NASA Contractor Report 152089

Final Report

Application of Advanced Technologies to Small, Short-Haul Aircraft

D. G. Andrews, P. W. Brubaker, S. L. Bryant, C. W. Clay,
B. Giridharadas, M. Hamamoto, T. J. Kelly, D. K. Proctor,
C. E. Myron, and R. L. Sullivan
Boeing Commercial Airplane Company

CONTRACT NAS2-9506
MARCH 1, 1978

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

For U.S. Government Agencies
and their Contractors Only

1 Report No NASA CR-152089	2 Government Accession No	3 Recipient's Catalog No
4 Title and Subtitle APPLICATION OF ADVANCED TECHNOLOGIES TO SMALL, SHORT-HAUL AIRCRAFT		5 Report Date March 1, 1978
		6 Performing Organization Code B-7220
7 Author(s) D. G. Andrews, P. W. Brubaker, S. L. Bryant, C. W. Clay, B. Giridharadas, M. Hamamoto, T. J. Kelly, D. K. Proctor, C. E. Myron, and R. L. Sullivan		8 Performing Organization Report No D6-46320
9 Performing Organization Name and Address Preliminary Design Department Boeing Commercial Airplane Company P.O. Box 3707 Seattle, Washington 98124		10 Work Unit No
		11 Contract or Grant No NAS2-9506
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Ames Research Center Moffett Field, California 94035		13 Type of Report and Period Covered Contractor Final Report
		14 Sponsoring Agency Code FVS

15 Supplementary Notes
Technical Monitor: Louis J. Williams
NASA Ames Research Center
Moffett Field, California 94035

16 Abstract

This report presents the results of a preliminary design study which investigates the use of selected advanced technologies to achieve low-cost design for small (50-passenger), short-haul (50- to 1000-mile) transports.

The largest single item in the cost of manufacturing an airplane of this type is labor. A careful examination of advanced technology to airframe structure was performed since one of the most labor-intensive parts of the airplane is structures. Also preliminary investigation of advanced aerodynamics flight controls, ride control and gust load alleviation systems, aircraft systems and turbo-prop propulsion systems was performed.

The most beneficial advanced technology examined was bonded-aluminum primary structure. The use of this structure in large wing panels and body sections resulted in a greatly reduced number of parts and fasteners and therefore, labor hours. The resultant cost of assembled airplane structure was reduced by 40% and the total airplane manufacturing cost by 16% -a major cost reduction. With further development, test verification and optimization appreciable weight saving is also achievable.

Other advanced technology items which showed significant gains are as follows:

- Advanced turboprop—reduced block fuel by 15-30% depending on range
- Configuration revisions (vee-tail)—empennage cost reduction of 25%
- Leading-edge flap addition—weight reduction of 2500 pounds

17. Key Words (Suggested by Author(s)) Short-haul airplane; Advanced technology; Low cost		18 Distribution Statement	
19 Security Classif (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 221	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161

CONTENTS

CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Concluded)

LIST OF TABLES

FOREWORD

The work described in this document covers phase I of an ongoing effort to examine and evaluate the benefits derived from the application of advanced technologies to small, short-haul transports. The primary emphasis of phase I is the reduction of airplane initial (manufacturing) costs through the use of advanced bonded-aluminum structure. Additional activities are recommended which would emphasize the reduction of airplane initial and operating costs through the use of advanced systems. Additional aerodynamic trades, mission analysis, and configuration options should also be investigated to enable an optimized small transport to be selected and matched to specific market requirements.

1.0 SUMMARY

This report presents the results of phase I of an ongoing study to examine and evaluate the benefits derived from the application of advanced technologies to small, short-haul transports. This study emphasizes a 50-passenger baseline aircraft shown in figure A for application of advanced materials and structures, flight controls, airfoils and propulsion. The 50-passenger aircraft was selected because:

- Past NASA/Boeing and Boeing funded studies indicated this size to be attractive for future local service markets.
- The design problems were scopable to obtain realist . cost.
- Developmental hardware could be manufactured at very low risk and low capital investment.

Emphasis during phase I was placed on providing an in-depth evaluation of bonded aluminum honeycomb structure. Also conducted were preliminary evaluations of "all-electric" systems, aerodynamic improvements, and turboprops.

Results indicate several cost savings are possible through the application of advanced technology to CTOL short-haul transports.

The use of bonded aluminum primary structure provides a manufacturing cost savings of 40% resulting in a total airplane manufacturing cost reduction of 16% a major cost reduction. This cost reduction is achieved through lower labor and material requirements and is illustrated in figure B. These lower requirements are achieved through the reduction in part count (figure C) and design simplification as illustrated in figure D. Airplane structural components definitions are described in section 6.2.

Potential for significant cost savings in the area of electrical systems exists. Breakthroughs are occurring in micro-electronics and the application of rare-earth metals for powerful small motors. These new technologies could make an "all-electric" airplane feasible (similar to that outlined in table 1), thereby making possible elimination of the costly installation and maintence associated with the conventional hydraulic and control cable sytems.

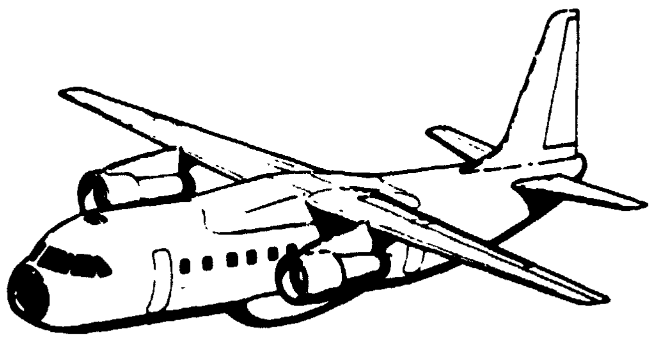


Figure A Small Short-Haul Transport Baseline Aircraft

An example of the potential benefits of all-electric technology systems is the electric power hinge actuator concept. In contrast to conventional hydraulic systems that transmit power in hydraulic lines from engine mounted pumps, the all-electric system uses electrical power generated at the engines and transmits the power by wire to electric motors that are directly connected to structure and flight control systems. Potential benefits of these systems are enhanced reliability, weight reduction, easier maintenance, and reduced transmission line loss. Also, electric powered hingeline actuators have the advantage of allowing removal of a unit from the airplane by means of an electrical quick-disconnect, thereby eliminating the problems of hydraulic system contamination and fluid loss due to leakage from hydraulic couplings.

Other advanced technology items that showed significant gains were the advanced turboprop (block fuel reduction by 15 to 30%, depending on range), configuration revisions, such as a Vee-tail empennage (empennage cost reduction of 25%) and leading edge flap addition (airplane weight reduction of 2500 lb). Before these revisions can be incorporated into the baseline airplane, additional trades will be required to determine the impact on other systems' maintenance and operating costs assessment.

The primary objective of this study was to reduce the initial or production costs while maintaining acceptable airplane performance and economics. The study airplane did indeed achieve this objective and is more than competitive with current short-haul transports, as shown in figures E, F, G, and H.

Table 1 All-Electric Systems Technology

PRESENT	PROPOSED
ELECTRICAL • 80,000 wire segments CSD systems generators (157 lb)	**ELECTRICAL** • Samarium cobalt generators (? WT) • Wire segments ? • Fiber optics • Electric anti-ice • Electric geared flaps • Electric-driven air conditioner
HYDRAULIC • 3 independent systems • Actuators, accumulators, valves • Control units • 3000 ft of tubing and hoses (1000 parts) • 1500 parts of valves, controls units, etc	**HYDRAULIC** None (electric or electro/hydraulic actuators)
CONTROL CABLES • Propulsion and flight controls • Pulley, brackets, gromets • 4000 feet of rigged cable	**CONTROL CABLES** • None (fly-by-wire)
ELECTRONICS • Radio rack • Control heads • Instruments	**ELECTRONICS** • Micro electronics • Fiber optics • No radio rack • Electrical flat panels • Radios integrated with antenna assembly and control heads

Several advanced technology items with the potential for significantly reducing the initial and/or operating cost were identified but were not included in the baseline airplane because of the limited scope of phase I. These items (listed below) should be included in more in-depth future studies to determine if they should be incorporated into the baseline design:

- Advanced composite primary structure
- Fly-by-wire digital control system
- Advanced integrated avionics with digital data systems and propulsion controls
- Natural laminar flow wing and tail surfaces
- Wing-tip devices
- Advanced turboprops (prop-fans)
- Vee-tail empennage
- Advanced high-lift devices

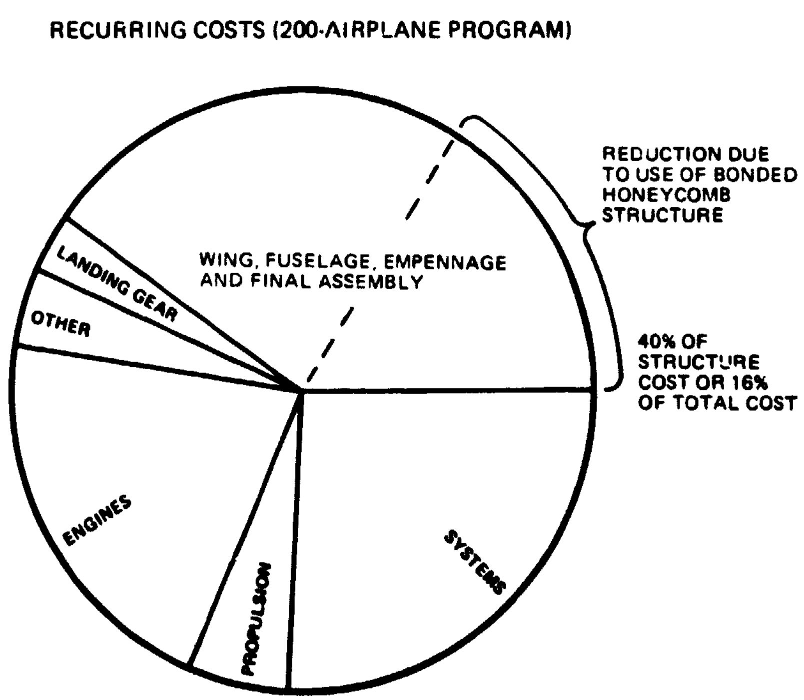


Figure B Manufacturing Cost Comparison

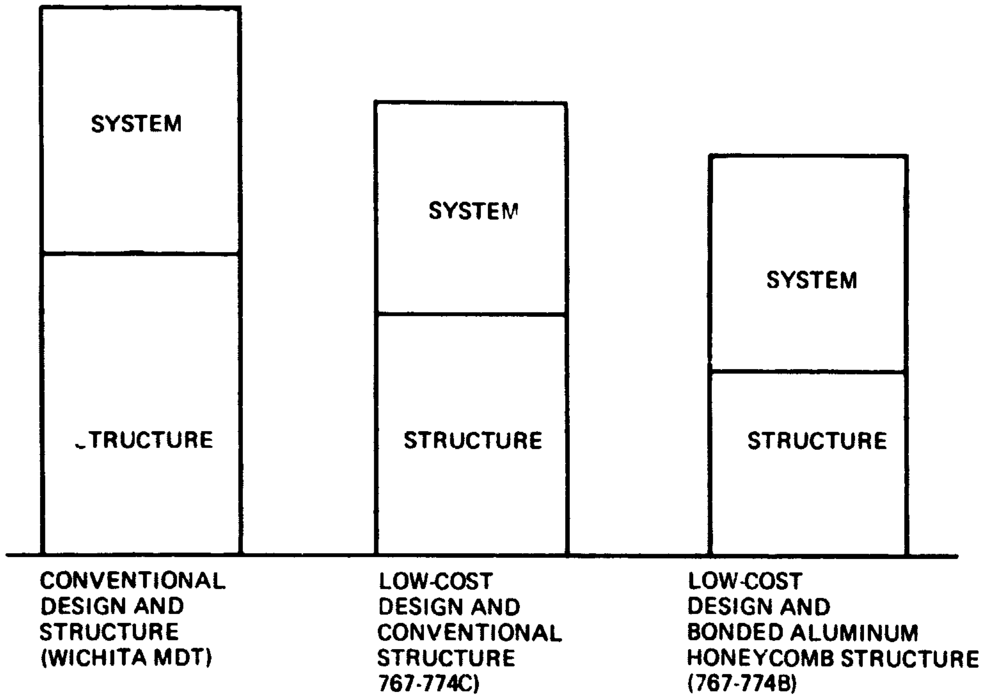


Figure C Part-Count Comparison

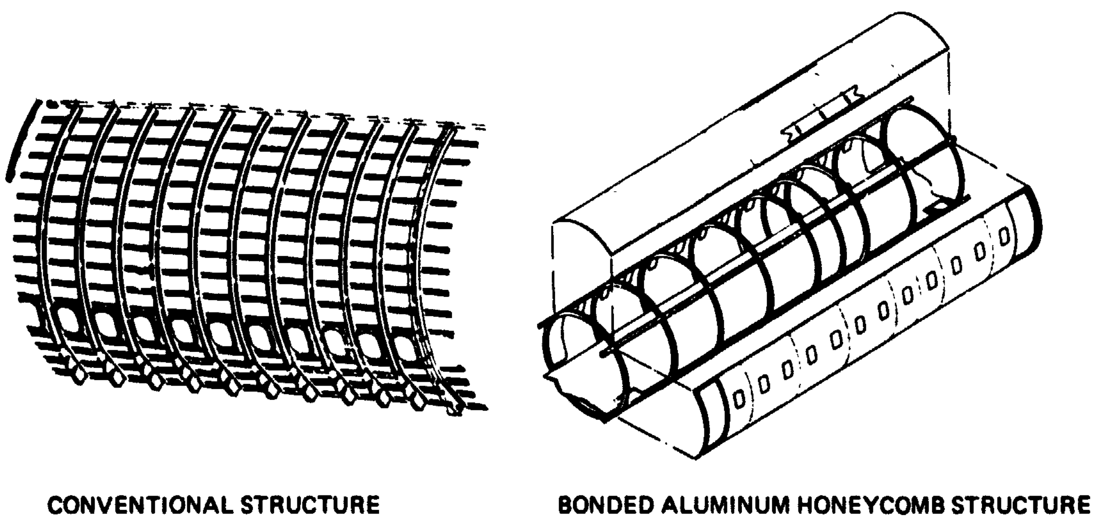


Figure D Conventional and Aluminum Honeycomb Structure

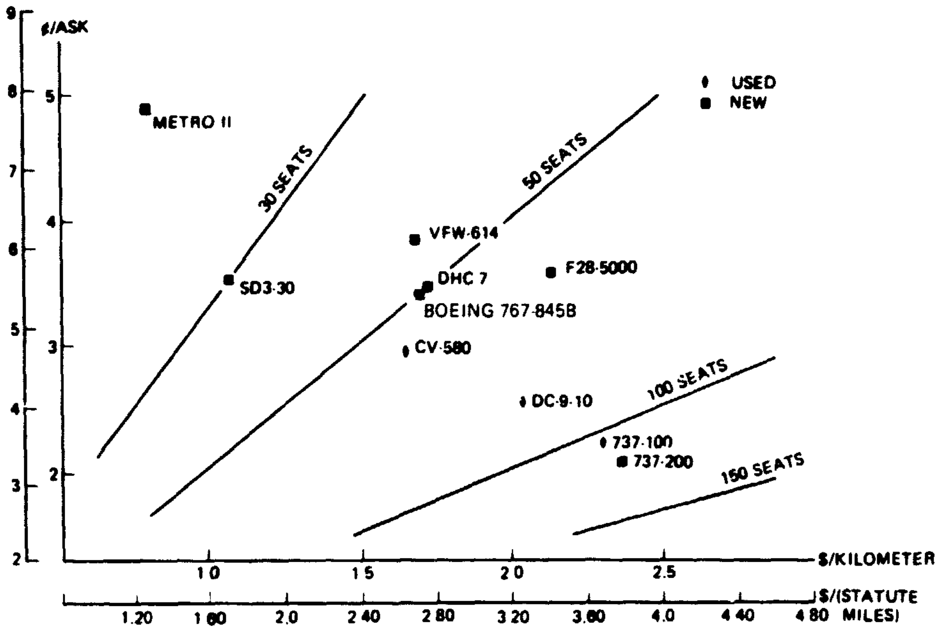


*Figure E   Direct Operating Costs, 1977 U.S. Domestic Rules
280-km (150-nmi) Average Trip, 1977 Dollars*

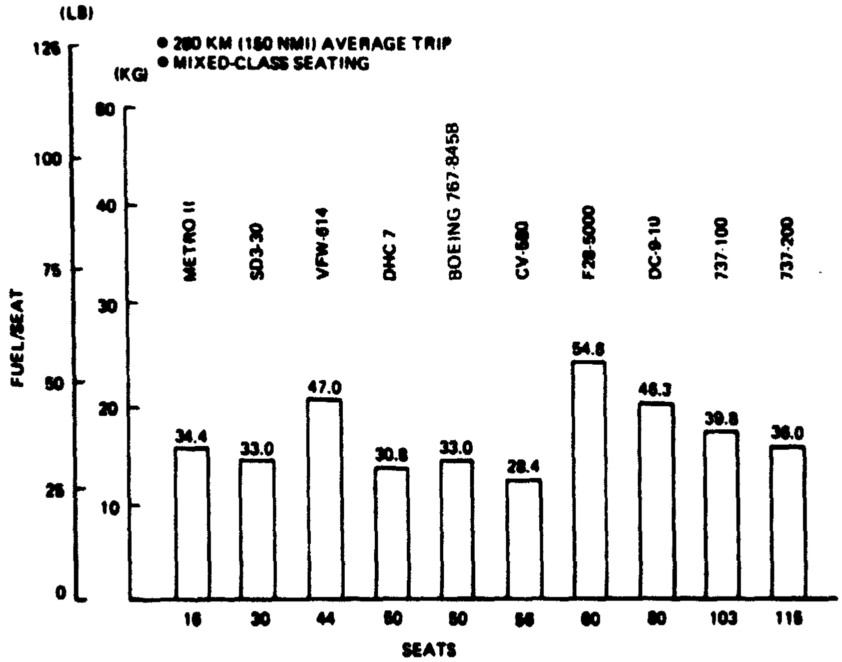


Figure F   Fuel-per-Seat Comparison

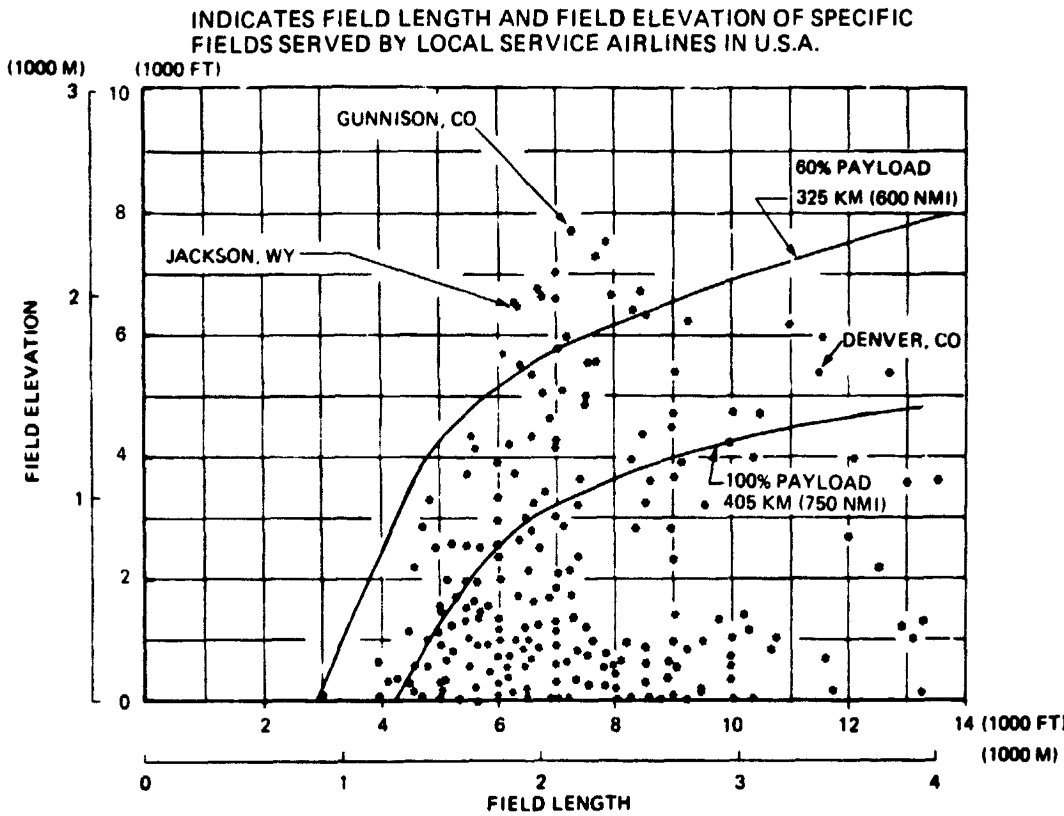


Figure G Advanced Short-Haul Transport Takeoff Field Performance

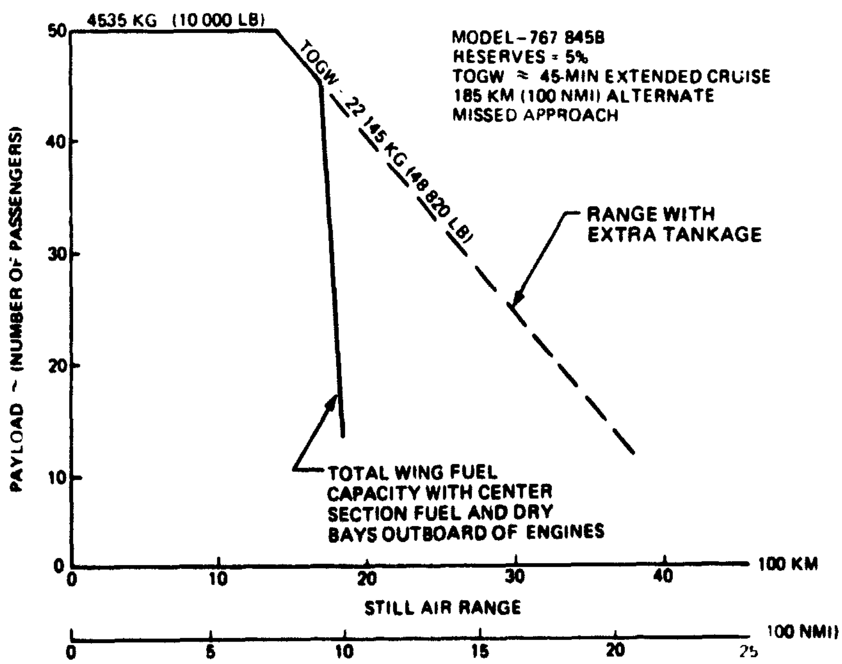


Figure H Advanced Short-Haul Transport—Payload vs Range

2.0 INTRODUCTION

The regional and commuter airlines in the United States are currently served by aging propeller airplanes for which there is no similar size modern replacement of U.S. manufacture. A need for an efficient, reliable, small, short-haul transport airplane exists, but, to date, no single airplane design has been able to resolve the diverse and exacting performance requirements at acceptable economic levels.

Any new transport for this market must have very low initial cost or the operator cannot afford it, but it also must be a modern pressurized design capable of operating from the short high-altitude fields characterizing the regional airline routes in the Western United States.

These critical economic requirements, with overpowering emphasis on low cost, performance, and operating requirements, provide a real challenge to the aircraft designer. NASA has studied the small (30 to 80 passenger), short-haul (50 to 1000 mile) CTOL transport many times in order to better understand the small community market and its transport requirements. To appeal to the traveling public and the community, the aircraft must offer excellent noise characteristics, passenger accomodations, and ride comfort when operating from community airports and over route structures involving low-altitude operations consistent with short-range lengths.

In the past, technology has been employed primarily to meet demanding performance goals, which usually results in increased costs. The question for the small short-haul transport then is, "Can new developing technology be exploited primarily to reduce costs and still maintain acceptable performance?"

Based upon these demanding performance requirements, this study accepted the challenge by investigating the possibility of exploiting various technological advancements for the primary purpose of providing a modern, high performing, small, short-haul transport at very low manufacturing and operating costs.

The study consisted of three tasks:

- Task I—Selection of design mission requirements and a current-technology baseline airplane configuration.

  The design mission requirements were based on operational and economic characteristics of the commuter and local service airlines serving the short-haul market. To reserve maximum effort for the task II technology study, previous Boeing-sponsored, low-cost, short-haul studies were used to select the baseline configuration.

- Task II—Examine advanced technologies as they appear individually or in combinations to meet the technical, economic, and performance objectives for the mission and airplane configuration selected during task I.

  Within the scope of this study, all technological advancements could not be examined in depth. Therefore, only the most promising cost savers were selected for detail design, with others receiving superficial examiniation or being postponed for more detail study later. The impact of the technological advancements was investigated using trade studies, which measured potential improvements through comparison with the task I current-technology baseline configuration.

- Task III - Incorporate into an advanced short-haul configuration only those technological advancements that had low-cost features and also had significant performance improvements.

  Only those advancements which had creditable cost assessments were incorporated into the baseline at this time. This configuration was performance-sized to meet the baseline-design mission requirements and the technological and economic performance was compared to the current-technology baseline to evaluate potential improvements.

Abbreviations and symbols are listed in section 3.0, the design mission and candidate configurations are discussed in section 4.0, the conventional-technology baseline airplane is defined in section 5.0, and the advanced-technology trade studies are summarized in section 6.0. Section 7.0 contains the advanced short-haul transport definition and evaluation results of the comparison to the conventional-technology baseline airplane. Recommendations for future research and technology comprise section 8.0.

3.0 SYMBOLS AND ABBREVIATIONS

A/C	air conditioning
APR	automatic power reserve
APU	auxiliary power unit
AR	aspect ratio (b^2/S_W)
ASK	available seat kilometers
AR_v	aspect ratio of the vertical
ASM	available seat miles
b	wingspan
BL	buttock line
BLKF	block fuel
BPR	bypass ratio
BS	body station
c	chord
c'	low-speed airfoil total chord with Fowler motion
CAB	Civil Aeronautics Board
c'/c	ratio of airfoil chord with total Fowler motion to basic airfoil chord
C_D	drag coefficient
c'_F	distance from airfoil rear spar to trailing edge, including Fowler motion
C_{D_L}	drag coefficient due to lift
$C_{D_{P_{MIN}}}$	parasite drag coefficient
C_L	lift coefficient
$C_{L_{MAX_{1G}}}$	maximum lift coefficient to maintain level flight
$C_{L_{MAX_{IN}}}$	maximum lift coefficient in ground effect
$C_{L_{MAX_{OUT}}}$	maximum lift coefficient out of ground effect
$C_{L_{MAX_{WT}}}$	maximum lift coefficient from wind tunnel
$C_{L_{S_{FAR}}}$	FAR stall lift coefficient
CLI	initial cruise lift coefficient
CLR	lift coefficient at initial cruise altitude capability to lift coefficient for maximum L/D
cm	centimeter

c_n	yawing moment coefficient
CTOL	conventional takeoff and landing
DA	drooped ailerons
DHC	de Havilland Corporation
DIA	diameter
DOC	direct operating cost
EPNdB	effective perceived noise measured in decibels
ESkW	equivalent shaft kilowatts
ESHP/ft^2	propeller disk loading in equivalent horsepower per square foot
ESKW/m^2	propeller disk loading in equivalent kilowatts per meter squared
FAR	Federal Air Regulation
FCS	flight control system
F_n	engine net thrust
FS	front spar
FWD	forward
GS	glide slope
H/C	honeycomb
HQSAS	handling qualities stability augmentation system
IAP	integrated actuator package
ICAC	initial cruise altitude capability
IEG	internal engine generator
ILS	instrument landing system
INBD	inboard
IR&D	independent research and development
keas	knots equivalent airspeed
kg	kilogram
kg/m^2	kilograms per square meter
km	kilometer
kN	kilonewton
kt	knot
kTAS	knots true airspeed
kVA	kilovolt ampere
lbf	pound force
L/D	lift-to-drag ratio
LE	leading edge

LH	left hand
m	meter
M	Mach number
MAC	mean aerodynamic chord
M_c	maximum operating Mach number
MDD	McDonnell Douglas
MDT	medium-density transport
MLG	main landing gear
MLW	maximum landing weight
mm	millimeter
N	newton
nam	nautical air mile
NC	numerical control
NDI	nondestructive inspection
NLF	natural laminar flow
N/m^2	newton per square meter
nmi	nautical mile
OEW	operational empty weight
OVBD	overboard
pcf	pounds per cubic foot
psf	pounds per square foot
RCS	ride control system
RH	right hand
RMS	root mean square
R/T	research and technology
SAR	still air range
sec	second
SFC	specific fuel consumption
Shp	shaft horsepower
SkW	shaft kilowatts
SHX	secondary heat exchanger
SL	sea level
SLST	sea level static thrust
SNP	stability neutral point
SOB	side of body

S_{REF}	reference area
S/S	skin and stringer
SSC	skin and stringer construction
S_W	wing area
TAI	thermal anti-icing
TBO	time between overhauls
t/c	thickness to chord ratio
TE	trailing edge
TOFL	takeoff field length
TOGW	takeoff gross weight
TSFC	thrust effective fuel consumption
TSO	Technical Standard Order
T/W	thrust to weight ratio
V_{APP}	approach speed
V_c	maximum operating cruise speed
$\overline{V}_H$	horizontal tail coefficient
V-N	velocity load
V_{ROT}	rotation speed
V_S	stall speed
V_{TAS}	velocity true airspeed
V_v	vertical tail volume coefficient
W/S	wing loading
η	distance to semi-span ratio
σ_{η_z}	rms vertical acceleration
α_W	wing angle of attack
δ_F	flap deflection
δ_{F_c}	flap angle
$\Delta C_{D_{GEAR}}$	landing gear drag coefficient
$\Delta C_{D_{\delta r}}$	drag due to rudder deflection
ΔW_F	incremental in fuel weight
$\Lambda_{C/4}$	sweep of quarter chord
^oC	degree Celsius
^oF	degree Fahrenheit

4.0 MISSION AND CANDIDATE CONFIGURATIONS DEFINITION

4.1 SUMMARY

This section discusses the investigation leading to the selection of an airplane design mission. It includes a synopsis of a recent route and marketing analysis, and the definition of two reference airplane configurations used to select specific design features for the baseline airplane.

The design mission was selected to be 50 passengers over 1400 km (750 nmi) at cruise speeds up to Mach 0.70 with emphasis on reducing airplane operating costs for short-haul (under 500 km) operations. The relatively high design cruise speed is in recognition of a potential demand for longer stage length applications. The basic design objective is to produce competitive operating costs and block times for short and medium range stage lengths.

4.2 SHORT-HAUL MISSION DESCRIPTION

The basic mission for the advanced small short-haul transport is to provide economical scheduled passenger service in markets that are too small, by level of traffic, to support 737 or DC-9 type airline service. Potential routes are those now being served by the regional airlines with old CV-580, FG-227, and M-404 equipment and the denser commuter airline markets. Regulatory reform and the service-to-small-community proceedings could have a dramatic impact on how these markets are served and the future composition of required airplane fleets.

Figure 1 is a 1980 Boeing projection of domestic onboard passengers, distributed by range and market density for all city pairs of the certificated air carriers. Most small community markets are contained in the 3.2% segment of 50 passengers per day and 465 km (250 nmi): the exceptions are those markets served through-stop with higher number of onboard passengers. The basic domestic scheduled passenger mission for the small short-haul transport falls within the market segment with routes under 930 km (500 nmi) and carrying fewer than 150 passengers per day—approximately 11% of the onboard passengers. Depending upon its relative economics, passenger frequency-of-service demand, and competitive service requirements, the study airplane also could penetrate the more dense and longer range markets (shaded area).

Table 2 lists the number of nonstop city pairs within each market density category and the percentage of total city pairs receiving nonstop service (including commuter airline service). While not addressing the quality of nonstop service, the percent of total city pairs receiving nonstop service is observed to be dropping in all market sectors listed. Particularly dramatic is the decline, from 81% to 39%, in the 500- to 1300-passenger per day segment of the 500-to-1300 km distance markets. One-stop or multi-stop operations in the under 500 km market inordinately adds to passenger travel time. The availability of a suitable small airplane could improve the quality of air service in the shorter ranges and stimulate air travel.

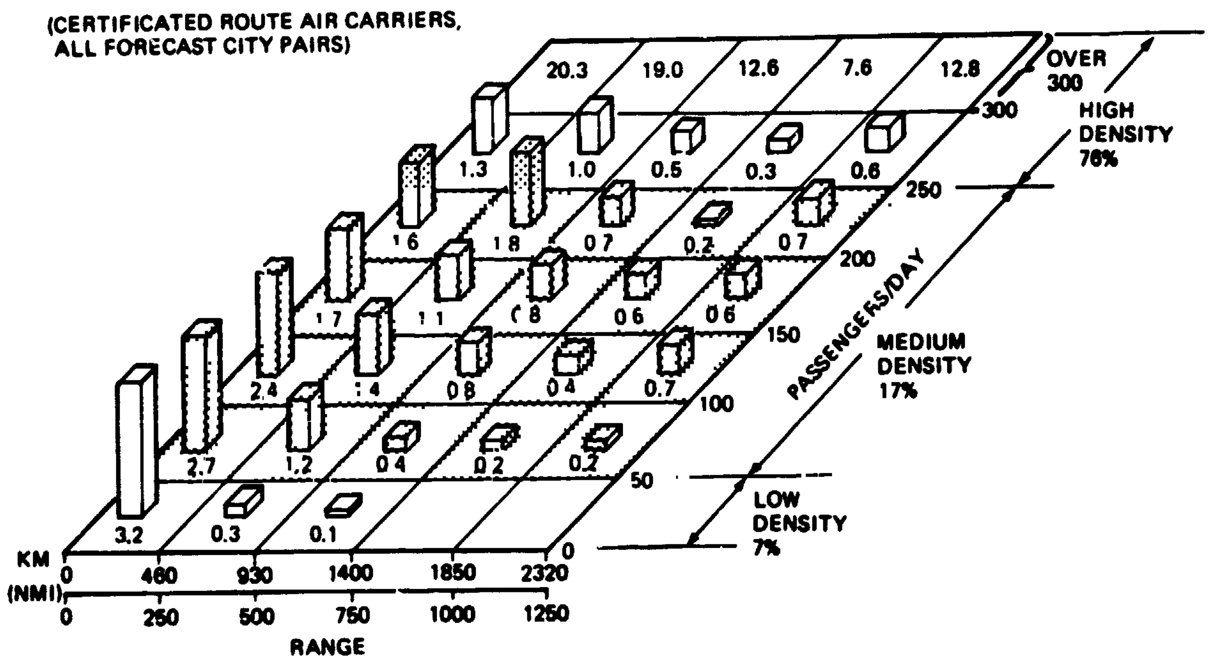


Figure 1 1980 Onboard Passenger Percentage Distribution, by Range and Density

Table 2 City Pair and Percent Nonstop Service – Historical Distribution by Market Size and Distance

MARKET SIZE (PASSENGERS PER DAY)												
DISTANCE	UNDER 500 KM (300 STATUTE MI)						500 TO 1300 KM (300 TO 800 STATUTE MI)					
PASSENGERS	20 — 49		50 — 99		100 — 199		20 — 49		50 — 99		100 — 199	
YEAR	* NO.	** %	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
1968	195	85	128	95	123	100	47	29	66	81	105	97
1970	190	72	129	87	98	96	53	15	83	48	118	88
1972	203	75	118	85	110	97	50	13	86	42	115	81
1974	198	76	124	84	104	94	42	10	69	33	123	80
1975	186	74	135	83	96	97	37	9	84	39	124	81

* NUMBER OF NONSTOP CITY PAIRS   ** PERCENT OF TOTAL CITY PAIRS

NOTE:
- September QRE nonstop service data
- Market size defined as O&D plus interline connect

4.3 MARKET ANALYSIS

4.3.1 DESIGN MISSION APPLICATION

In 1975 the domestic scheduled passenger market for small short-haul airplanes was studied in depth by the McDonnell Douglas Company under a NASA contract (reference 1) and by the Boeing Commercial Airplane Company. These studies attempted to project small airplane requirements as an extrapolation of the current environment for scheduled passenger service. Table 3 summarizes the market projections developed through these studies.

Several different factors that may influence the perceived operating environment for small, short-haul transports have surfaced since the 1975 studies. The impact of the oil crisis on the long-term demand for short-haul air transportation, possible changes in domestic airline Federal operating regulations and the small-community air service proposal of the Civil Aeronautics Board (CAB) could influence both design requirements and the marketplace for the small short-haul airplane. However, the 1975 studies do provide a reasonable, though uncertain, scope for viewing the market needs. Further study of market requirements developed for an extended time frame will be warranted following the enactment, or rejection, of the pending regulatory reform legislation.

4.3.2 OTHER AIRPLANE APPLICATIONS

Although this study was emphasized satisfying the needs of domestic scheduled passenger service in the shorter ranges, it is recognized that the airplane or its modifications must meet the competitive market requirements for other applications to increase the total market for the airplane in order to attain desirable production levels. Table 4 lists alternative applications for the small short-haul transport and the basic mission for which the airplane now is designed. Even if competitive airplanes are available, the market potential of a suitable small short-haul airplane for other applications could be considerable. As an example, figure 2 suggests a 1984 potential market requirement of approximately 3,000 aircraft of the 20-to-60 passenger capacity to satisfy the western-world scheduled air service needs now being served by larger propeller airplanes. In addition, the recent extensions of sovereignty over the world's coastlines have created a sizeable requirement for military and fisheries surveillance airplanes. Available production airplanes, from small single-engine models to large turbofan equipment with modifications, have been proposed to satisfy this requirement. With appropriate modification, the advanced-technology small short-haul airplane could fulfill some of these missions. Assessing the full market potential for a small short-haul, advanced-technology airplane for these applications will require extensive research that is beyond the scope of this project.

4.3.3 STUDIES DISCUSSION

McDonnell Douglas (with the assistance of representative airlines under subcontract) conducted an in-depth, 9-month study of the market requirements for small (30-to-80 passenger) short-haul airplanes under NASA contract (reference 1). The results were published in March 1975. Predicted passenger traffic within a specifically tailored traffic network (representative of a certificated regional carrier) and a mission computer model were used to evaluate airplane requirements and to analyze the airplane economic characteristics. The study also evaluated the impact of increased fuel cost on airplane operations.

Table 3 Market Requirements for 30–60 Seat, Short-Haul Turbofan Airplanes—U.S. Scheduled Passenger Service

• McDonnell Douglas	
STUDY CONTRACT NAS2-8135, MARCH 1975	
1985 REQUIREMENT FOR 30–60 PASSENGER AIRPLANES	103
• Boeing Commercial Airplane Company	
MARKET EVALUATION, 1975	
1980 MARKET POTENTIAL FOR 50-PASSENGER AIRPLANES, CURRENT SERVICE PROJECTIONS	190-239

Table 4 Market Applications for Small, Short-Haul Airplanes

- CIVIL TRANSPORT MARKET APPLICATIONS
  - DOMESTIC AND INTERNATIONAL OPERATIONS
  - PASSENGER, CARGO AND PASSENGER/CARGO COMBINATIONS
- SPECIAL REVENUE SERVICE
  - HIGH-VALUE CARGO
  - CHARTER MARKET
    - VACATION
    - BUSINESS TOURS
    - EQUIPMENT TRANSPORT
- PRIVATE OWNERSHIP
  - BUSINESS TRANSPORT
  - CARGO TRANSPORT
  - SURVEY AND INSPECTION
  - MOBILE SHOWROOM/FACILITY
- GOVERNMENT USE — CIVIL AND MILITARY
  - TRANSPORT
  - AREA SURVEILLANCE
  - SEARCH AND RESCUE
  - EVACUATION/HOSPITAL SERVICE
  - SYSTEMS TESTING AND PROVING
  - TRAINING

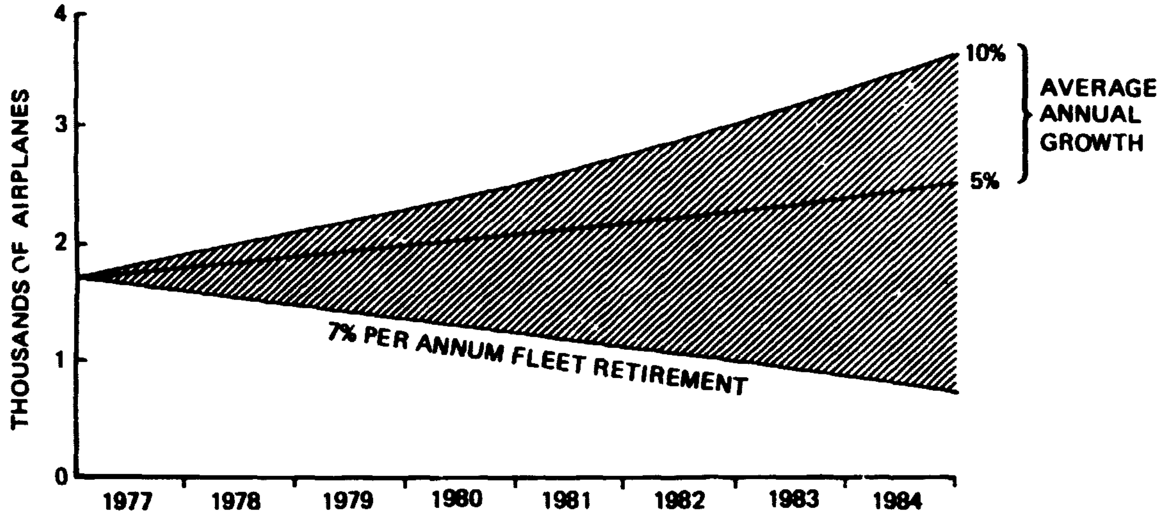


Figure 2 Potential Short-Haul Transport Market (20 – 60 Passenger Size), Western World Scheduled Service

During 1975, the Boeing Commercial Airplane Company analyzed the operations of the U.S. regional airlines to determine the market potential for a small short-haul airplane. Current traffic systems were projected to 1980 and the study airplane's market potential was evaluated under three separate scenarios: equipment requirements with and without study airplane availability, and for an all-jet fleet operation. The study airplane's application to the projected market was predicated on accommodating traffic demand at minimum cost while considering the influence of increasing frequency of service in the less dense travel markets.

Small-airplane operating costs, relative to 737/DC-9 type airplanes, had a prime influence on the forecasts made in these studies. Even though this work was developed from baseline airplanes different from the advanced technology airplane presented in this document, they do provide a spectrum of potential market requirements as projected from the 1975 operating environment.

4.3.4 SYSTEM AND ECONOMIC CHANGES

Recent abrupt system and economic changes have increased market projection uncertainties for domestic scheduled passenger service.

The energy crisis and subsequent increases in fuel prices have influenced the demand for air transportation in the short-haul markets. As fuel prices continue to rise, further diversion from the automobile to the airplane for short trips may occur. The commuter airlines have been developing joint-fare agreements with the certificated carriers and are striving for legislated joint-fare participation as part of their program to become a more recognized part of the U.S. air transport system. Convenient joint-fare flights feeding the long-distance carriers also are drawing passengers away from automobile travel for short distances.

The projected influence of regulatory reform on short-haul airplane requirements is uncertain at this time. However, the service-to-small-community proposal, which has the support of the CAB, may increase the demand for small airplanes to serve these markets. The subsidy now being proposed is based on the cost for 15-passenger, twin-turboprop operation of at least two flights per day to communities boarding 40 or fewer passengers per day. These flights would provide transportation to the nearest, most convenient large airport. The final form of small-community air service legislation, and resolutions concerning through-stop service to these communities, may increase the requirement for the small short-haul airplane considered in this study.

More precise estimates of passenger demand for a particular flight could allow the airlines to match airplane size closely with a particular market. Advanced booking and group charter programs are improving this correlation. Increased economic pressures, as well as regulatory action, could increase demand for smaller airplanes.

Fundamental to the study of advanced technologies for small short-haul airplanes is the effort to reduce their seat-mile operating costs relative to the larger turbofan equipment. As noted, market requirements for the study airplane are sensitive to its relative economics. Therefore, as a follow-on to advanced technology application studies, market projections based on airplane price and the resulting economics should be pursued. Such studies, in addition to projecting current operations, should investigate potential economic changes and their influence on demand.

4.4 BASELINE MISSION CHARACTERISTICS

Evaluating short-haul route systems and markets led to the preliminary definition of design mission requirements used for this study. Table 5 lists these requirements, and table 6 shows mission definitions selected to comply with all requirements and compliment earlier short-haul studies.

The relatively high cruise speed was selected with the knowledge that even though the basic scheduled passenger mission for this airplane is in the very short-range category, the airplane also could serve in the longer-range thin markets as a function of the attainable relative economics. As flight ranges increase, the optimum cruise speed increases relative to both minimum cost and competitive flight times.

4.5 REFERENCE AIRPLANE DEFINITIONS

The mission requirements and design criteria established for the present study closely match the airplane configuration resulting from previous Boeing short-haul transport analyses (ref. 2). The first reference airplane, the Wichita medium density transport (MDT), was considered as a possible current-technology baseline. However, this aircraft was analyzed under different ground rules from the present study and it is presented here as a reference airplane for information purposes only.

4.5.1 WICHITA MEDIUM-DENSITY TRANSPORT

The MDT study used existing short-haul routes and computer marketing analyses to select the optimum payload size and cruise speed for the given routes. It also used extensive Class I parametric trades to select the optimum wing planform for a defined airplane size and design cruise speed. Using selected data from the MDT to establish the current-technology baseline airplane for this study enabled the current study to emphasize advanced technology, the area in which large payoffs should be found.

Table 5 Airplane Design Mission Requirements – Preliminary Definition

RANGE	1100–1300 KILOMETERS (700–800 STATUTE MILES) IS REASONABLE, 90% OF THE STAGE LENGTHS ARE EXPECTED TO BE UNDER 500 KILOMETERS (300 MILES). RANGE REQUIREMENTS ARE BASED ON THROUGH-STOP OPERATIONS.
SPEED	DESIGN SPEED SHOULD BE OPTIMIZED FOR BEST AIRPLANE ECONOMICS WHILE PROVIDING OPERATIONAL BLOCK TIMES WITHIN 10 MINUTES OF A M0.75 AIRPLANE AT 240 KILOMETERS (150 STATUTE MILES).
AIRFIELD PERFORMANCE	FULL PAYLOAD TO 500 KILOMETERS (300 STATUTE MILES) OF A 1220-METER (4000-FOOT) FIELD IS ADEQUATE. REASONABLE HOT-DAY/HIGH-ELEVATION AIRPORT PERFORMANCE IS REQUIRED.
PASSENGER COMFORT	A MODERN, QUIET INTERIOR IS REQUIRED. DUE TO THE SHORT TRIP TIME, ONLY MINIMAL INTERIOR FEATURES ARE NECESSARY. DENSE SEATING WITH NONRECLINING SEATS WILL BE CONSIDERED. PRESSURIZATION IS REQUIRED.
SAFETY AND ENVIRONMENT	THE AIRPLANE MUST MEET ANTICIPATED REGULATORY STANDARDS.
SIZE	PASSENGER CAPACITIES OF 30 TO 60 SHOULD BE CONSIDERED. FINAL SIZE OR SIZES WILL BE A FUNCTION OF ATTAINABLE ADVANCED AIRPLANE ECONOMICS, INDEPTH MARKET STUDIES, AND INDUSTRY RESPONSE.
OPERATING	A GOAL FOR A 30–60 SEAT AIRPLANE OF 1/2 TO 2/3 THE COST PER MILE OF A MODERN 56 165-KILOGRAM (115 000-POUND) TOGW TURBOFAN AIRPLANE (737-200) IS REASONABLE. MAXIMUM ACCEPTABLE MILE COSTS ARE 2/3 TO 3/4 THAT OF THE LARGER AIRPLANE.

Table 6 Small Short-Haul Transport Baseline Mission Definition

	PAYLOAD	
	30 PASSENGERS	50 PASSENGERS
RANGE	1100 KM (600 NMI)	1375 KM (750 NMI)
SPEED	UP TO 0.70 MACH	UP TO 0.70 MACH
ALTITUDE	≥ 7600 M (≥ 25 000 FT)	≥ 9150 M (≥30 000 FT)
FIELD LENGTHS		
SL, 32°C (90°F)	1370 M (4500 FT)	1370 M (4500 FT)
1830 M (6000 FT), 32°C (90°F)	REASONABLE	REASONABLE
V_{APP}, MLW, 32°C (90°F)	205 KM/HR (110 KTS)	205 KM/HR (110 KTS)

RESULTING APPROXIMATE AIRPLANE DESIGN CRITERIA

W/S = 340–490 KG/M^2 (70–100 PSF)
T/W = 0.34–0.38
t/c = 0.12–0.16 (0 RAD, 0° SWEEP)

Figure 3 shows the Wichita MDT configuration: its prinicpal features are listed in table 7. The fuselage cross-section is shown in figure 4, the inboard profile in figure 5, and the passenger or freight interior arrangements in figure 6. Efficient aircraft servicing is very important to a short-haul operator because the airplane makes many stops each day. Figure 7 shows the aircraft servicing arrangements for both through-stop and turn-around servicing. The operating plan is to refuel and reprovision the airplane only during turnaround stops. The remaining MDT principal characteristics are shown in table ".

Many of the key features and design characteristics of the Wichita MDT were used directly on the current-technology baseline airplane defined in section 5.0.

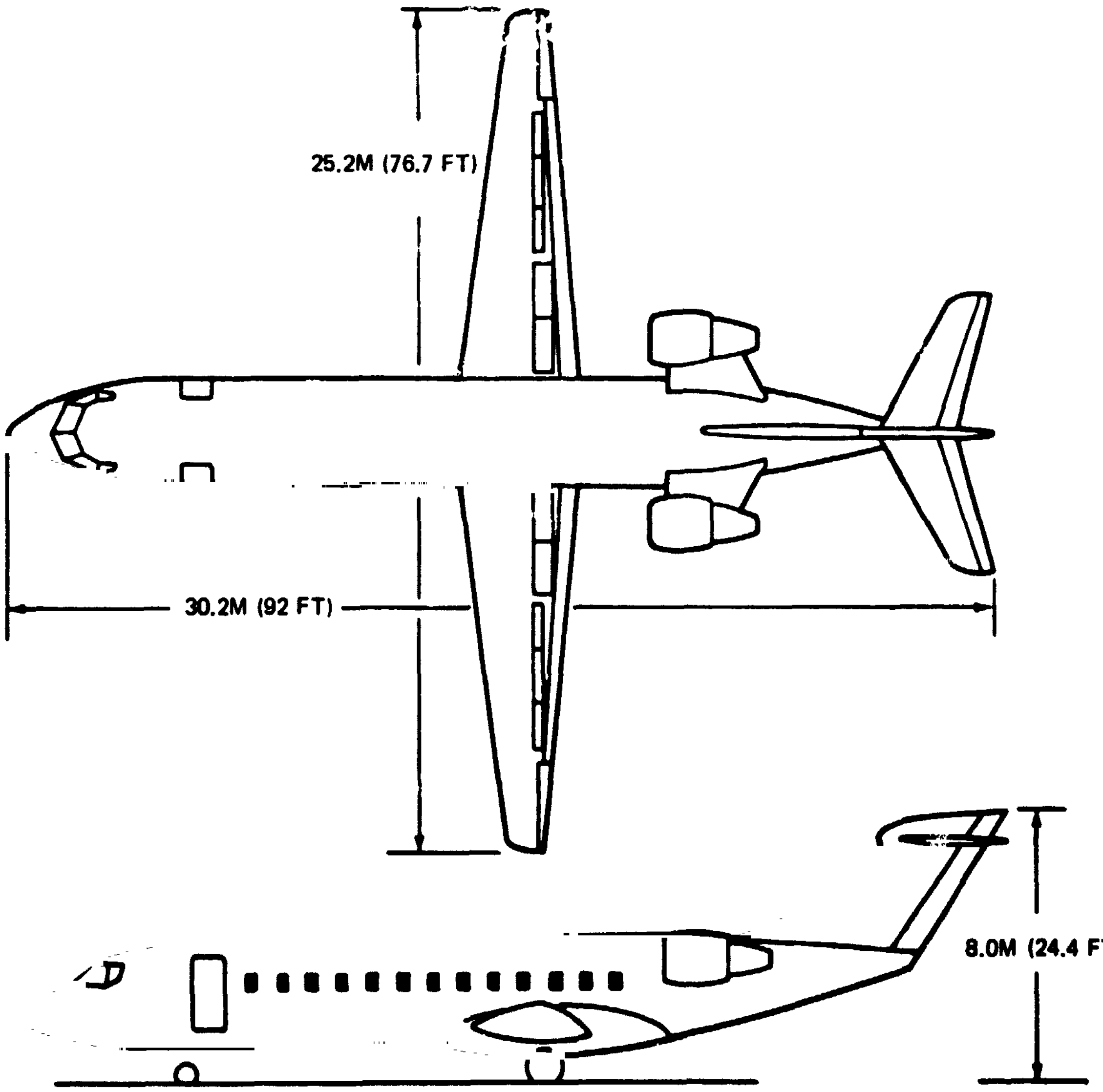
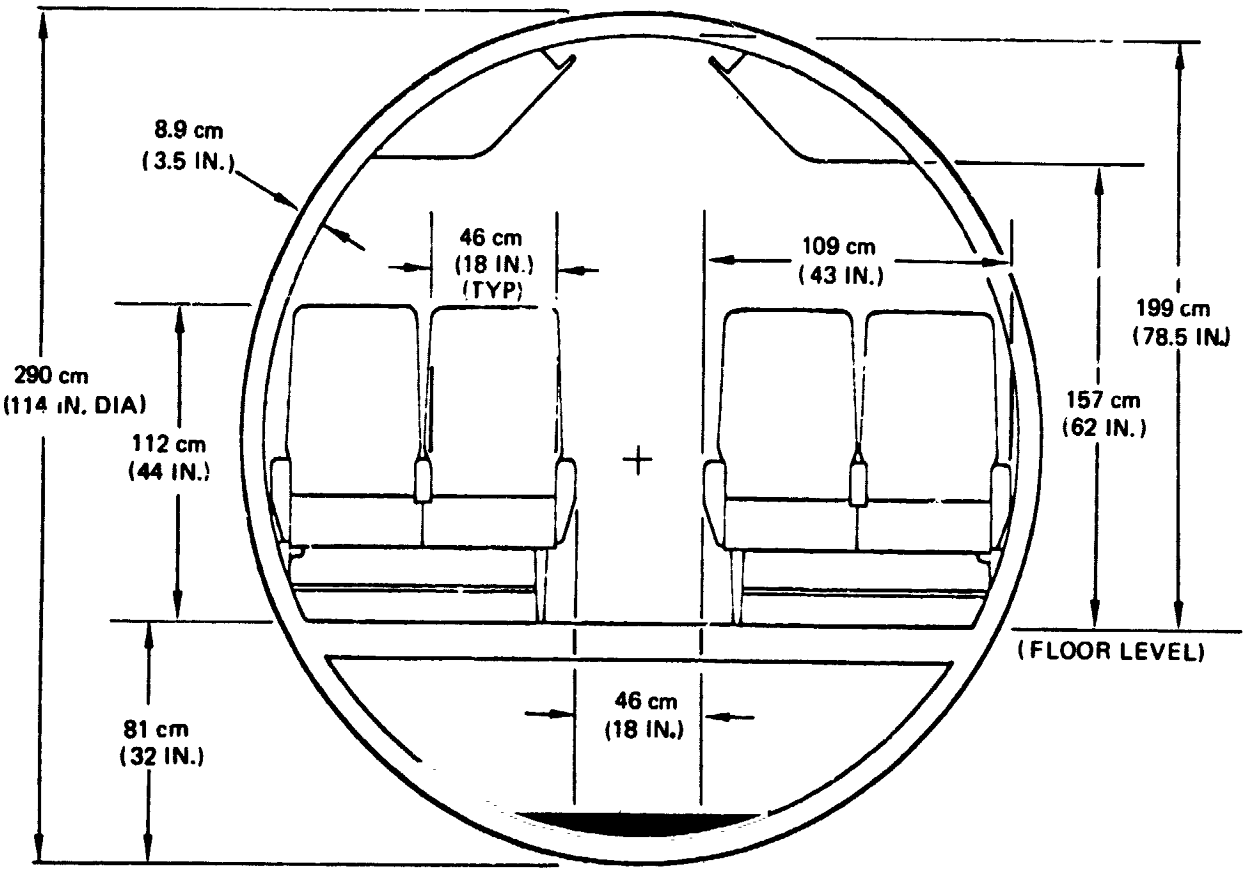


Figure 3 Wichita Medium-Density Transport — 50 Passengers



Fuselage Cross-Section

Figure 4 Medium Density Transport

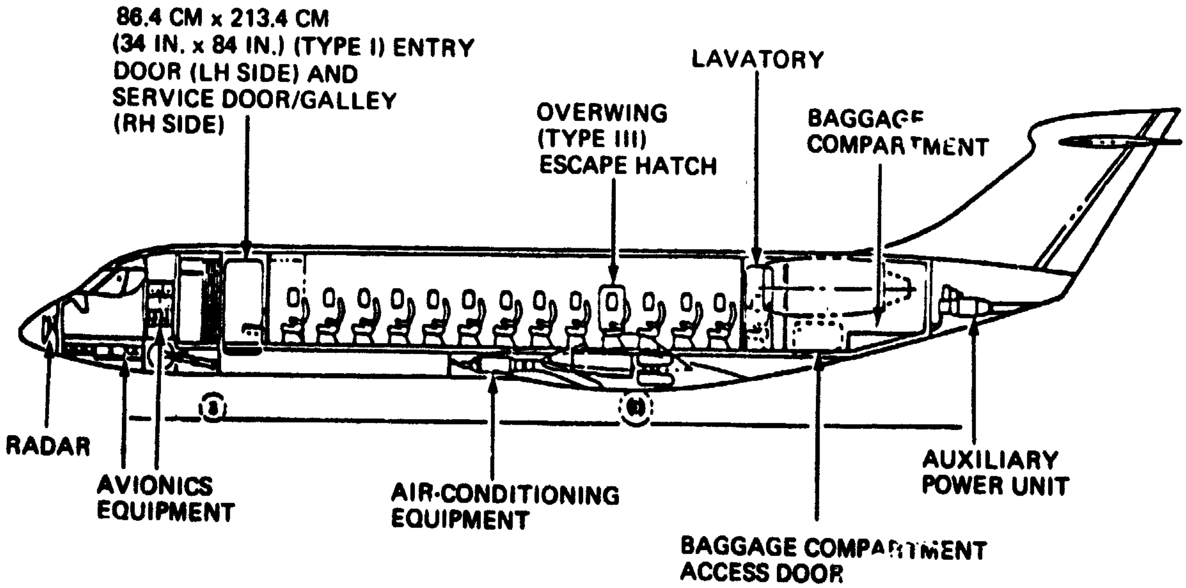


Figure 5 Medium Density Transport Inboard Profile

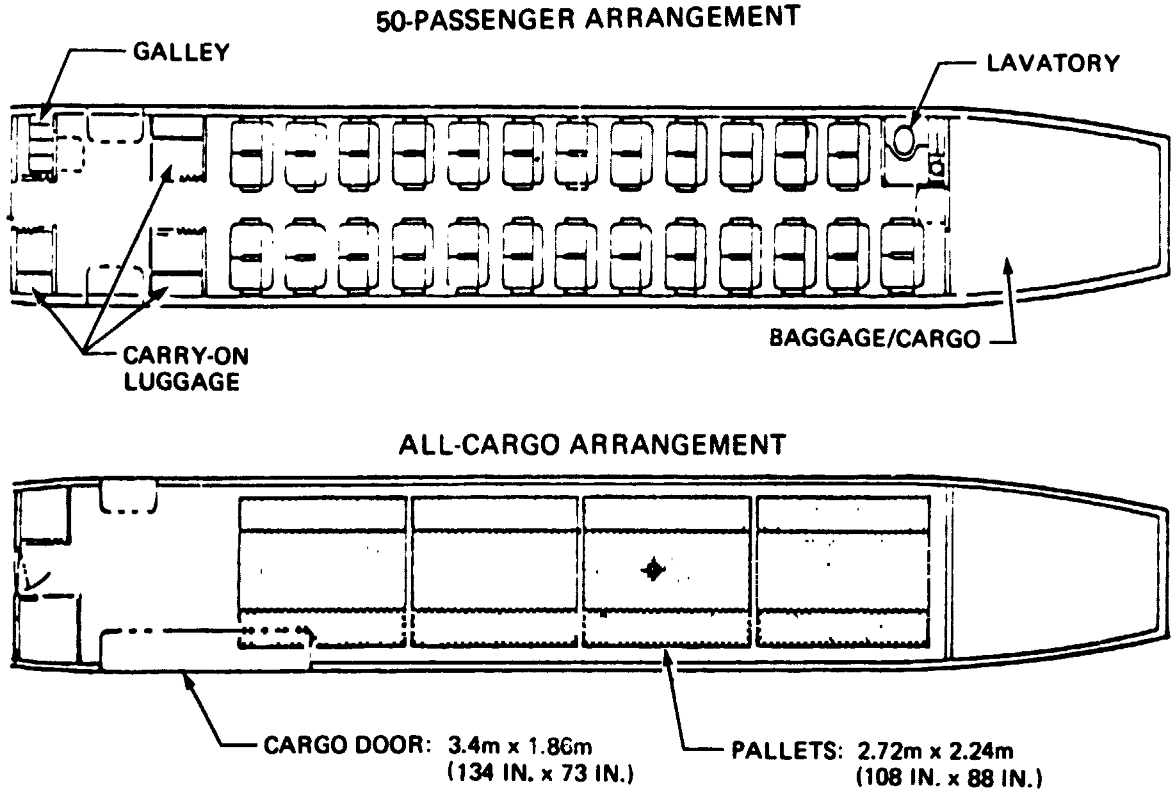


Figure 6 Medium-Density Transport Deck Plan

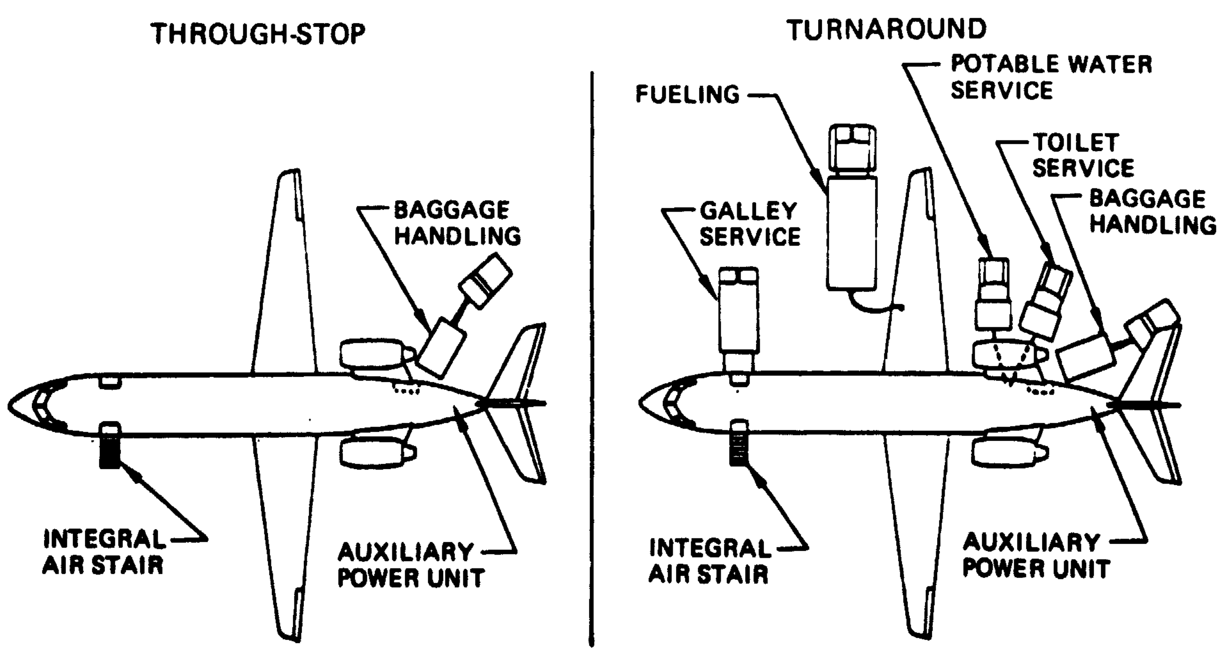


Figure 7 Medium-Density Transport Aircraft Servicing

Table 7 Principal MDT Features

- Modern Turbofan Engines
  - Good fuel economy
  - Meet FAR/ICAO noise requirements
  - Meet 1980 U.S. emission standards
  - Off-the-shelf
- "Jet Quality" Passenger Accommodations
  - 0.9-meter (34-inch) seat pitch, four abreast
  - Superior head room
  - 0.5-meter (18-inch) wide aisle
  - Under-seat and overhead stowage
  - Large stowage for carry-on luggage
- Self-supporting
  - APU
  - Integral air stairs

Table 8 Reference Airplane (MDT) Configuration Principal Characteristics

Maximum taxi weight, kg (lb)	21 450	(47 300)
Zero fuel weight, kg (lb)	18 410	(40 600)
Operating empty weight, kg (lb)	13 880	(30 600)
Number of seats at seat pitch	50 at 1.27 m	50 at (34 in.)
Power plant	GE CF-34	
Wing area, m^2 (ft^2)	62.6	(674)
Wing span, m (ft)	25.0	(82)
Maximum wing loading, kg/m^2 (lb/ft^2)	341.8	(70)
Overall length, m (ft)	28.6	(94)
Fuel capacity, liters (U.S. gallons)	11 850.0	(3130)
Cargo volume, lower lobe, m^3 (ft^3)	2.8	(100)
Cargo volume, main deck, m^3 (ft^3)	4.5	(160)
Cargo volume, main deck (all-cargo) configuration, m^3 (ft^3)	54.4	(1920)

4.5.2 BOEING LOW-COST AIRPLANE

The second reference airplane emphasizes low manufacturing cost. It is the result of a Boeing-sponsored 1976 study to investigate cost-reduction design features appropriate to small, short-haul aircraft. Most of these low-cost features are shown in figure 8. This study showed the importance of reducing part count and labor to reduce overall manufacturing costs.

Unfortunately, many of these cost-reducing features, such as the strut-braced constant section wing, proved to be performance reducing features as well and the airplane shown (model 767-759B) cannot meet the current design mission requirements with the CF-34 engines shown. Many other features of the model 767-759B proved to be very cost effective and were incorporated into the baseline airplane defined in the next section.

These features, which measurably reduce overall airplane cost, include: bonded aluminum honeycomb structure, simple wing-body joint, no body cutouts for main landing gear (no keel beam), and all doors in the constant section of the body.

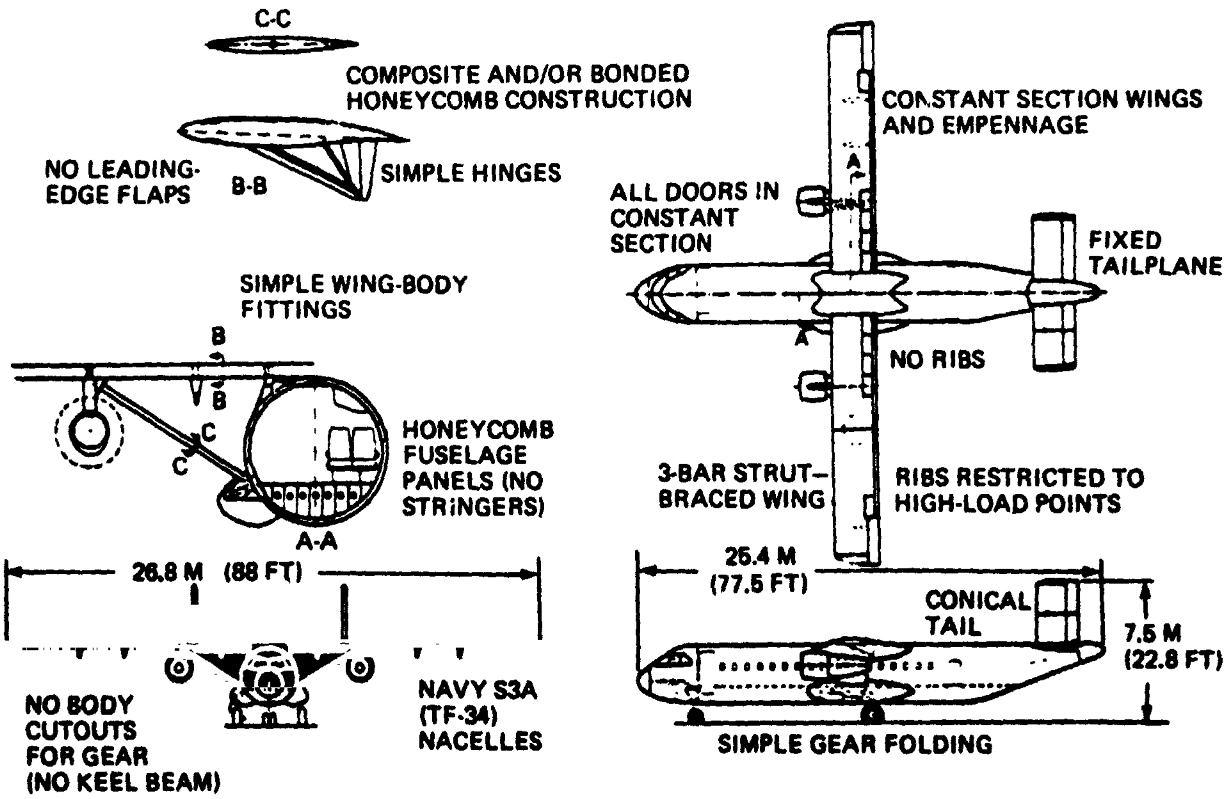


Figure 8 Low-Manufacturing-Cost Features, Model 767-759B

5.0 CURRENT-TECHNOLOGY BASELINE AIRPLANE AND ANALYSIS

5.1 SUMMARY

This section analyzes the current-technology baseline airplane configuration. It describes the short-haul airplane operational criteria and basic design philosophy used to define the uncycled (not performance sized) current technology baseline airplane, model 767-774A. The airplane individual analyses include: aerodynamics, structures, weights, propulsion, noise, flight controls, systems, and performance sizing.

5.2 SHORT-HAUL DESIGN PHILOSOPHY

A successful small, short-haul-transport depends more than most commercial airplanes on low initial cost and good operational economics. The operational characteristics required for a successful small, short-haul transport have been summarized in the following design philosophy:

I. THE AIRPLANE SHALL BE DESIGNED FOR LOW OPERATING COSTS

A. The airplane must have excellent through-stop characteristics

1. All maintenance done at home-base hangar
2. Modular systems approach - no spares at the through-stop airport, redundant systems in airplane where necessary
3. Carry-on baggage provisions-minimum personnel needed at through stops
4. Adequate range to fuel at turnarounds only

B. Maintenance costs shall be minimized

1. Design for simplicity (which could result in weight and drag penalty)
2. Planned dedicated raceways for wiring/hydraulics (might be external)
3. Simple flaps with no leading-edge devices
4. Derated turbofan engine-minimize variable geometry through advanced technology

C. Fuel costs shall be minimized

1. Select configuration for low drag (high aspect ratio wings, smooth curved windshield, drag reduction fairings, etc.)
2. Fuel-efficient high-bypass/turboprop engines
3. Computerized autopilot and navigation

D. Airplane acquisition costs shall be minimized

1. Advanced structure to substantially reduce parts count and labor hours
2. Simplified design to reduce engineering hours
3. Reduced system costs through advanced design
4. Twin-engine airplane design

E. Crew costs shall be minimized

1. Minimum block time operation through advanced avionics
2. "Mom and pop" crew operation where copilot functions as steward/stewardess during flight?

II. THE AIRPLANE SHALL BE DESIGNED FOR GOOD PASSENGER APPEAL AND COMFORT

A. Cabin comfort and pressurization level shall be equivalent to a 737

1. Four-abreast with standard seat widths
2. Thirty-two-in. pitch standard—34 in. with reclining seat
3. Provision for pressurization to 10 700 m (35 000 ft) and above with onboard oxygen system (alternate would be pressurization to 7620 m (25 000 ft) and bottled oxygen)
4. Airplane designed to give the commuter passenger between Roseburg, Oregon and Portland International Airport the same feeling of security that he has when he transfers to a 727-200 bound for Denver

B. The airplane shall have acceptable ride standards

1. Advanced ride control system?
2. Higher wing loading or more flexible wing?

5.3 CURRENT-TECHNOLOGY BASELINE AIRPLANE DEFINITION

The current-technology baseline airplane (model 767-774A) (fig. 9) has features of both reference airplanes discussed in section 4.0. The baseline airplane has numerous added low-cost design features, such as external wing mounting, external main-gear stowage, and conical aft-body section. The external wing mount simplifies the body structure, reducing part count and labor hours. Mounting the main gear externally eliminates the need for a structural keel beam and a pressurized floor above the wheel well, which requires many additional parts and extensive final assembly time.

The high-wing, wing-mounted engine configuration was preferred to the low-wing, aft-mounted engine configuration for four reasons. First, a configuration with wing-mounted engines has far better balance characteristics (less c.g. travel with loading because the wing is more centrally located on the fuselage and has a longer tail moment arm), which are especially important below the 40-passenger size. Second, it is desirable to study advance turboprops (propfans) as an alternate power plant for the basic or derivative airplane configurations, and this is a more direct comparison if the basic configuration has wing-mounted engines. Third, the integral door/loading-ramp concept, which is a highly desirable feature on a small short-haul airplane, requires a floor low to the ground to function properly. A low-wing airplane would require the wing to be integrated into the fuselage to keep the proper floor height, negating a major cost-saving device. Finally, the engine on the wing provides bending relief for a reduction in wing weight. Based on the Boeing Wichita MDT studies (ref. 3), aspect ratio (10.0), sweep (4.5 deg), taper ratio (0.275), and t/c (root 15%, tip 12%) were chosen as the baseline wing geometry. A 30-passenger derivative is shown in figure 10 and two 50-passenger seating arrangements are shown in figure 11.

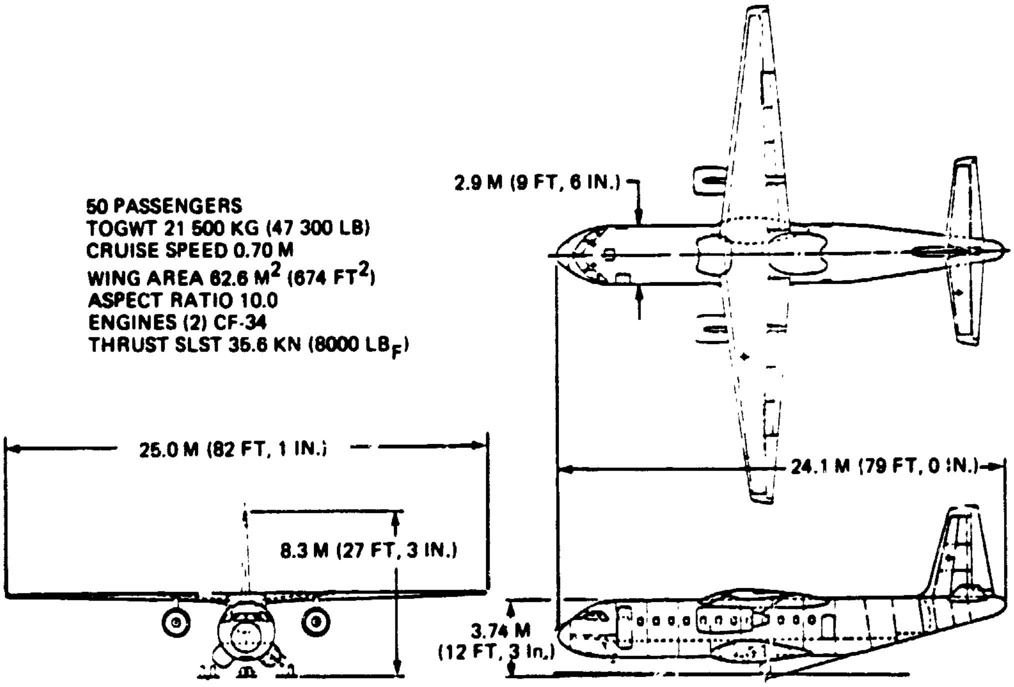


Figure 9 Uncycled Baseline Airplane, Model 767-774A

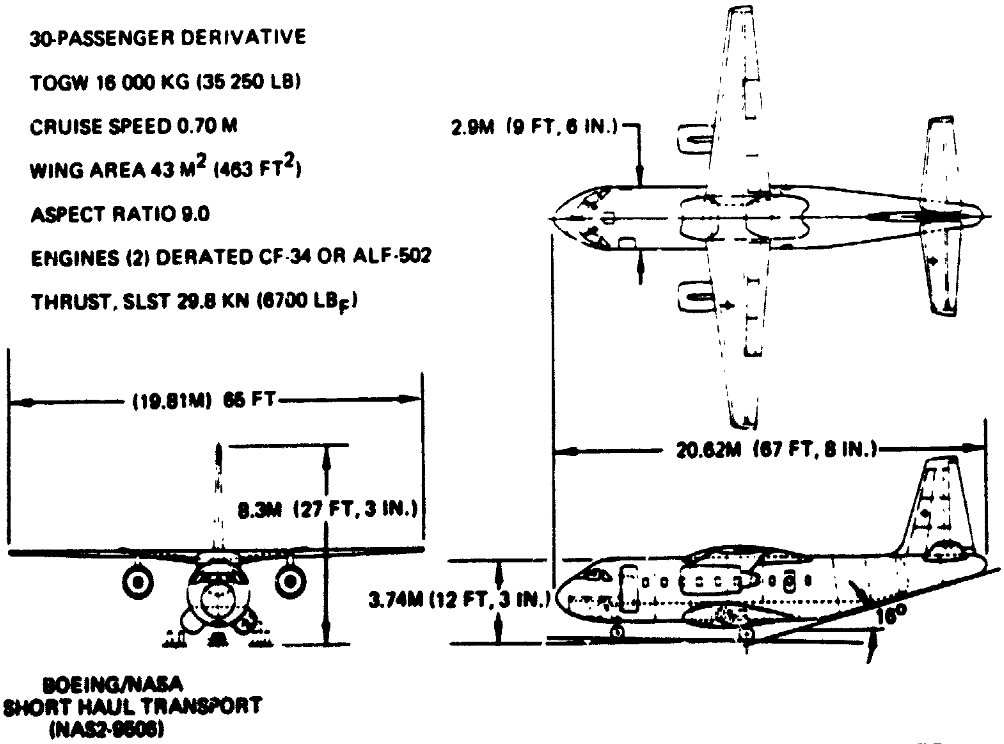
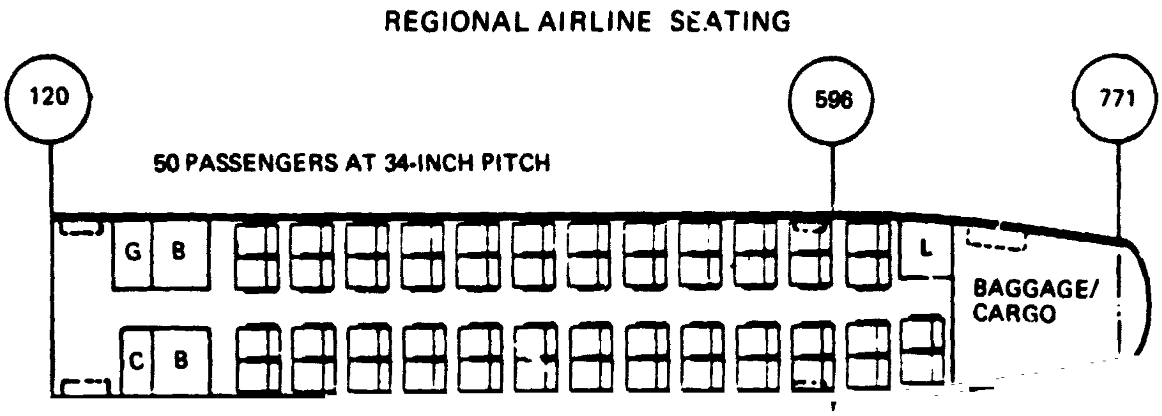


Figure 10 30-Passenger Derivative Airplane, Model 767-777



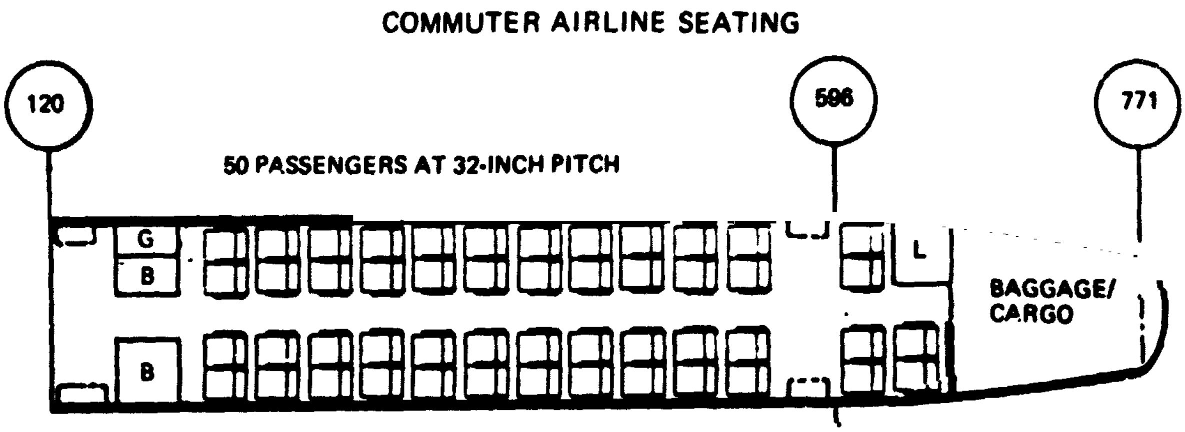


Figure 11 Seating Arrangements

5.4 AERODYNAMIC ANALYSIS

The high-speed drag, high-lift system and low-speed performance of the conventional-technology baseline airplane are discussed in this section. The low-speed capability with a leading edge device provides good L/D ratios at relatively high takeoff C_L. However, approach C_L capability is marginal for meeting objective approach speeds and landing field lengths.

5.4.1 HIGH-SPEED DRAG

The high-speed drag polar for model 767-774A is shown in figure 12. Airplane drag characteristics are based on current Boeing technology wing airfoil design and reflect recent wind-tunnel data. The wing has a linear ratio in t/c from root to tip; thus the mean aerodynamic chord represents the typical wing section for drag rise and polar shape characteristics. At 0.70 Mach, a maximum L/D of 17.0 is obtained at C_L = 0.65. Investigation of the individual airplane parasite drags shows the gear-pod drag to be a significant component. Reducing the gear-pod drag by half (slimmer pod) would improve cruise drag by about 2%. An example drag breakdown is shown in section 7.4.

5.4.2 HIGH-LIFT SYSTEM

Low-speed performance characteristics for the 767-774A are based on a new variable-camber trailing-edge flap concept (fig. 13). Deflection of a 0.27c single slotted flap with Fowler action (0.17c) is combined with a variable camber bending of the wing upper surface aft of the rear spar location (0.60c), and a simultaneous lowering and drooping of the wing spoilers. This provides, in effect, a very large extended trailing-edge flap chord of 0.57c in the landing-flap configuration as shown in figure 14. Spanwise locations of the trailing-edge flaps are as indicated in figure 9; the flaps extend from the fuselage side (η = 0.092) to the wing ailerons (η = 0.729) with a small cutout for engine pylons (η = 0.020). However, chordwise locations of spoilers are further aft than indicated in figure 9, with the flap cove, or spoiler trailing edge, located 0.90c as depicted in figure 14. Flap actuation is assumed to be accomplished by a combination of internal linkage and external flap tracks.

To provide for landing approach at a positive angle of attack for this combination of large effective flap chord with the high-aspect ratio, unswept wing, the slotted flap deflection was limited to values of 0.5 rad (30 deg). Figure 13 shows the schedule of effective flap cove deflection and Fowler actions with flap deflection angle used to maximize the benefit achieved from the drooped spoiler and variable-camber features of this system. These arrangements provide high level of lift and L/D capability relative to conventional flap systems as a result of the combination of large effective flap chord with relatively low flap deflection angles.

Estimated lift curves and L/D envelopes for takeoff and landing are presented for the 767-774A without wing-leading edge devices in figures 15 and 16. Figure 17 contains incremental drag due to the rudder deflection. The yawing drag for the airplane is low, due to relative long tail moment arm and high vertical-tail aspect ratio.

