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WEASEL WORKS
SA-150

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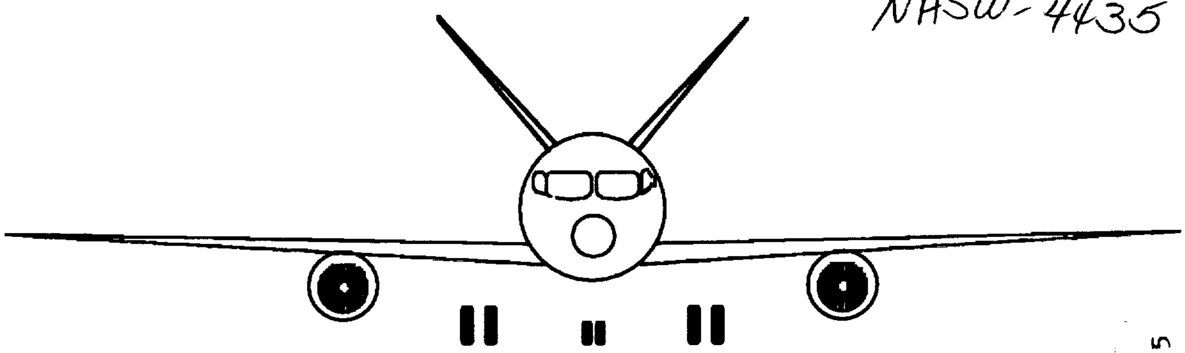

Design Study of a 100 to 150 Passenger Transport Aircraft

Aeronautical Engineering Department
California Polytechnic State University
San Luis Obispo
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Weasel Works Design Team
Kevin Alkema
Michael Comeaux
Timothy Gilbert
Victor Para
George Toepfer

N94-24975

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ABSTRACT

As the year 2000 rapidly approaches, the airlines are faced with an extremely competitive and environmentally restrictive marketplace. In order to survive, commercial air carriers will need to find new ways to lower their direct operating costs, increase load factors and comply with tightening federal and international constraints. The SA-150 has been designed to meet these demands by focusing on the areas of aerodynamic efficiency, an improved level of passenger comfort, and a limited application of advanced technology.

The SA-150 has been optimized for a 500 nmi. mission to help the airlines meet the challenges of the short haul, quick turnaround flight. With a maximum capacity of 124 passengers, and full baggage, the SA-150 is also capable of covering a range of 1500 nmi. This additional range capability will provide the airlines with flexibility when scheduling their routes. The aircraft features a "V" tail, fly-by-wire system and is powered by two turbofans mounted under a twelve aspect ratio wing. The SA-150 will have an initial production run of 800 units and have a purchase price of $37.7 million in 1993 dollars.

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NOMENCLATURE

AOA	Angle of Attack
APU	Auxiliary Power Unit
AR	Aspect Ratio
ASM	Available Seat Mile
CG	Center of Gravity
C_D	Coefficient of Drag
C_{Di}	Induced Coefficient of Drag
C_L	Coefficient of Lift
$C_{Lmax\ l}$	Maximum Coefficient of Lift at Landing
$C_{Lmax\ to}$	Maximum Coefficient of Lift at Take Off
C_d	Section Coefficient of Drag
C_l	Section Coefficient of Lift
C_m	Pitching Moment Coefficient
DOC	Direct Operating Cost
°F	Degrees Fahrenheit
FAR	Federal Aviation Regulation
FCS	Flight Control System
FOD	Foreign Object Damage
GPS	Global Positioning System
ICA	Initial Cruise Altitude
ICAO	International Civil Aviation Organization
INS	Inertial Navigation System
IOC	Indirect Operating Cost
K_β	Sideslip to Rudder Feedback Gain
LCC	Life Cycle Cost
LCN	Landing Classification Number
L/D	Lift to Drag Ratio
LE	Leading Edge
M	Mach Number
MAC	Mean Aerodynamic Chord
MGTOW	Maximum Gross Take Off Weight
MSL	Mean Sea Level Altitude
NO_x	Nitrogen Oxides Emission

OEI	One Engine Inoperative
PAX	Passengers
RAT	Ram Air Turbine
RDTE	Research, Development, Test, and Evaluation
RFP	Request For Proposal
S	Surface Area
SAS	Stability Augmentation System
S/L	Sea Level Altitude
S_h	Horizontal Projected Surface Area
S_{ref}	Reference Surface Area
S_v	Vertical Projected Surface Area
S_{wet}	Wetted Surface Area
TACAN	Tactical Air Navigation System
TE	Trailing Edge
T/O	Take Off
T/W	Thrust to Weight Ratio
V_A	Maneuver Velocity
V_C	Cruise Velocity
V_D	Dive Velocity
V_S	Stall Velocity
W/S	Wing Loading
W_e	Empty Weight
W_f	Fuel Weight
W_g	Gross Take Off Weight
W_{oe}	Operational Empty Weight
W_{pl}	Payload Weight
W_{to}	Take Off Weight
Xcg	Longitudinal Location of the Center of Gravity
Ycg	Lateral Location of the Center of Gravity
Zcg	Vertical Location of the Center of Gravity
b	Wing Span
c	Chord Length
e	Efficiency Factor
fps	Feet per Second
ft	Feet

g	A Unit Earth Gravitational Force
hr	Hour
kVA	Kilo Volt-Amperes
lb	Pound
mph	Miles per Hour
nmi	Nautical Miles
psi	Pounds per Square Inch
sfc	Specific Fuel Consumption
sq. in.	Square Inches

