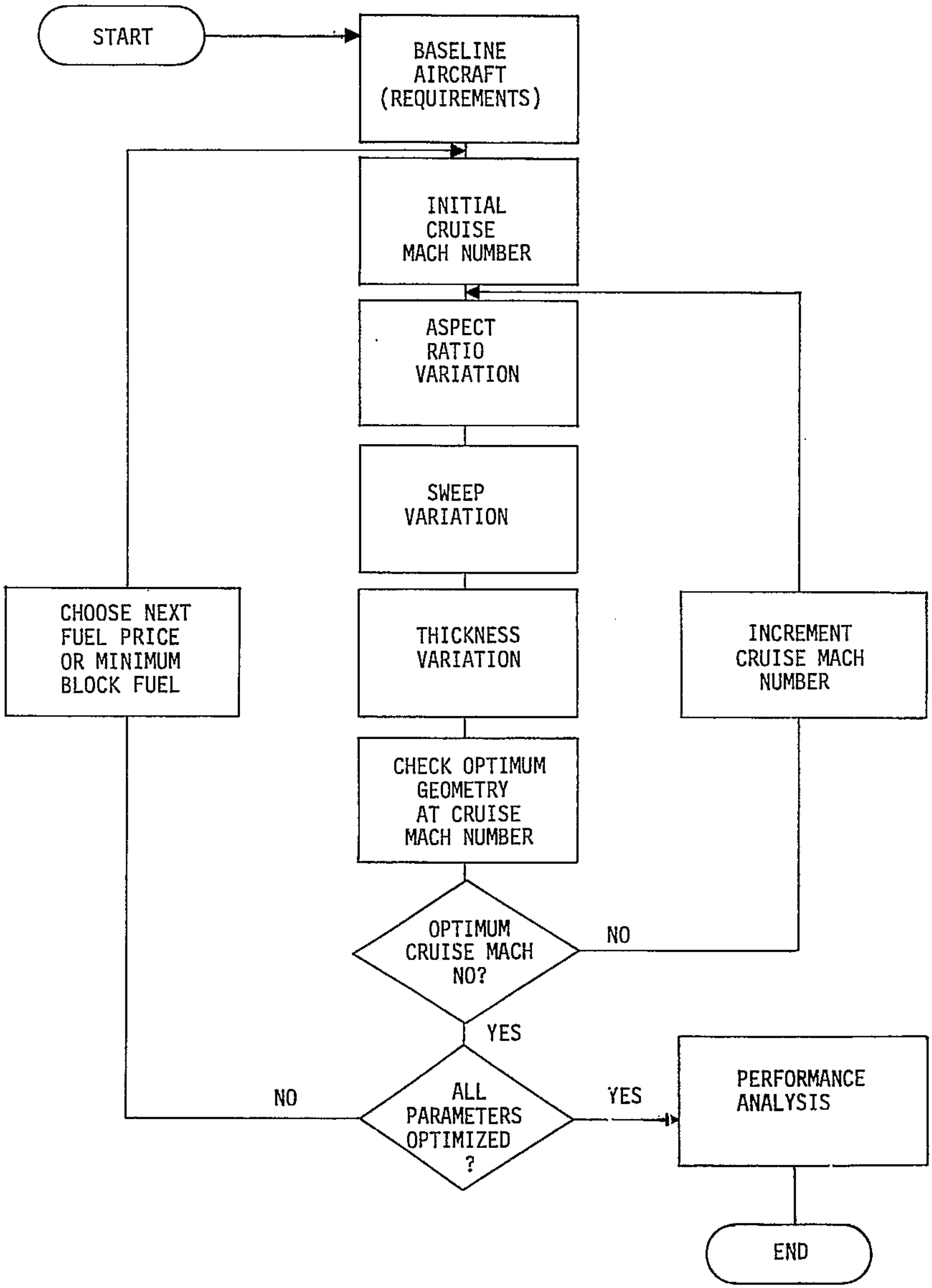


FIGURE 56. SIZING PROCEDURE

5.3 N80-2.15 Series Aircraft

Each member of the Model N80-2.15 series is characterized by two wing-mounted engines, a capacity of 201 passengers, and a design range of 1,500 nautical miles.

5.3.1 Configuration Trade Studies

The baseline N80-2.15 aircraft was sized for minimum DOC at three fuel prices (15, 30, and 60 cents per gallon) and also for minimum block fuel. The sizing was performed in accordance with the ground rules and methods previously described.

The resulting sizing charts for the N80-2.15 minimum DOC aircraft at the three study fuel prices are presented in Figures 57, 58 and 59. As cruise Mach number increases, the wing geometry tends to decrease in aspect ratio, and increase in thickness and sweep. If the wing is constrained to be kept straight, the thickness is reduced as Mach number is increased to minimize the drag rise. At any given fuel price, the effect of not choosing the absolute minimum DOC airplane is shown in Figure 60. The effect is minimal. For example, if the design cruise Mach number of a "minimum DOC" airplane was chosen to be 0.85 instead of 0.81 at a fuel price of 30 cents per gallon, the relative DOC increases only 0.60 percent.

The sizing chart for the minimum block fuel aircraft is presented in Figure 61. Due to ground rules, no Mach numbers below 0.70 were investigated. The increased block time caused by flying at less than 0.70 Mach number would probably be unsuitable for commercial use. The high aspect ratio of 15.5 at Mach 0.70 was chosen from sizing studies (Figure 62). This high aspect ratio approaches the limits of present wing weight prediction techniques without further test information. For a one percent increase in block fuel, the aspect ratio could be reduced to about 13.

5.3.2 Optimum Design Characteristics

Plan views of the optimized N80-2.15 configurations are shown in Figure 63. The characteristics of the N80-2.15 series are summarized in Table 57. Additional design data is given in Table 58, and a weight statement for the airplanes appears in Table 59. In these tab[illegible]s, column headings give the optimization parameter for each aircraft. For example, DOC_{15} refers to the aircraft optimized for DOC at a fuel price of 15 cents per gallon, and so forth.

5.3.3 Optimum Geometry

The variation of optimum geometry and optimum cruise Mach number with fuel price is given in Figure 64. The results indicate that as design fuel price increases, the importance of short block time decreases, and cruise Mach number is reduced. As cruise Mach number decreases, the optimum geometry changes (increased aspect ratio, decreased sweep and thickness) to reduce drag which results in reduced engine size and fuel consumption.

5.3.4 Energy Efficiency

The variation of block time and block fuel with range at 58 percent load factor is presented in Figure 65. This load factor was chosen as a typical operational value. The energy efficiency parameters (BTU/NM, ASNM/GAL, BTU/ASNM) of the N80-2.15 airplanes at 58 percent load factor are presented in Figure 66. These results appear tabulated in Tables 60 and 61.

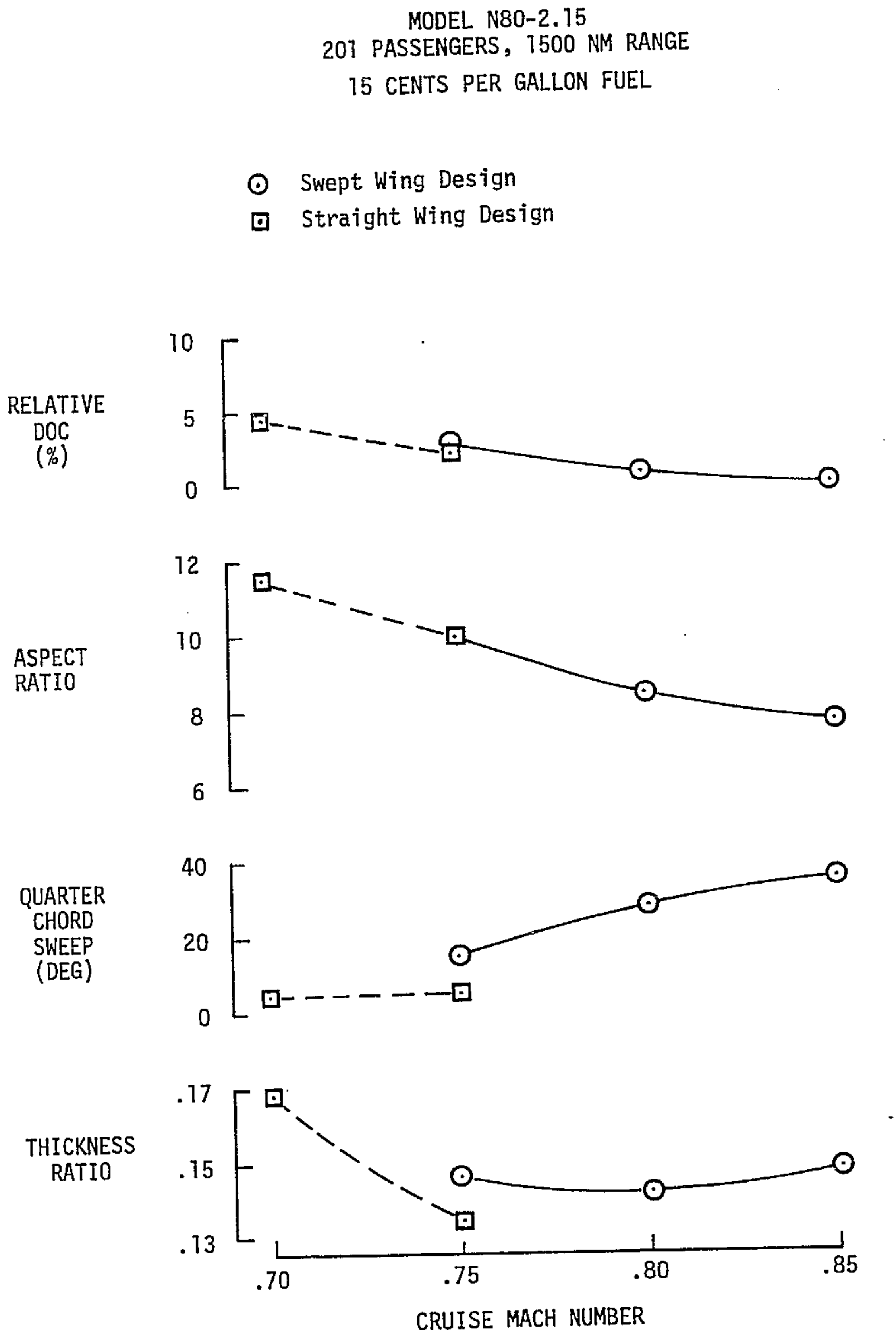


FIGURE 57. N80-2.15$_{15}$ OPTIMUM AIRCRAFT GEOMETRY AND RELATIVE DOC VS. CRUISE MACH NUMBER

MODEL N80-2.15
201 PASSENGERS, 1500 NM RANGE
30 CENTS PER GALLON FUEL

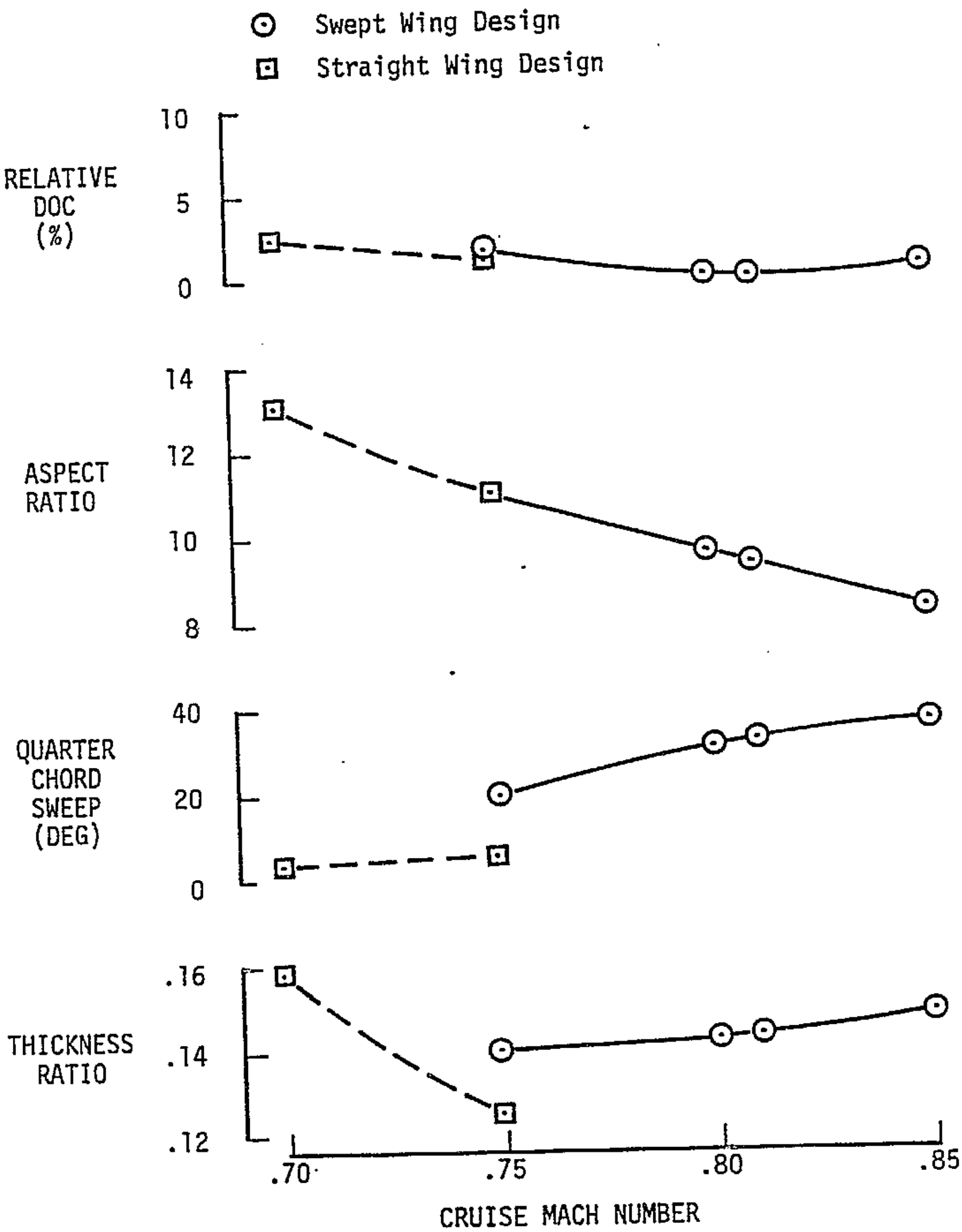


FIGURE 58. N80-2.15$_{30}$ OPTIMUM AIRCRAFT GEOMETRY AND RELATIVE DOC VS. CRUISE MACH NUMBER

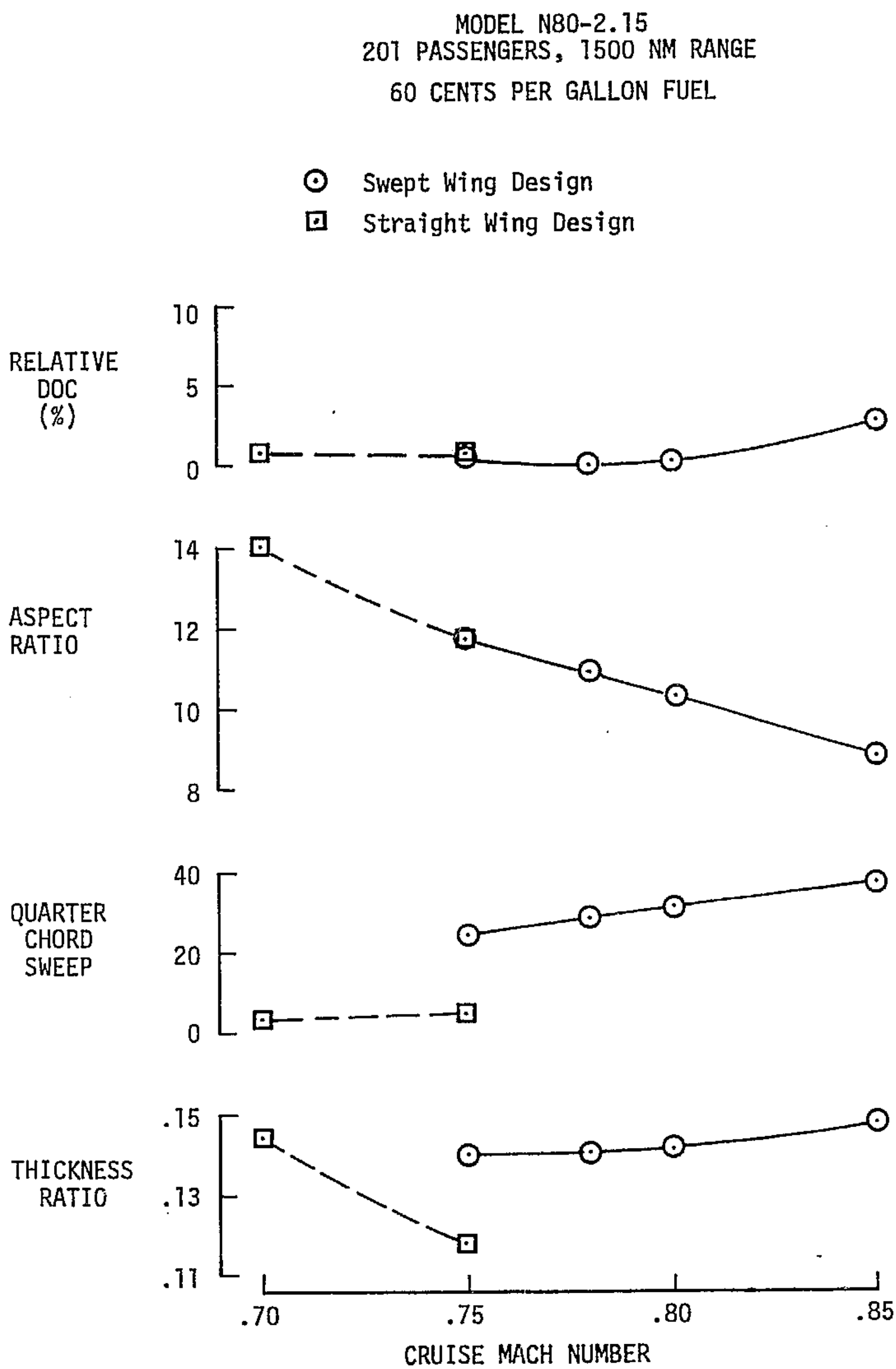


FIGURE 59. N80-2.15$_{60}$ OPTIMUM AIRCRAFT GEOMETRY AND RELATIVE DOC VS. CRUISE MACH NUMBER

MODEL N80-2.15
201 PASSENGERS, 1500 NM RANGE

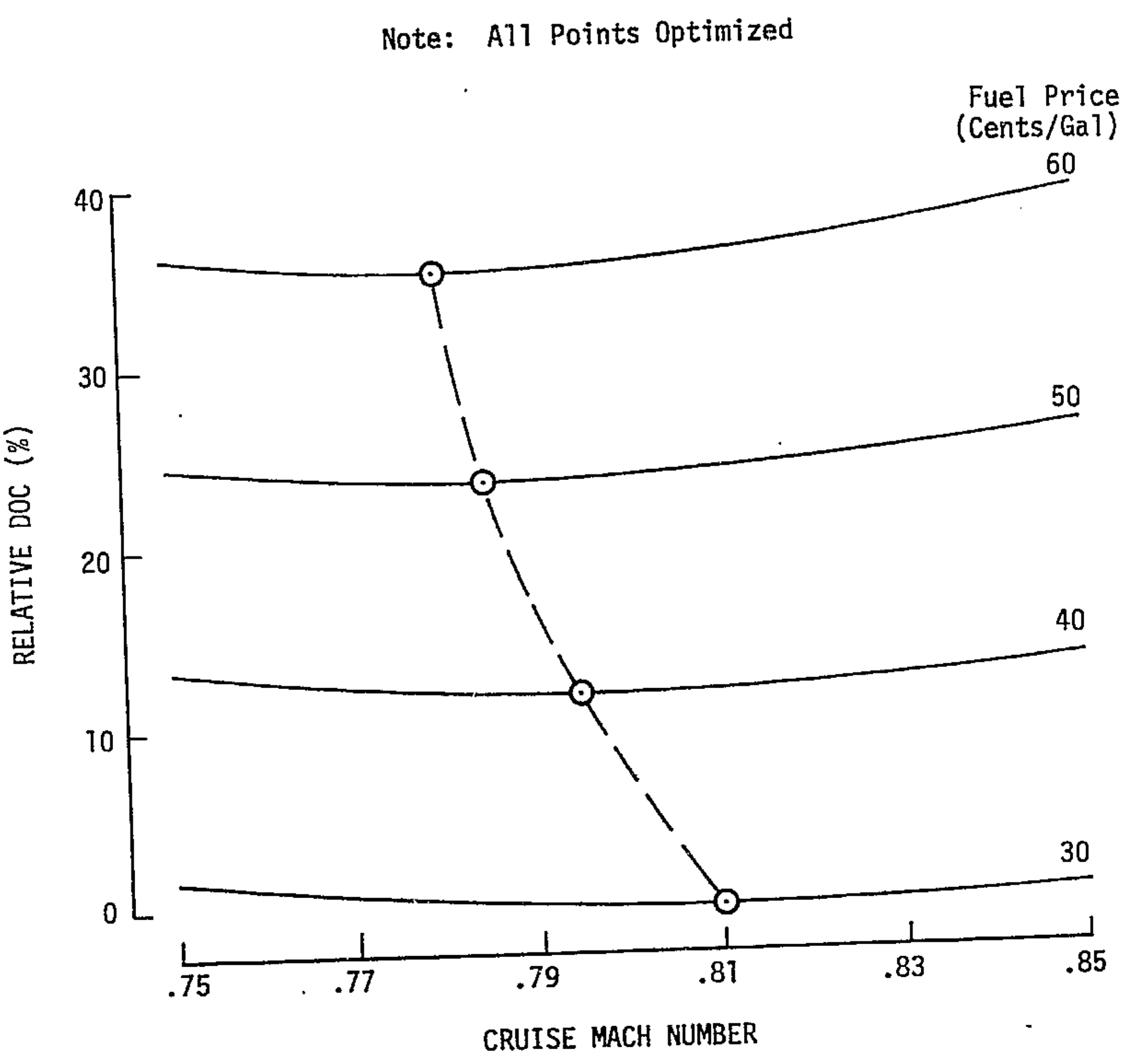


FIGURE 60. RELATIVE DOC VS. CRUISE MACH NUMBER AND FUEL PRICE FOR OPTIMUM GEOMETRY N80-2.15 AIRCRAFT

MODEL N80-2.15
201 PASSENGERS, 1500 NM RANGE
MINIMUM BLOCK FUEL

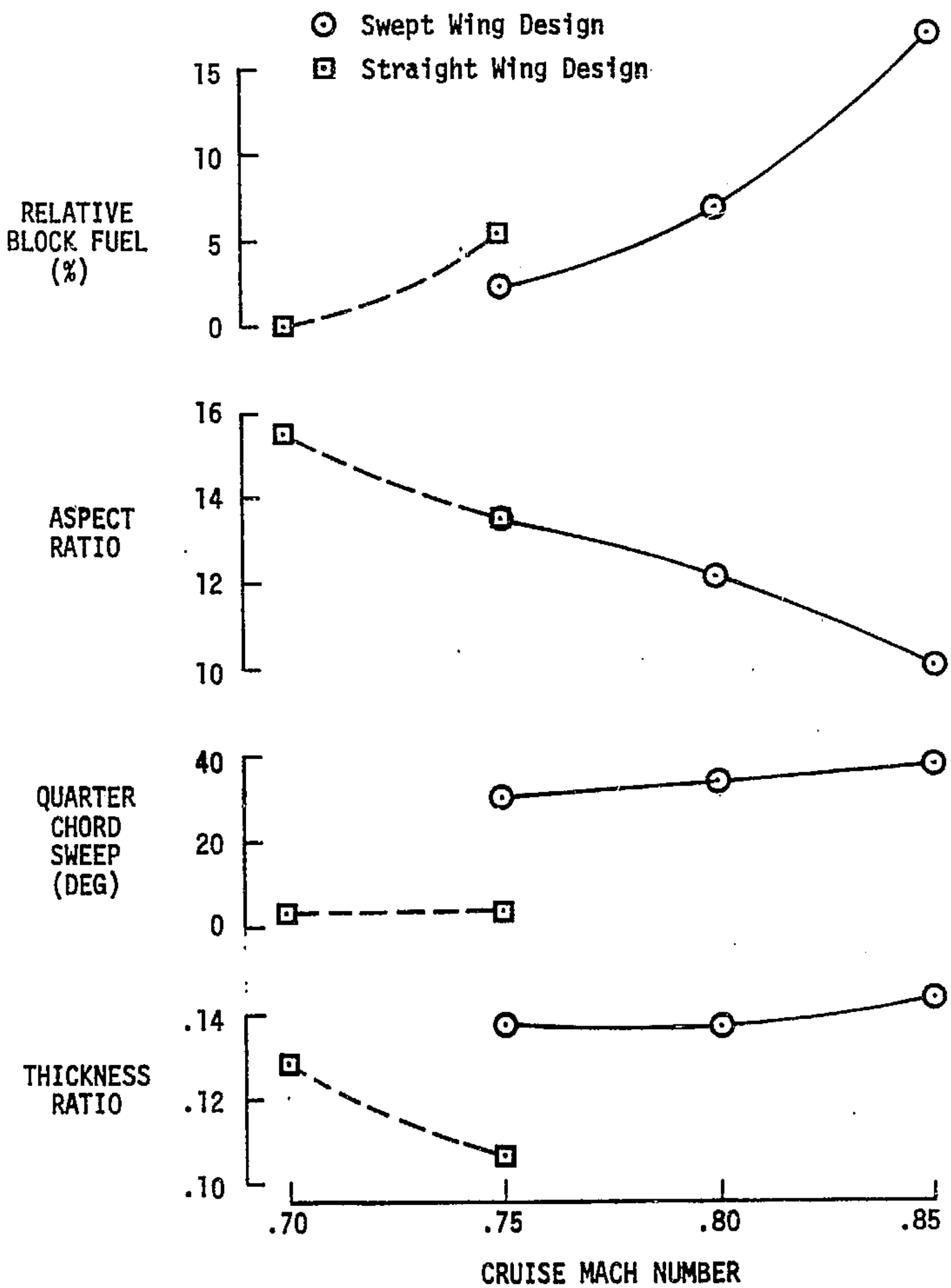


FIGURE 61. N80-2.15$_{MF}$ OPTIMUM AIRCRAFT GEOMETRY AND RELATIVE FUEL USE VS. CRUISE MACH NUMBER

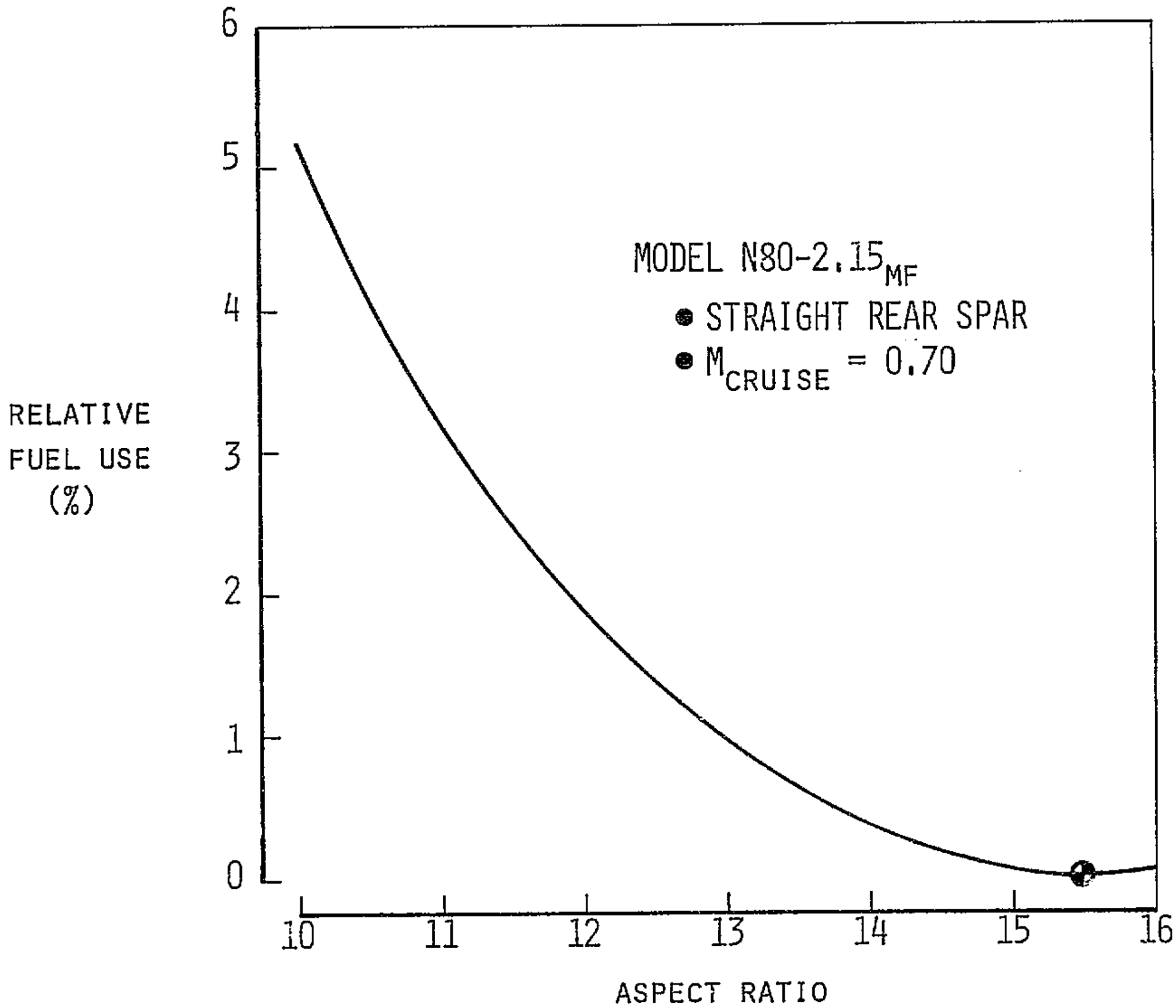


FIGURE 62. EFFECT OF WING ASPECT RATIO ON N80-2.15$_{MF}$ BLOCK FUEL

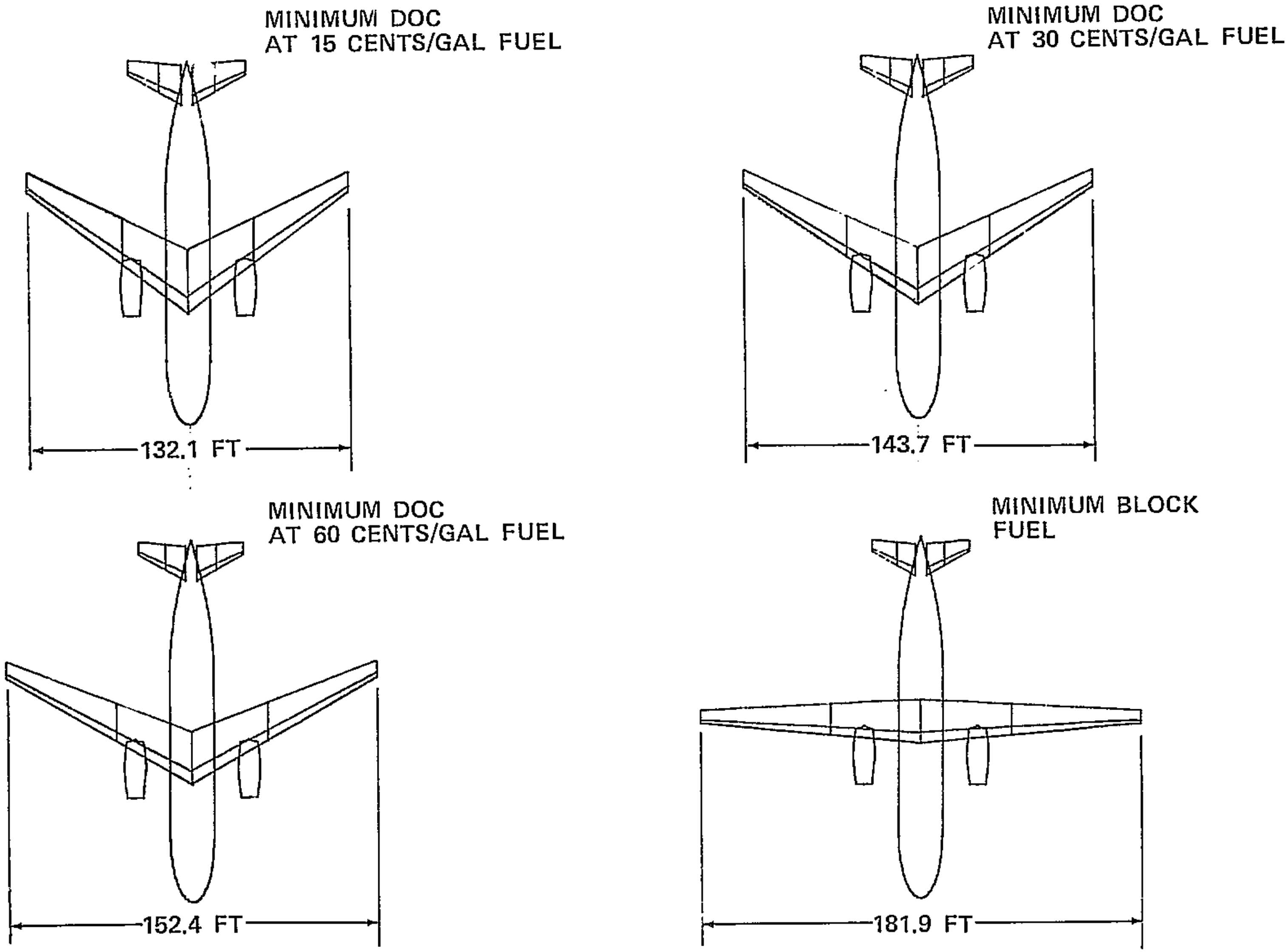


FIGURE 63. PLAN VIEWS OF OPTIMIZED N80-2.15 AIRCRAFT

TABLE 57

OPTIMUM N80-2.15 AIRCRAFT CHARACTERISTICS

2 CF6-6D Type Engines, 201 Passengers, 1,500 NM Range

		OPTIMIZATION PARAMETER			
		DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
Takeoff Gross Weight	Lb	234,700	231,200	231,600	236,300
Operational Empty Weight	Lb	148,900	149,100	151,200	159,000
Cruise Mach Number		0.85	0.81	0.78	0.70
Block Time (1)	Hr	3.43	3.57	3.69	4.05
Block Fuel (1)	Lb	33,220	30,440	29,030	27,250
Critical Field Length	Ft	7,000	7,000	7,000	7,000
Approach Speed	KEAS	120	120	120	116
Thrust Per Engine Uninstalled	Lb	39,600	36,580	34,590	29,470
Direct Operating Cost (1)	¢/Seat·NM				
@ 15¢ Per Gallon		1.157	1.169	1.191	1.274
@ 30¢ Per Gallon		1.386	1.379	1.390	1.462
@ 60¢ Per Gallon		1.844	1.798	1.789	1.839
Geometry					
Aspect Ratio		7.7	9.4	10.9	15.5
Quarter Chord Sweep	Deg	35	32	28	3.2(2)
Average Thickness-To-Chord Ratio		0.148	0.143	0.140	0.128
Taper Ratio		0.30	0.30	0.30	0.30
Wing Area	Ft^2	2,267	2,197	2,130	2,135
Fuel Use @ 1,000 NM	BTU/ASNM	1,966	1,814	1,730	1,656

(1) At Design Range, 100 Percent Load Factor
(2) Straight Rear Spar

TABLE 58

N80-2.15 DESIGN DATA

DESIGN ITEMS		OPTIMIZATION PARAMETER			
		DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
Wing Area - Trapezoidal	Ft^2	2,267	2,197	2,130	2,135
Wing Aspect Ratio		7.7	9.4	10.9	15.5
Wing Sweep @ C/4	Deg	35.0	32.0	28.0	3.20
Wing Taper Ratio		.30	.30	.30	.30
Wing Loading	PSF	103.5	105.2	108.7	110.7
Wing Thickness Ratio		.148	.143	.140	.128
Horizontal/Vertical Tail Area	Ft^2	472/426	414/432	361/439	304/473
Horizontal/Vertical Tail Arm	In	825/745	825/745	825/745	825/745
Horizontal/Vertical Tail Volume Coeff.		.760/.088	.760/.086	.760/.084	.760/.076
Thrust/Weight Ratio		.337	.316	.299	.249
Fuel Fraction		.190	.178	.169	.153
Fuselage Length	In	1,790	1,790	1,790	1,790
No. of Passengers (1st Class/Coach)		22/179	22/179	22/179	22/179
No. of Engines		2	2	2	2

TABLE 59

N80-2.15 WEIGHT DATA (LB)

WEIGHT ITEMS	OPTIMIZATION PARAMETER			
	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
Wing	28,475	31,009	34,546	45,334
Horizontal Tail	2,019	1,793	1,598	1,389
Vertical Tail	1,555	1,588	1,638	1,794
Fuselage	28,746	28,733	28,749	28,602
Landing Gear	9,651	9,505	9,520	9,718
Flight Controls & Hydraulics	4,210	4,037	3,878	3,834
Propulsion System	24,347	22,493	21,266	18,119
Fuel System	1,029	1,101	1,187	1,417
Auxiliary Power Unit	1,312	1,312	1,312	1,312
Instruments	944	925	909	882
Air Conditioning & Pneumatics	2,852	2,852	2,852	2,852
Electrical System	4,037	4,037	4,037	4,037
Avionics	2,215	2,215	2,215	2,215
Furnishings	24,420	24,420	24,420	24,420
Anti-Ice	619	612	605	605
Handling Gear	69	68	68	70
Manufacturer's Empty Wt.	136,500	136,700	138,800	146,600
Operator Items	12,400	12,400	12,400	12,400
Operational Empty Weight	148,900	149,100	151,200	159,000
Payload	40,200	40,200	40,200	40,200
Zero Fuel Weight	189,100	189,300	191,400	199,200
Fuel	45,600	41,900	40,200	37,100
Takeoff Gross Weight	234,700	231,200	231,600	236,300