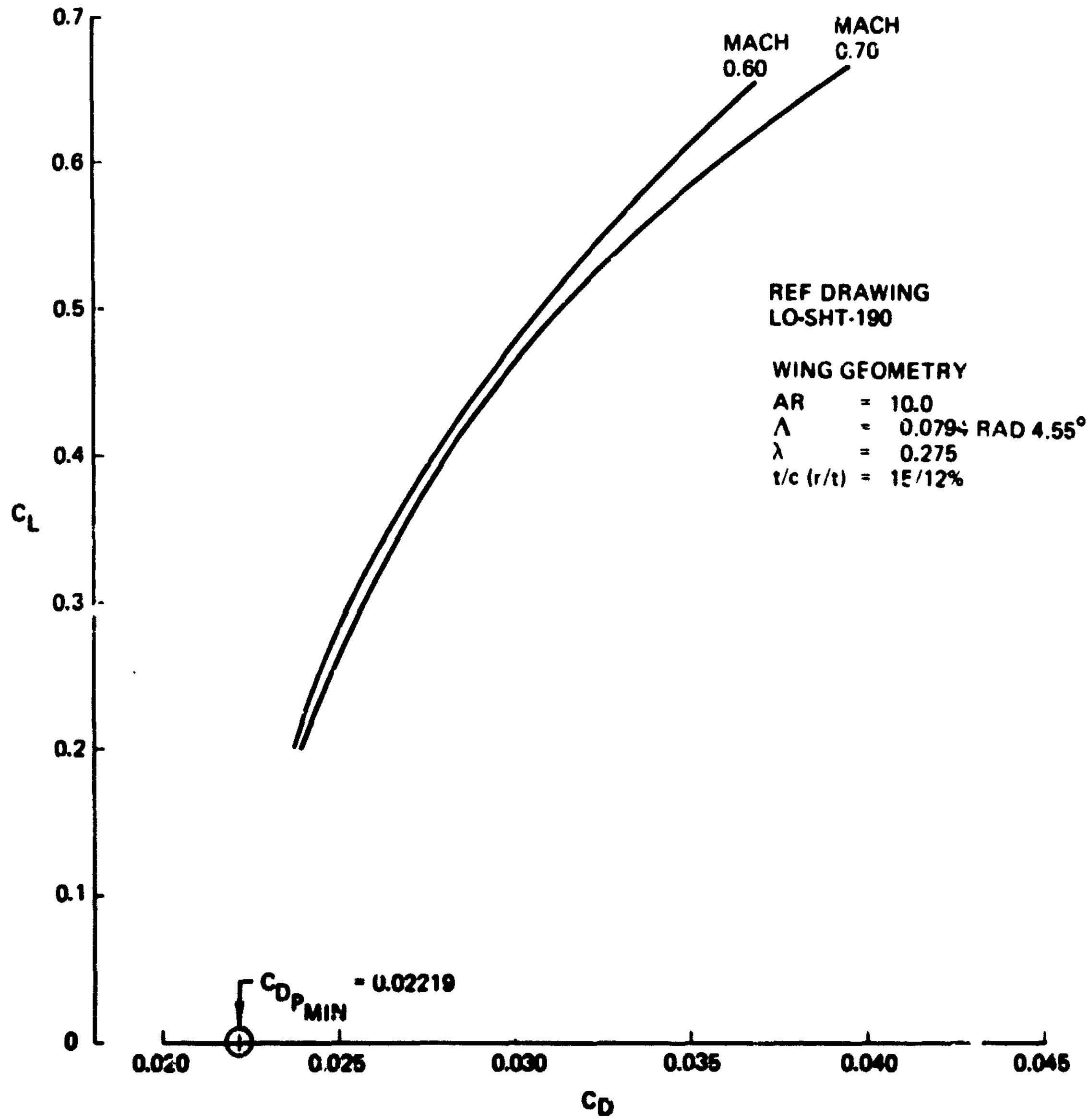


Figure 12 Short-Haul Transport Drag Polar, Model 767-774A

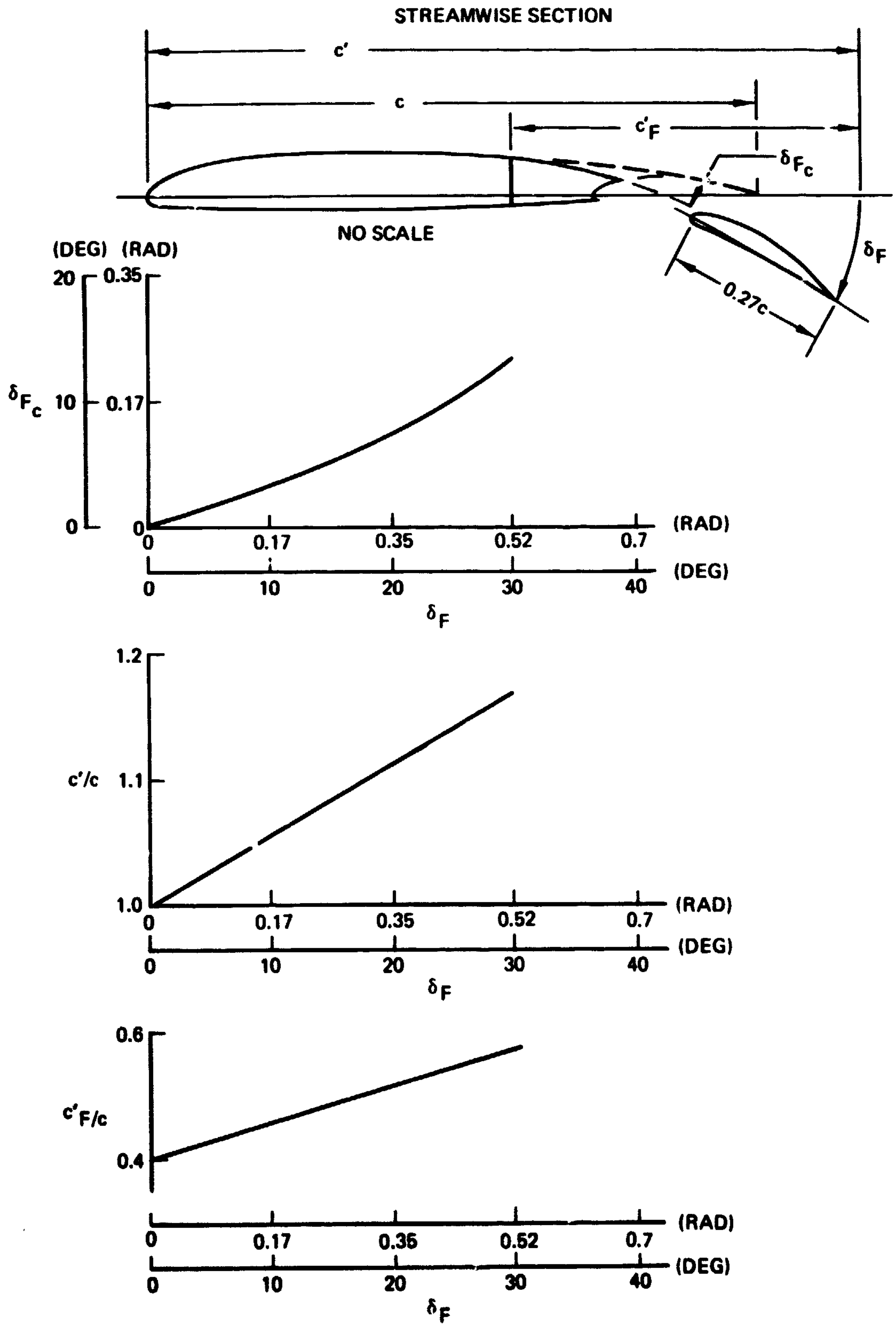


Figure 13 High-Lift System, Model 767-774A

STREAMWISE SECTION

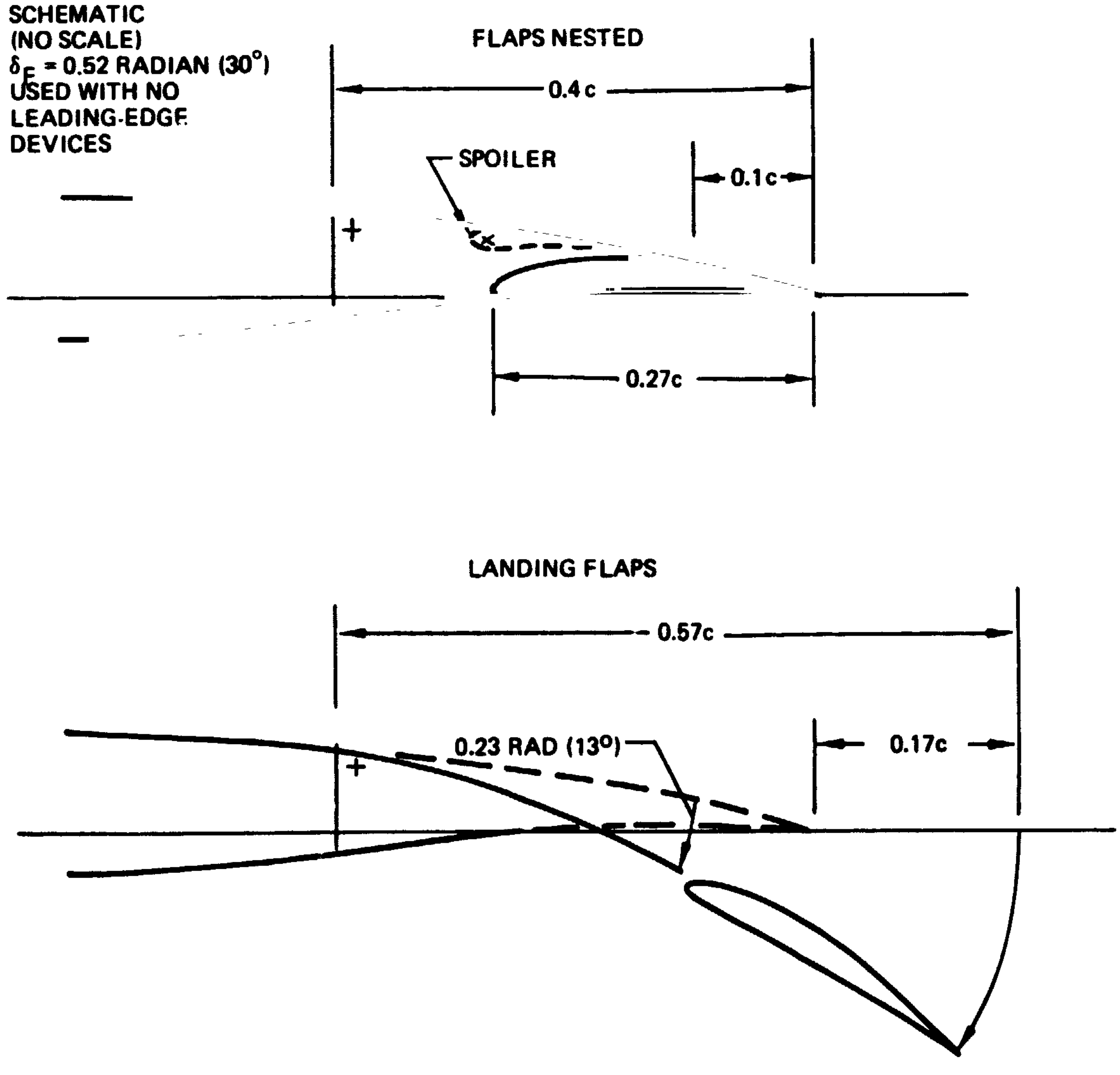


Figure 14 Short-Haul High-Lift System Schematic, Model 767-774A

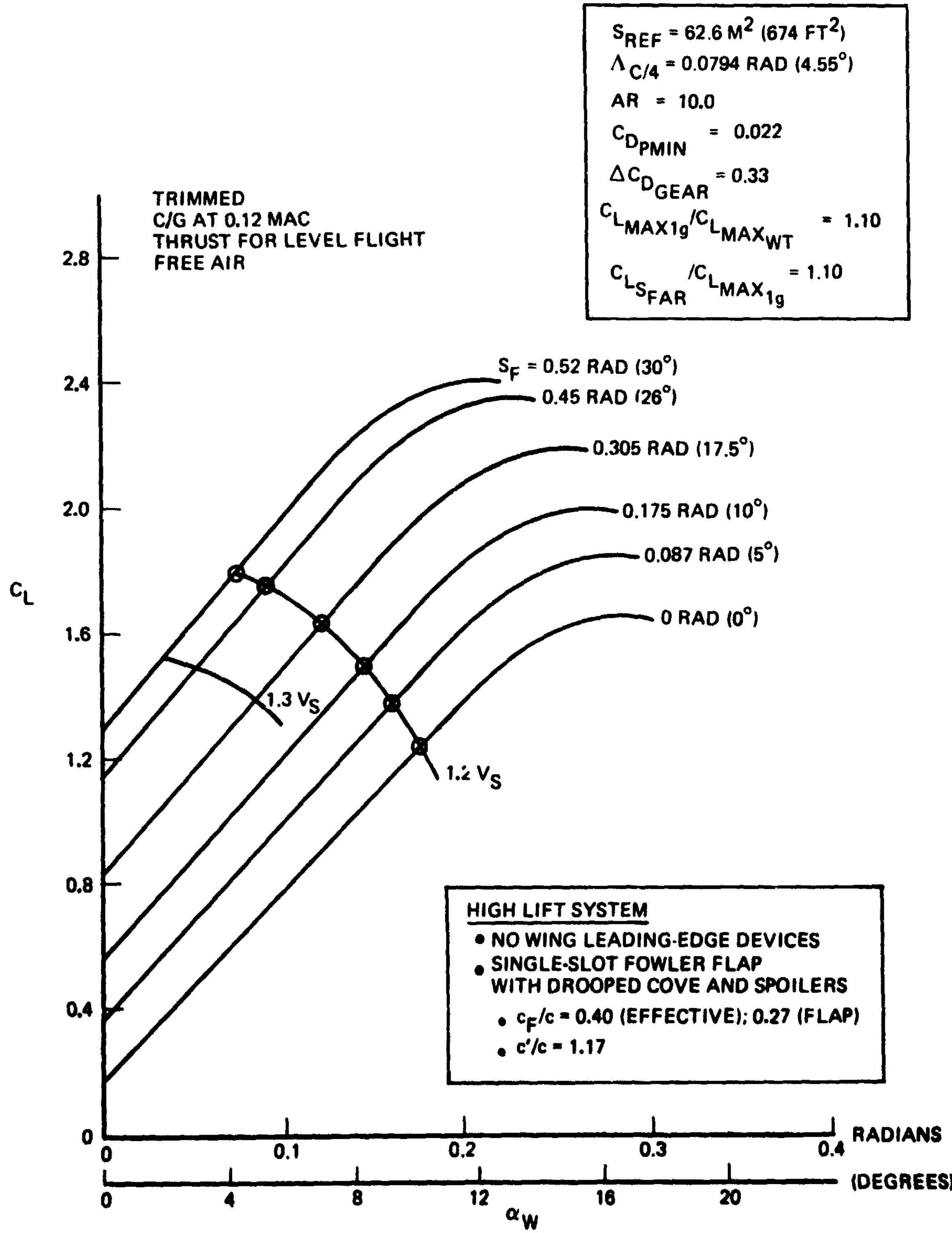


Figure 15 Low-Speed Lift Curves, Short-Haul Model 767-774A

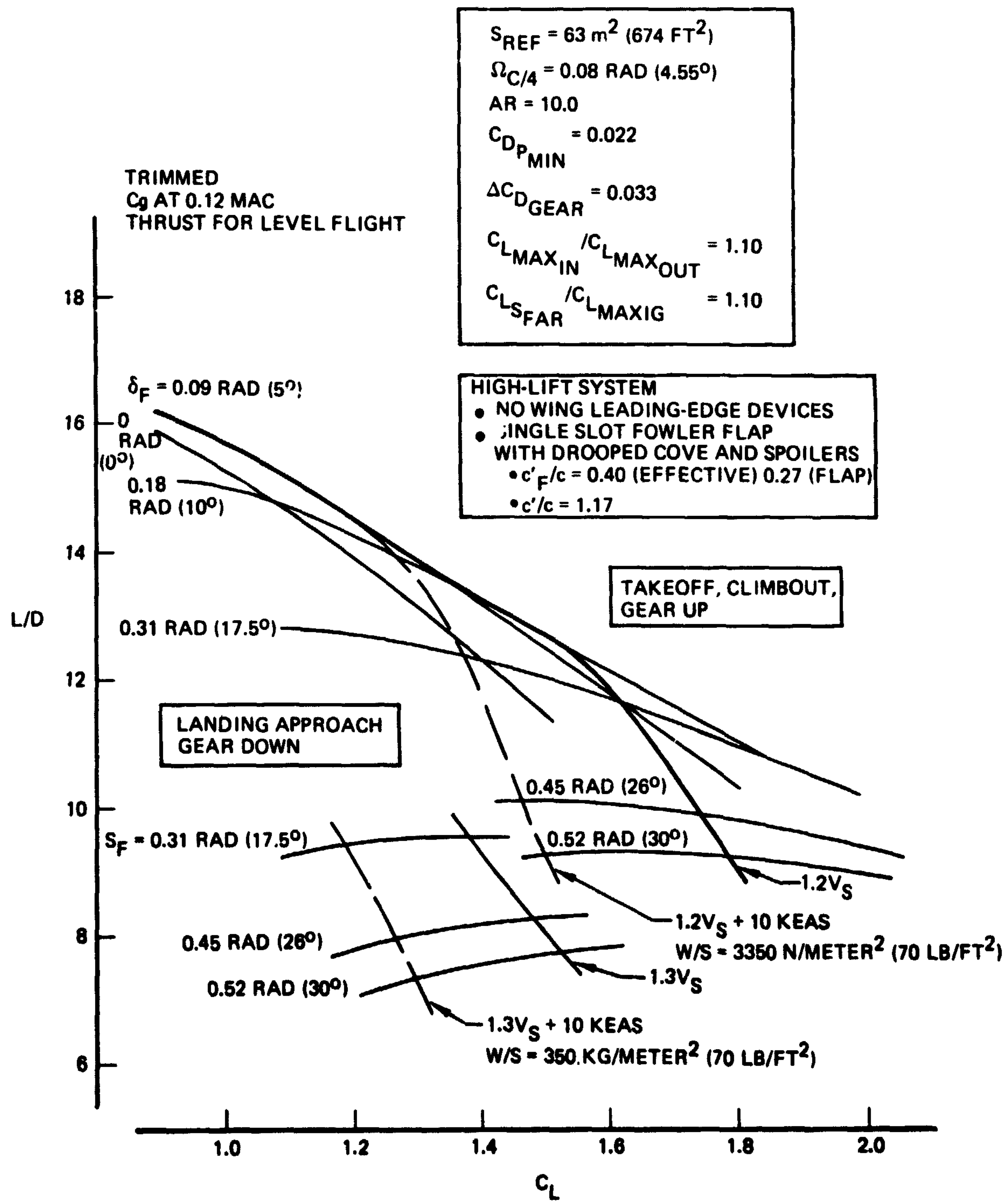


Figure 16 Low-Speed Performance Envelopes, Takeoff and Landing, Short Haul Model 767-774A

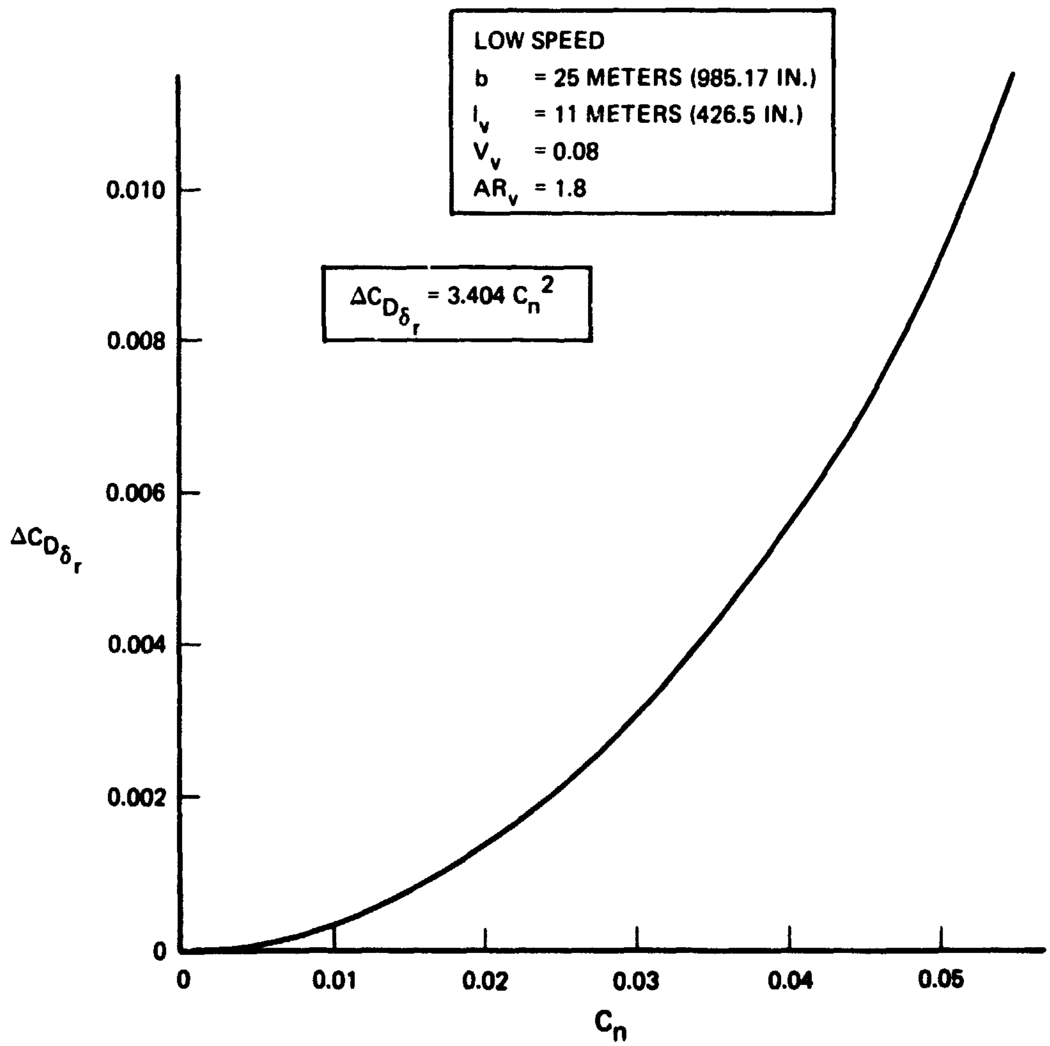


Figure 17 Estimated Drag Due to Rudder Deflection, Model 767-774A

5.5 STRUCTURAL DESIGN

The conventional-technology baseline airplane has 737 technology skin-and-stringer construction throughout. Typical examples of the type of primary structure used in conventional construction are shown in figures 18, 19, and 20. Structural design speed-altitude envelopes and speed-load factor (V-N) diagrams were determined for the baseline configuration. The speed-altitude envelope is shown in figure 21. The maximum gross weight maneuvering and gust V-N diagrams are shown in figure 22 for sea-level altitude and in figure 23 for an altitude of 6100 m (20 000 ft). These V-N diagrams show that the short-haul airplane is gust critical.

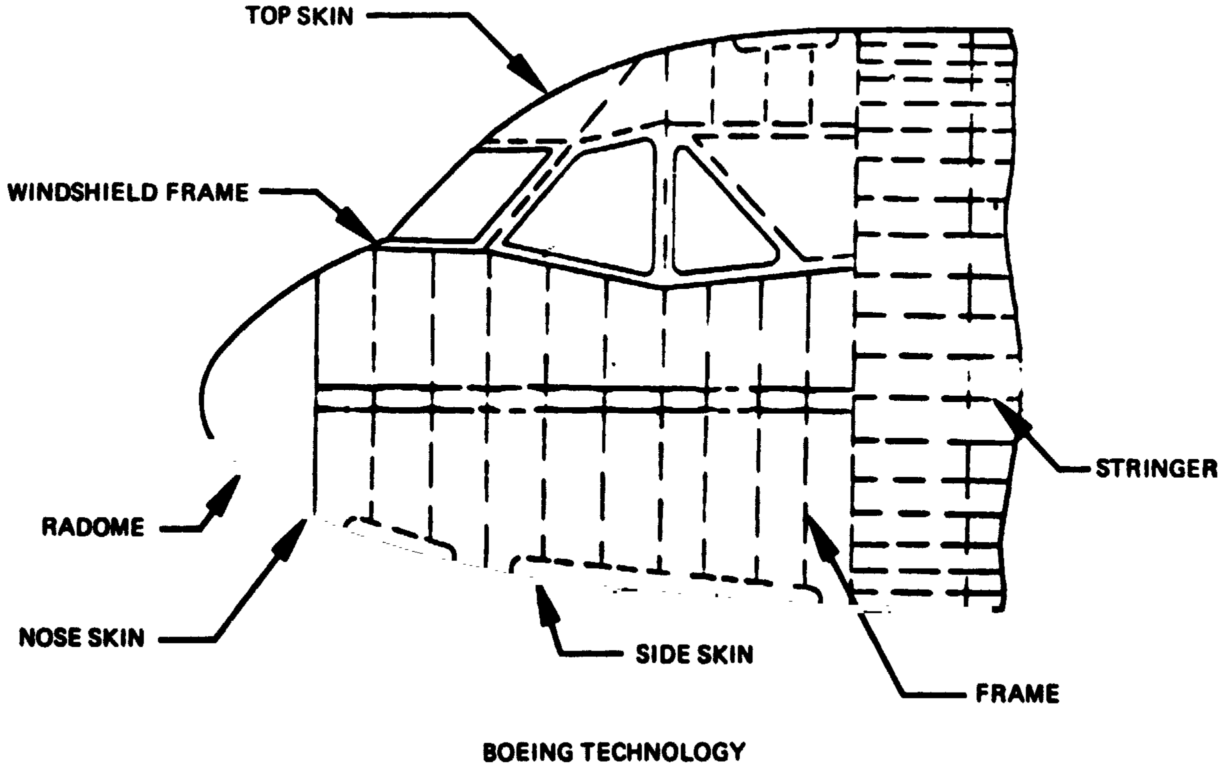


Figure 18 Conventional Section 41 (Pilot's Cab)

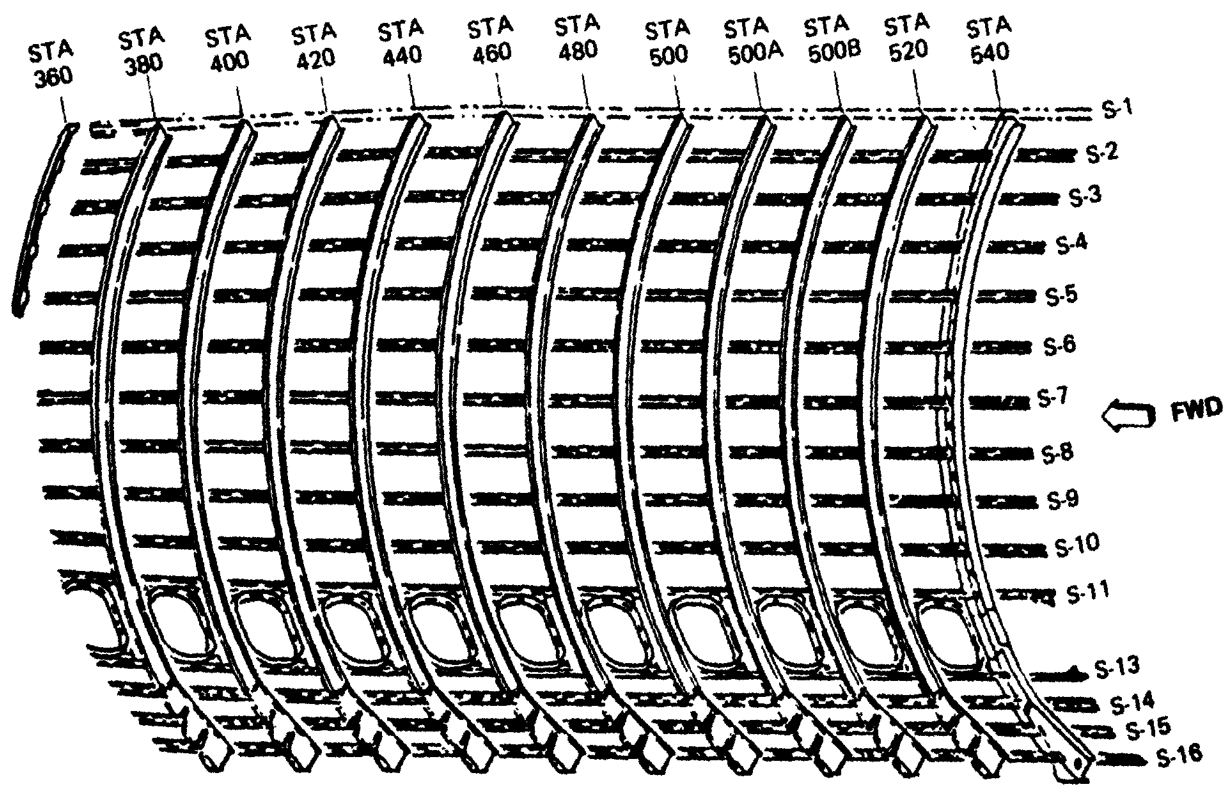


Figure 19 Conventional Body Section

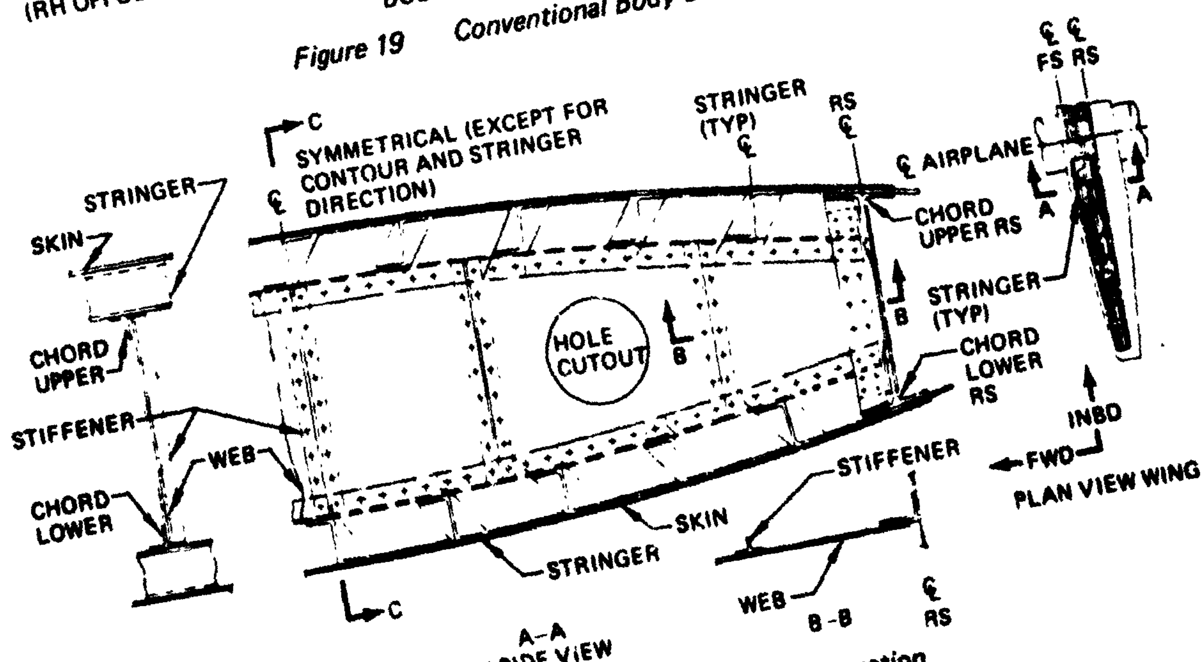


Figure 20 Conventional Wing-Box Construction

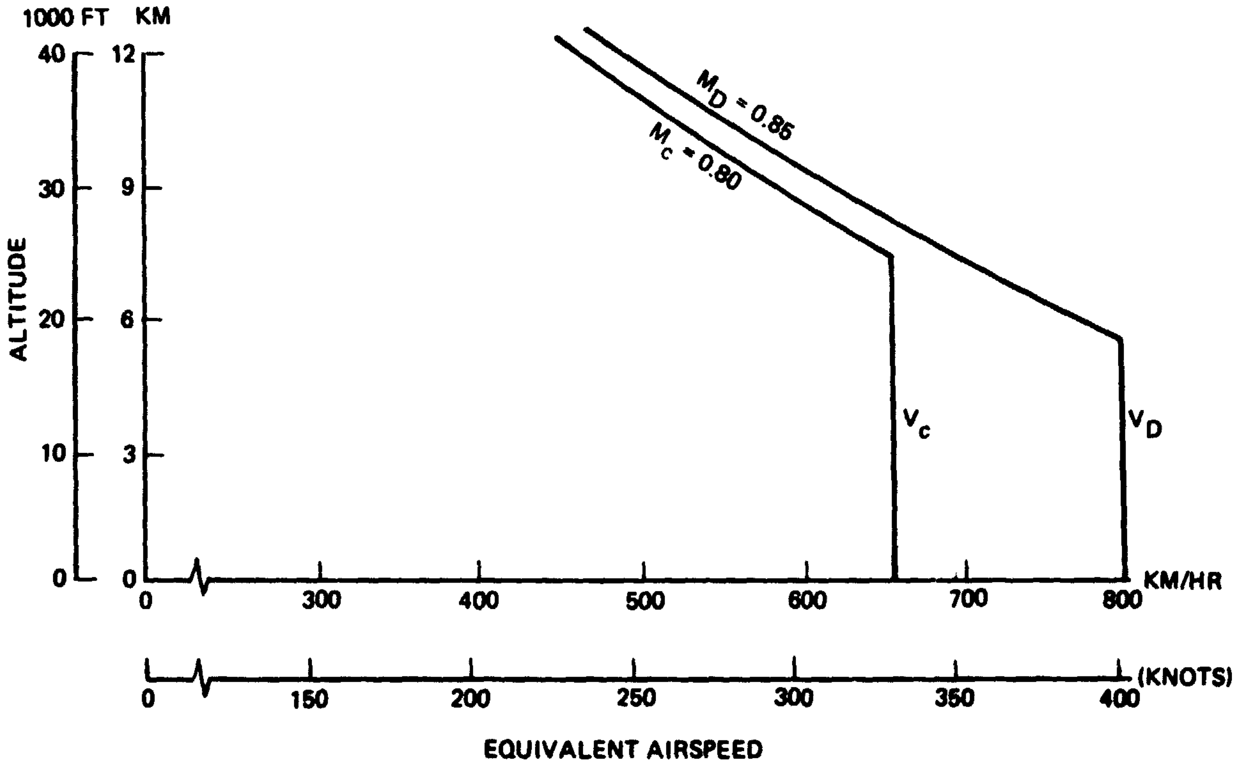
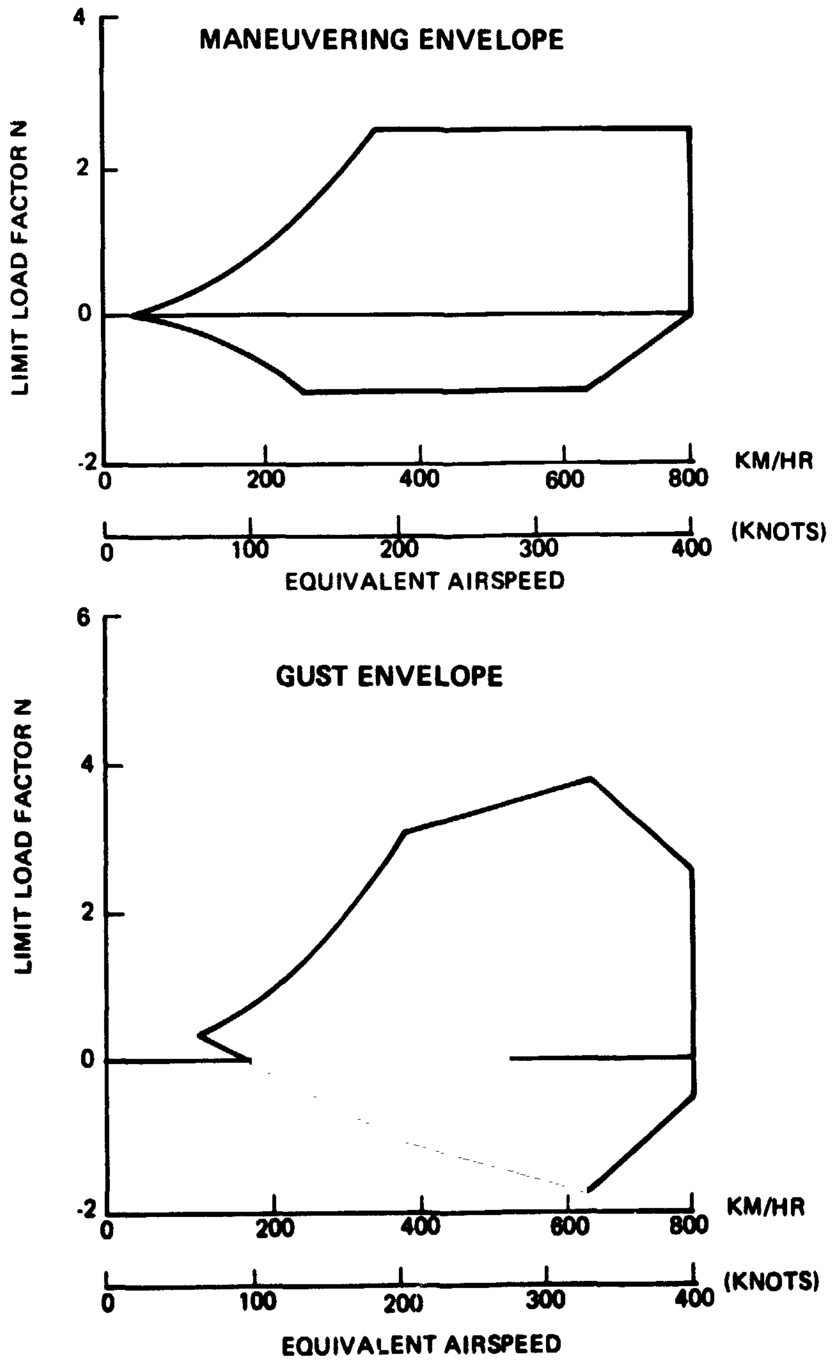
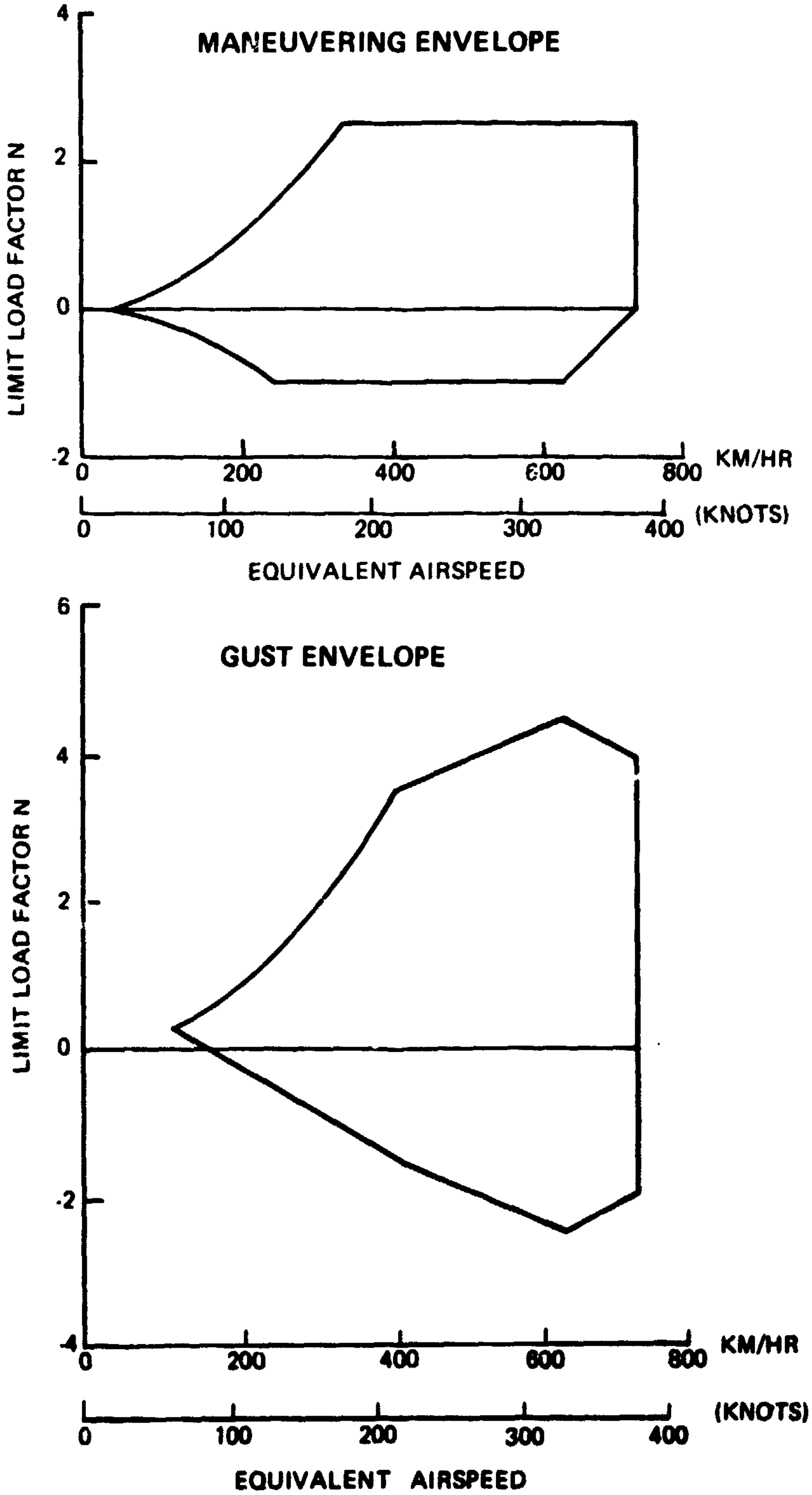


Figure 21 Structural Design Speeds



- FLAPS UP
- GROSS WEIGHT = 21 450 KG (47 300 LB)

Figure 22 V-N Diagrams, Altitude 0



- FLAPS UP
- GROSS WEIGHT = 21 450 KG (47 300 LB)

Figure 23 V-N Diagrams, Altitude 6100 Meters (20 000 Feet)

5.6 WEIGHTS AND BALANCE

A weight analysis of the model 767-774A short-haul airplane, prior to performance sizing, showed an operating empty weight (OEW) of 14 990 kg (33 050 lb). This weight is based on conventional aluminum skin-and-stringer construction in the wing, fuselage, and empennage. The 767-774A also was analyzed with bonded-aluminum honeycomb primary structure, and this resulted in a weight reduction of 295 kg (650 lb), for an OEW of 14 695 kg (32 400 lb).

The preliminary balance evaluation indicates that an aft wing shift of 0.25 m (10 in.) is required for the airplane to have acceptable loadability within the available center-of-gravity range of 12% to 35% MAC. A baggage allowable of 18 kg (40 lb) per passenger is assumed. Additionally, the forward and aft cargo compartments are configured so that 60% of the required cargo volume is located aft.

Weight Analysis—The wing planform of the 767-774A configuration was identical to that developed by Boeing-Wichita for the MDT configuration (fig. 3). The primary difference was that the 767-774A had two wing-mounted engines while the Wichita airplane had a clean wing. Results of a detailed, computerized beam analysis on the Wichita wing box were updated to reflect 767-774A design changes. The resultant wing box weight was combined with statistically/parametrically developed weights for the nonoptimum and wing secondary structure to yield the total wing weight.

The remainder of the airframe structural weight (e.g., body, empennage, landing gear, and nacelles) also was developed using statistical/parametric techniques. An acoustical treatment (fiberglass) allowance of approximately 120 kg (270 lb) was included in the body to satisfy cabin-noise level requirements. Engine weights were developed from manufacture-provided data.

Fixed equipment, and standard and operational weight items were extracted from a 1975 Boeing-funded IR&D project on a short-haul airplane with an identical passenger count as the 767-774A. Passenger-comfort levels and system functions were simplified to a level characteristic of similar aircraft in service, such as the VFW-614 and the DHC-7. Additionally, some of the systems were identical to the 737 aircraft after adjusting to the lower passenger count of the 767-774A.

5.7 PROPULSION

The propulsion unit for the short-haul airplane consists of two CF-34 turbofan engines installed in a Boeing-configured nacelle. The CF-34 is a commercial version of the TF34-GE-100 turbofan engine, which is a dual-rotor, front-fan engine with a bypass ratio of 6.3. It has a single-stage fan with a pressure ratio of 1.4 to 1, and a 14-stage axial flow compressor with variable stators and a nominal pressure ratio of 13.4 to 1. The combustor is an annular type with 18 fuel injectors. The gas-generator (core engine) high-pressure turbine has two axial flow stages, both air cooled. The fan low-pressure turbine has four axial flow stages and drives the fan through a concentric shaft passing forward inside the core engine rotor. The engine-mounted accessory gearbox, driven through the six o'clock front frame strut by the gas generator rotor, provides combined hydraulic and electrical power extraction capability. The lube system, including the engine oil tank, is completely self-contained. The engine design is an early 1970 in-service technology. Basic engine components and data are shown in figure 24.

The Boeing-configured engine nacelle (fig. 25) consists of a pod installation with an inlet length-to-diameter ratio of 0.8 having peripheral acoustic treatment. A 3/4-length fan duct with peripheral acoustic treatment is included in the pod design. Installed engine performance has been generated for this configuration using 30 kW (40 hp) per engine power extraction, 0.23 kg (0.5 lb) per second air conditioning bleed (14th stage), and 0.15 kg (0.33 lb) per second fan duct bleed for the air conditioning system intercooler. The nozzle performance has been calculated using General Electric furnished installation data.

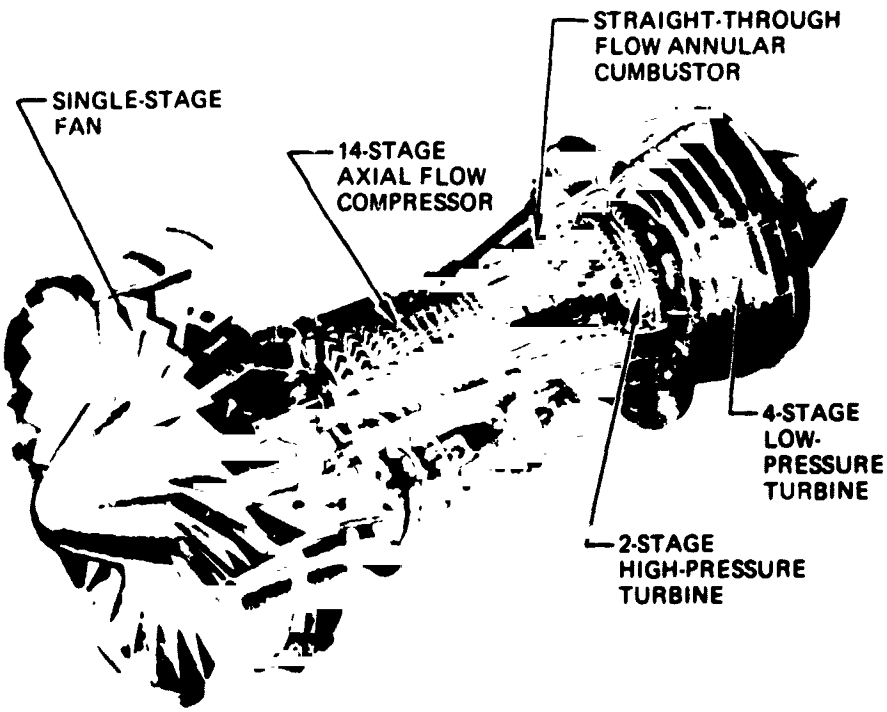
The CF-34 engine is equipped with 10th-stage bleed for supplying high pressure air to the environmental control system. Engine bleed limits have constrained the use of 10th-stage air for cabin conditioning only. Therefore, engine cowl and wing anti-icing must be solved by alternate methods for all-weather airplane. These methods are described in section 5.10.

Studies of techniques to meet the airplane's bleed air requirement (table 9) are continuing. This requirement can be met except at low power settings or flight idle. An engine bleed limit of 4% reduces available bleed to approximately 0.11 kg/sec (0.25 lb/sec per engine, 10th-stage bleed, varying with altitude and flight velocity. Discussions with General Electric on increasing the bleed limit have resulted in no change. During idle descent the 4% limit will be sufficient to replace leakage losses. Cowl and wing anti-icing requirements will be met with an electrical pneumatic system. Horsepower extraction for anti-icing and other airplane systems will equal 75 kW per engine. At idle descent, power extraction is limited to approximately 60 kW per engine. To obtain more power the engine throttle setting will have to be increased.

Table 9 Engine Power Setting Required for Cowl and Wing Anti-Icing, Short-Haul Transport

1. 10th-stage bleed for cabin air conditioning, 14th-stage bleed for cowl and wing TAI	34% MAX CRUISE minimum	Requires engine modification to incorporate 14th-stage bleed
2. 10th-stage bleed for cabin air conditioning, 14th-stage bleed for cowl TAI, electrical wing de-icing	6.5% MAX CRUISE minimum	Requires engine modification to incorporate 14th-stage bleed
3. 10th-stage bleed for cabin air conditioning, electrical wing and cowl de-icing	Flight idle with two-generator operation, 2.5% MAX CRUISE with one-generator operation	Requires 90-kVA generator on each engine
4. 10th-stage bleed for cabin air conditioning, electrical cowl de-icing, pneumatic boot wing de icing	Flight idle	Requires 50-kVA generator on each engine

NOTE: The above engine power settings are based on two engine operation. In a one-engine-out condition, engine power must be increased to meet the bleed flow requirement.



SPECIFICATIONS

• THRUST	35.6 KN (8000 LB)
• SPECIFIC FUEL CONSUMPTION	0.356
• BYPASS RATIO	6
• OVERALL PRESSURE RATIO	18
• FAN PRESSURE RATIO	1.45
• ENGINE DIAMETER	117 CM (46.3 IN.)
• LENGTH	198 CM (78.03 IN.)
• WEIGHT	700 KG (1540 LB)

Figure 24 General Electric CF-34 Engine

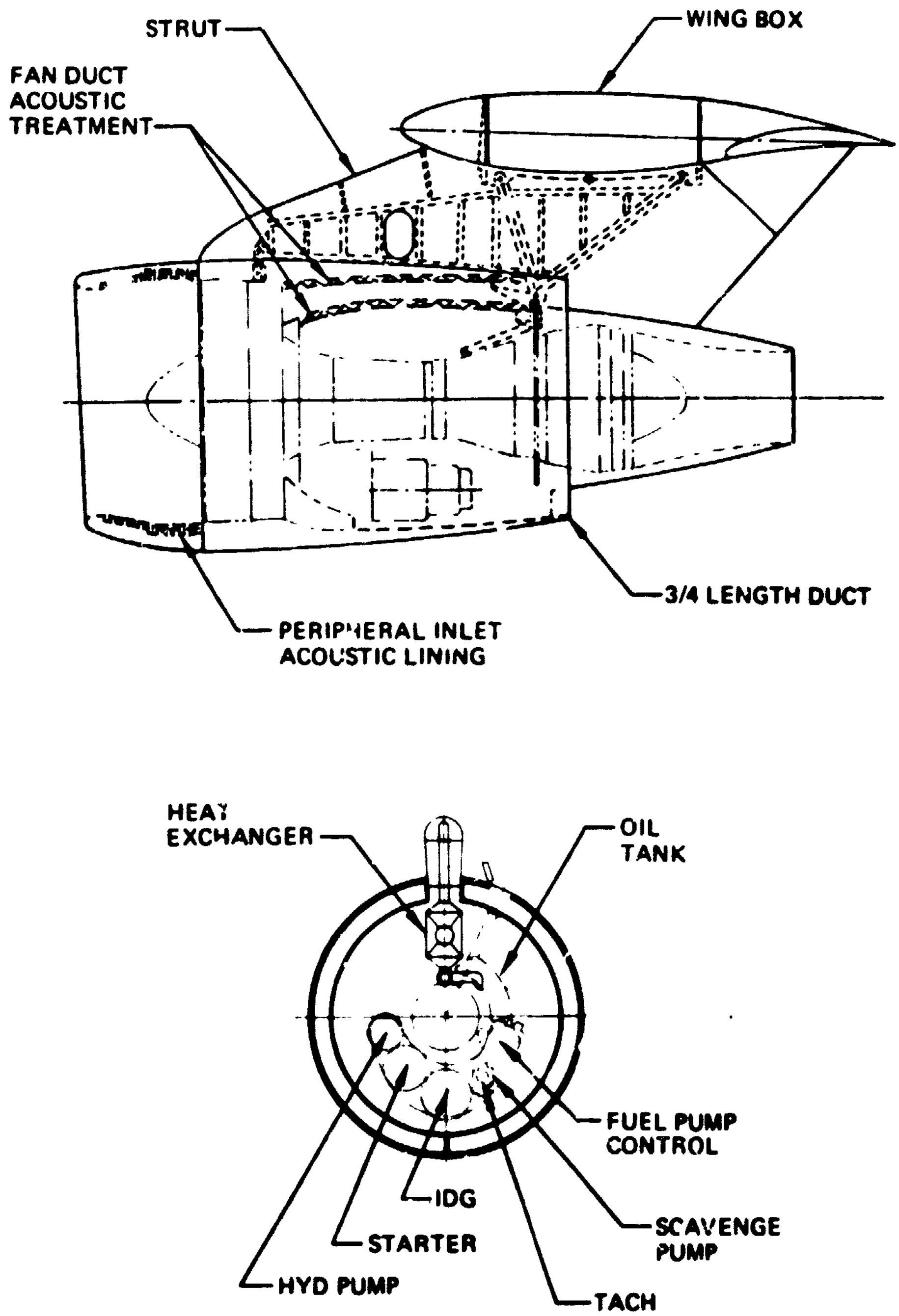


Figure 25 Nacelle Installation

5.8 NOISE

Preliminary studies indicate that the short-haul-airplane with CF-34 engines will meet the projected noise rules of FAA NPRM 75-37C. A noise study, including engine lining design, has been completed (see sec. 6.5.2.).

5.9 FLIGHT CONTROLS

The conventional-technology baseline airplane is configured with a longitudinal-axis handling qualities stability augmentation system (HQSAS). This system requires the unaugmented airplane to have a pitch instability of no less than 6 seconds time to double amplitude ($t_2 = 6$). The HQSAS is duplex or triplex for adequate redundancy but, in the event of total failure, it is a non-flight-critical system; the unaugmented airplane has safe flying qualities with only increased pilot workload. The empennage is a conventional low, fixed stabilizer with 40% chord single-hinged elevator. The minimal horizontal size is limited by unaugmented dive stability ($t_2 = 6$ sec) at the aft limit, and takeoff rotation at the forward limit.

The vertical tail with a 30% chord single-hinged rudder is sized by engine-out control. A conventional yaw damper will be included if the dynamic directional stability is unsatisfactory.

The baseline flight control system is defined to be the same as the 737's system for all axes. This is characterized by power control surfaces (two hydraulic systems) with manual reversion capability on the elevator and ailerons, no manual reversion on spoilers, and a standby third hydraulic system for rudders.

5.10 SYSTEMS

5.10.1 PNEUMATIC SYSTEMS

The bleed airflow allowable from the CF-34 engine is limited to 4% of engine core flow, compared to the 10% of core flow normally allowed on existing engines on commercial jet airplanes. With the 737-type systems, the cabin air conditioning and airplane thermal anti-icing requirements exceed the engine bleed flow limit during idle descent. Detailed engine bleed airflow requirements are shown in figure 26 and table 10. If the bleed airflow requirements are above the current limit, the engine inlet and wing leading edge should be anti-iced with a heat source other than engine bleed air. Another alternative is to increase engine power setting at flight idle when the airplane encounters icing conditions.

Cabin air conditioning normally is supplied by engine intermediate-stage bleed air during climb and cruise, and the bleed source is switched to high-stage bleed at the idle descent condition. The CF-34 engine 14th-stage bleed air is contaminated and not suitable for cabin air conditioning use. Therefore, 10th-stage bleed air will be used for cabin air conditioning and pressurization throughout the flight, with some degradation in cabin cooling performance and ventilation rate during descent. See figure 27 for system schematic.

During ground operation the APU supplies high-pressure air for starting the engines and running the air conditioning system. High-pressure air from a ground cart also can be used for these functions.

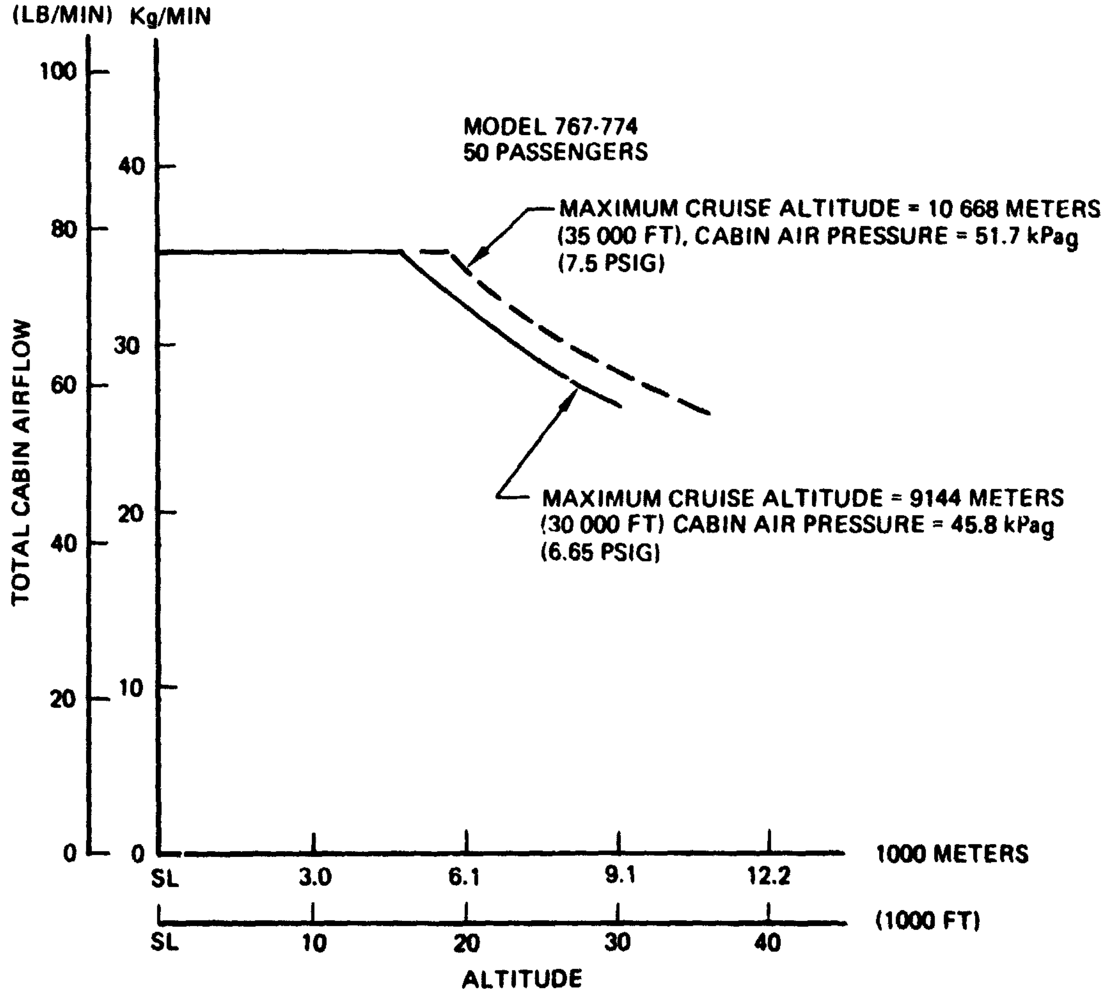


Figure 26 Short-Haul Airplane Total Cabin Airflow

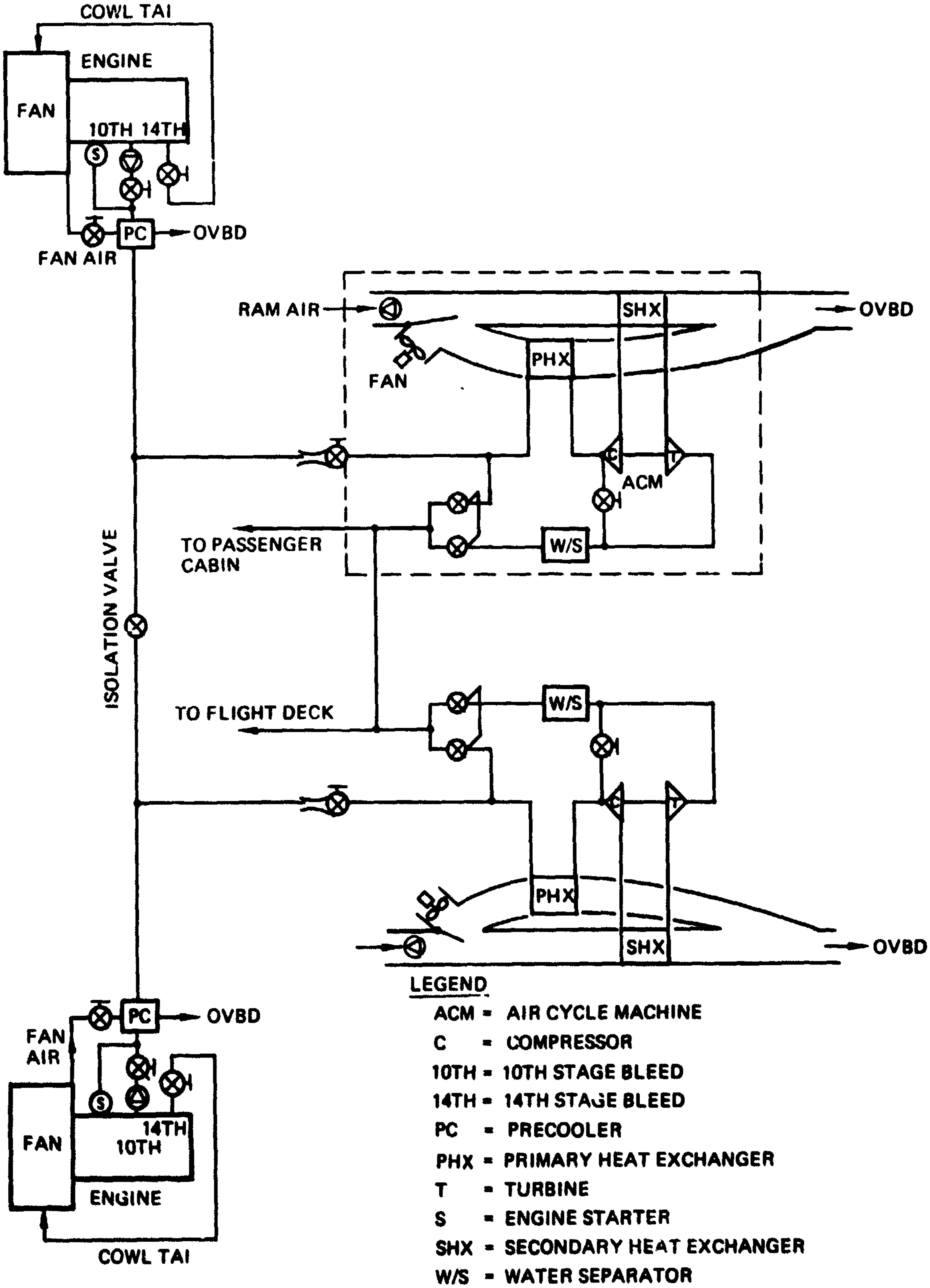


Figure 27 Pneumatic Air Conditioning System (Gulfstream II Air Cycle Cooling Packs)

Table 10 Short-Haul Airplane Engine Bleed Flow Requirements

	SEA LEVEL KG/MIN (LB/MIN)	4600 METERS (15 000 FT), KG/MIN (LB/MIN)	7600 METERS (25 000 FT), KG/MIN (LB/MIN)	9200 METERS (30 000), KG/MIN (LB/MIN)
• Two-Engine Operation				
• Cabin Air Conditioning	35 (78)	35 (78)	29 (64)	26 (58)
• Engine Cowl TAI	31 (68)	26 (58)		
• Wing TAI	45 (100)	37 (82)		
• One-Engine Out Condition				
• Cabin Air Conditioning	18 (39)	18 (39)	15 (32)	13 (29)
• Engine Cowl TAI	15 (34)	13 (29)		
• Wing TAI	45 (100)	37 (82)		

NOTE: Compressor discharge air is used for cowl TAI
10th-stage bleed is used for cabin air conditioning
Engine power extraction = 40 HP

5.10.2 ENGINE INLET AND WING ANTI-ICING SYSTEMS

All Boeing commercial jet transports use bleed air (thermal) anti-icing (TAI) systems to prevent ice buildup from the wing leading edges and engine inlets. The pneumatic TAI system is the most reliable and simple method of removing ice; however, due to bleed air shortage of the CF-34 turbofan engine during idle descent, the engine power setting must be increased considerably to meet the TAI system bleed flow requirements.

Electric de-icing is currently used on the Concorde supersonic transport, small business jets, and other general-aviation airplanes where bleed airflow is very scarce to nonavailable. It is a reliable, efficient method of de-icing surfaces. An example of an electric de-icer is shown in figure 28.

An electric de-icing system may be applied to remove ice from the wing and empennage leading edges of the short-haul transport. This system requires relatively little maintenance and would not require a higher engine power setting to generate extra electrical power for wing de-icing. However, the wing alone would require 45 kW of electrical power. The increase in electrical system weight associated with expanded generator capacity appears substantial.

The cyclic electrical de-icing method is not recommended for engine inlets, because runoff ice may form downstream from the heated section. The electrical anti-icing method, where power is continuously supplied to evaporate all the impingement, is normally used on engine inlets of small aircraft. Each CF-34 engine cowl would require approximately 32 kW to anti-ice electrically.

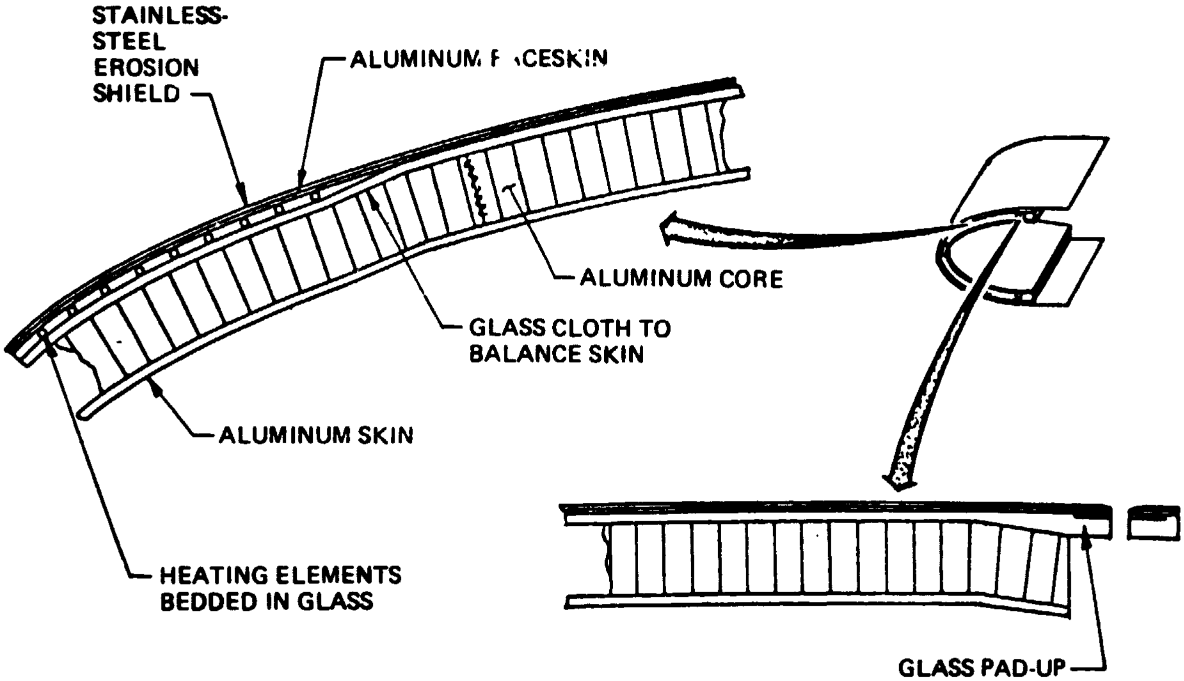


Figure 28   Electric De-icer

The pneumatic boot de-icer made by the B. F. Goodrich Company is currently used on business jets and other general-aviation aircraft. This de-icer is essentially a fabric-reinforced rubber sheet with built-in inflation tubes that is bonded to the leading edge of the surface to be protected. This de-icer requires 124 kPag (18 psig) pneumatic pressure at a very low flow rate and weighs approximately 0.3 kg/sq m (0.7 lb/sq ft).

The pneumatic boot de-icer is selected for de-icing the wing leading edges because of its very low energy requirement. It appears durable; however, it requires replacement every 3 to 5 years, depending on airplane utilization. Service life and cost of maintenance should be explored before the system is used on production airplanes.

The pneumatic boot-de-icer was not recommended for the CF-34 engine inlet installation by the engine manufacturer because of possible inlet air disturbances.

A conventional engine bleed-air thermal anti-icing system is recommended for the engine nacelles. Engine 14th-stage bleed air will be used for cowl anti-icing. The CF-34 engine currently defined could provide 4% 10th-stage bleed but no 14th-stage bleed. According to the engine manufacturer, up to 6% 14th-stage bleed is possible from the CF-34 engine, but it would require some redesign.

5.10.3 AIR CONDITIONING SYSTEM

A cabin ventilation rate of 0.6 cm/min (20 cfm) per passenger has been used as a standard comfort criterion throughout the U S. aircraft industry. Current Boeing commercial jet airplanes have been designed with this cabin ventilation rate to ensure a comfortable environment in the passenger cabins. To minimize engine bleed airflow, the cabin ventilation rate on the short-haul transport will be reduced to 0.5 cm/min (17 cfm) per passenger.

Engine 10th-stage bleed air will be supplied to two air-cycle air conditioning packs and used for cabin air conditioning and pressurization. The cabin conditioning packs will be sized to maintain 27°C (80°F) cabin temperature on the ground and 21°C (70°F) during flight with the assumption that the cabin wall and fuselage skin under the floor are installed with 3.8-cm (1.5-in.) thick fiberglass blankets.

Two Gulfstream II air conditioning packs (fig. 27) could be used on this airplane. This pack is approximately one-half the size of the 737 but has the same number of components. The cost of purchased equipment would be approximately 15% less than for the 737.

If a new air-cycle pack similar to the DC-10 system design is developed for this airplane, the system would probably cost more but the installation cost can be reduced considerably. The air-cycle pack could be assembled into one unit at the vendor site instead of installing 13 separate components piece-by-piece into the airplanes. (See fig. 29 for the system schematic.)

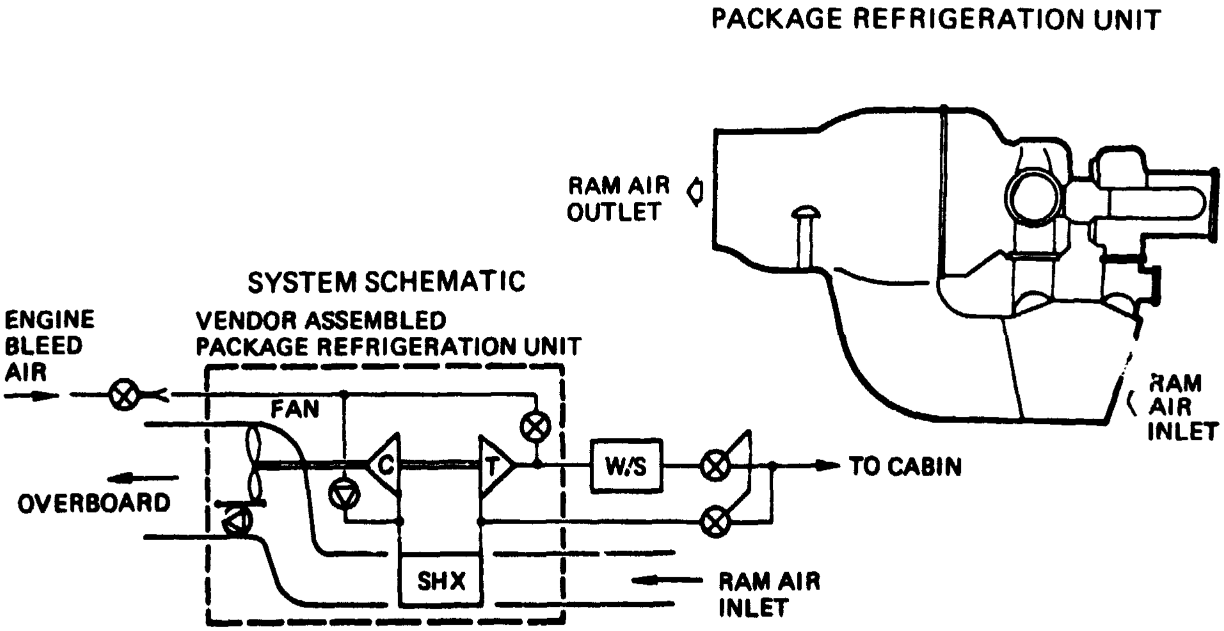


Figure 29 New Simple-Bootstrap Air-Cycle Cooling Pack

The air conditioning packs will be installed in both main landing gear fairings. Fixed-geometry inlet and exit will be used for the ram-air cooling circuit. The fixed-geometry system will have higher ram-air drag than the variable inlet and exit used on 737 airplanes, but system installation will be simplified.

The cabin air distribution system will be greatly simplified by installing a single, large overhead duct, and a single riser connecting the distribution manifold located under the floor to the overhead duct. Using a single riser instead of the multiple small risers used on 737 airplanes would greatly reduce the number of parts required in the cabin air distribution system. However, one passenger window could be blocked to install the riser duct. A schematic of the cabin air distribution system is shown in figure 30.

A gasper system (passenger-directed air stream) may be eliminated from this airplane because the cabin air conditioning system with APU operation on the ground provides adequate cabin comfort. The gasper system is, however, very effective in dispersing cigarette smoke.

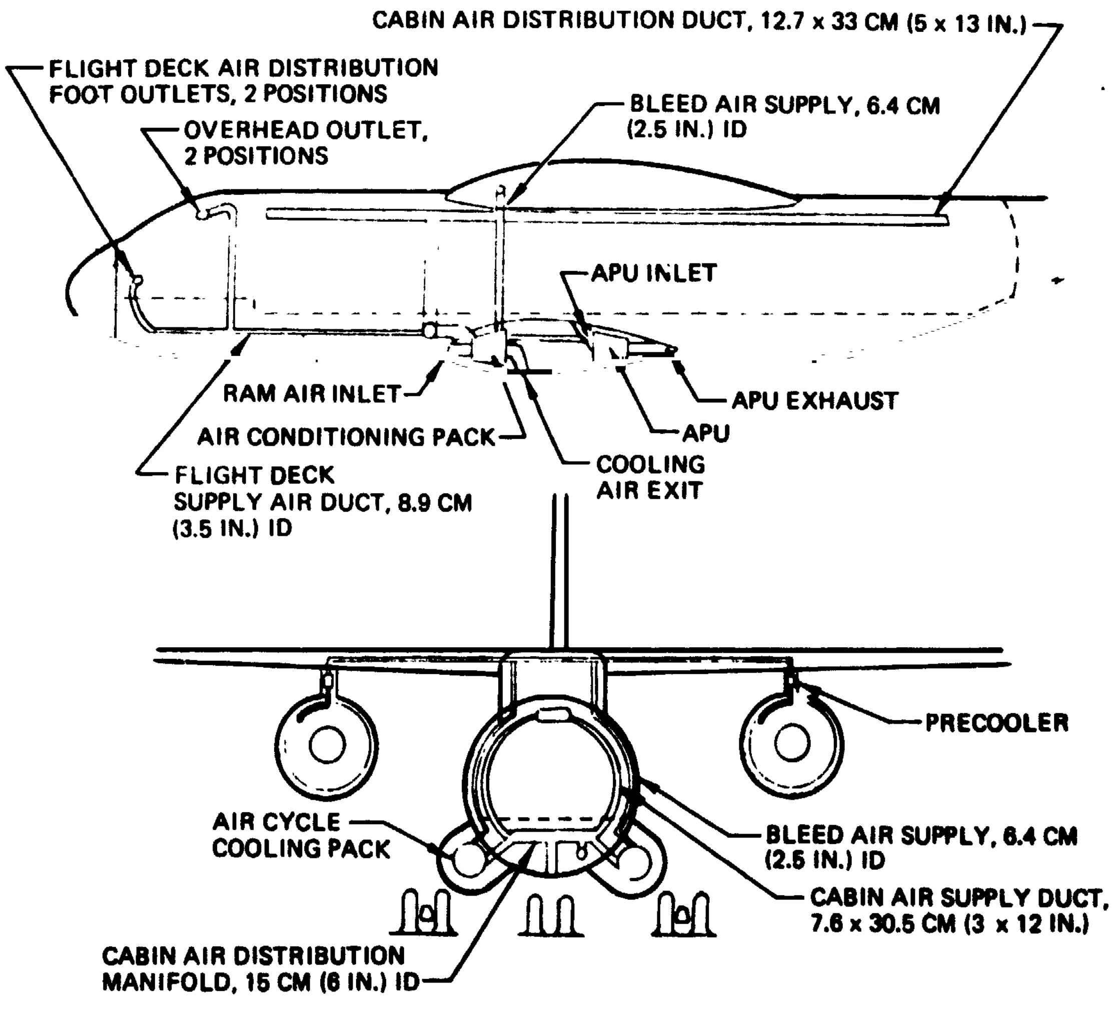


Figure 30 Cabin Air-Conditioning System – Air-Distribution System

The cabin will be pressurized to 2440 m (8000 ft) at maximum cruise altitude. Either the 737 or Gulfstream cabin pressure control system can be used. Both systems are electrically actuated, electronically controlled units. If the 737 system is used, a new outflow valve will be required because the 737 outflow valve would be too large for this application. Two outflow valves will be required if the Gulfstream II system is used.

5.10.4 OXYGEN SYSTEM

Because the current, maximum-design cruise altitude of this airplane is above 9145 m (30 000 ft) the oxygen system must have dispensing units that are automatically presented to the passengers. A seat-group chemical oxygen system will be used. The number of dispensing units will be 10% more than the number of passengers. The dual-seat-group chemical oxygen unit used on the DC-10 is approximately 8 by 30 cm (3 x 12 in.). The flight crew oxygen system will be a high-pressure, gaseous system similar to that used on the 737.

If operation of the airplane is limited to below 9145 m (30 000 ft), dispensing units connected to oxygen supply terminals will be required but need not be automatically presented to the occupants. The system also should have sufficient capacity to provide oxygen to 10% of the passengers for 30 minutes (current FAA requirement).

5.10.5 ELECTRICAL SYSTEMS

The short-haul transport electrical system will be the same one used on the 737. Three 40-kVA generators, one on each engine and the APU, will supply electrical power.

5.10.6 HYDRAULIC SYSTEM

The hydraulic system also will be the same as the 737 system. It consists of two full-time systems powered by two 75-liter/min (20-gpm) engine-driven pumps, two 23-liter/min (6-gpm) electric-motor-driven pumps, and one standby system powered by 11-liter/min (3-gpm) electric-motor-driven pump.

Schematic diagrams of the landing gear retraction and wheel braking systems are shown in figures 31 and 32, respectively.

5.10.7 APU

The baseline airplane has a flight-operable APU, GTCP-36, installed in the aft end of the starboard main landing gear wheelwell. The APU provides high-pressure bleed air for engine starting and ground air conditioning system operation, and powers a backup generator in flight.

5.10.8 AVIONICS

Equipment needed for avionics requirements established by FARs and by the environment the airplane may operate in (such as Category I and Category II weather for lnding) are listed in table 11. Avionics currently used in various commuter and air-taxi airplanes are identified in table 12. The list includes instruments used on the Citation, Jetstream Mk 1, Falcon 50, and Merlin 4 at gross takeoff weight of 5670 kg (12 500 lb) or less and Gulfstream II, CL-600 Challenger, and the DHC-7 at gross takeoff weight over 5670 kg (12 500 lb).

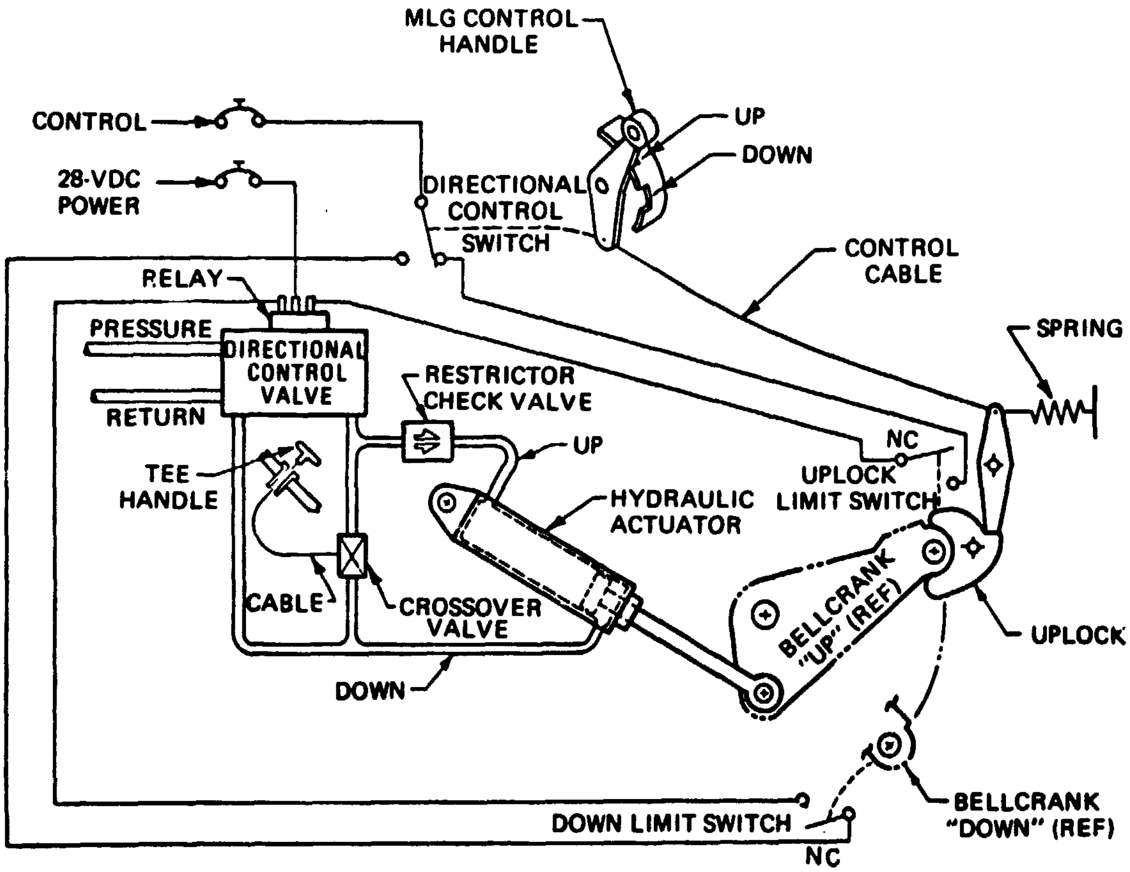


Figure 31 Landing Gear Retraction System

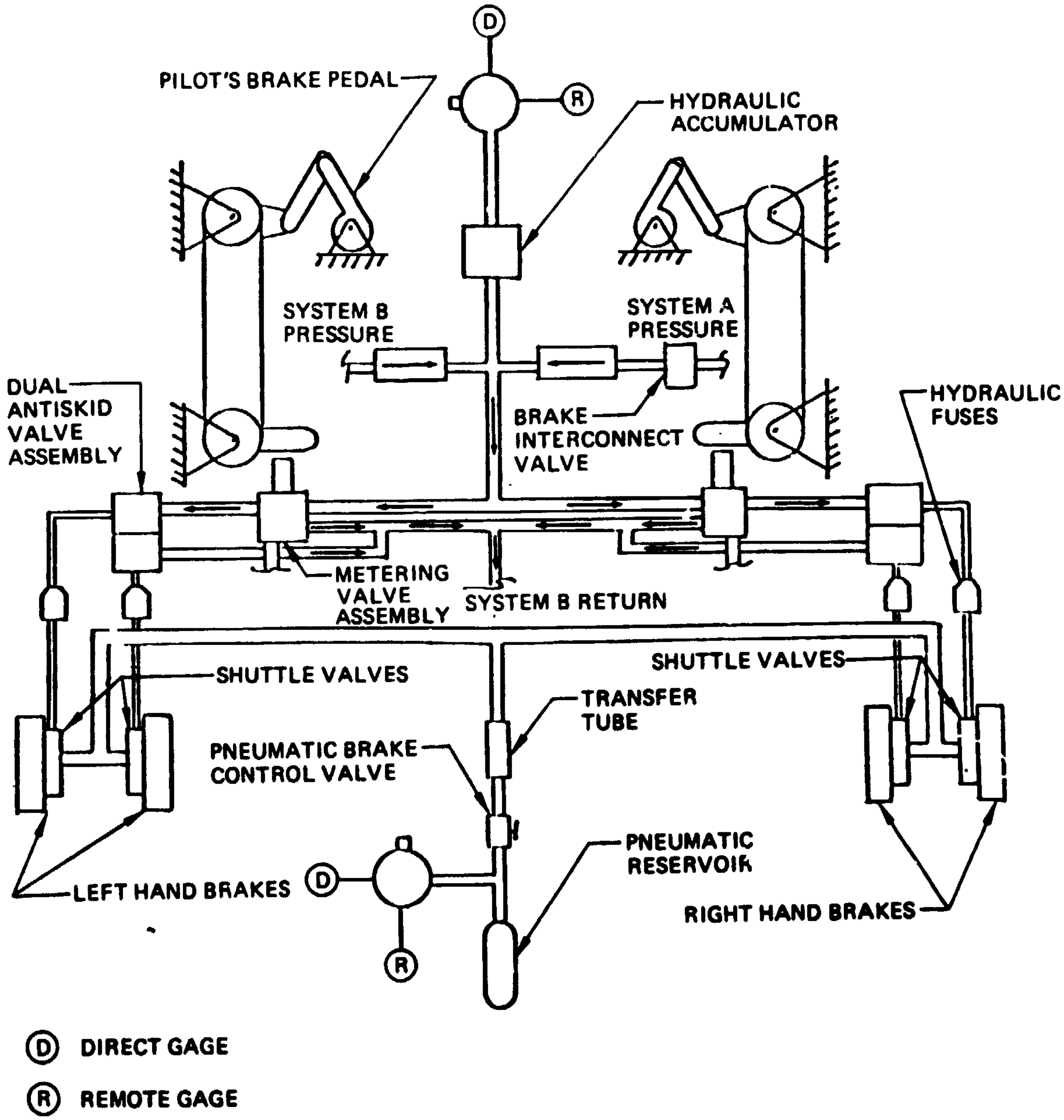


Figure 32 Brake Systems

Table 11 Avionics Requirements

EQUIPMENT	FAR	TSO	ADVISORY CIRCULAR	NUMBER REQUIRED
DOMESTIC				
VHF communications	25.1307	C37b, C38b		2
VHF navigation	25.1307			
	121.349a, e	C40a	90.45	2
ATCRBS	91.24b	C74c		1
DME	121.349c	C66a	170.38	1
Weather radar	121.357	C63b		1
Marker	121.349a	C35c		1
ADF	121.349b	C41b		1 [1]
Cockpit recorder	25.1457			1
Voice	121.359	C84		1
Aircraft flight recorder	121.343	C51a		1
Ground proximity warning	121.360	C92a,b		1
Public address and interphone	121.318 121.319			1 [2] 1
Pressure altitude digitizer		C88		1
Altitude alerting system	91.51			1
OCEANIC HF SSB	91.191	C31c, C32c		2
Area navigation (R-Nav)			90-45	Optional
INS and/or	121.355		25-4	2 [3]
Doppler radar	121 Appendix G	C65	90-45	
Omega	121.103 121.121		120-31	1

[1] One ADF OK if two VOR receivers are operable

[2] Required if there are more than 19 passenger seats

[3] Two INS, one INS and one Doppler radar, or two Doppler radars

Table 11 (Continued)

EQUIPMENT	FAR	TSO	ADVISORY CIRCULAR	NUMBER REQUIRED
CATEGORY I LANDING				
Single flight director for single automatic approach coupler		C52a	120-29	1
Instrument failure warning system			120-29	1
Localizer and glide receiver	121.349a	C36b C34b	120-29 120-28b	1 each
CATEGORY II LANDING				
Instrument failure warning system	91 Appendix A		AC120-29	1
Crew assignment and procedure			AC120-29	1
ILS and GS receivers	91 Appendix A		AC120-29 AC 91-16	2
Single flight director with dual displays and single automatic approach coupler, or two independent flight director systems	91 Appendix A	C52a	AC120-29	1 and 1 or 2
Decision height equipment [4]	91 Appendix A		AC120-29	1
Missed approach attitude guidance			AC120-29	1
Auto throttle system (if turbojet operation uses dual flight director)			AC120-29	1
Rain removal equipment	91 Appendix A		AC120-29	1

[4] Equipment can be either radar altimeter or inner marker

Table 11 (Continued)

EQUIPMENT	FAR	TSO	ADVISORY CIRCULAR	NUMBER REQUIRED
CATEGORY IIIa LANDING				
ILS localizer and glide slope receiver 5			AC120 28A	2
Radar altimeter			AC120-28A	2
Flight control system 6		C67	AC120-28A and N8400.18	2
Missed approach attitude guidance			AC120-28A	1
Auto throttle				1
Failure detection and warning system				1

5 Equipment can be (a) altitude gyros with calibrated pitch markings, or (b) flight director pitch commands, or (c) computed pitch commands

6 The fail-passive automatic flight control system shall comply with Advisory Circular 20-57 (Automatic Landing Systems) and the applicable performance and reliability criteria outlined in AC120-28A, Appendix 1

Table 12 Current Commuter and Air-Taxi Avionics

AVIONICS	QTY
Communication/Navigation Equipment	
Dual communication/navigation/ILS (Bendix CA2011A)	1
Interface unit (Bendix IU2016A)	1
Navigation computer programmer (Bendix NP2041A)	1
Distance measuring equipment (Narco DME 190RC)	1
Interface adapter (Narco SA11)	1
Automatic direction finder (Bendix ADF-2070)	1
ATC transponder (Bendix TPR-2060)	1
Weather radar (Bendix RDR-160)	1
Encoding servoed altimeter (IDC)	1
Vertical guidance computer/alerter (IDC)	1
No lag electric vertical speed indicator (IDC)	1
Autopilot (Sperry SPZ 500)	
Autopilot computer	1
Autopilot controller	1
Mode selector	1
Autopilot servo drive	3
Autopilot servo brackets	3
Flight Control Instruments (Sperry)	
5-in. attitude director indicator, Pilot (AD600)	1
4-in. attitude director indicator, Copilot (HZ-444)	1
5-in horizontal situation indicator, Pilot (RD-600A)	1
4-in. horizontal situation indicator, Copilot (RD-500A)	1
Dual remote heading and course select controller	1
Radio magnetic indicator RH-444	2
Attitude indicator (FAR 121.305j)	1
Flag amplifier (FA200)	2
Flight director computer	1
Air Data System (Sperry)	
Air data computer (Jet)	1
Altimeter	1
Mach airspeed indicator	1
Vertical speed indicator	1
Airspeed sensor	1
Airspeed navigation coupler (VC-200)	1
Heading, Pitch, and Roll Systems (Sperry)	
Directional gyro (C-14)	2
Flux valves	2
Dual remote compensator (DRC-1)	1
Vertical gyro (VG-14)	2
Altitude control (AC-200)	1
Altitude alert controller (FAR 91.51)	1
Comparator monitor (CM-200)	1
Audio and Recording Systems	
Public address audio system (Collins 387C-4)	1
Cockpit voice recorder (Collins 642C-1)	1
Flight recorder	1

5.11 BASELINE AIRPLANE PERFORMANCE

The baseline short-haul transport (model 767-774A) was sized to meet the following performance design constraints:

- Payload = 50 passengers or 4540 kg (10 000 lb)
- Still air range = 1400 km (750 nmi)
- FAR TOFL, sea level 32°C (90°F) = 1370 m (4500 ft)
- Initial cruise altitude capability ≥ 9145 m (30 000 ft)
- Cruise Mach = 0.70
- Mission approach speed = 220 km/hr (120 kt)

These design conditions were used to generate two performance-sized airplane configurations: the model 767-774B with advanced bonded-aluminum honeycomb primary structure, and the model 767-774C with conventional aluminum skin-and-stringer primary structure. Either model could be used as a basis for further advanced technology trade studies but, because of the greater depth of detail design and the likelihood that the final advanced short-haul configuration would have bonded-aluminum honeycomb construction, the 767-774B was selected. Henceforth the 767-774B will be called the basepoint airplane configuration.

The 767-774C configuration was not investigated sufficiently for computer analysis, so its performance sizing is based on results of performance sensitivity studies using the 767-774B. Drawings of the 767-774B and 767-774C appear in figures 33 and 34. The 767-774B airplane is sized by both TOFL and approach speed constraints. The 220-km/hr (120-kt) approach speed represents a FAR wet landing field length of approximately 1370 m (4500 ft) at the mission landing weight.