Stability and Control Derivatives

C_{Lu}	Lift due to speed derivative
C_{mu}	Pitching moment due to speed derivative
$C_{L\alpha}$	Lift due to angle of attack derivative
$C_{m\alpha}$	Pitching moment due to angle of attack derivative
$C_{L\alpha\text{-dot}}$	Lift due to angle of attack rate derivative
$C_{m\alpha\text{-dot}}$	Pitching moment due to angle of attack rate derivative
C_{Lq}	Lift due to pitch rate derivative
C_{mq}	Pitching moment due to pitch rate derivative
$C_{l\beta}$	Rolling moment due to sideslip derivative
$C_{n\beta}$	Yawing moment due to sideslip derivative
$C_{y\beta}$	Sideforce due to sideslip derivative
$C_{l\beta\text{-dot}}$	Rolling moment due to sideslip rate derivative
$C_{n\beta\text{-dot}}$	Yawing moment due to sideslip rate derivative
$C_{y\beta\text{-dot}}$	Sideforce due to sideslip rate derivative
C_{lr}	Rolling moment due to yaw rate derivative
C_{nr}	Yawing moment due to yaw rate derivative
C_{yr}	Sideforce due to yaw rate derivative
C_{lp}	Rolling moment due to roll rate derivative
C_{np}	Yawing moment due to roll rate derivative
C_{yp}	Sideforce due to roll rate derivative
$C_{l\delta a}$	Rolling moment due to aileron deflection derivative
$C_{n\delta a}$	Yawing moment due to aileron deflection derivative
$C_{l\delta r}$	Rolling moment due to rudder deflection derivative

$Cn\delta r$	Yawing moment due to rudder deflection derivative
$Cy\delta r$	Sideforce due to rudder deflection derivative
$Cl\delta s$	Rolling moment due to spoiler deflection derivative
$Cn\delta s$	Yawing moment due to spoiler deflection derivative
$CL\delta e$	Lift due to elevator deflection derivative
$Cm\delta e$	Pitching moment due to elevator deflection

1.0

INTRODUCTION

Since the introduction of the Boeing 737 and the McDonnell Douglas DC-9 series in the mid-sixties, manufacturers have not presented the commercial air carriers with a new aircraft design in the 100 to 150 passenger capacity category. Instead, the old designs have been stretched and re-engined to meet increased capacity requirements and more stringent environmental constraints.

The DC-9-50, first flown in 1965, was grown into the MD-80 family in 1979 by stretching the fuselage to a length of 135 ft using plugs fore and aft of the wing, and by adding root plugs and a 2 ft tip extension increasing the wing span to 108 ft. While many systems and components of the aircraft were upgraded, the fuselage diameter, wing and basic empennage design have remained the same. This series of aircraft was further modified by re-engining in 1989 with the International Aero Engines V2500-D turbofans in place of the Pratt & Whitney JT-8D family to create the MD-90 series.[1]

The Boeing 737-200 first flew in 1967 and was also powered by the Pratt & Whitney JT-8D family of engines. It remained relatively unchanged until the next variant of this aircraft, the 737-300, flew in 1984. The most noticeable changes were the switch to the CFM International CFM-56 power plant, a lengthening of the fuselage by addition of plugs fore and aft of the wing, and the addition of 1 ft wing tip extension. Once again there were a number of system and component upgrades, but the basic design of the wing, fuselage and empennage remained the same.[1]

This method of upgrading aircraft has been an economically effective procedure for many years, but it has limits. It is not possible to widen a fuselage or to significantly redesign a wing planform and cross section without incurring considerable design and development costs. In addition, modifying existing equipment to improve efficiency and squeeze out savings will become increasingly expensive as the room for improvement on current designs keeps decreasing.

Another limiting factor will be the airlines refusal to pay a substantially higher price for what is seen as the "same" aircraft.[2] It can be

difficult to justify spending 30 to 35 million dollars for an updated version of an old design when a new and more efficient aircraft can be purchased for 38 million dollars. In the 100 to 150 passenger transport category current aircraft designs have reached the point of diminishing returns. To continue stretching and modifying them will quickly result in aircraft that are unprofitable for the manufacturer to produce.

The SA-150 has been designed to meet the challenges of a highly competitive marketplace and to comply with the proposed Stage IV environmental restrictions on noise and emissions.[3] Optimized to a range of 500 nmi. with a maximum capacity of 124 passengers, the SA-150 will fill the requirement for an advanced, short haul, quick turn around, feeder route aircraft. In addition, the SA-150 has the capability to complete a 1500 nmi. mission, with full passengers and baggage, without modification. This longer range and an unrestricted cruise speed of Mach 0.76 present the airlines with the flexibility they need for route scheduling.

The centerpiece of this new design is the high aspect ratio, all composite wing. With an aspect ratio of 12, the SA-150 gains a significant advantage over the competition by minimizing induced drag and allowing for the utilization of a simple, light weight, high lift system. In addition, a “V” tail configuration has been adopted to reduce interference drag and further enhance the aerodynamics of the aircraft. The incorporation of a fly-by-wire flight control system removes the complex mechanical linkage associated with this configuration and decreases fuel burn by improving the efficiency of the auto pilot system.

While the use of carbon fiber laminate for the construction of the wing structure will be expensive, the increased strength and rigidity of the material is required to prevent the aeroelastic flutter effects associated with the high aspect ratio. Although the initial purchase price of the SA-150 will be affected by this design choice, the decreased weight and reduced surface area of the structure will result in lower direct operating costs for the airlines. With its clean burning and quiet engines, wide cabin, enhanced passenger conveniences, and distinctive configuration, the SA-150 will provide the airlines with the tool they need to effectively compete in the next century.

