NASA Contract Report 152363

(J. Galloway)

Application of Advanced Technologies to Small, Short-haul Transport Aircraft

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LOCKHEED-CALIFORNIA COMPANY
BURBANK, CALIFORNIA

NAS2-10264
June 1980

National Aeronautics and
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APPLICATION OF ADVANCED TECHNOLOGIES TO SMALL, SHORT-HAUL TRANSPORT AIRCRAFT

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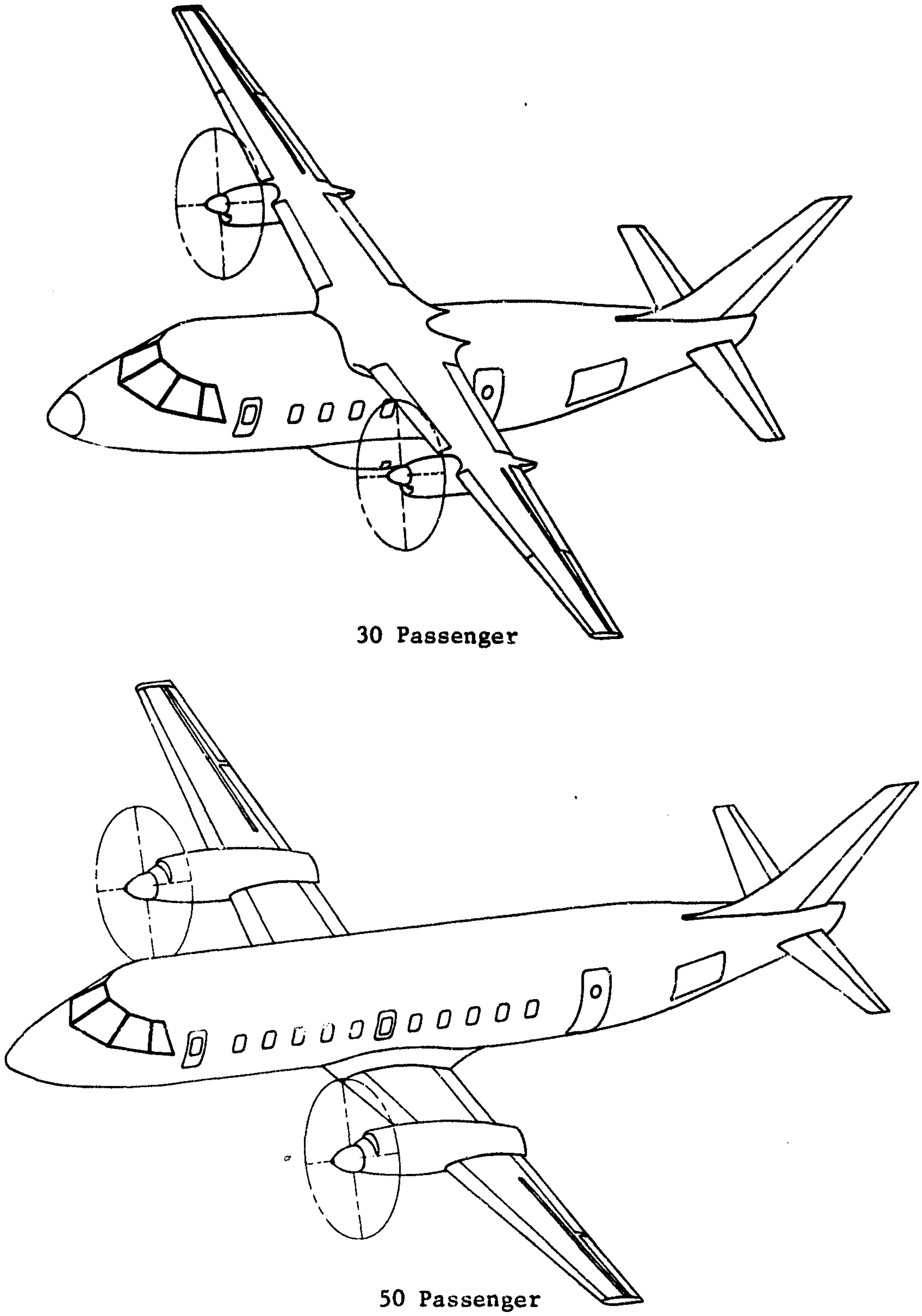
1. SUMMARY

This report presents the results of a study entitled "The Application of Advanced Technologies to Small, Short-Haul Transport Aircraft" accomplished by the Lockheed-California Company for the NASA-Ames Research Center under Contract NAS 2-10264. The study utilizes two baseline aircraft configurations, 30 passenger and 50 passenger capacity, for application of active controls, advanced materials and structures, advanced propulsion, assessment of advanced systems, and alternate aircraft configurations. Selection of baseline aircraft capacities was based on:

- Previous NASA and Lockheed studies which indicated that these sizes of aircraft will be required for future commuter and local service markets.
- Aircraft stretch/shrink concepts which can be readily adapted to provide a family of aircraft which satisfy the market projections.
- Application of advanced technologies, and their subsequent benefits, which would be assessed for both a commuter type aircraft as well as a higher speed configuration better suited for the local service carrier.
- The selected cruise speed capability of the aircraft included in this study is higher then that normally associated with the small, short-haul aircraft. As part of the NASA study ground rules, minimum cruise speed of 250 knots indicated was required, however, higher cruise speeds (and cruise altitudes) were selected as being better suited to the design mission requirements. Incorporation of the higher cruise speed capability results in about 5% reduction in DOC at the 1100 km (600 n.mi.) design range. Utilization of the higher cruise speed for the 184 km (100 n.mi.) stage imposes a penalty of 1.8% in DOC which can be eliminated by restricting the cruise speed to approximately M 0.5 for the shorter stage lengths.

Four major tasks were accomplished during this study:

Task 1 - Definition of baseline aircraft configuration and mission requirements.



30 Passenger

50 Passenger

Figure 1. - Short-haul aircraft.

Task 2 - Application of advanced technologies to baseline aircraft designs.

Task 3 - Evaluation of advanced technologies and assessment of aircraft benefits.

Task 4 - Identification of future research and technology requirements.

The baseline aircraft selected for this study were those designs previously developed for Lockheed-funded short-haul studies, which were then modified to incorporate the specific requirements of the NASA statement of work. The baseline designs, depicted in figure 1, utilize current technology and design practices in aerodynamics, propulsion, structure, and systems and include consideration for stretch/shrink capability to provide the potential for a family of aircraft.

Primary emphasis during this study was placed on evaluation of advanced technology items which, when incorporated into the baseline aircraft, would:

- Reduce acquisition cost and/or operating cost
- Improve fuel efficiency
- Enhance passenger appeal

Results indicate significant cost savings are possible by application of selective advanced technologies to the small short-haul transports considered during this study.

The use of advanced composite materials with either the orthogrid or isogrid structural configuration provides a manufacturing cost savings of 23% for the airframe structure which results in a 10% reduction in the aircraft total production cost. This cost reduction is achieved through utilization of fewer parts and design simplification along with lower labor costs by use of a fully automated manufacturing process for fabrication of the orthogrid or isogrid structure.

Active controls, integrated with an adaptive flap configuration for gust load alleviation, cannot be quantified with respect to their impact on aircraft operating costs. Incorporation of the adaptive flap system will provide passenger comfort levels equivalent to that currently experienced with today's turbofan aircraft. Active controls concepts, as applied to unconventional aircraft configurations (i.e., aft engines or tandem wings), result in improvements in aircraft performance and small reductions in operating costs.

Incorporation of advanced propulsion concepts (engine cycles and propellers) indicates significant reductions in block fuel and DOC. Using the projected values for advanced engine cycles provided by AiResearch, as part of their STAT study effort under NASA-Lewis sponsorship, results in reductions in block fuel of about 22% with a reduction in DOC of 10 - 12% for both the 1100 km (600 n.mi.) design range and the 184 km (100 n.mi.) average stage.

Investigation of advanced systems concepts, although not quantified during this study, indicates significant potential advantages particularly for an all-electric aircraft configuration. Assessment of the benefits available by incorporating advanced systems into short-haul aircraft is currently being accomplished by Lockheed under NASA-JSC contract NAS 9-15863. For the advanced technology short-haul aircraft, the following systems concepts should be evaluated and the benefits quantified as a follow on to this study:

- Recirculating ECS (approximately 50% recirculation)
- Electric ECS with either engine driven or electric compressors
- Digital fly-by-wire and possibly fly-by-light (fiber optics) for the far term.
- Loads management.

Emerging technologies in areas such as microelectronics, advanced small, high-powered motors for electromechanical actuators, and highly reliable rare-earth metals generators make the all-electric aircraft feasible with possible elimination of installation and maintenance problems associated with conventional hydraulic systems.

During this study effort 2, 3, and 4 abreast seating arrangements were investigated with the 4 abreast interior selected as the preferred configuration to provide a common fuselage for both the 30 pax and 50 pax aircraft. The 4 abreast interior enhances the growth capability of the aircraft and will provide added space available for carry-on baggage which is an important feature for the short-haul aircraft.

2. INTRODUCTION

The short-haul system is an important element of the national transportation system. Currently, the domestic local service and commuter markets utilize either larger turbofan aircraft, such as the DC-9 or B737, or larger aging propeller driven aircraft for which there is no modern replacement manufactured in the U.S., or smaller general aviation derived propeller driven aircraft. Since utilization of these aircraft does not provide the desired economic efficiency on the short-haul routes, what is needed is a modern, efficient, and reliable family of short-haul transport aircraft.

Introduction of a new transport into the short-haul market imposes a demanding set of design goals to provide an aircraft with improved performance, superior operating characteristics, and major emphasis on low cost. These major design goals are summarized as follows:

- Reduced initial cost
- Lower operating cost
- Improved fuel efficiency
- Improved field performance
- Improved environmental characteristics (community noise, emissions)
- Better passenger appeal (pressurized, low cabin noise, ride quality).

As part of the NASA Small Transport Aircraft Technology program, significant market studies have focused on the short-haul CTOL transport with a capacity of 15 to 60 passengers and a range of 92 to 1840 km (50 to 1000 n.mi.). Previous analyses accomplished by Lockheed have identified two distinct aircraft for the short-haul market. For this study effort, two baseline aircraft configurations were selected, one of 30-passenger capacity and one with 50-passengers, both with a design range of 1110 km (600 n.mi.).

Previous NASA-sponsored studies have identified several advanced technologies which will provide significant performance and economic benefits for medium-and long-range CTOL commercial aircraft. The focus of this study was identification and evaluation of those advanced technologies which, when incorporated into the short-haul aircraft, would enhance the performance, economic, and operating characteristics.

The study consisted of four tasks:

- Task I - Baseline Aircraft and Mission Definition
  Previous Lockheed-sponsored, short-haul aircraft studies were used to select the baseline configurations. Design mission requirements were based on previous NASA and Lockheed evaluations of the operational characteristics of local service and commuter airlines.

- Task II - Application of Advanced Technology
  Identification of those advanced technology items, which when incorporated into the baseline aircraft, could provide significant performance and economic benefits while adhering to the previously established design goals of the study.

- Task III - Evaluation of Advanced Technology
  Assessment of the technical, economic, and market benefits attained by incorporation of the selected advanced technology items into the short-haul aircraft. This assessment was accomplished by incorporating advanced technologies singularly and in combination.

- Task IV - Recommendations for Future Research
  Identification of those technology items, evaluated during Task III, which should be considered for future research.

Abbreviations and symbols are listed in Section 3, baseline design mission and aircraft selections are discussed in Section 4, definition of current technology baseline aircraft is included in Section 5, and the identification and application of advanced technologies is discussed in Section 6. Section 7 contains the evaluation of the advanced technology short-haul aircraft when compared to the current technology baseline. Conclusions of the study and recommendations for future research comprise Section 8.

3. ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A.P.	Auto-pilot
APU	Auxiliary power unit
ASM	Available seat mile (n.mi.)
c.g.	Center of gravity
cm	Centimeter
CTOL	Conventional takeoff and landing
DME	Distance measuring equipment
DOC	Direct operations cost
ECS	Environmental control system
EPNdB	Equivalent perceived noise level, decibels
FAR	Federal Air Regulations
fps - ft/sec	Feet per second
ft	Feet
gal.	Gallon
G.E.	General Electric
GR-EP - GR-E	Graphite - Epoxy
hp	Horsepower
IFR	Instrument flight rules
in.	Inch
in/in	Inch per inch
kg	Kilogram
kg/m^2	Kilograms per square meter
kg/s	Kilograms per second
km	Kilometers per hour
kPa	Kilopascals
kVA	Kilovolt-ampere
kW	Kilowatt
lb	Pound - mass
lb/ft^2	Pound per square foot
lb/shp/hr	Pound per shaft horsepower per hour
LFL	Landing field length m,(ft)
m	Meter
MAC	Mean aerodynamic center
m/s	Meters per second
n.mi.	Nautical miles
OASPL	Overall sound pressure level
OEW	Operational empty weight kg(m)
PAX	Passengers
ppm	Pounds per minute
psf	Pounds per square foot
psi	Pounds per square inch
PaW	Pratt and Whitney
rad	Radian
SFC	Specific fuel consumption
SHP	Shaft horsepower
S.L.	Sea level

SLS	Sea level static
SPS	Secondary power system
TOFL	Takeoff field length m (ft)
TOGW	Takeoff gross weight kg (lb)
Vdc	Volts, direct current
VA	Volt-Amps

Symbols

AF	Activity factor
AR	Aspect ratio
B	Number of blades
b	Wingspan m (ft)
C	Chord
C_D	Drag coefficient
C_L	Lift coefficient
C_{Lmax}	Maximum lift coefficient
ct/cr	taper ratio
^oC	Degrees Centigrade
D	Diameter
dB	Decibels
E^3	Energy Efficient Engine
fre	Fuselage reference line
^oF	Degrees Farenheit
iaft	Incidence of aft wing
L/D	Lift to Drag ratio
M	Mach number
Mcr	Critical mach number
m	Meter
Sref	Reference Wing area
Stot	Total wing area
t/c	Thickness ratio
T/W	Thrust to Weight ratio
W/s	Wing loading Gross weight to wing area
Lfrl	Angle of attack, fuselage reference line
δ	Deflection
δ_e	Elevator deflection
δ_f	Flap deflection
λ	Taper ratio

4. BASELINE MISSION AND AIRCRAFT SELECTION

This section covers the analysis and investigation leading to selection of the short-haul baseline mission and aircraft configurations. Included is a summary of a marketing analysis previously accomplished by Lockheed and a brief description of the candidate configurations to be utilized as baselines for this study effort.

4.1 Short-Haul Mission

The short-haul mission, as identified for this study effort, is two fold:

- provide an efficient, economical aircraft for the commuter market
- provide an efficient, economical short-haul transport for the local service markets which are too small for efficient operation with the DC-9 or B737 type of aircraft.

Primary emphasis was placed on reducing aircraft operating costs for 184 km (100 n.mi.) stage length. The design cruise speed selections, which are higher than the minimum required by the NASA study ground rules, were made to be consistent with the potential demand for longer stage lengths and efficient operation at the design range. Section 5.4.1 describes the process used to select the design cruise speed.

4.2 Market Requirements

Numerous studies of both domestic scheduled airline and commuter operations have been previously accomplished by various government agencies (NASA, FAA, DOT, etc.) and private industry. The overall concensus of these studies lead to the following conclusions for the post 1985 market:

- Significant increase in total passenger miles.
- Majority of passenger miles and greatest frequency of service is accomplished for stage lengths of 920 km (500 n.mi.) or less
- Local service market is currently served with aircraft that are too large (i.e., DC-9, B737, B727) to be economically efficient in this market environment.
- Deregulation will increase commuter airline demand to provide service for those communities previously served by the local service or regional carriers.
- Opinions regarding short-haul aircraft size are diverse with the most commonly mentioned capacities of 20-30 seats, 36-44 seat, and 40-60 seat.

A summary of the results of Lockheed funded studies of the short-haul market is depicted in figure 2. It appears that the short-haul market will be best

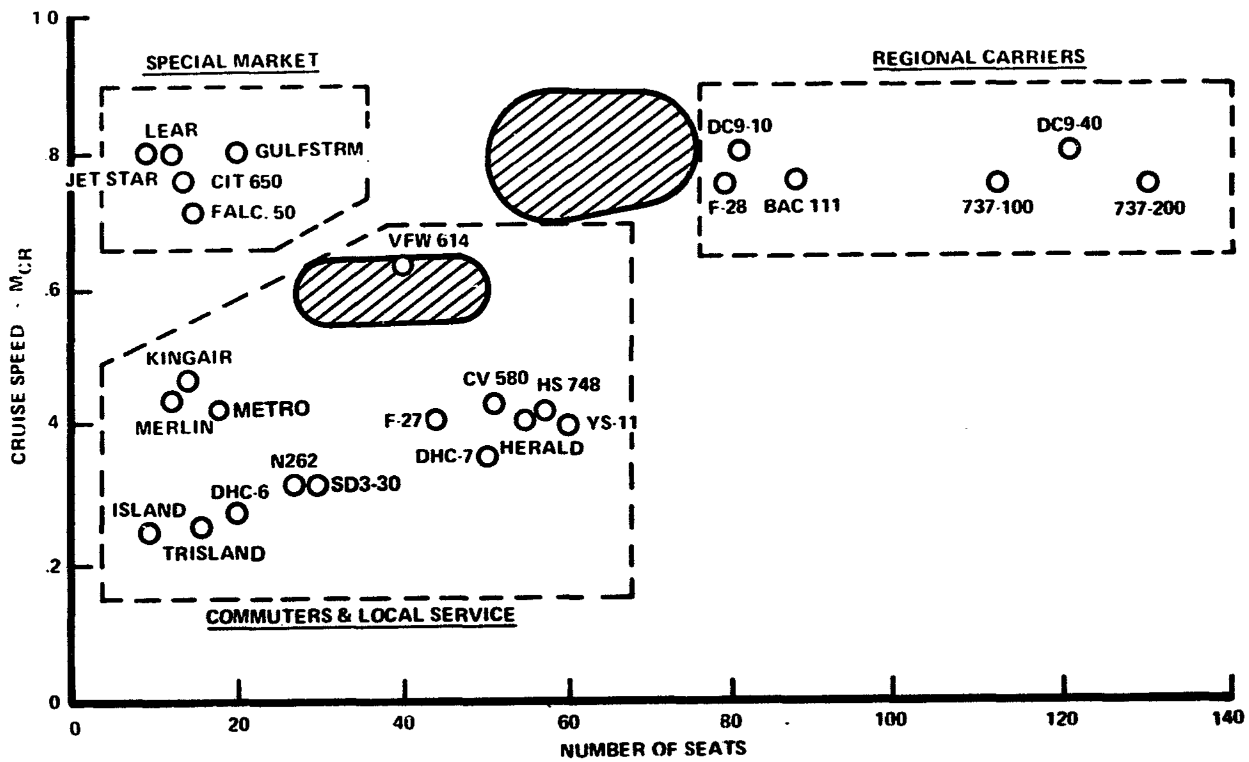


Figure 2. - Short-haul market study.

served by two distinct types of aircraft: an updated commuter aircraft which is capable of efficient, economical operation from airfields typical of small communities with superior environmental characteristics (i.e., community noise) and improved passenger appeal; and a modern replacement for the CV-580, F-27 type of aircrft with improved environmental characteristics and higher speed for efficient operation at longer stage lengths.

Predictions as to the number of aircraft required for two market segments are also diverse; however, the results of a recent FAA forecast to the year 2000 predicts a worldwide requirement of up to 3000 aircraft with a capacity of 20-39 passengers and 1500 aircraft with a capacity of 40-60 passengers.

4.3 BASELINE MISSION CHARACTERISTICS

The baseline mission characteristics were derived from the previously described analyses and those requirements, are incorporated as baseline missions to be used throughout the study effort:

	Commuter	Local Service
Design Range	1110 km (600 n.mi.)	1100 km (600 n.mi.)
Typical Range	184 km (100 n.mi.)	184 km (100 n.mi.)
Capacity (No. PAX)	30	50
Cruise Speed	Mach 0.60	Mach 0.70
Field Length	1219 m (4000 ft)	1219 m (4000 ft)

4.4 Baseline Aircraft Definition

As previously described, two baseline aircraft configurations were selected for this study. One aircraft, designed for low density and high utilization on short stage lengths, is needed to fulfill the requirements of the commuter operator. The second aircraft, designed for higher density and with performance approaching current airliners, is required to fill an identified market gap and provide an advanced technology aircraft for the local service carrier. The baseline designs chosen are representative of current technology levels and design practices and incorporate all of the requirements specified by the NASA statement of work.

30 passenger baseline. - This configuration, sized to provide an updated replacement for current commuter aircraft, is designed for a passenger capacity of 30 and incorporates a 1219 m (4000 ft) field length capability, at 32°C (90°F) and sea level, to provide maximum operational flexibility. Fuselage diameter is 2.90 m (114 in.) with a 4 abreast interior at 81.28 cm (32 in.) seat pitch. Growth of the aircraft to approximately 40 passengers can be readily attained by the incorporation of fuselage plugs. Design range was selected as 1110 km (600 n.mi.), plus reserve fuel, to provide sufficient fly-through capability for the 184 km (100 n.mi.) average stage lenghts. A cruise speed capability of Mach 0.60 is provided with a minimum cruise altitude of 8.53 km (28 000 ft.) for the design range.

50 passenger baseline. - This configuration was selected to provide an aircraft for the local service carrier and, as such, incorporates the design characteristics and performance similar to current commercial airlines. Cruise speed capability of Mach 0.70 at an altitude of 10.97 km (36 000 ft.), was incorporated to provide efficient performance characteristics for the 1110 km (600 n.mi.) design range. Fuselage diameter of 2.90 m (114 in.), with 4 abreast seating, was utilized so that commonality of fuselage sections with the 30 PAX aircraft could be attained. For future aircraft growth considerations, a shrink/stretch capability of 40 to 72 passengers is readily attainable. This aircraft, when combined with the 30 passenger commuter, described above, will serve to provide a family of aircraft for the short-haul market.

5. CURRENT TECHNOLOGY BASELINE AIRCRAFT

5.1 Summary

This section describes the design philosophy, design and performance requirements, and configurations for the current technology baseline aircraft. Technical and economic performance summaries for the current technology aircraft, optimized for minimum operating costs, are also included.

5.2 Design Philosophy

As specified in the NASA statement of work, the current technology baseline aircraft used for this study were to be either an existing current or near-current production short-haul design or one which is designed to incorporate current state-of-the art technologies in aerodynamics, propulsion, structures, and systems. Two baseline aircraft were selected as representative of the requirements to meet projected market demand for the post 1985 time frame. As previously described, a 30 passenger commuter type aircraft and a 50 passenger local service type were chosen to provide the capability of broad market coverage by stretch/shrink concepts so that passenger capacities of 30 to 70 could be encompassed with the two aircraft.

The design philosphy selected was to utilize, to the fullest possible extent, previously developed Lockheed short-haul designs and to modify these designs to incorporate specific requirements of the NASA work statement. Previous short-haul aircraft designs, used to initate this study effort, are depicted in figures 3 and 4. As a part of this study effort, one primary goal was the incorporation of design features which would provide reduction in aircraft first cost and provide commonality of airframe structure for both aircraft. As a result, a fuselage diameter of 2.90 m (114 inches) with four abreast seating was selected for both aircraft to enhance future growth potential and to allow common usage of fuselage parts (i.e., tailcone, cockpit, and constant sections). Development of the current technology baseline aircraft designs was minimized in keeping with the major goals of this study with the major emphasis placed on use of advanced technologies to enhance performance and economic characteristics of future short-haul transports.

5.3 Aircraft Configurations

The two current-technology baseline aircraft are depicted in figures 5 and 6. Each aircraft is of conventional, state-of-the art design and has been sized for minimum direct operating cost at 184 km (100 n.mi). stage length.

30 passenger. - The configuration selected for this aircraft is similar to current production commuter type aircraft with the primary exception being a higher cruise speed capability of Mach 0.60 to provide efficient, economical operation at the 1110 km (600 n.mi.) design range. Selection of the Mach 0.60 cruise speed dictates a wing loading of 390.6 kg/m^2 (80 lb/ft^2) as compared to wing loading on the order of 195.3 to 244.1 kg/m^2 (40 to 50 lb/ft^2) for current, lower speed commuters. One advantage of the higher wing loading is improvement in ride quality during operation in turbulence. A NASA GAW-1 type airfoil with

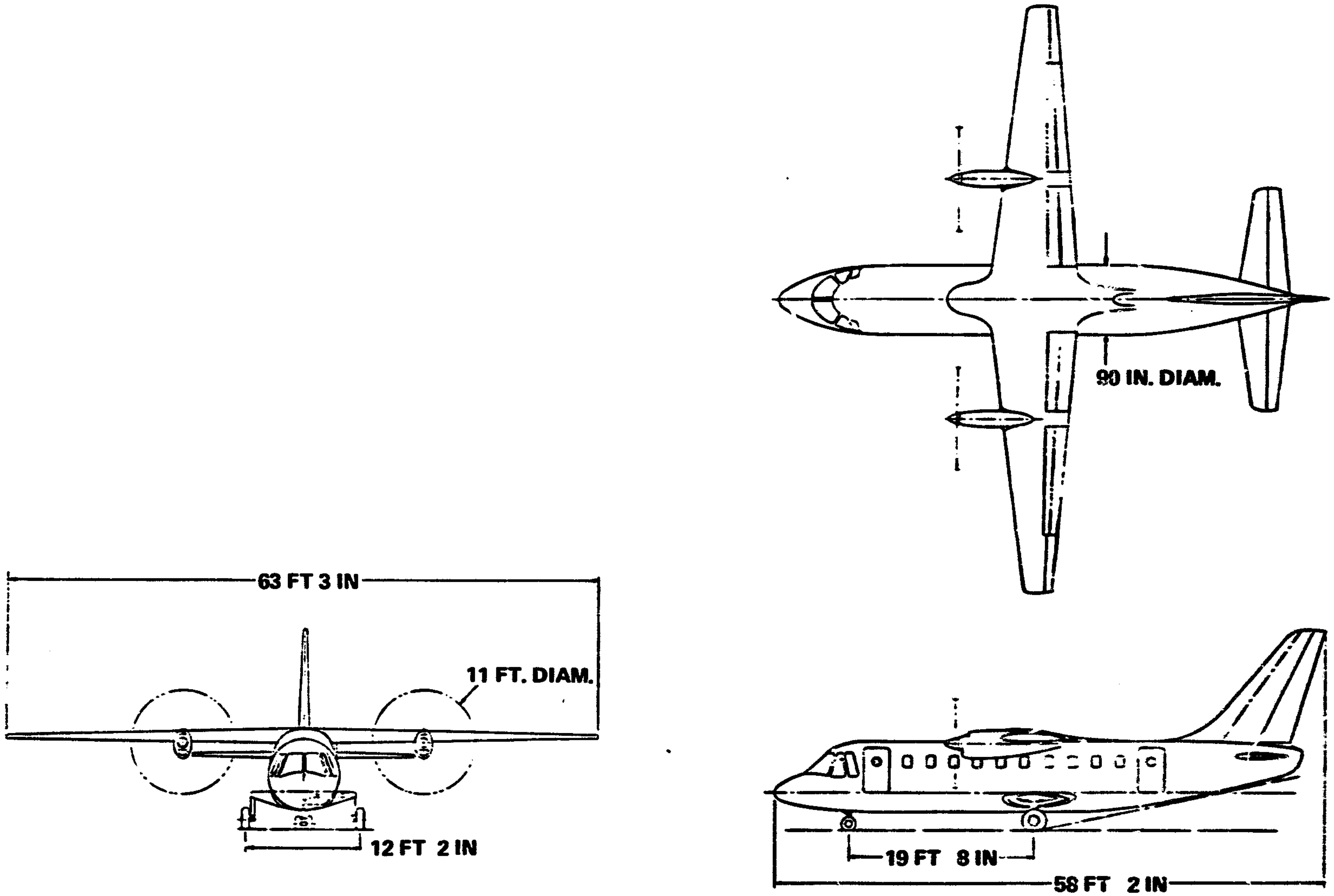


Figure 3. - Previous 30-passenger configuration

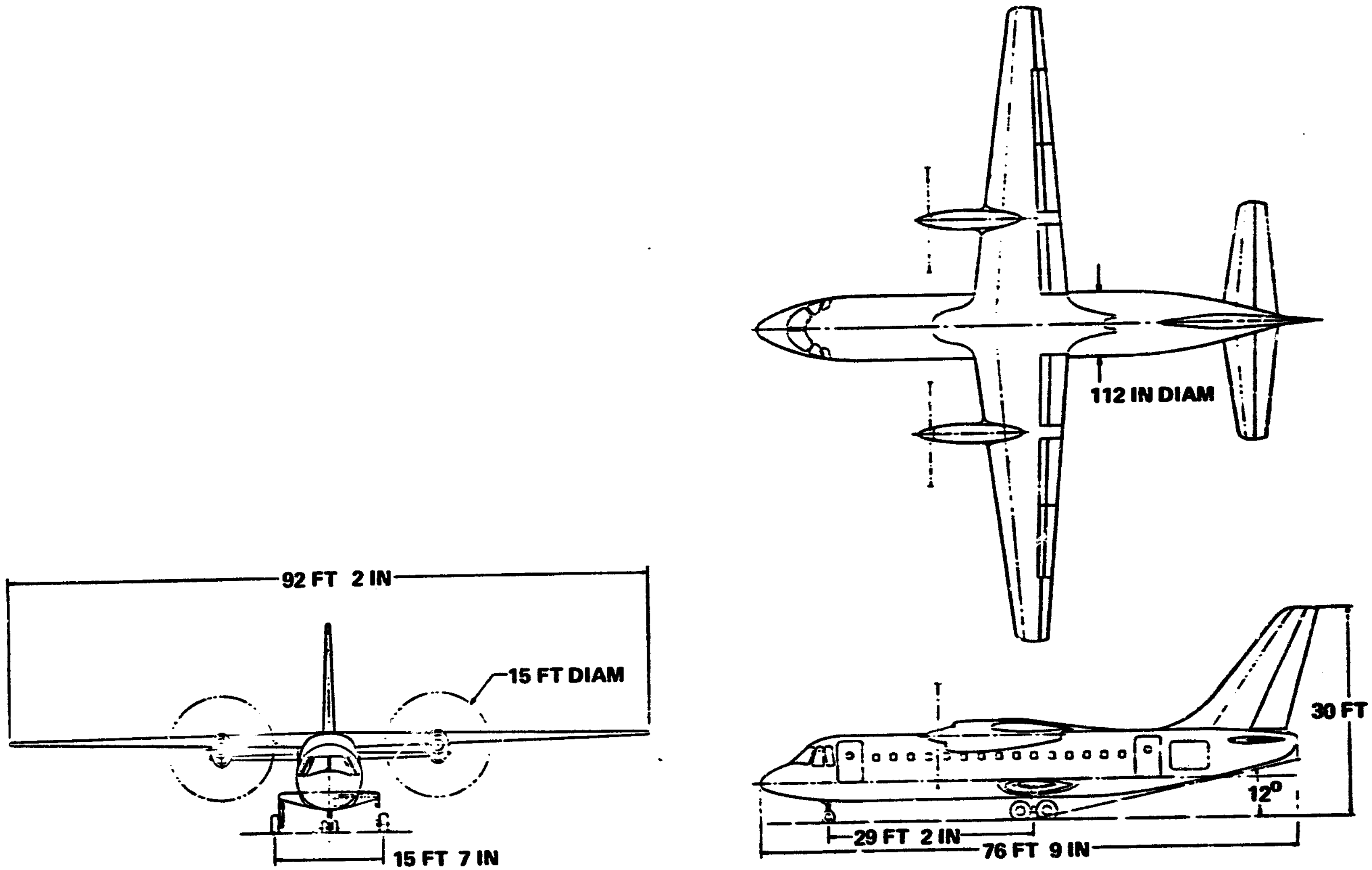


Figure 4. - Previous 60-passenger configuration.

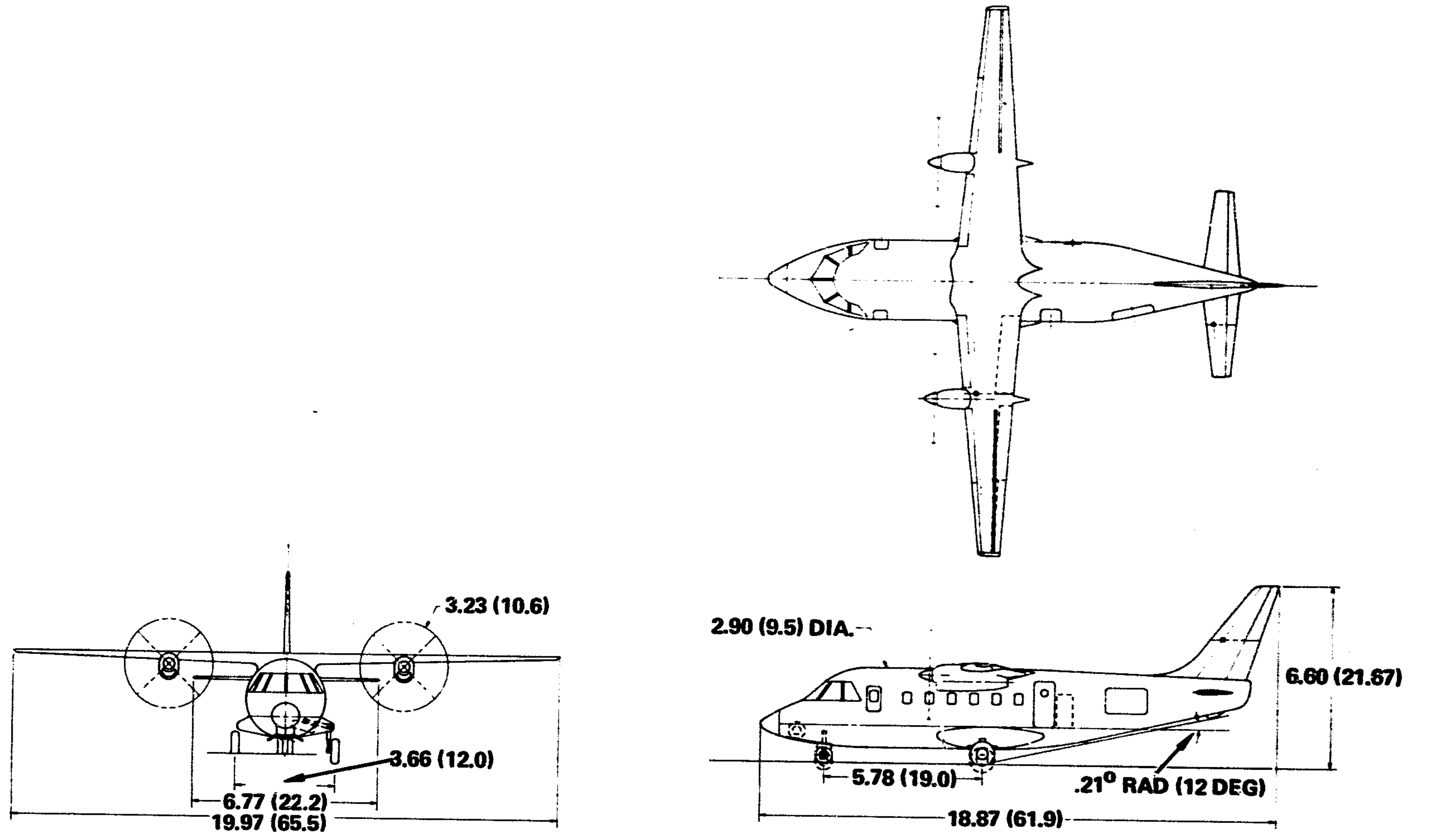


Figure 5. - Baseline 30-passenger short-haul.

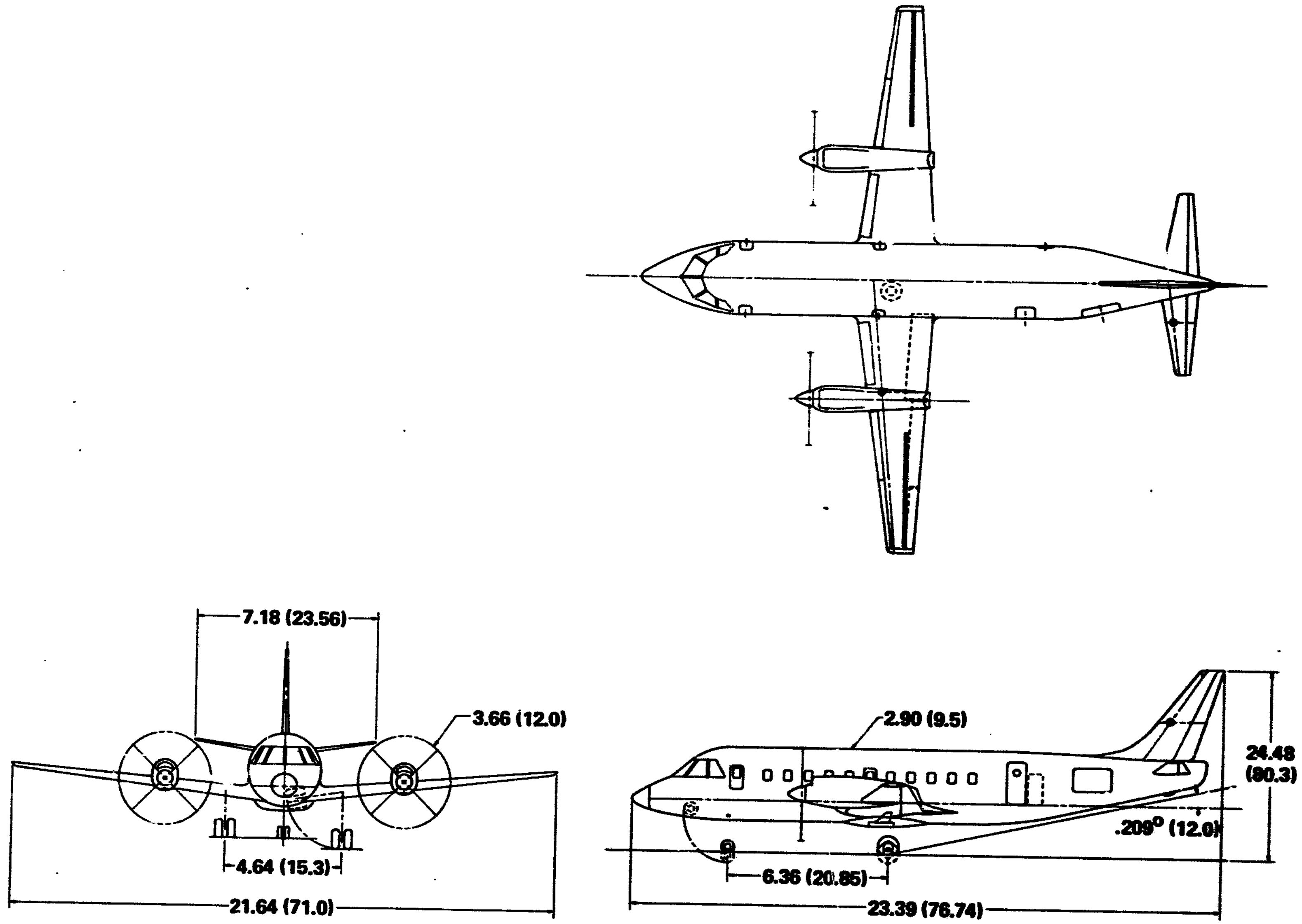


Figure 6. - Baseline 50 passenger short-haul.

an average thickness ratio of 16% is incorporated. The high aspect ratio (AR 12) cantilever wings are mounted above the cabin and require no exterior support struts. The current technology turboprop engines are underslung and are placed, at 43% half span (0.4 diameter propeller to fuselage clearance) to minimize cabin interior noise. Attainment of the NASA required cabin interior noise levels of 85 dB OASPL results in incorporation of 431 kg (950 lb) of acoustic treatment.

To meet the balanced field length requirement of 1219 m (4000 ft) at sea level and 32°C (90°F), full span, full translation single-element Fowler flaps and full span slats are incorporated as depicted in figure 7. These high lift devices result in a $C_{L_{max}}$ of 3.5 at the 42° flap setting used for landing. Two-piece spoilers are included on the wing upper surface to provide roll control.

The fuselage has a minimum of compound curves to reduce manufacturing complexity and costs. The windshield is composed of flat panes rather than a curved, wrap-around type, also to reduce costs. The cabin is pressurized to maintain a nominal 6000 ft. elevation.

The nose and main landing gear wheels retract into the fuselage; the nose gear retracts cleanly without protruding fairings, while the main gear requires small fairings to enclose the main support struts. Four abreast seating (7 1/2 rows) was chosen so that a fuselage stretch could be accommodated at a later time. The aircraft can be stretched to a maximum passenger capacity of 40. A fuselage diameter of 2.90 m (114 in.) was chosen to meet aisle and seat width requirements and to provide 4 abreast seating. Passenger carry-on baggage is stowed in overhead lockers, and checked baggage is stowed in a compartment aft of the cabin which is accessible from an exterior door. A lavatory, beverage service bar, and coat storage comprise the aft end of the cabin. Passenger and crew entry/exit is through the single main door at the rear left-hand side of the cabin. The cabin floor is 1.32 m (52 in.) above ground which permits entry with an airstair door, so no extra ground equipment is necessary for passenger loading. The exterior cargo door permits access from a pick-up truckbed. Three emergency passenger exits are provided as per FAR Part 25. Acoustic insulation is included throughout the cabin from floor to ceiling to attenuate propeller tip noise. The treatment thickness is graduated from a maximum, in the zone which extends from immediately in front of the prop disc plane to a few feet aft, to a minimum at the cabin ends. The hydraulic service center and ECS units are located beneath the cabin floor forward of the main landing gear bay. The layout of interior arrrangement along with an inboard profile is shown in figure 8.

50 passenger. - This aircraft was configured to provide a cruise speed capability of Mach 0.70 for a design range of 1110 km (600 n.mi.). The wing design and high lift devices are essentially identical to the 30 passenger aircraft expcept that wing AR is 10 and the wing is mounted under the cabin floor. High mounting of the wing was considered but not incorporated since the root section of the wing would protrude too far above the top of the fuselage when the minimum required interior height is attained. Figure 9 depicts an early high wing configuration 50 passenger aircraft and shows the amount of protrusion of the wing above the fuselage. The engines are over-wing mounted to minimize gear length for the required ground clearance.

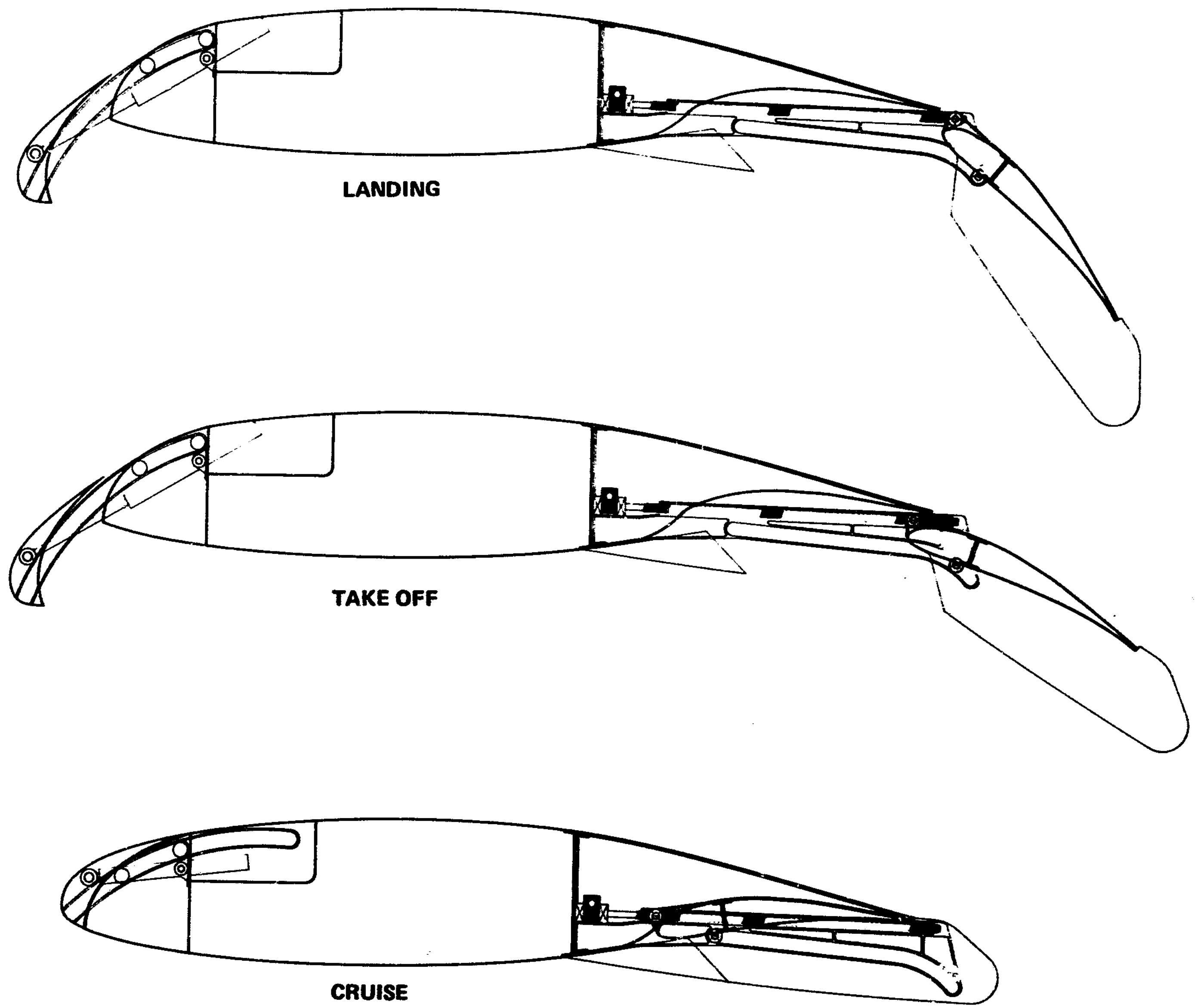
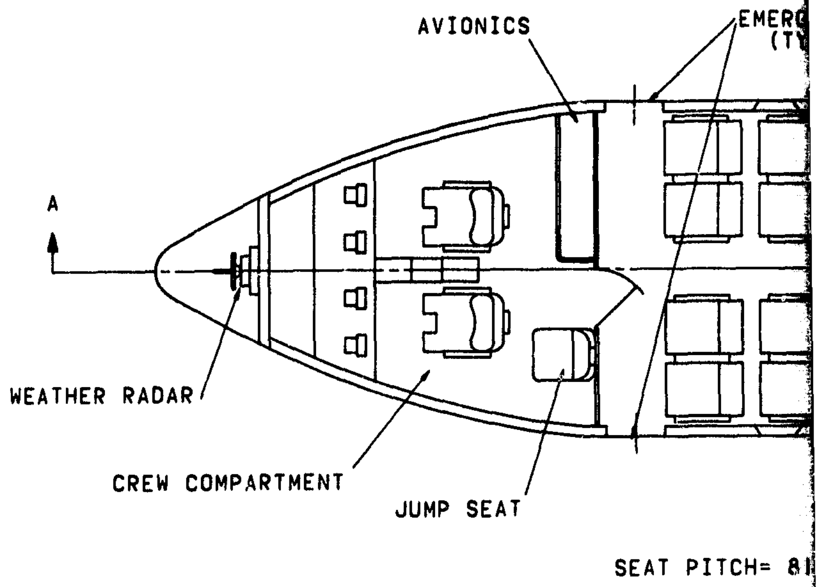


Figure 7. - Baseline high lift system.

The fuselage is identical to that of the 30 passenger except that a 4.06 m (160 in.) plug was added, and the fuselage/wing junction was changed. Future growth can be obtained by stretching the fuselage for a total capacity of approximately 70 passengers. Two lavatories are placed in the extreme aft end of the cabin along with increased coat storage and beverage bar capacities. The cabin floor height is 2.08 m (82 in.) above ground and requires a specially-designed airstair for passenger entry/exit. Baggage loading in the aft compartment requires some means of ground equipment to reach the door. Three emergency exits are provided as per FAR Part 25. Acoustic treatment of the fuselage is provided in a similar manner as that for the 30 passenger, however due to the higher propeller helical tip speed at Mach 0.70, the acoustic weight penalty is increased to 680 kg (1500 lb). Landing gear for this aircraft are fully retractable; the nose gear retracts cleanly into the fuselage, and the main wheels also retract into the fuselage rather than into the engine nacelles. The main gear leg pivots are supported on the rear spar of the wing. The ECS and hydraulic service center are located beneath the floor in front of the front spar. The layout of interior arrangement and inboard profile are depicted in figure 10.

5.3.1 Design requirements. - The design requirements incorporated into the baseline short-haul aircraft were largely dictated by the NASA statement of work. These requirement are reiterated as follows:

- full design payload to be carried over a range of 1110 km (600 n.mi.) with reserves for a 184 km (100 n.mi.) alternate and 45 minutes at maximum endurance power.
- field length shall not exceed 1219 m (4,000 ft) for a hot day 32.2°C (90°F) at sea level.
- aircraft shall meet FAR 36 stage 3 minus 8 EPNdB community noise level requirements at all measurement locations.
- an airframe design life of at least 30 000 hours and 60 000 cycles.
- a cruise speed capability of at least 463 km/hr (250 kt) indicated airspeed at 1829 through 3048 m (6000 through 10 000 ft) altitudes - standard day conditions.
- a terminal area speed capability of at least 333.4 km/hr (180 knots) indicated airspeed with gear and flaps extended in order to stay with large jet aircraft.
- a stall speed less than 172.2 km/hr (93 kt) in landing configuration at maximum landing weight in order to qualify for operations in Instrument Approach Category B aircraft requirements.
- passenger weight @ 90.7 kg (200 lb) passenger including baggage.
- 2 man crew + provision for one cockpit observer jump seat.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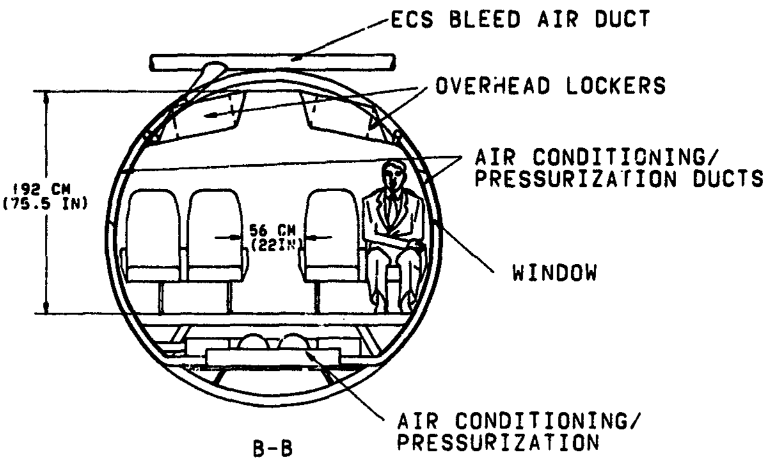
A
WEATHER RADAR
CREW COMPARTMENT
JUMP SEAT
SEAT PITCH= 8


ECS BLEED AIR DUCT
OVERHEAD LOCKERS
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PRESSURIZATION DUCTS
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WINDOW
AIR CONDITIONING/
PRESSURIZATION

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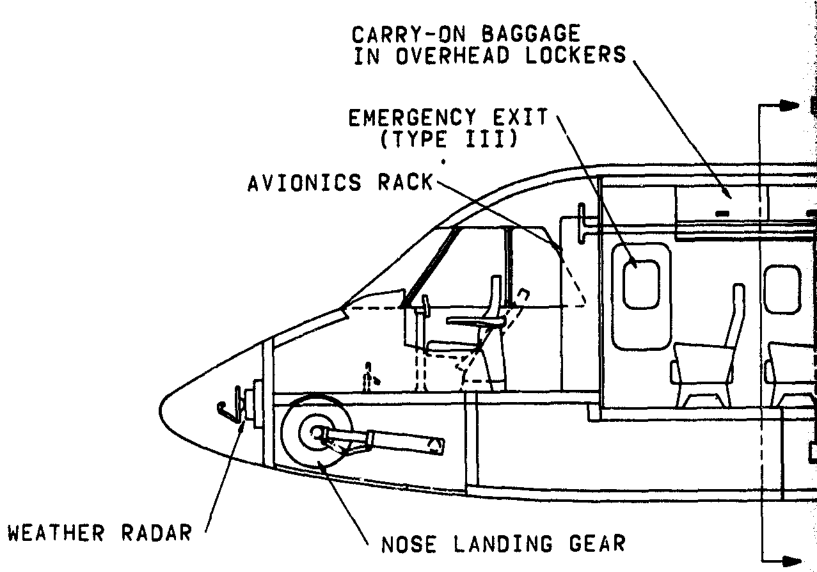
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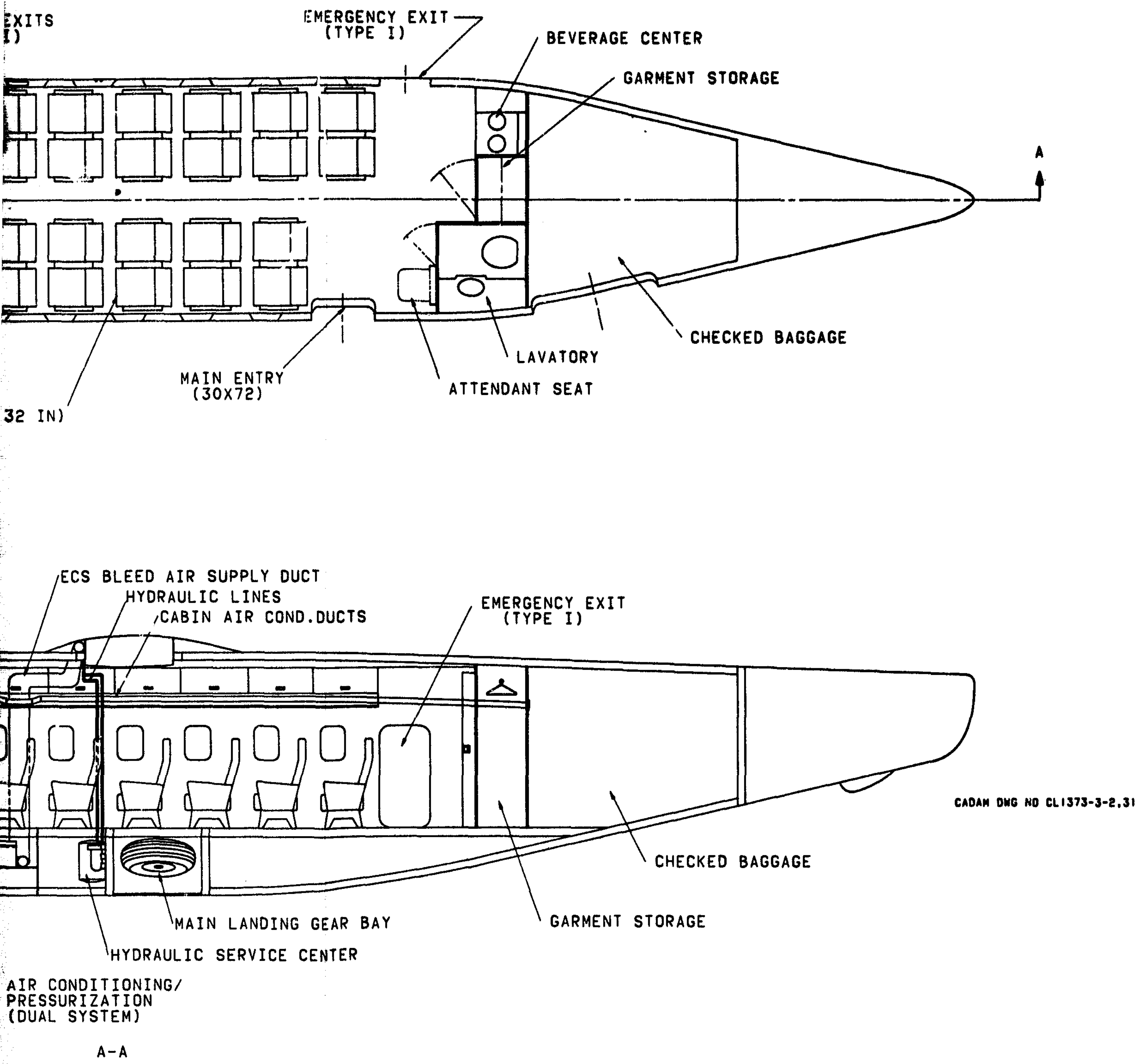


Figure 8. - 30-passenger inboard views.

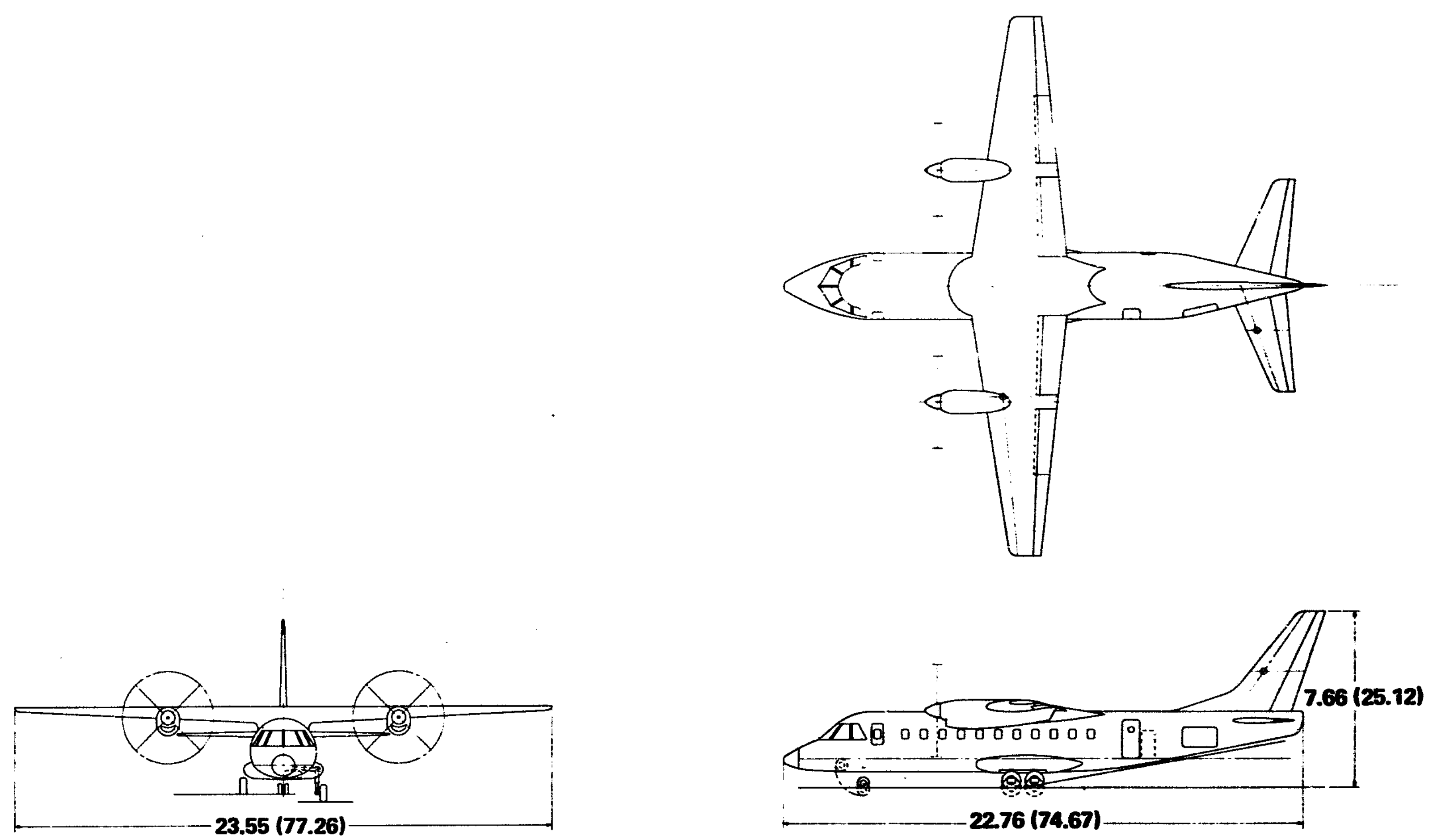


Figure 9. - 50-passenger high wing design.

- 1 flight attendant @ 57.0 kg (130 lb) per 50 passengers

- 183 cm (6 ft) minimum interior aisle height.

- minimum 81.3 cm (32 in.) seat pitch, 45.7 cm (18 in.) seat width between armrests and 45.7 cm (18 in.) aisle width.

- garment stowage area @ 2.0 cm (0.8 in.) width/passenger.

- under or overhead stowage for carry-on baggage of dimensions 51 cm by 51 cm by 28 cm (20 in. by 20 in. by 11 in.) per passenger.

- provison for easy loading of preloaded baggage @ 0.14 m^3 (5 ft^3) passenger.

- beverage service provision.

- space provision for one lavatory per 50 passengers.

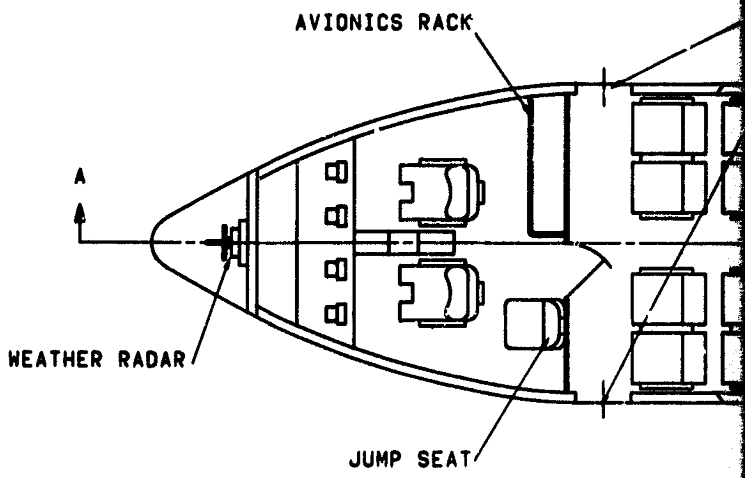
- maximum cabin interior noise level less than 85 dB OASPL and speech interference level (SIL) of less than 65 dB.

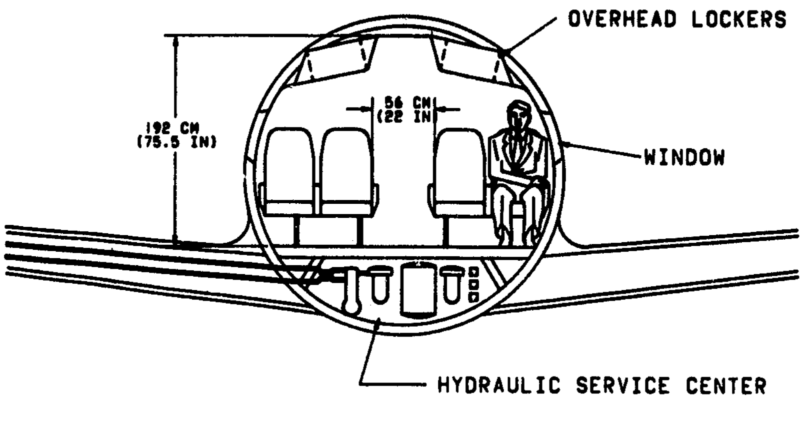
- cabin pressurization of at least 34.5 kPa (5 psi).

The baseline aircraft configurations selected meet or exceed the above requirements.

5.3.2 Performance requirements - The minimum performance requirements for each of the baseline aircraft were specified by the NASA statement of work. Each aircraft was configured to meet the following criteria which met or exceeded the NASA specification:

	30 PASSENGER	50 PASSENGER
Design Range	1110 km (600 n.mi.)	1100 km (600 n.mi.)
Cruise Speed	M 0.60	M 0.70
Initial Cruise Altitude	7620 m (25 000 ft.)	9144 m (30 000 ft.)
Mission Fuel	1100 km (600 n.mi.) + Reserves	1110 km (600 n.mi.) + Reserves
Balanced Field Length	1220 m (4000 ft) (S.L., 90°F)	1220 m (4000 ft) (S.L., 90°F)





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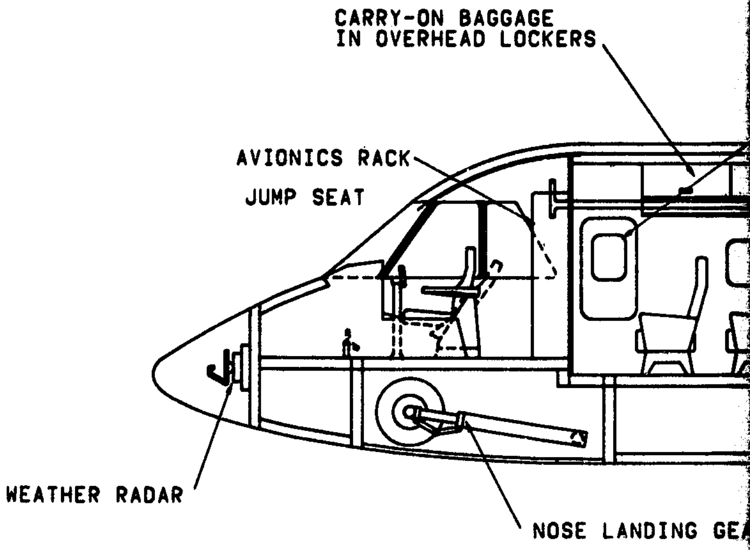

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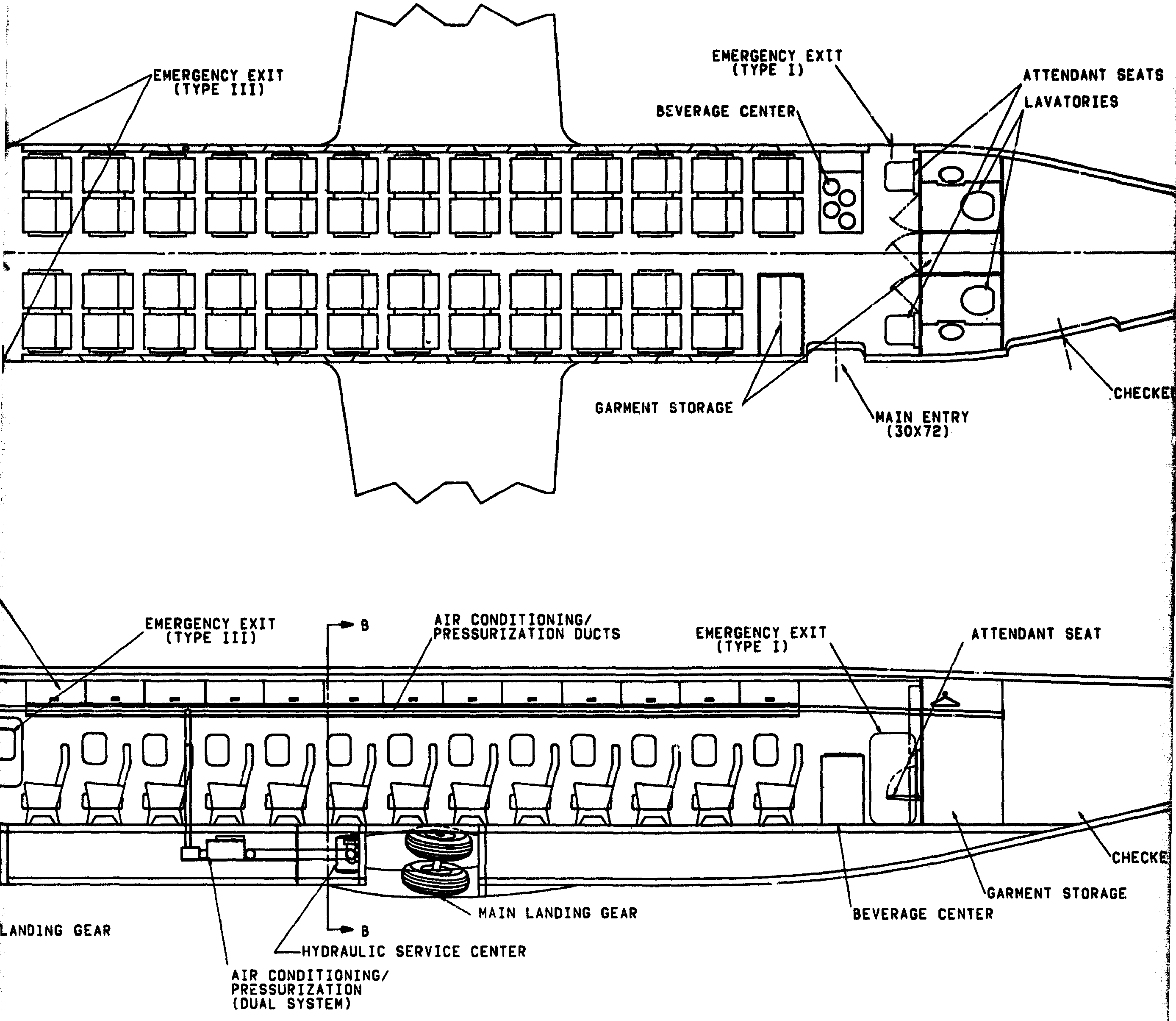

A-A

Figure 10. -

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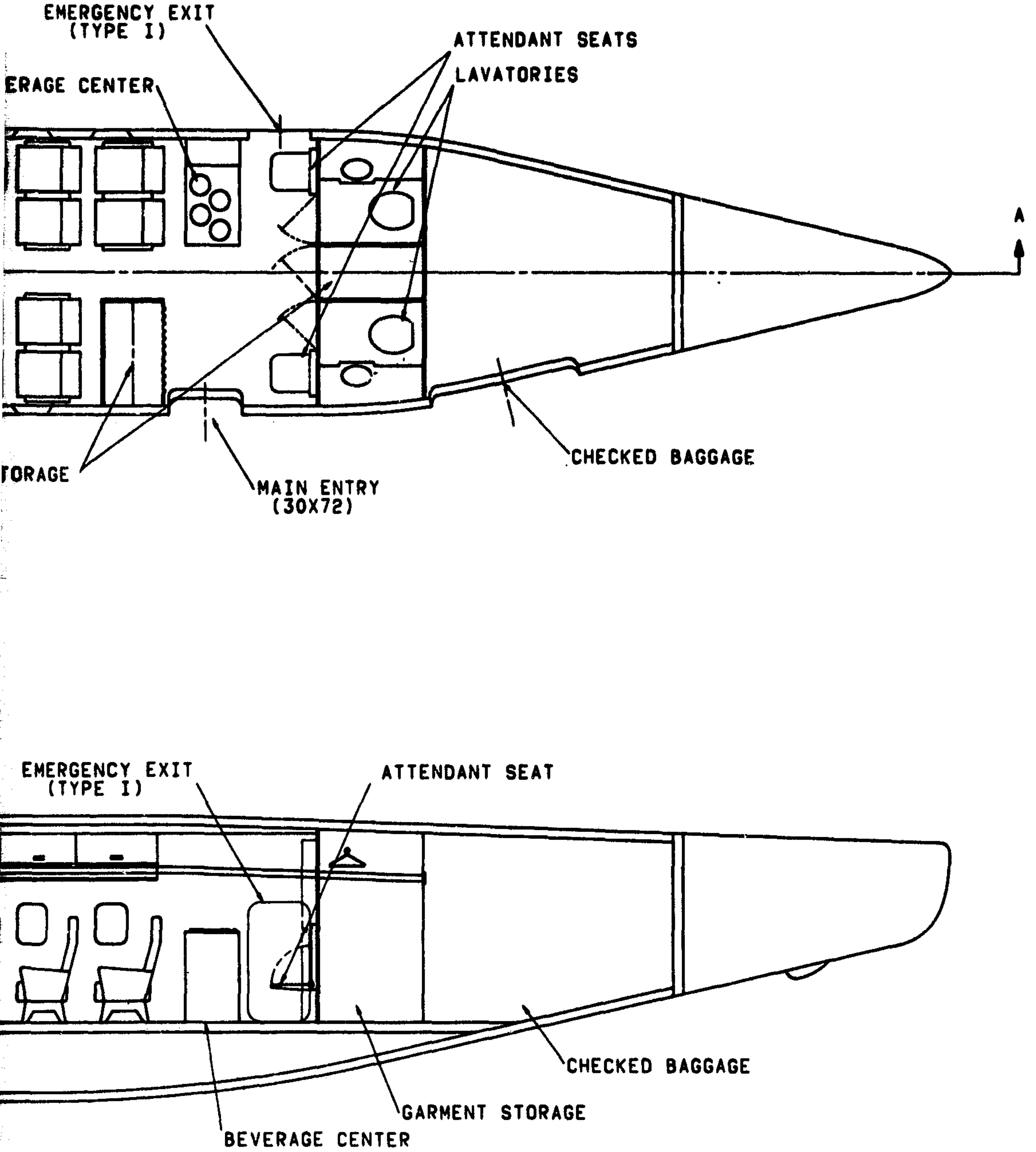


Figure 10. - 50-passenger inboard views.