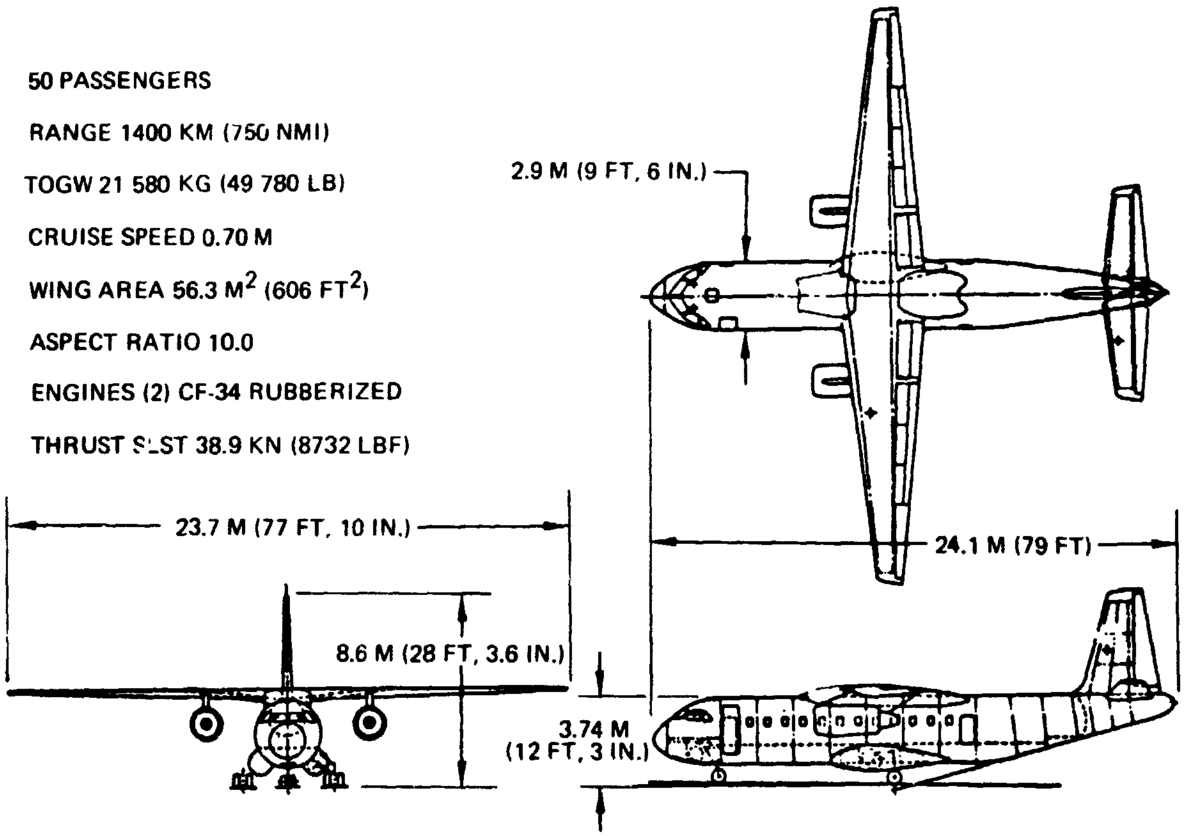


Figure 33 Advanced-Structures Trade Study Airplane, Model 767-774B

50 PASSENGERS

RANGE 1400 KM (750 NMI)

TOGWT 23 240 KG (51 120 LB)

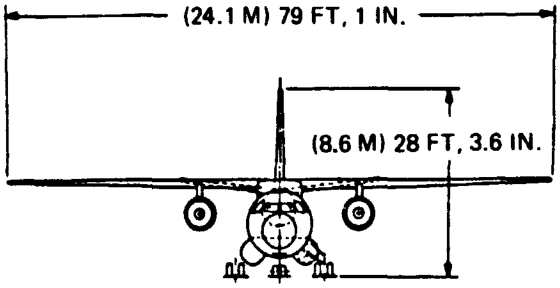
CRUISE SPEED 0.70 M

WING AREA 58.2 M^2 (626 FT^2)

ASPECT RATIO 10.0

ENGINES (2) CF-34 RUBBERIZED

THRUST SLST 39.7 kN (8932 LBF)



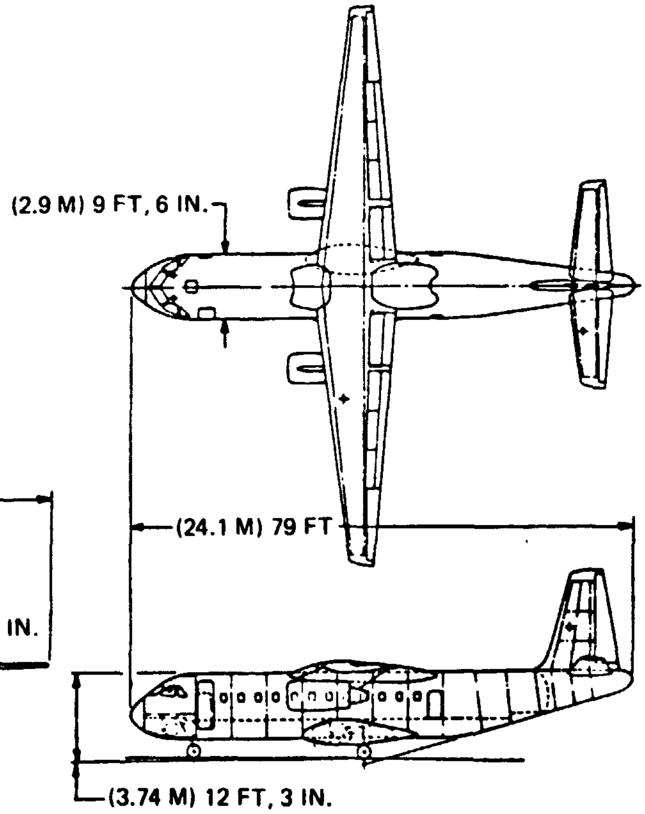


Figure 34 Conventional-Technology Baseline Airplane, Model 767-774C

5.11.1 MISSION RULES AND SIZING

The "Thumbprint" sizing program was used to simulate the flight profile and mission rules shown in figure 35. Takeoff performance is calculated at sea level on a 32°C (90°F) day. Climb time, fuel, and distance were based on calculations for airplanes with similar T/W, W/S and L/Ds. The climb performance increments used are shown under the mission flight profile. A constant cruise altitude was used due to the relatively short design mission range and small mission weight change (i.e., the penalty for this procedure is quite small). The sizing program inputs for descent time, fuel, and distance versus altitude represent typical jet transport values with fuel flow adjusted for short-haul transport requirements. Reserve fuel is based on the following rules:

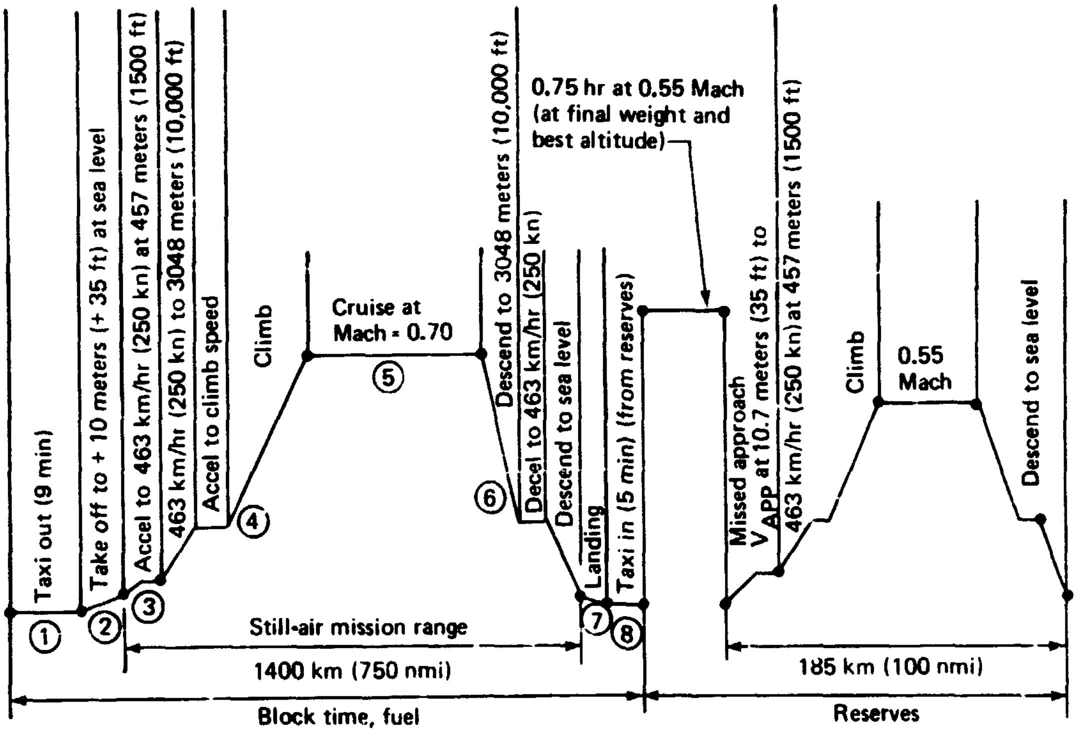
- Forty-five minutes extended cruise at end of cruise altitude and best cruise Mach
- Missed approach (2 min. at maximum takeoff fuel flow)
- Climb, cruise, and descent to 185-km (100-nmi) range

An allowance of 5% TOGW is used to simulate the reserve fuel for the initial T/W and W/S trades.

Figure 36 shows the short-haul transport design selection chart. This chart shows that two design constraints are sizing the airplane. Wing loading of 400 kg/m^2 (82 psf) was chosen by the 222-km/h (120-keas) mission approach speed, which represents a FAR wet landing field length at sea level standard day of about 1370 m (4500 ft). Ride quality and/or cruise thrust to drag matching may require higher wing loadings. Engine thrust loading is sized by the FAR TOFL of 1370 m (4500 ft) sea level, 32°C (90°F) constraint.

The effect of wing loading at constant FAR TOFL = 1370 m (4500 ft) at sea level, 32°C (90°F) is shown in figure 37. The selected point design airplane at W/S = 400 kg/m^2 (82.2 lb/sq ft) is 2.8% higher in block fuel and 0.4% higher in TOGW over the minimum, which occurs at W/S = 440 kg/m^2 (90 lb/sq ft) on the 1370-m (4500 ft) TOFL design constraint. The minimum block fuel point of 2050 kg (4500 lb) occurs on the design selection chart at W/S = 457 kg/m^2 (93.5 psf) and CLR (ratio of C_L at initial cruise altitude to C_L for L/D max) = 0.90. The minimum [illegible] fuel occurs in a location where small improvements in field performance would permit sizing at [illegible] point. However, the minimum TOGW is found at W/S = 610 kg/m^2 (125 psf), which has TOFLs greater than 2285 m (7500 ft). Although approximately 6% in TOGW and engine size could be saved at the higher wing loading, this field length performance is unacceptable, and projected high-lift improvements are unlikely to recover the large takeoff field length deficit of 2285 versus 1370 m (7500 ft versus 4500 ft).

With a point design CLR = 0.73 and initial cruise C_L = 0.47 (C_L for L/D maximum = 0.65), small changes in takeoff thrust can have large effects in ICAC and cruise L/D. (See fig. 37.) Therefore, as basic airplane parameters are updated (OEW, takeoff, F_n, low-speed drag polars, cruise drag, etc.) some design constraints may require improved performance levels to maintain good cruise performance matching.



(1) Taxi out – 9 minutes taxi thrust

(2)&(3) Takeoff – field length performance per FAR Part 25, sea level 32°C (90°F)
- 1-minute takeoff thrust
- Takeoff and sideline noise calculated per FAR Part 36 conditions

(4) Enroute climb – Δrange, ΔW_F, Δtime, from table below

(5) Initial cruise – determined by level flight, maximum cruise thrust, at altitude and cruise Mach

Procedure – constant cruise altitude

(6) Descent – Δ range, ΔW_F Δ time varies with altitude

(7) Landing – performance per FAR Part 25 (sea level)
- approach noise calculated per FAR Part 36 conditions

(8) Taxi in – 5 minutes taxi thrust

(9) Reserves – from table below

Climb			Reserves
Time (hrs)	Distance km (nmi)	Fuel % TOGW	Fuel % TOGW
0.500	185 (100)	2.60	5.0

Figure 35 Flight Profile and Mission Rules Used in Airplane Sizing

SHORT-HAUL TRANSPORT

PAYLOAD	=	50 PASSENGERS, 4550 KG (10 000 LB)
RANGE	=	1400 KM (750 NMI)
CRUISE MACH	=	0 70
Λ c/4	=	0.08 RAD (4.5°)
AR	=	10.0
t/c (R/T)	=	15/12%

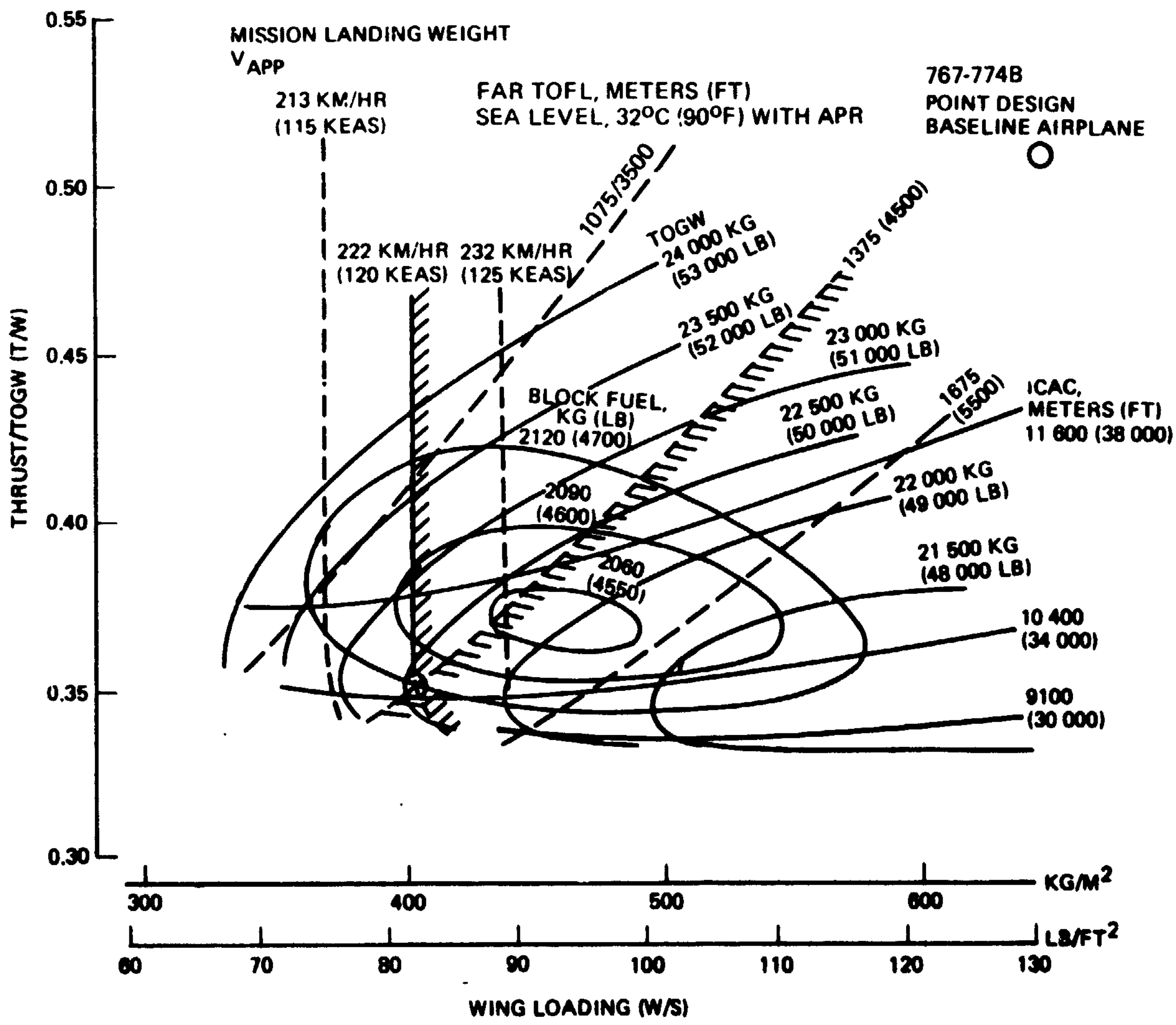


Figure 36 Design Selection Chart

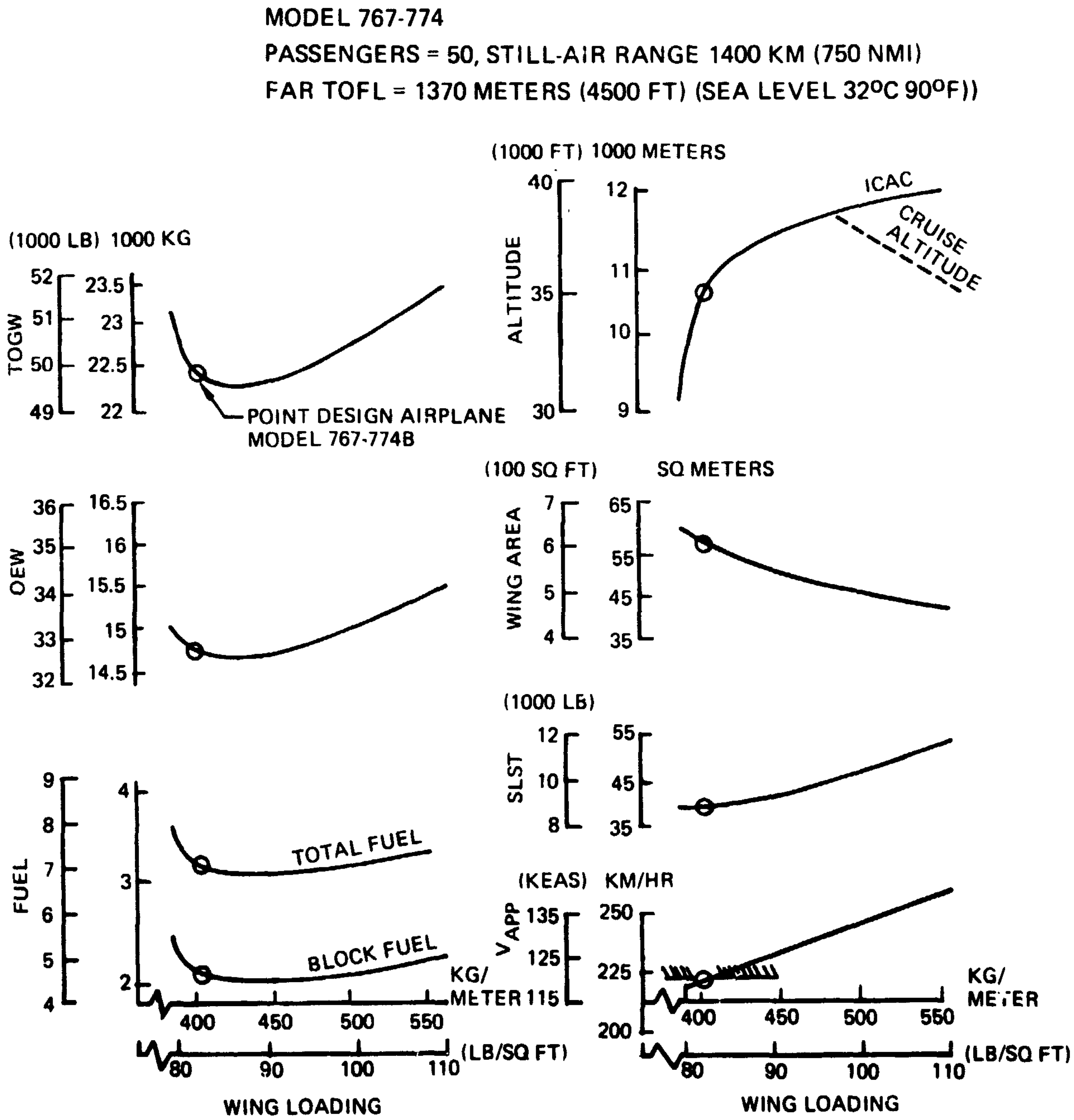


Figure 37 Effect of Wing Loading

5.11.2 BASEPOINT AIRPLANE CHARACTERISTICS AND PERFORMANCE

The advanced structures trade study airplane (model 767-774B performance and basic characteristics are shown in table 13. The same design constraints that sized the baseline airplane were used to size this airplane.

The field performance was calculated using automatic power reserve (APR), which for scaled CF-34 engines at sea level and 32°C (90°F) is about a 10% thrust increase for the second segment climb gradient requirement. Initial cruise altitude capability (ICAC) results from matching initial cruise thrust power to airplane drag at Mach 0.70. The average cruise weight specific range at 10 760 m (34 300 ft) is 0.725 km/kg (0.178 nmi/lb). Mission range, fuel, and time are listed below.

	Climb	Cruise	Descent	Block Totals
Time				
Hours	0.5	1.332	0.281	2.364
Fuel				
Kilograms	585	1367	66	2123
(Pounds)	(1291)	(3014)	(146)	(4680)
Distance, still air				
Kilometers	54	290	61	405
(nmi)	(100)	(537)	(113)	(750)

Payload range and field performance for the basepoint airplane are shown in figure 38.

5.11.3 BASEPOINT AIRPLANE SENSITIVITIES

The major airplane uncycled parameters and the cycled effects are listed in table 14.The cycled sensitivity results are for the basepoint airplane performance constraints.

Table 13 Advanced-Technology Airplane (767-774B) Characteristics and Performance

TOGW	22 580 KG (49 780 LB)
OEW	14 850 KG (32 730 LB)
BLOCK FUEL	2120 KG (4680 LB)
RESERVES	1130 KG (2490 LB)
MISSION LANDING WEIGHT	20 510 KG (45 220 LB)
WING	
S_W/b_W/MAC	563 M^2/23.71 M/62.63 M (606 FT^2/77.8 FT/8.62 FT)
$AR/\Lambda_c/\lambda/t/c_{(R/T)}$	10/0.79 RAD/0.25/15/12% (10/4.55 DEG/0.25/15/12%)
EMPENNAGE	
$S_H/L_H V_H$	2.566 M^2/3.391 M/1.027 (147 FT^2/36.5 FT/1.027)
$S_v/L_v/V_v$	2.496 M^2/3.14 M/0.103 (143 FT^2/33.8 FT/0.103)
BODY LENGTH/DIAMETER	24.1 M/2.9 M (79 FT/114 INCHES)
PROPULSION	
ENGINE TYPE/NO./BPR	SCALED CF-34/2/6
$SLST_{UNINST}$	38.9 KN (8730 LB)
T/W	0.35
W/S	401 KG/M^2 (82.2 LB/FT^2)
ICAC	10 760 M (35 300 FT)
AVERAGE CRUISE ALTITUDE	10 760 M (35 300 FT)
RF	15 460 KM (8350 NMI)
$L/D/C_L/C_D$	14.5/0.46/0.0317
SFC	0.0198 KG/KN-SEC (0.70 LB/LB-HR)
$C_{D_{P_{MIN}}}$	0.02417
FAR TOFL, SL (90°)	1370 M (4500 FT)
$C_{L_{V2}}/L/D_{V2}/V_2$	1.76/9.25/217 KPH (1.76/9.25/117 KEAS)
$C_{L_{APP}}/L/D_{APP}/V_{APP}$ (1.3V_s)	1.53/7.66/222 KPH (1.53/7.66/120 KEAS)
OEW/TOGW	65.8%
PL/TOGW	20.1%
RES/TOGW	5.0%
$(M)L/D_c$	10.1

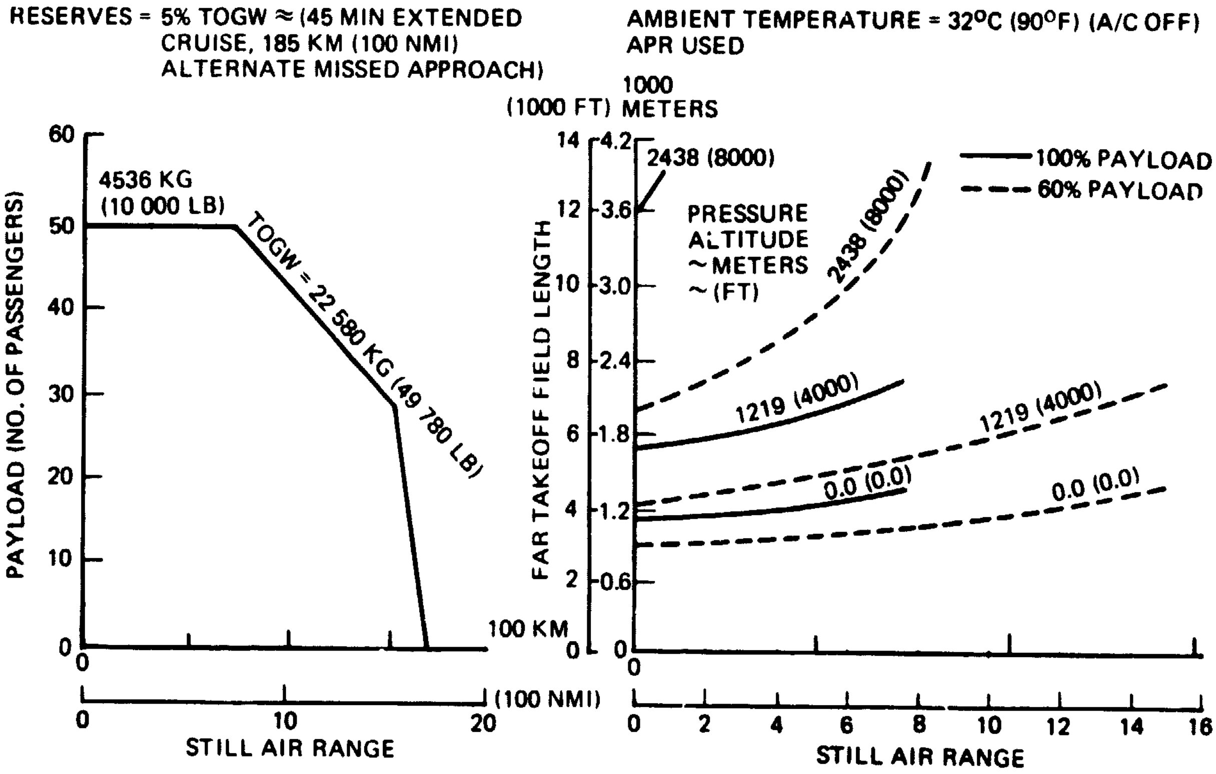


Figure 38 Advanced-Technology Short-Haul Transport, Model 767-774B—Takeoff Field Length and Payload vs Range Comparison

Table 14 Parameters and Cycled Effects

Uncycled parameter		Cycled changes				
Changes %		TOGW, %	OEW, %	BLKF, %	SLST, %	SW, %
OEW	+5 −5	6.4 −5.2	8.9 −7.9	+3.0 +1.7	6.9 −4.6	6.6 −6.6
Cruise F_N	+5 −5	−0.6 3.8	−0.3 2.8	−3.5 19.1	−0.8 7.4	−0.3 2.5
Cruise drag	+5 −5	3.1 −1.2	1.8 −0.7	18.8 −6.9	4.6 −1.2	1.3 −0.7
Cruise SFC	+5 −5	0.5 −0.5	0.3 −0.3	3.1 −2.8	0.7 −0.6	0.2 −0.3
Takeoff F	+5 −5	+2.3 1.0	0.3 1.8	+22.1 −2.0	−0.7 6.1	0.3 1.3

6.0 ADVANCED-TECHNOLOGY AND LOW-COST TRADE STUDIES

6.1 SUMMARY

Appropriate advanced technologies are examined in this section, both individually and in combination, to determine how they best apply in meeting the technical and economic performance objectives of the baseline mission. The recurring cost breakdown of the conventional technology baseline airplane is shown in figure 39. The largest portion of recurring cost is for construction and assembly of the primary structure, and this will be the first item addressed in the application of advanced technology. The advanced technologies and low-cost features that appear to offer the greatest improvements in performance and/or cost are incorporated into new airplane configurations for analysis and comparison purposes. The development of these trade study airplanes is shown schematically in figure 40.

Several advanced technologies cannot be accurately assessed relative to a short-haul transport without an all-encompassing study that would be beyond the scope of the current contract. This is especially true for accurate cost assessment of advanced technology items such as cost of very close tolerances required in manufacturing a natural-laminar-flow wing or cost of manufacturing and maintaining advanced-composite primary structure.

Advanced technologies that could not be accurately assessed are given only cursory coverage in this report and probably will not be included in the advanced short-haul design because they would tend to obfuscate the performance and cost of the final airplane. These advanced technologies are discussed in section 8.0, recommendations for further research and technology.

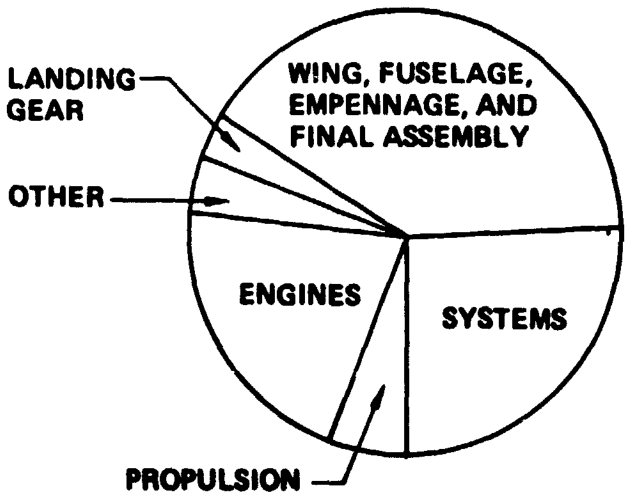
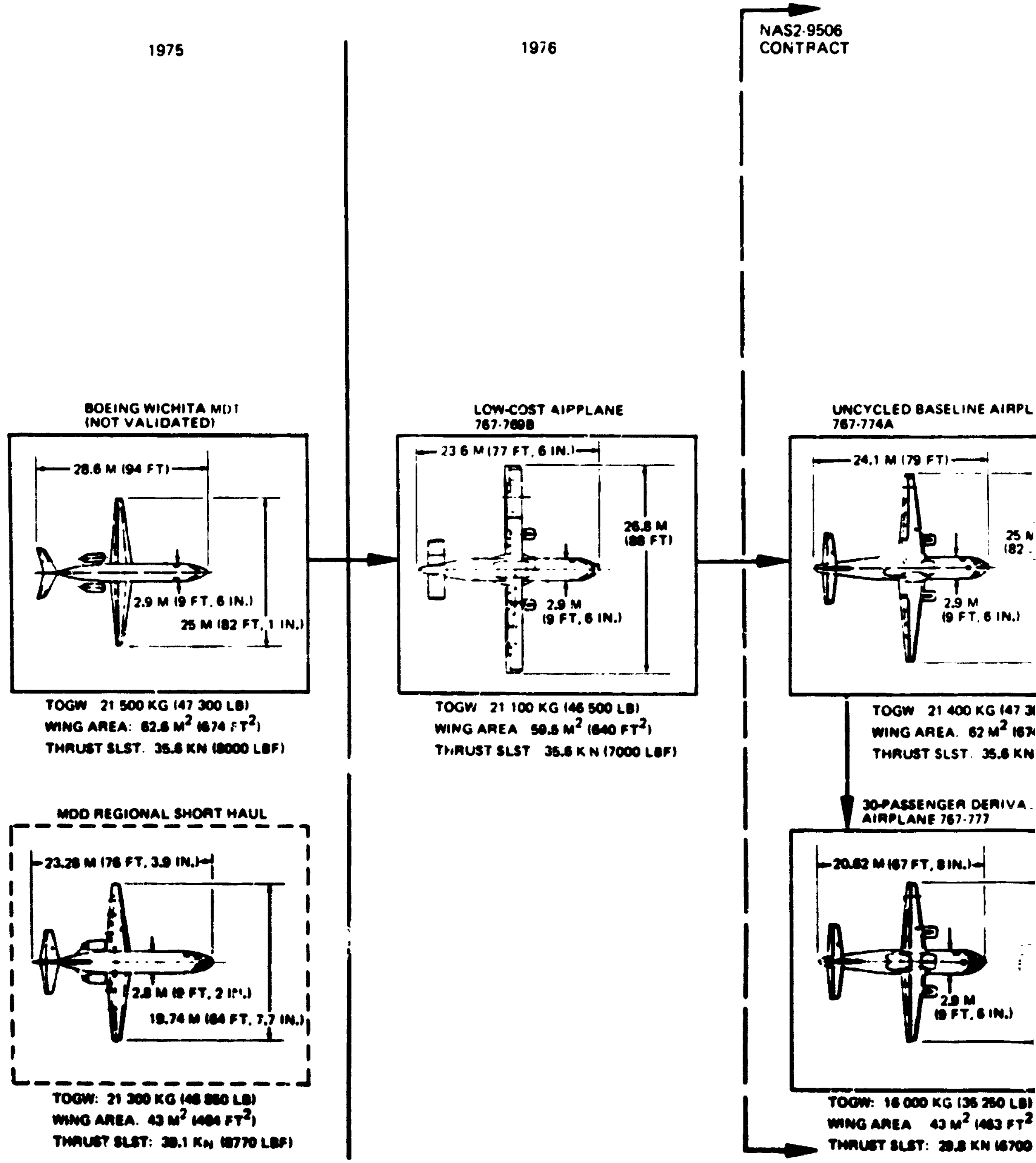


Figure 39 Short-Haul Airplane Recurring Costs (200 Airplane Program)

FOLDOUT FRAME



FOLDOUT FRAME 2

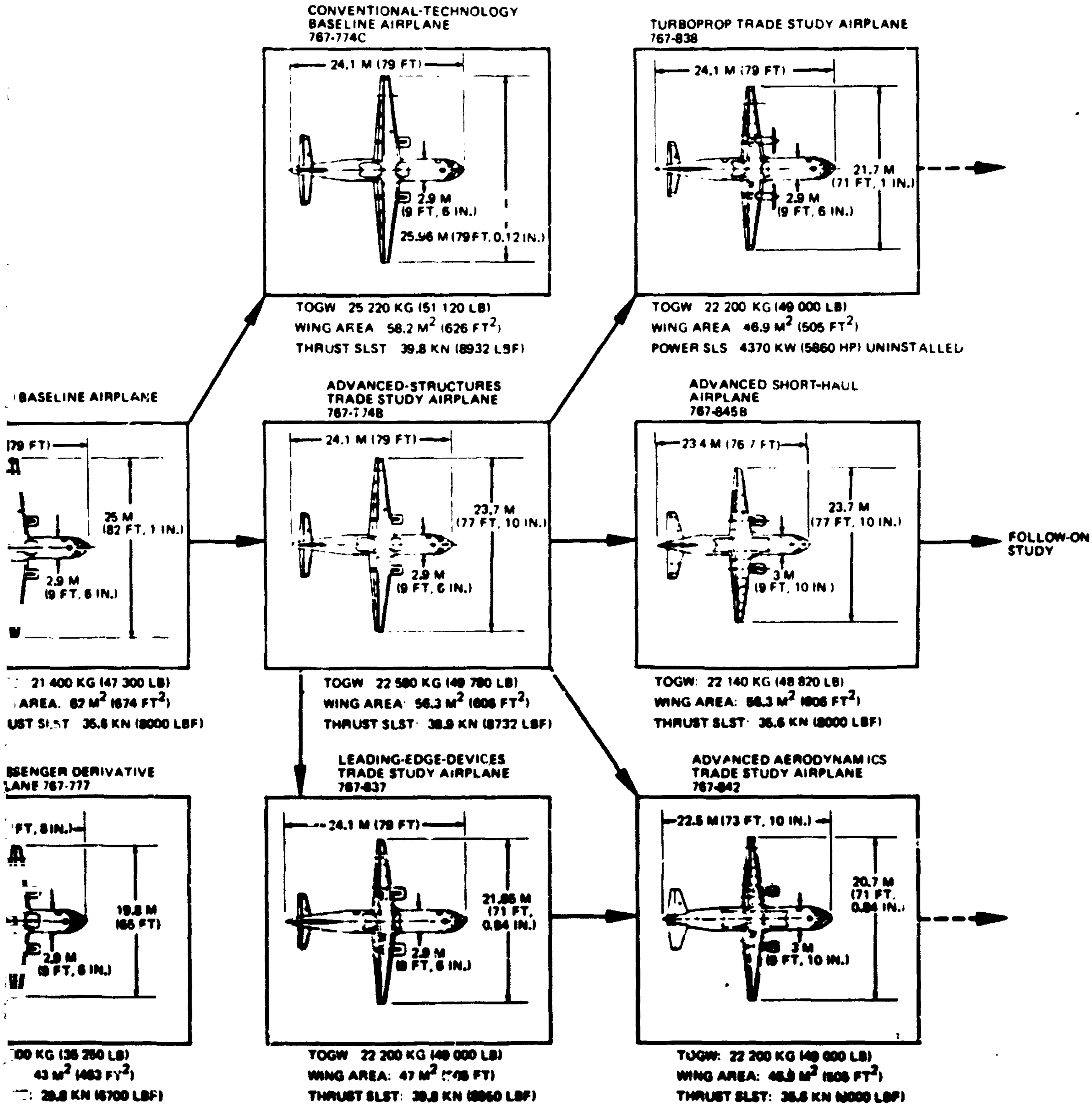


Figure 40 Short-Haul Airplane Configuration Studies

The application of new technology is treated as follows:

- Structures and materials in section 6.2
- Advanced aerodynamics in section 6.3
- Advanced flight controls in section 6.4
- Advanced propulsion in section 6.5
- Advanced ride control and load alleviation in section 6.6
- Advanced systems in section 6.7
- The effect of additional low-cost features in section 6.8

6.2 ADVANCED STRUCTURES AND MATERIALS

The affect of advanced composite primary structure on the empty weight of conventional subsonic transports has been studied extensively in large research efforts such as the NASA AC [illegible] program. These studies have developed high confiden[illegible] that significant weight can be saved by use of advanced composites on a variety of structural components. At the present time, the predicted costs on most of these components is higher than for conventional structure.

Because this airplane will have a large amount of minimum gage material, and minimum gage composite structure is probably no lighter than fiberglass, the weight saved by use of advanced composites will be a much smaller percentage than for a typical jet transport. In addition, the unsolved problems of lightning-strike resistance and of in-the-field repairability tend to rule out the use of composite primary structure at this time for a short-haul transport. Hence, in the description of advanced structures that follow[illegible] primary structure is almost entirely bonded-aluminum construction.

Becaus[illegible]e cost was the overriding factor on this study, the approach used to design primary and secondary structure consisted of trade studies comparing conventional skin/stringer construction with metal-bonded structure. Airplane components were defined in sufficient detail to justify selection of structural make-up of the advanced-structures airplane.

Based on low cost, planning for the Study of the Application of Advanced Technology to Small Short-Haul Transport Aircraft included a past production survey for evidence of changes in structural assembly design resulting directly in cost reduction. Without exception, the incorporation of bonded-structure assemblies reduced the airplane cost. Bonded assemblies required fewer parts, simplified manufacturing assembly, and, in most cases, resulted in far more stiffness without adding weight.

Boeing has steadily increased bonding capability through major in-house investments such as large autoclaves, huge cleaning tankage, and ultrasonic inspection methods, in addition to personnel with in-depth experience. Why, then, isn't more bonded structure being used at this time? The acceptance of any structure's integrity is based on time - time to design, time to test, time to incorporate changes, time to evaluate. Any change from an acceptable existing design is always a major task.

In the case of bonded structure, the evaluation of its acceptance has progressed through all secondary structural elements of the airplane, e.g., flaps, elevators, rudders, ailerons, and tabs. Problems associated with early bonded structure are known throughout the aircraft industry and the military services, but evaluation of bonded-structure integrity has increased dramatically in the last 5 years. New bonding systems, such as Boeing's BAC 5555, have proven exceptionally durable in continuous-service applications. The PABST programs recently recommended incorporation of BAC 5555 into that vehicle's bonded-structure assembly.

The application of advanced technology to primary structure has resulted in a proposed all-aluminum bonded-honeycomb wing, empennage, and constant body section for the short-haul transport.

6.2.1 ADVANCED-STRUCTURES TRADE STUDY AIRPLANE

Basic design features of the advanced-structures trade study airplane (see model 767-774B, fig. 40) are listed below.

- The body is a simple, cylindrical pressure vessel with no cut-outs for the wing attachment or main gear stowage
- The wing has a straight-line rear spar with constant taper and is mounted completely separate from the body pressure vessel
- The tail is a conventional tail geometry with interchangeable components between right- and left-hand sections
- The power plants are two CF-34 turbofan, strut-mounted engines positioned on the wing
- The landing gear is supported and stowed in a gear pod external to the body pressure vessel
- The two doors are internal passenger doors located on the left-hand side of the aircraft with two emergency doors directly opposite on the right-hand side

Figure 41 shows the composition of airframe pieces itemized below:

- Graphite/Nomex-core honeycomb
    - Spoiler
- Graphite multi-ply frame
    - Pilot's window frame assembly
- Skin/stringer
    - Engine struts and nacelles
- Fiberglass/Nomex-core honeycomb
    - Radome
    - Gear pod
    - Wing/body fairing
    - Access panels
    - Elevators
    - Rudders
    - Tail cone
    - Fin cap
- Bonded-aluminum honeycomb
    - Body pressure vessel
    - Wing primary structure
    - Wing control surfaces
    - Passenger floor
    - Empennage primary structure

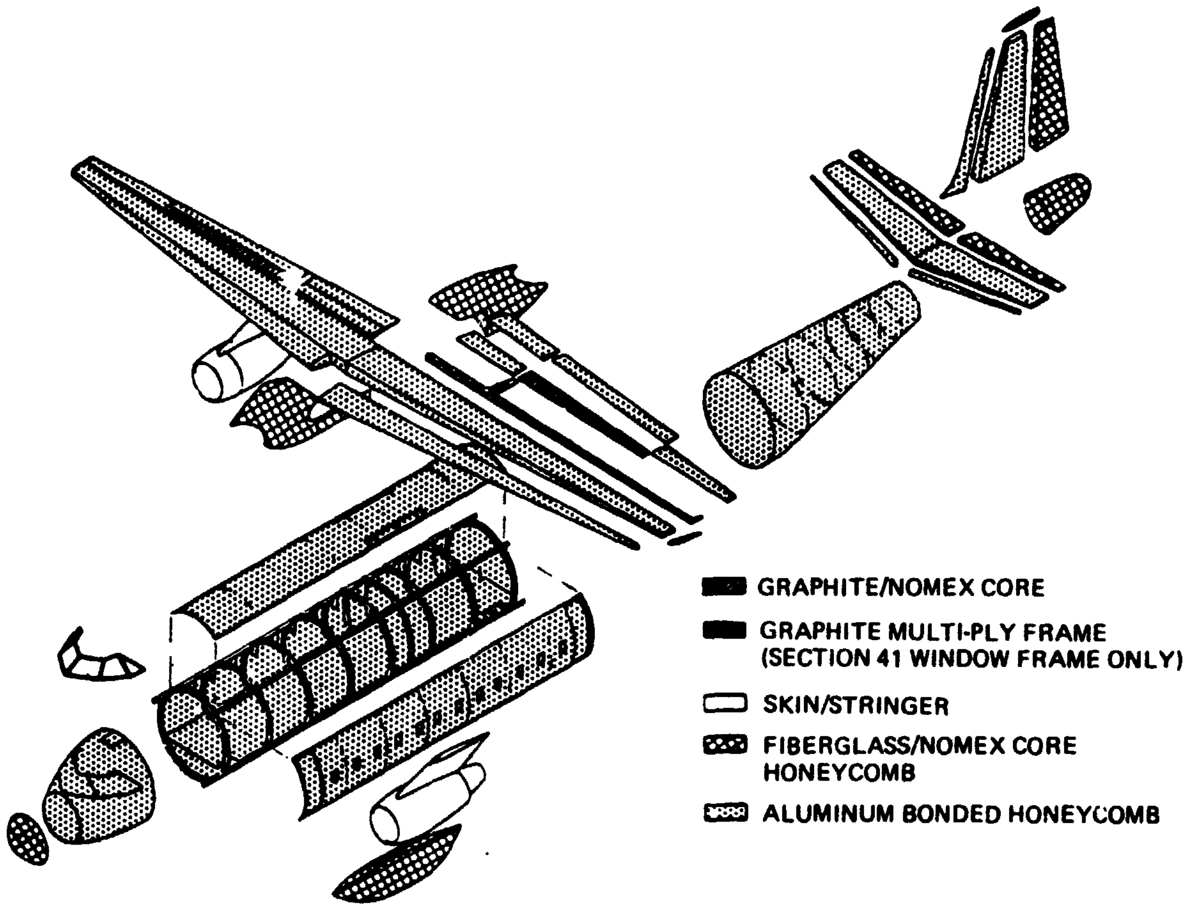


Figure 41 Short-Haul Transport Structure

6.2.2 ADVANCED-STRUCTURES DESCRIPTION

6.2.2.1 Constant-Section Body

The constant-section-body plug design, figure 42, is based upon IR&D work performed in 1967, 1974, and 1977. Parts count is minimized by eliminating stringers and circumferential joints. Very large skin sections are used to permit the body plug to be made of four panels with four longitudinal splice joints.

The lack of sufficient-size panels could require splices in the outer face skins of the honeycomb-sandwich panels. Such a splice would be accomplished using mechanical fasteners and adhesive bonding or, alternately, by weld bonding. This would allow the panel, after bonding, to be handled as one unit for assembly purposes. In this concept, the skin is tooled to the outer contour and the mechanically fastened shear tie and frame permit the frames to fit the skin. A typical section illustrating the honeycomb-sandwish construction is shown in figure 43. (Square-edged-panel technology was developed originally for use on the 747 trailing-edge flaps, and within the last 3 years used extensively on the YC-14 prototype empennage.) Figure 44 shows detail of the outer face of the crown skin panel. This panel would be sculptured by chemical milling; pad-ups are created by masking the metal to prevent removal. This design was used extensively on the two flying YC-14 vertical and horizontal primary-torque boxes.

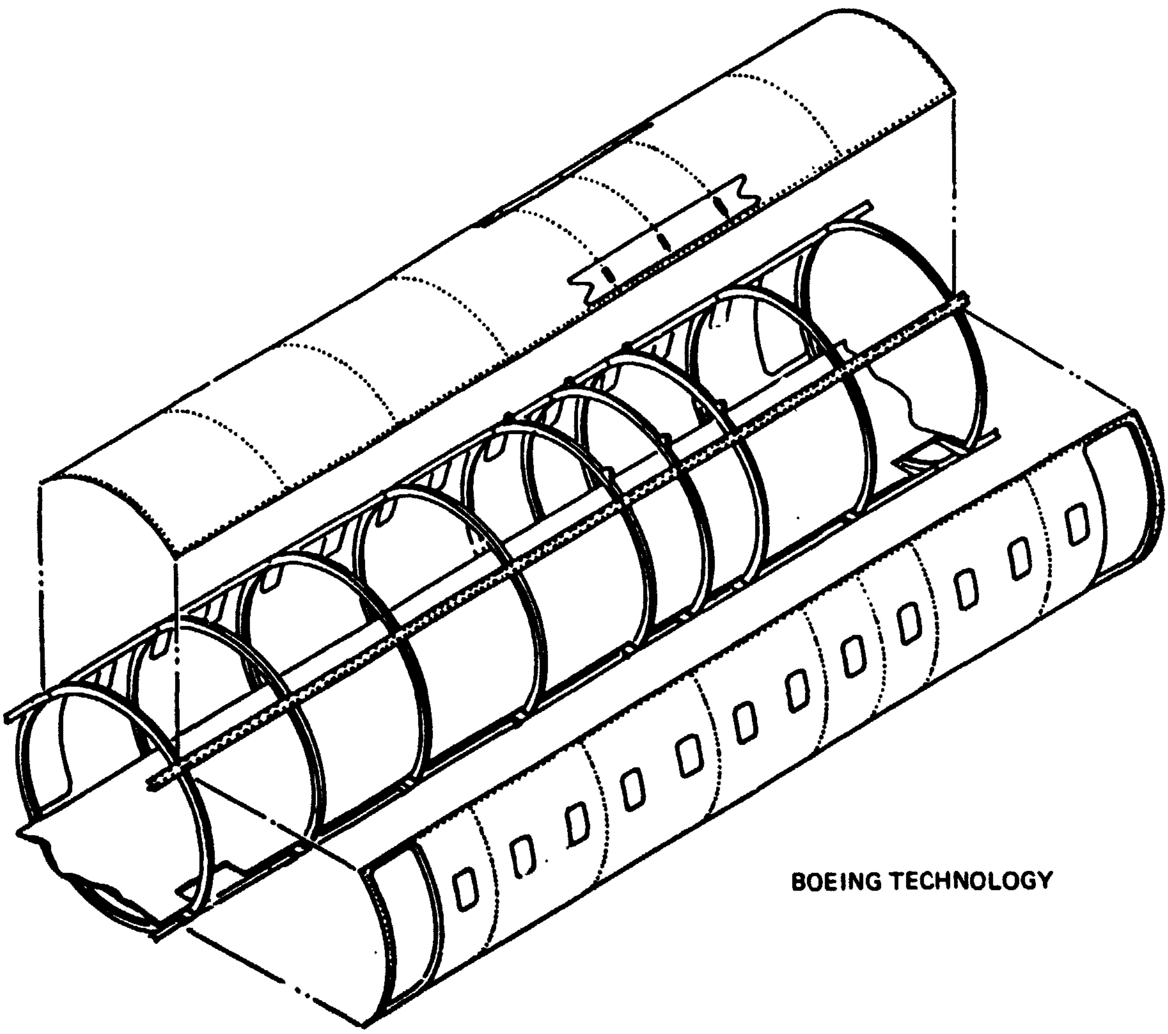
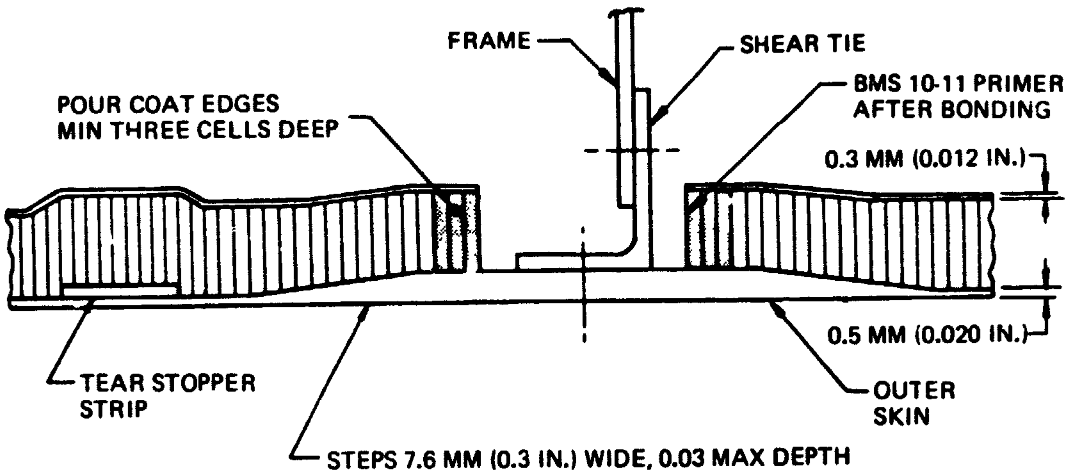
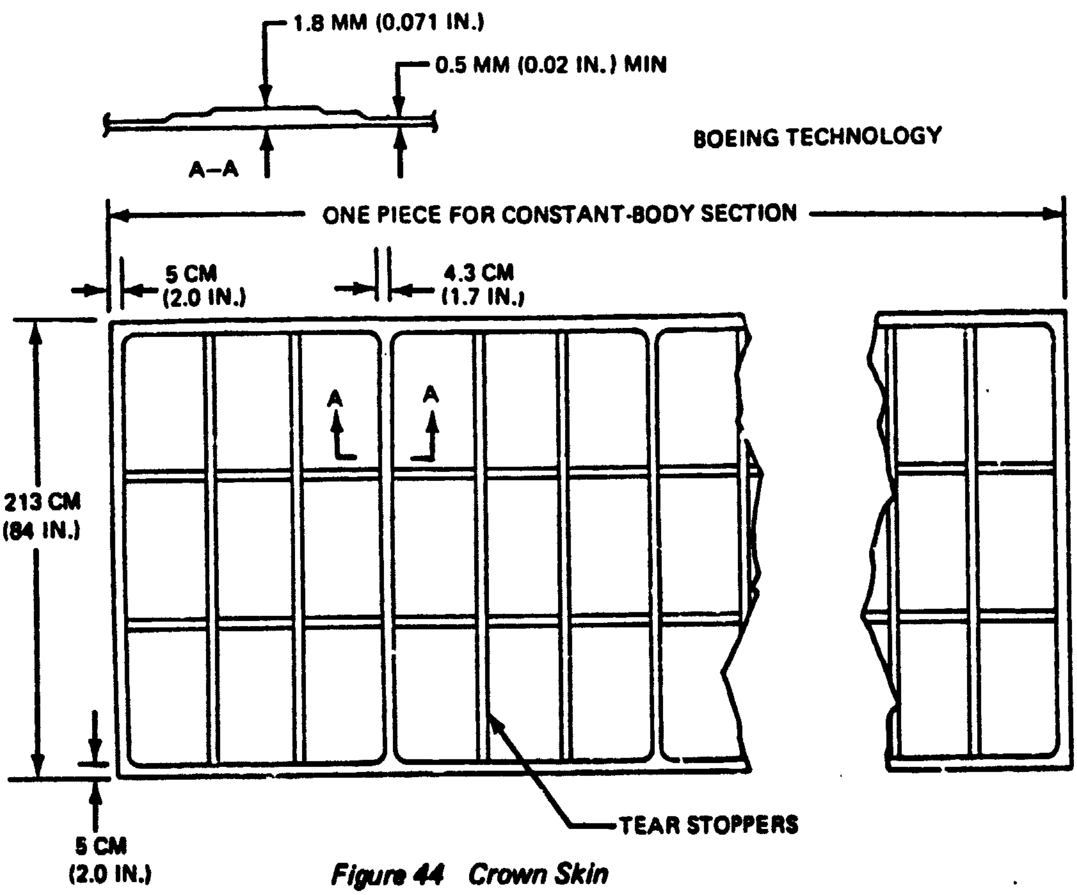


Figure 42 Short-Haul Honeycomb Constant-Body Section



BOEING TECHNOLOGY

Figure 43 Square-Edged Fuselage Panel Concept



BOEING TECHNOLOGY

Figure 44 Crown Skin

The side skin outer face is shown in figure 45. The skin is full thickness in the window and door areas. Pockets are removed by chemical milling. Doublers added around the door areas by adhesive bonding. A detail of the window belt is shown in figure 46. A multiple function "pickle-fork" insert is used at each window cutout. The long leg (section A-A, figure 46) provides pad-up for the outer skin. The short leg provides attachment for the inner skin. Potting anchors the core and stabilizes the fitting after cure. The edge of the fitting provides support for the window. The window is similar to one used on the 747 except for the different body diameter. The belly skin, figure 47, is effected by a corrosion problem. Moisture collects during flight and drains into the bilge area, and the corrosive mixture that accumulates eventually is a major cause of fuselage corrosion. A longitudinal bilge trough is installed, as shown in figure 48. Metal closures are provided for maximum protection to the honeycomb core. Automatic drain valves are installed on each side of the frames, eliminating the need for limber holes that would weaken the frame in fatigue and that are subject to blockage. The automatic drain valves open whenever the fuselage is depressurized. The exposed honeycomb core next to each frame is protected by an overcoat of polysulfide rubber in the belly skin area.

A trade study was made comparing the conventional skin/stringer constant body section and the all-bonded body section previously discussed. The skin/stringer type of constant-section body has been used over a period of years for commercial airplanes. Production costs are very predictable, with future cost reduction possibilities negligible. The all-bonded body section reduced part count by 15% over the skin/stringer body section, allowed frame spacing to be increased from 50.8 cm (20 in.) to 172.7 cm (68 in.) required 830 fasteners less per square meter than conventional structure, and resulted in an extremely smooth outer contour.

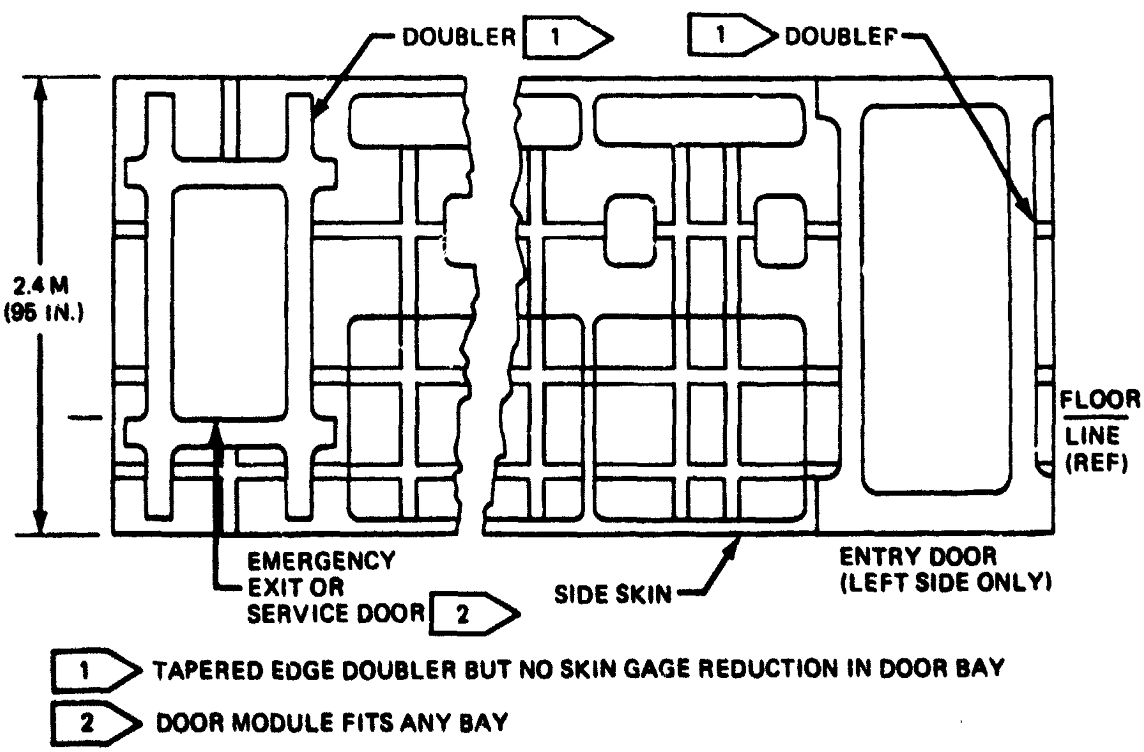


Figure 45 Side Skin

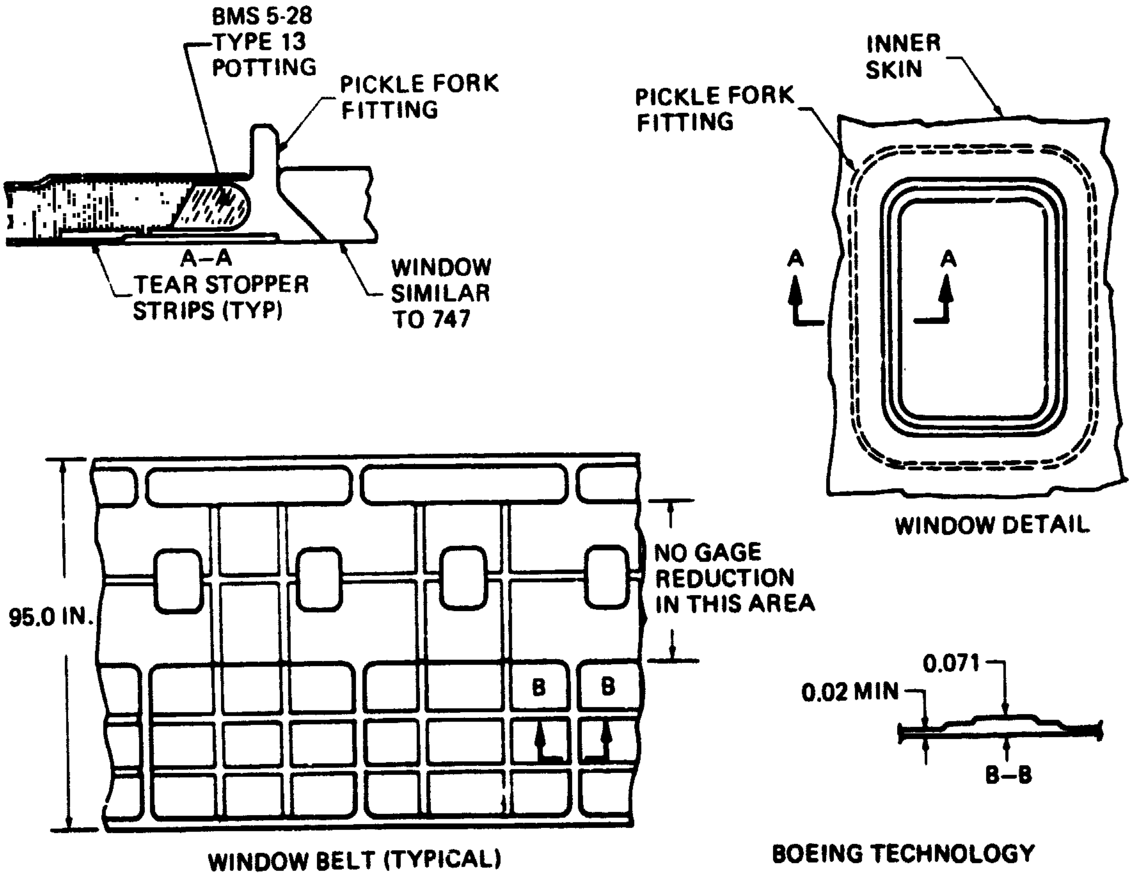


Figure 46 Window Belt

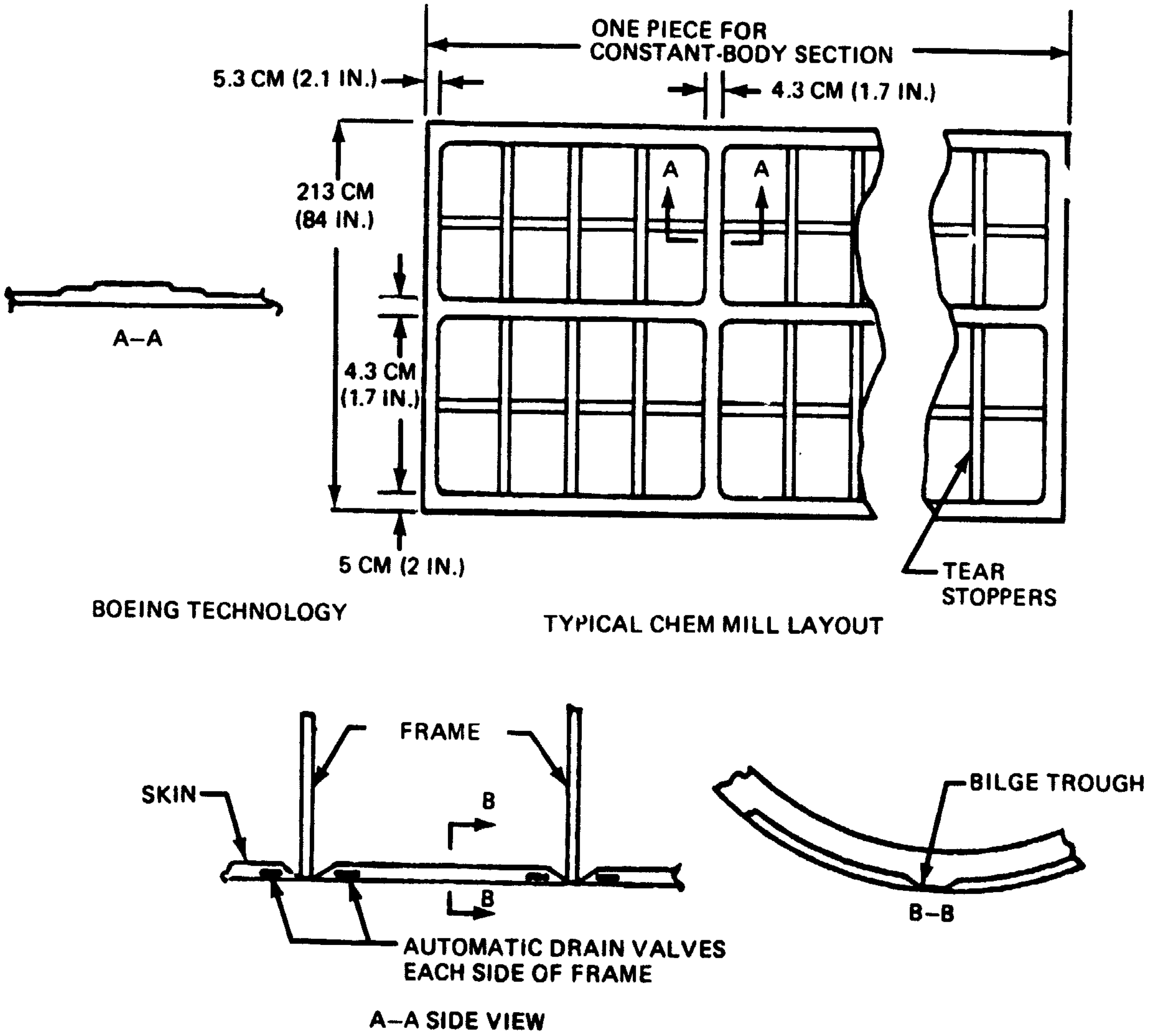


Figure 47 Belly Skin

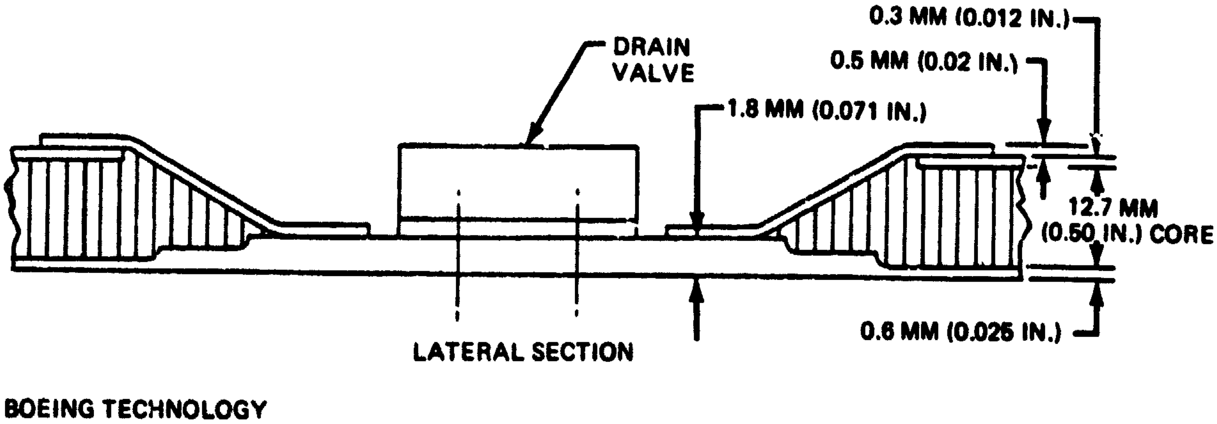


Figure 48 Bilge Trough

6.2.2.2 Fuselage Center Section Frames

The short-haul commuter airplanes will make many landings, probably more than one per flight hour. This requires an airframe designed for 30 000 flight hours also to be designed for 40 000 to 50 000 landings. The frames that support the wing and landing gear are thus fatigue designed. A relatively low-cost, fail-safe design with an exceptionally high fatigue rating is required because fuselage frames are not easily replaceable or repairable.

As shown in figure 49, the main frame serves to react landing-gear loads into the fuselage and fuselage loads into the wing. In a high-wing airplane, a bulkhead or floor beam is required to react horizontal loads from the landing gear, because the wing spar cannot perform this function.

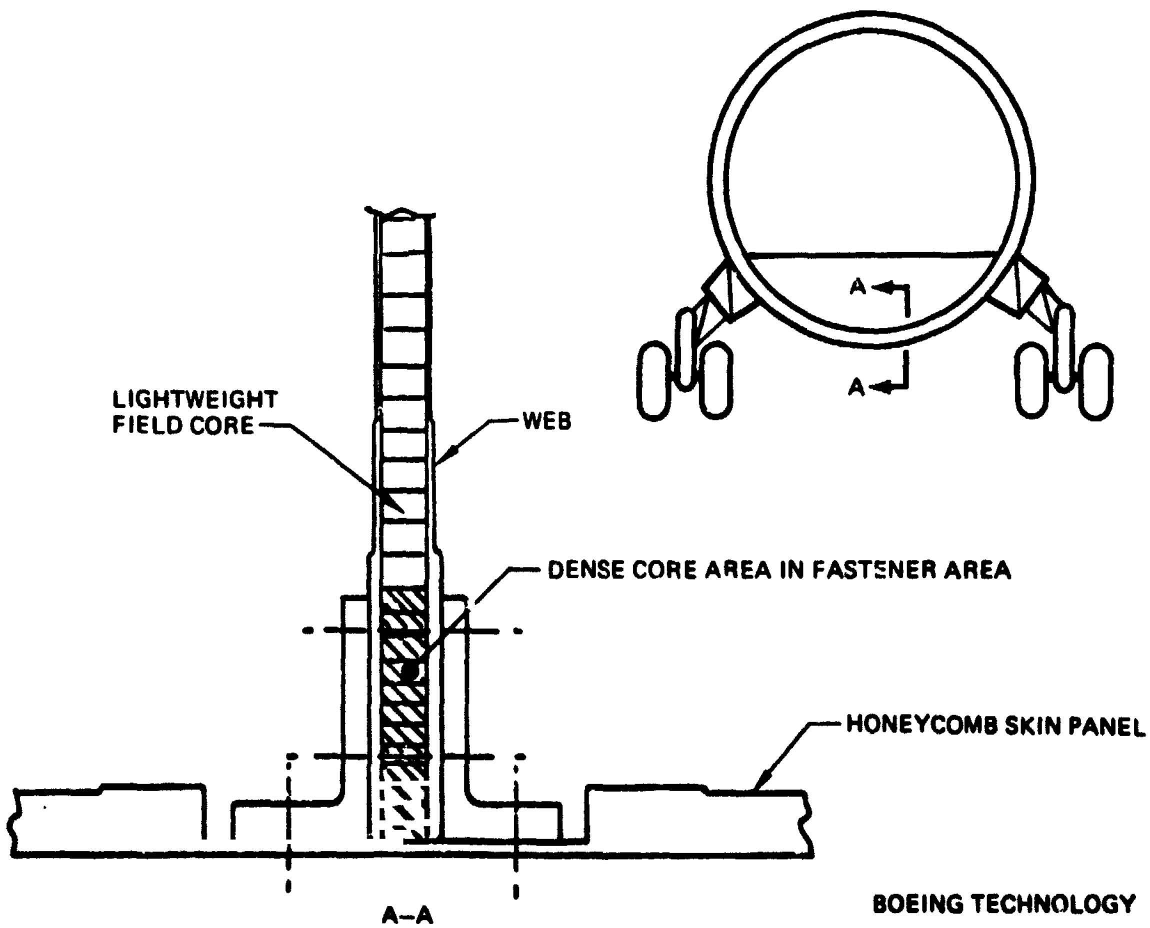


Figure 49 Center Section Frame, A–A

A sandwich bulkhead is used below the floor line. The sandwich is made of webs (with pad-ups on the outside) and constant-thickness core between the webs. During assembly of the fuselage, the frame chords are mechanically fastened to the skin and to the web. A plan view of the beam chord is shown in figure 50. Chord angles with stepped flanges are mechanically fastened through dense core. This joint is the primary load path for horizontal-landing-gear reactions. A cutaway view of the joint is shown in figure 51. The web continues some distance up the frame, with the core spliced where a step is necessary.

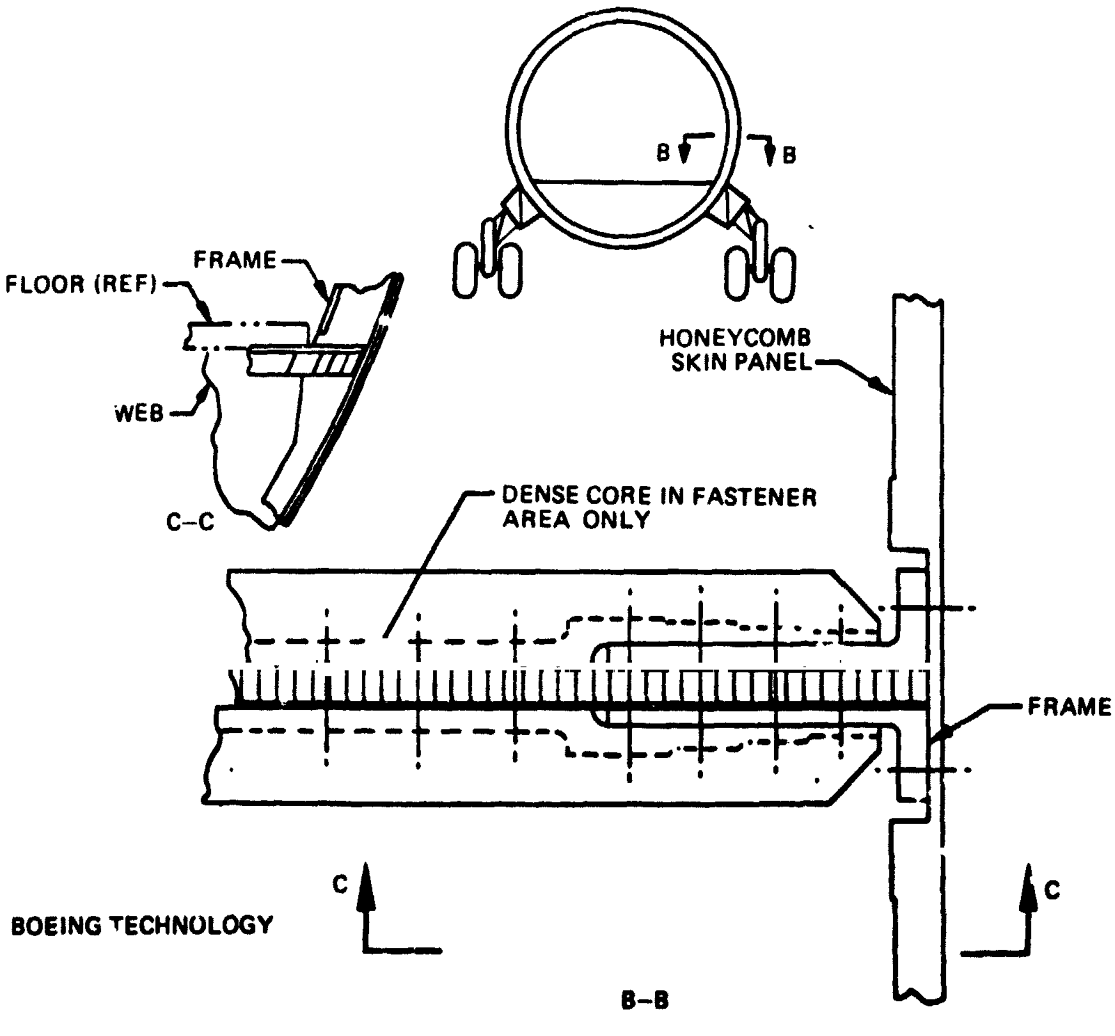


Figure 50 Center Section Frame, B–B

Figures 52, 53, and 54 show a means of attaching the high wing through shear plates. Note that this avoids the use of fasteners in tension for better fatigue life. The shear plates are mechanically fastened between frame chords (fig. 53) and the wing is fastened to the shear plates by links (fig. 54). A doubler is required on the fuselage skin to carry skin loads around the cutout for the shear plates. A shear-tie wiggle plate, figure 55, is required to react drag loads and shear loads in a fore and aft direction, but must be soft in a vertical direction to prevent stress concentrations induced by wing deflections to bending. Dense core, plus an additional doubler on the wing face skin, are used with mechanical fasteners to tie the wiggle plate to the fuselage skin.

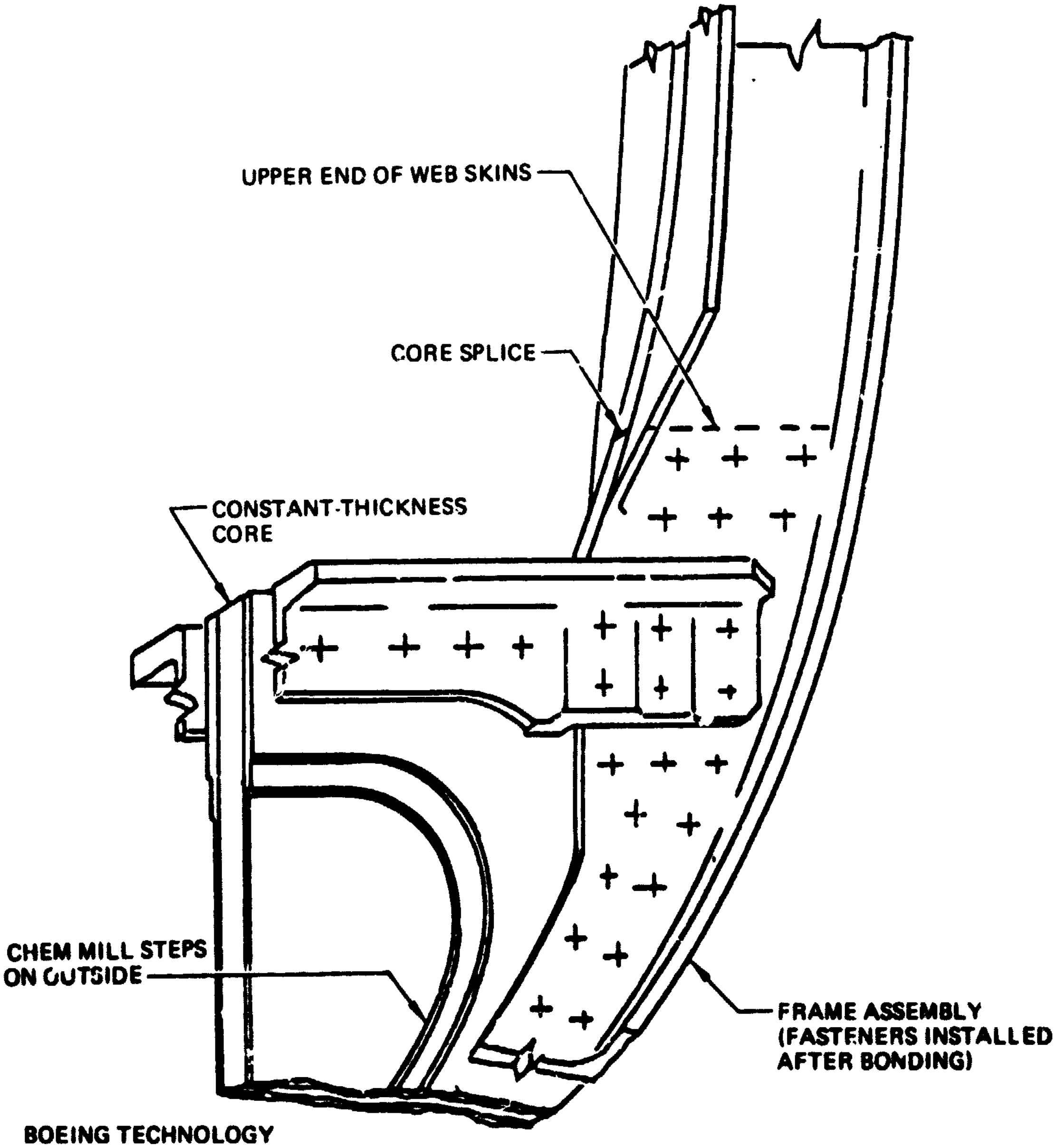


Figure 51 Assembly Detail

This configuration has several unique structural-load paths that are significantly different than conventional low-wing jet transports. The high wing results in an unusual wing-to-body attachment and body-supported main landing gears. The wing-to-body attachment, as shown in figure 54, has three pinned joints per side to carry vertical and side load. Drag load is carried on the wiggle plate. The weight penalty of this multi-pinned design and the adaquacy of the wiggle plate to carry all of the shear load due to drag and yet flex enough to withstand vertical motion without cracking needs more study.

Since the landing gear is completely supported off the body, certain design conditions, such as one-half-g ground turn, will result in large bending moments in the frames at the front, mid, and rear spars. The 0.09 m (3.5 in.) allowed for frame depth may result in substantial weight penalty. Consideration will be given to allowing this frame depth to be greater at these points by locally encroaching on the inside contour.

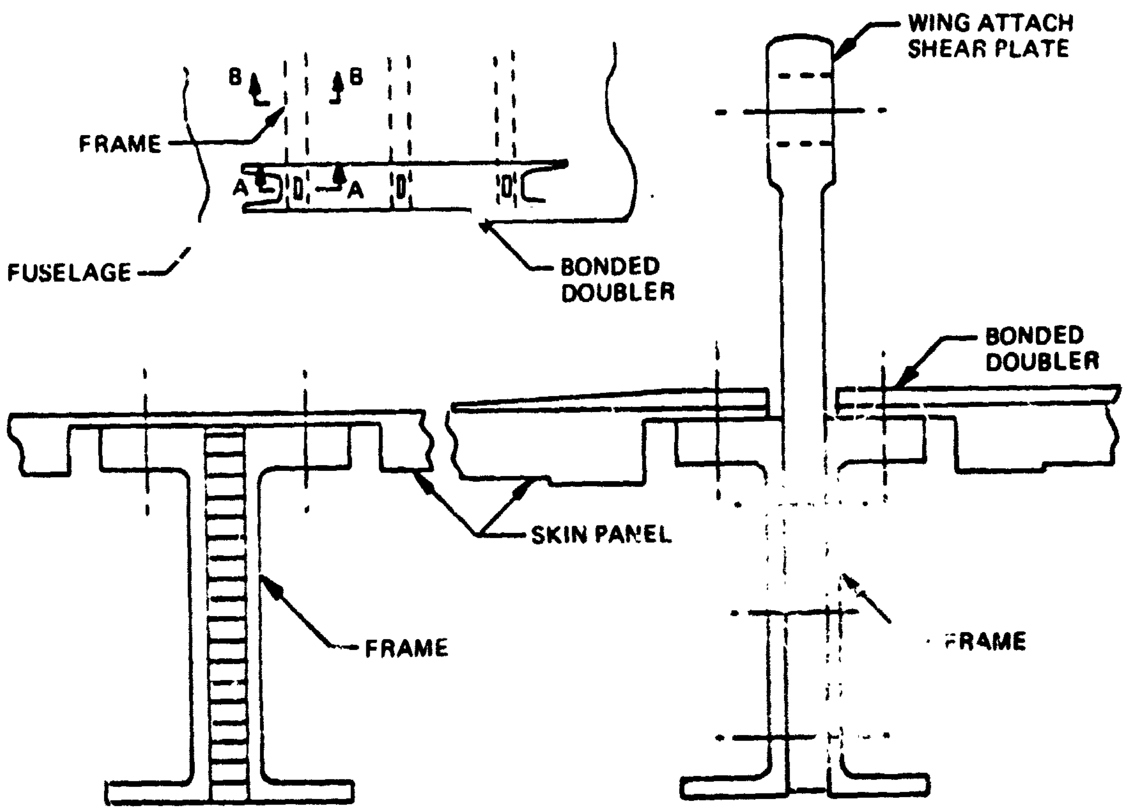


Figure 52 Wing-Attach-Fitting Structure

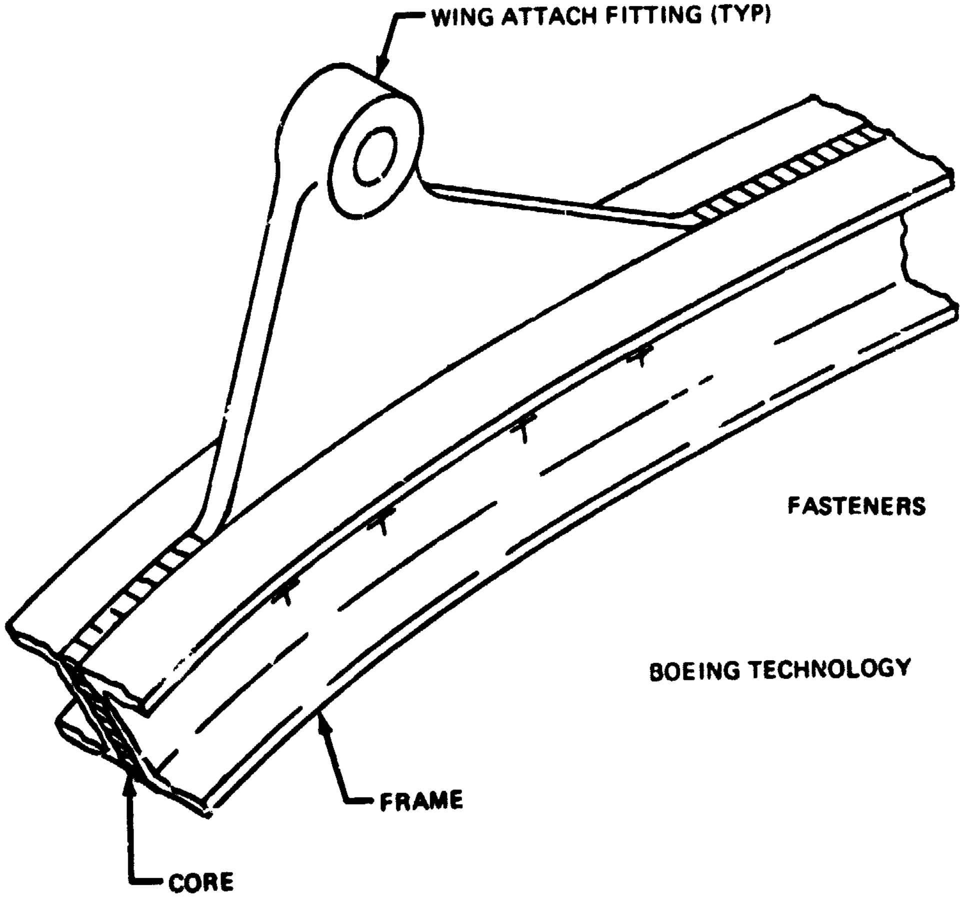


Figure 53 Wing Attach Fitting

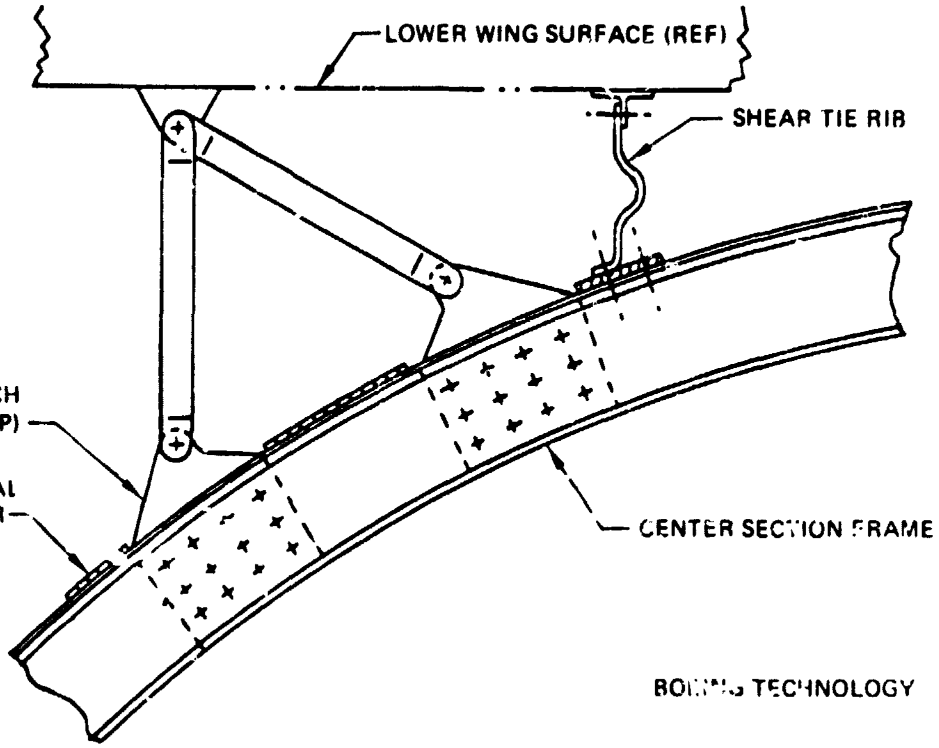


Figure 54 Wing Attach Structure

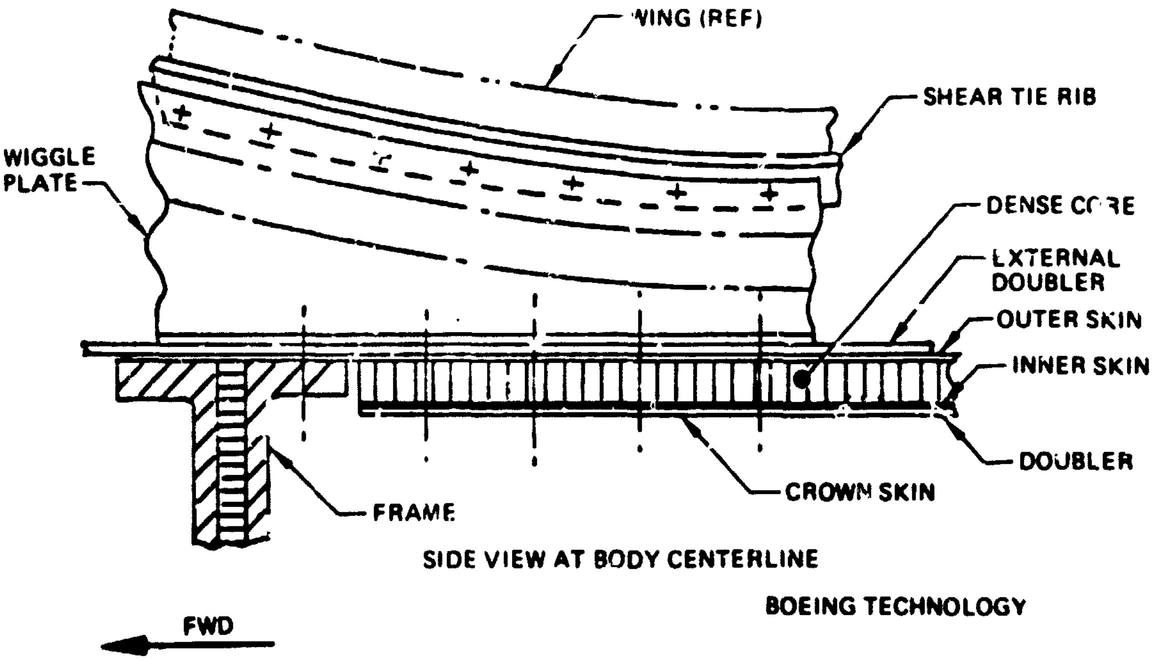


Figure 55 Wing Shear Tie

6.2.2.3 Door Frame Structure

Four doors are provided in the constant diameter section, one located on each side of each end. The right-hand side doors are 122-by-61-cm (48-by-24-in.) plug-type emergency exit and service doors. Except for the fuselage diameter, these doors would be similar to doors used on B727 airplanes. The left-hand doors are both swing-down, plug-type doors with built-in stair wells (fig. 56). The door hinge mechanism is similar to that used on United Airlines 737-aircraft overwing exit hatches. An articulated lower hinge allows vertical movement of the door (when depressurized) to clear the door stops. The door then can be rotated to loading position.

A method of reinforcing the door cutout and reacting door-stop loads is shown in figure 57. The edge of the honeycomb core is filled with high-strength potting. Mechanical fasteners anchor the shear tie angle and also anchor the stub-frame fasteners to the shear-tie angle. The door seal is fastened to a second angle that is attached to the shear-tie angle. The second angle reacts pressure loads so that tension loads do not put the bond line in cleavage at the edge of the sandwich panel. The door stop is fastened to the stub frame, shear tie, and thus to a gusset. The gusset reacts the torque from the door stop into a bonded tee and doubler.