MODEL N80-2.15
201 PASSENGERS, 1500 NM RANGE

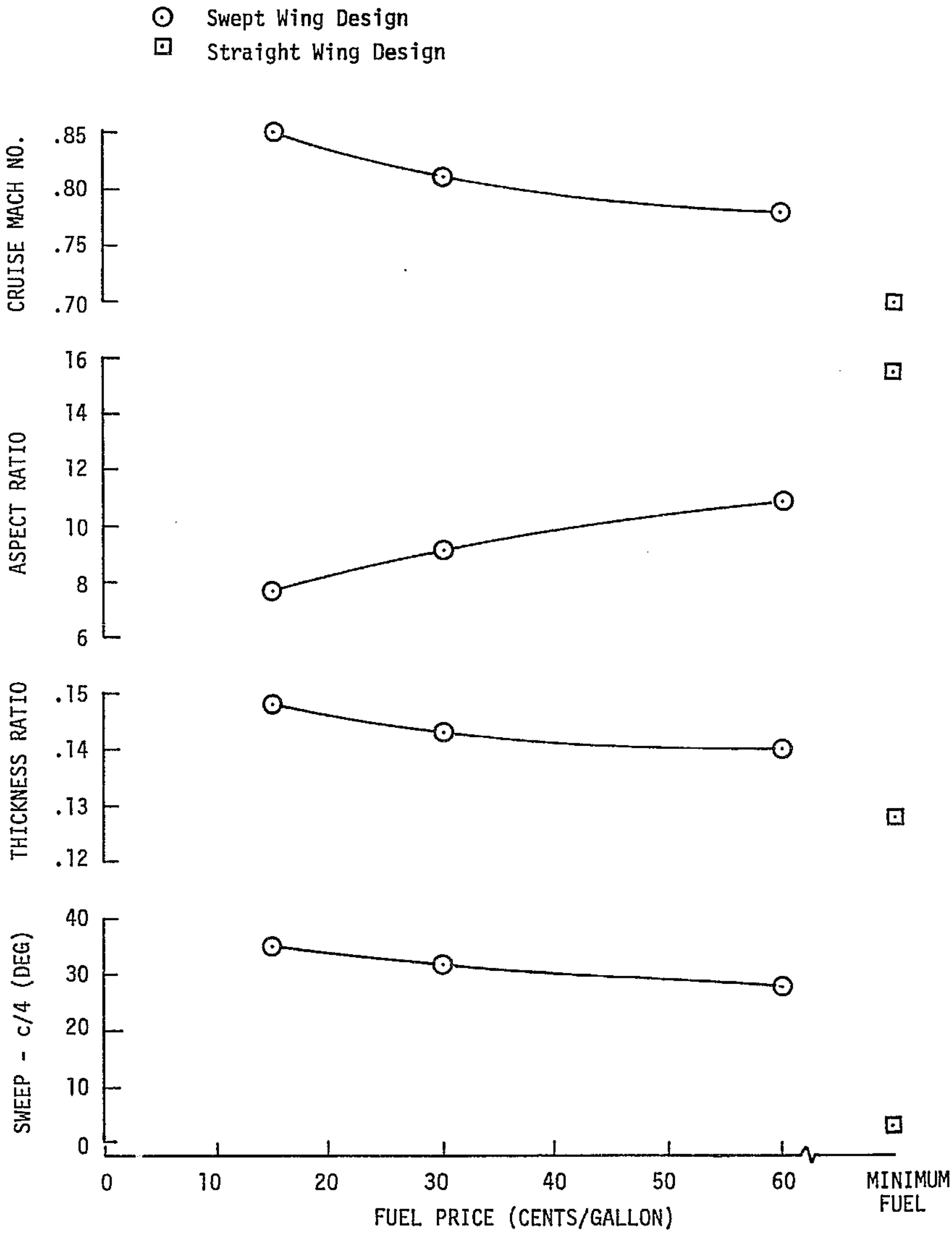


FIGURE 64. EFFECT OF FUEL PRICE ON N80-2.15 OPTIMUM AIRCRAFT GEOMETRY AND CRUISE MACH NUMBER

MODEL N80-2.15

- DESIGN FLIGHT PROFILE (FIGURE 51)
- 58% LOAD FACTOR

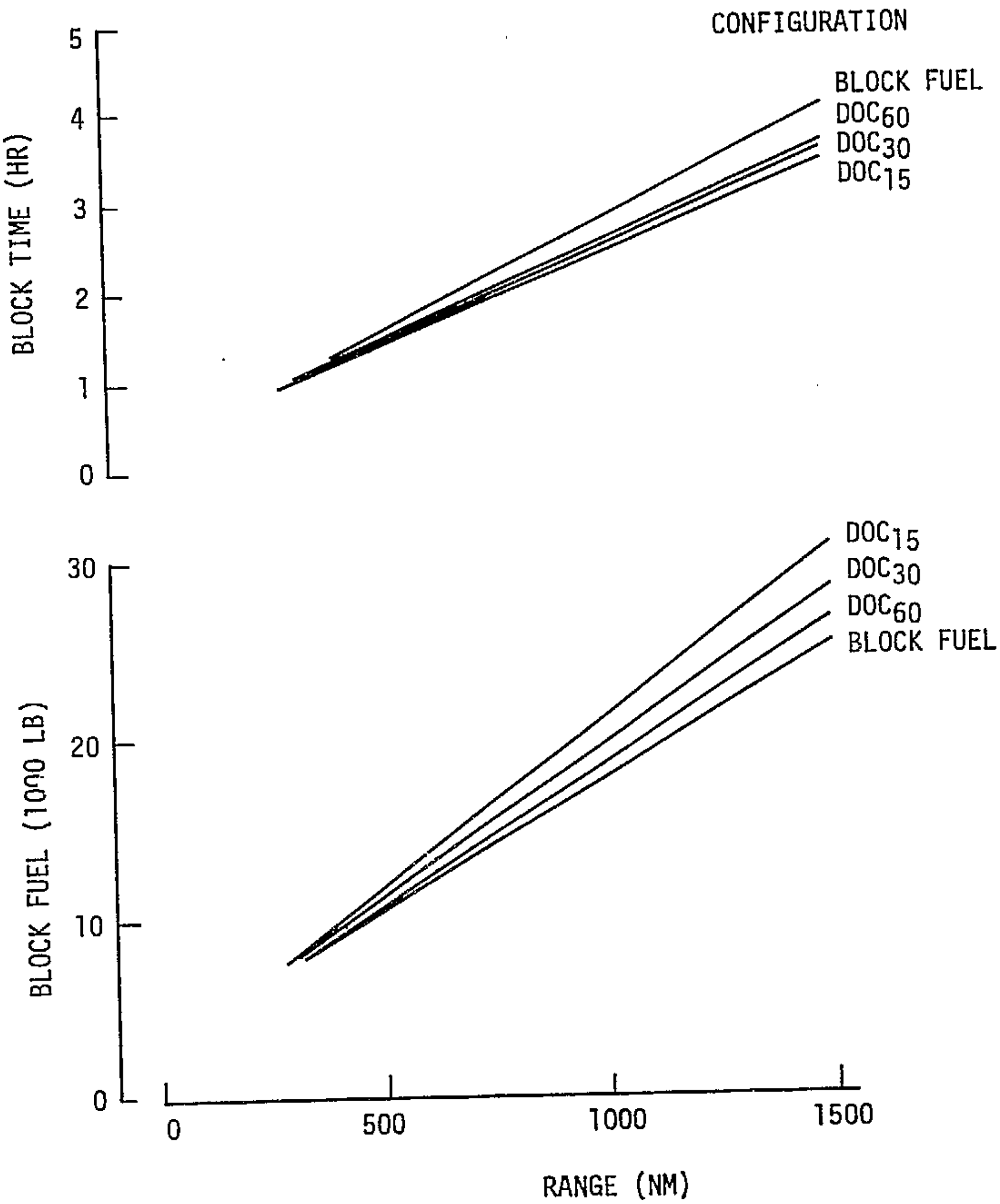


FIGURE 65. BLOCK TIME AND BLOCK FUEL VS. RANGE - OPTIMUM N80-2.15 AIRCRAFT

MODEL N80-2.15

- DESIGN FLIGHT PROFILE (FIGURE 51)
- 58% LOAD FACTOR

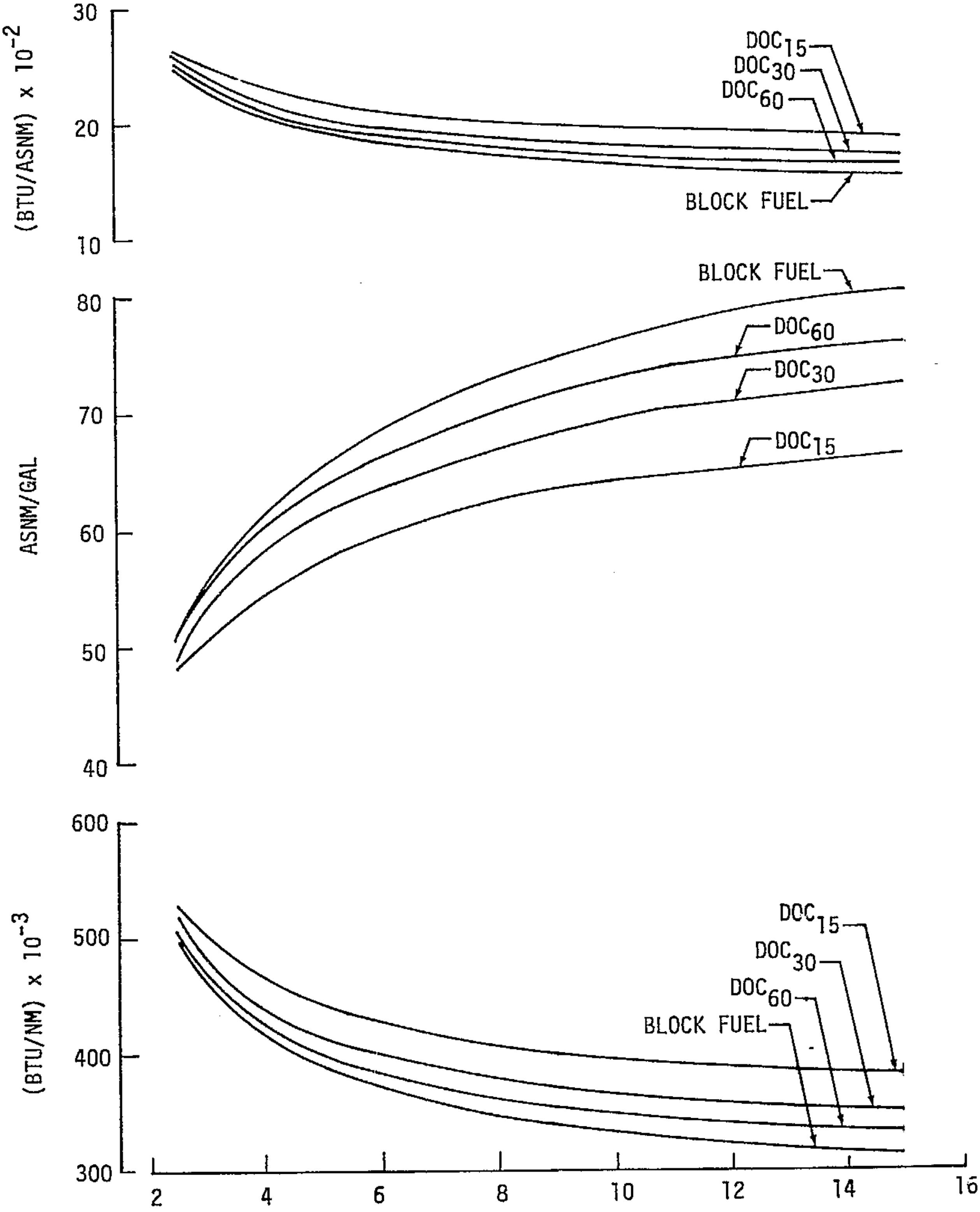


FIGURE 66. ENERGY EFFICIENCY PARAMETERS VS. RANGE
OPTIMUM N80-2.15 AIRCRAFT

TABLE 60

BLOCK TIME AND BLOCK FUEL VS. DISTANCE

OPTIMUM N80-2.15 AIRCRAFT

58 PERCENT LOAD FACTOR

DISTANCE (NM)	BLOCK TIME (HR)				BLOCK FUEL (LB)			
	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
100	.50	.50	.50	.50	4,300	4,300	4,300	4,300
250	.86	.87	.89	.90	7,100	7,000	6,800	6,700
500	1.36	1.39	1.43	1.53	11,900	11,100	10,700	10,500
750	1.90	1.95	2.01	2.16	16,500	15,500	14,750	14,200
1000	2.40	2.48	2.55	2.77	21,250	19,600	18,700	17,900
1250	2.92	3.02	3.10	3.41	26,000	24,000	22,750	21,500
1500	3.43	3.57	3.68	4.03	30,800	28,200	26,900	25,400

TABLE 61

ENERGY EFFICIENCY PARAMETERS VS. DISTANCE - OPTIMUM N80-2.15 AIRCRAFT

58 PERCENT LOAD FACTOR

BTU/NM	DISTANCE (NM)	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	799,800	799,800	799,800	799,800
	250	528,200	520,800	505,900	498,400
	500	442,600	412,900	398,000	390,600
	750	409,200	384,400	365,800	352,100
	1,000	395,200	364,500	347,800	332,900
	1,250	386,800	357,100	338,500	319,900
	1,500	381,900	343,600	333,500	314,900
ASNM/GAL	**DISTANCE (NM)**	**DOC_{15}**	**DOC_{30}**	**DOC_{60}**	**BLOCK FUEL**
	100	31.79	31.79	31.79	31.79
	250	48.13	48.81	50.25	51.00
	500	57.43	61.57	63.87	65.09
	750	62.13	66.14	69.50	72.19
	1,000	64.32	69.73	73.09	76.36
	1,250	65.71	71.19	75.10	79.47
	1,500	66.56	72.70	76.22	80.72
BTU/ASNM	**DISTANCE (NM)**	**DOC_{15}**	**DOC_{30}**	**DOC_{60}**	**BLOCK FUEL**
	100	3,979	3,979	3,979	3,979
	250	2,628	2,591	2,517	2,480
	500	2,202	2,054	1,980	1,943
	750	2,036	1,912	1,820	1,752
	1,000	1,966	1,814	1,730	1,656
	1,250	1,925	1,777	1,684	1,592
	1,500	1,900	1,740	1,660	1,567

5.4 N80-2.30 Series Aircraft

Each member of the Model N80-2.30 series is characterized by four wing-mounted engines, a capacity of 201 passengers, and a design range of 3,000 nautical miles.

5.4.1 Configuration Trade Studies

Like the previous N80-2.15, the baseline N80-2.30 aircraft was sized for minimum DOC at three fuel prices (15, 30, and 60 cents per gallon) and also for minimum block fuel. Charts of optimum aircraft geometry versus cruise Mach number are presented in Figures 67, 68, 69 for the minimum DOC aircraft. Because of experience gained from the N80-2.15 studies, Mach numbers below 0.75 were not evaluated for the minimum DOC configurations. The same general geometry trends appear as described for the N80-2.15 aircraft. The effect on DOC of not choosing the design cruise Mach number for an absolute minimum DOC airplane is again very small as shown in Figure 70. In Figure 70, each solid line represents relative DOC for an aircraft operating at the fuel price for which it was optimized. Figure 71 shows the effect on DOC of optimizing the aircraft for a fuel price different from the operating fuel price. It is shown that between 0.80 to 0.85 Mach number, neither design fuel price nor design cruise Mach number greatly effects DOC. However, the DOC penalty associated with optimizing for too low a fuel price is greater than the DOC penalty associated with optimizing for too high a fuel price.

The sizing chart for the minimum block fuel aircraft is shown in Figure 72. The cruise Mach number, aspect ratio, and sweep were chosen for reasons previously discussed in Section 5.3.1.

5.4.2 Optimum Design Characteristics and Geometry

Plan views of the resultant optimum airplanes are shown in Figure 73. A summary of the N80-2.30 characteristics is given in Table 62. The effect of increased range has resulted in optimum N80-2.30 airplanes with larger wing areas than the N80-2.15 airplanes. The N80-2.30 aircraft are heavier because of their increased range capability; therefore, larger wing areas are required to meet the specified approach speeds. Additional design data is given in Table 63, and a weight statement for the airplanes is given in Table 64. The variation of optimum geometry with fuel price is presented in Figure 74. This variation is almost identical to the N80-2.15 results.

5.4.3 Energy Efficiency

The variation of block time and block fuel with range at 58 percent load factor is presented in Figure 75. The energy efficiency parameters (BTU/NM, ASNM/GAL, BTU/ASNM) of the N80-2.30 series at an operational load factor of 58 percent are presented in Figure 76. The optimum range for fuel efficiency appears to be about 2,500 nautical miles. These results are also tabulated in Tables 65 and 66.

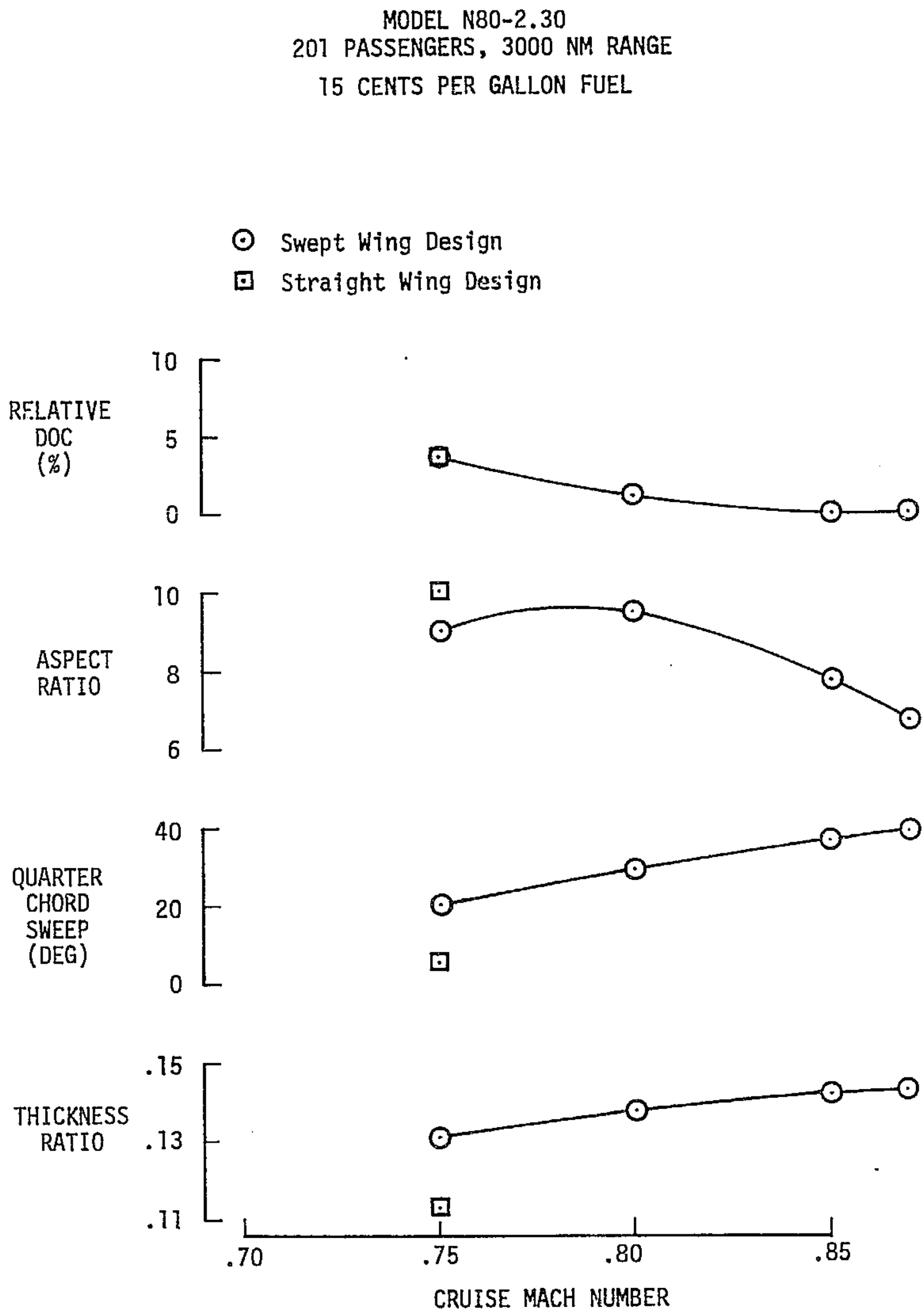


FIGURE 67. N80-2.30$_{15}$ OPTIMUM AIRCRAFT GEOMETRY AND RELATIVE DOC VS. CRUISE MACH NUMBER

MODEL N80-2.30
201 PASSENGERS, 3000 NM RANGE
30 CENTS PER GALLON FUEL

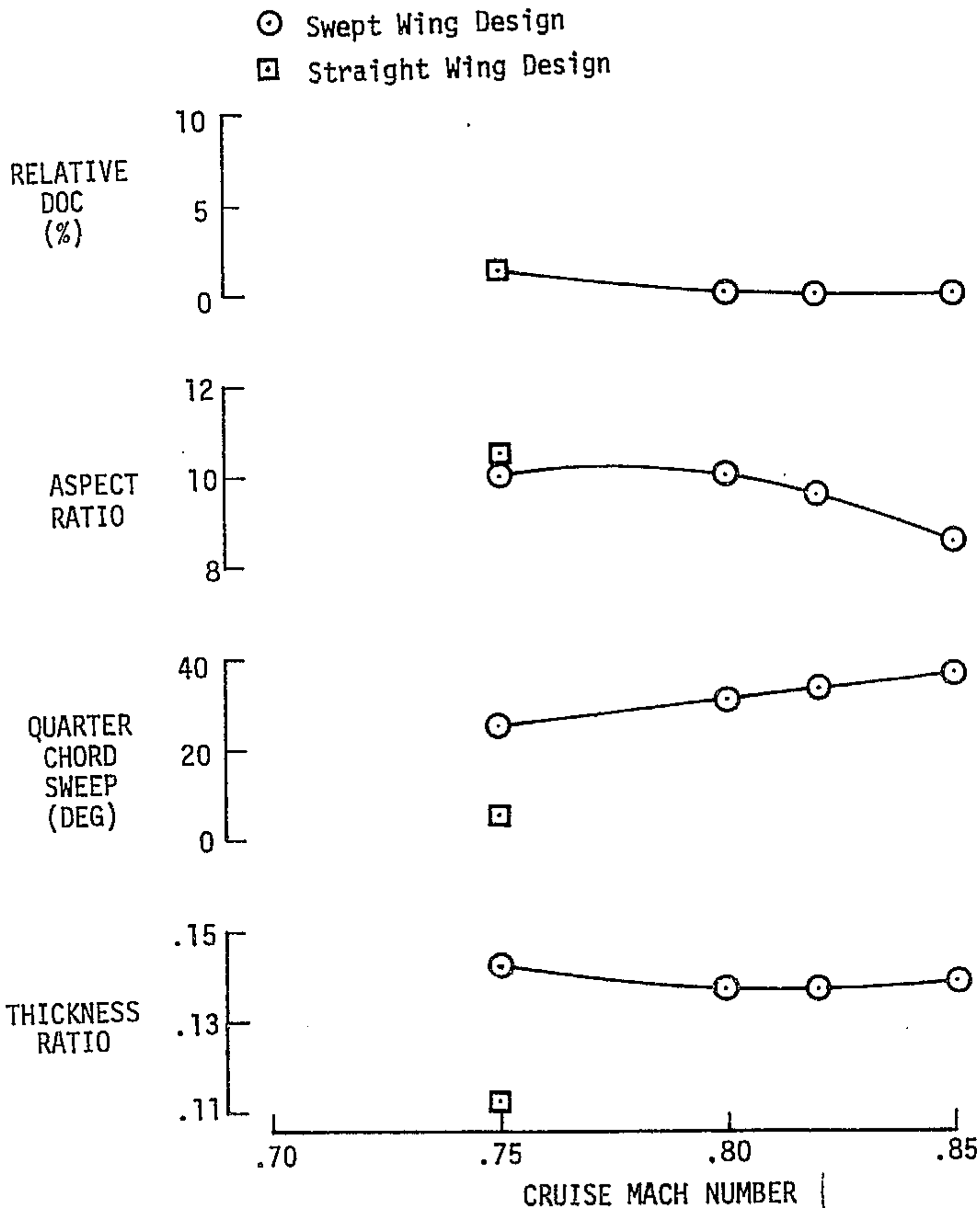


FIGURE 68. N80-2.30$_{30}$ OPTIMUM AIRCRAFT GEOMETRY AND RELATIVE DOC VS. CRUISE MACH NUMBER

MODEL N80-2.30
201 PASSENGERS, 3000 NM RANGE
60 CENTS PER GALLON FUEL

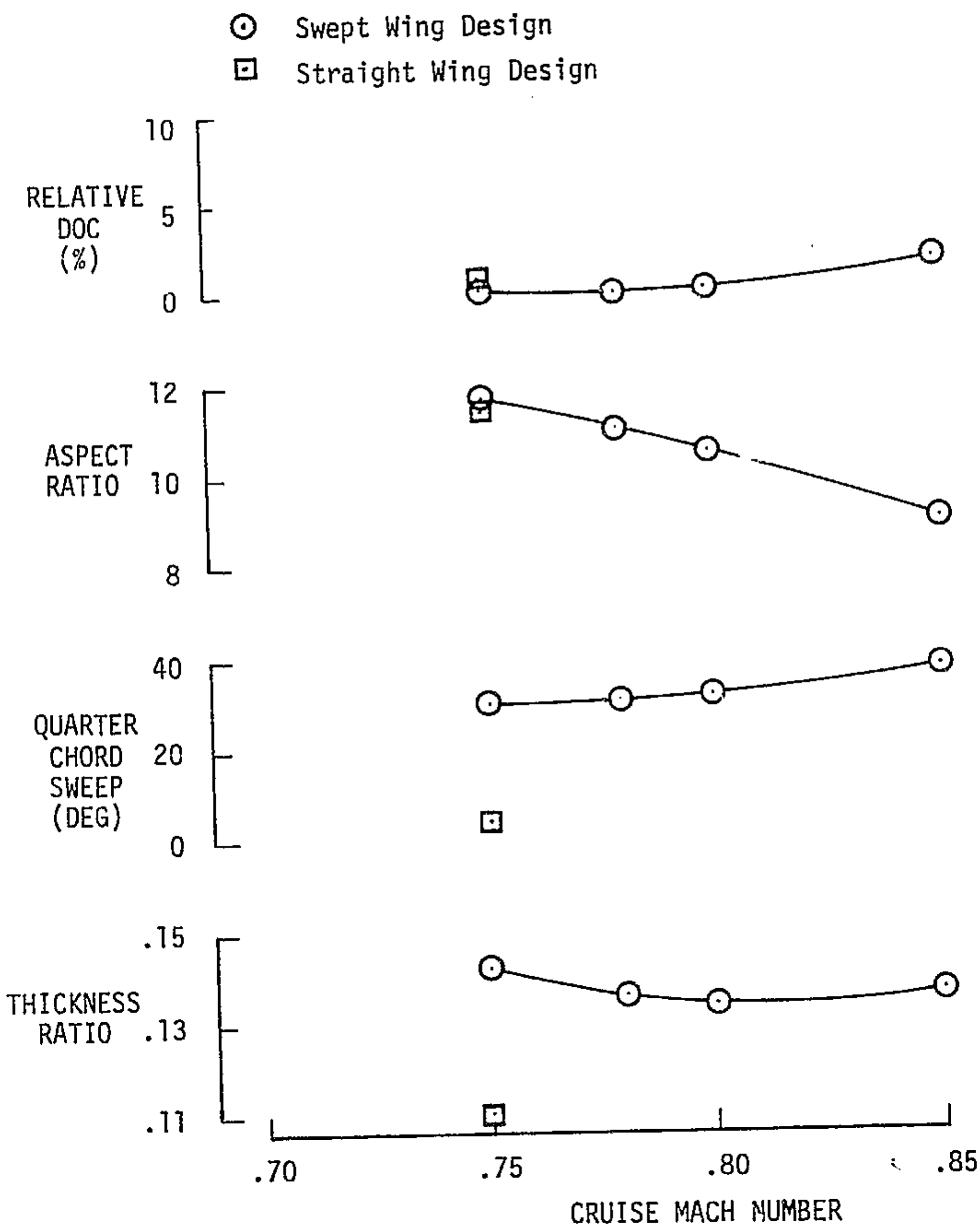


FIGURE 69. N80-2.3060 OPTIMUM AIRCRAFT GEOMETRY AND RELATIVE DOC VS. CRUISE MACH NUMBER

MODEL N80-2.30
201 PASSENGERS, 3000 NM RANGE

Note: All Points Optimized

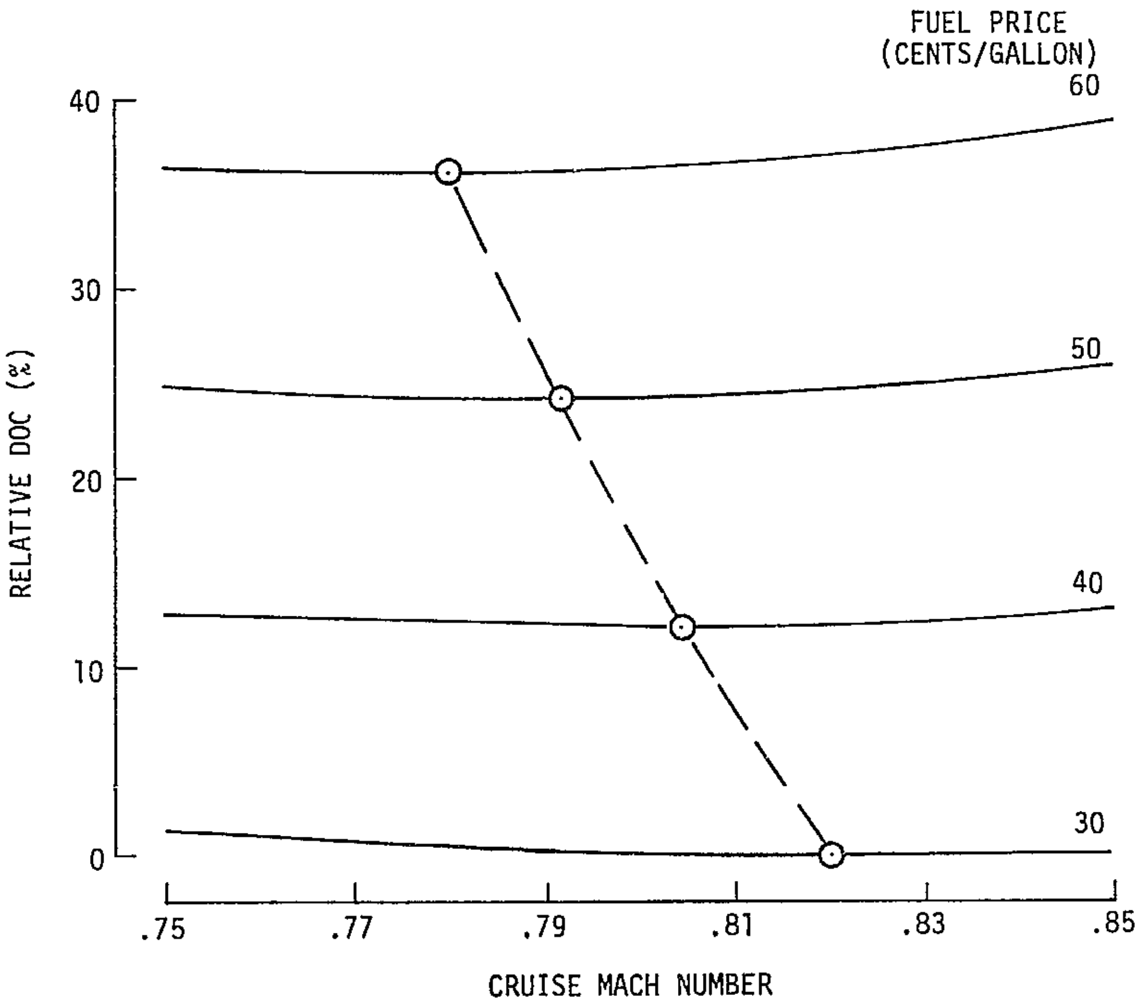


FIGURE 70. RELATIVE DOC VS. CRUISE MACH NUMBER AND FUEL PRICE FOR OPTIMUM GEOMETRY N80-2.30 AIRCRAFT

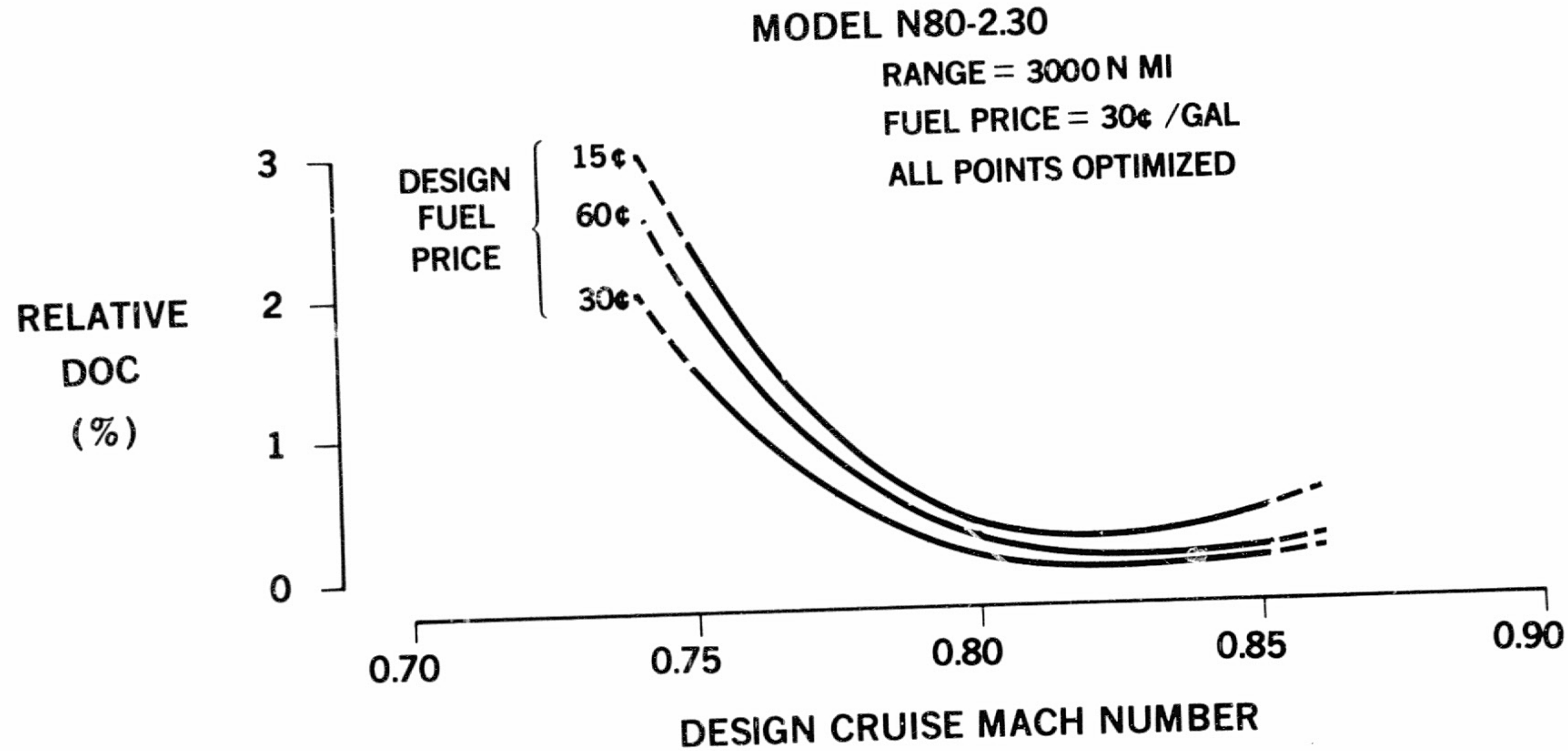


FIGURE 71. EFFECT OF DESIGN CRUISE MACH NUMBER ON DOC

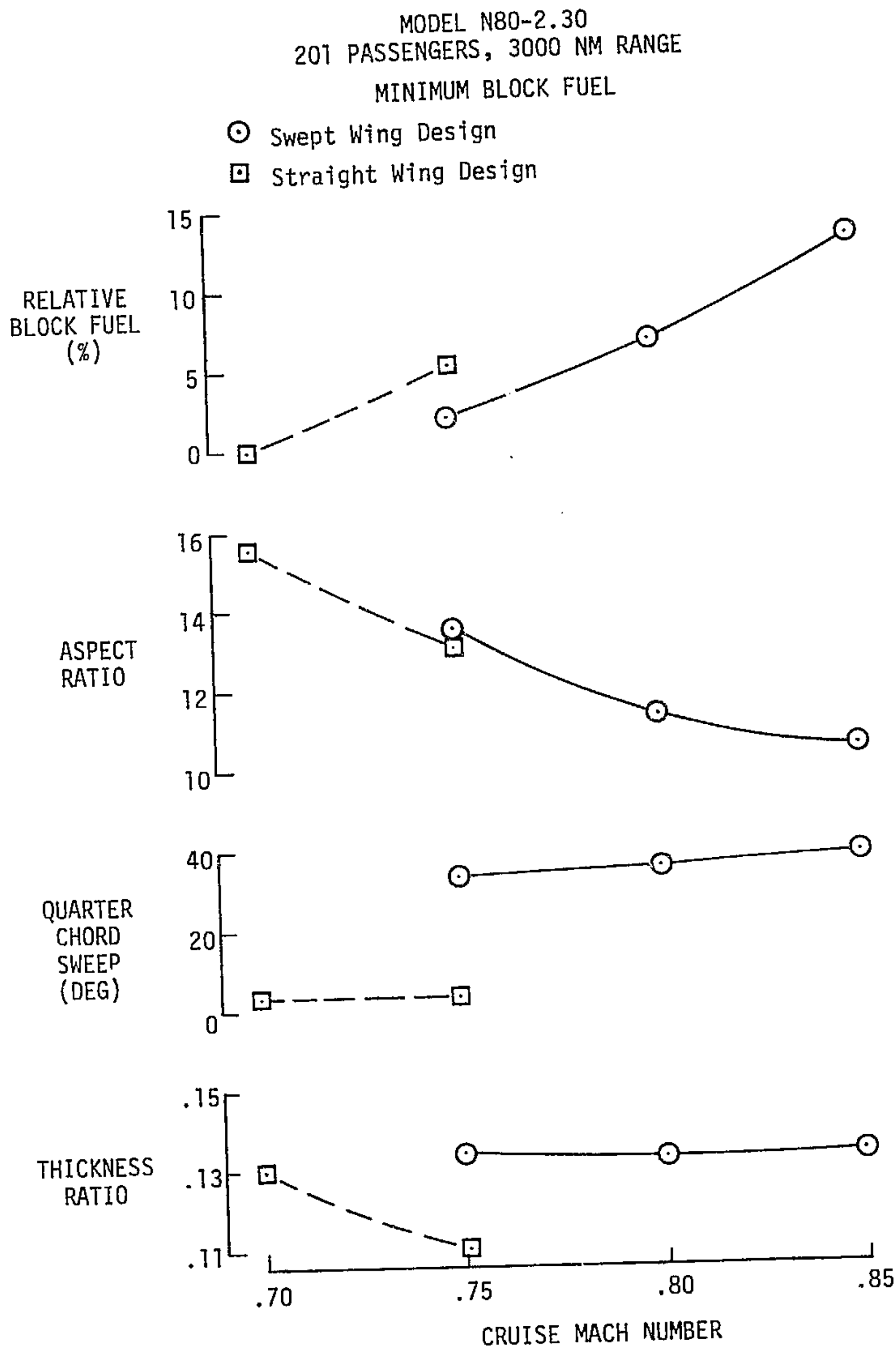


FIGURE 72. N80-2.30$_{MF}$ OPTIMUM AIRCRAFT GEOMETRY AND RELATIVE FUEL USE VS. CRUISE MACH NUMBER

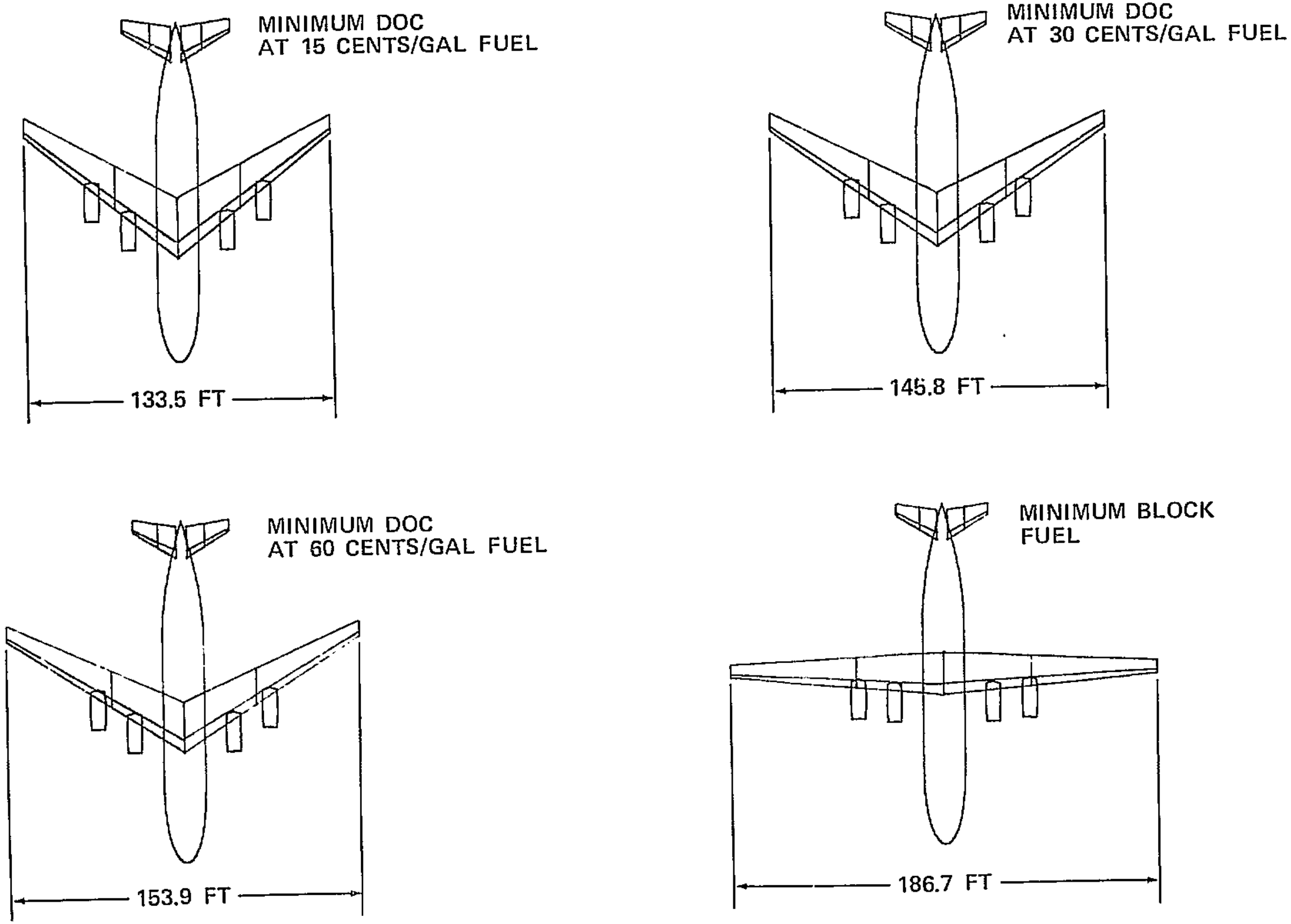


FIGURE 73. PLAN VIEWS OF OPTIMIZED N80-2.30 AIRCRAFT

TABLE 62

OPTIMUM N80-2.30 AIRCRAFT CHARACTERISTICS

4 CFM-56 Type Engines, 201 Passengers, 3,000 NM Range

		OPTIMIZATION PARAMETER			
		DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
Takeoff Gross Weight	Lb	279,800	275,700	271,500	274,300
Operational Empty Weight	Lb	156,000	157,400	157,500	164,700
Cruise Mach Number		0.85	0.82	0.78	0.70
Block Time (1)	Hr	6.52	6.74	7.05	7.77
Block Fuel (1)	Lb	69,660	65,190	61,550	58,150
Critical Field Length	Ft	6,790	6,877	7,660	8,000
Approach Speed	KEAS	125	125	125	116
Thrust Per Engine Uninstalled	Lb	20,670	18,590	16,580	13,980
Direct Operating Cost (1)	¢/Seat-NM				
@ 15¢ Per Gallon		1.187	1.205	1.237	1.335
@ 30¢ Per Gallon		1.429	1.427	1.448	1.535
@ 60¢ Per Gallon		1.908	1.879	1.872	1.937
Geometry					
Aspect Ratio		7.8	9.6	11.0	15.5
Quarter Chord Sweep	Deg	36.5	33.0	30.7	3.2 (2)
Average Thickness-To-Chord Ratio		0.1418	0.137	0.136	0.130
Taper Ratio		0.30	0.30	0.30	0.30
Wing Area	Ft^2	2,286	2,215	2,150	2,250
Fuel Use @ 1,000 NM	BTU/ASNM	2,064	1,962	1,879	1,832

(1) At Design Range, 100 Percent Load Factor
(2) Straight Rear Spar

TABLE 63

N80-2.30 DESIGN DATA

DESIGN ITEMS		OPTIMIZATION PARAMETER			
		DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
Wing Area - Trapezoidal	Ft^2	2,286	2,215	2,150	2,250
Wing Aspect Ratio		7.8	9.6	11.0	15.5
Wing Sweep @ C/4	Deg	36.5	33.0	30.7	3.20
Wing Taper Ratio		.30	.30	.30	.30
Wing Loading	PSF	122.4	124.5	126.3	122.1
Wing Thickness Ratio		.142	.137	.136	.130
Horizontal/Vertical Tail Area	Ft^2	443/429	381/438	340/442	307/490
Horizontal/Vertail Tail Arm	In	814/750	814/750	814/750	814/750
Horizontal/Vertical Tail Volume Coeff.		.700/.088	.700/.085	.700/.084	.700/.073
Thrust/Weight Ratio		.296	.270	.244	.207
Fuel Fraction		.295	.280	.268	.249
Fuselage Length	In	1,810	1,810	1,810	1,810
No. of Passengers (1st Class/Coach)		22/179	22/179	22/179	22/179
No. of Engines		4	4	4	4

TABLE 64

N80-2.30 WEIGHT DATA (LB)

WEIGHT ITEMS	OPTIMIZATION PARAMETER			
	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
Wing	29,874	34,306	37,276	47,139
Horizontal Tail	1,969	1,716	1,562	1,423
Vertical Tail	1,812	1,873	1,906	2,113
Fuselage	29,297	29,308	29,313	29,026
Landing Gear	11,536	11,367	11,192	11,320
Flight Controls & Hydraulics	4,185	4,008	3,868	3,996
Propulsion System	25,530	22,957	20,475	17,522
Fuel System	1,040	1,136	1,198	1,455
Auxiliary Power Unit	1,312	1,312	1,312	1,312
Instruments	936	916	905	890
Air Conditioning & Pneumatics	2,852	2,852	2,852	2,852
Electrical System	4,037	4,037	4,037	4,037
Avionics	2,215	2,215	2,215	2,215
Furnishings	25,512	25,512	25,512	25,512
Anti-Ice	621	614	607	617
Handling Gear	82	81	80	81
Manufacturer's Empty Weight	142,810	144,210	144,310	151,510
Operator Items	13,190	13,190	13,190	13,190
Operational Empty Weight	156,000	157,400	157,500	164,700
Payload	40,200	40,200	40,200	40,200
Zero Fuel Weight	196,200	197,600	197,700	204,900
Fuel	83,600	78,100	73,800	69,400
Takeoff Gross Weight	279,800	275,700	271,500	274,300