	30 PASSENGER	50 PASSENGER
Terminal Area Speed	333.4 km/hr > (180 kt)	333.4 km/hr > (180 kt)
Stall Speed	172.2 km/hr < (93 kt)	172.2 km/hr > (93 kt)
Optimization Criteria	Min. DOC @ 185 km (100 n.mi.) Stage Length	
Fuel Prices	\$0.75, \$1.00, and \$1.50 per gallon	

As specified by NASA, a minimum cruise speed capability of 250 knots indicated airspeed at 182.9 through 304 km (6000 through 10 000 ft) is required. For the baseline configurations developed for this study, higher cruise speed capability was selected to provide improved operating economics at the specified design range. Utilization of the higher cruise speed at short stage lengths of 93 and 185 km (50 and 100 n.mi.) does impose a slight penalty in DOC. During this study, assessment of cruise speed selection was accomplished, as described in Section 5.4.1, and the results indicate that a high cruise speed capability for the longer stage lengths (370 to 1110 km) (200 to 600 n.mi.) provides lower DOC. Conversely, when operating at the shorter stage lengths (up to 370 km (200 n.mi.), cruise speed should be reduced to approximately Mach 0.50.

5.4 Baseline Mission Characteristics

The mission requirements for the short-haul aircraft were specified as 1110 km (600 n.mi.) design range with full payload and reserve fuel for 184 km (100 n.mi.) alternate plus 45 minutes at maximum endurance power. Additionally, the short-haul aircraft must be sized for minimum DOC characteristics at a stage length of 184 km (100 n.mi.) with full payload plus the above stated reserves. For both stage lengths, flight profiles were established which provided a significant cruise segment. The flight profiles used throughout this study are depicted in figures 11 and 12 .

5.4.1 Cruise speed selection. - Cruise speed capability was selected at initiation of the study to be M 0.60 at 7620 m (25 000 ft) for the 30 passenger aircraft and M 0.70 at 9144 m (30 000 ft) for the 50 passenger aircraft. Previous studies conducted by Lockheed indicate that higher speed than that currently used for today's commuter aircraft will provide a payoff in DOC for the design range specified. The cruise speed selection for the 50 passenger local service aircraft, particularly when considering growth potential to 70 or 80 passengers, should be comparable to current capability (i.e., DC-9, B-737) to enhance marketability, provided a significant penalty in DOC is not incurred by the higher cruise speed.

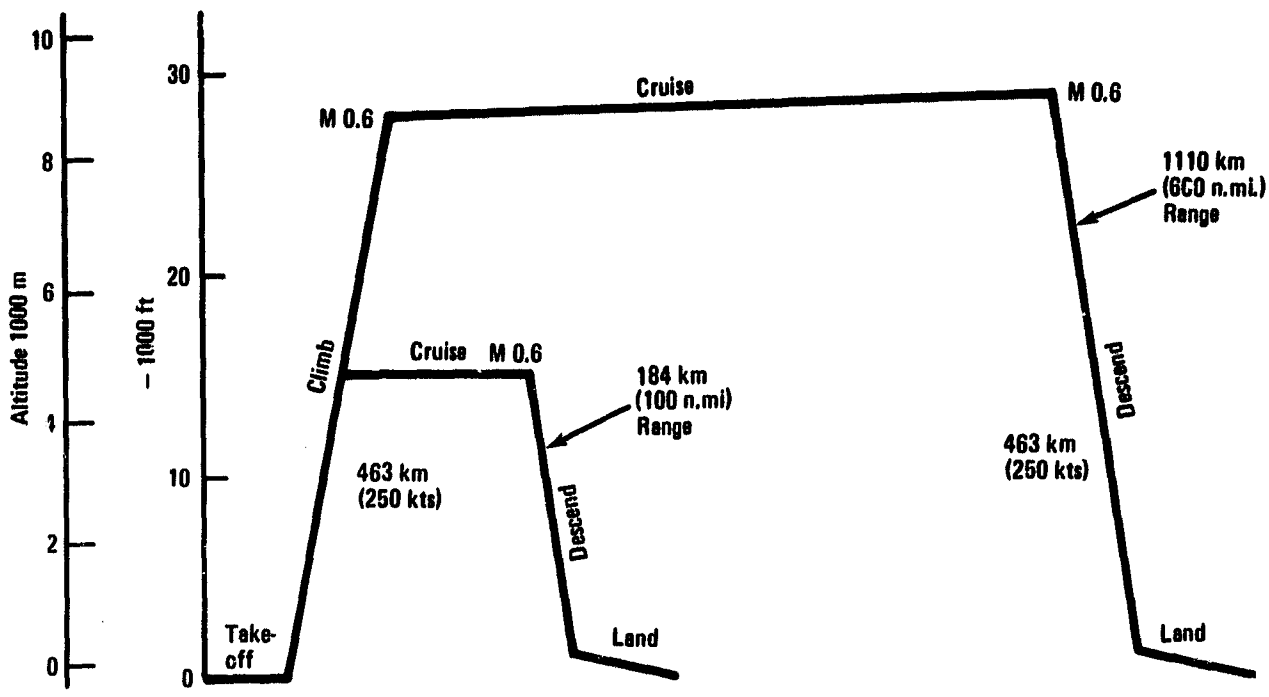


Figure 11 Mission Profile - 30 PAX Short-Haul

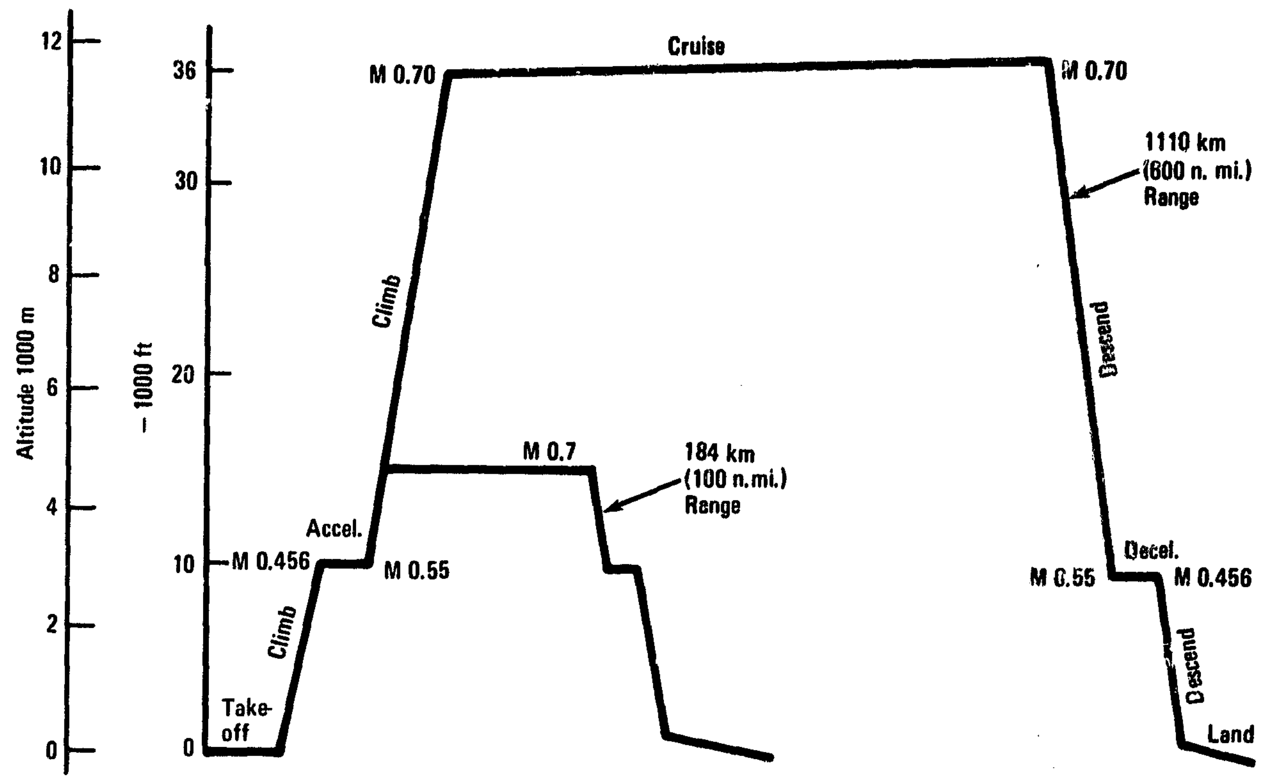


Figure 12 Mission Profile - 50 PAX Short Haul

During this study effort, each of the baseline aircraft was analyzed at different cruise speeds to assess the effect on DOC. The results of this assessment for the 30-passenger aircraft is shown in figure 13.

For the 30-passenger aircraft, the baseline configuration was flown at Mach 0.60, 0.50, and 0.456 at both the 1110 km (600 n.mi.) and 184 km (100 n.mi.) stage lengths with the result that lower DOC was obtained at Mach 0.60 for 1110 km (600 n.mi.) and a small penalty incurred at 184 km (100 n.mi.). The 50-passenger aircraft was similarly analyzed and also showed a DOC advantage for Mach 0.70 over Mach 0.60 at the design range of 1110 km (600 n.mi.).

In summary, the most efficient aircraft design appears to be incorporation of high speed cruise capability for the 600 n.mi. design range with operation at reduced cruise speeds for the shorter stage lengths. Lower values for DOC at the higher cruise speeds for 600 n.mi. are the result of decrease in crew costs due to a significant decrease in block time at the higher speed. The data obtained for the 30 and 50 passenger aircraft is included in tables 1 and 2.

5.5 Aerodynamics

5.5.1 High speed drag. - The high speed drag polars for both the 30-passenger and 50-passenger baseline aircraft are depicted in figure 14. The aircraft drag characteristics are based on current Lockheed technology wing design. The wing for each aircraft has linear ratio of t/c of 16.8% at the root to 13.5% at the tip- with a mean aerodynamic t/c of 16%. The L/D's and C_L's for each of the baseline aircraft at their respective cruise speeds are:

	Cruise Speed	L/D	CL
30 PAX	M 0.60	15.5	0.45
50 PAX	M 0.70	16.75	0.48

For the 30-passenger aircraft, individual aircraft drag breakdown shows that the landing gear-pod drag is a significant component, which adds approximately 6% to the cruise drag of the aircraft. Early in the study, during definition of the baseline configurations, several landing gear configurations were investigated for the high wing, 30-passenger aircraft. A summary of those concepts investigated is depicted in figure 15. The baseline configuration (Concept 2) was selected based on simplicity of design and lower cost even though it was recognized that a drag penalty would be incurred. Subsequent advanced technology configurations for the 30-passenger aircraft, as described in Section 6, eliminate the necessity for a gear-pod.

5.5.2 High-lift system. - Because of the high wing loadings on the 30 and 50 passenger aircraft, a moderately effective high-lift system was required to keep landing and take-off distances to a minimum. Thus, full-span .30C single-slotted Fowler flaps with 0.30C translation and 0.73 rad (42^{o}) maximum deflection were incorporated, with roll control relegated solely to spoilers. The flaps extend from the fuselage side to the inboard side of the engine nacelle, then from the outboard side of the nacelle to the wing tip.

TABLE 1. - 30 PAX SHORT-HAUL AIRCRAFT

	Baseline Configuration		Reduced Cruise Speed				Redesigned	
Cruise Speed	M 0.6	M 0.6	M 0.5	M 0.5	M 0.456	M 0.456	M 0.456	M 0.456
Range n.mi.	600	100	600	100	600	100	600	100
W/S	80	80	80	80	80	80	70	70
T/W	0.379	0.379	0.379	0.379	0.379	0.379	0.340	0.340
AR	12	12	12	12	12	12	12	12
TOGW lb	28 606	27 111	28 330	26 962	28 236	26 950	28 189	26 941
OEW lb	19 499	19 499	19 499	19 499	19 499	19 499	19 965	19 965
Block Fuel lb	2146	671	1902	551	1892	625	1820	589
Block Time	2.00	0.58	2.30	0.61	2.47	0.62	2.47	0.62
DOC ($1.00)	4.977	9.946	5.265	9.764	5.513	10.173	5.412	9.881

TABLE 2. - 50 PAX SHORT-HAUL AIRCRAFT

	Baseline Configuration		Reduced Cruise Speed
Cruise Speed	M 0.7	M 0.7	M 0.6
Range n.mi.	600	100	600
W/S	80	80	80
T/W	0.344	0.344	0.344
AR	10	10	10
TOGW lb	40 427	38 511	40 046
OEW lb	26 156	26 156	26 156
Block Fuel lb	2816	933	2545
Block time k	1.71	0.47	1.94
DOC ($1.00)	3.759	7.505	3.879

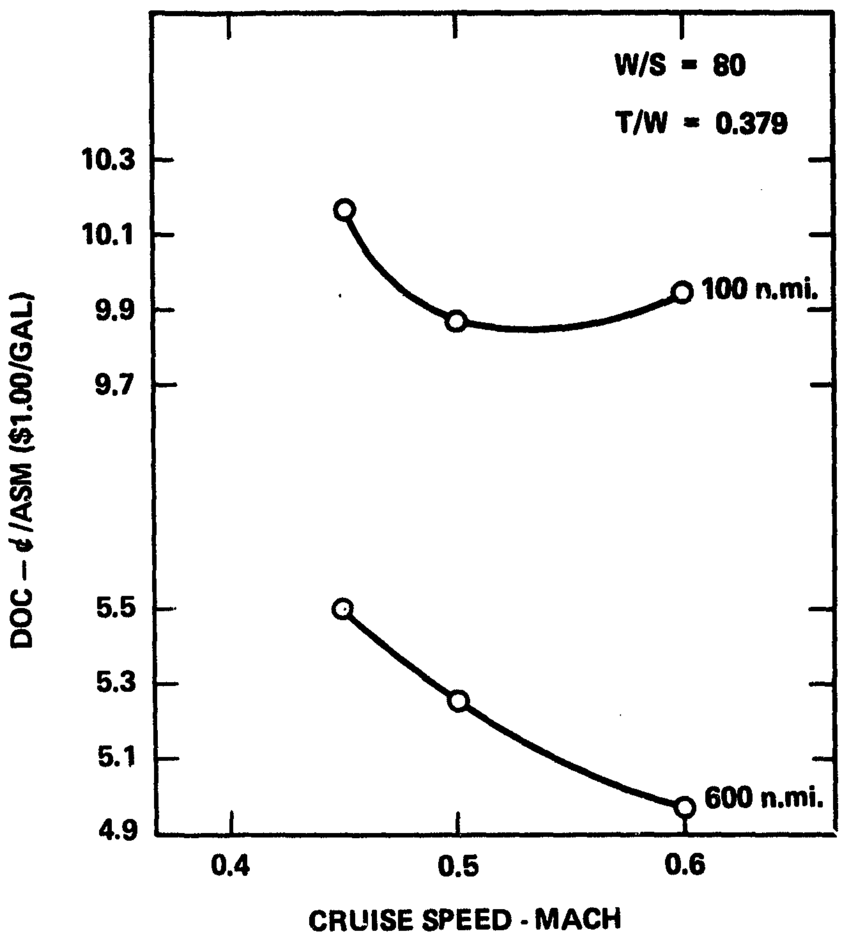


Figure 13. - 30 PAX short-haul aircraft.

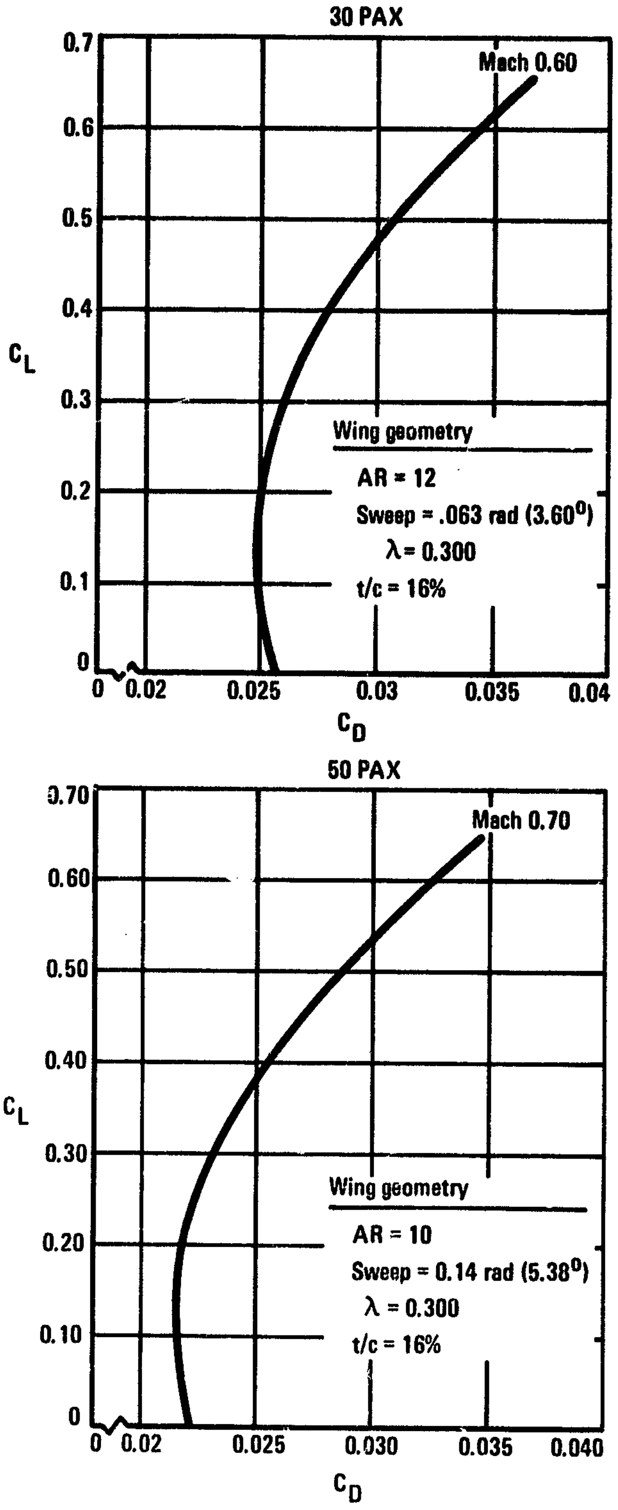
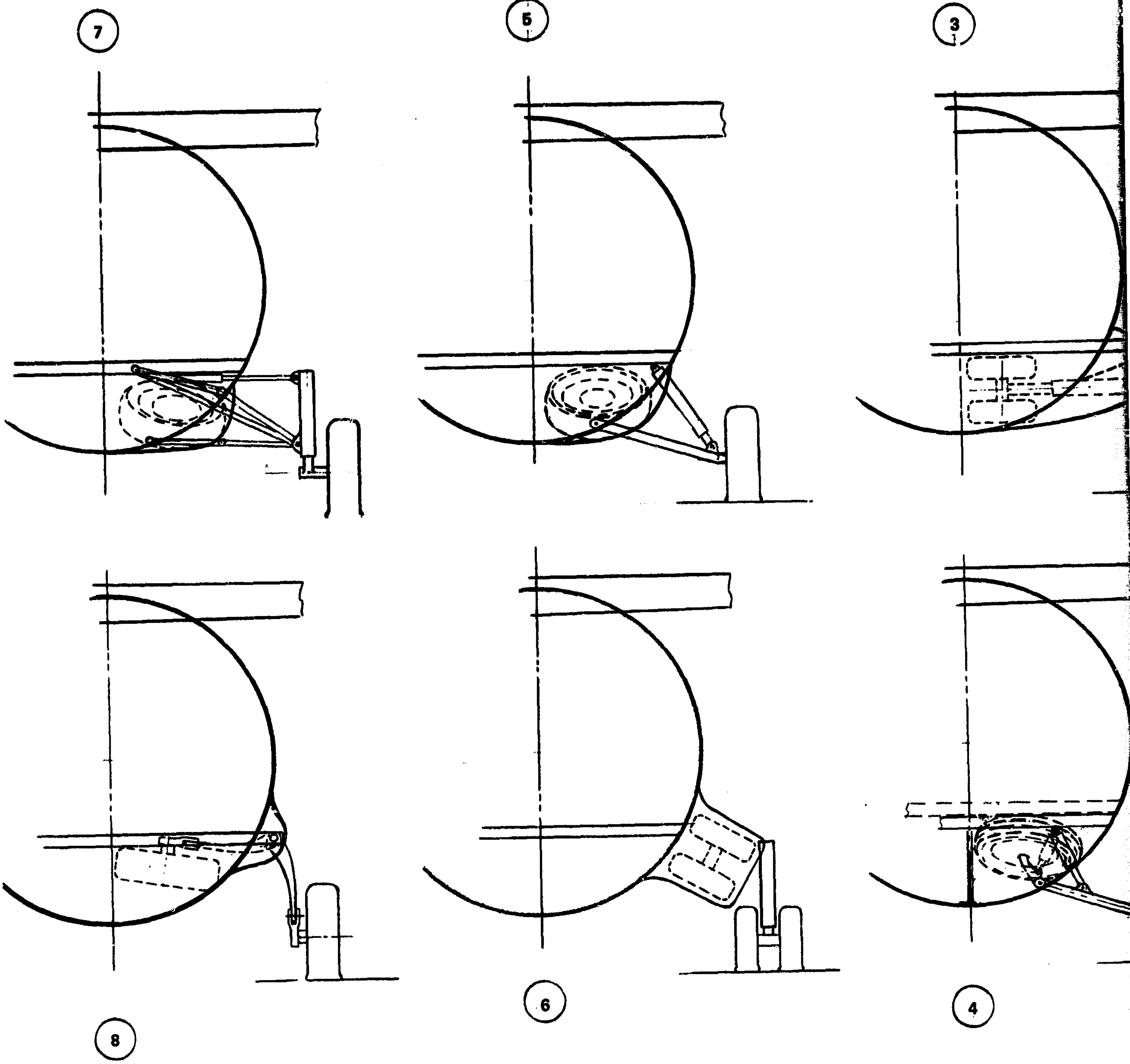


Figure 14. - Baseline short-haul drag polars.



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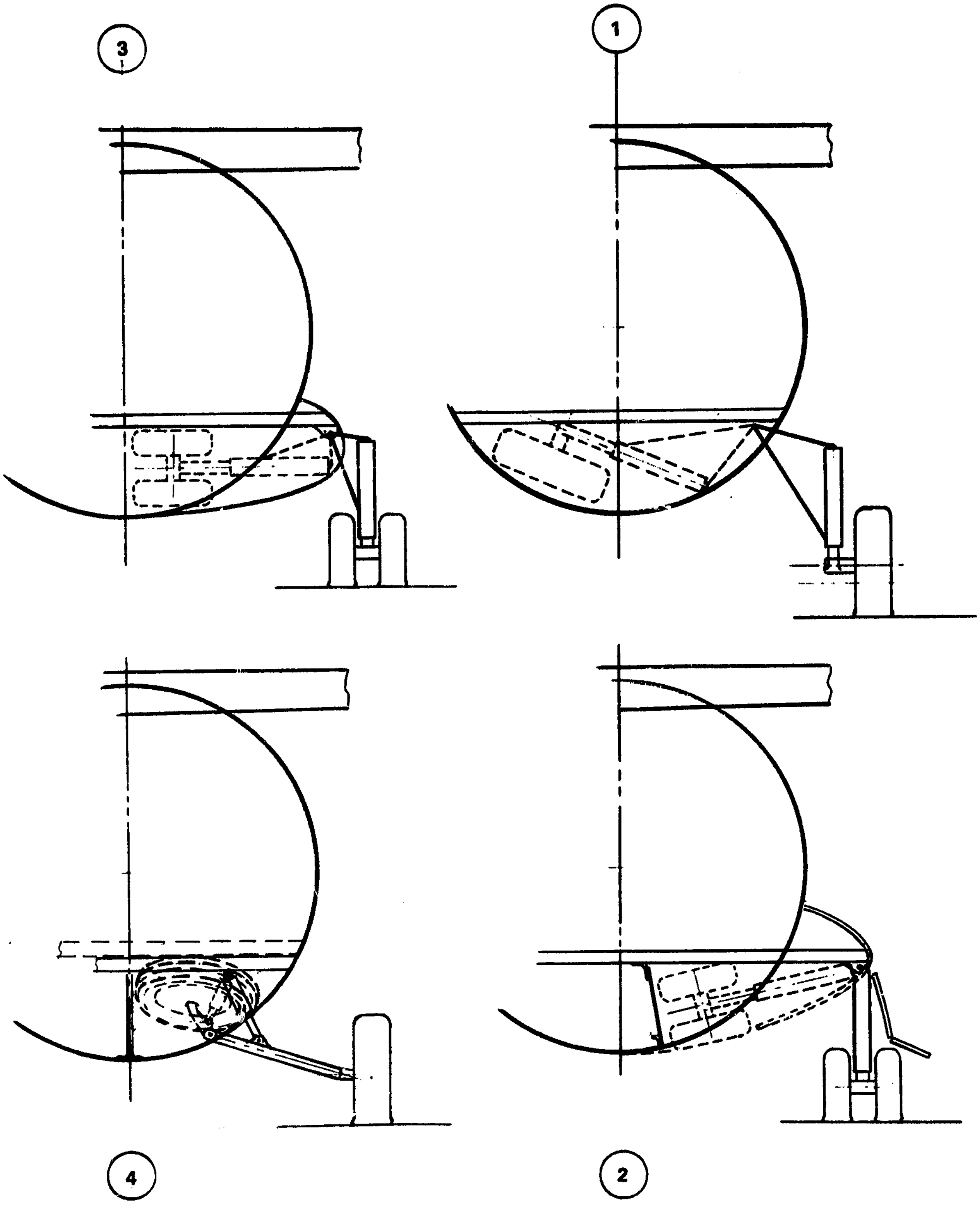


Figure 15. - Landing gear concepts.

FOLDOUT 2

Flap extension is accomplished by fixed tracks and flap-mounted rollers, and actuation is via torque tube-driven screw jack. Also included are full-span leading edge slats with the same spanwise coverage as the flaps. Maximum deflection of the slats is 0.52 rad (30°), and slat-mounted tracks and fixed rollers perform the extension. Hydraulic linear actuators are employed on the slats. Figure 7 depicts a typical cross-section of the high-lift system, which is common to both aircraft. Because of the long translation of the rear flap a fixed track and jackscrew were implemented. This design eliminated any holes in the rear spar web as well as the necessary long tunnels into the wing box which would house a hydraulic linear actuator. The screwjack is included in the same forging which supports the tracks, and an exterior fairing houses the whole assembly. The same design could not be used on the leading-edge slats because of the exterior fairing required at wing leading edge; however, the short translation of the slat requires only a small tunnel depth into the wing box.

Figure 16 shows the low speed polars for both baselines. A desirable feature of the flap design is that the flap translation reaches 0.23C, (near maximum limit) before its deflection exceeds 0.17 rad (10°). The benefit of this is increased C_L values (due to increased in wing area) equivalent to those of much higher flap deflections but without the associated higher C_D values. The resultant take-off roll is shorter due to reduced drag at take-off flap settings.

5.6 Structural Design

The baseline short-haul aircraft configurations employ current technology structural arrangement and materials typical of those utilized for Lockheed's L-1011 commercial transport. The fuselage is a conventional semi-monocque structure of aluminum alloy with a circular cross section of 2.90 m (114 in.) in diameter in the constant sections. Figure 17, which is a structural layout of a typical constant section of the L-1011 fuselage, is representative of the baseline short-haul fuselage structural arrangement. Wing and empennage utilize skin-stringer construction with aluminum alloy material and are typified by the L-1011 wing box structure, as shown in figure 18. The structural design concepts incorporated into the baseline configurations, while considered to be conventional technology, are also labor intensive due to the high number of component parts and fasteners, and are therefore well-suited to advanced structual arrangements and materials.

5.7 Flight Controls and Avionics

Conventional control systems were employed on both the 30-and 50-passenger baseline aircraft. As depicted in figure 19, hydraulic boost systems were minimized; however, it was considered necessary to prevent the roll control spoilers from floating at cruise and for control force attenuation. A boost system was also utilized for rudder control on the 50 passenger aircraft for engine-out conditions at low speeds.

All systems incorporate dual control cables as well as dual actuators where actuators are implemented. The roll spoilers are split, two spoilers per side,

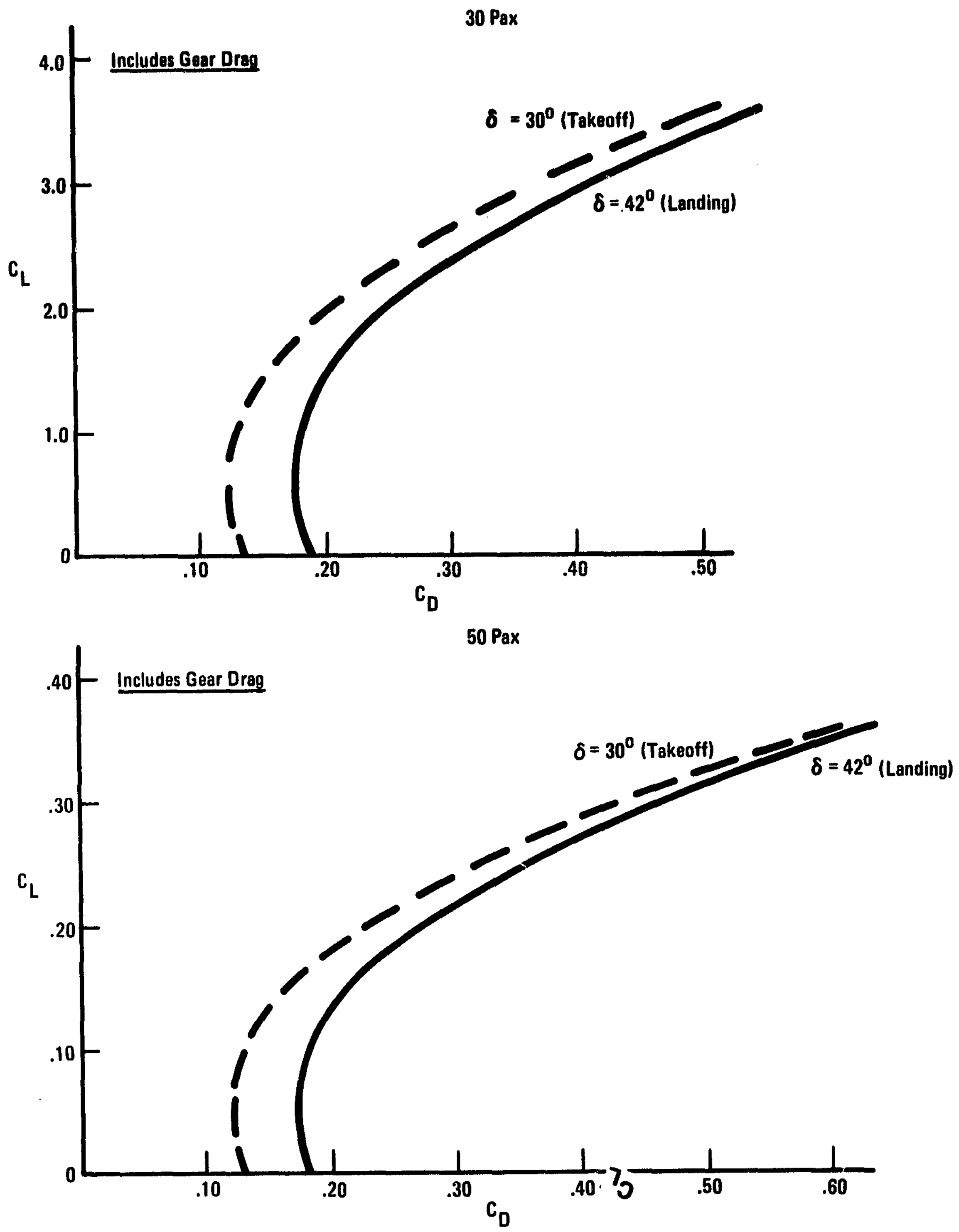


Figure 16. - Baseline short-haul low speed drag polars.

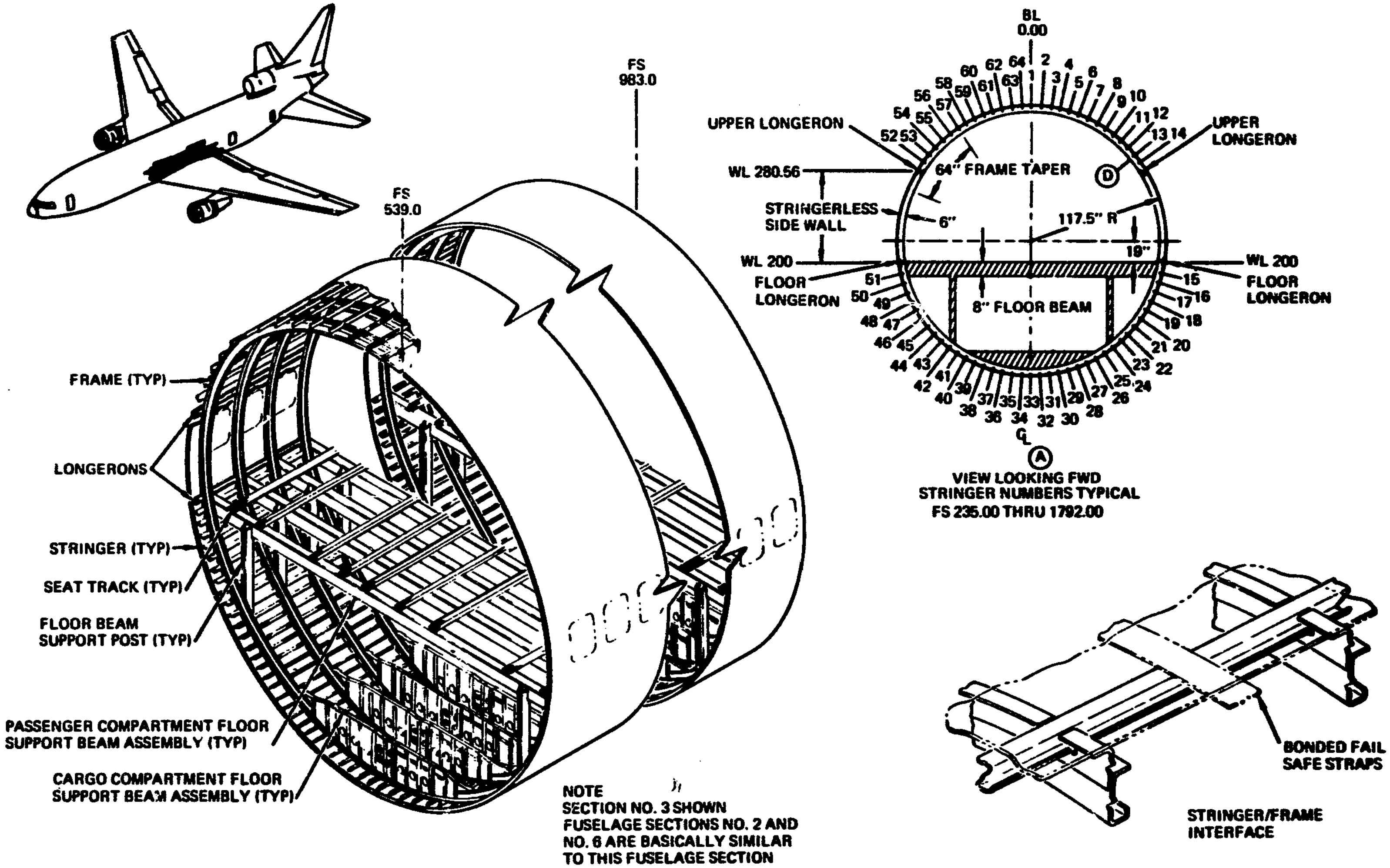


Figure 17. - L-1011 fuselage section.

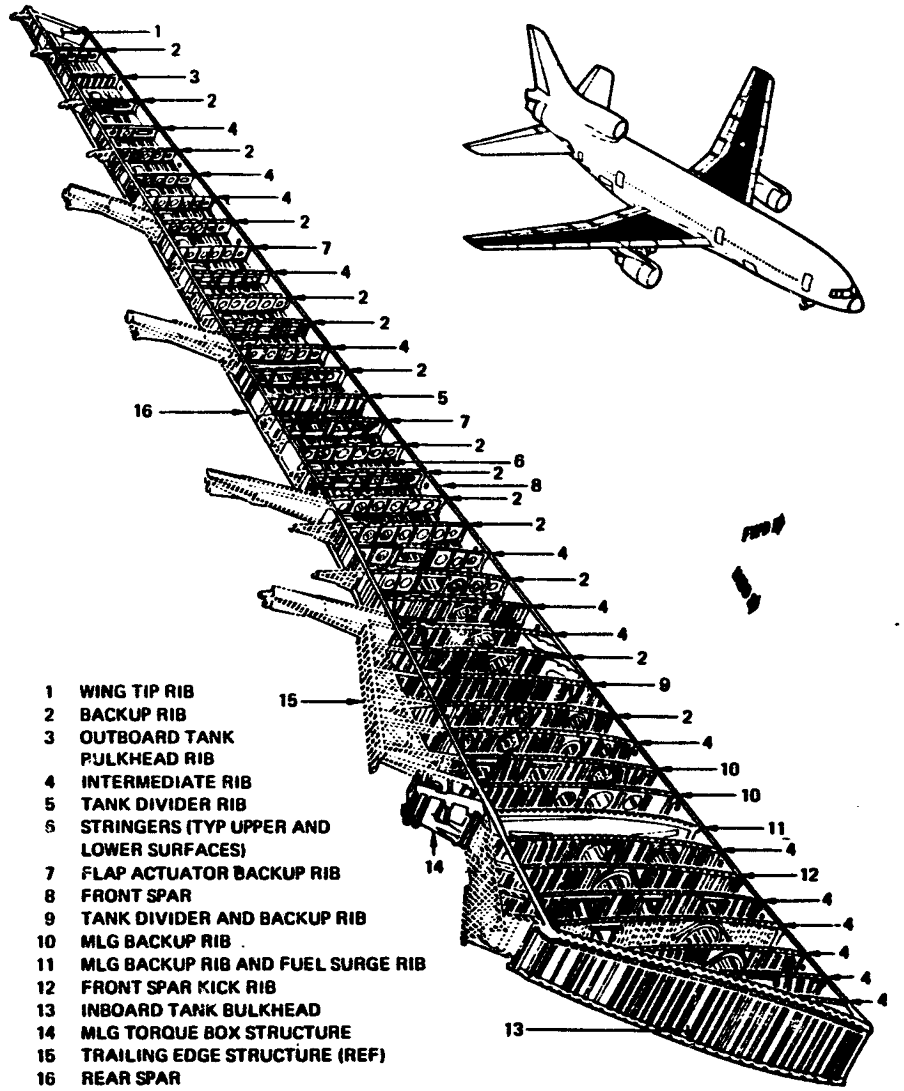
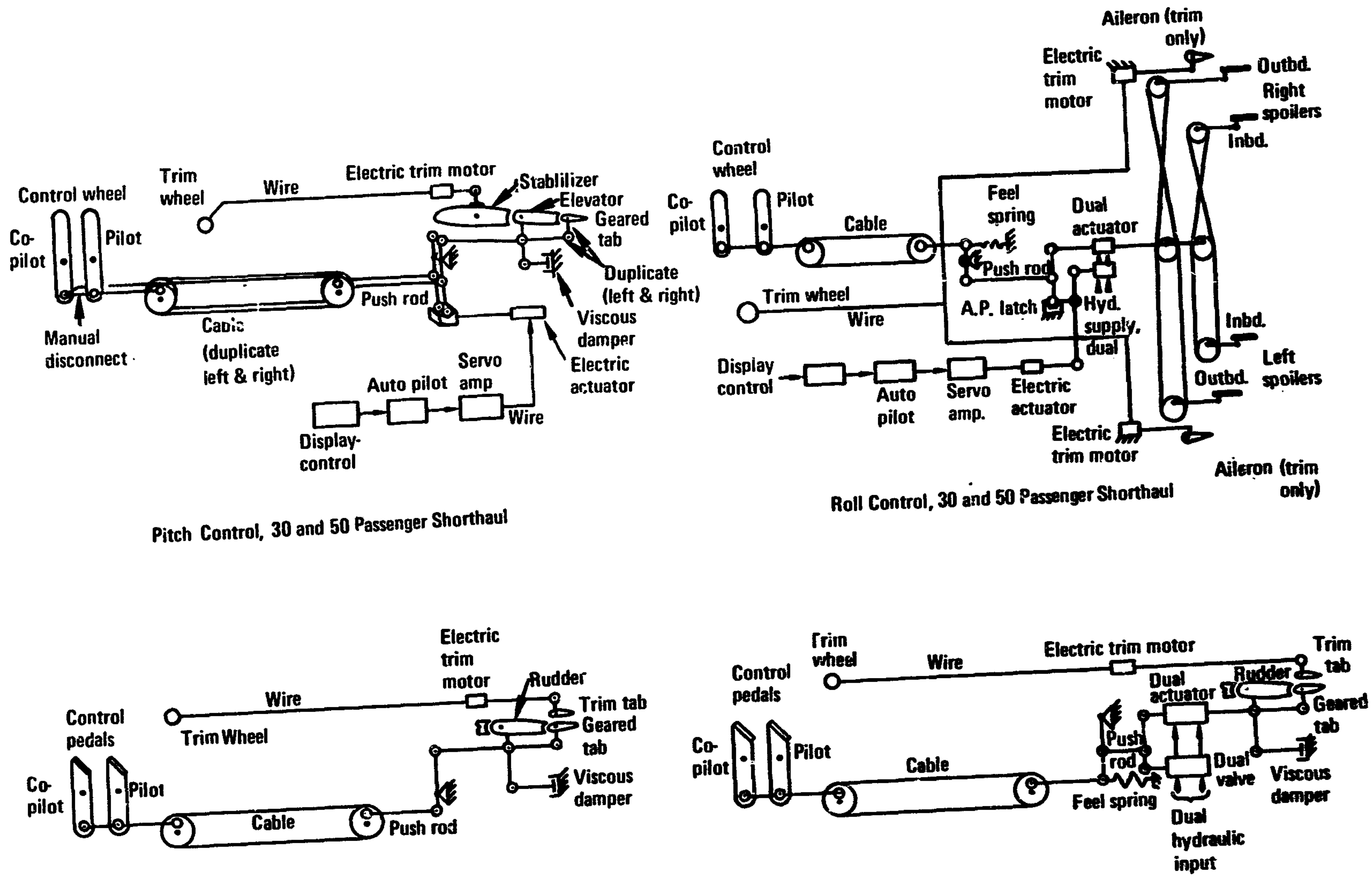


Figure 18. - L1011 Wing section.



Pitch Control, 30 and 50 Passenger Shorthaul

Roll Control, 30 and 50 Passenger Shorthaul

Yaw Control, 30 Passenger Shorthaul

Yaw Control, 50 Passenger Shorthaul

Figure 19. - Primary control systems, 30- and 50-passenger short-haul aircraft.

with one actuator each. Flaps and slats have a single hydraulic motor each, with spanwise torque tubes, which drive the actuator jackscrews.

The short-haul avionics, as shown in table 3, have complete IFR capability with dual navigation, communication and DME radios. Weather radar is included for weather front penetrations, and a radio altimeter is used for positive decision height determination at IFR minimum conditions. A flight director coupled to an autopilot significantly reduces pilot workload during instrument approaches. This is paticularly important on short-haul aircraft which will make several approaches during a single day.

5.8 Systems

Secondary power, by definition, refers to power extracted from the propulsion system for the purpose of supplying the service-system in the aircraft; hydraulic, fuel, electric, and environmental control systems. Typically, and in the past, engine bleed air has been the primary power source for the ECS, and the engine/wing deicing, while hydraulics have been used for landing gear/door operations, nose wheel steering, and for powering the primary and secondary flight control surfaces. The electric system, for the main part, has been used to furnish heating, lighting, instrumentation, avionics, motor loads, and other miscellaneous electrical function.

For the advanced technology short-haul transports, fuel efficiency and fuel conservation are the key considerations in the design of the secondary power systems. The other important design criteria relative to short trip/quick turn around operation of the aircraft are the logistic support, maintenance and reliability aspects. In earlier studies of short-haul transports, fan-jets were considered and the core flow on these engines permitted a consideration of engine bleed air for the typical ECS/engine start functions. In later studies, fuel efficiency concerns resulted in selection of turboprops. This has had two significant impacts; 1) the engine core flows inhibited the use of bleed air for secondary power 2) the propellors require icing protection. As a consequence of those two factors, alternative means of cabin pressurization and air conditioning were required and the generator capacity has to increase to meet the projected increase in electrical loads. Engine driven compressors are candidates for the ECS and both involve mechanical extraction which is much more fuel efficient than bleed power extraction.

5.8.1 Environmental control system. - The ECS is designed to provide a comfort level similar to current aircraft such as B737 and DC-9. Pressurization requirements are reflected by a 6000 ft cabin altitude and a total cabin airflow, for the 50-passenger aircraft, of approximately 70 ppm up to 15 000 ft decreasing to approximately 55 ppm at 25 000 ft. Cabin heating is furnished by heat of compression and supplementary dual electric heaters.

5.8.2 Electric system. - The system capacity of the electric system is determined by the type of ECS, the baseline system for the 50-passenger aircraft utilizes two 150/200 amp. 28 Vdc starter generators to 3 phase, 200 V, 400 Hz, 75 kVA generators and furnish 28 Vdc power and engine start capability. A 500/750 VA inverter is used to furnish emergency ac power. The generators are

TABLE 3. - SHORT-HAUL TYPICAL AVIONICS COMPONENTS

VHF #1, Collins VHF-20A, 20 watts
VHF #2, Collins VHF-20A, 20 watts
VOR-Localizer-Glideslope-Marker, Collins VIR 30
ADF, 190-1750 kHz, Collins ADF-60
ADF Antenna
DME #1, Collins DME 40
DME #2, Collins DME 40
Transponder, Collins TDR-90
Radar, Collins WXR-300
Radar Indicator
Radar Antenna, 12 in.
Audio Control Center, Collins 346B-3
Speakers, 6 at 3 pounds
Cockpit Voice Recorder, Collins AVR-101
Locator, Garrett RESCU/88
Navigation and Communication Control, Collins NCS-31
Remote Readout, Collins 339R (3)
Radio Control Adapter, Collins 899P-1 (6)
Mode Select Panel
Radio Altimeter, Collins ALT50
Indicator
Antenna (2)
Compass, King KCS 305
Autopilot, Collins AP106A
Flight Director, FD 1112 v/c

direct engine driven and require no interposing type power conversion systems. Electrothermal wing deicing is estimated at 22.5 kW continuous and 5.5 kW cyclic. Prop/spinner deicing is estimated at 12 to 15 kW and windshield heating reflects an additional 6 kW.

5.8.3 Auxiliary power unit. - The utilization of an APU in the short-haul transport is a customer option that is appropriate to the 50-passenger aircraft. Its primary advantage would be in providing ECS power in the aircraft without running one of the engines during passenger loading and unloading. The other advantage would be in supplying power on the ground when electrical power was not available. Provisions for installation of an APU have been incorporated into each of the baseline aircraft.

5.9 PROPULSION

Propulsion for both the 30 passenger and 50 passenger baseline aircraft consists of current technology turboprops installed in Lockheed configured nacelles. This study was conducted simultaneously with advanced technology propulsion system studies awarded by NASA-Lewis to Allison, Garrett, and General Electric. To define an appropriate scalable baseline engine and to insure a degree of consistency with the engine manufacturer technology studies, Allison, Garrett, and GE were asked to recommend a baseline engine for each of the Lockheed study aircraft and to provide scalable performance for the recommended engines.

The engine manufacturers responded with the engines described in table 4. In general, the list represents the latest turboprop engine each manufacturer has to offer.

Estimates at the initiation of this study of nominal engine power ratings for the 30 and 50 passenger baseline aircraft were 1429 kW (2000 hp) and 2984 kW (4000 hp), respectively. Since none of the recommended engines are of these sizes, scaling corrections are required to match engine power capability with aircraft thrust requirements. Allison and Garrett provided estimates for scaling corrections of their recommended powerplants.

The 1793 kW (2403 hp) and 3582 kW (4802 hp) baseline scaled engine performance, weight, geometry, and cost data transmitted herein were established in consultation with NASA personnel, based on a synthesis of the engine manufacturer recommended engine data and scaling corrections. The following discussions describe the basis for establishing the baseline gas generator definitions, installed engine performance, and selection rationale for the baseline propeller performance, weight and cost estimates.

Gas generator performance. - Figure 20 depicts the sea level static uninstalled engine brake specific fuel consumption (SFC) for existing production turboprop engines as a function of thermodynamic rated horsepower. The performance level of each of the engine manufacturer's recommended gas generators are included. On the basis of this data, a baseline engine performance trend was established (i.e., dashed line on the figure). The SFC level upon which the installed performance for the baseline 30 pax 2403 horsepower and 50 pax 4802 horsepower aircraft/engine combinations are noted.

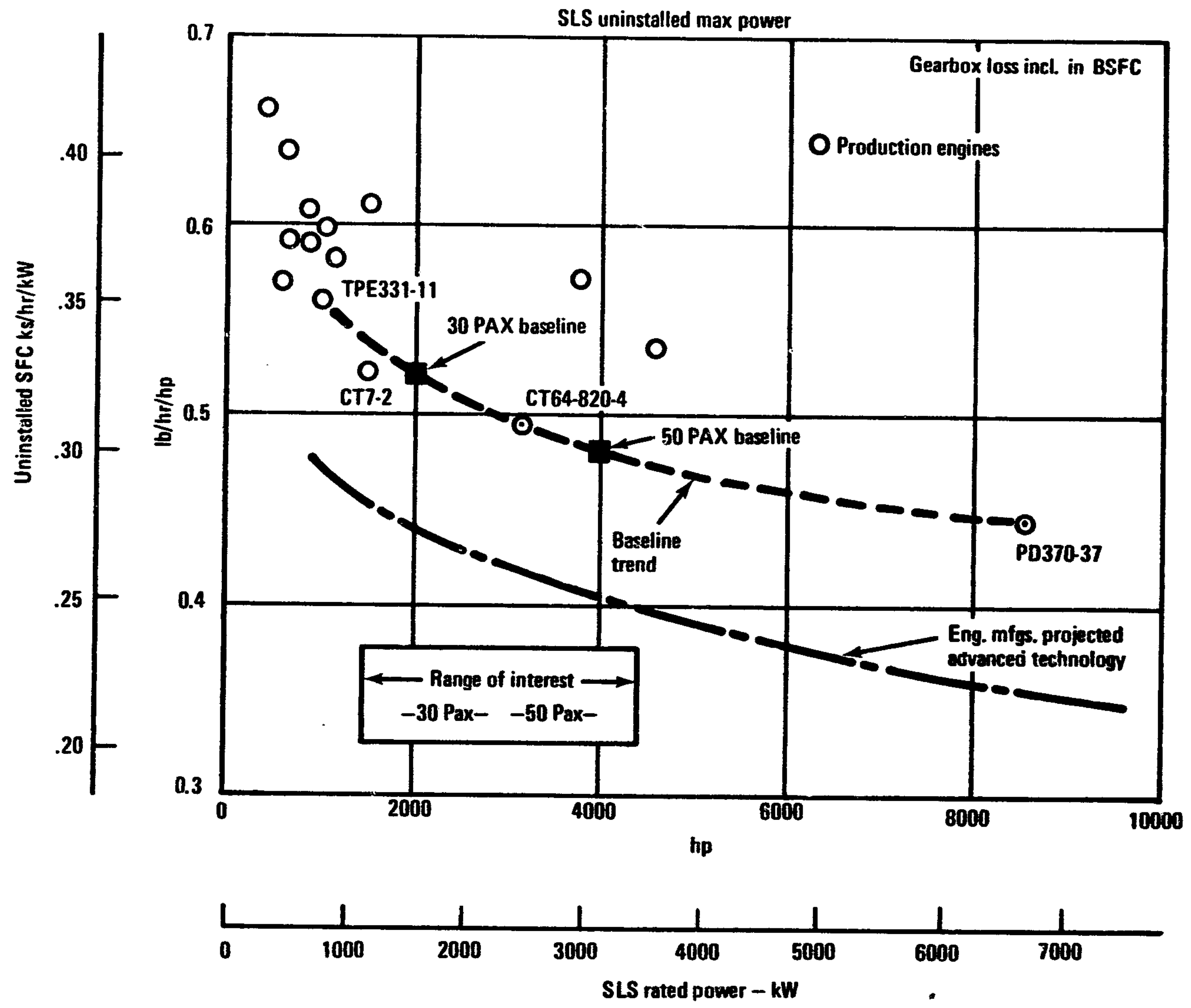


Figure 20. - Engine SFC comparison.

TABLE 4. - ENGINE MANUFACTURER RECOMMENDED BASELINE ENGINES

Engine M'fg	Engine	kW	(shp) Rating	Basis	Comments
Allison	PD370-37	6304	(8450)	Proposed turboprop version of T701-AD-700 HLH engine developed through PPFRT (Cancelled 1975) – Now in stationary powerplant use.	Scaling corrections provided to scale engine to 1492 kW (2000 hp) range.
Garrett	TPE331-11	746	(1000)	Production engine – Latest in T76 family.	Scaling corrections provided to scale engine to 2238 kW (3000 hp).
GE	CT7-2	1119	(1500)	Proposed turboprop version of T700 turboshaft engine (preliminary data).	
	CT64-820-4	2340	(3137)	Production engine (1960 vintage).	
P&W Canada	None	–	–	–	Only provided acquisition and maintenance cost estimates.

The engine performance trend projected by the engine manufacturers for advanced technology gas generators in the same size range is shown for reference as the dash-dot line in figure 20. The similarity of trends, i.e., increasing SFC with reduced engine size (SHP), for both current and advanced technologies, is primarily due to Reynolds number effects, increased relative blade clearance heights, and reduced design pressure ratios and turbine inlet temperatures at the smaller engine sizes.

Gas generator weight. - Figure 21 presents the gas generator (including gearbox) horsepower to weight ratios for the engine manufacturer's baseline engines and for other production engines. The selected trend of horsepower to weight ratio with rated power as well as the values chosen for the 30-and 50-passenger aircraft gas generators are noted.

Gas generator geometry. - A cross-section drawing of the representative baseline turboprop engine is shown in figure 22 to identify pertinent engine dimensions and to characterize a typical short haul engine configuration. Figures 23 through 25 present the baseline trend established for engine length, overall envelope width, and overall envelope height, respectively, based upon the recommended and existing production engines. It is assumed that engine-mounted accessories are located in the horizontal plane. The baseline 30 and 50 passenger aircraft propulsion system geometries are also noted on these figures.

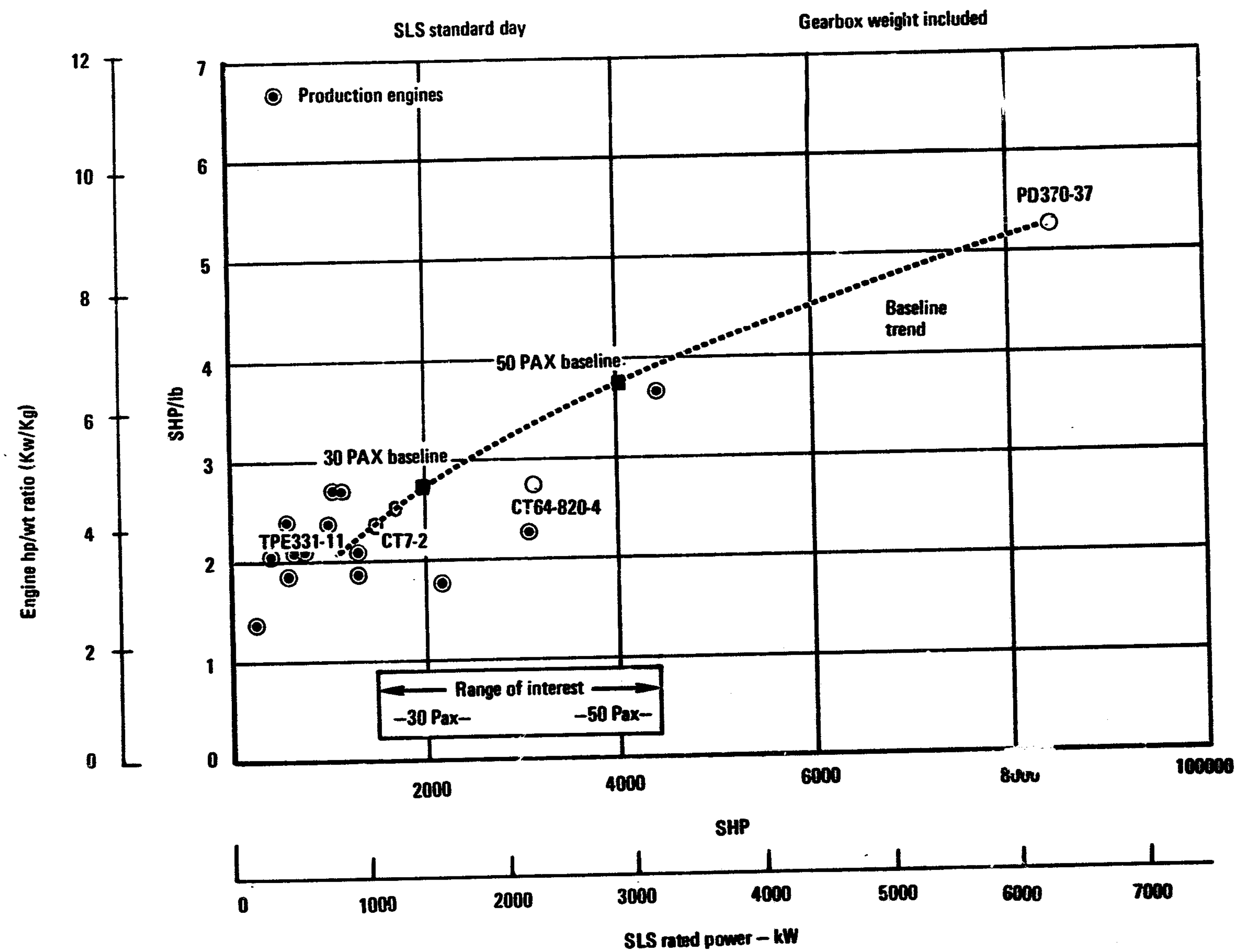


Figure 21. - Engine horsepower to weight ratio comparison.

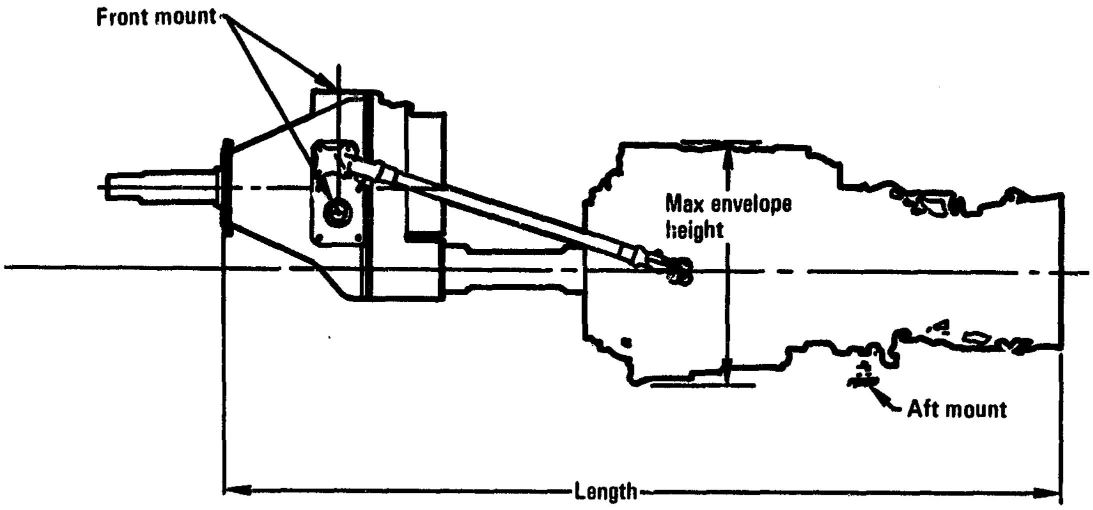


Figure 22. - Typical short-haul engine cross section.

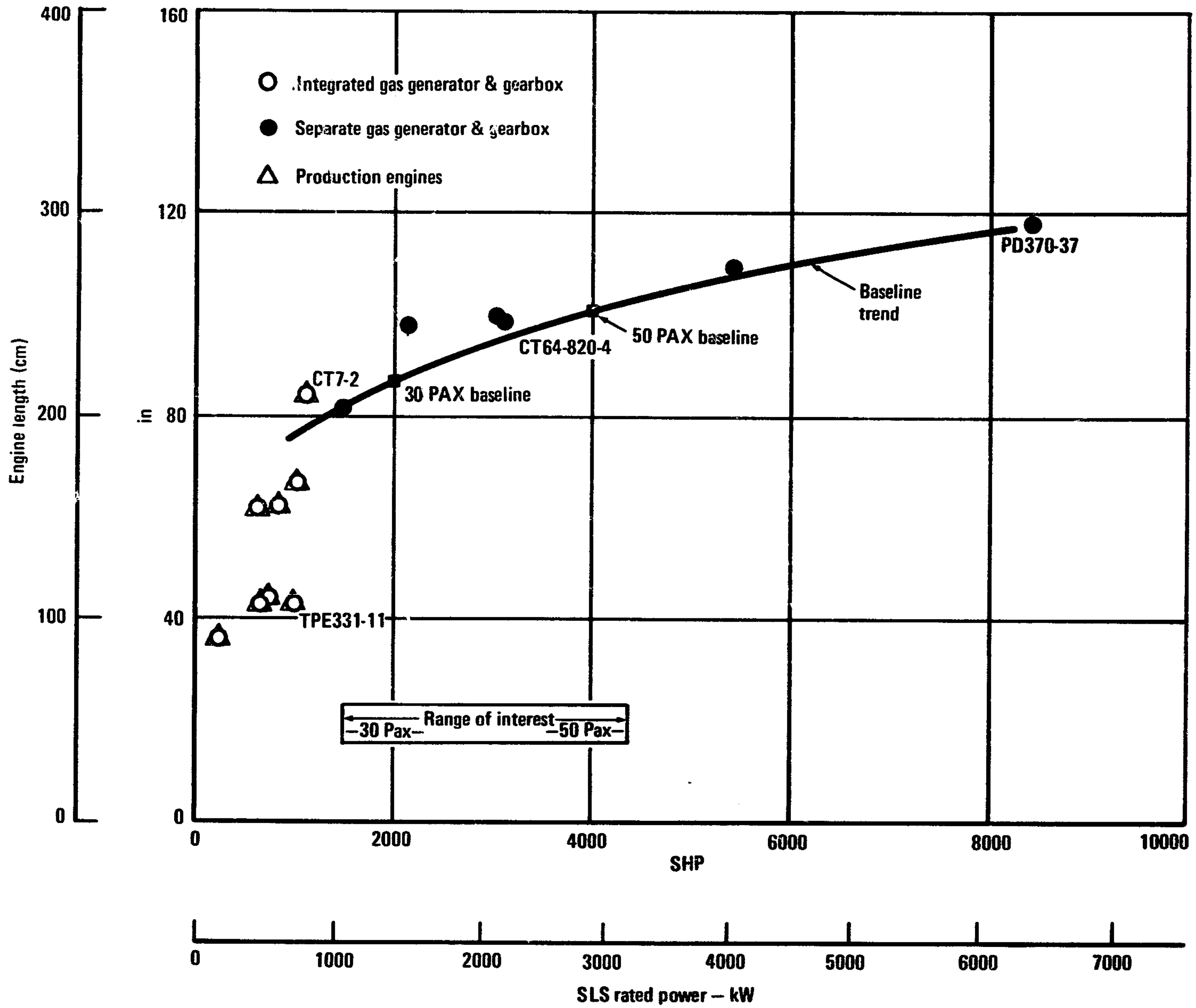


Figure 23. - Engine horsepower to length ratio

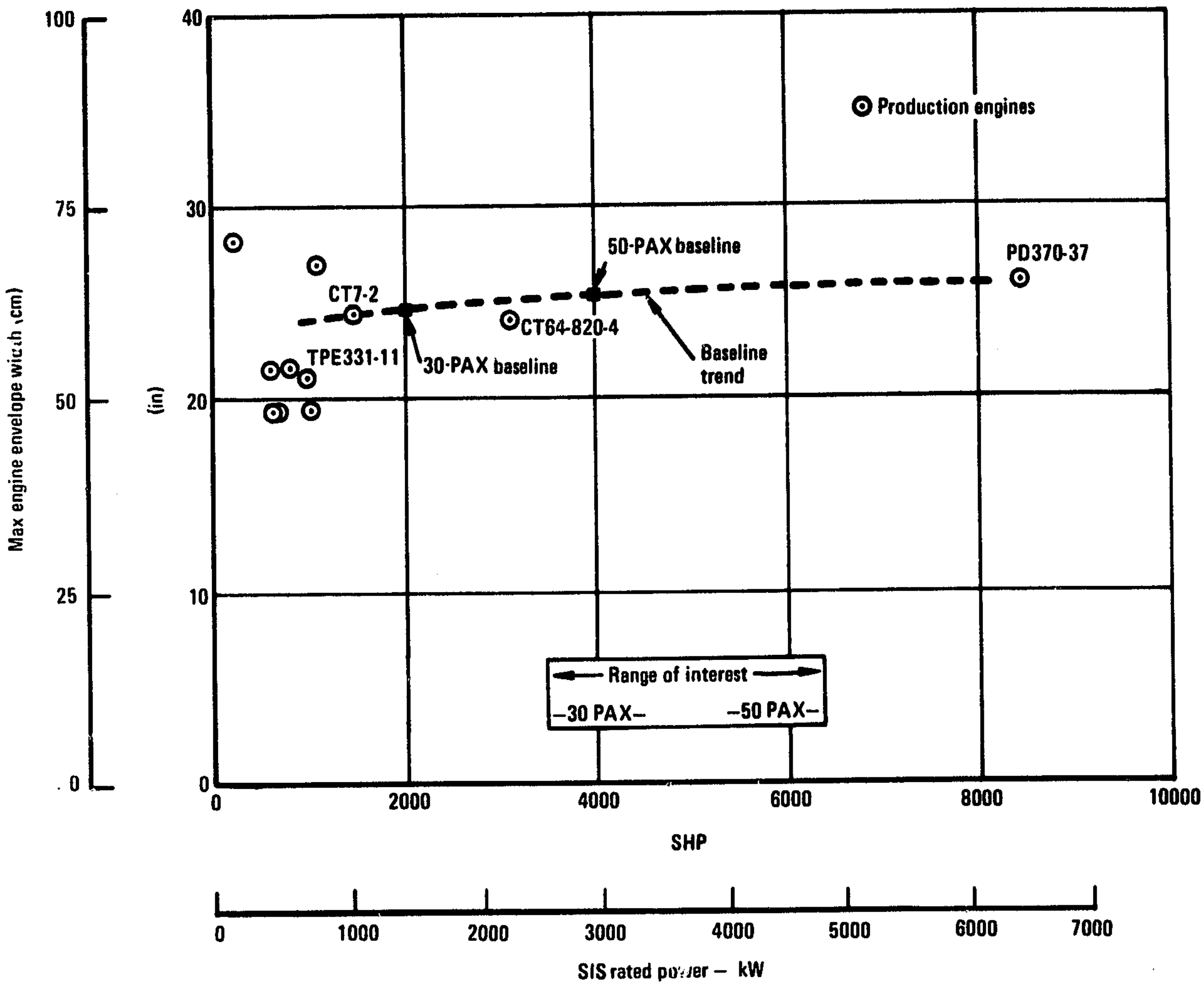


Figure 24. - Engine max envelope width.