2.0

MISSION PROFILE

2.1 Mission Requirements

A Request for Proposal was presented to the Weasel Works Design Team to design an aircraft in the 100 to 150 passenger category. The SA-150 is required to perform a 1500 nmi. mission. This is to be done with an initial climb to altitude of 35,000 ft, in 25 minutes, and cruise at a Mach number of 0.76. A one hour loiter time and domestic fuel reserves are also included for this aircraft. Step climbing is permitted in 4000 ft increments, and the maximum design altitude of the SA-150 is 40,000 ft. Figure 2.1 illustrates this mission profile.[4]

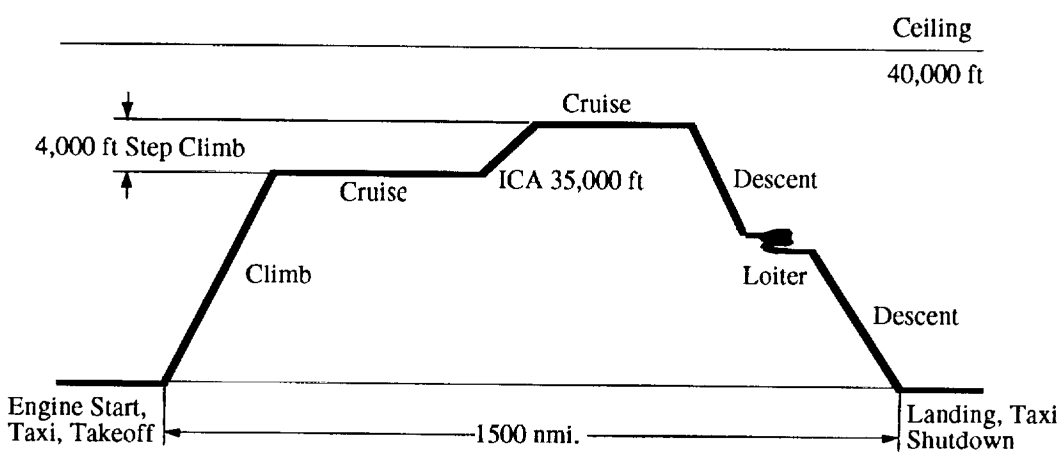


Figure 2.1 SA-150 RFP Mission Profile

2.2 Primary Mission

Although the SA-150 will meet all specified mission requirements, the aircraft will be optimized to a 500 nmi. mission, since airlines typically use small aircraft in this size category as feeder aircraft. As a feeder aircraft, the SA-150 would normally be used by commuters and business travelers between city pairs that are relatively close to one another. By looking at ranges between these city pairs, such as Portland to San Francisco, it was

found that a 500 nmi range was a typical average. For this mission, as illustrated in Figure 2.2, the cruise altitude will be below 30,000 ft to increase the L/D ratio and step climbs will be performed in 2,000 ft increments as required by FAR[3].

With this relatively small range, airline operators will demand that the aircraft be easy to service, capable of relatively short field operations, and very efficient in take-off and climb configurations. The SA-150 is designed to meet these needs, while still retaining the ability for a 1500 nmi flight.

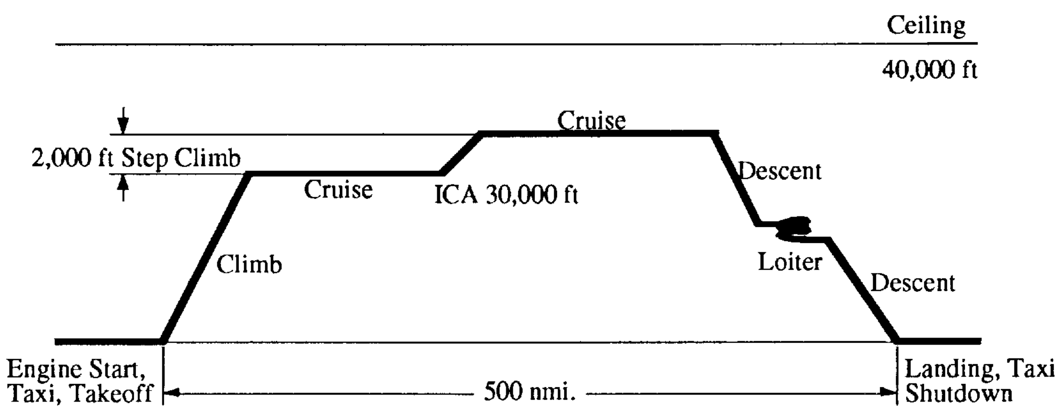


Figure 2.2 SA-150 Primary Mission Profile

3.0

SIZING ANALYSIS

3.1 Preliminary Sizing

The SA-150 was initially sized using the method outlined in Reference 4. This method of fuel fraction weight build is base on historical data and empirical equations. The method yielded a baseline weight and capacity that was iterated during the weight and balance phase of the design. The assumptions used for the initial sizing are listed in Table 3.1a.

Table 3.1a SA-150 Initial Sizing Assumptions

Maximum Range (nmi.)	1500
Passengers	125
Weight/Passenger (lbs.)	175
Baggage/Passenger (lbs)	35
Number of Crew	5
Weight/Crew (lbs.)	175
Crew Baggage (lbs.)	35
Cruise SFC (lbs/lbs/hr)	0.66
Cruise L/D	18
Loiter SFC (lbs/lbs/hr)	0.6
Loiter L/D	20

Early on in the development phase it was decided that the SA-150 would serve primarily as a feeder aircraft. This means that the aircraft would be optimized to a shorter range of 500 nmi. and the RFP required mission of 1500 nmi. would be the outside range of the aircraft. The SA-150 was initially sized to carry a maximum of 115 passengers and a minimum load of less than 100. Research was done on the passenger carrying ability of the aircraft in this size to see if these capacities were being utilized. The result was that the SA-150 was increased in size to a maximum of 125 PAX. The minimum passenger load is 108 which is equal to that of the minimum seating in the Boeing 737-500.[1]

Initial sizing of the aircraft yielded a maximum take-off weight of approximately 112,000 lb. Since the decision was made to build the wing with composite materials, which reduced both structure and fuel weight, the final maximum take-off weight was set at 104,000 lb The composite wing saves 4,500 lb in structural weight and another 3,500 lb in fuel weight.[5] To complete the 1500 nmi. mission with reserves, 23,000 lb of fuel is required.