MODEL N80-2.30
201 PASSENGERS, 3000 NM RANGE

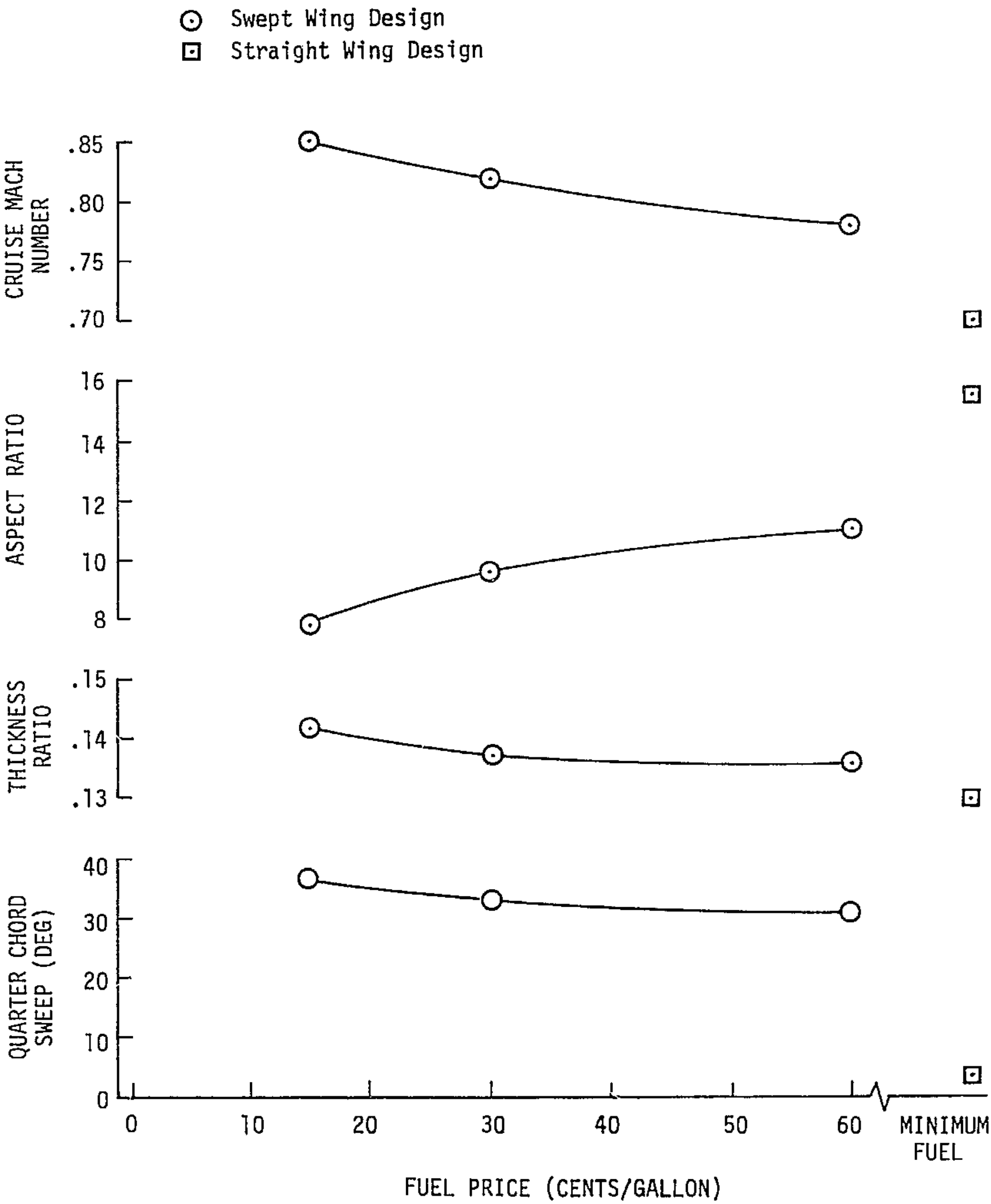


FIGURE 74. EFFECT OF FUEL PRICE ON N80-2.30 OPTIMUM AIRCRAFT GEOMETRY AND CRUISE MACH NUMBER

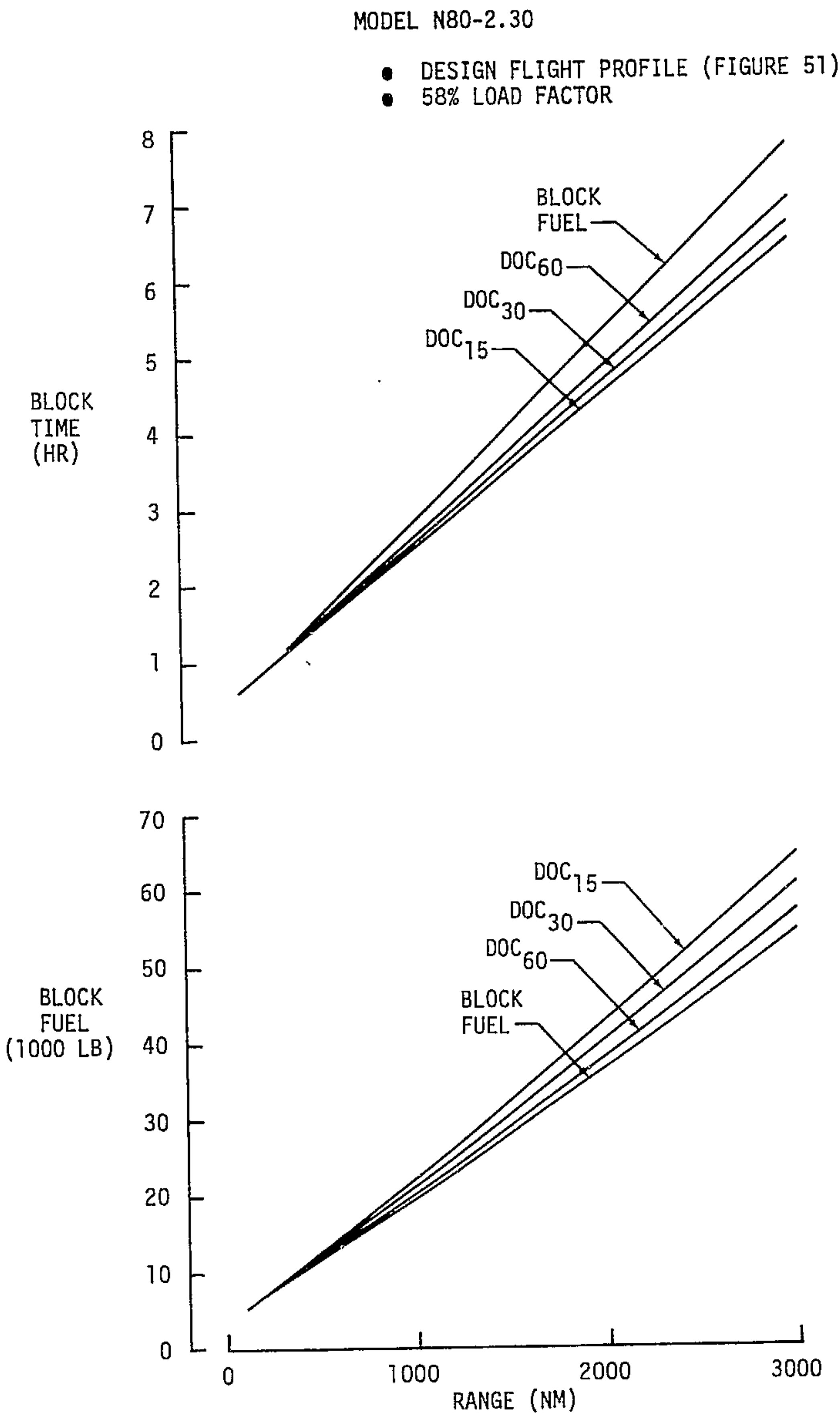


FIGURE 75. BLOCK TIME AND BLOCK FUEL VS. RANGE - OPTIMUM N80-2.30 AIRCRAFT

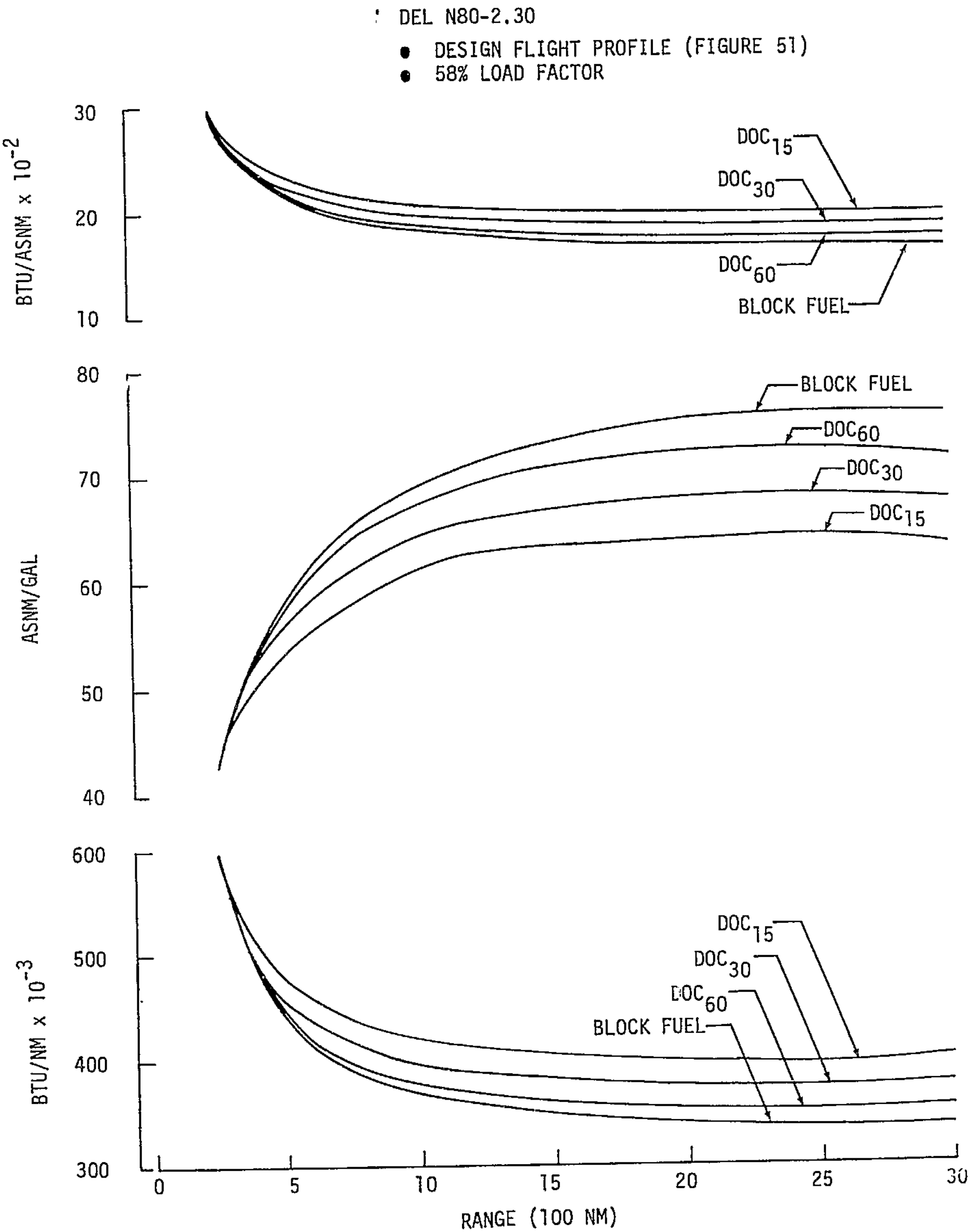


FIGURE 76. ENERGY EFFICIENCY PARAMETERS VS. RANGE
OPTIMUM N80-2.30 AIRCRAFT

TABLE 65

BLOCK TIME AND BLOCK FUEL VS. DISTANCE

OPTIMUM N80-2.30 AIRCRAFT

58 PERCENT LOAD FACTOR

DISTANCE (NM)	BLOCK TIME (HR)				BLOCK FUEL (LB)			
	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
100	.60	.60	.60	.60	5,300	5,300	5,300	5,300
250	.90	.90	.91	.91	8,000	8,000	8,000	8,000
500	1.40	1.41	1.42	1.51	12,800	12,200	11,900	11,800
750	1.89	1.93	2.00	2.15	17,700	16,800	16,000	15,700
1000	2.41	2.47	2.56	2.78	22,300	21,200	20,300	19,800
1500	3.45	3.54	3.69	4.02	32,300	30,700	28,900	28,000
2000	4.45	4.60	4.80	5.27	42,800	40,200	37,900	36,300
2500	5.50	5.68	5.94	6.50	53,050	50,050	47,100	45,050
3000	6.52	6.74	7.05	7.77	64,700	60,600	57,100	54,100

TABLE 66

ENERGY EFFICIENCY PARAMETERS VS. DISTANCE - OPTIMUM N80-2.30 AIRCRAFT

58 PERCENT LOAD FACTOR

	DISTANCE (NM)	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
BTU/NM	100	985,800	985,800	985,800	985,800
	250	595,200	595,200	595,200	595,200
	500	476,100	453,800	442,600	438,900
	750	438,900	416,600	396,800	389,300
	1,000	414,700	394,300	377,500	368,200
	1,500	400,500	380,600	358,300	347,200
	2,000	398,000	373,800	352,400	337,500
	2,500	394,600	372,300	350,400	335,100
	3,000	401,100	375,700	354,000	335,400
ASNM/GAL	DISTANCE (NM)	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	25.79	25.79	25.79	25.79
	250	42.71	42.71	42.71	42.71
	500	53.39	56.02	57.43	57.92
	750	57.92	61.02	64.07	65.29
	1,000	61.29	64.47	67.33	69.03
	1,500	63.47	66.78	70.94	73.22
	2,000	63.87	68.00	72.13	75.31
	2,500	64.41	68.27	72.55	75.85
	3,000	63.38	67.66	71.81	75.79
BTU/ASNM	DISTANCE (NM)	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	4,904	4,904	4,904	4,904
	250	2,961	2,961	2,961	2,961
	500	2,369	2,258	2,202	2,184
	750	2,184	2,073	1,974	1,937
	1,000	2,064	1,962	1,879	1,832
	1,500	1,993	1,894	1,783	1,727
	2,000	1,980	1,860	1,754	1,680
	2,500	1,964	1,853	1,743	1,668
	3,000	1,996	1,869	1,761	1,669

5.5 N80-2.55 Series Aircraft

Each member of the Model N80-2.55 series is characterized by four wing-mounted engines, a capacity of 201 passengers, and an intercontinental range of 5,500 nautical miles.

5.5.1 Configuration Trade Studies

Due to the relative insensitivity of optimum geometry and optimum cruise Mach number to variations in range at each fuel price, no additional geometric trade studies were performed on the N80-2.55 series. The geometries were chosen from the N80-2.30 study. Configurations were sized for minimum DOC at two fuel prices (30 and 60 cents per gallon) and for minimum block fuel.

5.5.2 Optimum Design Characteristics

Plan views of the resulting intercontinental aircraft are shown in Figure 77. The N80-2.55 characteristics are summarized in Table 67. Additional design and weight data for these aircraft are given in Tables 68 and 69, respectively.

5.5.3 Energy Efficiency

The variation in block time and block fuel with range at 58 percent load factor is presented in Fi⌃ure 78. The energy efficiency parameters (BTU/NM, ASNM/GAL, BTU/ASNM) of the N80-2.55 series at 58 percent load factor are shown in Figure 79. The optimum range for maximum fuel efficiency appears to be about 2,100 to 2,500 nautical miles. These results also appear in tabular form in Tables 70 and 71.

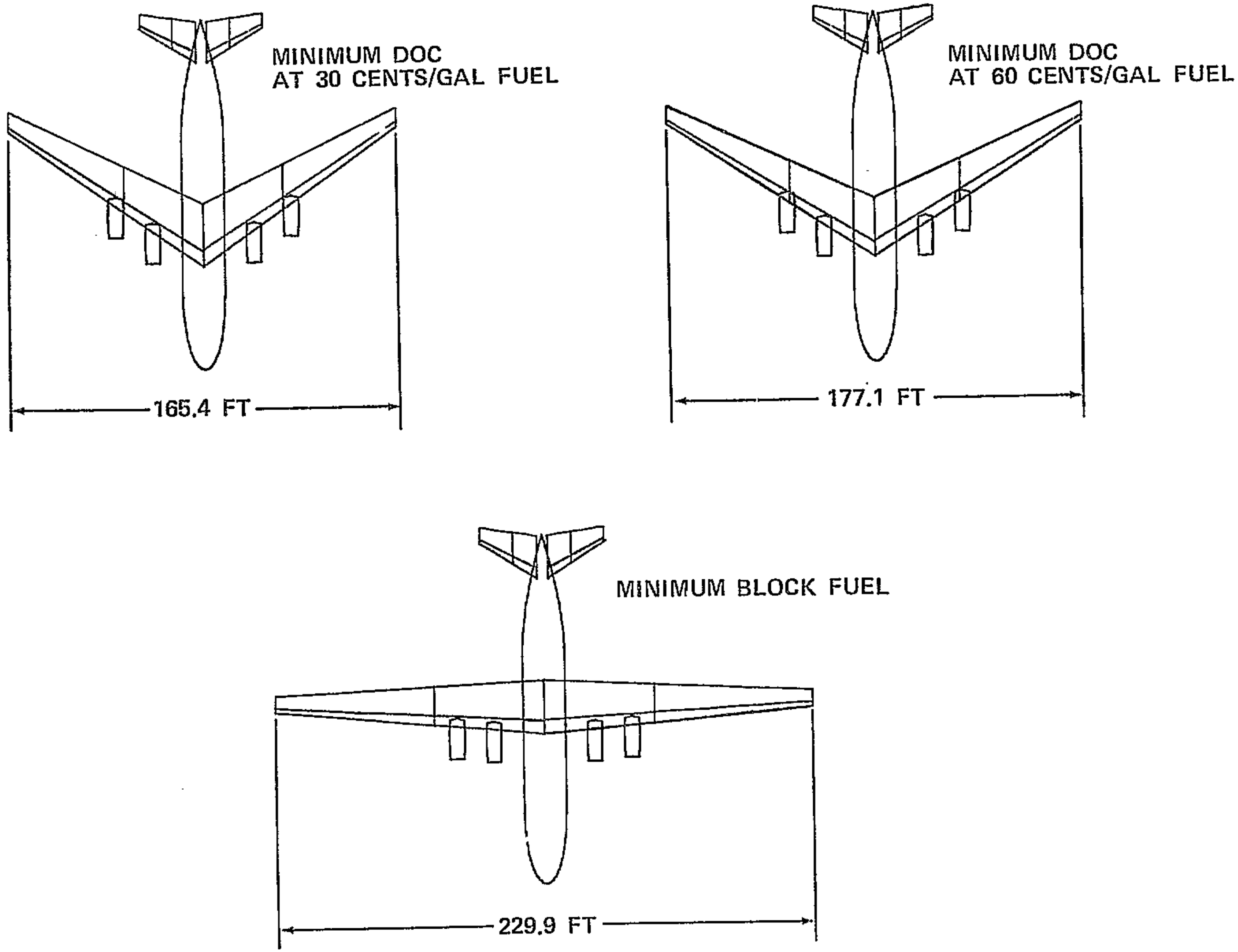


FIGURE 77. PLAN VIEWS OF OPTIMIZED N80-2.55 AIRCRAFT

C.3

TABLE 67

OPTIMUM N80-2.55 AIRCRAFT CHARACTERISTICS

4 CFM-56 Type Engines, 201 Passengers, 5,500 NM Range

		OPTIMIZATION PARAMETER		
		DOC_{30}	DOC_{60}	BLOCK FUEL
Takeoff Gross Weight	Lb	375,100	367,500	386,900
Operational Empty Weight	Lb	184,400	186,000	208,900
Cruise Mach Number		0.82	0.78	0.70
Block Time (1)	Hr	12.05	12.64	14.00
Block Fuel (1)	Lb	136,060	127,590	124,330
Critical Field Length	Ft	8,216	8,850	8,316
Approach Speed	KEAS	117.5	116.1	103.6
Thrust Per Engine Uninstalled	Lb	22,720	20,240	17,780
Direct Operating Cost (1)	¢/Seat-NM			
@ 15¢ Per Gallon		1.309	1.349	1.511
@ 30¢ Per Gallon		1.567	1.591	1.749
@ 60¢ Per Gallon		2.082	2.074	2.225
Geometry				
Aspect Ratio		9.6	11	15.5
Quarter Chord Sweep	Deg	33	30.7	3.2 (2)
Average Thickness-To-Chord Ratio		0.137	0.136	0.13
Taper Ratio		0.30	0.30	0.30
Wing Area (3)	Ft^2	2,850	2,850	3,410
Fuel Use @ 1,000 NM	BTU/ASNM	2,128	2,017	2,017

(1) 100 Percent Load Factor at Design Range
(2) Straight Rear Spar
(3) Fuel Volume Limited

TABLE 68

N80-2.55 DESIGN DATA

DESIGN ITEMS		OPTIMIZATION PARAMETER		
		DOC_{30}	DOC_{60}	BLOCK FUEL
Wing Area - Trapezoidal	Ft^2	2,850	2,850	3,410
Wing Aspect Ratio		9.6	11.0	15.5
Wing Sweep @ C/4	Deg	33.0	30.7	3.20
Wing Taper Ratio		.30	.30	.30
Wing Loading		131.6	128.9	113.4
Wing Thickness Ratio		.137	.136	.130
Horizontal/Vertical Tail Area	Ft^2	556/517	519/534	572/682
Horizontal/Vertical Tail Arm	In	814/750	814/750	814/750
Horizontal/Vertical Tail Volume Coeff.		.700/.068	.700/.066	.700/.054
Thrust/Weight Ratio		.242	.220	.184
Fuel Fraction		.399	.382	.354
Fuselage Length	In	1,810	1,810	1,810
No. of Passengers (1st Class/Coach)		22/179	22/179	22/179
No. of Engines		4	4	4

TABLE 69

N80-2.55 WEIGHT DATA (LB)

WEIGHT ITEMS	OPTIMIZATION PARAMETER		
	DOC_{30}	DOC_{60}	BLOCK FUEL
Wing	48,531	53,650	76,907
Horizontal Tail	2,441	2,258	2,385
Vertical Tail	2,340	2,411	3,042
Fuselage	30,165	30,099	29,767
Landing Gear	15,521	15,203	16,014
Flight Controls & Hydraulics	5,162	5,125	6,088
Propulsion System	28,067	25,003	21,962
Fuel System	1,289	1,379	1,791
Auxiliary Power Unit	1,312	1,312	1,312
Instruments	975	965	972
Air Conditioning & Pneumatics	2,852	2,852	2,852
Electrical System	4,037	4,037	4,037
Avionics	2,215	2,215	2,215
Furnishings	25,512	25,512	25,512
Anti-Ice	681	681	740
Handling Gear	110	108	114
Manufacturer's Empty Weight	171,210	172,810	195,710
Operator Items	13,190	13,190	13,190
Operational Empty Weight	184,400	186,000	208,900
Payload	40,200	40,200	40,200
Zero Fuel Weight	224,600	226,200	249,100
Fuel	150,500	141,300	137,800
Takeoff Gross Weight	375,100	367,500	386,900

MODEL N80-2.55

- DESIGN FLIGHT PROFILE (FIGURE 51)
- 58% LOAD FACTOR

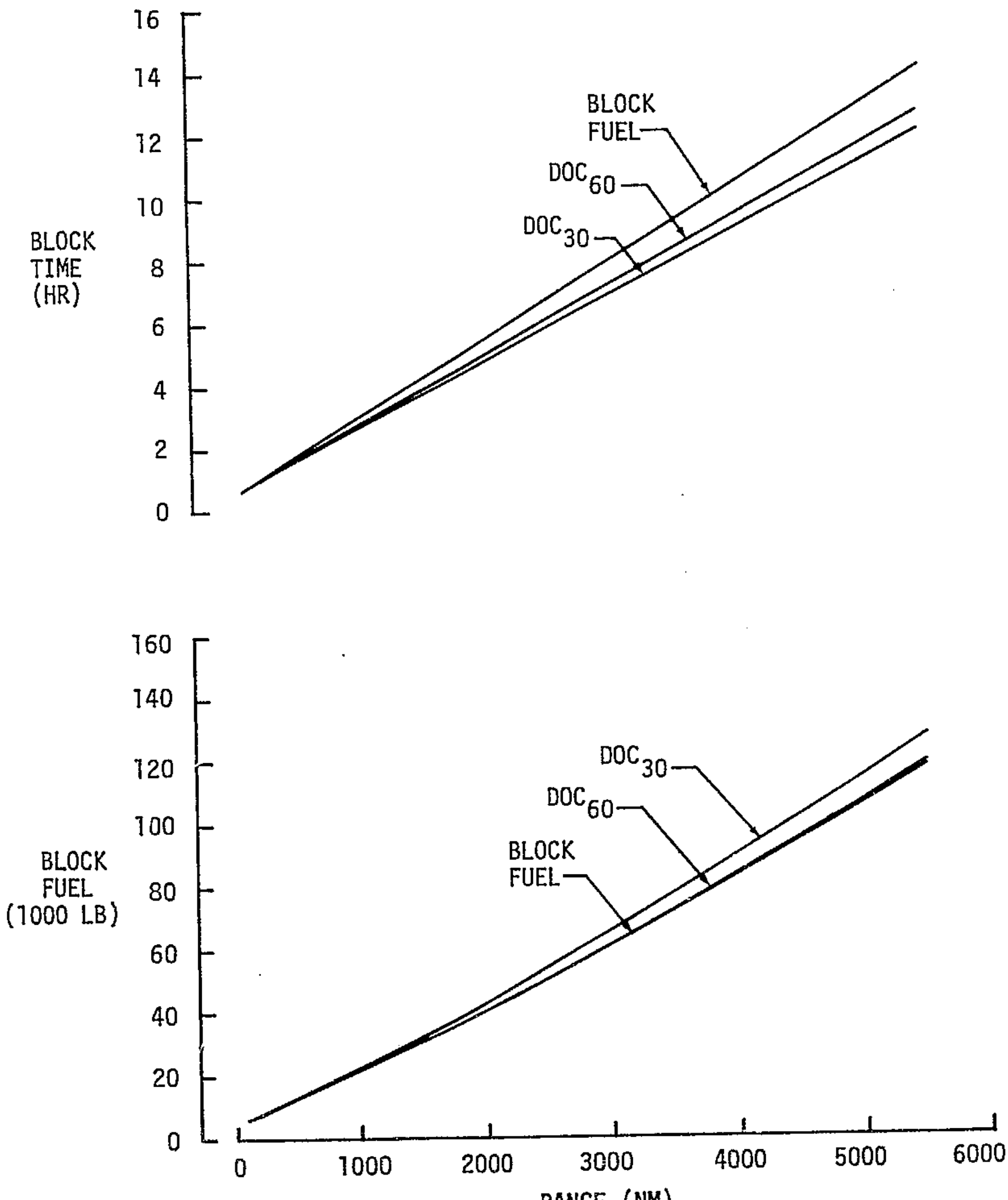


FIGURE 78. BLOCK TIME AND BLOCK FUEL VS. RANGE
OPTIMUM N80-2.55 AIRCRAFT

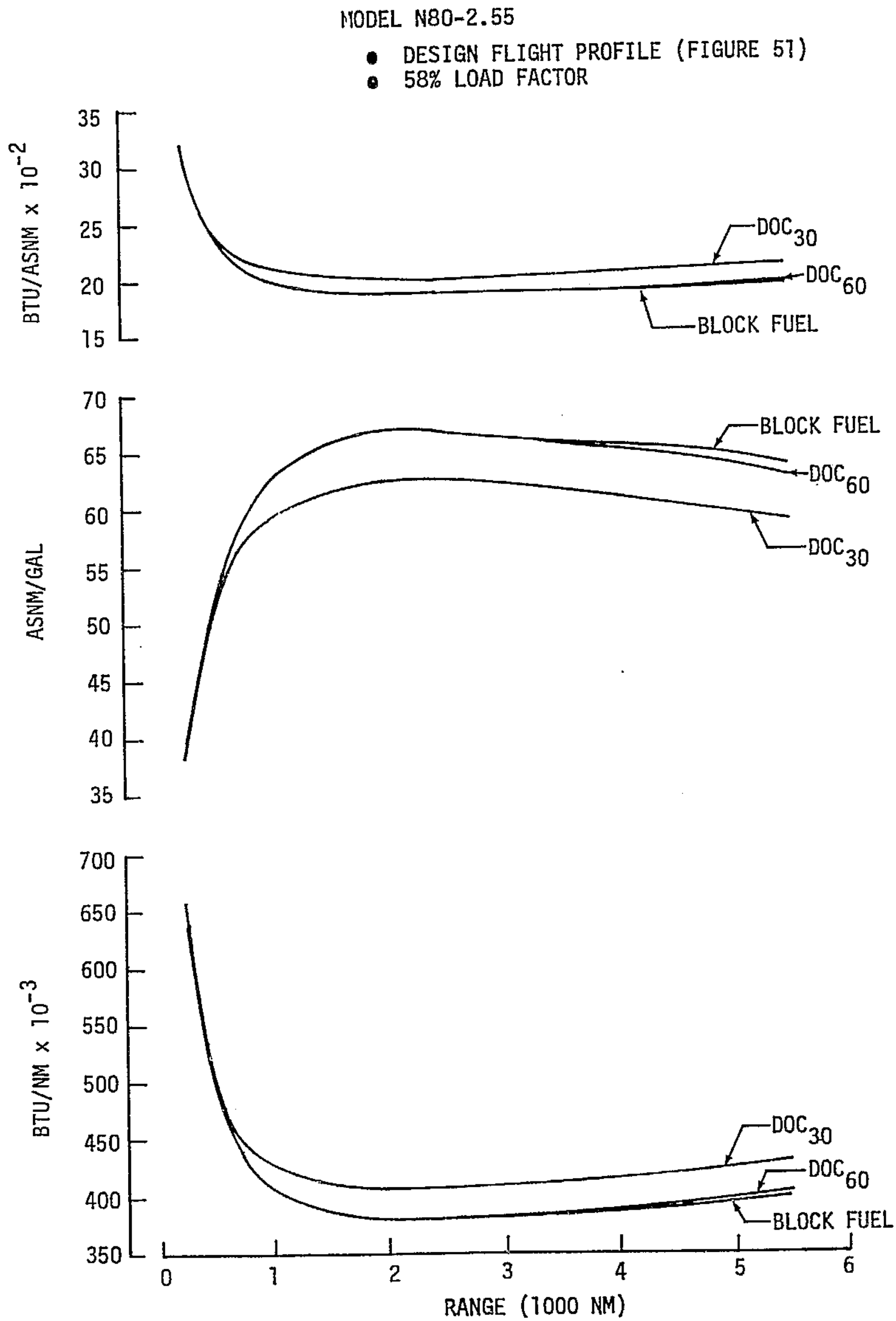


FIGURE 79. ENERGY EFFICIENCY PARAMETERS VS. RANGE
OPTIMUM N80-2.55 AIRCRAFT

TABLE 70

BLOCK TIME AND BLOCK FUEL VS. DISTANCE

OPTIMUM N80-2.55 AIRCRAFT

58 PERCENT LOAD FACTOR

DISTANCE (NM)	BLOCK TIME (HR)			BLOCK FUEL (LB)		
	DOC_{30}	DOC_{60}	BLOCK FUEL	DOC_{30}	DOC_{60}	BLOCK FUEL
100	0.63	0.65	0.67	6,000	6,000	6,000
250	0.95	0.98	1.04	8,800	8,600	8,500
500	1.48	1.54	1.66	13,300	13,200	13,200
750	2.01	2.09	2.28	18,000	17,400	17,400
1,000	2.54	2.65	2.90	23,000	21,800	21,800
1,500	3.59	3.76	4.14	33,300	31,200	31,200
2,000	4.65	4.87	5.38	43,700	40,800	40,800
3,000	6.77	7.10	7.86	65,600	61,800	61,800
4,000	8.89	9.32	10.34	89,200	83,700	83,200
5,000	11.01	11.55	12.82	114,200	106,700	105,500
5,500	12.07	12.66	14.06	127,300	119,400	117,600

TABLE 71

ENERGY EFFICIENCY PARAMETERS VS. DISTANCE - OPTIMUM N80-2.55 AIRCRAFT

58 PERCENT LOAD FACTOR

BTU/NM	DISTANCE(NM)	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	1,116,000	1,116,000	1,116,000
	250	654,700	639,800	632,400
	500	494,700	491,000	491,000
	750	446,400	431,500	431,500
	1,000	427,800	405,400	405,400
	1,500	412,900	386,800	386,800
	2,000	406,400	379,400	379,400
	3,000	406,700	383,100	383,100
	4,000	414,700	389,200	386,800
	5,000	424,800	396,900	392,400
	5,500	430,500	403,700	397,700
ASNM/GAL	DISTANCE(NM)	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	22.78	22.78	22.78
	250	38.83	39.73	40.20
	500	51.38	51.77	51.77
	750	56.95	58.91	58.91
	1,000	59.43	62.70	62.70
	1,500	61.57	65.71	65.71
	2,000	62.55	67.00	67.00
	3,000	62.51	66.35	66.35
	4,000	61.29	65.32	65.71
	5,000	59.84	64.05	64.78
	5,500	59.05	62.96	63.92
BTU/ASNM	DISTANCE(NM)	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	5,552	5,552	5,552
	250	3,257	3,183	3,146
	500	2,461	2,443	2,443
	750	2,221	2,147	2,147
	1,000	2,128	2,017	2,017
	1,500	2,054	1,925	1,925
	2,000	2,022	1,888	1,888
	3,000	2,023	1,906	1,906
	4,000	2,064	1,936	1,925
	5,000	2,114	1,975	1,953
	5,500	2,142	2,009	1,979

5.6 N80-4.30 Series Aircraft

Each member of the Model N80-4.30 series is characterized by four wing-mounted engines, a capacity of 404 passengers, and a range of 3,000 nautical miles.

5.6.1 Configuration Trade Studies

Based upon the results of the N80-2.15 and N80-2.30 trade studies, a general variation of optimum geometry and cruise Mach number with fuel price was derived. Due to the weak sensitivity of DOC to geometry changes, as determined earlier for the N80-2.15 and N80-2.30 series, this general variation (Figure 80) was assumed to be valid for the N80-4.30 series. The configurations were sized for minimum DOC at three fuel prices (15, 30, and 60 cents per gallon) and also for minimum block fuel.

5.6.2 Optimum Design Characteristics

Plan views of the resulting N80-4.30 aircraft are shown in Figure 81. A summary of the optimum characteristics is given in Table 72. Additional design data is given in Table 73, and a weight statement appears in Table 74.

5.6.3 Energy Efficiency

The variation of block time and block fuel with range at 58 percent load factor is presented in Figure 82. The energy efficiency parameters (BTU/NM, ASNM/GAL, BTU/ASNM) of the N80-4.30 series at 58 percent load factor are presented in Figure 83. The optimum range for maximum fuel efficiency appears to be about 2,000 to 2,500 nautical miles. The results are also given in tabular form in Tables 75 and 76.

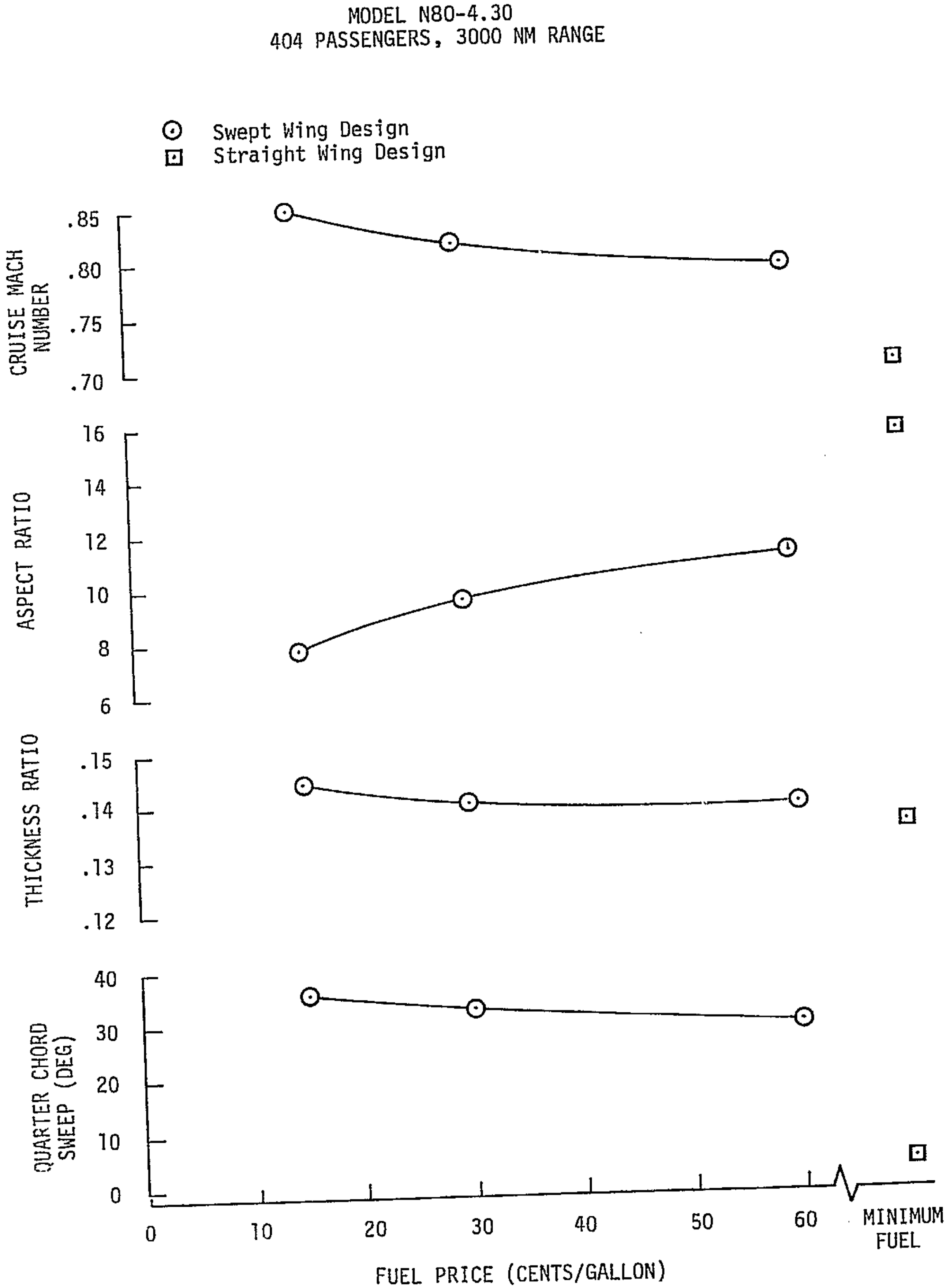


FIGURE 80. EFFECT OF FUEL PRICE ON N80-4.30 OPTIMUM AIRCRAFT GEOMETRY AND CRUISE MACH NUMBER

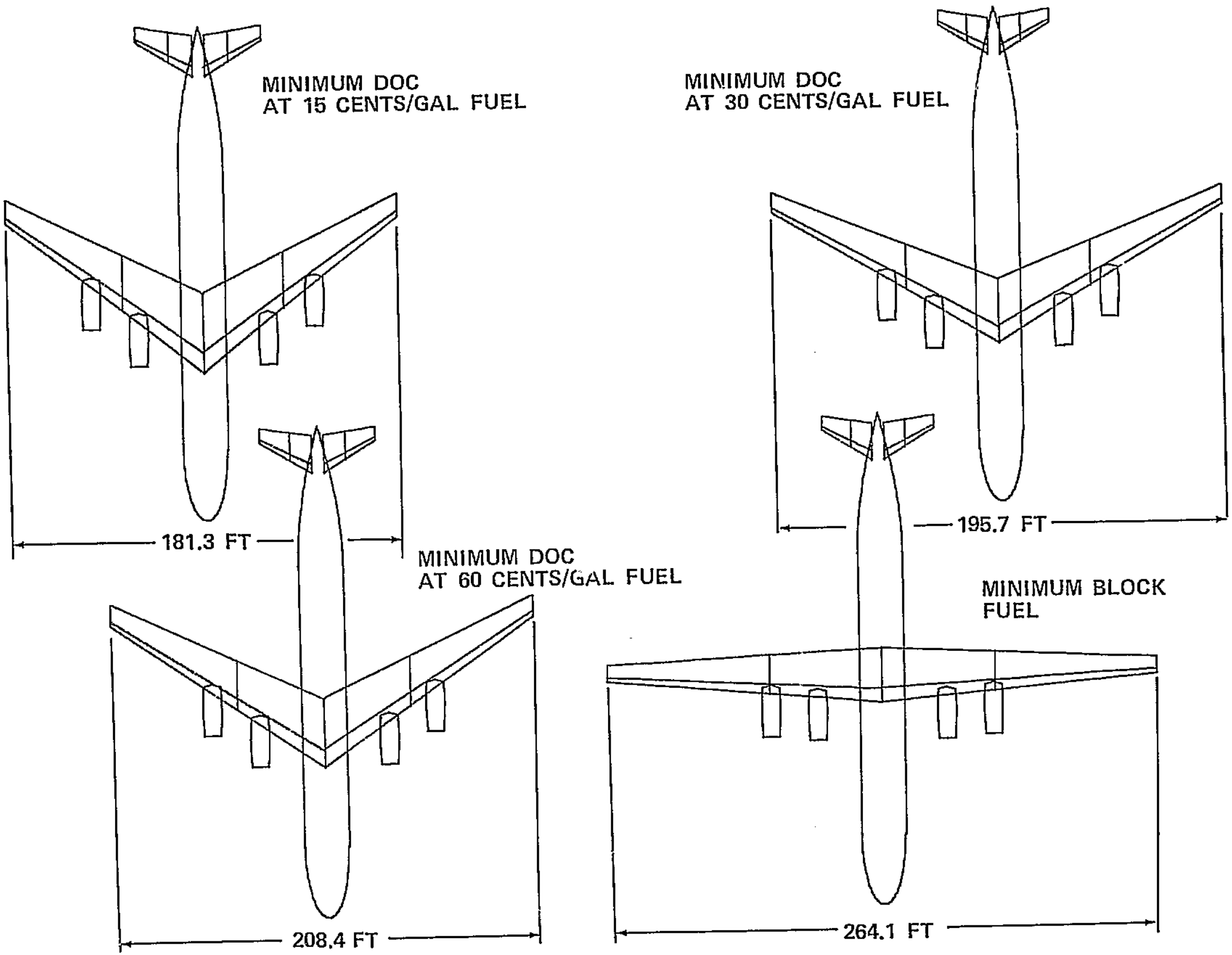


FIGURE 81. PLAN VIEWS OF OPTIMIZED N80-4.30 AIRCRAFT

TABLE 72

OPTIMUM N80-4.30 AIRCRAFT CHARACTERISTICS

4 CF6-6D Type Engines, 404 Passengers, 3,000 NM Range

		OPTIMIZATION PARAMETER			
		DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
Takeoff Gross Weight	Lb	527,400	519,100	517,200	548,200
Operational Empty Weight	Lb	301,400	304,700	309,100	345,300
Cruise Mach Number		0.85	0.82	0.79	0.70
Block Time (1)	Hr	6.52	6.78	6.96	7.77
Block Fuel (1)	Lb	121,910	111,740	106,420	102,960
Critical Field Length	Ft	9,000	9,000	9,000	9,000
Approach Speed	KEAS	123	125	125	115
Thrust Per Engine Uninstalled	Lb	35,830	32,120	29,600	27,600
Direct Operating Cost (1)	¢/Seat-NM				
@ 15¢ Per Gallon		0.843	0.846	0.857	0.959
@ 30¢ Per Gallon		1.050	1.036	1.038	1.136
@ 60¢ Per Gallon		1.464	1.416	1.400	1.489
Geometry					
Aspect Ratio		7.75	9.5	11.0	15.5
Quarter Chord Sweep	Deg	35.5	32.5	29.0	3.2 (2)
Average Thickness-to-Chord Ratio		0.144	0.140	0.139	0.135
Taper Ratio		0.30	0.30	0.30	0.30
Wing Area	Ft^2	4,240	4,030	3,950	4,500
Fuel Use @ 1,000 NM	BTU/ASNM	1,740	1,611	1,542	1,533