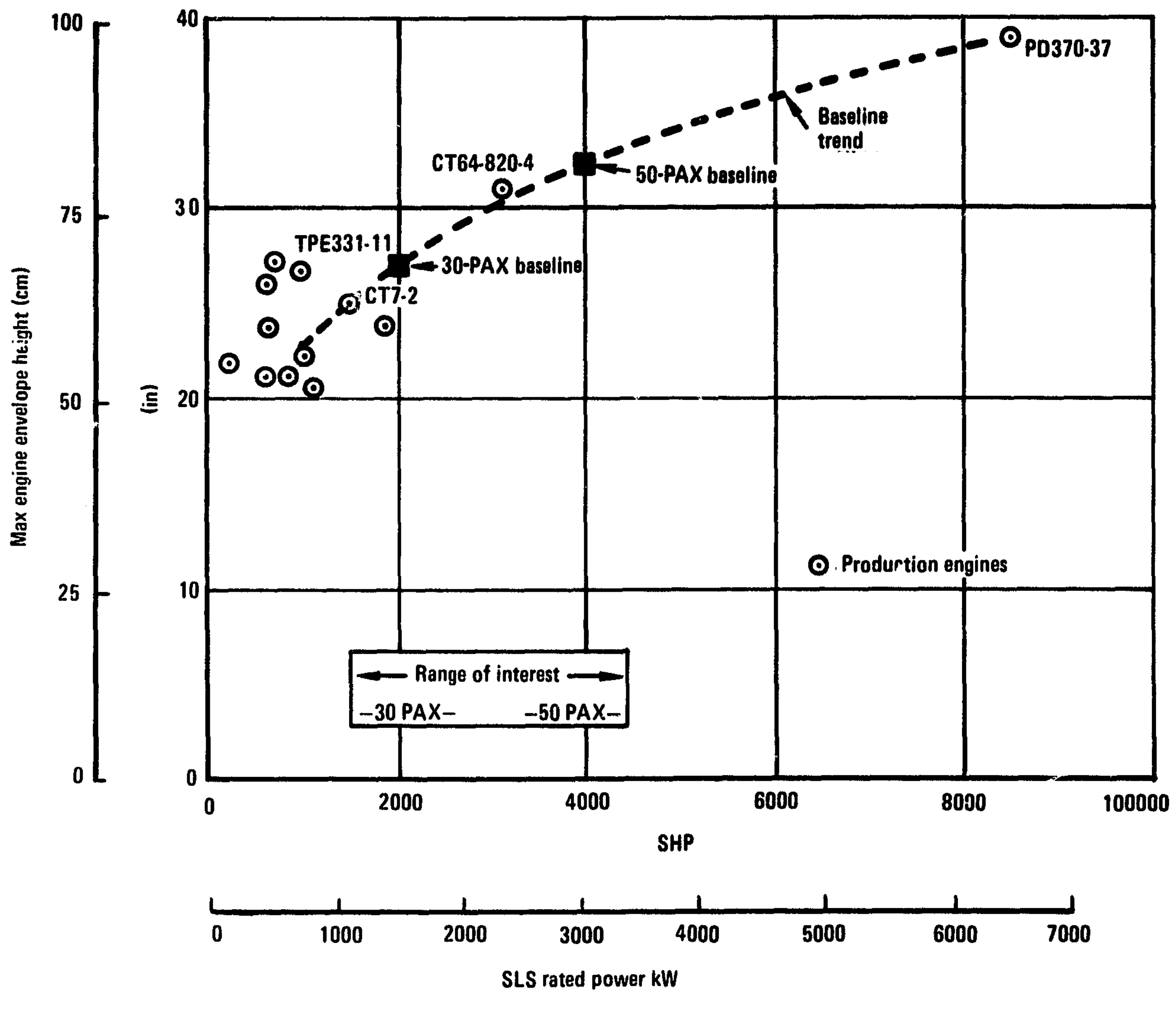


Figure 25. - Engine max envelope height.

Gas generator economics. - Allison, Garrett, GE, and P&W of Canada were asked to define engine (including gearbox) acquisition and maintenance cost estimates (1979 dollars) as a function of engine rated horsepower for engines representative of todays technology and design practices. Figure 26 presents manufacturer's estimated acquisition cost in terms of dollars per horsepower. Ground rules include the assumptions that the gearbox price is included and that the engine is mature. The recommended baseline trend is shown as the dashed line and 30 and 50 passenger baseline values are noted. Similarly, the manufacturer's estimates and selected baselines for the 30 and 50 passenger aircraft are shown in figure 27 for burdened maintenance cost.

5.9.1 Propeller system characteristics. - Unfortunately, there are no Mach 0.6 or higher commuter turboprop aircraft in airline service. Today's commuter aircraft engine props are similar to those described in Hamilton Standard's "Brown Book," reference 1. They are characterized by low activity factor, high camber, and low number of blades to give good low speed performance at low weight. Application of these propeller systems is limited to Mach 0.3 to 0.4 since compressibility losses are significant at higher speeds.

After discussions with Hamilton Standard, it was agreed that the Electra/P-3 54H60-77 propeller system, reference 2, appears to be the best baseline available for this study, as it employs low camber to suit the high speed application. The Electra propeller was, therefore, selected to establish baseline performance, weight, and cost estimates.

The principal features of the baseline propeller system are tabulated below.

- 4 blades, 163 activity factor, 0.286 integrated lift coefficient
- solid aluminum blades
- constant speed (220 m/s (721 fps) tip speed)
- double acting pitch control
- negative torque control, overspeed pitch lock, and beta controls
- reversing capability
- deicing

Propeller performance: Propeller net efficiency levels for the 54H60-77 propeller system have been provided by Hamilton Standard and have been used to generate the installed performance transmitted herein. Typical cruise efficiency levels at Mach 0.6 and 0.7 are shown in figure 28 for reference.

Propeller weight: For the purpose of scaling the Electra propeller system weight to other engine powers and prop diameter, a weight-estimating equation has been derived based on the weight correlation presented in the Hamilton Standard "Red Book", reference 3, for conventional shaft mounted propellers with solid aluminum blades. The Hamilton Standard correlation, equation (1),

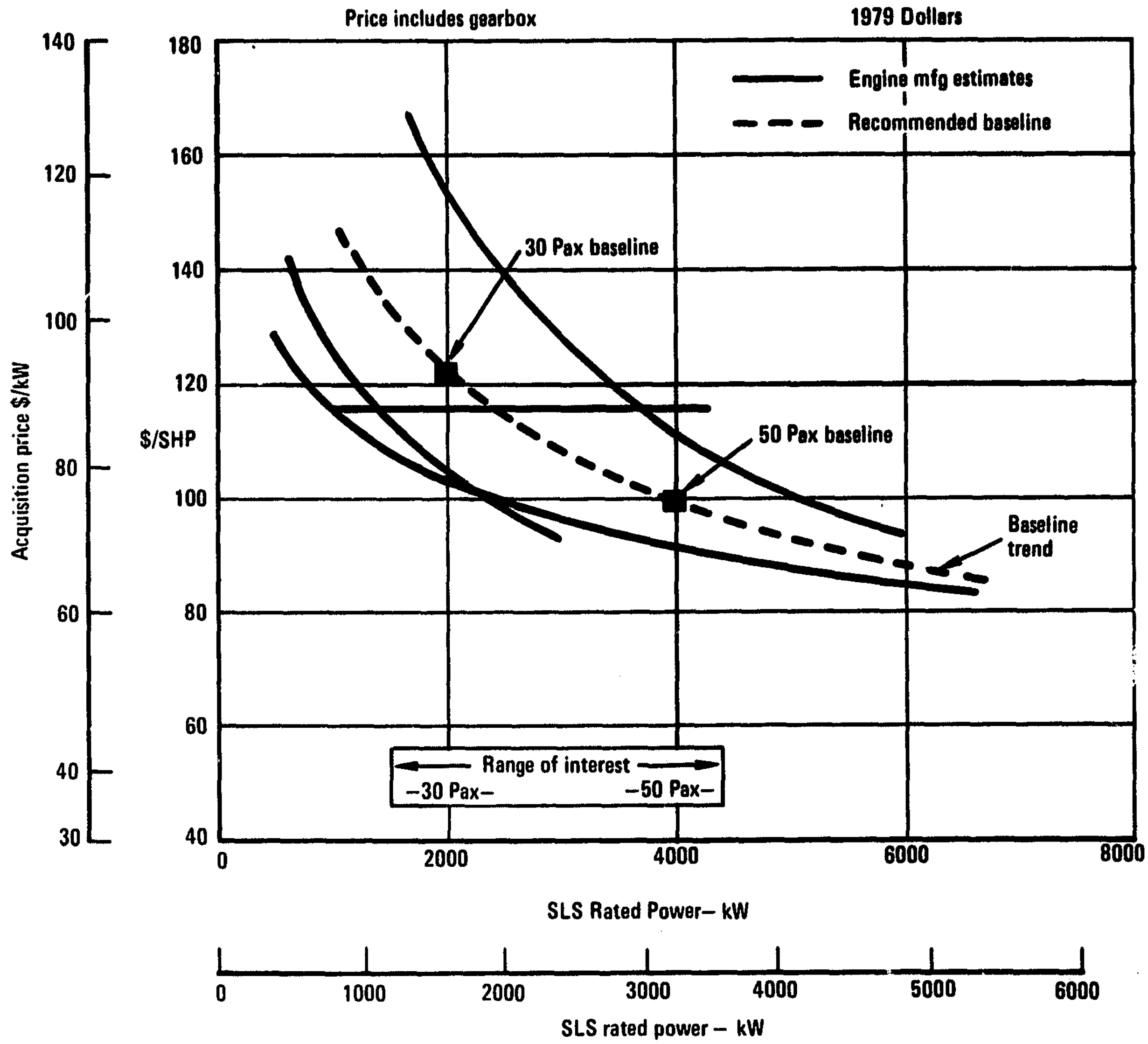


Figure 26. - Engine acquisition price comparison.

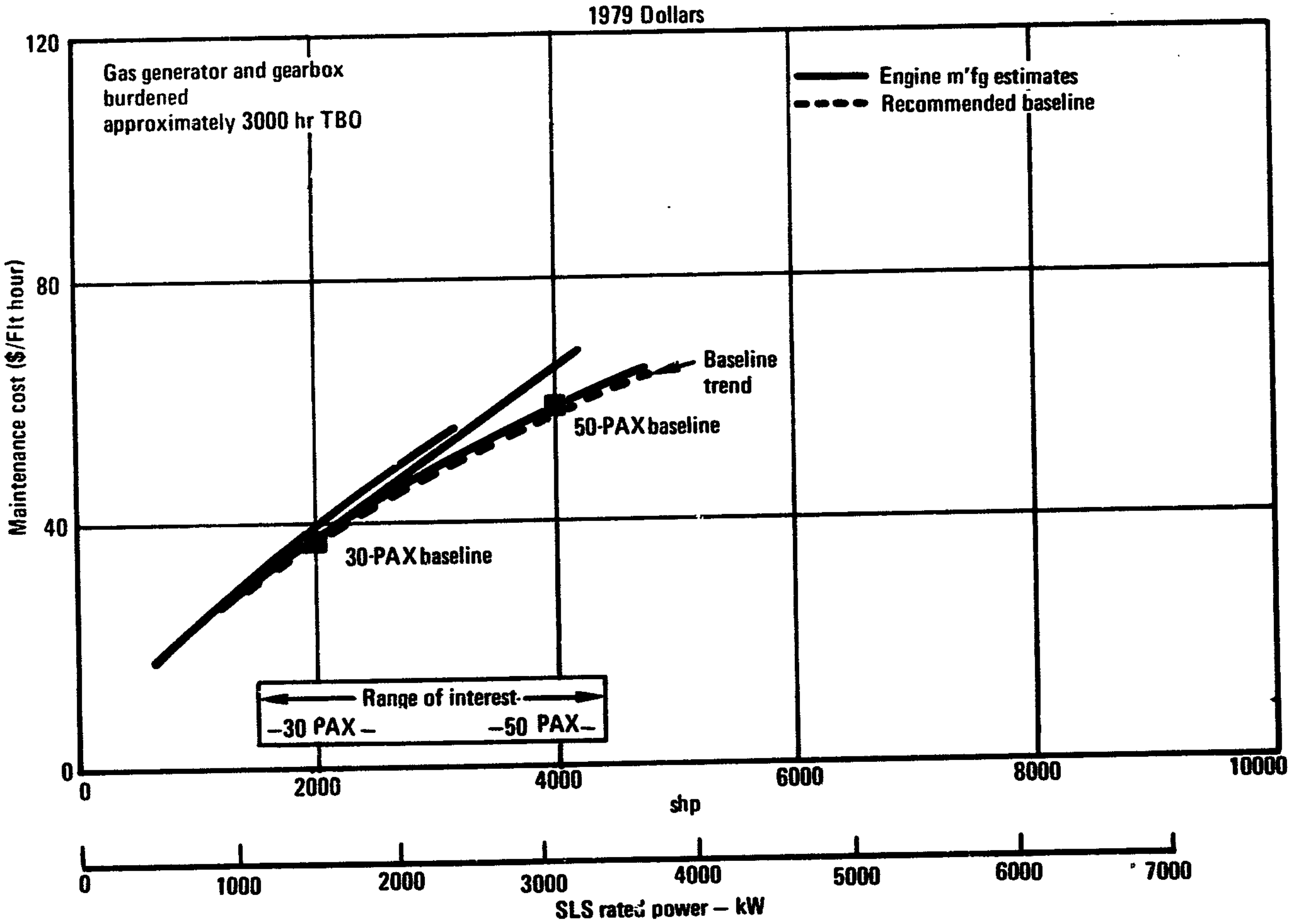


Figure 27. - Engine maintenance cost comparison.

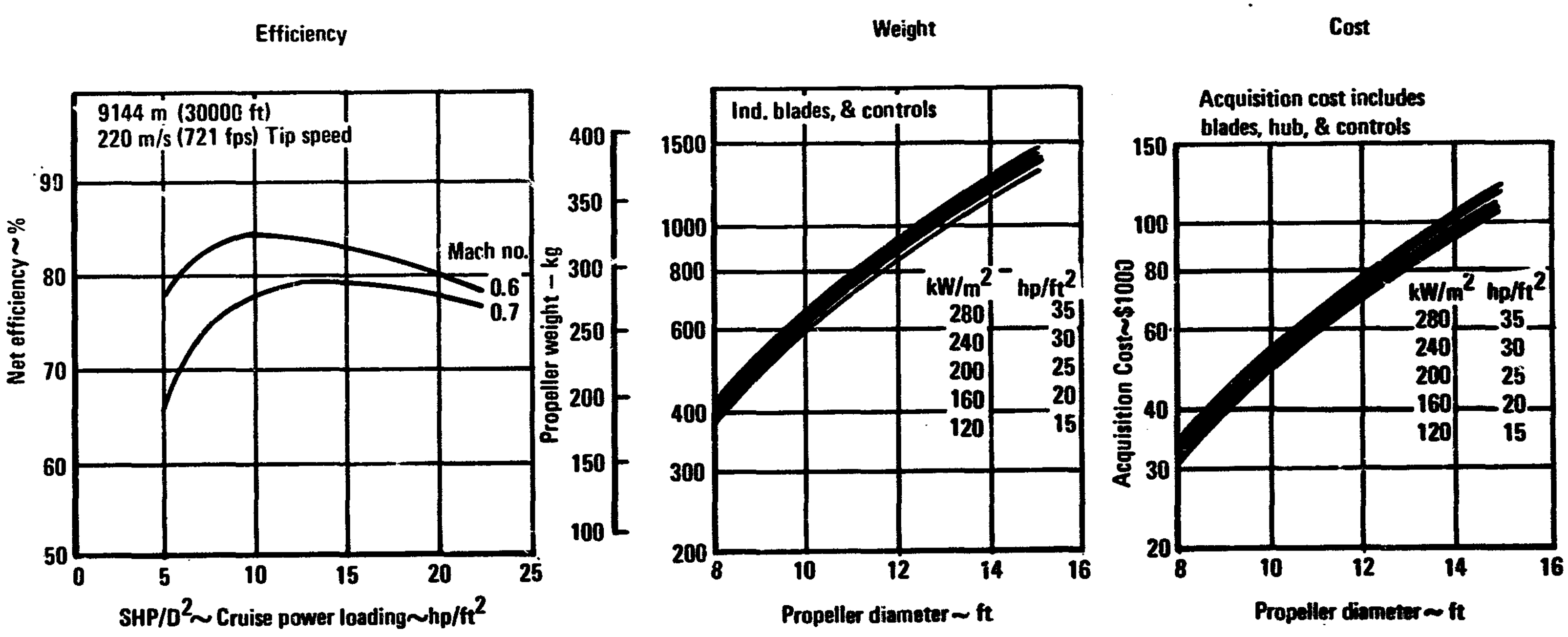


Figure 28. - Baseline propeller performance, weight, and cost.

incorporates propeller geometry and operational parameters which experience has shown to have the predominant effect on weight. The exponents have been established to best fit weight trends of past and current prop construction. The generalized weight equation is for the complete propeller system and includes blades, spinner, hub, controls, deicing, and oil.

$$\text{(1)}\quad \text{Prop Wt.} = \text{Const.} \left(\frac{D}{10}\right)^2 \left(\frac{B}{4}\right)^{0.7} \left(\frac{AF}{100}\right)^{0.75} \left(\frac{ND}{1000}\right)^{0.5} \left(I{+}M\right)^{0.5} \left(\frac{SHP}{D^2}\right)^{0.12}$$

For this study, the baseline propeller is assumed to have 4 blades, an activity factor (AF) of 163, a tip speed of 721 fps, and a maximum cruise speed of 0.7. Including these constants into equation (1) reduces the weight correlation to the following expression.

$$\text{Prop Wt.} = 425 \left(\frac{D}{10}\right)^2 \left(\frac{SHP}{D^2}\right)^{0.12} \qquad (2)$$

See Table 5

The constant, 425, was determined such that at the 54H60-77 prop diameter, D (ft) and maximum power loading, shp/d^2 (hp/ft^2), equation (1) predicts the specification weight for the Electra/P-3 system. Baseline propeller weights, (Eqn. 2) are shown in figure 28 as a function of propeller diameter and maximum power loading.

Propeller acquisition and maintenance cost: The results of Hamilton Standard's advanced general aviation propeller studies, reference 4, have been used to establish a propeller acquisition cost model. It was shown in the Hamilton Standard study that for a specific propeller category (in this case, constant speed, full feather, deicing, reversing, 4 blades, double-acting pitch control, etc.), acquisition cost is directly proportional to propeller system weight. Based on the current 54H60-77 prop cost (including control), a baseline propeller cost of \$37.38/kg (\$82.38/lb) (1979 \$) is assumed. Combining this figure with the weight correlation (equation 2) results in the following equation for acquisition cost as a function of prop diameter and maximum power loading.

$$\text{Acquisition Cost} = \$350.11\ (D^2) \left(\frac{SHP}{D^2}\right)^{0.12} \qquad (3)$$

See Table 5

The resulting baseline acquisition cost is shown in figure 28 as a function of prop diameter and maximum power loading.

A study of turboprop system reliability and maintenance costs was completed in May 1977 by Allison and Hamilton Standard for NASA-Lewis, reference 5. One facet of the study was to determine reliability and maintenance costs of past and current turboprop systems. Using data from 1966 through 1969 for Electra L-188 operation averaging 0.8 hours per flight, the fully burdened propeller (Hamilton Standard 54H60) maintenance cost was \$4.15 per flight hour in 1979 dollars. For this short-haul study, a constant propeller maintenance cost of \$4.15 is assumed.

5.9.2 Baseline engine data for ASSET. - The variations in engine and propeller performance, weight, geometry, and economic trends with size established in the preceding two sections have been quantified in equation form and are tabulated in table 5. These data define the principal characteristics of existing technology turboprop propulsion systems in the 746 to 5970 kW (1000 to 8000 shp) range.

Baseline engine performance has been generated and included for a 1492 kW (2000 hp) (30 PAX) and 2984 kW (4000 hp) (50 PAX) scalable engines. Characteristic gas generator rated SFC levels (sea level static, standard day, max. power) for the two engines are shown in figure 20. For flight operating conditions, the baseline gas generator performance in terms of horsepower, residual jet thrust, and fuel flow (SFC) versus Mach number, altitude, and power setting (i.e., lapse rates) have been modeled based on a synthesis of the performance data provided by the engine manufacturers for their recommended current technology STAT baseline engines.

Similarly, the trends established for gas generator weight, geometry, and cost and the propeller performance, weight and cost have been used to complete the definition of the 1492 kW (2000 hp) (30 PAX) and 2984 kW (4000 hp) (50 PAX) scalable short haul aircraft turboprop engines.

For the 30-passenger, Mach 0.6 aircraft, three sets of installed engine performance were provided for a 1492 kW (2000 hp) gas generator size and different propeller diameters as shown below. SFC, weight, geometry, and cost characteristics were selected consistent with the baseline trends previously shown. Similarly, three engine decks were also included for the 50 passenger aircraft. Baseline engine identification gas generator size, and prop diameters are shown below.

Engine Deck ID	Application	Rated Power For Scalable Baseline Engine		Prop Dia-ft	
		kW	Shp	m	ft
421	30 PAX	1492	(2000)	3.04	(10.0)
422	30 PAX	1492	(2000)	2.74	(9.0)
423	30 PAX	1492	(2000)	2.44	(8.0)
424	50 PAX	1492	(4000)	4.27	(14.0)
425	50 PAX	2984	(4000)	3.81	(12.5)
426	50 Pax	2984	(4000)	3.35	(11.0)

TABLE 5. - SHORT-HAUL BASELINE ENGINE MODEL

- Synthesis of existing engine/gearbox/propeller characteristics
  Representative of today's technology and design practices

Engine BSFC (lb/hr/hp) – incl. gb loss	$1.200\ (shp)^{-0.11}$
Propeller efficiency	Hamilton Standard 54H60-77 Propeller (TS = 721 fps)
Weights (lb):	
Engine and Gear Box	$12.24\ (shp)^{0.54}$
Propeller	$425\ (d/10)^2\ (shp/d^2)^{0.12}$
Geometry (in.):	
Length – Prop mount flange to rear engine flange	$17.57\ (shp)^{0.21}$
Max Envelope Height	$3.75\ (shp)^{0.26}$
Max Envelope Width	$18.21\ (shp)^{0.04}$
Acquisition cost (1979 \$):	
Engine and Gearbox	$1192\ (shp)^{0.7}$
Propeller (4 blade, Electra type)	$350.11\ (d)^2\ (shp/d^2)^{0.12}$
Maintenance cost (1979 \$/flt hr):	
Engine and Gearbox	$0.243\ (shp)^{0.66}$ } Includes Labor & Materials
Propeller (4 blade, Electra type)	4.15 } Includes Labor & Materials

- Definitions:

d – prop diameter (ft)

shp – engine thermodynamic max. rated horsepower, sea level static standard day

BSFC – engine brake specific fuel consumption at thermodynamic max. rated horsepower, sea level static, standard day. Assumes exhaust nozzle area sized for turboprop application (NPR $\approx$ 1.12 – 1.15)

The installed performance levels were obtained by correcting uninstalled baseline engine performance for losses attributable to the aircraft installation. These losses include engine air inlet duct pressure loss (inlet recovery); compressor bleed and power extraction for ECS, hydraulics, and avionics; and propeller gearbox loss. Typical values for each of these loss items are presented in table 6 for the 30-and 50-passenger aircraft. Nacelle friction drag and pressure drags, as well as interference drag, are included in the aircraft drag polar.

As is shown in table 6, no net inlet total pressure loss is assumed on the basis that the inlet duct loss is equal and opposite to the total pressure rise across the propeller.

TABLE 6. - ENGINE INSTALLATION LOSSES

	30 PAX Aircraft	50 PAX Aircraft
Inlet Recovery (PT2/PT0)	1.000	1.000
Customer Bleed (ppm)	0	0
Customer Power Extraction (kW/eng) (hp/eng)	37.3 (50)	56.0 (75)
Gearbox Power Efficiency (incl. [illegible] generator performance)	0.98	0.98

Notes: 1 Exhaust nozzle thrust and airflow coefficients included in uninstalled engine performances.

2 Nacelle drag included in aerodynamics drag polar.

Cabin pressurization and environmental control are provided by engine-driven compressors, rather than bleed air, to avoid the potentially large losses associated with bleeding the relatively small gas generators (gas generator airflows are approximately 6.8 kg/s (15 pps) at 1492 kW (2000 hp) and 13.6 kg/s (30pps) at 2984 kw (4000hp)). An estimated 100 and 150 horsepower per aircraft has been allowed for the 30-passenger and 50-passenger aircraft, respectively, for cabin pressurization, environmental control, hydraulic power, and avionics.

5.10 Noise

The requirements imposed on the short-haul aircraft were as follows:

- Interior cabin noise levels of 85 dB OASPL and speech interference level (SIL) of 65 dB or less

- Community noise level of FAR36-XYZ-8dB at the flyover, sideline, and approach locations.

5.10.1 Community Noise. -

30 passenger aircraft: Table 7 shows the estimated community noise levels at the three standard certification points, (a) flyover: beneath the flight path at 6500 m (21325 ft) from the beginning of the takeoff roll,) (b) sideline: the peak noise level at a lateral distance of 450 m (1476 ft) and (c) landing approach: below the aircraft when at an altitude of 120 m (394 ft) and at a distance of 2000 m (6561 ft) from the landing touchdown point while on a 3 degree glide slope. It is seen that the 30-passenger aircraft satisfies the requirements of FAR 36 Stage 3 minus 8 EPNdB. This estimate is based upon the propeller characteristics previously defined, and the climb profile characteristics as calculated by the Lockheed ASSET computer program.

50 passenger aircraft. - The 50-passenger baseline aircraft was sized with a 3.66 m (12 ft) diameter, conventional, unswept, 4-bladed propeller, operating at a tip speed of 219.5 m/s (720 ft/sec). For this configuration, the sideline noise level is 91 EPNdB. On a traded basis with the flyover noise, -5dB can be attained. To achieve the desired level of - 8dB would require a large diameter propeller of 4.27 m (14 ft) and a reduction in tip speed to 198 m/s (650 ft/sec). This propeller design results in approximately a 10% increase in aircraft gross weight and lengthening of the landing gear by approximately 12 inches. Since one of the items of advanced technology deals with incorporation of improved propellers (propfan), which will enhance the community noise situation, it was decided not to increase the baseline aircraft size to attain the additional - 3dB on sideline noise.

Summary of community noise aspect: - It appears that the 30 passenger aircraft can meet the FAR 36 Stage 3 minus 8 EPNdB noise levels with the baseline aircraft.

TABLE 7. - COMMUNITY NOISE LEVELS FOR THE 30 PASSENGER AIRCRAFT

	Predicted Levels EPNdB	FAR 36 Stage 3 Requirement EPNdB	Predicted Margin
Flyover	80	89	-9
Sideline	87	94	-7
Traded F/O γ SL	–	–	-8
Landing Approach	87	98	-11

The 50-passenger aircraft with the 3.66 m (12 ft) propeller diameter and operating at a 219.5 m/s (720 ft/sec) tip speed would make Stage 3 noise levels minus 3 EPNdB at sideline, or Stage 3 minus 5 EPNdB on a traded basis with the flyover noise. If the propeller diameter is increased to 4.27 m (14 ft) and operated at a tip speed of 198 m/s (650 ft/sec) then the aircraft is estimated to be capable of achieving Stage 3 minus 8 EPNdB on a traded basis between sideline and flyover noise, provided the gross weight increase is not more than 10 percent relative to a baseline value of 8336 kg (40 424 lb).

5.10.2 Interior cabin noise. - Preliminary estimates for the acoustical treatment mass penalties for the two aircraft were obtained by using estimates of the required sidewall surface density versus noise reduction obtained from studies of other aircraft, and then multiplying the surface density by the ratio of treatment area of the original aircraft compared to the present aircraft. The treatment area is proportional to the product of fuselage diameter times propeller diameter. This process led to penalty estimates of 408 kg (950 lb) for the 30-passenger aircraft and 680 kg (1500 lb) for the 50-passenger aircraft to achieve an interior noise overall sound presesure level of 85 dB.

5.11 Baseline Aircraft Performance

The baseline short-haul aircraft were sized in accordance with the following performance constraints:

	30 PAX	50 PAX
• Payload	2721.6 kg (6000 lb)	4536 kg (10 000 lb)
• Design Range	1110 km (600 n.mi.)	1110 km (600 n.mi.)
• Field Length	1219 m (4000 ft)	1219 m (4000 ft)
	(Sea level, 32.2°C (90°F)	
• Cruise Mach	0.60	0.70
• Approach Speed	224 km (121 kt)	224 km/hr (121 kt)
• Fuel Reserves	185 km (100 n.mi.) + 45 minutes endurance	

Drawings of the 30-passenger and 50-passenger aircraft are previously included as in figures 5 and 6. The 30-passenger aircraft is sized by the take-off field length (engine out) condition while the 50-passenger aircraft is sized by landing field length at maximum gross takeoff weight. Summaries of the design and performance characteristics of the baseline aircraft are included as table 8.

5.11.1 Sizing

The Lockheed developed Advanced System Synthesis Evaluation Technique (ASSET) program was used to size each of the baseline configurations to conform to the above stated mission constraints. Optimization criteria for each of the baseline aircraft was minimum DOC at the 184 km (100 n.mi.) stage length with full payload and fuel reserves for a 184 km (100 n.mi.) alternate plus 45 minutes endurance.

TABLE 8. - SHORT-HAUL AIRCRAFT DESIGN AND PERFORMANCE CHARACTERISTICS

	30 PAX	50 PAX
Mission		
Design Range	1110 km (600 n.mi.)	1100 km (600 n.mi.)
Typical Range	184 km (100 n.mi.)	184 km (100 n.mi.)
Cruise Speed	M 0.60	M 0.70
Init. Cruise Altitude	28 000 ft	36 400 ft
Field Length	4000 ft	4000 ft
Approach Speed	110 kts	110 kts
Design		
Configuration	Twin Turboprop	Twin Turboprop
W/S	80	80
T/W	0.375	0.344
AR	12	10
TOGW	28 606 lb	40 427 lb
Wing Span	65.5 ft	71.1 ft
Body Length	58.7 ft	74.7 ft
Body Diameter	114 in.	114 in.
Performance		
Engine Power	2403 hp	4802 hp
Block Fuel – 600 n.mi.	2146 lb	2816 lb
Block Fuel – 100 n.mi.	671 lb	933 lb
*DOC – 600 n.mi.	4.977	3.759
*DOC – 100 n.mi.	9.946	7.505

*At $1.00/gallon fuel cost.

30 passenger baseline: Optimization of the 30 passenger baseline was accomplished using the following design matrix to vary wing AR, wing loading, thrust /weight ratio, and propeller diameter to find the best design aircraft (minimum DOC criteria) which meets the previously imposed mission constraints:

AR	Wing Loading, W/S				Thrust/Weight, T/W				Prop. Dia (ft)	SLS Prop SHP/D^2 hp/ft^2
10	60	70	80	90	0.38	0.34	0.30	0.26	8	31
12	60	70	80	90	0.38	0.34	0.30	0.26	8	31
14	60	70	80	90	0.36	0.32	0.28	0.24	8	31
10	60	70	80	90	0.42	0.40	0.36	0.32	9	25
12	60	70	80	90	0.42	0.38	0.34	0.30	9	25
14	60	70	80	90	0.42	0.38	0.34	0.30	9	25
10	60	70	80	90	0.48	0.44	0.40	0.36	10	20
12	60	70	80	90	0.48	0.44	0.40	0.36	10	20
14	60	70	80	90	0.46	0.42	0.38	0.34	10	20

From the results of this parametric analyses, point designs (designs with minimum DOC values) for each wing AR and propeller diameter were selected. Figures 29 and 30 depict selection of wing loading and thrust/weight ratio for AR 12 and 14 and are typical of the carpet plots used to select the 30 passenger baseline point designs summarized in table 8. Point design results were evaluated as shown in figure 31 and the baseline aircraft design characteristics (AR, W/S, T/W, and Propeller diameter) selected based on minimum DOC at the 100 n.mi. stage length for \$.379/li (\$1.00 per gallon) fuel cost.

50 passenger baseline: Sizing of the 50 passenger baseline was accomplished using the identical process as that employed for the 30 passenger aircraft. Variations in W/S, T/W, AR, and propeller diameter were evaluated with the point design selected for minimum DOC at the 184 km (100 n.mi.) stage length and .379/li (\$1.00 per gallon) fuel cost. Figure 32 is typical of the carpet plots generated for the 50 passenger baseline aircraft and shows the selection of W/S and T/W for the baseline.

5.11.2 <u>Baseline aircraft sensitivities</u>. - Sensitivity factors were calculated for each baseline aircraft, after sizing, in accordance with the matrix shown in table 9. The results are presented in tables 10 and 11.

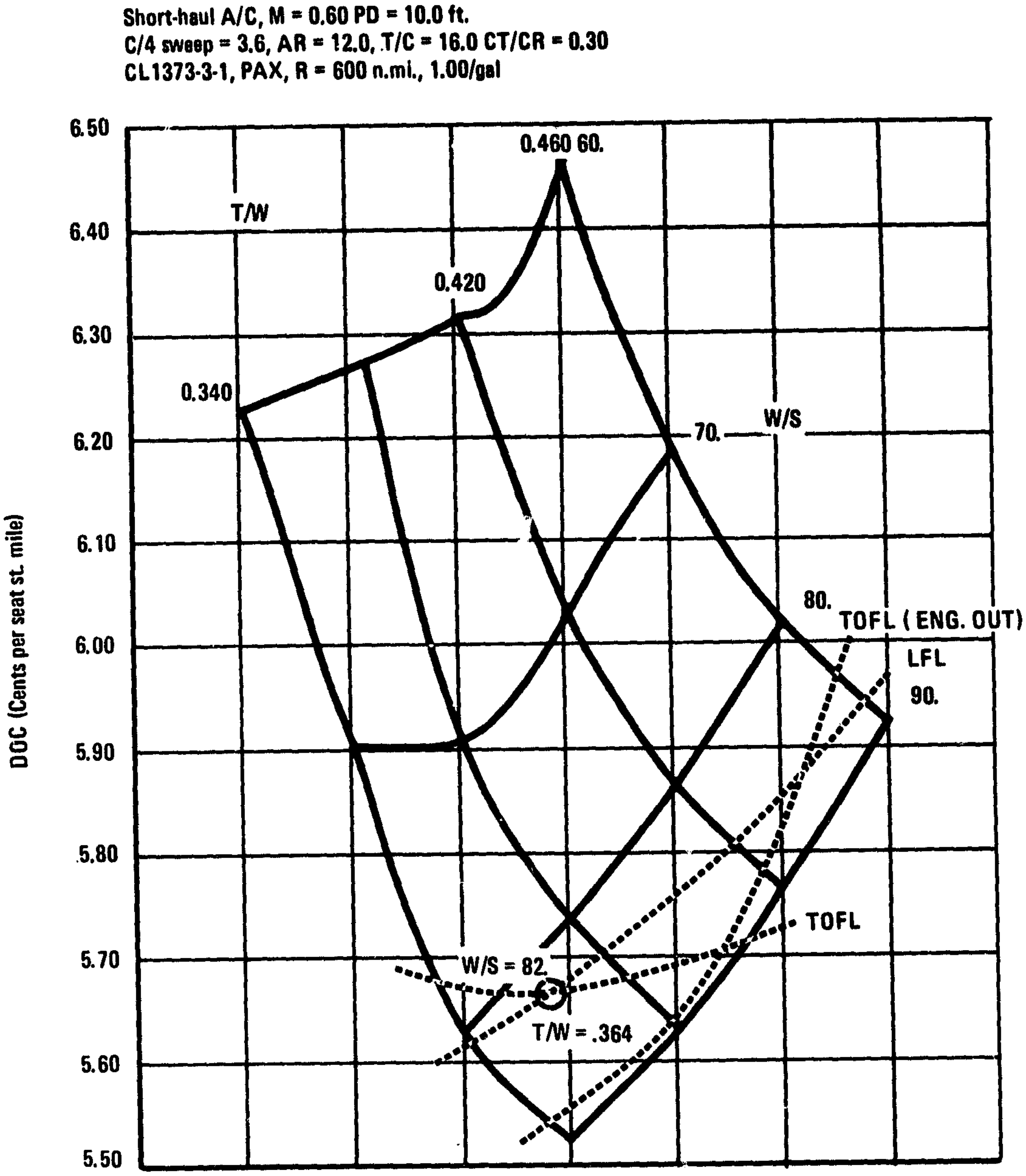


Figure 29 . - Direct operating cost.

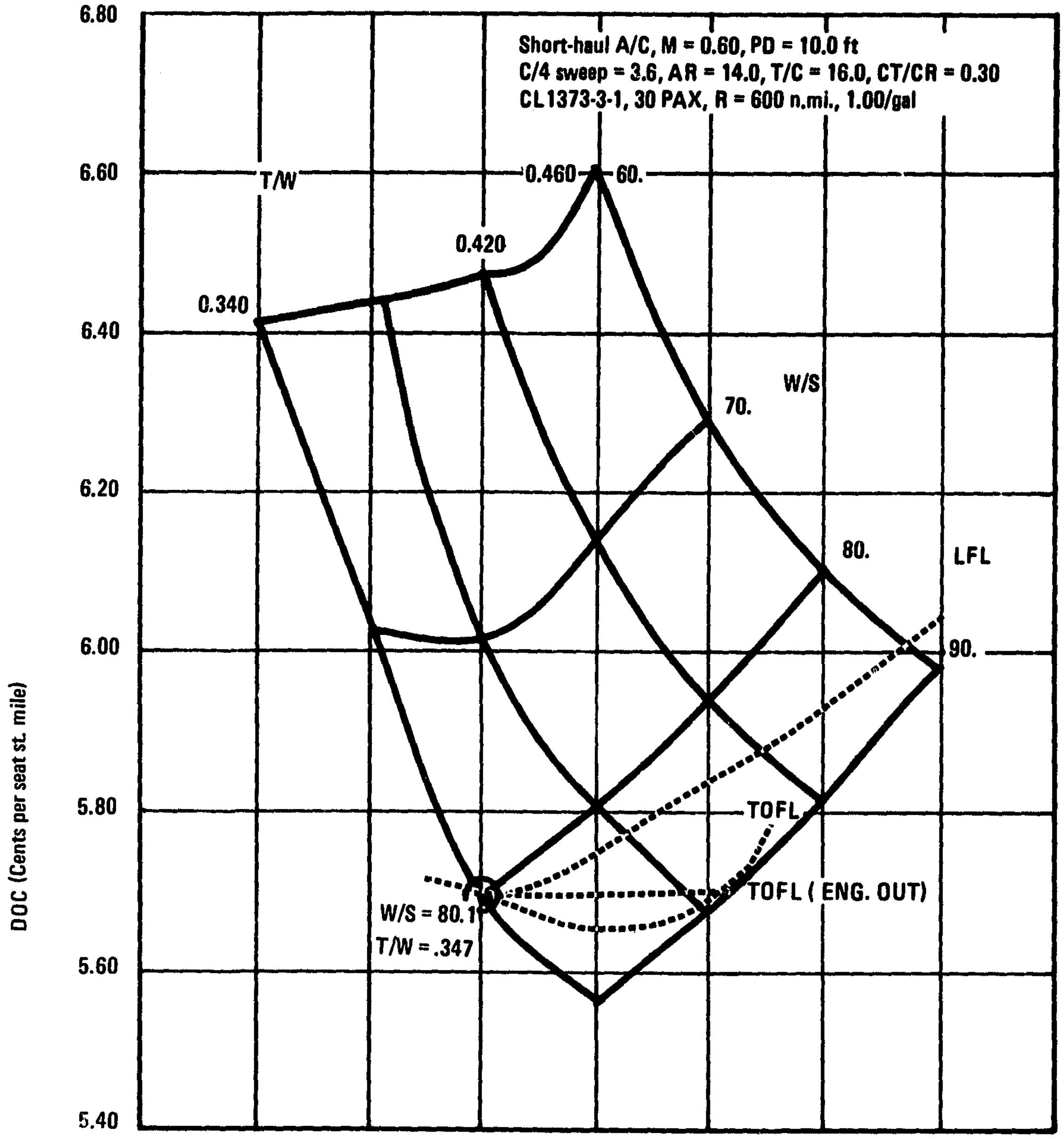


Figure 30. - Direct operating cost.

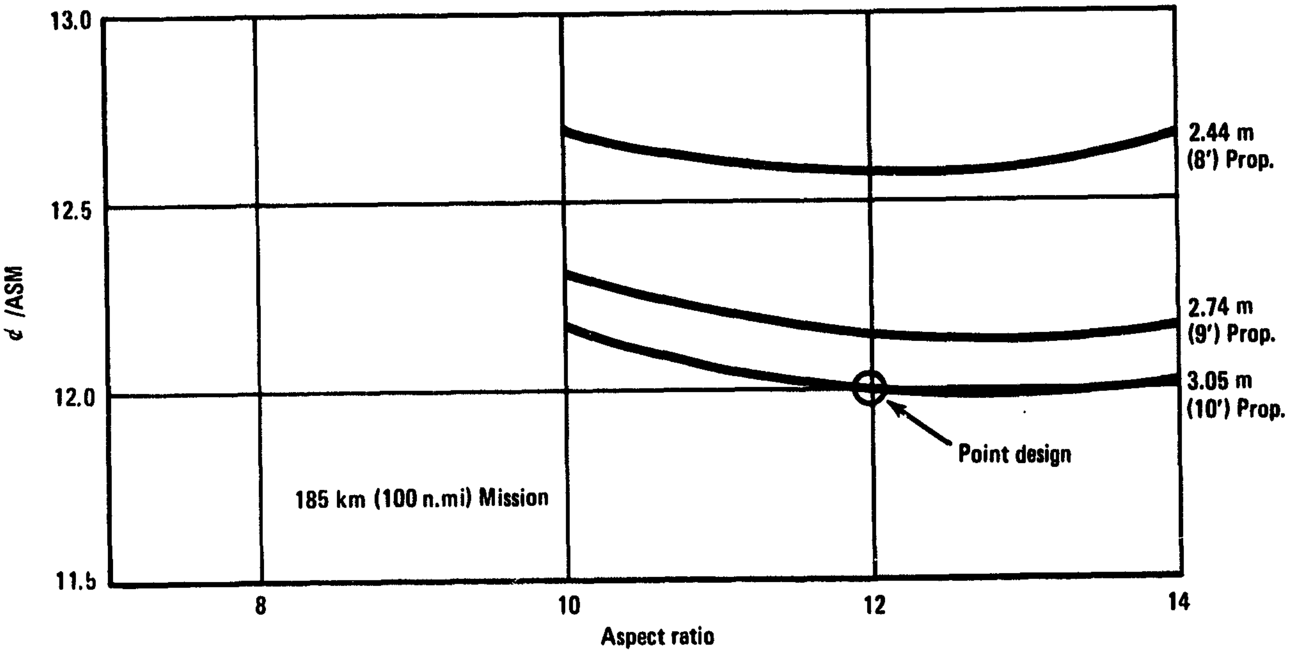


Figure 31. - 30 PAX short-haul aircraft.

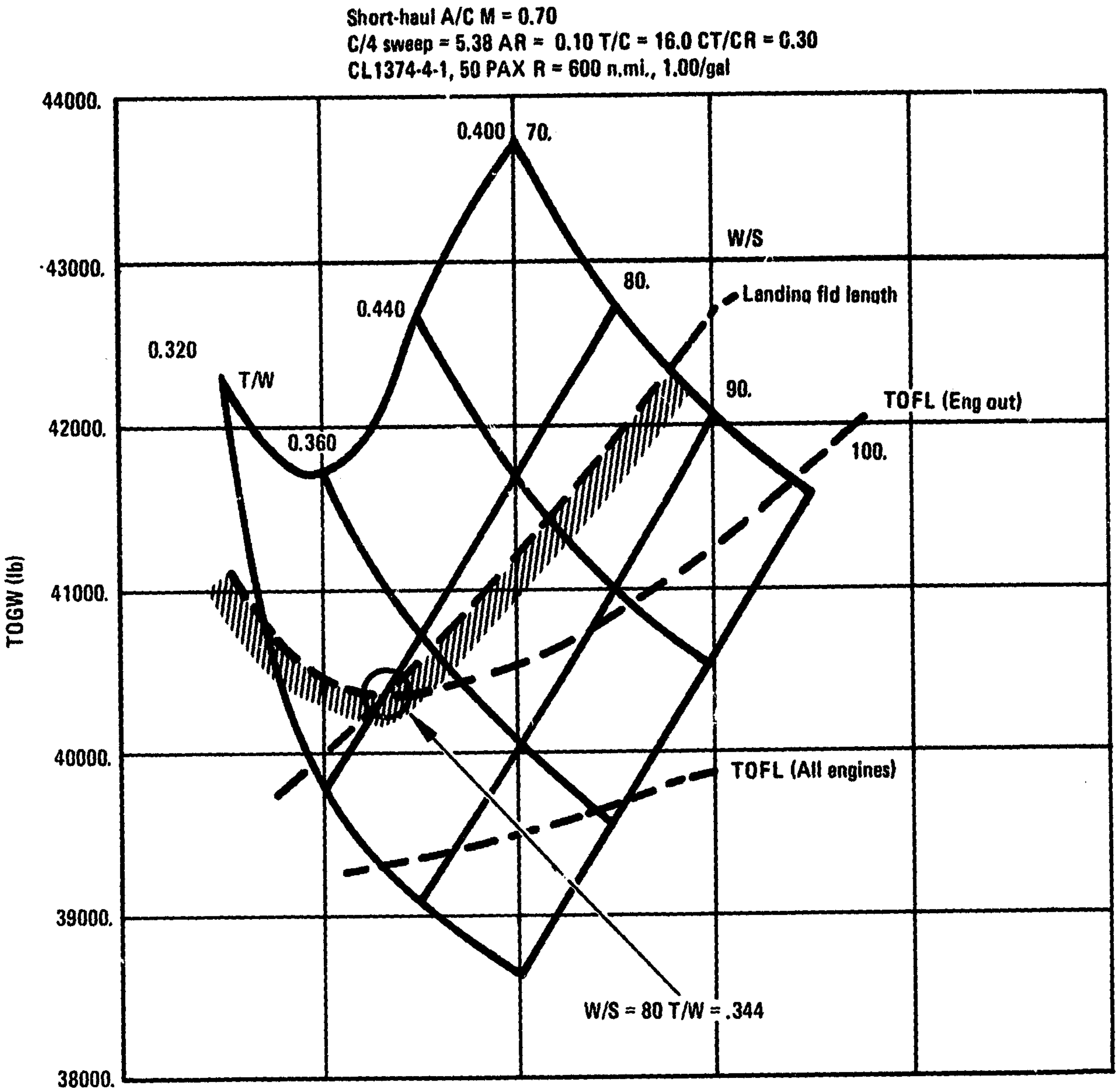


Figure 32. - Takeoff gross weight.

TABLE 9. - SHORT-HAUL SENSITIVITY FACTORS

	SFC ±5% ±15%	Eng. Wt. ±500 lb	Airframe wt. ±3000 lb	Engine Length ±10%	Engine dia ±10%	Engine Maint. ±25%	Engine Cost ±50K$	Airframe Maint. ±25%
TOGW	X	X	X	X	X			
OEW	X	X	X	X	X			
Block Fuel	X	X	X	X	X			
DOC	X	X	X	X	X	X	X	X
Aircraft Price	X	X	X	X	X	X	X	X

5.11.3 Baseline aircraft mission fuel. - The major performance characteristics for each baseline aircraft, in terms of block time, mission fuel, and distance for both the design range and 185 km (100 n.mi.) stage length, are listed below:

30 Passenger (1110 km) (600 n.mi.)

	Climb	Cruise	Descent	Block Total
Time (Minutes)	47.1	45.8	11.1	120
Fuel kg (lb)	481 (1060)	395 (870)	467 (103)	973 (2146)
Distance km (n.mi.)	533 (288)	504 (272)	107 (58)	1110 (600)

Cruise Altitude = 28 000 ft

30 Passenger (100 n.mi.)

	Climb	Cruise	Descent	Block Total
Time (Minutes)	5.4	7.5	5.9	34.8
Fuel kg (lb)	81.2 (179)	87 (192)	30 (67)	296 (652)
Distance km (n.mi.)	46 (25)	87 (47)	52 (28)	185 (100)

Cruise Altitude = 15 000 ft

TABLE 10. - 30 PAX SHORT-HAUL AIRCRAFT-SENSITIVITY FACTORS

Condition	Factor	TOGW	OEW	Fuel 600	Fuel 100	DOC 600	DOC 100
Engine Weight	+500#	+881	+823	+49	+15	+.093	+.202
	0	0	0	0	0	0	0
	-500#	-817	-817	-50	-15	-.094	-.203
Mfg. Empty Wt.	+3000#	+4959	+4609	+274	+84	+.740	+1.615
	0	0	0	0	0	0	0
	-3000#	-4961	-4640	-266	-85	-.736	-1.687
SFC	+15%	+680	+199	+302		+.250	+.120
	+5%	+223	+65	+101		+.080	+.040
	0	0	0	0	0	0	0
	-5%	-215	-63	-101		-.080	-.039
	-15%	-650	-190	-302		-.250	-.119
Engine Length	+10%	+52	+25	+3	+2	+.018	+.018
	0	0	0	0	0	0	0
	-10%	50	-25	-3	-2	-.016	-.015
Engine Diameter	+10%	+58	+30	+5	+3	+.020	+.022
	0	0	0	0	0	0	0
	-10%	-58	-29	-5	-3	-.018	-.019
Engine Maint.	+25%	–	–	–	–	+.306	+.797
	0					0	0
	-25%	–	–	–	–	-.306	-.797
Engine Cost	+50K$	–	–	–	–	+.115	+.285
	0					0	0
	-50K$	–	–	–	–	-.116	-.285
Airframe Maint.	+25%	–	–	–	–	+.119	+.435
	0					0	0
	-25%	–	–	–	–	-.125	-.454
Baseline Values		28 606	19 499	2146	671	4.977	9.946

TABLE 11. - SENSITIVITY FACTORS - 50 PAX SHORT-HAUL AIRCRAFT

	TOGW (lb)	OEW (lb)	Block Fuel (lb)		DOC (c/SM-$1.00/gal)	
			600 n.mi.	100 n.mi.	600 n.mi	100 n.mi.
SFC						
-15%	-957	-284	-441	-16	-0.242	-0.099
-5%	-321	-96	-148	-5	-0.082	-0.033
+5%	+323	+95	+150	+5	+0.081	+0.099
+15%	+963	+284	+452	+16	+0.247	+0.099
Engine Weight						
-500 lb	-960	-889	-43	-17	-0.057	-0.132
+500 lb	+950	+884	+43	+17	+0.056	+0.130
Airframe Weight						
-3000 lb	-5037	-4666	-224	-92	-0.399	-0.921
+3000 lb	+4981	+4628	+225	+89	+0.384	+0.885
Engine Maintenance						
-25%					-0.213	-0.571
+25%					+0.213	+0.571
Airframe Maintenance						
-25%					-0.087	-0.328
+25%					+0.083	+0.314
Engine Cost						
-50K$					-0.061	-0.153
+50K$					+0.062	+0.151
Engine Length						
-10%	-90	-46	-21	-4	-0.014	-0.019
+10%	+85	+45	+21	+4	+0.013	+0.019
Engine Diameter						
-10%	-90	-58	-25	-5	-0.016	-0.022
+10%	+90	+57	+25	+5	+0.015	+0.022
Baseline Values	40 427	26 156	2816	933	3.759	7.505

50 Passenger (185 km) (100 n.mi.)

	Climb	Cruise	Descent	Block Total
Time (Minutes)	4.7	6.1	4.2	26.2
Fuel kg (lb)	130 (287)	131 (288)	40 (88)	425 (938)
Distance km (n.mi.)	44 (24)	81 (44)	59 (32)	185 (100)

Cruise Altitude = 15 000 ft

50 Passenger (600 n.mi.)

	Climb	Cruise	Descent	Block Total
Time (Minutes)	37.5	40.9	13.3	102.6
Fuel kg (lb)	621 (1370)	433 (954)	62 (136)	1277 (2816)
Distance km (n.mi.)	457 (247)	505 (273)	144 (78)	1110 (600)

Cruise Altitude = 36 000 ft

5.11.4 Alternate stage length. - As specified in the NASA statement of work, each of the sized baseline aircraft configurations, were analyzed to compute their DOC's at stage lengths of 92.6, 185, 288, 370, 741 and 11 110 km (50, 100, 150, 200, 400, and 600 n.mi.) for fuel prices of ($0.75, $1.00, and $1.50 per gallon. Results of these calculations are presented in figures 33 and 34.

5.11.5 Alternate field performance. - One of the design/mission constraints for each of the short-haul aircraft was a requirement to operate from field lengths of not greater than 1220 m (4000 ft) at sea level and 32°C (90°F) conditions. Subsequent to sizing of the baselines, each aircraft was examined for different field lengths as follows:

- Baseline design operated from 914 m (3000 ft) field at sea level and 32°C (90°F).
- Baseline design operated from 2134 m (7000 ft) field at 1829 m (6 000 ft) elevation and 90°F.
- Aircraft redesigned to incorporate a requirement for 914 m (3000 ft) field at sea level and 32.2°C (90°F).

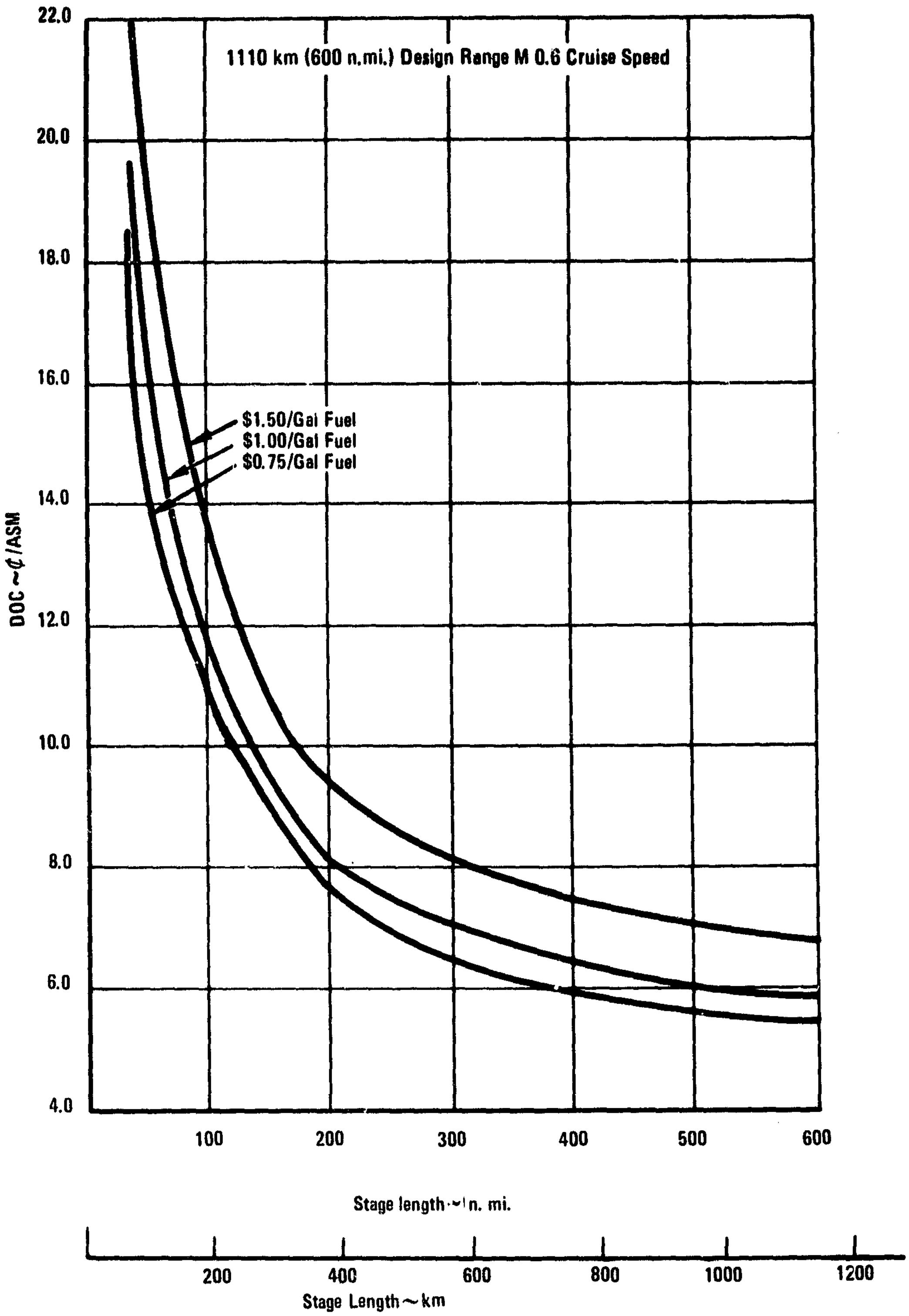


Figure 33. - Direct operating cost vs. stage length 30 PAX short-haul baseline.

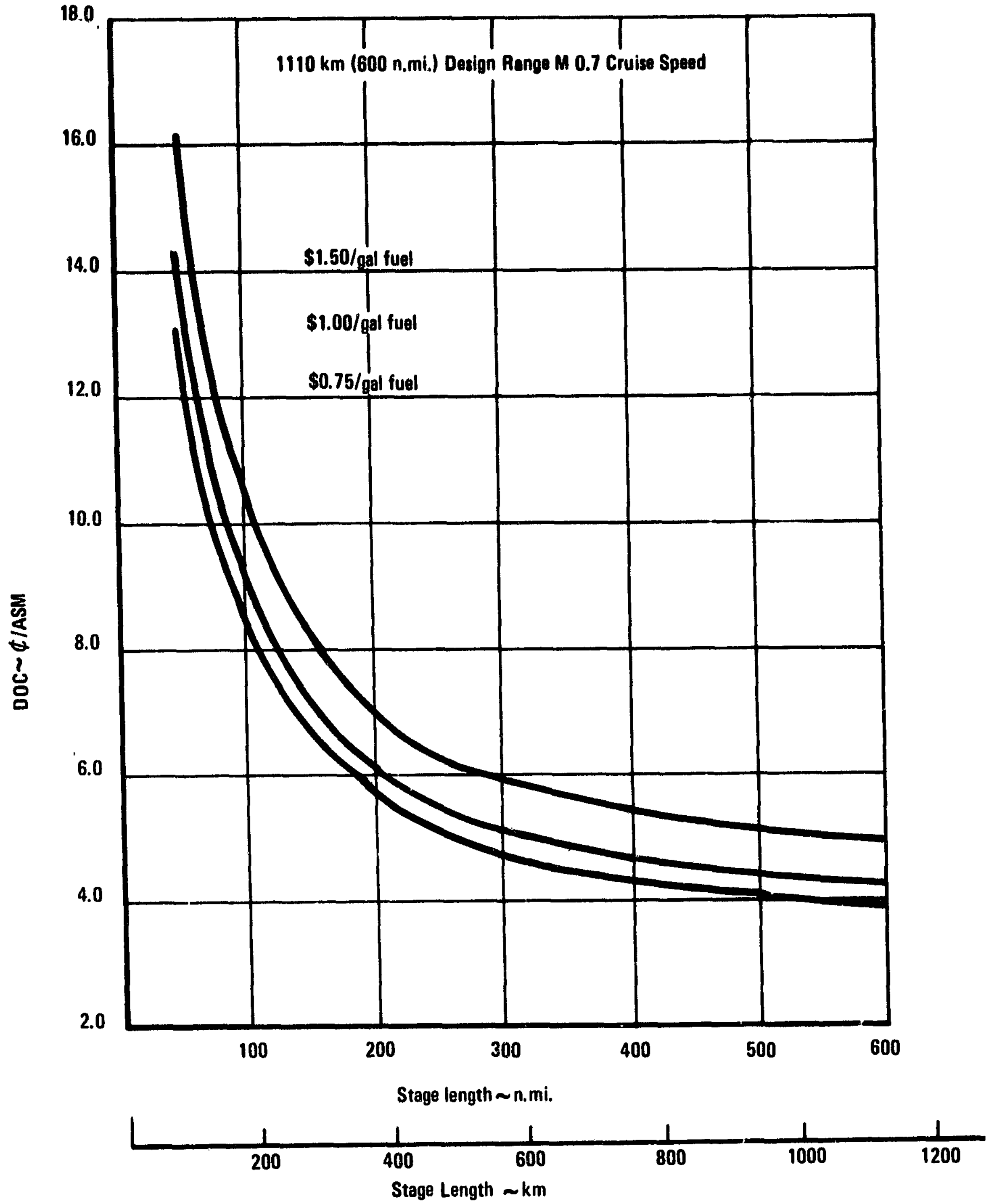


Figure 34 - Direct operating cost vs. stage length 50 PAX short-haul baseline.

The results of this examination are presented in table 12.

5.12 Economic Analysis

The economic analysis accomplished for the short-haul baseline aircraft along with results, comparative data, and the methods utilized is included in Appendix A. For each of the baseline aircraft, DOC was calculated for both the design range of 1100 km (600 n.mi.) at fuel prices of $0.75, $1.00, and $1.50 per gallon. DOC results for each aircraft, optimized for minimum DOC at 185 km (100 n.mi.) stage length, are as follows:

	30 PAX		50 PAX	
	1100 km	184 km	1110 km	184 km
DOC ($0.75)	4.535	9.004	3.607	7.408
DOC ($1.00)	4.977	9.812	3.956	8.105
DOC ($1.50)	5.867	11.434	4.656	9.505

TABLE 12. - FIELD PERFORMANCE-CHARACTERISTICS

Requirement	AR	Configuration W/S	T/W	TOGW	TOFL (All Eng.)(ft)	TOFL (Eng. Out)(ft)	LFL (ft)	Comments
30-PAX-4000 ft Fld. Length @ S.L. & +90°F	12	80.0	0.379	28 606	3346	3996	3038	Airplane sized to meet 4000 ft fld. length
30 PAX-3000 ft Fld. Length @ S.L. & +90°F	12	80.0	0.379	24 606	2591	3020	3003	Off Loaded (-4000# TOGW) For 3000 ft fld. length
30 PAX-7000 ft Fld. Length @ 6000 ft & +90°F	12	80.0	0.379	28 206	6061	6879	3938	Off Loaded (-400# TOGW) For 7000 ft fld. length
30 PAX-3000 ft Fld. Length @ S.L. & +90°F	12	65.0	0.400	30 352	2629	3014	2955	Airplane sized to meet 3000 ft fld. length
50 PAX-4000 ft Fld. Length @ S.L. & +90°F	10	80.0	0.344	40 325	3454	3995	3997	Airplane sized to meet 4000 ft fld. length
50 PAX-3000 ft Fld. Length @ S.L. & +90°F	10	80.0	0.344	34 325	2658	2996	3022	Off Loaded (-6000# TOGW) for 3000 ft fld. length
50 PAX-7000 ft Fld. Length @ 6000 ft & +90°F	10	80.0	0.344	40 325	5394	6131	4306	Meets 7000 ft fld. length with no off load
50 PAX-3000 ft Fld. Length @ S.L. & +90°F	10	65.0	0.375	42 746	2602	2999	2978	Airplane sized to meet 3000 ft fld. length

NOTE: Landing Weight = TOGW

6. APPLICATION OF ADVANCED TECHNOLOGY

This section describes appropriate advanced technologies, which when applied to the baseline short-haul aircraft configurations, both singularly and in combination, result in significant technical and economic performance benefits. Evaluations were accomplished in the following areas:

- Advanced structures and materials
- Advanced aerodynamics
- Advanced propulsion
- Active controls and alternate aircraft configurations

Figure 35 depicts the recurring cost breakdown of the conventional baseline short-haul 30-passenger aircraft (which is also typical for the 50 passenger). The largest portion of production cost is manufacture and assembly of the basic airframe, thus a major objective of this study was an evaluation of low cost primary structural concepts and advanced materials which could provide significant cost reductions.

The remaining advanced technology items are aimed at reducing the aircraft operating costs by increasing the fuel efficiency. Incorporation of active controls is used to enhance ride quality (better passenger appeal) by utilizing active flaps to damp the gust loading during operation in turbulence and to provide more efficient aircraft configurations.

Advanced systems are given cursory coverage in this study and have not been quantitatively assessed, although they promise significant potential benefits. A qualitative assessment is included in Section 8, along with recommendations for future research and technology.

6.1 Advanced Structures and Materials

As previously described in Section 5.5, the conventional aircraft primary structure is a skin/stringer configuration using current aluminum alloys. This type of structural arrangement is widely used on current air transports such as the Lockheed L-1011. For the advanced technology, low cost primary structure of the short-haul aircraft, the following structural/material arrangements were evaluated:

Fuselage

- Multilongeron design with aluminum and composites
- Orthogrid and isogrid composites

Wing/Empennage

- Multispar (minimum ribs) with aluminum and composites
- Orthogrid composites

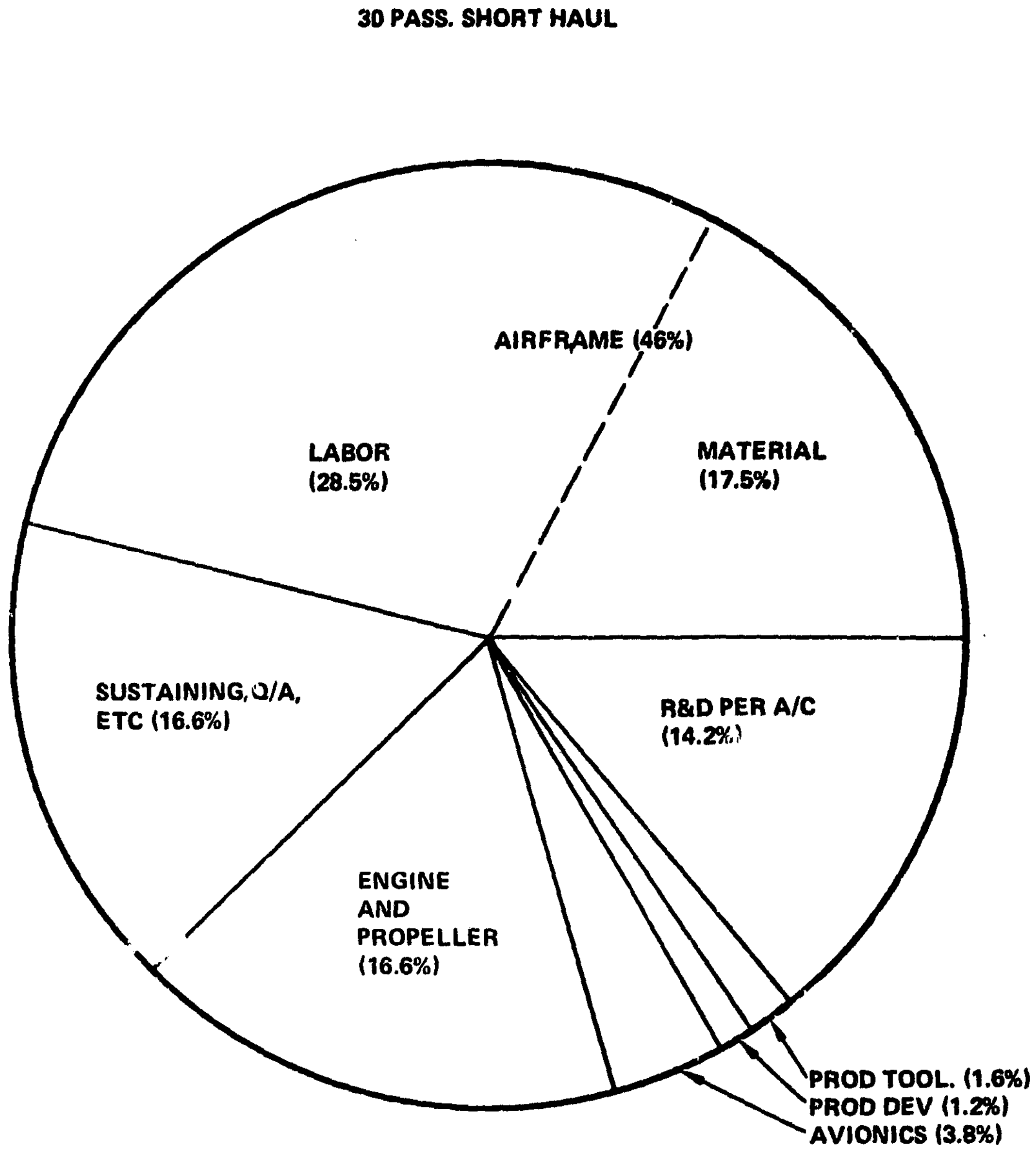


Figure 35. - Production cost breakdown.

These arrangements are formulated to reduce labor costs by reducing the number of parts to be manufactured and assembled, incorporate automated manufacturing processes, and provide weight savings. New design features and methods of fabrication have been the subject of continuous studies at Lockheed, and in past years in-house and funded studies have made significant advances in the analyses and fabrication methods, testing, and product durability. These studies have developed high confidence that significant weight and cost savings can be attained by use of advanced composite materials with the above design concepts.