Figure 3.1 indicates the design point for the SA-150 and the limiting performance parameters. The critical thrust to weight ratio of the SA-150 is primarily determined by direct climb requirements. Calculations indicated that FAR part 25 OEI requirements are not a determining factor in the sizing of this aircraft. A final thrust to weight ratio of 0.28 lb/lb has been selected and the wing loading of the SA-150 will be 109 lb/ft^2. This value is similar to wing loading used by Boeing 737 and Douglas MD-80 aircraft and was selected to give the SA-150 the best ride qualities possible without requiring the wing to generate unreasonably high coefficients of lift. The preliminary sizing results are listed in Table 3.1b.

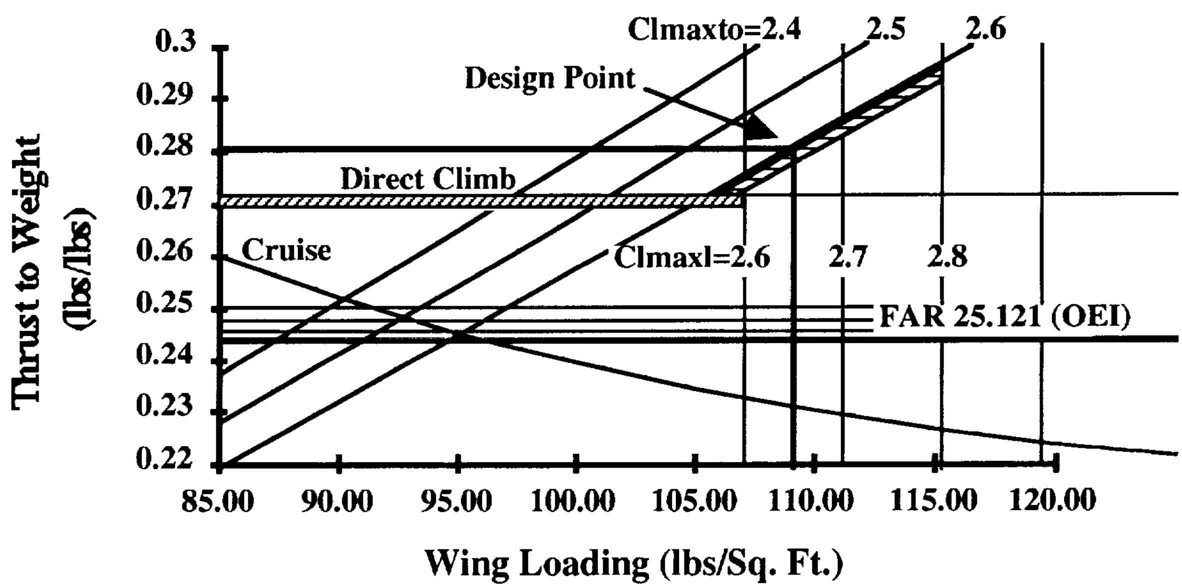


Figure 3.1 SA-150 Design Point Graph for SA-150: 1500 nmi. Mission

Table 3.1b SA-150 Final Sizing Results

Cruise Mach No.	0.76	Range (nmi.)	1500
Passengers	124	Wing Area (sq. ft.)	955
Wfuel (lb.)	23,000	Wgross (lb.)	104,000
W/S	110	T/W	0.28

4.0 AIRCRAFT CONFIGURATION

4.1 Aircraft Three View

The SA-150 went through many design revisions before a final design was settled upon. This configuration is shown in Figure 4.1. In many ways the SA-150 is a conventional aircraft. The major features of the SA-150 are the high aspect ratio wing and the "V" tail. These aspects of the design were selected to improve the efficiency of the aircraft and lower direct operating costs.

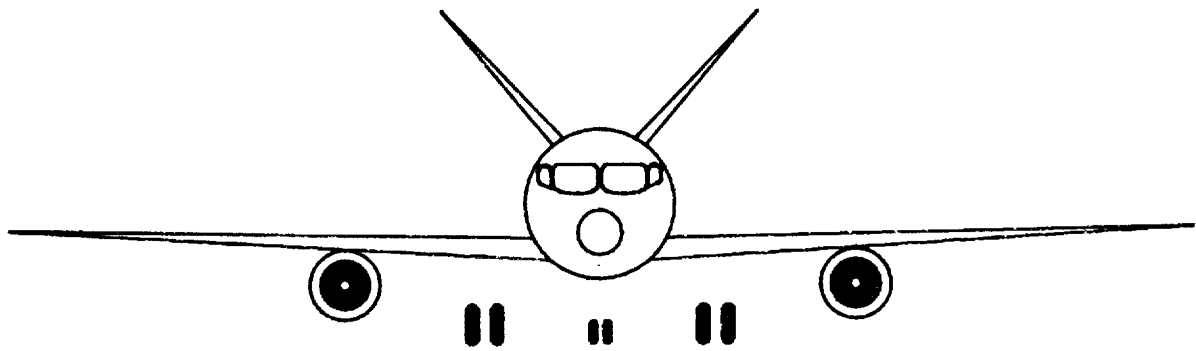
4.2 Aircraft Design Concepts

Before the final configuration of the SA-150 was determined, many different ideas were considered. The design approach was to consider current overall designs of aircraft already in service and determine the advantages and disadvantages of each design.