(1) At Design Range, 100 Percent Load Factor
(2) Straight Rear Spar

TABLE 73

N80-4.30 DESIGN DATA

DESIGN ITEMS		OPTIMIZATION PARAMETER			
		DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
Wing Area - Trapezoidal	Ft^2	4,240	4,030	3,950	4,500
Wing Aspect Ratio		7.8	9.5	11.0	15.5
Wing Sweep @ C/4	Deg	35.5	32.5	29.0	3.20
Wing Taper Ratio		.30	.30	.30	.30
Wing Loading	PSF	124.4	128.8	130.9	121.8
Wing Thickness Ratio		.144	.140	.139	.135
Horizontal/Vertical Tail Area	Ft^2	677/560	566/566	511/577	523/692
Horizontal/Vertical Tail Arm	In	1,350/1,260	1,350/1,260	1,350/1,260	1,350/1,260
Horizontal/Vertical Tail Volume Coeff.		.700/.076	.700/.075	.700/.074	.700/.061
Thrust/Weight Ratio		.272	.247	.229	.201
Fuel Fraction		.271	.253	.242	.219
Fuselage Length	In	2,750	2,750	2,750	2,750
No. of Passengers (1st Class/Coach)		42/362	42/362	42/362	42/362
No. of Engines		4	4	4	4

TABLE 74

N80-4.30 WEIGHT DATA (LB)

WEIGHT ITEMS	OPTIMIZATION PARAMETER			
	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
Wing	68,266	77,451	85,319	121,249
Horizontal Tail	2,799	2,334	2,112	2,113
Vertical Tail	2,506	2,586	2,670	3,216
Fuselage	56,434	56,293	56,197	55,764
Landing Gear	21,890	21,540	21,465	22,762
Flight Controls & Hydraulics	6,991	6,571	6,401	7,227
Propulsion System	44,054	39,447	36,398	33,944
Fuel System	1,412	1,524	1,624	2,057
Auxiliary Power Unit	1,380	1,380	1,380	1,380
Instruments	1,771	1,701	1,670	1,657
Air Conditioning & Pneumatics	6,549	6,549	6,549	6,549
Electrical System	8,126	8,126	8,126	8,126
Avionics	2,215	2,215	2,215	2,215
Furnishings	52,805	52,805	52,805	52,805
Anti-Ice	827	805	797	855
Handling Gear	155	153	152	161
Manufacturer's Empty Weight	278,180	281,480	285,880	322,080
Operator Items	23,220	23,220	23,220	23,220
Operational Empty Weight	301,400	304,700	309,100	345,300
Payload	80,800	80,800	80,800	80,800
Zero Fuel Weight	382,200	385,500	389,900	426,100
Fuel	145,200	133,600	127,300	122,100
Takeoff Gross Weight	527,400	519,100	517,200	548,200

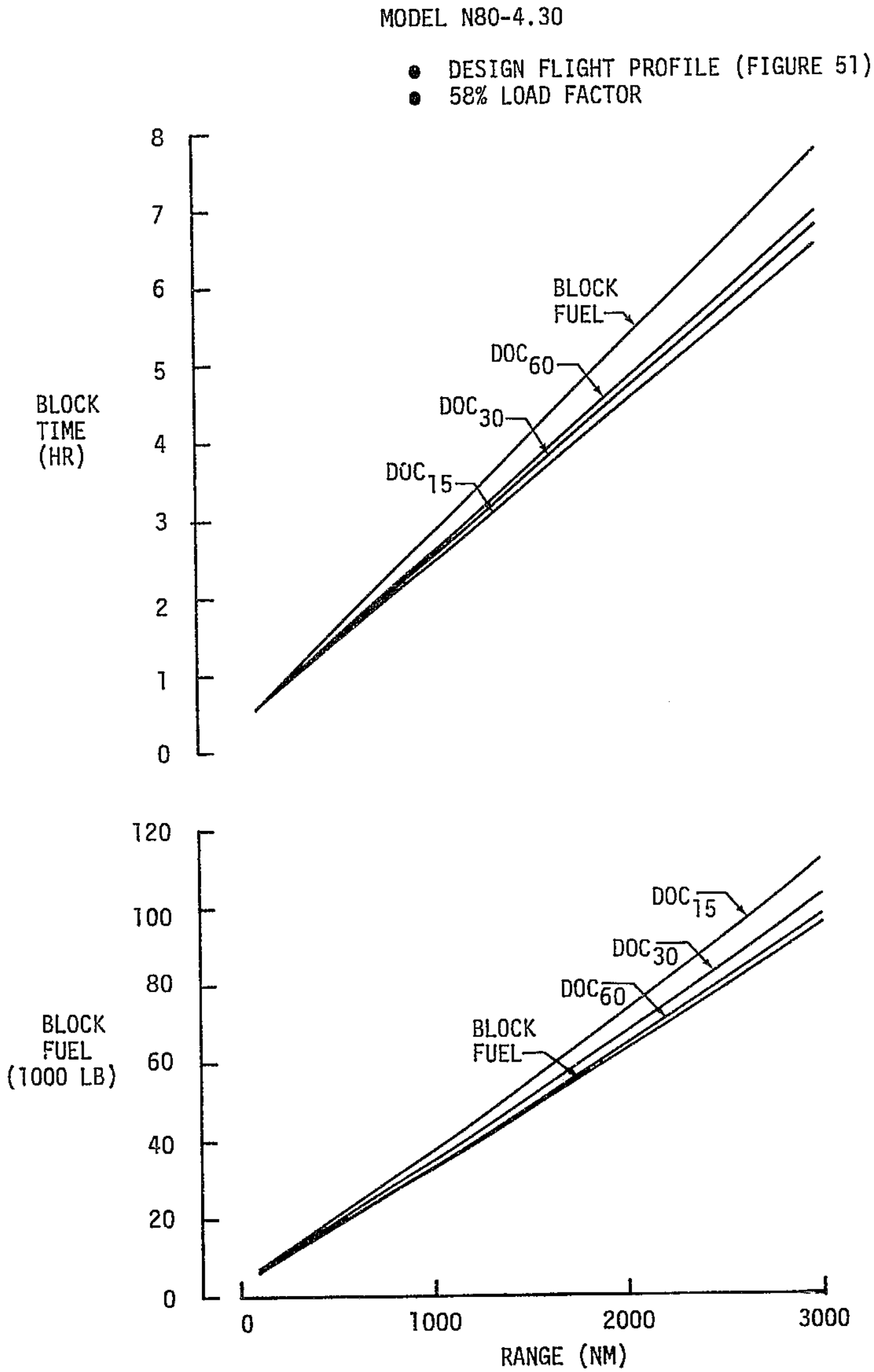


FIGURE 82. BLOCK TIME AND BLOCK FUEL VS. RANGE OPTIMUM N80-4.30 AIRCRAFT

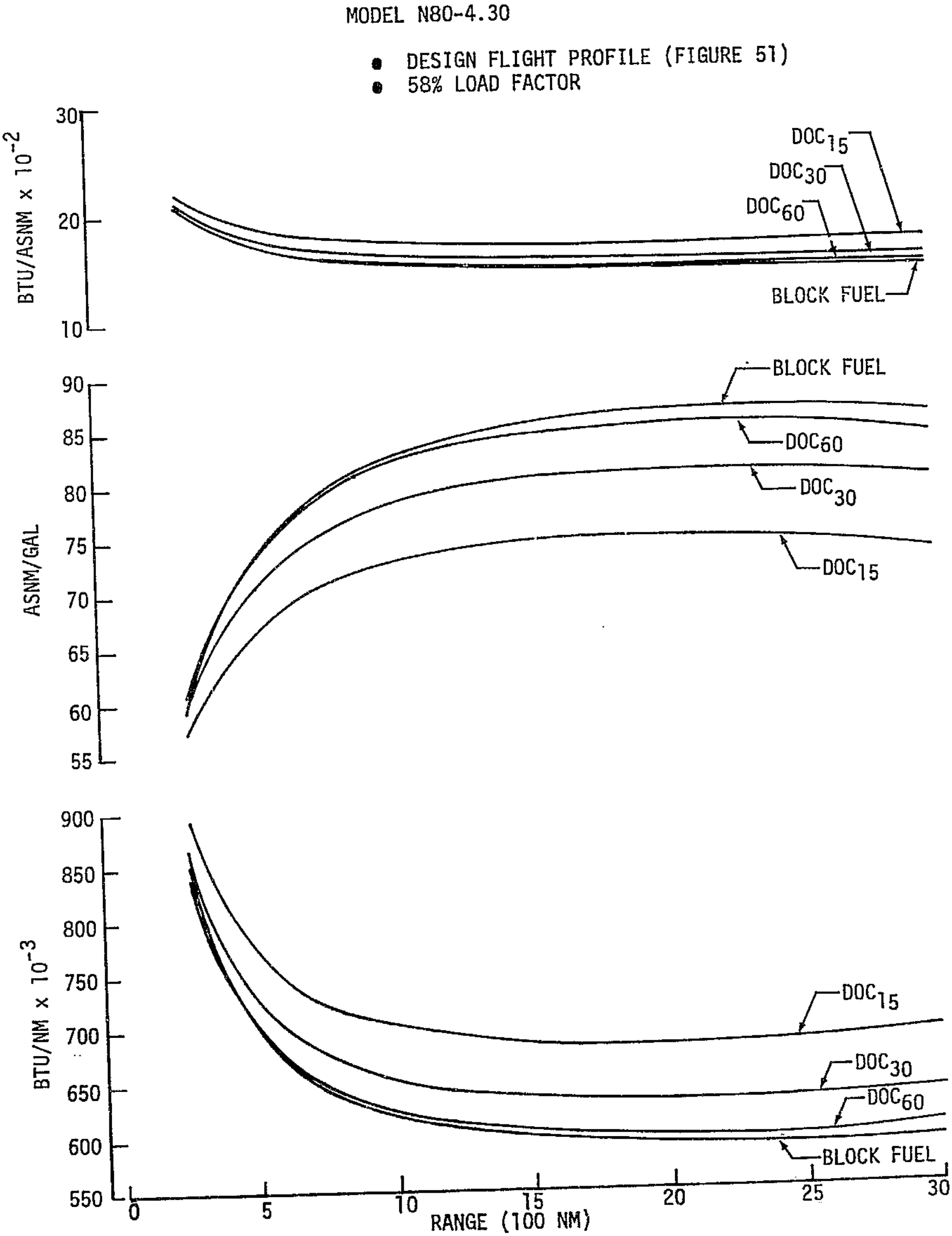


FIGURE 83. ENERGY EFFICIENCY PARAMETERS VS. RANGE OPTIMUM N80-4.30 AIRCRAFT

TABLE 75

BLOCK TIME AND BLOCK FUEL VS. DISTANCE

OPTIMUM N80-4.30 AIRCRAFT

5' PERCENT LOAD FACTOR

DISTANCE (NM)	BLOCK TIME (HR)				BLOCK FUEL (LB)			
	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
100	.55	.55	.55	.55	6,800	6,800	6,800	6,800
250	.88	.89	.92	.93	12,000	11,600	11,400	11,300
500	1.38	1.44	1.46	1.55	20,700	19,500	18,800	18,800
750	1.90	1.97	2.03	2.18	29,100	27,300	26,100	26,000
1000	2.42	2.50	2.57	2.80	37,800	35,000	33,500	33,300
1500	3.44	3.58	3.67	4.05	55,200	51,200	48,800	48,200
2000	4.48	4.63	4.76	5.28	73,400	67,800	64,500	63,500
2500	5.50	5.69	5.87	6.52	92,000	84,800	80,400	79,200
3000	6.52	6.78	6.96	7.77	112,000	102,800	97,900	95,700

TABLE 76

ENERGY EFFICIENCY PARAMETERS VS. DISTANCE - OPTIMUM N80-4.30 AIRCRAFT

58 PERCENT LOAD FACTOR

BTU/NM	DISTANCE (NM)	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	1,264,800	1,264,800	1,264,800	1,264,800
	250	892,800	863,000	848,100	840,700
	500	770,000	725,400	699,300	699,300
	750	721,600	677,000	647,200	644,800
	1,000	703,000	651,000	623,100	619,300
	1,500	684,400	634,800	605,100	597,600
	2,000	682,600	630,500	599,800	590,500
	2,500	684,400	630,900	598,100	589,200
	3,000	694,400	637,300	606,900	593,300
ASNM/GAL	DISTANCE (NM)	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	40.40	40.40	40.40	40.40
	250	57.23	59.21	60.25	60.78
	500	66.36	70.44	73.06	73.06
	750	70.80	75.47	78.94	79.25
	1,000	72.68	78.49	82.01	82.50
	1,500	74.65	80.48	84.44	85.49
	2,000	74.86	81.04	85.18	86.53
	2,500	74.65	80.99	85.42	86.72
	3,000	73.59	80.17	84.18	86.12
BTU/ASNM	DISTANCE (NM)	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	3,131	3,131	3,131	3,131
	250	2,210	2,136	2,099	2,081
	500	1,906	1,796	1,731	1,731
	750	1,786	1,676	1,602	1,596
	1,000	1,740	1,611	1,542	1,533
	1,500	1,694	1,571	1,498	1,479
	2,000	1,690	1,561	1,485	1,462
	2,500	1,694	1,562	1,481	1,459
	3,000	1,719	1,578	1,502	1,469

5.7 N80-4.55 Series Aircraft

Each member of the Model N80-4.55 series is characterized by four wing-mounted engines, a 404 passenger seating capacity, and an intercontinental range of 5,500 nautical miles.

5.7.1 Configuration Trade Studies

Due to the relative insensitivity of optimum geometry and optimum cruise Mach numbers to variations in range, no additional geometry optimization trades were conducted for the N80-4.55 series. The geometries were chosen from the N80-4.30 results. The configurations were sized for minimum DOC at two fuel prices (30 and 60 cents per gallon) and minimum block fuel.

5.7.2 Optimum Design Characteristics

Plan views of the resulting N80-4.55 intercontinental aircraft are shown in Figure 84. A summary of the characteristics of the series is given in Table 77, and additional design and weight data for these aircraft are given in Tables 78 and 79.

5.7.3 Energy Efficiency

The variation of block time and block fuel with range at 58 percent load factor is presented in Figure 85. The energy efficiency parameters (BTU/NM, ASNM/GAL, BTU/ASNM) of the N80-4.55 aircraft at 58 percent load factor are presented in Figure 86. The optimum range for maximum fuel efficiency appears to be about 3,000 nautical miles. These results are also tabulated in Tables 80 and 81.

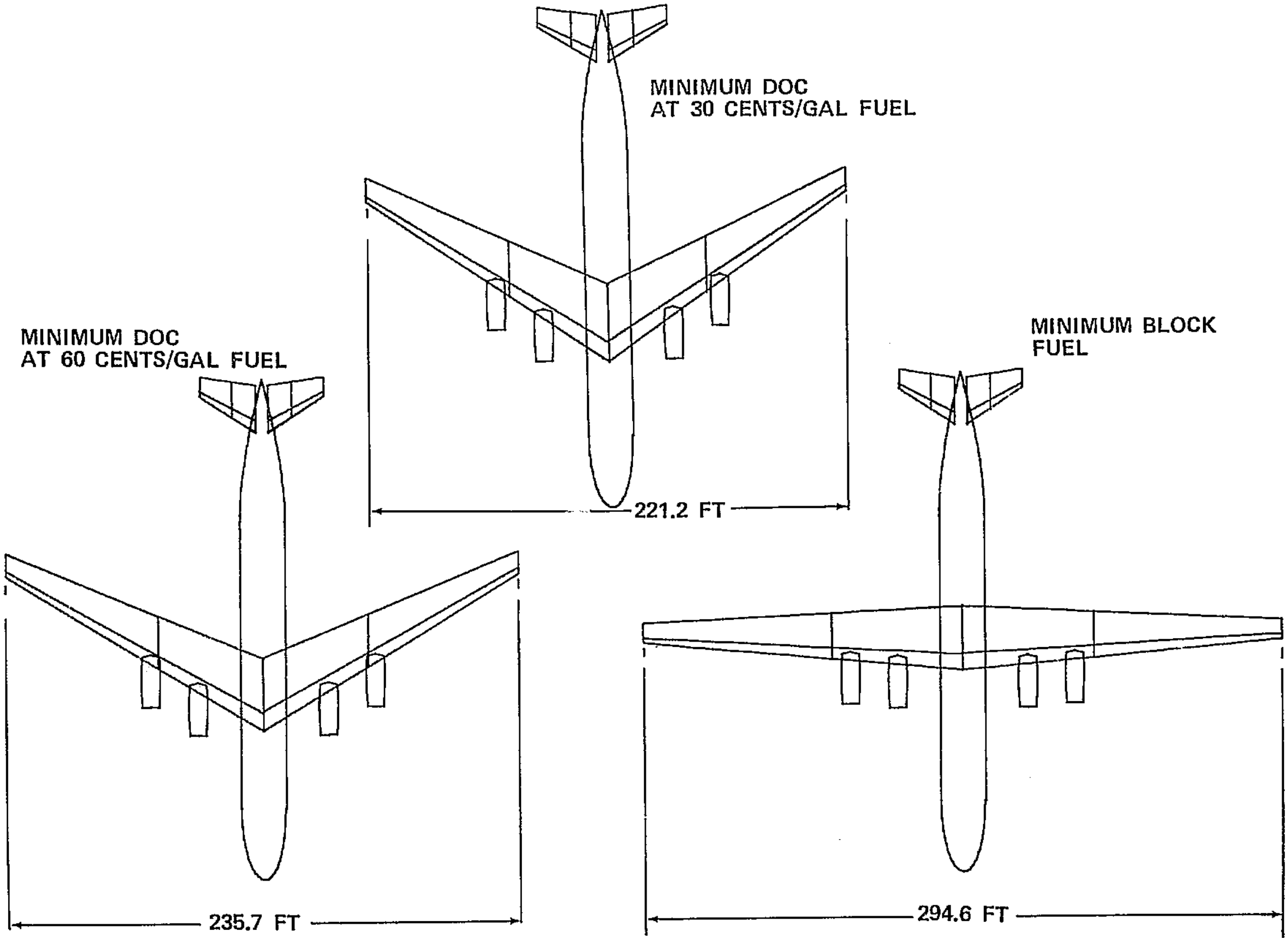


FIGURE 84. PLAN VIEWS OF OPTIMIZED N80-4.55 AIRCRAFT

TABLE 77

OPTIMUM N80-4.55 AIRCRAFT CHARACTERISTICS

4 CF6-6D Type Engines, 404 Passengers, 5,500 NM Range

		OPTIMIZATION PARAMETER		
		DOC_{30}	DOC_{60}	BLOCK FUEL
Takeoff Gross Weight	Lb	704,700	701,400	747,600
Operational Empty Weight	Lb	361,200	368,400	420,400
Cruise Mach Number		0.82	0.79	0.70
Block Time (1)	Hr	12.12	12.48	13.95
Block Fuel (1)	Lb	238,170	228,690	223,880
Critical Field Length	Ft	11,000	11,000	11,000
Approach Speed	KEAS	118.4	118.1	112.0
Thrust Per Engine Uninstalled	Lb	40,240	37,290	35,160
Direct Operating Cost (1)	¢/Seat-NM			
@ 15¢ Per Gallon		0.947	0.968	1.100
@ 30¢ Per Gallon		1.169	1.182	1.311
@ 60¢ Per Gallon		1.612	1.610	1.735
Geometry				
Aspect Ratio		9.5	11.0	15.5
Quarter Chord Sweep	Deg	32.5	29.0	3.2 (2)
Average Thickness-To-Chord Ratio		0.140	0.139	0.135
Taper Ratio		0.30	0.30	0.30
Wing Area	Ft^2	5,150	5,050	5,600
Fuel Used @ 1,000 NM	BTU/ASNM	1,842	1,846	1,848

(1) At Design Range, 100 Percent Load Factor
(2) Straight Rear Spar

TABLE 78

N80-4.55 DESIGN DATA

DESIGN ITEMS		OPTIMIZATION PARAMETER		
		DOC_{30}	DOC_{60}	BLOCK FUEL
Wing Area - Trapezoidal	Ft^2	5,150	5,050	5,600
Wing Aspect Ratio		9.5	11.0	15.5
Wing Sweep @ C/4	Deg	32.5	29.0	3.20
Wing Taper Ratio		.30	.30	.30
Wing Loading	PSF	136.8	138.9	133.5
Wing Thickness Ratio		.140	.139	.135
Horizontal/Vertical Tail Area	Ft^2	818/676	738/692	726/837
Horizontal/Vertical Tail Arm	In	1,350/1,260	1,350/1,260	1,350/1,260
Horizontal/Vertical Tail Volume Coeff.		.700/.062	.700/.061	.700/.053
Thrust/Weight Ratio		.228	.213	.188
Fuel Fraction		.370	.357	.327
Fuselage Length	In	2,750	2,750	2,750
No. of Passengers (1st Class/Coach)		42/362	42/362	42/362
No. of Engines		4	4	4

TABLE 79

N80-4.55 WEIGHT DATA (LB)

WEIGHT ITEMS	OPTIMIZATION PARAMETER		
	DOC_{30}	DOC_{60}	BLOCK FUEL
Wing	109,934	121,584	172,925
Horizontal Tail	3,458	3,064	2,930
Vertical Tail	3,330	3,459	4,302
Fuselage	58,245	57,979	57,329
Landing Gear	29,303	29,169	31,094
Flight Controls and Hydraulics	8,449	8,223	9,054
Propulsion System	49,478	45,863	43,215
Fuel System	1,723	1,836	2,295
Auxiliary Power Unit	1,380	1,380	1,380
Instruments	1,855	1,809	1,771
Air Conditioning & Pneumatics	6,549	6,549	6,549
Electrical System	8,126	8,126	8,126
Avionics	2,215	2,215	2,215
Furnishings	52,805	52,805	52,805
Anti-Ice	923	913	971
Handling Gear	207	206	219
Manufacturer's Empty Weight	337,980	345,180	397,180
Operator Items	23,220	23,220	23,220
Operational Empty Weight	361,200	368,400	420,400
Payload	80,800	80,800	80,800
Zero Fuel Weight	442,000	449,200	501,200
Fuel	262,700	252,200	246,400
Takeoff Gross Weight	704,700	701,400	747,600

MODEL N80-4.55

- DESIGN FLIGHT PROFILE (FIGURE 51)
- 58% LOAD FACTOR

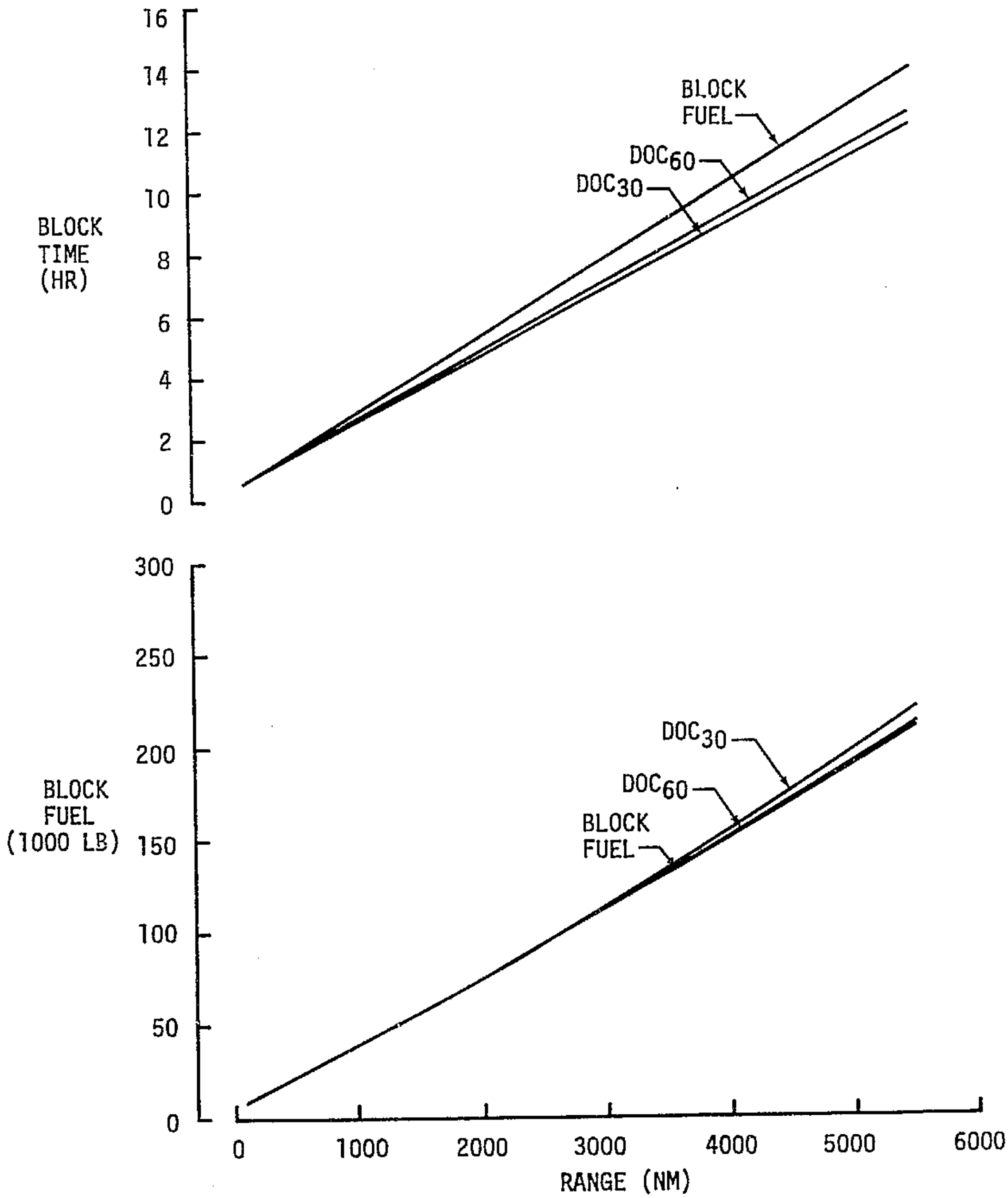


FIGURE 85. BLOCK TIME AND BLOCK FUEL VS. RANGE
OPTIMUM N80-4.55 AIRCRAFT

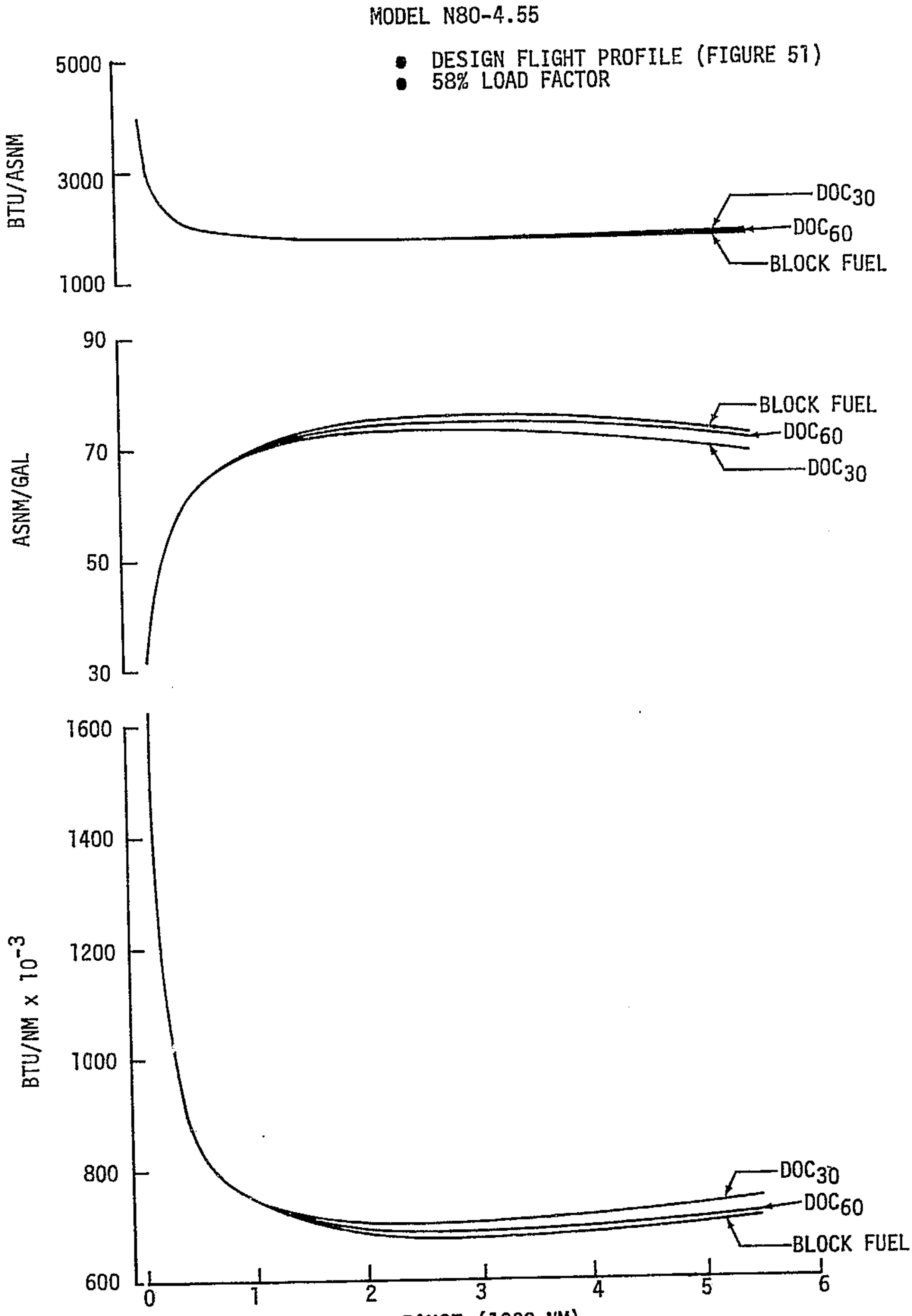


FIGURE 86. ENERGY EFFICIENCY PARAMETERS VS. RANGE
OPTIMUM N80-4.55 AIRCRAFT

TABLE 80

BLOCK TIME AND BLOCK FUEL VS. DISTANCE - OPTIMUM N80-4.55 AIRCRAFT

58 PERCENT LOAD FACTOR

DISTANCE (NM)	BLOCK TIME (HR)			BLOCK FUEL (LB)		
	DOC_{30}	DOC_{60}	BLOCK FUEL	DOC_{30}	DOC_{60}	BLOCK FUEL
100	0.57	0.63	0.52	8,750	8,750	8,750
250	0.89	0.96	0.90	13,860	13,920	13,960
500	1.42	1.51	1.52	22,470	22,590	22,660
750	1.96	2.06	2.14	31,180	31,310	31,390
1,000	2.49	2.60	2.76	40,000	40,100	40,150
1,500	3.56	3.70	4.00	57,660	57,450	57,130
2,000	4.63	4.80	5.24	75,560	74,800	73,820
3,000	6.77	7.00	7.73	113,420	111,240	109,280
4,000	8.90	9.19	10.21	154,000	150,000	147,500
5,000	11.04	11.38	12.70	197,320	191,090	188,480
5,500	12.11	12.48	13.94	220,000	212,500	210,000

TABLE 81

ENERGY EFFICIENCY PARAMETERS VS. DISTANCE - OPTIMUM N80-4.55 AIRCRAFT

58 PERCENT LOAD FACTOR

BTU/NM	DISTANCE(NM)	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	1,627,500	1,627,500	1,627,500
	250	1,031,100	1,035,600	1,038,600
	500	835,800	840,300	842,900
	750	773,200	776,400	778,400
	1,000	744,000	745,800	746,700
	1,500	714,900	712,300	708,400
	2,000	702,700	695,600	686,500
	3,000	703,200	689,600	677,500
	4,000	716,100	697,500	685,800
	5,000	734,000	710,800	701,100
	5,500	744,000	718,600	710,100
ASNM/GAL	DISTANCE(NM)	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	31.40	31.40	31.40
	250	49.55	49.34	49.20
	500	61.13	60.81	60.62
	750	66.08	65.81	65.64
	1,000	68.68	68.51	68.42
	1,500	71.47	71.73	72.13
	2,000	72.72	73.45	74.43
	3,000	72.66	74.09	75.42
	4,000	71.36	73.26	74.50
	5,000	69.61	71.88	72.88
	5,500	68.68	71.10	71.95
BTU/ASNM	DISTANCE(NM)	DOC_{30}	DOC_{60}	BLOCK FUEL
	100	4,028	4,028	4,028
	250	2,552	2,563	2,571
	500	2,069	2,080	2,087
	750	1,914	1,922	1,927
	1,000	1,842	1,846	1,848
	1,500	1,770	1,763	1,753
	2,000	1,739	1,722	1,699
	3,000	1,741	1,707	1,677
	4,000	1,773	1,726	1,698
	5,000	1,817	1,760	1,736
	5,500	1,842	1,779	1,758

5.8 Comparison of New Near-Term Aircraft

The results of the new near-term aircraft study are discussed in terms of fuel savings, the effects of fuel price on design, and payload-range capabilities.

5.8.1 Fuel Savings Comparison

The fuel use parameters for all of the N80 aircraft at their design ranges are shown in Figure 87. The results show the effect of design fuel price on energy efficiency. The energy efficiency penalty for long ranges is also shown. As the range increases, the payload capacity must also be increased to maintain high energy efficiencies.

The sensitivity of N80 fuel use with design fuel price is shown in Figure 88. Each curve in Figure 88 represents data at one-third of the aircraft design range, which corresponds to typical average ranges for aircraft in the domestic fleet. Fuel savings due to geometry optimization improve more gradually at the higher fuel prices. Both design fuel price and design cruise Mach number have a large effect on fuel use, as shown for the N80-2.30 at its design range in Figure 89. Note that the airplane optimized for DOC at a fuel price of 60 cents per gallon has fuel efficiency very close to that of the minimum fuel aircraft.

Figure 90 shows the effect of design range on the additional fuel used by a minimum DOC design, relative to a minimum fuel design. The difference varies little with design range.

The N80 aircraft can save a considerable amount of fuel, relative to existing baseline aircraft in the fleet, as shown in Figure 91. Comparisons are made in terms of BTU/ASNM at one-third of the design range of the N80 airplanes. The fuel use improvements due to new technology appear to be very large, but require some qualification because airplanes with unequal capabilities are being compared. In particular, the N80 airplanes were designed to carry only a full cabin payload plus baggage, while existing aircraft in the fleet are sized to carry cargo in addition to a full load of passengers and bags. Also, the design flight profiles for the N80 airplanes include cruise climb, which is more efficient than the step altitude profiles used to calculate fuel burned by the baseline airplanes in the fleet.

The N80-2.15 family has a considerable edge over the DC-9-30 in seat-mile fuel economy, most of which is due to the N80-2.15 having more than twice as many seats. Also, in comparing the N80-2.15 to the DC-10-10, it must be emphasized that the relatively long-range DC-10-10 is being compared at 500 nautical miles to an aircraft family optimized for short ranges. Similarly, the N80-4.30 family seat-mile fuel economy is substantially better than the substantially smaller DC-8-61 and DC-10-10; and the design ranges of the DC-8-61 and DC-10-10 are greater than for the N80-4.30.

The N80-2.30 and DC-8-61 have similar passenger capacities, but different design ranges. The N80-2.30 and DC-10-10 have different capacities and design ranges. So comparisons are not on a consistent basis, but these are the closest aircraft types for which comparisons are available. By interpolating the 30 cent and 60 cent cases for the N80-2.30 in Figure 91, it appears that, at a design fuel price of 45 cents per gallon, the N80s are approximately 26 percent more efficient than current narrow-body aircraft and 16 percent more efficient than current wide-body aircraft. However, considering differences in payload-range capabilities and cruise altitude profiles, the efficiencies of the N80s would be more accurately placed at 20 percent better than narrow-body aircraft and 10 percent better than current wide-body aircraft.

5.8.2 Effect of Fuel Price on N80 Designs

The optimum cruise Mach numbers for the N80 families are shown in Figure 92 as a function of the design fuel price and the optimization parameter. The N80 prefix is deleted from the aircraft designations for simplification.

All N80 minimum fuel designs have a cruise Mach number of 0.70, which was a study groundrule lower limit (see Sections 5.1 and 5.3.1). However, independent DAC studies for aircraft having a similar technology level have indicated that the optimum Mach number for energy efficiency is closer to 0.65M. The exact value is highly dependent upon the assumed relationship between aspect ratio and wing weight; and the high aspect ratios associated with minimum fuel designs make accurate preliminary wing weight predictions difficult, because of limited data on flutter weight penalties for high aspect ratio wings.

Figure 93 shows the effect of the design fuel price and the optimization parameter on aspect ratio. All N80 families follow a similar trend. The aspect ratio values for the DC-8-63, DC-10-40, and B-747 are shown for comparison. Higher design fuel prices for the N80 aircraft resulted in significantly higher aspect ratios for the minimum DOC airplanes. The aspect ratios for minimum fuel designs are even higher, but were limited to a maximum of 15.5 because predicted wing weights for higher aspect ratios are less reliable.

Large wing spans are associated with the high aspect ratios of the N80 airplanes, as shown in Figures 63, 73, 77, 81, and 84, and summarized in Figure 94. In particular, the wing spans of the minimum fuel designs all exceed the span of the DC-10-40; and the N80-4.55$_{MF}$ wing span is nearly 300 feet.

The airline co-contractor expressed concern about the airport terminal compatibility of high aspect ratio winged aircraft. Consequently, the sensitivities of DOC and fuel use to changes in aspect ratio were examined. Figure 95 shows that the DOC for minimum DOC designs increases only about one percent when the aspect ratio is reduced 2 points from the optimum. Figure 62 shows that the fuel burned by minimum fuel designs increases only about one percent when the aspect ratio is reduced from the optimum value of 15.5 to 13.

5.8.3 Payload-Range Capability

The N80 aircraft payload-range capabilities are presented in Figures 96 and 97. The N80-2.55 series is fuel volume limited.