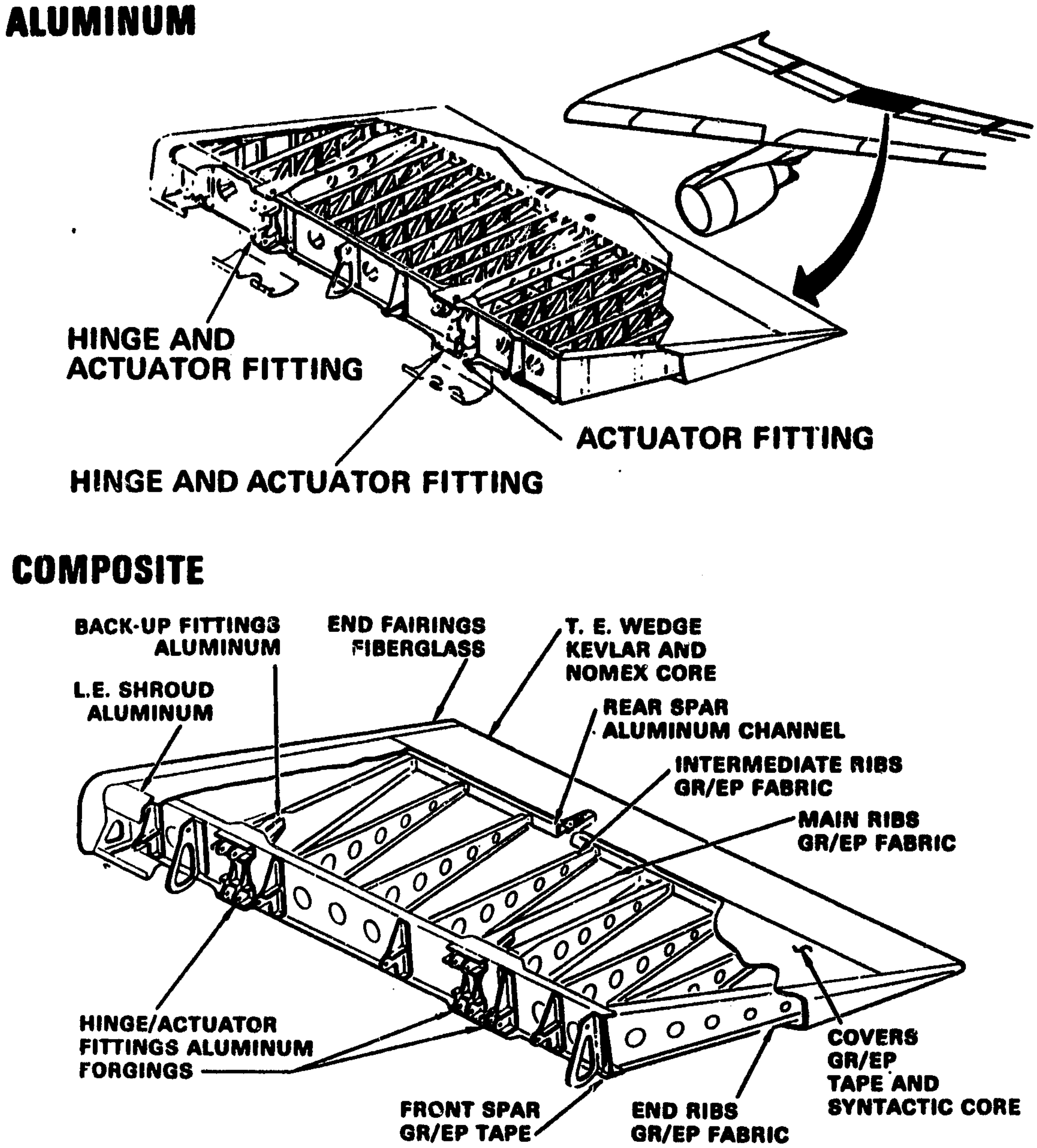
6.1.1 Low cost structural concepts. - Low cost structural concepts are those designs which have fewer parts to reduce costs of manufacture and assembly. This has been demonstrated on the L-1011 inboard composite aileron structure, depicted in figure 36, which shows a markedly reduced number of ribs in that design. The following design concepts were adopted for the low cost structure for the advanced technology short-haul aircraft:

Wing and empennage: Since these are heavily loaded structures, surface panel stability under compression loads is of primary importance. There are two approaches to the design of these structures: 1) multispar design as shown in figures 37 and 38 and an orthogrid composite design as shown in figure 39.

The multispar design concept is compatible with a high aspect ratio wing or empennage and could employ either aluminum (conventional and advanced alloys) or composite material. Basic objective of this design is elimination of stringers and numerous clips between ribs and stringers. In addition, approximately 60% of the ribs can be eliminated except at the highly loaded locations such as the root area, engine support, and edge structure supports. The fixed leading edge and trailing edge panels are honeycomb construction which has proved to be a cost effective, light weight approach. Since the depth of both leading edge slats and trailing edge flaps and ailerons is less than three inches, the full depth honeycomb construction, with insertions of spar and stub ribs, will transmit the highly concentrated loads and retain the necessary stiffness for structural design. This arrangement is considered for reduction in manufacturing costs as well as potential reduced weight. A similar design concept is applied to both the horizontal and vertical stabilizers.

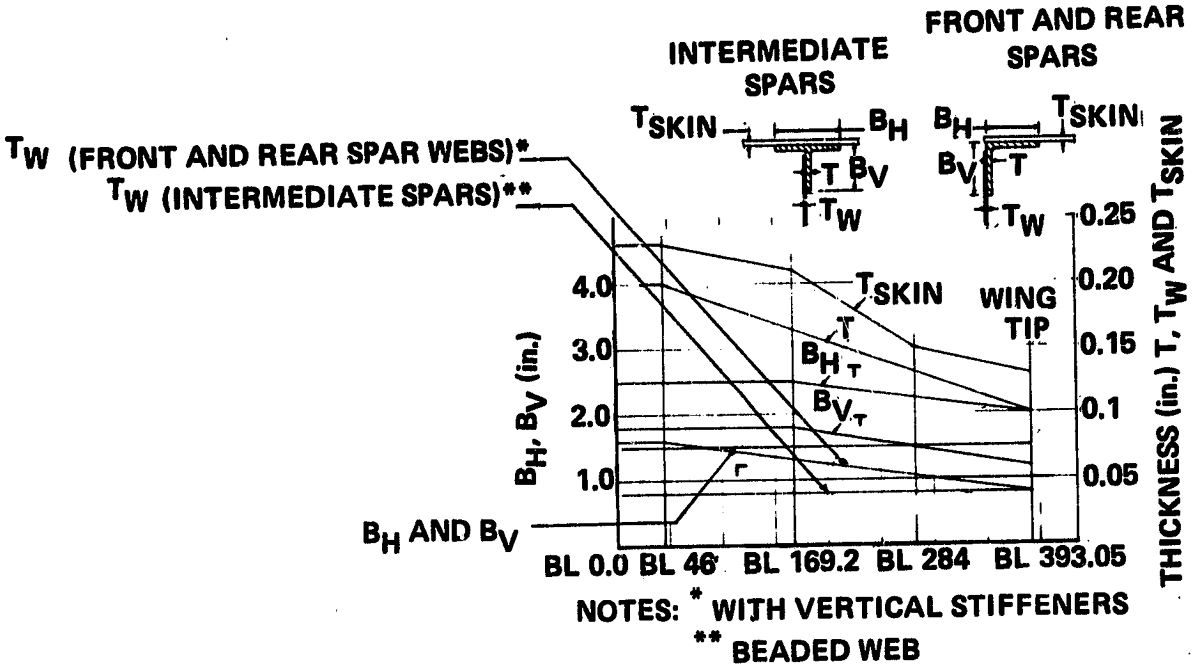
The composite orthogrid design which has been studied by Lockheed for several years is one of the most promising design concepts for panels. Figure 40 and figure 41 show the major dimensions of a test panel designed to verify the orthogrid capabilities. The panel is typical of a transport wing upper panel, and is designed for compression loads up to 20,000 lb/in. The test results are shown in figure 42. An aluminum panel of equivalent strength with an ultimate stress of 54,350 psi would weigh 5.3 psf, the reduced-parts design of the orthogird panel weighs 3.3 psf. Therefore this design achieves a significant weight saving as well as being cost effective.

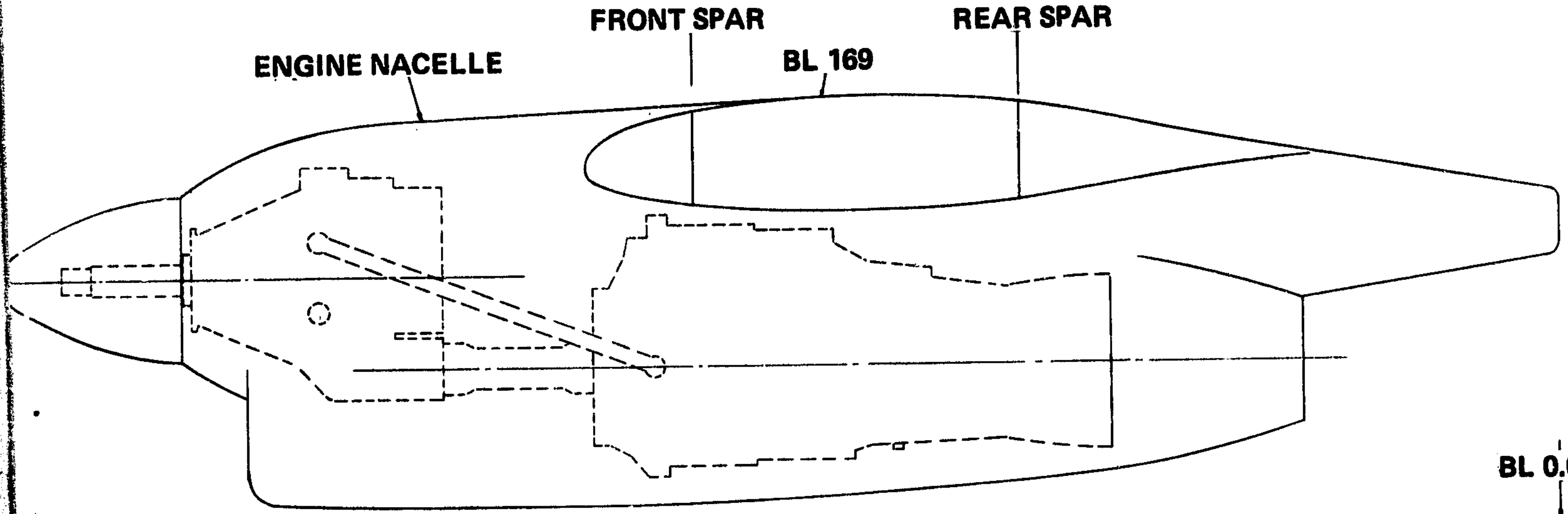
A development of this work at Lockheed has resulted in a technique for automated manufacturing of the stiffeners. In this technique, alternate layers of resin and graphite are used to produce more efficient joints at the intersection of the stiffeners. Lockheed, working with selected prepreggers,

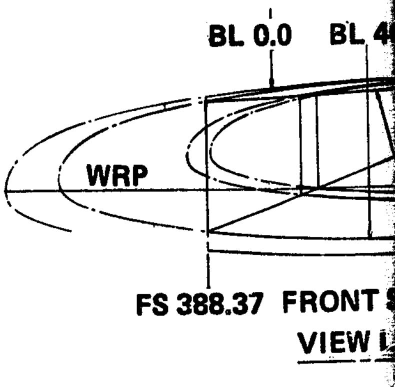


	ALUMINUM	COMPOSITE
WEIGHT (lb)	140.4	100.1
WEIGHT SAVED (lb)	0	36.5 (26%)
NO. RIBS	18	10
NO. PARTS	398	205
NO. FASTENERS	5253	2574

Figure 36. - L-1011 Composite aileron structure.







SECTION C - C

FOLDOUT FRAME

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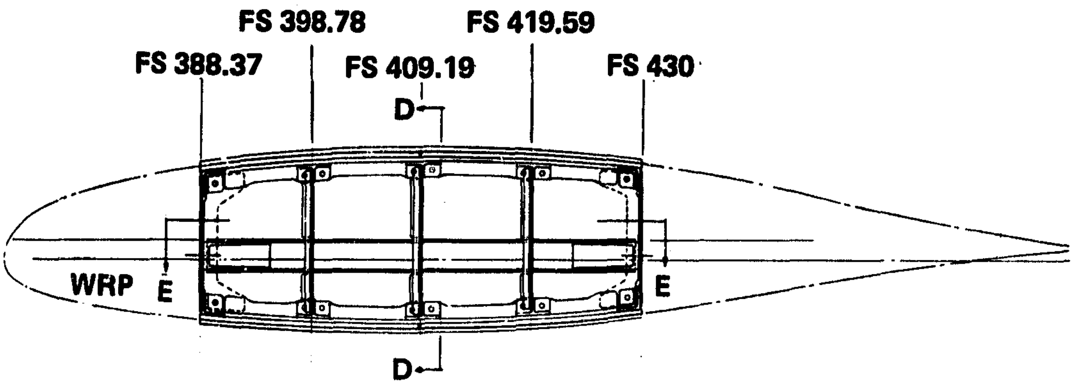
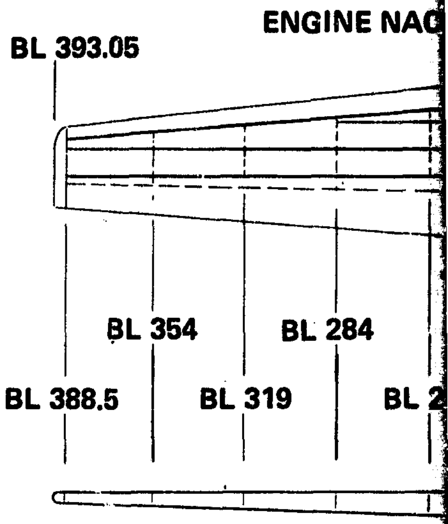
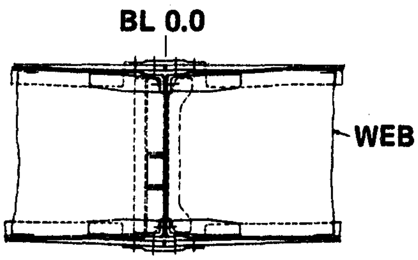
OF POOR QUALITY

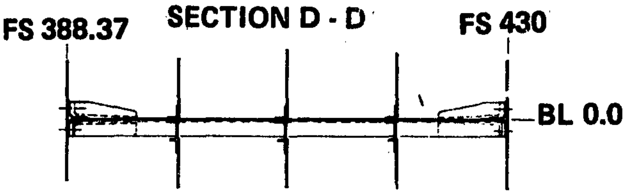


SECTION A - A

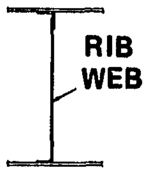




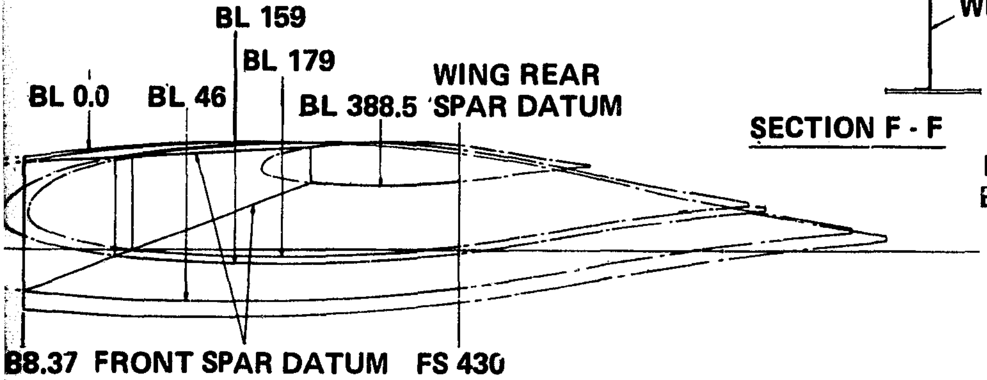
SECTION D - D



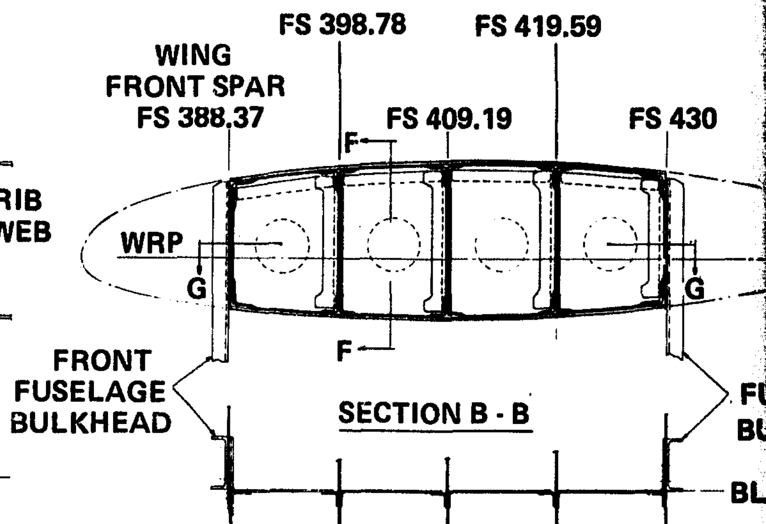
SECTION E - E



SECTION F - F



VIEW LOOKING INB'D



SECTION B - B

SECTION G - G

FOLDOUT FRAME 2

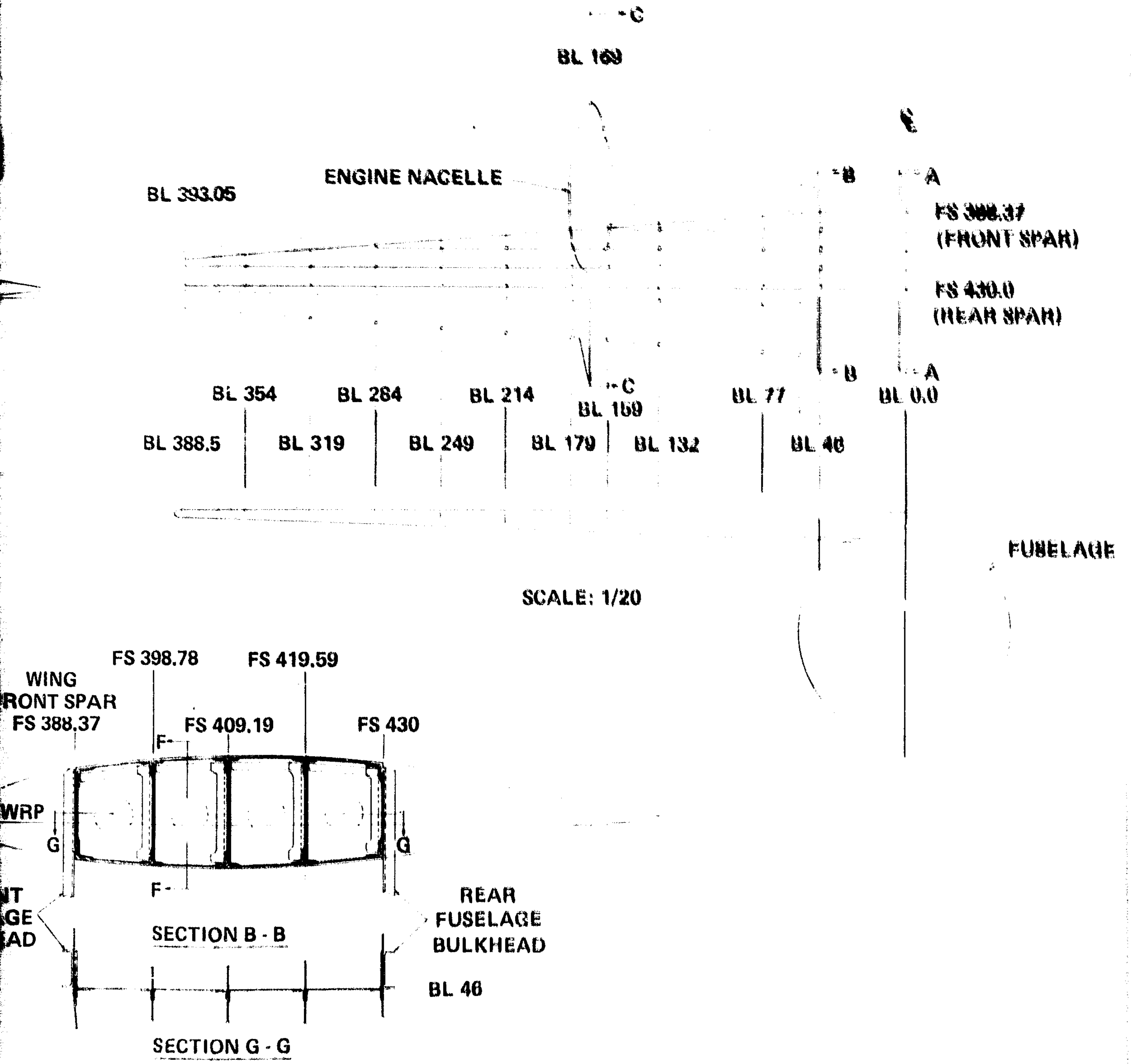
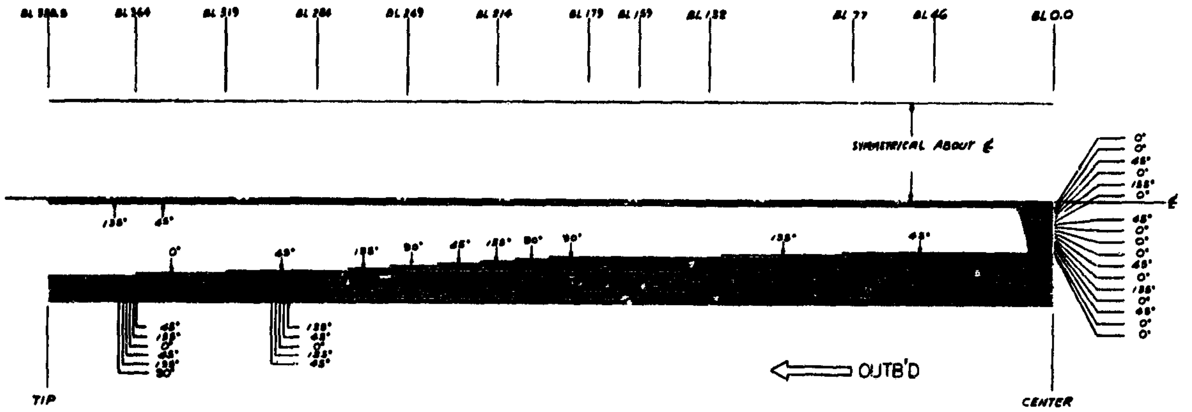
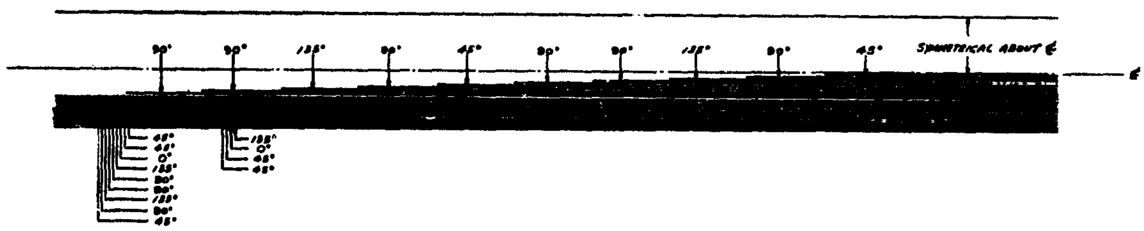


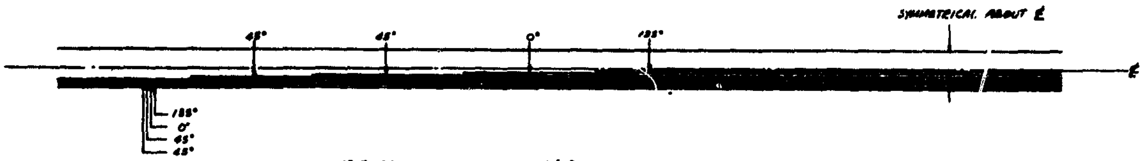
Figure 37. - Multi-spar aluminum wing.



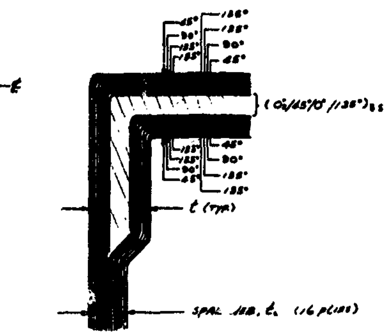
WING SKIN PANEL LAY-UP - VIEW LOOKING FWD
(UPPER AND LOWER PANEL ARE IDENTICAL)



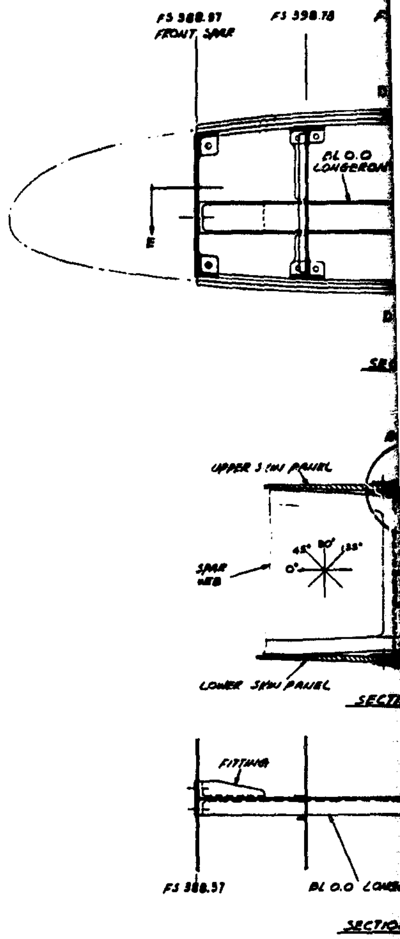
WING SPAR CAP FLANGE (t) - VIEW LOOKING FWD



TYP. SPAR WEB THICKNESS (t_w) - VIEW LOOKING DOWN



TYP. FOR BOTH FRONT & REAR SPAR CAP - BL 46
(FS 388.97 & FS 430.0)



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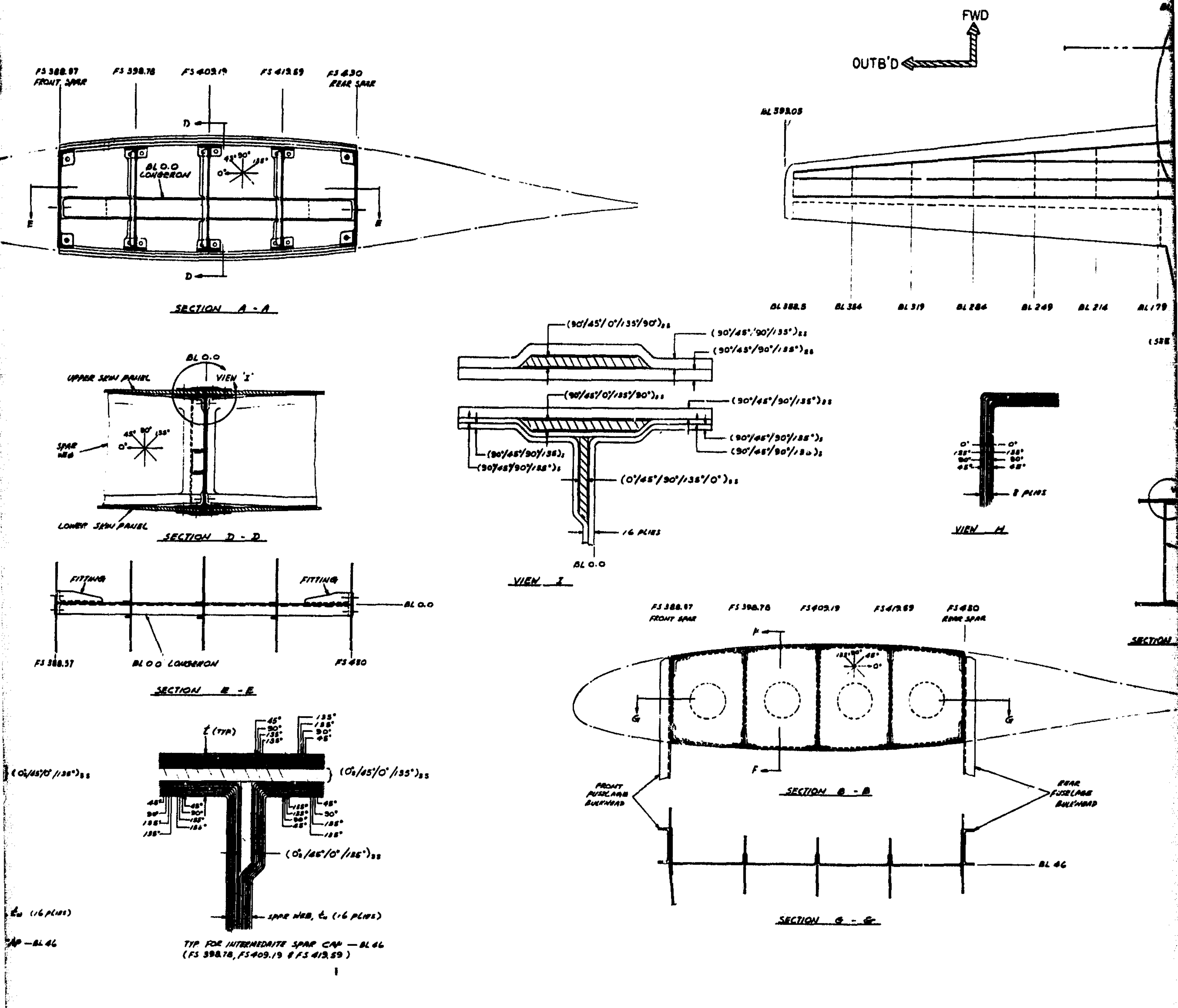

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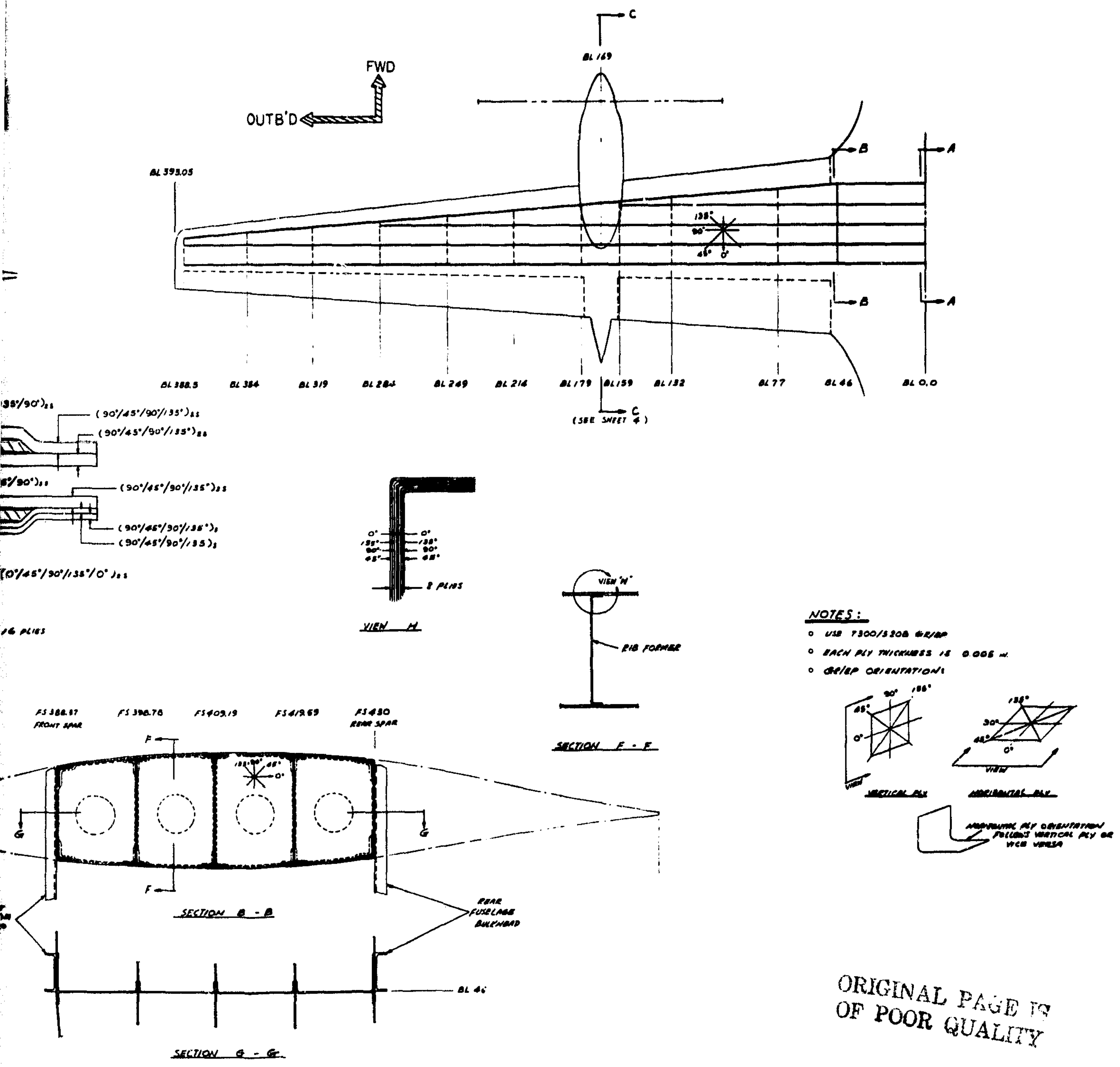
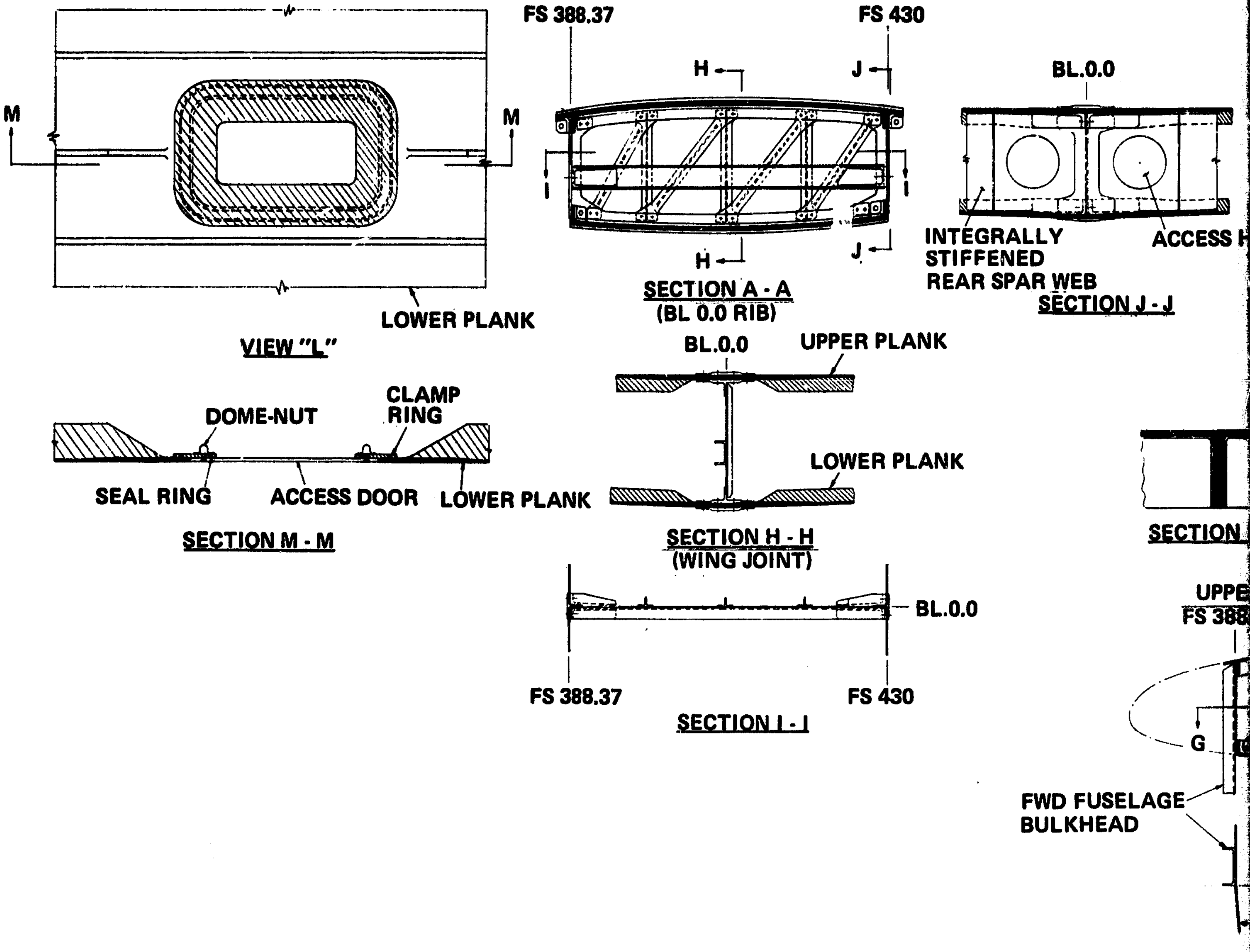
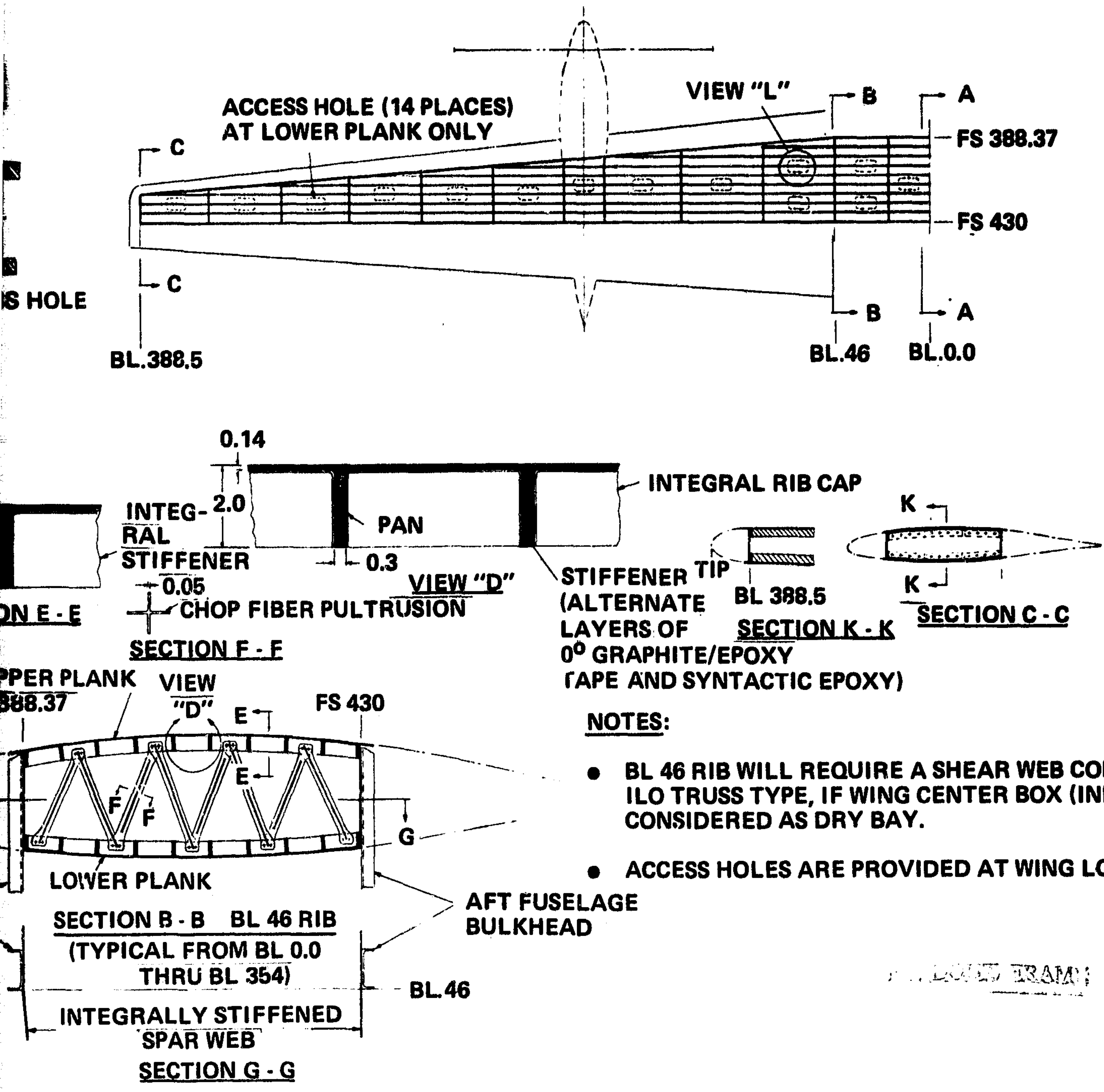


Figure 38. - Multi-spar composite wing.


M
M
LOWER PLANK
VIEW "L"
FS 388.37
FS 430
H
J
I
I
H
J
SECTION A - A
(BL 0.0 RIB)
BL.0.0
INTEGRALLY
STIFFENED
REAR SPAR WEB
SECTION J - J
DOME-NUT
CLAMP
RING
SEAL RING
ACCESS DOOR
LOWER PLANK
SECTION M - M
BL.0.0
UPPER PLANK
LOWER PLANK
SECTION H - H
(WING JOINT)
BL.0.0
FS 388.37
FS 430
SECTION I - I
G
FWD FUSELAGE
BULKHEAD



NOTES:

- BL 46 RIB WILL REQUIRE A SHEAR WEB CONSTRUCTION ILO TRUSS TYPE, IF WING CENTER BOX (INB'D OF BL 46) CONSIDERED AS DRY BAY.
- ACCESS HOLES ARE PROVIDED AT WING LOWER PLANK.

FOLDOUT FRAME 2

Figure 39. - Orthogrid composite wing.

80 FOLDOUT FRAME

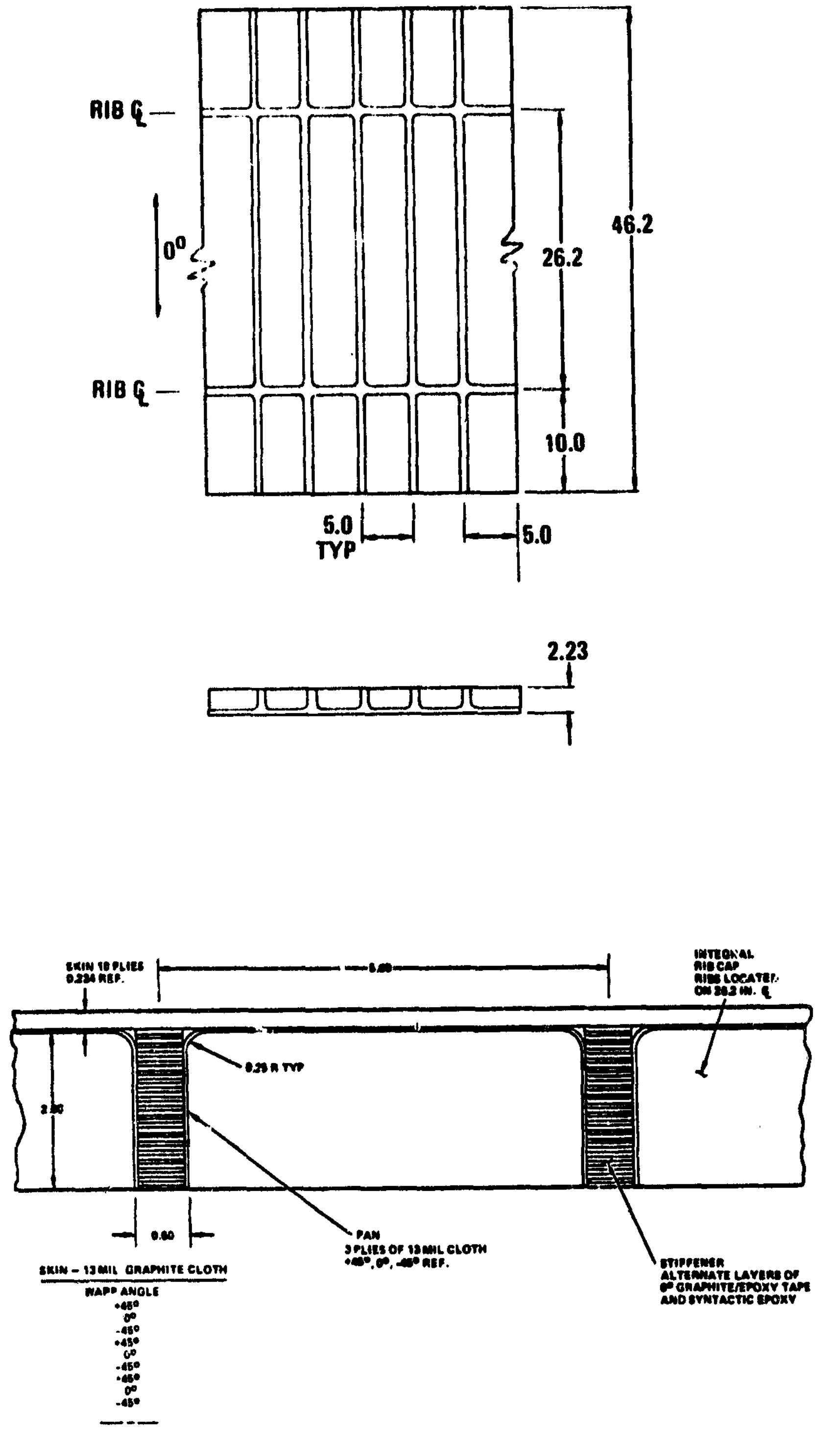


Figure 40. - Orthogrid wing plank configuration.

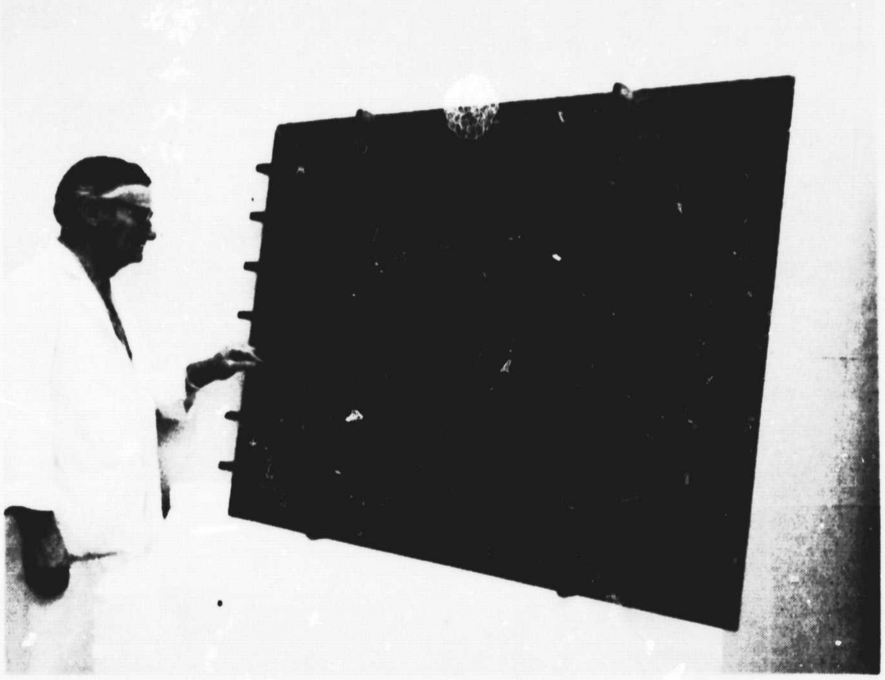


Figure 41. - Orthogrid test panel.

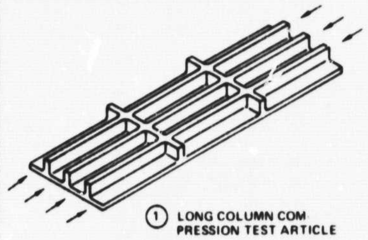
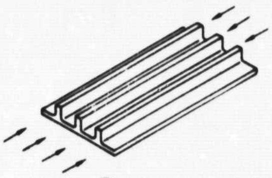
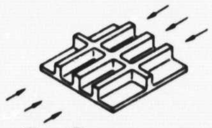
PANEL DESCRIPTION	COMPRESSION FAILURE LOAD (LB/IN)	FAILURE STRAIN (AVG) 10^{-6} IN/IN
 (1) LONG COLUMN COMPRESSION TEST ARTICLE	19480	6020
 (2) SHORT COLUMN COMPRESSION TEST ARTICLE	21850	6660
 (3A) & (3B) SHORT COLUMN COMPRESSION TEST ARTICLES	6660	20910
	18630	6120

Figure 42. - Orthogrid test panel test results.

C-2

has made available prepregged syntactic resin tape which may be handled in the same manner as a prepregged graphite tape and can be obtained in specific widths to suit particular stiffener geometries. Combinations of Graphite and Syntactic prepregged tape may be obtained in combined form so that both layers may be laid together. The fundamental concept is based on the demonstrated economies of machine layup techniques, and this concept further reduces the layup time as an entire layer of each bar may be laid down with each pass of the machine. An automatic machine to use this type of tape is under development at the Lockheed-California Company and has produced experimental panels. The manufacturing process consists of machine winding the tape on to a flexible rubber mandrel, placing the skin in a female mold, inserting the mandrel containing the wound grid; and curing the entire assembly. The flexible rubber mold is easily removed from the grid after curing. The designer has considerable flexibility in choosing the grid size and pattern to meet specific requirements of load distribution and fail-safe characteristics. As the stiffened skin is stable, much of the substructure normally required is minimized, saving both the cost of the parts and the cost of the assembly. The wing box construction can be easily assembled. The longitudinal stiffeners are used to resist wing bending and local aerodynamic pressure and the transverse (90° perpendicular to the wing span) stiffeners can be used as wing rib caps. Between the upper and lower rib caps, cruciform members are used to form a truss rib. The spar webs are made of one piece channel section with the vertical stiffeners integrally molded on the spar web. This design concept has been successfully used for the L-1011 vertical fin, as shown in figure 43.

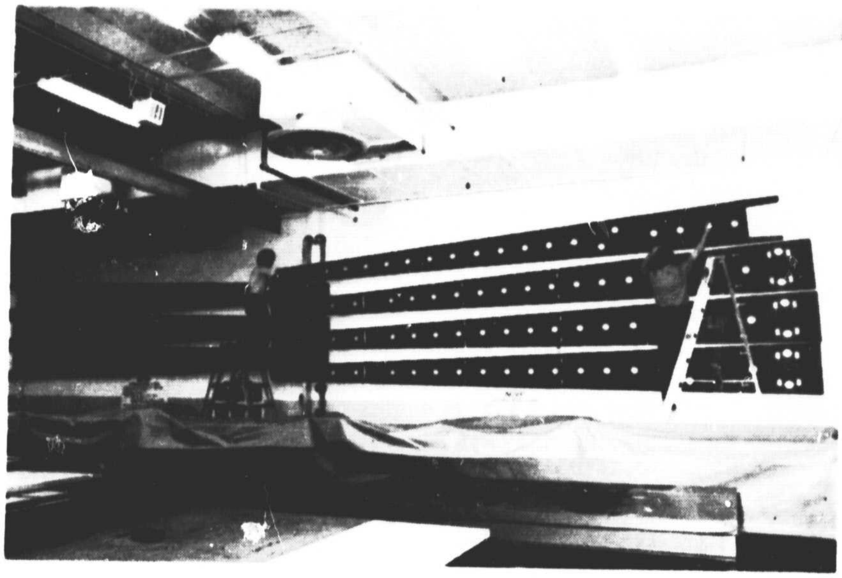
Fuselage: The fuselage is not a highly loaded structure; cabin pressurization is the significant loading condition for sizing of the structure. Conventional skin/stringer design has been successfully used, but this design has been recognized by aircraft manufacturers as a labor intensive, high cost arrangement due to the large number of parts. Two methods can be used for reducing fuselage cost; 1) reduction of parts, and 2) utilization of automated manufacturing processes. Previous Lockheed studies show that the following design concepts are best suited to low cost fuselage structure:

- Aluminum or composite fuselage using longerons and frames with wide spacing (see figure 44 and figure 45)

- Composite orthogrid design (figure 46)

- Composite isogrid design (see figure 47)

The first concept is a simplified design that uses fewer longitudinal longerons and frames. This design eliminates numerous clips, since there are less stringers and frames. To provide required fuselage skin thickness and prevent skin buckling at lower load conditions, the sandwich panel construction is the lightest and cheapest method to meet that requirement. Furthermore, this sandwich panel inherently has fail-safe features to withstand cabin pressure in the event of face sheet cracking. The core material is replaced by aluminum around the cut-out areas such as doors, windows and windshields to form a solid skin to prevent local high stress concentration, (see figure 45).



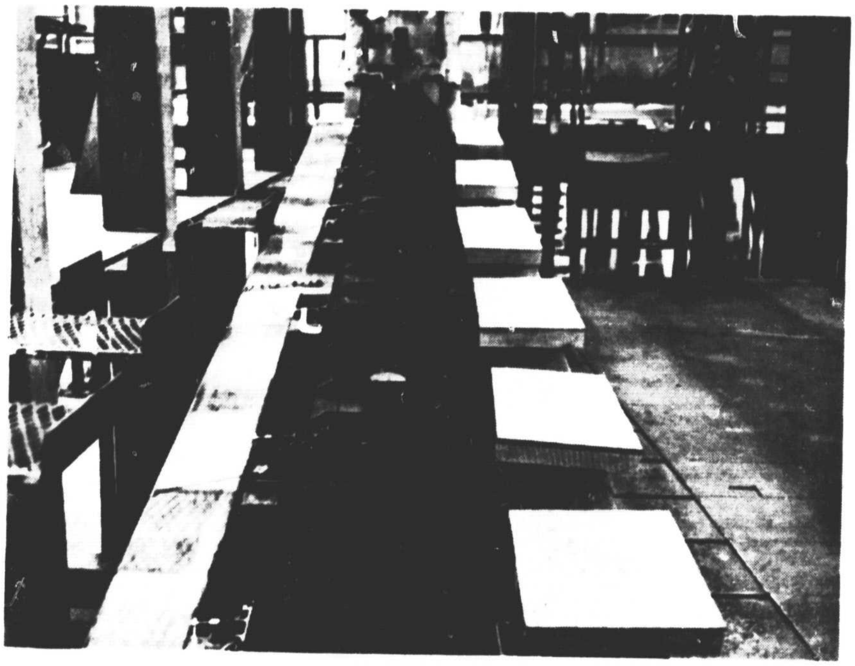
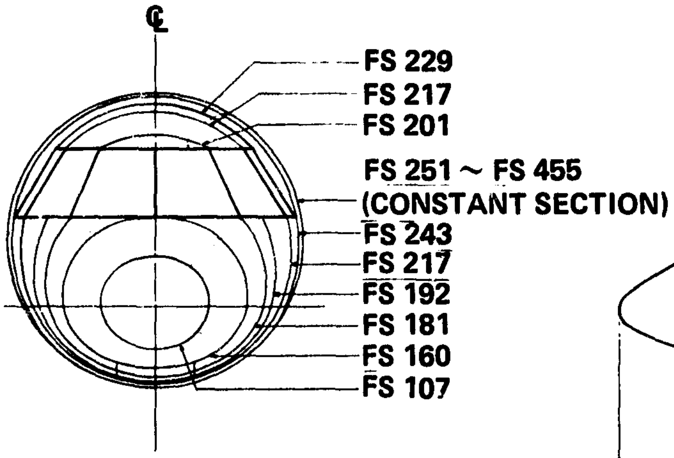
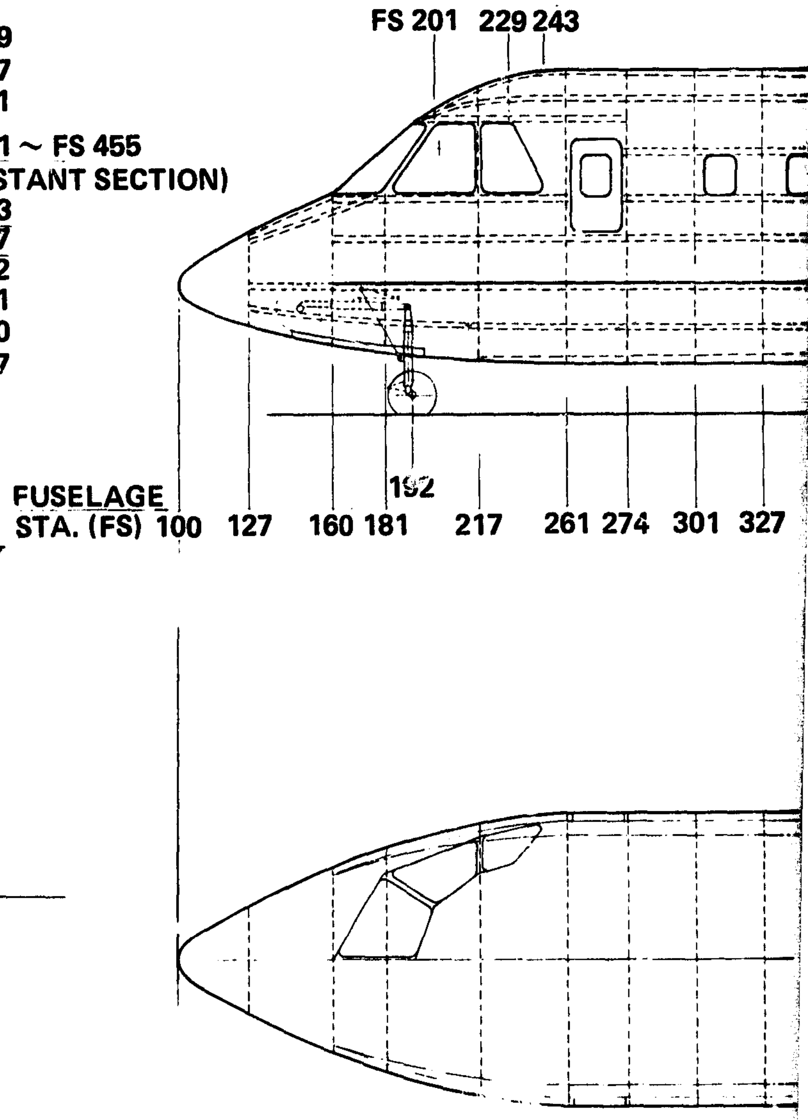
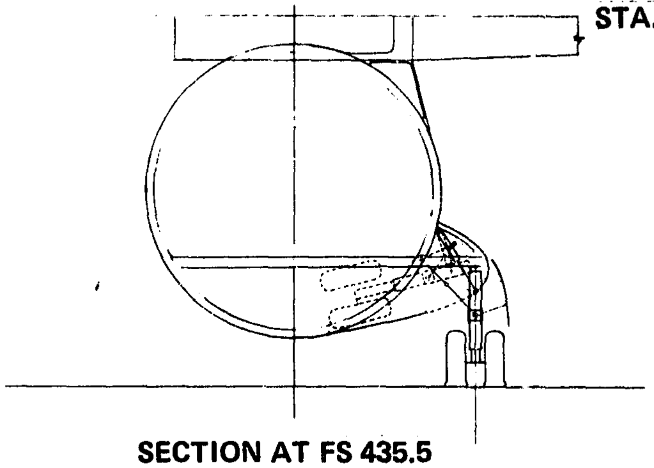


Figure 43. - L-1011 vertical fin.

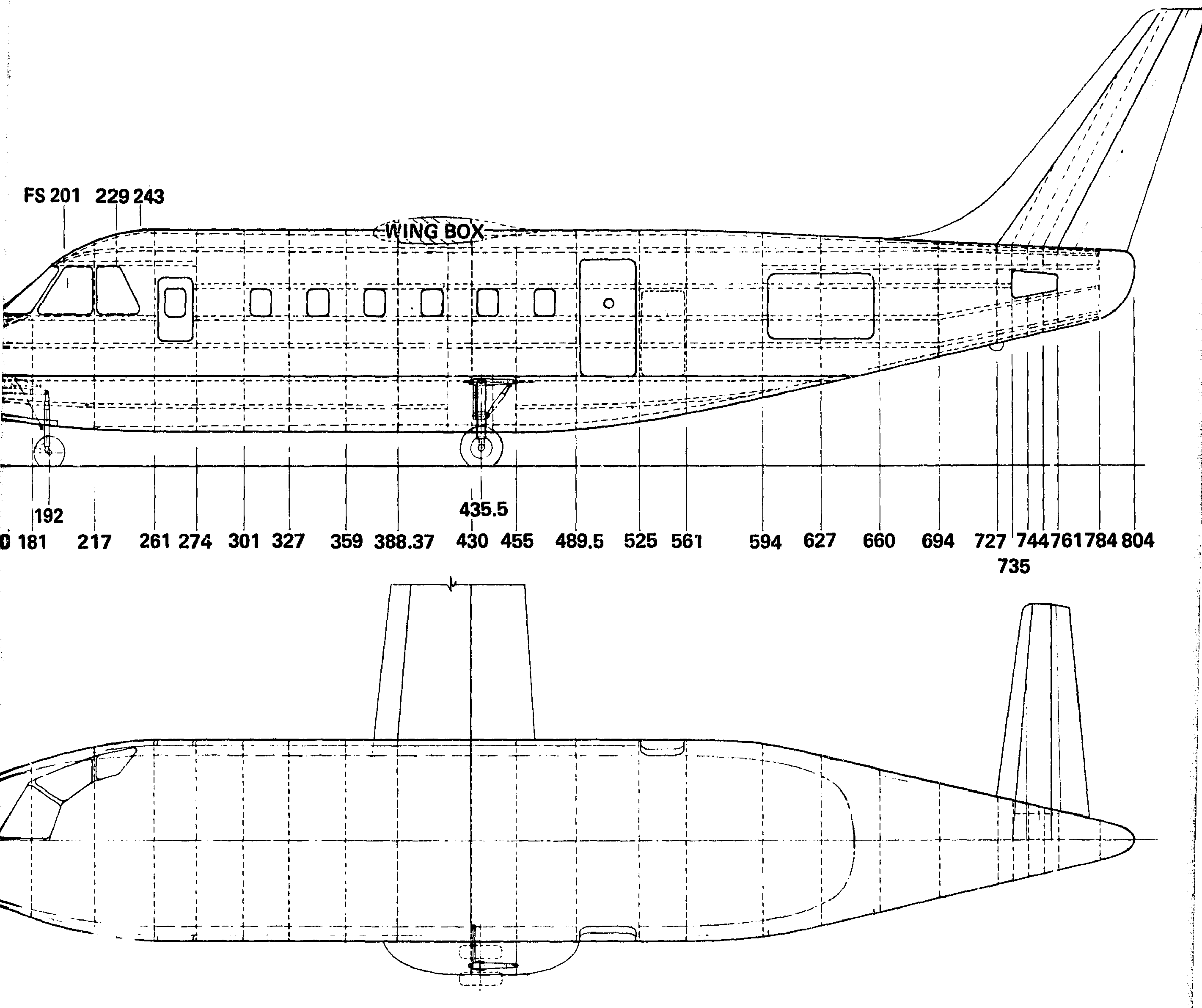




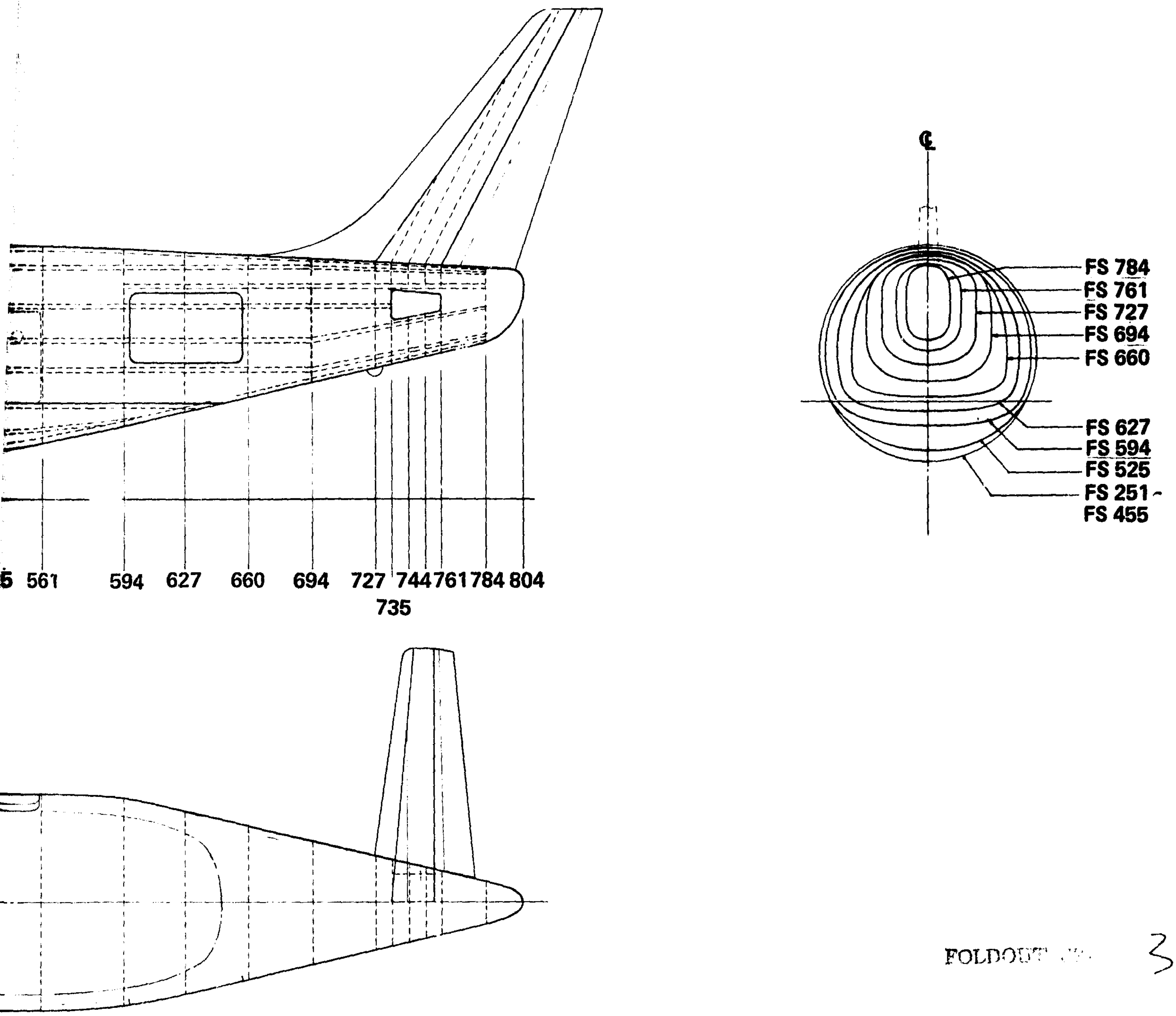


SECTION AT FS 435.5

FOLDOUT FRA

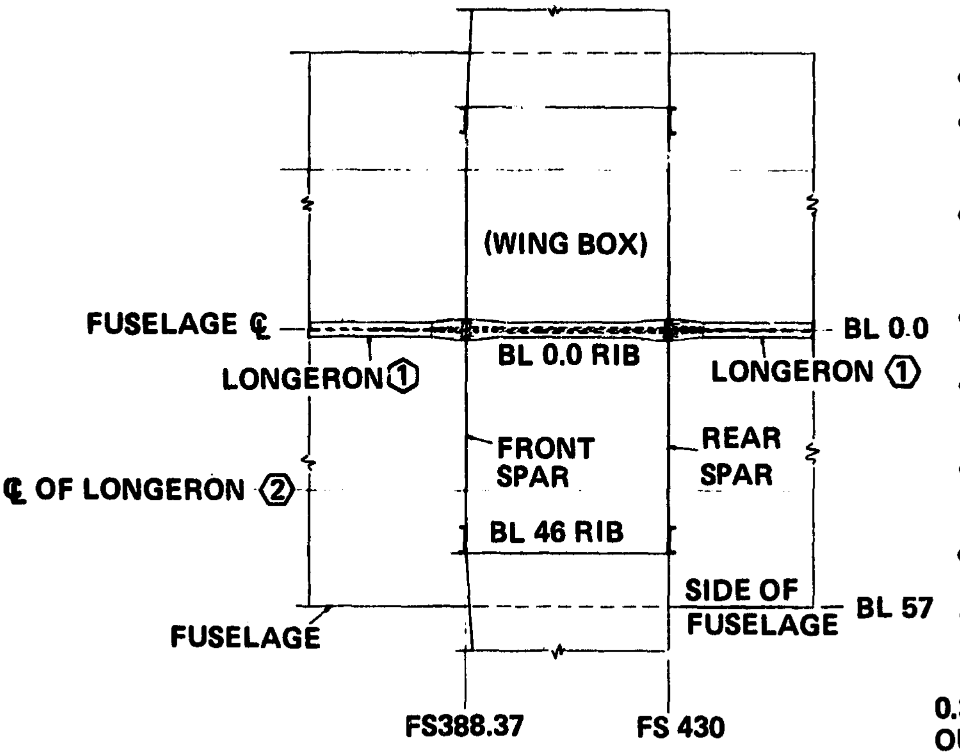


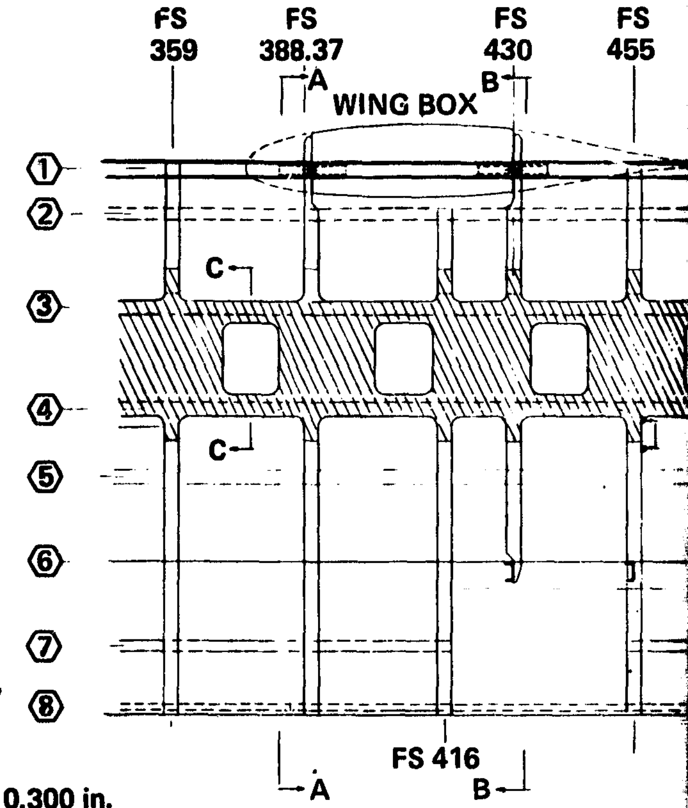
FOLDOUT FRA 2

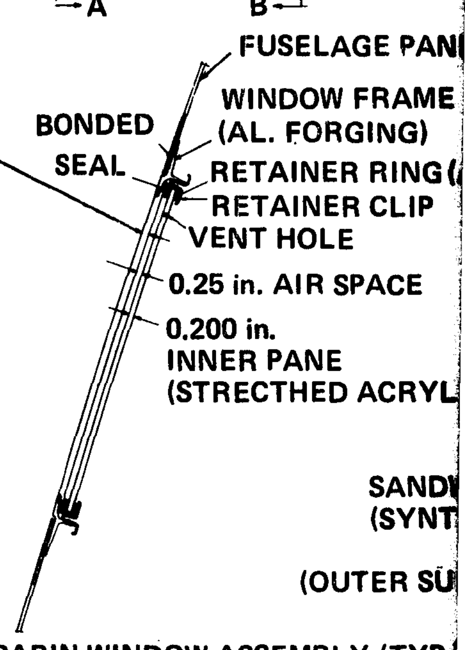


FOLDOUT 3

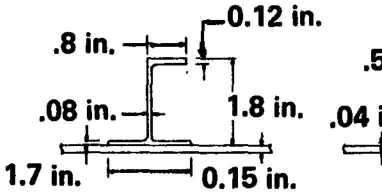
Figure 44. - Simplified fuselage structure.