The door header or sill beam is shown in figure 58. This beam is attached to the skin with mechanical fasteners through potted core; each end of the beam reacts pressure-induced shear into adjacent circumferential frames. The header beam and stub beams are tied off by a box structure, as shown in figure 59. An internal doubler is used to react pressure-induced hoop tension around the door cutout.

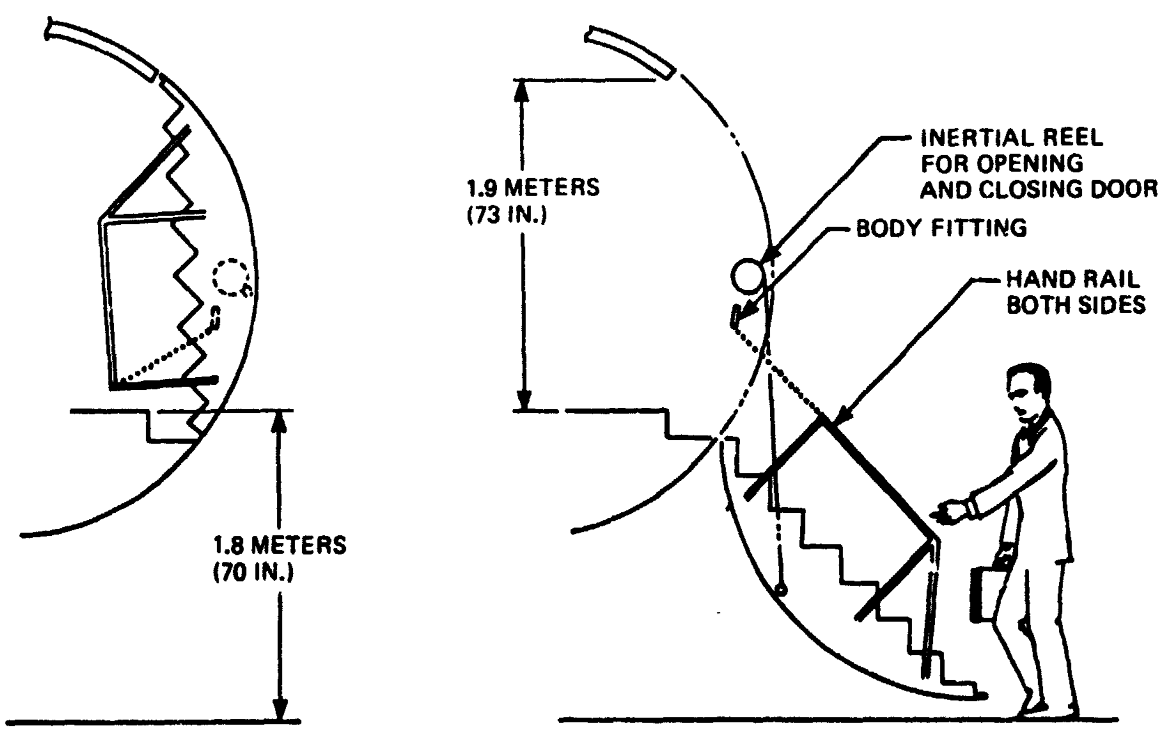
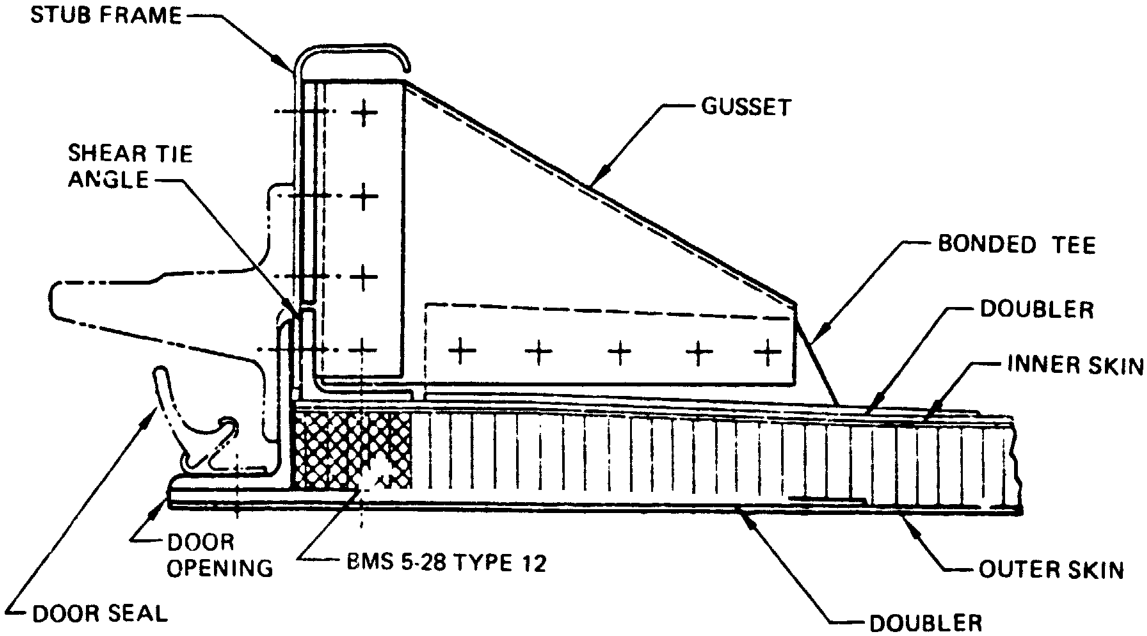
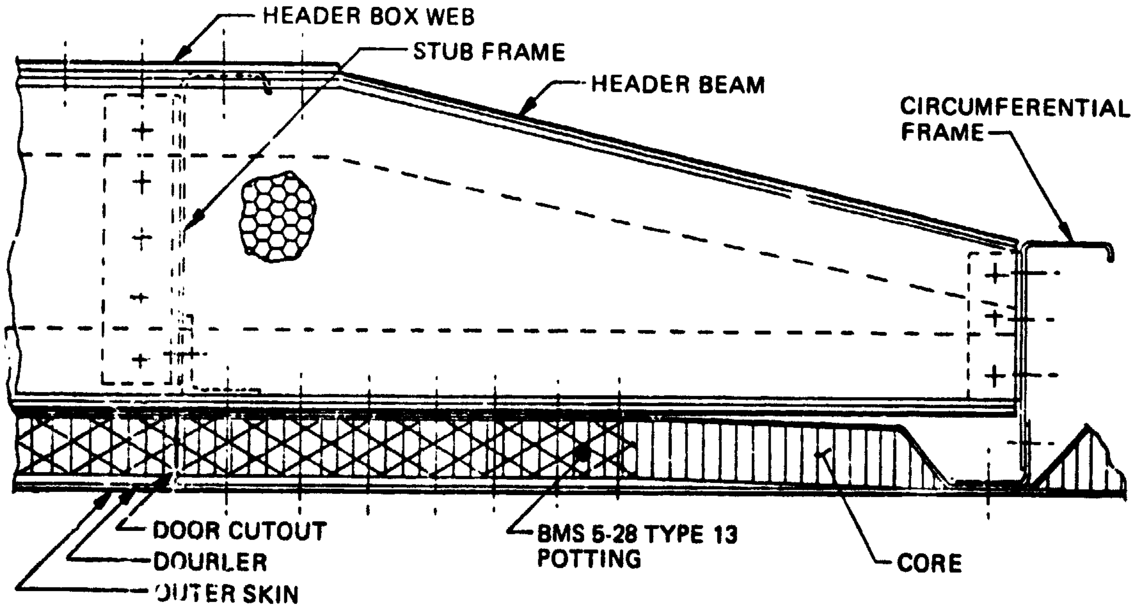


Figure 56 Passenger-Door Hinge at Floor Line



BOEING TECHNOLOGY

Figure 57 Passenger-Door Reinforcement



BOEING TECHNOLOGY

Figure 58 Door Header

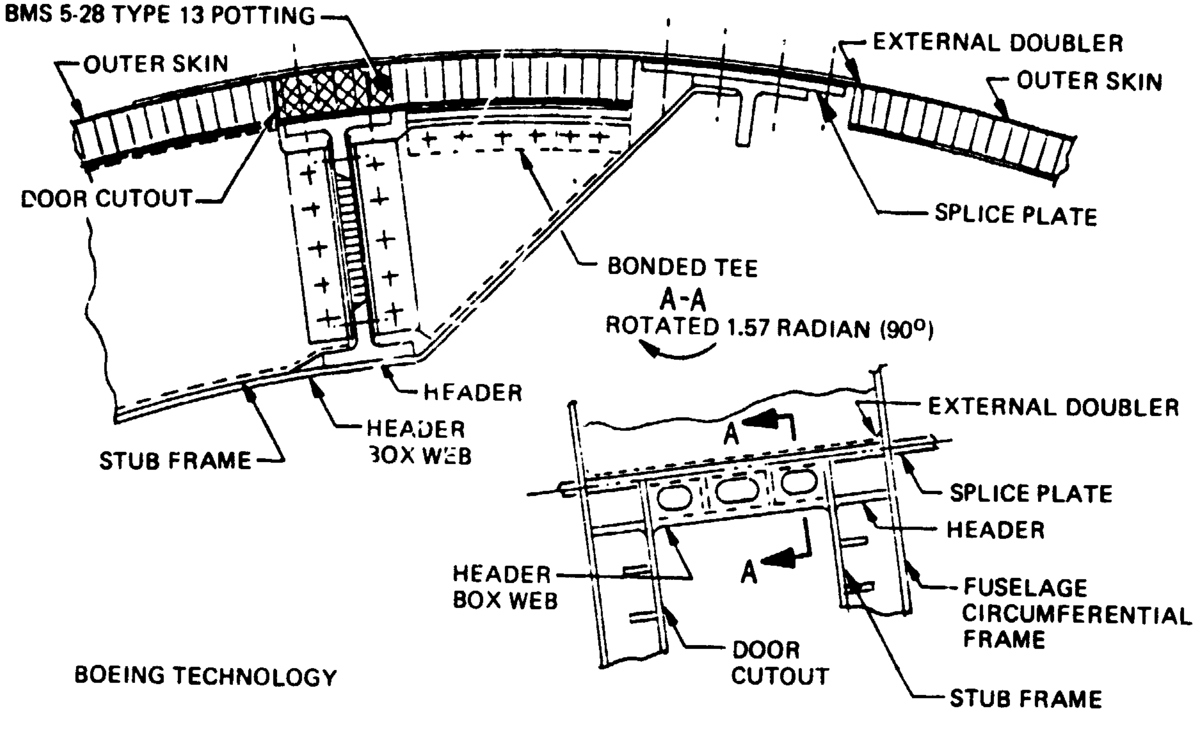


Figure 59 Header and Stub Frame Tie

6.2.2.4 Floor Panel Construction

A conventional fuselage floor assembly has many parts with mutual mechanical fasteners. The floor is built as subassemblies, which then are loaded into a jig and the fuselage is built around the floor. An IR&D concept developed in 1972 showed that a honeycomb floor would be a much simpler structure. A part count reduction of 22 to 1 was shown. Weight was comparable to existing-type structure.

The major assembly concept, based on the IR&D work, is shown in figure 60. The floor assembly (complete with beams, seat tracks, and systems) is slid into the fuselage plug and fastened in place.

Figures 61, 62, and 63 illustrate the sandwich floor panel construction. Lightweight core is used, except under seat-track locations and along the panel edge, where high-density core is used. The high-density core reacts local compressive or clamp-up loads. The light-gage face skins are padded by doublers adjacent to the dense core. The floor-beam upper chords are bonded to the floor panel.

The method of crash-load shear restraint is illustrated in figure 63. Part of the crash load (9 g) can be reacted by the column strength of the floor panel. The remaining load must be reacted through shear restraints to the fuselage shell. These shear restraints are attached to the bottom of the floor panel and top of the beam using mechanical fasteners. The load is transferred into the frame that is fastened to the fuselage shell. A tear stop prevents the frame from pulling off the fasteners below ultimate load. The shear restraint is positioned so that normal pressure deflections of the skin and up and down deflections of the floor do not induce high local strain that would cause fatigue problems.

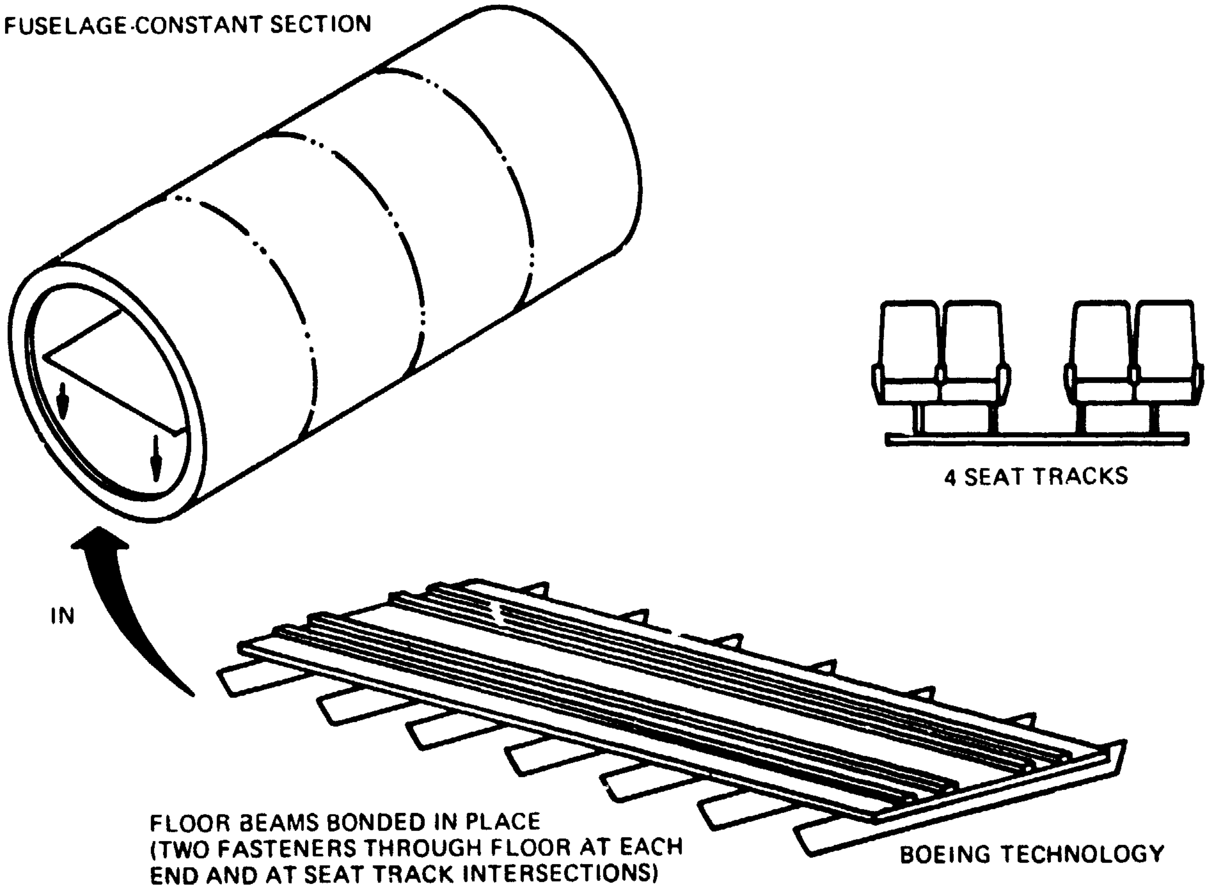


Figure 60 Passenger Floor Major Assembly

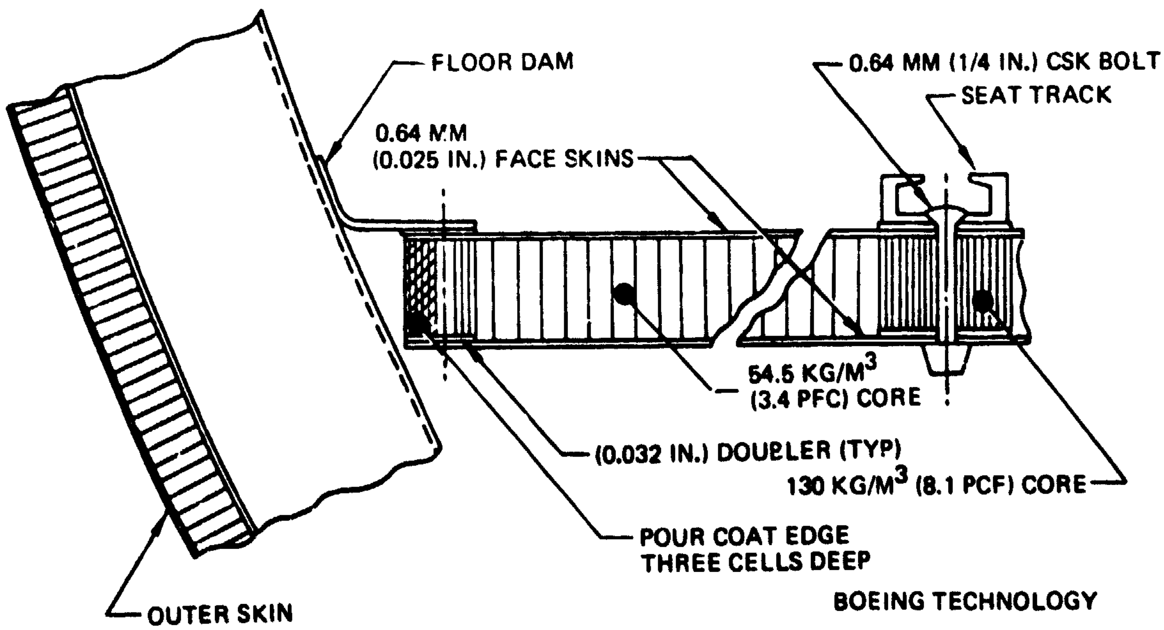


Figure 61 Floor Panel Construction

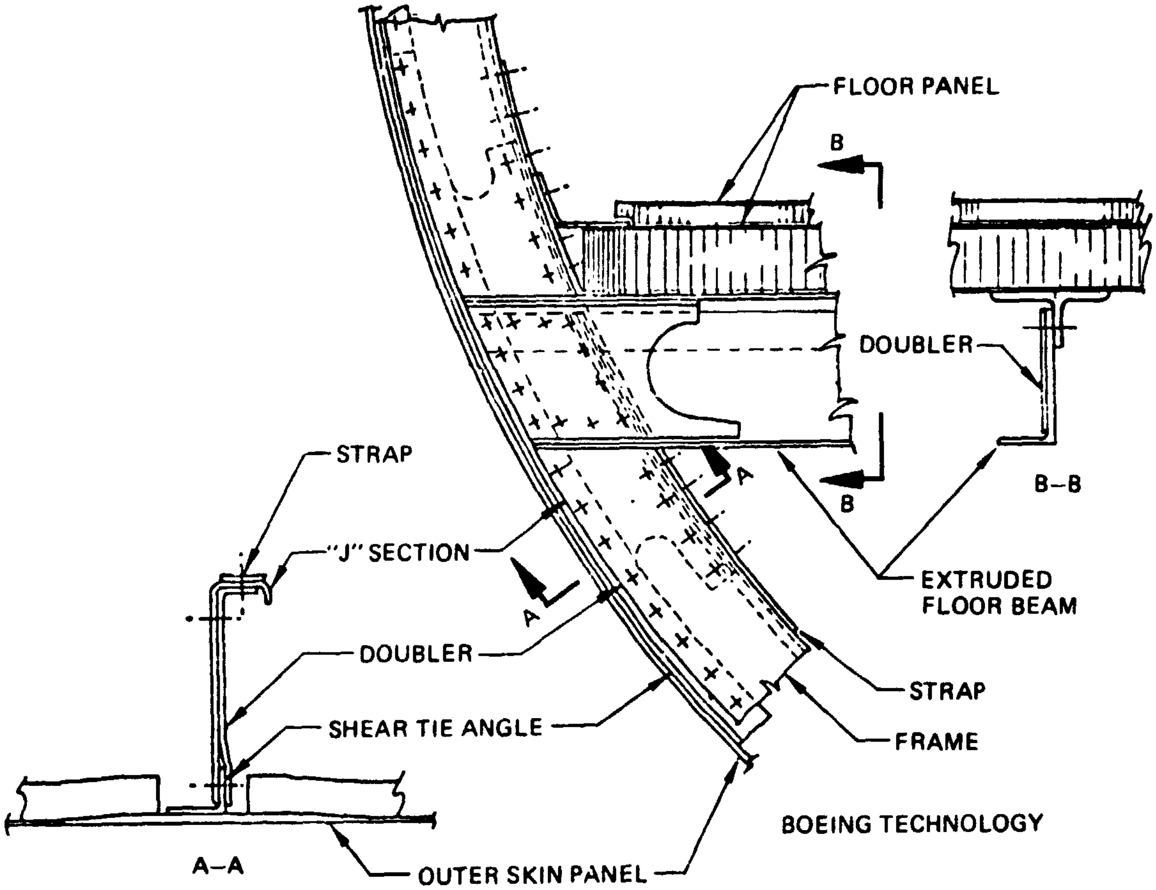


Figure 62 Frame/Floor Beam Assembly

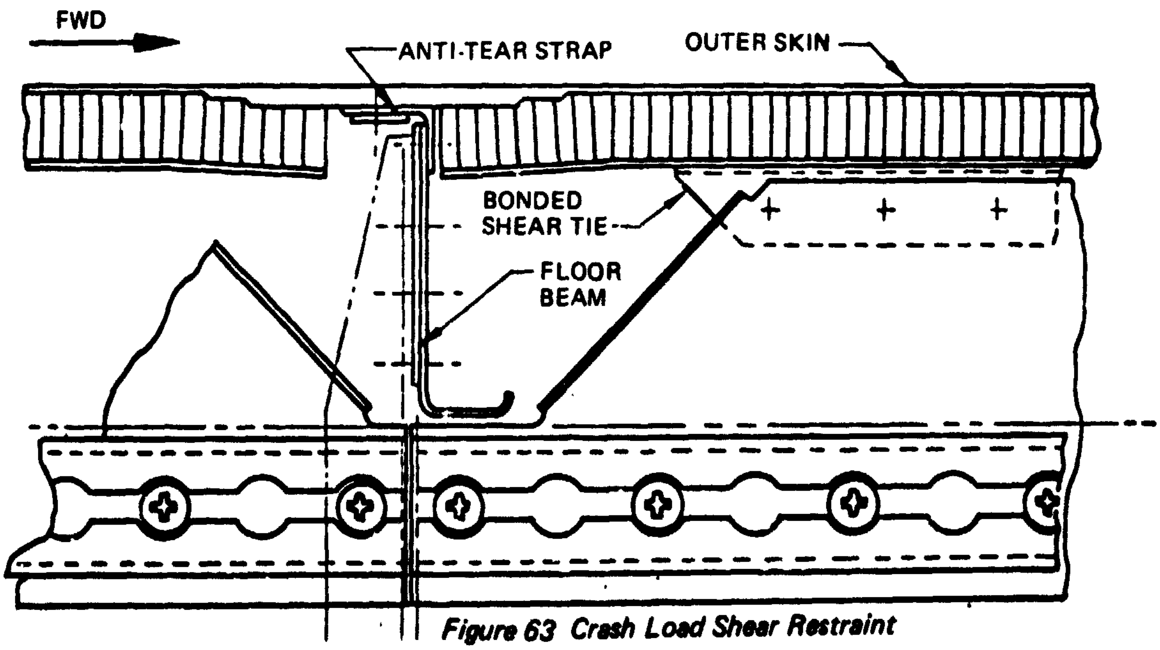
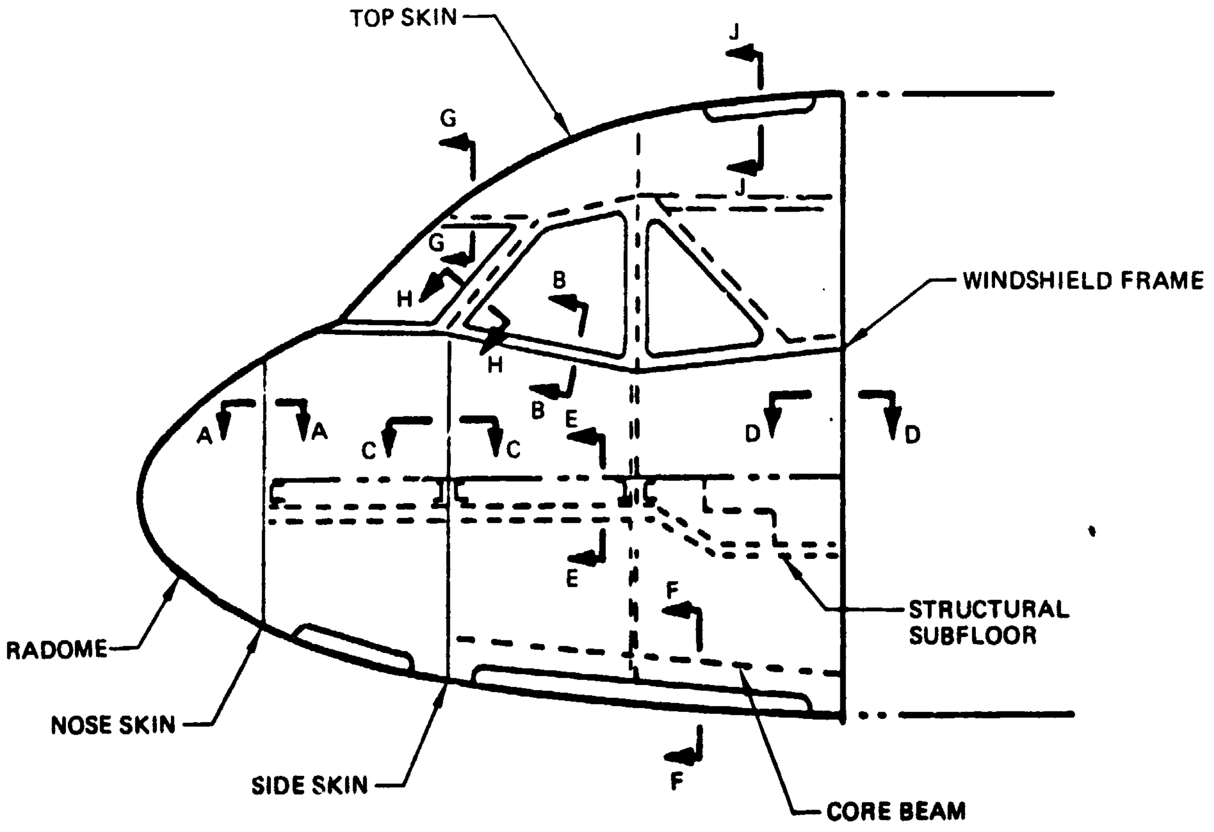


Figure 63 Crash Load Shear Restraint

6.2.2.5 Control Cab (Boeing Section 41)

The control cabin, section 41, for a 727 or 737 airplane takes about 18% of the structural partcount or about 10% of the total partcount in the airplane. If the short-haul section 41 were built using a similar design approach, the partcount would not change significantly, but the total number of partcount in the airplane would be less due to the reduced size of the airplane. Thus, section 41 would use 25% of the structural partcount, or about 18% of the total partcount in the airplane. If the complexity does not change, the partcount is a direct measure of the relative cost.

An overall view of section 41 is shown in figure 64. The main assemblies are top skin, side skin, nose skin, windshield frame, structural subfloor, and radome.



Note: See next 10 figures for detail views.

BOEING TECHNOLOGY

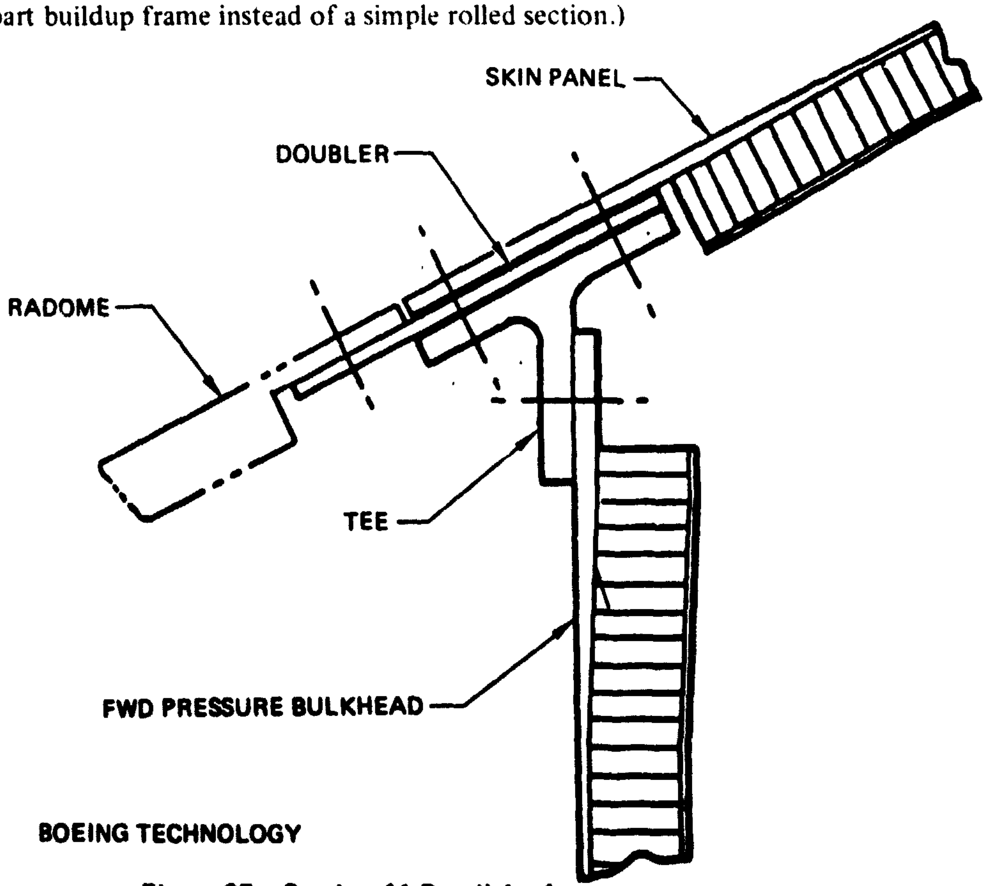
Figure 64 Section 41 (Pilot's Cab)

This concept requires a predominant circular cross-section of the cabin so that pressure loads are reacted as hoop stress in the skins. This allows the frames and pressure bulkhead to be designed for general stability and not large pressure-induced bending loads. A horizontal splice is used between the top skin and side skin and a vertical splice is used between the nose and side skins to minimize the degree of skin forming required. A major reduction in partcount for the windshield frame is achieved by making the sill, header, and posts as a one-piece molded-composite assembly. The structural subfloor is a separate subassembly that includes the forward floor beam, intermediate floor beam, and nose wheel well. The structural subfloor assembly is attached to the pressure bulkhead, forward frame, intermediate frame, splice frame, and core beam. The core beam is an integral part of the side skin.

Figure 65 illustrates the method of attachment for the pressure bulkhead, skin panel, and radome. The doubler provides a support for the radome and a fail-safe crack stop for the tee.

Figure 66 illustrates the method of attaching top or side skin to the constant-diameter body section. The doubler provides a fail-safe crack stop for the splice tee. A rolled section provides general stability for the shell and a means of attaching the cabin bulkhead or equipment racks.

Figure 67 illustrates the method of splicing the nose skin to the side skin. The doubler provides a fail-safe crack stop for the frame chord. The frame is a bonded assembly composed of two chords, face skins, and core. This type of frame construction has been in use on Vertol helicopters since 1963. (The bonded frame usually becomes cost and/or weight effective whenever loads require a multiple part buildup frame instead of a simple rolled section.)



BOEING TECHNOLOGY

Figure 65 Section 41 Detail A–A

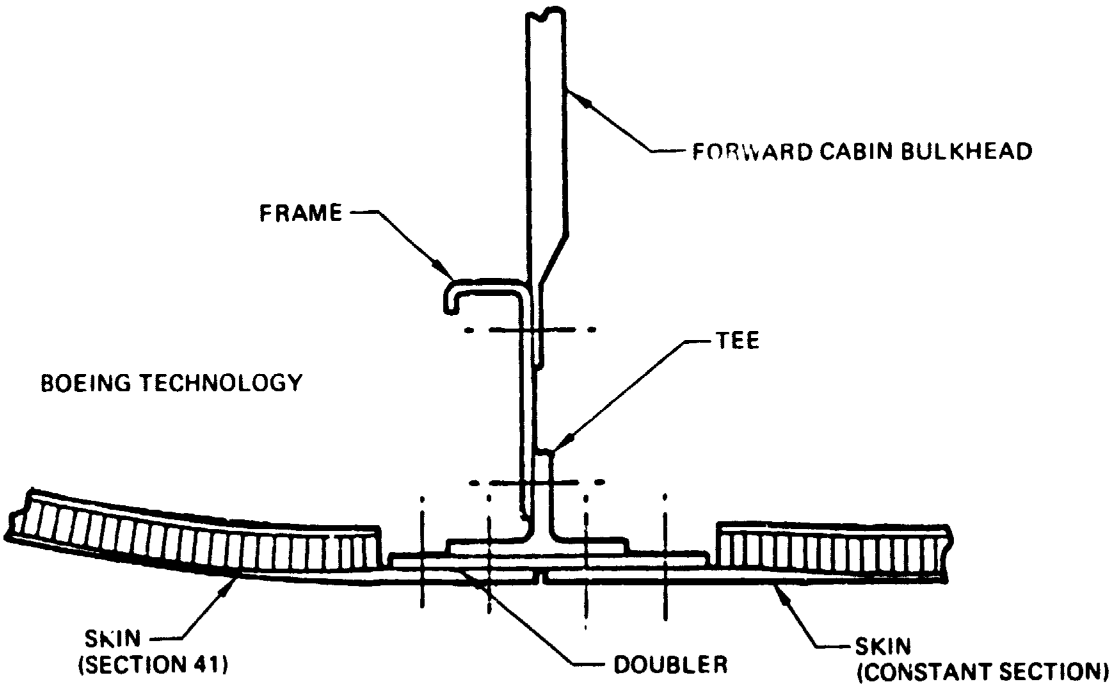


Figure 66 Section 41 Detail D–D

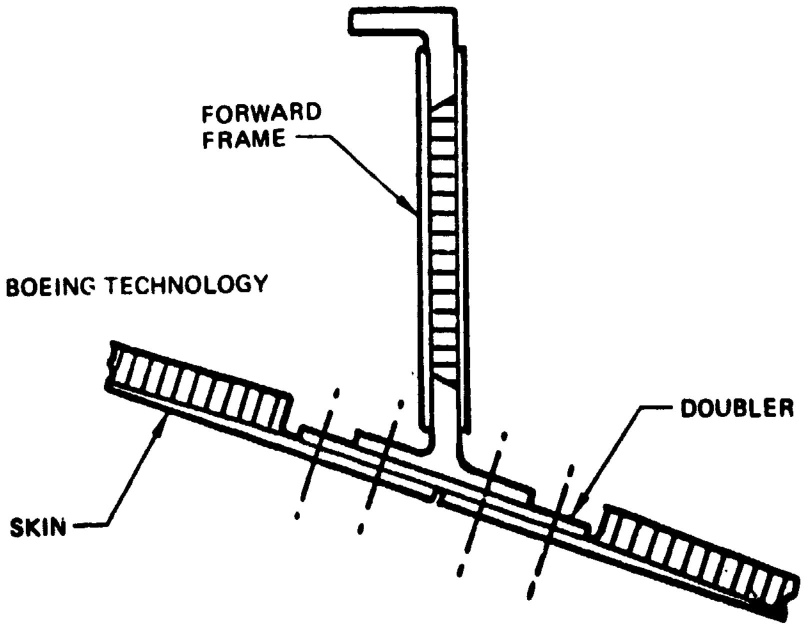


Figure 67 Section 41 Detail C–C

Figures 68, 69, and 70 illustrate the windshield-frame structure. The sill is made of graphite-S glass/epoxy hybrid composite. The amount of S-glass is selected to provide improved fracture toughness. The graphite is imbedded in a glass cover to provide maximum toughness and protection against nicks, scratches, and other factors that would degrade reliability of the graphite. The skin is attached to the sill and fail-safe crack-stop doubler. The reveal is removable for window replacement. Shear due to pressure load on the window is reacted by the sill. The functions of the header and doubler are similar to the sill and doubler. The window post carries bending due to pressure loads on the flat window panel and carries tension due to hoop stresses since the windows do not carry tension loads. The post is a hybrid structure similar to the sill. Zero-rad (0-deg) graphite-fiber bundles isolated from the ±0.8 rad (±45 deg) attach flanges provide a fail-safe load path for the hoop-stress bending. The reveal will be titanium to minimize thermally induced stresses. It may become necessary to divide this window cage into a number of sections to relieve induced stresses.

Figure 71 illustrates the structural subfloor and nose wheel well. The subfloor is made of adhesive-bonded aluminum-sandwich structure. Dense core is used wherever fasteners are required. Skins overlap and provide pad-up at the break in the floor. The center portion of the floor is the pressure deck for the nose wheel well.

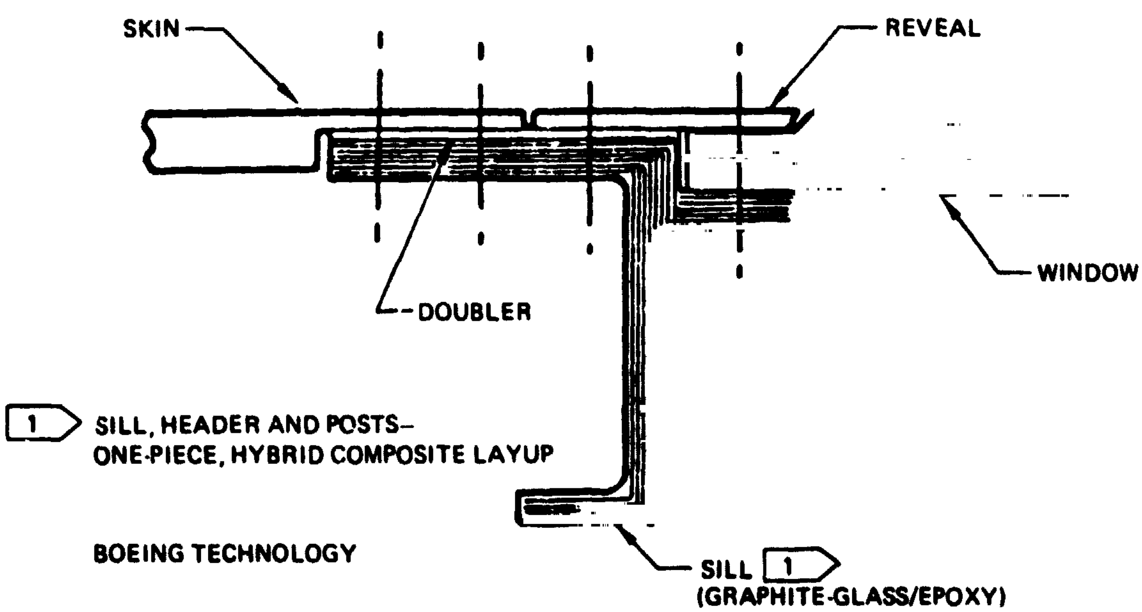
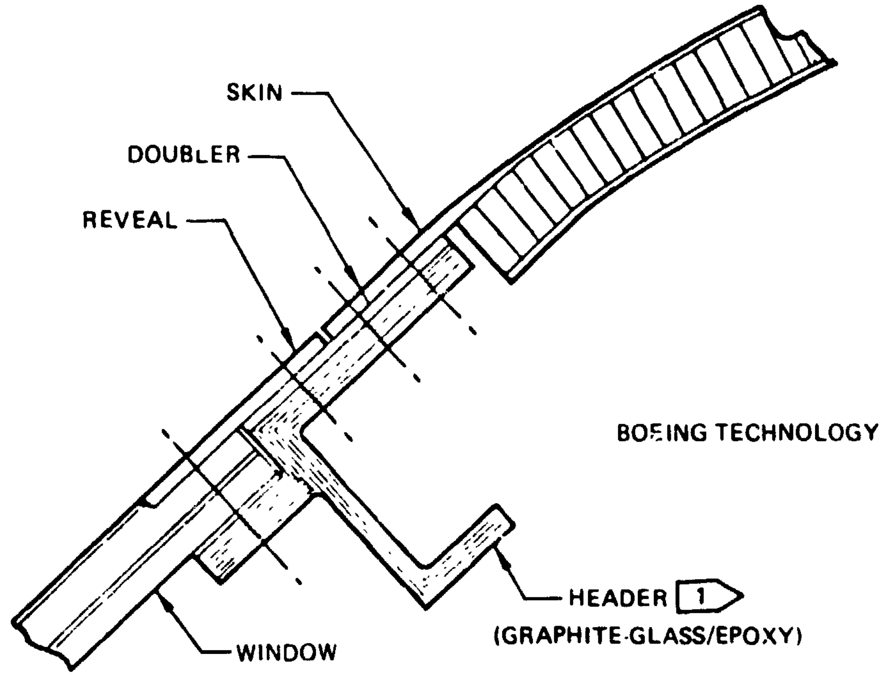
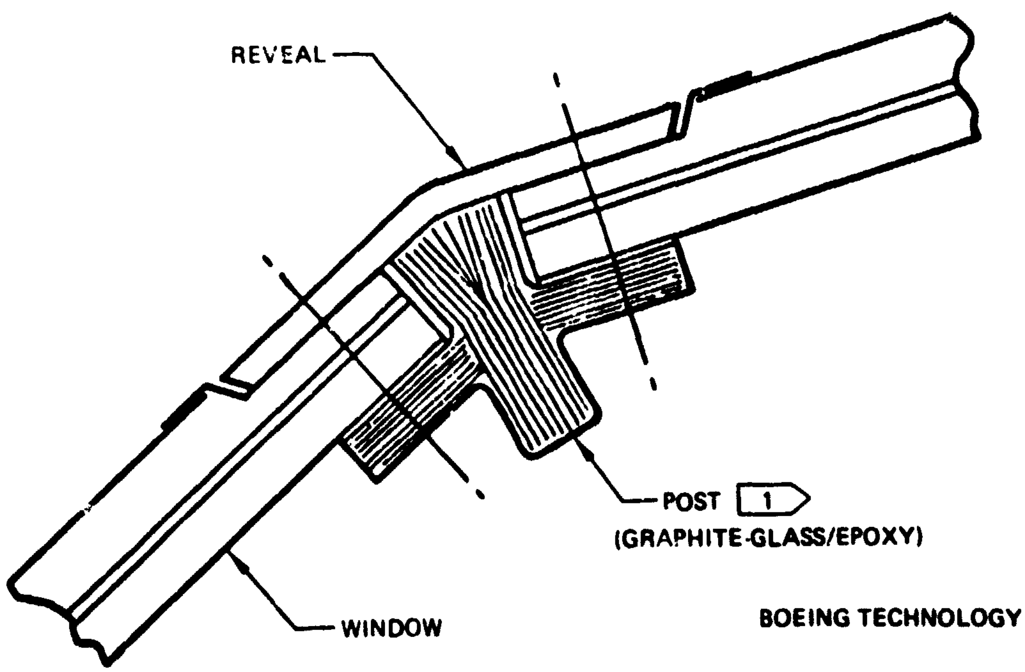


Figure 68 Section 41 Detail B–B



1 SILL, HEADER AND POSTS -ONE-PIECE, HYBRID COMPOSITE LAYUP

Figure 69 Section 41 Detail G–G



1 SILL, HEADER AND POSTS–ONE-PIECE HYBRID COMPOSITE LAYUP

Figure 70 Section 41 Detail H–H

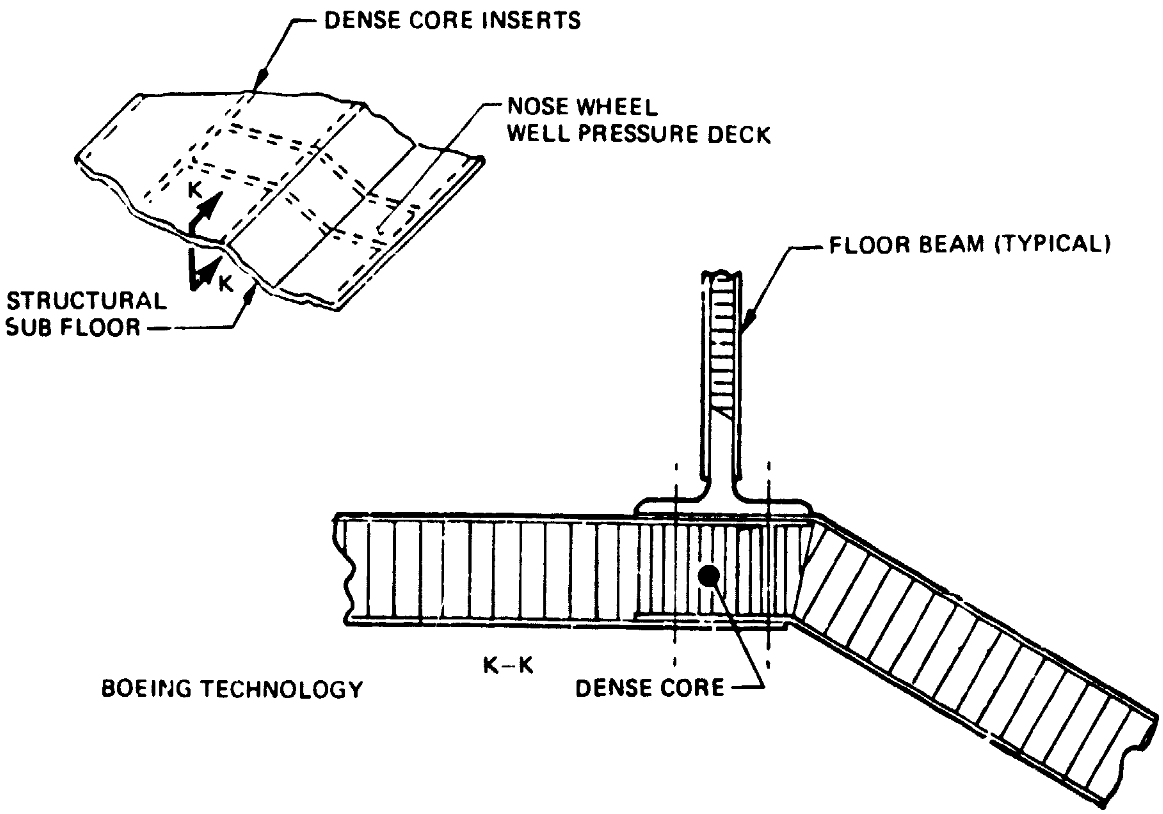


Figure 71 Section 41 Detail K–K

The nose wheel-well panels, figure 72, are fastened to the subfloor using dense core and angles. The forward floor beam is an extrusion with system cutouts. The pilot's seat track is a standard extrusion, cut out as necessary to fit the floor beam, with potted inserts. Removable floor panels provide access for maintenance.

The pressure load due to the cut frame in the nose wheel well is reacted by the core beam to adjacent frames, figure 73. The core beam is integral with the skin and consists of local pad-up and extra height core. The wheel well is sealed along the lower edge and the frame is tied to the wheel well by a stiffener.

The top escape hatch, figure 74, is required in a high-wing airplane. The support frame is made from a machined insert. This insert is a part that performs four functions.

1. Provides pad-up for outer face skin
2. Supports inner face skin
3. Closed out core and stabilizes fitting with high strength potting
4. Supports plug type hatch

This section 41 is an adhesive-bonded metal structure. Although this design could be adapted readily to composite materials, it is not a low-cost option at the present time.

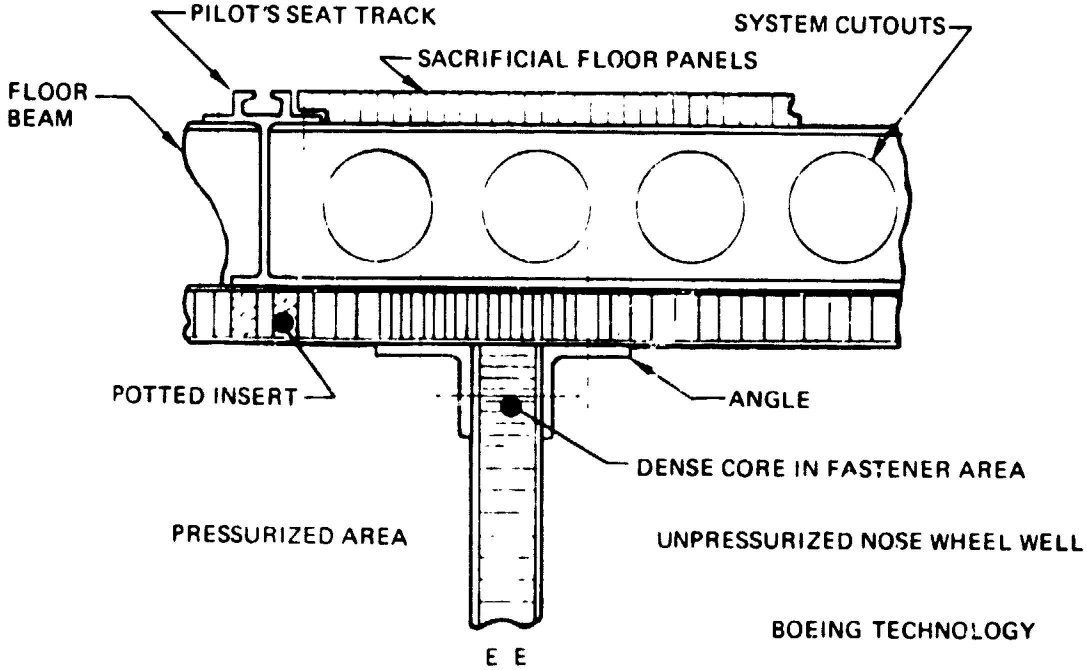


Figure 72 Section 41 Detail E–E

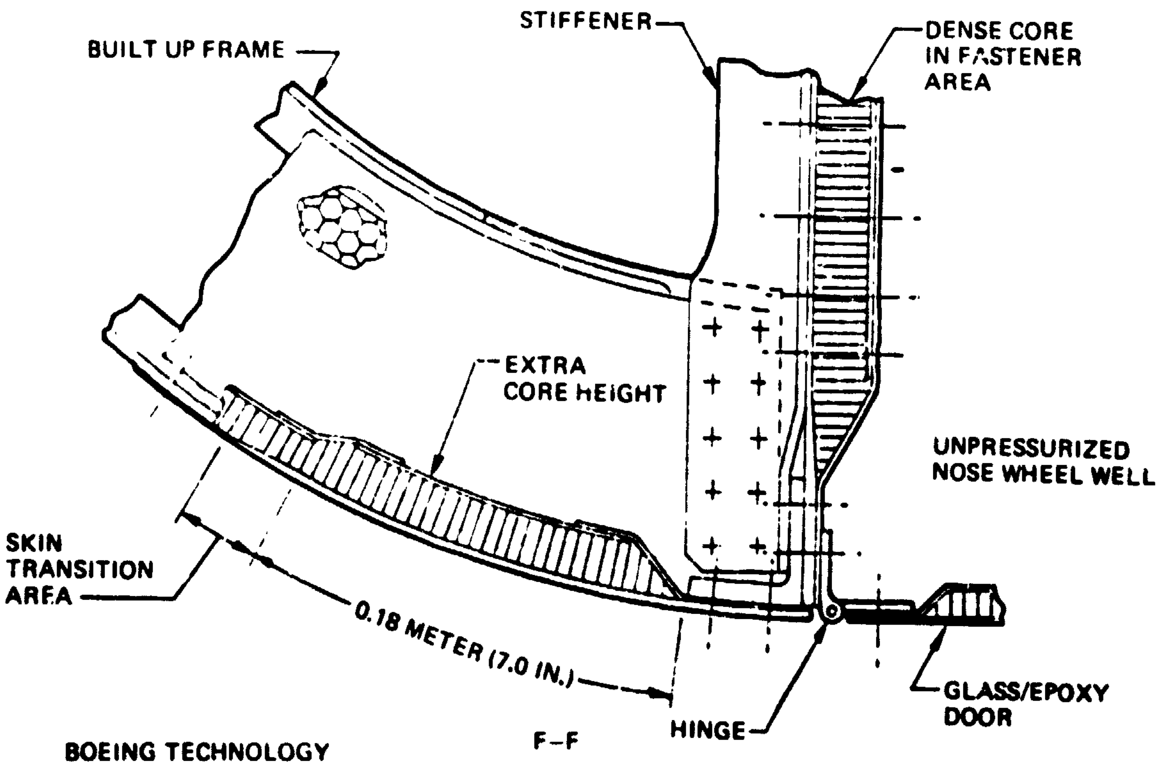


Figure 73 Section 41 Detail F–F

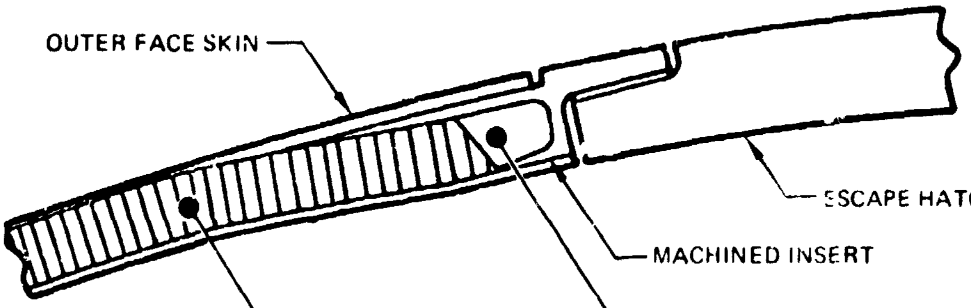


Figure 74 Section 41 Detail J–J

6.2.2.6 Vertical Tail

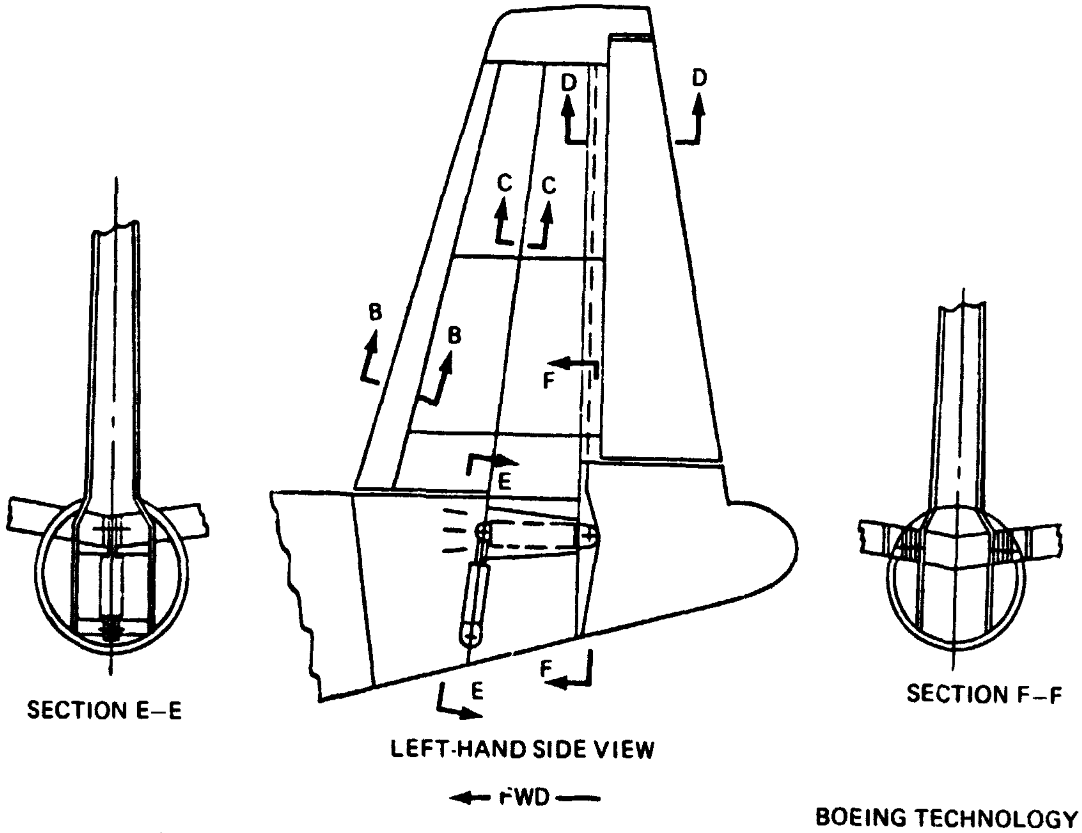
Of the various approaches to design of a vertical fin attachment to the aft body of an airplane, two of the more popular are:

- Allow the fin primary spars to penetrate the body crown line and be the aft body bulkheads, figure 75. This type design is used on many fighter aircraft.

- Design the vertical fin with a flush rib-attachment fitting at the fin body intersection. This fitting is attached by tension bolts directly to a similar fitting in the crown line of the body. It is used on 747 airplanes and has a proven low installation cost plus allowing quick fin removal (fig. 76).

The only drawback of the fin/body common attach fitting is that if the horizontal stabilizer is a body-mounted trimline stabilizer, it must be located substantially below the body crown-line structure, leaving enough primary structure above the horizontal stabilizer cutout to support loads of the fin/body attachment.

At this time, the short-haul configurations have a body-mounted, fixed horizontal tail. However, it is almost a certainty that a trimmable horizontal tail will be required on future models. Therefore, a fin/body interface attachment using fin spars that penetrate the body crown line and form the aft body bulkheads is used on the short-haul baseline airplane.



Note: See Figures 77, 78, and 79 for detail views

Figure 75 Vertical Tail

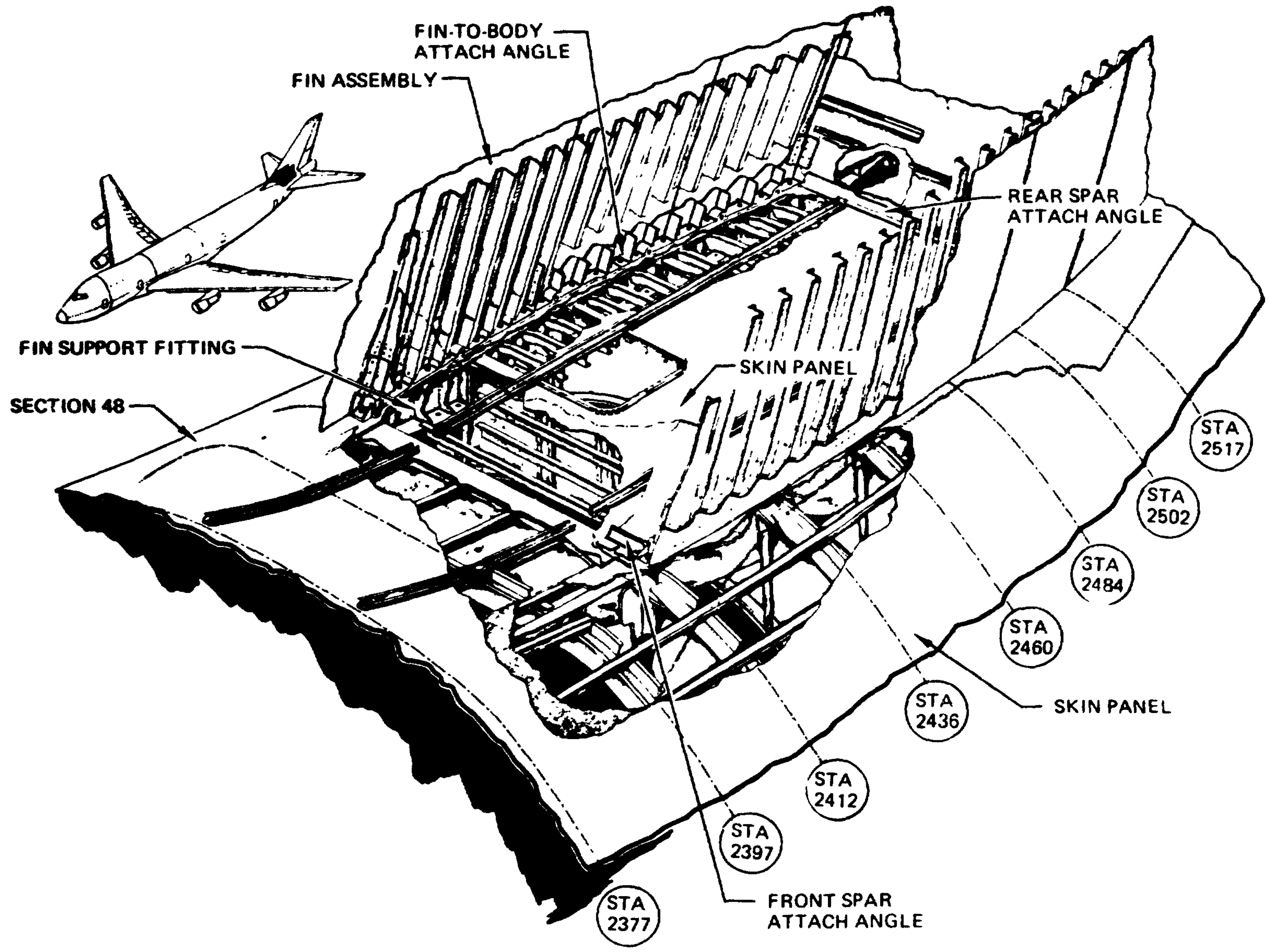


Figure 76 Fin-to-Body Join

The vertical-tail primary structural box consists of a forward spar and a rear spar and three ribs. The two spars extend below the body crown line and form the two aft body bulkheads (fig. 75, 77, and 78).

An additional forward auxiliary spar supports the leading-edge section and, with the three ribs assists in transferring the airloads aft to the main-fin primary box. The three ribs back up the rudder hinge fittings projecting aft of the rear spar. The area between the fin rear spar and the rudder front spar are covered by removable nonstructural fiberglass panels. All cover panels on the fin between the forward auxiliary spar and the rear spar are square-edged aluminum-bonded-honeycomb panels.

The fin tip fairing is a nonstructural fiberglass fairing, very similar to the wing and stabilizer tip fairings. The fin leading edge is a single-part, square-edged, aluminum-bonded-honeycomb assembly. Although it supports some fin bending and torsional loads, it is designed to sustain damage due to hail stones. Suggested sizing is 0.76-mm (0.030-in.) outer skins; 12.7-mm (0.5-in.) deep, 32-mm (0.125-in.) cell size 5052 aluminum core and an inner skin of 0.4-mm (0.016-in.). There is a closure rib at either end of the assembly.

The rudder is a single-spar, fiberglass-honeycomb-panel wedge assembly similar to the flap concept shown in figure 79.

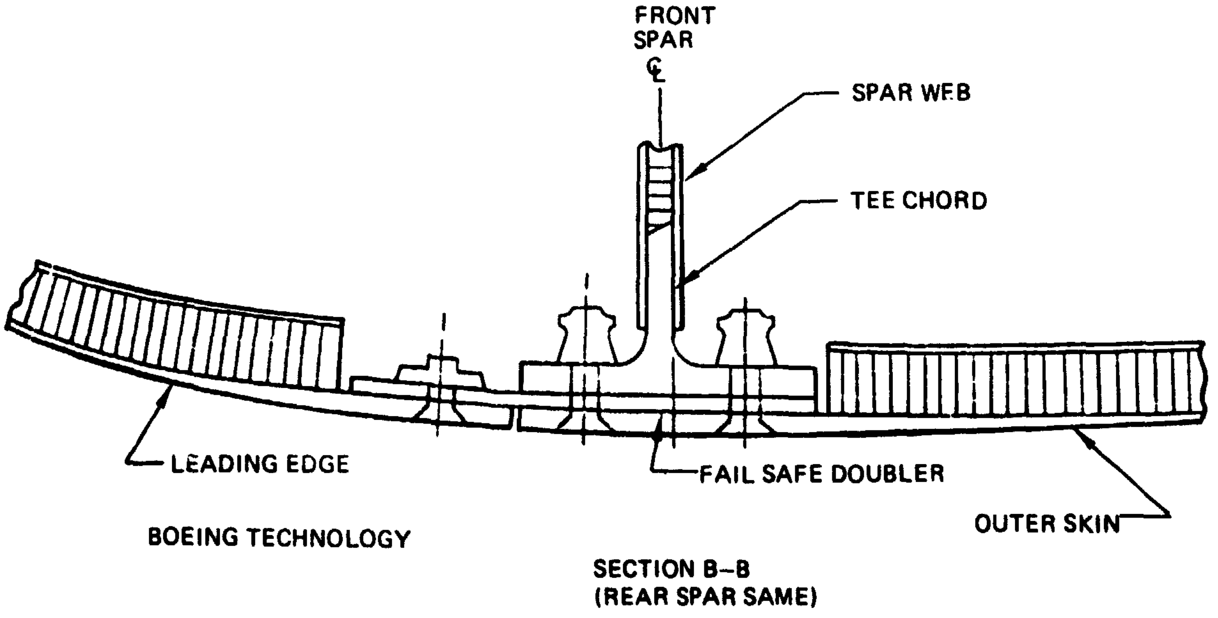


Figure 77 Vertical Tail Front Spar

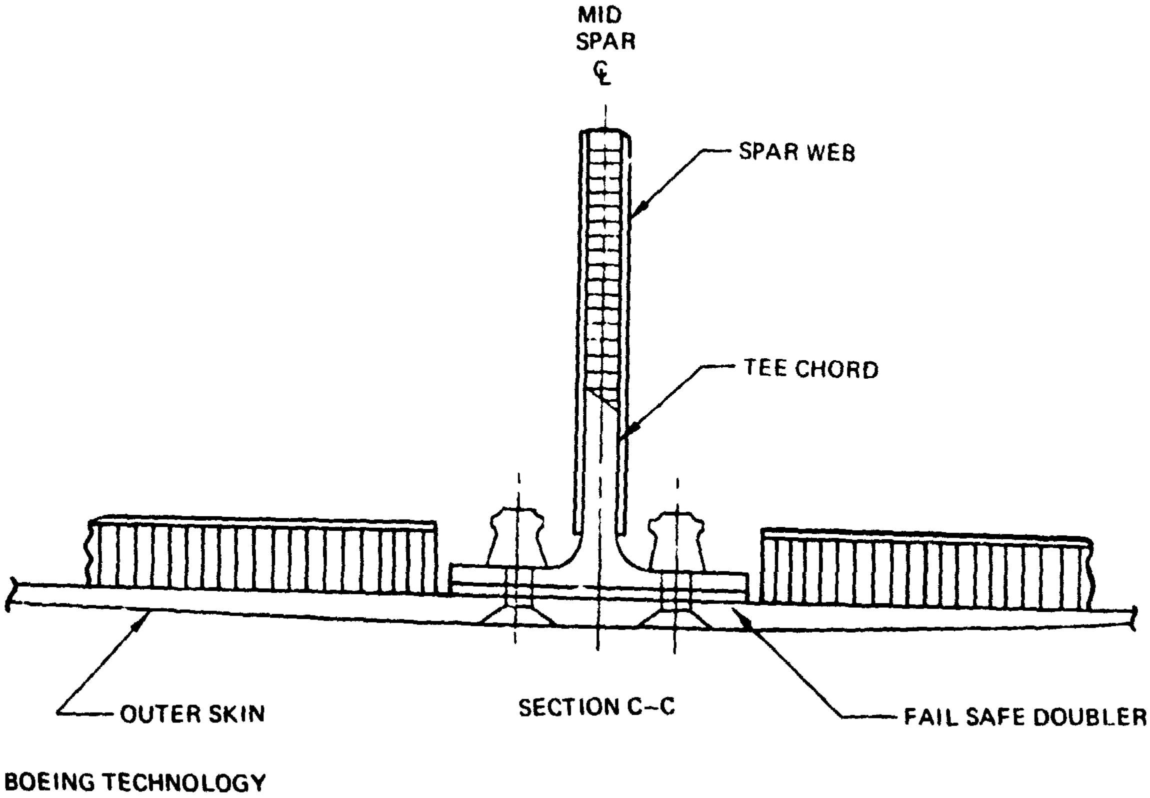


Figure 78 Vertical Tail Mid Spar

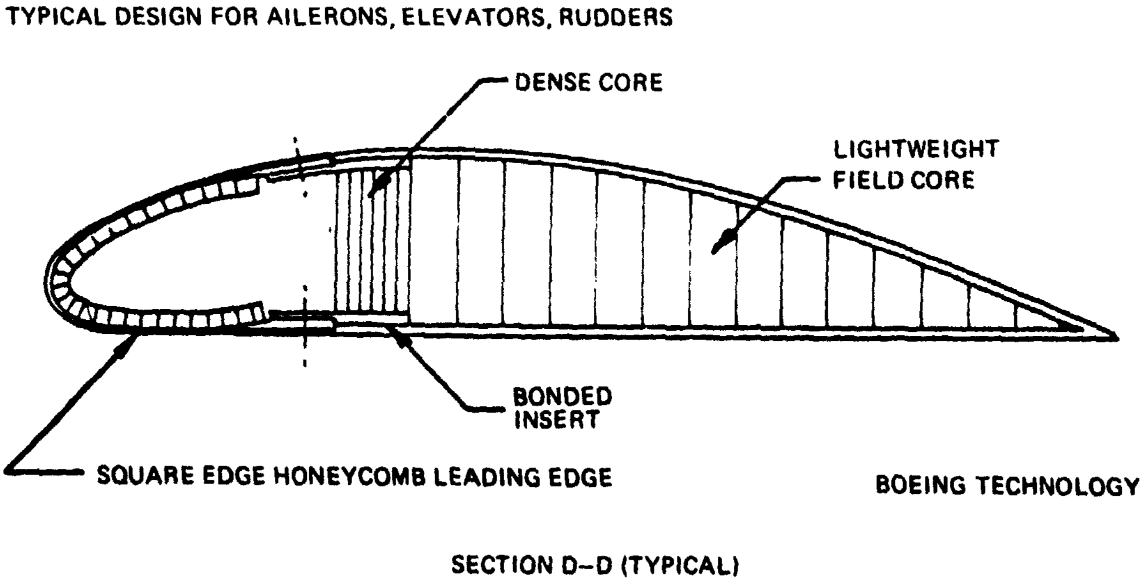


Figure 79 "Sparless" Flap Concept

6.2.2.7 Horizontal Tail

The true planform outline of either outline of the horizontal tail is identical to the same portion of the wing tip, allowing common tooling between the horizontal tail and wing-tip section (fig. 80).

The stabilizer primary box consists of three spars, three ribs, and an aluminum-honeycomb-bonded outer skin, top and bottom. The leading edge is a symmetrical, aluminum-honeycomb-bonded assembly (fig. 80).

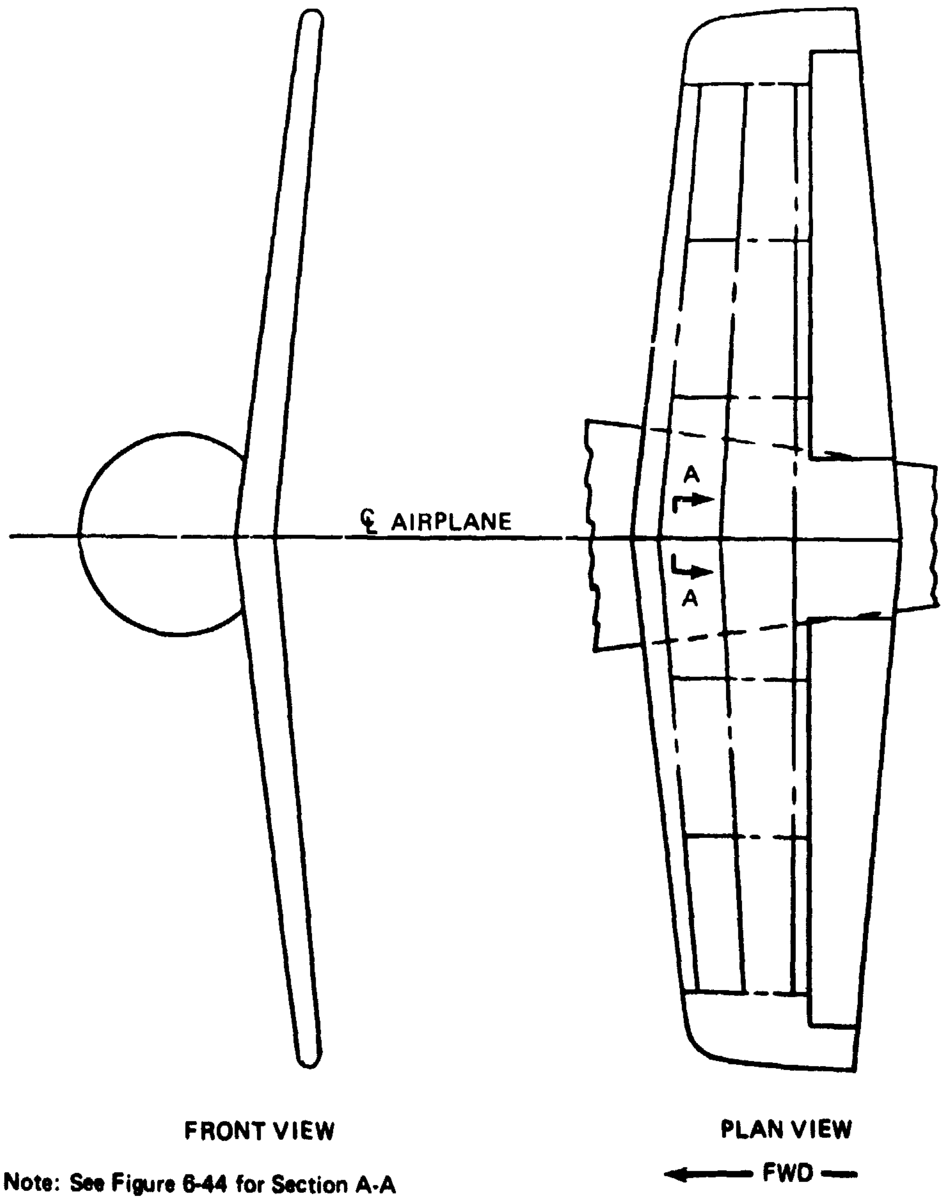


Figure 80 Horizontal Stabilizer

Due to taper ratio and dihedral there is a major joint in the stabilizer at centerline of body. This joint incorporates the use of a bonded, machined pickle fork fitting, figure 81. The design was tested extensively and first used on the two YC-14 horizontal stabilizers.

Early in the contract, the elevator was identical to the ailerons. This commonality provided low cost and interchangeability. The intent of commonality of control surfaces was lost when the wing was detail designed. At present, the elevators, like the ailerons, are to be of sparless, honeycomb wedge design, figure 79.

The stabilizer tip fairings are identical to the wing-tip fairing, providing low-cost interchangeable assemblies.

As stated in section 6.2.2.6, Vertical Tail, the original horizontal tail was fixed to the body, but further studies have shown that a trimmable horizontal tail is desirable, so a body clearance hole for stabilizer motion envelope has been provided, figure 75.

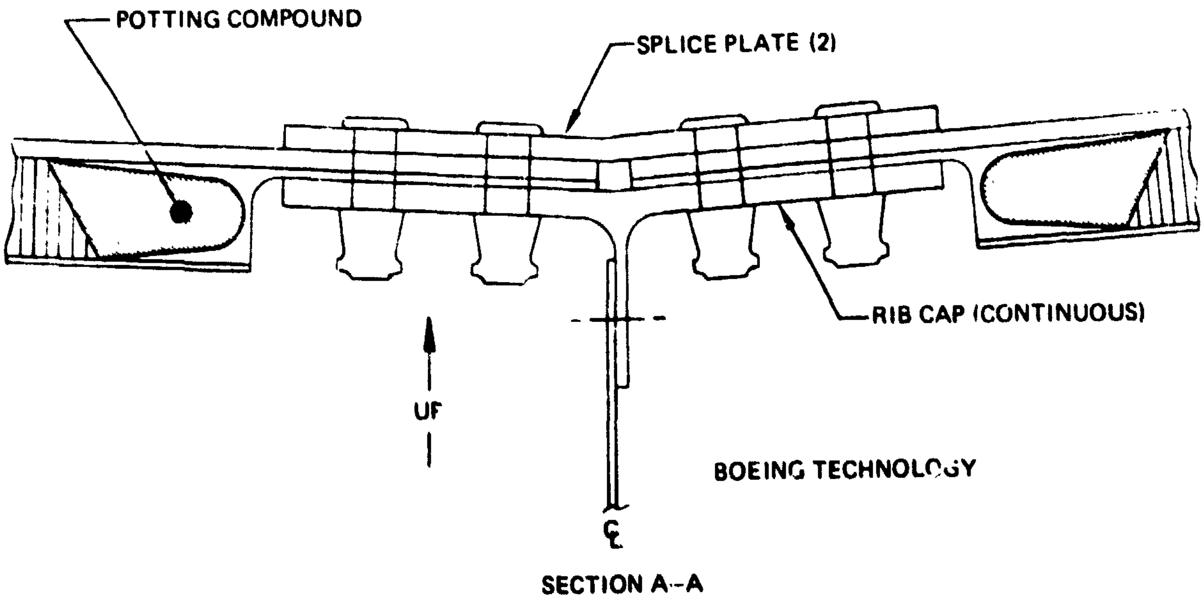


Figure 81 Stabilizer Centerline Splice

6.2.2.8 Wing Box

The three-spar configuration, figure 82, was selected to provide a fail-safe design and to reduce the sandwich panel width. The critical buckling stress varies as the inverse square of the panel width. Thus, closer spacing of spars and/or stiffeners will allow the sandwich panel to carry a higher end load.

The outer skin has increased thickness to allow for fasteners and to have adequate strength at the spar caps, resulting in a flat area on the inner-face skin for ease of bonding the tee chord. Shear-tie angles are mechanically fastened to the rib and spars for ease of assembly.

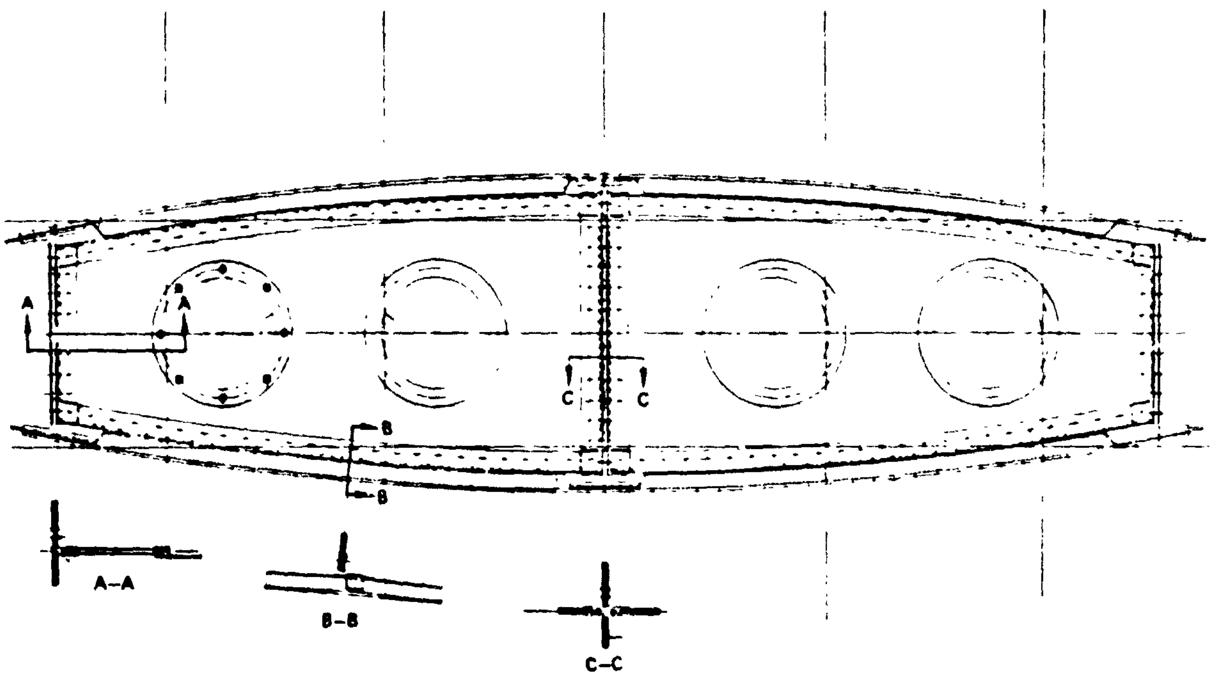


Figure 82 Outboard Wing Box

A conventional skin/stringer box, figure 83, was used as a baseline for the wing-box trade study, requiring a high part count and many fasteners. This type of construction has been used for commercial airplanes for many years. Cost to produce are very predictable; however, future possibilities to reduce cost are negligible.

The all-honeycomb wing box assembly shown in figure 84 features:

- Multi-spar redundancy
- Aluminum-bonded-honeycomb outer-skin panels
- Extremely smooth outer contour
- Reduced fasteners over skin/stringer construction by 70%
- Reduced part count over skin/stringer construction by 40%

An all-aluminum-bonded-honeycomb primary-structure wing on this airplane results in the same benefits realized on the YC-14 empennage, namely, reduced part count and reduced cost.

The all honeycomb wing box with bonded-on tee-chord rib ties is shown in figure 84. Wing end loads of ≤30 newton m/m (≤7 kips/in.) are the optimum design for a honeycomb wing-box assembly. Also, this configuration reduces fasteners by 70% compared to a skin/stringer wing box.

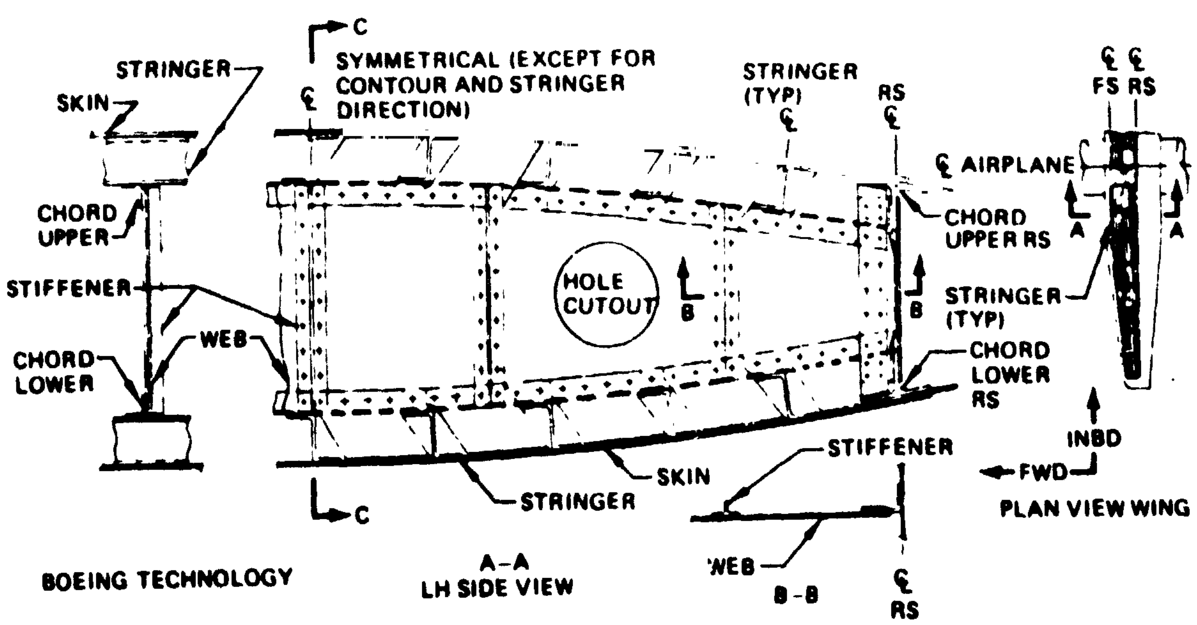


Figure 83 Conventional Wing-Box Construction

A rib chord that is simple to fabricate is shown in section B-B of figure 84. This concept uses a bonded tee chord. Because the load on the skin-to-chord bond is essentially shear, fasteners are not required. Peel or cleavage loads, due to spanwise deflections, are avoided by tapering both legs of the tee. The curvature of the wing skin normally causes vertical compression loads on the rib, thus flatwise tension should not be a problem. Critical design tension load occurs during refueling if a vent valve sticks in the closed position.

The outer face skins, figure 85, are continuous between the front and rear spar. Elimination of a spanwise skin splice over the mid-spar eliminates two rows of fasteners, and, as an additional benefit, provides a smoother contour. The one-piece skin stabilized with honeycomb also is beneficial for natural laminar flow. A fail-safe strap is bonded to the skin over each spar in the area of the fasteners. The zee closures are required only in fuel tank areas. The spars are bonded assemblies made from two extrusion, two face skins, and honeycomb core. The extruded fail-safe strap is flat on one side to match the spar-chord extrusion, and contoured on the bonded side to match wing contour.

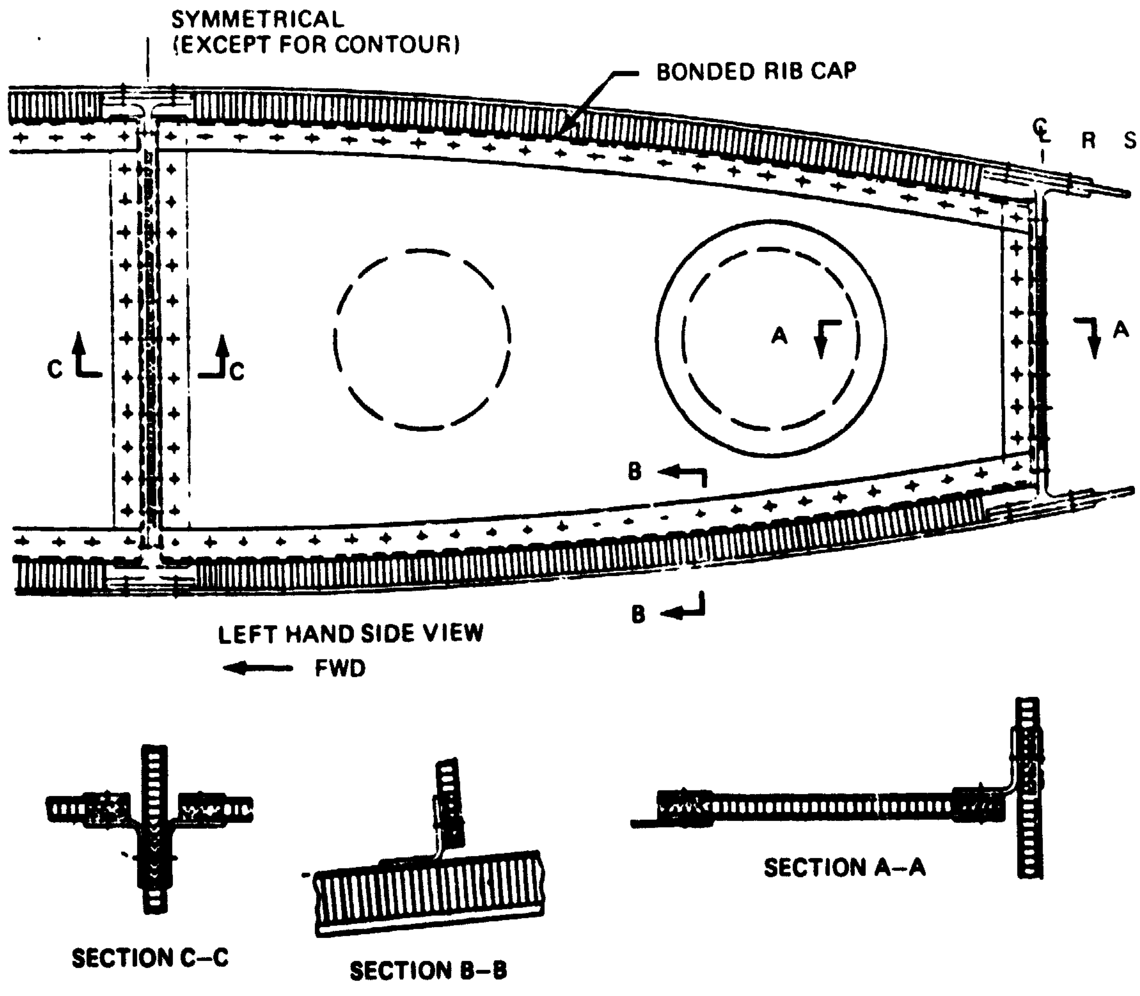


Figure 84 Bonded-Honeycomb Wing Box

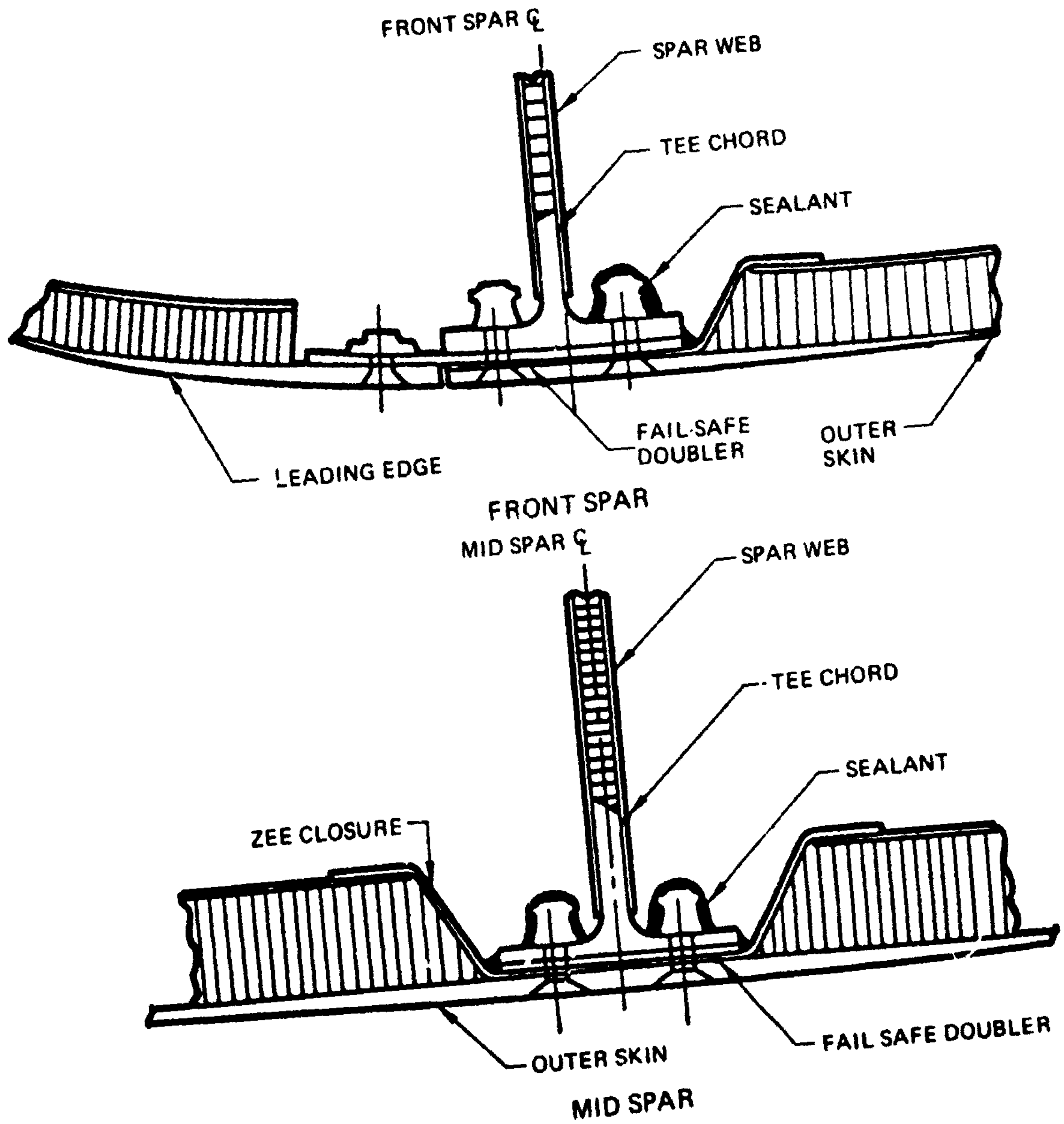


Figure 85 Outboard Wing Panel

The front and rear spar detail is similar to the mid-spar, except that the doubler is extended to facilitate mounting the leading and trailing edge panels.