One proposal was to mount the engines on the aft end of the fuselage, much like an MD-80, but this would necessitate attaching the wing much farther back than if an under-wing engine configuration was used. Aircraft with this design have a real problem with CG shifts and are very load sensitive. The main reason for a rear mounted engine configuration is to eliminate clearance problems that arise when engines are mounted under the wing. This is a definite concern, especially considering the trend towards larger and larger fan inlets to achieve high bypass ratios.

Adding a canard to the aft engine configuration was investigated to increase control power and to trim the aircraft with an up-load instead of the down force associated with a conventional tail design. This reduction in trim drag would result in a more efficient aircraft. The main problem with the canard configuration is in its placement on the aircraft. If the canard is placed at the top of the fuselage, the possibility exists that it would obstruct the placement of the jetway or be damaged during its positioning. A high

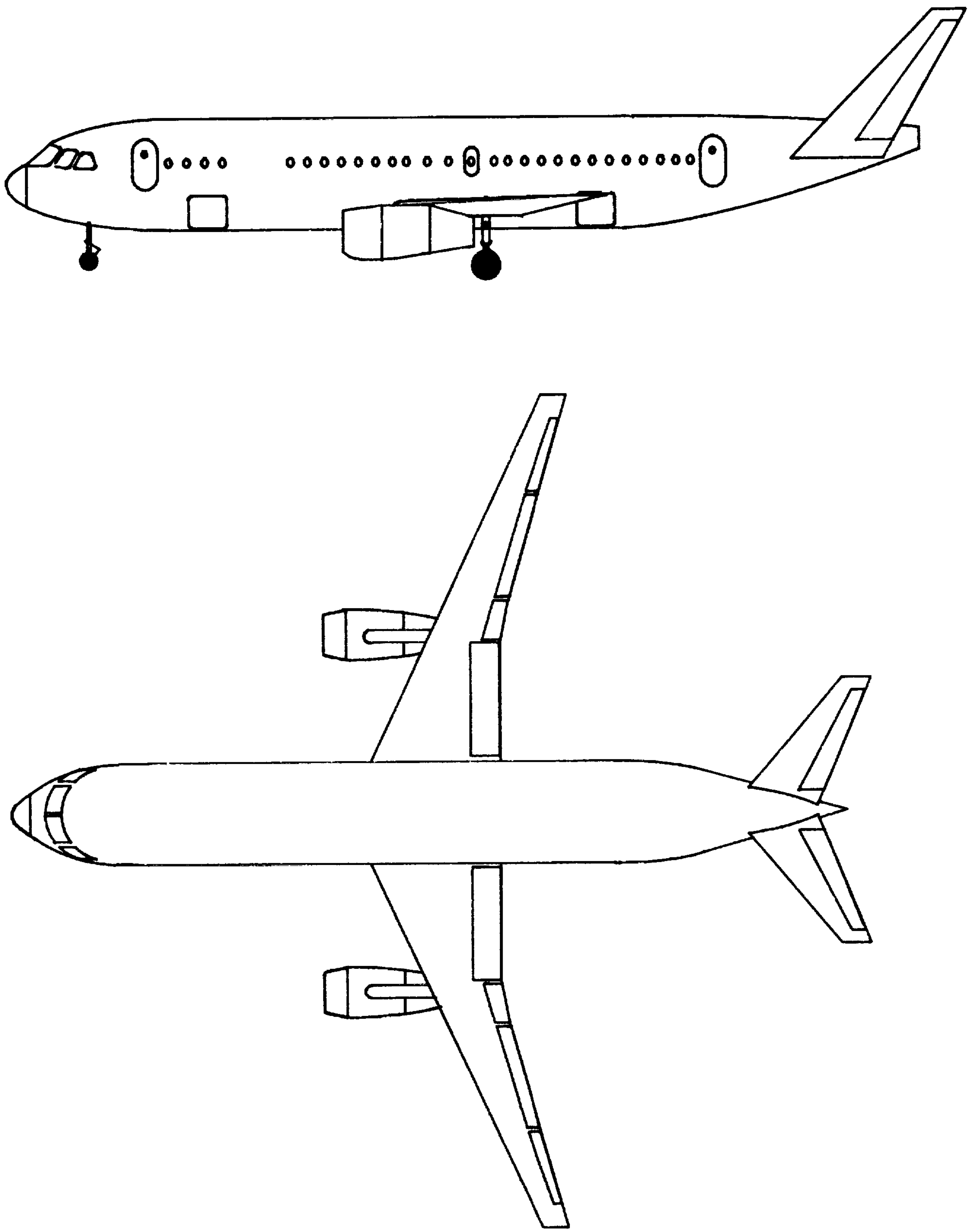
FOLDOUT FRAME



Length = 107 ft
Span = 107 ft
Height = 31 ft

Figure 4.1 SA-150 Aircraft Three View

FOLDOUT FRAME 2 .



mounted canard would also cause a downwash to flow across the wing, reducing it's effectiveness. If the canard is placed on the lower side of the fuselage the possibility exists that a maintenance or servicing vehicle could collide with the canard. Both of these locations proved unacceptable for a commercial transport, so a canard was eliminated from the options for the design of the SA-150.

Sweeping the wing forward was also considered. This option had the advantage of relieving some of the CG shift problems of a rear engine aircraft.. The combination of manufacturing and research and development costs, however, would make the price and weight of an aircraft design of this type prohibitive. Since no satisfactory solution could be found to eliminate the control problems and CG shifts associated with a rear engine design this configuration option was abandoned.

After rejecting the problems associated with a rear engine design, a wing mounted arrangement was investigated. Proposals for using two large turbofan engines or four smaller engines were considered. Due to thrust limitations and the probability of failure associated with a three or four engine design, it was decided that a twin engine arrangement would be best. The option of using turboprops was eliminated due to the limited cruising speeds obtainable and the low marketability of such a design. Propfans were considered but eliminated because they would have to be mounted on the aft end of the fuselage. They were also eliminated because it is unlikely they could be produced in time for the SA-150's introduction into service date of the year 2000 and cost would be prohibitive.