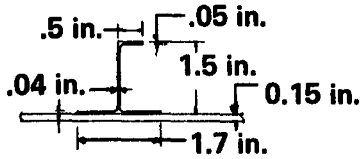




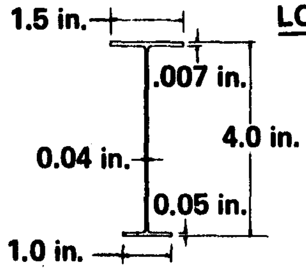
CABIN WINDOW ASSEMBLY (TYP.)
SECT. C - C



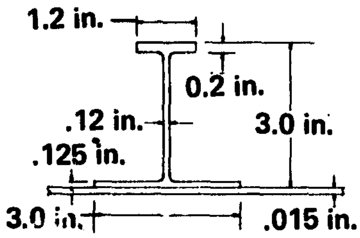
LONGERON NO. ② ③ AND ⑦
(FULL SIZE)



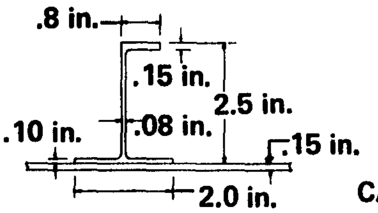
LONGERON NO.
④ ⑤ AND ⑥
(FULL SIZE)



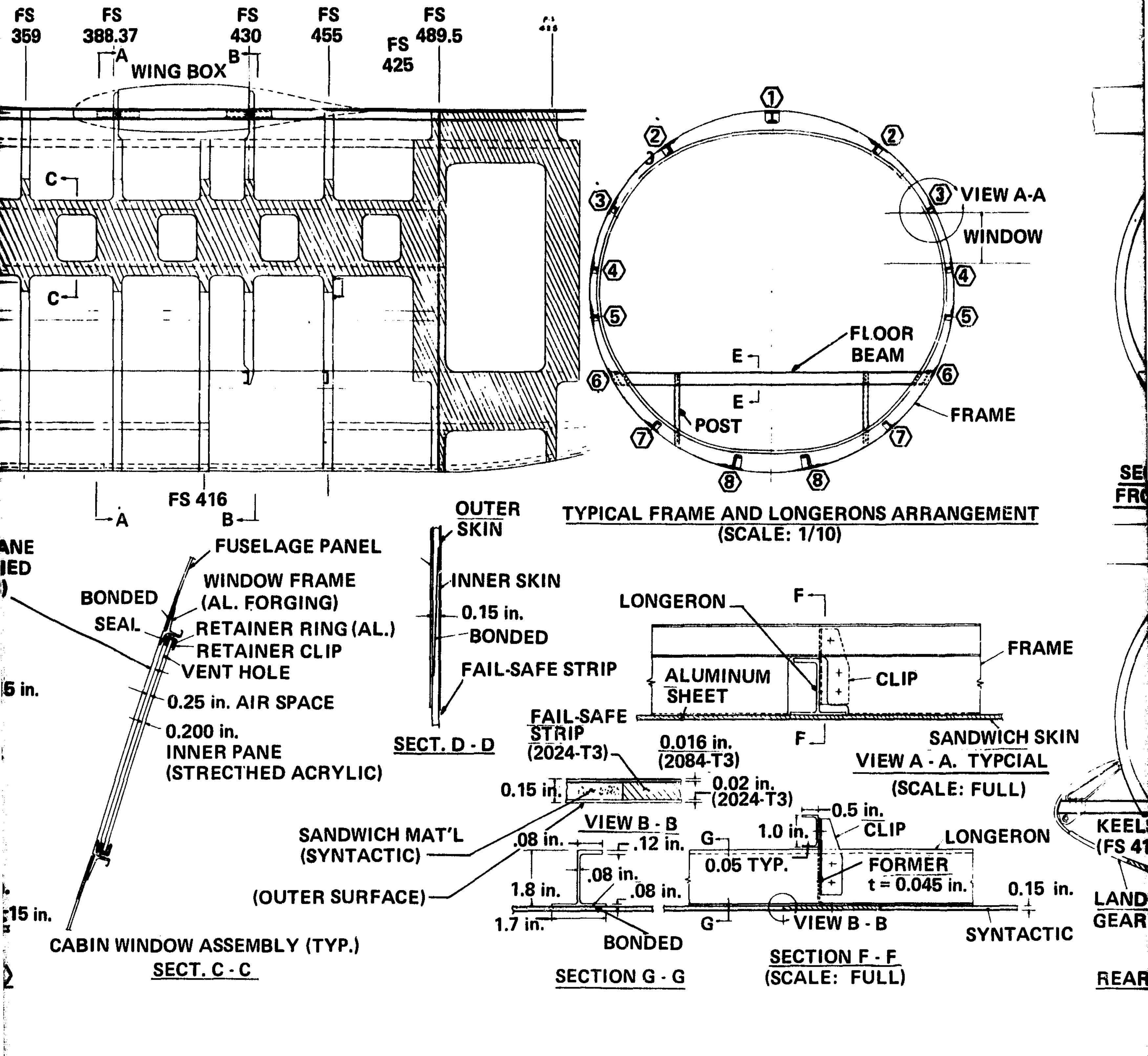
FLOOR BEAM (TYP)
SECT. E - E



LONGERON NO. ①
(FULL SIZE)



LONGERON NO. ⑧
(FULL SIZE)


FS 359
FS 388.37
FS 430
FS 455
FS 425
FS 489.5
WING BOX
A
B
C
C
FS 416
A
B
1
2
3
4
5
6
7
8
VIEW A-A
WINDOW
FLOOR BEAM
E
E
POST
FRAME
TYPICAL FRAME AND LONGERONS ARRANGEMENT
(SCALE: 1/10)
FUSELAGE PANEL
WINDOW FRAME
(AL. FORGING)
BONDED
SEAL
RETAINER RING (AL.)
RETAINER CLIP
VENT HOLE
0.25 in. AIR SPACE
0.200 in.
INNER PANE
(STRETCHED ACRYLIC)
CABIN WINDOW ASSEMBLY (TYP.)
SECT. C - C
OUTER SKIN
INNER SKIN
0.15 in.
BONDED
FAIL-SAFE STRIP
SECT. D - D
LONGERON
F
ALUMINUM SHEET
CLIP
FRAME
SANDWICH SKIN
VIEW A - A. TYPCIAL
(SCALE: FULL)
FAIL-SAFE STRIP
(2024-T3)
0.016 in.
(2084-T3)
0.02 in.
(2024-T3)
0.15 in.
SANDWICH MAT'L
(SYNTACTIC)
(OUTER SURFACE)
VIEW B - B
.08 in.
.12 in.
.08 in.
.08 in.
1.8 in.
1.7 in.
BONDED
SECTION G - G
G
0.05 TYP.
0.5 in.
1.0 in.
CLIP
LONGERON
FORMER
t = 0.045 in.
0.15 in.
VIEW B - B
SYNTACTIC
SECTION F - F
(SCALE: FULL)
KEEL
LAND
GEAR
REAR

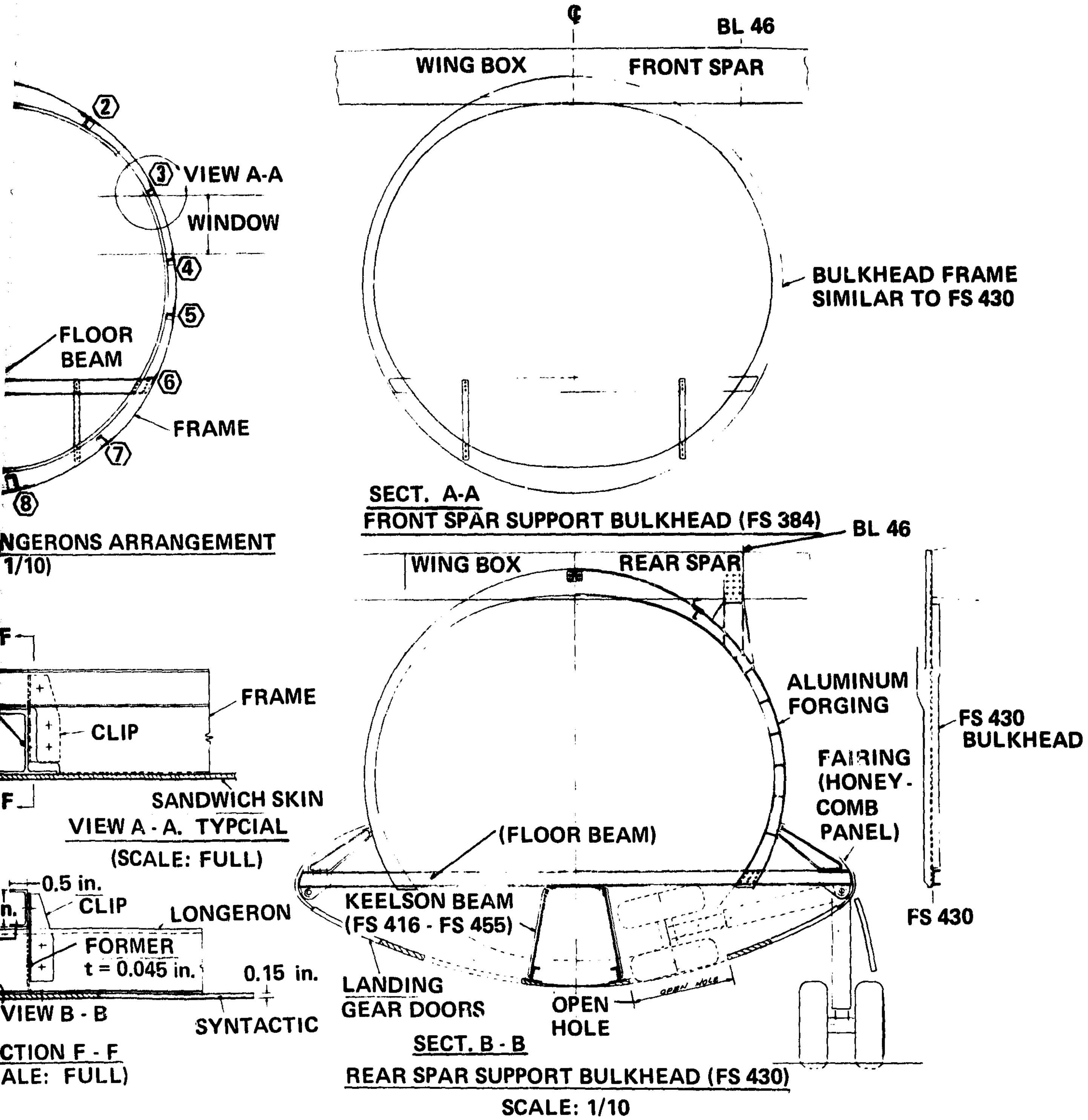
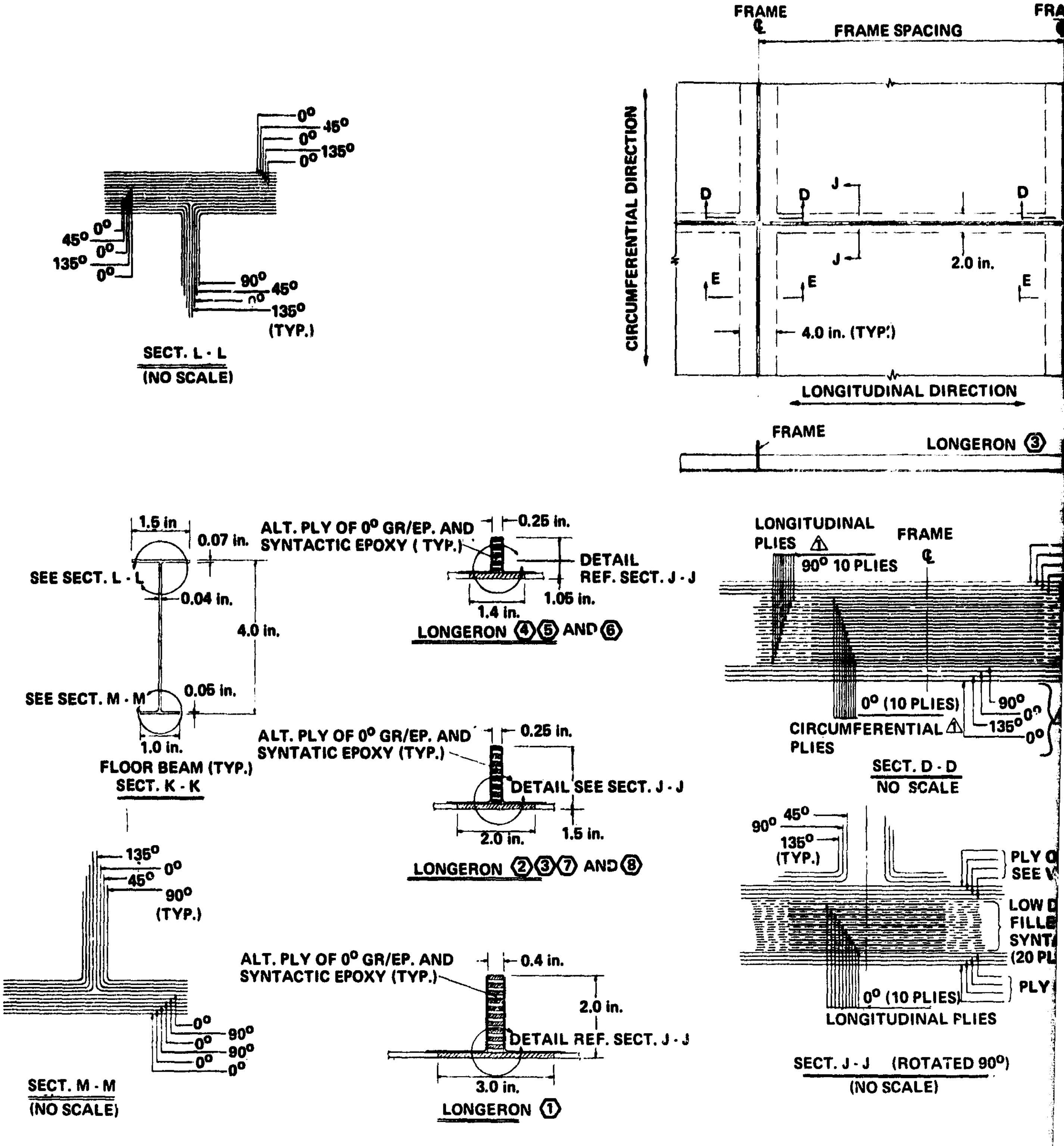
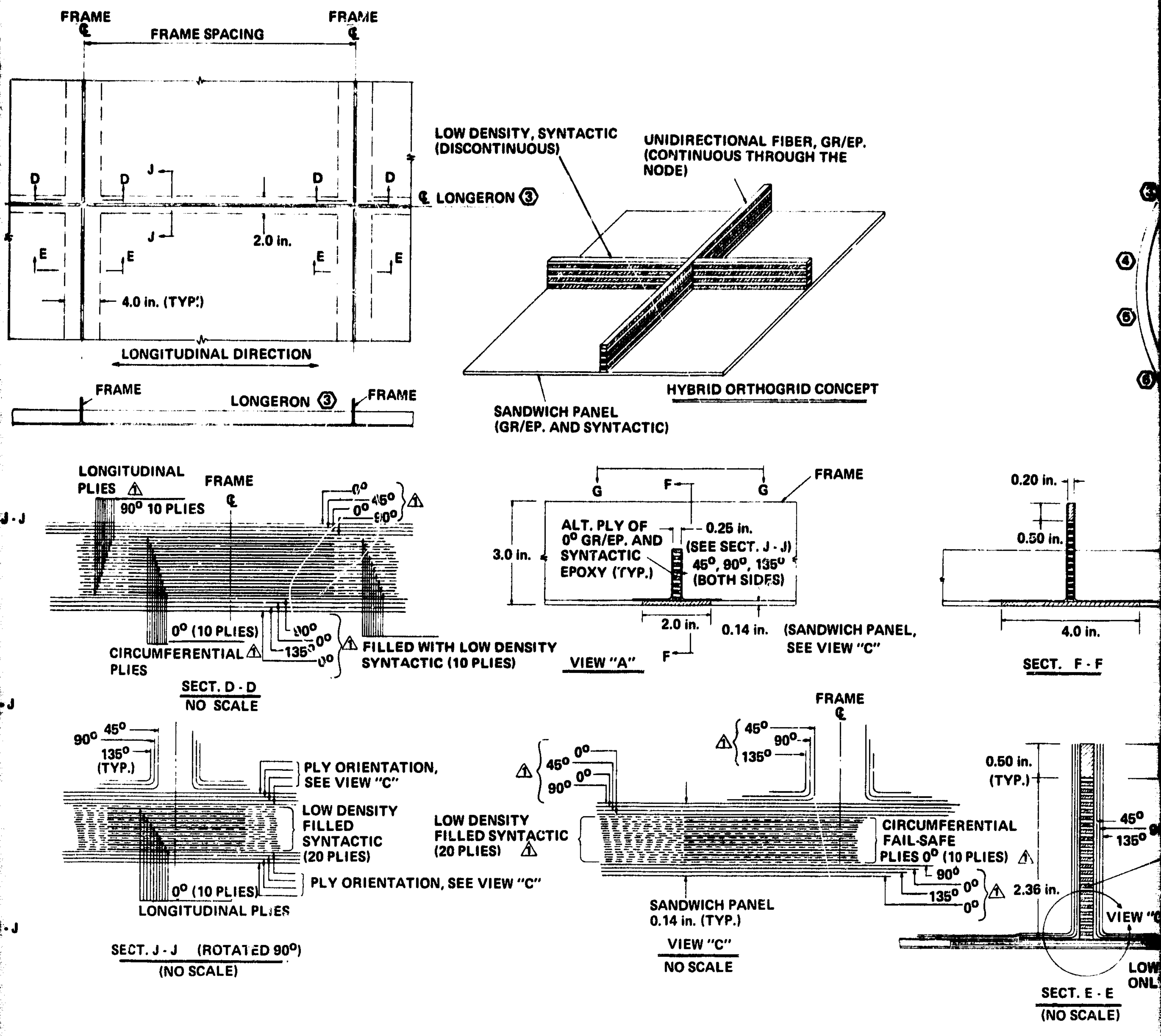


Figure 45. - Aluminum longeron fuselage.


0°
45°
0°
0° 135°
45° 0°
0°
135° 0°
90° 45°
0°
135°
(TYP.)
SECT. L - L
(NO SCALE)
FRAME
FRAME SPACING
CIRCUMFERENTIAL DIRECTION
D
J
2.0 in.
E
4.0 in. (TYP.)
LONGITUDINAL DIRECTION
FRAME
LONGERON ③
1.5 in
0.07 in.
SEE SECT. L - L
0.04 in.
4.0 in.
SEE SECT. M - M
0.06 in.
1.0 in.
FLOOR BEAM (TYP.)
SECT. K - K
ALT. PLY OF 0° GR/EP. AND SYNTACTIC EPOXY (TYP.)
0.25 in.
DETAIL REF. SECT. J - J
1.4 in.
1.05 in.
LONGERON ④⑤ AND ⑥
ALT. PLY OF 0° GR/EP. AND SYNTATIC EPOXY (TYP.)
0.25 in.
DETAIL SEE SECT. J - J
2.0 in.
1.5 in.
LONGERON ②③⑦ AND ⑧
135°
0°
45°
90°
(TYP.)
0°
90°
0°
90°
0°
0°
SECT. M - M
(NO SCALE)
ALT. PLY OF 0° GR/EP. AND SYNTACTIC EPOXY (TYP.)
0.4 in.
2.0 in.
DETAIL REF. SECT. J - J
3.0 in.
LONGERON ①
LONGITUDINAL PLIES
FRAME
90° 10 PLIES
0° (10 PLIES)
90°
0°
135°
0°
CIRCUMFERENTIAL PLIES
SECT. D - D
NO SCALE
90° 45°
135°
(TYP.)
0° (10 PLIES)
LONGITUDINAL PLIES
SECT. J - J (ROTATED 90°)
(NO SCALE)



FRAME ℄
FRAME SPACING
FRAME ℄
D
D
J
D
D
℄ LONGERON ③
J
2.0 in.
E
E
E
E
4.0 in. (TYP.)
LONGITUDINAL DIRECTION
FRAME
LONGERON ③
FRAME
LOW DENSITY, SYNTACTIC (DISCONTINUOUS)
UNIDIRECTIONAL FIBER, GR/EP. (CONTINUOUS THROUGH THE NODE)
SANDWICH PANEL (GR/EP. AND SYNTACTIC)
HYBRID ORTHOGRID CONCEPT
④
⑤
⑥
LONGITUDINAL PLIES
90° 10 PLIES
FRAME ℄
0°
45°
0°
90°
0° (10 PLIES)
90°
0°
135°
0°
CIRCUMFERENTIAL PLIES
FILLED WITH LOW DENSITY SYNTACTIC (10 PLIES)
SECT. D - D
NO SCALE
G
F
G
FRAME
ALT. PLY OF 0° GR/EP. AND SYNTACTIC EPOXY (TYP.)
0.25 in.
(SEE SECT. J - J)
45°, 90°, 135° (BOTH SIDES)
3.0 in.
2.0 in.
0.14 in.
(SANDWICH PANEL, SEE VIEW "C"
F
VIEW "A"
0.20 in.
0.50 in.
4.0 in.
SECT. F - F
90°
45°
135° (TYP.)
PLY ORIENTATION, SEE VIEW "C"
LOW DENSITY FILLED SYNTACTIC (20 PLIES)
PLY ORIENTATION, SEE VIEW "C"
0° (10 PLIES)
LONGITUDINAL PLIES
SECT. J - J (ROTATED 90°)
(NO SCALE)
FRAME ℄
45°
90°
135°
45°
0°
90°
0°
LOW DENSITY FILLED SYNTACTIC (20 PLIES)
CIRCUMFERENTIAL FAIL-SAFE PLIES 0° (10 PLIES)
90°
135°
0°
0°
SANDWICH PANEL 0.14 in. (TYP.)
VIEW "C"
NO SCALE
0.50 in. (TYP.)
45°
135°
2.36 in.
SECT. E - E
(NO SCALE)

2

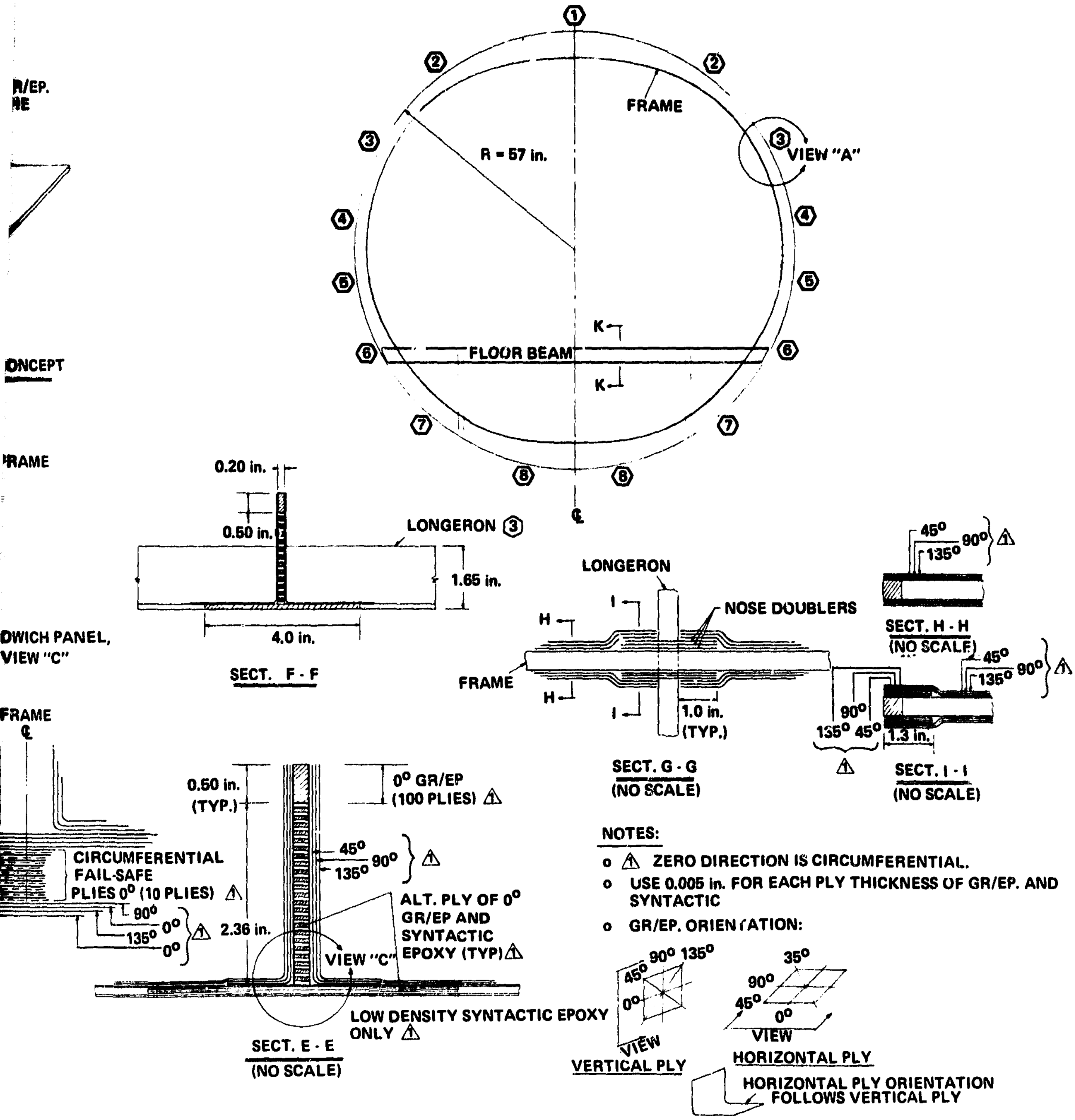


Figure 46. - Composite orthogrid arrangement.

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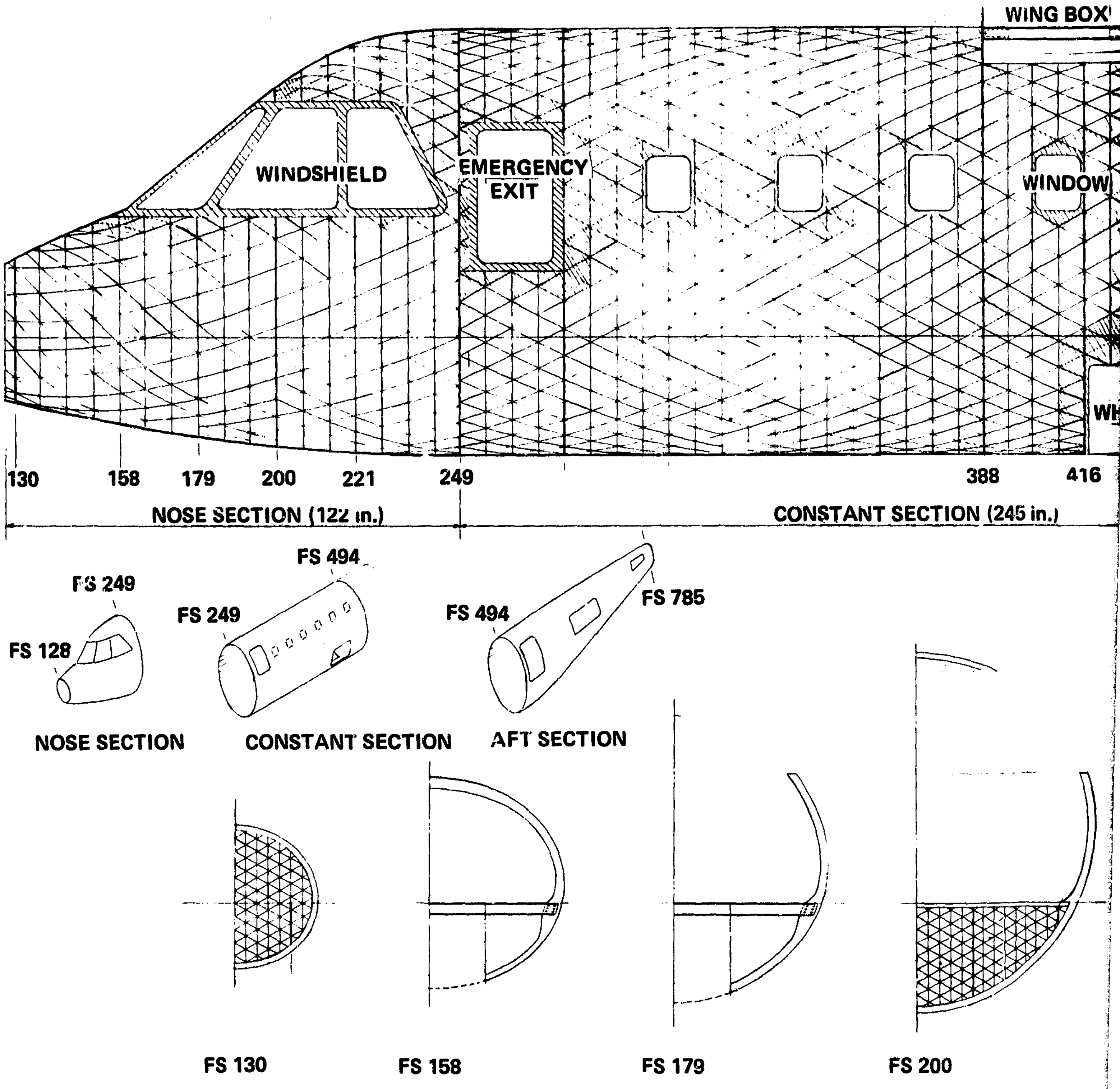

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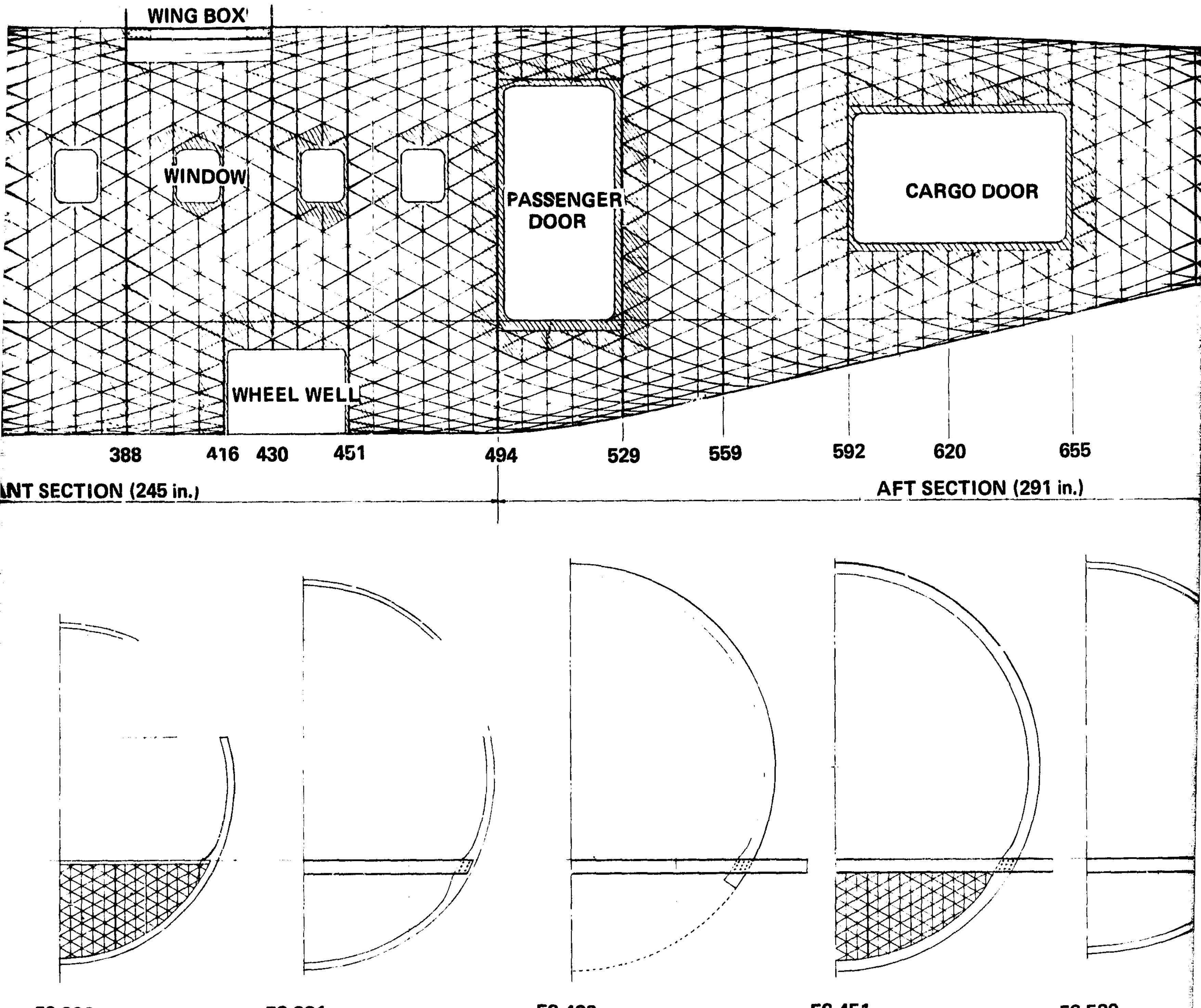

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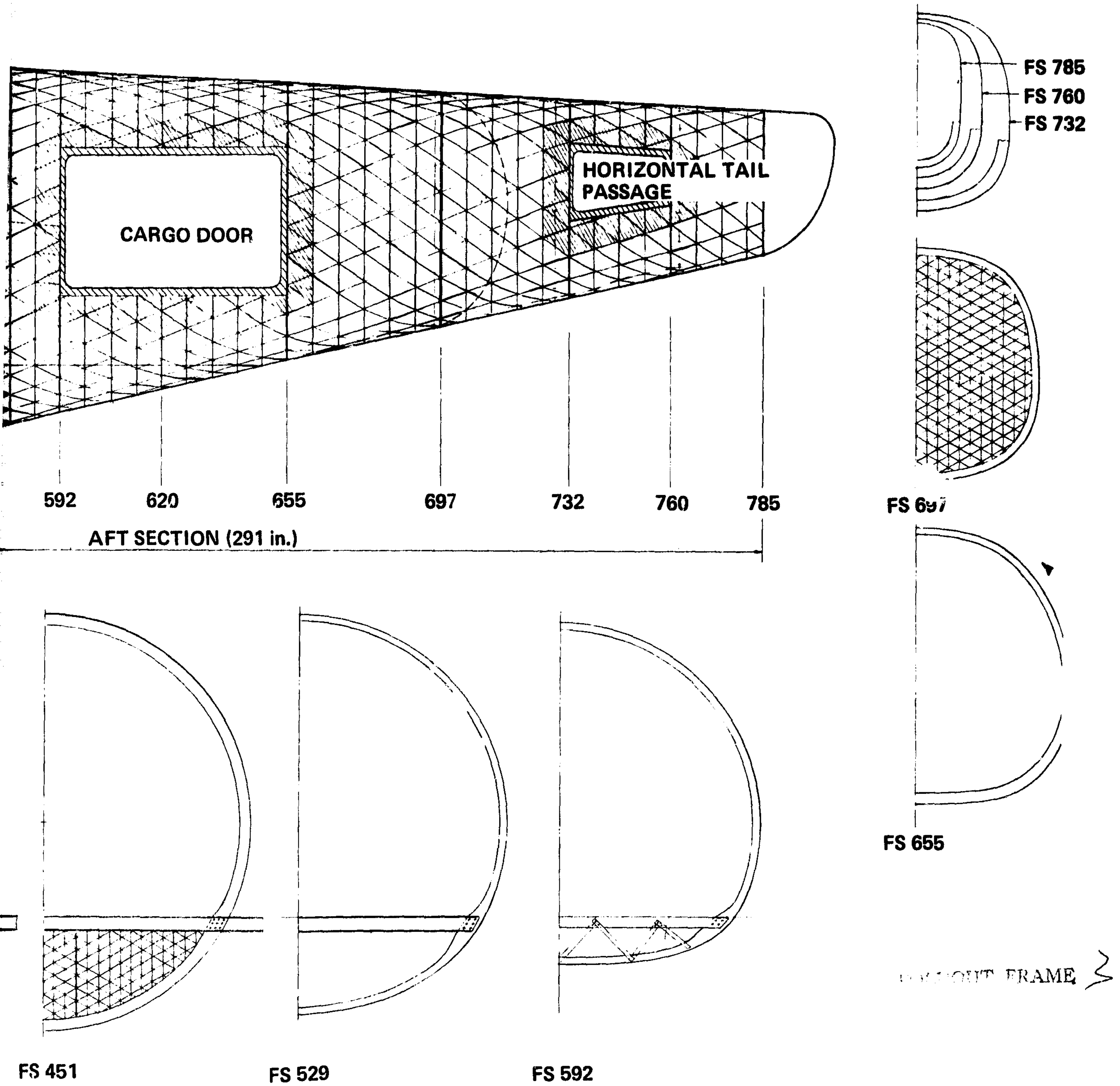


Figure 47. - Composite isogrid fuselage.

The composite orthogrid design employs a structural arrangement similar to that of the simplified aluminum fuselage, except that longeron and frame construction utilize automated lay-up with composite materials. Similar to the aluminum fuselage design, the skin is constructed as a sandwich with composite material as face sheets and syntactic core.

The search for efficient, light-weight, and economical structural concepts for aircraft structures is a continuing objective of the aircraft industry. The most promising concept shown in figure 48 and figure 49 is found to be the fuselage skin stiffened by a repetitive equilateral triangular pattern of the stiffening members, namely isogrid. Isogrid acts like an isotropic plate and not only offers good resistance to general instability failure but can be designed to withstand compression and shear without internal supports.

An advanced composite hybrid isogrid concept is being developed by Lockheed that is intended to be structurally efficient while overcoming the major difficulty of high manufacturing costs. The latest manufacturing innovation is based on the use of automated machine layup techniques for the orthogrid design concept. In order to manufacture composite isogrid by this process, a design concept must be made that defines the triangular stiffener pattern, with special attention paid to the stiffener intersection. To simplify the manufacturing method at this intersection, a technique of so-called offset joint concept as shown in figure 50 is used.

Airstair door: Normally, the short-haul airplane is designed to operate at those airports that lack ground equipment to accommodate a passenger loading system. Therefore, an airstair door is considered more suitable to this type of aircraft. This is a plug-type door design and has simple hinges at the root of the door to provide for the door to rotate up and down, see figure 51. The construction of this door is mainly of built-up sandwich honeycomb panels, which is considered a low cost design.

6.1.2 Advanced materials. - The utilization of advanced structural materials, of light weight and high strength, can be used to provide significant advantages in aircraft structural weight. Two materials, advanced aluminum alloys and advanced composites, are currently in development for use in aircraft primary structure and are applicable to the short-haul configurations used in this study.

Advanced aluminum alloys: Improvement in the weight and structural properties of aluminum can be applied directly to any of the current conventional aircraft with a benefit of structural weight savings, providing the material price is not excessive. Certain of the advanced aluminum alloys offer large gains in particular properties of prime importance to the short-haul type of aircraft. Figure 52 shows comparative tensile, stress corrosion, and toughness properties of current aluminum alloys and advanced alloys. The high strength combined with high corrosion resistance and toughness of aluminum-lithium-magnesium alloys are of prime importance in view of the many cycles of takeoff and landing inherent in short-haul operation. Figure 53 compares the strength to density and specific modulus to density for several materials. Again the aluminum-lithium-magnesium alloys are noteworthy because of their high

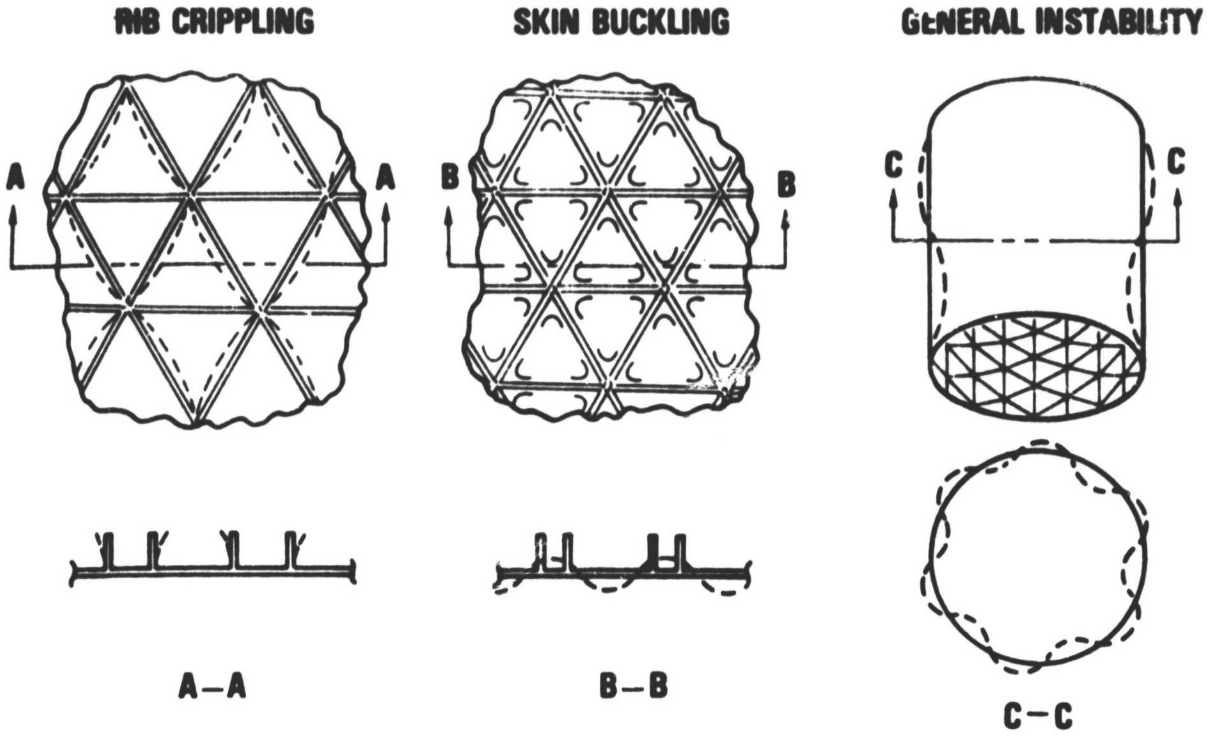


Figure 48. - Isogrid stiffener, skin and general instability buckling modes.

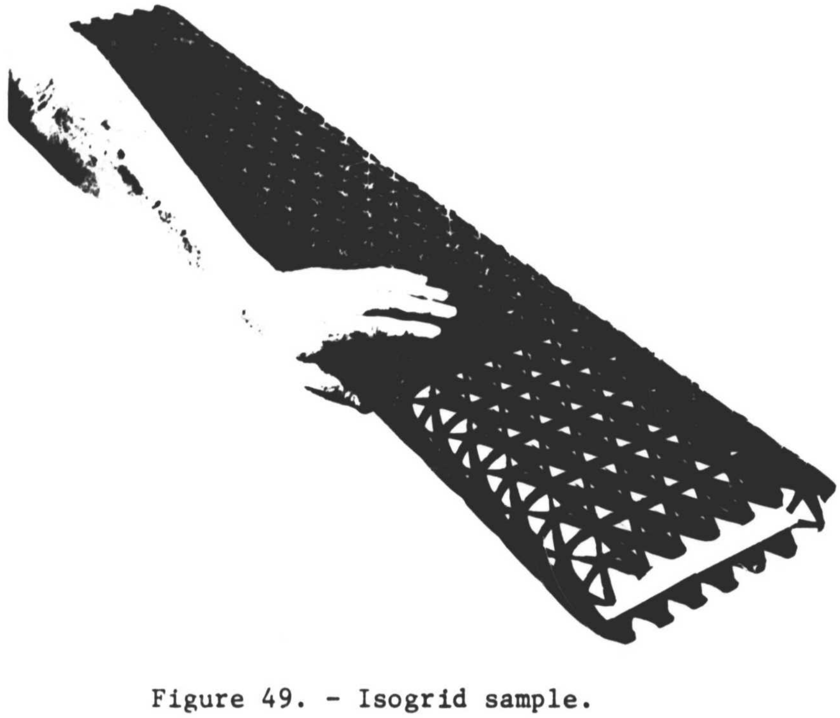


Figure 49. - Isogrid sample.

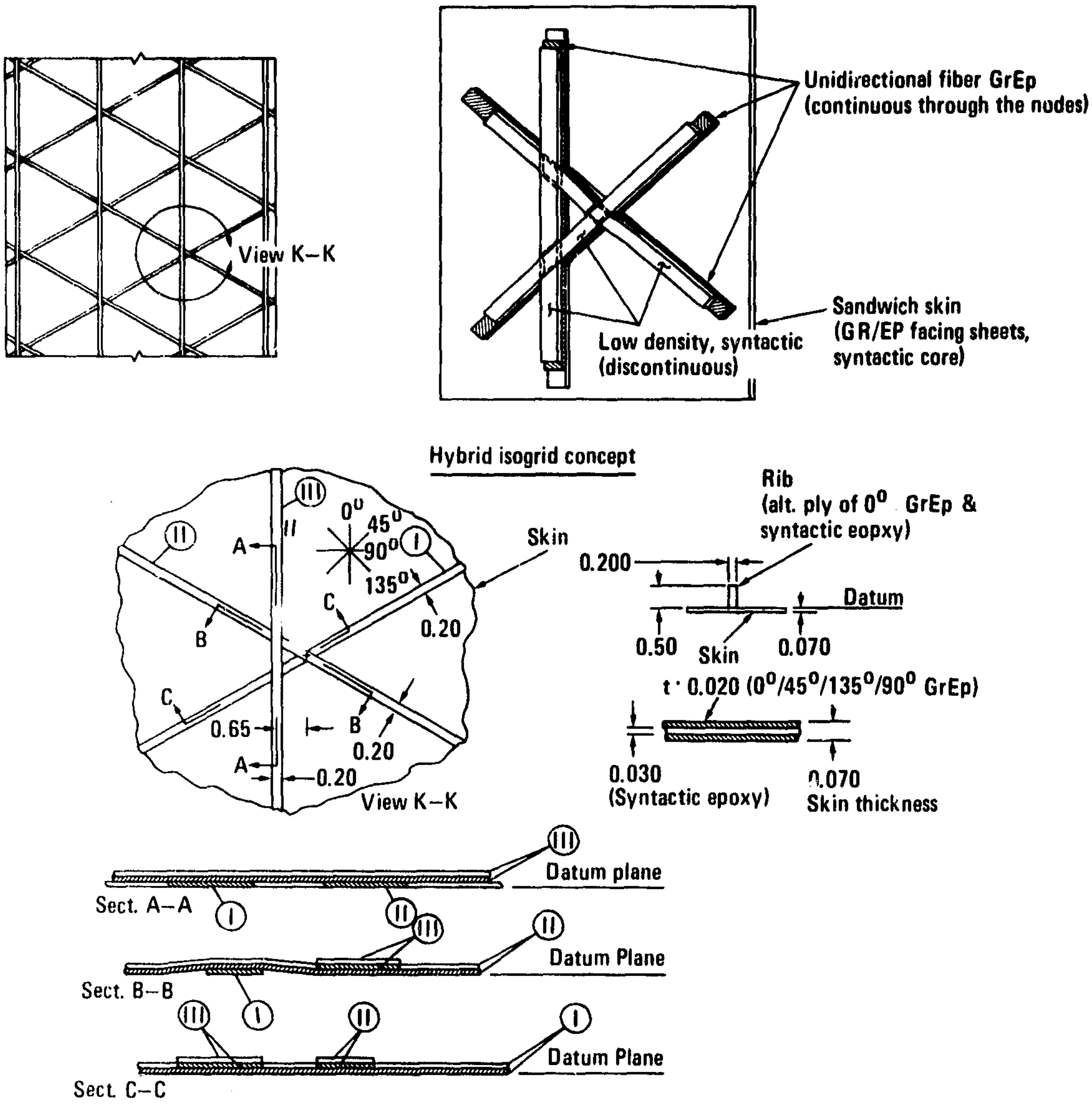


Figure 50. - Hybrid isogrid concept.

stiffness combined with high strength. For this study, an in-depth evaluation of the advanced aluminum alloys was not accomplished. Previous and ongoing studies at Lockheed indicate that structural weight savings on the order of 10% are possible with advanced aluminum alloys. It is projected that wide spread utilization of these new alloys, provided the development process is pushed, could be in the 1985 time frame. The low cost, aluminum, multilongeron fuselage and multispar wing designs previously decribed are suitable for incorporation of the advanced aluminum alloys.

Advanced composite materials: It is anticipated that future aircraft primary structure will utilize advanced composite materials to take advantage of structural weight savings and reduced fabrication cost. Automated manufacturing techniques such as pultrusion, automated layup, and filament winding are currently being implemented to reduce aircraft manufacturing cost. Composite materials are generally recognized as primary candidates for the next generation of aircraft, but there are difficulties which must be overcome so that the potential savings can be realized:

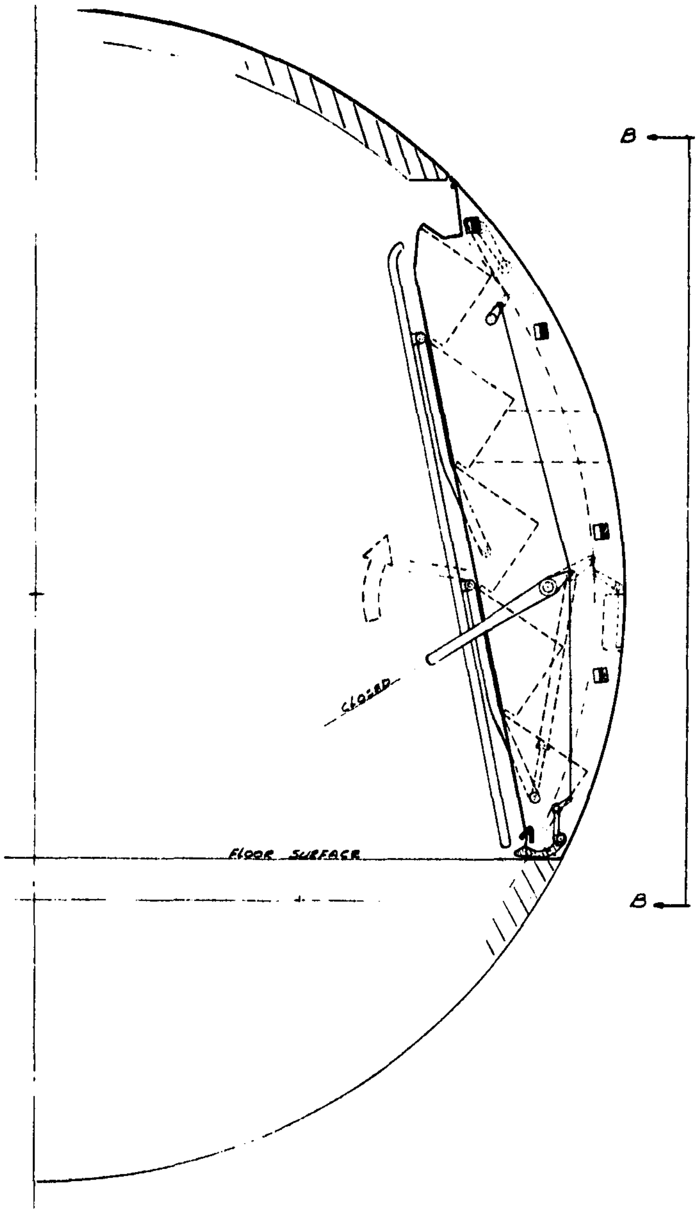
- high material and manufacturing costs
- lack of service experience
- effects of environmental conditions
- foreign object damage and lightning strike.

Foreign object impact tests made on the specimens are summarized in figure 54 which shows that the thin sandwich is considerably more robust than the honeycomb core sandwiches. The techiques for designing and handling the graphite syntactic resin composites in these thin sandwiches have been further developed in the last few years and are now being applied in the advanced composite aileron (ACA) for the L-1011 aircraft. A series of tests made with one-inch diameter hail stones are summarized in figure 55. The thin sandwiches of graphite syntactic resin are quite superior in impact resistance.

For more heavily loaded structure, the stability under structural load becomes of primary importance. The impact on both the weight and thickness required for shear panels can be seen in figure 56. In this figure the weight parameter is plotted against the shear stability parameter.

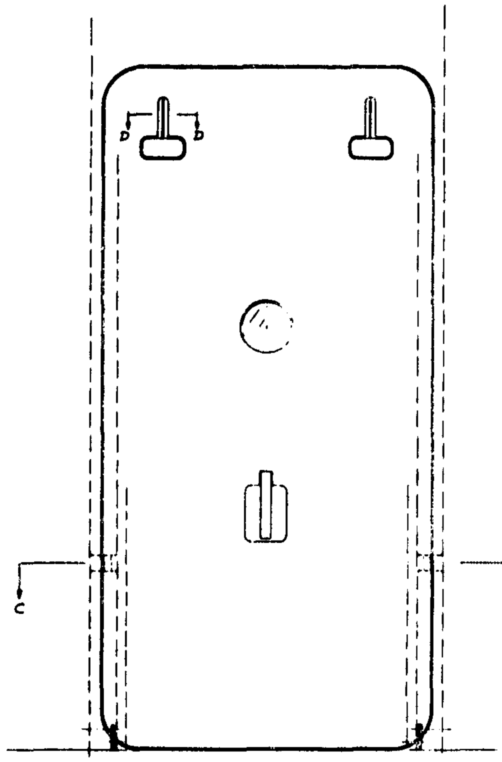
Lightning strike: Aircraft mold line surfaces made from advanced composite materials require lightning strike protection coating. The most common of these is to provide a metallic layer as the outer-most surface of the composite. However, some other protection systems as shown in table 13, in general will satisfy the design requirements.

6.1.3 Producibility and cost considerations. - Producibility of the advanced structural concepts was examined with respect to its influence on design concepts and also for the purpose of assessing manufacturing cost impact. Optimum producibility and low cost is attained by minimizing the manhours

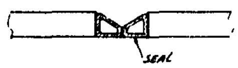


DOOR IN CLOSED POSITION

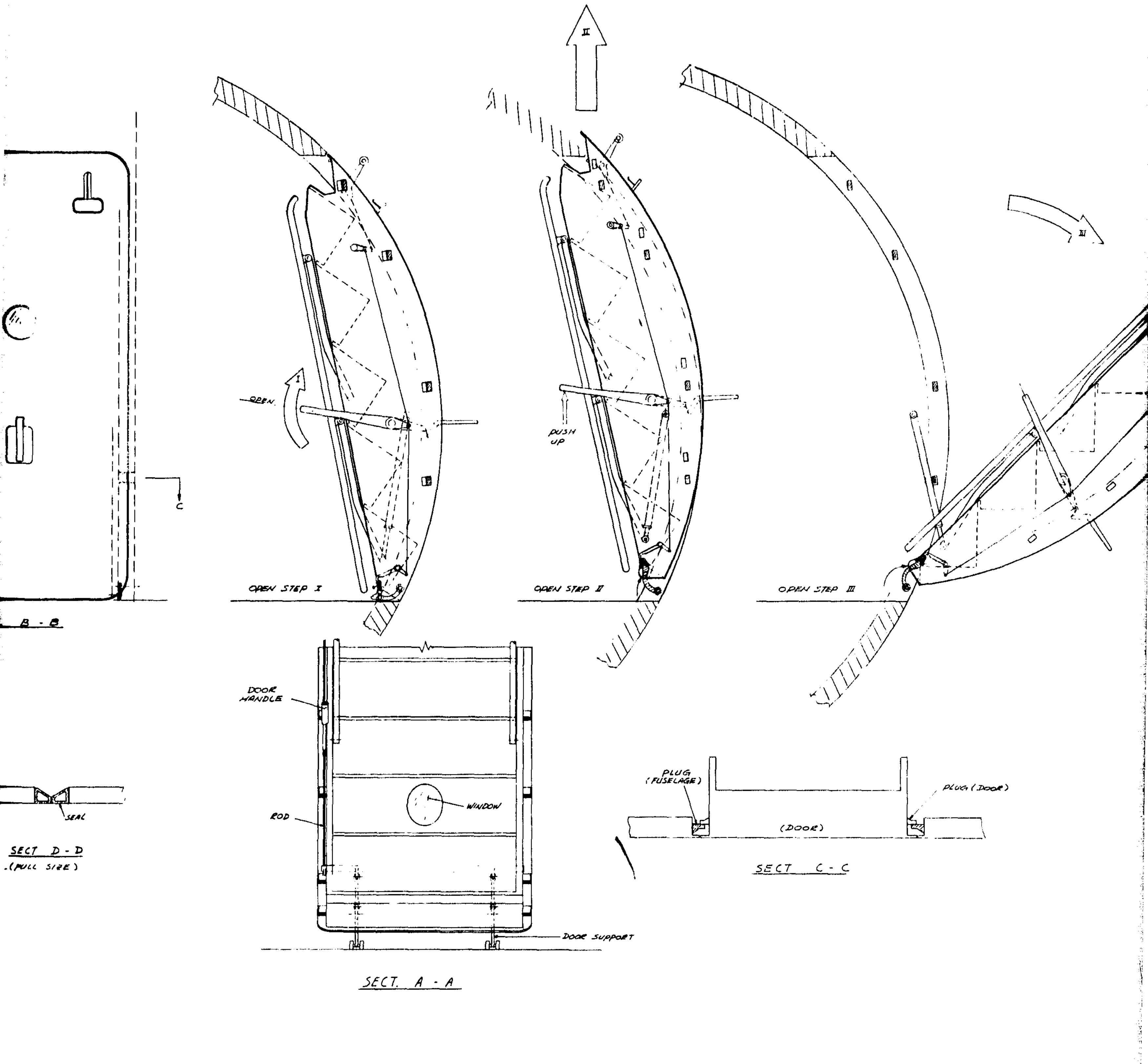
GROUND SURFACE



SECT. B - B



SECT. D - D
(FULL SIZE)



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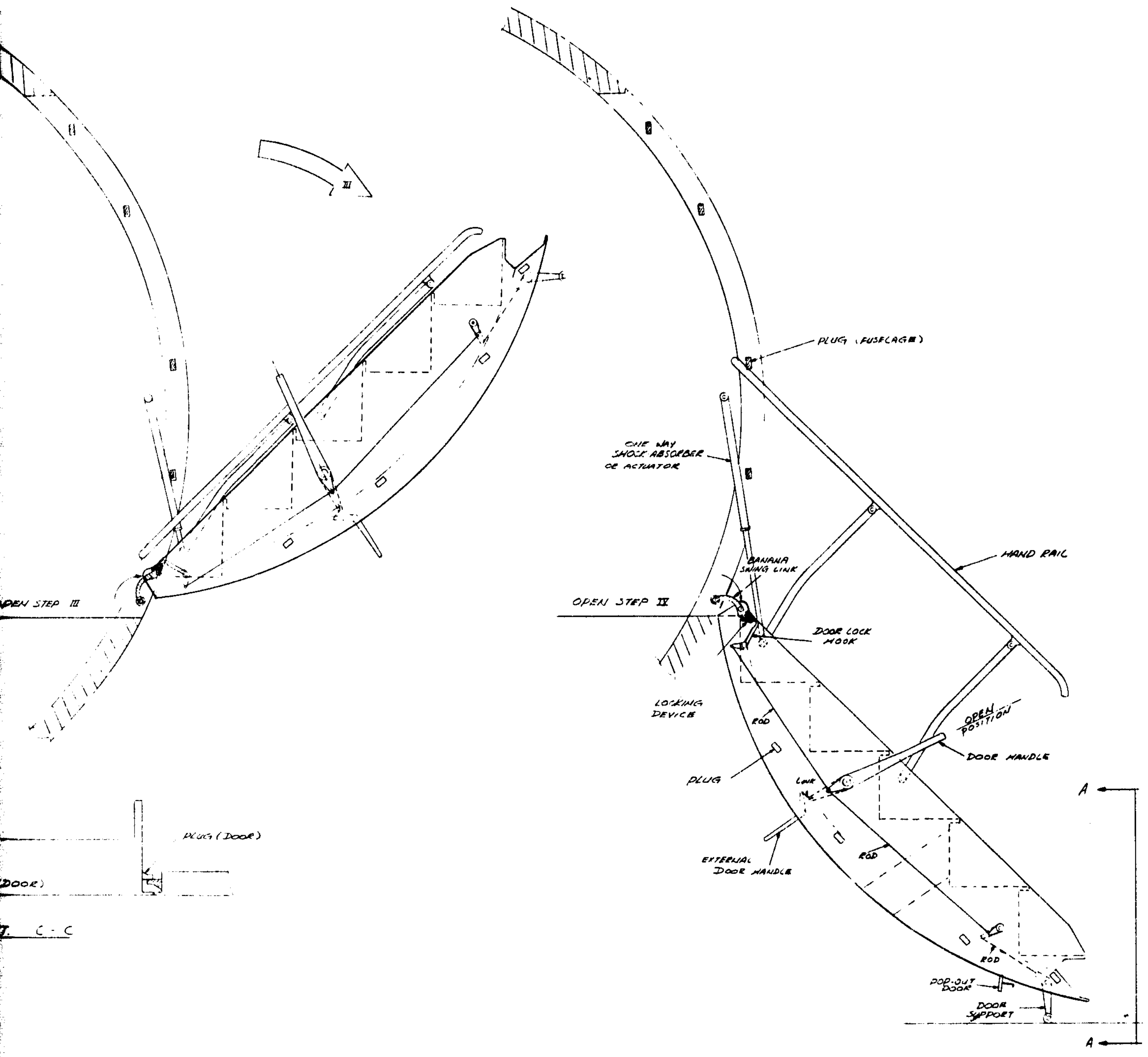

Figure 51. - Airstair door.

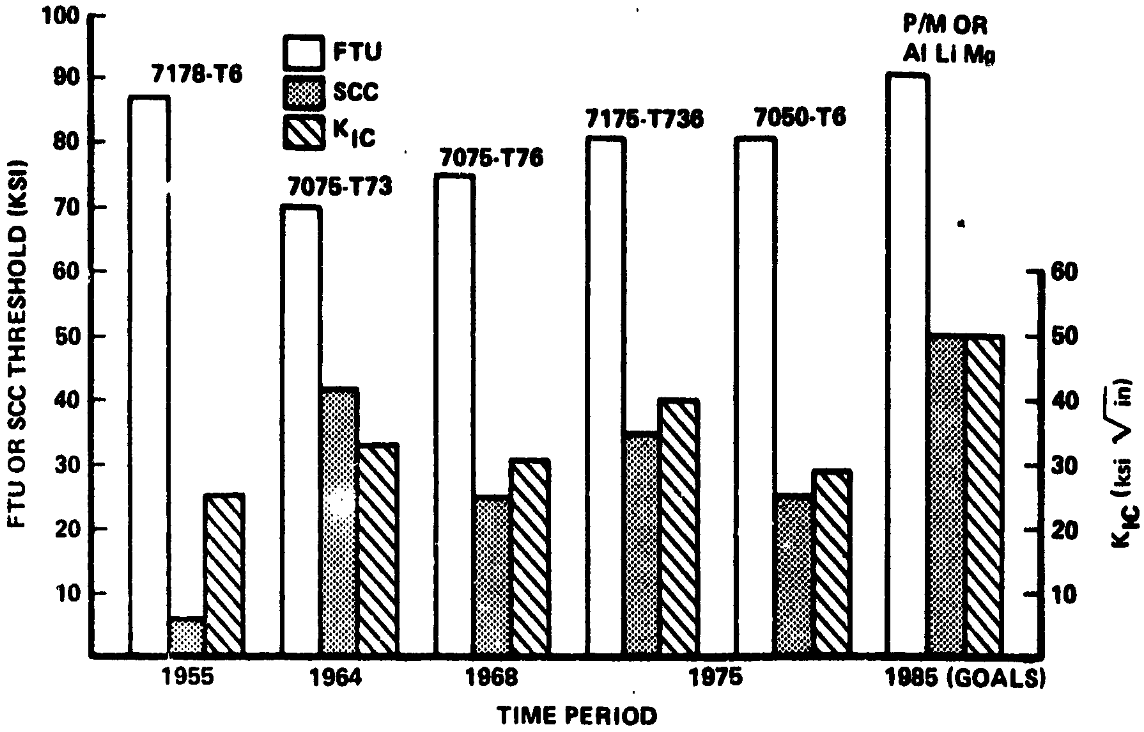

Figure 52. - Aluminum alloy trends.

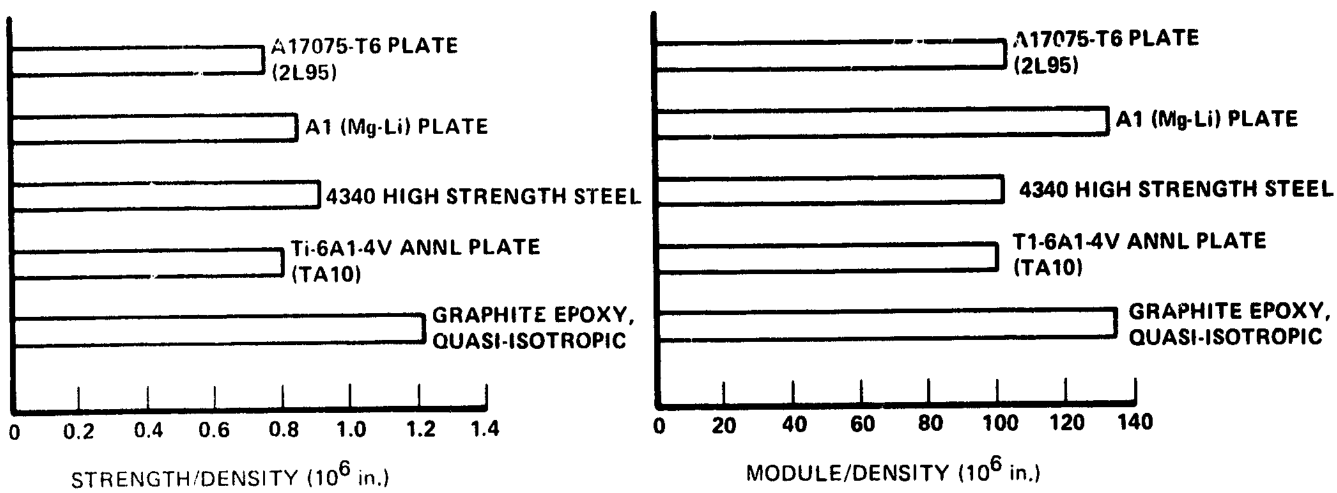

Figure 53. - Aircraft primary structural materials.

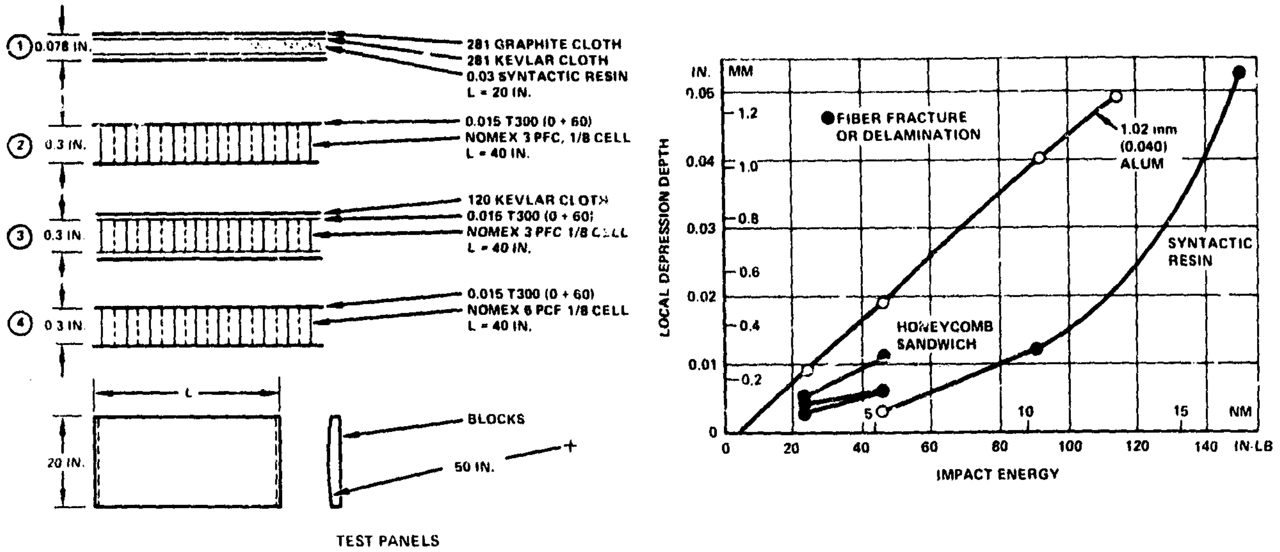

Figure 54. - Panel Impact Tests

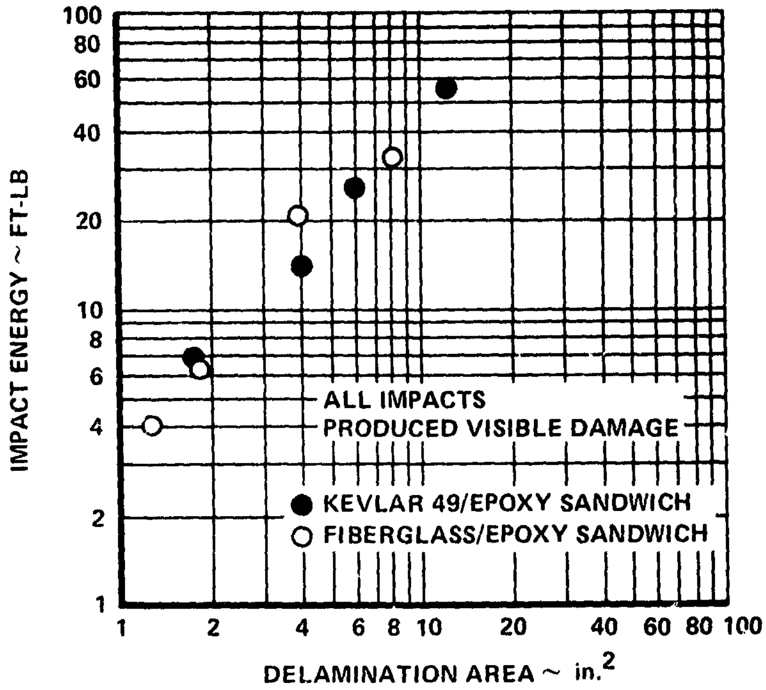

Figure 55. - 1.0 Inch diameter hailstone impact effects on graphite/syntactic/graphite panels.