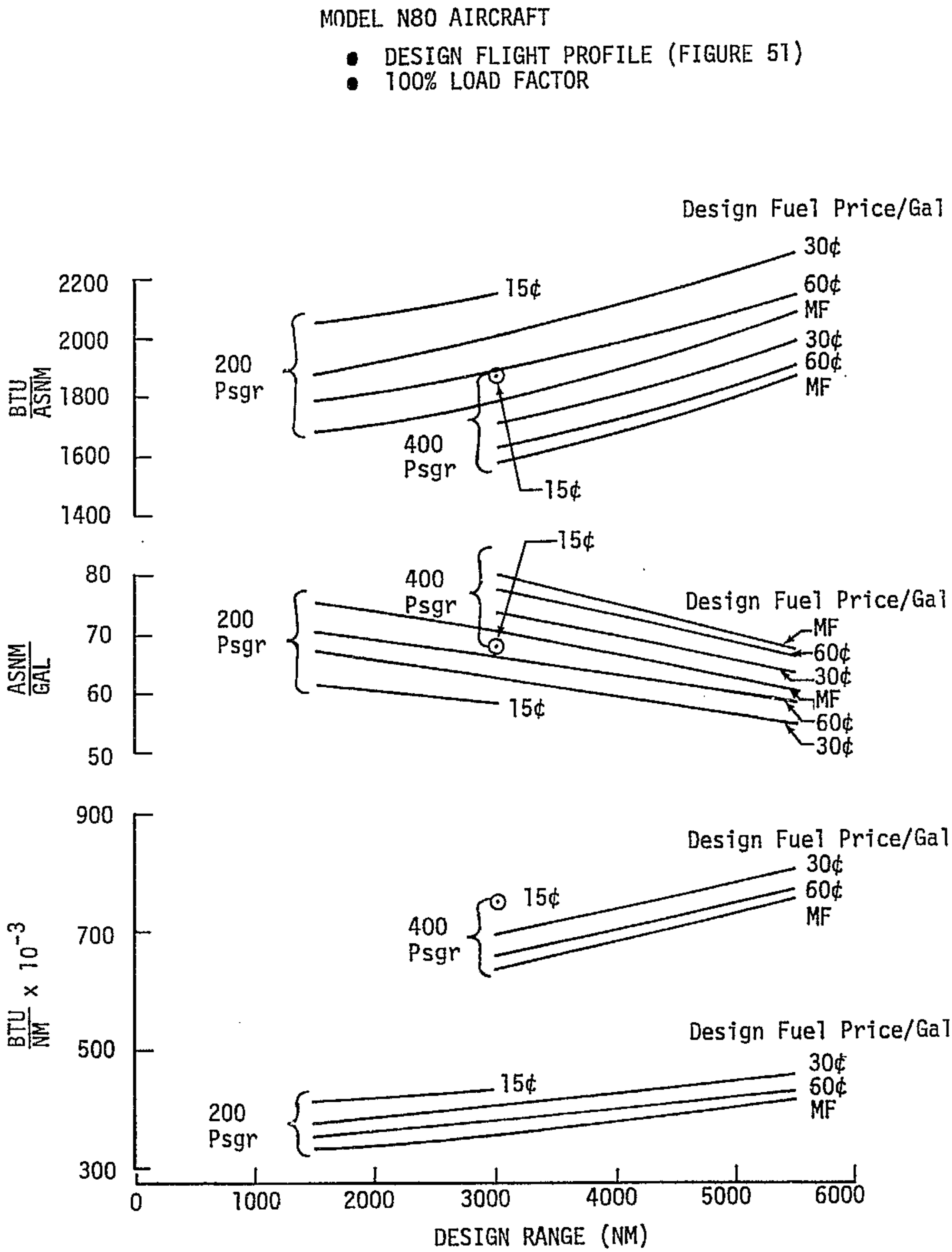


FIGURE 87. ENERGY EFFICIENCY PARAMETERS AT DESIGN RANGE FOR OPTIMUM N80 AIRCRAFT

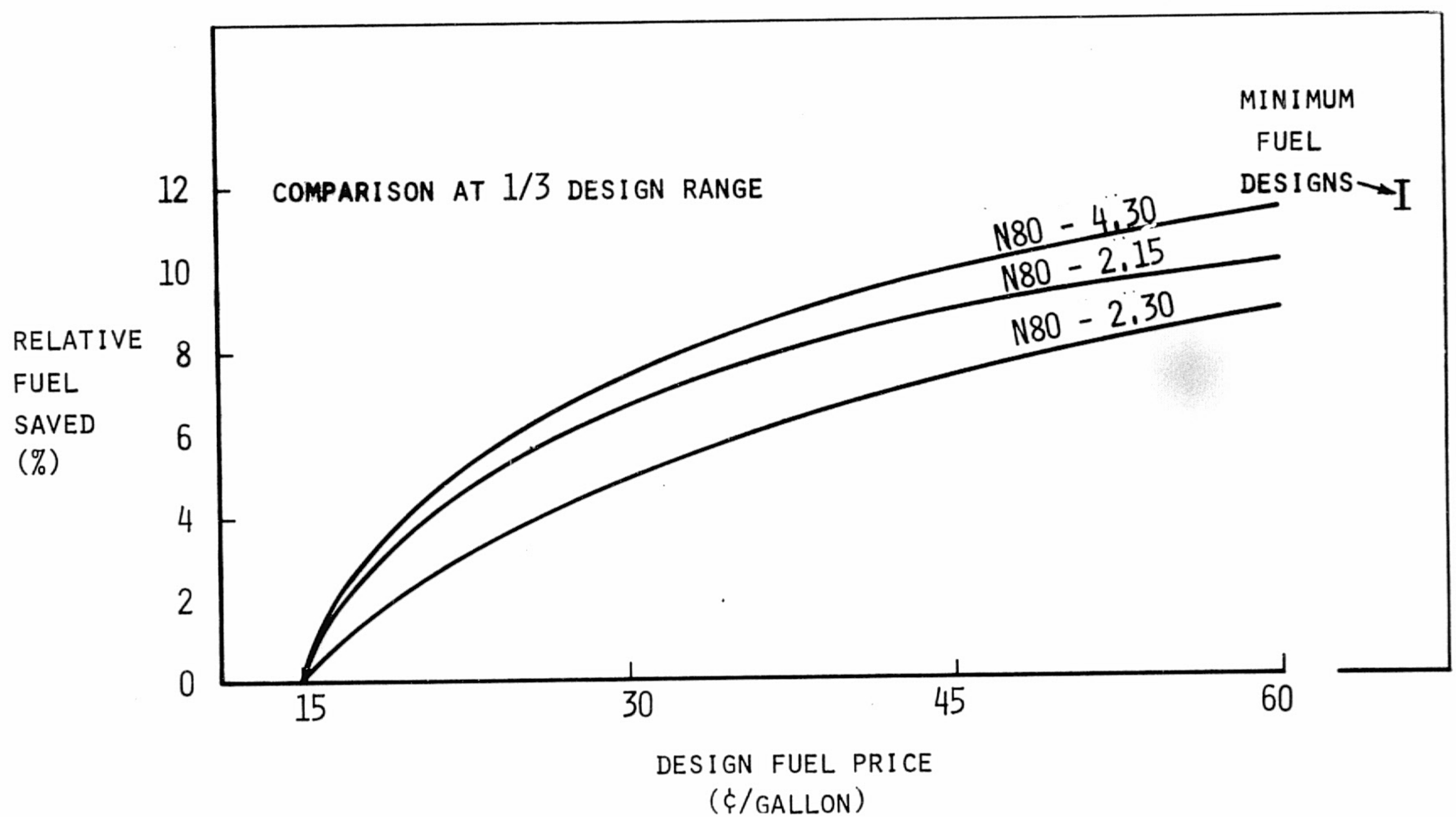


FIGURE 88. EFFECT OF DESIGN FUEL PRICE ON FUEL USE

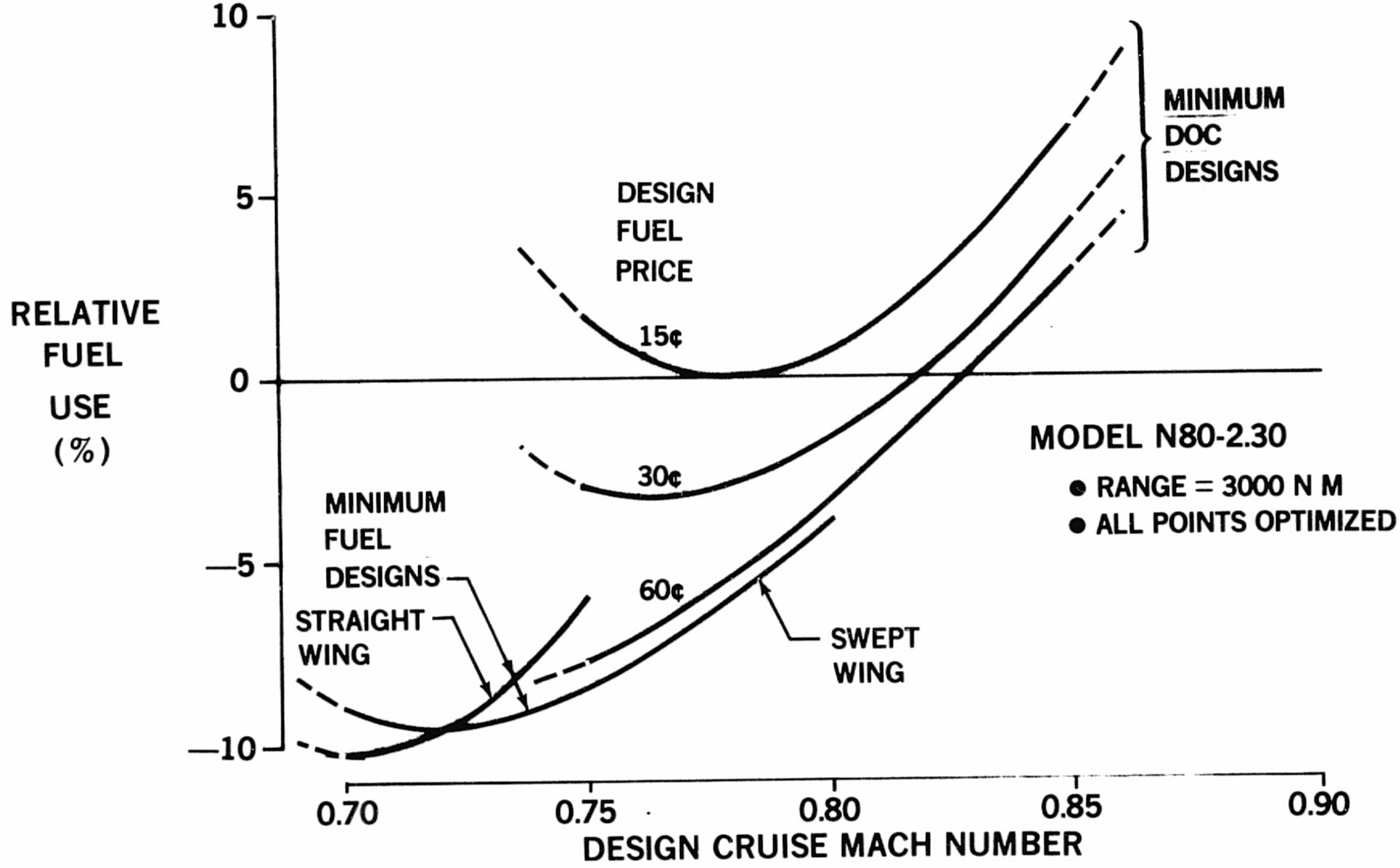


FIGURE 89. EFFECT OF DESIGN CRUISE MACH NUMBER AND DESIGN FUEL PRICE ON FUEL USE

N80 AIRCRAFT

- GEOMETRY OPTIMIZED FOR MINIMUM DOC @ 30 CENTS/GALLON

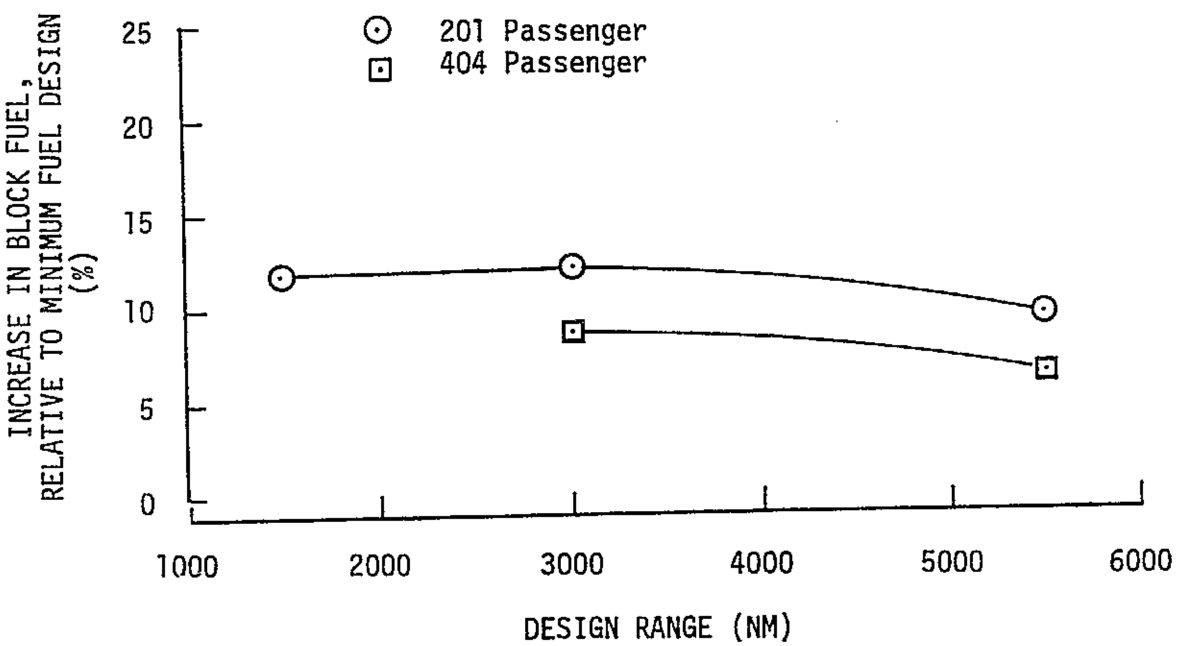


FIGURE 90. N80 BLOCK FUEL VS. DESIGN RANGE

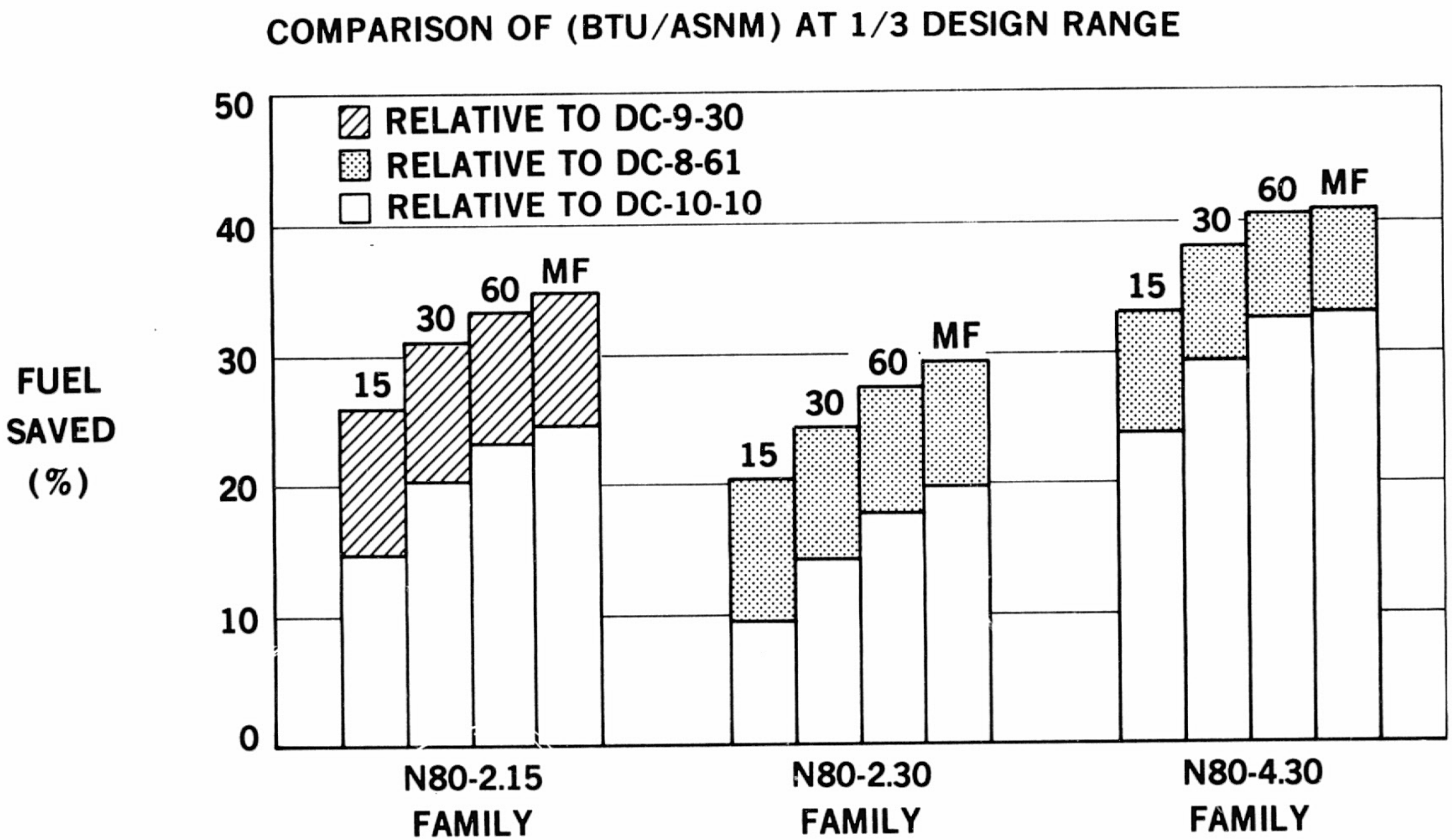


FIGURE 91. NEW NEAR-TERM AIRCRAFT FUEL SAVINGS

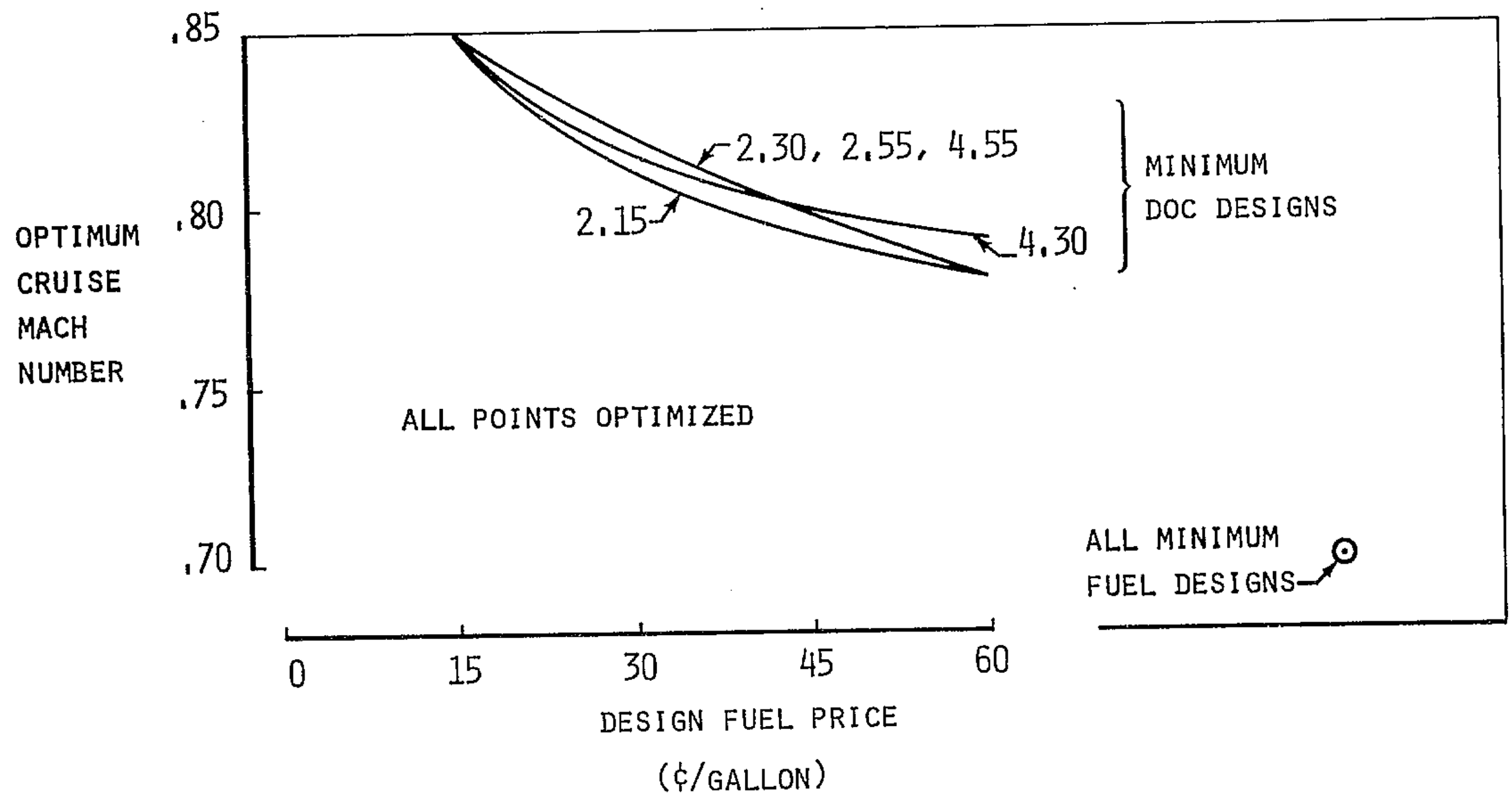


FIGURE 92. NEW NEAR-TERM AIRCRAFT CRUISE MACH NUMBER COMPARISON

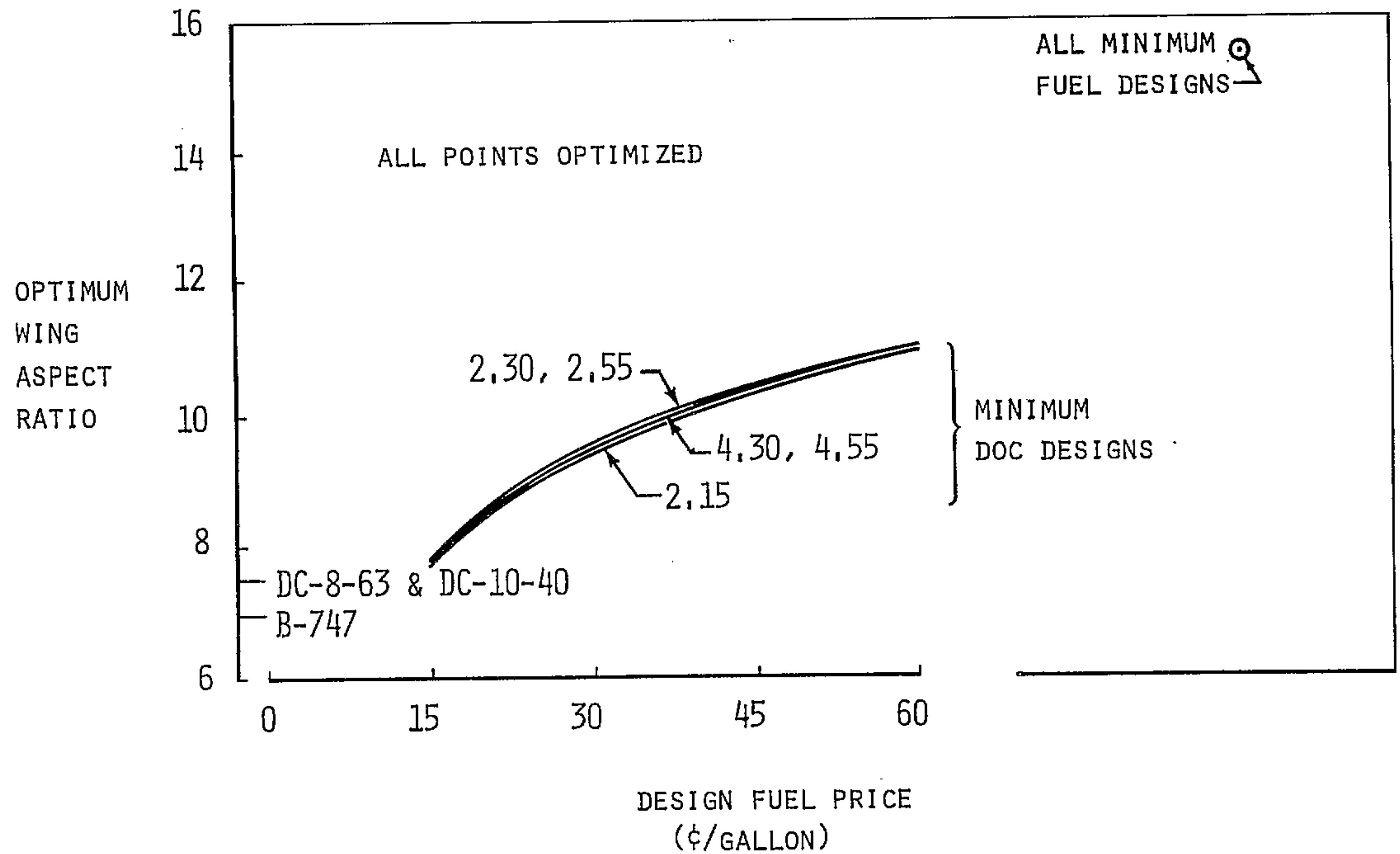


FIGURE 93. NEW NEAR-TERM AIRCRAFT ASPECT RATIO COMPARISON

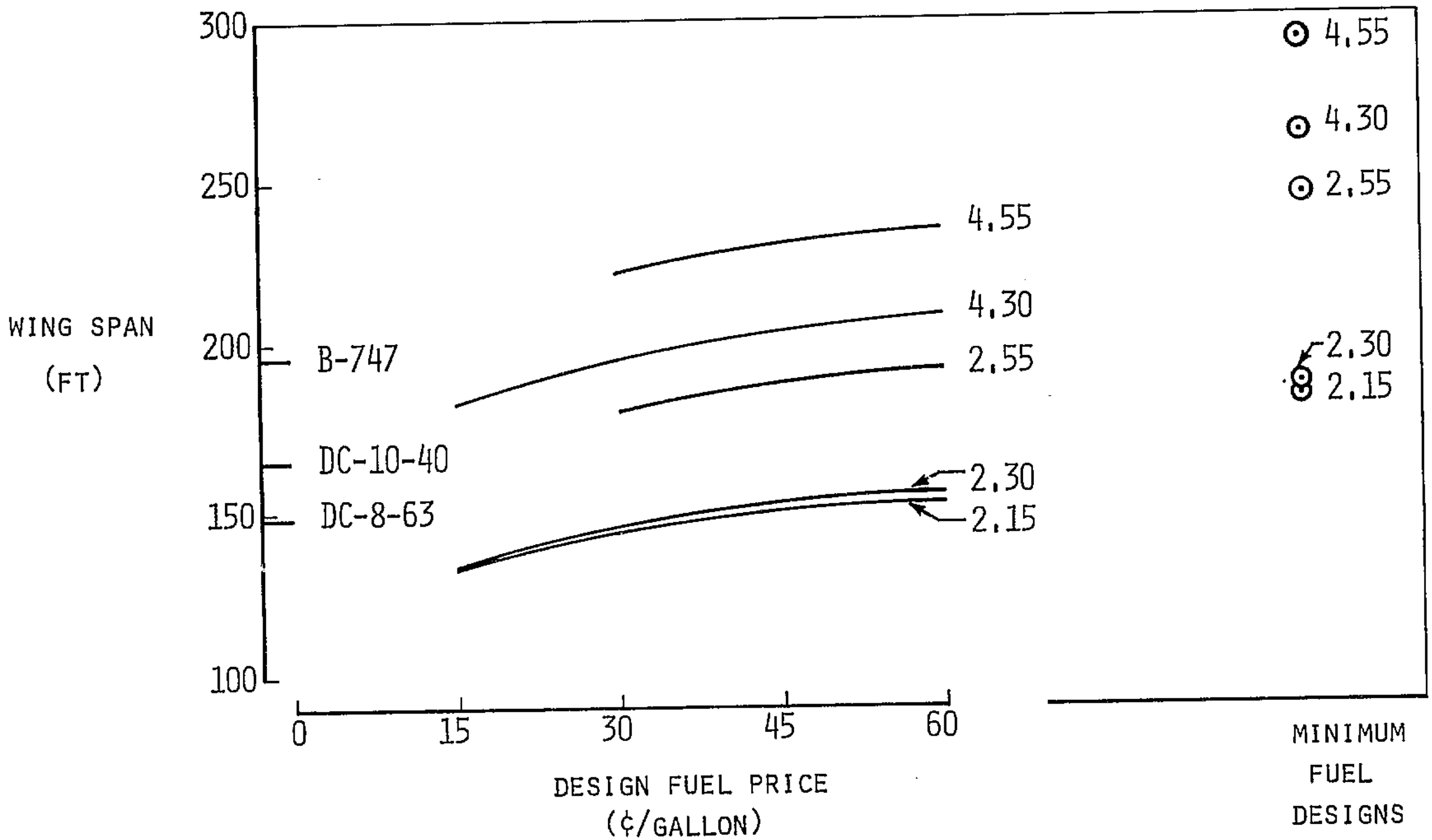


FIGURE 94. NEW NEAR-TERM AIRCRAFT WING SPAN COMPARISON

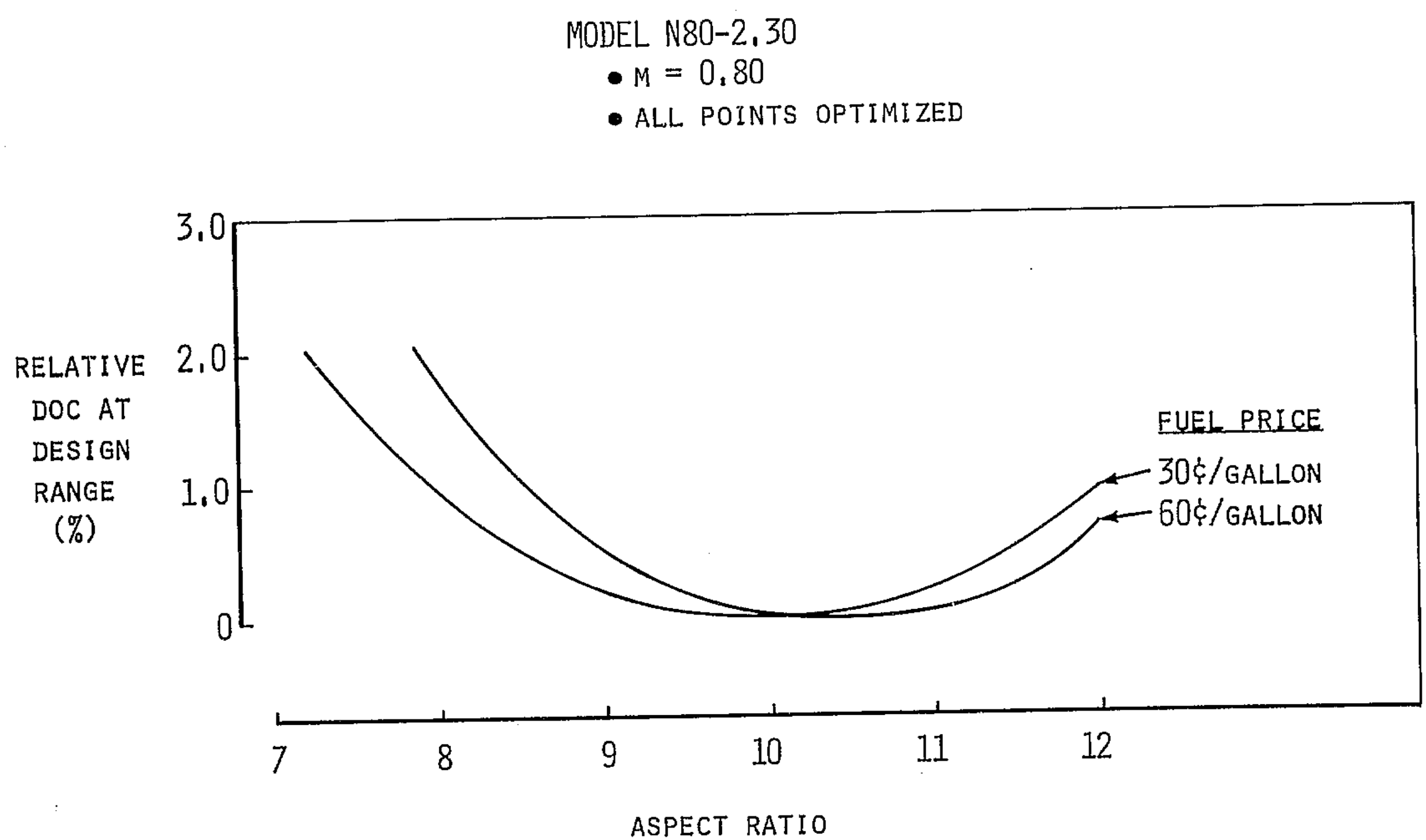


FIGURE 95. EFFECT OF WING ASPECT RATIO ON DOC

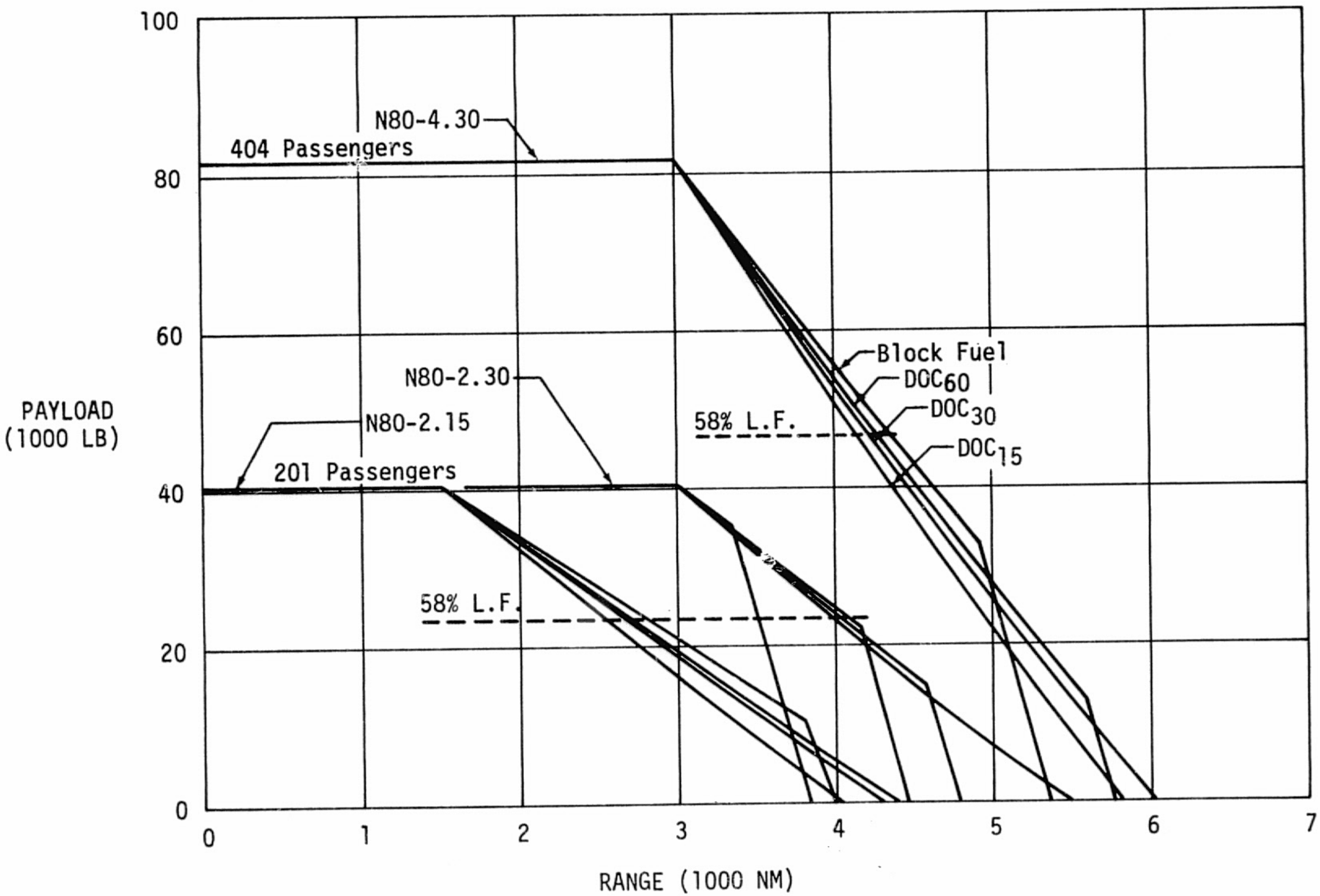


FIGURE 96. PAYLOAD-RANGE ENVELOPES FOR DOMESTIC RANGE N80 AIRCRAFT

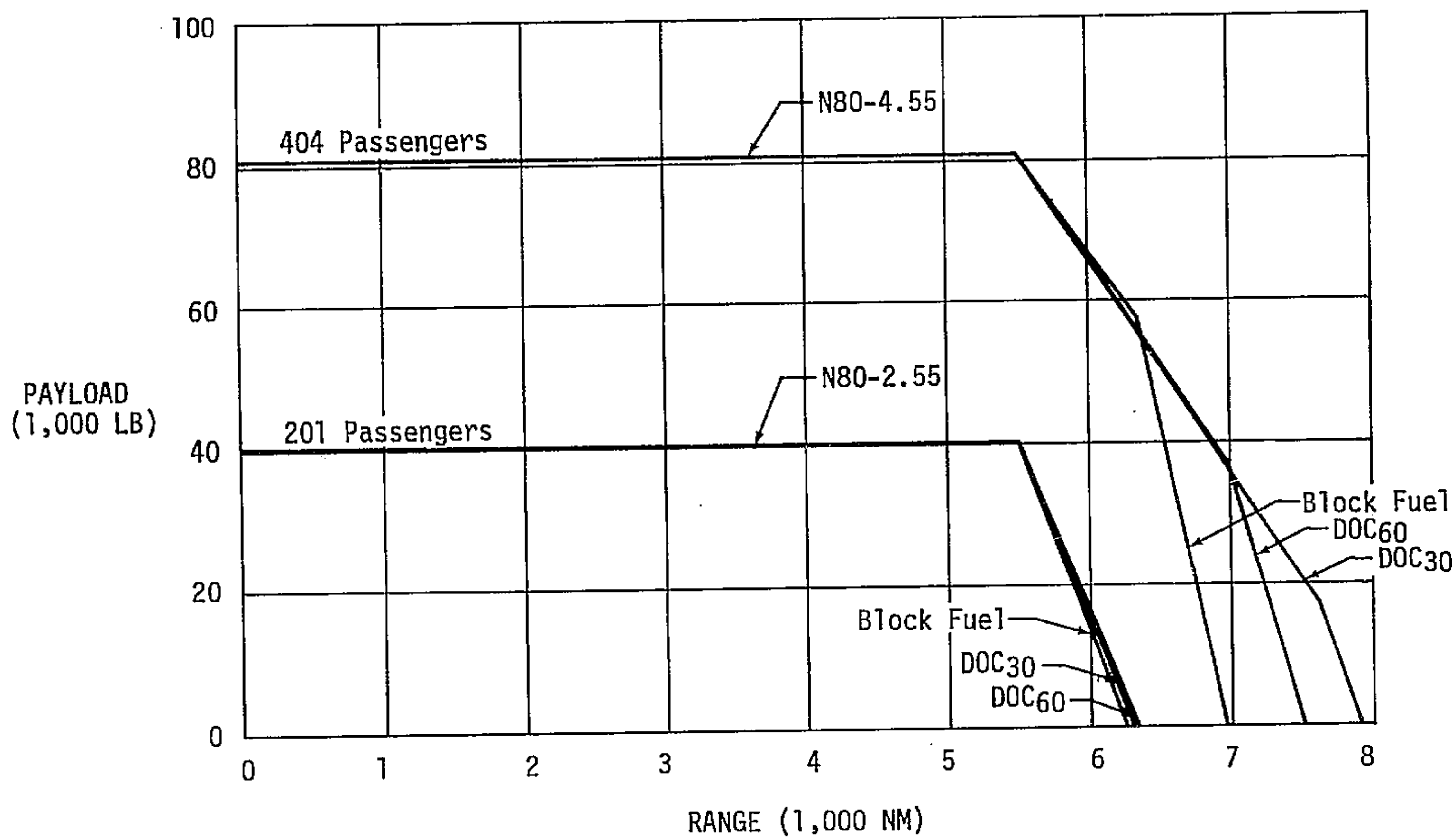


FIGURE 97. PAYLOAD-RANGE ENVELOPES FOR INTERNATIONAL RANGE N80 AIRCRAFT

5.9 Acoustical Analysis

FAR Part 36 noise levels were estimated for the three domestic range families of N80 aircraft. Effective perceived noise level (EPNL) maps and 85, 90, and 95 EPNdB noise contours were generated for six of the aircraft configurations.

5.9.1 Nacelle Configuration Definition

Exhaust nozzle configuration - A separate exhaust nozzle configuration (coaxial) was used to evaluate the N80-2.15 and N80-4.30 aircraft, which used CF6-6D type engines. A conical exhaust, mixed nozzle configuration was used to evaluate the N80-2.30 aircraft with CFM-56 type engines.

Nacelle acoustic treatment configuration - Acoustic treatment was applied to the fan inlet, fan exhaust, and the turbine cowl walls. Acoustically treated rings were not included in the analysis. Multiple degree of freedom acoustically absorptive liners were assumed for the fan inlet and fan exhaust duct acoustic treatment. A single degree of freedom acoustically absorptive liner was assumed for the turbine exhaust acoustic treatment.

5.9.2 Noise Analysis Procedure

FAR Part 36 noise levels and EPNL maps - The engines used for the noise analysis of the N80 aircraft were the CF6-6D and CFM-56 high bypass ratio turbofan engines scaled in thrust and size as necessary to meet the aircraft performance requirements. Engine cycle parameters and aircraft performance parameters obtained from the PASAP sizing program provided the inputs for the DAC noise prediction technique used in estimating flyover noise levels and for generating EPNL maps.

The prediction procedure utilized static noise data from engines A and C of the NASA Quiet Engine Program (References 17 and 18) and flyover noise data from DC-8, DC-9, and DC-10 aircraft. Data inputs included fan pressure ratio, fan tip velocity, bypass ratio, total inlet flow rate, nozzle exit velocity, and nozzle exit area. The peak perceived noise levels (PNLM) were calculated for the fan inlet, fan exhaust, turbine, core, and jet noise sources. Adjustments were made for the number of engines, distance from the airplane, and acoustic treatment. The flyover noise level (EPNL) was determined by adjusting the maximum calculated PNL for flight effects and duration.

Noise Contours - Using a Douglas-developed noise contour program, noise contours of 85, 90, and 95 EPNdB were generated for the takeoff and 3 degree approach flight paths of the aircraft optimized for minimum DOC at 15 cents per gallon and for minimum fuel use. The program inputs consisted of EPNL map data, airplane altitude, airspeed, flap setting, and fan rotor speed. Adjustments were made to the calculated EPNL values for airspeed variation from the reference airspeed and for ground attenuation based on Reference 19.

5.9.3 FAR Part 36 Noise Level Estimates

Sideline - The sideline noise levels are below the FAR Part 36 requirement by 9 EPNdB for all two-engine aircraft and by 12 EPNdB or more for all four-engine aircraft (see Table 82a).

Takeoff (Cutback) - The takeoff (cutback) noise levels are below the FAR Part 36 requirements by 10 EPNdB or more for the two-engine and four-engine 201 passenger aircraft, and are 6 to 8 EPNdB below the FAR Part 36 requirement for the four-engine 400 passenger aircraft (See Table 82b).

Approach - The minimum fuel optimized aircraft within each family have the lowest approach noise levels, ranging from 5 to 9 EPNdB below the FAR Part 36 requirement (see Table 82c). The two-engine, 201 passenger family of aircraft (N80-2.15) have estimated approach noise levels ranging from 3 to 7 EPNdB below the requirement. The four-engine, 201 passenger family of aircraft (N80-2.30) have estimated approach noise levels ranging from 5 to 9 EPNdB below the requirement. The four-engine, 404 passenger family of aircraft (N80-4.30) have estimated approach noise levels ranging from 1 to 5 EPNdB below the requirement.

5.9.4 EPNL vs Distance and Noise Contours

EPNL maps are presented in Figures 98 through 103. Noise contours of 85, 90, and 95 EPNdB are presented in Figures 104 through 109.

Figure 110 presents a comparison of noise contour areas as a function of noise levels of the contours for the aircraft configurations studied. The N80-2.30 four-engine aircraft family with the CFM-56 type (mixed flow) engines resulted in the smallest contour areas. The N80-4.30 four-engine aircraft family with the CF6-6D type engines had the largest contour area.

The differences in total contour areas between the aircraft optimized for DOC at 15 cents per gallon and the minimum fuel aircraft are small within each aircraft family.

The approach areas for the minimum fuel configurations range from 50 to 75 percent less than those for the minimum DOC at 15 cents per gallon configurations, due to the lower landing thrust requirements for the minimum fuel aircraft. The takeoff areas for the minimum fuel configurations range up to 31 percent greater than those for the minimum DOC at 15 cents per gallon configurations, due mainly to the lower altitudes attained by minimum fuel aircraft during takeoff. The net effect of optimization parameter on total noise contour area is small as shown in Figure 110.