Again, a canard was considered, but quickly rejected for the same reasons as stated for the rear engine design. A “V” tail was proposed early on, but was rejected since not much was known about the design. Therefore, the first tangible configuration that became a base to work from was very conventional, much like the Boeing 737 family of aircraft. This was considered the best design and Boeing has proven the reliability and cost effectiveness of such an aircraft.

Midway through the design process, the “V” tail was reborn to improve the airplane's drag characteristics by 2-3%. This has proved to be of limited benefit, since drag reductions are smaller than anticipated, yet the “V” tail has been retained for its ease of manufacture and its distinctive look, which gives the SA-150 the advantage of instant recognition. A high aspect

ratio wing was also added at this time in an attempt to minimize induced drag. This addition requires the use of advanced composite construction techniques to counter the effects of aeroelastic flutter. As a side benefit to this method of construction, weight is reduced by 15% which improves the efficiency of the SA-150 and lowers direct operating costs. The results of all these trades is the final configuration of the SA-150 illustrated in Figure 4.1.

5.0

WING DESIGN

5.1 Wing Sizing

The wing selection was based on the premise that the SA-150 would be optimized to a mission length of 500 nmi. Since the aircraft will be spending a considerable amount of time in the takeoff and climb configurations, it is important to keep total drag to a minimum for these segments of the flight. Under these conditions, induced drag is the largest contributor and the most effective way to minimize it is to increase the aspect ratio of the wing. The first conceptual design of the SA-150 had a relatively high AR of 10, which is comparable with the Douglas MD-80 & 90 series aircraft.[1] However, when considering an entry into service date of the year 2000, and the rapidly advancing field of composite construction techniques, it was felt that the AR could safely be pushed to a value of 12 to lower induced drag[6]. Since induced drag is the largest contributor to the total aircraft drag the SA-150 was designed to reduce it as much as possible, Figure 5.1.

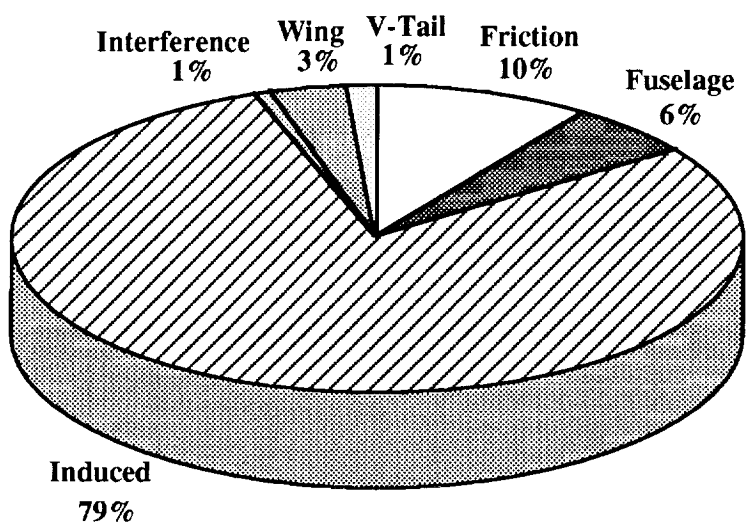


Figure 5.1 SA-150 Take-off Drag Breakdown

The leading edge sweep angle was established at 25° after examining drag rise vs. Mach number curves for NACA airfoils.[7] A minimum amount of sweep was desired so that wing weight could be kept low but this angle

could not be so shallow that wave drag penalties would be incurred at cruise speed.

To reduce the Dutch roll mode for the aircraft the dihedral of the wing was set at 1°. This is lower than comparable aircraft, but it is necessary to reduce the adverse Dutch Roll characteristics associated with a "V" tail. The wing also has a 3° angle of incidence so that the fuselage is at a 1.5° nose up attitude during cruise. The attitude angle of the fuselage is important for comfort and safety reasons. The comfort of the passenger is increased when the fuselage is not at a high angle during cruise because they do not feel like they are always climbing. There are safety considerations for the flight attendants as well as the passengers. The food servicing cart could roll on its own down the aisle and collide with someone.

Wing span was constrained so that the aircraft would be able to fit into existing gate facilities and maintenance docks. The result is a total span of 107 ft, which is the same as the wing span of the Douglas MD-90. The SA-150 has the largest wing possible without the aircraft having to use gate facilities that are usually reserved for larger aircraft. This will allow prospective operators to incorporate the SA-150 into their inventory without the need to modify their facilities or obtain larger gate spaces. As a consequence of this restraint, and the desire to minimize induced drag, the wing of the SA-150 has a planform area of 955 square feet. This is the needed surface area to obtain the wing loading that is desired due to the sizing of the aircraft. Calculations have verified that there is adequate room in the wing for fuel, landing gear and control systems and that the wing area is sufficient for the aircraft to climb and cruise efficiently. The root cord of the wing is 17 ft, including yehudi, providing enough depth to attach the wing to the fuselage without adding a wing glove or extra fairings.

Wing loading, at 109 lb/ft^2, is comparable to that of existing aircraft in the small commercial transport category. The Boeing 737-300 has the same loading and the Douglas MD-80 has a wing loading of 115 lb/ft^2. This loading will provide good ride quality and still allow the wing to generate the necessary take-off coefficient of lift. The wing loading is also low enough to allow the aircraft to rotate for take-off at 130 knots. For a summary of critical wing parameters refer to Table 5.1.