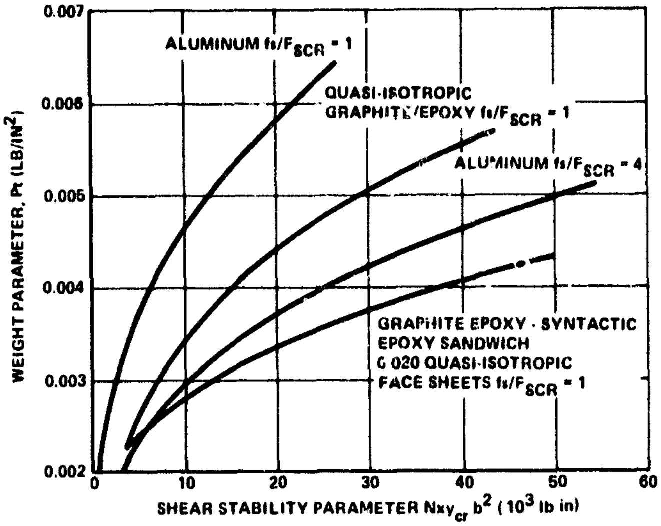

Figure 56. - Shear stability efficiency comparison of several materials.

TABLE 13. -- BASIC LIGHTNING STRIKE PROTECTION SYSTEMS

Protection System	Weight (lb/ft^2)	Installation Method	Advantages	Disadvantages
Aluminum Flame Spray (6 mils) △1	0.070 - 0.080 + Adhesive	Cocured △2	1. Independent of surface shape and size 2. Repairable 3. Low maintenance 4. Partial environmental seal of composite surface	1. Coating weight and quality is operator-dependent 2. Aluminum flame spray quality cannot be determined prior to part cure 3. Limited long term service fatigue experience record
Aluminum Foil (5 mils) △1	0.070 0.070 + Adhesive	Cocured △2 Adhesive Bonded	1. Environmental seal of composite surface 2. Uniform surface Conductivity 3. Surface material completely replaceable	1. Foil stock width limitations 2. Difficult to install on compound contours 3. Poor repairability characteristics 4. Poor part handleability characteristics 5. Heaviest system
Aluminum Wire Mesh △1 (Preferred)	0.091 (120 x 120 Wire Mesh Impregnated with Resin)	Cocured △2	1. Minimum shape constraint 2. Lightest-weight system 3. Repairable 4. Low maintenance 5. Lowest cost system (mesh cocured with laminate)	1. Mesh stock width limitations 2. Inadequate environmental seal for composite

NOTES: △1 Minimum or lighter weight coating designs are possible for secondary lightning strike zones

△2 The mold line surface protective coating is generally bonded and/or impregnated with matrix resin during composite cure required to produce the structure. Reducing the number of parts and fasteners has proven to be a successful measure for achieving producibility goals.

For the simplified aluminum concept, producibility is improved through part/fastener reduction. The number of frames is reduced, and the stringers are replaced with fewer longerons. The mechnical fastening time is reduced through adhesive bonding; however, to achieve the improved producibility in the sub structure, the skins have been stiffened by increasing their thicknesses with the addition of syntactic form cores in sandwich.

The compos...e concepts have been analyzed to ascertain producibility improvements. The use of preplied prepreg graphite-epoxy broadgoods and tapes have been examined. The higher material costs can be nullified by the advantages sustained through co-curing large assemblies which combine the skin with the substructure thus minimizing assembly labor costs. Further reduction in labor costs may be achieved through advanced winding of graphite-epoxy prepreg tapes in an orthogrid or isogrid pattern. This concept is applicable to both fuselage and wing structure.

Assessment of the manufacturing cost impact was based on the following:

- Baseline. - The baseline fuselage structure is conventional aluminum skin, stringer, and frame construction. Stringer and frame spacing are approximately 4.5 inches and 20 inches respectively. Fail-safe straps run circumferentially between frames. The wing box is conventional skin and stringer with built-up ribs and a front and rear spar. The balance of the airframe structure is considered primarily conventional aluminum, with steel, titanium and other materials employed where necessary such as in the landing gear, heat zones, and radomes. Conventional fasteners and joining methods are used throughout the airframe. Fasteners are wet-installed.

- Simplified aluminum structure. - This fuselage concept is of aluminum sandwich construction. Inner and outer aluminum skins are bonded to a syntactic core. Aluminum splice plates are bonded between skins for longitudinal joining. Aluminum fail safe straps are bonded between skins. The skins are assumed to be quarter panels. Aluminum stretch-formed longerons are secondary bonded to the skins. Aluminum frames are secondary bonded to the skins on 32 inch centers. Frames are attached to the longerons with clips by squeeze riveting. Conventional fasteners are wet installed. The rest of the airframe structure is the same as the baseline. The use of bonding reduces the number of detail parts and fasteners. This structural concept reduces the number of frames and fail-safe straps required.

- Simplified composite structure. - This concept is an advanced composite sandwich structure. It is a cocured structure of skins, frames and longerons. The inner and outer face sheets of the skins are Gr-Ep with a syntactic core. Fail-safe straps and longitudinal splice plates are Gr-Ep. The skins are assumed to be quarter panels. The longerons are Gr-Ep and B staged, roll formed and cut to length. The frames are Gr-Ep on 32 inch centers. This concept reduced the number of parts and fasteners over the baseline, and the number of frames and fail-safe straps are reduced. No clips are required for frame to longerons. Although fewer fasteners are required, they will be primarily titanium Hi-Loks. Hole preparation and fastener installation are much more sensitive. The wing is a Gr/E multispar concept. Manufacturing cost estimates were accomplished using the data which has been generated during the NASA-Langley-sponsored L-1011 composite fin program currently underway at Lockheed.

- Orthogrid and isogrid composites. - Manufacturing cost impacts were accomplished using the data currently being generated on Lockheed-funded research programs for development of the orthogird and isogrid composite structures. In summary, fabrication of these structures is accomplished by use of an automated tape-laying machine to wind the skin and stringers onto a reusable mandrel (tool) which is then inserted into a female mold with the entire assembly then cocured in an autoclave. One advantage of this process is the ability to control tightly the structure contours and surface. These manufacturing techniques have been successfully used to produce test specimens, and continuing development funded by Lockheed is proceeding to develop the techniques and equipment necessary for fabrication of structural components similar in size to those required for the short-haul aircraft.

6.1.4 Benefits. - Evaluation of the benefits to be gained by incorporation of advanced structural concepts and materials into the baseline short-haul 30-passenger aircraft was accomplished using the ASSET synthesis program. Each concept, previously described was analyzed separately from ASSET for impact on structural weight, manufacturing cost, and maintenance/reliability aspects. Analysis data were input to the ASSET weight and cost subroutines, and the aircraft was resized to perform the baseline mission. Data, obtained from the ASSET resizing and compared to like values for the baseline design, are presented in table 14. Results indicate that the composite isogrid fuselage and composite orthogrid wing design provide the greatest improvements in aircraft technical and economic performance. Use of this structural concept provides a potential benefit of about 23% reduction in aircraft structural cost. This relates to approximately 11% reduction in aircraft total production cost and a 4% reduction in DOC at $1.00 per gallon fuel cost at the design range. In addition a savings in block fuel for the design mission of 2.5% is attained. These results indicate significant benefits are potentially available by incorporation of the advanced structural concepts, particularly with the orthogrid or isogrid concepts which, if subjected to the necessary development programs, could be available in the 1985 to 1990 time frame.

Although evaluated in depth only for the 30 passenger aircraft, it is expected that equivalent benefits may be attained for the 50-passenger baseline.

TABLE 14. - 30 PAX SHORT-HAUL-ADVANCED STRUCTURE AND COMPOSITES

	Baseline	Simplified Aluminum Structure	Simplified Composite Structure	Orthogrid Composite Structure	Isogrid Fuselage Orthogrid Wing Structure
Gross wt (lb)	28 606	28 666	27 286	27 456	27 399
Empty wt (lb)	18 512	18 568	17 287	17 445	17 392
Structure wt (lb)	7 831	7 568	6 776	6 912	6 866
Fuselage	3 545	3 583	3 156	3 268	3 213
Wing	2 304	2 311	1 815	1 829	1 825
Tail	458	460	353	357	355
Land Gear	1 110	1 112	1 069	1 074	1 072
Nacelle	413	413	383	384	389
Struct. Cost	$794 850	$759 480	$709 010	$609 260	$609 880
Fuselage	$417 740	$393 380	$385 430	$288 730	$289 960
Wing	$198 190	$186 920	$162 840	$163 970	$163 590
Tail	$42 580	$42 710	$35 320	$35 650	$35 540
Land Gear	$65 660	$65 740	$63 960	$64 180	$64 100
Nacelle	$70 670	$70 740	$61 450	$56 740	$56 690
Total Devel. Cost*	$162.2M	$161.86M	$150.97M	$150.14M	$149.79M
Total Procurement Cost	$3.705M	$3.734M	$3.559M	$3.434M	$3.432M
Flyaway Cost	$4.14M	$4.09M	$3.89M	$3.77M	$3.77M
Block Fuel (lb) @ 600 n.mi.	2 146	2 146	2 084	2 087	2 093
DOC (c/ASM) @ $1.00/gal Fuel & 600 n.mi.	4.977	4.962	4.810	4.773	4.769

*Development effort associated with establishing the technology readiness of advanced composites and automated manufacturing processes are covered by in-house and contract funded R&D programs. Costs included here are limited to those items peculiar to the specific design (mfg tooling, mandrels, and fixtures) – special tooling such as automated tape laying machine and inspection equipment are assumed to be capital expenditures.

6.2 Active Controls

Utilization of active control concepts, currently being developed for large commercial aircraft such as the L-1011, can be used to advantage for the small, short-haul aircraft. The short field performance required for the short-haul aircraft results in wing loadings and aspect ratios which are unsuitable for smooth rides in turbulence. Active flap systems can be utilized to provide gust load alleviation during operation (other than approach) in gusty conditions. In addition, the characteristics of the short-haul mission when combined with the possibilities opened by the use of active controls lead to some unconventional aircraft configurations that show certain advantages for this mission.

6.2.1 Ride quality improvement. - Extensive studies to evaluate passenger ride quality in transport aircraft have been previously accomplished. One of these studies (reference 6) shows that the percentage of satisfied passengers exceeds 90% for a wing loading over 54 lb/ft^2. For the short-haul aircraft, selected for the study, with wing loadings of 80 lb/ft^2, the inherent ride quality will be superior to that currently experienced with commuter aircraft.

For the advanced technology short-haul aircraft, to enter service in the post 1985 time frame, active controls concepts which are currently entering service on Lockheed's L-1011 commercial aircraft can be used to further enhance ride quality so that it is similar to that experienced on today's turbofan transports. As depicted in figure 57, an adaptive flap, for gust load alleviation, has been incorporated as part of the high lift devices for the advanced technology aircraft. The adaptive flap, which is a 20% chord plain flap nested in a 30% chord Fowler flap, can be used for gust alleviation during climb and cruise. Analysis of this flap system indicates that a C_L MAX of 3.1, in the landing condition with 42° flap deflection can be attained in lieu of a C_L MAX of 3.5 for the baseline configuration. Utilization of the adaptive flap system on the 30 passenger aircraft results in a small penalty, when compared to the baseline, to meet the field length requirements of 1219 m (4000 ft) at sea level and 32°C (90°F) conditions:

	Adaptive Flap	Baseline Flap
Take off gross weight kg (lb)	28 983	28 606
Block fuel, kg (lb)	2247	2146
* DOC - 1100 km (600 n.mi.)	5.068	4.977
* DOC - 184 km (100 n.mi.)	9.960	9.946
W/S	74.0	80.0
T/W	0.370	0.379

* - $1.00 per gallon fuel cost

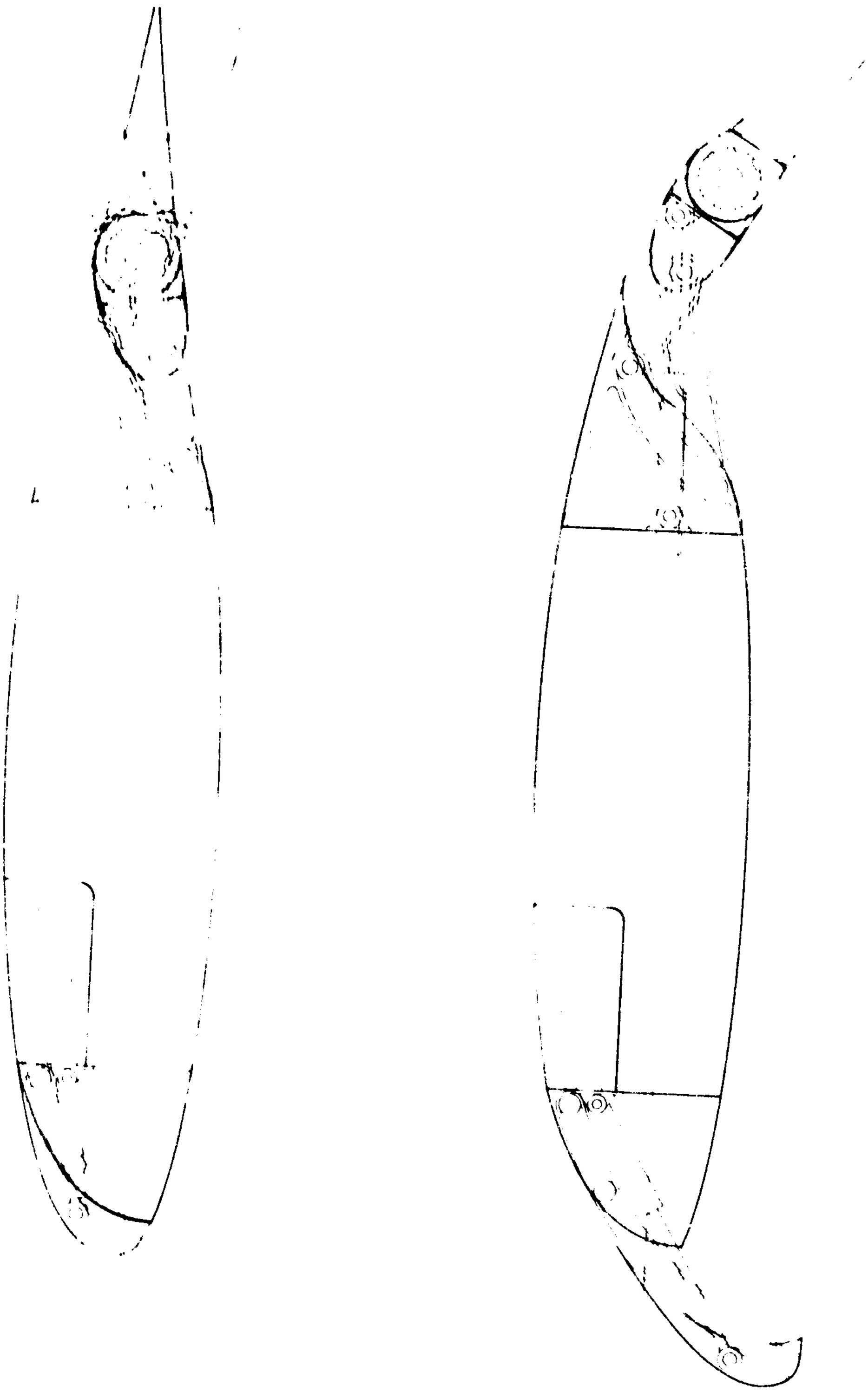

Figure 57. - Gust alleviation flap.

Analysis of the potential improvements in longitudinal ride qualities for the advanced technology short-haul aircraft is in process. The analytical results will be incorporated into the final submittal of this study report.

This analysis will involve two steps. The first step will be the development of a longitudinal time history program with which to analyze the effects of gust-alleviation devises on aircraft motion. The second step will be to develop the control logic network that determines control surface reaction to the aircraft disturbances.

The time history analysis program will be a three degree of freedom (pitch, vertical, longitudinal) representation of the aircraft's motion. The program will accept aerodynamic, propulsion and inertial data in any degree of complexity required for the analysis. Vertical and horizontal gust inputs of variable intensity and spectral characteristics will be applied to the aircraft through the aerodynamic terms. The Dryden form of gust intensity and frequency characteristics, which is representative of atmospheric conditions in clear air turbulence, will be used for the evaluation.

Three control surfaces available for ride qualities modification are wing spoilers, horizontal stabilizer and compound trailing-edge flaps. Spoilers and flaps will be used primarily to reduce the wing lift increment due to high frequency gust inputs which occur above the aircraft's short period frequency. The horizontal stabilizer will be used to attenuate the aircraft pitch response to lower frequency gusts and to compensate for pitching moments due to flaps or spoilers.

Control system logic development will involve selection of the aircraft state measurements (vertical load factor, pitch rate, etc.) and the signal shaping required in the control logic network. The number and kinds of inputs to the controller will be evaluated with respect to system complexity and input reliability and noise. Filtering and phasing of the input signals, as well as optimization of system gains, will be main thrust of the evaluation.

Outputs from the analysis program will be in the form of rms values of perturbations in the state variables due to gusts. Optimization of the systems and determination of relative merits of individual control surfaces for gust-alleviation will involve minimization of these disturbances.

6.2.2 Aircraft configurations. - The characteristics of the short-haul mission, when combined with the possiblities opened by the use of active controls, lead to some unconventional configurations that show certain advantages for this mission. As previously indicated, the 30-passenger airplane carries almost 1000 pounds of empty weight in additional cabin noise suppression material, while for the 50-passenger airplane the penalty is 1500 pounds. As the propellers are the primary source of noise, moving the propellers aft of the passenger cabin is an immediate solution to the weight problem - providing it can be done efficiently. This observation leads to the investigation of aft engine lifting tail airplanes described in this section.

The development of an advanced configuration follows the usual procedure of a step-by-step departure from a known baseline airplane. This enables each element of the final design to be separately evaluated and its impact on DOC and fuel consumption separated from the other changes made. A basic premise is to remove stability as a constraint in selecting the configuration features. Each feature is incorporated for its possible improvement in DOC or fuel consumption with the asumption that active controls will provide a solution to whatever stability problems are involved. Once a desirable configuration has been identified, the very real problems of mechanization of the necessary stability provisions and of the reliability demanded of this system are then evaluated.

The various steps followed in implementing the general approach are:

- Remove the acoustic treatment
- Relocate the propulsion system to the aft end of the airplane
- Incorporate a lifting tail
- Optimize the wing/tail design

Each of these steps is discussed and the resulting configuration described. A brief description of some alternate configurations that were not found suitable is also included.

6.2.2.1 Elimination of acoustic treatment: The benefits of the weight saving represented by removing the acoustic treatment are available with no configuration changes and no need to incorporate advanced technology, and this therefore represents an attractive approach for those operators who are not faced with the direct competition of improved propeller airplanes or turbofan equipment. Applying the sensitivity factors for the 30-passenger baseline airplane, the saving; in DOC and fuel at the 184 km (100 n.mi.) stage are each 4.4%; the savings at 1110 km (600 n.mi.) are 4% in DOC and 4.2% in fuel.

6.2.2.2 Aft-engine configuration: This configuration is developed to evaluate the net effect of removing the propeller noise from the cabin by locating the propellers aft of the pressure bulk-head, thereby eliminating the need for the acoustic treatment. This airplane uses conventional technology and stability margins. The airplane is balanced by simply moving the wing aft to preserve the same c.g.-MAC relationships as in the baseline, and preserving the same wing characteristics of span, aspect ratio and wing loading. The resulting arrangement is shown in figure 58.

The straightforward arrangement of tractor propellers mounted at the tips of the horizontal stablizer results in a compact configuration with adequate propeller clearance in tail-down wing-down situations, a thrust line close to the c.g., and a sturdy, direct load path to the fuselage. The aspect ratio of the horizontal tail has been reduced from that of the baseline and the cross section of the tail cone increased somewhat to accommodate the loads from the propulsion system. Pusher installations are not attractive, primarily because of the problems imposed by the tail wake with deflected control surfaces. The

CHARACTERISTICS	WING	HORIZONTAL TAIL	V'TAILS (EACH)
AREA m^2 (FT^2)	33.22 (357.6)	10.43 (112.3)	3.97 (42.75)
ASPECT RATIO	12	4.35	1.7
SPAN	19.96 (65.50)	6.74 (22.1)	2.60 (8.52)
ROOT CHORD	2.56 (8.4)	2.04 (6.69)	2.26 (7.43)
TIP CHORD	.77 (2.52)	1.06 (3.48)	.79 (2.60)
TAPER RATIO	0.30	0.52	0.35
MAC	1.82 (6.0)	1.60 (5.25)	1.65 (5.41)
SWEEP RAD (DEG)	.063 (3.6)	.082 (4.67)	.61 (35)
T/C ROOT (%)	16.8	17	10
T/C TIP (%)	13.5	8.5	10

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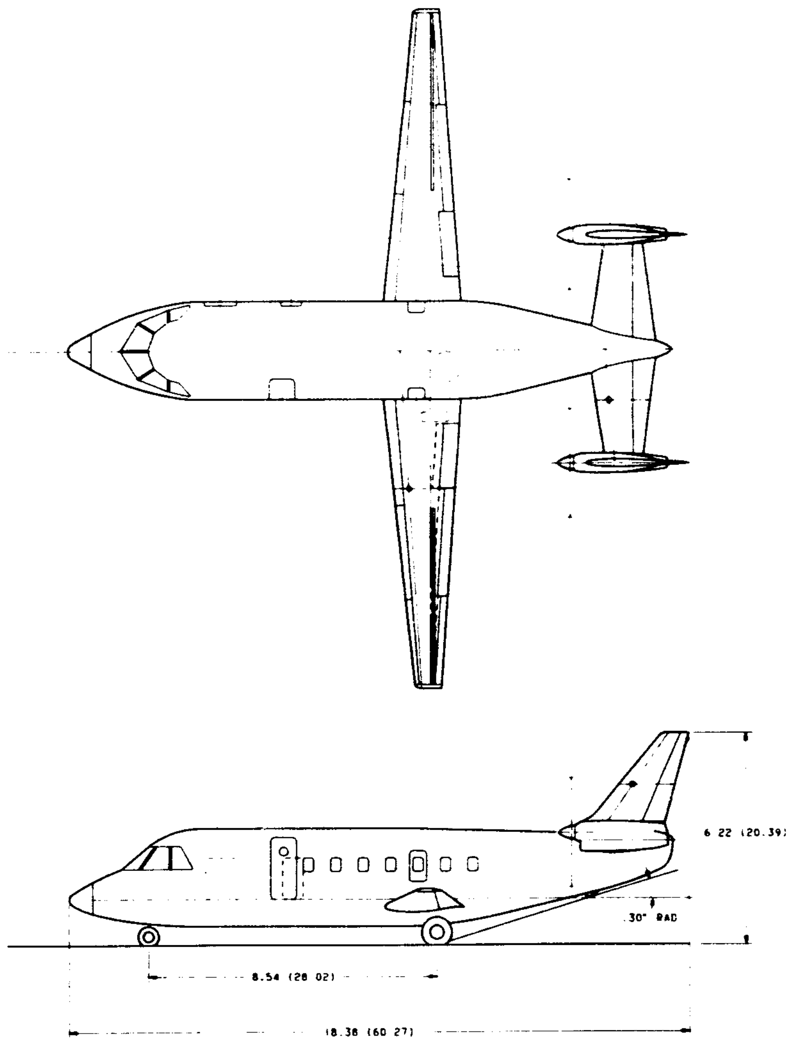


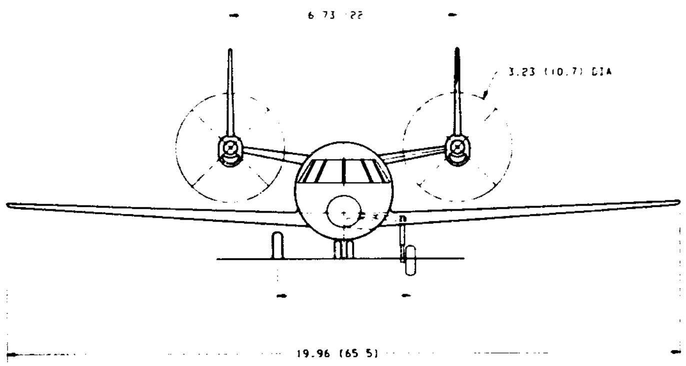
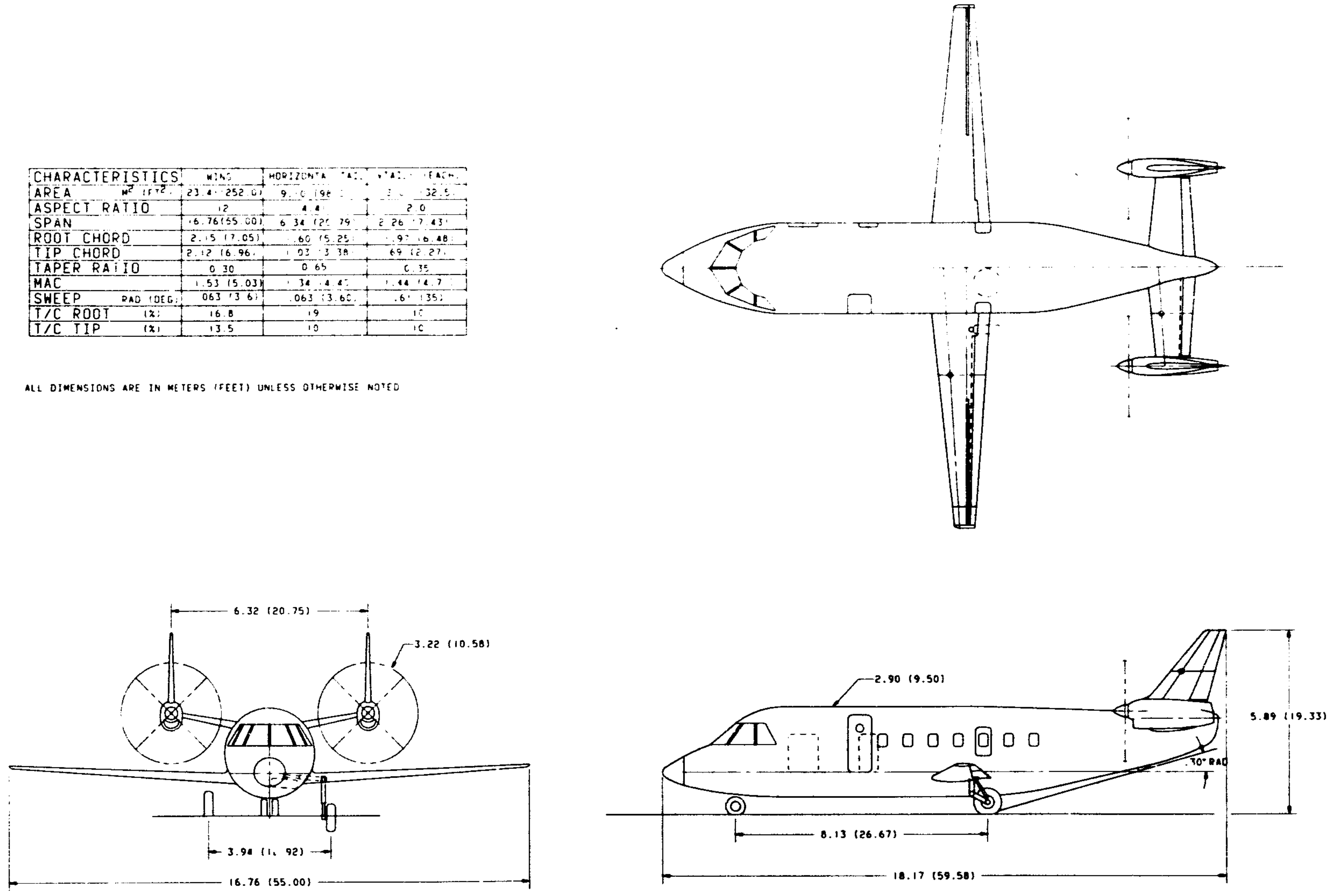


Figure 58. - 30-passenger aft - engine configuration.

TABLE 15. - 30-PASSENGER SHORT-HAUL AFT ENGINE EVALUATION

	Baseline	Aft Engine	Δ ~ %
W/S	80	80	-
T/W	0.379	0.379	-
AR	12	12	-
Takeoff gross wt.	28 606	27 997	-2.2%
Empty wt. (operating)	19 499	18 812	-3.6%
Wing area (ft^2)	358	350	
Wing span (ft)	65.5	64.8	
SHP/engine	2403	2352	
Block Fuel - 600 n.mi.	2146	2219	+3.4%
Block Fuel - 100 n.mi.	671	669	-0.03%
DOC ($1.00/gal) - 600 n.mi.	4.977	4.984	+1.1%
DOC ($1.00/gal) - 100 n.mi.	9.946	9.849	-1.0%
TOFL (all engines)	3346	3351	-
TOFL (engine out)	3942	4000	-
LFL	3938	3937	-
Aircraft Flyaway Cost	$4.14M	$4.07M	-2 4%



CHARACTERISTICS	WING	HORIZONTAL TAIL	V TAIL (EACH)
AREA m^2 (ft^2)	23.4 (252.0)	9.[illegible] (98.[illegible])	[illegible] (32.5)
ASPECT RATIO	12	4.4	2.0
SPAN	16.76 (55.00)	6.34 (20.79)	2.26 (7.43)
ROOT CHORD	2.15 (7.05)	1.60 (5.25)	1.97 (6.48)
TIP CHORD	2.12 (6.96)	1.03 (3.38)	.69 (2.27)
TAPER RATIO	0.30	0.65	0.35
MAC	1.53 (5.03)	1.34 (4.4[illegible])	1.44 (4.7[illegible])
SWEEP RAD (DEG)	.063 (3.6)	.063 (3.60)	.61 (35)
T/C ROOT (%)	16.8	19	10
T/C TIP (%)	13.5	10	10

ALL DIMENSIONS ARE IN METERS (FEET) UNLESS OTHERWISE NOTED

Figure 59. - 30-passenger aft engine, lifting tail configuration.

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TABLE 16. - 30-PASSENGER SHORT-HAUL AFT ENGINE, LIFTING TAIL

	Baseline	Aft Engine, Lifting Tail	Δ%
W/S	80	85	–
T/W	0.379	0.398	–
A/R	12	12	–
Takeoff gross wt	28 606	27 342	-4.4%
Empty wt (operating)	19 499	18 327	-6.0%
Wing area (ft^2)	358	322	–
Wing span (ft)	65.5	62.1	–
SHP/engine	2403	2412	–
Block Fuel - 600 n.mi.	2146	2062	-3.9%
Block Fuel - 100 n.mi.	671	664	-1.04%
DOC ($1.00/gal) - 600 n.mi	4.977	4.869	-2.2%
DOC ($1.00/gal) - 100 n.mi.	9.946	9.788	-1.6%
TOFL (all engine)	3346	3342	–
TOFL	3942	4000	–
LFL	3938	3969	–
Aircraft Flyaway Cost	$4.14M	$4.04M	-2 4%

pusher arrangement also results in a high thrust line and an ungainly structure to obtain the necessary ground clearance.

As the c.g. has moved aft and the tail arm has decreased, the vertical tail area required to maintain the same volume coefficient as the baseline, has been increased. A single large vertical tail has its MAC far above the airplane c.g., and to avoid the associated rolling moment a twin tail arrangement is used.

A major change to the configuration is the use of a low wing instead of a high wing. This is done to avoid placing the propellers in the wing wake in cruise and to provide a gap between the wing and horizontal stabilizer to reduce the induced drag increment. The effect at high angles of attack where the disturbed wing wake might impinge on the propellers will have to be carefully investigated. The low wing provides a clean landing gear installation which avoids the use of the pods, and as the gear and wing have moved to the aft end of the cylindrical part of the fuselage, an adequate scrape angle is obtained with a short landing gear. Changes to the interior arrangement to relocate the doors to the forward end of the fuselage are also required, as the aft wing location and the propellers make the aft located doors impractical.

The integrated effects of these changes on significant weight, drag, fuel, and cost factors are summarized in table 15. The gross takeoff weight of the aft engine configuration is 609 lb or 2.2% lighter than the baseline. This weight decrease is due to removal of the 950 lb. of acoustic treatment weight combined with a slight increase in wing weight (elimination of load relief provided by wing mounted engines) and a slight increase in tail weight (mounting of engines on tail and resulting increase in tail down load and torsion). The lift to drag ratio at the cruise conditions has decreased as well, as a result of the increased trim drag.

6.2.2.3 Aft engine with lifting tail and active controls: A logical progression from the aft engine configuration is one with a lifting tail. Incorporation of the lifting tail concept provides the potential for reducing the trim drag by reducing the lift requirement from the wing on a conventional configuration. With an up-load on the tail the wing C_L requirement is reduced, which reduces the aircraft induced drag. The configuration for this aircraft is depicted in figure 59 and is identical to the aft-engine configuration, except the wing is moved forward to ensure that the horizontal tail load is always in the up direction. Stability and control requirements are attained by using an active control system for both the wing and tail to provide the necessary control power for stall recovery, aircraft trim and power effects. The active control system is assumed to incorporate sufficient reliability such that the stability margins are always attained.

Sizing of the aft engine, lifting tail configuration was accomplished and the results are indicated in table 16.

6.2.2.4 Aft engine plus tandem wing plus active controls: The aft engine arrangements, described previously, suffer from a short tail arm resulting from the aft movement of the center of gravity. The tandem arrangement seeks to recover this penalty by using the full length of the fuselage to separate the two lifting surfaces. Each surface is then proportioned to carry its share of the load and a minimum of load redistribution is required to counter to c.g. shifts. The configuration using this approach is shown in figure 60. The aft wing has become the larger of the two, and as the wings have been proportioned for balance rather than stability, the requirement of a complete active control system is implied. A low wing position has been chosen for the forward surface to minimize the induced drag in cruise. However, a high wing would be attractive for the greater flexibility in ground access and in cabin arrangement. A final choice will depend on a detailed study of the effect of the forward wing wake on the aft wing and on the propulsion system.

The wings have been sized and the induced drag evaluated by the Lockheed VORLAX procedure which accounts for the relative positions of the wing in plan and elevation and for the sizes of the fuselages and the wings. To provide the same loading capability as the baseline airplane, a c.g. travel of 20 inches total is provided by the following procedure:

- The same wing plan form used for the baseline airplane is preserved for each of the wings of the tandem, that is each wing has an aspect ratio of 12 and a taper ratio of 0.3.

- The wing areas are chosen to give each wing the same wing loading with a c.g. in the mid position.

- The effect of the downwash of the forward wing on the aft wing in the cruise position is evaluated by the VORLAX technique as follows. With the c.g. in the mid position, and the flaps in the up cruise position, the incidence of the forward wing is set to develop the proper lift coefficient with the fuselage reference line level and the incidence of the aft wing is determined to maintain the trim. The results of these calculations are shown in figure 61. The upper part of the figure shows the lift coefficient on each wing referred to its own area. The cruise points are marked by the vertical lines. The lower part of the figure shows the incidence required of the aft wing to maintain trim at various C_{LS}. As the wings are to be fixed in position on the fuselage, a mean angle of incidence for each is selected, and trim is acheived in practice by adjusting the flaps on the two wings. Notice that the lift coefficient for the total airplane, which is referred to the total wing area, is appreciably greater than the lift coefficient of each wing working separately. The difference represents the sizeable contribution of the relatively large fuselage. The induced drag of the resulting configuration is shown on figure 62.

- The VORLAX technique is then applied to the landing condition with a forward c.g. With the c.g. in the maximum forward position, the flap on the forward wing is set at 30 degrees, and the deflection required of the flap on the aft wing for trim is determined. The results are shown in figure 63, which gives the lift coefficient on each wing, the airplane lift coefficient, and the position of the aft flap as a function of angle of attack on the fuselage reference line. As in cruise, the fuselage

CHARACTERISTICS	WING	HORIZONTAL TAIL	VERTICAL (EACH)
AREA m² (ft²)	[illegible]	4.7? (59.??)	[illegible]
ASPECT RATIO	2	2	[illegible]
SPAN	[illegible]	[illegible] (43.66)	2.26 (7.43)
ROOT CHORD	1.43 (4.70)	[illegible]	1.97 (6.48)
TIP CHORD	.43 (1.4?)	[illegible]	.69 (2.27)
TAPER RATIO	0.30	0.30	0.35
MAC	1.14 (3.74)	[illegible]	1.44 (4.7?)
SWEEP RAD (DEG)	.063 (3.6)	.063 (3.60)	.6 (35)
T/C ROOT (%)	16.8	16.8	10
T/C TIP (%)	13.5	13.5	10

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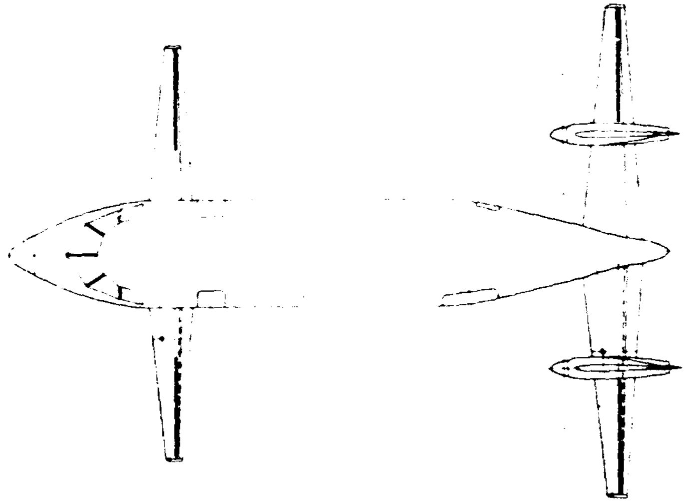

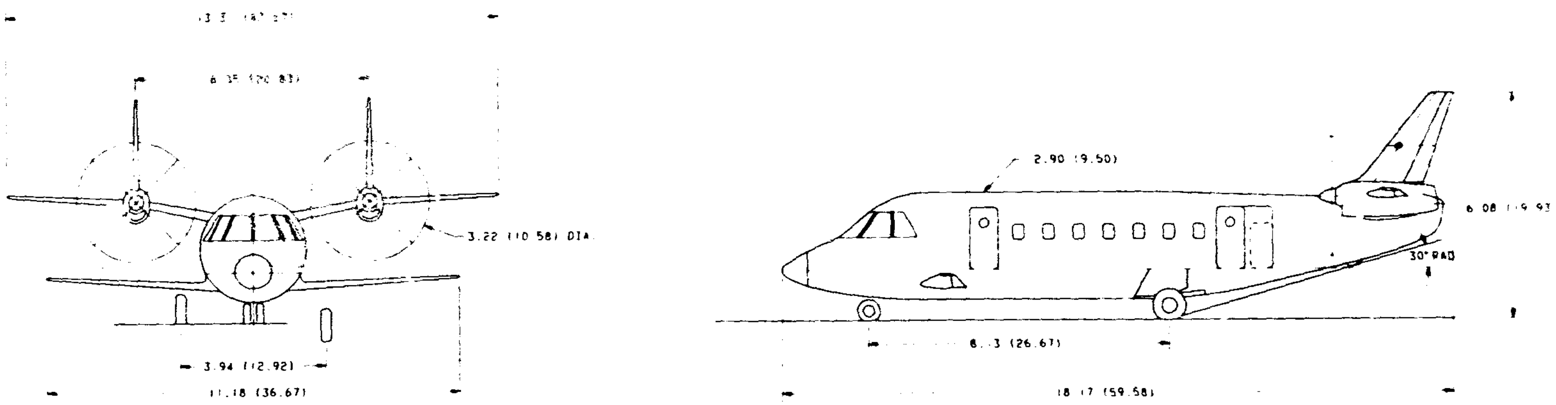

Figure 60. - 30-passenger tandem wing configuration.

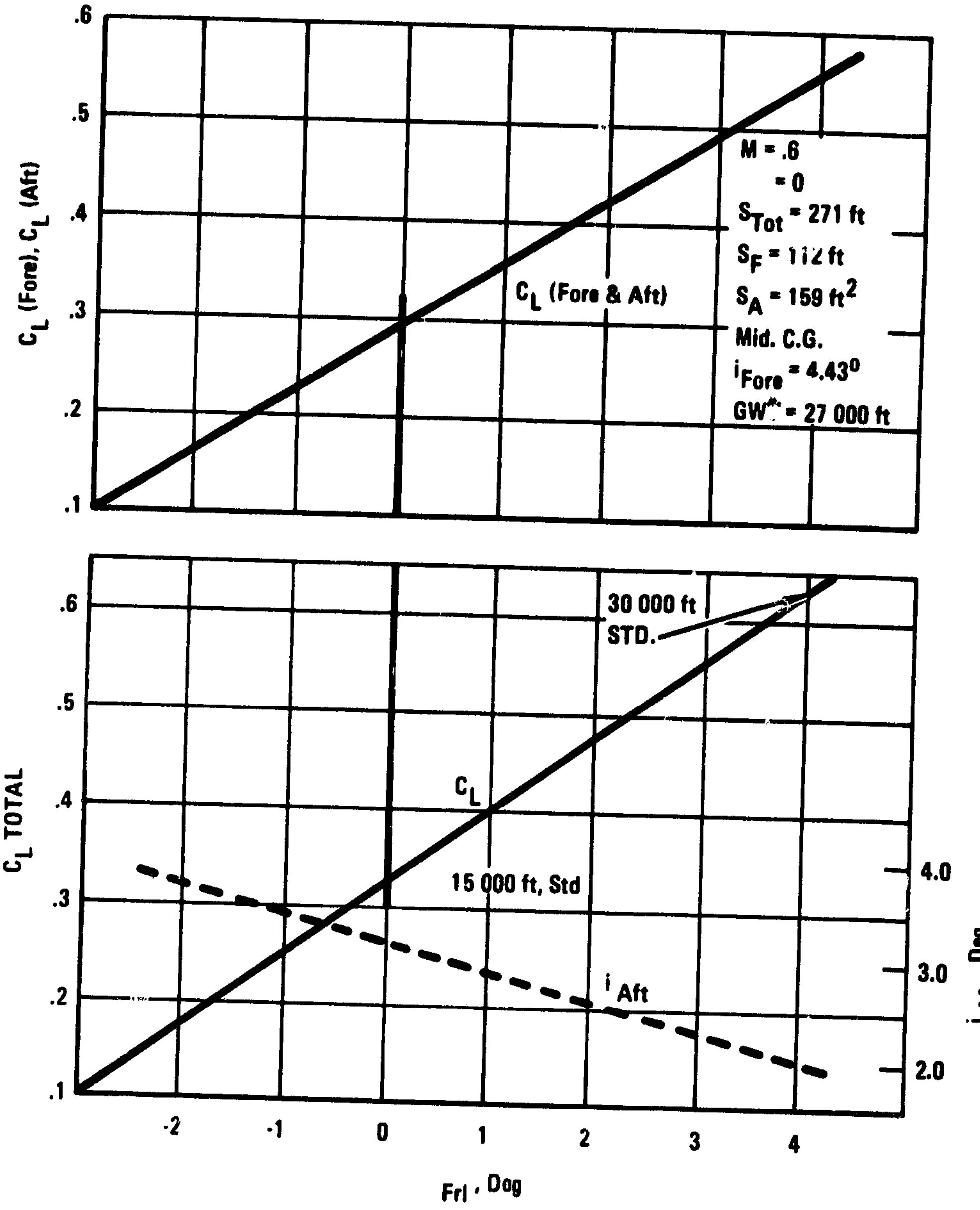

Figure 61. - Tandem wing C_L and lift sharing trimmed.

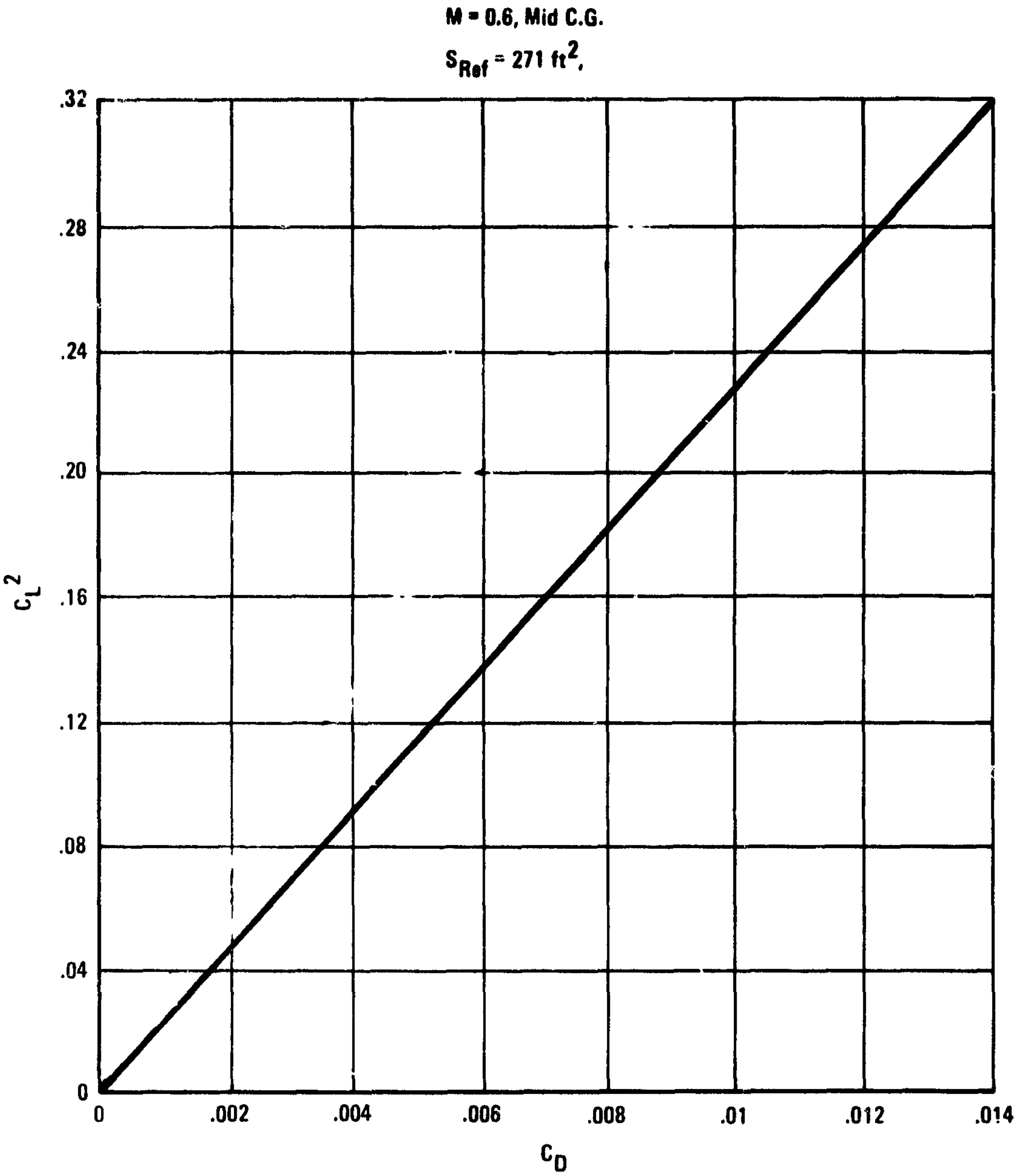

Figure 62. - Tandem wing trimmed C_L^2 VS C_D.

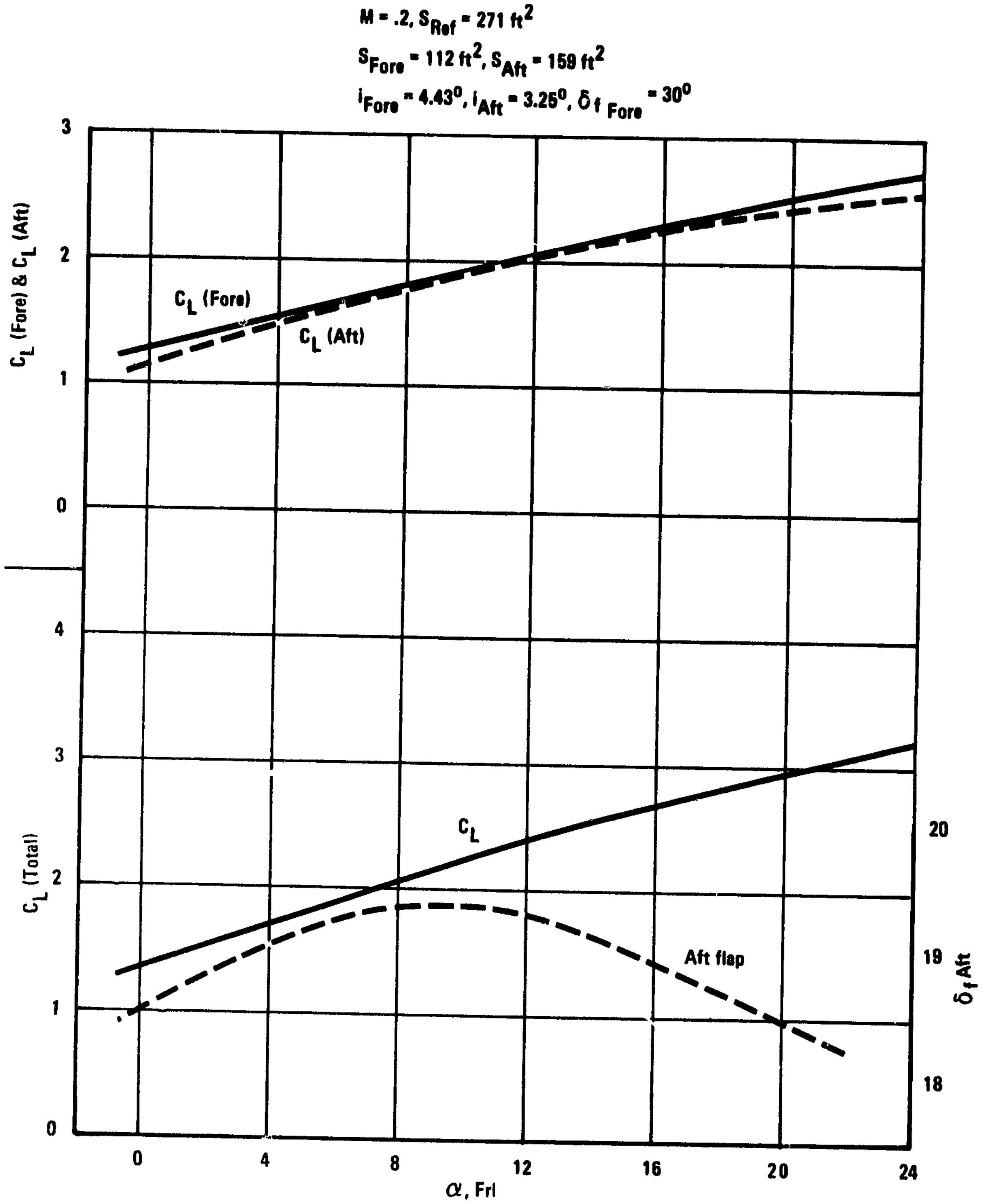

Figure 63. - Tandem wing trimmed data landing config., fwd c.g., lift sharing.

provides an appreciable increment in lift. The induced drag in this landing configuration is shown on figure 64.

- Landing with an aft c.g. is treated in a similar manner, the aft flap is fixed at its high lift positon of 30 degrees and the flap on the forward wing adjusted for trim as indicated in figure 65.

Using the airplane lift coefficients obtained in the above procedure, the wings are sized to meet the required stall speed of 93 knots at a $C_{L_{max}}$ of 3.5 and the induced drag used in the ASSET program is matched to the induced drag calculated by VORLAX.

As the baseline airplane has the same fuselage as the tandem, one would expect the baseline to also have appreciable fuselage lift. To insure that a valid comparison is obtained, the VORLAX technique is applied to the baseline and the results are shown in figures 66 through 71. These calculations show relatively small differences between the wing C_L and the airplane C_L in both cruise and landing; and, as expected, the baseline has appreciably less induced drag in cruise. The induced drag increment of the tandem over the baseline used in the ASSET program is derived from these comparative calculations.

As the engines-out take-off is the critical performance requirement for the 30 passenger airplane a matrix of wing loadings and thrust-to-weight values was run on ASSET to select the minimum DOC combination. Induced drag and weight being major factors, the combination of a graphite wing of aspect ratio 14 was found to be slightly better than the aluminum wing with an aspect ratio of 12. The results are summarized in figure 72. As shown, those combinations of low T/W and high W/S which have lower DOC's than the baseline do not meet the 4000 foot engine-out take off requirement. Only the airplane with the same wing loading as the baseline meets the takeoff requirement and approaches the baseline DOC; the concept appears better suited to types which are not span-critical, e.g. executive or corporate aircraft.

6.3 Advanced Propulsion

Concurrent with this study effort, advanced technology propulsion system studies are being accomplished under direction of the NASA-Lewis Research Center as a part of the overall STAT program. These efforts are being accomplished by Detroit Diesel Allison, Garrett-AiResearch, General Electric, and Hamilton Standard and are concerned with the application of advanced technologies to engine cycles for the post 1985 time frame as well as technology advances for propellers in this same time frame. At initiation of this study by Lockheed, information regarding baseline aircraft configurations, performance characteristics, and sensitivity factors were transmitted to each of the above participants. Unfortunately, the progress of the engine studies has not been sufficient to be useful for this study, and so an assessment of advanced propulsion can be made only in terms of potential improvements projected by the engine companies and Hamilton Standard for the post 1985 time frame.

6.3.1 Engine cycles. - During the course of the NASA Lewis STAT propulsion technology improvement studies it is expected that component efficiencies, new

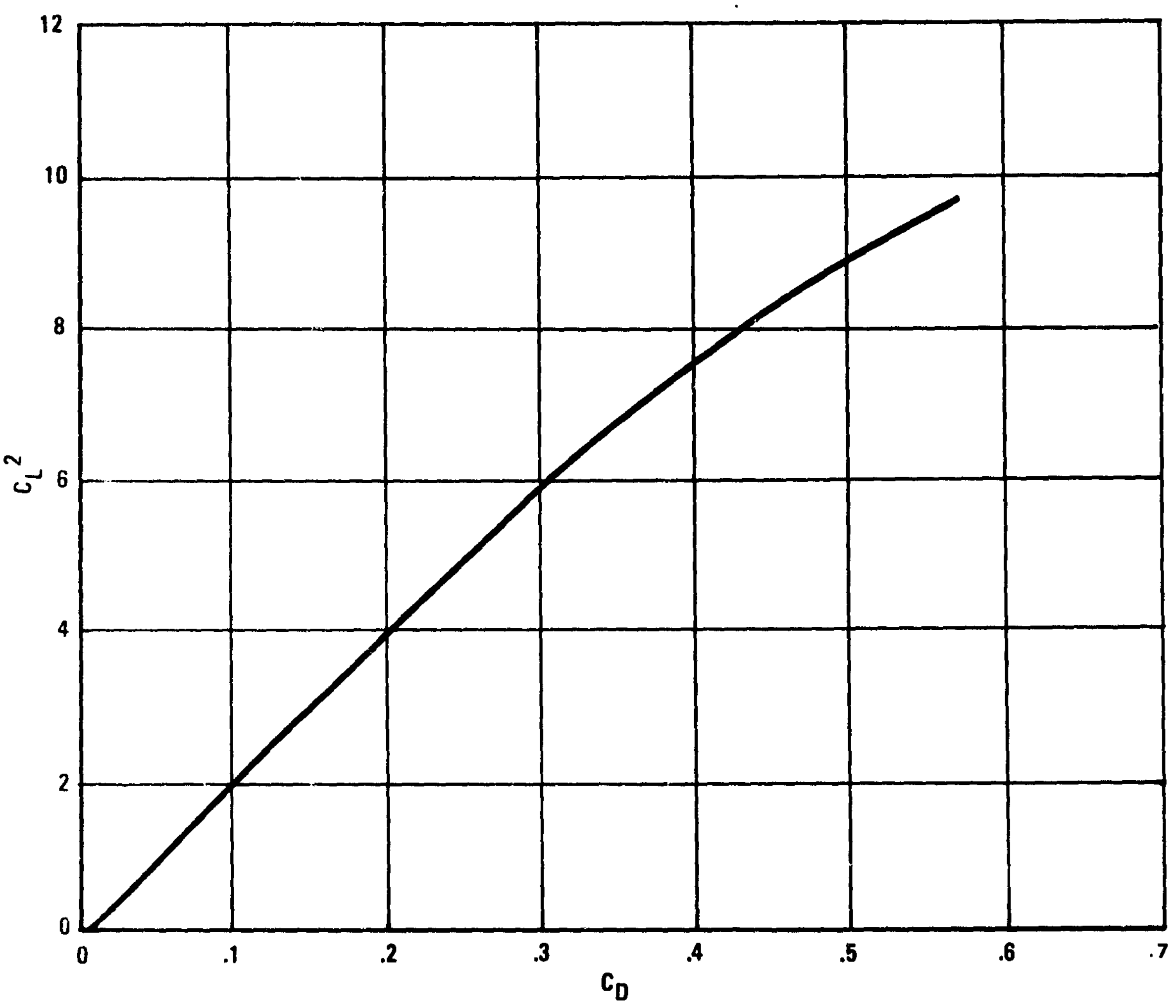

Figure 64. - Tandem wing trimmed C_L^2 VS C_D landing config., fwd c.g. $M = 0.2$, $S_{Ref} = 271\ ft^2$.

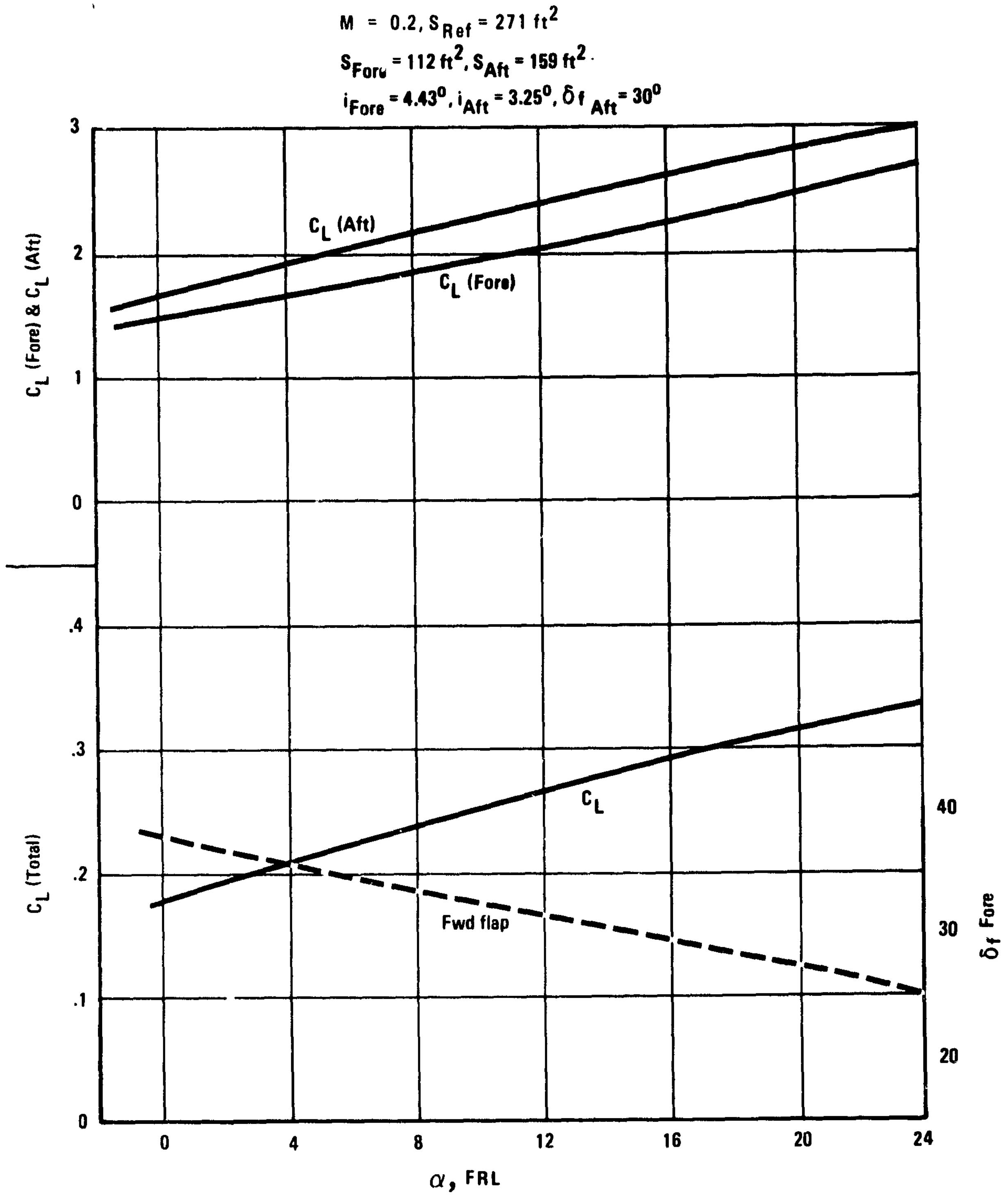

Figure 65. - Tandem wing trimmed data landing config., aft c.g., lift sharing.

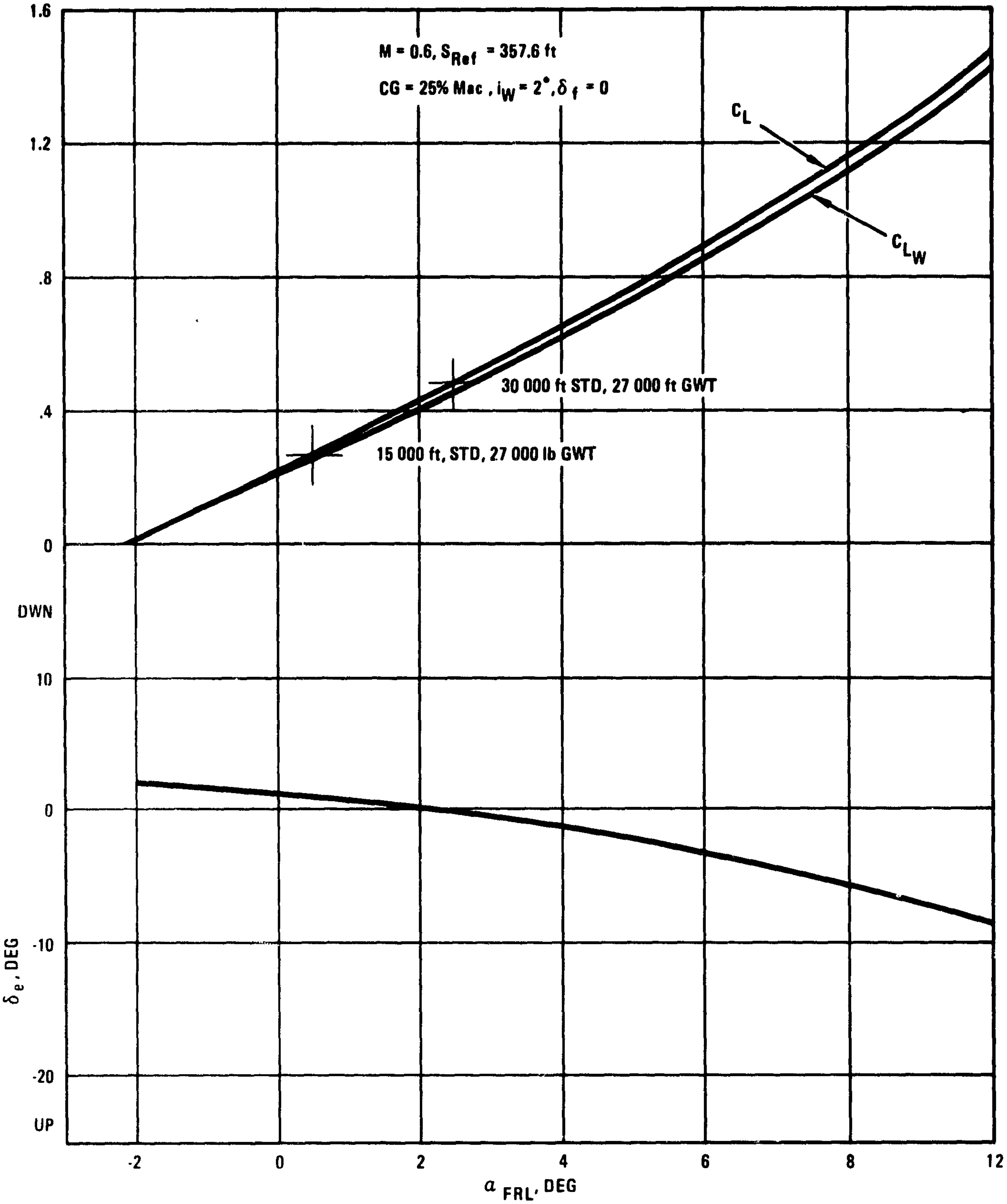

Figure 66. - Baseline 30 PAX trimmed cruise lift vs α.

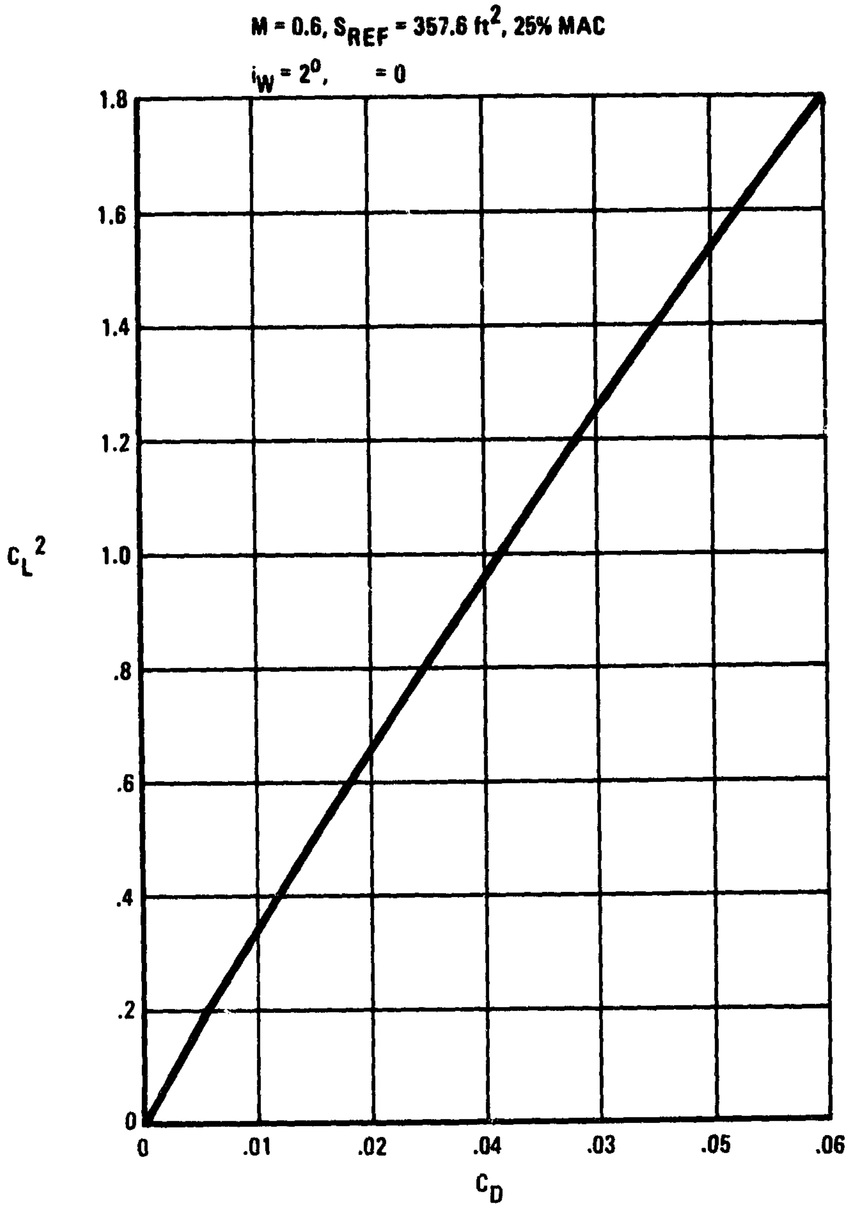

Figure 67. - Baseline 30 PAX trimmed cruise C_L^2 vs. C_D.