Fuel tank access is provided by a mechanical insert as shown in figures 86 and 87. The fitting performs multiple functions and is thus cost effective. The lower flange provides pad-up around the contour; the staggered lips provide ease of assembly; the recessed edge, filled with high-strength potting, anchors the core and stabilizes the fitting; and the inner edge provides the mounting flange for the tank access door.

A side view of the skin undergoing ultrasonic through-transmission inspection is shown in figure 88. Automated ultrasonic scanning equipment provides a low cost means of verifying void-free panels.

Figure 89 shows the spar details before bonding. The light-colored circular areas are potting, which later will be cut out for access holes. Figure 90 shows the spars and ribs after bonding, with doublers added, and access holes cut on three parts.

Figure 91 shows the assembled wing box. This section was designed and built during the last quarter of 1976, using IR&D funds. It represents a wing-box section outboard of the wing-mounted engines. The access holes were made to illustrate the technique involved and do not necessarily represent what would be required in an actual part. Accessibility through the fuel-cell access and spar-web cutouts is illustrated in figure 92.

A chordwise wing splice is shown in figures 93 and 94. The skin and fail-safe doubler overlap the rib chord. The-out-of-contour strap acts as a fail-safe for the rib chord and places the fasteners in double shear. The spar chord is cut short of the rib chord and spliced with blade-type splice fittings. The webs are shear tied with angles.

When the end load becomes too high for a weight-effective, simple, sandwich panel, stringers are bonded in place as shown in figure 95. This figure illustrates a rib where a shear tie is not required. Where shear ties are necessary, ties are bonded to the skin and the spar web as shown in figure 96. Mechanical fasteners may be required at each end of the shear tie to contain peel loads. The shear tie to the spar web is shown in figure 97. A mechanically fastened angle is used to provide ease of assembly.

Stringer runout creates a hard-spot problem due to the sudden change in section. The load transfer is facilitated by tapering the end of the stringer as shown in figure 98. Mechanical fasteners through the stringer end and a toe plate protect the bond line from peel loads. Figure 99 illustrates the toe plate when the stringer ends at a splice rib. Figure 100 shows the use of a bonded toe plate to end the stringer at a shear-tied rib.

The resultant all-honeycomb wing box with integrated stringer is shown in figures 101, 102, and 103. This honeycomb wing-box design accommodates higher load requirements than did the prior design. It is considerably more complicated to manufacture, but still provides a cost saving when compared to skin/stringer design. The design results in an extremely smooth outer contour and yet accepts high loads such as 76 N m/m (17 kips/in.).

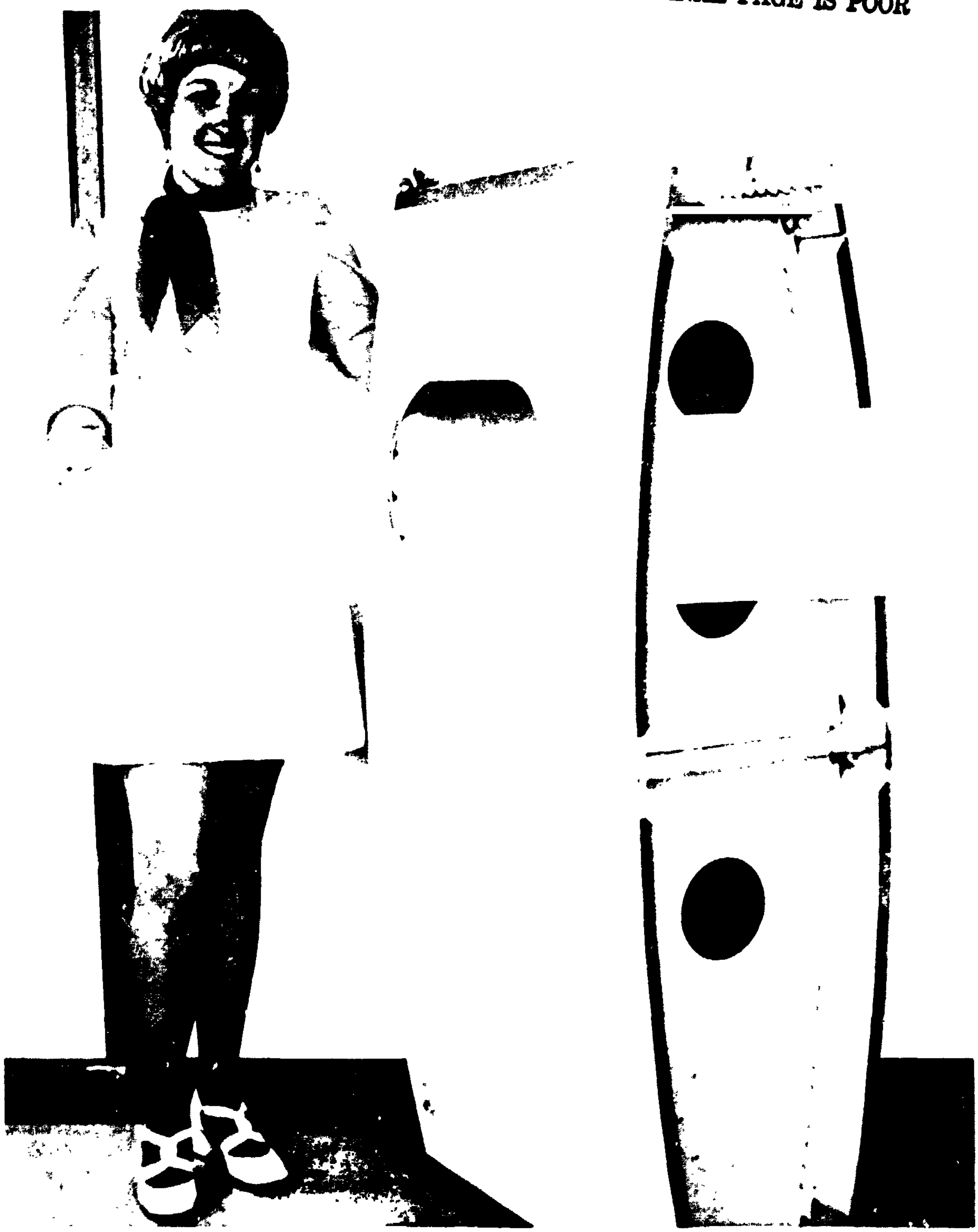


Figure 86 Fuel-Tank Access

Figure 87 Fuel-Tank Access Assembly

Figure 88   Skin Undergoing Ultrasonic Through-Transmission Inspection

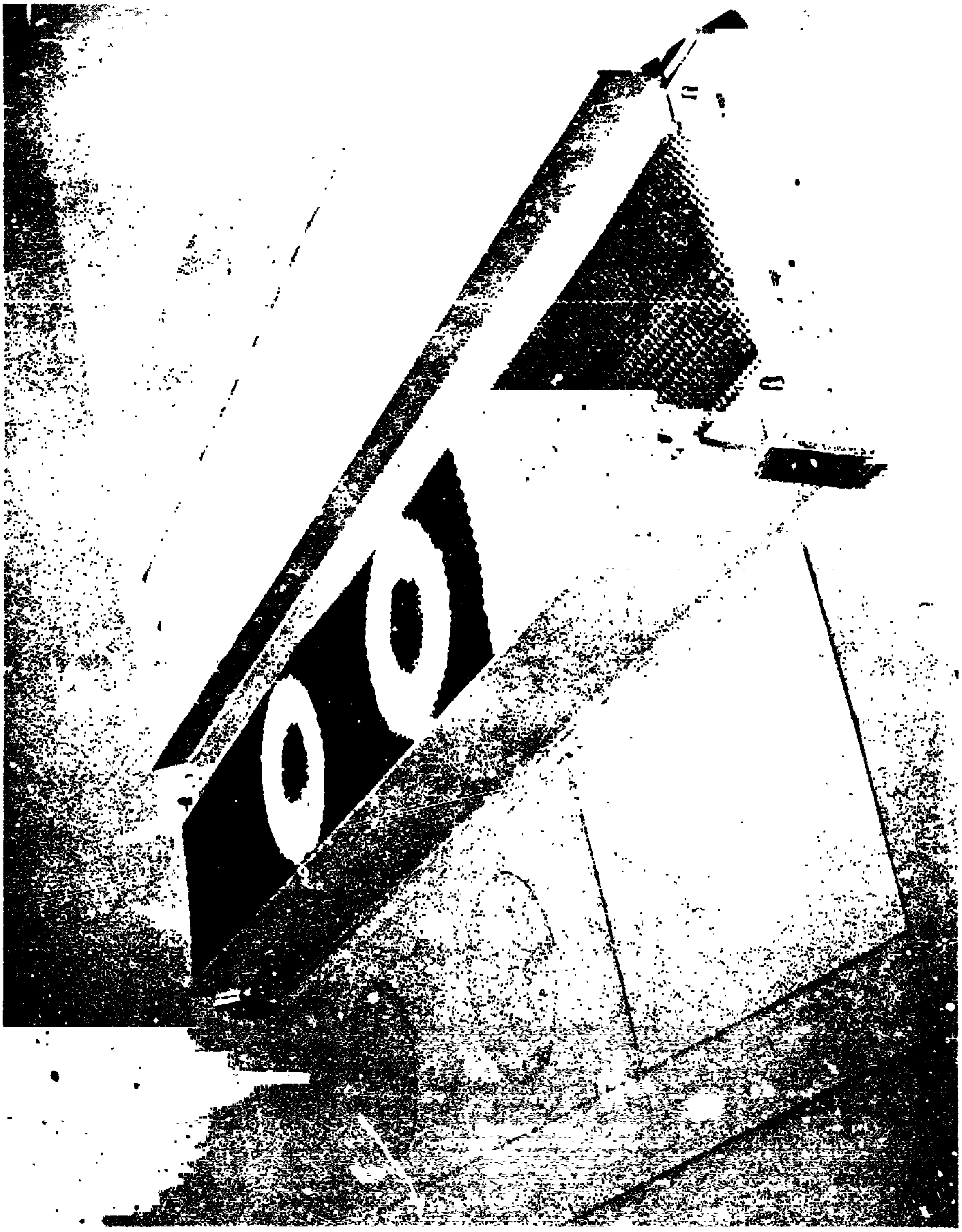


Figure 89 Spar Assembly Details

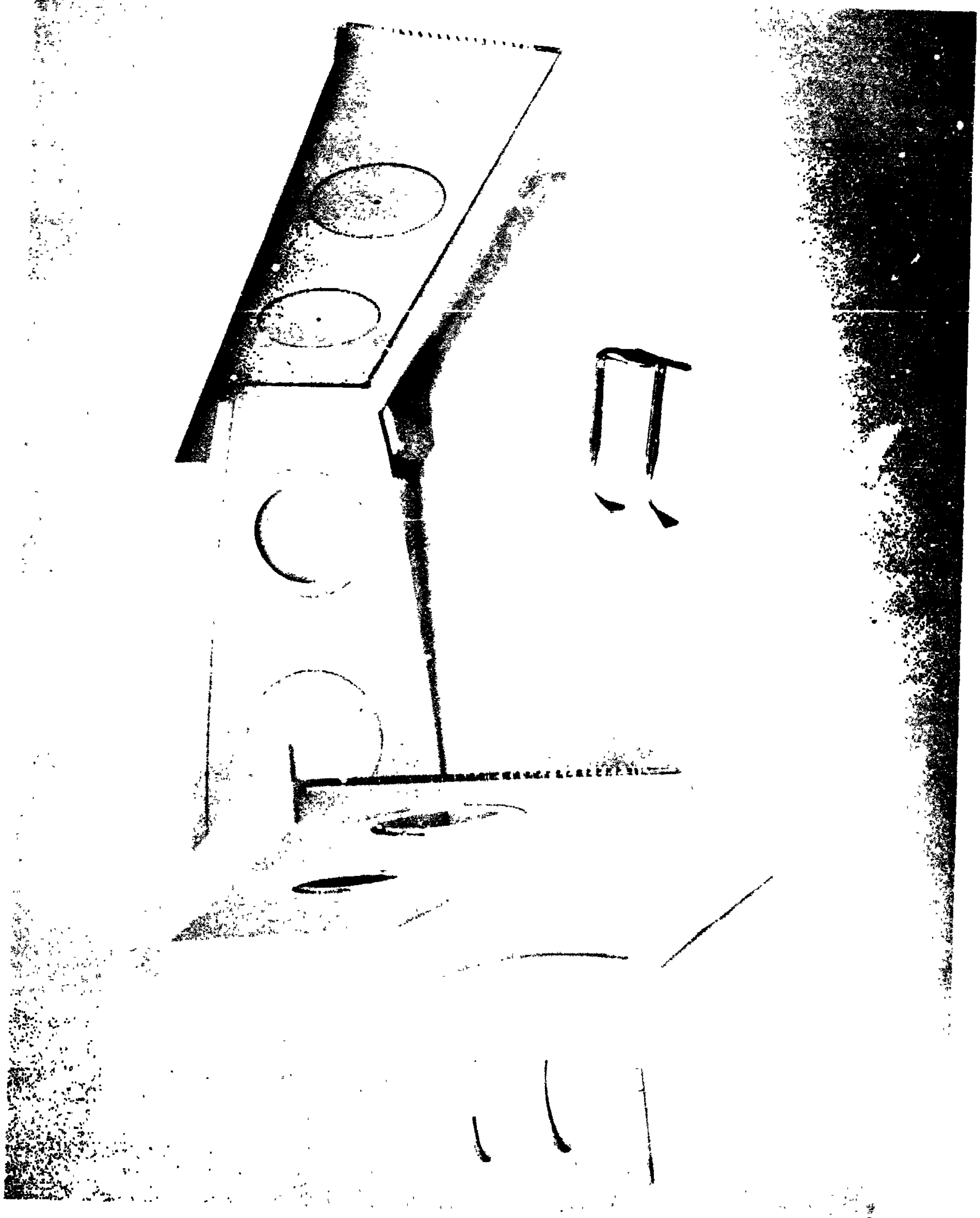


Figure 90 Spar Assembly After Bonding

Figure 91   Assembled Wing Box

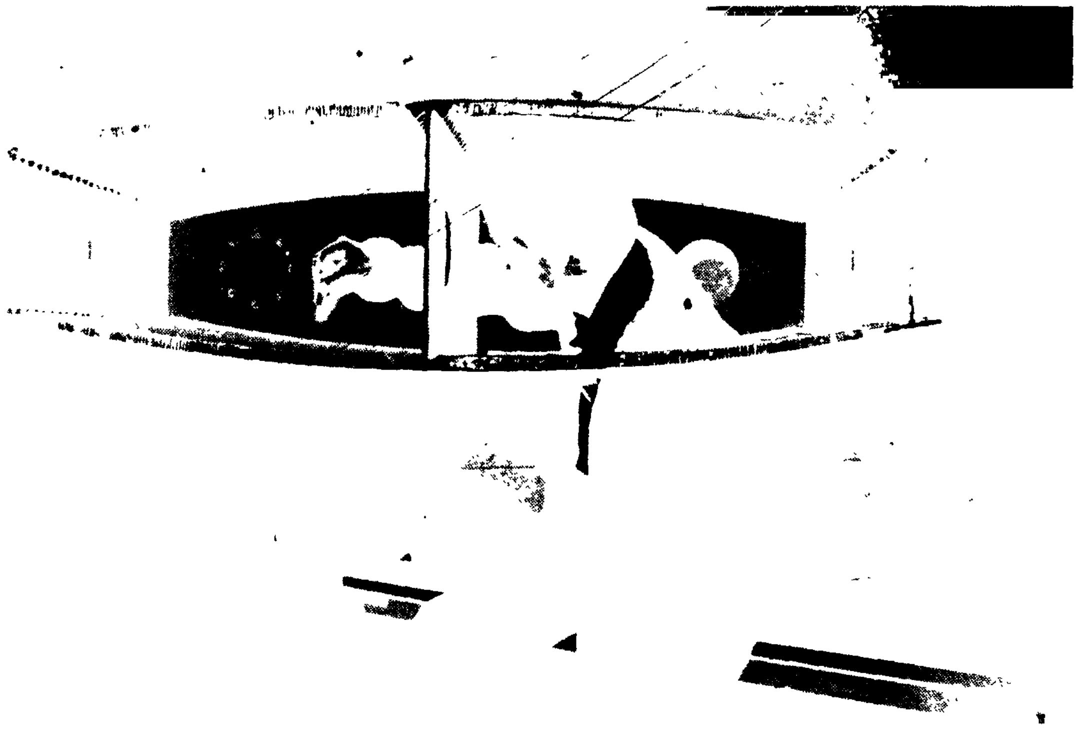


Figure 92 Wing Box Accessibility

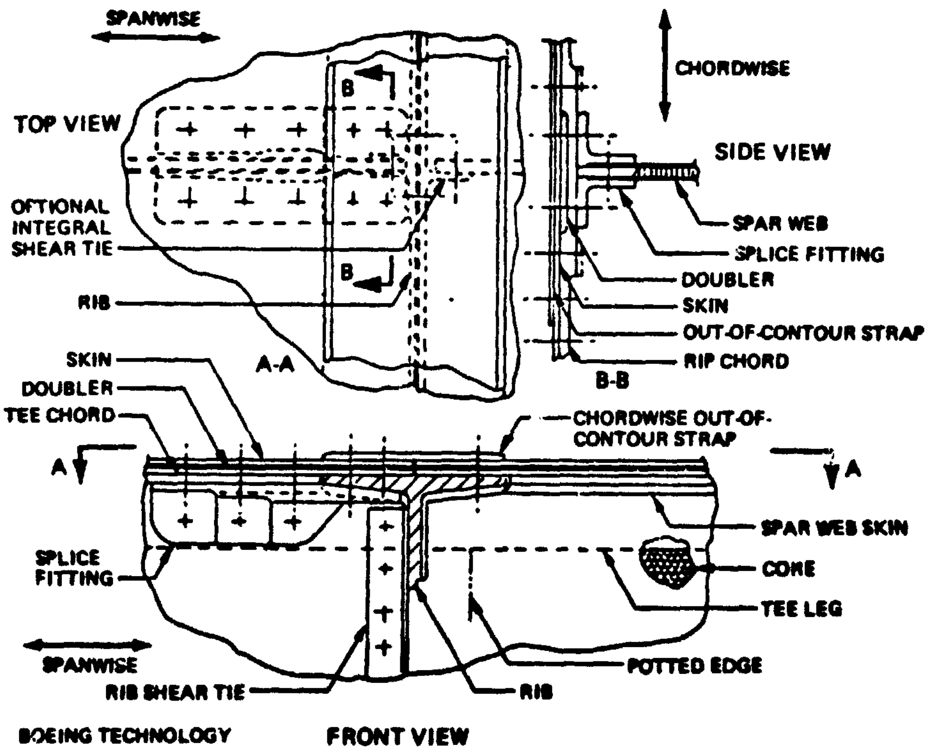


Figure 93 Chordwise Wing Splice Details

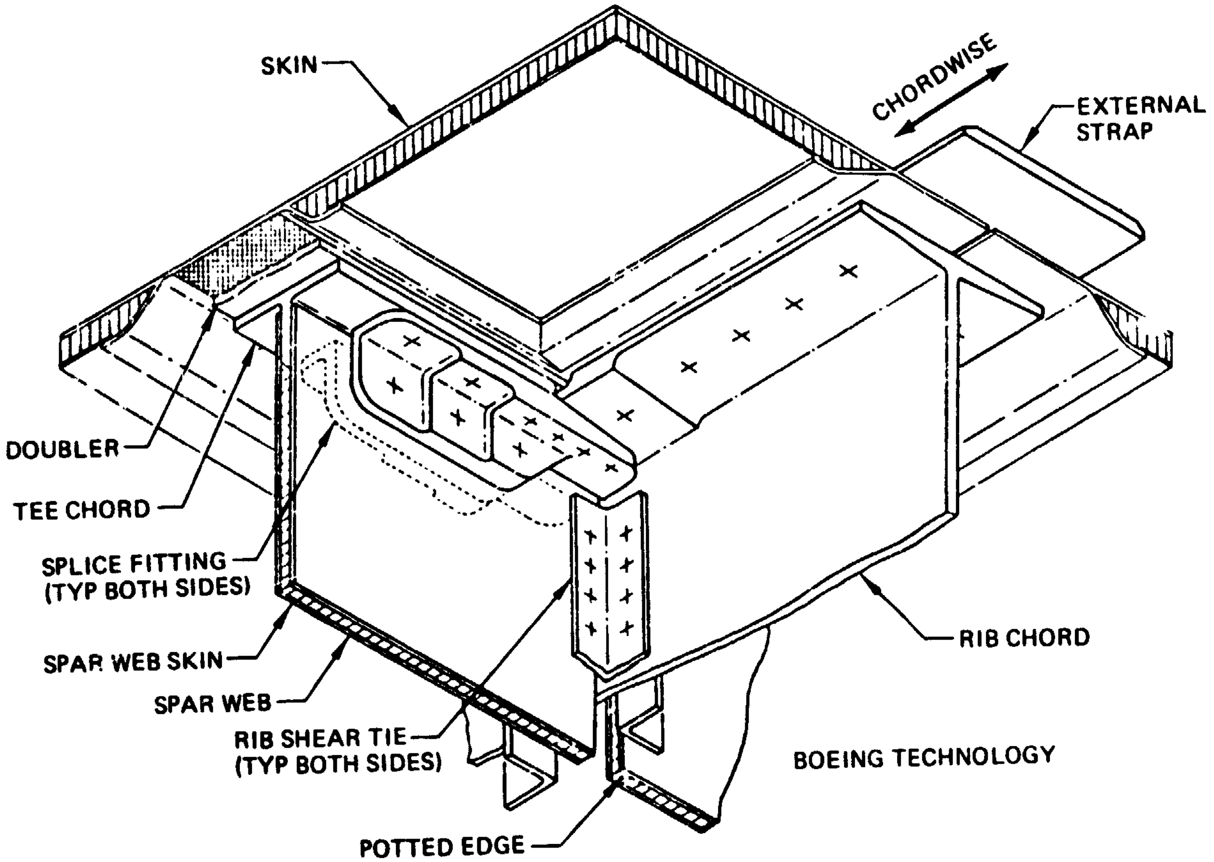


Figure 94 Chordwise Wing Splice

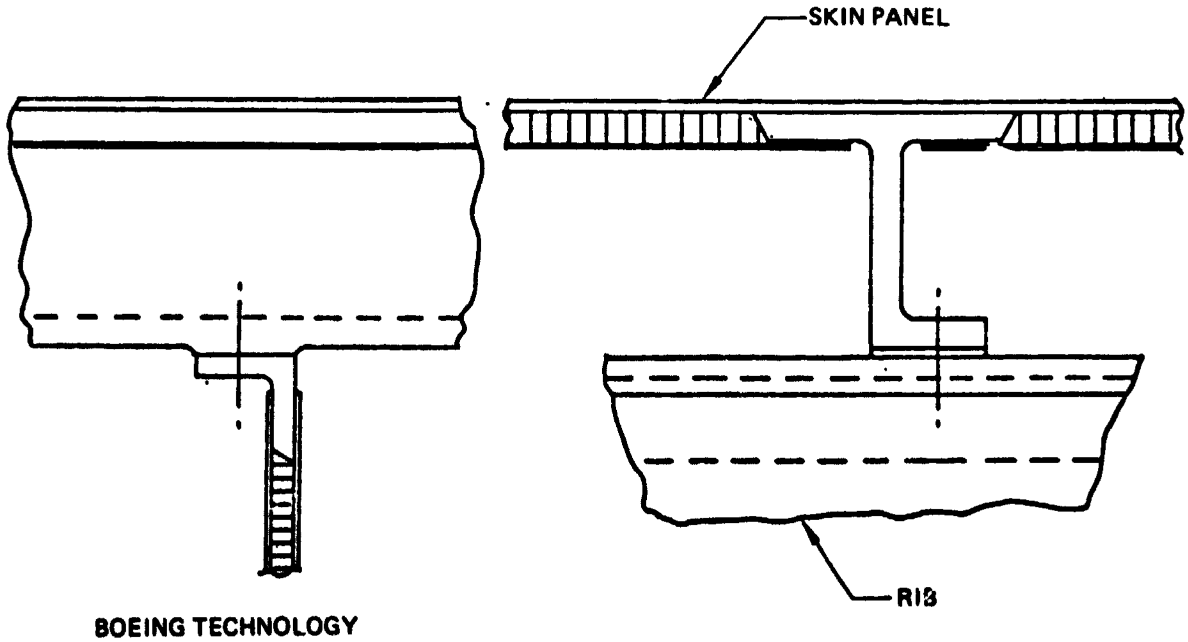


Figure 95 Bonded-in Stiffener, Inboard Wing

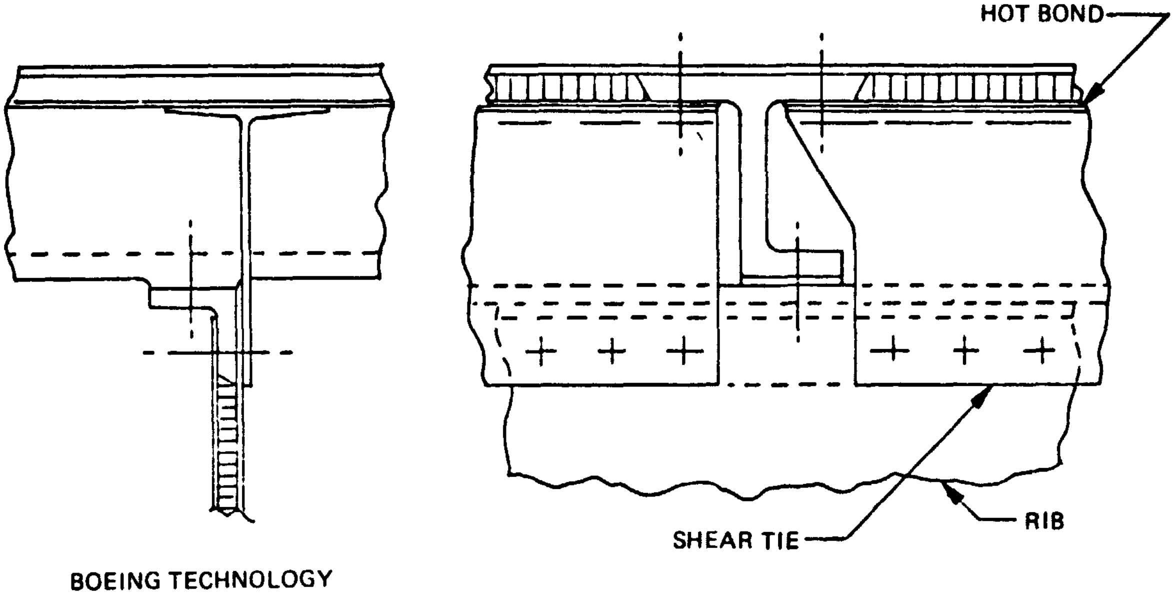


Figure 96 Shear-Tie Rib, Inboard Wing

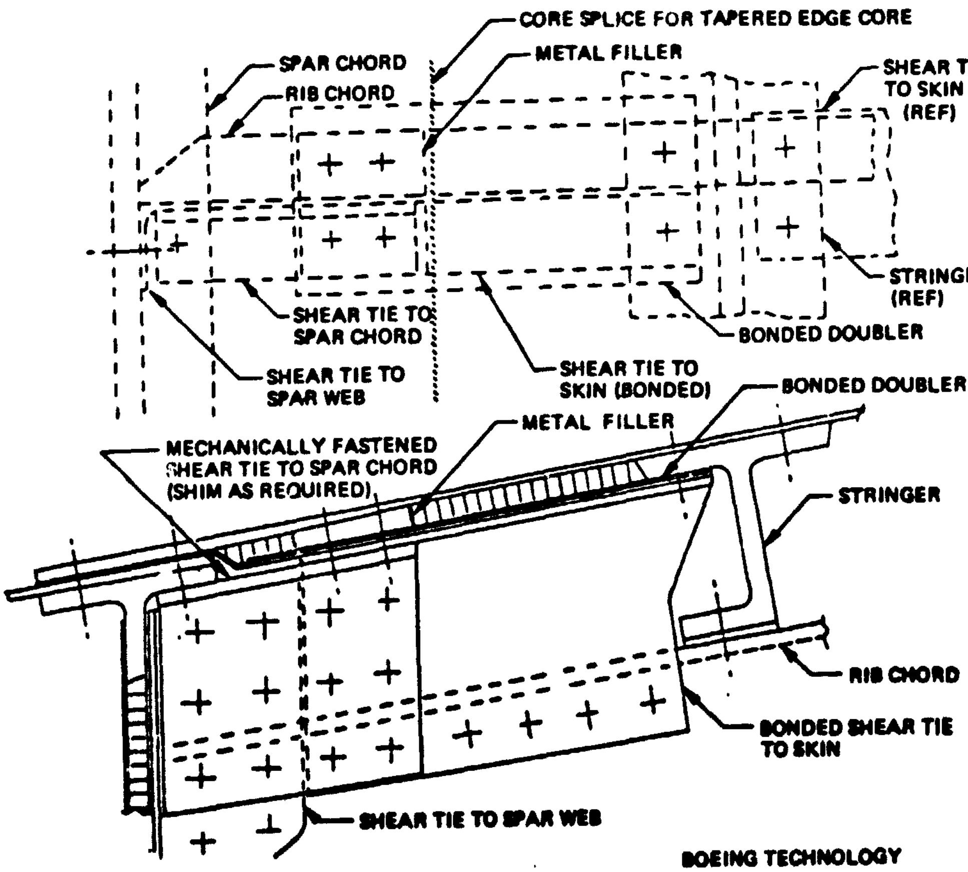


Figure 97 Shear Tie to Spar

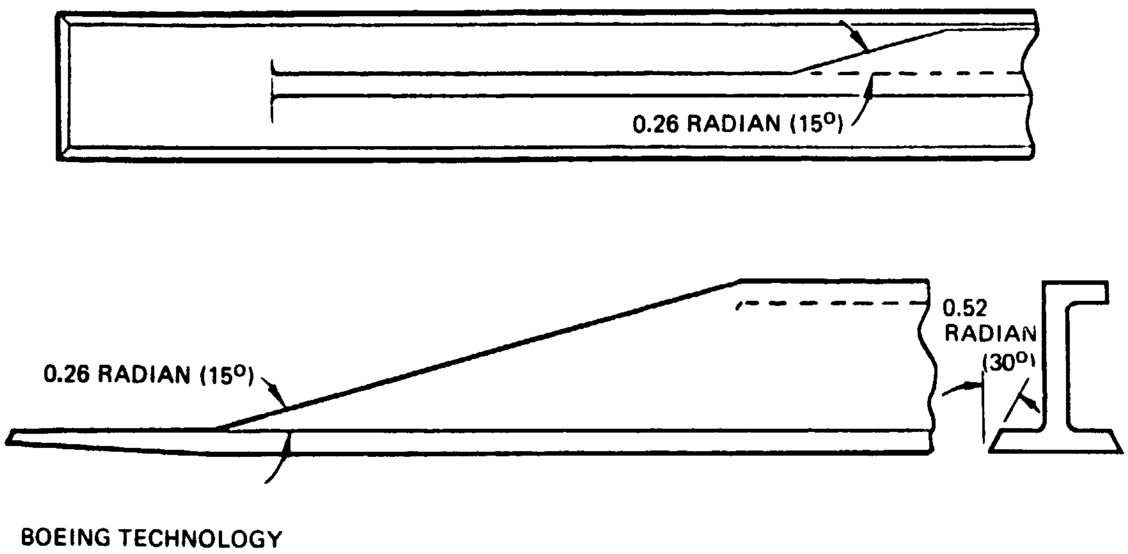


Figure 98 Stringer Ends

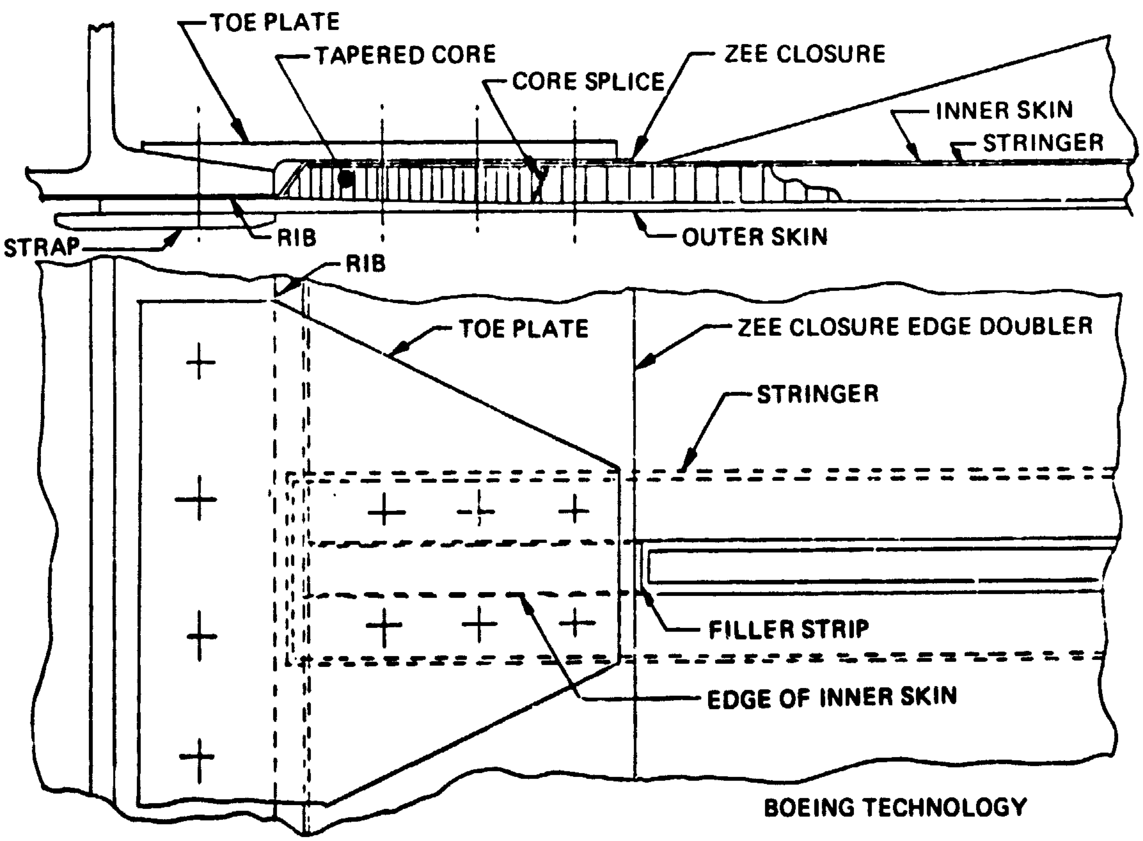
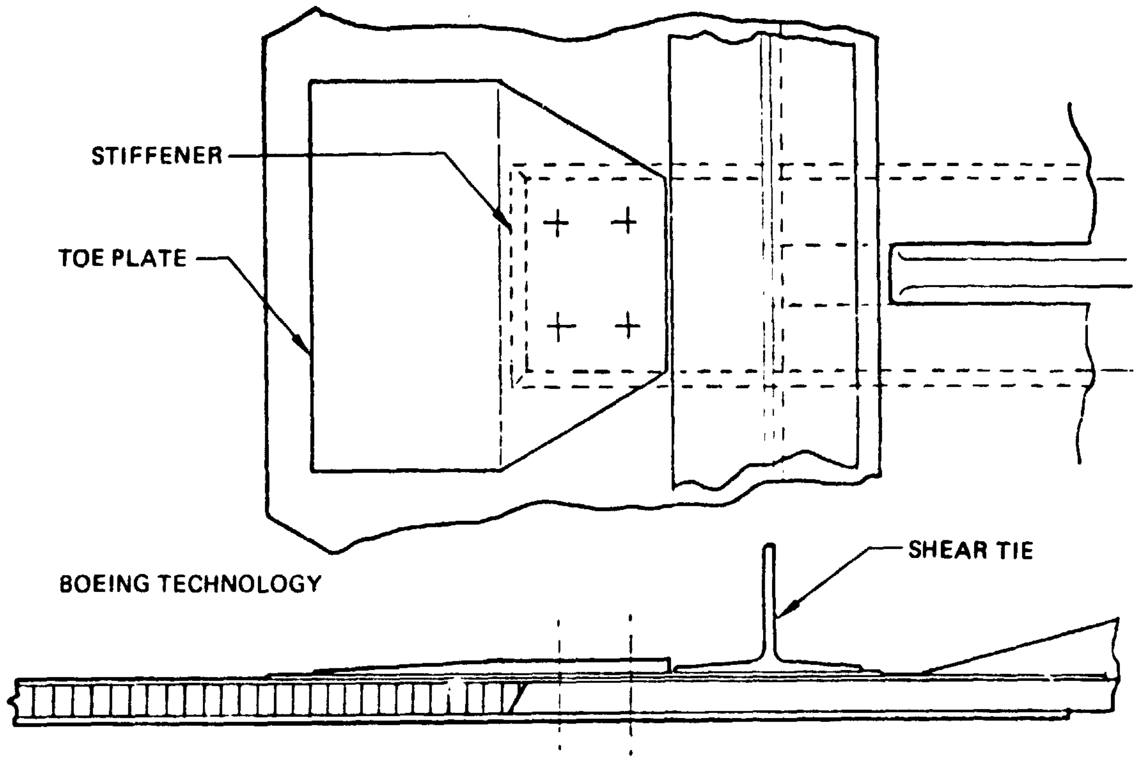
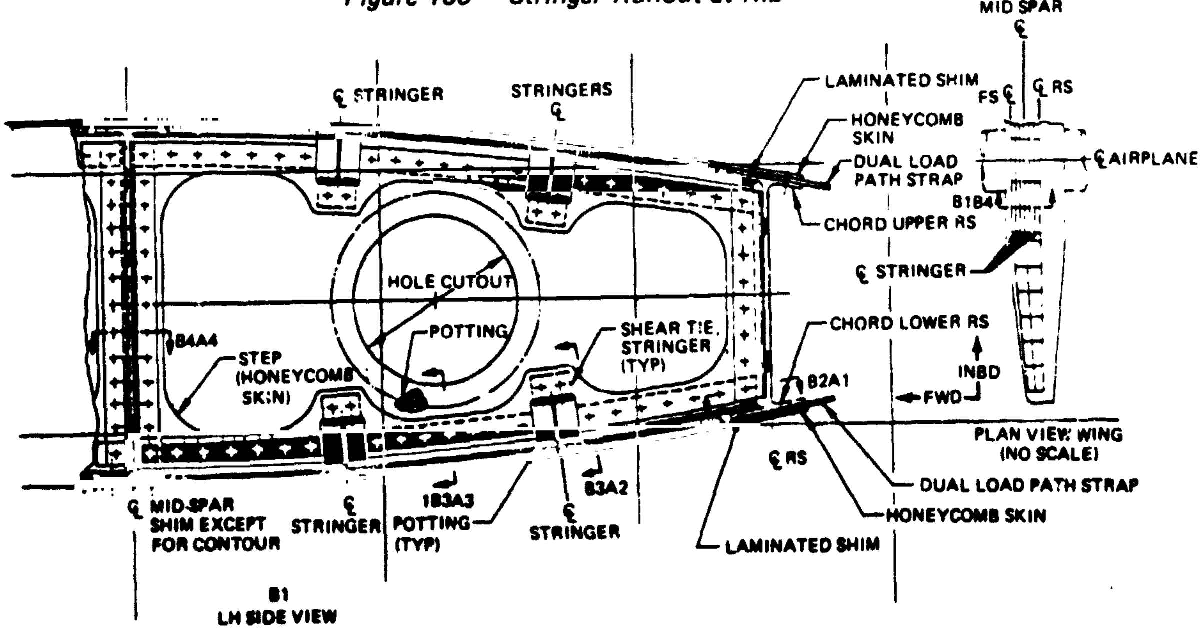


Figure 99 Stringer Runout at Splice



BOEING TECHNOLOGY

Figure 100 Stringer Runout at Rib



BOEING TECHNOLOGY

Figure 101 Honeycomb Integrated-Stringer Wing Box

Figure 102 All-Honeycomb Wing Box with Integrated Stringer Detail

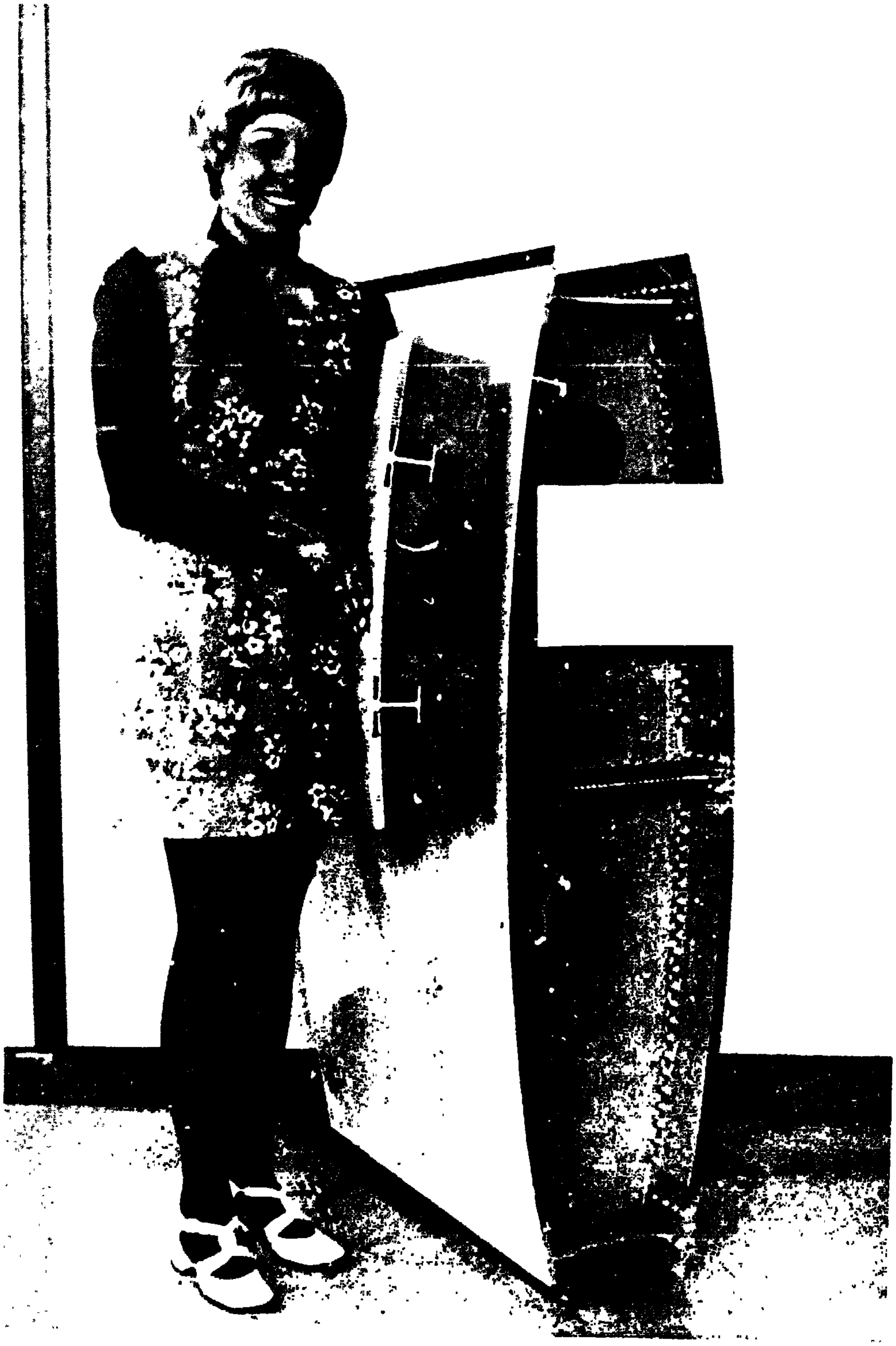


Figure 103 All-Honeycomb Wing Box with Integrated Stringer Assembly

One of the most significant advantages of bonded structure is its impressive behavior under fatigue-type loadings. The reason for this is that most fatigue cracks in conventional structure start from fastener holes, whereas bonded structure uses only a small percentage of fasteners compared to conventional structure. At joints and splices where fasteners are required, special attention is paid to details to ensure that fatigue goals are met.

A preliminary fatigue analysis of the basic wing was made. This analysis followed standard Boeing fatigue-analysis methods that assume 77 000 flights over a 20-year span and account for the ground-air-ground cycles, as well as the maneuver and gust cycles. This analysis shows that the wing bending material, as currently sized, has an adequate fatigue margin. Much more work must be done to determine the adequacy of the fatigue performance of the joints, splices, and all other details.

An all-graphite wing box was investigated and based on studies currently being performed for a 727 composite wing box; its characteristics are presented below and in figure 104.

- Graphite outer skin panels
- Extremely strong
- Very smooth contour
- Fewer parts than skin/stringer box
- Difficult to provide internal inspection

This configuration represents an advanced-technology wing-box assembly using graphite outer-skin panels. Costs at present make it the most expensive configuration investigated; however, in the 1985-and-later time period, a composite-design wing box may provide a strong candidate for a production airplane design. Many more configurations in composites need to be investigated. However, for the new technology (1985) short-haul transport, the bonded aluminum structure was selected for cost comparison.

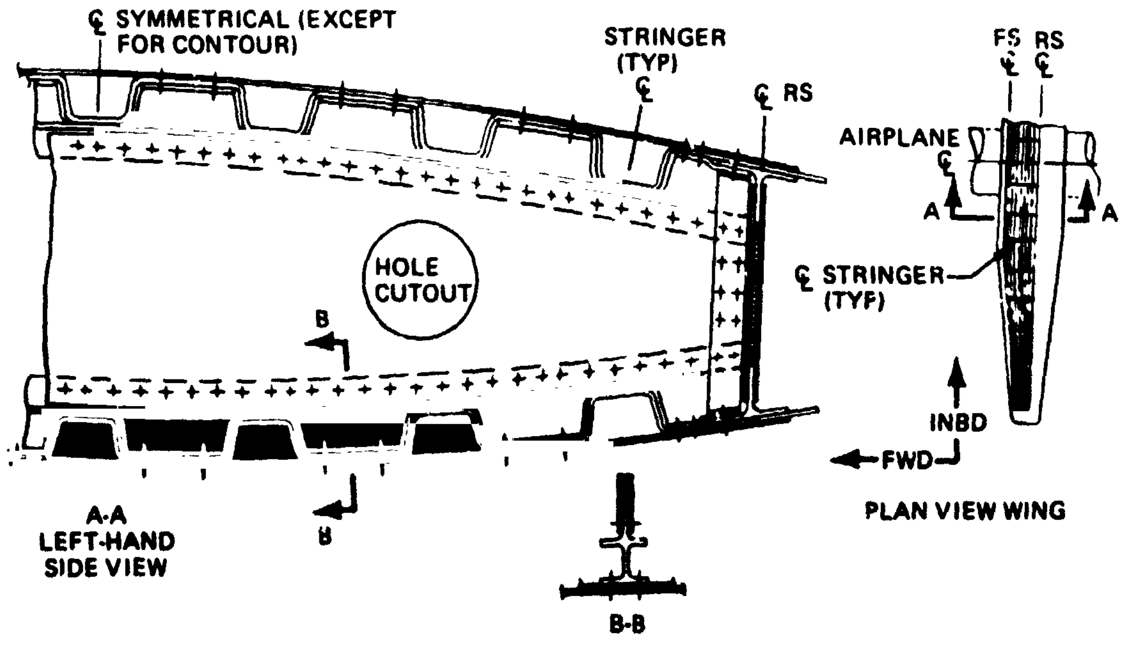


Figure 104 Composite Wing Box

6.2.2.9 Control Surfaces

The use of hybrid-composite Nomex honeycomb skin panels is the most cost-effective method of constructing control surfaces. Construction details of a typical rudder or elevator are shown in figure 105. The use of honeycomb allows a reduction in part-card count of the substructure as shown on the B737. Ribs are required only at hinges, actuators, and for closeout. The graphite provides the necessary stiffness. The thin layers of glass protect the graphite fibers and provide excellent crack-stopping capability.

Cost- and weight-effective spoilers can be built of graphite. The NASA/Boeing graphite spoilers have been proven in commercial service on the B737. Although graphite spoilers cost more than metal-sandwich construction, new designs combined with reduced cost of graphite will provide a price that is competitive with advanced metallic designs of similar weight.

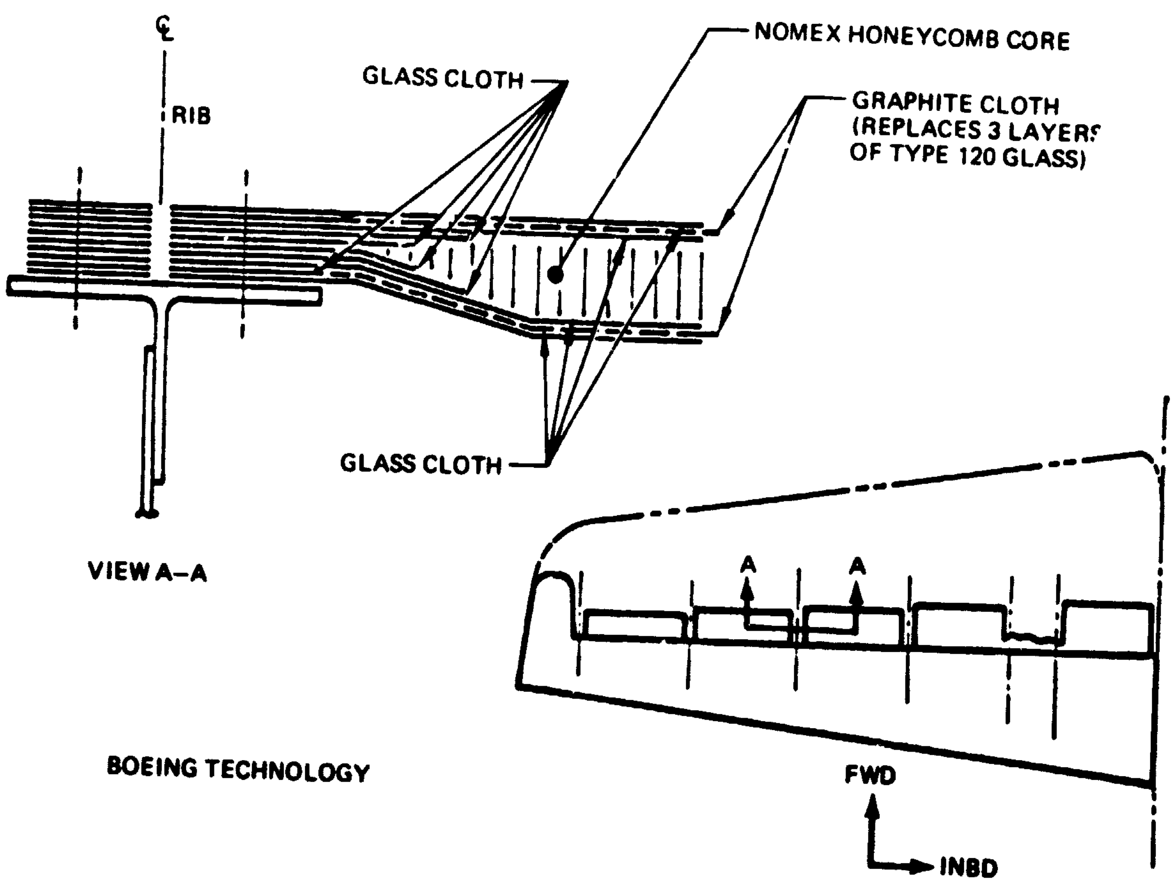


Figure 105 Composite Control Surfaces

6.2.2.10 Wing Flaps

The wing flap is made of aluminum honeycomb. The sparless-flap concept is shown in figure 79. The term "sparless" is used because a piece of dense core replaces the machined spar used on other flap designs. The dense core, together with the bonded insert, is functionally a spar and carries shear and bending. A full-scale flap section for the B727 was tested in 1977 and was lighter, stronger, and much cheaper to produce than the existing B747 design. This design is in production on the B727. Use of a square-edged honeycomb leading edge would provide further cost reduction.

6.2.2.11 Main Landing Gear

A concept for the main-landing-gear support frame is shown in figure 106. The commuter mission dictates a design with a high fatigue life. The use of diffusion-bonded titanium structure can be justified by cost saving due to less weight and maintenance cost. Figure 107 illustrates the use of symmetrical parts to make the assembly.

6.2.2.12 Interiors

Figure 108 illustrates the passenger-model body cross-section. Sufficient baggage stowage in the front and rear allow elimination of overhead racks, facilitating incorporation of a "wide-body-look" interior decor. A standard Hardman seat is used (fig. 109).

Interior sidewall construction (fig. 110) is similar to ceiling panels used on the B747. Glass insulation batts, required for thermal/acoustic insulation, are attached to the interior panel for support. The interior panels are attached to support clips on each frame using press-in strips. (fig. 111). These press-in strips are sacrificial if panels are removed for maintenance. Belly insulation is attached to the underside of the floor by lacing between frames, figure 112. Because of its isolated air-cell construction, the honeycomb aluminum body construction offers a potential improvement in noise and thermal isolation possibilities without added thermal/acoustic insulators. These qualities are subject to further investigation for potential synergetic weight reduction.

6.2.3 BONDING CREDIBILITY

During the past few years, significant breakthroughs have been made in adhesive-bonded structure. New surface preparations and new bonding materials have virtually eliminated bonding failures and corrosion problems. Most of the new technology has been evaluated in the laboratories and on a few commercial aircraft. Boeing is actively involved in independent R&D with the primary objective of evaluating these recent advancements in adhesive-bonded honeycomb structure. The evolution of adhesive-bonding materials and processes are shown in table 15 and protective finishes in table 16.

Prior to the YC-14 program, all bonded honeycomb was placed only in secondary structure. With the advent of the Boeing BAC 5555 bonding process, the integrity of aluminum-bonded honeycomb was considered to be sufficient for use in primary structural areas. As a result, the YC-14 empennage was composed of 100% aluminum-bonded honeycomb primary skin panels. These panels were manufactured at the Boeing Auburn complex.

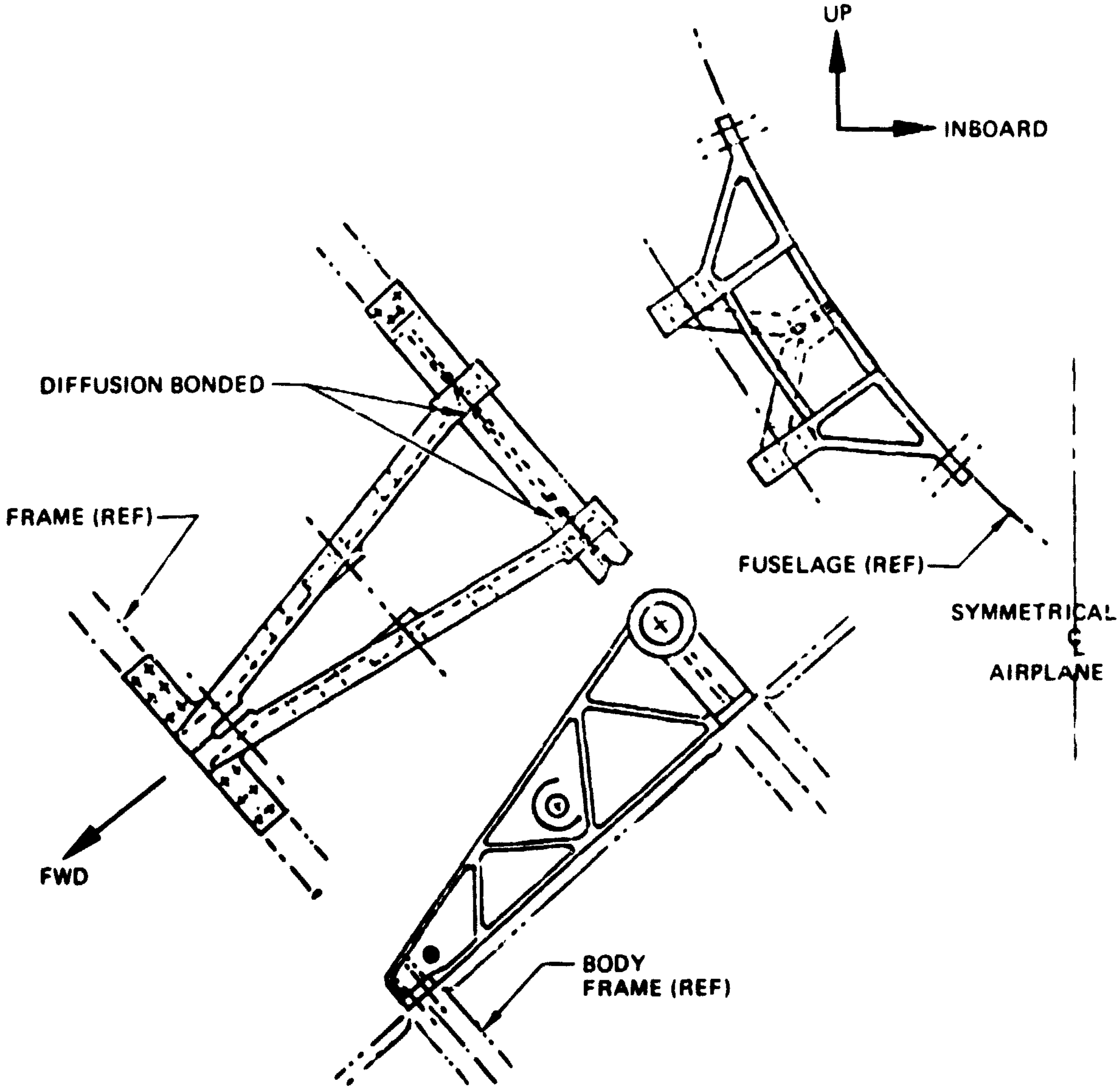


Figure 106 MLG Support Frame—Diffusion-Bonded Titanium

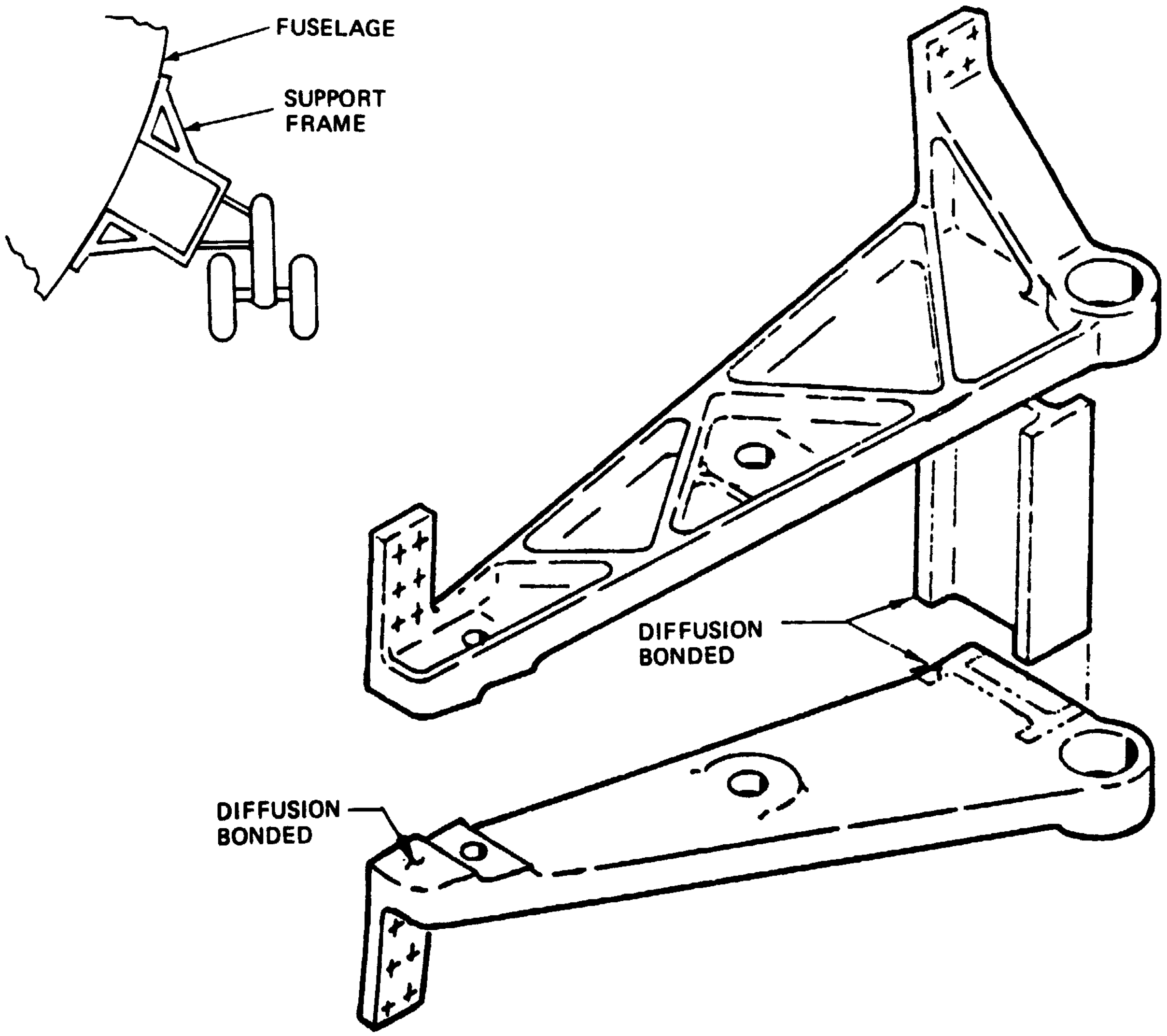


Figure 107   MLG Support Frame—Symmetrical Parts

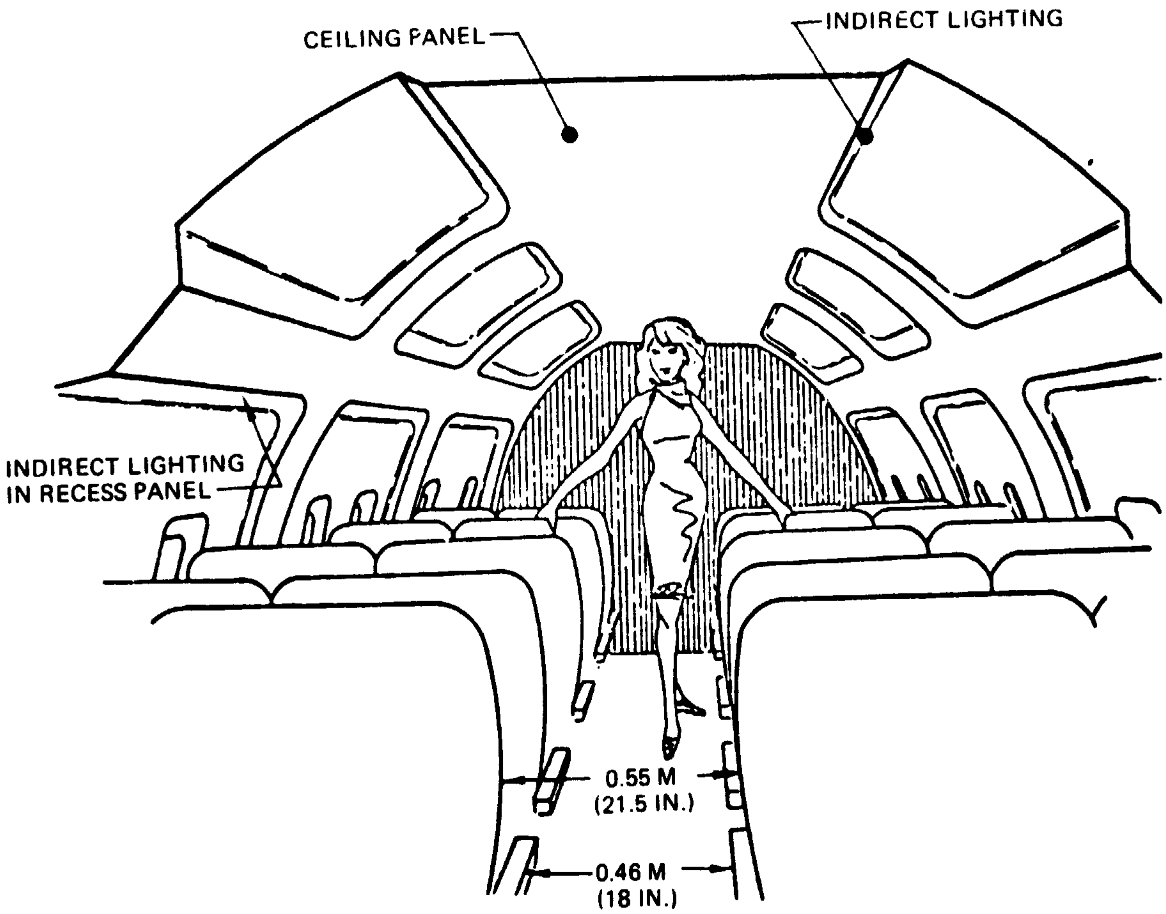


Figure 108 Wide-Body Look

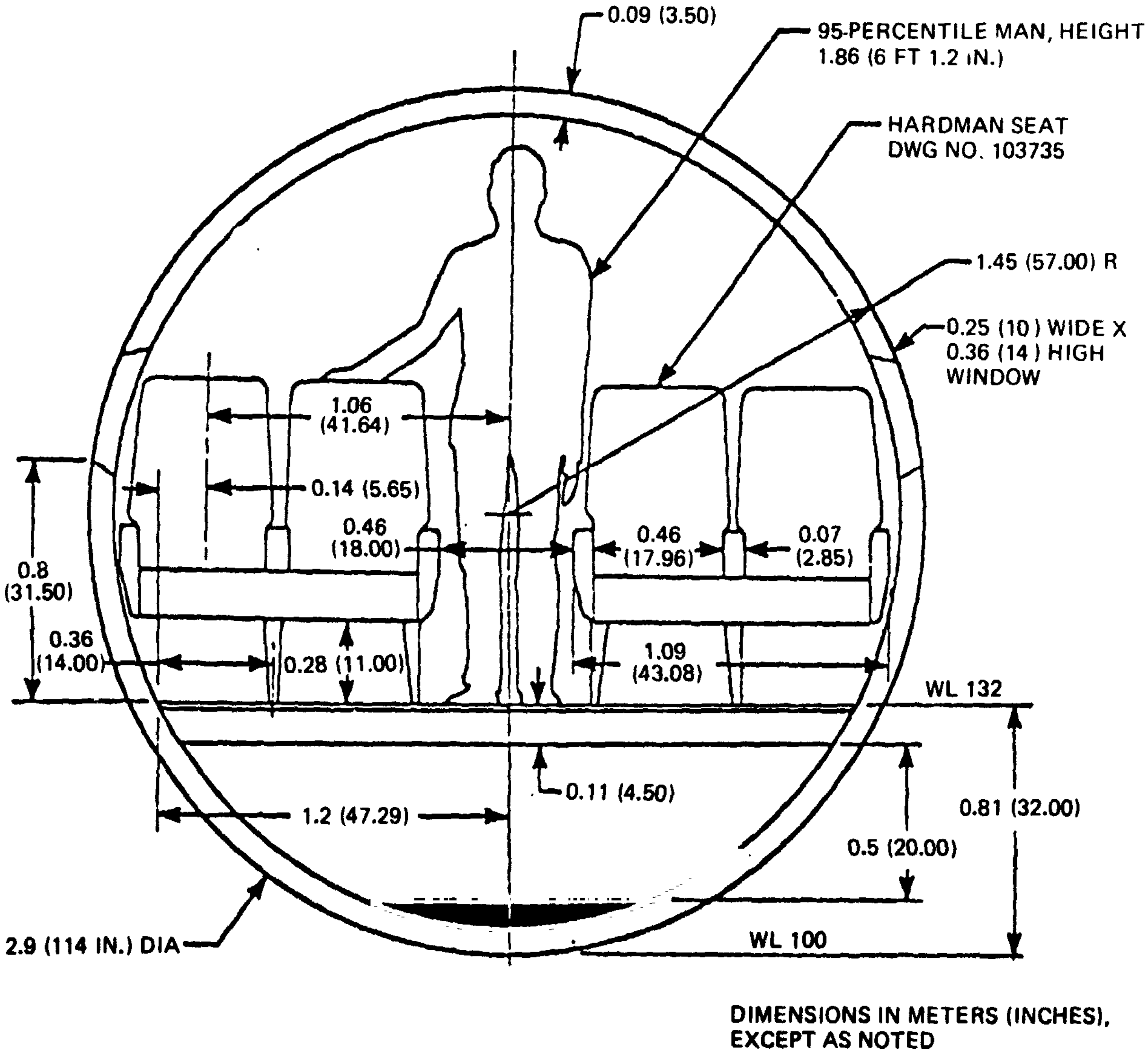


Figure 109 Body Cross-Section

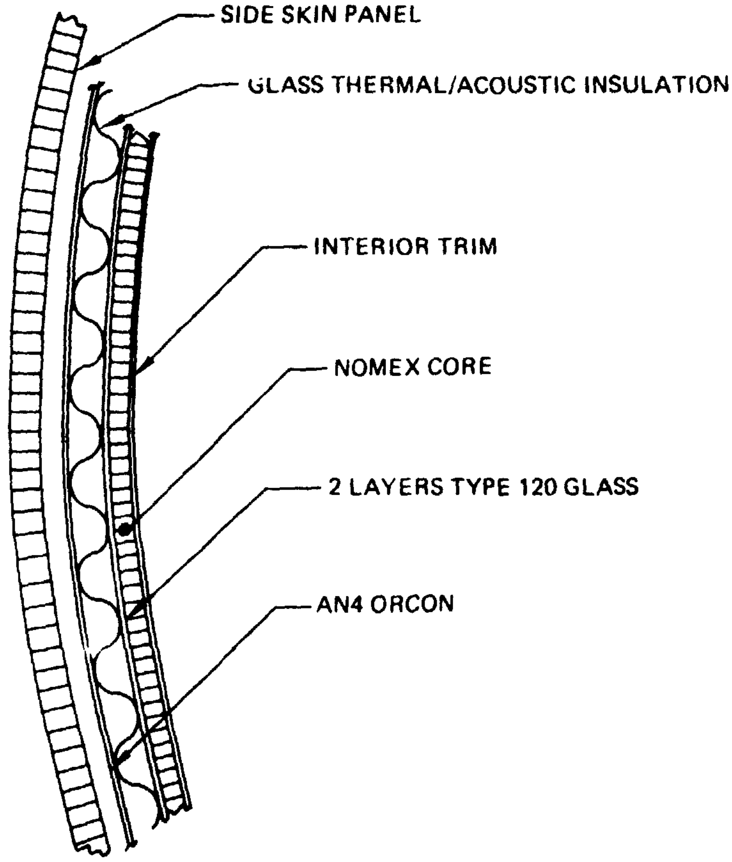


Figure 110 Sidewall Construction

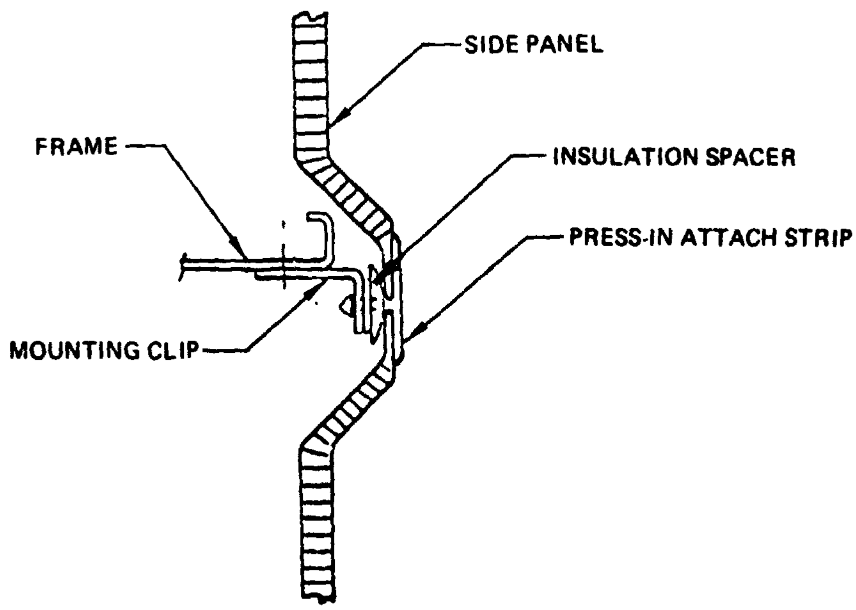


Figure 111 Sidewall Construction, Detail I

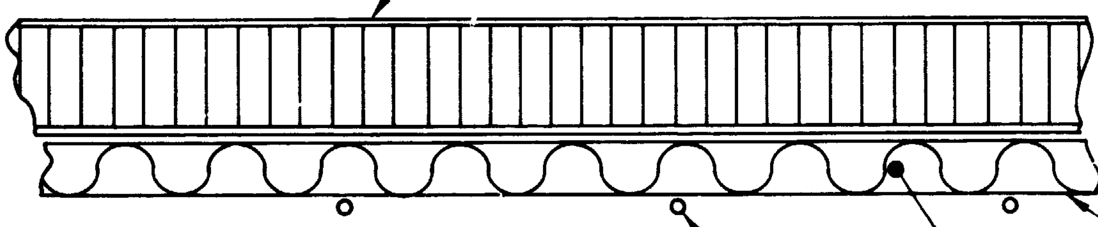


Figure 112 Belly Insulation

Table 15 Evolution of Materials and Processes

TECHNOLOGY	FACE SHEETS	SURFACE PREPARATION	PRIMERS	ADHESIVES	CORE	EDGE PROTECTION	AIRCRAFT USAGE	NDI TECHNIQUES
PRE-1960	2024 2024 CLAD 7075 7075 CLAD	SULFURIC ACID SODIUM DICHROMATE ETCH (FPL ETCH)	PHENOLICS	PHENOLICS	PERFORATED STANDARD CORE	METAL EDGE CLOSEOUTS	B-52 KC-135	COIN TAP
MID-1960s	2024 2024 CLAD 7075 7075 CLAD	SULFURIC ACID SODIUM DICHROMATE ETCH (FPL ETCH)	MODIFIED EPOXIES	MODIFIED EPOXIES	STANDARD CORE	METAL EDGE CLOSEOUTS	F-111 C-141 727 737	ULTRASONICS
1970	2024 2024 CLAD 7075 7075 CLAD	SULFURIC ACID SODIUM DICHROMATE ETCH (FPL ETCH)	CIAP	MODIFIED EPOXIES	CORROSION-RESISTANT CORE	METAL EDGE CLOSEOUTS SQUARE-EDGE POUR COAT, PRIMER	727 737 747	C-SCAN RECORDING
1973	2024 2024 CLAD 7075 7075 CLAD	OPTIMIZED FPL ETCH WEDGE TEST	CIAP	MODIFIED EPOXIES	CORROSION-RESISTANT CORE	METAL EDGE CLOSEOUTS SQUARE-EDGE POUR COAT, PRIMER	727 737 747	MULTI-LEVEL C-SCAN RECORDING
19/	2024 2024 CLAD 7075 7075 CLAD	PHOSPHORIC ACID ANODIZE	CIAP	MODIFIED EPOXIES	CORROSION-RESISTANT CORE	METAL EDGE CLOSEOUTS SQUARE-EDGE POUR COAT, PRIMER	727	MULTI-LEVEL C-SCAN RECORDING
1976-1980	2024 BARE 7075 BARE	PHOSPHORIC ACID ANODIZE	CIAP	IMPROVED 250°F CURING MODIFIED EPOXIES	CORROSION-RESISTANT CORE	METAL EDGE CLOSEOUTS SQUARE-EDGE POUR COAT, PRIMER	YC-14	MULTI-LEVEL C-SCAN RECORDING ELECTROMAGNETIC BOND TESTER

Table 16 Protective Finishes on Bonded-Aluminum Honeycomb Panels

SEQUENCE	ITEM	PROCESS OR MATERIAL	SPECIFICATION	FINISH CODE
DETAILS PRIOR TO BONDING	SURFACE PREPARATION	PHOSPHORIC ACID ANODIZE	BAC 5555 ANODIZE	XBAC 5558 BF-4-C
	PRIME	CORROSION-INHIBITING ADHESIVE PRIMER	BMS 5-89 TYPE I PRIMER PER XBAC 5546	
ASSEMBLY AFTER BONDING	EXTERIOR SURFACE	URETHANE COMPATIBLE PRIMER	BMS 10-79 PRIMER PER BAC 5882	SRF-14.9863-707
		POLYURETHANE FLEXIBLE ENAMEL, GLOSS GREY	BMS 10-60 TYPE II ENAMEL BAC 5845	
	INTERIOR SURFACE	EPOXY PRIMER	BMS 10-11 TYPE I PRIMER PER BAC 5736	F-20.02

6.2.4 FACILITIES AND EQUIPMENT

All facilities and equipment used for this program are Boeing-owned (fig. 113 and 114).

Boeing maintains extensive manufacturing capability for metal bonding, bonded-honeycomb structures, and fiberglass lamination, as well as capability in standard metal fabrication techniques. The majority of fabrication required for this program was performed by the Fabrication Division in Auburn, Washington. This single facility has the flexibility to produce small quantities of specialized test specimens or production runs of a variety of aircraft components. The Boeing Structural and Material Test Laboratories, capable of a full range of testing, provided nearly all material and component testing.

6.2.4.1 Tooling Shop

The tooling shop provided additional precision equipment in the manufacturing area to support the program.

6.2.4.2 Quality Assurance Facilities

To ensure a quality product, Boeing maintains in the Seattle area a wide array of nondestructive inspection equipment and facilities that were used on this program.

6.2.4.3 Test Facilities

All test and related equipment used in support of program evaluation efforts are contained in the Boeing Materials Technology and Structural Test Laboratories. The Boeing Materials Technology Laboratory has a large quantity of high specialized equipment for the evaluation of both metallic and nonmetallic materials. The Structural Test Laboratories contain all equipment necessary to test a complete range of specimens, from small material coupons to a full-scale airplane.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

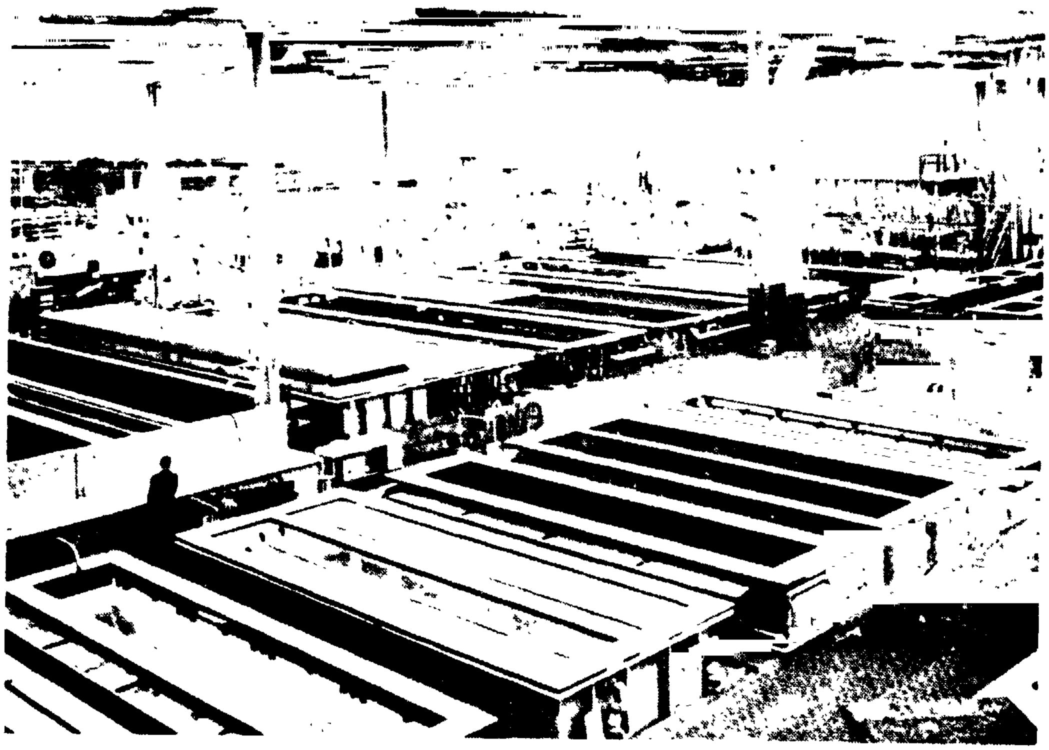


Figure 113 Boeing Manufacturing Facility

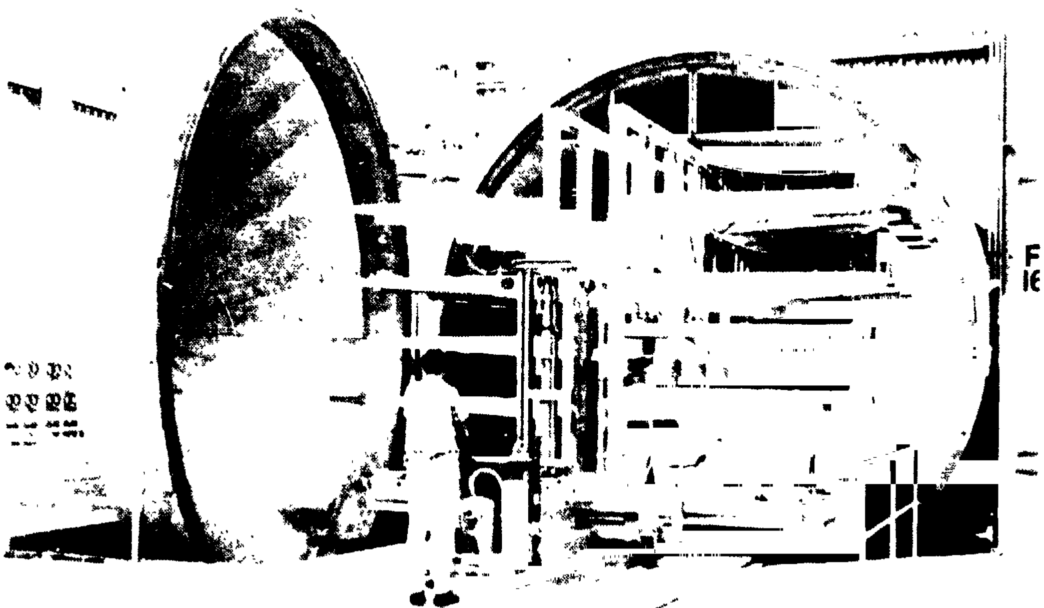


Figure 114 Air-Heated Autoclave

6.2.5 FOREIGN-OBJECT DAMAGE

Foreign-object damage occurs from natural causes (e.g., hail stones, bird strikes, articles flying through the air due to high winds, and runway rocks flying from landing gear tires) and man-made causes (e.g., maintenance stands, ladders, fork-lift trucks, dropped tools, or collisions with other aircraft or buildings).

If aluminum-bonded honeycomb is to be used in the lower body area, it must be able to sustain strikes from rock flying off the runway. This usually results in increasing the outer skin gage far more than is required for basic design aircraft loads.

In cases such as the skin/stringer design of the C-130 belly skin, the basic gages have been increased from 1.0 to 2.0 mm (0.04 to 0.08 in.). An alternate means for sustaining belly-skin rock damage was investigated, covering the belly skin in select areas with multiple layers of 181 glass cloth or a thin layer of polyurethane foam. Sample test parts showed this approach to have merit. Further tests should result in a selection of the best material to absorb rock impact and have a minimum affect on airplane structural weight.

Leading edges on the wing and empennage surfaces are of aluminum-bonded honeycomb construction with a minimum of 9.0-mm (0.036-in.) outer skin, 12.7-mm of 15 kg per cubic-m (0.5-in. of 3-lb/cubic-ft) core, and an inner skin of 0.4mm (0.016 in.) to sustain damage from 12.7mm (0.5-in.) hail stones while traveling at 463 km/hr (250 kt). A test part was assembled using multiple layers of 181 glass cloth between the outer skin and the core to assist in absorbing hail-impact loads. Consideration also was given to use of an external steel patch over the leading edge area to protect against hail and rain erosion. Test parts of this configuration show excellent protection from hail stones.

6.2.6 ANALYSIS OF AIRPLANE COST

The estimating approach objective for the various short-haul configurations was to arrive at consistent costs and prices so that the estimates would reflect true design differences. It must be recognized that estimates and prices prepared during a conceptual phase are preliminary and are subject to considerable revision as the program progresses.

The assumption was made that required facilities and technology would be available prior to program go-ahead. Study prices were calculated with consideration of the manufacturer's portion of the market quantity.

6.2.6.1 Responsibilities and Study Flow

The Boeing Commercial Airplane Company is organized into functional departments that have specific responsibilities and are the repositories of the company experience in their particular scope of activities. The Preliminary Design department, responsible for short-haul transport management, draws from the other departments the skills necessary to produce the inputs required for economic evaluation of prospective new products. Figure 115 shows the responsibilities and flow of information between the responsible groups. The individual inputs required to generate a cost estimate are shown in table 17. Preliminary Design produces the technical description and drawings of the configurations to be studied. The Technical Staff analyzes these designs and is responsible for the weight, noise, pro-

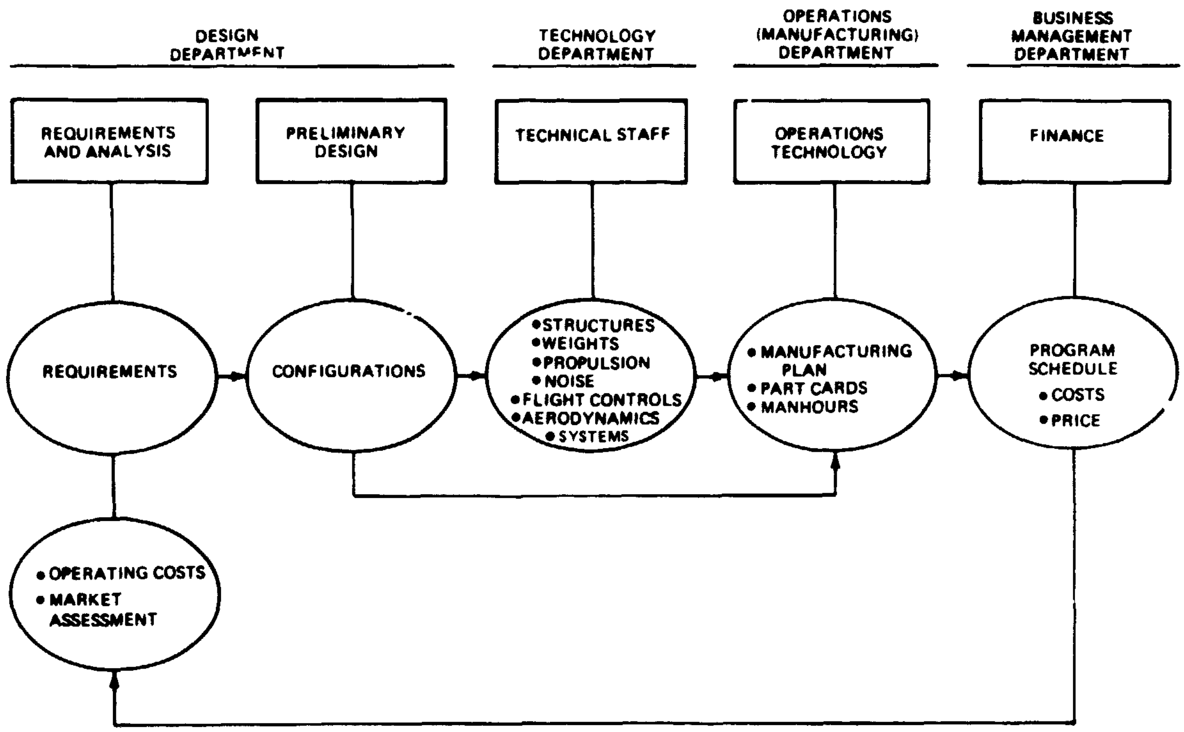


Figure 115 Responsibility and Study Flow for Pricing and Costing Methodology

Table 17 Cost-Estimating Input Requirements

AIRPLANE DESCRIPTION	CONFIGURATION DRAWINGS	AIRPLANE WEIGHT

• Speed
• Materials technology
• Systems technology
• Engine technology
• Unique features
  • Bonded primary structure
  • Straight rear spar wing
  • Wing and gear externally mounted
  • All doors in constant section
  • Conical tail section
  • Other
	• Size
	• Number of landing gears
	• Number and location of engines
	• Sweep and aspect ratio
	• Wing and empennage areas
		• Structure section
		  • Wing
		  • Fuselage
		  • Empennage
		  • Gear
		  • Propulsion
		• Systems and equipment by system
		• Engine thrust
		• Material type

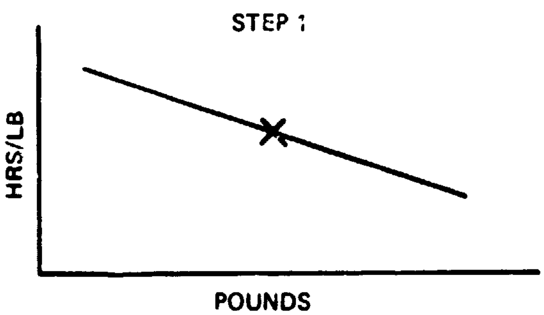
PART COUNT ESTIMATE	**DEVELOPMENT/PRODUCTION SCHEDULE**	**COMMONALITY/COMPLEXITY ASSESSMENT**

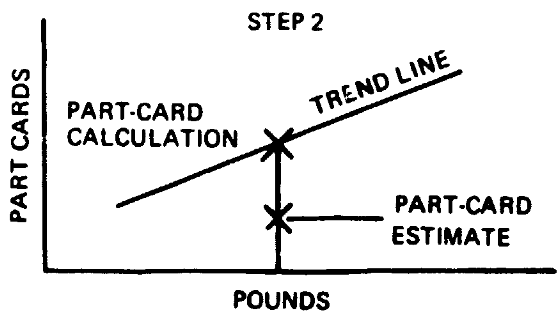
• Structure section
  • Wing
  • Fuselage
  • Empennage
  • Gear
  • Propulsion
• Nonstructure by system
	• Development schedule
	  • Months from go-ahead to rollout of No. 1 airplane
	  • Months from go-ahead to certification
	• Production schedule
	  • Airplane rollouts by month
		• Commonality assessment
		  • Commonality of existing models
		  • Commonality within configuration
		• Complexity assessment
		  • Material
		  • Speed

The process by which an advanced-preliminary-design concept such as this can be estimated is to relate to Company experience with similar projects in the past. The analysis technique consists of making a detailed estimate of the flow times and manloading required for each of the steps in the manufacturing process for a particular level of production, e.g., the 100th unit. Boeing has collected and maintained extensive manufacturing experience records such as comparisons of early preliminary estimates with actual shop performance, learning-curve experience, and comparison of shop performance with ideal performance under controlled conditions. The preliminary ideal estimate for the 100th unit is then adjusted upward by the appropriate historical experience factors and learning-curve effects for the particular operation being studied.