TABLE 82

NOISE LEVELS OF OPTIMIZED N80 AIRCRAFT

a) SIDELINE NOISE LEVELS

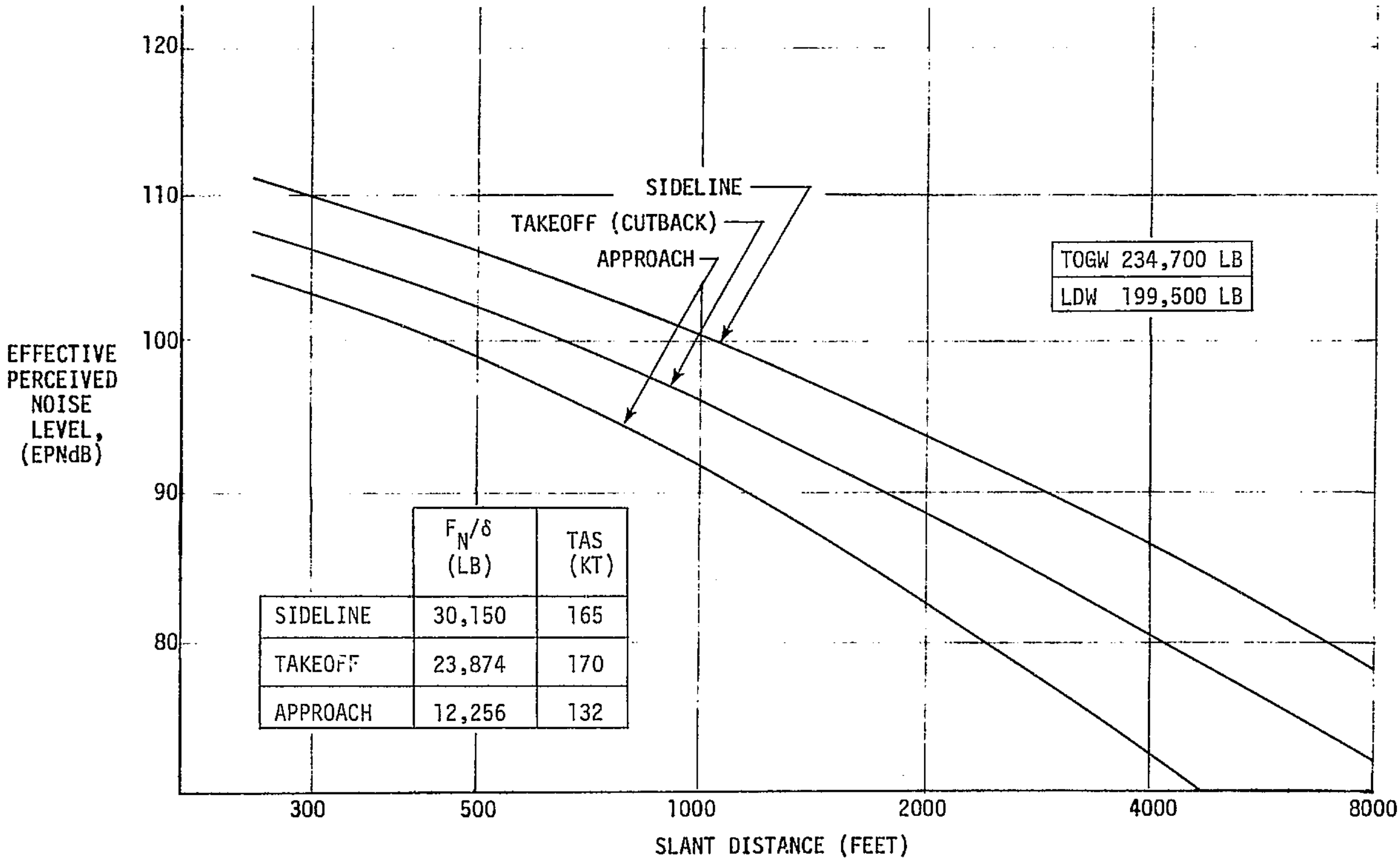
AIRCRAFT	EPNdB/ΔEPNdB RELATIVE TO FAR 36			
	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
N80-2.15	96/-9	96/-9	96/-9	96/-9
N80-2.30	87/-19	87/-19	87/-19	87/-19
N80-4.30	95/-13	95/-13	95/-13	96/-12

b) TAKEOFF (CUTBACK) NOISE LEVELS

AIRCRAFT	EPNdB/ΔEPNdB RELATIVE TO FAR 36			
	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
N80-2.15	87/-14	87/-14	88/-13	88/-13
N80-2.30	88/-14	89/-13	91/-11	92/-10
N80-4.30	99/-8	100/-7	100/-7	101/-6

c) APPROACH NOISE LEVELS

AIRCRAFT	EPNdB/ΔEPNdB RELATIVE TO FAR 36			
	DOC_{15}	DOC_{30}	DOC_{60}	BLOCK FUEL
N80-2.15	102/-3	101/-4	100/-5	98/-7
N80-2.30	101/-5	100/-6	100/-6	97/-9
N80-4.30	107/-1	106/-2	105/-3	103/-5



	F_N/δ (LB)	TAS (KT)
SIDELINE	30,150	165
TAKEOFF	23,874	170
APPROACH	12,256	132

FIGURE 98. EPNL MAP FOR N80-2.15$_{15}$ AIRCRAFT

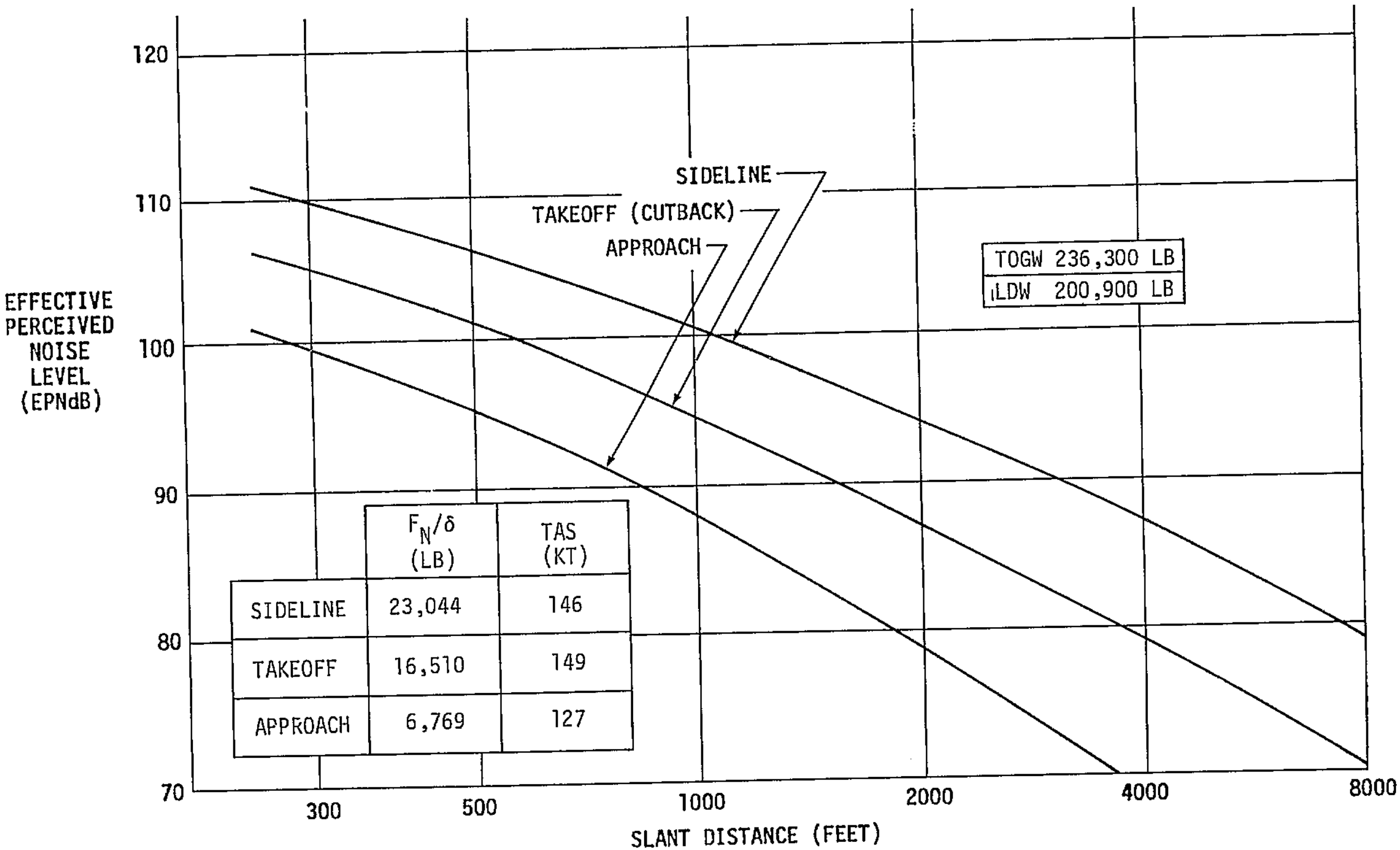


FIGURE 99. EPNL MAP FOR N80-2.15$_{MF}$ AIRCRAFT

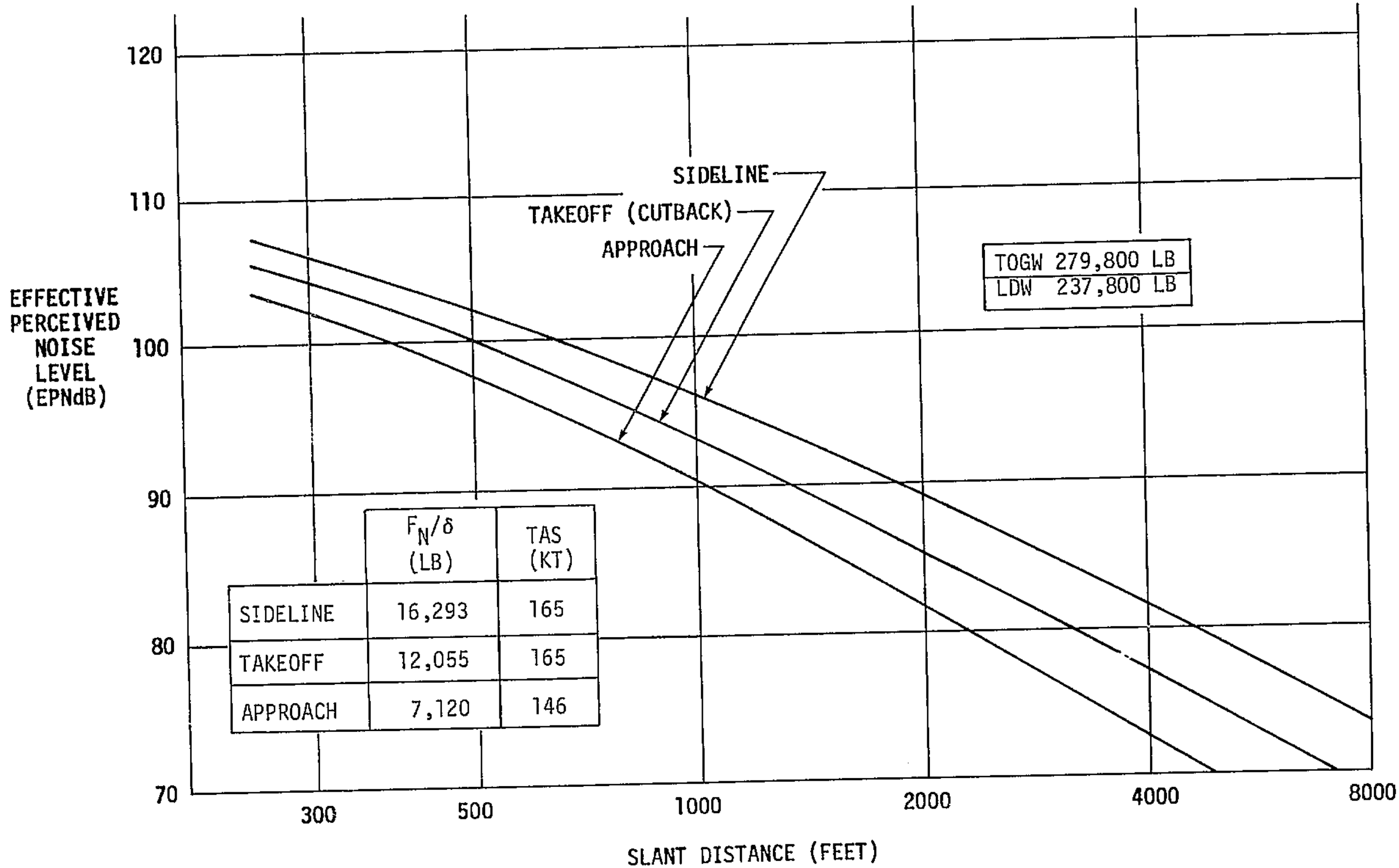


FIGURE 100. EPNL MAP FOR N80-2.30$_{15}$ AIRCRAFT

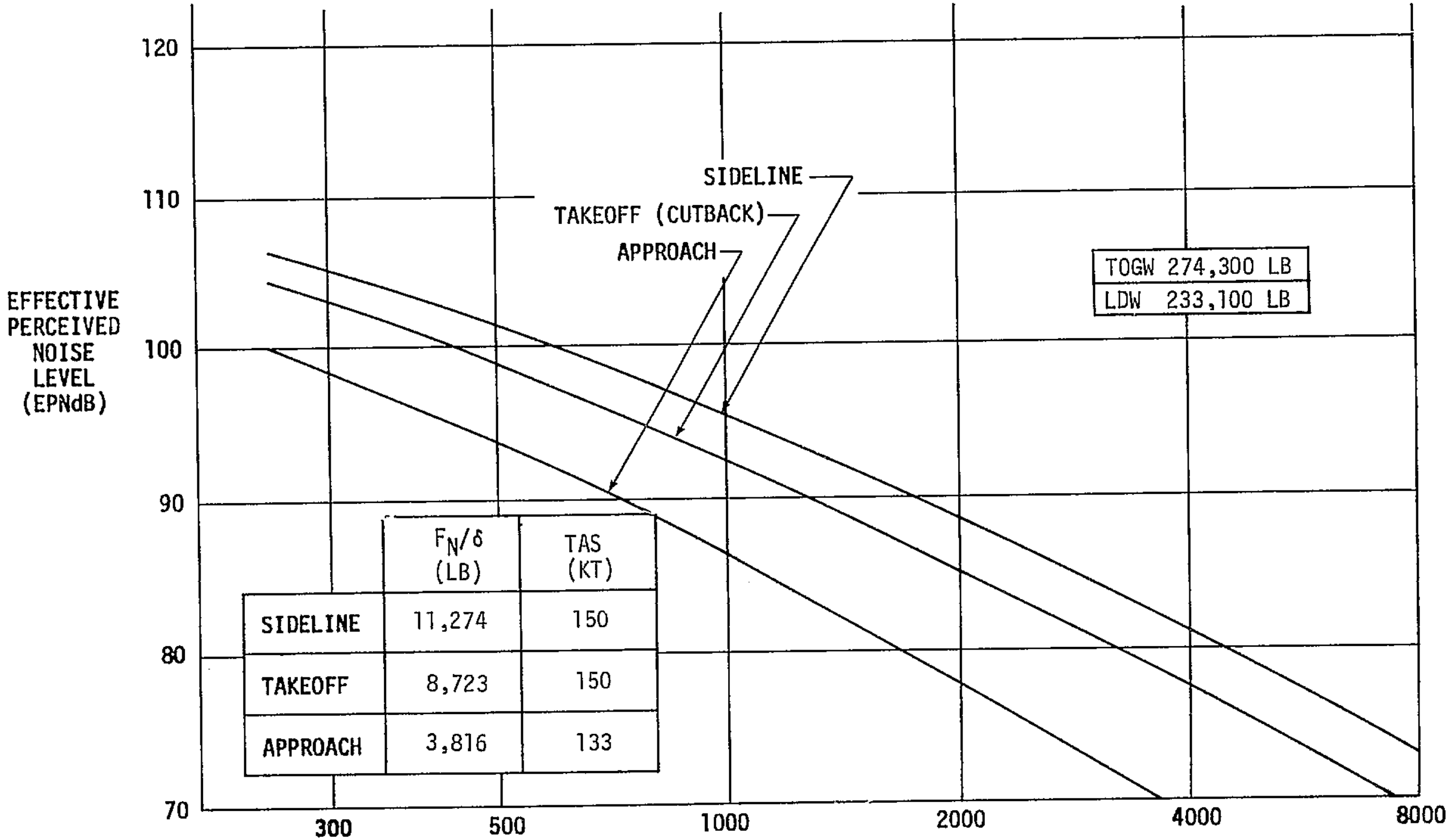


FIGURE 101. EPNL MAP FOR N80-2.30$_{MF}$ AIRCRAFT

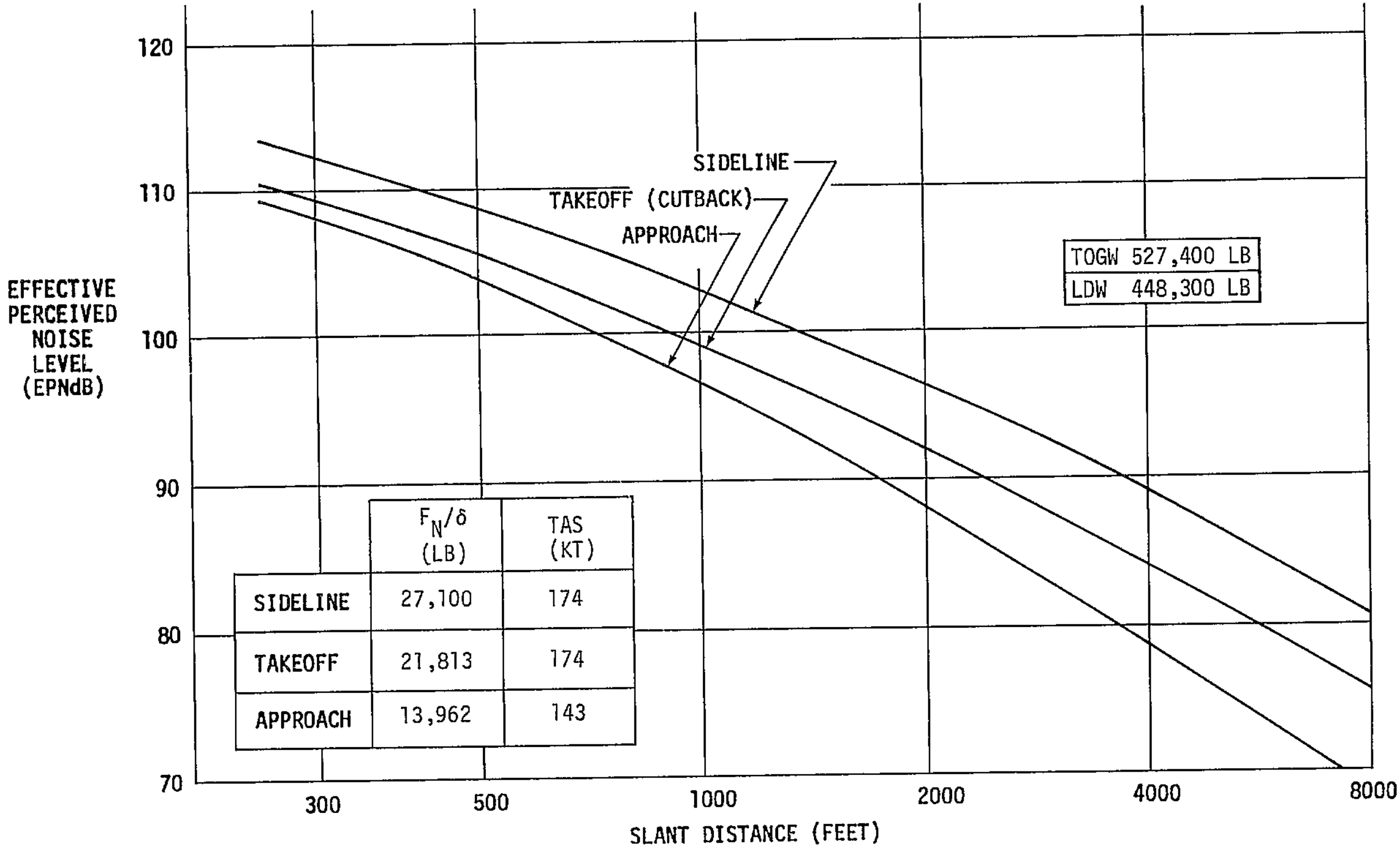
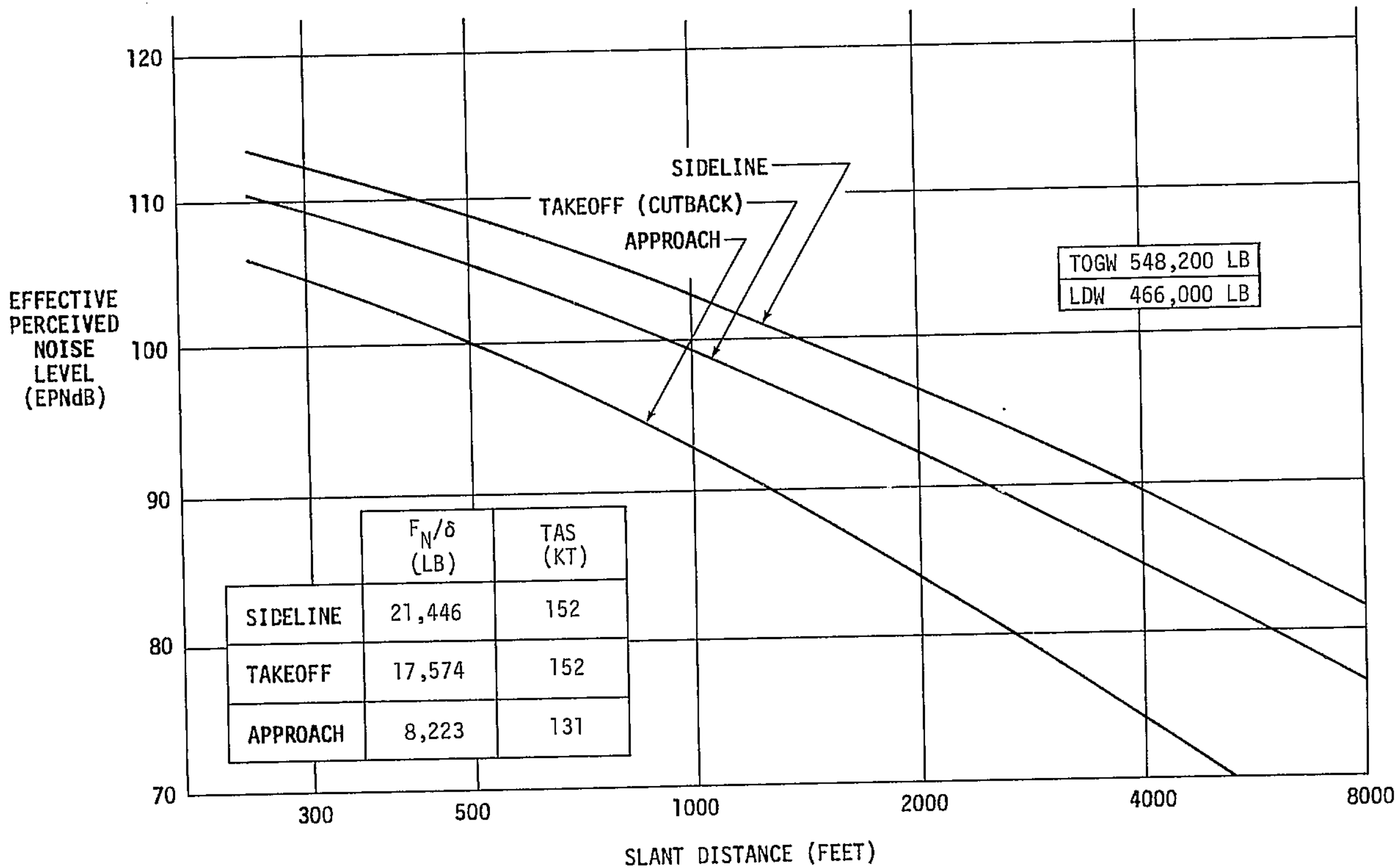


FIGURE 102. EPNL MAP FOR N80-4.30_{15} AIRCRAFT



	F_N/δ (LB)	TAS (KT)
SIDELINE	21,446	152
TAKEOFF	17,574	152
APPROACH	8,223	131

FIGURE 103. EPNL MAP FOR N80-4.30$_{MF}$ AIRCRAFT

CONTOUR (EPNdB)	AREA	
	Sq.Mi	Sq.NM
95	1.8	1.3
90	4.0	3.0
85	7.4	5.5

TAKEOFF GROSS WEIGHT 234,700 LB
LANDING WEIGHT 199,500 LB

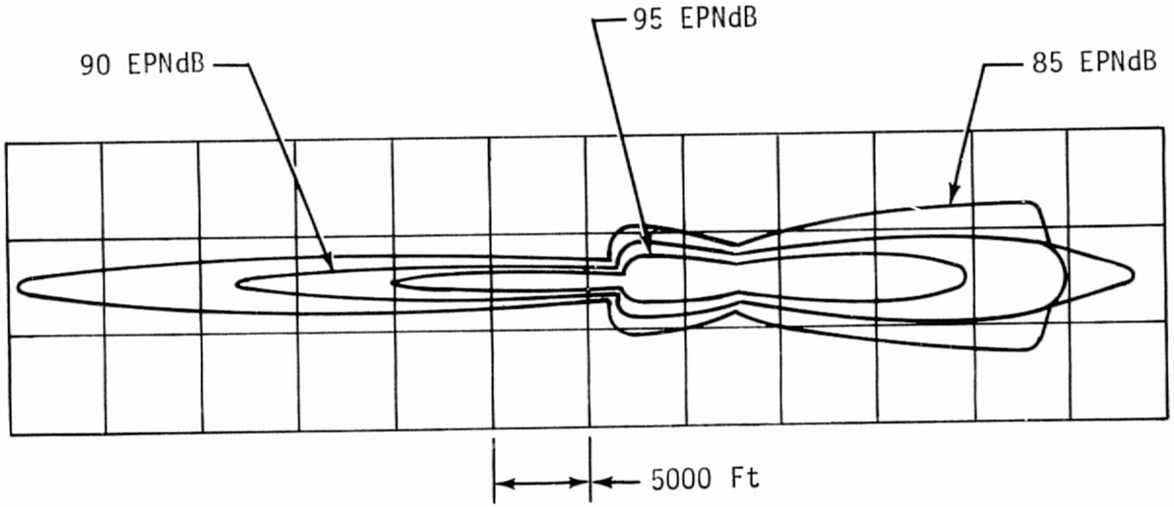


FIGURE 104. ESTIMATED NOISE CONTOURS FOR $N80\text{-}2.15_{15}$ AIRCRAFT

CONTOUR (EPNdB)	AREA Sq.Mi	Sq.NM
95	2.0	1.5
90	3.7	2.8
85	6.7	5.0

TAKEOFF GROSS WEIGHT 236,300 LB
LANDING WEIGHT 200,900 LB

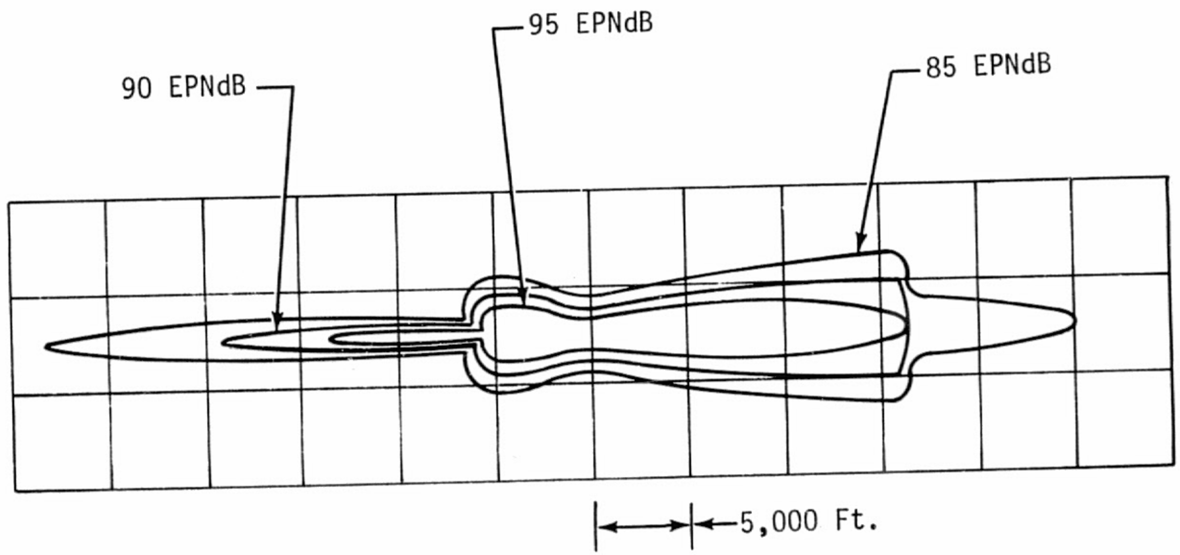


FIGURE 105. ESTIMATED NOISE CONTOURS FOR N80-2.15$_{MF}$ AIRCRAFT

CONTOUR (EPNdB)	AREA	
	Sq.Mi	Sq.NM
95	1.2	.9
90	2.7	2.0
85	5.9	4.5

TAKEOFF GROSS WEIGHT 279,800 LB
LANDING WEIGHT 237,800 LB

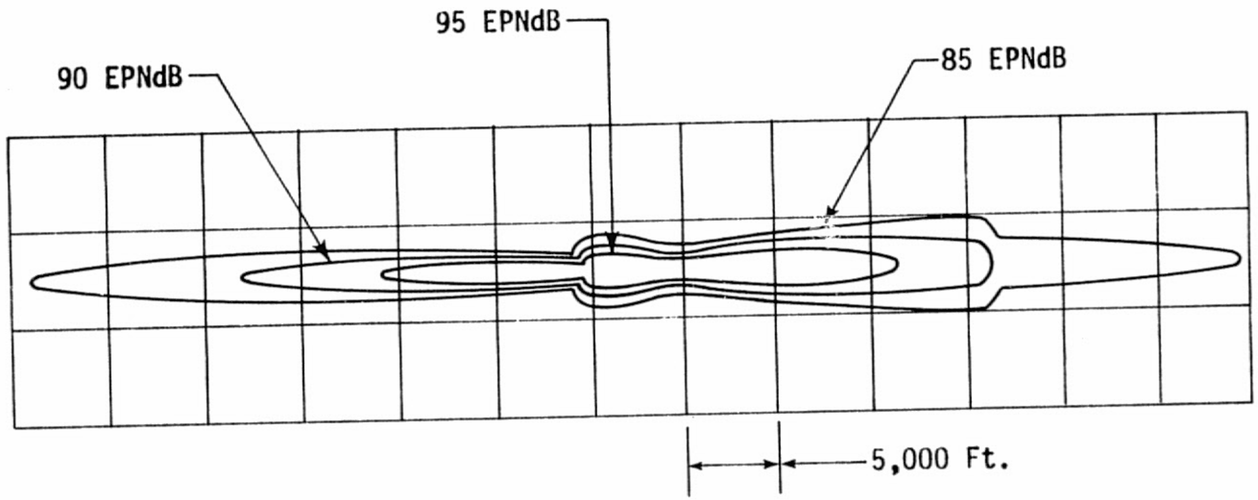


FIGURE 106. ESTIMATED NOISE CONTOURS FOR N80-2.30$_{15}$ AIRCRAFT

CONTOUR (EPNdB)	AREA Sq.Mi	Sq.NM
95	1.2	.9
90	2.4	1.8
85	6.2	4.7

TAKEOFF GROSS WEIGHT 274,300 LB
LANDING WEIGHT 233,100 LB

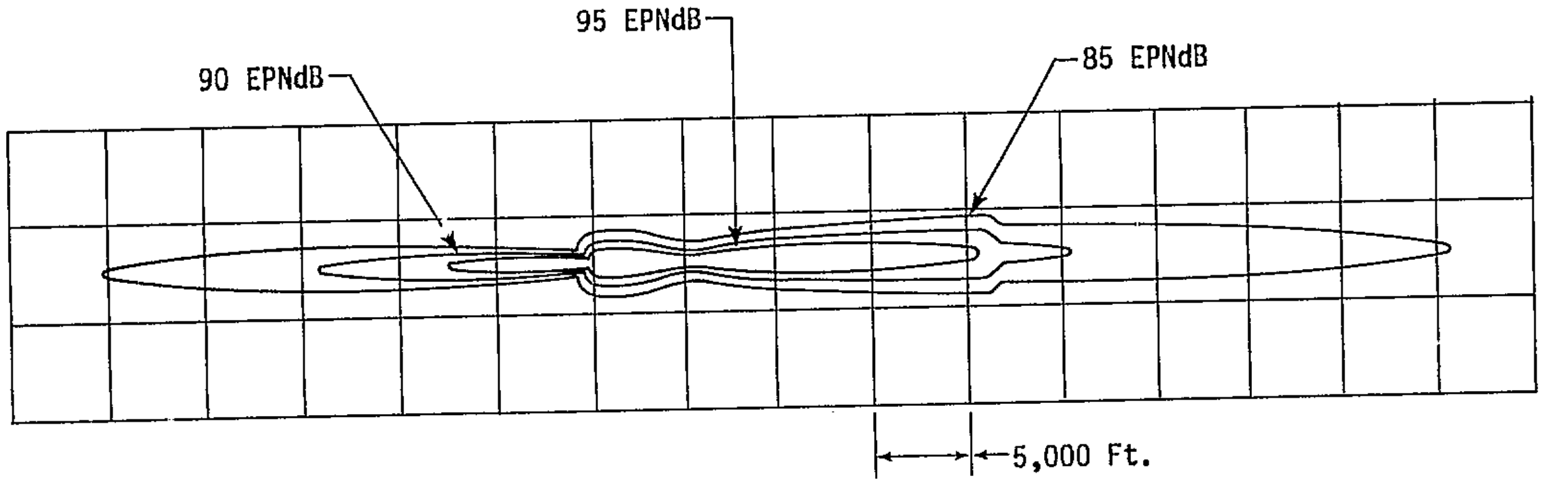


FIGURE 107. ESTIMATED NOISE CONTOURS FOR N80-2.30$_{MF}$ AIRCRAFT

CONTOUR (EPNdB)	AREA Sq.Mi	AREA Sq.NM
95	3.7	2.8
90	9.0	6.8
85	21.5	16.2

TAKEOFF GROSS WEIGHT 527,400 LB
LANDING WEIGHT 448,300 LB

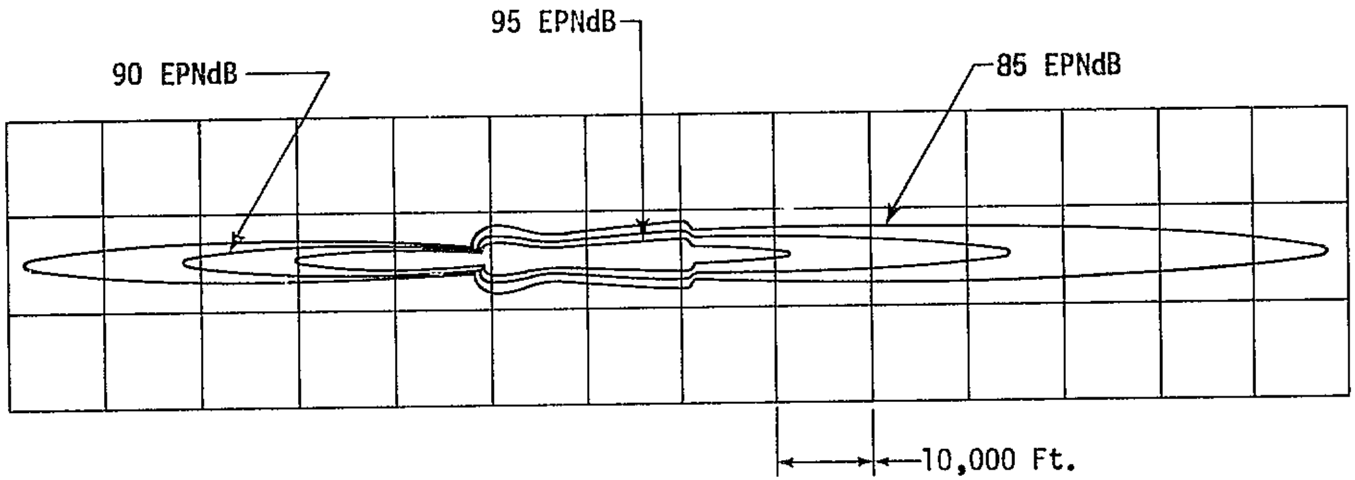


FIGURE 108. ESTIMATED NOISE CONTOURS FOR N80-4.30$_{15}$ AIRCRAFT

CONTOUR (EPNdB)	AREA	
	Sq.Mi	Sq.NM
95	3.8	2.9
90	9.5	7.2
85	22.8	17.2

TAKEOFF GROSS WEIGHT 548,200 LB
LANDING WEIGHT 466,000 LB

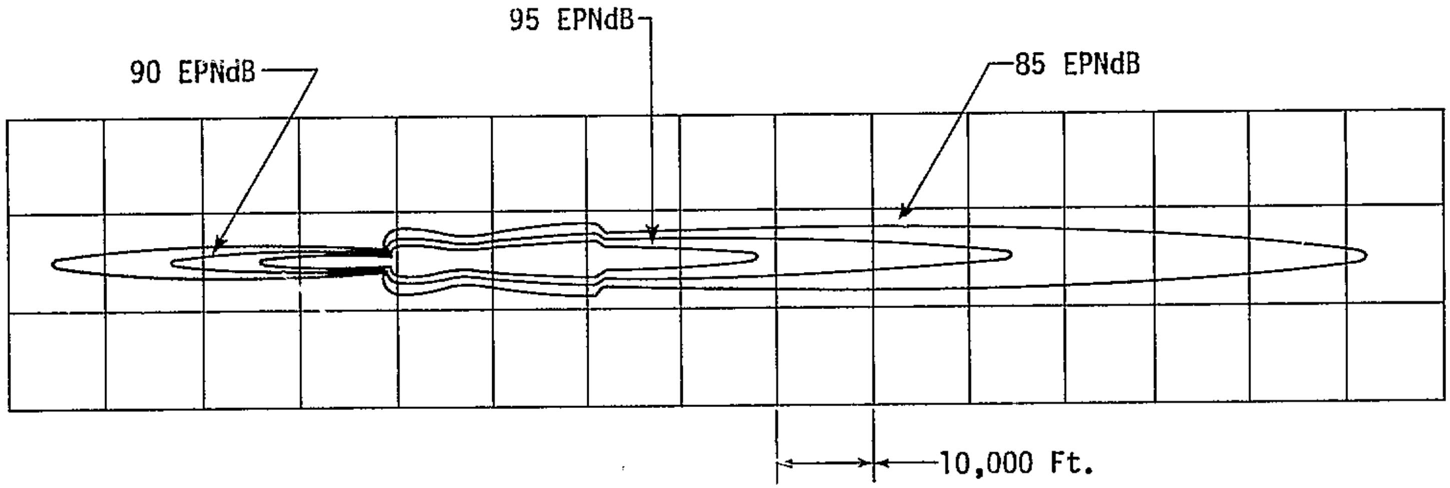


FIGURE 109. ESTIMATED NOISE CONTOURS FOR N80-4.30$_{MF}$ AIRCRAFT

CURVE NO.	AIRCRAFT CONFIGURATION				
	AIRCRAFT	NO. ENG.	NO. PSGR.	RANGE (NM)	OPTIMIZATION PARAMETER
1	N80-2.15	2	201	1500	DOC @ 15¢/GAL.
2	N80-2.15	2	201	1500	BLOCK FUEL
3	N80-2.30	4	201	3000	DOC @ 15¢/GAL.
4	N80-2.30	4	201	3000	BLOCK FUEL
5	N80-4.30	4	404	3000	DOC @ 15¢/GAL.
6	N80-4.30	4	404	3000	BLOCK FUEL

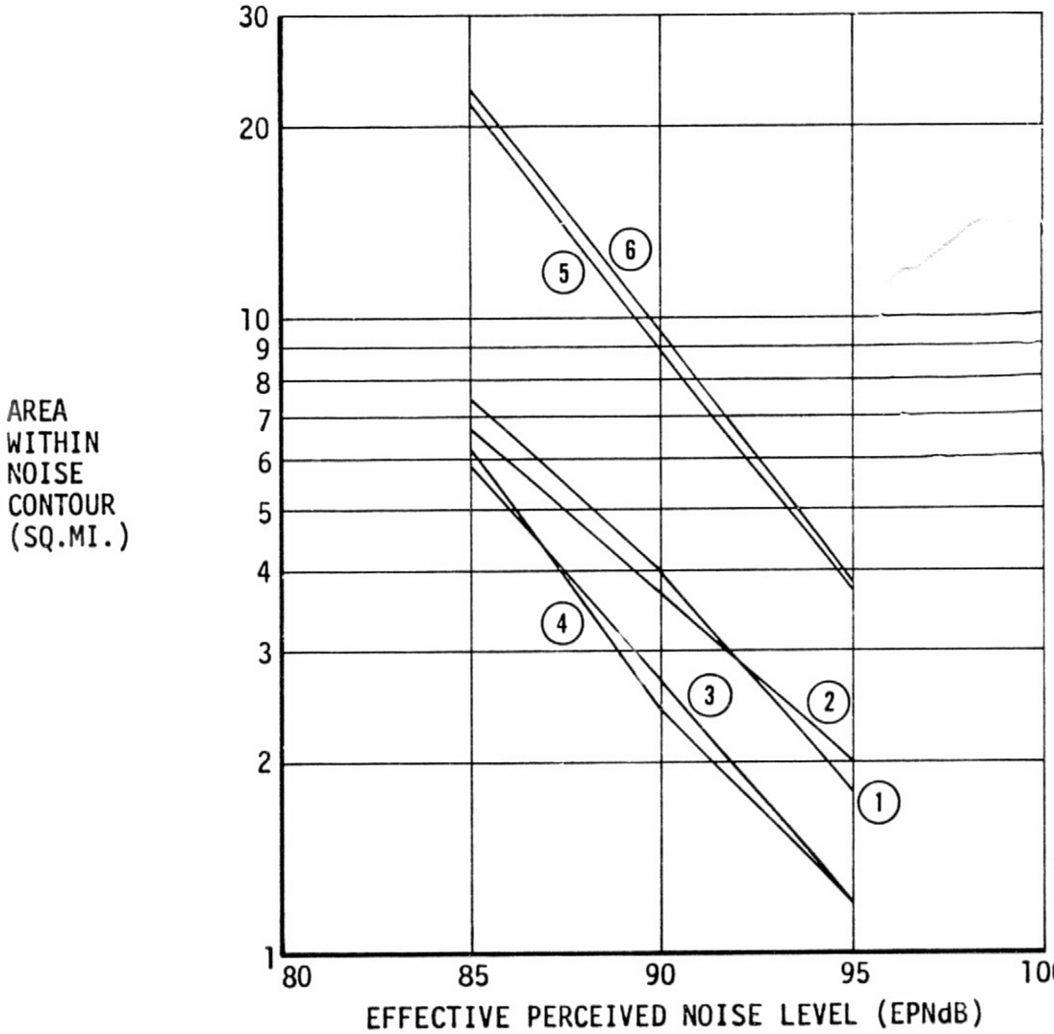


FIGURE 110. EPNL CONTOUR AREA COMPARISON FOR AIRCRAFT CONFIGURATIONS WITH OPTIMIZATION PARAMETERS OF MINIMUM DOC @ 15¢/GALLON AND MINIMUM FUEL

SECTION 6.0
TURBOPROP CONFIGURATION STUDIES

Fuel conservation studies for modified, derivative, and new near-term aircraft were previously analyzed and reported in Sections 4.0 and 5.0. This section considers potential improvements in fuel use due to advances in turboprop propulsion system technology and wing aerodynamics. Advanced structures technology was not considered. The advanced propulsion and aerodynamic technologies were incorporated on a DC-9-30 baseline aircraft, and the potential savings in fuel and improvements in range capability were assessed.