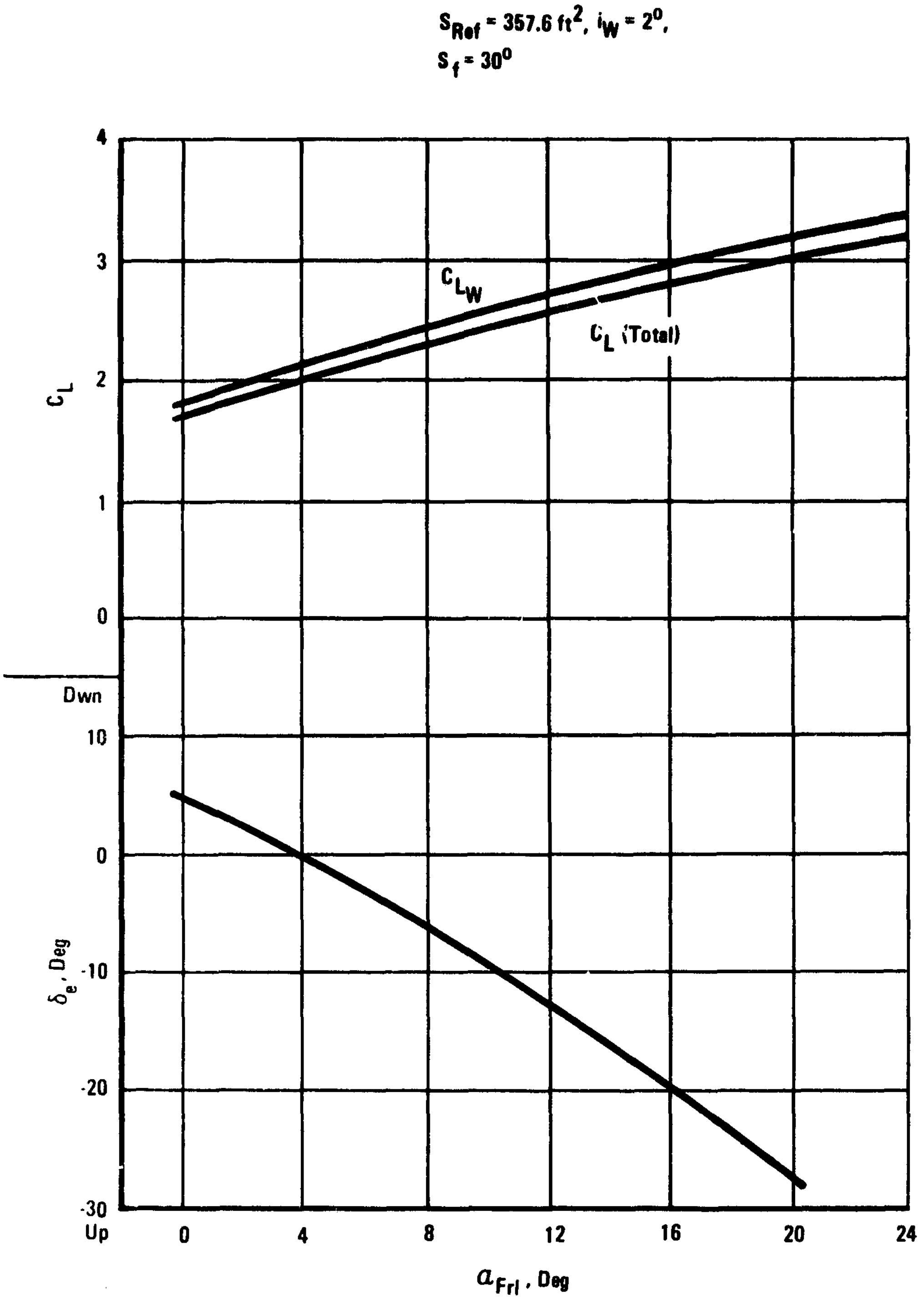

Figure 68. - Baseline 30 PAX landing config., trimmed C_L vs α data 15% mac c.g. M = 0.2.

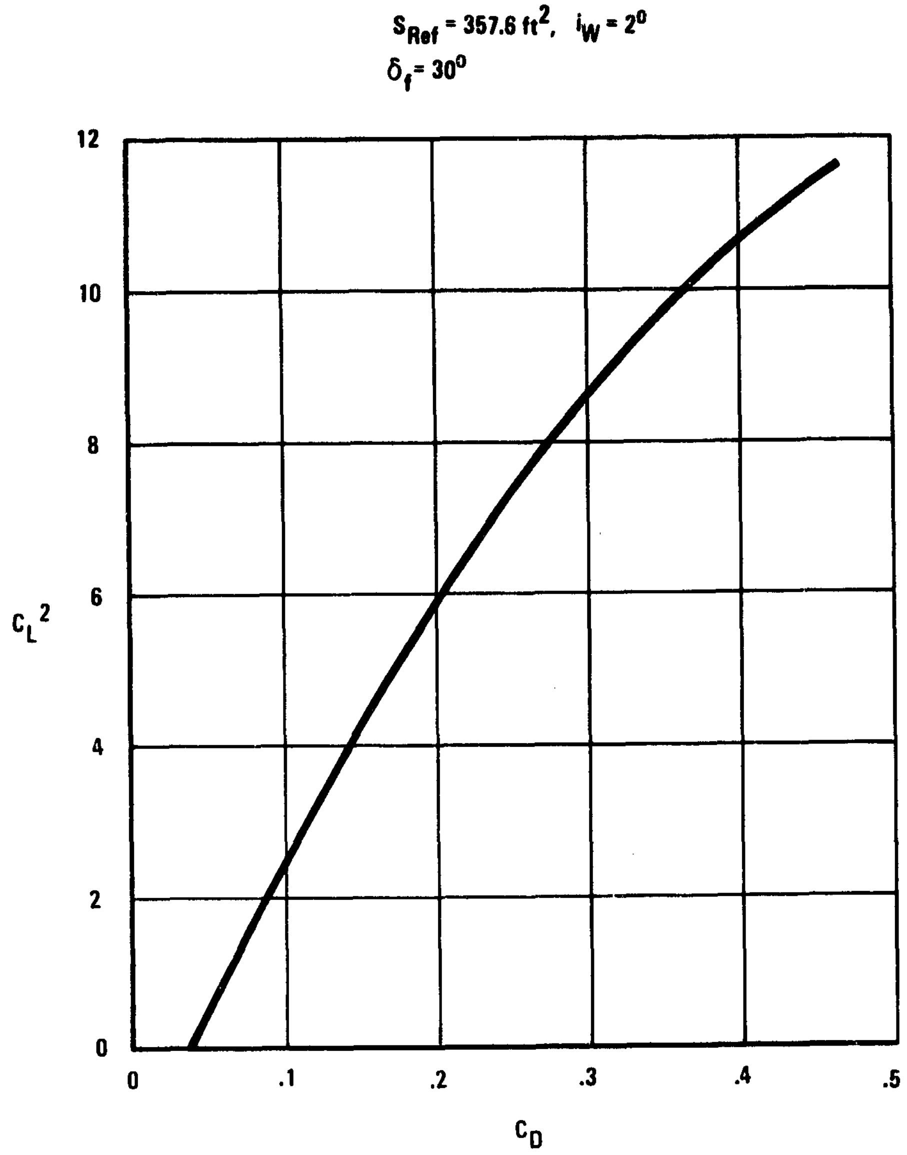

Figure 69. - Baseline 30 PAX landing config., trimmed C_L^2 vs C_D c.g. = 15% mac M = 0.2.

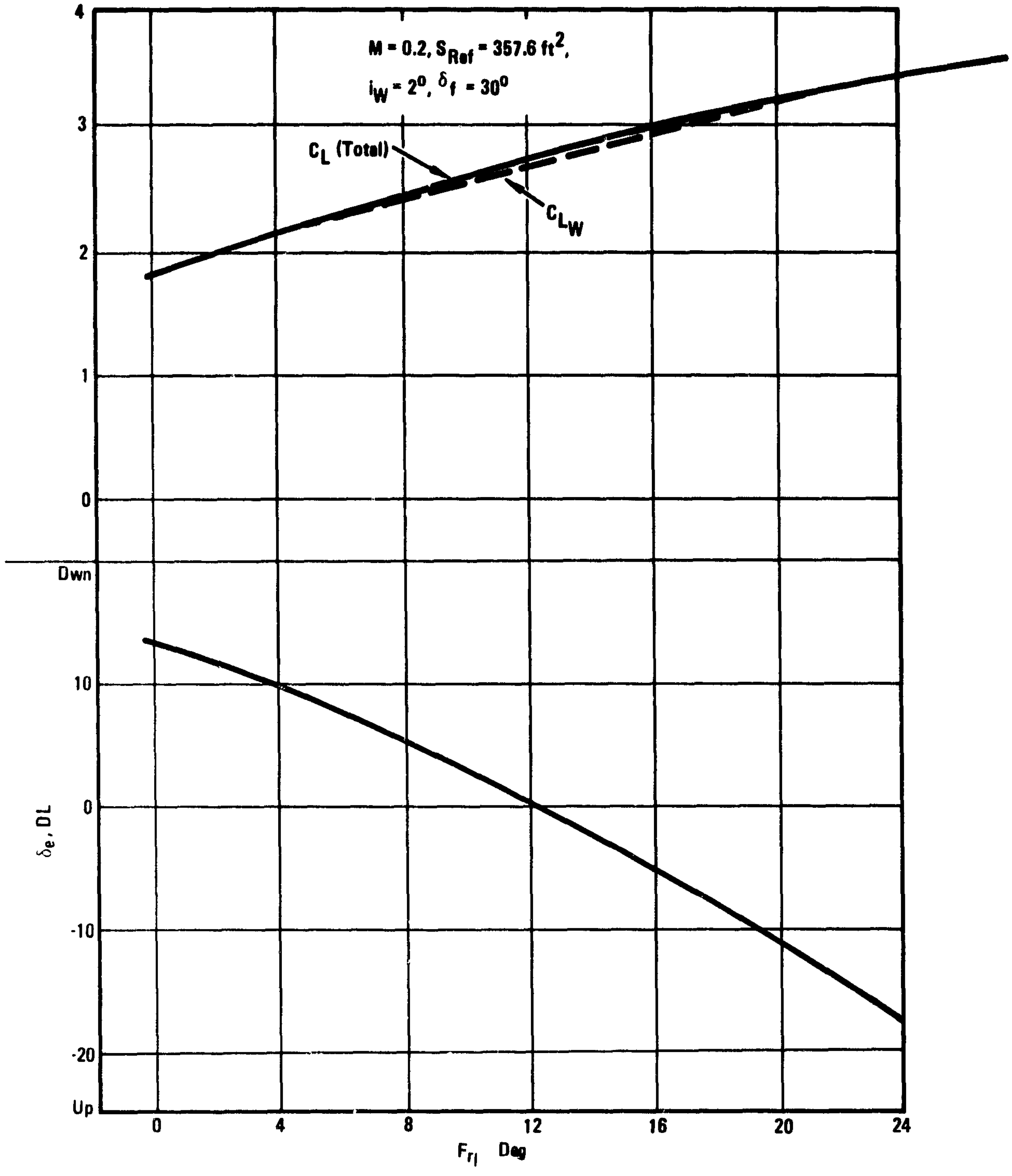

Figure 70.- Baseline 30 PAX landing config., trimmed C_L vs data 40% mac c.g.

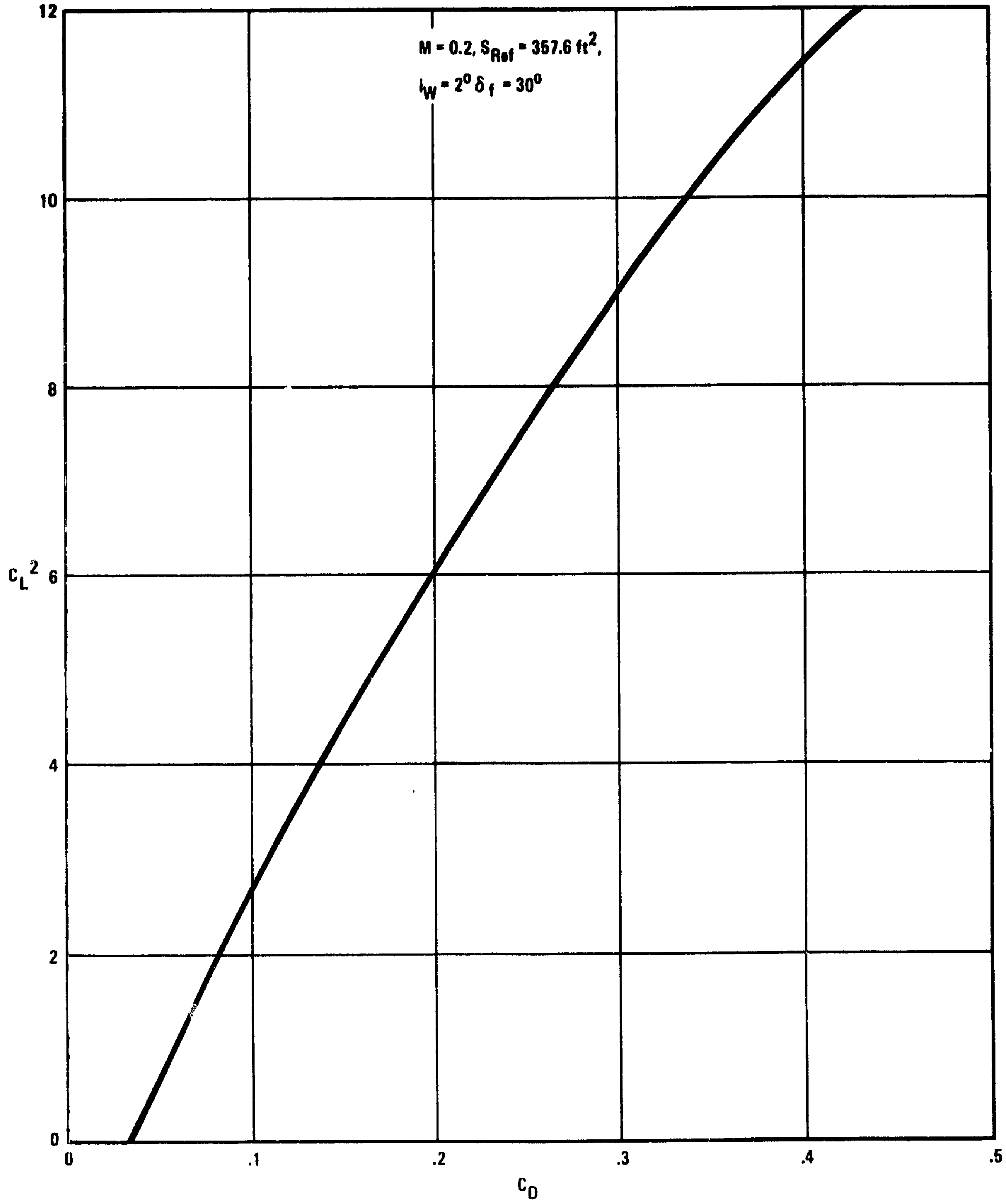

Figure 71. - Baseline 30 PAX landing config., trimmed C_L^2 vs C_D c.g. = 40% mac.

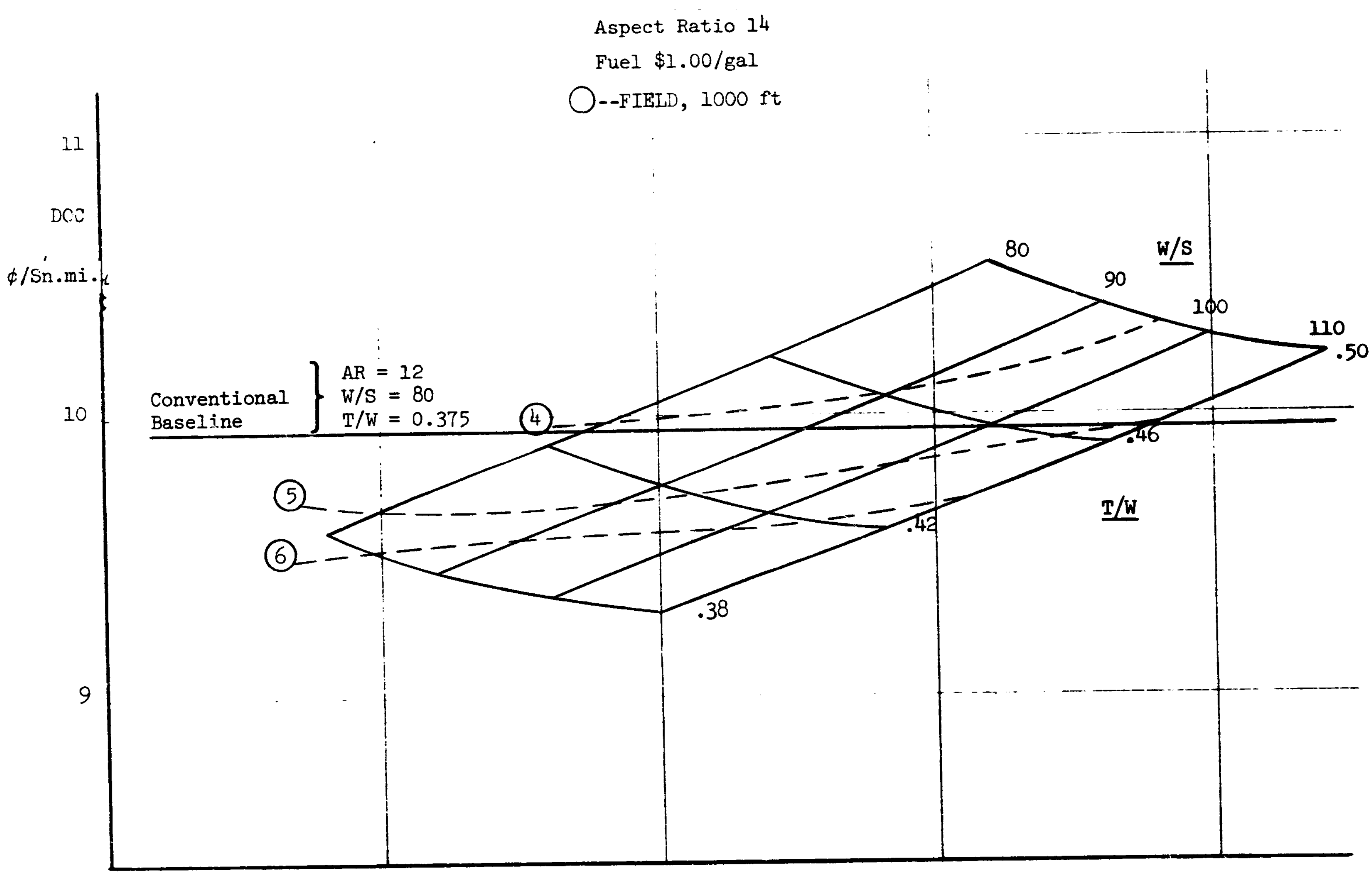

Figure 72. - Tandem DOC 100 n.mi. graphite wing.

or improved materials, and higher overall pressure ratios and turbine inlet temperatures will be evaluated to assess the impact on engine SFC, size, weight, acquisition cost, and maintenance cost. General Electric has discussed several different cycles of investigation during its STAT propulsion studies. Permutations of the following characteristics are being investigated. Overall pressure ratios from 11.5 to 30; turbine inlet temperatures from 2250 to 2500^{o}F; various configurations such as conventional turboshaft, boosted turboshaft, 3-rotor turboshaft and turbofan; single- and two-stage high pressure turbines.

Although the details of the engine cycle studies being conducted by Allison, Airesearch, and General Electric are not yet completed, it is expected that cycle variations similar to those being included in the NASA-Lewis-sponsored Energy Efficient Engine (E^3) program will apply. The E^3 engine cycles incorporate improvements in component efficiencies, use of new or improved materials for lighter weight/higher strength and increased temperature capability, increased pressures, and improved performance retention. These technology improvements are expected to be demonstrated by 1985, and assessment of the benefits shows that approximately 12 to 15% reduction in SFC is available

In addition to the expected performance improvements, engine maintenance and reliability are expected to improve. Recent studies conducted by Allison addressed the maintenance problems which have been inherent with earlier turboprop engines and also investigated design considerations to utilized for future turboprops, so that maintenance cost would be at least comparable to current turbofan engines. It is expected that these concepts will be included in preliminary design evaluations of advanced technology STAT propulsion.

Airesearch has supplied preliminary information concerning its expected technology improvements for both a 1985 derivative engine and a 1990 advanced engine, as shown in table 17. It is recognized that these projections will probably change during the course of the STAT propulsion study; however, the assessment of the aircraft benefits available with advanced engine cycles are accomplished by resizing the 30 passenger and 50 passenger aircraft to include these improvement factors.

6.3.2 Propeller - As previously described in Section 5.9.1, the propeller selection for the 30 passenger, M 0.60, and 50 passenger, M 0.70 aircraft was the Electra/P-3 propeller system. The propeller systems used on current commuter type of aircraft are quite different in that they are characterized by low activity factor, high camber, and low number of blades for good low speed performance and low weight; however, these systems are limited to M 0.3 to M 0.4 due to significant compressibility losses at higher speed and are therefore not applicable to the short haul aircraft under study.

Hamilton Standard is currently in the process of defining those advanced technologies which would be applicable for an improved propeller for the post-1985 time frame. Current analysis being conducted by Hamilton Standard for the NASA STAT program is concerned with propeller improvements for the lower speed (250 knot) aircraft with the result that these configurations will probably be

TABLE 17. - STAT TECHNOLOGY IMPROVEMENT FACTORS

Technology Improvement Factors		% Of Baseline Value	
		1985 Derivative Engine	1990 Advanced Engine
SHP	Shaft Horsepower	--	--
SFC	Specific Fuel Consumption at Normal Cruise, 10 000 ft, 260 kts, ISA	92	80
$/HP	Acquisition cost/hp	100	83
MC/FH	Maintenance cost/flight hour	90	50
LB/HP	Weight/shaft horsepower	95	85
GGD	Gas generator diameter, in.	92	92
GBD*	Gearbox diameter, in.	100	85
L	Engine length, in.	90	90

very similar to Hamilton Standard current Model 14RF propeller. Since the short-haul aircraft selected by Lockheed for this study encompass higher cruise speed capabilities, Hamilton Standard was queried as to applicable advanced propeller configurations for the M 0.60 and M 0.70 aircraft.

30-passenger, M 0.60 aircraft: Advanced propeller configuration is assumed to be a 6-bladed design, similar to the 6-bladed propfan design previously supplied as part of the RECAT studies.

50-passenger, M 0.70 aircraft: Ten-bladed propfan design with swept blades, similar to the 10-bladed propfan previously supplied during the RECAT studies.

Quantitative results were not supplied for these propeller designs for the short-haul aircraft, however it is expected that performance levels and noise characteristics (near field and far field) will be similar to those values predicted for the propfan designs and will therefore enhance both the 30 passenger and 50 passenger short-haul aircraft included in this study. Subsequent to definition of improved propeller characteristics by Hamilton Standard for the NASA-LERC STAT program, quantitative benefits for each of the aircraft can be established.

6.3.3 Advanced propulsion benefits. - Assessment of the aircraft benefits by incorporation of advanced propulsion was accomplished by use of the following assumptions (note: this assessment may change subsequent to completion of the advanced propulsion studies being conducted by Allison, AiResearch, General Electric and Hamilton Standard):

- Engine Cycle. - Reduce SFC, cost (aquisition and maintenance), weight and envelope dimensions as shown previously in table 17.

- Propeller. - No quantification of benefits is included, since optimization studies of propeller power loading versus efficiency versus weight were not accomplished.

It is expected that incorporation of the propfan (either 6-bladed or 10-bladed) will result in 2 to 3% improvement in efficiency at M 0.6 and a 7 to 9% improvement at M 0.7, as indicated in figure 73, combined with higher power loading (smaller propeller diameter), and less installed weight. In addition, a new propeller will include the fiberglass spar-shell contruction, in lieu of aluminum as currently used, with an additional weight and cost saving expected.

Assessment of the potential benefits with advanced engine cycles are depicted in table 18 and indicate that significent advantages in DOC can be attained by the projected reductions in SFC, engine aquisition cost, and engine maintenance cost.

6.4 High Lift Systems

As cruise speeds have increased, transport wing loadings have also been driven up, and the baseline aircraft of this study follow this trend in response to the M 0.60 and 0.70 requirements. The effect on wing area, and thus on friction drag, is illustrated in figure 74 for the 28,600 pound 30-passenger airplane. As the design point is near the "knee" it is evident that the realization of worthwhile gains by developing improved high lift devices is difficult; however, the combination of advanced aerodynamics and structural techniques offers some promising answers. These are explained in this section, and the limitations improved by the mechanical and configuration design problems implied are defined. As the configuration problems are largely the induced drag-wing weight trades introduced by shrinking span or growing aspect ratio, the effects of using increased area, which alleviate this problem are briefly reviewed.

6.4.1 Conventional high lift devices. - Typical high lift devices, and their respective C_{Lmax} attainable, and the wing characteristics resulting from their use are summarized in figure 75 for the 30 passsenger airplane. To maintain take-off performance, the span is held constant and the reduced aspect ratio is used to reduce wing weight. A minimum aspect ratio of 7.5 is used, as the induced drag influence on fuel at 600 n.mi. becomes a factor at the lower wing loadings. The effects of wetted area, induced drag, and wing weight are traded off by use of the sensitivities of Section 5, and the results summarized in figure 76. While some improvement in DOC is indicated for systems slightly less complex than that selected for the baseline, the fuel penalties at the design cruise speeds are more significant. A similar study for the 50 passenger airplane is shown in figure 77.

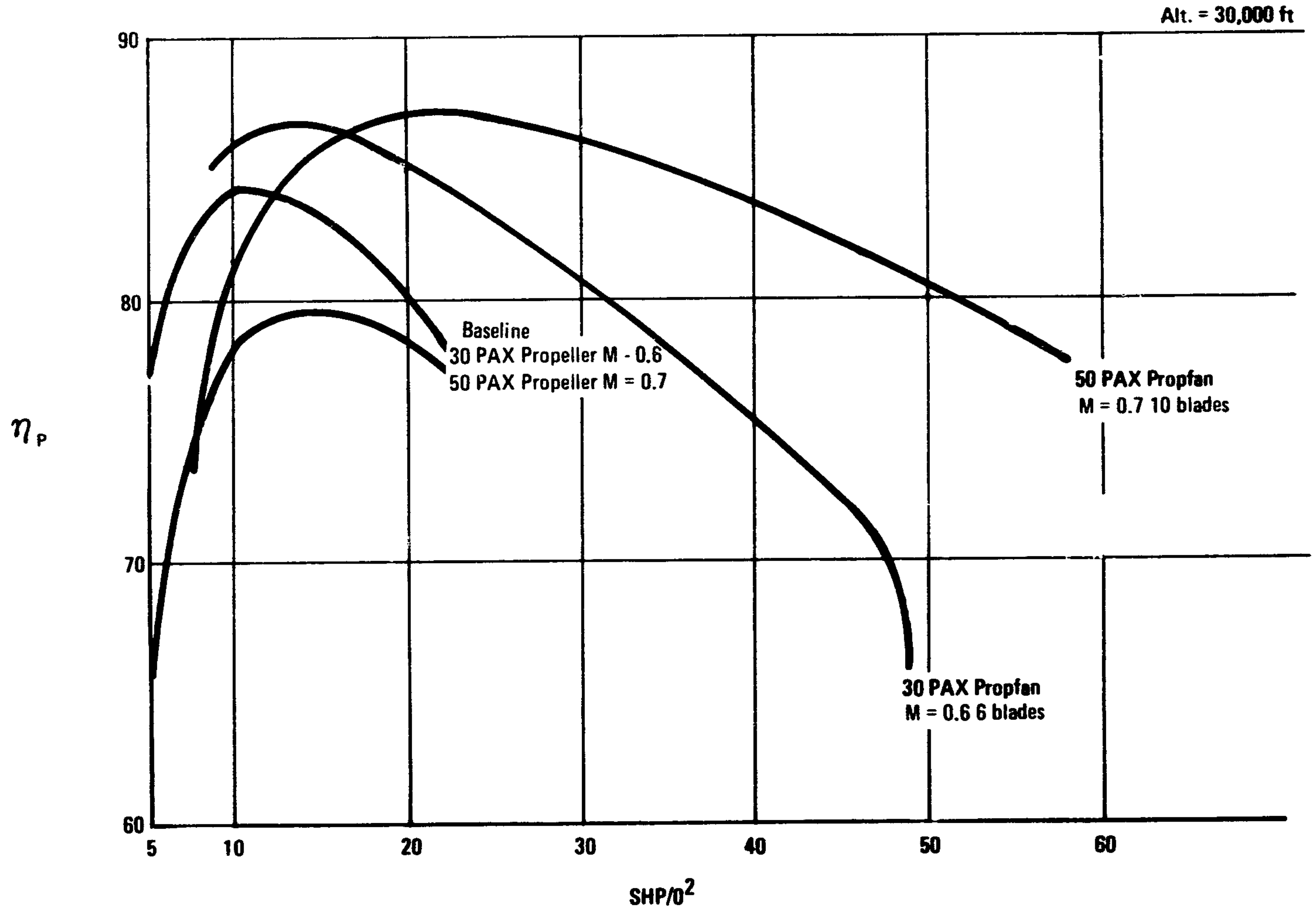

Figure 73. - Efficiency vs disc loading for baseline propellers and propfans.

TABLE 18. - ADVANCED PROPULSION BENEFITS - 30 PASSENGER

	Baseline	Advanced Propulsion	Δ~%
W/S	80	80	-
T/W	0.379	0.379	-
AR	12	12	-
Takeoff gross wt	28 606	27 248	- 4.8%
Operating empty wt	19 499	18 820	- 3.5%
Wing area (ft^2)	358	341	- 4.7%
Wing span (ft)	65.5	63.9	- 2.4%
SHP/engine	2403	2289	- 4.7%
Block fuel - 600 n.mi.	2146	1679	-21.8%
Block fuel - 100 n.mi.	671	649	- 3.3%
DOC ($1.00/gal) - 600 n.mi.	4.977	4.473	-10.1%
DOC ($1.00/gal) - 100 n.mi.	9.946	9.592	- 4.6%
TOFL (all engine)	3346	3352	-
TOFL (eng. out)	3942	4000	-
LFL	3938	3937	-
Cruise L/D - 600 n.mi.	15.47	15.03	-
Cruise L/D - 100 n.mi.	10.54	10.53	-
Aircraft Flyaway Cost	$4.14M	$3.94	- 4.8%

Includes advanced engine and improved propeller.

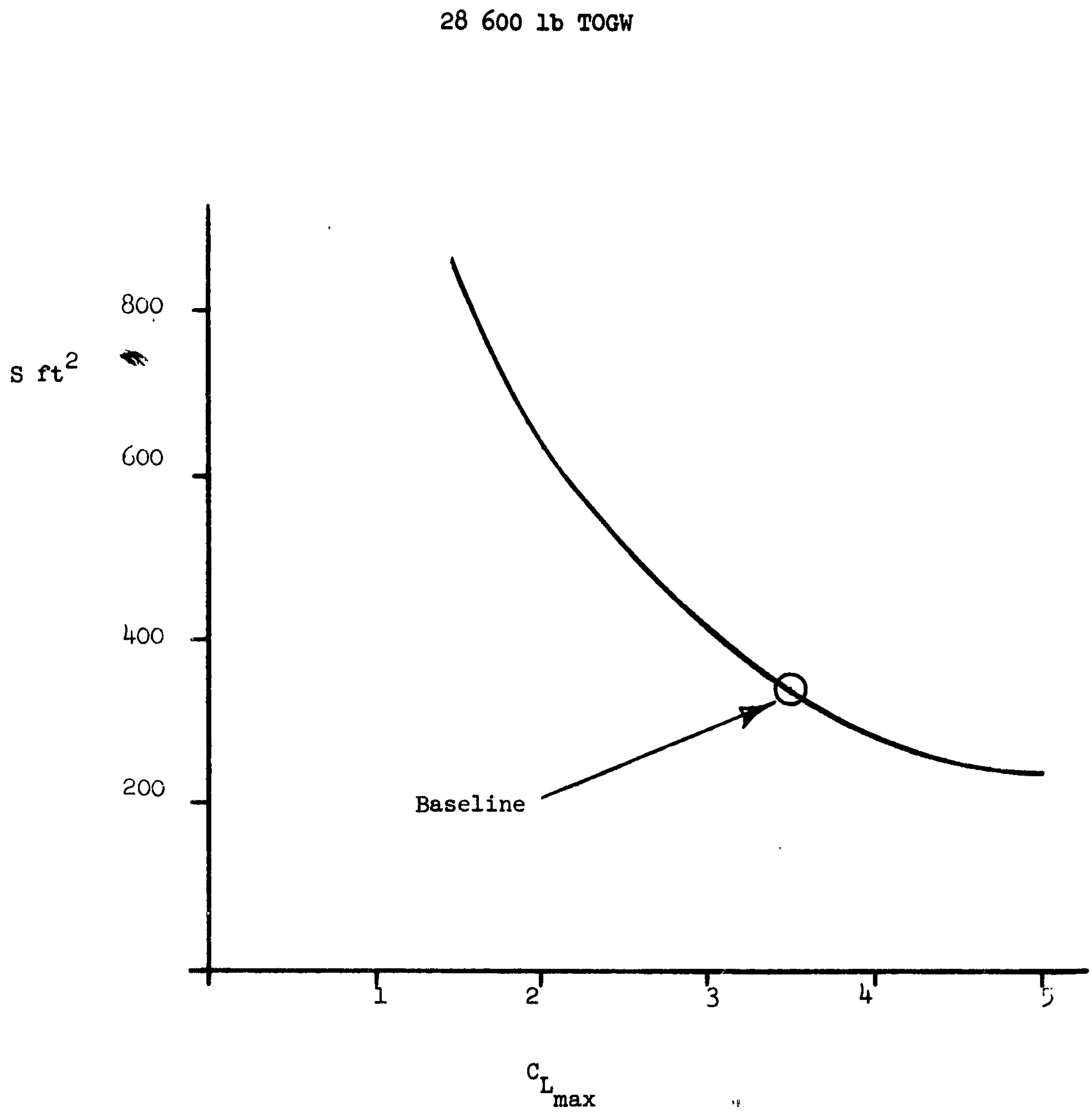

Figure 74. - Wing area vs $C_{L_{max}}$.

		Single Slot Flap	Double Slot Flap	Fowler Flap	Fowler & Slat Baseline
High Lift Basic Data	$C_{L_{max}}$	2.0	2.6	3.1	3.5
	CHORD %: SLAT	-	-	-	-
	FLAP	30	30	30	
	SPAN %: SLAT	-	-	-	87
	FLAP	70	70	82	82
	UNIT WT. PSF	3.0	4.5	5.55	5.55
30 PAX	WING AREA ft^2	626	482	404	358
	AREA ft^2: SLAT	-	-	-	47
	FLAP	131	101	99	88
	SPAN ft	68.5	65.5	65.5	65.5
	ASPECT RATIO	7.5	8.9	10.6	12.0
	WING WT. lb	1934	1847	2010	2304
50 PAX	WING AREA ft^2	882	679	569	504
	AREA ft^2: SLAT	-	-	-	66
	FLAP	185	142	140	124
	SPAN ft	81.3	71.4	71.0	71.0
	ASPECT RATIO	7.5	7.5	8.9	10.0
	WING wt lb	2896	2376	2554	2906

Figure 75. - Conventional high lift wings.

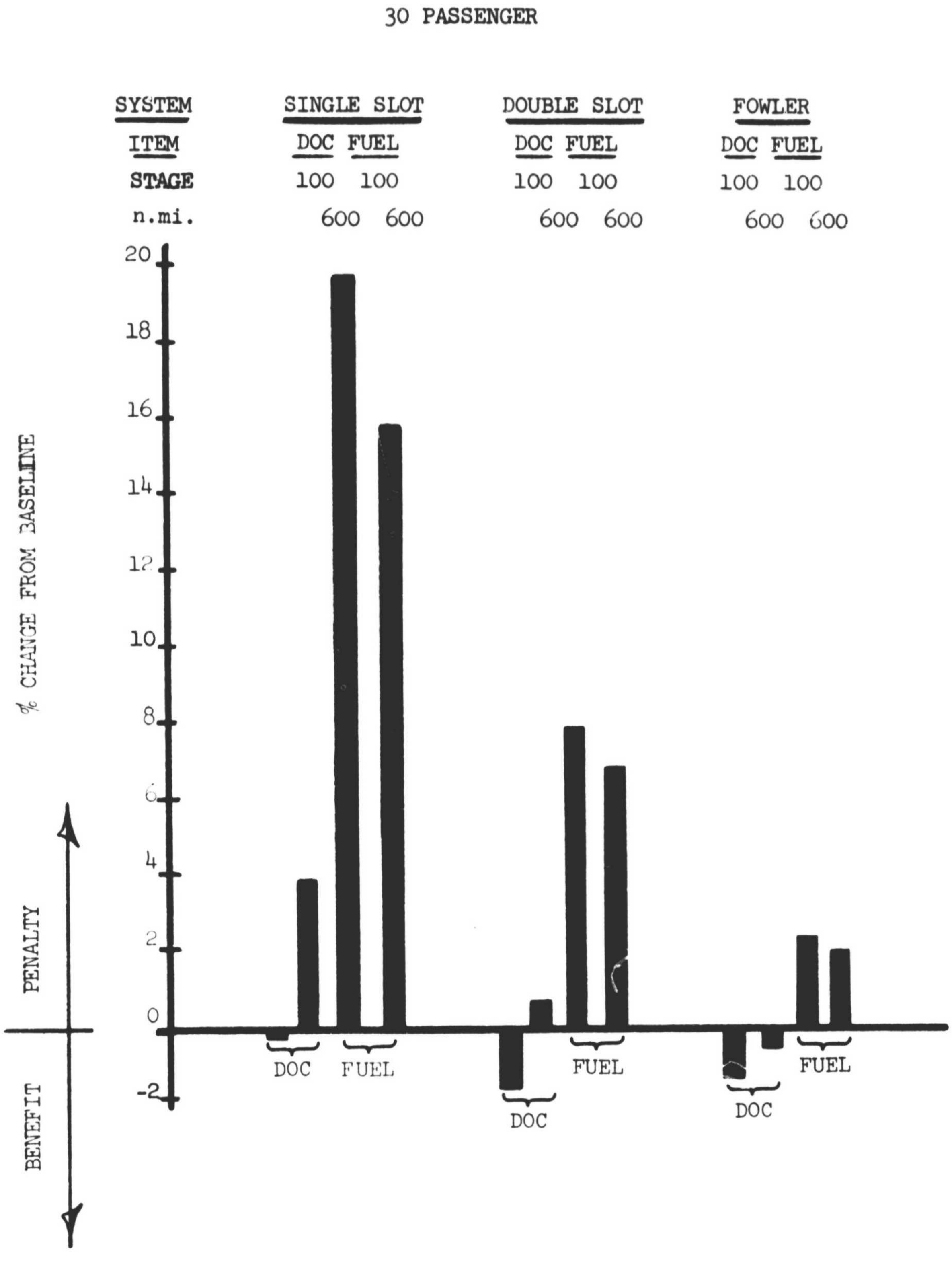

Figure 76. - Conventional high lift effects.

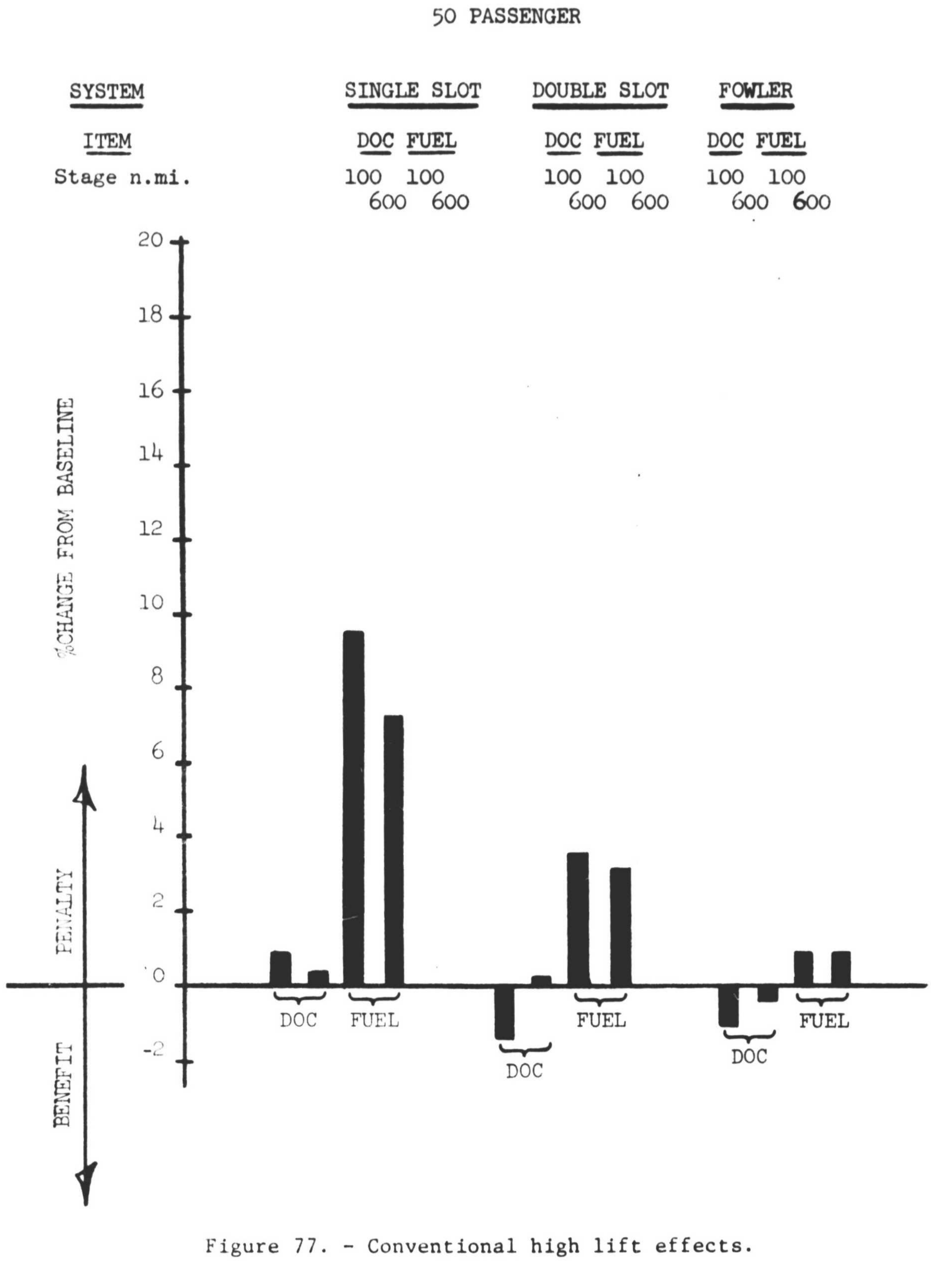

Figure 77. - Conventional high lift effects.

6.4.2 Advanced high lift devices. - The combination of advanced aerodynamics and material offers potential improvements in the C_{Lmax} available and in the reduction of weight and complexity of the high lift devices. Several variants are examined in this section to evaluate the tradeoffs of aerodynamic refinement and mechanical complexity at wing loadings over 80 lb/ft^2 for the design mission. While details are proprietary, all of the concepts feature simple links rather than tracks and rollers, have very smooth upper surfaces, and have a form of variable camber to achieve the combination of cruise and low speed performance. Just as the conventional devices can use lower aspect ratios to save weight yet maintain low induced drag, the advanced systems are driven to higher aspect ratios, and the use of composite primary structure as well as for some members of the variable camber systems is considered. The characteristics of each concept and the results of the ASSET evaluation are presented below.

CONCEPT 1: This concept employs an extreme change in camber to achieve a C_{Lmax} of 5.0 while preserving the baseline contour for cruise. This is the highest C_{Lmax} considered, and also the heaviest.

CONCEPT 2: This concept uses the same basic principle as concept 1, but uses a thicker section to simplify the high lift mechanization and to reduce the weight penalty inherent in the higher aspect ratios. The thickness ratio of 21% chosen for this comparison (compared to 16% for the baseline) imposes a cruise drag penalty, and the C_{Lmax} is reduced to 4.5.

CONCEPT 3: This concept uses an entirely diffent mechanizaton than concepts 1 and 2 and is considerably simpler and lighter, however a C_{Lmax} of 4.0 is anticipated.

The concepts described above show the potential for significant benefits to the small, short-haul aircraft with short-field performance requirements. Further analyses to assess the benefits available by incorporation of these high-lift devices into the baseline aircraft is proceeding and the results will be included in the final submittal of this study report.

6.5 Advanced Systems

The forcing functions in this type of aircraft are the economic and ecological factors. These two basic considerations dictate the selection of high-energy-efficient engines and the selection of a secondary power system (SPS) which has minimum impact on the airplanes fuel consumption, engine thrust loss and other engine installation (drag) losses. It is also implicit in the economic consideration, that such an SPS must have high reliability, low-maintainability costs and, most of all, the viability to meet the diverse power demands of the short-haul transport.

From preliminary studies it is evident that one of the major gains to be made in the energy area is to remove the "customer" bleed-air demands on the engine and return it to its basic role as a propulsor. Our proposed method of achieving this is to use an electric-generator as the sole source of (mechanical) power extraction on each engine. Implied in this also is the fact that a large generator would be necessary to power the all-electric airplane. Typically, the cabin pressurization requirement alone can be in the range of 50 to 75 hp. Added to this, we have the typical loads of deicing, galley, lighting, landing gear, miscellaneous actuator/motor loads etc.

The advanced aircraft power-generation system might therefore require generators in the 75 to 120 kVA power range. However, these generators would then be adequately well sized to perform the basic engine starting function, albeit that this would require an onboard APU (and static power converter) to provide self-sufficiency to the airplane. Unlike the large commercial transports, which could depend upon external electric-power for starting, the short-haul would be best served by internal electric power (an APU).

The following features should be included in an advanced short-haul transport:

- Elimination of bleed air (except for engine deicing.)

- Elimination of engine-driven hydraulic pumps and pressurized hydraulic lines in the wings and pylons. Also, the elimination of leakage/ contamination problems.

- The elimination of pneumatics for boot or hot wing deicing systems.

- Simplification of accessory power provisions on the engines.

- Reduction of engine frontal-area drag and the reduction of clutter in the power-plant, caused by mounting of the accessories.

- An advanced SPS design that will be sourced only by a multiredundant electric power system. (Note, four-channel redundancy could be easily furnished, even in a twin-engine airplane).

- Electro-impulse deicing (on which Lockheed has proprietary information and experience) is a novel method of reducing the high power-demands of deicing systems.

- Electro-mechanical stored-energy systems for short-time loads, such as landing gear, spoilers, flaps, doors, etc.

- A fly-by wire control system, for an airplane with active controls and supercritical wings.

- Advanced electric control system with:

    - Automatic load management
    - A prioritized load-shedding system.
    - Current-limiting to eliminate many circuit-breakers, and reduce smoke/fire hazards.
    - Solid-state equational-logic, for sophisticated circuit control.

- An advanced hardwire control system (AHCS) (using miniature-gage/mass-terminated system) to provide a viability normally associated with a complex multiplex microprocesser system.
- Wire programming to allow the customer to accommodate mission changes and equipment updates, without costly wiring changes.
- quick-attach/detach modular panel designs.

- An SPS system that requires the minimum of ground support equipment.

- A system that will be reliable, lightweight and efficient.

- A system in which the extensive design hours/test hours and maintenance hours of separate electric, hydraulic and pneumatic systems will be significantly minimized.

The short-haul transport is a good candidate for many advanced electrical technology improvements, but, unlike the wide-bodied jets, it cannot afford the design/development costs and complexity of a computer/multiplex system for automatic load management and control. The Lockheed AHCS is unique, and it offers the same degree of viability and wire weight reduction as the sophisticated mux/processer system.

Landing gear systems, historically in the province of hydraulics, could be well handled by electro-mechanical stored-energy systems, in which the elctric motor could be down-sized from 15 or 25 hp to 2 or 3 hp. This, and other technology, are available with relatively low technical risk.

As part of the NASA-Johnson Space Center Contract, NAS9-15863, entitled "Application of Advanced Electrical/Electronic Technologies to Commercial Aircraft", several advanced systems technologies are being investigated for the baseline short-haul aircraft developed for this study. Those technologies being investigated are depicted in table 19. To date, significant savings, as indicated by the weight savings in figure 78, are projected for a large commercial transport(L-1011 type) and it is expectd that similar savings can be projected (for selected advanced technologies) for the short-haul aircraft. Since a detailed investigation of the benefits available with incorpoation of advanced systems was not accomplished as part of this study, it is suggested that the potential benefits being quantified under contract NAS9-15863 can be used as the basis for future analytical and development requirements. These benefits, in terms of weight, cost (acquisition and operating), reliability, and aircraft operational characteristics, for the short-haul aircraft will be logical candidates for inclusion in future NASA STAT efforts.

6.6 Acoustics

6.6.1 Community noise. - As previously described in Section 5.10, the required commumnity noise levels for the baseline 30-passenger and 50-passenger aircraft are attained with the exception that the sideline noise for the 50-passenger aircraft is 3dB higher than required with the propeller diameter and tip speed selected. Adherence to the sideline noise level requirement for

TABLE 19. - TECHNOLOGY APPLICABILITY

	Large Transport ATA 500 PAX	Short Haul 50	Short Haul 30
1 Conventional Technology	X	X	X
2 Digital FBW	X	TBD	NA
3 MUX + 2	X	X	X
4 RLG Integrated Sensors + 3	X	NA	NA
5 Integrated Displays, FMS, ACS, ADC + 4	X	X	X
6 All Electric Aircraft + 5	X	X	X
7 All Electric Aircraft + Load Management + 6	X	X	X
8 Fiber Optics	X	X	X

the 50-passenger aircraft can be attained by: 1) increasing the propeller diameter and reducing propeller tip speed (at the expense of increased aircraft weight) or 2) incorporating an improved propeller (propfan). The Lockheed approach was to not resize the 50-passenger aircraft and rely on incorporation of the propfan into the advanced technology aircraft to meet the community noise requirements as well as to provide a performance and cost benefit. Incorporation of a 10-bladed propfan of 10.7 ft. diameter operating at 650 ft/sec tip speed into the 50-passenger, M 0.70 aircraft results in adherence to the FAR 36-XYZ-8dB requirement, as indicated in figure 79.

6.6.2 Cabin noise. - Original estimates of the acoustic treatment mass penalty required for the 30-passenger and 50-passenger aircraft were established as 950 lb and 1500 lb respectively. These penalties were obtained by estimates of the required sidewall surface density versus noise reduction obtained from studies of other aircraft, and then multiplying the surface density by the ratio of treatment area of the original aircraft compared to the present aircraft. The treatment area is proportional to the product of fuselage diameter times propeller diameter.

Subsequent to sizing of the baseline aircraft configurations, a detailed study of cabin acoustic environment was accomplished using the actual fuselage structure and propeller characteristics, primarily for the purpose of assessing the acoustic treatment weight benefits inherent in the orthogrid or isogrid composite structure. These studies indicated that the acoustic weight treatment for the 30-passenger aircraft was sufficient to attain the required 85dB OASPL cabin noise level; however, the required treatment weight of the 50-passenger aircraft was inadequate.

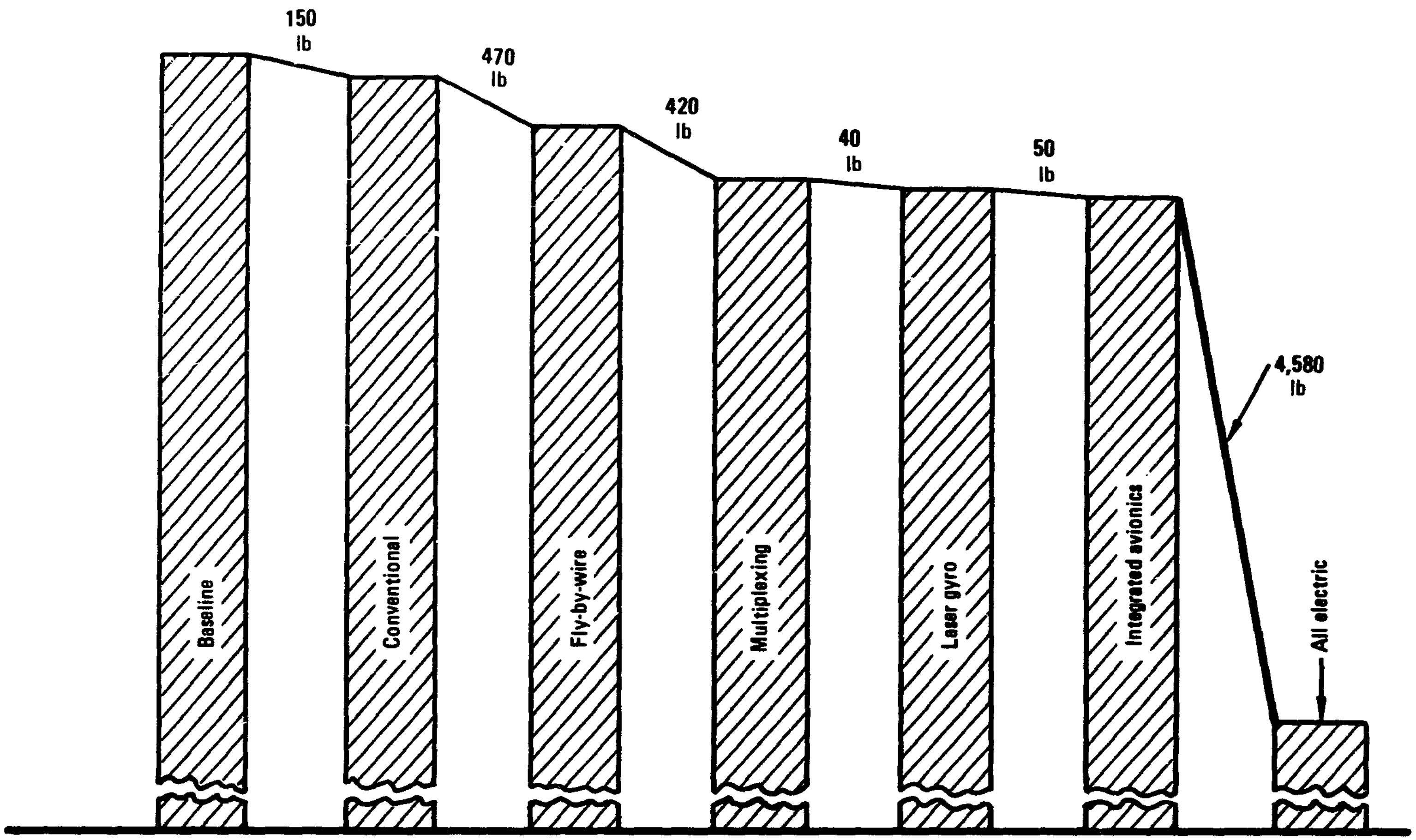

Figure 78. - Equipment weight savings - large transport.

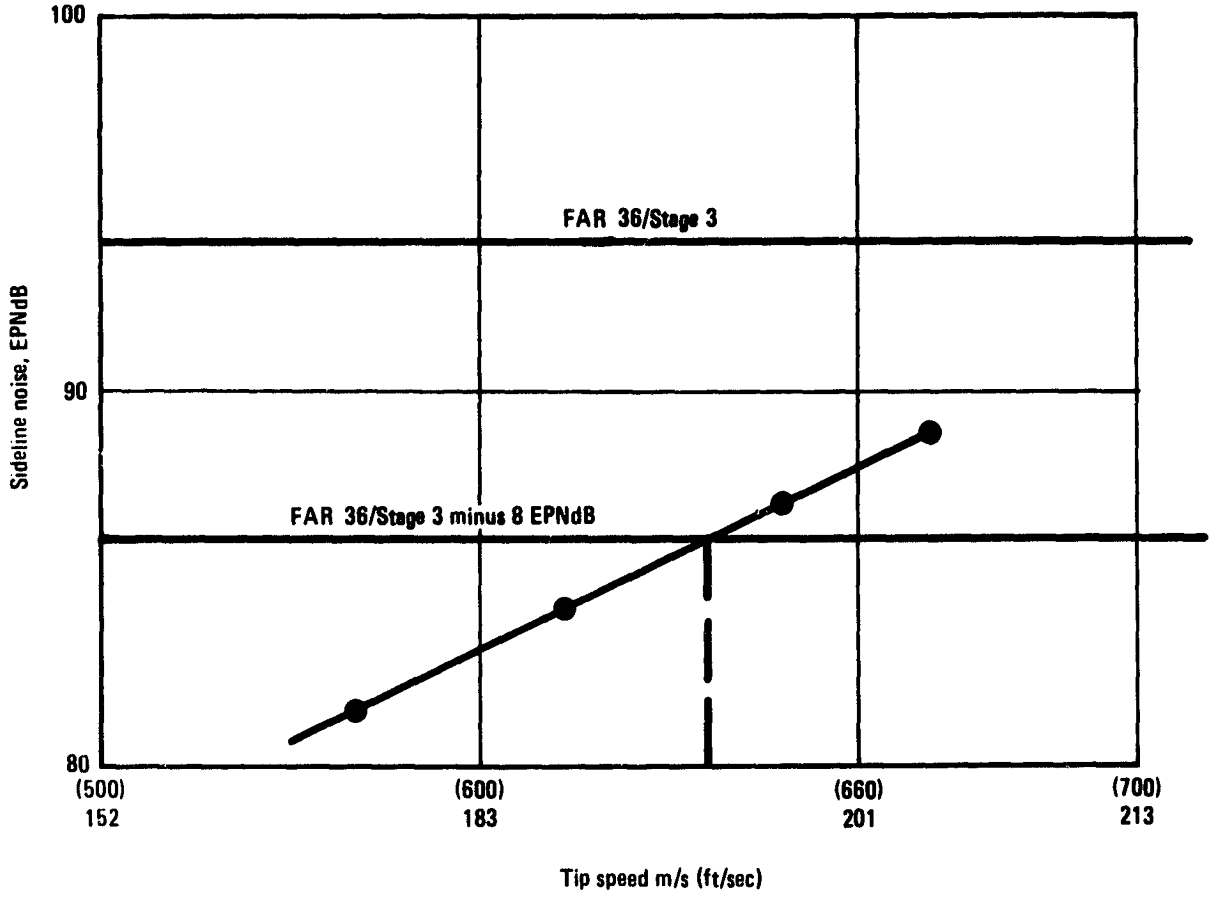

Figure 79. - Sideline noise vs tip speed for 10 bladed propfan (constant thrust).

The 50-passenger aircraft, was analyzed using two types of baseline sidewall structure (a) aluminum and (b) isogrid composite fuselage construction. The results are summarized in figure 80. The exterior noise level is shown as a variable since several estimates are available, depending upon the operating conditions assumed. The original Lockheed estimates were based upon an exterior OASPL of 133 dB. This level is similar to that estimated for the Lockheed P-3 at altitudes between 10 000 and 20 000 ft at a Mach number of 0.5. This is however, applicable only for helical tip Mach numbers of 0.90 or less. According to a recent private communication from Hamilton Standard, a level as high as 143 dB may be applicable at a cruise Mach number of 0.7 and a helical tip Mach number of 0.97.

6.6.3 Discussion of weight penalties:

6.6.3.1 Aluminum structure: - Using Lockheed's nominal estimate of 133 dB for the external OASPL, 1605 kg (3538 lb) of treatment mass is required. The treatment includes an interior trim panel of 73.0 kg/m^2 (14.96 psf) with 5.1 cm (2 in.) fiberglass blanket weighing 0.49 kg/m^2 (0.10 psf). The spacing between the double walls is 10.2 cm (4 in.). The penalty surface density in the peak noise region is 81.5 kg/m^2 (16.7 psf).

The above estimate is much higher than the original rough estimate, but it may be more realistic. This value represents 8% of TOGW which is very severe, but the requirement of 85 dB for OASPL is very stringent requirement for propeller aircraft.

It is noted that double wall effect is not beneficial for the low blade passage frequency (59 Hz) application, unlike previous studies which employed 8-bladed propfans having blade passage frequencies between 162 and 283 Hz. In the present application the double wall resonant frequency is above the blade passage frequency; therefore, the double wall effect is adverse, at the present 10.2 cm (4 in.) wall depth because commercial aircraft require an easily maintainable, washable nonporous interior trim panel.

Detailed studies show that reducing the blade passage frequency at the present 10.2 cm (4 in.) wall space is beneficial. This is because the blade passage frequency is operating below the double wall resonant frequency. Likewise, advanced stiffness-controlled outer wall design may prove to be beneficial, as is indicated by the isogrid/composite results discussed below.

With regard to advanced propellers, it is noted that a 10-bladed propfan with a diameter of 3.29m (10.7 ft) would require much lower treatment penalties, since the double wall effect for heavily treated sidewalls would again be advantageous. A typical blade passage frequency is 192 Hz for 10 blades at 3.29 m (10.7 ft) diameter and a tip speed of 201 m/sec (660 ft/sec). Also, the 10-bladed propfan is estimated to satisfy the required community noise levels (FAR 36-XYZ minus 8 EPNdB).

6.6.3.2 Composite Isogrid Structure: The acoustical treatment mass penalties for the composite/isogrid structure are considerably less than for the aluminum design for this low blade passage frequency application. The present

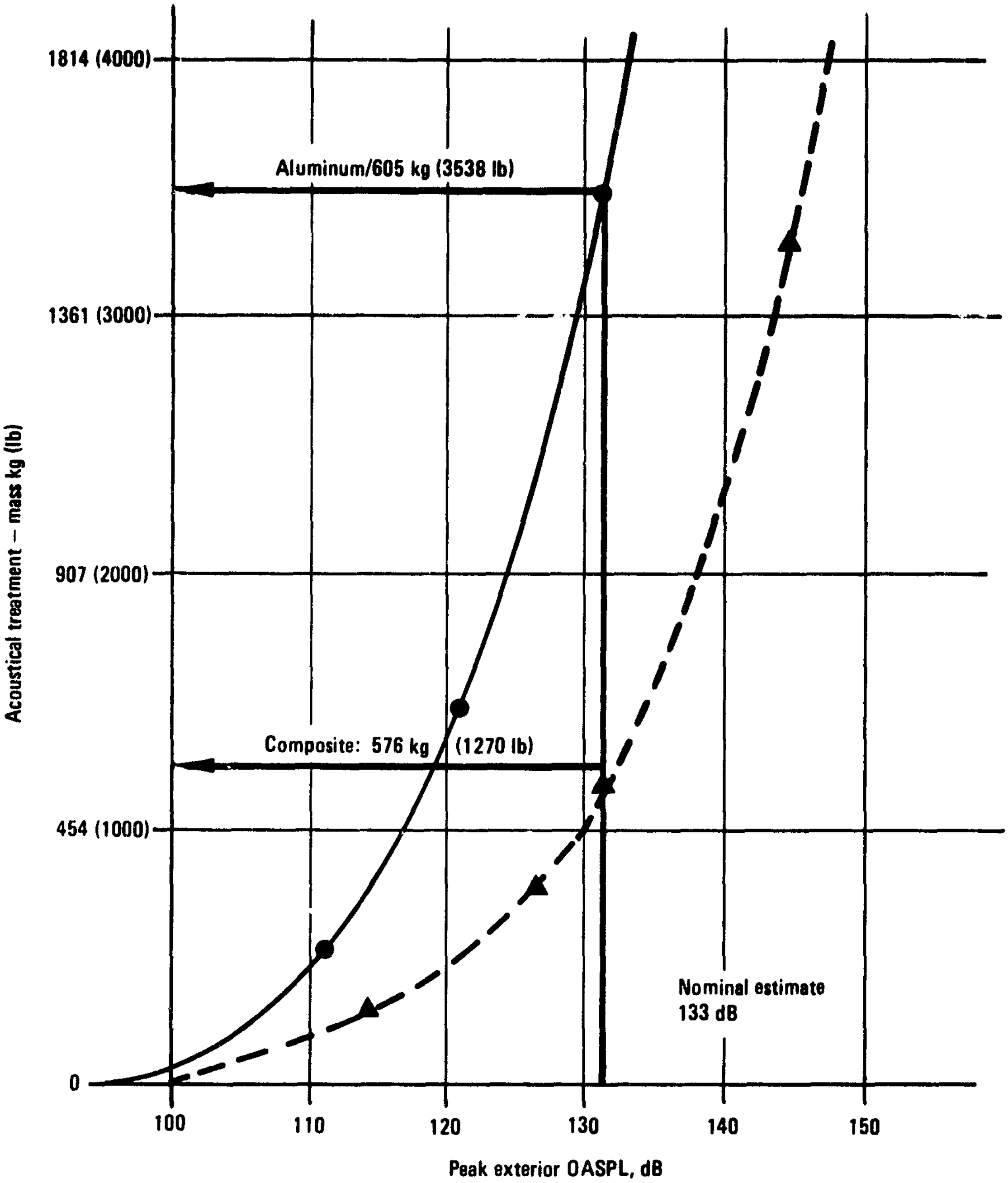

Figure 80. - Acoustical treatment penalties for 50 passenger aircraft.

isogrid structure has small, light weight triangular panels whose natural frequencies are high enough not to be affected by the first 10 propeller harmonics. In this study the isogrid was analyzed as an equivalent isotropic construction. The baseline surface density of the isogrid structure is 0.143 kg/m^2 (0.70 psf) and the trim panel mass is varied for several outer wall mass values to achieve an optimum double wall design. In this case as with the aluminum, the baseline (minimum) outer wall mass was the optimum value and the treatment mass increments were applied to the interior trim panel. The estimated penalty mass for the nominal exterior noise OASPL of 133 dB is 576 kg (1270 lb). The noise control improvement derived from the isogrid/composite is a dramatic mass penalty reduction of 1029 kg (2268 lb) or 5.11 percent of TOGW. The above results along with the usual strength design benefits and the estimated manufacturing cost reductions make the composite isogrid or orthogrid concepts extremely attractive and should be given high priority among the many possible new technology alternatives being considered for STAT.

It is noted that the above results are by no means optimum designs. The recent study for NASA Langley shows that deliberate additional stiffening is especially efficient with composite orthogrid construction. A similar result could be expected for the STAT program; however, an extensive parametric study would be required, which would be tailored to the fuselage and propeller characteristics envisioned for the STAT program.

7. EVALUATION

In this section, evaluation of the potential benefits gained by incorporation of advanced technologies into the baseline aircraft is discussed. Also included is the advanced technology configuration for both the 30- and 50-passenger short-haul aircraft along with a comparison with the baseline designs.

7.1 Advanced Technology Features

The following advanced technology features were selected for incorporation into the short-haul aircraft:

- Isogrid fuselage structure combined with orthogrid structure for the wing and empennage.

- Advanced propulsion including improved engine cycles and a propfan-type propeller.

- Active controls for use with a gust alleviation flap and to provide the required stability for an aft-mounted engine configuration with a lifting tail.

- A curved windshield using light weight polycarbonate plastic for reduced weight, drag, and manufacturing cost.

7.2 Advanced Technology Aircraft

General arrangement drawings of the 30-passenger and 50-passenger advanced technology aircraft are included as figures 81 and 82. The fuselage diameter used for the baseline aircraft is unchanged.

For the 30-passenger, short-haul, the high wing design of the baseline has been changed to include a low wing with tail-mounted engines at the aft end of the aircraft. Interior arrangement has been changed to provide cargo space forward and a forward passenger entry door so that passenger loading/unloading can be accomplished as far as possible from the propeller plane. Main landing gear is retracted into the fuselage, eliminating the gearpods used for the baseline (less drag), with the distance from ground to floor identical to the baseline.

The 50-passenger aircraft is similar to the baseline design except that aft tail-mounted engines have been included and the cargo compartment and passenger doors have been relocated forward.

7.2.1 <u>Aircraft geometry</u>. - Of the advanced technology aircraft evaluated during this study, the most promising in terms of mission fuel savings and DOC reduction, is the aft engine configuration with a lifting tail. The engines were removed from the wing and placed at the tips of the horizontal stabilizers, which were in turn enlarged and strengthened to handle the added weight. The thickness ratio of the stabilizers was increased somewhat to provide the

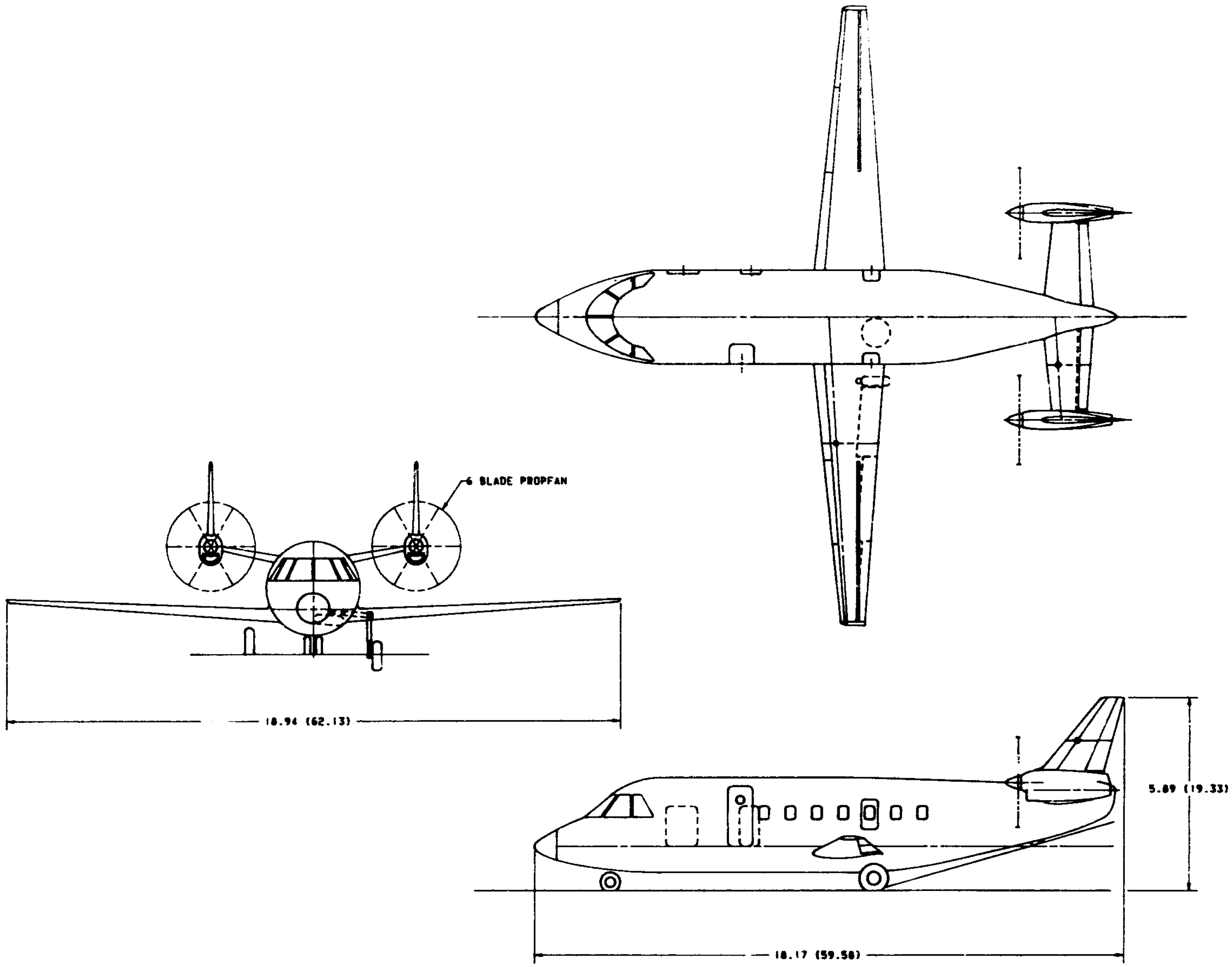

Figure 81. - 30-passenger advanced technology aircraft.