This departmental approach, in addition to the conventional estimating techniques on the remaining portions of the airplane, is incorporated into a total estimate. This data is compared to the Finance department estimate, which is as follows:

Engineering Labor—The basic estimating approach utilizes hours-per-pound of design weight for major components of the airplane. Design weight is the weight that Engineering designs rather than the total weight. Examples are the design of landing gear, engine nacelles, and struts. If all are identical, the weight to be considered is the weight of one end item. Adjustment to the base hours is made based upon the part-count deviation from historical part-count versus weight relationship. This particularly affects components of the airframe that have a high degree of commonality within that component.





The formula for a major component of the airplanes is:

Engineering hours = hours/pounds x pounds x part-count estimate/part-count calculations

Developmental Labor—The developmental-labor estimate is composed of tests in support of Engineering and the fabrication of mockups. Developmental test labor is estimated as a factor of engineering labor and developmental mockup is estimated using weight as a parameter.

Tool Labor—The basic estimating approach uses an initial hour-per-pound of peculiar tooled weight, extrapolating from existing airplane data. For example, if the nacelles and struts are identical for all locations, the weight of one determines the initial set of tools. Similarly, the wing may have multiple common parts due to a nontapered configuration. The initial tooling requirements are based upon only the determined peculiar tooled weight. Adjustments, however, are considered for final assembly or major tools that are not necessarily affected by common parts.

pulsion, drag, flight controls, airplane sizing, and performance characteristics. This information and the configuration definition are given to Engineering Costs and Schedules for an engineering manhour estimate and to the Operations (Manufacturing) department for a management plan, part card, and manhour estimate. The Finance group in the Business Management department makes an independent estimate, coordinates with departmental inputs, develops a program schedule and estimates the final costs and prices. The Requirements and Analysis group in Preliminary Design takes these prices and determines the operating costs, investment costs, and indirect costs to assess the market potential. In this manner, the full experience and resources by the appropriate authorities in every field are utilized to give Preliminary Design answers that can be represented as a responsible company output.

6.2.6.2 Basic Requirements and Assumptions

Cost and price data were estimated in 1977 dollars. The program cost for various production quantities provided a base for determining a price allowing the airframe manufacturer a reasonable return on investment. The resultant price was used as one element in calculating the economics and direct-operating cost. Fuel price was varied at 35, 50, and 68 cents per gallon (1977 dollars). A crew of two was assumed. Direct operating cost was calculated using the 1967 Air Transportation Association equations, updated with the 1977 Boeing coefficients.

The analysis techniques used in the development of the airplane prices to be inserted in these DOC equations are described in the following paragraphs.

6.2.6.3 Cost Estimating Methodology

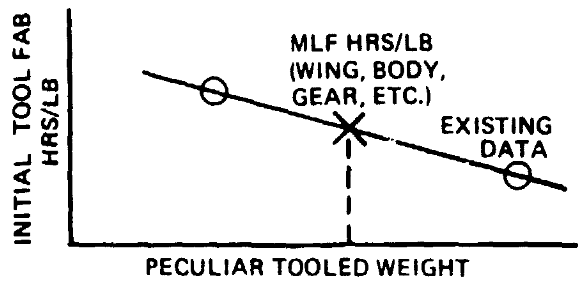
The approach used in estimating the costs of short-haul transports is to separate those components of the airplane that are similar to conventional airplanes into one category and those components that are unique to this concept into another. The components in the first category are handled by conventional techniques based upon correlation with Boeing manufacturing experience. Both the structure of the body and the main wing box with its trailing edge surfaces, and the manufacturing methods being considered to produce them, fall into the secondary category and were studied in much greater detail by the Operations and the Engineering Cost and Schedules departments to establish credibility for the estimate. Operations' manhour estimates for the body, the wing box, and the trailing-edge surfaces are used as an example to illustrate this activity.

Manufacturing Plan—The cost estimating process starts with a manufacturing plan establishing the manufacturing methods to be used and the sequence of manufacturing steps for the complete airplane. Proposed plant layouts, including considerations for handling the large ≤15-m (≤50-ft) bonded-skin panels are prepared as part of this activity. A program schedule coordinating the flow times of the parts production and the assembly times of subassemblies and final assemblies is then made. This is an iterative process requiring reconciling detailed manhour estimates, process flow times, and man loading inputs.

6.2.6.4 Operations Manhour Estimate Example

The main wing box and the fixed leading and trailing edges are built entirely of honeycomb components. Production bonding of these parts and their partial assembly could be accomplished through the use of a proprietary process in a special facility that permits continuous bonding of parts up to 15m (50 ft) in length. Considerable depth of analysis and detailed listing of component parts are required to produce manhour estimates for these parts to an acceptable level of confidence.

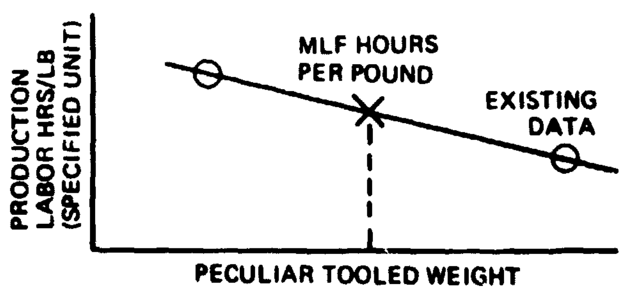
Airplane sectional estimates are made from peculiar weight as follows:



Design and coordination requirements are added as factors of initial fabrication.

Duplication and/or rate tool hours are determined from the production schedule as well as the commonality assessment and are factored from initial tooling. Recurring tooling is estimated as a factor of basic tooling or production labor

Production Labor—In the case of the tool estimating approach, hours-per-pound of peculiar weight are used.



As an example, identical nacelles are estimated by unit from historical data and extrapolated to total program requirements (e.g., two per airplane x 250 airplanes = 500 units) on an improvement curve.

Because of multiple common parts in the wing, the peculiar portion (by weight) is estimated as a unit and extrapolated on an improvement curve to total airplane and program requirements. For example, if the wing is determined to be 40% peculiar by weight, each airplane includes 2.5 equivalent units of peculiar construction with cost reduction reflected due to the improvement curve application.

Planning requirements are added as a factor of labor hours. Nonrecurring planning is calculated from part-count estimates.

Quality Control—Quality control is based upon a factor of operations labor.

Material–Tool materials and development materiel are estimated from historical data as a dollar-rate-per-tool or developmental hours. Production material is calculated as a cost-per-pound of structure and nonstructure weights.

Purchased Equipment–Requirements are assessed from existing airplane cost data.

Engines–Engines are based upon the engine manufacturer's latest available data within The Boeing Company for either existing or study engines.

Flight Test–Flight test is estimated as a rate-per-flight hour.

Parametric Versus Point Design Costing–The selected and reference point design configurations are costed and priced using the methodology discussed above. The techniques used for the parametric study differ, however, from the above methods. The parametric study requires less detail because the interest is the relative comparison of similar configurations. The parametric costing is based on data from previous Boeing studies of short-haul aircraft.

Recurring costs are estimated based on differences in airframe weight and engine quantities.

6.2.6.5 Pricing Methodology

Commercial pricing incorporates the effect of the program schedule, production rate, production quantity, program costs, receipts, and expenditures. These elements are used to establish a price that will yield a reasonable return on the manufacturer's investment.

6.2.7 SENSITIVITY OF BASEPOINT AIRPLANE TO LOW-COST FEATURES

Preliminary cost estimates were completed for the short-haul transport with conventional skin stringer construction (model 767-774C) and with bonded-aluminum honeycomb construction (model 767-774B). Independent estimates were prepared for both configurations by Engineering Manufacturing and the Finance departments. Results indicated a substantial reduction in cost for the bonded-honeycomb design. This reduction was due to simplified manufacturing processes for tool fabrication and for airplane structure fabrication and assembly.

Low-cost design and construction efforts were concentrated on the airplane wing, fuselage, and empennage sections, resulting in a 40% cost reduction. Five percent of this reduction is due to reduced material costs and the remainder due to reduced part-count and assembly time. In the conventional airplane these sections (fig. 116) comprise 40% of the total cost of a 200-airplane program (including engines). Hence the use of bonded-aluminum honeycomb primary structure reflects a total overall reduction of 16% in airplane cost. The cost elements included in the wing, fuselage, and empennage are: engineering design, tooling, production labor, production material, and quality control.

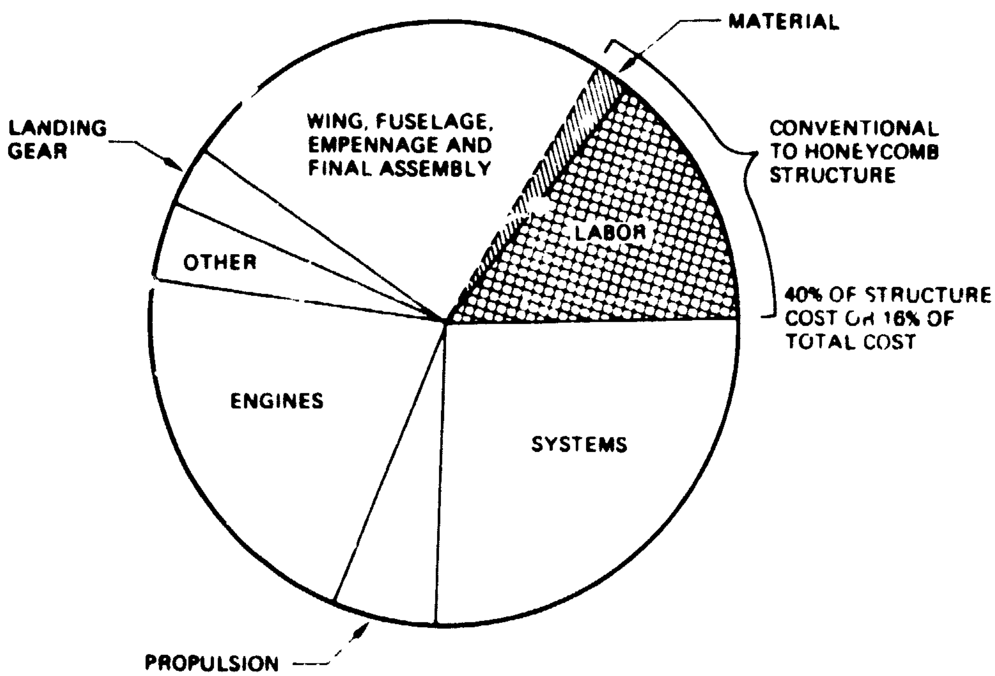


Figure 116 Short-Haul Airplane Recurring Cost (200-Airplane Program)

6.3 ADVANCED AERODYNAMICS

Design selection and sensitivity studies using the baseline airplane configuration (fig. 9) showed the importance of good high-speed/low-speed performance matching to achieve an optimum airplane design. The key factor in high-speed low-speed matching is airplane aerodynamics, which is examined in detail in this section.

6.3.1 HIGH-LIFT DEVICES TRADE STUDY

Four different high-lift configurations were analyzed to determine the best combination of high-lift devices to match short-haul mission requirements. The various high-lift devices used in this trade study are shown in figure 117. The following combinations investigated were: trailing-edge devices only, trailing-edge plus variable-camber leading-edge devices, trailing-edge and leading-edge devices plus drooped ailerons, and full-span leading-edge and trailing-edge devices with spoilers for roll control.

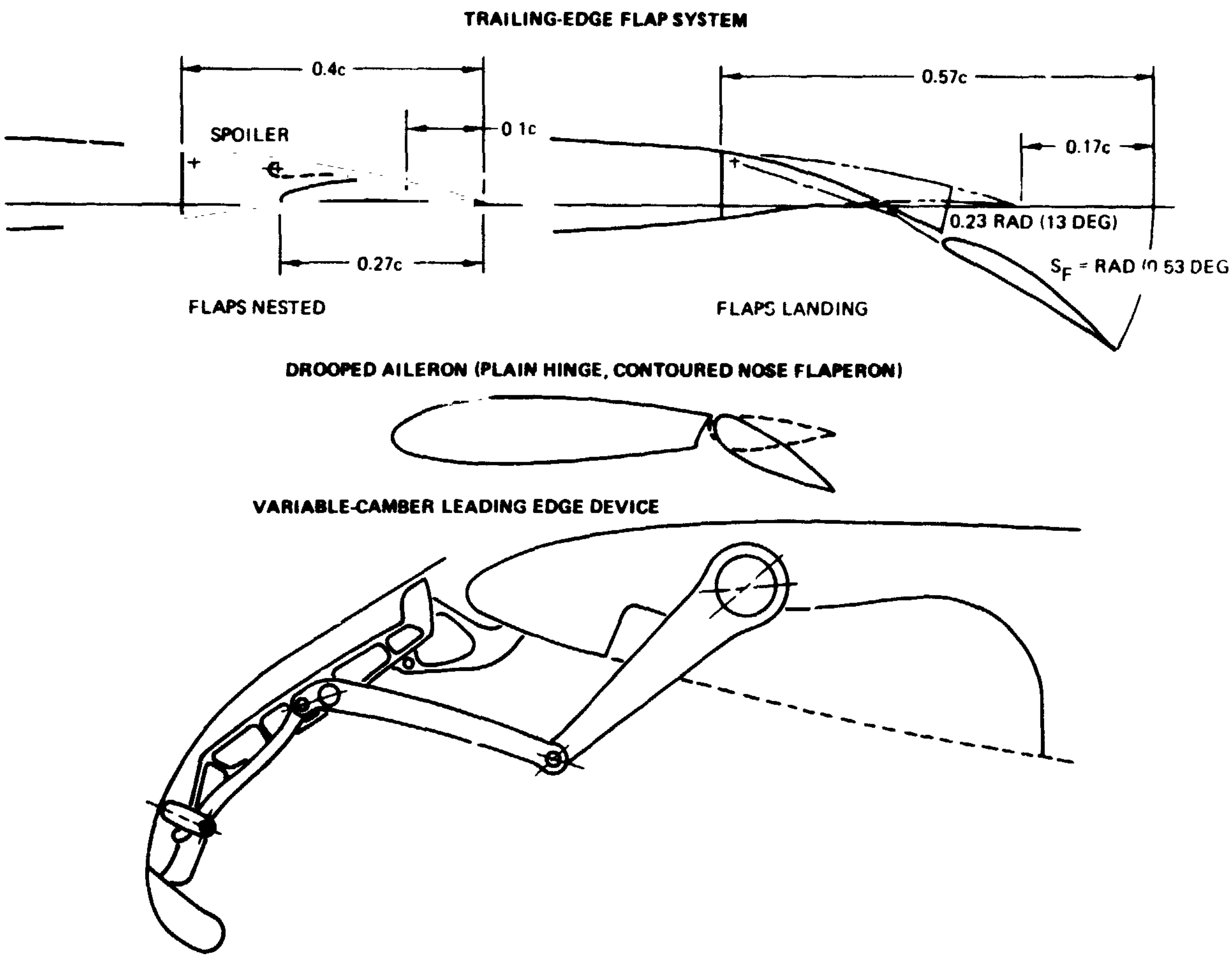


Figure 117 High-Lift Devices Trade Study (Low-Speed Configuration)

The low-speed L/D–C_L characteristics used in the high-lift devices trade study are shown in figure 118. The design selection chart for the first three high-lift combinations is shown in figure 119. Constraint A in this figure shows the optimum design point of the basic high-lift configuration (trailing-edge devices only). The design point shown represents an airplane with the wing area required to meet a 1372-m (4500-ft) wet landing-field length constraint at maximum TOGW, and a thrust loading selected to minimize block fuel and TOGW. This results in a 1082-m (3550-ft) TOFL because the engine is sized for cruise and not for takeoff.

Constraint B in figure 119 shows the effect of adding a variable-camber-leading-edge device and constraint C shows the additional effect of a variable-camber leading edge plus a drooped aileron. A size and performance comparison showing the technical benefits of enhanced high-lift devices is shown in table 18. Even at design ranges as short as 1400 km (750 nmi), the addition of a leading-edge device reduces the wing area by 16.3 sq m (175 sq ft), the TOGW by 1200 kg (2650 lb), and SLST by 4.2 kN (940 lb).

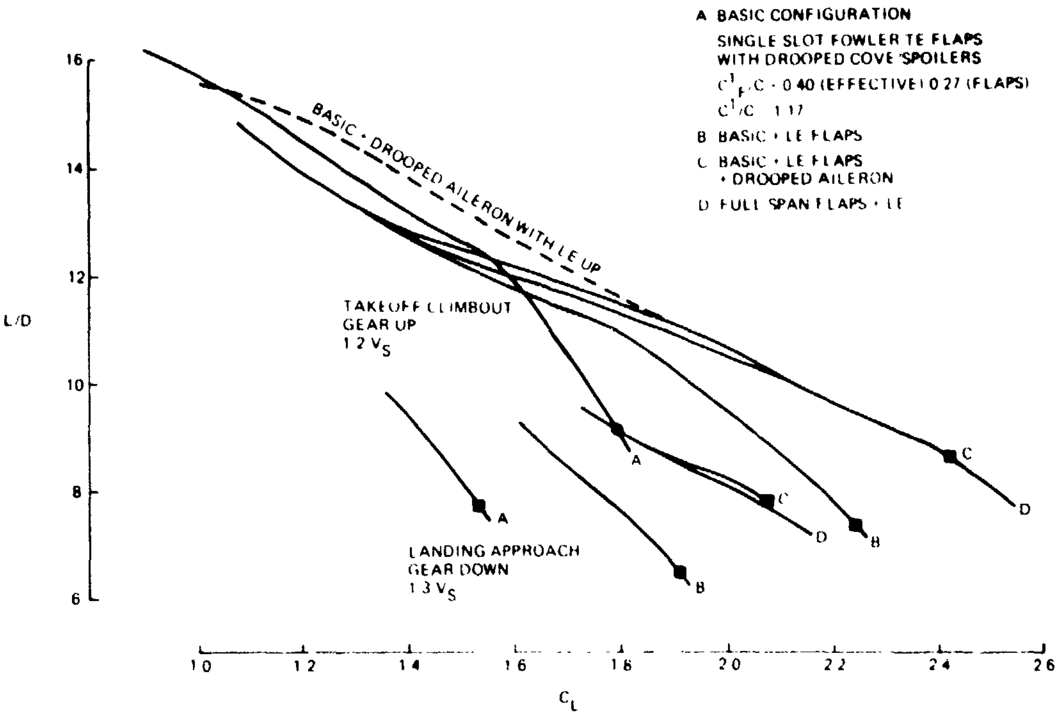


Figure 118 High-Lift Trade Study (Low-Speed Drag Comparison)

Table 18 High-Lift Trade Study Airplanes

- Payload = 50 passengers/4500 kg (10 000 lb)
- Still air range = 1400 km (750 nmi)
- Cruise mach = 0.70

FLAP SYSTEM	TE ONLY	TE + LE	TE + LE + DA
W/S, kg/m^2(lb/ft^2)	352 (72.2)	440 (90.1)	470 (97.0)
$C_{L_{APP}}$	1.53	1.91	2.06
TOGW, kg (lb)	23 610 (52 050)	22 400 (49 400)	22 100 (48 800)
OEW, kg (lb)	15 800 (34 800)	14 700 (32 300)	14 300 (31 500)
BLKF, kg (lb)	2160 (4750)	2140 (4720)	2200 (4840)
SW, m^2(ft^2)	67 (725)	51 (550)	47 (503)
SLST, kg (lb)	4320 (9530)	3900 (8590)	3780 (8330)
FAR TOFL at 32°C (90°F), m (ft)	1080 (3550)	1400 (4500)	1400 (4500)
Sizing	Cycled	Cycled (minimum SLST)	

TE = trailing edge Fowler flap
LE = variable-camber leading-edge device
DA = drooped ailerons

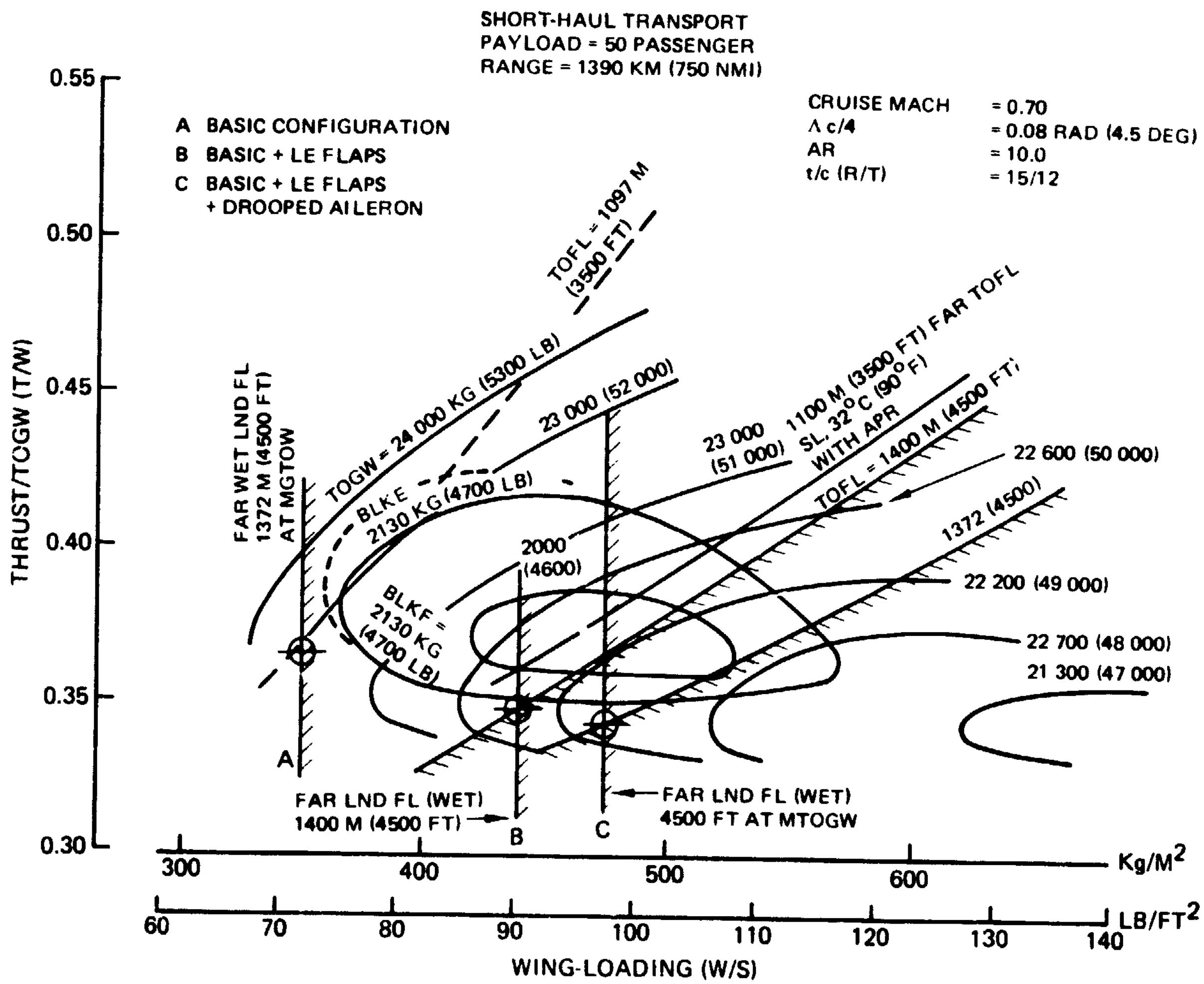


Figure 119 Design Selection Chart for High-Lift Devices Trade Study

The relative cost of adding a leading-edge device is shown in figure 120. These curves show that for airplanes sized to meet landing-field length = 1370 m (4500 ft), the relative wing cost to be slightly reduced with leading-edge devices, but this does not include the effect of the reduction in TOGW and engine size, which would tend to increase savings available with leading-edge devices. The increase in maintenance expense caused by adding variable-camber leading-edge devices appears to be minimal. However, additional trade studies, including DOC, would be required before incorporating a leading-edge device into the basic airplane.

At the conclusion of this phase of the study, an advanced trade study airplane sized for minimum block fuel was configured incorporating all the high-lift devices. This is the model 767-837 shown in figure 121 and was used for many following trade studies.

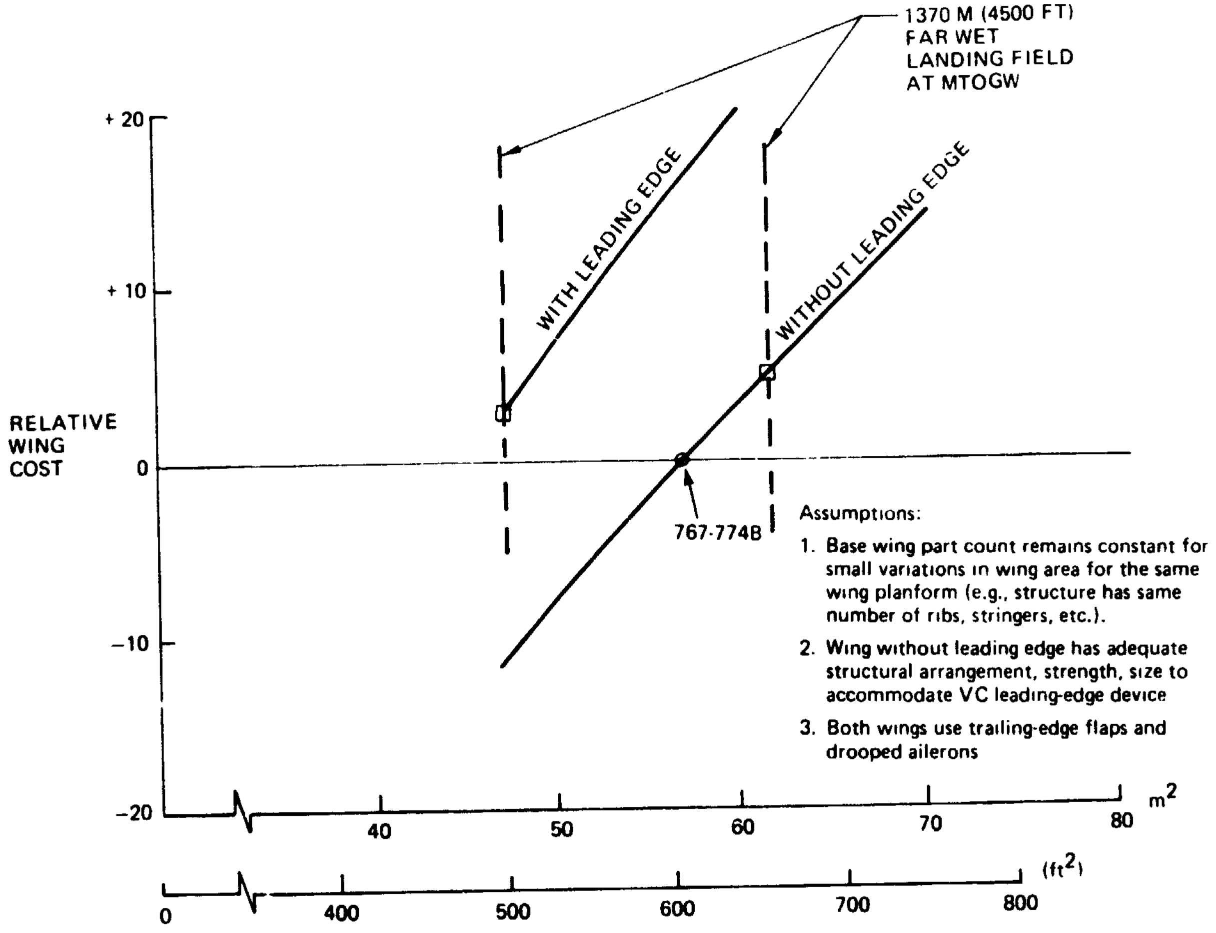


Figure 120 Cost of Leading-Edge Devices

50 PASSENGERS
TOGW 22 2000 KH (49 000 LB)
CRUISE SPEED 0.70 M
WING AREA 47 m^2 (505 FT^2)
ASPECT RATIO 10.0
ENGINES (2) CF-34 RUBBERIZED
THRUST SLST 39.8 kN (8950 LBF)

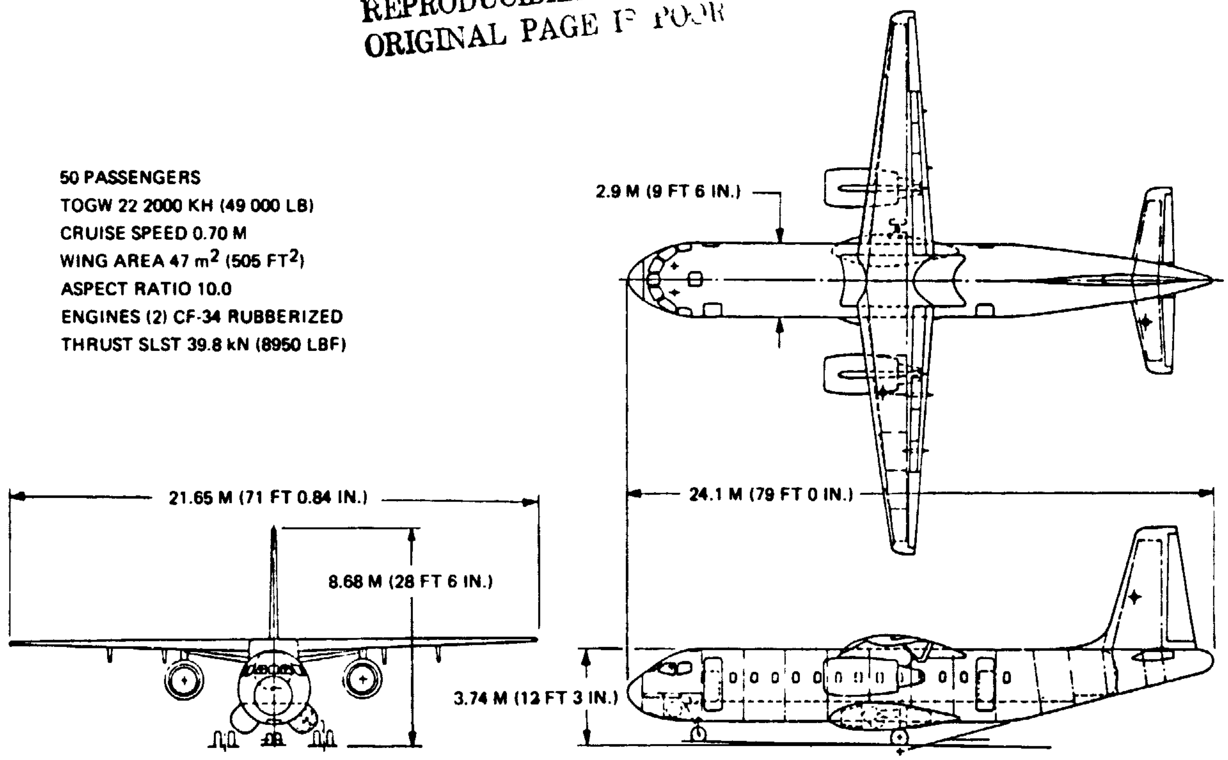


Figure 121 High-Lift Devices Trade Study Airplane, Model 767-837

6.3.2 ADVANCED AIRFOILS

An investigation was made to determine the effect on airplane performance of an appreciable region of natural laminar flow on the wing and empennage. The assumptions used for this portion of the study are shown in figure 122.

The effect of natural laminar flow on the short-haul transport wing-profile drag is shown in figure 123. For the trade study airplane (model 767-837, fig. 40), an improvement in drag of 40 drag counts is obtainable from a 50% laminarized wing. In addition, similar levels of natural laminar flow applied to the horizontal and vertical tail results in a reduction of 18 counts of tail surface profile drag. The total improvement from both wing and tail surfaces (58 counts) reduces cruise drag 15%. This effect on a cycled airplane relative to the 767-837 base sized to a cruise match point is shown below:

CRUISE SIZED [W/S = 475 kg/m^2 (97 lb/sq ft), CLR = 0.9, AR = 10]

ΔC_{D_C} = −15%

TOGW = − 6%

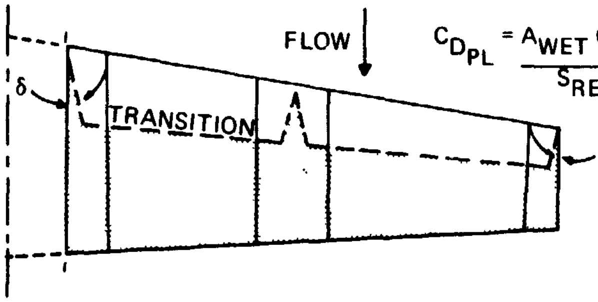
SLST = −20%

TOFL = +30% (Does not meet TOFL constraint)

BLKF = −13%

ASSUMPTIONS USED IN CALCULATING PROFILE DRAG WITH PARTIAL LAMINAR FLOW

- WING SWEEP IS SMALL, <0.14 RAD (<8 DEG)
- FRICTION AND PROFILE DRAG COEFICIENTS CAN BE REPRESENTED BY VALUES DERIVED FROM AVERAGE CHORD
- TRANSITION AT CONSTANT (X/C), EXCEPT FOR WEDGES ORIGINATING AT LE



$$C_{D_{PL}} = \frac{A_{WET}\, C_{F_{PL}}}{S_{REF}} (1 + K_T \cdot K_{XT}) + \text{(TURBULENT WEDGE CORRECTION)}$$

WHERE:

- $C_{F_{PL}}$ = FLAT PLATE SKIN FRICTION COEFFICIENT WITH PART LAMINAR FLOW
- K_T = PROFILE DRAG FACTOR FOR FULLY TURBULENT FLOW
- K_{XT} = CORRECTION TO PROFILE DRAG FACTOR FOR PART LAMINAR FLOW

Figure 122 Advanced Low-Drag Airfoils

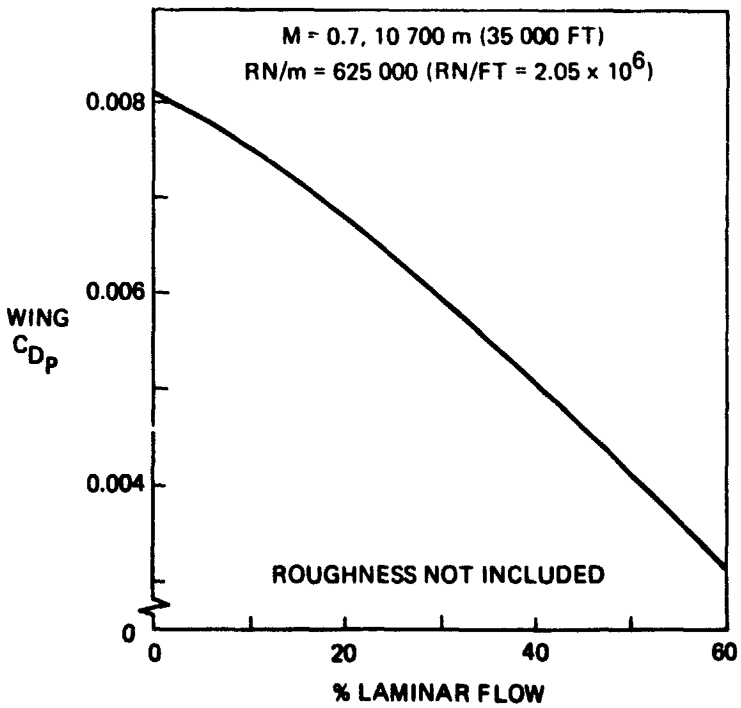


Figure 123 Effect of Laminar Flow on Short-Haul Wing Profile Drag

Constraining the airplane to meet TOFL, 1370 m (4500 ft) at sea level, 32°C (90°F), with the reduction in cruise drag results in smaller airplane improvements relative to sizing to a cruise match point only. The 767-774B sensitivities give a better answer to the effect of NLF than do the cruise sensitivities since the TOFL performance quickly becomes limiting with improvements in cruise drag, thrust, or OEW. The following results show the effect of NLF on a cycled airplane that is TOFL constrained.

TOFL SIZED (W/S is constant, TOFL is constant)

ΔC_{D_C}	=	15%	
TOGW	=	4%	
SW	=	2%	Note: If initial match LW
OEW	=	2%	is below optimum BLKF,
BLKF	=	13%	savings could increase
SLST	=	4%	

The reality of maintaining natural laminar flow on a wing operating frequently at low altitudes should be studied in more detail. Based on previous NLF flight-test studies, it may be that only a small percent of the wing chord may operationally see NLF unless the surfaces can be made to resist perturbances from bugs, scratches, etc. NASA-sponsored on-going studies that are examining various surface coatings could find a solution to this problem.

As expected for the short-haul transport design mission, the results only show small improvements to airplane size, but provide large block fuel savings due to high-speed drag improvements. Low-speed lift and drag improvements and lowering the OEW will have the stronger leverage for reducing overall airplane size and cost. Even with almost full credit for NLF improvements in drag, only a small savings in airplane size is realized. This NLF study does not reflect any additional weight to obtain NLF surface finish requirements.

6.3.3 WING-TIP DEVICES

A survey of wing-tip device concepts has shown potential improvements in low-speed L/D of 5 to 10%. The actual improvements in off-design field performance requires a detailed trade study of structural concepts and analysis, weight increase versus lift-drag improvements with various wing-tip devices, and the resulting cost and performance. The evaluation of the performance payoff must be determined using the same methods outlined in section 6.6 for active-control-system evaluation.

6.4 ADVANCED FLIGHT CONTROLS

6.4.1 LATERAL CONTROL STUDIES–FULL-SPAN FLAPS

One portion of the high-lift trade study was to use full-span flaps with spoilers used as an alternative lateral control system. To implement full-span flaps on the short-haul transport airplane, alternate lateral control surfaces must be used to satisfy the following requirements selected for a 1985 short-haul aircraft.

1. Meet level I MIL-F8785B low-speed roll-response criteria for a medium-weight aircraft of 0.50 rad (30 deg) in 1.8 sec with a roll time constant, t = 1.4 sec
2. Have required aerodynamic linearity and sensitivity compatible with autopilot requirements, especially localizer tracking
3. Have manual reversion capability or use full-time powered actuation (three independent hydraulic systems)
4. Have acceptable trim drag at second-segment-climb engine out trim
5. Have provisions for high-speed lateral trim
6. Have acceptable control actuation mechanism

6.4.2 FULL-SPAN SPOILERS

Full-span spoilers are expected to provide satisfactory roll control, especially for the flaps-down configuration. However, nonlinear lift-loss characteristics with initially low sensitivity will cause autopilot damping and sensitivity problems, particularly in the localizer tracking mode, which may be crucial for future CAT III approach requirements. While spoiler roll control can be a superior method for gust load alleviation, it could be unsatisfactory for roll attitude control near the ground due to overall airplane lift loss. High-speed lateral trim will be unacceptable with spoilers; however, a special trailing-edge flap section can be used for trim as with the Mitsubishi MU-2 airplane. Lateral trim for engine-out control may be restricted by drag requirements during second-segment climb. Spoiler hinge moments must be manageable by the pilot if the airplane is designed with manual reversion capability. Though low-speed, light aircraft have been designed with unpowered spoiler actuation, jet transport aircraft have required powered actuation to meet required deflection angles. Other problems associated with conventional flap spoilers are increased pitching moments, poor high-alpha effectiveness and complex control systems.

New spoiler design, such as those for light aircraft, could solve all these problems but the development could require considerable wind-tunnel and flight testing.

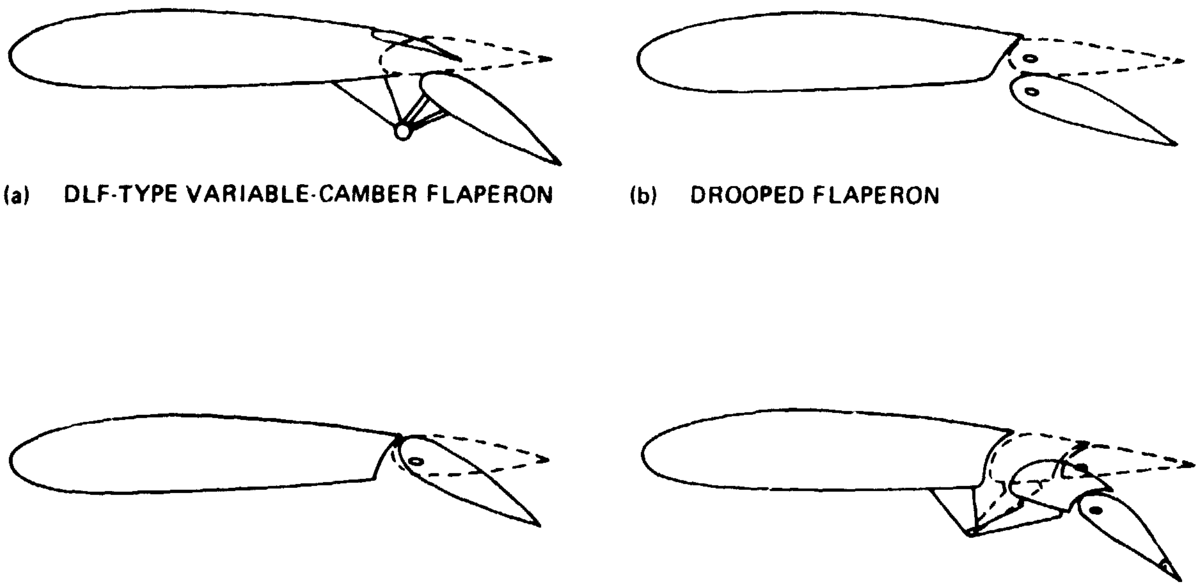
6.4.3 OUTBOARD FLAPERONS

A rough analysis shows that if an outboard dropped aileron (or flaperon) is desired, a single-slotted, fast actuation flap, operated about a nominal 0.3-rad (15 deg) position, will provide enough roll control (along with conventional spoilers) to meet the stated roll criteria.

Several concepts of fast-actuating slotted flaps have been considered:

- A variable-camber trailing-edge flap developed in previous Boeing programs (fig. 124a)
- A "drooped aileron" that exposes a slot in the flaps-down configuration (fig. 124b)
- A plain hinged flap with a contoured nose to create a slot at the higher deflections (fig. 124c)
- Buffalo-type flaperon (fig. 124d)

All would operate as ailerons at a nominal 0.6-rad (15-deg) deflection in the flaps-down configuration and have an overall maximum deflection of +0.6 and −0.35 rad (+35 and −20 deg).



(a) DLF-TYPE VARIABLE-CAMBER FLAPERON (b) DROOPED FLAPERON

(c) PLAIN HINGE CONTOURED NOSE FLAPERON (d) DHC BUFFALO FLAPERON

Figure 124 Candidate Flaperons

Manual reversion for these single-slotted flaperons is not likely, except for the DHC Buffalo type (fig. 124d) where the capability has been demonstrated. Aerodynamic linearity and sensitivity at a nominal 0.3-rad (15-deg) deflection is expected to be satisfactory. The best flaperon concept will depend upon cost, weight, and complexity of the actuating mechanism.

The basepoint airplane plain hinged flap with a contoured nose was selected for simplicity and lowest cost. This flaperon does not have manual reversion capability: therefore, the airplane has triple-redundant-powered [illegible]

6.4.4 VEE-TAIL

To lower manufacturing costs, a vee-tail-empennage configuration was considered (fig. 125). A brief tail-sizing analysis was conducted for replacing the conventional tail of the 767-837 configuration with a vee tail. Results indicated that a vee-type tail may be installed with an overall empennage area of 80% of the conventional tail area.

The horizontal tail (V_H = 1.3) of the advanced short-haul transport airplane was sized by takeoff rotation and dive stability using a nonflight critical SAS and a trimming tail. The vertical tail was sized by low-speed, engine-out control. The vee tail was sized to meet the same levels of stability and control as the conventional tail. The vee tail used in the analysis has the same elevator chord ratio but a slightly higher aspect ratio than the conventional tail.

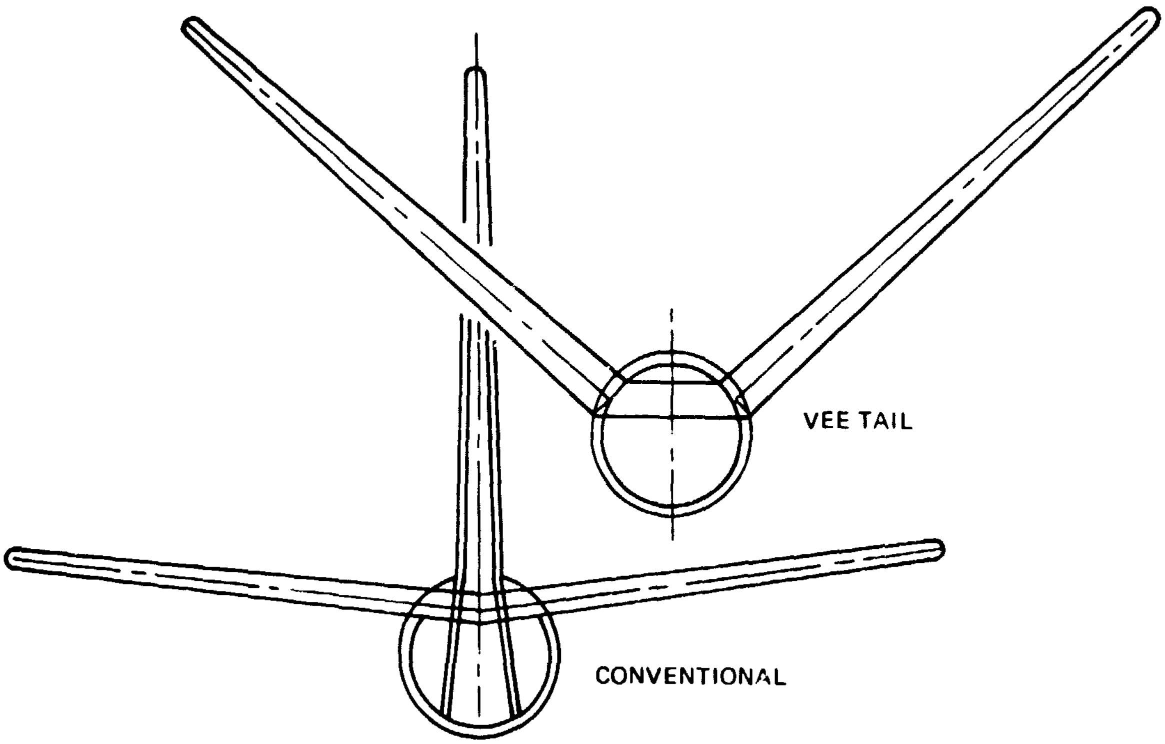


Figure 125 Tail Comparison

The major differences of a vee tail over a conventional tail are:

- A smaller influence from downwash due to a higher effective tail plane
- A wing vortex sidewash influence on a vee tail that decreases the downwash
- Decreased side force effectiveness due to interfering pressure fields
- Loss of longitudinal stability with the $COS^2\ \Gamma$ (dihedral angle) and directional stability with the $SIN^2\ \Gamma$
- Loss of longitudinal control with the $COS\ \Gamma$ and directional control with the $SIN\ \Gamma$

Figure 126 is a tail-sizing chart used to select the vee-tail area as a function of tail dihedral angle. The two most critical tail-sizing factors are pitch and directional control required for takeoff rotation with an engine failed.

The results show that the vee tail should have a dihedral angle of approximately 0.75 rad (42-deg) and a tail area approximately 80% of the conventional tail area of the 767-837 configuration, however, a vee tail may not show an area reduction compared to a T-tail configurations. Because it takes both control surfaces of the vee tail to yaw and pitch the airplane in an uncoupled manner, loss of any one control surface is unacceptable. Consequently, lower control-system reliability compared to that of a conventional tail would result for the same degree of redundancy of surface actuation. A more complex control system will be required for a vee tail configuration. If the 767-837 airplane has an advanced flight control system, programming of the fly-by-wire digital computer may be included at no additional cost. A conventional control system will require a mechanical mixing box for elevator-rudder operation.

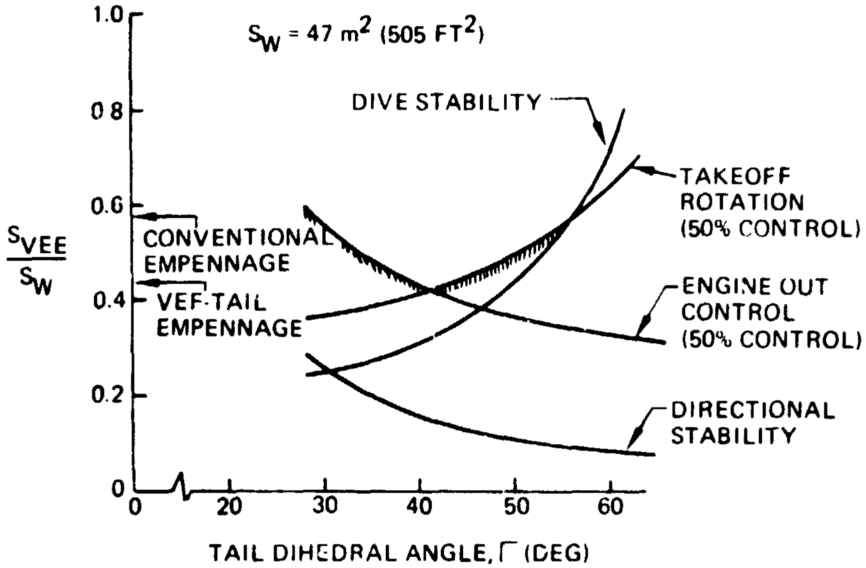


Figure 126 Vee Tail vs Conventional Empennage Trade Study

The relative cost of a vee-tail configuration is compared to the baseline tail configuration in figure 127. Both tail configurations were assumed to have bonded-aluminum honeycomb construction and identical left and right components. With the 20% reduction in tail area, this resulted in a part count reduction of approximately 60% for the vee tail and a relative cost savings of approximately 20% relative to the baseline tail configuration. More detailed study is required to minimize the cost of integrating with flight controls before vee-tails could be incorporated.

6.5 ADVANCED PROPULSION

The propulsion system is the second most important factor in low-speed/high-speed performance matching and the key to low-maintenance costs. The specific propulsion items addressed in this section are the advantages of an automatic power reserve, the effect of nacelle duct length on design performance, the effect of advanced turboprop (propfan) installation on performance, and the prospects for reducing the initial and maintenance costs of a turbofan engine through inovative design and advanced technology.

6.5.1 AUTOMATIC POWER RESERVE (APR)

The thrust performance of a CF-34 engine, with and without an automatic power reserve rating of 10%, is shown in figure 128. Note that this reset position does not exceed currently certified engine-operating limits, but results in approximately a 20% improvement in TOFL performance for sea level 32°C (90°F) conditions. A design selection chart showing this effect of APR on the baseline airplane configuration is shown in figure 129. The use of APR allows the airplane to be matched to a smaller engine (less cost), and for a given engine size, significant improvements in the off-design takeoff performance are available (e.g., Denver hot day). All of the advanced-technology trade study airplanes have APR included.

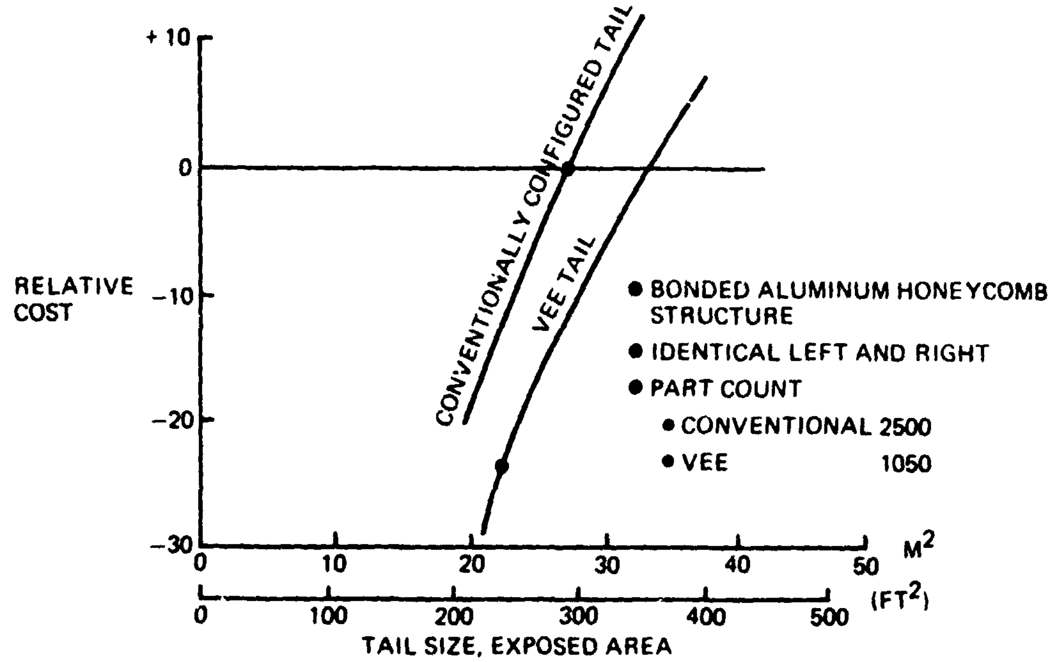


Figure 127 Vee Tail vs Conventional Tail Cost Trade Study

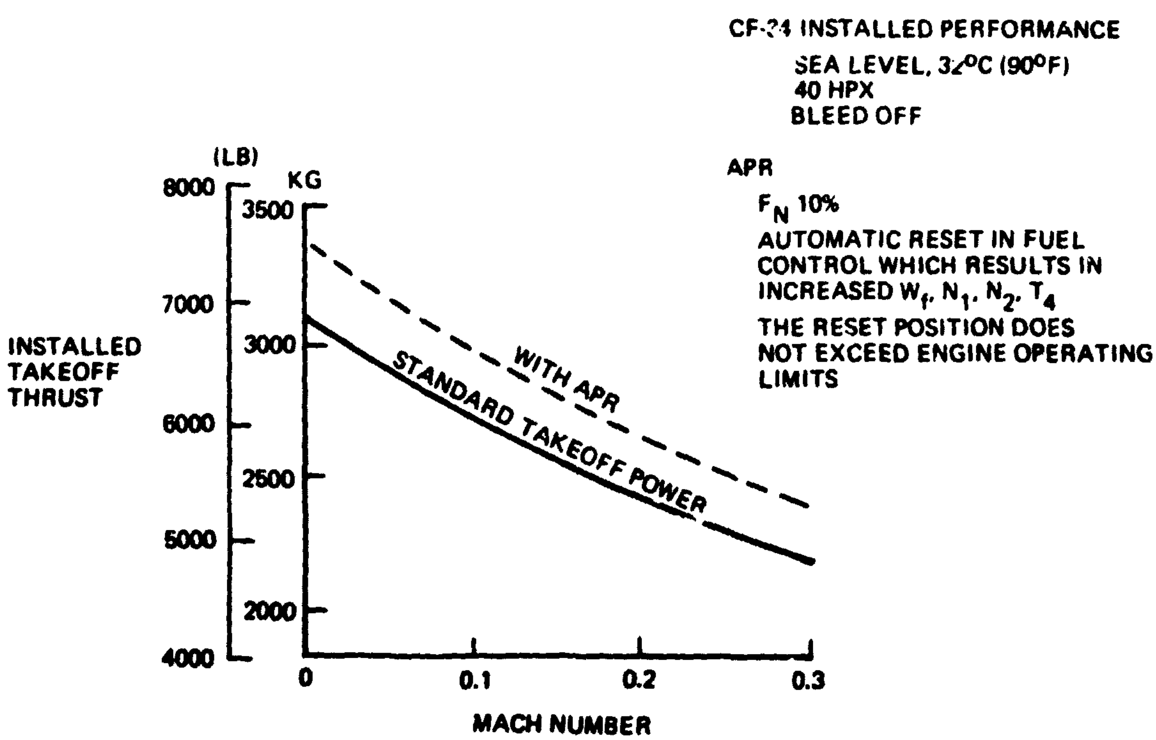


Figure 128 CF-34 Engine Thrust With and Without Automatic Power Reserve

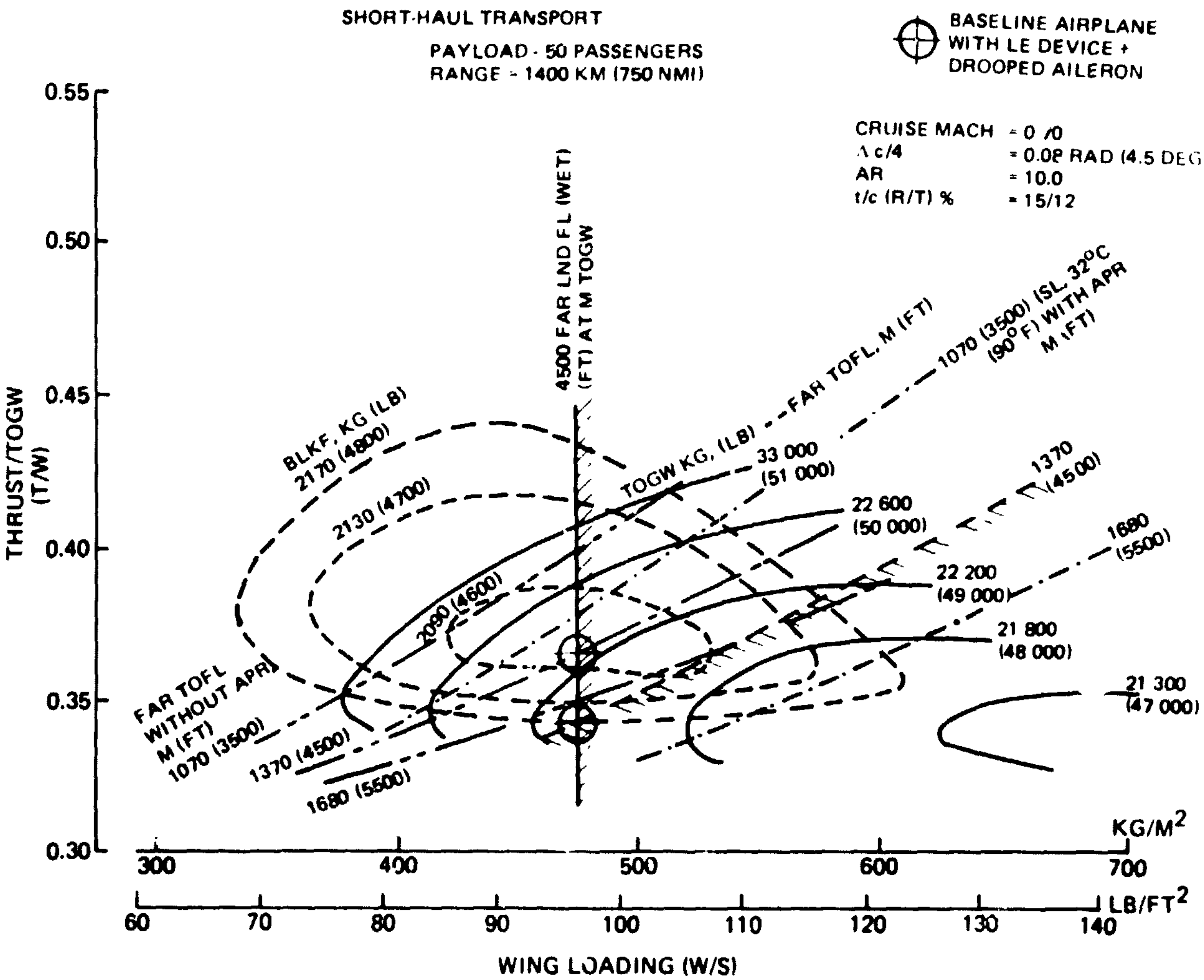


Figure 129 Effect of Automatic Power Reserve Design Selection

6.5.2 ONE-HALF-DUCT VERSUS THREE-QUARTER-DUCT NACELLE

The uncycled results from the study of 1/2- (short) versus 3/4-length-duct nacelle used on a short-haul airplane is discussed in this section. The short nacelle geometry is similar to the S-3A nacelle but with peripheral lining. A comparison picture of the two types of nacelles is shown in figure 130.

One-half Duct–The 1/2-duct nacelle has an inlet L/D of 0.5 and an aft fan duct extending to 1/2 the total nacelle length. Fully lined, the inlet has 25 cm (10 in.) of 10-cm (4-in.) deep buzz-saw lining and 19 cm (7.5 in.) of 12-mm (0.4-in.) fan-tone lining. The aft fan duct has 57 cm (22.5 in.) of peripheral lining.

Three-quarter Duct–The 3/4-duct nacelle shown in figure 130 has an inlet L/D of 0.5 and an aft fan duct extending to 3/4 of the total nacelle length. Fully lined, the long-duct nacelle has 152.4 cm (60 in.) of aft fan peripheral liner and the same 44.45 cm (17.5 in.) of inlet liner as the 1/2-duct nacelle.

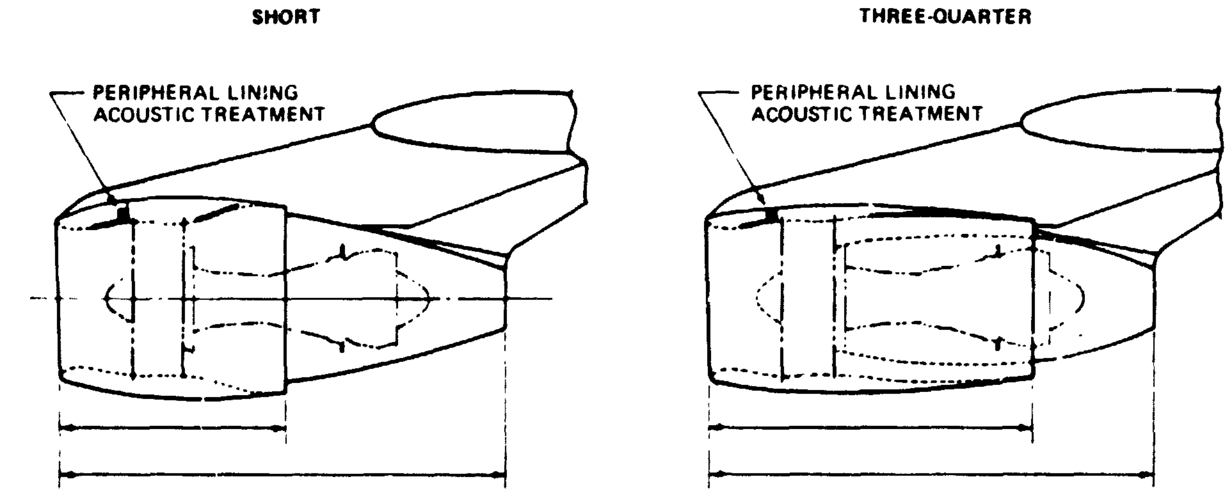


Figure 130. Nacelle/Strut Configuration for Fan-Duct-Length Study

The fully lined, 3/4-length duct nacelle is 2.5 EPNdB quieter than the fully lined 1/2-duct nacelle. However, both configurations meet FAR 36-X, -Y, -Z. As a result, there is a trade possibility between the noise reduction of a 3/4-length-duct nacelle and the lighter weight of a 1/2-duct nacelle.

The weight analysis was based on a propulsion installation using the CF-34 with a 38.8-kN (8732-lb) SLST rating. A weight analysis shows that the 1/2-duct is approximately 132 kg (290 lb) per installation lighter than the 3/4-duct configuration. This weight differential is based on geometry changes only and assumes a single layer of acoustical treatment (therefore, a constant noise level is not maintained).

The community noise levels are shown in table 19. Airplane noise estimates indicate less than 1.0 EPNdB effect on engine noise estimate (approach only).

Table 19 Community-Noise Levels, ½-Duct versus ¾-Duct Peripheral-Lined Nacelles

	Altitude		V_{TAS}		Power
	m	(ft)	km/hr	(kt)	%
Takeoff	722	2370	217	135	100
Sideline	—	—	—	—	100
Approach	113	370	219	136	29

	½ duct lined, EPNdB	¾ duct, lined, EPNdB	FAR 36-X, -Y, -Z EPNdB
Takeoff	85 [1]	82.5	89
Sideline	86 [1]	83.0	94
Approach	93 [1]	90.5	98

Notes:

- Model 767-774B
  - No leading edge device
  - S_W = 56 m^2 (606 ft^2)
- Two scaled engines (with CF-34 technology) at 38.8 kN (8730 lb) SLST
- Predicted values nominal
- Design tolerance required (85% Confidence Level)

[1] One-half-duct nacelle noise levels are compared at the same performance conditions as the ¾-duct nacelles; only the ¾-duct represents cycled airplane performance

6.5.3 ADVANCED TURBOPROP (PROPFAN) PROPULSION

An advanced scaled version of the General Electric T-64 turboshaft engine was selected for the turboprop trade study. A cursory analysis is of an advanced propeller with 183-m/sec (600-ft/sec) radial tip speed has shown that a cruise disc loading of 1.42 ESkW/m^2 (SHP/ft^2 = 20.5) is a good compromise point for minimum OEW, TOGW and blockfuel. The 600-ft/sec tip speed results in a subsonic (barely) total helical tip speed which should greatly reduce interior and community noise. Using 1.42-1.42-kW/m^2 (20.5-ESHP/ft^2) power loading and sizing for the same thrust level at initial cruise as the aerodynamic trade study airplane (model 767-837) results in a 3.35-m (11-ft) diameter propeller on a 4370 ESkW (5860 ESHP) uninstalled engine. Three views of the advanced-turboprop trade study airplane (model 767-838) are shown in figure 131.

Details of the nacelle installation are shown in figure 132.

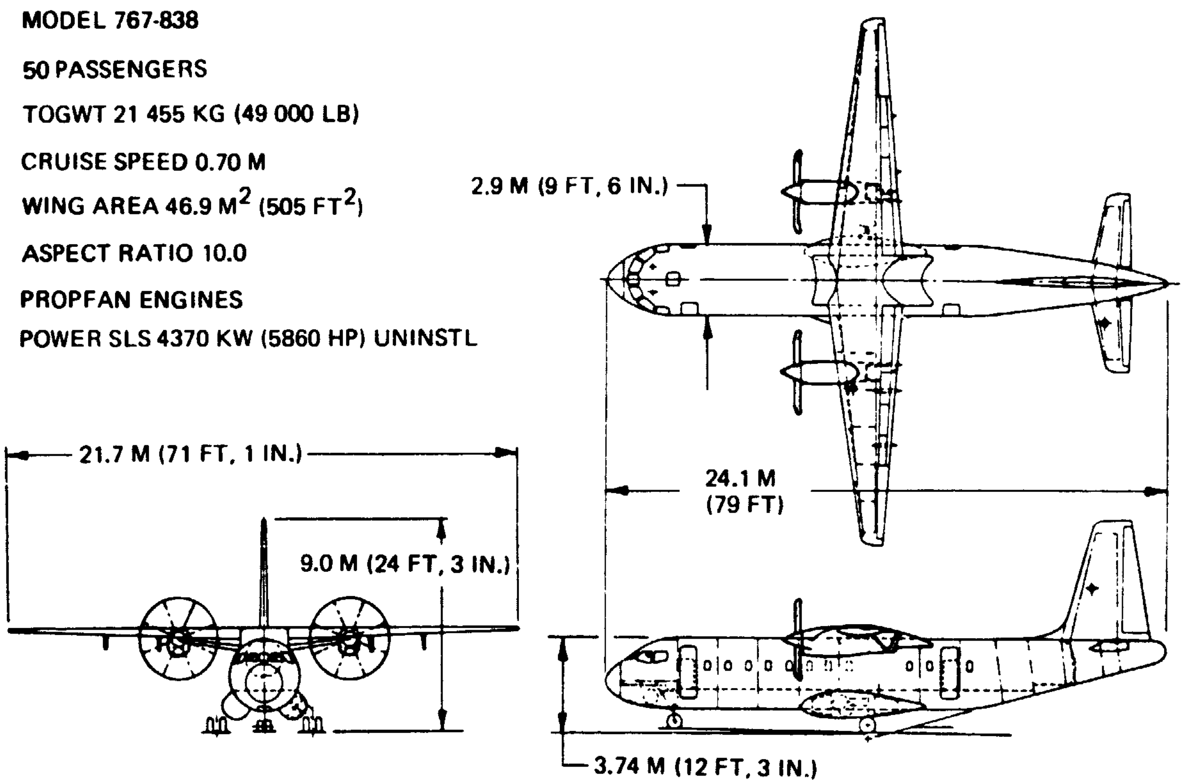


Figure 131 Advanced Technology Turboprop Airplane, Model 767-838

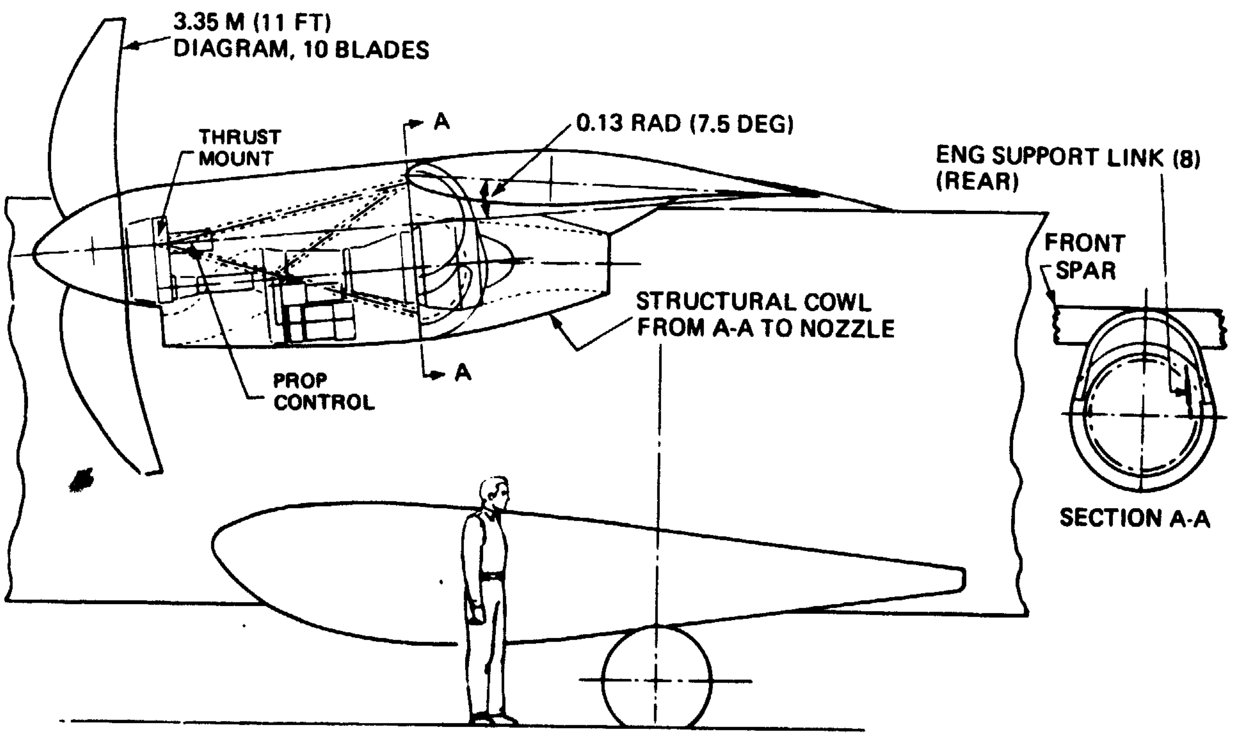


Figure 132 Propfan Nacelle Installation

6.5.3.1 Study Ground Rules

The ground rules selected for conducting the advanced turboprop study are given below. These rules were designed for a sensitivity study, not a detailed, total-airplane design and sizing exercise.

1. Engine sized to model 767-837 turbofan cruise F_N
2. 183-m/sec (600-ft/sec) radial tip speed
   - Helical tip speed ~ 0.95 Mach
   - Airplane cruise Mach = 0.70
3. Weight installation of turboprop
4. Airplane not rebalanced for turboprop installation
5. Tail size corrected for engine-out control and stability based on results of previous Boeing prop-fan study (ref. 4)
6. Interior noise level a fall out
7. Arbitrary penalty assessed for sonic fatigue, using engineering judgement (essentially zero weight penalty
8. Fuselage modified to be flyable with loss of propeller blade through cabin (approximately 100 kg (200 lb) of additional tear stoppers)
9. Leading-edge up for takeoff
10. Takeoff field length a fallout
11. No community noise constraints

6.5.3.2 Advanced Turboprop Installation Weight

The engine weight is based on T64 engine weight of reference 5 and scaled by a weight scaler of 1.15 obtained from reference 6. The scaled T64 turboshaft engine weight is:

$$W_{ENG\ DRY} = 330 \left(\frac{SLS\ ESkW}{3266}\right)^{1.15}, \text{kg or} = 720 \left(\frac{SLS\ ESHP}{4380}\right)^{1.15}, \text{lb}$$

To meet design conditions, a cruise thrust of 7.544 kN (1696 lb) at 10 670 m (35 000 ft) and 0.7 Mach is required. This results in SLS uninstalled shaft power = 4370 ESkW (5860 ESHP) and a dry-engine weight of 457 kg (1006 lb) per engine.

The bare gear box is sized to maximum torque transmitted, based on reference 7, and its weight is:

$$W_{GB} = 0.0268\ (SLS\ ESkW)$$

This results in a bare gear box weight of 210 kg (464 lb) for the 4370 ESkW (5860 ESHP) engine.

In addition to the bare weight, the complete gear-box weight includes the heat exchanger, oil cooler, oil supply system, engine-to-gear-box shaft, and support structure.

The propeller is a Hamilton Standard advanced-technology eight-bladed propeller, whose weight varies with engine size. Based on reference 7, the equation is:

$$W_{PROP}\ 0.011\ (ESkW) + 220$$

This results in a propeller weight of 305 kg (675 lb) for the 4370 ESkW (5860 ESHP) engine.

These weights are for a 4370 ESkW (5860 ESHP) SLS engine with a takeoff-power disc loading ($ESHP/D^2$) of 495 $ESkW/m^2$ (61.7 ESHP/sq ft). Scaling is limited to ±25% of takeoff-power.

6.5.3.3 Changes in Airplane Systems Required because of Turboprop Engines

Installation of turboprop engines influences systems configuration because of extremely limited engine bleed air availability. Engine shaft power extraction required for the secondary power system is presented below.

Differences in systems from the baseline system used on the turbofan engine short-haul airplane are as follows:

- Engine shaft-driven compressor used as a source of high-pressure cabin air supply
- Electric de-icing system used for removing ice from the propellers
- Engine inlets anti-iced with engine bleed air
- Wing leading edges either de-iced with electric de-icing system or with pneumatic-boot de-icing system

Engine shaft power extraction and air supply to the systems are tabulated in table 20. Normally, turboprop engines maintain constant N_2 speed throughout the power range. Therefore, the shaft driven compressor is powered from the engine N_2 rotor with a single-speed gear box.

The engine shaft driven compressor consists of multi-stage axial-flow compresso[illegible] -sensing venturi, surge bleed valve, and variable-position inlet-guide vane. The compressor is d[illegible]d for maximum pressure ratio of 4.35.

Ram air is throttled through a variable-position inlet-guide vane at low altitude to minimize flow through the compressor and, hence, minimize the engine power extraction.

The compressor is powered from a single power train capable of being disconnected but not automatically re-engaged to the accessor drive systems during operation at engine speed.

The engine is equipped with an eight-bladed propeller. Electric heating elements are installed on the leading edge of the blades to remove any ice formed on the propeller. A cyclic de-icing method is applied to keep electrical power demand to a minimum with four blades de-iced at one time to prevent any propeller off-balance.

Table 20 Short-Haul Transport Secondary Power System Requirement for Turboprop Engine

SYSTEM	SHAFT-DRIVEN COMPRESSOR AIRFLOW		ENGINE BLEED AIRFLOW		ENGINE POWER EXTRACTION
	KILOGRAMS/ MINUTE	(POUNDS/ MINUTE)	KILOGRAMS/ MINUTE	(POUNDS/ MINUTE)	
• BASIC UTILITY ELECTRICAL LOAD					40 KVA
• PROPELLER ELECTRIC DE-ICING LOAD					12 KW
• WING ELECTRIC DE-ICING LOAD					43 KW
• ENGINE INLET ANTI-ICING					
• SEA LEVEL			15	32	
• 522 METERS (15,000 FEET)			12	26	
• SHAFT-DRIVEN COMPRESSOR					
• SEA LEVEL	50	(110)			242 HP
• 522 METERS (15 000 FEET)	50	(110)			220 HP
• 1218 METERS (35 000 FEET)	26	(58)			104 HP

Note: Units in total airplane load.

6.5.3.4 Turboprop Airplane Characteristics

The airplane characteristic most changed when switching from turbofan to turboprop propulsion is engine TSFC. Figure 133 shows the TSFC reduction with the advanced turboprop to be 23% during climb and 14% during cruise.

Table 21 shows the advanced turboprop installation to have a relative weight increase of approximately 470 kg (1040 lb) and a relative drag increase of 16 counts (4%).

The changes in performance characteristics caused by the increments in weight, drag, and TSFC are shown in table 22. The significant changes are the 3% increase in OEW and the large decreases of 15 and 28%, respectively, in block fuel and fuel reserves.

- BASED UPON PRELIMINARY PROPFAN DATA AT V_{TIP} = 180 M/SEC (600 FT/SEC)
- UPDATED CF-34 TURBOFAN DATA NOT INCORPORATED
- TURBO-SHAFT ENGINE DATA BASED ON T64-415 DATA UNSCALED

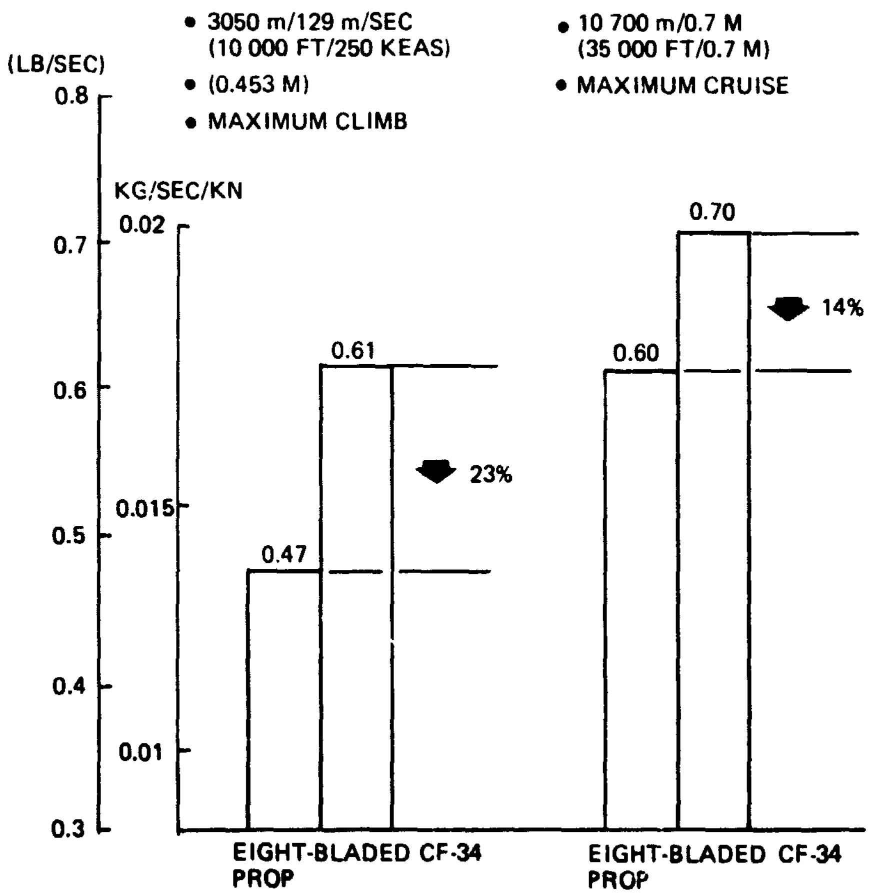


Figure 133 Preliminary Evaluation of Turbofan vs Propfan Comparison

Table 21 Installation Effects of a Turbofan Propulsion System

WEIGHT	kg	lb
• Propulsion SHP = 5860 HP vs TSLS = 4060 kg (8950 lb)		
• Engine and controls	– 671	– 1480
• Thrust Reverser (fan only)	– 222	– 490
• Propeller, 3.4 m (11 ft) diameter	+ 612	+ 1350
• Gear box	+ 580	+ 1280
• Structure		
• Wing, Body, and horizontal and vertical tail	+ 227	+ 500
• Nacelle and strut	– 281	– 620
• Fixed equipment plus standard and operational items	+ 227	+ 500
	+ 472	+ 1040

$\boxed{\Delta OEW \sim +3 \text{ to } 4\%}$ • No weight allowance for cabin noise attenuation

DRAG

ΔC_D tail size	= 0.0006
ΔC_D nacelle	= 0.00065
ΔC_D scrubbing (wing plus nacelle)	= 0.0003
	0.00155

$\Delta C_{D_{cruise}} \cong +4\%$

$\Delta C_{L_{S(\text{maximum flaps})}} \cong -5\%$

• No allowance for propeller swirl interference drag

Table 22 Performance Summary

		TURBOFAN 767-837 (BASE)	TURBOPROP 767-838
	• Payload, passenger/kg (passenger/lb)	50/4500 (50/10 000)	50/4500 (50/10 000
	• Range, km (nmi)	1400 (750)	1400 (750)
	• Cruise mach	0.70	0.70
	• Wing area, m^2 (ft^2)	47 (505)	47 (505)
WEIGHTS	• TOGW, kg (lb)	22 200 (49 000)	– 0.7%
	• OEW, kg (lb)	14 560 (32 100)	+ 3.2%
	• Mission landing weight, kg (lb)	20 200 (44 550)	+ 0.8%
SIZE	• Horizontal tail area, m^2 (ft^2)	10 (110)	+ 20%
	• Vertical tail area, m^2 (ft^2)	14 (147)	+ 13%
	• TSLS, kN (lb)	39.8 (8950)	NA
	• SHP diameter, kW/m (hp/ft)	NA	4370/13.0 (5860/11.0)
	• Cruise thrust, $F_N \sim$ kg ($F_N \sim$ lb) at 10 700 m (35 000 ft), M = 0.70	770 (1700)	770 (1700)
PERFORMANCE	• TOFL, m (ft)	1150 (3800)	≤ 1150 (≤ 3800)
	• V_{APP} at TOGW, m/sec (keas)	60.7 (118)	+ 2%
	• Block fuel, kg (lb)	2080 (4580)	1770 (3900), – 15%
	• Reserves, kg (lb)	1110 (2450)	800 (1760), – 28%

- No weight allowance for cabin noise attenuation
- No allowance for propeller swirl interference drag

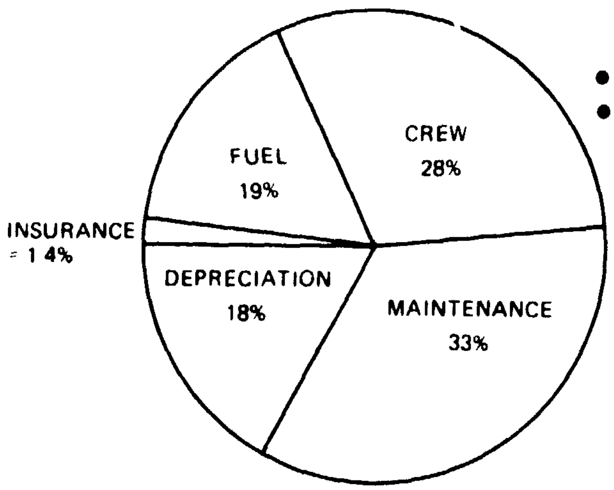
6.5.4 REDUCTION OF PROPULSION-RELATED COSTS

Economic studies (fig. 134) using the basepoint airplane (model 767-774B) have shown maintenance costs to be 33% of the direct operating costs, and engine maintenance to be 53% of total maintenance (table 23).

Therefore, engine maintenance accounts for 18% of DOC, making it as important a factor in airplane economics as block fuel or initial airplane price, the two major considerations in this study.

Engine maintenance can be reduced by increasing the time between overhauls and the ease of access. These techniques for reducing engine maintenance are primarily the responsibility of the engine manufacturer.

Turboprop engines have had a history of high maintenance costs, but recent data (ref. 8) indicate that an advanced turboprop system might have maintenance costs competitive with a comparable high-bypass turbofan.



- 767-774B BASELINE AIRPLANE
- 1977 RULES, 280 KM (150 NMI) TRIP

NOTES ON REDUCING OPERATING COSTS

1. A REDUCTION IN MAINTENANCE COST HAS ALMOST TWICE THE IMPACT OF THE OTHER ELEMENTS INFLUENCED BY THE MANUFACTURER.
2. IMPROVING RELIABILITY AND THROUGH-STOP CAPABILITIES WILL INCREASE UTILIZATION AND THUS DECREASE DEPRECIATION PER TRIP.

Figure 134 Direct-Operating-Cost Elements

Table 23 Maintenance Cost Elements—767-774B Baseline Airplane

ELEMENT	PERCENT OF TOTAL	POSSIBLE TECHNOLOGICAL IMPROVEMENTS
AIRFRAME		
• MATERIALS	12.0%	GEAR, BRAKES AND TIRES AVIONICS RELIABILITY, MAINTAINABILITY
DIRECT MAINTENANCE LABOR	11.8	EASE OF ACCESS—MODULARIZATION
• INDIRECT MAINTENANCE (BURDEN)	23.6	
ENGINE		
• MATERIALS	23.0	BLADE TECHNOLOGY INCREASED TIME BETWEEN OVERHAUL
• DIRECT MAINTENANCE LABOR	9.9	EASE OF ACCESS
• INDIRECT MAINTENANCE (BURDEN)	19.7	
	100.0%	

Note: 1977 rules—81-kilometer (150 nmi) trip.

6.6 ADVANCED RIDE CONTROL AND LOAD ALLEVIATION

6.6.1 AIRPLANE RIDE CONTROL

The baseline short-haul configuration (767-774A), with a cruise wing loading of about 3100 N/sq m (65 psf) would undoubtedly have an uncomfortable vertical-ride quality in quite moderate turbulence conditions. When compared with a 707 at cruise meeting the same vertical gust, the resulting vertical g's would be about 50% larger for this airplane.

Two methods are available to improve the vertical ride quality of the short-haul transport:

1. Configuration change
   - Increase wing loading (major effect)
   - Decrease wing aspect ratio (minor)
   - Increase wing sweep (minor)
   - Increase wing flexibility (minor)
2. Control system addition
   - Ride control system added to existing FCS

These two methods were examined for the short-haul transport and provided the following conclusions:

1. A configuration change will provide ride quality that is no better than present-day jet transports.
2. A ride-control system can provide a quality appreciably improved over present-day jet transports.

Figure 135 shows the vertical acceleration experienced in a 1-8 m/sec (6 fps) RMS vertical gust for a number of airplanes including the short-haul baseline 767-774A; the passenger comfort ratings are from references 9 and 10. The reference vertical gust chosen at 1.8 m/sec (6 fps) RMS is based on statistical data available in reference 9, which indicate that this gust could be encountered on about 1 in 100 flights up to 3048-m (10 000-ft) altitude and about 1 in 10 flights below 610 m (2000 ft); in a similar vein the Wichita report (ref. 11) used a 2-m/sec (7-fps) RMS gust with a quoted exceedance probability of one percent. Figure 135 indicates that the short-haul transport has a vertical ride quality, in terms of vertical g's, slightly higher than current airplanes, resulting in a slightly increased possibility of discomfort and sickness for the short-haul passenger.