Table 5.1 SA-150 Wing Parameters

Aspect Ratio	12
Wing Sweep Angle	25°
Wing Span (ft)	107
Reference Area (sq. ft.)	955
Root Thickness Ratio	0.15
Tip Thickness Ratio	0.1
Root Chord w/ Yehudi (ft)	18
Tip Chord(ft)	3.25
Wing Loading (lbf./sq. ft.)	109

5.2 Airfoil Selection

The wing of the SA-150 utilizes a NACA 64a-215 airfoil at the root, which tapers to a NACA 64a-210 at the tip. The 15 percent thickness ratio at the root will provide adequate dimensions to build an efficient structure. While the taper to the 10 percent thick section improves the final L/D performance of the aircraft. This family of airfoils have laminar flow design and operates at a C_l of 0.4, which was the initial prediction for the wing of the SA-150 at cruise.[5] These airfoils were chosen when it was examined for both lift and drag characteristics at speeds around the cruise Mach number of the SA-150. A cross section view of the airfoil is provided in Figure 5.2.

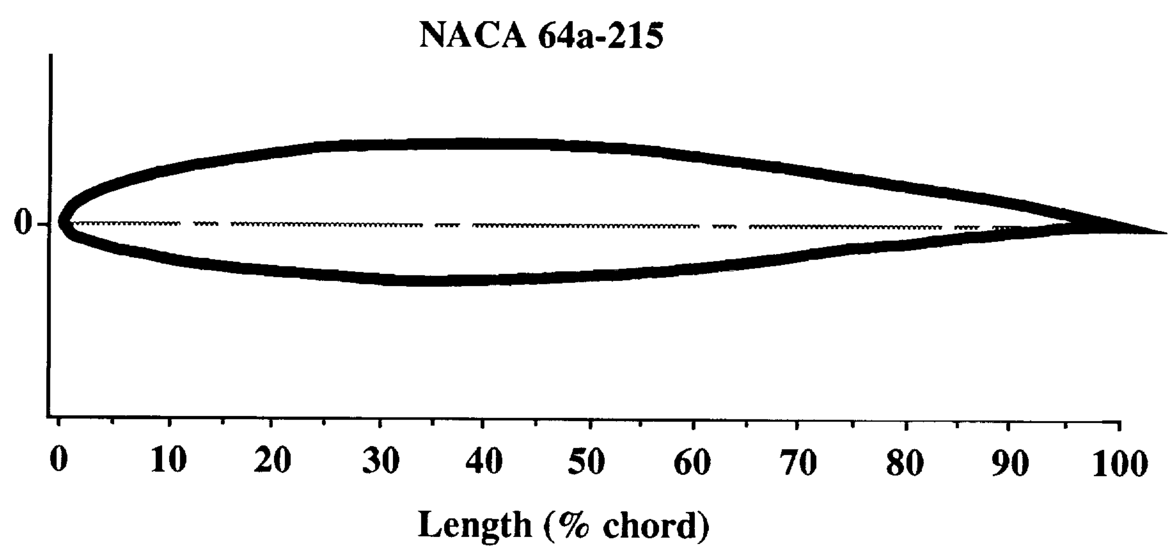


Figure 5.2 SA-150 Root Airfoil Cross Section

5.3 High Lift Devices

High lift devices were selected on the basis of simplicity and light weight and the delta Cl that they could produce. Therefore, the use of an expensive and complex flap system, like a double slotted Fowler arrangement, was to be avoided if at all possible. Initial flap surface area estimations were conducted with an aircraft design program and the method described in References 4 and 5. An analysis, using a 5000 ft runway distance, 95° F conditions, and single slotted flaps indicated that more flapped span was needed than was available on the wing. The design team felt that the use of double slotted flaps was an unacceptable alternative so the runway length requirement of the RFP was increased by a 1000 ft The deviation from the RFP does not result in any determent in take-off performance when compared to other aircraft of the same size (refer to section 10.1 and Figure 10.1b for further explanation).

The methods mentioned above were applied again and a final required flapped span of 60% was calculated. Spoilers were used for high speed roll control and were sized by maneuvering requirements. Figure 5.3 illustrates the position of the high lift devices and control surfaces. Spoiler are not shown because they would obscure the flaps in this view.

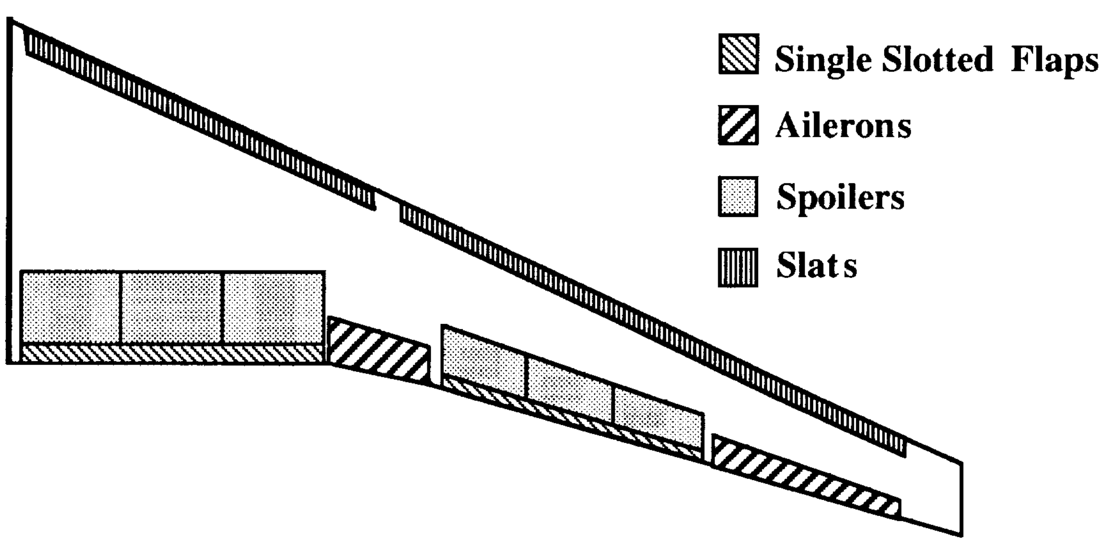


Figure 5.3 SA-150 High Lift Devices

Leading edge devices were also installed on the wing to promote a delay of the onset of wing stall during take-off and landing operations.[8] The leading edge slats were sized according to accepted rules of thumb.[9] The combination of high lift devices installed on the SA-150 allow the aircraft to achieve a maximum AOA of 18° before the wing begins to stall. The high lift devices generate a delta C_L of 1.1 for take-off and 1.2 for landing. Table 5.3 lists the critical parameters of the high lift devices.