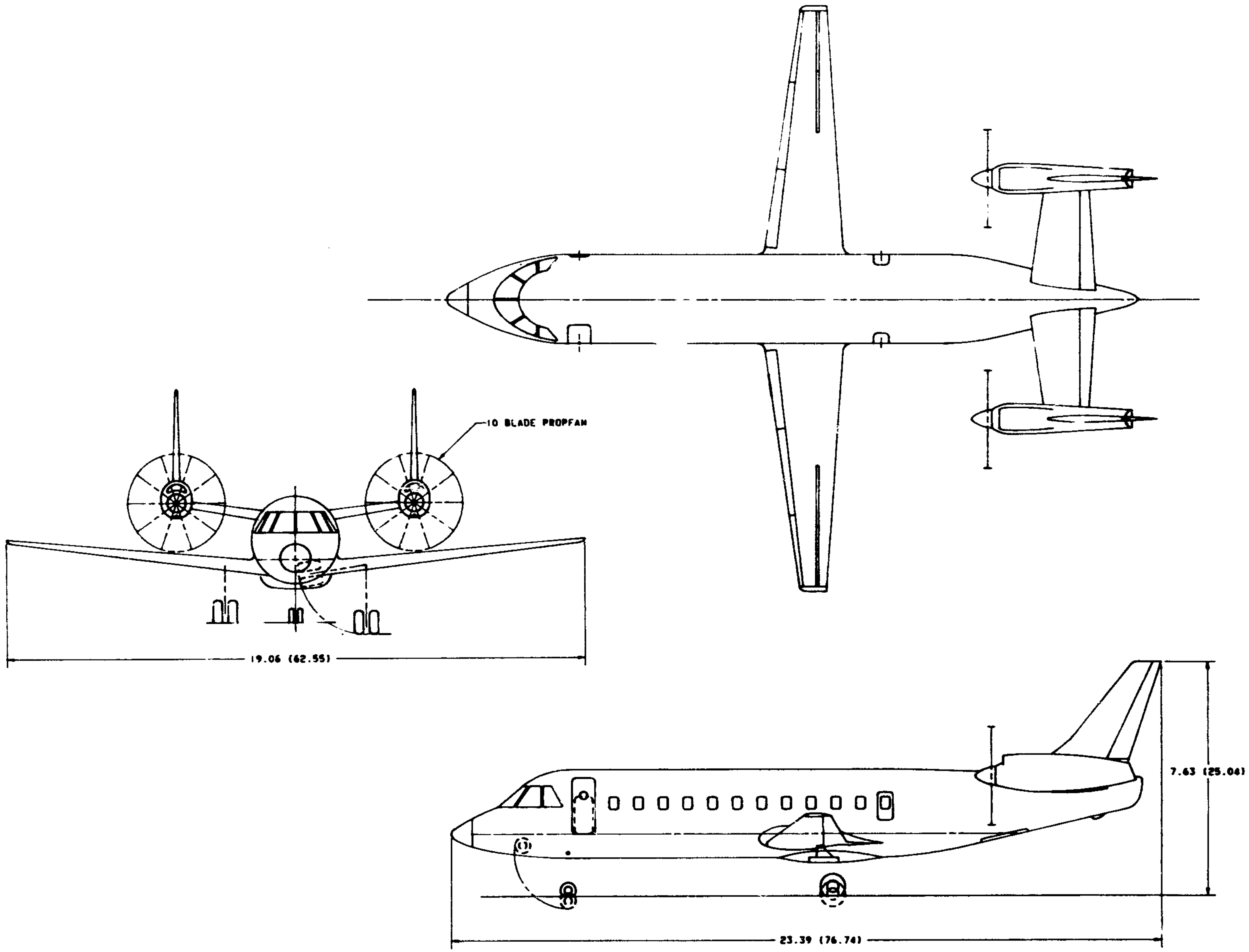

Figure 82. - 50-passenger advanced technology aircraft.

necessary extra strength. The baseline four-bladed propellers were replaced by 6-bladed propfan type propellers on the 30-passenger, and 10-bladed propfans on the 50-passenger version. Advanced technology turboshaft engines were also included. Twin vertical stabilizers were added, mounted on each engine nacelle, instead of the single control fin on the baseline. On the 30-passsenger version the wing was moved from the top of the cabin to beneath the floor and several feet aft. On the 50-passenger, the wing was simply moved aft several feet. On both versions the wing area is decreased, and the main landing gear is mounted on the rear spar of the wing and retracted inward into the fuselage.

The interior arrangement was also changed as a result of moving the propulsion aft. The cargo compartment and main passenger entry door were moved to the front, immediately aft of the flight deck to allow safe passage of passengers and cargo without engine shutdown. The cabin floor height of the 30-passenger was unchanged, while the 50-passenger floor height was reduced, since prop-ground clearance was no longer a factor. The flat-pane windshields were replaced by curved, wrap-around types constructed of polycarbonate plastics.

Construction of the airframe was also changed from aluminum bulkheads, stringers, and stressed skin to graphite composite isogrid construction on the fuselage and orthogrid composite construction on the wings and empennage. Material costs were increased to reflect utilization of composites.

Several advantages of this configuration are significantly noteworthy at the outset. First, since the prop discs are located behind the cabin, and thus the tip noise no longer impinges upon the cabin walls, the acoustic treatment weight penalty is removed. Also, the propfans offer reduced noise and increased propulsive efficiency at the high subsonic cruise speeds. The vertical stabilizers are located directly aft of the props, which in turn provide more airflow over them and thus greater control effectiveness during single engine operations. Also the engines are mounted closer to the aircraft centerline which reduces asymmetrical power yawing moments with one engine out.

An important concept of this configuration is the lifting tail feature. The forward c.g. limit of the aircraft is 55% MAC, which is much further aft than the aft limit of the baseline. Because the c.g. is behind the wing aerodynamic center, the horizontal tail provides a percentage of lift, rather than a down-force to offset the pitching moment of the wing which is normally encountered on a conventional configuration; however, this configuration is statically unstable, and so active controls are included to counteract associated undesirable control tendencies. The end result is that for equivalent field performance, the lifting tail configuration requires a smaller wing than the baseline configuration, and offers comparable cruise performance with less power required.

The graphite composite construction offers significicent savings in DOC and aircraft cost and provides an airframe of equal strength but less weight than aluminum contruction. The surface finish is smoother and will hold its contour better than standard aluminum construction. Oilcanning normally associated with aluminum structure is eliminated, and the rivetless surface of the composites offers potential improvements in skin friction and parasitic drag. Improvement in aircraft drag, for composites; was not included in the performance analysis.

Because of the surface smoothness and consistency (without rivets) of graphite composite construction, a reduction in wing drag is possible through extended "natural" laminar flow. With a specially designed airfoil that can maintain a favorable boundary layer pressure gradient, laminar flow can extend over a much longer length of chord before it trips to higher-drag turbulent flow, and thus a reduction in wing drag is realized. The laminar flow is termed "natural" because no direct boundary layer control (i.e., suction, blowing, slats, slots, etc.) is employed; the wing is clean. The drawback is that the wing in the area of anticipated laminar flow must be virtually free of surface imperfection and roughness, or even skin ripples. The graphite composite wing meets the requirements.

The wings incorporate full-span adaptive flaps with gust load alleviation capabilities. The adaptive flaps are nested in the aft portion of the main flap, and are actuated by hingeline-axis electric rotary actuators. They are controlled by the pilot and can be deflected to provide the optimum camber airfoil for certain flight regimes such as first and second segment climb, cruise, and descents. These flaps also perform gust load alleviation as a means of direct lift control by deflecting up or down to offset updrafts and downdrafts. The active control system coupled with accelerometers automatically deflects the flaps. The primary intent of this system is to provide a more comfortable ride for the passengers. This is a particularly welcome feature on a low wingloading aircraft which flies at low altitudes and is subject to higher incidence of turbulence.

7.3. Advanced Technology Benefits

7.3.1 Advanced structures and materials. - The benefits in aircraft performance and economics by incorporation of an isogrid composite fuselage and orthogrid composite wing and empennage, as compared to the base 30-passenger and 50-passenger short-haul aircraft, are presented in table 20. These results show that significent benefits in terms of aircraft empty weight reduction, savings in DOC, and total aircraft cost savings can be expected with the composite structure selected. As a part of this assessment, simplified structural concepts using conventional aluminum and advanced composites, as described in Section 6.2, were evaluated. Those results are shown in table 21 and indicate that the greatest benefits are available with the isogrid composite fuselage and orthogrid composite wing and empennage.

An additional potential benefit with the composite orthogrid wing and empennage, although not quantified in this study, is the capability to control closely airfoil contour and surface finish due to the manufacturing process involved. This control will tend to enhance wing aerodynamic characteristics toward that of natural laminar flow. As described in Section 6.7, the use of the isogrid fuselage concept provides a potential added benefit in that the amount of acoustic weight treatment required for a cabin interior noise level of 85 OASPL is significantly reduced.

7.3.2 Active controls. - The concept of incorporating active controls into the short-haul aircraft has not been quantified in terms of benefits to be gained. Active control systems are required to enable incorporation of an adaptive flap

TABLE 20. - ADVANCED STRUCTURES AND MATERIALS BENEFITS

(DOC AT $1.00/GAL FUEL)

	30 Passenger			50 Passenger		
	Baseline	Adv. Composites	Δ~%	Baseline	Adv. Composites	Δ~%
Takeoff Gross Weight	28 606	27 399	-4.2	40 427	38 255	-5.4
Operating Empty Wt	19 499	18 377	-5.8	26 155	24 155	-7.6
Block Fuel – 600 nm	2146	2092	-2.5	2816	2720	-3.4
Block Fuel – 100 nm	671	649	-3.3	933	903	-3.2
DOC – 600 nm	4.977	4.767	-4.2	3.759	3.544	-5.7
DOC – 100 nm	9.946	9.509	-4.4	7.505	7.380	-1.7
Flyaway Cost	$4.14M	$3.77M	-8.9	$5.50M	$4.89M	-10.9

TABLE 21. - ADVANCED STRUCTURES AND MATERIALS SAVINGS

30 PASSENGER AIRCRAFT

(DOC AT $1.00/GAL FUEL)

	Baseline	Config 1	Config 2	Config 3	Config 4
Takeoff Gross Weight	Base	+0.2%	-4.6%	-4.0%	-4.2%
Manufacturers Empty Weight	Base	+0.3%	-6.6%	-5.8%	-6.0%
Structural Weight	Base	+0.6%	-13.5%	-11.7%	-12.3%
Fuselage Weight	Base	+1.1%	-11.0%	-7.8%	-8.9%
Wing Weight	Base	+0.3%	-21.2%	-20.6%	-20.8%
Tail Weight	Base	0	-23.0%	-22.1%	-22.5%
Structural Cost	Base	-4.4%	-10.8%	-23.4%	-23.3%
Flyaway Cost	Base	-1.2%	-6.0%	-8.9%	-8.9%
Block Fuel – 600 nm	Base	+0.1%	-2.7%	-2.4%	-2[illegible]
DOC – 600 nm	Base	-0.3%	-3.4%	-4.1%	-4.2%

Configurations: Baseline – Frame/Stringer Fuse and Multi-Rib Wing – Aluminum
1 – Longeron Fuse and Multi-Spar Wing – Aluminum
2 – Longeron Fuse and Multi-Spar Wing – Composites
3 – Orthogrid Fuse and Orthogrid Wing – Composites
4 – Isogrid Fuse and Orthogrid Wing – Composites

system, to enhance the ride quality of the aircraft at low altitudes in turbulence, and to provide the necessary stability and control characteristics of the aft engine and tandem wing configurations previously described. During the ASSET evaluations accomplished for the aircraft configurations with active controls, appropriate weights and cost data were included for the active control systems and are reflected in aircraft technical and economic performance characteristics.

7.3.3 Advanced propulsion. - Incorporation of advanced propulsion concepts, based on data supplied by AiResearch, as described in 6.3, provide the largest single benefit, in terms of fuel savings and DOC reductions, of any of the advanced technology items. As indicated in table 22, block fuel savings of approximately 22% and DOC reductions of approximately 10% for the 600 n.mi. design mission are available with incorporation of an advanced technology, 1990 time frame engine. These projected savings are not suprising, since the current generation of turboprop engines has not been optimized for fuel or cost efficiency and reflects a technology base which is significantly behind that of the current turbofans. It can be expected that incorporation of the same technology base that is currently used in the E^3 turbofan engines will provide the turboprop performance improvement factors established by AiResearch.

TABLE 22. - ADVANCED PROPULSION BENEFITS

(DOC AT $1.00/GAL FUEL)

	30 Passenger			50 Passenger		
	Baseline	Adv Propulsion	Δ~%	Baseline	Adv Propulsion	Δ~%
Takeoff Gross Weight	28 606	27 248	-4.8	40 427	38 473	-4.8
Operating Empty Weight	19 499	18 820	-3.5	26 156	25 155	-3.8
Block Fuel – 600 nm	2146	1679	-21.8	2816	2194	-22.1
Block Fuel – 100 nm	671	518	-22.9	933	719	-22.9
DOC – 600 nm	4.977	4.473	-10.1	3.759	3.254	-13.4
DOC – 100 nm	9.946	8.940	-10.1	7.505	6.402	-14.7
Flyaway Cost	$4.14M	$3.94M	-4.8	$5.50M	$5.20M	-5.5

7.3.4 Alternate configurations. - Several alternate configurations for the 30-passenger aircraft were evaluated. These configurations included mounting of the engines at the aft end of the aircraft, incorporation of a lifting tail, and a tandem wing configuration. As shown in Section 6.3.2.4, the tandem wing configuration does not indicate a significant benefit in terms of fuel consumed or DOC over the baseline configuration. Evaluation of the results obtained with the aft engine configurations, both conventional and lifting tail, indicate an advantage over the baseline in terms of block fuel and DOC. One of the primary considerations for the aft engine configuration is to eliminate or minimize the amount of acoustic weight treatment required for cabin interior noise levels. This configuration was deemed advantageous not only for the DOC benefit but from the standpoint of the ability to eliminate the uncertainty of acoustic weight treatment required. The advantages and disadvantages of a lifting tail concept, with aft engines, over the baseline are:

- Relocation of engines to aft end
  - Remove acoustic weight treatment requirements and uncertainties.
  - Provide Aerodynamically "clean" wing with possibility of natural laminar flow advantages.
- Aerodynamics
  - Reduced trim drag
  - Wing operates at lower C_L, less induced drag.
- Weights
  - Lighter wing, because of reduced lift requirement.
  - Acoustic treatment weight eliminated.
  - Horizontal tail is strengthened to carry engines and other loads - net weight increase for tail.
  - Active controls required - added weight.
- Controls
  - Control power for stall recovery, trim, and power effects increase over baseline.

The results discussed above indicate selection of the aft engine, lifting tail configuration for the 30-passenger short-haul aircraft will be advantageous. Although not quantified for the 50-passenger aircraft, it is expected that similar results would be obtained.

Table 23 provides a summary performance characteristics obtained for each of the configurations evaluated.

7.3.5 <u>Combined benefits of advanced technology</u>. - Each baseline aircraft was resized, using the ASSET program, to incorporate various combinations of advanced technologies to evaluate the benefits in terms of DOC at both the design range and the 184 km (100 n.mi.) stage length. The results for the 30-passenger aircraft are shown in table 24 and indicate that the following advanced technologies and aircraft configuration provide the greatest benefits

TABLE 24. - ADVANCED TECHNOLOGY AIRCRAFT BENEFITS

30 PASSENGER AIRCRAFT

(DOC AT $1.00/GAL FUEL)

	Baseline	Adv. Techn.	Benefits
Takeoff Gross Weight	28 606	24 931	-12.8%
Operating Empty Weight	19 499	16 292	-16.5%
Wing Area, ft^2	358	312	-12.8%
Engine Power, shp	2403	2094	-13%
Block Fuel – 600 n.mi.	2146	1572	-26.7%
Block Fuel – 100 n.mi.	671	496	-26.1%
DOC – 600 n.mi.	4.977	4.197	-15.7%
DOC – 100 n.mi.	9.946	8.350	-16%
Flyaway Cost	$4.14M	$3.50M	-15%

in terms of DOC at the 184 km (100 n.mi.) stage length, which is the criteria established at initiation of this study:

- o Advanced technologies
  - Isogrid composite fuselage and orthogrid composite wing and empannage.
  - Advanced engine cycles and improved propeller (6-bladed for the 30-passenger and 10-bladed for the 50-passenger).
  - Active controls for gust alleviation and relaxed static stability.
- o Configuration
  - Aft Engines
  - Lifting tail with aft c.g. for the aircraft
  - Adaptive flap system
  - Low wing design for both aircraft

8. CONCLUSIONS AND RECOMMENDATION FOR TECHNOLOGY DEVELOPMENT AND FUTURE STUDY EMPHASIS

The results of this study indicate that there is the potential for significant benefits, in short-haul aircraft performance and economics, available by development and future incorporation of selected advanced technologies. The use of advanced composites and improved structural arrangement for aircraft primary structure, advanced engine cycles and improved propellers, and active controls systems provides significant benefits when compared to a baseline, current technology, short-haul aircraft. These technologies, when combined with an aft mounted engine, lifting tail configuration yield the following benefits:

30 PASSENGER AIRCRAFT

	600 n.mi.	100 n.mi.
• Block fuel reduction	25%	26%
• DOC Savings ($1.00/Gal fuel)	15%	16%

- 15% reduction in aircraft acquisition cost.

50 PASSENGER AIRCRAFT

	600 n.mi.	100 n.mi.
• Block fuel reduction	24.6%	24%
• DOC Savings ($1.00/Gal fuel)	18%	18%

- 16% reduction in aircraft acquisition cost.

Of particular interest is the potential reduction in aircraft acquisition cost, primarily by use of advanced structural arrangement and composite materials. For this study, it was assumed that the development effort associated with establishing the technology readiness of advanced composites and the automated manufacturing processes would be accomplished by in-house and contract funded research and development programs. The development costs included in the short-haul aircraft are therefore limited to those items peculiar to the specific design (i.e., manufacturing tooling, mandrels, and fixtures). Specialized tooling such as the automated tape laying machine and inspection equipment were assumed to be capital expenditures and are not included in the short-haul development costs.

The use of an aft-mounted engine configuration provides the potential of minimizing the engine/wing integration concerns and utilizing "natural" laminar flow airfoils for the wing. Also, the concerns about the amount of fuselage weight treatment required to attain an acceptable cabin interior noise level are minimized by placement of the engines aft of the passenger cabin. Aft-mounted engines do, however, require additional consideration for aircraft control and stability and the effects of propeller slipstream.

Future Research and Technology

There are several areas of advanced technologies which require further effort to provide the technology readiness for incorporation into the next generation of small, short-haul transports.

- Structures

  Perform design-analysis, fabrication, test, and evaluation of isogrid composite fuselage and orthogrid composite wing and empennage designs. Conduct a series of element tests to evaluate the basic design features: (1) coupon tests to establish the tension, compression and shear properties of the geodesic bar element without the skin, (2) element tests to evaluate the tension, compression, shear and fatigue properties of the skin and stiffener.

  Conduct subcomponent tests of representative panels to verify the basic strength and durability of the designs: (1) isogrid fuselage side shell and (2) orthogrid wing surface panel.

- Propulsion

  - Develop improved turboprop engine cycles in the 2000 to 5000 shp range. Technologies currently being developed for the NASA sponsored E^3 turbofan engine cycles should be considered if applicable.

  - Incorporate maintenance improvements into advanced turboprop engines such as modularization of components and low cost on-board engine diagnostic systems.

  - Investigate use of integrated engine and flight control systems for improved fuel management.

  - Develop improved, more highly loaded, lightweight, quiet, and efficient propellers for the advanced engine cycles.

- Aerodynamics

  - Construct powered nacelle wind tunnel model of advanced technology 30 to 50 passenger configurations for analysis of stability and control characteristics with aft-mounted engines. This model would also be used to determine cabin noise level due to supersonic prop-tip speeds.

- Refine and develop a gust alleviation flap system which would offer the performance of a full translation Fowler yet still be effective as a gust load alleviating device. Analytic methods could be used to size the gust flap chord according to control power required. Then an aircraft could be modified to demonstration the viability and effectiveness of the devices for improvement of passenger ride comfort.

- Determine the feasibility, practicality and necessary design criteria of relaxed static stability, aft c.g., for aircraft of this size. Once again an aircraft could be used to determine performance increases and possible airframe modifications such as reduced wing and tail areas. A stability augmentation system would be required to induce artificial stability, but c.g. could be easily moved aft by weight shifting.

- Systems

  - Investigate incorporation of all-electric secondary power systems and environmental control system designs for the short-haul transport application.

  - Study incorporation of advanced avionics systems for improved all-weather capability.

  - Investigate improved anti-ice or deicing systems.

- Noise

  - Develop parametric data for acoustic treamtment mass versus cabin noise reduction for short-haul transport applications.

  - Perform laboratory demonstration of noise reduction designs on conventional fuselage structure.

  - Perform acoustic tests on an advanced composite isogrid cylindrical section representative of an advanced technology fuselage.

APPENDIX

ECONOMIC ANALYSIS-SHORT-HAUL AIRCRAFT

CONTRACT NAS2-10264

February 1, 1980

LOCKHEED-CALIFORNIA COMPANY

LIST OF FIGURES

LIST OF TABLES

COST ANALYSIS - SHORT HAUL AIRCRAFT

The cost analysis for the short haul aircraft is an attempt at arriving at a realistic DOC for aircraft designed specifically for the short haul market. The approach is to examine available CAB data on aircraft currently being operated in the short haul market and relate that experience to the new-design 30 and 50 passenger aircraft.

The first step in the analysis is to establish guidelines and cost ground rules. Table 1 provides the general guidelines that are used and Table 2 provides specific guidelines and factors. The factors in Table 2 have been established by NASA from data received from each contractor (Cessna, General Dynamics, and Lockheed) and a survey of data from the commuter and local service operators. These cost factors are provided to maintain consistency between the three contractors and provide costs that reflect current experience. The additional analysis required to complete the DOC estimate is that dealing with depreciation and maintenance. The cost drivers in depreciation are depreciation period and aircraft price.

The NASA survey indicated that 12 years is typical for commuter and local airline aircraft. There is reason to believe that this time might be extended to values approaching the current wide body time period of 16 years. The reason is that for this study the aircraft is designed specifically for this market and would be designed for a longer life than the aircraft currently in use. In many cases the aircraft currently in use for the short haul market are used aircraft obtained from the long haul operators or are business type aircraft which are not designed for the rigors of short haul operations. The cost tradeoffs and final baseline aircraft selection is based on the 12 year depreciation period but the impact of a longer period due to the design criteria is also examined.

TABLE 1. COST ANALYSIS

1.	DOC IS USED FOR OPTIMIZATION CRITERIA.
2.	IOC AND ROI ARE NOT CONSIDERED FOR THIS STUDY.
3.	DOC CALCULATED BY ATA METHOD (MODIFIED).
4.	DOC FACTORS PROVIDED BY NASA - AS DETERMINED FROM ANALYSIS OF COMMUTER OPERATIONS.
5.	ENGINE MAINTENANCE COST DETERMINED FROM DATA SUPPLIED BY ENGINE MANUFACTURERES.
6.	DEVELOPMENT AND PRODUCTION COST FOR THE BASELINE AIRCRAFT BASED ON EXISTING TECHNOLOGY.
7.	DEVELOPMENT COST IS AMORTIZED INTO PRICE OF AIRCRAFT.
8.	THE PRODUCTION COST IS BASED ON A PRODUCTION QUANTITY OF 250 AIRCRAFT AND A PRODUCTION RATE OF 5 AIRCRAFT PER MONTH.

TABLE 2. COST GROUND RULES (NASA)

1. 1979 DOLLARS
2. CREW COST 2.5 x SEATS

   30 PAX = 75 $/BLK HR
   50 PAX = 125 $/BLK HR

3. MAINTENANCE LABOR AND BURDEN

   MAINTENANCE LABOR $10/HR.
   MAINTENANCE BURDEN 80% OF LABOR

4. BLOCK TIME = FLIGHT TIME + 10 MINUTES
5. INSURANCE RATE 1.5% OF AIRCRAFT PRICE
6. SPARES % = .2 x SEATS +2.0

   30 PAX = 8%
   50 PAX - 12%

7. DEPRECIATION + [(AIRCRAFT PRICE + SPARES)*(1-.15)] /12
8. ANNUAL UTILIZATION 2800 HOURS -
9. ENGINE MAINTENANCE COST = $.243(SHP)^{0.66}$

   PROP MAINTENANCE = 4.15 $(BLK HR)

The price of the aircraft must also be realistic to provide an accurate estimate of the depreciation cost. The primary elements of cost for the aircraft are shown in Figure 1. The airframe labor and material cost including the associated sustaining, Q/A, etc. comprises approximately 79% of the total cost. Since the R&D is generally recouped in the price of the airplane it is also included. The most efficient way to reduce the pro-rate share of R&D is to sell large quantities of the aircraft. The quantity assumed for the study is 250, but from all indication this may be low.

The curves in Figure 2 illustrate the relationship between quantity and cost with the difference noted between quantity 250 and 500. Engines and avionics are off-the-shelf buys and are constant cost at all quantities.

The question is; how accurate is the price estimate? The price for current jet and turboprop aircraft is used as a guideline for checking the accuracy of the price estimate for the 30 and 50 passenger short haul aircraft. Figure 3 shows the plot points for various aircraft in terms of empty weight and aircraft price. In general there is a consistant trend of price for pressurized aircraft. A lower trend line can be estimated for unpressurized aircraft with low cruise speeds. Note that the price for the 30 and 50 passenger aircraft are slightly above the trend line for pressurized turboprop and turbojet aircraft. The guideline as stated in Table 1 is that the short haul aircraft incorporates the best of the existing technology and would have features that are more advanced than some of the aircraft shown in Figure 3; and would have a commensurate cost. In Figure 4 the comparison is in terms of $/LB of weight empty. In terms of $/LB of weight empty the trend exhibits the sizing relationship; the larger the aircraft the lower the $/LB. The relationship of the short haul aircraft to the trend line is the same as in Figure 3 for pressurized aircraft. The EMB-110 is currently unpressurized but will be offered as a pressurized aircraft in the future.

Another attempt at correlating the cost estimate for the short haul with current aircraft was to examine the cost in terms of $/seat (see Figure 5 and Table 3). This comparison is not as conclusive as the others. If the long range high speed business jets are excluded (No.'s 17, 11, 14, 5 & 16) there appears to be a consistancy in the cost per seat at approximately

30 PASS. SHORT HAUL

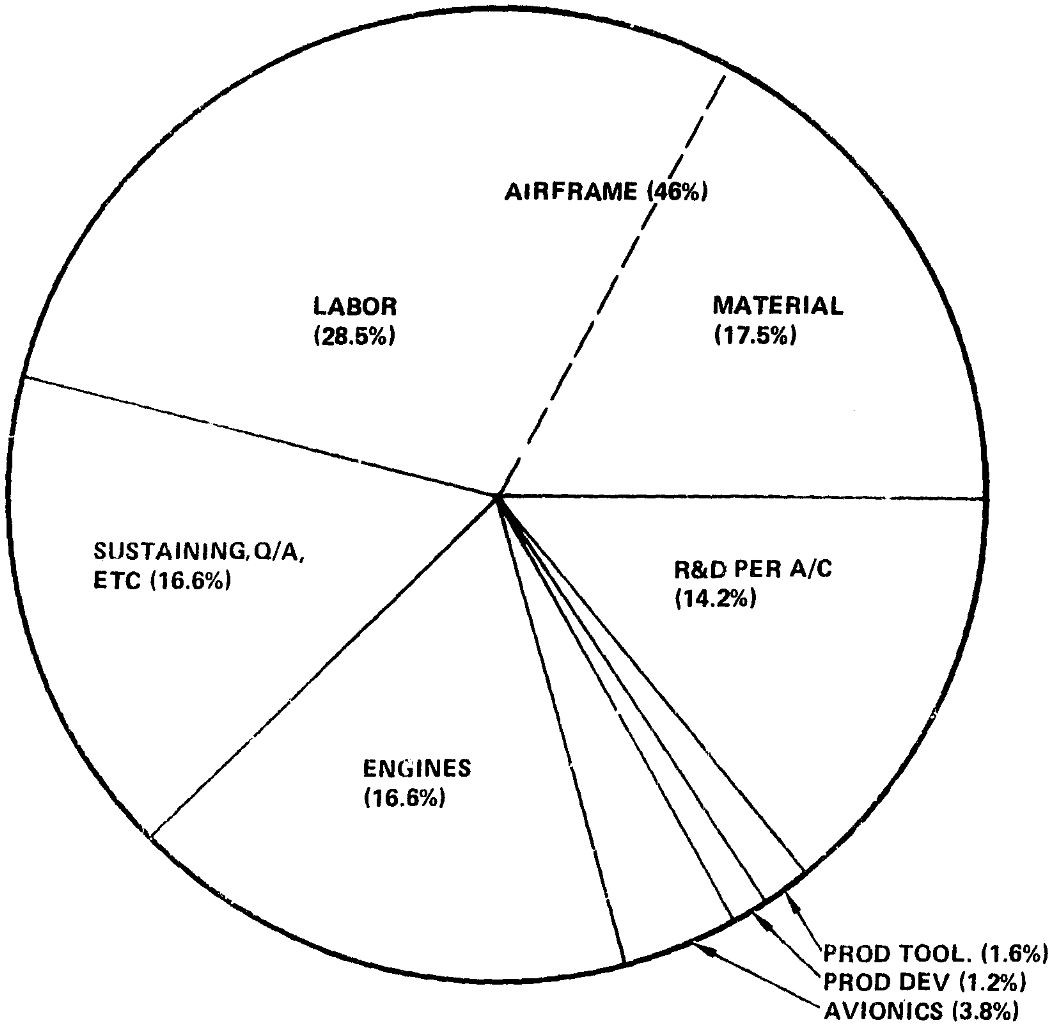

Figure 1. Production Cost Breakdown

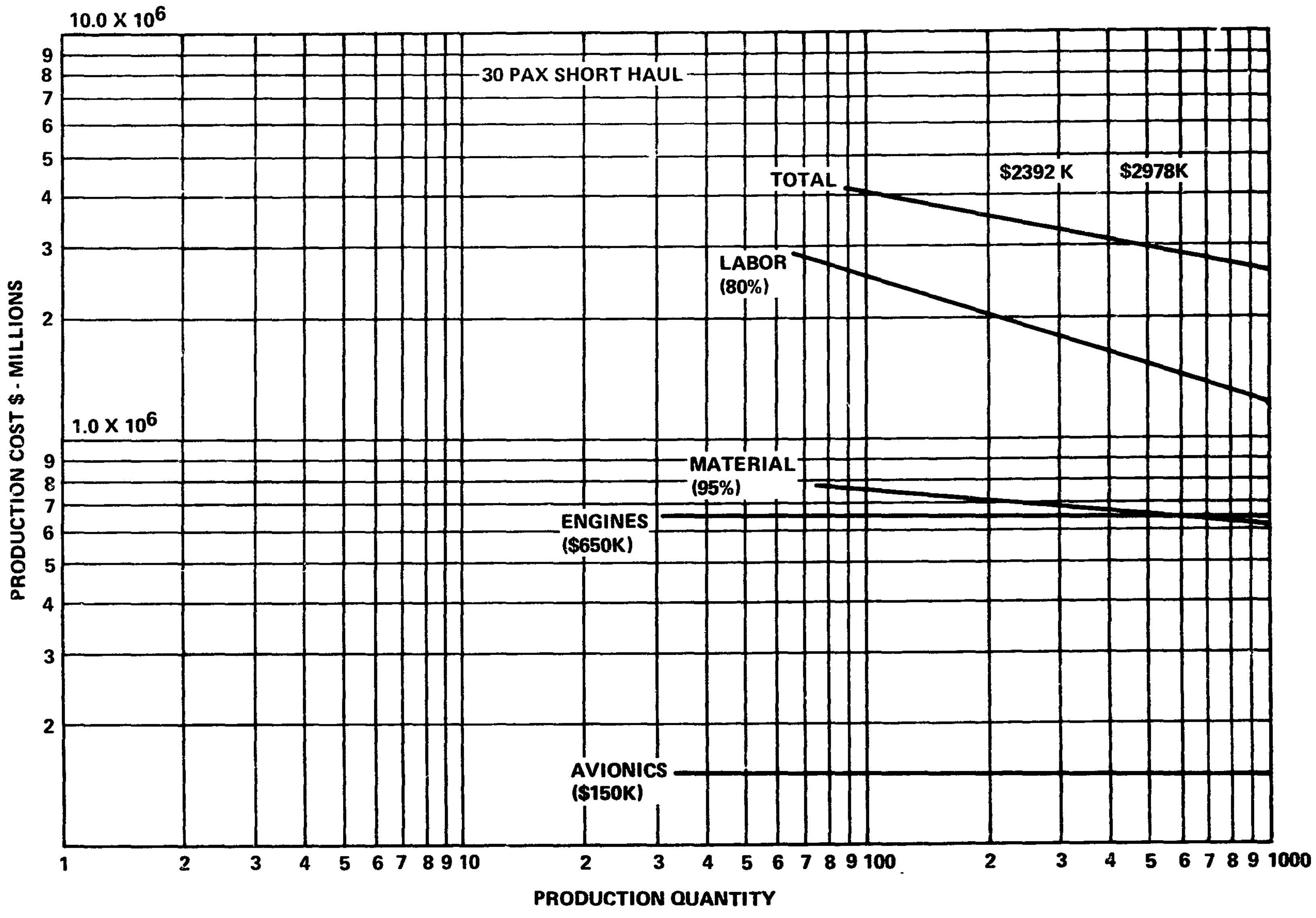

Figure 2. Learning Curves for Major Elements of Production Cost

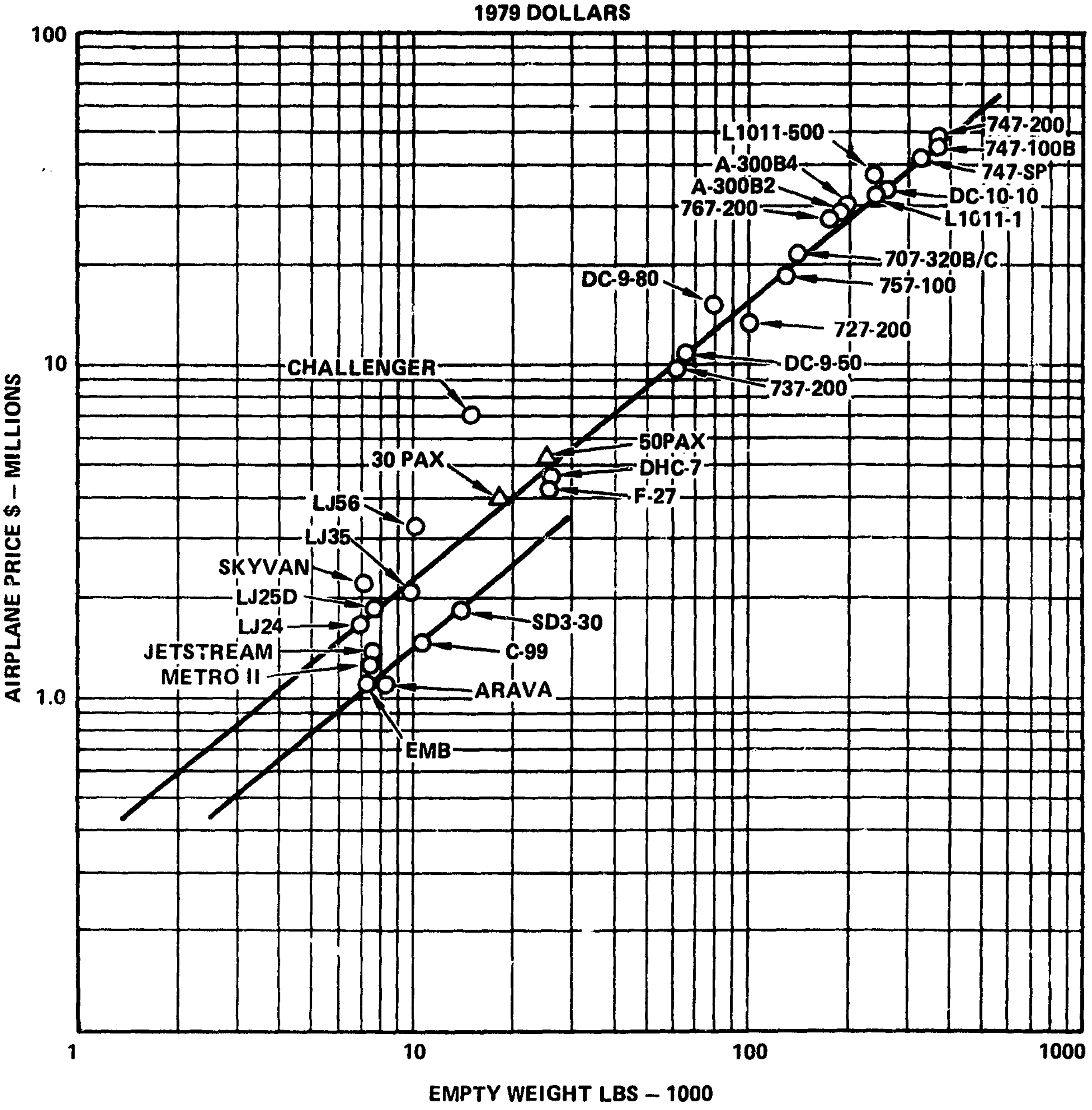

Figure 3. Aircraft Price vs Empty Weight - 1979 Dollars

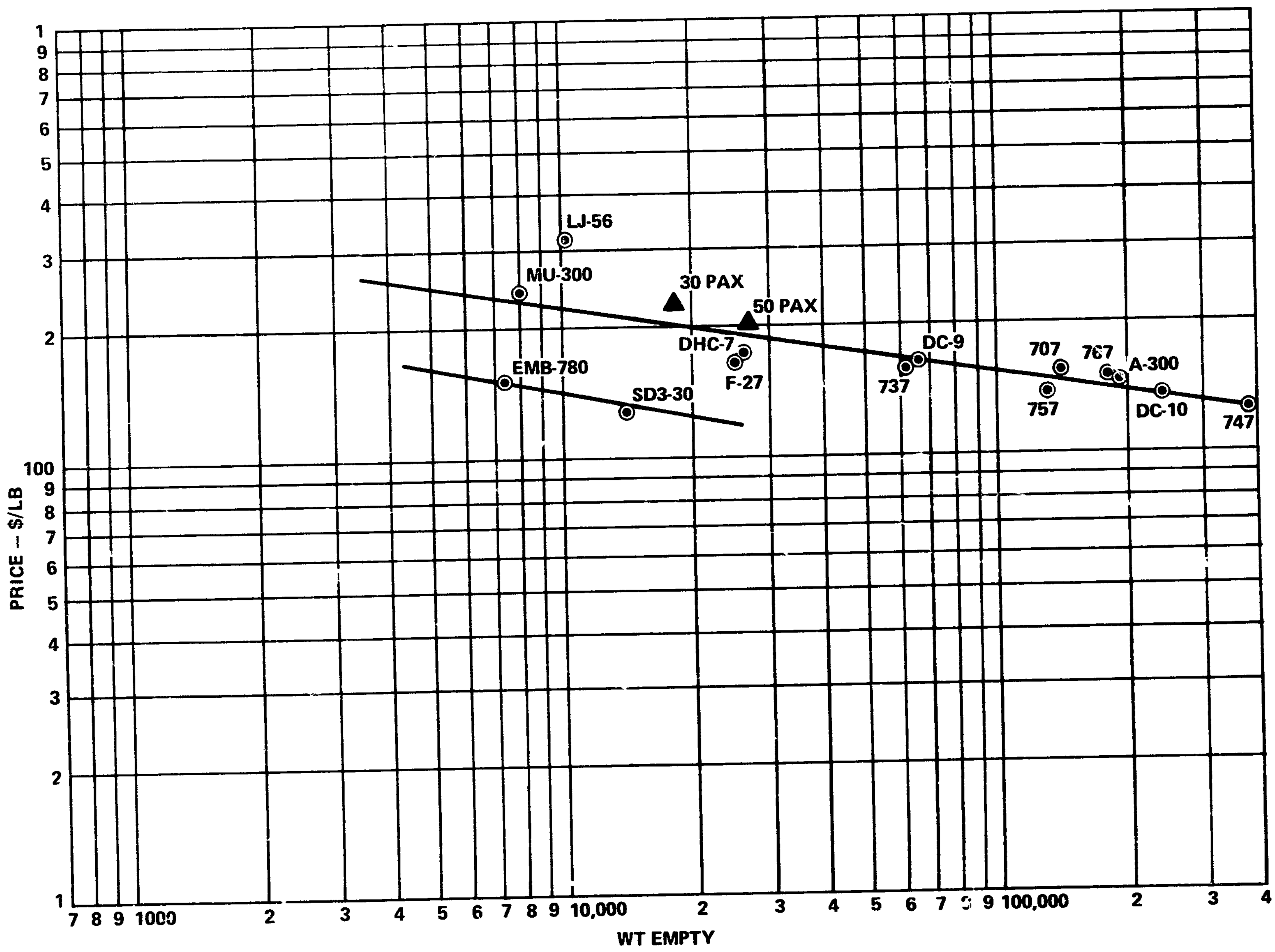

Figure 4. Aircraft Price $/lb vs Weight Empty

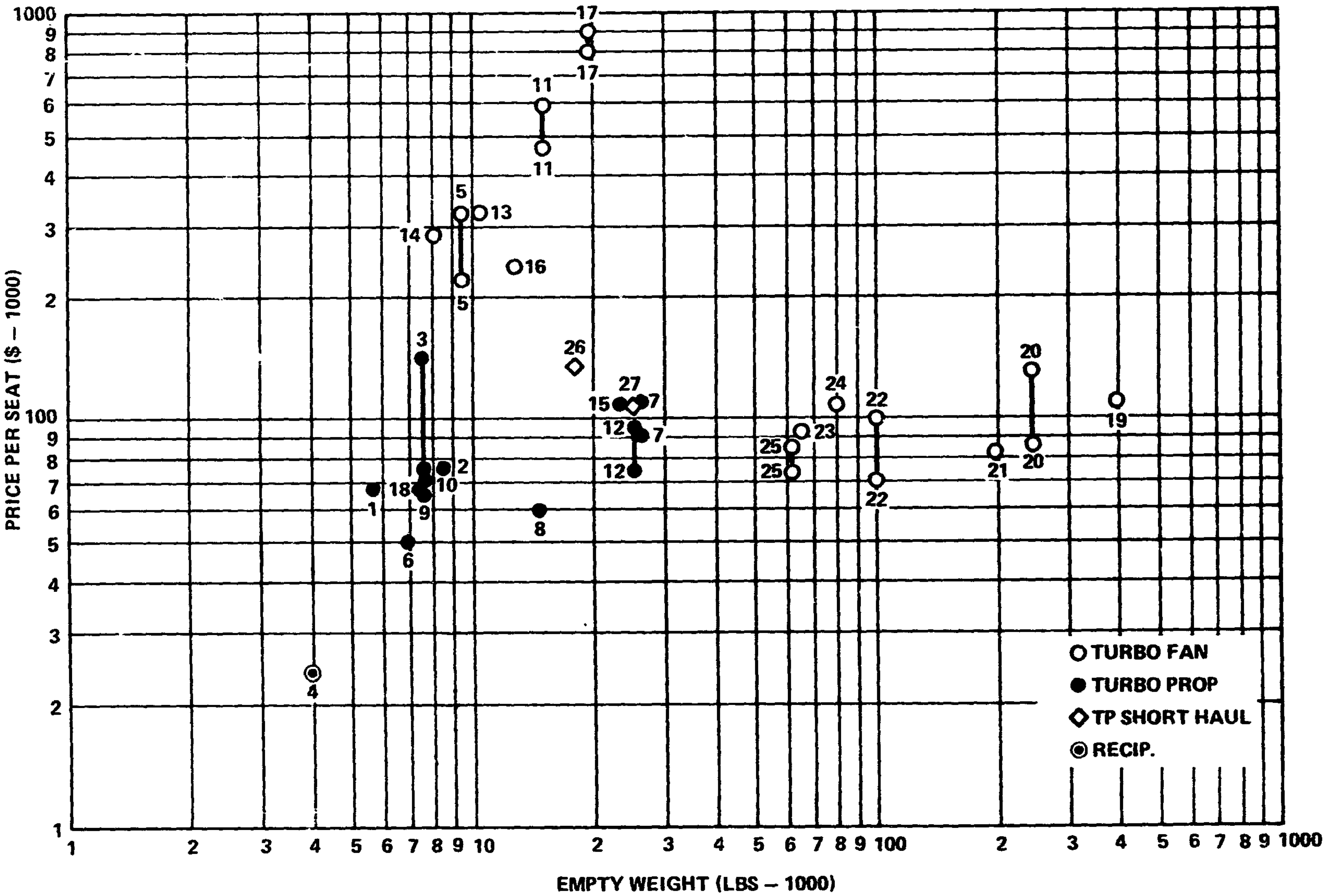

Figure 5. Aircraft Price $/Seat vs Weight Empty

TABLE 3. AIRCRAFT PRICE VS. NUMBER OF SEATS

ENGINE TYPE	AIRCRAFT	NUMBER OF SEATS	FLYAWAY PRICE	PRICE PER SEAT	EMPTY WEIGHT
1 T.P.	BEECH C-99	15	1.015	67,667	5777
T.P.	BEECH 1300	13	1.015	78,000	
2 T.P.	BEECH 1900	19	1.45	76,315	8400
3 T.P.	BEECH KING AIR	8-15	1.15	144,000/ 76,670	7437
4 RECIP.	CESSNA 402	9	.22	24,444	3904
	CESSNA TITAN	11	.30	27,272	
5 T.F.	CESSNA CITATION 3	10-15	3.3	330,000/ 220,000	9325
6 T.P.	DHC-6	19	.95	50,000	6878
7 T.P.	DHC-7	50	4.5- 5.5	90,000/ 110,000	26200
8 T.P.	SHORTS SD3-30	30	1.8	60,000	14600
9 T.P.	METRO 2	19	1.25	65,790	7450
10 T.P.	JETSTREAM 31	18	1.30	72,222	7606
11 T.F.	CHALLENGER CL-600	11-14	6.5	590,000/ 464,000	15085
12 T.P.	F-27-600	44-56	4.25	96,590/ 75,900	25990
13 T.F.	LEARJET 55	10	3.23	323,000	10216

TABLE 3. AIRCRAFT PRICE VS. NUMBER OF SEATS (CONTINUED)

ENGINE TYPE	AIRCRAFT	NUMBER OF SEATS	FLYAWAY PRICE	PRICE PER SEAT	EMPTY WEIGHT
14 T.F.	MU DIAMOND 1	7	1.98	282,857	[illegible]
15 T.P.	GULFSTREAM 1	32	3.5	109,375	23000
16 T.F.	WESTWIND 1124	10	2.40	240,000	12786
17 T.F.	FALCON 50	10-12	8- 9.0	800,000/ 900,000	19840
T.P.	CAC-100	40-44	2.60	65,000/ 59,000	
18 T.P.	EMB-110	16	1.10	68,750	7324
19 T.F.	747-200C	442	48.6	109,950	386800
20 T.F.	DC-10-10	250-380	32.6	130,000/ 85,790	241274
21 T.F.	A-300B4	345	28.62	82,956	194000
22 T.F.	727-200	134-189	13.5	100,000/ 71,400	100000
23 T.F.	DC-9-50	114	10.6	92,980	64900
24	DC-9-80	137	15.0	109,490	79757
25 T.F.	737-200	115-130	9.7	84,350/ 74,600	61000
26 T.P	30 PAX SHORT HAUL	30	4.14	138,000	18512
27 T.P.	50 PAX	50	5.4	108,000	25034

$100,000/seat; with a spread between 70,000 and 120,000 $/seat. The spread in cost shown for each data point is due to the number of seats that may be placed in each aircraft. The type of aircraft that corresponds to each data point is designated by the information in Table 3.

Another approach to verifying the production cost is illustrated in Table 4. In this approach the airframe and systems production cost is determined by two alternative cost models and compared to the results obtained from the ASSET program. One of the models used is a recent development by the Air Force(1). This model is to be used in evaluating advanced systems and provide total life cycle cost. The model was developed by Grumman Aircraft for the Air Force Dynamic Lab. and is to the same approximate level of detail as the group weights statement.

The Air Force model is higher in structure cost than the NASA model or ASSET but lower than both the other models in systems cost. It is not unlikely that the Air Force model would predict systems costs that would not be consistent with ASSET or the NASA model since the data base is so much different. The data base for the Air Force model is primarily historical data for fighter aircraft whereas the data base for the NASA model(2) and ASSET is transport aircraft. The inputs to the ASSET model are derived for the type of aircraft being evaluated and in this case are based on Lockheed transport aircraft experience. The estimate from the Air Force model is within 25% of the other estimates and at least provides a reinforcement along with the NASA model that the estimate from the ASSET model is reasonable.

The next task was to investigate the maintenance cost. As in the production cost the approach is to compare the estimates with actuals or reported direct operating costs (DOC). The first step in this task was to obtain

(1)Modular Life Cycle Cost Model For Advanced Aircraft Systems - Phase II AFFDL-TR-78-40, VOL. I

(2)Parametric Study of Transport Aircraft Systems - Cost and Weight, NASA, April 1977, NASA CR151970

TABLE 4. PRODUCTION COST COMPARISON - AIRFRAME

CUM. AVE COST 250 AIRFRAMES	30 PAX COMMUTER		
	NASA METHOD (CR151970)	AIRFORCE METHOD	ASSET
WING	253.2	336.9	326.8
TAIL	74.6	215.5	59.4
BODY	431.1	412.4	361.3
LANDING GEAR	79.8	70.0	66.7
NACELLES	136.8	98.5	106.6
	975.5	1133.3	920.8
ENGINE INSTL	-	11.7	2.3
ENGINE CONTROLS	14.0	-	2.1
STARTING SYSTEM	-	-	1.6
FUEL SYSTEM	10.6	2.6	9.6
FLT CONTROLS	97.6	231.0	80.5
INSTRUMENTS	171.6	-	51.5
HYD & PNEUMATIC	8.8	179.0	25.3
ELECTRICAL	180.8	35.0	151.6
AVIONICS INSTL	-	-	62.6
FURN. & EQUIP	271.0	13.0	228.8
AIR COND.	190.8	22.3	186.1
ANTI-ICING	43.4	-	36.2
SYS. INTEG.	*528.5	38.0	62.7
ECO'S SUSTAIN. ETC.	-	318.3	660.0
TOTAL	2471.6	1984.2	2481.7

*INCLUDES ECO'S SUSTAIN. ETC.

C-3

reported data from commuter type operations that would be consistent with the ground rules established for the new-design 30 and 50 passenger aircraft. The data obtained for this purpose is shown in Table 5. These data are CAB data prepared by AVMARK for Air Transport World, July 1979, and indicates systems parameters, airline operators and type of aircraft. Reported data was not available on the DHC-7 and the block speed and block time were caluclated from source data. The other parameters are the same as those for the new short haul aircraft. Fortunately the reported data for the airlines and aircraft are in close agreement with the parameters chosen for the study aircraft. This is due to the coordination of factors accomplished earlier by NASA. In addition to the reported data shown in Table 5, DOC data on the SD3-30 was obtained from Golden West Airlines. These data provided a real world comparison with the 30 and 50 passenger new-design aircraft DOC estimate.

The reported and calculated maintenance costs for the short haul aircraft are shown in Table 6. The maintenance cost is broken down into; airframe, engine, and other. Maintenance burden is also shown separately. The calculated maintenance for the 30 and 50 passenger aircraft is based on the ATA method. The calculated maintenance cost is determined by applying modifiers to the ATA formulas to convert it to short haul operations. The determination of the modifiers is the item of concern at this point.

The engine companies provided a maintenance cost relationship which was used as the basis for modifying the engine maintenance cost relationship in the ATA method. The L-1011 experience was used to modify the airframe maintenance formulas. The maintenance cost relationship provided by the engine companies was a constant cost in terms of $/black hour regardless of range. This caused difficulty in determining at which point, in terms of range, the cost would be applicable. The problem is illustrated in Figure 6. The maintenance cost by the ATA method is reduced with increase in range. This is due to the lesser number of cycles flown per year and consequently the fewer number of takeoff and landings and engine thermo cycles. The engine maintenance cost shown as a constant (Figure 6) may be correct at one point but is incorrect at all other. If the correct point is at 50 N.mi

TABLE 5. SYSTEM PARAMETERS

	CAB DATA PREPARED BY AVMARK						CALCULATED DATA/EST.		
AIRCRAFT	CV-580			CV-600	FH227	METRO LINER	30 PAX	50 PAX	DHC-7
AIRLINE	FL	NC	AL	TI	OZ	SO			(1)
*STAGE LENGTH	114	86	131	131	97	102	100	100	100
UTILIZATION	2592	2774	2263	1460	2482	2883	2800	2800	2800
NO. OF SEATS	50	48	50	40	44	18	30	50	50
LOAD FACTOR	57	55	67.6	57.5	57.6	51.9	-	-	-
BLOCK SPEED	169	158	170	156	136	150	172	213	147
BLOCK TIME	.674	.544	.770	.840	.713	.680	.58	.47	.68
TRIPS/YEAR	3846	5099	2939	1738	3481	4240	4861	6006	4118

*N.MI.

(1) SYSTEM PARAMETERS CALCULATED.

TABLE 6. TOTAL MAINTENANCE COST

	REPORTED MAINT. COST* ($/BLK HR)						CALCULATED MAINT COST	
	CV 580			CV 600 TI	FH 227 OZ	METRO SO	30 PAX	50 PAX
	FL	NC	AL					
AIRFRAME	56.38	59.82	39.42	44.13	56.87	13.51	68.90	93.0
ENGINE	71.54	45.28	40.30	57.41	71.69	20.77	65.90	121.0
OTHER	17.14	18.28	44.68	15.17	27.31	9.02	-	-
TOTAL DIRECT	145.06	123.37	124.40	91.36	155.86	43.31	134.80	214.0
BURDEN	108.46	88.76	46.43	37.49	99.80	38.91	51.20	68.0
TOTAL MAINT	253.52	212.13	170.83	128.85	255.66	82.22	186.00	282.0

*CAB DATA PREPARED BY AVMARK FOR AIR TRANSPORT WORLD - JULY, 1979

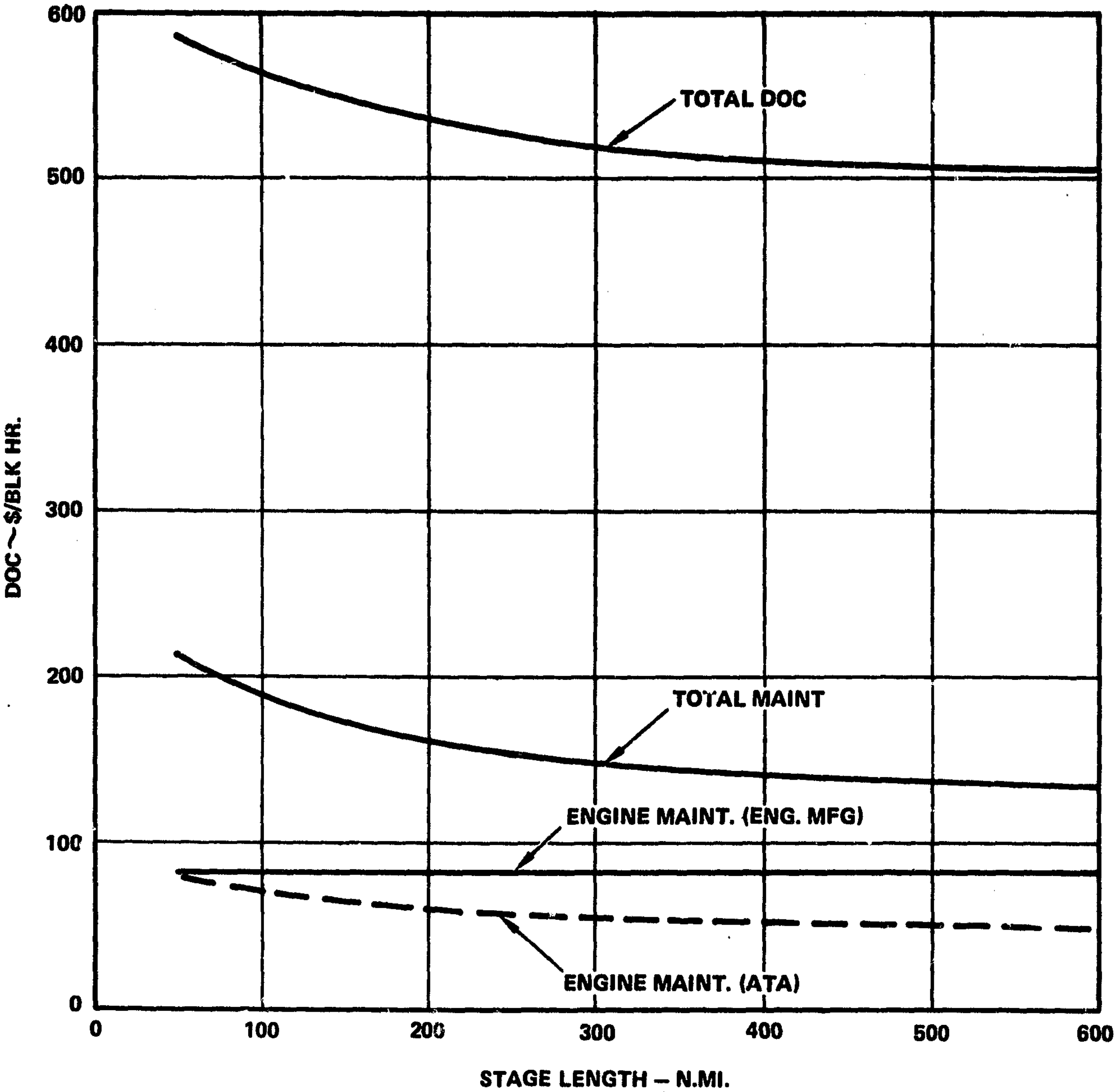

Figure 6. Doc & Maintenance Cost - 30 Pass. Aircraft

range then at all ranges greater than 50 N.mi the aircraft is being penalized by the differences shown. The engine maintenance costs shown in Table 6 for for the 30 and 50 passenger airplanes are based on the constant engine maintenance cost and airframe maintenance as determined from L-1011 experience. Noting the differences in maintenance cost for similar size aircraft the calculated costs are considerably higher than the reported maintenance cost. The next step is to compare the calculated cost with the reported cost for all aircraft for total DOC. The comparison between the calculated DOC and reported DOC is shown in Tables 7 and 8. The comparison for aircraft similar in size to the 30 passenger new design aircraft is contained in Table 7 and the comparison for aircraft similar to the 50 passenger airplane in Table 8. The fuel and oil costs shown in Tables 7 and 8 are all normalized to 50 cents per gallon. There are such varied reasons for differences in crew cost that changes cannot be made with specific justification and therefore no adjustment is made. Insurance is a matter of policy with the particular airline and the 1.5% factor as obtained by NASA from their survey of commuter and local airline is used.

Depreciation is a function of the aircraft price and the amortization period. The justification for the price for the new design aircraft is indicated in the previous Figures and Tables and appears to be reasonable. The higher depreciation cost for the new-design aircraft is to be expected as the higher performance incorporated into these aircraft must come at a higher price. The effect of a longer depreciation period is shown later. The maintenance cost is considerably higher for the new-design aircraft in both sizes. Since the new design aircraft are using turboprop engines that will have maintenance features that will be as good or better than the turboprop engines used by the aircraft shown on Table 7 and 8 it is reasonable to assume that the maintenance cost for the engine and airframe for the new design aircraft would be consistent with the reported cost for these aircraft.

TABLE 7. DOC COMPARISON - 30 PAX 100 N.MI.

	30 PAX		METRO (1)		DS3-30 (2)	
	CALC	REPORT	CALC	REPORT	CALC	REPORT
CREW	75.0		47.5	50.6	75.0	108.0
FUEL & OIL	84.4		36.4	36.4	76.0	76.0
INSURANCE	22.4		6.7	2.2	9.6	9.0
DEPRECIATION	111.5		33.5	46.7	49.2	60.0
MAINTENANCE	185.9		93.7	82.2	95.2	73.0
TOTAL ($/BLK HR)	479.2		217.8	218.1	305.0	326.0
TOTAL (¢/SM)	9.20		8.06		10.17	
SEAT MI/YR(10^6)	14.58		7.78		8.4	

CALC: CALCULATED COSTS BY ATA METHOD AND NASA GROUND RULES.
FUEL COST 50¢ PER GALLON.

REPORT: DOC OBTAINED FROM THE FOLLOWING SOURCES:

(1) DATA PREPARED FOR AIR TRANSPORT WORLD, JULY 1979, BY AVMARK (CAB DATA)

(2) INFORMATION FROM GOLDEN WEST AIRLINES

TABLE 8. DOC COMPARISON - 50 PAX 100 N.MI. STAGE LENGTH

	50 PAX		FH 227(1)		DHC-7(3)		CV580(1)	
	CALC	REPORT	CALC	REPORT	CALC	REPORT	CALC	REPORT
CREW	125.0		110.0	140.3	125.0	100.0	75.0	181.6
FUEL & OIL	150.0		143.0	143.0	123.0	123.0	166.0	166.0
INSURANCE	29.0		22.8	2.0	24.0	17.0	26.1	2.9
DEPRECIATION	146.0		*119.1	4.7	127.5	125.0	*138.3	42.3
MAINTENANCE	284.0		159.7	255.7	216.5	136.0	217.6	212.1
TOTAL ($/BLK HR)	734.0		554.6	545.7	616.0	501.0	623.0	604.9
TOTAL (¢/SM)	6.85		8.98		8.38		7.06	
SEAT MI/YR(10^6)	30.0		17.28		20.59		24.70	

CALC: CALCULATED COST BY ATA METHOD AND NASA GROUND RULES.
FUEL COST 50¢ PER GALLON.

REPORT: DOC OBTAINED FROM THE FOLLOWING SOURCES:

(1) DATA PREPARED FOR AIR TRANSPORT WORLD, JULY 1979, BY AVMARK (CAB DATA)

(3) INFORMATION FROM COMMUTER AIR, JUNE 1979.

*DEPRECIATION BASED ON NEW AIRCRAFT PRICE.

The airframe and maintenance costs were split out of the total maintenance cost and analyzed separately. Table 6 shows the reported maintenance cost by airframe, engine and "other". The "other" category was prorated into engine and airframe maintenance cost by their ratio. The adjusted reported airframe maintenance cost in terms of $/blk hr. is shown in Table 9. Table 9 also shows the airframe maintenance in terms of $/blk hr/1000 lbs of gross weight.

The reported airframe cost in terms of $/blk hr/1000 lbs g.w. shows a good correlation. The average for these aircraft is 1.43. The calculated airframe cost for the 30 and 50 passenger new design aircraft is 2.41 and 2.30; considerably more than actual experience. The result of this analysis is to reduce the airframe maintenance modifier from .65 (L-1011 experience) to .40 (short haul experience). The same procedure is followed for engine maintenance. The engine maintenance cost as calculated by the ATA formula (modified by the data from the engine companies) is compared to the reported cost (Table 10). This comparison indicates that the engine cost modifier as derived from the engine company data may be reduced from 1.13 to 1.0, or that the unmodified ATA provides the best estimate. This agrees with experience on the L-1011. The accumulation of maintenance data over the years indicates that on high bypass engines the engine maintenance is predicted by the ATA formula at 100% of the formula values for the beginning of operations and drops to 90% of the values for mature systems (6 years).

The maintenance modifiers are incorporated into the ASSET cost model and the baseline aircraft (30 and 50 PAX) are reevaluated. The DOC comparison is shown in Tables 11 and 12. The first column in Tables 11 and 12 shows the DOC with the new maintenance cost factors applied. The second column shows the impact of increasing the depreciation period from 12 years to 16 years in addition to the new maintenance factors. The depreciation cost is a major contributor to the DOC and for the new design aircraft is considerably more than the current short haul aircraft. The higher cost for the new design aircraft is due to price that has to be paid for added productivity. The block speed of the new design aircraft is considerably

TABLE 9. AIRFRAME MAINTENANCE COST COMPARISON (EXCLUDING BURDEN)

	GROSS WEIGHT	REPORTED AIRFRAME MAINT ($/BLK HR)	AIRFRAME MAINT. ($/BLK HR/1000 LB)	FACTOR FOR SHORT HAUL ($/BLK HR/1000 LB)	REVISED MAINT. COST FOR NEW DESIGN A/C ($/BLK HR)
CV 580	52000	77.0	1.48	1.43	77.0
CV 600	44000	52.0	1.18		52.0
FH 227	45500	71.0	1.56		71.0
METRO	12500	18.5	1.48		18.5
30 PAX	28000	62.0	2.41	1.43	38.0
50 PAX	40000	88.0	2.30	1.43	54.0

TABLE 10. ENGINE MAINTENANCE COST COMPARISON (EXCLUDING BURDEN)

	TOTAL ESHP PER AIRCRAFT	REPORTED ENGINE MAINT. ($/BLK HR)	CALCULATED ENG. MAINT. ($/BLK HR)	REVISED CALC COST FOR NEW DESIGN AIRCRAFT
METRO	1880	25.5	37.0	25.5
FH-227	4640	87.0	53.0	87.0
CV-580	9000	65.0	80.0	65.0
30 PAX	4804	-	59.0	52.0
50 PAX	9608	-	100.0	88.0

TABLE 11. DOC COMPARISON - 30 PAX 100 N.MI. STAGE LENGTH

	30 PAX		METRO		SD3-30	
	CALC	CALC(1)	CALC	REPORTED	CALC	REPORTED
CREW	75.0	75.0	47.5	50.6	75.0	108.0
FUEL & OIL	84.4	84.4	36.4	36.4	76.0	76.0
INSURANCE	22.4	22.4	6.7	2.2	9.6	9.0
DEPRECIATION	111.5	84.0	33.5	46.7	49.2	60.0
MAINTENANCE	133.0	133.0	93.7	82.2	95.2	73.0
TOTAL ($/BLK HR)	426.3	398.8	217.8	218.1	305.0	326.0
TOTAL (¢/SM)	8.19	7.71	8.06		10.17	
SEAT MI./YR (10^6)	14.58	14.58	7.78		8.4	

(1) 16 YEAR DEPRECIATION PERIOD RATHER THAN 12 YEARS.

TABLE 12. DOC COMPARISON - 50 PAX 100 N.MI. STAGE LENGTH

	50 PAX		FH 227		DHC-7		CV-580	
	CALC	CALC(1)	CALC	REPORTED	CALC	REPORTED	CALC	REPORTED
CREW	125.0	125.0	110.0	140.3	125.0	100.0	75.0	181.6
FUEL & OIL	150.0	150.0	143.0	143.0	123.0	123.0	166.0	166.0
INSURANCE	29.0	29.0	22.8	2.0	24.0	17.0	26.1	2.9
DEPRECIATION	146.0	110.0	119.1	4.7	127.5	125.0	138.3	42.3
MAINTENANCE	195.0	195.0	159.7	255.7	216.5	136.0	217.6	212.1
TOTAL ($/BLK HR)	645.0	609.0	554.6	545.7	616.0	501.0	623.0	604.9
TOTAL (¢/SM)	6.85	5.73	8.98		8.38		7.06	
SEAT MI/YR(10^6)	30.0	30.0	17.28		20.59		24.7	

(1) 16 YEARS DEPRECIATION PERIOD RATHER THAN 12 YEARS.

more than a like size current aircraft shown in Table 5. When the productivity is combined with the cost the results (cents/seat mi) for the new design aircraft are competitive with the current aircraft. It must be pointed out at this time that the new design aircraft incorporates only that technology that is available at this time. Advanced technology features will be also evaluated at a later time to determine their impact on cost and productivity.

Another approach to determing the maintenance cost was to perform a statistical analysis on the reported data for the current aircraft and apply the results to the new-design aircraft. The results of the statistical analysis are shown in Table 13. The estimates from the multiple regression analysis from either formula for the new design aircraft are lower than the estimates chosen from the comparative analysis shown in Tables 11 and 12. There are too few data points (5) for the statistical data to be more accurate than the comparative analysis. The standard error is high and the estimates from the comparative analysis could easily fall within the bandwidth of the correlation. Therefore the estimates from the comparative analysis is chosen as more reasonable.

The indications at this point are that:

- The new-design aircraft meet the performance requirement set forth for the short haul aircraft.
- The higher performance requirements exact a higher price than current jet or turboprop aircraft of similar size (excluding the Challenger and Falcon aircraft).
- The higher productivity for the new-design aircraft (seat miles/year) offsets the higher price and the new-design aircraft are competitive with current aircraft.

TABLE 13. STATISTICAL ANALYSIS - TOTAL MAINTENANCE 100 N.MI. STAGE LENGTH

EQUATION	CORRELATION COEFFICIENT	STANDARD ERROR	MAINT. ESTIMATE	
			30 PAX	50 PAX
MAINTENANCE COST ($/BLK HR)				
(1.) $-66.33 + .0053(\text{WT EMPTY}) + .404(\text{BLK SPEED})$	.861316	57.7	101	152
(2.) $\left[(\text{WT EMPTY})^{.59} \times (\text{BLK SPEED})^{1.52}\right]/11316$	.919516	36.6	76	126

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