The vertical ride acceleration can be improved by changing the wing planform as indicated in figure 136; aspect ratio has a small effect whereas wing loading (W/S) has a major influence. As shown, the short-haul airplane can be made comparable to the 707 by increasing the wing loading from 320 to 450 kg/m^2 (65 to 90 psf). Other influences not shown, which change wing-lift curve slope, as does aspect ratio, are wing sweep and wing flexibility. The Wichita study (ref. 11) goal of 0.03-g RMS vertical acceleration is not achievable with practical designs of wing platform and wing loading.

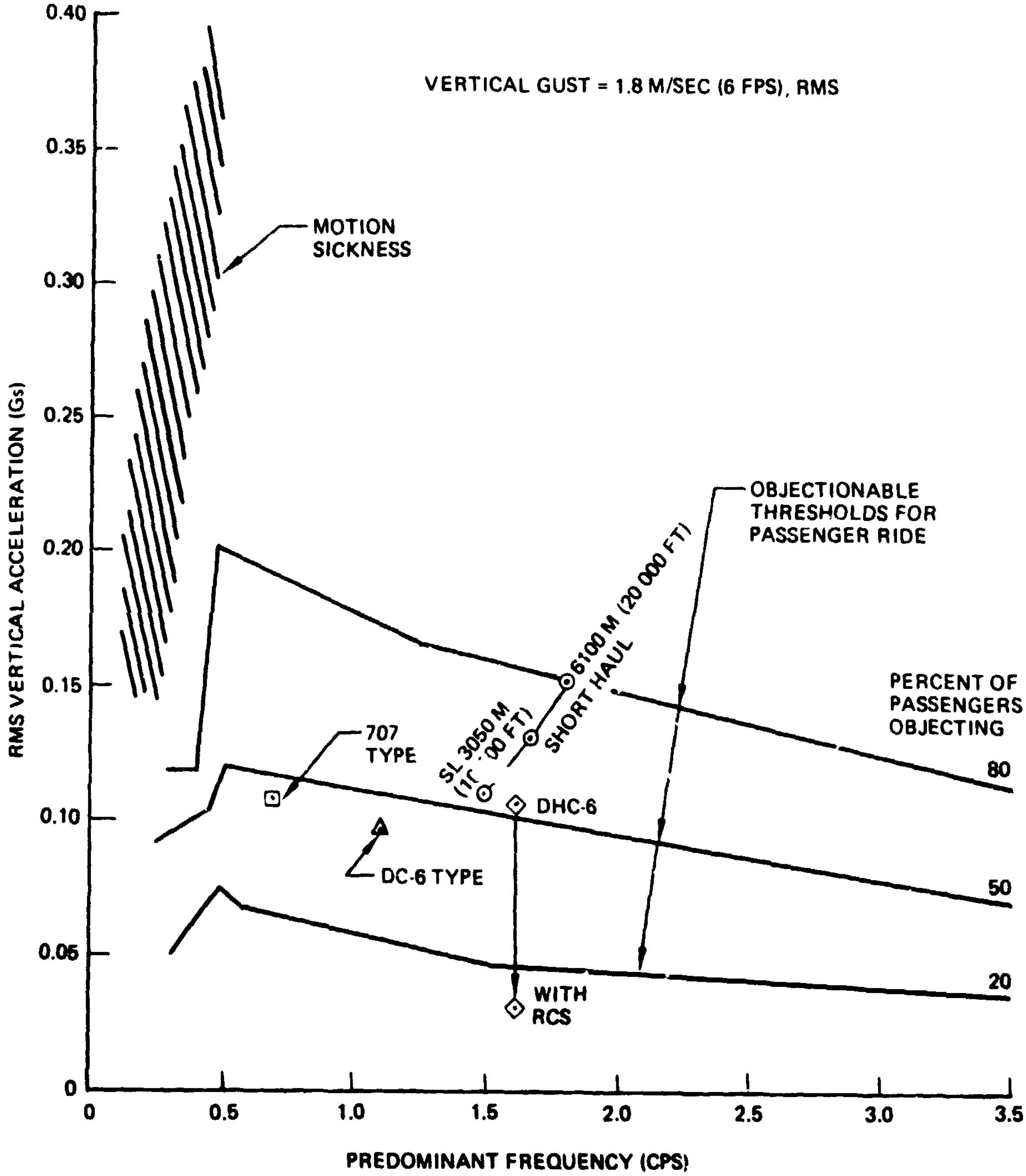


Figure 135 Vertical Ride Quality at Cruise Flight

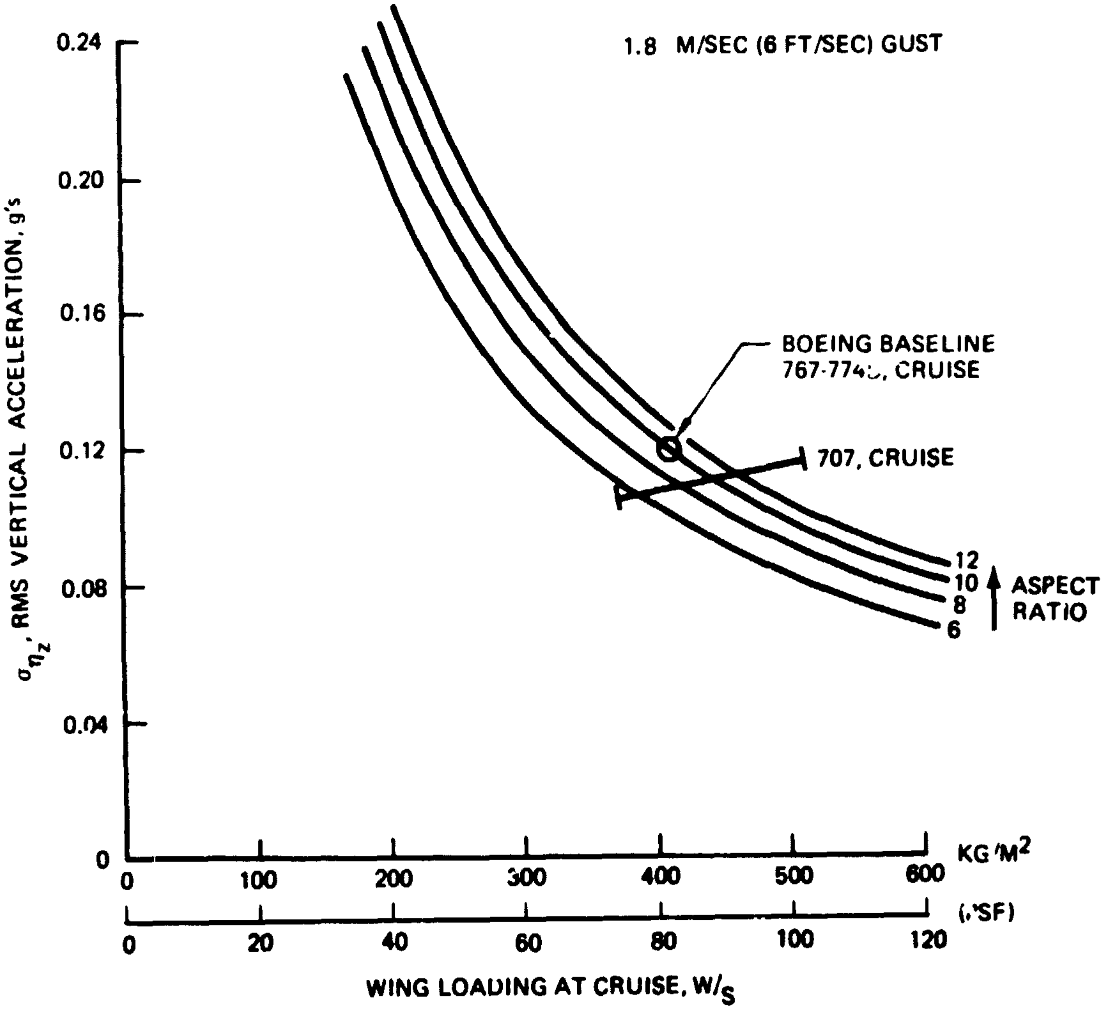


Figure 136 Ride-Quality Trade Study—Vertical-Ride Quality with Design Vertical Gust

The addition of a ride control system (RCS) can show a considerable reduction in the vertical g's of a short-haul transport. Figure 137 is replotted from reference 11 and shows the vertical acceleration reduction with RCS as a function of vertical gust velocity encountered at cruise conditions (the study airplane is the deHavilland Twin Otter, 20-passenger, short-haul transport with characteristics similar to the present study configurations . The ride-control system proposed in the Wichita study can be adapted for the short-haul airplane. Vertical acceleration feedback from accelerometers mounted near the c.g. will deflect ailerons and spoilers symmetrically to cause a direct lift change and compensate for the lift change caused by the gust. Pitch rate feedback from either a rate gyro or an accelerometer will deflect elevators to maintain trim and compensate the pitching moment increments caused by the gust and the wing-control surfaces. This system also is shown in figure 137.

6.6.2 GUST LOAD ALLEVIATION

Active control systems can be used to reduce structural material requirements and consequently airplane OEW. These weight reductions can occur as a result of the application of a maneuver and gust load alleviation system, a fatigue reduction system, and a flutter suppression system. The magnitude of the payoff for these systems is sensitive to both the configuration characteristics and the design mission.

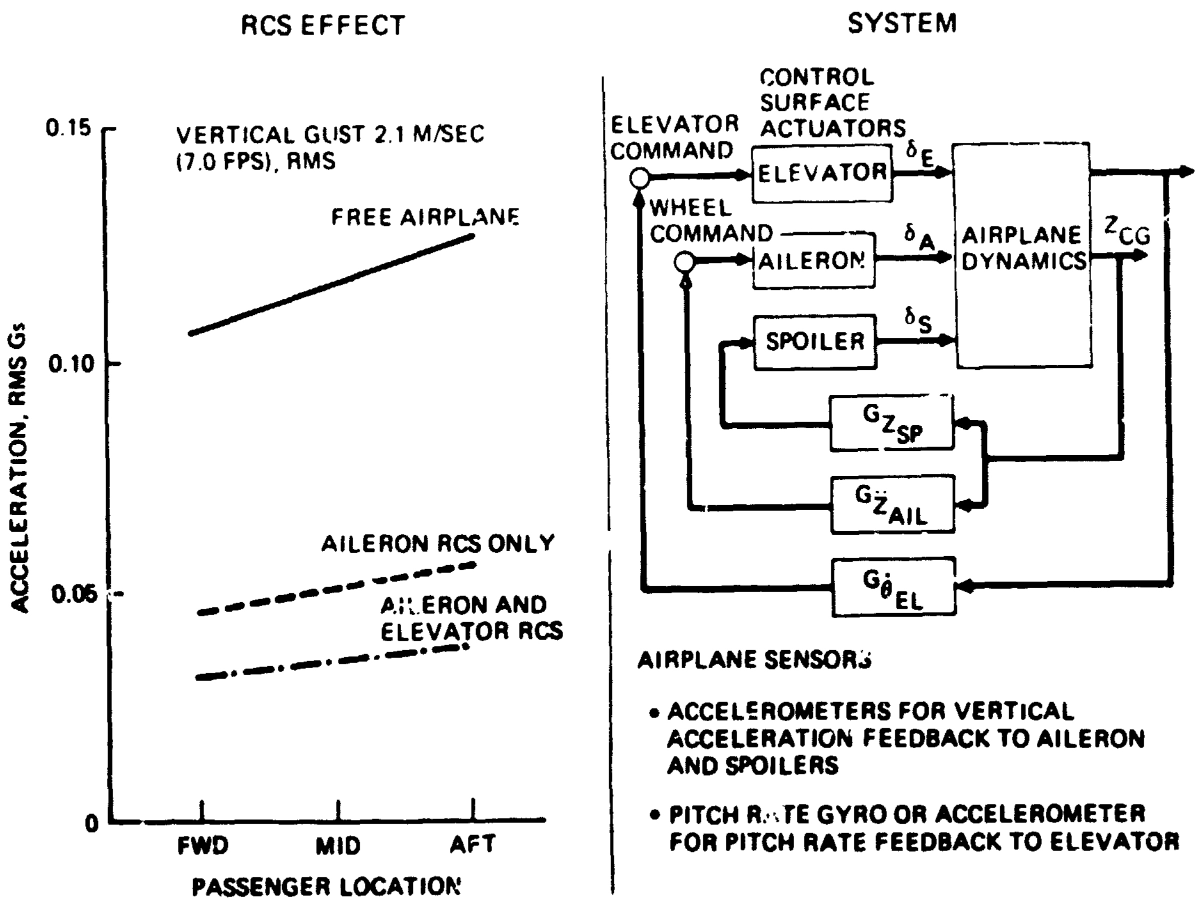


Figure 137 Ride Control System

Load alleviation is accomplished by automatically deflecting a control surface to produce an inboard shift of wing loading at maximum design conditions. Calculation of the weight payoff for such a system must be supported by aeroelastic analysis. The control-surface effectiveness is dependent upon the wing stiffness. A honeycomb wing has relatively more material effective in torsion than does conventional stiffened skin type of construction. This tends to improve the control-surface effectiveness at high speed and, thus, makes it easier to apply maneuver load alleviation to the configuration. The fatigue penalty of a strength-designed wing that includes the benefit of maneuver load alleviation must be determined. If this penalty is sufficient, a fatigue reduction system reducing the structural damage due to gusts could be considered. However, configurations with body-mounted landing gear are historically more sensitive to ground-air-ground and taxi cycles than to gust cycles. This may limit the payoff of a fatigue-reduction system for the short-haul configuration.

Finally, the flutter penalty must be established. This penalty depends on the wing aspect ratio, engine location, and strut stiffness, as well as wing stiffness. The high ratio of torsion stiffness to bending stiffness of honeycomb may be advantageous in minimizing the flutter penalty.

6.7 ADVANCED SYSTEMS

Some of the advanced technology items presented here [e.g., the all-electric system airplane, actuator package (IAP) and rotary hingeline actuator, internal engine generator (IEG)] are still in the early development stage. These items will require additional hardware development before they can be used on any commercial airplanes.

6.7.1 HYDRAULIC SYSTEM

An IAP or rotary hingeline actuator system may be used for actuating primary-flight-control surfaces such as spoilers, ailerons, rudder, elevators, landing gears, and brakes. An electric motor drive may be used for actuation of [illegible] the flap extension rate is relatively slow.

In contrast to conventional hydraulic systems that transmit power in hydraulic lines from engine mounted pumps, the all-electric system uses electrical power generated at the engines and transmits the power by wire to electric motors that are integrated with self-contained pumps or are directly connected to structure and flight control systems (fig. 138). Potential benefits of these systems are enhanced reliability, weight reduction, easier maintenance, and reduced transmission line loss

Figure 139 shows an example of the servopump-type IAP system. A continuous-duty electric motor powers a hydraulic and an auxiliary pump that are integrated into one unit. Figure 140 compares two types of IAP systems with a conventional hydraulic system used on the C-14 airplane. Figure 141 shows an example of the hingeline actuator.

Both the IAP and hingeline actuator have the advantage of allowing removal of a unit from the airplane by means of an electrical quick-disconnect. The IAP system eliminates the problems of hydraulic system contamination and fluid loss due to leakage from hydraulic couplings. However, considerably more complex pumps are used on each IAP, which would increase initial component cost. The overall cost comparison with a conventional hydraulic system will require detailed investigation and is recommended as a possible follow-on study.

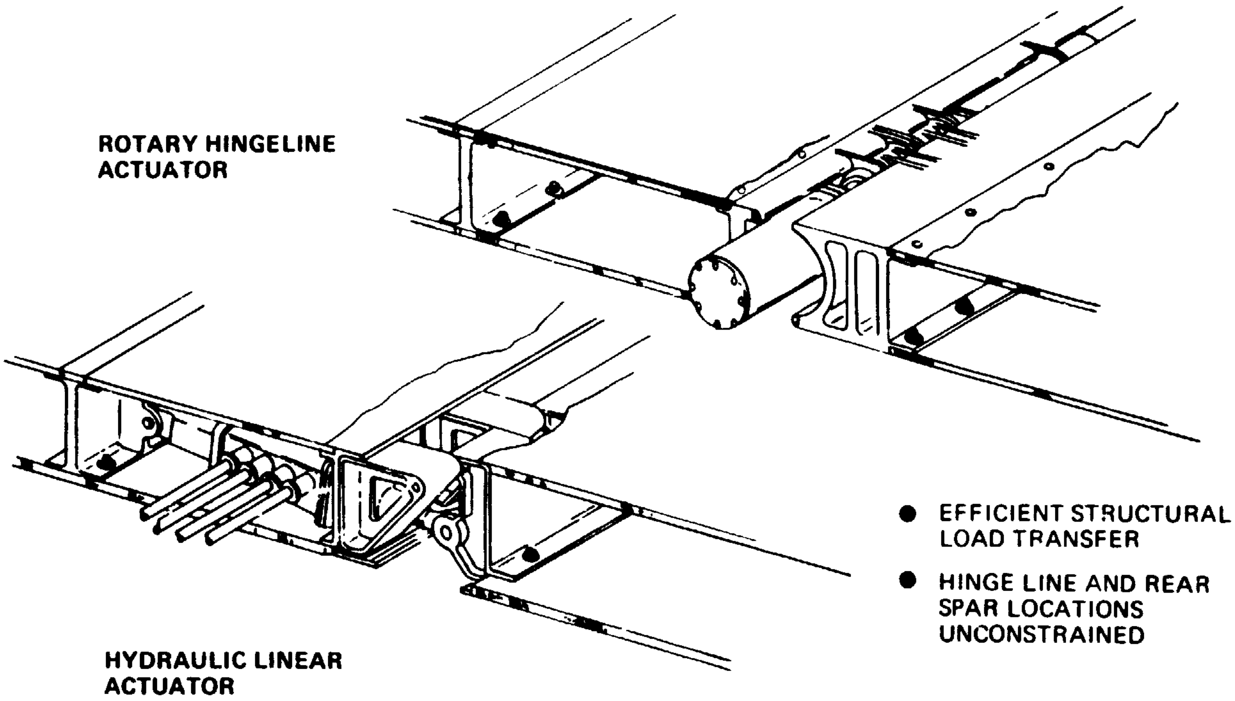


Figure 138 Flight Control Subsystem Comparison

Figure 139 Integrated Actuator Package Example

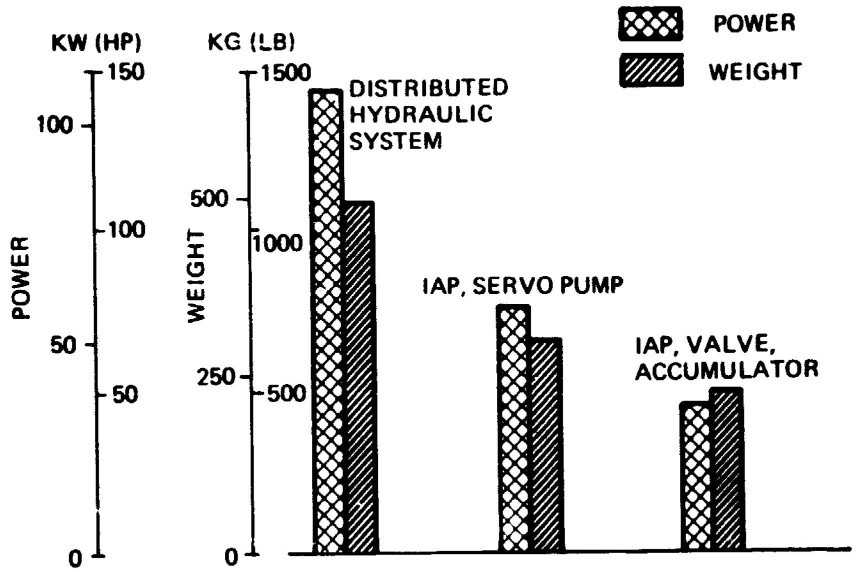


Figure 140 Power and Weight Comparison of Distributed-vs-Integrated Actuator Package

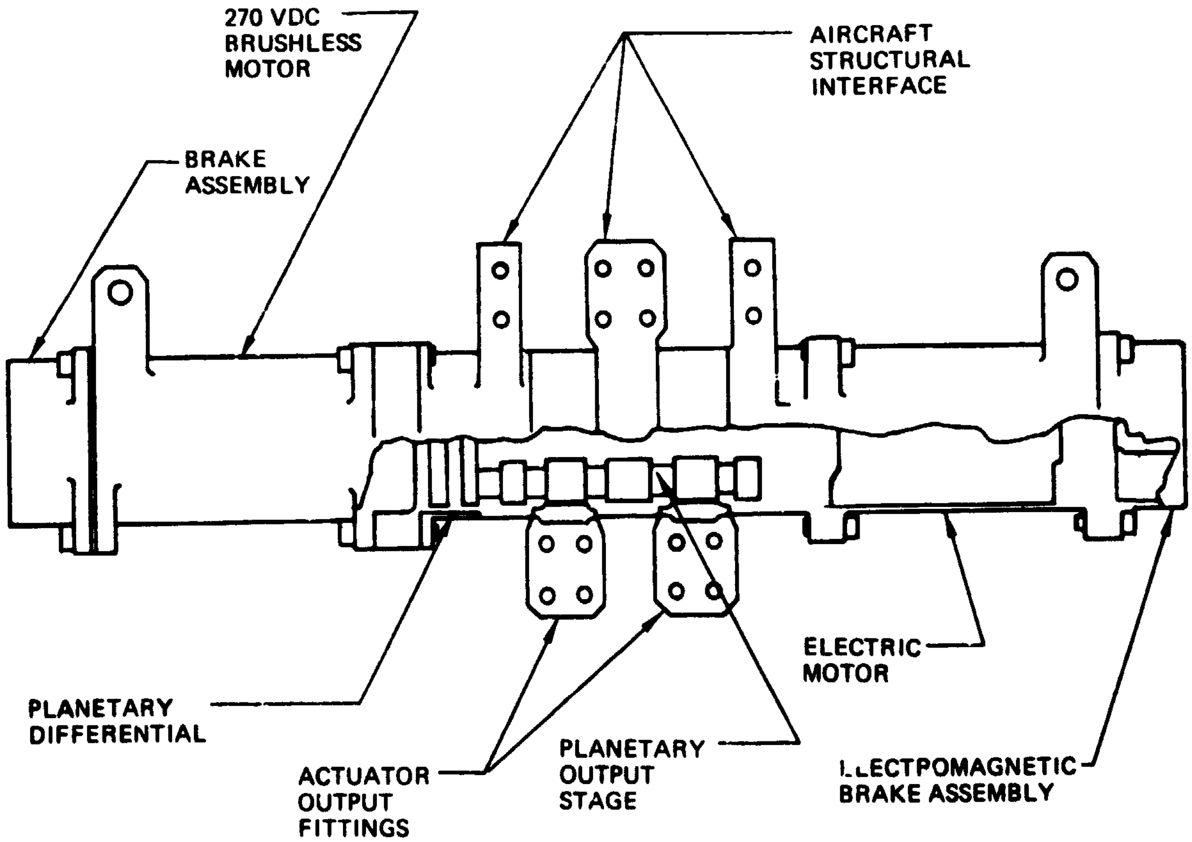


Figure 141 Primary Flight Control Hingeline Actuator

6.7.2 ELECTRICAL SYSTEM

Although use of electrically powered flight controls would reduce the total power requirement of actuating the flight control surfaces by eliminating the hydraulic system, electrical power requirement will be increased. All electric system airplanes may use IEGS to supply all normal airplane utility electrical power in addition to supplying electrical power to the wing de-icing system and flight control systems. The IEG combines the function of electrical power generation and engine starting, which reduces the number of accessories required on the engine. Each IEG has a capacity of satisfying the maximum airplane electrical power demand.

One possibility is the use of a high-frequency, multiphase, brushless ac generator driven from the main engine to supply power to a frequency generator whose output is a precision, three-phase, 115/200-volt, 400-Hz aircraft power, using the cycloconverter principle. The cycloconverter conducts power in both directions and operates in the engine-starting mode without undue complications. During engine starting, 400-Hz power is supplied to the constant frequency terminals of the converter from either an external source or onboard APU. The 400-Hz power converted to the variable frequency and variable voltage required by the generator operating as a motor.

Another method of producing aircraft electrical power is to use a 270-Vdc generator driven by the main engines. The advantage of this system is the production of 270-Vdc for the high-power-demand flight control surfaces. The generator supplied with 270-Vdc power operates as a motor for starting the engines. More in-depth study is required to determine the optimum power generating equipment for this new technology short-haul transport.

6.7.3 AIR CONDITIONING SYSTEM

Engine high-pressure bleed air normally is required to produce cooling in the air-cycle cooling pack and also to provide cabin ventilation and pressurization. Electric-motor driven, simple-bootstrap, air-cycle packs may be used in place of conventional air-cycle packs. The advantage of this system is that a high-pressure air source is not required to operate the air-cycle pack nor for cabin pressurization. The electric-motor-driven air-cycle machine delivers compressed and conditioned air for cabin air conditioning and pressurization.

During ground operation, cabin recirculation air is cooled in the air-cycle packs and supplied to the cabin. In flight, engine fan air is boosted in pressure and cooled in these packs and used for cabin air-conditioning and pressurization. Electric power from a ground power supply or engine-driven generator is used for powering the bootstrap air-cycle packs. The system schematic is shown in figure 142.

6.7.4 POWERED WHEELS

A wheelwell-mounted APU would be ideal for use of powered-wheel concepts. However, since the short-haul transport operates primarily from small under-utilized airfields, the use of powered wheels would result in little, if any, fuel savings and was not pursued under this contract.

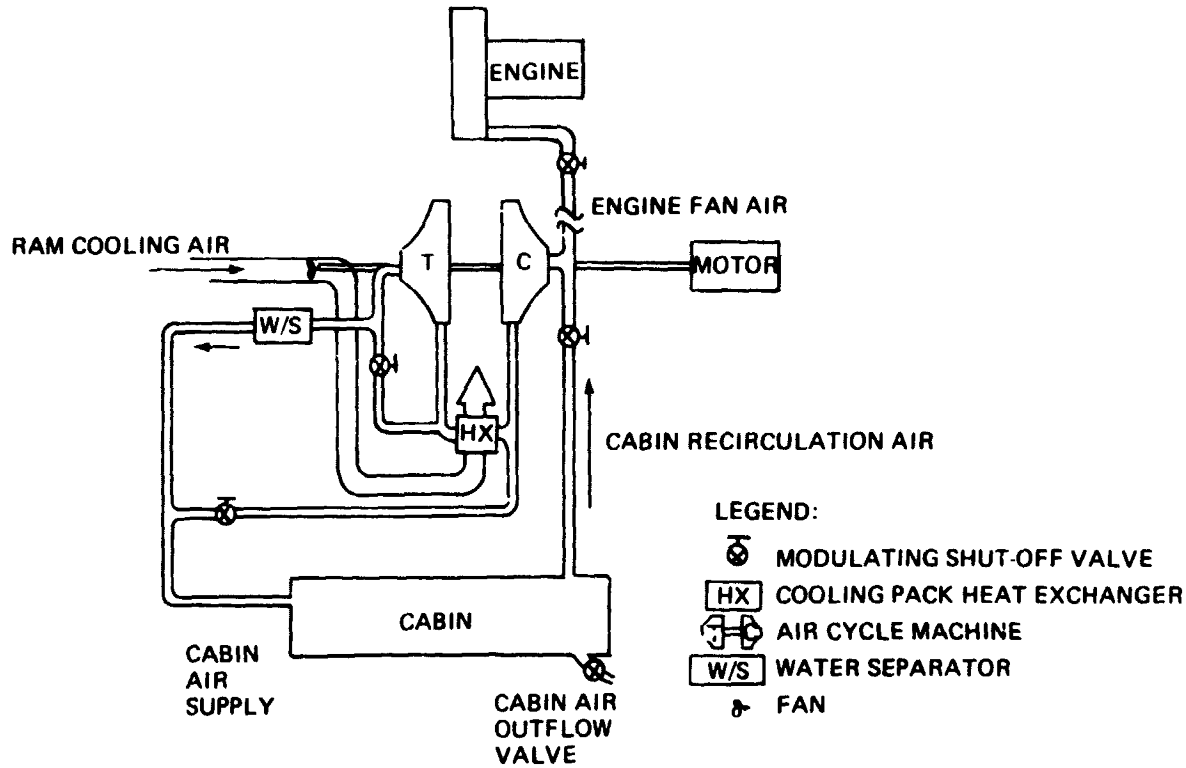


Figure 142 Powered, Simple-Bootstrap, Air-Cycle Cooling Pack

6.8 ADDITIONAL LOW-COST CONSIDERATIONS

Three additional non-advanced-technology items were considered for cost reduction. windshield design, airplane interior arrangement, and the auxiliary power unit.

6.8.1 WINDSHIELD DESIGN

Selecting the windshield for a new airplane involves a set of trade studies. A windshield can be flat or curved, made from glass or plastic, and can be dried/de-iced by a variety of techniques.

Flat windshields usually have better optical properties and cost one-half to one-third that of a similar curved windshield, but curved windshields are easier to integrate into the curved cabin section and usually result in less drag and a quieter cockpit.

Plastic windshields are lighter and cheaper than glass, but have unsatisfactory wear characteristics. Windshields with a protective layer of glass laminated over the plastic have had delamination problems during thermal de-icing, caused by the difference in thermal expansion rates.

The selected windshield design was based on engineering judgement, using the results of past airplane programs and current windshield technology. The windshield selected was of curved high-strength glass with electric de-icing. A windshield using this new glass was as strong and light as one of plastic, but requires less maintenance. A curved-windshield design was selected over a flat design because the \$3000 to \$5000 price for curved glass, even when multiplied by 200 airplanes, was judged to be less than the cost of additional design and construction hours, and fuel penalty for the additional drag and weight caused by a flat windshield design. The design is shown in figure 143.

6.8.2 REVISED INTERIOR ARRANGEMENT

The baseline airplane was sized for 50 passengers at a standard 86.4-cm (34-in.) pitch. However, examination of advanced interiors and of average mission blocktimes indicated that a nonreclining seat and revised 81.3-cm (32-in.) pitch seating arrangement could produce a superior interior arrangement with an equal comfort level. This revised interior, shown as figure 144, results in a reduction in body length of 0.71 m (28 in.)

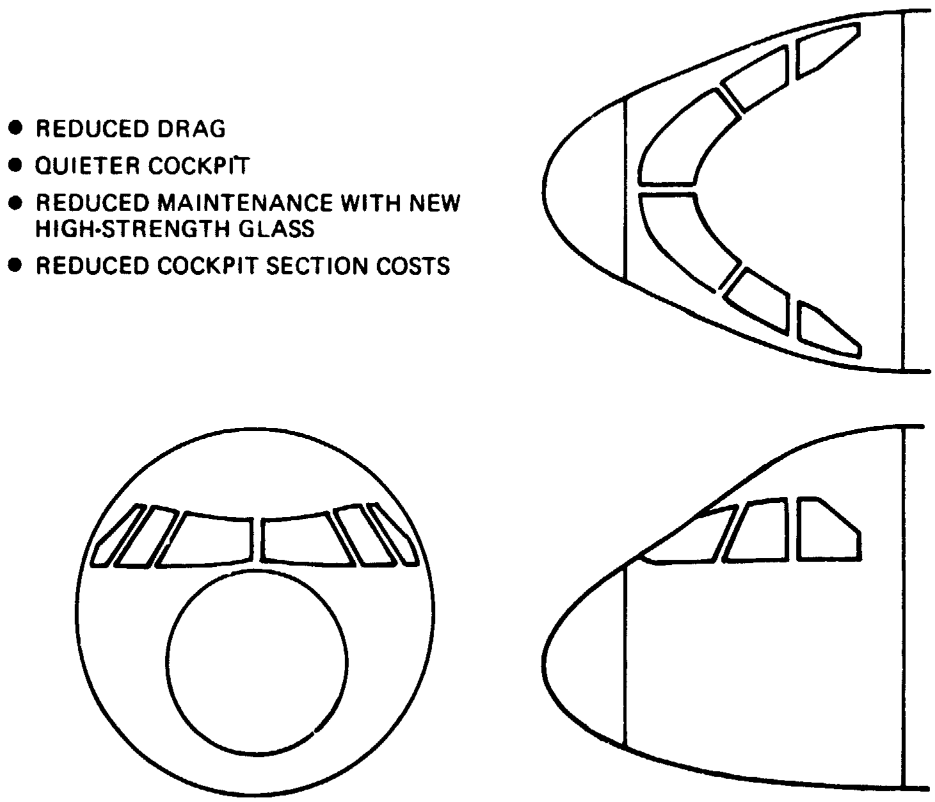


Figure 143 Curved-Glass Windshield Arrangement

6.8.3 AUXILIARY POWER UNIT

The use of an auxiliary power unit (APU) normally is optional for each airline; the manufacturer provides a place only for the APU installation plus a small weight penalty for APU provisions. The exception is the dedicated APU, which is required to be working for the airplane to perform certain operations. The historical economics of an APU versus the possible use of a ground power unit (table 24) are such that a dedicated APU was not considered for the advanced short-haul airplane.

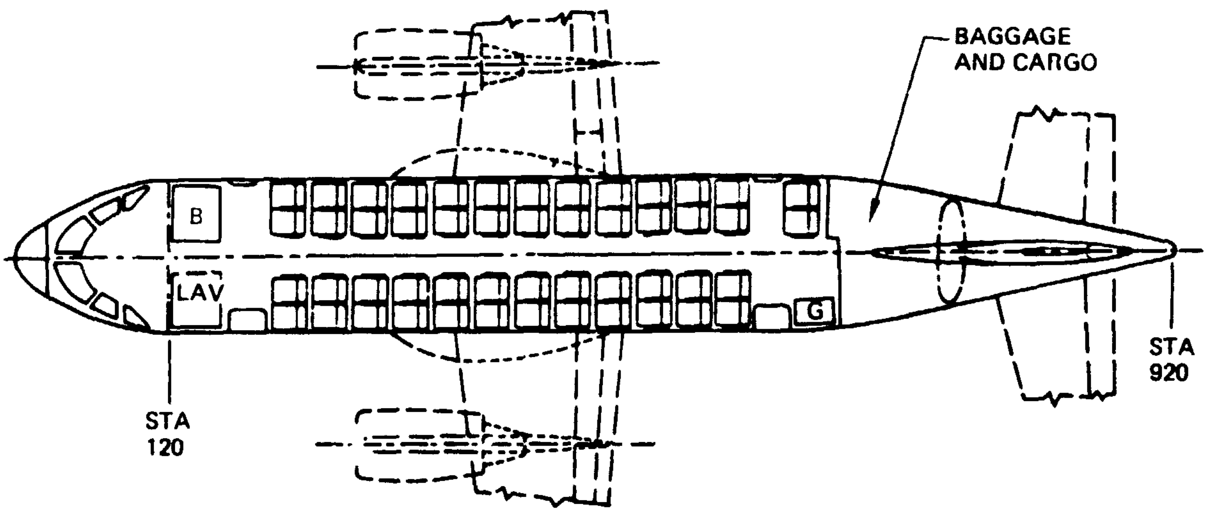


Figure 144 Fifty Passengers at 32-Inch Pitch Configuration

Table 24 Ground Power Costs

	COMMERCIAL POWER	GPU DIESEL	GPU GASOLINE	APU
1-kWh cost	\$0.022	\$0.03	\$0.07	\$ 0.98
1-kWh consumption (gallons)	0.07	0.08	0.15	2.6
737 10-kWh requirement	\$0.22	\$0.30	\$0.70	\$ 9.80
727 20-kWh requirement	\$0.44	\$0.60	\$1.40	\$19.60
707 25-kWh requirement (if installed)	\$0.55	\$0.75	\$1.75	\$23.60
747 40-kWh requirement	\$0.88	\$1.20	\$2.80	\$39.20

The costs listed in the table do not include maintenance costs for GPUs and APUs.

7.0 EVALUATION OF ADVANCED TECHNOLOGY

7.1 SUMMARY

This section pertains to the evaluation phase of the contract, task III, where the features of the advanced short-haul airplane are selected and the final airplane configuration of this phase of the study is defined (model 767-845A). This airplane, after being cycled and rebalanced to meet all performance and design requirements, becomes model 767-845B, which is compared to the current-technology baseline airplane (model 767-774C, fig. 40). This comparison allows the evaluation of the impact of advanced technologies (within the low-cost constraints) on short-haul transport performance and economics.

7.2 SELECTION OF AIRPLANE DESIGN FEATURES

The following low-cost design features were selected for the advanced short-haul airplane:

- High wing location using over-the-fuselage mounting to eliminate penetrations of the pressure hull
- External main-gear mounting to eliminate the keel beam and other gear-bay components that penetrate the pressure hull
- All fuselage doors located in the constant-section portion of the body to minimize design and fabrication hours; both port and both starboard doors are interchangeable
- A standard seat pitch of 0.81 m (32 in.) was selected to size the fuselage resulting in a 0.71 m (28 in.) reduction in body length with no sacrifice in passenger comfort when nonreclining seats are used as standard equipment
- Three-quarter-length duct nacelle to reduce propulsion noise, as discussed in section 6.5

The following advanced-technology features have been selected for the advanced short-haul airplane:

- Bonded-aluminum primary structure to reduce part count and manufacturing hours (see sec. 6.2 for estimated results)
- Advanced trailing-edge high-lift devices, including double-slotted Fowler trailing-edge flaps and drooped ailerons.
- Curved-glass windshields using advanced high-strength glass for reduced weight, drag, and design complexity
- Automatic power reserve (APR)

Certain features were selected for marketing and/or customer-preference reasons. They include·

- A body width having a 3-m (118.1-in.) diameter to allow the airplane to carry LD-3 containers and/or passengers on a single floor level (combi-option capability). This wider body also enhances the ability to carry palletized cargo for utility freighter or carrier-on-deck-delivery missions.

- Two large entry doors and large carry-on-baggage storage bins to minimize through-stop ground time

Because of the limited scope of this study, several advance-technology items with potential for significantly reducing initial and/or operating costs could not be analyzed sufficiently to be included in this airplane. The utilization of these items, which are listed below, will be postponed for later study, and are discussed in section 8.0, Research and Technology Recommendations.

- Advanced-composite primary structure
- Fly-by-wire digital control system
- Advanced integrated avionics with digital data systems and propulsion controls
- Natural-laminar-flow wing and tail surfaces
- Wing-tip devices (both low-speed and high-speed)
- New technology turboprop propulsion
- Vee-tail empennage

7.3 ADVANCED SHORT-HAUL AIRPLANE DEFINITION

A general arrangement drawing of the advanced short-haul airplane, model 767-845B, is shown in figure 145. The airplane is superficially quite similar to the basepoint airplane, model 767-774B (fig. 33), but actually contains many design features selected to reduce operating cost. A detailed description of the model 767-845B follows.

7.3.1 GEOMETRY

The model 767-845B has a revised interior arrangement (fig. 144) and increased body diameter (fig. 146) discussed in section 6.8. Both of these features facilitate passenger/cargo and pure cargo operations with this short-haul configuration.

Table 25 contains detailed-configuration geometry characteristics, as well as specified characteristics for the landing gear and engines. Further detail of the main landing gear is shown in figure 147 and of the nose landing gear in figure 148. The engine and nacelle details are identical to the 3/4-length duct example shown in section 6.5.

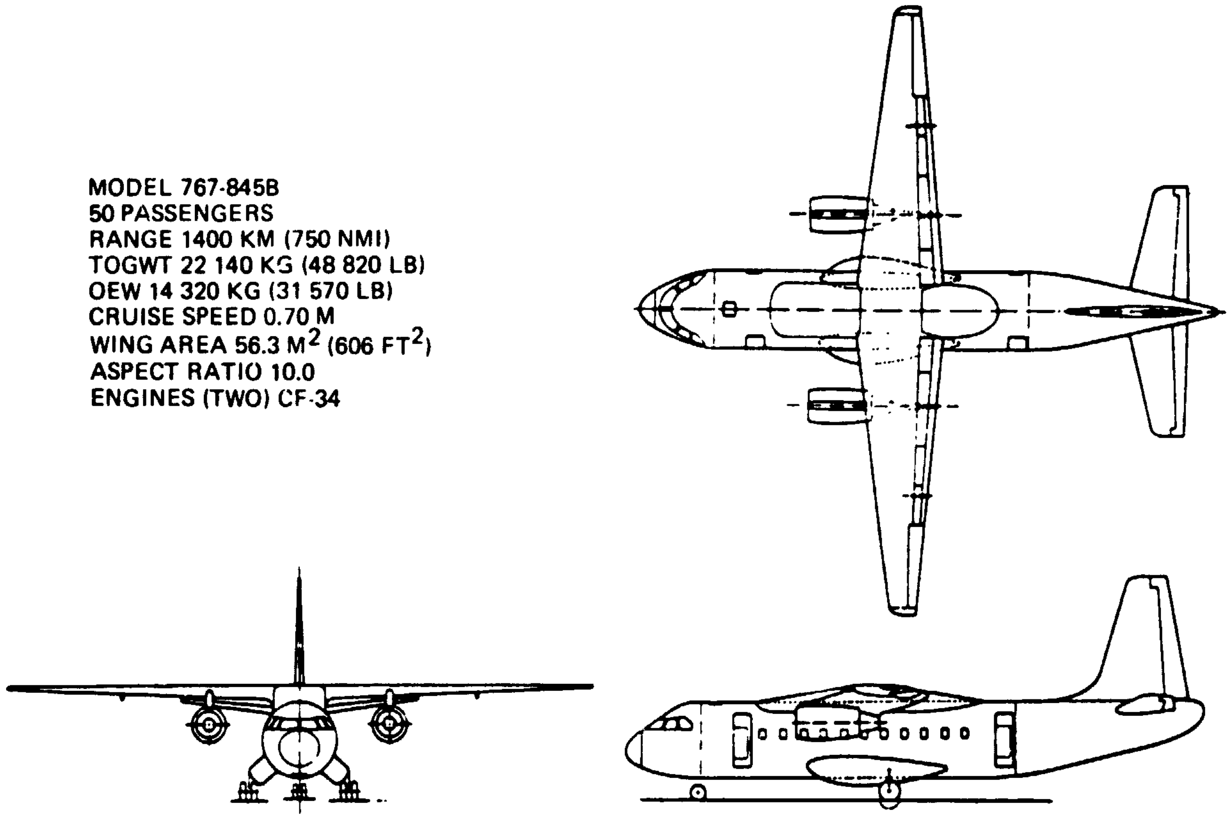


Figure 145. Advanced Short-Haul Airplane, Model 767-845B

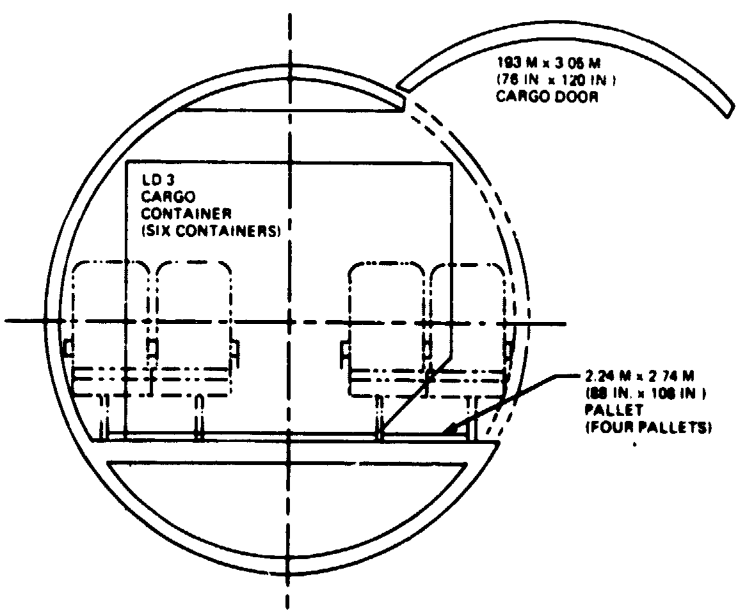


Figure 146 Short-Haul Transport Cargo System

GEOMETRY	WING	HORIZONTAL	VERTICAL
Area, m^2 (ft^2)	56.3 (606)	18.6 (200)	13.2 (143)
Aspect ratio AR	10.0	5.0	1.8
Taper ratio, λ	0.275	0.50	0.40
Sweep at c/4, rad (deg)	0.0794 (4.55)	0.175 (10.0)	0.175 (10.0)
Incidence at SOB, rad (deg)	0.052 (3)	–	–
Dihedral, rad (deg)	0 018 (1)	0.122 (7)	–
Root t/c, %	15	12	11
Tip t/c, %	12	12	11
MAC c, m (in.)	2.629 (103.5)	2.0 (78.7)	2.875 (113.2)
SPAN b, m (in.)	23.727 (934.15)	9.637 (379.5)	4.877 (192)
Tail arm, m (in.)	–	10.622 (418.2)	(10.216 (402.2)
Tail volume coefficient, V	–	1.334	0.101
LANDING GEAR	**NOSE**	**MAIN**	
Number of wheels	2	4	
Body station, m (in.)	2.92 (115)	10.67 (420)	
Spacing, m (in.)	0.36 (14)	0.46 (18)	
Tire size	24 x 7.7	32 x 8.8	
BODY			
Length	23.37 m (76.67 ft)		
Diameter	3.0 m (9.14 ft)		
PROPULSION	**ENGINE**		
Engine type	General Electric CF-34		
Thrust SLS	35.6 kN (8000 lb)		
Bypass ratio	6.3		

Table 25 Model 767-845B Configuration Geometry

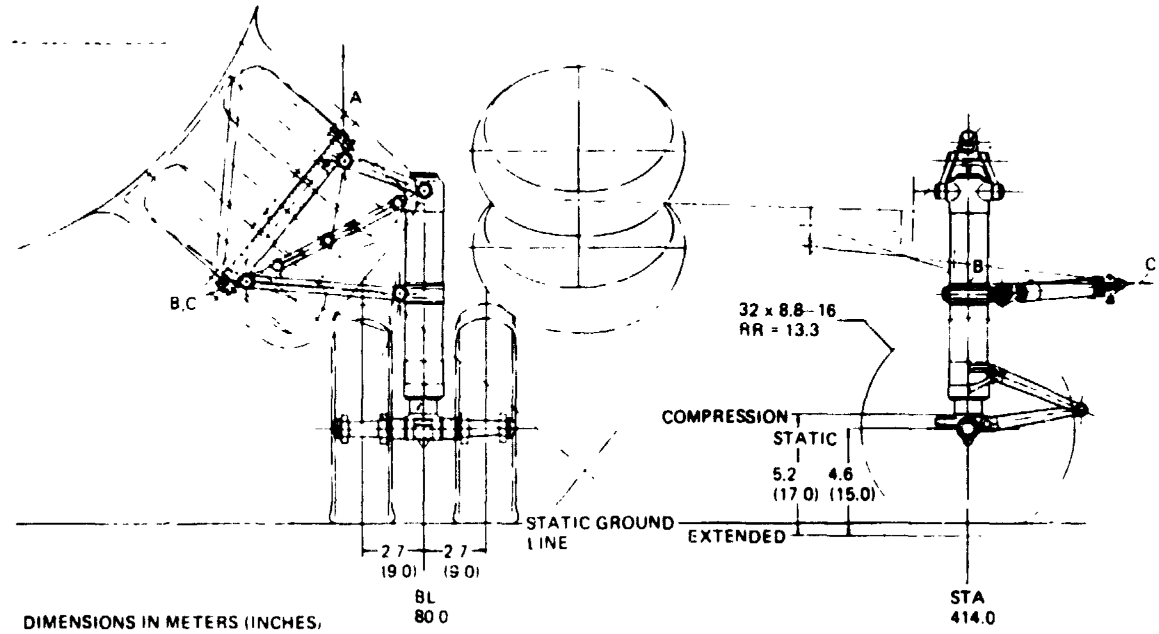
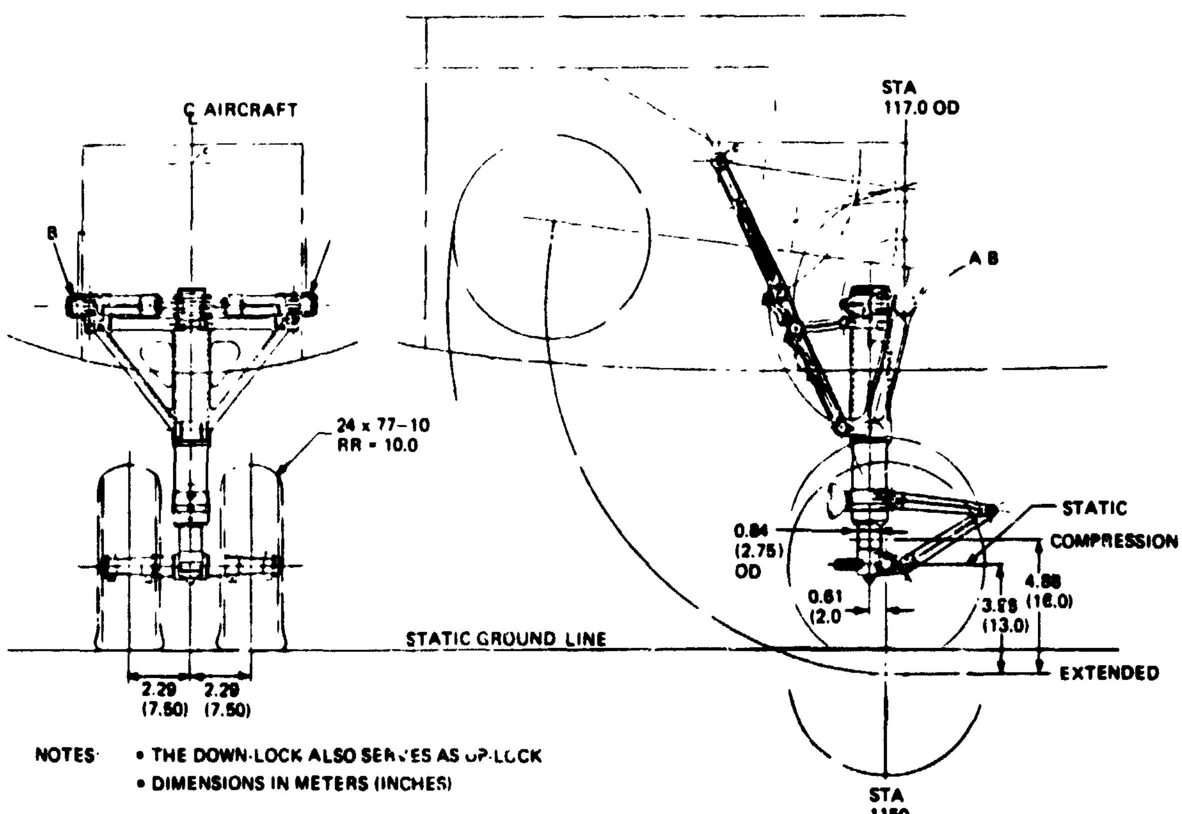


Figure 147 Main Landing Gear Arrangement



NOTES: • THE DOWN-LOCK ALSO SERVES AS UP-LOCK
• DIMENSIONS IN METERS (INCHES)

Figure 148 Nose Landing Gear Arrangement

7.3.2 WEIGHT AND BALANCE

The results of a weight evaluation on the thumbprint mission-sized 767-845B indicates an operating empty weight of 14 320 kg (31 570 lb). Weight analysis approach is the same as that discussed in section 5.6.1, but adjusted for advanced technology and configuration differences. The gross weights are the result of the detailed mission analysis shown in section 7.4.5.

Figure 149 confirms the results of a balance analysis sh[illegible]ing that the airplane has acceptable loadability within the specified center of gravity range dictated by stability and control considerations. This loading range also provides for conceptual OEW c.g. tolerances including the effect of possible customer variations. Baggage allowance per passenger and cargo compartment definition are the same as those previously established (sec. 5.6). It should be noted that the small MAC length associated with this size wing demands an accurate positioning of the wing on the body and makes airplane balance sensitive to both weight and c.g changes.

7.3.3 AIRFOILS AND HIGH-LIFT DEVICES

The advanced short-haul airplane, model 767-854B, has a different airfoil and different high-lift devices from those of the baseline or trade study airplanes.

The high-lift devices include a double-slotted trailing-edge flap (fig. 150) with large Fowler motion (c'/c = 1.362) to obtain good low-speed lift characteristics without a leading edge device. A plain-hinge, contoured-nose flaperon is used as a drooped aileron, as discussed in section 6.3. The nominal droop is 0.26 rad (15 deg).

The airfoil nose section is contoured to give high-stall angles of attack and prevent the leading edge from stalling before the trailing edge.

Analytical studies recently have shown that the stall lift characteristics of the original variable-camber cove flap system used on the baseline airplane (767-774A) may be difficult to achieve. This consideration and the complexity of maintaining exact aerodynamic contours for the previ[illegible] system were the reasons for changing to the current large, double-slotted Fowler flap.

7.3.4 SYSTEMS

The systems in the advanced short-haul transport are identical to those defined for th[illegible] technology baseline airplane, with the following exceptions:

- The APU is optional, not standard equipment
- The horizontal tail is trimable, not fixed
- The ailerons have droop capability and no longer have manual reversion
- The air conditioning is located in the wing fairing and is driven by electric motors, as discussed in section 6.7

Table 26 767-845B Weight Statement

ITEM	MASS (kg)	WEIGHT (lb)	ITEM	MASS (kg)	WEIGHT (lb)
Structure			Fixed equipment		
Wing	2420	5330	Instruments	90	200
Horizontal tail	450	1000	Surface controls	250	550
Vertical tail	320	710	Hydraulics	140	320
Body	2950	6510	Pneumatics	130	280
Main landing gear	990	2170	Electrical	600	1330
Nose landing gear	150	330	Electronics	150	320
Nacelle and strut	750	1650	Flight provisions	220	480
			Passenger accommodations	1400	3080
Total	8030	17 700	Cargo handling	70	160
Propulsion			Emergency equipment	210	460
Engine	1430	3160	Air conditioning	210	470
Engine accessories	90	190	Anti-icing	100	220
Engine controls	50	100	Total	3570	7870
Starting system	40	80	Paint		
Fuel system	210	460	Exterior paint	50	100
Thrust reverser	200	440			
Total	2020	4430			

	MASS (kg)	WEIGHT (lb)
Total manufacturer's empty weight	13 670	30 100
Standard and operational items	670	1470
Total operational empty weight	14 340	31 570
Maximum taxi weight	22 390	49 250
Maximum brake-release weight	22 350	49 170
Maximum landing weight	22 350	49 170
Maximum zero fuel weight	19 010	41 820

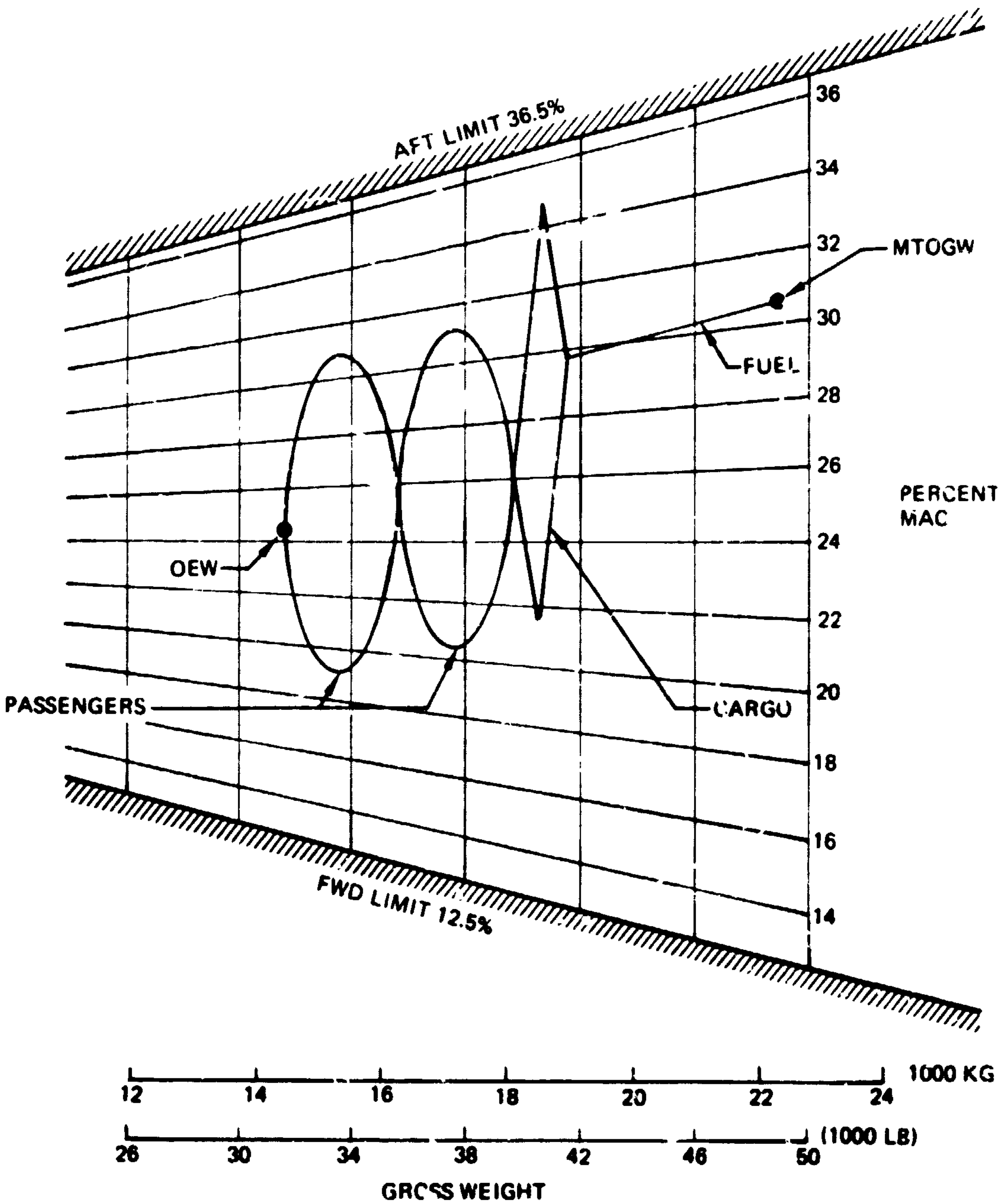


Figure 149 Loadability Diagram, 767-845B

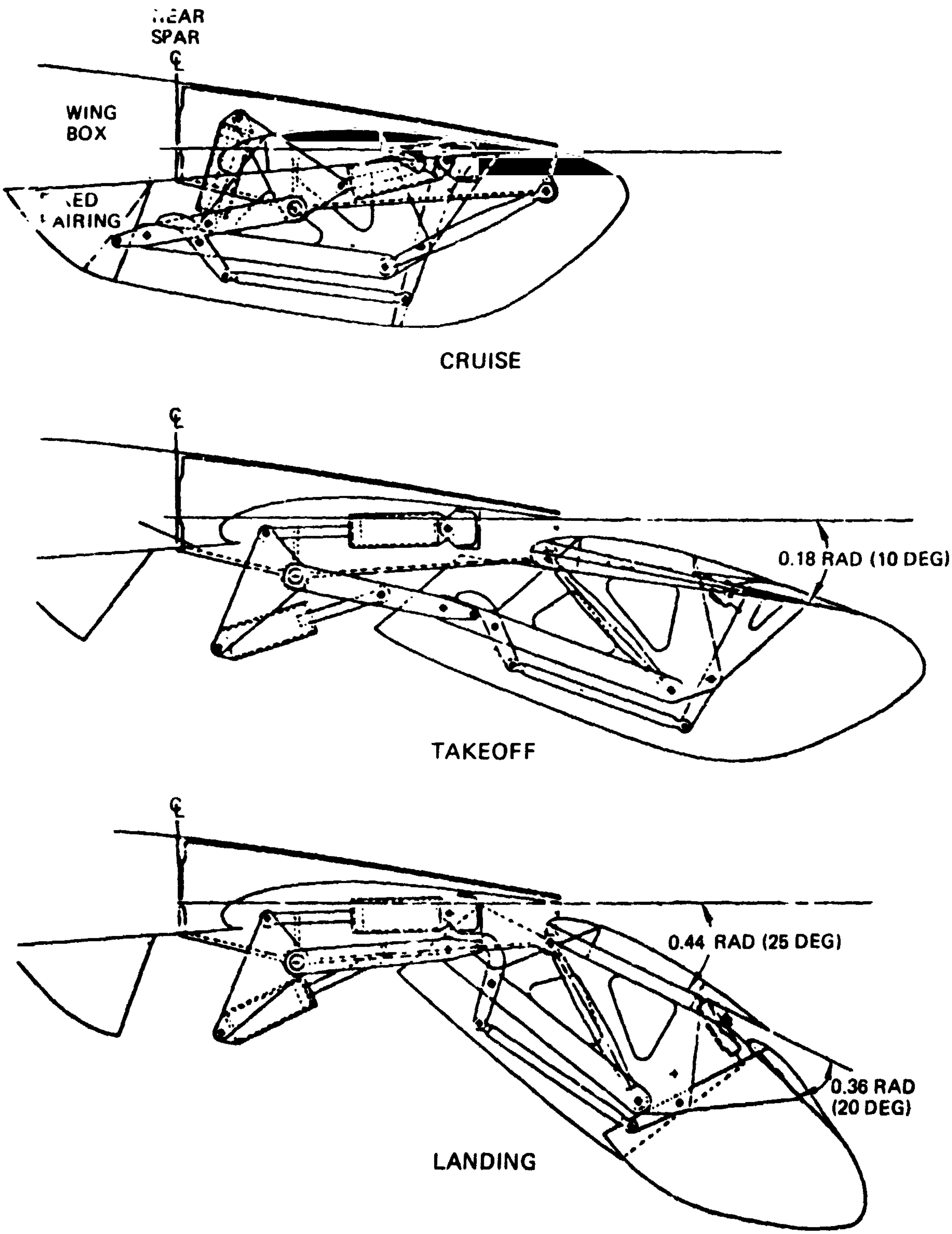


Figure 150 Double-Slotted Fowler Flap

7.4 ADVANCED SHORT-HAUL AIRPLANE SIZING AND PERFORMANCE

In this section the advanced short-haul airplane configuration selected (sec. 7.3) is sized to meet specific mission requirements, its technical characteristics are defined, and a mission analysis is presented.

7.4.1 MISSION RULES

The advanced short-haul transport (model 767-845A) was sized to meet the same design mission used to size previous airplanes, i.e.,

- Payload = 50 passengers, 4535 kg (10 000 lb)
- Design range = 1400 km (750 nmi)
- FAR landing field length (TOGW, wet) ≤ 1370 m (4500 ft)
- FAR takeoff field length (SL, 32°C, 90°F) ≤ 1370 m (4500 ft)
- Cruise Mach number = 0.70
- Initial cruise altitude = 9140 m (30 000 ft)

An additional constraint was placed upon the advanced short-haul configuration in that it was to use two General Electric CF-34 engines at the quoted production thrust level.

The flight profile and mission rules for the thumbprint airplane sizing remained unchanged from that used previously.

7.4.2 AIRPLANE SIZING

The design selection chart for the advanced short-haul airplane is shown in figure 151. Note that the takeoff and landing constraints lines were not used to select the airplane design characteristics. The final airplane design parameters were chosen by selecting a fixed engine size, (CF-34 turbofan) 35.6-kN (8000-lb) SLST (uninstalled), and by fuel volume considerations. The usable fuel capacity for the 767-845B airplane with 606 ft^2 of wing area) is 3630 kg (8300 lb). The wing is built in three sections, two are outboard of the engine struts. The absence of fuel from these outboard sections eliminates the cost and weight of additional access panels and wing sealant, thus leading to a lighter, less expensive wing.

Figure 151 shows that the block-fuel contours have shifted far to the left and slightly down compared to design charts for previous airplanes. The change in T/W is due to an improvement in climb and cruise-thrust ratings announced by the manufacturer, General Electric. The reduction in W/S for minimum block fuel relative to that shown on the 767-774B sizing chart is due to change in airfoil characteristics for the two configurations. The airfoil section used on the 767-774B had a design C_l of 0.57 at a t/c of 0.12. Calculating the corresponding design C_l for a three dimensional wing with a MAC t/c of 0.137 requires extrapolation. Another airfoil section, which had also been windtunnel tested, was available and had a design of C_l of 0.48 at a t/c of 0.141. The second airfoil was selected for the final airplane to reduce errors in scaling airfoil properties and give the final result more validity. But, the combination of increased profile drag for the thicker airfoil and a lower design C_l combined to reduce maximum L/D for the same wing area from approximately 16 to about 14. Airplane maximum L/D could probably be improved by increasing the design C_l for the thicker airfoil.

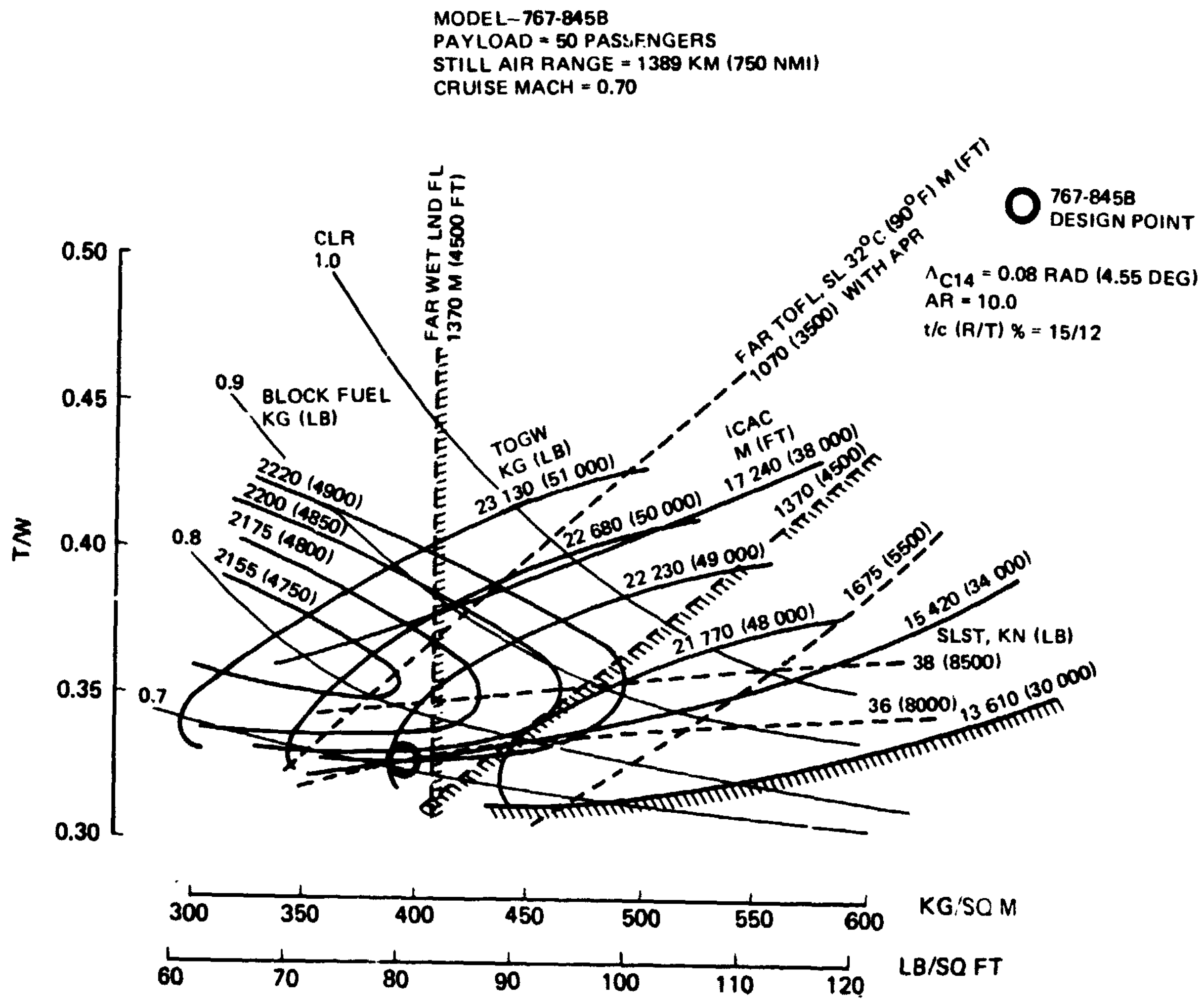


Figure 151 Advanced Short-Haul Transport Design Selection Chart, Model 767-845B

The block-fuel contours on the sizing chart show the effect of the increase in profile drag. The combination of increased lift-dependent profile drag and lower airfoil design C_l tend to minimize block fuel at lower wing loadings (i.e., larger wings that increase maximum L/D and decrease $C_{D_{P_{MIN}}}$).

The design point shown on the sizing chart (model 767-845B) is W/S = 393 kg/m^2 (80.5 lb/ft^2), T/W = 0.328 and TOGW = 22 145 kg (48 820 lb), which results in SW = 56.3 m^2 (606 ft^2), and SLST = 35.6 kN (8000 lb).

These airplane characteristics produce a FAR TOFL (SL, 32°C, 90°F) and a FAR landing-field length (wet) of approximately 1250 m (4100 ft).

Figure 152 shows the effect of wing loading on size and performance characteristics for a constant engine size. These curves indicate that slightly higher wing loadings might be desirable, but this would require increased landing C_L (i.e., leading-edge devices).

The payload range curve for the 767-845B is shown in figure 153. The decision to limit fuel to the wing center section has severly limited off-design range capability. Later studies should examine whether additional fuel should be carried in the outboard wing or in fuel tanks in the wing farings, as in the Shorts SD3-30

Off-design takeoff performance is shown in figure 154.

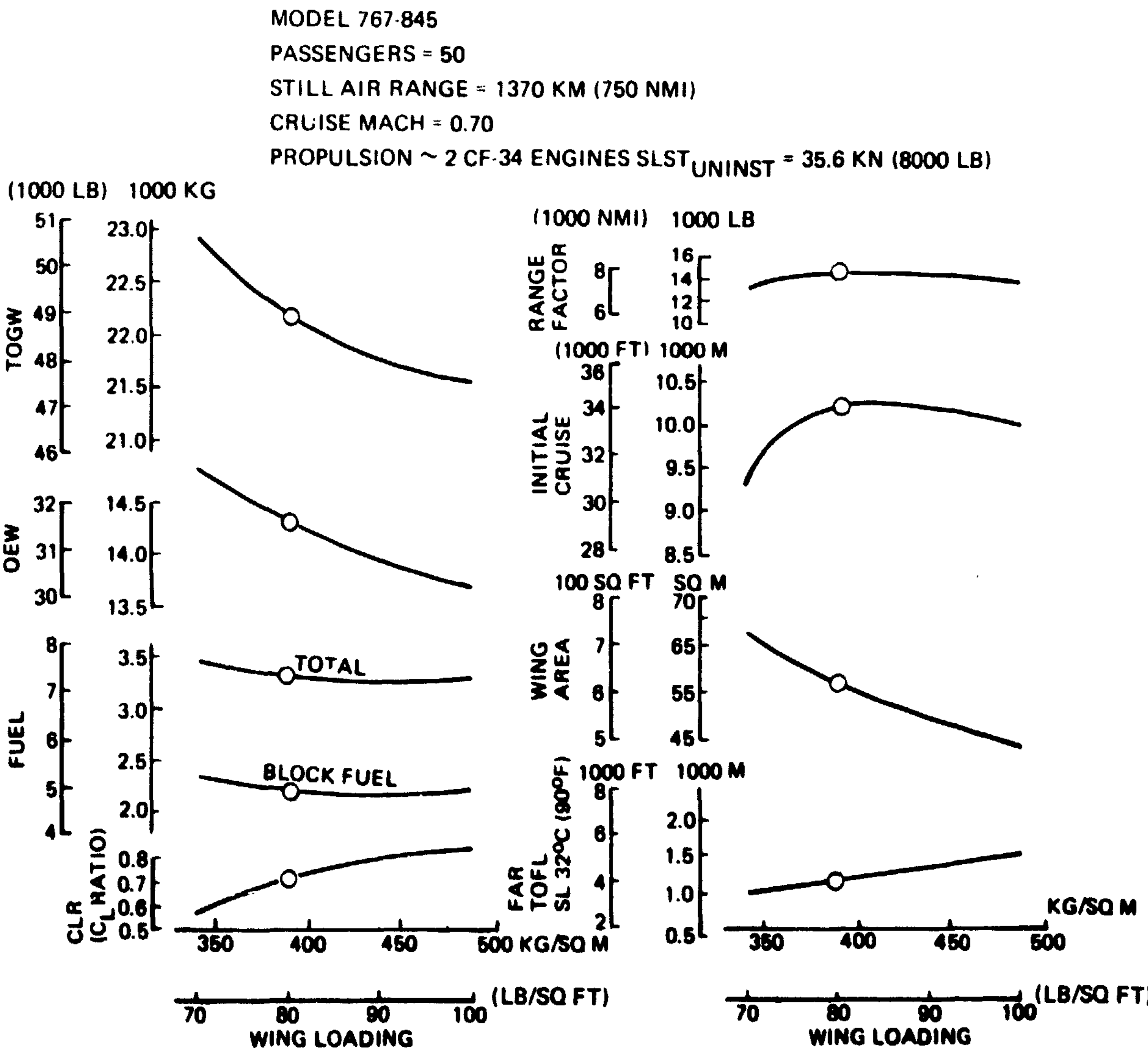


Figure 152 Effect of Wing Loading

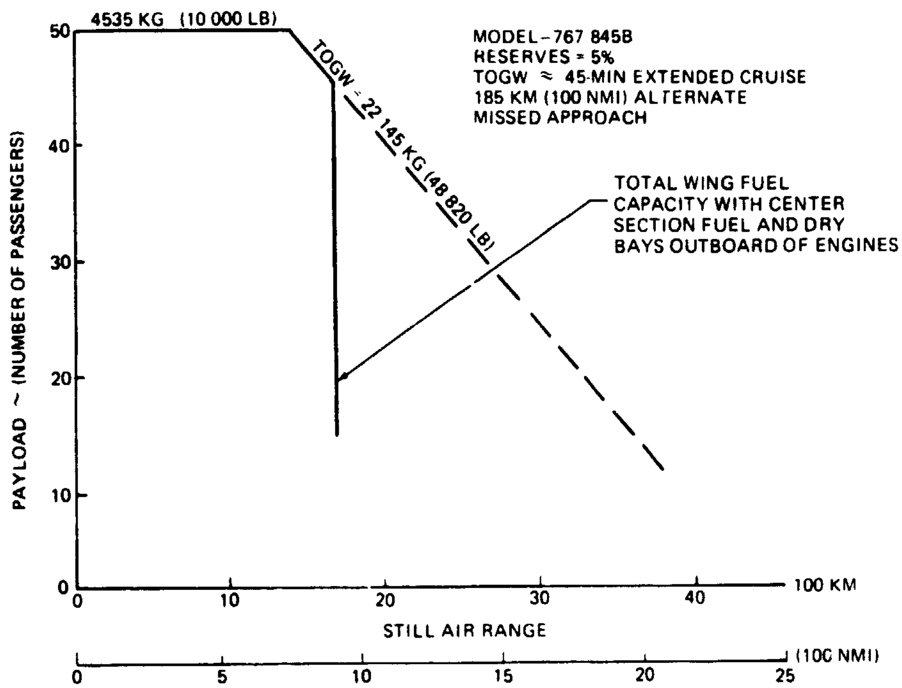


Figure 153 Advanced Short-Haul Transport—Payload vs Range

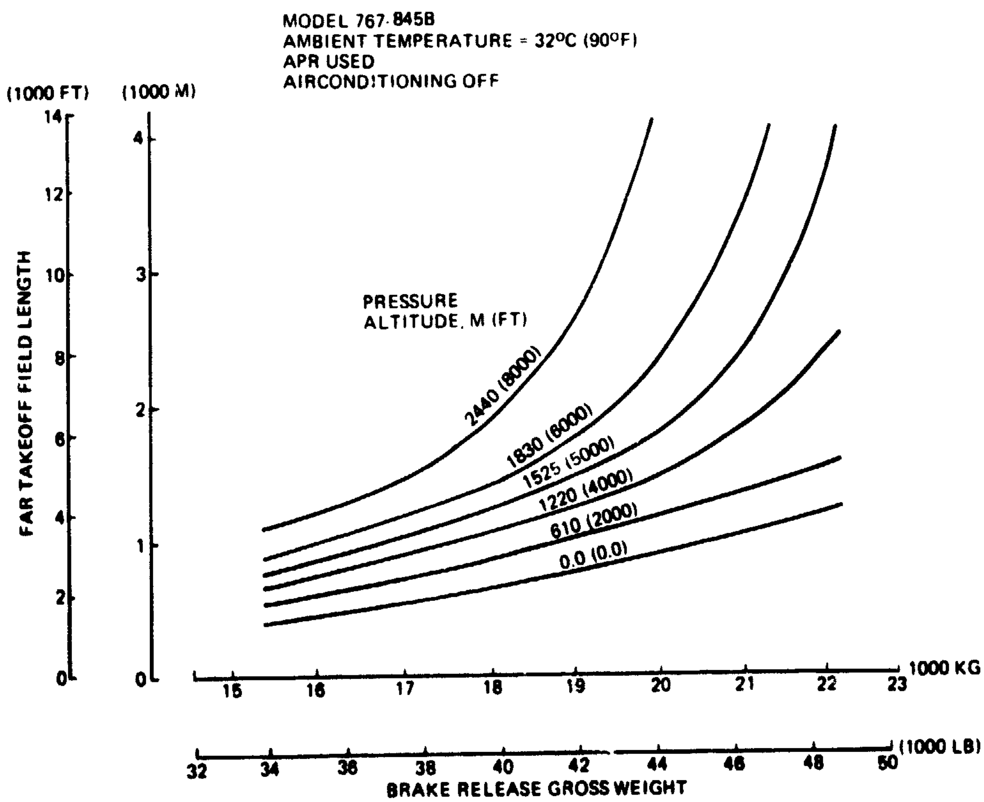


Figure 154 Advanced Short-Haul Takeoff Performance

7.4.3 TECHNICAL CHARACTERISTICS

7.4.3.1 Aerodynamics

The high- and low-speed aerodynamic characteristics of the model 767-845B are shown in figures 155 through 158. The high-speed drag polar and parasite drag breakdown is shown in figure 155. The maximum high-speed L/D at Mach 0.74 is 14.3. Low-speed C_L versus alpha, both in and out of ground effect, is shown in figure 156. The low-speed takeoff and landing polars are in figure 157 and 158, respectively.

The second segment lift coefficient $C_{L_{V_2}}$ of 1.97 at a TOGW of 22 145 kg (48 820 lb) produces a V_2 of 204 km/hr (110 keas). The corresponding L/D at V_2 was 9.6, which includes the engine-out windmill and yawing drag increment (ΔC_D) of 0.0075. The forward trimmed c.g. limit for the low-speed performance is 12.5%.

7.4.3.2 Propulsion

The CF-34 engine installed takeoff thrust versus Mach number used in the airplane sizing computer program is shown in figure 159. The installed climb and cruise performance are in figure 160 and 161, respectively. All the data shown is for a nominal 1/2 length-duct peripheral lined nacelle. The 767-845B configuration has a 3/4-length duct that should improve cruise thrust and SFC approximately 1%. The 767-845B was performance sized using the nominal 1/2-length-nacelle-data, which may provide a small performance margin.

7.4.3.3 Flight Controls

The horizontal tail was sized by the c.g. range requirement of 0.26 MAC (fig. 162). This established the forward c.g. limit at 0.125 MAC for takeoff rotation and aft c.g. limit at 0.385 MAC for dive stability. The aft limit was determined using handling qualities SAS with a T_2 = 6 second limitation identical to that used on earlier trade study airplanes.

The vertical tail was sized to meet minimum engine-out control speeds, $V_{MC_{air}}$, $V_{MC_{ground}}$, and minimum directional stability, $C\eta_\beta$ (0.115 per radian). Engine thrust was assumed to be increased 10% due to APR. V_{mcg} was assumed equal to V_1 175 km/hr (95 keas).

7.4.4 NOISE

The 767-845B airplane community noise is less than the proposed Rule NPRM 75-37C at all of the measuring points. The noise estimates are based upon the TOGW, 22 140 kg (48 820 lb), and community heights and speeds generated by the thumbprint computer program. Table 27 summarizes the noise characteristics of the short-haul transport with a 3/4-length peripheral-lined nacelle.