The advanced turboprop propulsion system incorporates a Hamilton Standard propfan, which is a multi-bladed, variable pitch propeller using swept blade tips and supercritical blade sections. Aerodynamic improvements include a supercritical wing section, greater sweep, and a higher aspect ratio.

In addition to the baseline DC-9-30 aircraft (with turbofan power and conventional wing), three derivative aircraft will be discussed. The DC-9-30D4 has aft fuselage-mounted turbofan engines and an all new supercritical wing. The DC-9-30D4 is identical to the DC-9-30D3, described in Section 4.0, but was renumbered in this section because a different flight profile was used to allow consistent comparisons with the turboprop aircraft. This resulted in slightly different fuel consumption and payload-range capability. The DC-9-30 baseline flight profile was also changed slightly for the same reason, but its designation remains the same. The DC-9-30D5 has two propfan engines mounted on a strengthened, conventional DC-9-30 wing. The DC-9-30D6 has two propfan engines, mounted on a strengthened DC-9-30D4 supercritical wing.

6.1 Advanced Turboprop Propulsion

The turboshaft engine performance used in this study represents 1985 technology, as provided in recent Pratt & Whitney STS 476 and Allison PD 370 studies. The propeller performance is based upon the Hamilton Standard propfan.

As part of this study, a propfan parametric analysis was performed using the data contained in Reference 20. The analysis encompassed 6 and 8 blades, 600 to 800 fps static tip speed, power loading (SHP/D^2) values from 61 to 88 for takeoff and from 35 to 50 at 35,000 ft. cruise altitude, and resulting propeller efficiency values ranging from 0.65 to 0.80 at 35,000 ft. cruise altitude.

The propfan parametric study disclosed the following trends for a fixed cruise Mach number: (1) As propfan design tip speed is decreased: propfan cruise efficiency, maximum takeoff thrust, and takeoff thrust degradation decrease; while propfan diameter, engine size, and power plant weight (engine, gearbox, and propfan) increase. (2) As power loading is increased: cruise efficiency, takeoff thrust, diameter, and powerplant weight decrease; however, takeoff thrust degradation and required engine size increase.

Takeoff thrust degradation is illustrated in Figure 111. Propfan thrust levels at speeds below 0.1 Mach are unusually low for propellers, as a result of their being optimized for high speed cruise. Unlike current propellers, which have a static thrust-to-horsepower ratio of 3 to 5, the propfan ratio is less than 1.0. For the study propfan airplanes, the propfan diameter is 13.0 feet and the equivalent static shaft horsepower is 13,400 HP. With a static thrust of 5,650 pounds, the value of $(T/ESHP)_{Static} = 0.422$. The propfan static and low speed thrust can be improved somewhat if the throttle is applied gradually during the takeoff roll. This reduces the power loading, which helps to minimize blade tip stall. Static and low speed thrust can also be improved by choosing a larger diameter propeller, if necessary. The propeller chosen for the study airplane provides a weighted average thrust during the takeoff sequence equivalent to that of the JT8D-9 engine. Smaller diameter propfans require more power and have a greater thrust degradation below 0.1 M.

Because of the limited amount of propfan design data available when the above parametric study was conducted, an accurate selection of the optimum propeller for the propfan installation could not be completed. Accordingly, the following design ground rules were adopted for the propfan: (1) 8 blades to minimize diameter; (2) a static tip speed of 720 fps, in order that the Electra turboprop aircraft could be used as a possible reference point for future studies of interior noise levels; (3) a weighted average thrust during the takeoff sequence equivalent to that of the turbofan engine (to account for degradation in propfan thrust at speeds below 0.1 Mach); (4) a spanwise location for the powerplant representing a preliminary choice between

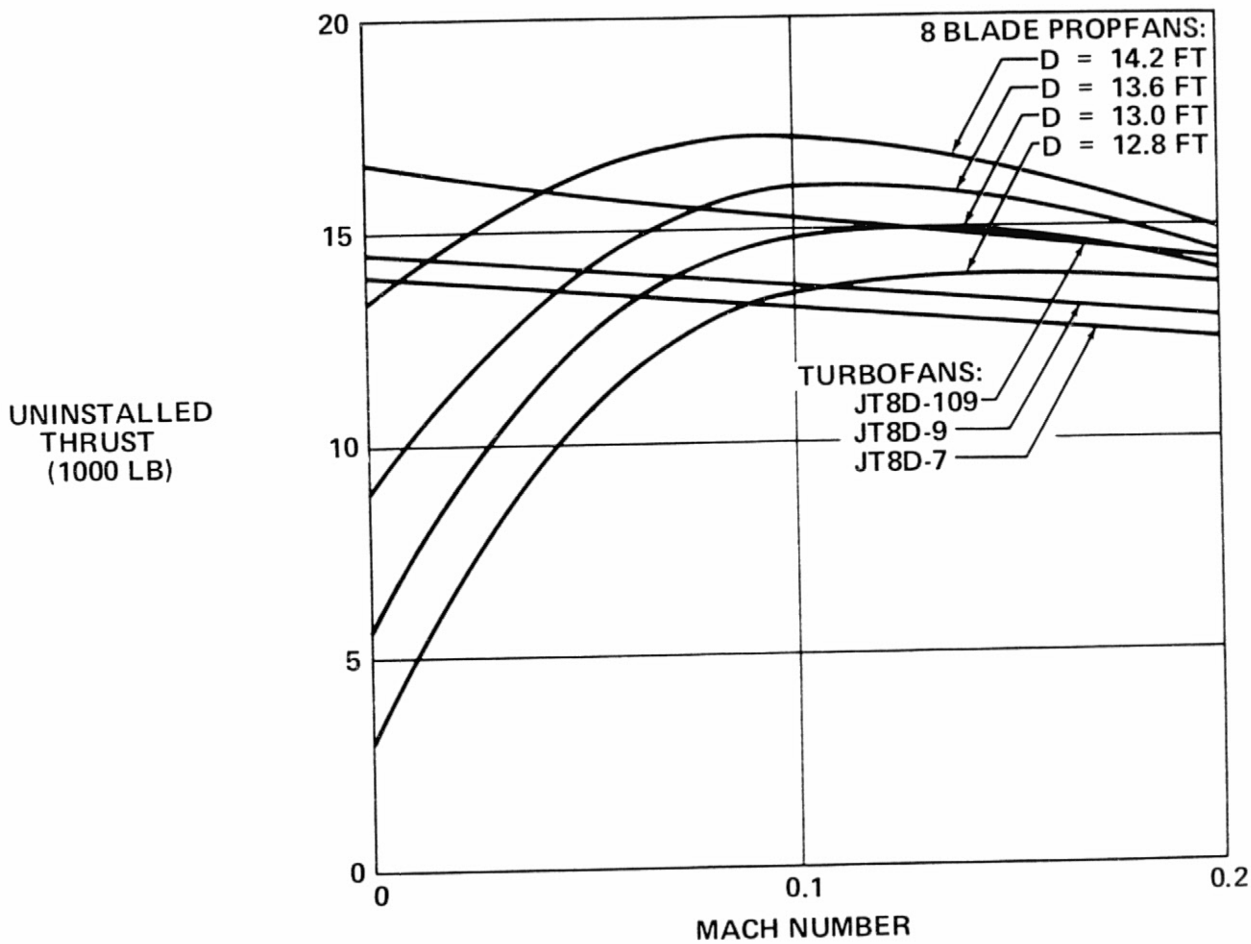


FIGURE 111. THRUST VS. MACH NUMBER FOR PROPFANS AND TURBOFANS

passenger comfort levels (interior noise and vibration), and the effects of the propfan slipstream on aileron control and of the one-engine-out emergency condition on the vertical tail size.

6.2 Configuration Studies

The new wing and/or powerplant were incorporated into the three derivative aircraft with a minimum of configuration changes to the baseline. The derivative airplanes were not resized to the same payload-range specifications as the baseline aircraft. Instead, the gross weight and payload were held constant; the supercritical wing was sized to meet the approach speed capability of the DC-9-30; the empty weight and fuel capacity were changed as required; and the range capability was determined as the result of the combination of fuel capacity changes and improved technology. The two propfan aircraft were rebalanced to allow for the forward location of the powerplants, and their vertical tails were resized for the one-engine-out emergency condition (the critical condition for determining vertical tail size for aircraft with wing-mounted engines). Specifications for takeoff, approach, and cruise performance of the propfan aircraft were chosen to match baseline DC-9-30 performance. The cruise condition for sizing the propfan installations was 0.80 Mach at 30,000 feet at maximum cruise weight.

The specifications and propfan design ground rules resulted in the selection of a propfan propulsion system installation with a sea level static power loading of $(SHP/D^2)_{Static} = 13{,}400/(13)^2 = 79.3$ and a design point cruise power loading of $(SHP/D^2)_{Cruise} = 45.3$. Figures 112 and 113 show the DC-9 propfan aircraft configurations. The propfan powerplants were located at 41 percent semi-span, and were mounted forward of the wing structural box to facilitate access and removal. This spanwise location provides a propeller tip-to-fuselage clearance of 56 percent of the propeller diameter and the propeller slipstream does not wet the ailerons. However, at this spanwise location, the asymmetric thrust in the one-engine-out condition requires a 30 percent increase in the vertical tail area and a change from a single to a dual hinge rudder. These changes in the vertical tail are required in addition to the large increase in tail arm resulting from a 100-inch forward relocation of the wing on the fuselage to rebalance the aircraft with the wing-mounted engines.

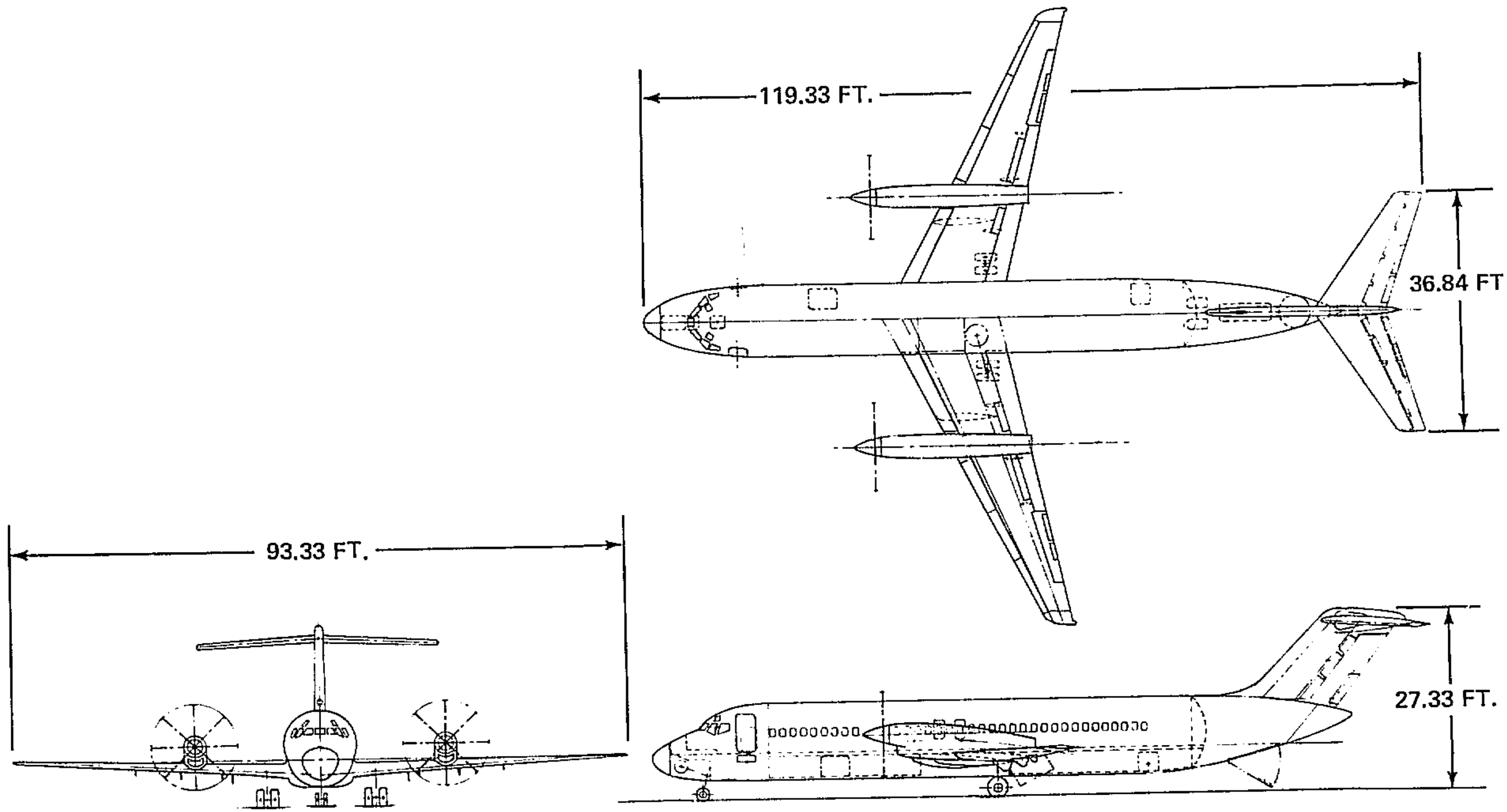


FIGURE 112. GENERAL CONFIGURATION, DC-9-30D5 PROPFAN

ITEM	WING*	HORIZONTAL TAIL		VERTICAL TAIL	
		A	B	A	B
AREA, SQ FT	900	276	340	209	230
ASPECT RATIO	10.2	4.93	4.00	1.07	1.60
TAPER RATIO	0.30	0.35	0.35	0.80	0.35
SWEEP	30.5°	31.6°	30.0°	43.5°	35.0°
DIHEDRAL	+3°	−3°	+10°	~	~

*SUPERCRITICAL AIRFOIL

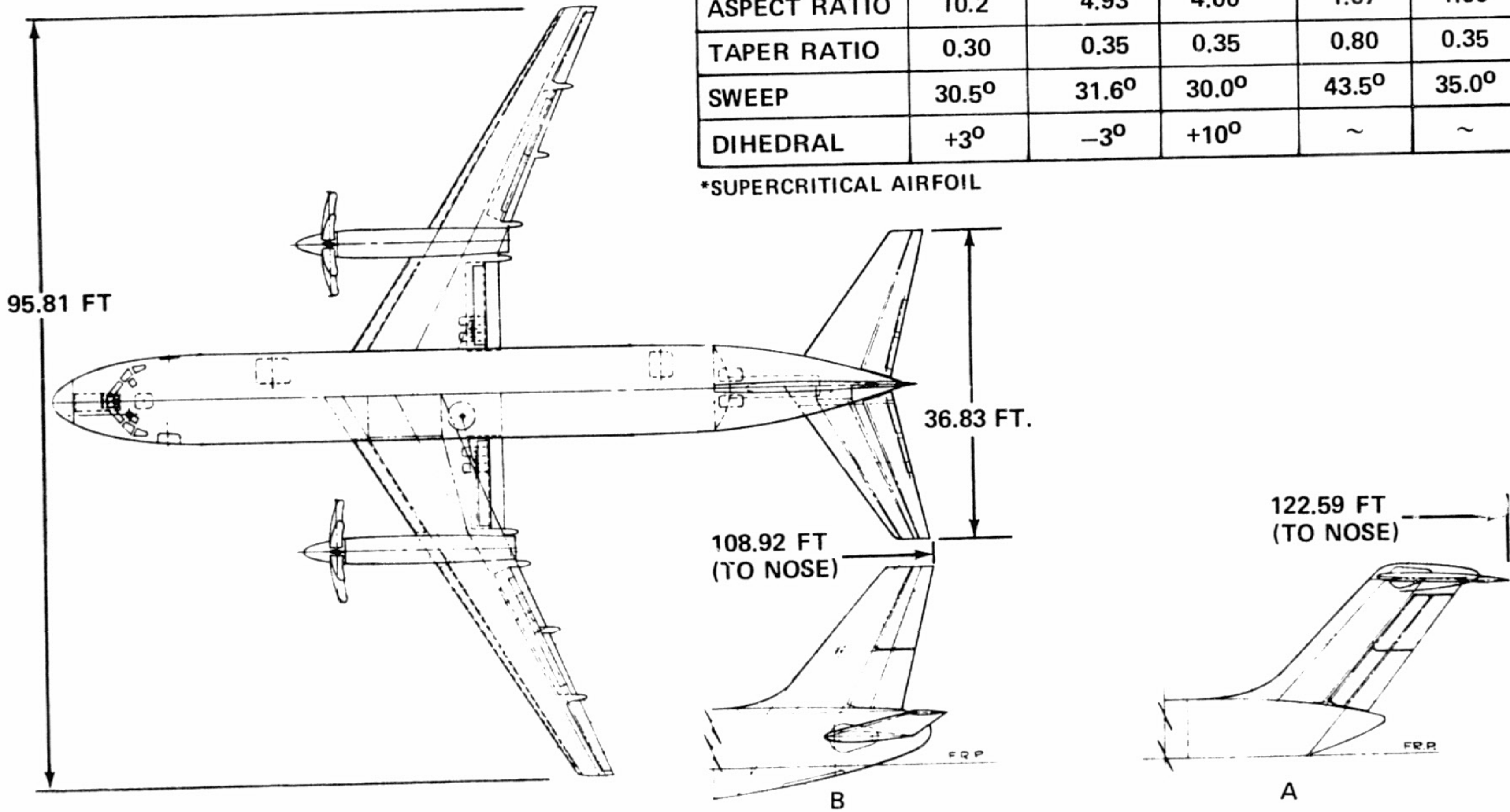


FIGURE 113. DC-9-30D6 PROPFAN, WING AND TAIL CONFIGURATIONS

Figure 113 summarizes the results of the tail configuration study. Two arrangements are shown, the current T-tail configuration and a conventional configuration made possible by the removal of the aft fuselage-mounted turbofans. In the T-tail arrangements, with the longer tail arm, the basic horizontal tail is adequate for control. In the conventional tail arrangement, the shorter tail arm requires a 24 percent increase in horizontal tail area. Because of the smaller tail area for the T-tail arrangement and its separation from the propeller slipstream, the T-tail configuration was chosen for this study.

Figure 114 shows the interior arrangement for the turboprop DC-9 configurations. Although the seating arrangement was changed from that of the baseline DC-9-30 (Figure 14), in order to locate the lavatories in the propeller plane, the total number of seats is unchanged.

Various nacelle and landing gear configurations were investigated for the turboprop airplanes. Figure 115 compares four landing gear arrangements on a nacelle with underwing exhaust. Spreading the wheels apart reduces nacelle depth but overall frontal area increases. The arrangement shown in Figure 116, with overwing exhaust, upper or lower inlet duct, and landing gear in the fuselage, allows for the slimmest nacelle and shortest main gear.

6.3 Aircraft Weights

Table 83 shows the summary of the geometry and weight data for the turbofan and propfan airplanes. The baseline airplane weights represent a typical DC-9-30 airplane. The three derivative airplanes were configured with maximum commonality to the baseline airplane and their weights were derived with the same philosophy. Design weight changes to the baseline airplane are as follows:

The D4 configuration represents a DC-9-30 with a supercritical airfoil wing and DC-9 type high lift devices. The weight change for the wing was the result of the combined effects of the increased depth of the ribs, bulkheads and leading edge for the supercritical airfoil, the higher wing aspect ratio, the higher wing sweep, and the smaller wing area. The flight controls and hydraulic system weights were reduced to reflect the smaller wing area.

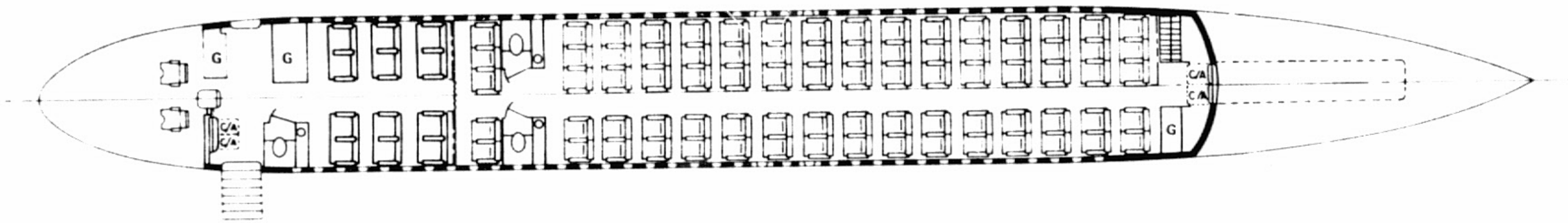
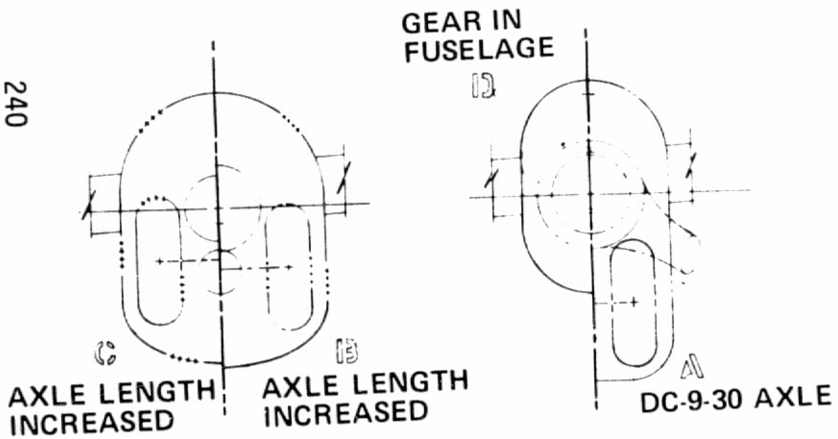


FIGURE 114. INTERIOR ARRANGEMENT, DC-9-30D5 AND DC-9-30D6 PROPFANS

ITEM	MAIN LANDING GEAR RETRACTED IN NACELLE A	B	C	MLG IN FUSELAGE D
FRONTAL AREA (SQ FT)	28.4	33.3	30.9	10.4
LANDING GEAR LENGTH (IN.)	69.5	69.5	76.0	65.6
WHEEL ℄ SPACING (IN.)	25.0	43.0	38.0	25.0



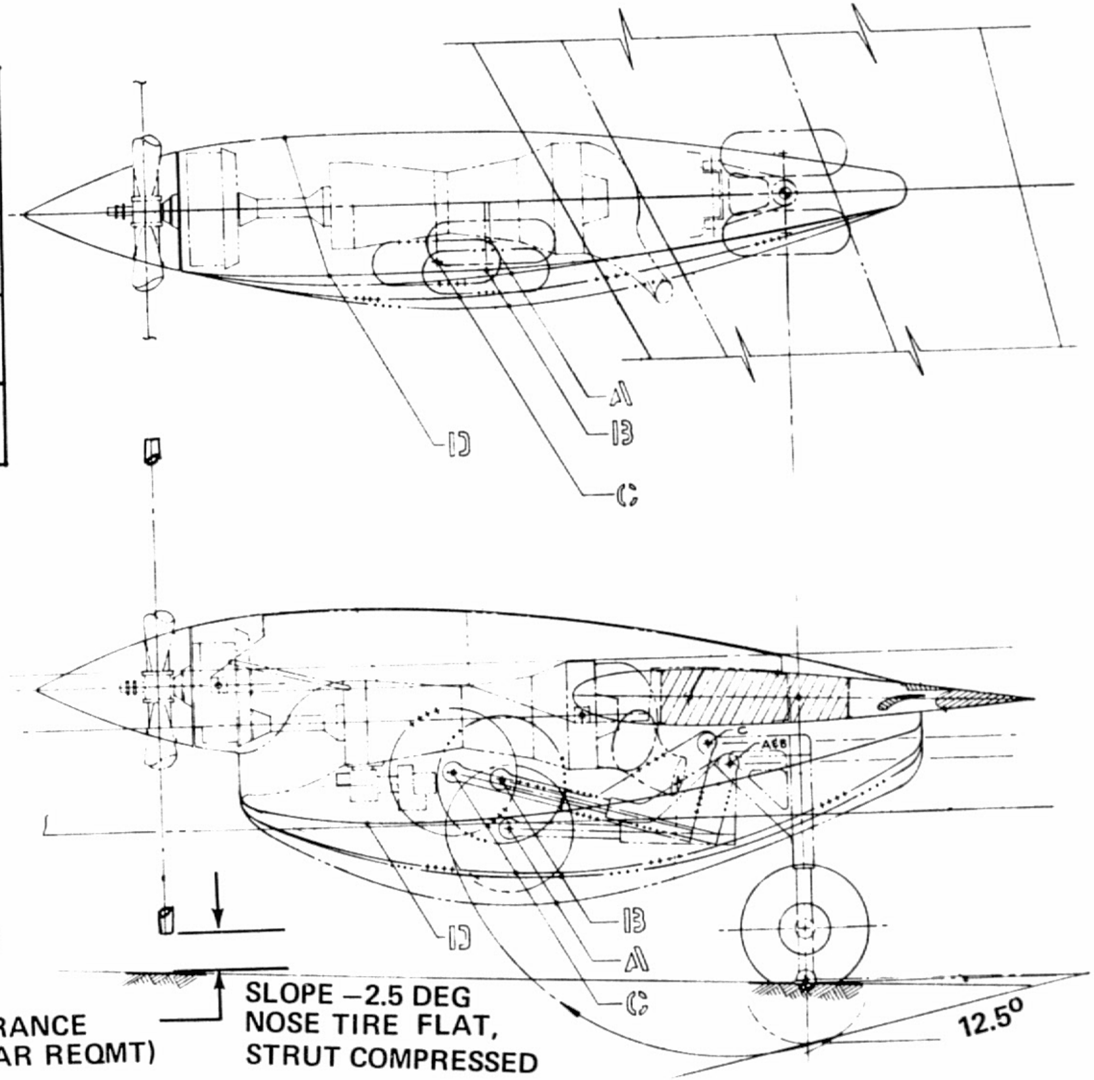


FIGURE 115. ALTERNATE DC-9-30 PROPFAN NACELLE CONFIGURATIONS WITH MAIN GEAR STOWED IN NACELLE

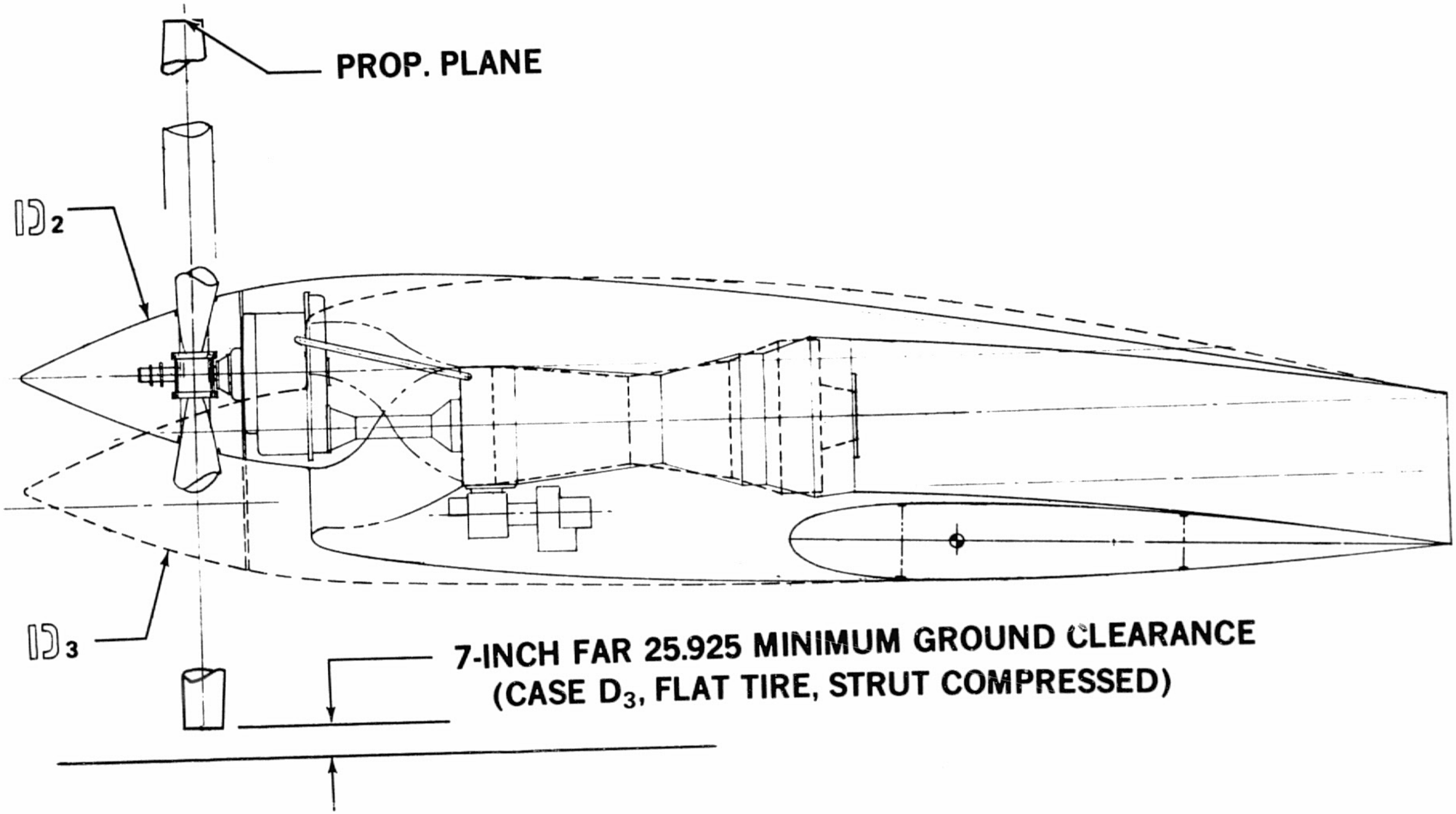


FIGURE 116. DC-9-30 PROPFAN NACELLE CONFIGURATION WITH MAIN GEAR STOWED IN FUSELAGE

TABLE 83

GEOMETRIC AND WEIGHT DATA

DESCRIPTION	DC-9-30 Baseline	DC-9-30D4 (TF, SCW)	DC-9-30D5 (TP, CW)	DC-9-30D6 (TP, SCW)
GEOMETRY DATA:				
Wing Area - Trapezoidal (Ft^2)	1,001	900	1,001	900
Wing Aspect Ratio	8.7	10.2	8.7	10.2
Wing Sweep @ C/4 (Deg)	24.5	30.5	24.5	30.5
Wing Thickness Ratio	.11	.139	.11	.139
Wing Taper Ratio	.2	.3	.2	.3
High Lift System	DC-9 Type	Same	Same	Same
Propulsion System	TF	TF	TP	TP
Wing Type	DC-9	SCW	DC-9	SCW
Horiz. Tail Area (Ft^2)	276	276	276	276
Vert. Tail Area (Ft^2)	161	161	209	209
No. of Passengers (Mixed Class)	92	92	92	92
WEIGHT DATA: (Lb/Airplane)				
Baseline Operational Empty Wt.	57,900	57,900	57,900	57,900
Weight Changes:				
Wing	0	280	167	447
Tail	0	0	346	346
Fuselage	0	0	417	417
Propulsion System	0	0	1,737	1,737
Furnishings	0	0	383	383
Remaining Systems	0	-100	270	170
TOTAL WEIGHT CHANGE	0	180	3,320	3,500
OPERATIONAL EMPTY WEIGHT	57,900	58,080	61,220	61,400
Maximum Payload	29,800	29,800	29,800	29,800
Maximum Zero Fuel Weight	87,700	87,880	91,020	91,200
Maximum Fuel Capacity	24,650*	23,865**	24,500*	23,715**
Maximum Landing Weight	99,000	99,000	99,000	99,000
Takeoff Gross Weight	108,000	108,000	108,000	108,000
Maximum Ramp Weight	109,000	109,000	109,000	109,000

NOTE: * Outer and center wing maximum capacity

** Outer wing maximum capacity

The D5 configuration represents a DC-9-30 with two wing-mounted propfan engines. The weight change for the wing was the result of the combined effects of the higher torsional loads created by the location of the engines and the additional engine support structure, and a weight savings resulting from relief in wing bending loads due to the dead weight of the engines.

The D6 configuration represents a DC-9-30 with two wing-mounted propfan engines and a supercritical airfoil wing with DC-9 type high lift devices. The weight change for the wing represents the combined penalties of configuration D4 and D5. The weight penalties for the tail, fuselage, propulsion system, and furnishings are the same as for configuration D5. The remaining system weights are the same as for configuration D5, except the flight control and hydraulic weights are reduced to reflect the smaller wing area.

The tail weight penalty for the D5 and D6 configurations was due to the larger vertical stabilizer with dual hinged rudder required for one-engine-out control. The fuselage weight penalty was the net result of removing the basic DC-9 aft engines, and adding fuselage structure for propeller noise and engine vibration attenuation. The removal of the aft-mounted engines reduces the aft fuselage bending moments, thereby reducing the weight of the fuselage structure. The aft engine mounting structure weight is also removed. The additional fuselage structure for propeller noise and engine vibration attenuation (placed one-half propeller diameter forward of the propeller plane to one propeller diameter aft of the propeller plane) includes higher skin gages, smaller longeron spacing, and additional vibration dampening material.

The propulsion system weight change reflects the replacement of the basic turbofan engine installation with a propfan engine installation. The propeller and gear box weights were derived from weight data in Reference 21.

The propeller and gear box weights reflect Hamilton Standard advanced technology weight reductions of 11 percent and 6 percent, respectively. The turboshaft engine weight is based on the Allison PD 370-17 shaft horsepower-to-weight ratio (Figure 117). The nacelle and engine systems weights were based on previous turboprop engine studies.

The furnishings weight change reflects additional cabin insulation required to reduce inside cabin noise produced by the propellers.

The remaining systems weight changes include a weight penalty for the pneumatic system for an additional supercharger and related equipment; flight controls and hydraulic system weight penalties for the larger, double hinged rudder; and a reduction in the electrical and fuel system weights due to the shorter run lengths.

6.4 Mission Profile and Performance Assumptions

The mission profile used for the DC-9-30, D4, D5 and D6 is the same as that shown in Section 1.1 with certain simplifying assumptions.

In general, no step cruise was assumed for high altitude operation, choosing instead constant 30,000 ft. altitude cruise at 0.80 Mach number. For low altitude (15,000 ft.) cruise, the DC-9-30 placard speed (350 knots) was chosen to demonstrate maximum high speed operation. All climb and descent speeds are for a DC-9 airplane. No speed schedule optimization was attempted to account for the effects of the supercritical wing or the turboshaft propulsion system.

Performance assumptions were made to accommodate the available turboshaft engine data. The warmup, taxi and takeoff fuel allowances for the basic DC-9-30 were used for all configurations. Idle descent fuel flows for all configurations were based on the fuel rate to produce zero net thrust. The performance comparisons in Sections 6.5 and 6.6 are based on the initial choice of a 720 fps rotational tip speed for the propfan, which resulted in a propeller efficiency of 0.73 and an installed cruise TSFC of 0.65 lb/lb/hr. In Section 6.7 the sensitivity of aircraft performance to propfan efficiency levels will be examined.

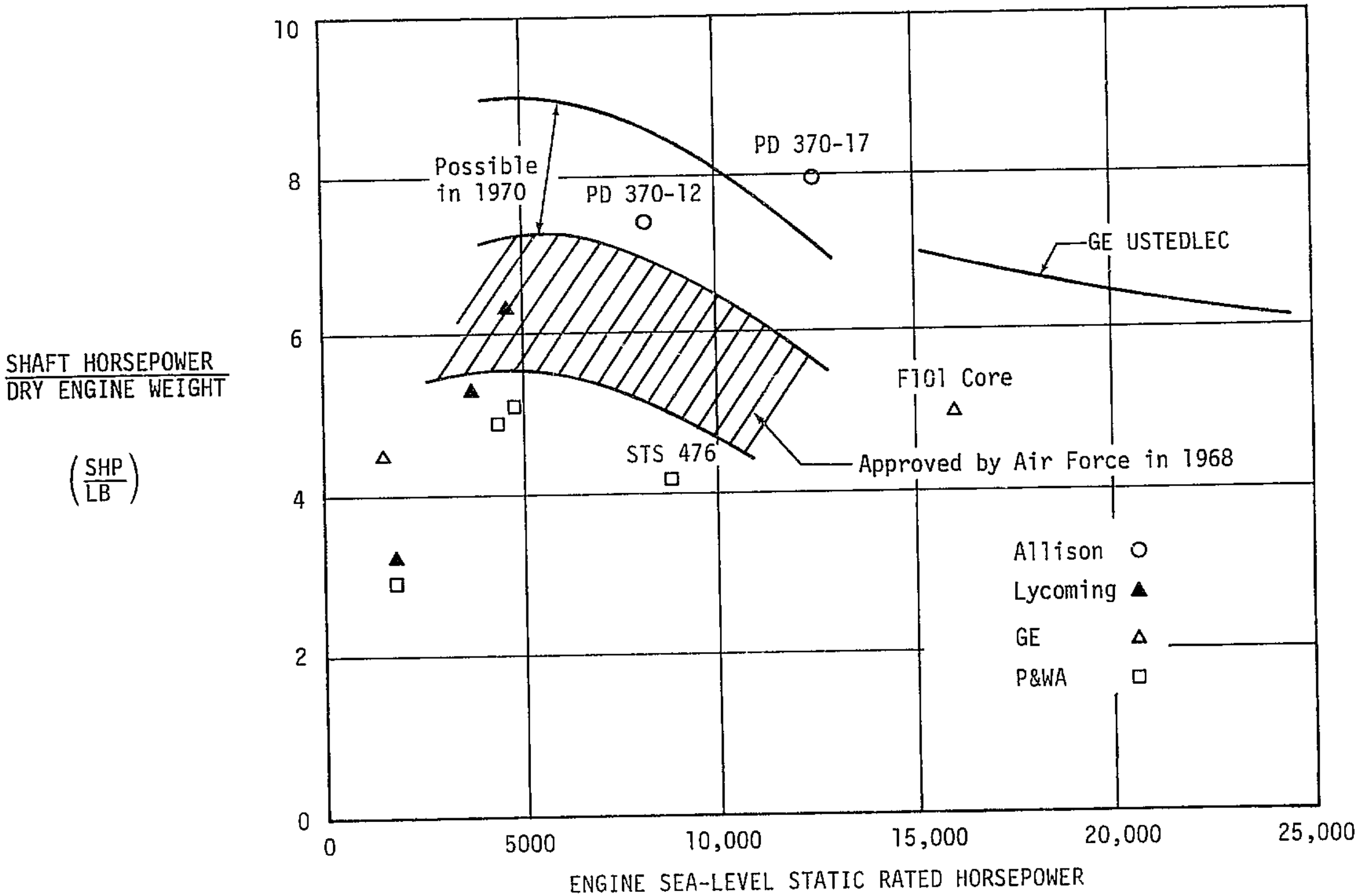


FIGURE 117. TURBOSHAFT ENGINE POWER-TO-WEIGHT RATIO VS. SHAFT HORSEPOWER

6.5 Payload-Range Comparisons

In Figure 118 the DC-9-30D4, D5, and D6 payload-range capabilities are compared to that of the basic DC-9-30. This figure illustrates the effects on range of changes in aerodynamics and propulsion technologies.

Range performance with the supercritical wing was attained with outer wing fuel tanks only, while both center section and outer wing fuel tanks were used on the basic DC-9 wing. This results in approximately 3.2 percent less fuel in the supercritical wing when compared to the basic DC-9 wing.

The passenger payload is based on 200 pounds per passenger, including baggage. The DC-9 type aircraft becomes fuel limited at payloads greater than the maximum passenger payload capacity.

When the aircraft are not fuel limited, the supercritical wing increases turbofan and turboprop range capability by 9 to 12 percent. For conditions when the aircraft are fuel limited, the range capability is increased by only 7 to 8 percent, as a result of the reduced fuel capacity of the smaller supercritical wings.

Compared to the turbofan, the propfan with either wing increases range 21 to 24 percent when the aircraft is not fuel volume limited, and 40 to 43 percent at payload-range points that are fuel capacity limited.

6.6 Block Fuel Comparisons

Figures 119 and 120 show block fuel versus range for the study aircraft at a typical long stage length cruise condition (30,000 ft. at 0.80 Mach) and at a typical short stage length cruise condition (15,000 ft. at 0.70 Mach). These figures demonstrate the superiority of the propfan over the turbofan, with either wing, at both cruise conditions.

Figure 121 shows the fuel savings due to the advanced supercritical wing, the propfan propulsion system, and the combination of both. The improvement due to the wing increases as range increases, for either propulsion system, from 6 to 9 percent at high altitude cruise and from 3 to 5 percent at low altitude cruise.