ITEM	REFERENCE SIZE	f PARASITE
		DRAG ~(FT^2)
WING	56.3 m^2 (606 FT^2)	3.890
BODY	23.37 m (76.67 FT)	5.806
HORIZONTAL TAIL	0.6 m^2 (200 FT^2)	1.303
VERTICAL TAIL	13.2 m^2 (143 ST^2)	1.157
TWO (NACELLE + STRUT)	8000 SLST	1.360
MAIN GEAR FAIRINGS	–	0.754
WING BODY FAIRING	–	0.414
f TOTAL	–	14.684
C_D = f/SW	–	0.02423
ΔC_D = (TRIM) (FLAP TRACKS)	–	0.00028 0.00009
$C_{D_{P_{MIN}}}$	–	0.02460

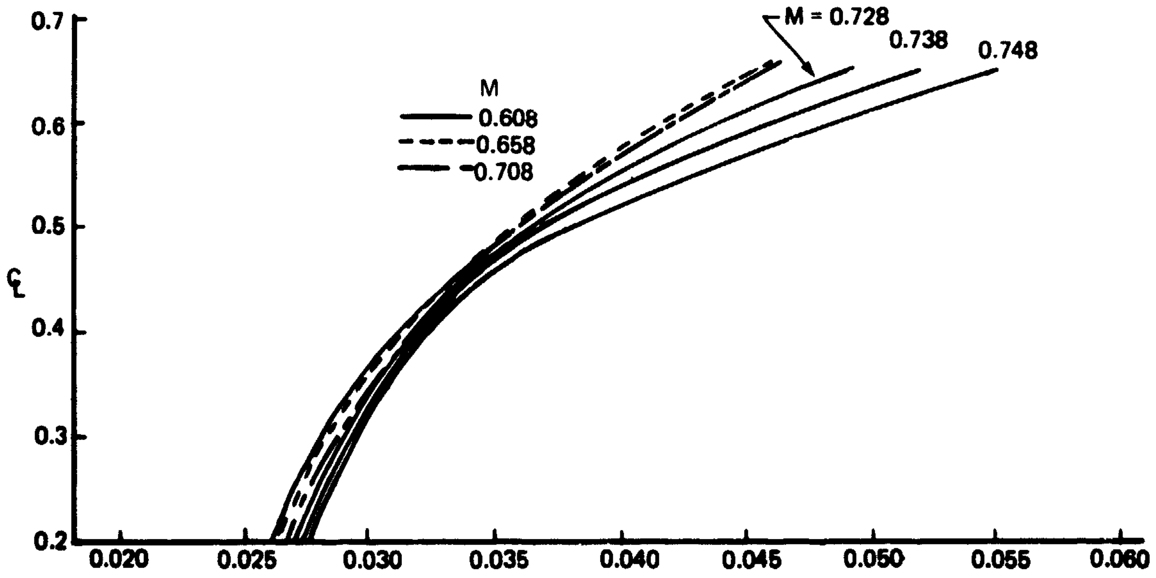


Figure 155 High-Speed Drag Polars, 767-845B

MODEL 767-845B

TRIMMED

Cg AT 0 12 MAC

S_{REF} = 56.3 SQ M (606 SQ FT)

$\Lambda_{C/4}$ = 0.08 RAD (4.55 DEG)

AR = 10.0

$C_{L_{MAX_{1G}}} / C_{L_{MAX_{WT}}}$ = 1.10

$C_{L_{S_{FAR}}} / C_{L_{MAX_{1G}}}$ = 1.10

HIGH-LIFT SYSTEM

- NO WING LEADING EDGE DEVICES
- DOUBLE-SLOTTED FOWLER TRAILING EDGE FLAPS
  - C_F/C = 0.35
  - C_F'/C = 0.376

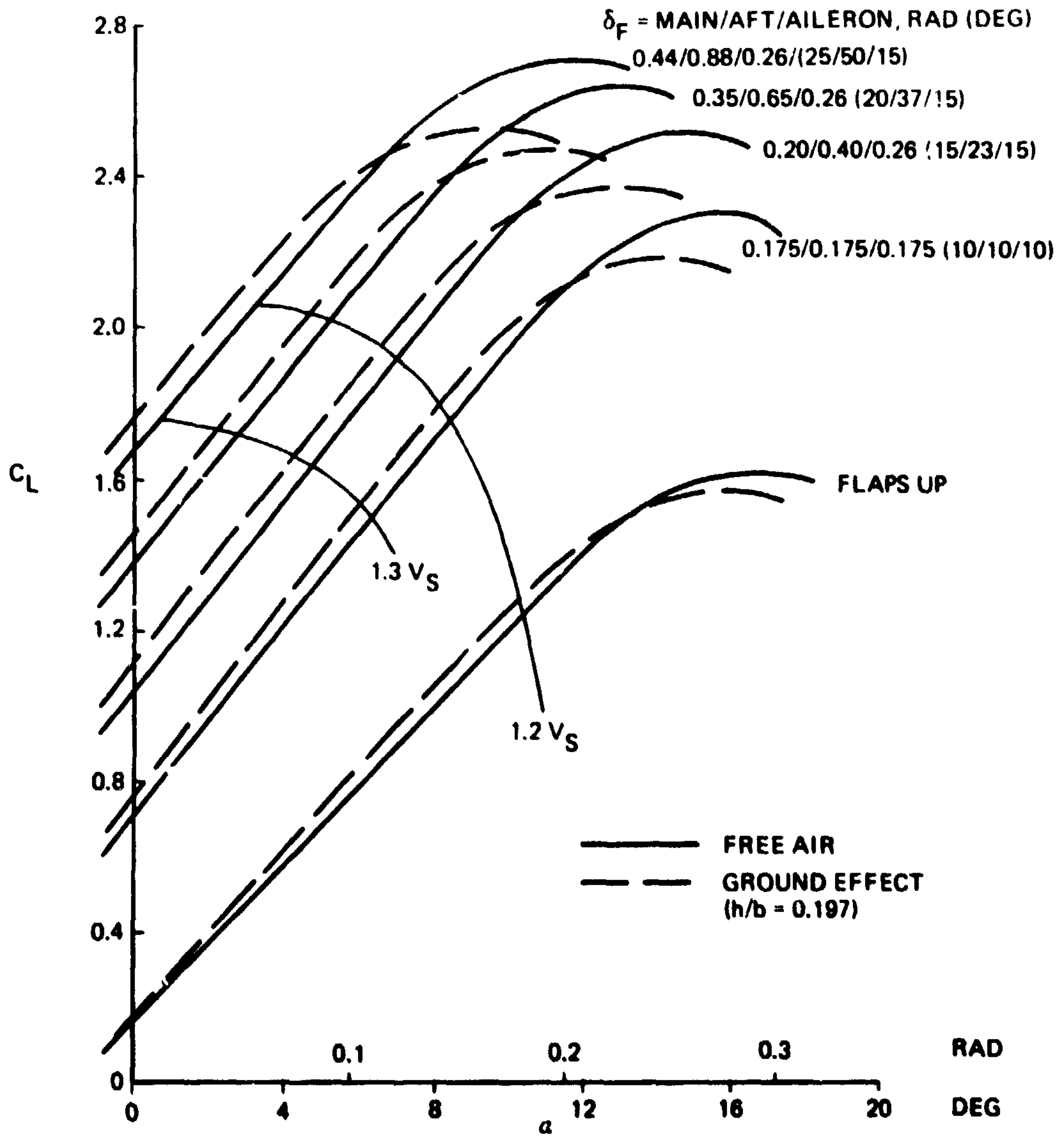


Figure 156 Low-Speed Lift Curves

MODEL 767-845
TRIMMED
Cg AT 0.12 MAC
GEAR UP
THRUST EFFECTS FOR LEVEL FLIGHT
S_{REF} = 56.3 SQ M (606 SQ FT)
$\Lambda_{C/4}$ = 0.08 RAD (4.55 DEG)
AR = 10.0
$C_{D_{P_{MIN}}}$ = 0.0247
$C_{L_{MAX_{1G}}} / C_{L_{MAX_{WT}}}$ = 1.10
$C_{L_{S_{FAR}}} / C_{L_{MAX_{IG}}}$ = 1.10

HIGH-LIFT SYSTEM
- NO WING LEADING EDGE DEVICES
- DOUBLE-SLOTTED FOWLER TRAILING-EDGE FLAPS
  - C_F/C = 0.35
  - C_F'/C = 0.376
  - C'/C = 1.362
- AILERON DROOP TO 0.26 RAD (15 DEG)

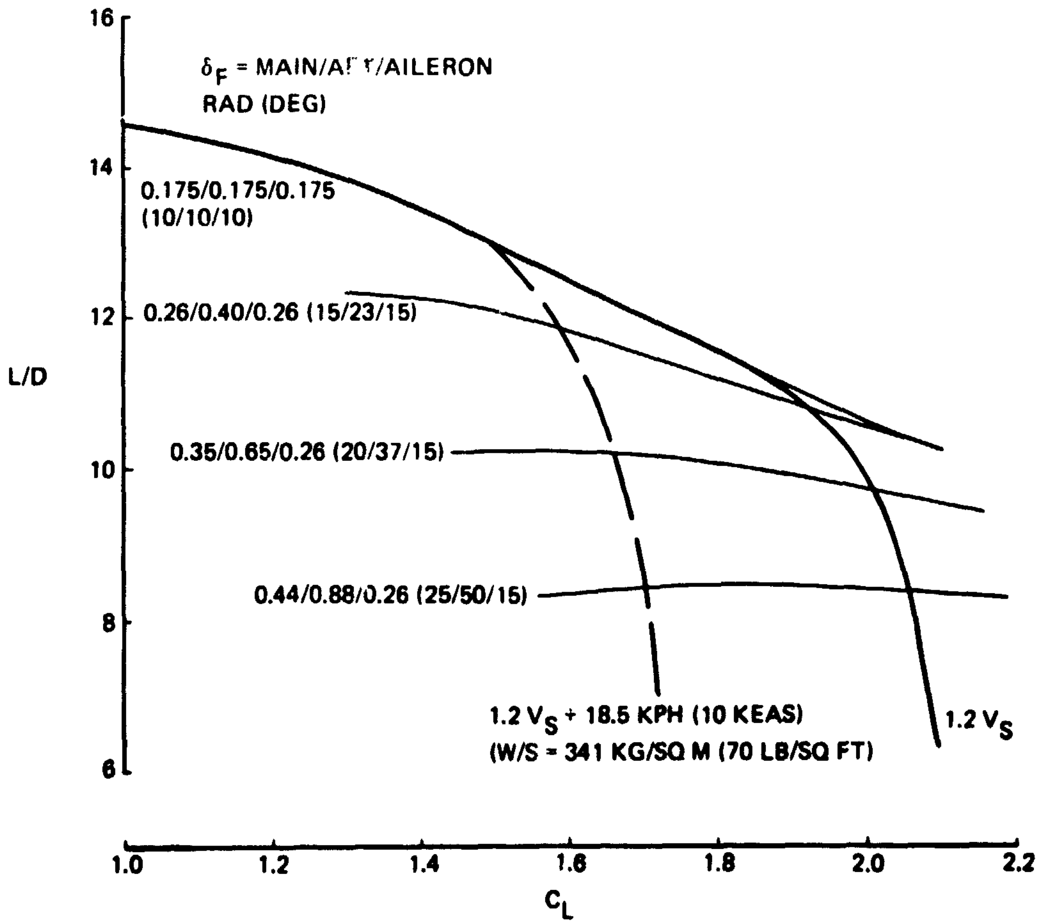


Figure 157 Advanced Short-Haul Low-Speed Takeoff Performance Envelopes

MODEL 767-845B
TRIMMED
C_g AT 0.12 MAC
GEAR DOWN
THRUST EFFECTS FOR LEVEL FLIGHT
S_{REF} = 56.3 SQ M (606 SQ FT)

$\Lambda_{C/4}$ = 0.08 RAD (4.55 DEG)

AR = 10.0

$C_{D_{P_{MIN}}}$ = 0.0247

$\Delta C_{D_{GEAR}}$ = 0.037

$C_{L_{MAX_{IG}}} / C_{L_{MAX_{WT}}}$ = 1.10

$C_{L_{S_{FAR}}} / C_{L_{MAX_{IG}}}$ = 1.10

HIGH-LIFT SYSTEM

- NO WING LEADING EDGE DEVICES
- DOUBLE-SLOTTED FOWLER TRAILING-EDGE FLAPS
  - C_F/C = 0.35
  - C_F'/C = 0.376
  - C'/C = 1.362
- AILERON DROOP TO 0.26 RAD (15 DEG)

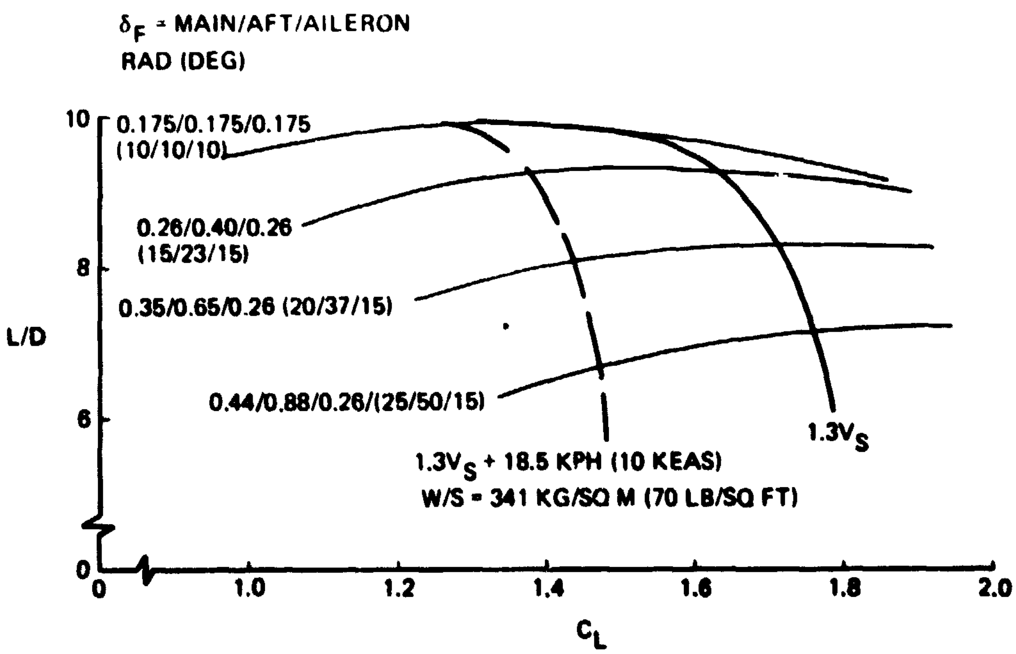


Figure 158 Advanced Short-Haul Low-Speed Landing Approach Performance Envelopes

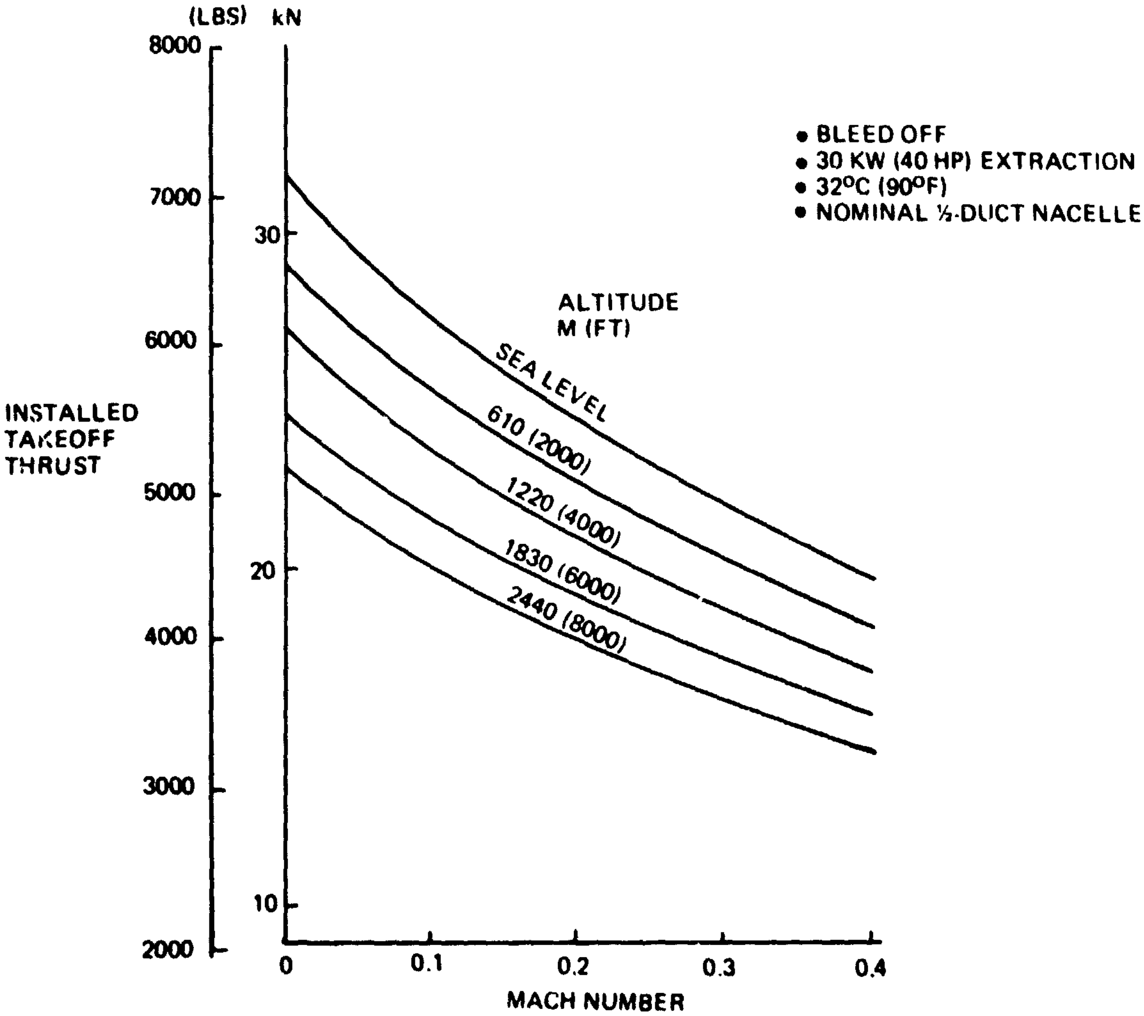


Figure 159 CF-34 Installed Takeoff Performance

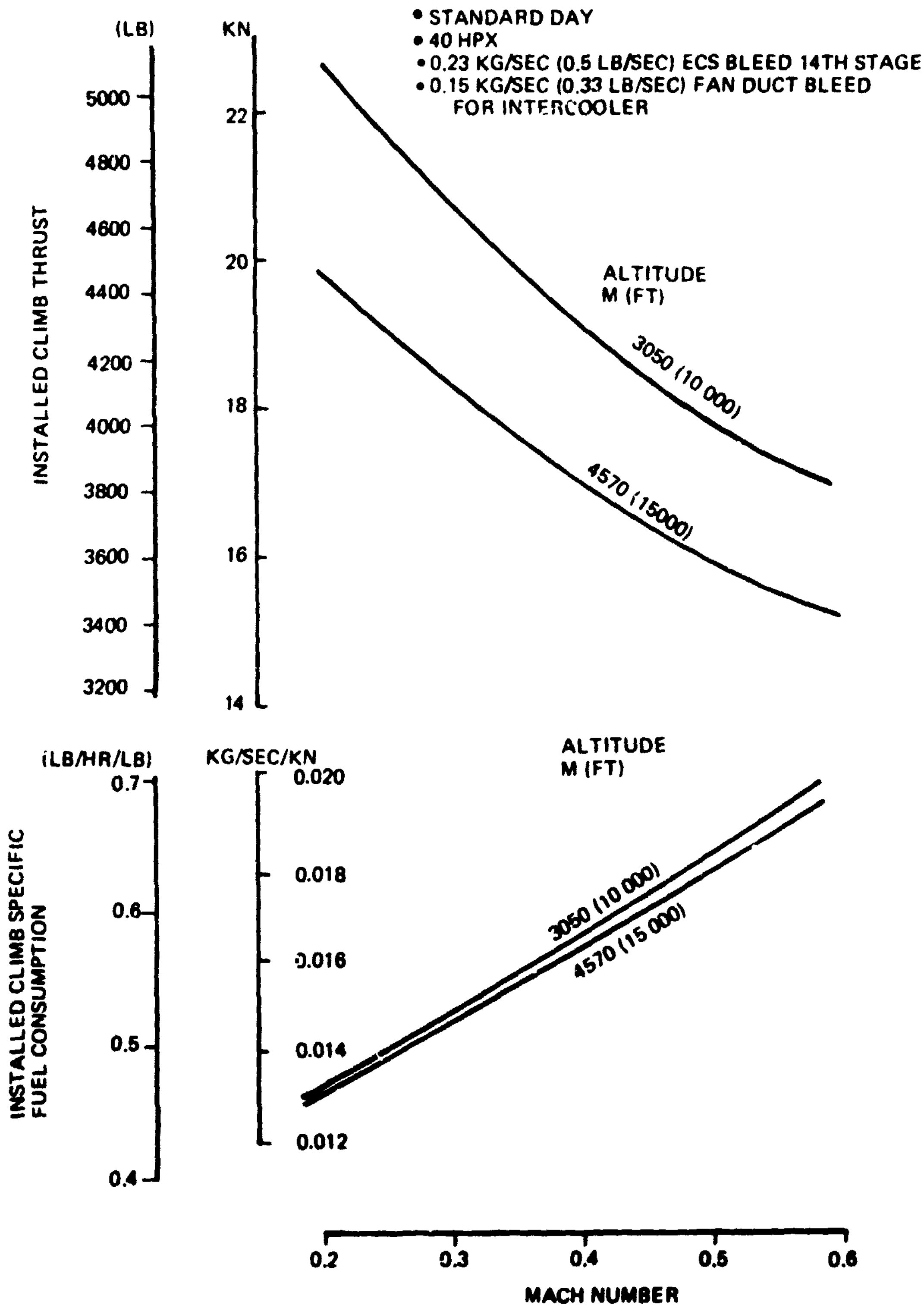


Figure 160 CF-34 Installed Climb Performance

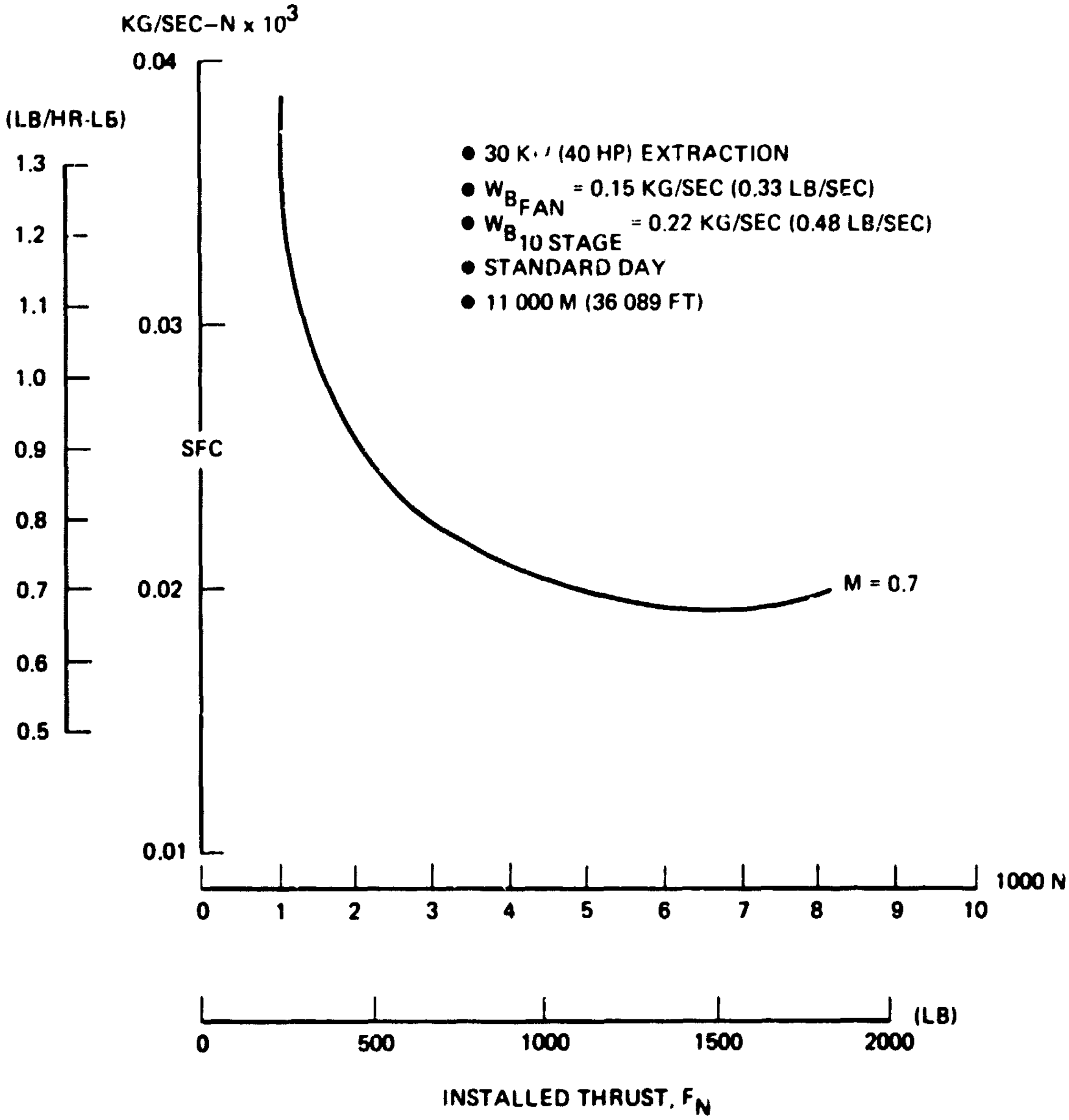


Figure 161 CF-34 Installed Cruise Performance

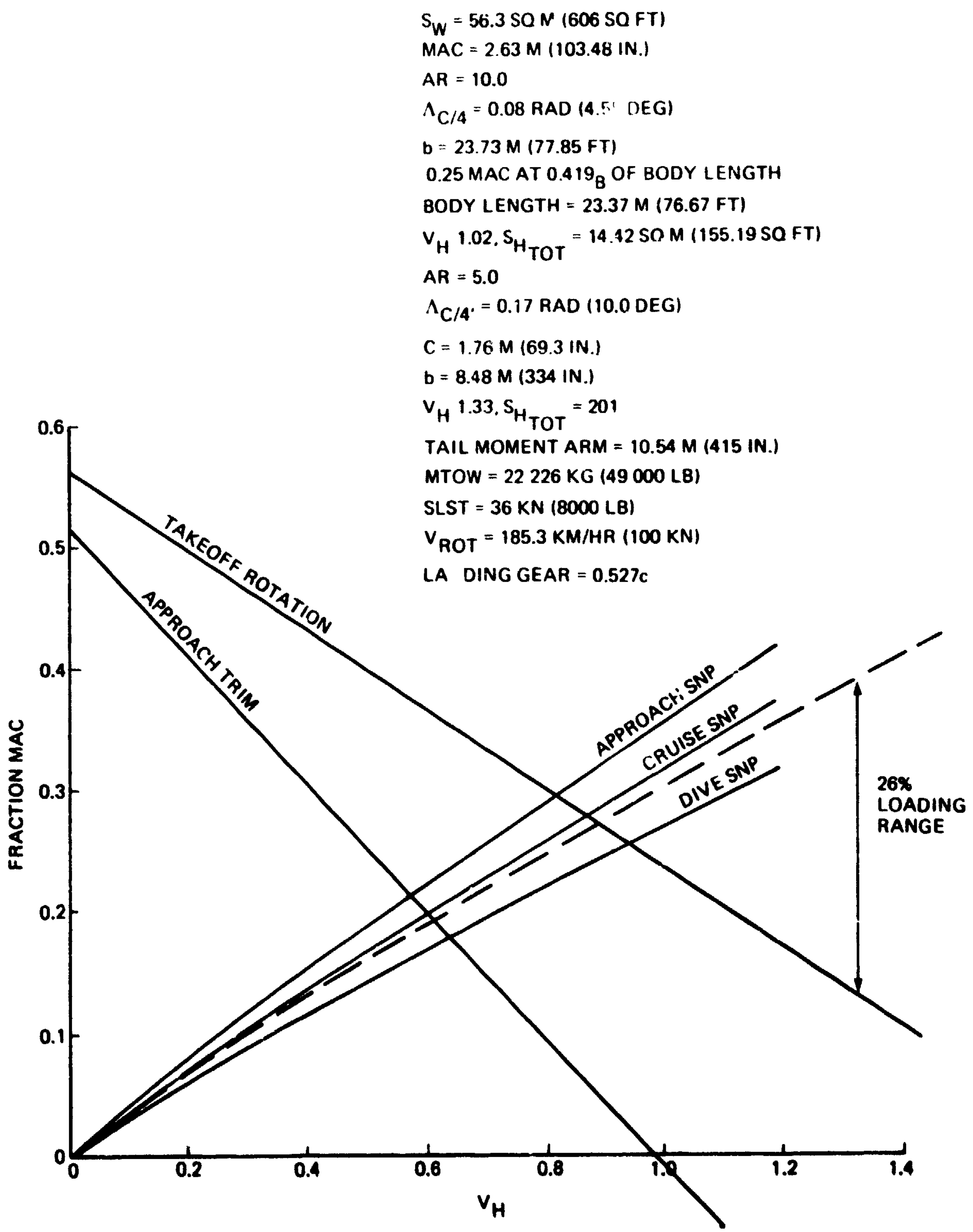


Figure 162 Advanced Short-Haul Horizontal-Tail sizing Requirements

Table 27 Noise Characteristics

MEASURING POINT	ALTITUDE		SPEED		NOISE, EPNdB	PROPOSED RULE NPRM 75-37C, EPNdB
	m	ft	km/hr	ktas		
Takeoff (no cutback)	785	2570	235	127	84.0	89.0
Sideline	245	800	235	127	85.5	94.0
Approach	120	394	239	129	96.0	98.0

Note: Nominal noise estimates are shown; appropriate design/demonstration tolerance required for certifiable/guarantee levels.

7.4.5 MISSION ANALYSIS

Detailed mission analysis for model 767-845B is documented in this section. The 50-passenger, 1390-km (750-nmi) mission required 3.7% more block fuel and an 0.7% increase in TOGW over that estimated by the parametric thumbprint method. The mission analysis flight profile and rules are shown in figure 163 and general airplane characteristics and performance are shown in table 28. The payload-range capability is illustrated in figure 164. TOGW, block fuel, and block time versus still air range are shown in figure 165.

The off-design range capability is limited by the fuel volume limit at about 90% maximum payload. All limit off-design missions were flown at a cruise altitude of 10 670 m (35 000 ft). Extension of the fuel tanks past the engine strut to the third outboard rib station would add approximately 1300 kg (3000 lb) additional fuel capacity. This would allow the fuel volume break to accur at 60% payload and increase range approximately 740 km (400 nmi) at 60% payload. Additional volume and range might be obtained by installing tanks in the wing-body fairings.

The advanced short-haul airplane, model 767-845B has a fuel utilization of 0.033 kg (0.136 lb) fuel/passenger mile for the design mission.

7.4.5.1 Mission Rules and Reserves

The mission profile and rules depected in figure 163 are based upon previous studies of short-haul operations. These rules meet current FARs and provide substantial reserve margins for the local service short-haul segments. The alternate 185 km (100 nmi) mission used in the reserve allowance was calculated with a climb and descent speed schedule identical to that used for the main mission. The alternate mission peak altitude with a payload of 4500 kg (10 000 lb) is 7320 m (24 000 ft), with 74 km (40 nmi) flown during the climb and the remaining 110 km (60 nmi) flown during descent and approach. The equivalent range of the enroute cruise allowance of 0.75 hours is 556 km (300 nmi). A plot of reserve fuel requirements for the rules defined in figure 163 is shown in figure 166. The design mission requires a total reserve fuel allowance of 1198 kg (2641 lb).

7.4.5.2 Mission Block Fuel and Block Time

Mission block fuel and block time for the 100% and 60% maximum payload (fig. 165) are at slightly higher levels than those shown on the thumbprint design selection chart. This difference is attributed to the slightly different climb and descent performance characteristics for the 767-845B airplane relative to earlier allowance estimates from other airplane studies. The 767-845B uses a quantity of fuel equal to approximately 3% of the TOGW to climb to cruise altitude. This climb fuel increase relative to the 2.6% TOGW quantity used in the "thumbprints" allowed the airplane to fly at a higher initial cruise altitude for the design mission at a slightly lower initial Mach number (0.68).

All mission range data were calculated for a standard day and those exceeding 460 km (250 nmi) were flown at 10 670 m (35 000 ft) at a Mach number = 0.70. Shorter ranges were flown at an altitude and Mach number that kept the cruise portion of the mission a small percentage of the total range. The flight profile procedure approximates a climb-descent profile for missions of less than 460 km (250 nmi).

Table 29 is a design mission summary and detailed breakdown in segment legs, distance, time, fuel, speed, altitudes, and weights. Table 30 lists the block fuel and block time for several still-air ranges with a design payload of 4540 kg (10 000 lbs) and 50 passengers. A common climb descent speed schedule (table 31) was used for all mission and reserve segment distances.

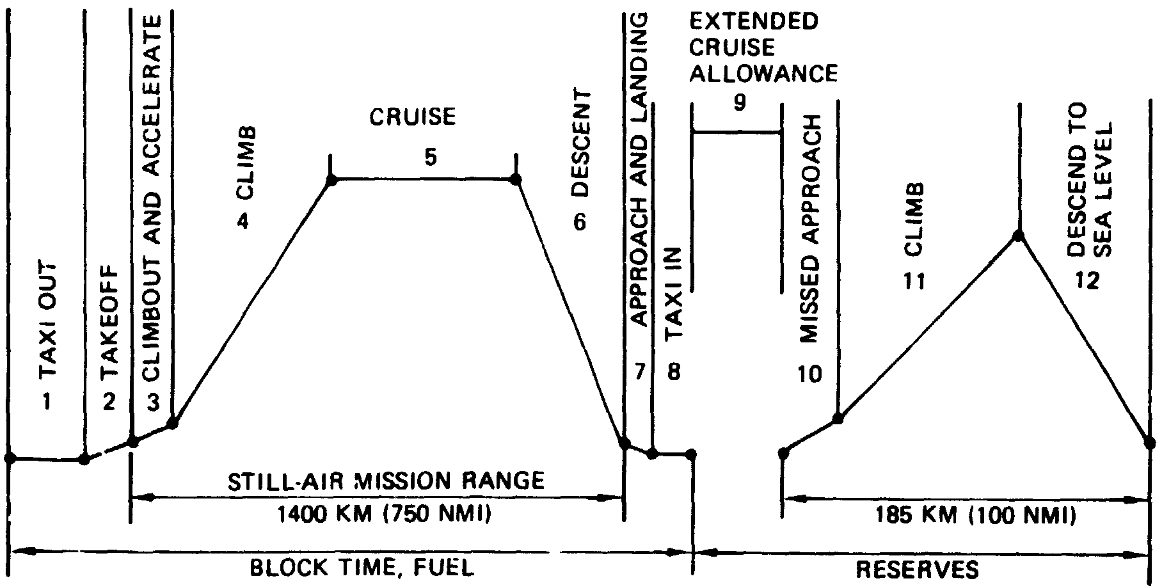
A common climb and descent speed schedule study was used for the 50-passenger 1390 km (750 nmi) design mission. This was done to check the validity of the initial speed schedule shown in table 31 and figure 163. Increments in climb and descent speeds of 334 to 482 km/hr (180 to 260 keas) in combination with Mach numbers of 0.55 to 0.70 were analyzed in the mission analysis program. The results showed that the base common-speed schedule of 408 km/hr (220 keas) and 0.60 Mach was within 0.2% of the minimum block fuel and 1% of the minimum block time.

The takeoff performance for model 767-845B airplane is shown in figures 167 and 168. Takeoff field length for a 32°C (90°F) day versus brake release gross weight (fig. 167) was calculated with APR available and air conditioning off. The off-design takeoff performance described in figure 168, field length versus field elevations shows that a full payload-range mission can be flown from the majority of the airports served by the regional airlines on a 32°C (90°F) day. The short-haul airplane flown with a full payload for a stage length of 1100 m (600 nmi) can operate out of approximately 90% of the same set of airports. Gunnison, Colorado, one of the most difficult airports to operate from due to its high density altitude, limits the takeoff gross weight on a 32°C (90°F) day to about 18 640 kg (41 100 lb). This gross weight would allow a payload of 25 passengers to be flown 556 km (300 nmi).

The design mission breakdown (table 29) shows the relative time, fuel, and distance for the various mission segment legs. The initial cruise range factor was approximately 14 800 km (8000 nmi). At 10 660 m (35 000 ft) ICA the available cruise thrust limits the Mach to 0.687. Cruise speed is adjusted to Mach 0.70 within the first 315 km (170 nmi) of the cruise leg and is held constant at Mach 0.70 for the remainder of the cruise segment.

Table 28 Advanced Short-Haul 767-845B, Characteristics and Performance

TOGW	22 298 KG (49 168 LB)
OEW	14 317 KG (31 570 LB)
BLOCK FUEL	2313 KG (5101 LB)
RESERVES	1195 KG (2641 LB)
MISSION LANDING WEIGHT	20 050 KG (44 211 LB)
WING	
S_w/b_w/MAC	56.3 M^2/23.71 m/62.63 m (606 FT^2/77.8 FT/8.62 FT)
$AR/\Lambda_c/\lambda/t/c_{(R/T)}$	10/0.79 RAD/0.25/15/12% (10/4.55 DEG/0.25/15/12%)
EMPENNAGE	
$S_H/L_H/V_H$	18.23 m^2 /10.62 m/1.334 (200 FT^2/34.85 FT/1.334)
$S_v/L_v/V_v$	13.04 m^2/10.21 m/0.101 (143 FT^2/33.5 FT/0.101)
BODY LENGTH/DIAMETER	23.38 m/3.0 m (76.7 FT/118 INCHES)
PROPULSION	
ENGINE TYPE/NO. BPR	CF-34/2/6.3
$SLST_{UNINST}$	35.6 KN (8000 LB)
T/W	0.33
W/S	393 KG/m^2 (80.6 LB/FT^2)
ICAC/MACH	10 670 m (35 000 FT)
AVERAGE CRUISE ALTITUDE/MACH	10 670 m (35 000 FT)
RF	14 520 Km (7840 NMI)
$L/D/C_L/C_D$	13.4/0.44/0.0328
SFC	0.0196 KG/SEC-KN (0.69 LB/HR-LB)
$C_{D_{P_{MIN}}}$	0.02460
FAR TOFL, SL (90°)	1295 m (4250 FT)
$C_{L_{V2}}/L/D_{V2}/V_2$	206 KPH (1.95/10.1/111 KEAS)
$C_{L_{APP}}/L/D_{APP}/V_{APP}$ (1.3V_s)	1.53/7.66/206 KPH (1.76/7.15/111 KEAS)
OEW/TOGW	64.2%
PL/TOGW	20.3%
RES/TOGW	5.4%
(M) L/D_c	9.4



1. Taxi Out
   - 5-min taxi thrust
2. Takeoff
   - Field length performance per FAR Part 25, sea level, 32°C (90°F)
   - To +11 m (+35 ft) at sea level
   - 1-min takeoff thrust
3. Climbout
   - Climb to 457 m (1500 ft)
   - Accelerate to climb speed of 407 km/hr, 220 keas 457 m (1,500 ft)
4. Climb
   - 407 km/hr, 220 keas/0.60 M
   - Accelerate to cruise Mach number
5. Cruise
   - Initial cruise—determined by level flight, maximum cruise thrust, at altitude cruise Mach
   - Procedure—constant cruise altitude
   - Cruise at 0.70 M
6. Descent
   - Decelerate to descent Mach
   - Descend at 0.60 M/220 keas
7. Approach and Landing
   - From 15 m (50 ft) to sea level
8. Taxi In
   - 4-min taxi thrust

Reserves

9. Extended cruise allowance
   - 0.75 hr at end of cruise, weight, and best altitude and Mach number
10. Missed Approach
    - 2-min at takeoff power
11. Climb
    - 407 km/hr (220 keas)/0.60 M
12. Descend
    - 0.60 M/407 km/hr (220 keas)

Figure 163 Flight Profile, 767-845B Mission Analysis Rules

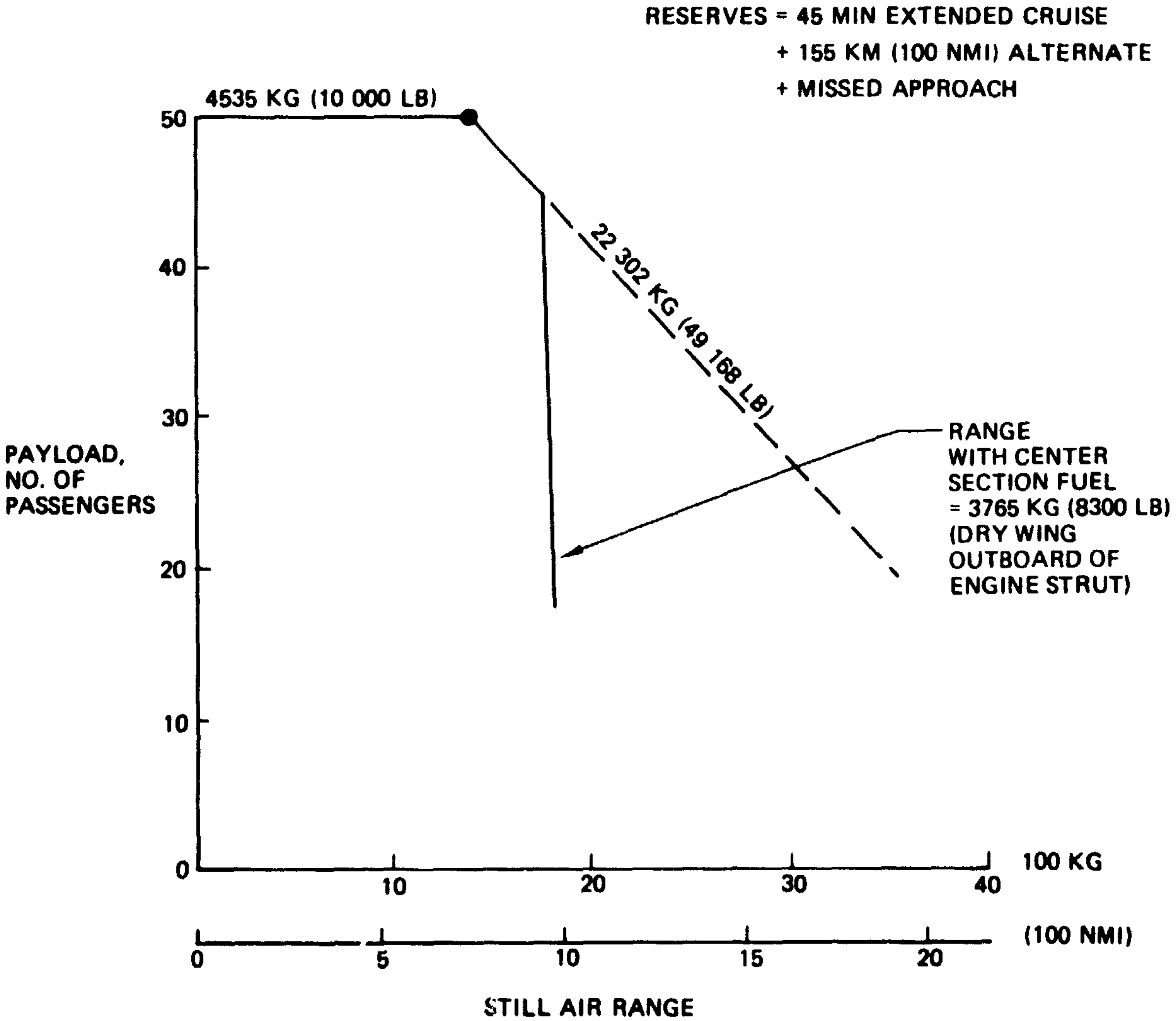


Figure 164 Short-Haul Model 767-845B, Payload vs Range

An airfoil with a higher design C_L, together with a higher wing loading, could provide a significant improvement in cruise range factor (5 to 10%). This would reduce the block fuel about the same amount, 5 to 10%.

The design mission of 50 passengers and 1390 km (750 nmi) has a fuel-burned efficiency of 0.033 kg (0.136 lb) fuel burned/passenger km (nmi). The average specific range at 10 660 m (35 000 ft) and Mach 0.70 is 703 km/kg (0.172 nmi/lb). At a mission distance of 370 km (200 nmi), the fuel usage increases 32% to 0.44 kg (0.18 lb)/passenger km (nmi).

Table 29 Summary Data for Design Mission

Ramp weight	22 339 kg (49 248 lb)	Block fuel	2314 kg (5101 lb)
Break release gross weight (TOGW)	22 302 kg (49 168 lb)	Extend cruise time	0.75 hr
Payload	4536 kg (10 000 lb)	Still air range (SAR)	1400 km (750 nmi)
OEW	14 320 kg (31 570 lb)	End cruise speed	747 km/hr (403.5 ktas)
OEW + payload	18 856 kg (41 570 lb)	Block time	2.25 hr

Extended cruise fuel	752 kg	(1658 lb)
Flight to alternate fuel	446 kg	(983 lb)
Reserves total	1198 kg	(2641 lb)

LEG NO.	LEG NAME	DISTANCE km	DISTANCE nmi	TIME, hr	INITIAL WEIGHT kg	INITIAL WEIGHT lb	INITIAL MACH	INITIAL ALTITUDE m	INITIAL ALTITUDE ft	FINAL WEIGHT kg	FINAL WEIGHT lb	FINAL MACH	FINAL ALTITUDE kg	FINAL ALTITUDE lb	FUEL WEIGHT kg	FUEL WEIGHT lb
1.	Taxi out	–	–	0.083	22 339	49 248	–	–	–	22 302	49 168	–	–	–	37	79
2.	Takeoff	–	–	0.017	22 302	49 168	–	–	–	22 260	49 074	–	–	–	42	95
3.	Climb out Accelerate	2.6 2.8	1.4 1.5	0.012 0.009	22 260 22 228	49 074 49 004	0.182 0.186	11 460	35 1500	22 228 22 205	49 004 48 954	0.186 0.342	460 460	1500 1500	32 23	70 50
4.	Climb Accelerate	241.7 53.3	130.5 38.8	0.416 0.077	22 205 21 540	48 954 47 488	0.342 0.600	460 10 670	1500 35 000	21 540 21 450	47 798 47 290	0.600 0.688	10 670 10 670	35 000 35 000	665 90	1466 198
5.	Cruise	911.9	492.4	1.226	21 450	47 290	0.687	10 670	35 000	20 154	44 431	0.700	10 670	35 000	1296	2859
6.	Decelerate Descent	8.7 159.5	4.7 86.1	0.013 0.302	20 154 20 150	44 431 44 425	0.700 0.600	10 670 10 670	35 000 35 000	20 150 20 070	44 425 44 245	0.600 0.352	10 670 460	35 000 1500	4 80	6 180
7.	Approach	8.5	4.6	0.029	20 070	44 245	0.241	460	1500	20 054	44 211	0.234	11	50	16	34
8.	Taxi in	–	–	0.067	20 054	44 211	–	–	–	20 025	44 147	–	–	–	29	64

Table 30 Block Fuel and Block Time

STILL-AIR RANGE km	STILL-AIR RANGE nmi	TOGW kg	TOGW lb	BLOCK FUEL kg	BLOCK FUEL lb	BLOCK TIME hr	CRUISE ALTITUDE m	CRUISE ALTITUDE ft	CRUISE MACH	% DISTANCE IN CRUISE
1390	750	22 506	49 618	2314	5101	2.250	10 670	35 000	0.70	65.7
1020	550	21 751	47 953	1763	3886	1.741	10 670	35 000	0.70	54.9
650	350	21 207	46 753	1218	2685	1.240	10 670	35 000	0.70	32.5
460	250	20 938	46 160	950	2095	0.989	10 670	35 000	0.70	8.0
370	200	20 804	45 865	814	1795	0.847	9140	30 000	0.65	20.2
200	108	20 526	45 252	536	1181	0.582	7320	24 000	0.52	0.0

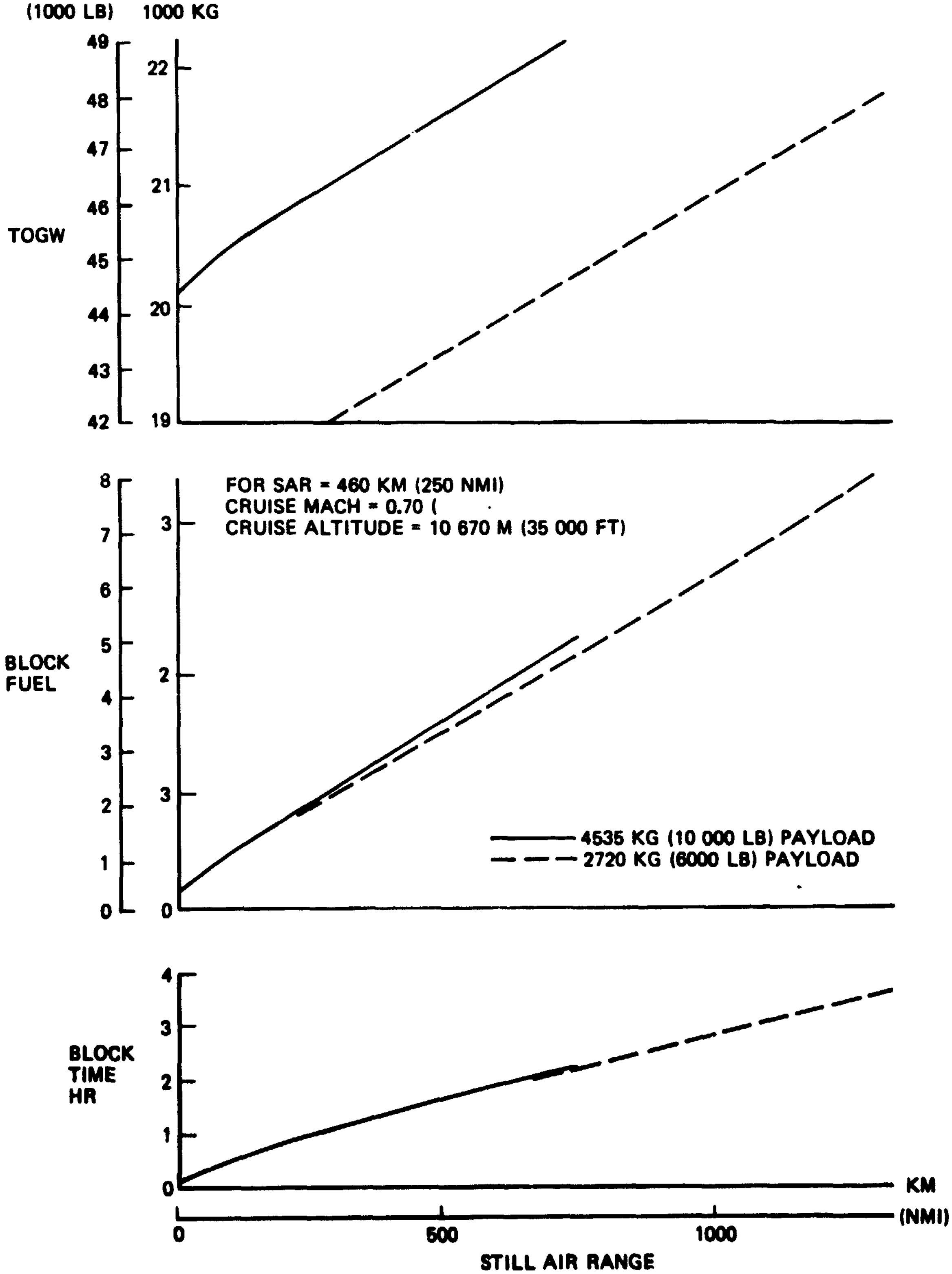


Figure 165 767-845B Mission Block Fuel and Time

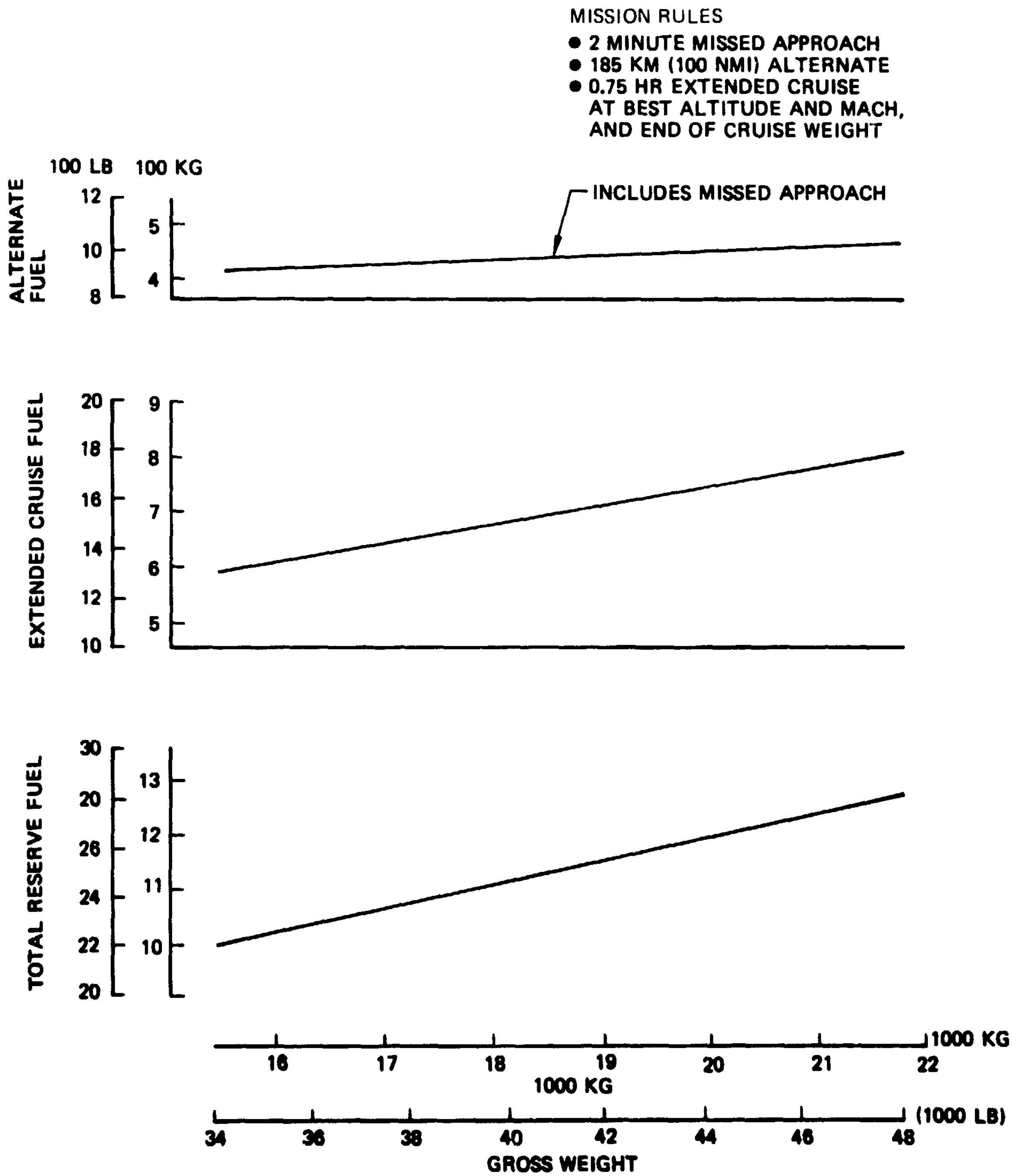


Figure 166 767-845B Reserves

Table 31   Climb and Descent Speed Schedule

SEGMENT I	SPEED		ALTITUDE
Climb Accelerate	410 km/h (220 keas) 0.60 Mach	– 0.60 Mach – Cruise Mach	460 m (1500 ft) - Cruise Cruise
Decelerate Descent	Cruise Mach 0.60 Mach	– 0.60 – 410 km/h (220 keas)	Cruise Cruise - 460 m (1500 ft)

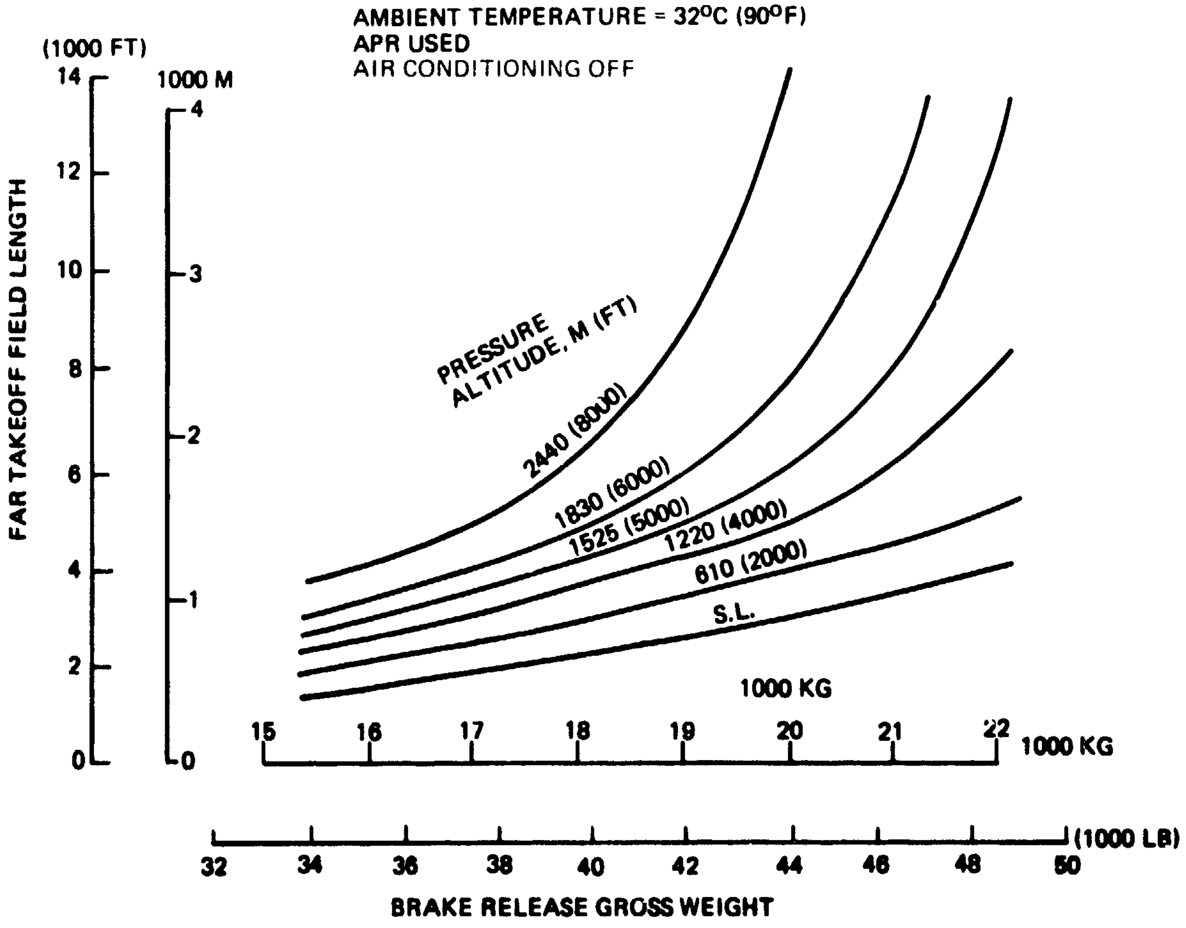


Figure 167   767-845B Takeoff Performance

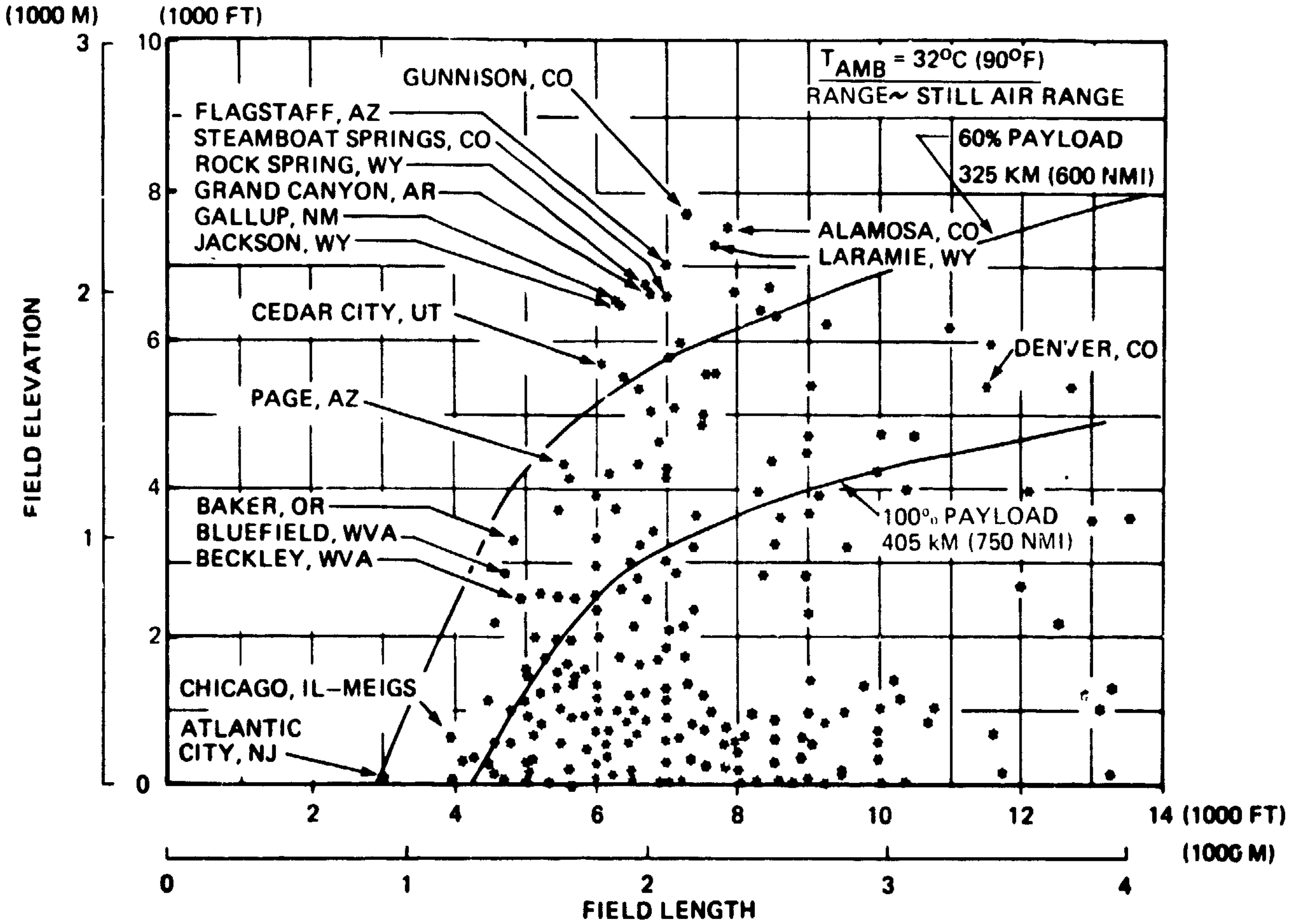


Figure 168. Advanced Short-Haul Transport Takeoff Field Performance

7.5 OPERATING ECONOMICS

7.5.1 OPERATING COST ELEMENTS

Direct operating costs (DOC) were calculated using 1977 local-service-airline cost coefficients and preliminary computer-generated thumbprint performance data. An airplane study price was used to approximate the influence of airplane investment on the airplane operating cost. Table 32 lists the basic ground rules for the Boeing 1977 DOC coefficients and table 33 compares the 1967 ATA and the 1977 Boeing DOC formulas. Engine-maintenance costs for the high-bypass TF-34 engines were calculated from previous high-bypass cost data. Mission profile and reserve rules are provided in figure 35.

Figure 134 presents the DOC elements for a 270-km (150-nmi) trip as a percent of total DOC, using 1977 rules and an airplane study price of $5 million, which is the target price for the current configuration. The actual airplane price, and cost, is indeterminate until all cost reduction studies are completed. Airplane maintenance is the most costly element; on a percentage basis, reductions in maintenance cost will provide almost twice the payoff in total DOC as compared to either fuel cost or depreciation. Noteworthy is that high-bypass-engine maintenance amounts to almost half the total maintenance cost. Through engine operating experience, it has been found that high-bypass-engine maintenance is significantly reduced when the engines are operated at reduced thrust. Trade studies evaluating installed thrust, required thrust, and engine maintenance for optimum total DOC are recommended.

Table 32 Basic Characteristics of Boeing 1977 DOC Coefficients

Applicability	U.S. local service, U.S. domestic trunk, U.S. international trunk
Mission profile	1967 ATA with revised taxi, air maneuver, and airway distance factors
Utilization	Approximately 95% 1967 ATA
Cruise procedure	Minimum cost constant M, step climb
Crew expense	Function of gross weight and speed
Fuel price	35¢/gal. U.S. domestic, 42¢/gal. U.S. intercontinental
Maintenance	Mature level maintenance based on detailed analysis Engine line maintenance labor is included in engine maintenance Labor rate = $9.70 manhour Burden = 200% of direct labor
Depreciation	15 years to 10% on airplane and spares
Insurance	0.5% year based on flyaway price
Spares	6% airframe price 30% engine price
Nonrevenue factor	2% added to fuel and amintenance for nonrevenue flying

Table 33 Domestic DOC Formula (Turbofan)

	ATA 1967	BOEING 1977
Crew pay		
2-man crew	0.05 (TOGW/1000) + 100.00	$(29.67\ F_W + 2.838)\ F_W + 19.80$
3-man crew	0.05 (TOGW/1000) + 135.00	$(33.54\ F_W + 3.483)\ F_W + 29.70$
Fuel ($/U.S. gallon)	0.10	0.35
Nonrevenue factor	1.02 on fuel	1.02 on fuel and maintenance
Maintenance formulas for perametric analysis only		
Airframe maintenance (cycle) [1]	$6.24\ Ca/10^6$	
Material ($/CYC)		0.260 (Wa/1000)
Direct labor (MH/CYC)	$0.05\ \frac{Wa}{1000} + 6 - \frac{630}{\frac{Wa}{1000} + 120}$	$0.07345\ (Wa/1000)^{0.7908}$
Airframe maintenance (hourly) [1]		
Material ($/FH)	$3.08\ Ca/10^6$	0.208 (Wa/1000)
Direct labor (MH/CYC)	$(0.3 + 0.037/10^3)$ Ne	0.35 Ne
Engine maintenance (cycle) [1]		Low bypass
Material ($/CYC)	$20.0\ (Ce/10^6)$ Ne	[0.145 (T/1000) + 4.60] Ne
Direct labor (MH/CYC)	$(0.3 + 0.37/10^3)$ Ne	0.50 Ne
Engine maintenance (hourly [1]		Low bypass
Material ($/FH)	$25.0\ (Ce/10^6)$ Ne	[0.135 (T/1000) + 6.80) Ne
Direct labor (MH/FH)	$(0.6 + 0.27T/10^3)$ Ne	
Burden (MM/direct labor MH)	1.8	2.0
Maintenance labor rate ($/MM)	4.0	9 70
Investment spares ration		
Airframe	0.10	0.06
Engine	0.40	0.30
Depreciation schedule (years/% residual)	12/0	15/10
Insurance rate (% of total price/year)	2.0	0.5
Utilization (block (hours/year)	Curve: $U = \frac{\text{BLK HRS}}{\text{YR}}$ vs T_b	$U = \frac{4000}{1 + \frac{1}{T_b + 0.05}} + 630$ (15 trips/day maximum)

Ca – airframe price ($)
Ce – engine price/engine ($) (excluding reverser)
CYC – cycle
FH – flight hours
MH – manhours

MH – manhours
Ne – no. of engines
T – sea level static thrust (lbs)
T_b – block time (hrs)

[1] 2% nonrevenue factor included in 1967 ATA maintenance equations

7.5.2 COMPARATIVE ECONOMICS

Airlines have particular system environments and the resulting operational requirements may significantly influence an economic comparison of one airplane with another. Airplane range and runway compatibility and enroute performance have economic worth that is a function of the particular route system; these differences are not appreciated in generalized operating-cost comparisons. Airplane design and operating differences must be recognized when comparing airplanes by price-per-seat, price-per-pound, or other unit pricing measures. However, comparing the direct operating costs of airplanes under generalized operating conditions based on reasonable, consistent ground rules provides one accepted measure of relative economic merit.

The 767-845B is compared in figure 169 with other airplanes on the basis of price per seat. These comparisons are based on standard seating configurations; however, seating equivalency at approximated equal passenger-comfort levels also must be considered. As an example, the VFW-614 is presented at 44 seats, which provides a seat pitch of 0.775 m (30.5 in.). The seating comfort might be more comparable at 40 seats at a pitch of 0.853 m (33.6 in.). At 40 seats, the VFW-614 price per seat increases from $105,000 to $116,000 (10.5%).

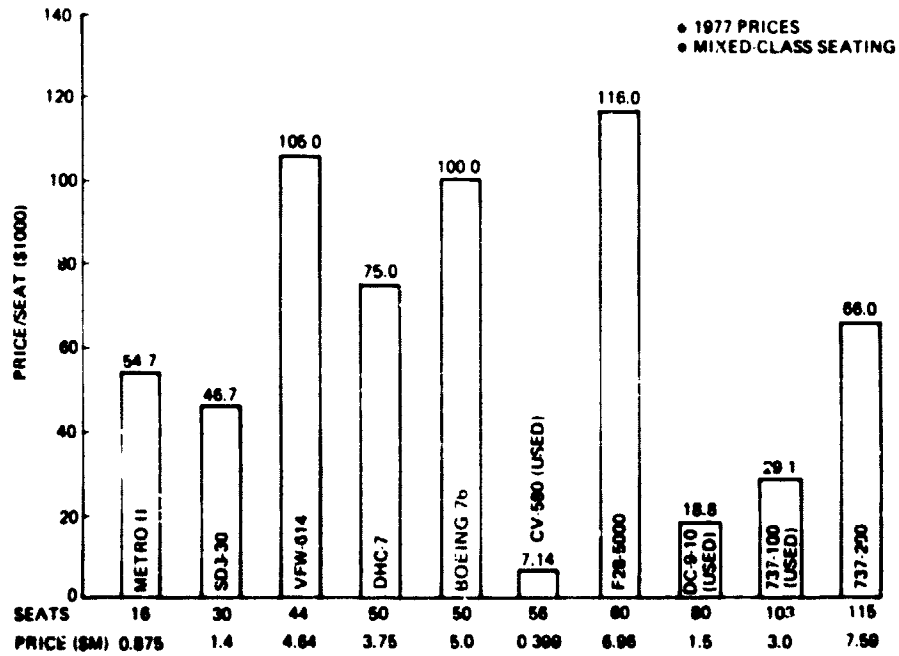


Figure 169 Price-per-Seat Comparison

Figure 170, 171, 172, and 173 are DOC comparisons of airplanes both by cost-per-mile and cost-per-seat mile. In these comparisons, it must be considered that the CV-580, DC9-10, and 737-100 are used airplanes at low prices and that the SD3-30 is an unpressurized, less sophisticated airplane. Figure 174 compares the airplanes on the basis of fuel efficiency.

Table 34 provides airplane DOC comparisons at the base 270-km (150-nmi) operating distance as well as a listing of DOC elements.

7.5.3 ECONOMIC SUMMARY

The 767-845B DOC estimates are very encouraging. The study airplane is competitive with current airplanes while possessing performance advantages that have economic value as a function of differing airplane operational requirements. Follow-on research to further reduce scheduled-service operating costs is recommended. Detailed trade studies between maintenance expense, performance parameters, and airplane price are required to optimize airplane economics for the design mission.

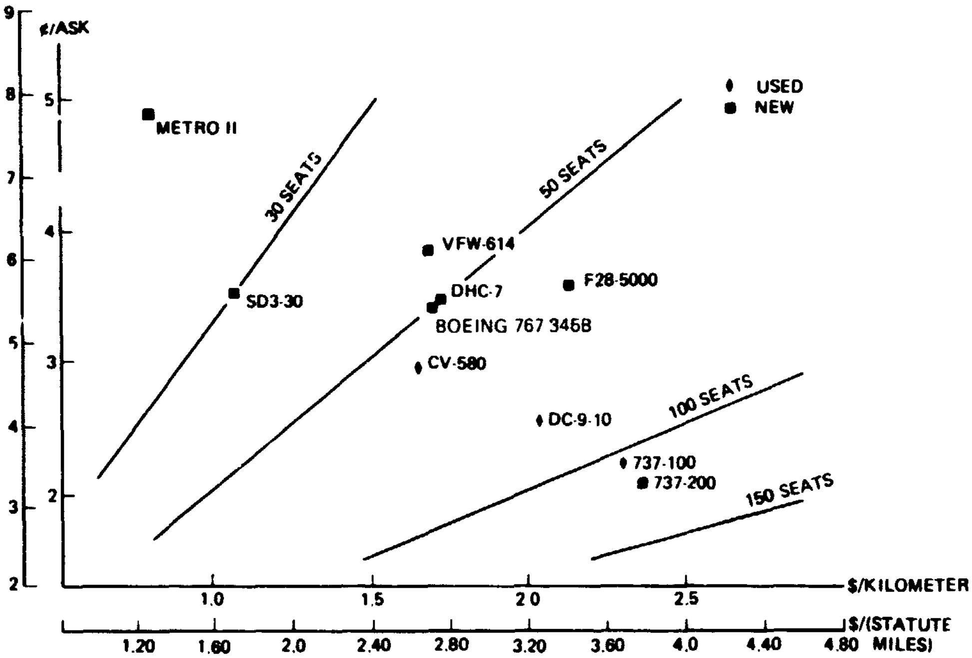


Figure 170 Direct Operating Costs, 1977 U.S. Domestic Rules, 280-km (150-nmi) Average Trip, 1977 Dollars

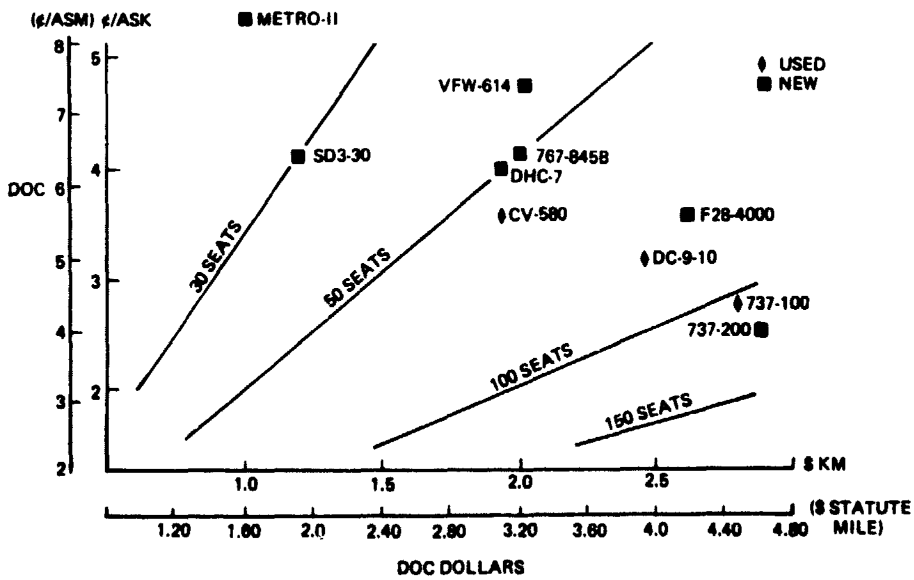


Figure 171 Direct Operating Costs, 1977 U.S. Domestic Rules, 185-km (100-nmi) Average Trip, 1977 Dollars

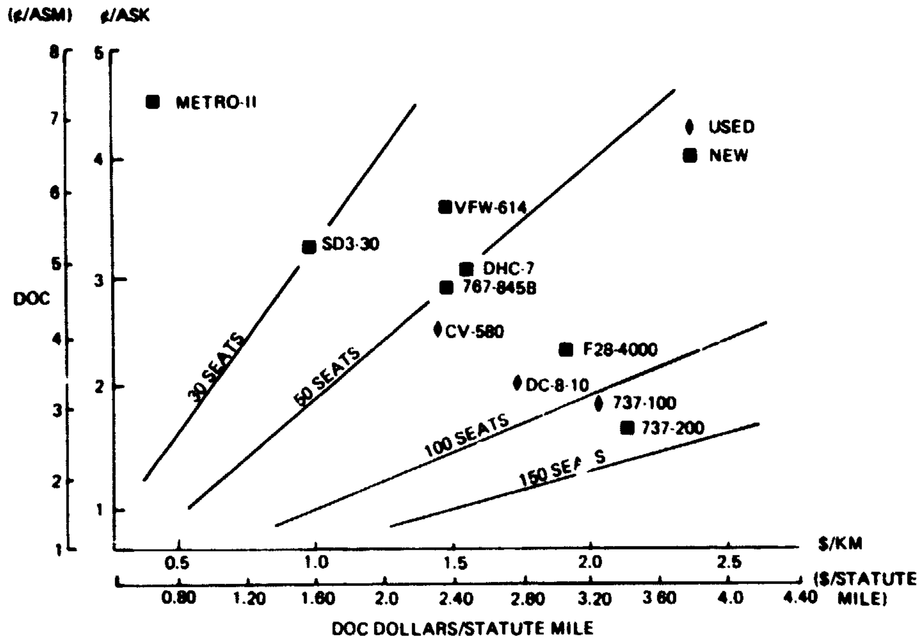


Figure 172 Direct Operating Costs, 1977 U.S. Domestic Rules, 660-km (300-nmi) Average Trip, 1977 Dollars

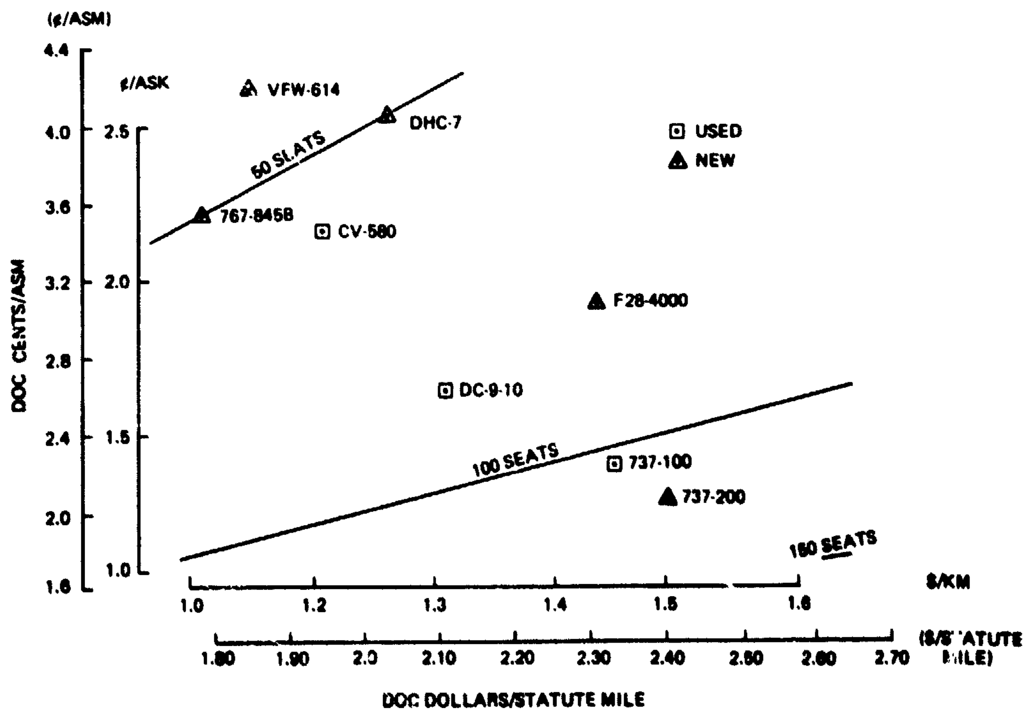


Figure 173 Direct Operating Costs, 1977 U.S. Domestic Rules, 925-km (500-nmi) Average Trip, 1977 Dollars

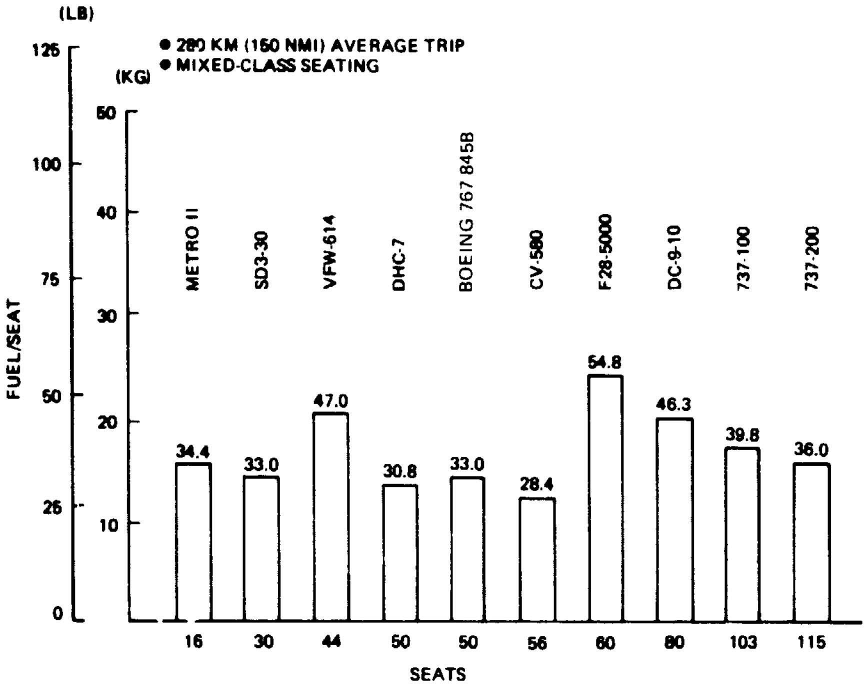


Figure 174 Fuel-per-Seat Comparison

Table 34 Direct Operating Costs

AIRPLANE IDENTIFIER	METRO II NEW	SD3-30 NEW	VFW-614 NEW	DHC-7 NEW	BOEING 767-845B	CV-580 USED
(No.) engines	(2)TPE-331	(2)PT6A-45	(2)RR M45H	(4)PT6A-50	(2)CF-34	(2)AL-501D
Study price, 1977 ($M)	0.875	1.45	4.64	3.75	5	4
Seats	16	30	44	50	50	56
Block fuel kg (lb)	250(550)	450(990)	940(2070)	707(1559)	753(1659)	720(1590)
Utilization at ATA range, nmi	150	150	150	150	150	150
a. hrs/trip (ATA)	0.82	1.07	0.7	0.930	0.72	0.79
b. hrs/year (adjusted)	2906	3073	2811	2983	2828	2883
trips/year	3543	2872	4016	3208	3928	3649
DOC elements, $ trip						
Crew	91.98	128.11	119.56	137.17	131.53	119.16
Fuel	29.31	52.75	110.30	83.07	87.92	84.72
Airframe direct maintenance						
Material	12.15	8.53	19.14	17.19	19.87	19.43
Labor	10.67	12.35	26.28	30.77	19.56	27.78
Engine direct maintenance						
Material	10.12	10.63	19,38	19.25	32.87	40.94
Labor	6.59	6.26	11.06	11.36	14.26	30.39
Burden	34.53	37.24	74.68	84 26	67.64	116.34
Insurance	1.23	2.52	5.78	5.84	6.36	0.56
Depreciation	16.37	33.81	77.33	77.46	84.72	15.78
Total	212.98	292.21	463.49	466.38	464.73	455.09
Dollars/statute mile	1.236	1.694	2.687	2.704	2.694	2.638
Cents/ASM	7.716	5.647	6.107	5.407	5.388	4.711

7.6 EVALUATION OF ADVANCED DESIGN FEATURES

Those features that showed promise for reducing initial and/or operating costs are evaluated for relative merit in the following section.

7.6.1 ADVANCED STRUCTURES AND LOW-COST DESIGN FEATURES

As part of Boeing's cost assessment of the Wichita MDT reference airplane, a part count and producibility assessment was made for this type of configuration. This assessment assumed a manufacturing technology and design sophistication very similar to the current Boeing commercial transport fleet. The partcount and complexity was high enough to raise the cost assessment to a level where the MDT was considered to risky for the potential market.

An analysis of the Wichita MDT identified high-cost areas which were studied to identify design improvements that would simplify the airplane and still meet the requirements for the potential market.

The result of that effort was the second reference airplane, the model 767-759B. This airplane could meet the manufacturing cost goals, but had inadequate overall performance. The best design features of both reference airplanes were combined using current assembly technology coupled with state-of-the-art metal bonding technology to significantly reduce the part count and assembly time of a short-haul airframe. Figure 175 shows the relative part counts between the MDT reference airplane, the conventional-technology baseline (model 767-774C), and the advanced-structures trade study airplane (model 767-774B). Note that the systems changes are not the result of simplification but the result of better configuration definition. As can be seen in figure 175, a very significant reduction in the estimated part count has been accomplished.

Only two of the four airplanes shown (see fig. 40) were costed using the same ground rules. These were the 767-774B and 767-774C, which had a 16% cost differential (total recurring cost).

7.6.2 ADVANCED AERODYNAMICS

As can be seen from previous sections of this study, the choice of airfoil section, wing loading, and high-life devices appears to be very important to a successful short-haul airplane. The baseline airplane (767-774A), using an airfoil with a design C_l = 0.57 (t/c = 0.12), optimized at higher wing loadings and produced better performance with a leading-edge device. The final airplane (767-845B), using a base airfoil whose t/c was closer to the average wing thickness and design C_l = 0.48 (t/c = 0.141), optimized at lower wing loadings where a leading-edge device is not required. An advanced airfoil should be designed to maintain the higher design C_l while maintaining the desired cruise Mach number capability at the higher thickness ratios. Obviously, additional trade studies are required in this area.

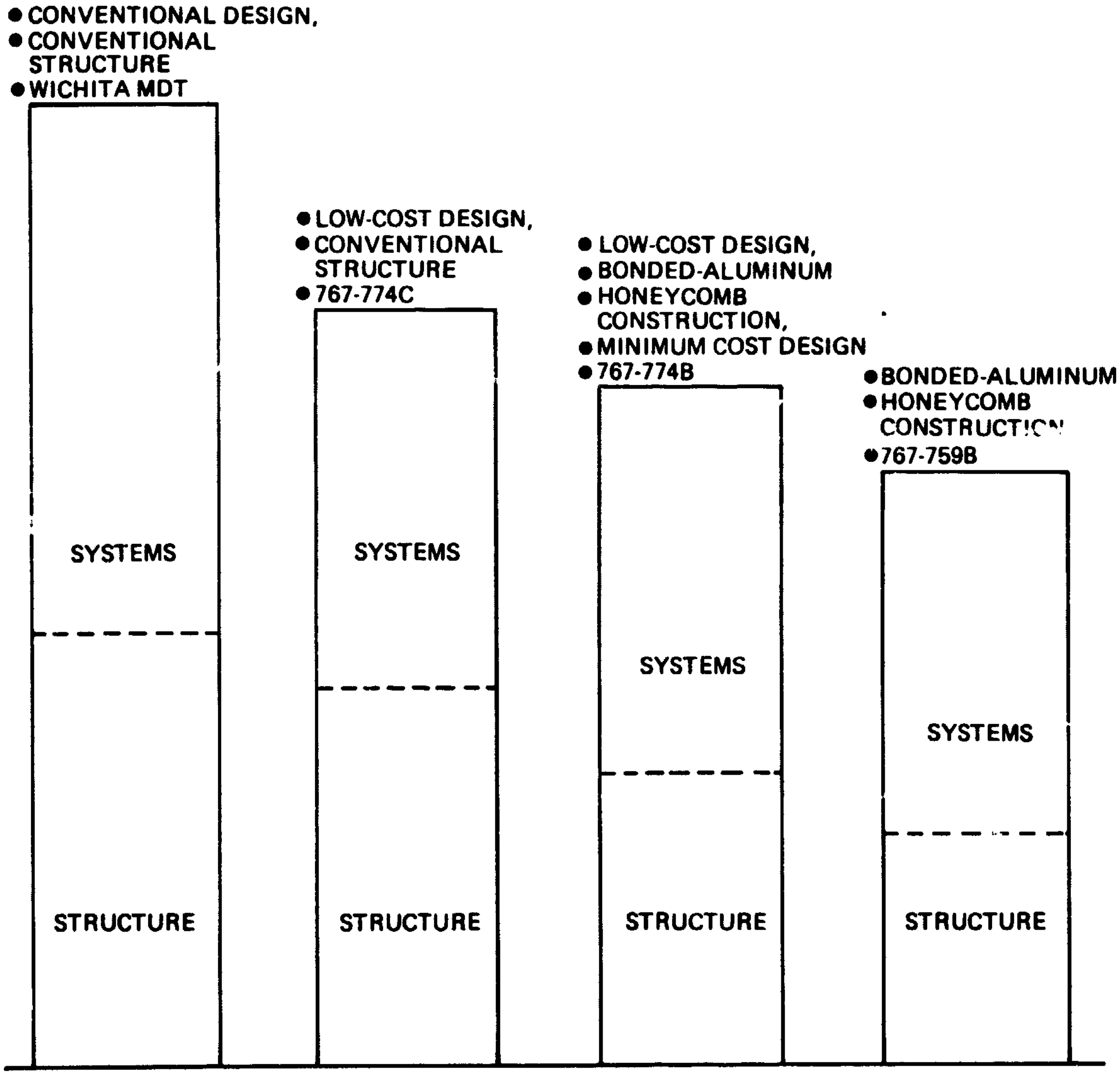


Figure 175 Part-Count Comparison

7.6.3 ADVANCED FLIGHT CONTROLS

Advanced flight controls items investigated included relaxed stability (aft c.g., and lifting tail), gust and maneuver load alleviation, ride control system (RCS), and use of a vee-tail configuration.

Of these items, the one that appears to have the most cost-effectiveness potential for use of small, short-haul airplanes is the Vee-tail. The horizontal and vertical tails are sized for maneuver, not stability; the structure is predominately minimum-gage construction so gust and maneuver load alleviation does not appear to produce much weight savings and wing loading appears to be high enough for reasonable ride comfort without a RCS.

Use of a Vee tail produces an estimated parasite drag reduction of almost 3% and total airplane cost reduction of 1%. If the airplane was sized to meet the same mission constraints with a Vee tail, the reductions in drag and cost would be even greater. Again, continued trade studies in this area are indicated.

7.6.4 ADVANCED PROPULSION

Use of an advanced turboprop (propfan) engine on a small, short-haul airplane on a typical 150 nmi flight appears to produce a savings in block fuel of 20 to 30%. This is equivalent to a 4 to 6% reduction in DOC, if all else is equal. This may not be the case. Under assumptions of this study, the airplane OEW has increased 3 to 4%, which increases airframe initial and maintenance costs; and propulsion system maintenance with an advanced turboprop engine is a major unknown. Current experience indicates a maintenance increase of over 10% for turboprop engines, while Hamilton Standard and Allison data for an advanced-technology-propfan propulsion unit indicate propulsion system maintenance might actually decrease slightly relative to an advanced turbofan (ref. 8). Note that 10% change in engine maintenance is almost equivalent to a 2% change in DOC for the current airplane.

The other advanced propulsion item, reduction of engine maintenance costs, must be considered. For the current airplane, a 20% reduction in maintenance cost could be worth an incremental million dollars in selling price. Obviously, engine and prop fan maintenance are high-leverage items and should be examined in greater depth.

7.6.5 ADVANCED SYSTEMS

The introduction of advanced bonded structures to reduce the airframe structure significantly has left systems as the largest category in airplane recurring costs (fig. 39 and 116). Obviously, systems are a prime candidate for cost reduction, but the advanced short-haul airplane has all current-technology systems. This is because in a preliminary design study of this type, the weight and costs of certain parts of the airplane are based on historical data and are not defined in detail. Systems fall into this category and current cost-estimating techniques use historical dollars-per-pound and hours-per-pound to estimate system costs.

To gain cost savings credit, advanced systems must be defined in much greater detail so that estimates of changes in weight and labor hours can be made. Because virtually all systems interact to some degree, the best results will be achieved when the airplane's systems are completely reworked, instead of approached piecemeal. A study of the aircraft systems is recommended in section 8.0

PRECEDING PAGE BLANK NOT FILMED

8.0 RESEARCH AND TECHNOLOGY RECOMMENDATIONS

Areas of technology that should be studied in more depth to further reduce the initial and operating costs of the small, short-haul transports are found in five major technology disciplines: airplane systems, aerodynamics, structures, propulsion, and noise. Although this study has used a short-haul transport as a basis for comparing cost/benefits of various technologies, these findings are applicable also to all civil transports in service to date. An outline of the recommended areas of study for these technologies is given below.

- SYSTEMS
  - Define the benefits of advanced technology airplane systems for reduced costs
    - Determine electric vs hydraulic and pneumatic cost trades
    - Develop flat panels/integrated cockpit displays
    - Develop mini-computer data transfer management (e.g., fiber optics)
    - Evaluate these three items for lowest initial and maintenance cost potential
- AERODYNAMICS
  - Develop airfoil designs appropriate for short-haul transport applications
  - Investigate alternate flight control concepts (e.g , Vee-tail and other multi-control surface concepts)
  - Study engine/airframe integration problems of proposed short-haul propulsion systems (e.g., propellers and high-bypass turbofans)
- STRUCTURES
  - Develop bonded-structure analysis tools
  - Validate analysis with tests of selected components
  - Establish inspection and repair techniques
  - Determine bond life under realistic environmental conditions
  - Develop structural integration of propulsion system and airframe
- PROPULSION
  - Study advanced turboprop, prop fans, and high-bypass ratio fans
  - Develop cost-effective on-board performance diagnostic systems
  - Study offset inlets for advanced turboprop blade system
  - Investigate integrated engine and flight control

- NOISE
  - Develop noise-reduction technology for curfew-free operation of short-haul transports

8.1 AIRPLANE SYSTEMS

Recognizing the high costs of airplane secondary power systems and the maintenance costs associated with them, an all-electric systems airplane has been proposed to meet the low-cost requirements of the study. The following trade studies are recommended to define the all-electric system:

- VSCF vs 270 Vdc electrical system
- Fly-by-wire and power-by-wire vs conventional control cables and hydraulic system
- Digital data management with microprocessors and fiber optics for communication links vs the conventional analog/electrical/mechanical communication links
- Redundancy in the fly-by-wire and power-by-wire flight control systems
- Flat panel multi-function displays vs conventional displays for the flight deck
- Emergency power system and requirements
- Environmental control system

The results of these and other studies will show cost comparisons of the all-electric vs the conventional system in use today.

8.2 AERODYNAMICS TECHNOLOGY

Several airfoil and wing design studies are proposed to take advantage of the potential technology to improve the short-haul airplane performance/operating economics. Specific wing/airfoil and aerodynamic/performance study items include:

- Wing-tip devices optimized for takeoff L/D improvement
- Appropriate airfoil design for short-haul design lift coefficient, Mach number and wing structure
- A compromised airfoil that maintains good high-speed drag characteristics while substantially improving the leading-edge stall angle obtainable without LE devices
- The effect of advanced airfoil design thickness on airplane weight and drag performed in conjunction with optimizing the wing spanwise thickness taper distribution
- Design and testing of low-drag airfoils (natural laminar flow) at full-scale flight design conditions (Re, M) using bonded-aluminum construction to build the full-size model
- Optimum integration of advanced turboprop/high bypass rario turbofan propulsion systems for high and low speed (especially takeoff and landing with engine out) flight regimes
- A conformal variable-camber leading-edge device designed to improve stall lift coefficient, help to maintain natural laminar flow at off-design conditions, and let flexing skin shed wing ice

Flight control studies should include the use of a Vee-tail, spoilers for roll control allowing trailing edge flaps to extend to full span, and the use of other multi-control concepts with their integrated effect while used with a fly-by-wire all-electric system powered airplane.

8.3 STRUCTURES TECHNOLOGY

The investigation of several bonded structure development tasks are required to widen the use of bonded metal structure in primary structure applications in commercial as well as military field.

These development tasks include the following:

- Stress analysis methodology and allowables
- Analysis verification testing
- Fatigue testing
- Crack propagation and fail safety
- Damage tolerances
- Corrosion test and prevention
- Lightning strikes and electromagnetic problems
- Sound attenuation
- Inspection repair/maintenance
- Durability
- Joint design
- Fastener installation

The structural integration of advanced propulsion concepts, (advanced propellers, high-bypass ratio turbofans), and the relative weight effect to the baseline concept should be studied. This study also should include the structural concept and weight trades when done for different materials, and construction techniques.

8.4 PROPULSION TECHNOLOGY

Advance propulsion system concepts and integrated propulsion design may provide substantial improvements in fuel burned levels and overall operating economics for the short-haul transport. Specific system concepts that should be considered are:

- Advanced turboprop, prop fans, and high bypass ratio fans
- The inlet total pressure recovery and flow distortion characteristics at the face of the turboshaft engine should be investigated for offset inlets in the flow field behind advanced turboprop blade systems
- Structural integration of engines and nacelles to improve initial TSFC and to reduce engine deterioration due to engine case distortions
- Integrated engine and flight controls to reduce pilot work load and improve engine and airframe performance
- On-board engine diagnostics system to aid in tracking and reducing maintenance costs

Short-haul transports, by virtue of their high-frequency of takeoff and landings and lower altitude operation, provide a more severe engine environment than do long-range aircraft. To obtain a low direct-operating-cost short-haul airplane, it will be necessary to minimize the influence of cyclic engine operation through improved engine operating techniques, improved engine nacelle structural integration, and improved engine monitoring. Selection of the engine configuration and engine cycle parameters also will have an important bearing on the system costs, and trades must be accomplished that balance fuel consumption against engine complexity and maintenance requirements.

8.5 NOISE TECHNOLOGY

The overall economic viability of the short-haul airplane may require a high utilization rate. The utilization rate may be increased by using the aircraft at night; however, night operations at many airports could require noise reductions to a level that make the airplane free of any curfew limits. A list of several technology study items that could reduce noise around the community area are:

- Jet Noise mixer/mixed flow and mechanical design
- Core and Turbine noise number of stages, high temperature linings
- Fan Noise Bypassing of boundary layer, noise/performance trades
- Inter-Relationship of Safety and Noise Abatement impact on certification

Technology efforts to achieve low noise should emphasize:

- Design of quiet propulsion pods with priority on part-power conditions
- Improved takeoff and landing aerodynamics
- Reduce core and fan noise through design and development of linings
- Innovative design and operational procedures

Passenger cabin and cockpit noise levels should be addressed complimentary to studying methods of reducing exterior noise.

REFERENCES

1. NASA CR 137605, *Analysis of Operational Requirements for Medium Density Air Transportation*, March 1975

2. D3-9861, Boeing Engineering Report, *Small Airplane Studies*, July 1975

3. D3-9692-1, Boeing Engineering Report, *Medium Density Transport Progress Review*, February 1975

4. NASA CR 137937, *Energy Consumption Characteristics of Transports Using the Prop-Fan Concept*, Final Report, October 1976

5. E1190A, *Model Specification, Engine, Aircraft, Turboshaft T64-GE-415*, General Electric, April 1973

6. Preliminary Data Pack, Pratt & Whitney, *STS 476 Turboshaft Engine*, April 1975

7. SP05A76, Hamilton Standard, *Prop-Fan Advanced Technology Estimates for Eight-Bladed Prop-Fan Configuration*, February 1976

8. 77-1223, AIAA Paper, J. F. Duggan, D. P. Beneze, and L. J. Williams, *Advanced Turboprop Technology Development*, August 1977

9. 679C, SAE Paper, C. B. Notess and P. C. Gregory, *Requirements for the Flight Control System of a Supersonic Transport*

10. NASA TM X-2620, *Symposium on Vehicle Ride Quality*, October 1972

11. NASA CR 2276, C. K. Gordon and R. O. Dodson, *STOL Ride Control Feasibility Study*, July 1973