DC-9-32 TURBOFAN, PROPFAN AND SCW DERIVATIVES

CRUISE CONDITIONS: Alt = 30,000 Ft, M = .8

AIRCRAFT	WING	POWERPLANT	OEW	WING AREA	ASPECT RATIO	SWEEP
DC-9-30	DC-9	JT8D-7	57,900	1,001	8.7	24.5
DC-9-30D4	SCW	JT8D-7	58,080	900	10.2	30.5
DC-9-30D5	DC-9	STS476 PROPFAN	61,220	1,001	8.7	24.5
DC-9-30D6	SCW	STS476 PROPFAN	61,400	900	10.2	30.5

Assumptions:

1. FAR 121.639 Domestic Reserve Fuel (200 NM)
2. Taxi and Maneuver Fuel = 1,150 lb.
3. Design TOGW = 108,000 lb.

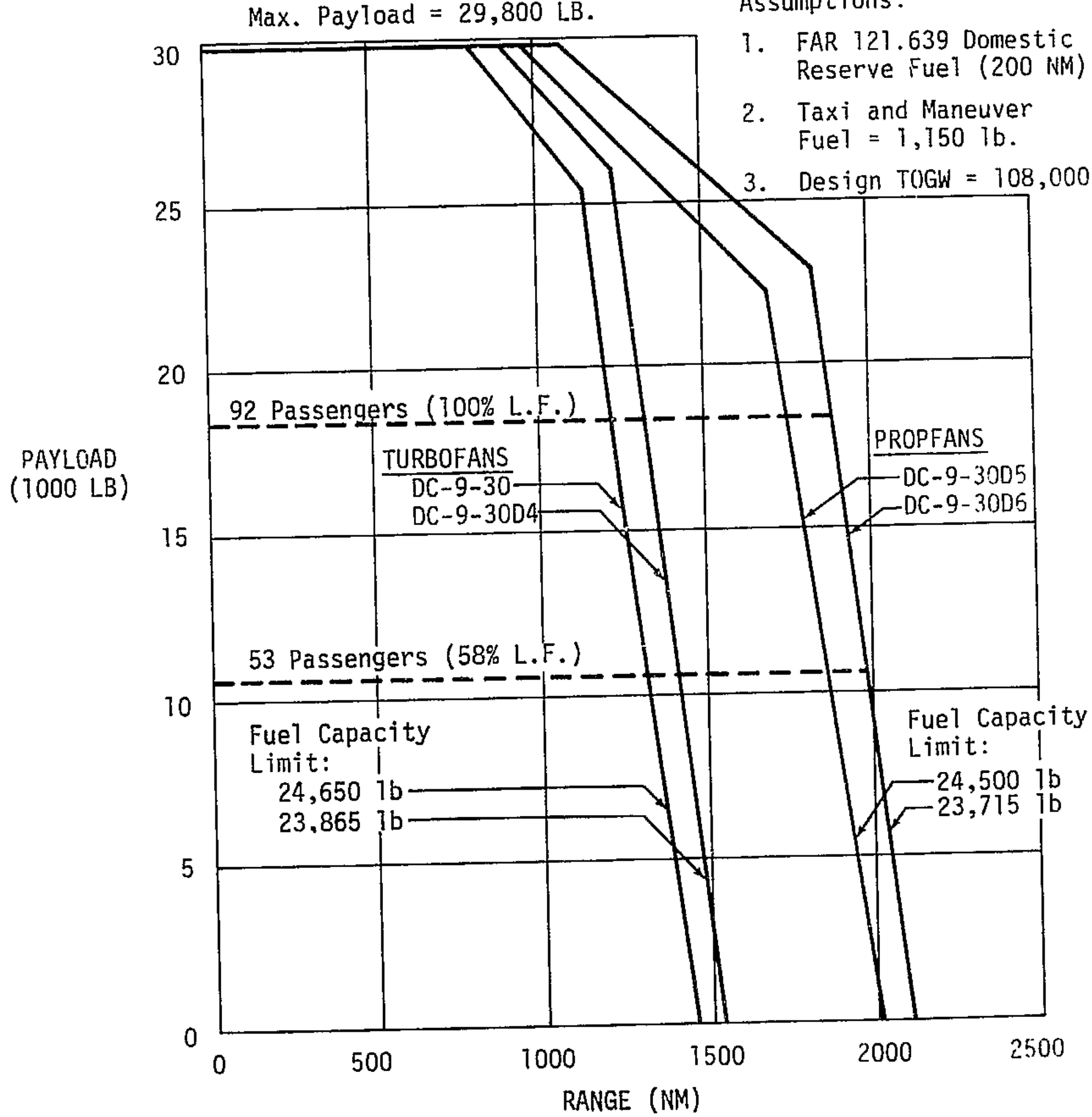


FIGURE 118. PROPFAN PAYLOAD-RANGE COMPARISONS

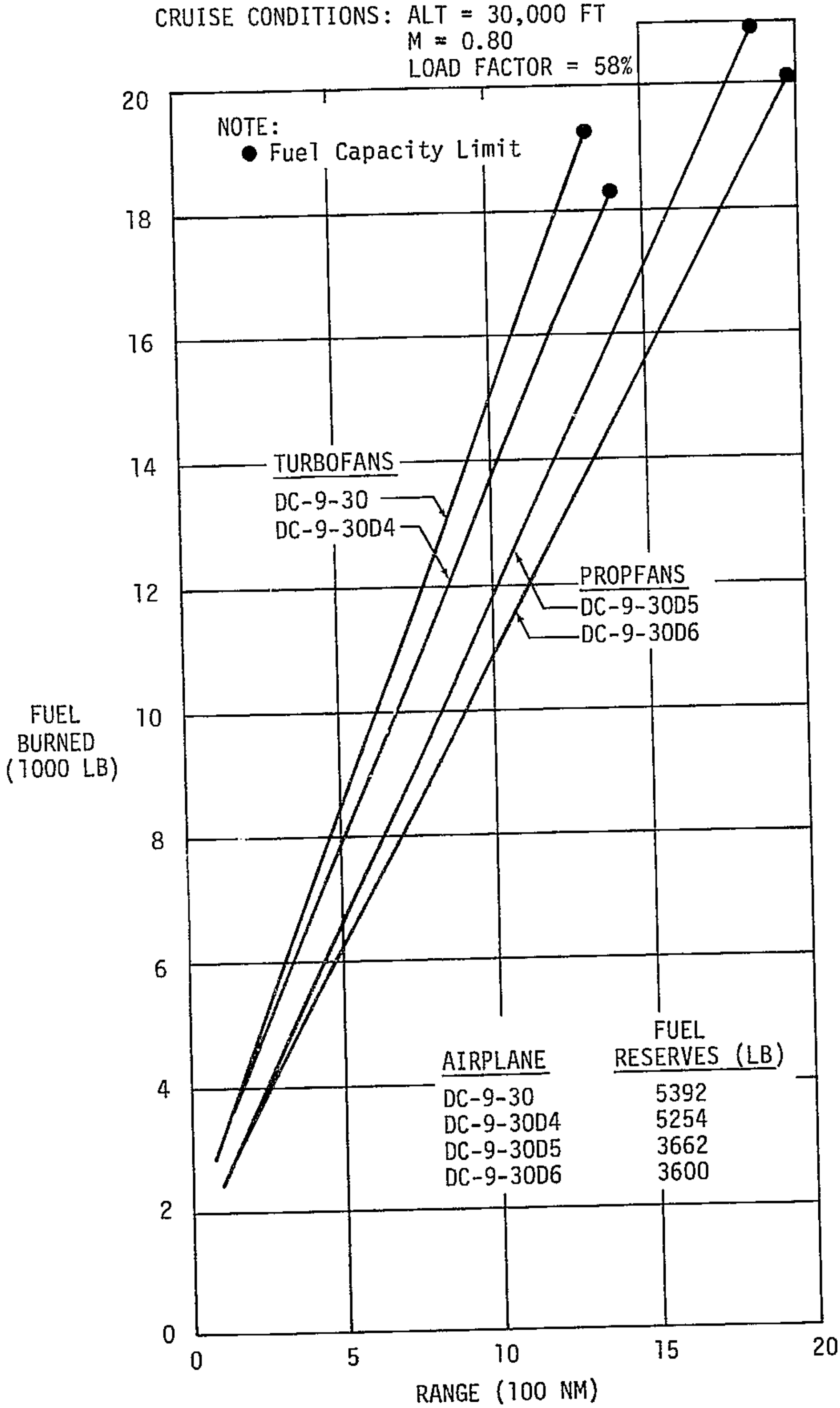


FIGURE 119. BLOCK FUEL COMPARISON OF DC-9-30 TURBOFAN, PROPFAN AND SCW DERIVATIVES
30,000 FT CRUISE ALTITUDE

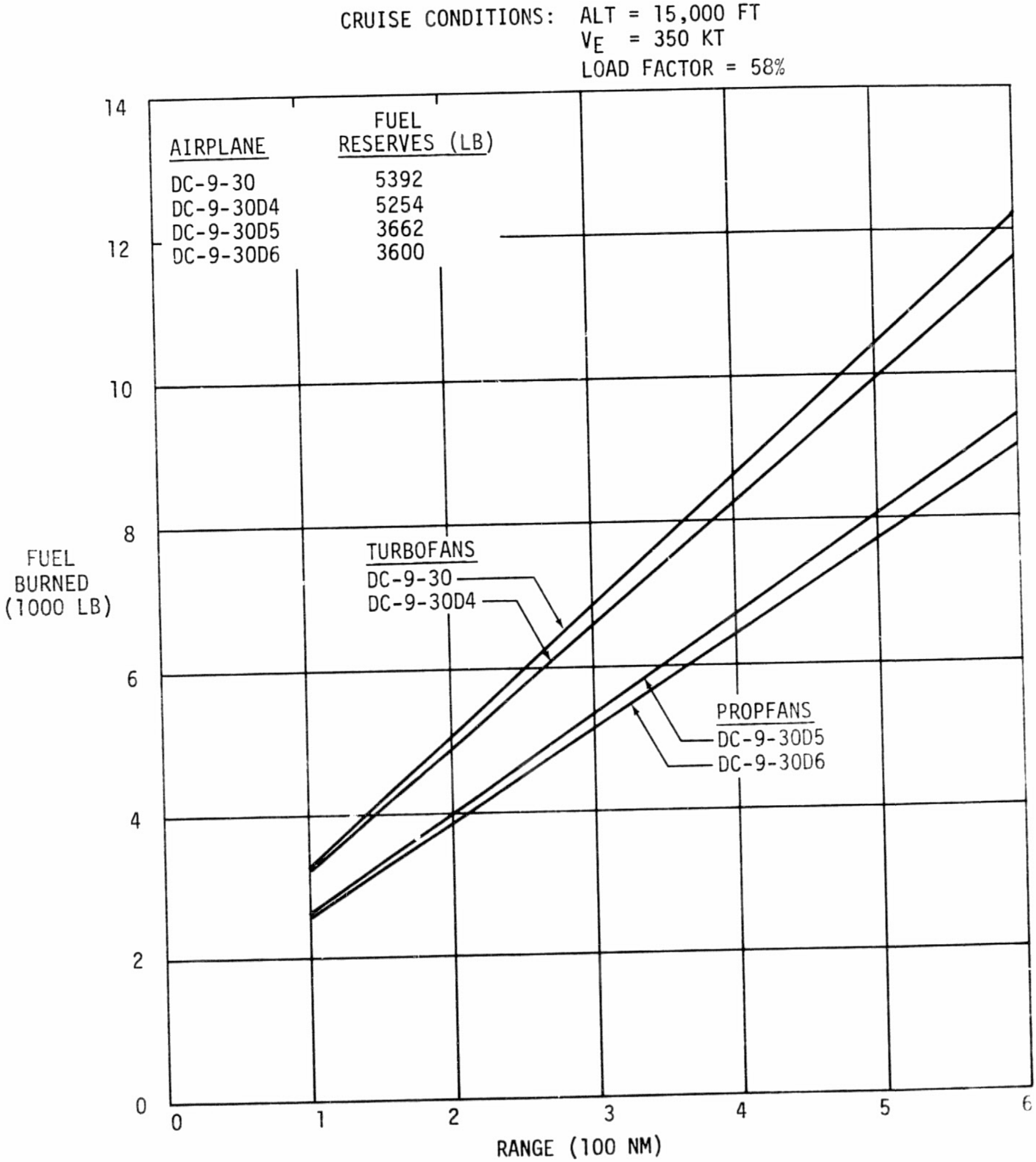


FIGURE 120. BLOCK FUEL COMPARISON OF DC-9-30 TURBOFAN, PROPFAN AND SCW DERIVATIVES
15,000 FT CRUISE ALTITUDE

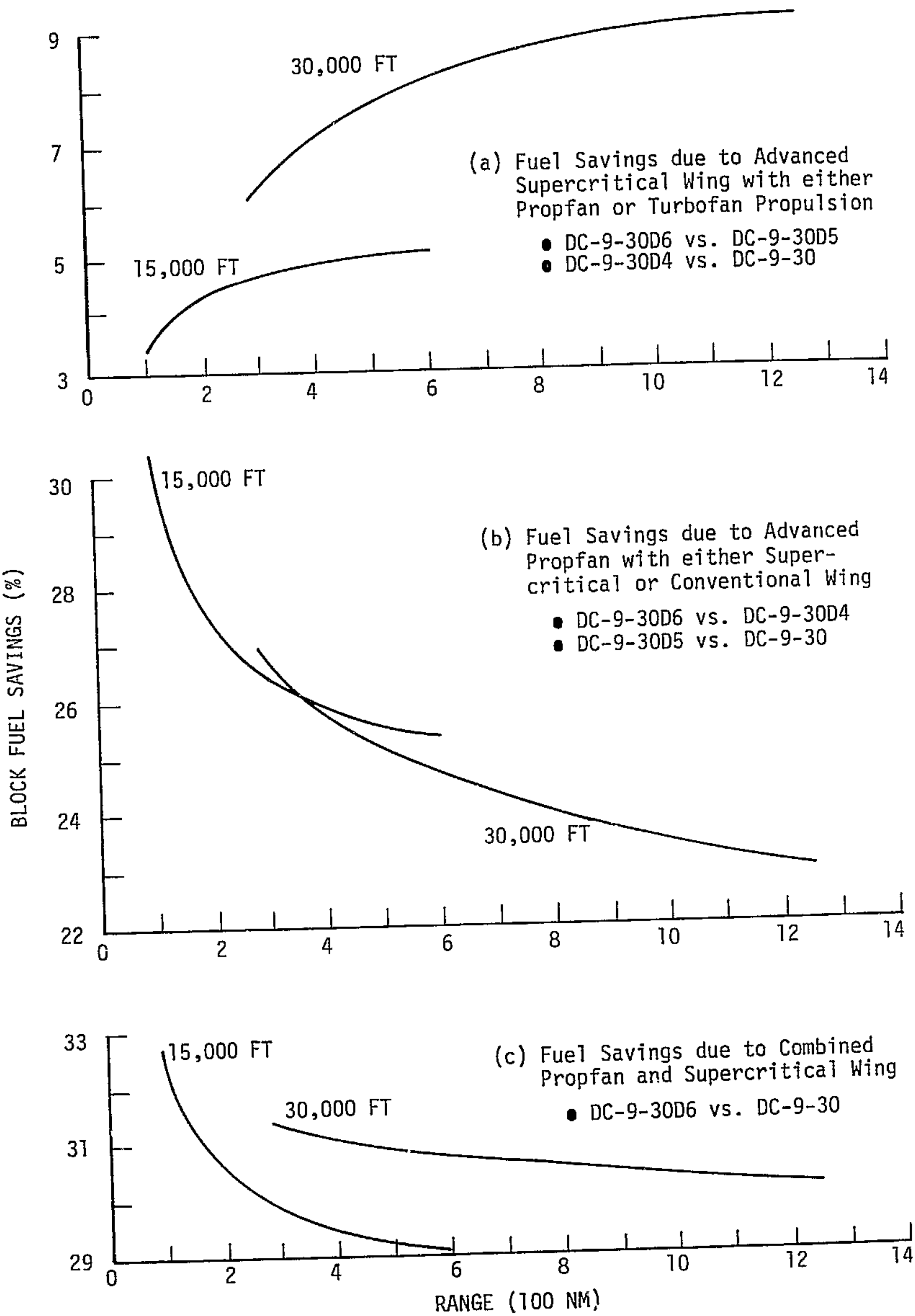


FIGURE 121. COMPARISON OF BLOCK FUEL SAVINGS

As shown in Tables 84 and 85, the propfan aircraft have a much shorter climb distance than the turbofan aircraft. For example, on a 1,250 nautical mile flight with a cruise altitude of 30,000 ft., the DC-9-30D5 reaches cruise altitude 102.7 - 54.6 = 48.1 nautical miles before the DC-9-30. At short ranges, a major part of the DC-9-30 flight profile involves climb. Since the specific range of the propfan aircraft in cruise is far greater than the specific range of the turbofan aircraft in climb, the propfan fuel savings at short ranges are very high, as is shown in Figures 121b and 121c.

For the cruise segments, the propfan specific ranges are higher than the turbofan specific ranges; but the propfan advantage in cruise is less than in the 48.1-nautical mile region, where only the propfan is in cruise while the turbofan is still climbing. Consequently, the propfan fuel savings, shown in Figure 121b, decreases as range increases from 27 to 23 percent at high altitude cruise and from 30 to 25 percent at low altitude cruise.

6.7 Effect of Improved Propulsive Efficiency

As initially selected, with a static tip speed of 720 fps, the propfan developed a propeller efficiency of 0.73, resulting in an installed TSFC of approximately 0.65 lb/lb/hr at cruise. This propfan design point was chosen because of noise considerations. However, a higher tip speed would improve efficiency. For example, an 8-bladed propfan with an 800 fps tip speed would have a propeller efficiency of 0.80 and an installed TSFC of approximately 0.59 lb/lb/hr at cruise. Furthermore, the latest information from engine manufacturers predicts a 10 percent improvement in turboshaft engine performance, which would result in an installed TSFC of 0.53 with the higher efficiency propeller.

Figure 122 shows the effect of a decrease in TSFC from 0.65 to 0.53 on the payload-range envelope of the DC-9-30D5. At 58 percent load factor, the range improvement over the DC-9-30 increases from 41 percent to 73 percent. Figure 123 shows the effect of the lower TSFC on fuel savings. At an average range of 290 nautical miles, fuel savings increase from 27 to 33 percent.

TABLE 84

SPECIFIC RANGE FOR FLIGHT WITH 15,000 FT CRUISE ALTITUDE

AIRCRAFT	FLIGHT SEGMENT	DISTANCE/FUEL = SPECIFIC RANGE (NM/LB)	
		100 NM	600 NM
DC-9-30 (TF,CW)	Climb	25.6/994 = 0.026	29.1/1133 = 0.026
	Cruise	31.3/533 = 0.059	527.8/9372 = 0.056
	Descent	43.1/603 = 0.071	43.1/603 = 0.071
	Total	100.0/2130 = 0.047	600.0/11108 = 0.054
DC-9-30D4 (TF,SCW)	Climb	24.2/945 = 0.026	27.6/1077 = 0.026
	Cruise	29.6/494 = 0.060	526.2/8815 = 0.060
	Descent	46.2/628 = 0.074	46.2/628 = 0.074
	Total	100.0/2067 = 0.048	600.0/10520 = 0.057
DC-9-30D5 (TP,CW)	Climb	14.7/537 = 0.027	16.2/591 = 0.027
	Cruise	46.9/631 = 0.074	545.4/7361 = 0.074
	Descent	38.4/323 = 0.119	38.4/323 = 0.119
	Total	100.0/1491 = 0.067	600.0/8275 = 0.073
DC-9-30D6 (TP,SCW)	Climb	14.3/524 = 0.027	15.7/575 = 0.027
	Cruise	45.0/574 = 0.078	543.6/6960 = 0.078
	Descent	40.7/335 = 0.121	40.7/335 = 0.121
	Total	100.0/1433 = 0.070	600.0/7870 = 0.076

TABLE 85

SPECIFIC RANGE FOR FLIGHT WITH 30,000 FT CRUISE ALTITUDE

AIRCRAFT	FLIGHT SEGMENT	DISTANCE/FUEL = SPECIFIC RANGE (NM/LB) 290 NM	1250 NM
DC-9-30 (TF,CW)	Climb	81.4/2153 = 0.038	102.7/2680 = 0.038
	Cruise	113.4/1406 = 0.081	1052.1/13499 = 0.078
	Descent	95.2/996 = 0.096	95.2/996 = 0.096
	Total	290.0/4555 = 0.064	1250.0/17175 = 0.073
DC-9-30D4 (TF,SCW)	Climb	73.6/1977 = 0.037	89.5/2383 = 0.038
	Cruise	115.9/1303 = 0.089	1060.0/12172 = 0.087
	Descent	100.5/1004 = 0.100	100.5/1004 = 0.100
	Total	290.0/4284 = 0.068	1250.0/15559 = 0.080
DC-9-30D5 (TP,CW)	Climb	46.7/1166 = 0.040	54.6/1353 = 0.040
	Cruise	154.3/1522 = 0.101	1106.4/11179 = 0.099
	Descent	89.0/641 = 0.139	89.0/641 = 0.139
	Total	290.0/3329 = 0.087	1250.0/13173 = 0.095
DC-9-30D6 (TP,SCW)	Climb	44.0/1110 = 0.040	50.5/1267 = 0.040
	Cruise	152.8/1375 = 0.111	1106.3/10107 = 0.109
	Descent	93.2/641 = 0.145	93.2/641 = 0.145
	Total	290.0/3126 = 0.093	1250.0/12015 = 0.104

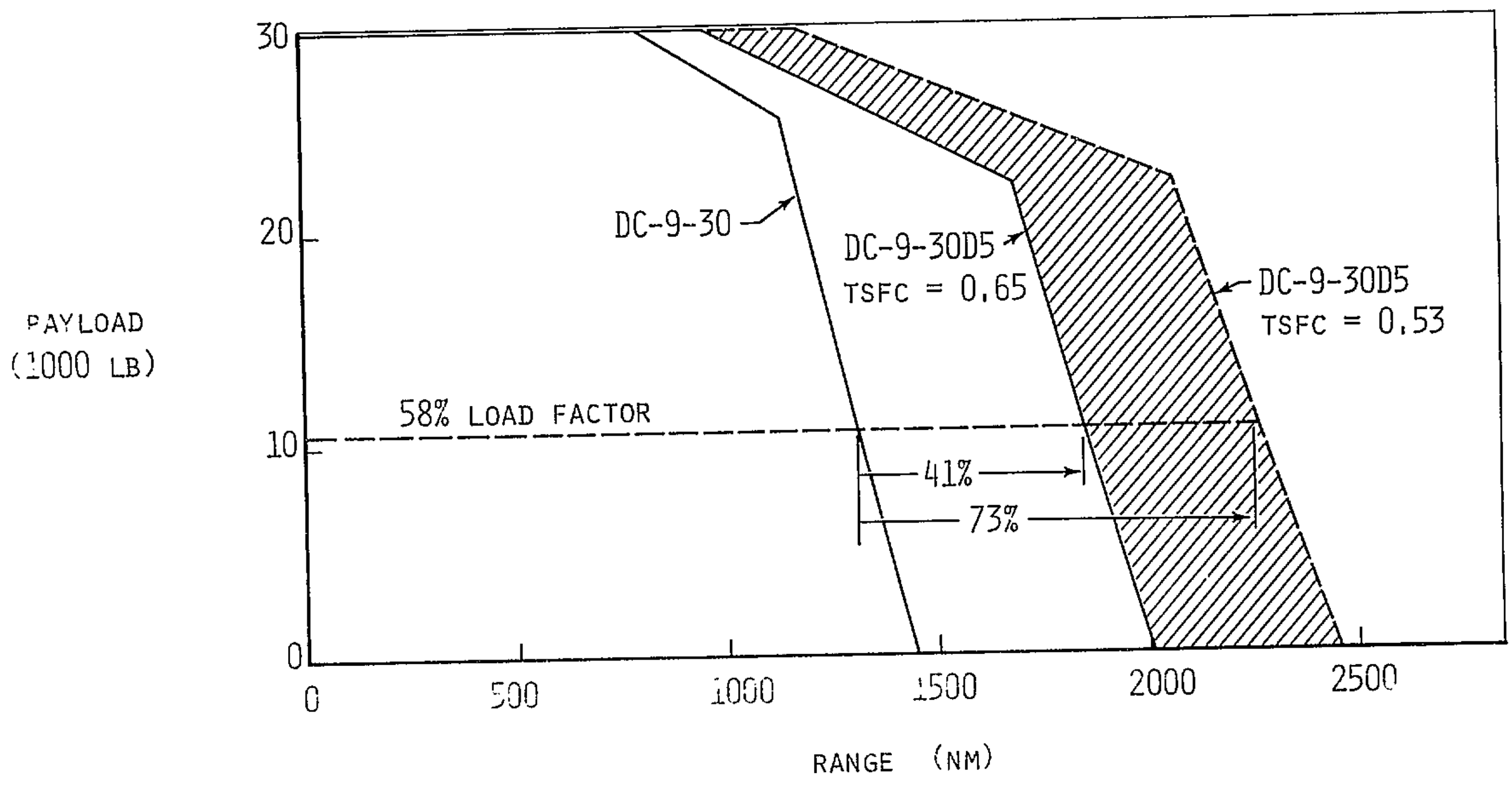


FIGURE 122. EFFECT OF TSFC ON PROPFAN PAYLOAD — RANGE ENVELOPE

MODEL DC-9-30D5 RELATIVE TO AFT JT8D-7 INSTALLATION

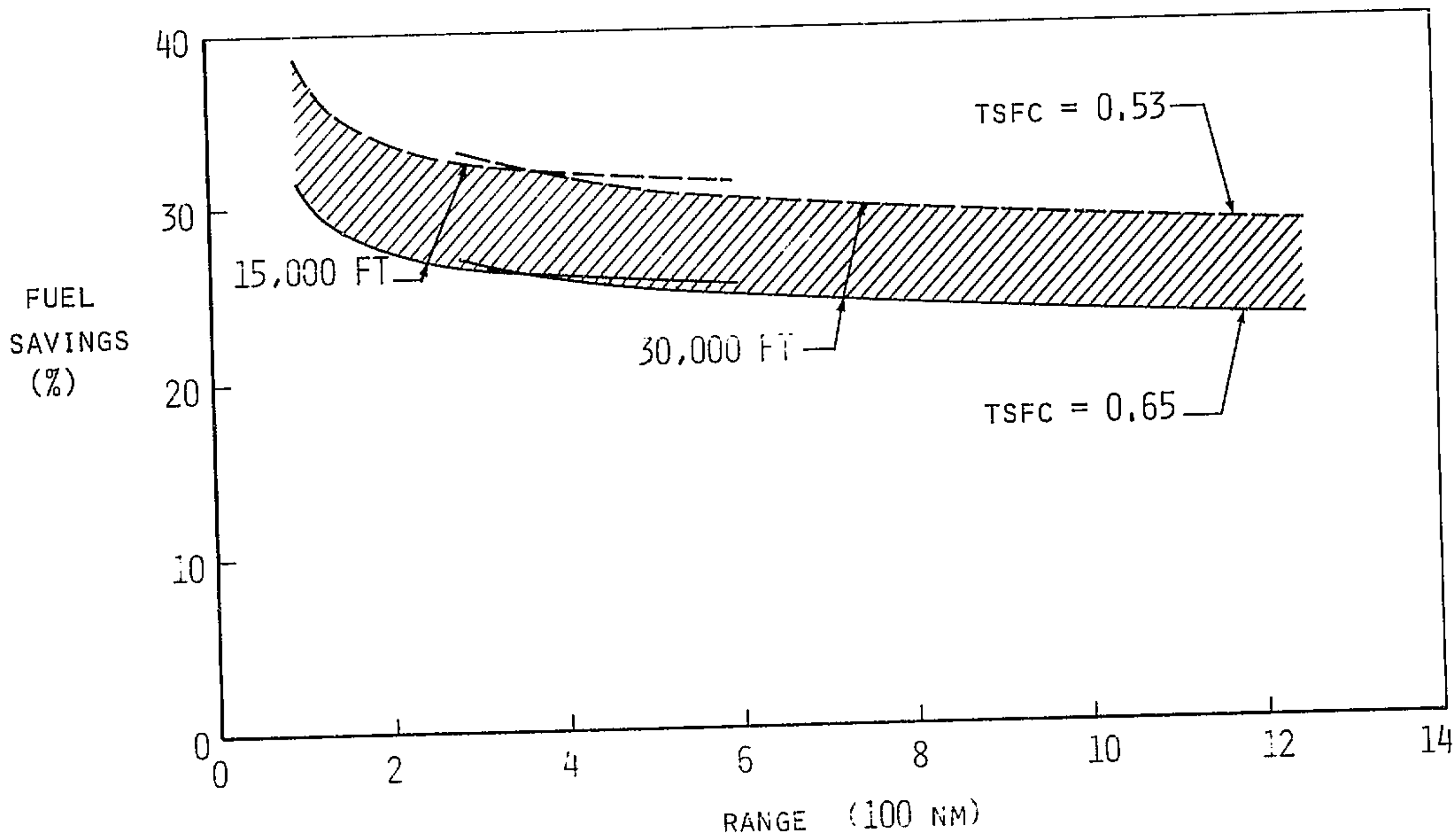


FIGURE 123. EFFECT OF TSFC ON PROPFAN FUEL SAVINGS

The advantage of a lower tip speed is in reduced noise levels. Using Reference 22, a preliminary acoustic analysis of 8-bladed propfans was conducted, which compared a propfan operating at a tip speed of 800 fps to the study configuration with a 720 fps tip speed. The noise level (OASPL) of the 720 fps study configuration was approximately 5 to 7 dB lower at the outer fuselage wall. Therefore, the study configuration results in considerable noise insulation weight savings, which could partially offset the reduced efficiency of the quieter propfan.

The selection of an optimum propfan installation for a given airframe consists of a detailed study of propfan design parameters and the concurrent effect of propfan spanwise location on interior noise, tail size, weight, and drag. The design of an optimum propfan aircraft for a set of mission-payload performance requirements is a more detailed study involving the propfan design parameters together with airframe and configuration variables.

SECTION 7.0
CONCLUSIONS AND RECOMMENDATIONS

7.1 Technology Conclusions

Actual aircraft seat-mile fuel efficiency is an average of 30.2 percent below the engineering values derived for ideal conditions at the 1973 CAB average stage length. Differences in actual values are caused by greater air holding and ground delay times, clearances to non-optimum altitudes, winds, high temperatures, engine and airframe deterioration, and excess fuel loads.

The results of the study of various fuel-saving options are summarized in Table 86. The column giving the range of possible fuel savings shows that opportunities for fuel savings vary widely from aircraft to aircraft. For a given option, the low value corresponds to the lowest fuel saving for any aircraft, and the high value corresponds to the greatest saving for any aircraft. For example, the minimum benefit for fuel-conservative flight operations in the current ATC system is approximately four percent for the DC-8-50, as shown in Table 15. In an advanced ATC system the maximum benefit is about 11 percent for the DC-10-40. Thus, the range shown in Table 86 is 4 to 11 percent.

The estimated maximum fleetwide near-term fuel-saving potential was derived for each option by assuming that the option is fully implemented in all aircraft, as qualified below. While the near-term period extends to the early to mid-1980's, no fleet projections are included in these estimates. The maximum fleetwide potential for each option was estimated by weighting the percent fuel savings for each aircraft type by its total yearly fuel use for 1974, as given in Table 2. The resulting estimates show the relative effect of each option in the fleet, but are not a substitute for the extensive fleet analysis given in Volume II. Also note that the results for the various options are usually not additive, since the same baseline aircraft are involved in each option.

Fuel-conservative operating procedures offer a significant and immediate potential for fuel savings. In the current ATC system, the different baseline aircraft could achieve fuel savings of 4 to 8 percent by means of long-range flight profiles instead of high-speed profiles. In an advanced

TABLE 86

FUEL SAVINGS SUMMARY - U.S. DOMESTIC FLEET

Fuel-Saving Option	Range of Possible Fuel Savings (%)	Estimated Maximum Fleetwide Near-Term Potential (%)
OPERATIONS	$\boxed{4 - 30}$	$\boxed{6+}$
- Flight	4 - 11	6
- Airline	5 - 13	?
MODIFICATIONS	$\boxed{4 - 28}$	$\boxed{6}$
- Retrofit	4 - 28	6
- Production	10	10
DERIVATIVES	$\boxed{4 - 28}$	$\boxed{18}$
NEW NEAR-TERM AIRCRAFT	$\boxed{10 - 41}$	$\boxed{17}$
- Relative to Existing Narrow Body	20 - 41	20
- Relative to Existing Wide Body	10 - 33	10
PROPFAN DC-9	$\boxed{27 - 33}$	$\boxed{30*}$

* 1990 Introduction date rather than near-term.

ATC system, allowing 4-D RNAV and 2,000 ft. steps or cruise climb, these fuel savings would increase to 8 to 11 percent. Thus, the range of possible fuel savings for fuel-conservative flight operations is 4 to 11 percent. However, the advanced ATC system is a far term option. Consequently, the maximum fleetwide near-term potential for fuel savings from improved flight operations is only about 6 percent, relative to early 1973 fuel consumption levels.

Direct operating costs for fuel-conservative flight operations in the current ATC system are generally higher than for the baseline flight profiles because of the increased block times associated with long-range flight profiles. Direct operating costs for fuel-conservative flight operations in an advanced ATC system are generally lower than for the baseline operations because the reduced delay time compensates for the increased block times associated with long-range flight profiles.

Increased seating density would improve seat-mile fuel economy by 5 to 13 percent, depending on the airplane and the extent of its interior modification. An increase in average load factor from 58 to 65 percent would improve passenger-mile fuel economy by 9 to 11 percent. Thus, the range of possible fuel savings by means of changes in airline operations is 5 to 13 percent. However, airline seating density and load factor values are functions of passenger acceptance and marketing strategy, rather than technical factors. As a result, no technical estimate has been made of the maximum near-term potential for fuel savings from these options.

Seat-mile direct operating costs are improved 5 to 14 percent by increased seating density. Increased load factor improves passenger-mile operating costs by 10 to 12 percent.

Combinations of fuel-saving operations are possible in the far term which together give fuel savings as high as 30.5 percent. This high figure requires an advanced ATC system, an increase in load factor from 58 to 65 percent, and high density seating. Thus, operational changes could possibly yield fuel savings of approximately 4 to 30 percent, depending on the aircraft and the operating options implemented. However, the probable near-term potential for operational fuel savings is only a little more than 6 percent, primarily from reductions in cruise speed. Some of this improvement has already been implemented by the airlines.

Aircraft design modifications offer significant potential for near-term fuel savings. On a percentage basis, drag and SFC reductions are approximately twice as effective as weight reductions in improving fuel consumption.

The fuel savings for study retrofit modifications range from 4 percent for DC-9 retrofits with aerodynamic improvements, to approximately 28 percent for the DC-8-20R with new JT8D-209 engines and aerodynamic improvements. However, considering the small number and limited remaining lifetime of the DC-8 aircraft in the domestic fleet, expensive DC-8 engine retrofits appear to be an unlikely option, and aerodynamic modifications offer more fleetwide potential for fuel savings. Thus, the probable maximum fleetwide near-term fuel savings, by means of retrofit modifications, is about 6 percent.

Production modifications could result in 10 percent fuel savings for the DC-10. Nevertheless, the maximum fleetwide near-term potential for fuel savings, by means of both retrofit and production modifications, is still approximately 6 percent.

Direct operating costs for retrofit and production modifications are generally higher than for the baseline aircraft. However, at higher fuel prices the DOC's for DC-10 aircraft with aerodynamic retrofits are lower than DC-10 baseline DOC's.

Derivative designs show more fuel-saving potential than either retrofit or production modifications. The study derivatives use from 5 to 28 percent less fuel per seat-mile than the airplanes they would replace. The stretched derivative airplanes show a substantial seat-mile fuel use reduction, ranging from approximately 20 percent for the DC-9-30D1 to 28 percent for the DC-10-40D. The supercritical wing on the DC-9-30D3 reduces fuel use by about 5 percent. The DC-10-10D uses about 3 percent less fuel per seat-mile than the baseline DC-10-10, and about 19 percent less fuel per seat-mile than the baseline DC-8-61. Assuming that the DC-10-10D replaces the DC-8s, the DC-9-30D2 replaces the DC-9-30, and the DC-10-40D replaces the DC-10-40, the maximum fleetwide near-term potential for fuel savings by introducing derivative aircraft is 18 percent.

At a fuel price of 30 cents per gallon, seat-mile DOC's for the stretched airplanes are improved 8 to 11 percent, relative to the study baselines, primarily due to the increased number of seats. Seat-mile DOC's for the supercritical wing DC-9-30D3 are reduced 0.3 percent at 30 cents per gallon and 1.5 percent at 60 cents per gallon, relative to the DC-9-30. Due to the decreased number of seats, the DC-10-10D seat-mile DOC's are about 15 percent higher than the baseline DC-10-10 at 30 cents per gallon and 10 percent higher at 60 cents per gallon.

The new near-term aircraft would substantially reduce seat mile fuel use, due to the higher design fuel prices and the incorporation of current technologies. All-new aircraft designed for a 1980 introduction date would be approximately 20 percent more fuel-efficient than current narrow-body aircraft and about 10 percent more fuel-efficient than current wide-body aircraft. Based on a fleetwide replacement of narrow-body and wide-body aircraft with new near-term aircraft, the maximum overall near-term potential for fuel savings is about 17 percent. However, the introduction of these new aircraft would, in fact, be too close to the introduction of the current wide-body aircraft and their derivatives to actually make any significant impact in the near term.

The optimization of aircraft for minimum DOC at high fuel prices, or for minimum fuel use, results in lower cruise Mach numbers and wings of very large span. However, reducing aspect ratio about two points from the optimum increases DOC's and fuel use only about 1 percent.

Aircraft optimized for minimum fuel use actually save very little more fuel than aircraft optimized for minimum DOC at 60 cents per gallon. However, DOC's for the minimum fuel airplanes are substantially higher than DOC's for aircraft optimized for minimum DOC at 60 cents per gallon.

The new near-term aircraft generally meet or are close to FAR 36 -10 sideline and takeoff noise levels. Approach noise levels do not meet the FAR 36 -10 goal, but improve with increasing design fuel price. Noise contour areas for the N80-2.30 family, with four CFM-56 type engines, were the lowest. The contour areas are primarily affected by payload-range capability, and are only mildly affected by the optimization parameters. Nevertheless, it is clear that energy conservative aircraft design is not in conflict with the desire for low noise.

The DC-9-30 propfan is included in Table 86 for completeness, even though it is more appropriately a far-term option. Depending on the assumed propulsive efficiency, the derivative propfan uses from 27 to 33 percent less fuel than the DC-9-30 at its average stage length of 290 nautical miles. Replacement of the entire domestic fleet with propfan aircraft would reduce air transport fuel consumption by approximately 30 per[illegible]

7.2 Research and Technology Recommendations

- Expand the study of fuel-conservative flight operations to include all aircraft types in the domestic fleet, and to include a wider scope of operational variations. The study results should be specific to each airline's market, fleet, and schedule.

- Study the costs and benefits of optimum cruise control, which would allow an aircraft to accurately follow a minimum-fuel flight profile within the mission and ATC system constraints.

- Perform an ATC system study in order to identify ways to reduce the constraints on minimum-fuel flight profiles.

- Continue the study and testing of winglets as a possible means of reducing the wing spans of future new transports designed for minimum DOC at high fuel prices.

- Study folding wing tips as an alternative approach for reducing wing spans in the airport terminal area.

- Continue the theoretical and experimental development of supercritical airfoil technology and three-dimensional applications.

- Study the contouring of aircraft surfaces to achieve more extensive natural laminar flow.

- Continue studies of active controls technology, including the use of active controls on derivatives of in-production aircraft.

- Study aeroelastic effects on the weight of very high aspect ratio transport wings.

- Demonstrate the full scale use of composite primary structure in transport aircraft.

- Conduct studies to improve the integration of high-bypass-ratio turbofan powerplants with airframes.

- Develop a broader spectrum of study engines for propfan applications.

- Conduct tests to verify theoretical propfan efficiency and noise levels.

- Study the effects of the propfan slipstream on airframe aerodynamics and also on noise and vibration in tail surfaces and the aft fuselage.

- Investigate propfan aircraft flight profiles, including takeoff performance and the effects of cruise altitude and Mach number on fuel use.

SECTION 8.0

REFERENCES

1. Malliaris, A.C. and Strombotne, R.L.: Demand for Energy by the Transportation Sector and Opportunities for Energy Conservation. ASME Paper 73-ICT-87, 1973.

2. Gibson, J.D., et al: The Energy Dilemna and Its Impact on Air Transportation. NASA CR-135993, prepared by the 1973 NASA-ASEE Summer Faculty Program in Engineering Systems Design, 1973.

3. Mutch, James J.: The Potential for Energy Conservation in Commercial Air Transport. Rand Corp. Report R-1360-NSF, October 1973.

4. Rice, R.A.: Toward More Transportation with Less Energy. Technology Review, February 1974, pp. 45-53.

5. Hirst, E.: Total Energy Use for Commercial Aviation in the U.S. Oak Ridge National Laboratory Report ORNL-NSF-EP-68, April 1974.

6. Pilati, D.A.: Energy Use and Conservation Alternatives for Airplanes. Transportation Research, October 1974, pp. 433-441.

7. Maddalon, D.V.: Rating Aircraft on Energy. Astronautics and Aeronautics, December 1974, pp. 26-43.

8. Ardema, M.D., Harper, M., Smith, C.L., Waters, M.H., and Williams, L.J.: Conceptual Design of Reduced Energy Transports. AIAA Paper 75-303, February 1975.

9. Nagel, A.L., Alford, W.J., Jr., and Dugan, J.F., Jr.: Future Long-Range Transports - Prospects for Improved Fuel Efficiency. AIAA Paper 75-316, February 1975.

10. Mascy, A. and Williams, L.J.: Air Transportation Energy Consumption - Yesterday, Today, and Tomorrow. AIAA Paper 75-319, February 1975.

11. Civil Aeronautics Board: Aircraft Operating Cost and Performance Report, Volume IX. July 1975.

12. Sallee, G.P., Kruckenberg, H.D., and Toomey, E.H.: Analysis of Turbofan Engine Performance Deterioration and Proposed Follow-On Tests. NASA CR-134769, prepared by American Airlines under contract NAS3-18537, 1975.

13. Gray, D.E.: Study of Turbofan Engines Designed for Low Energy Consumption. NASA CR-135002, prepared by Pratt & Whitney Aircraft Division of United Technologies Corporation under contract NAS3-19132, April 1976.

14. Hoffman, H.J., and Norr, W.E.: Ground Mobility for Large Transport Aircraft. Douglas Aircraft Company Report CAD-61, September 1970.

15. Hainline, B.C., Sellereite, B.K., and Swanke, K.V.: Powered Wheels - A Concept for Parking and Taxiing of Commercial Transport Airplanes. SAE Paper 710446, May 1971.

16. Schairer, G.S. and Olason, M.L.: Some Performance Considerations of a Jet Transport Airplane. Proceedings of the First Turbine Powered Air Transportation Meeting, Seattle, Washington, August 1954, pp. 111-121. Reprinted in J.M. Swihart (Ed.) Jet Transport Design. New York: American Institute of Aeronautics and Astronautics, 1969. pp. 41-53.

17. Kazin, S.B. and Paas, J.E.: NASA/GE Quiet Engine "A" Acoustic Test Results. NASA CR-121175, prepared by General Electric under contract NAS3-12430, October 1973.

18. Kazin, S.B. and Paas, J.E.: NASA/GE Quiet Engine "C" Acoustic Test Results. NASA CR-121176, prepared by General Electric under contract NAS3-12430, April 1974.

19. Society of Automotive Engineers: Procedures for Developing Aircraft Noise Exposure Contours Around Airports. Aerospace Recommended Practice Document SAE-ARP-1114, draft November 1969.

20. Hamilton Standard Division of United Aircraft Corporation: Generalized Prop-Fan Performance and Weight. Report SP 05A75, April 1975.

21. Hamilton Standard Division of United Technologies Corporation: Preliminary Prop-Fan Propulsion System Weight Estimates. Report SP 09A75, October 1975.

22. Hamilton Standard Division of United Technologies Corporation: Preliminary Prop-Fan Noise Estimation. Report SP 09A76, March 1976.