Table 5.3 SA-150 High Lift Device Parameters

	Slats	Single Slotted Flaps
Sflap	80.0 sq. ft.	157.0 sq. ft.
bflap/bwing	0.9	0.6
Max. Take-off Deflection	15.0°	30.0°
Max. Landing Deflection	30.0°	35.0°

6.0

EMPENNAGE DESIGN

6.1 Empennage Configuration

There are three basic empennage configuration possibilities: tail aft, canard, and three surface. Three surface designs, and to a lesser extent, canard configurations, have the advantage of potentially higher maximum trimmed lift coefficients and reduced trim drags. However, an aircraft with reduced longitudinal static stability can achieve reduced trim drags even with a tail aft configuration.

It was determined that the maximum lift coefficient obtainable with a conventional configuration will be sufficient to meet the mission requirements. It was decided to employ a conventional tail aft configuration and to use relaxed static stability to reduce trim drag.

Instead of a normal horizontal and vertical tail arrangement however, a "V" tail was chosen. There are three reasons for this selection: lower cost, drag reduction, and visual distinctiveness. First, manufacturing costs will be reduced since only two identical, symmetrical surfaces need to be produced instead of three structures. Second, a small drag reduction is achieved due to reduced interference effects. However, some studies suggest that this reduction may be almost entirely offset by increased surface area required relative to a conventional tail.[10] Finally, the distinctive look of the "V" tail will set the SA-150 apart from the competition.

Complications traditionally associated with "V" tails, such as cross coupling and Dutch roll, can be offset by the aircraft's use of a computer-controlled fly-by-wire flight control system. The cross-coupling effects of the "V" tail will be automatically compensated for by the flight control system, so the aircraft will "feel" completely conventional to the pilot. Using a "V" tail requires a control "mixer" to allow uncoupled pitch and yaw control. Since using a fly-by-wire system eliminates the mechanical linkages between the cockpit and the control surfaces, the added complexity and weight of a mechanically implemented control "mixer" is avoided.

6.2 Empennage Sizing

Tail volume coefficients were used as a guide for initial sizing of the vertical and horizontal tail areas. For the "V" tail configuration, projected vertical and horizontal areas of the two surfaces were used. The vertical and horizontal areas initially selected correspond to somewhat smaller volume coefficients than found from historical averages.[1] This is acceptable because the SA-150 is a relaxed static stability aircraft with a stability and control augmentation system (SCAS). The longitudinal static stability, as a function of tail area, is shown in the longitudinal X-plot in Figure 6.2a. Directional static stability as a function of tail area is shown in the directional X-plot in Figure 6.2b. Arrows on these two figures indicate the tail areas finally selected.

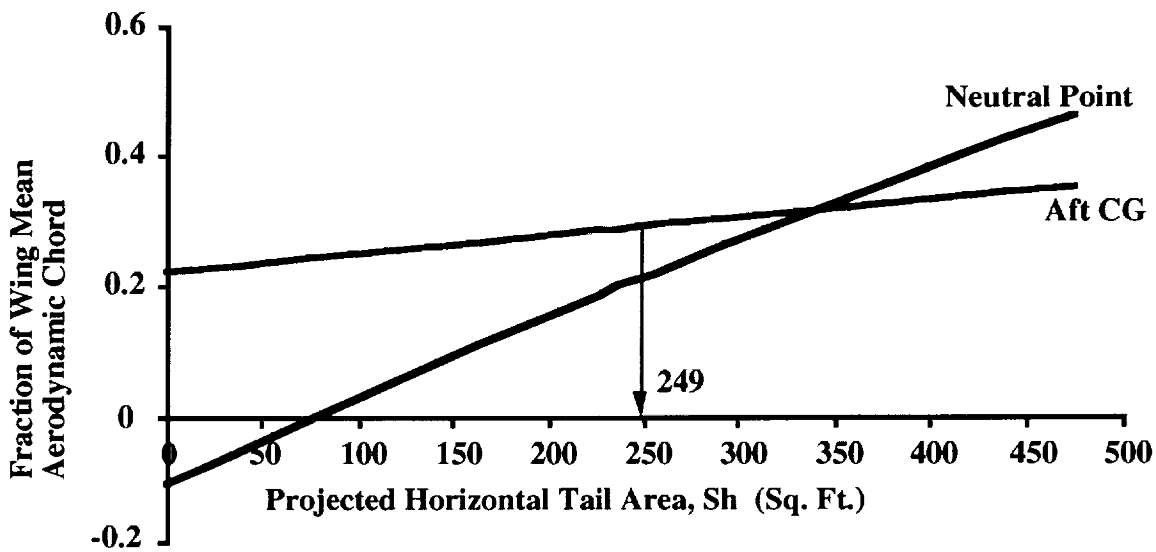


Figure 6.2a SA-150 Longitudinal X-plot

The directional X-plot shows approximately neutral directional stability in the absence of augmentation. This is a conservative estimate due to the uncertainty in analyzing a "V" tail configuration. As shown in the figure, sufficient positive directional static stability can be attained by using the SCAS to apply feedback to the rudder. This will be further discussed in the section on static stability.

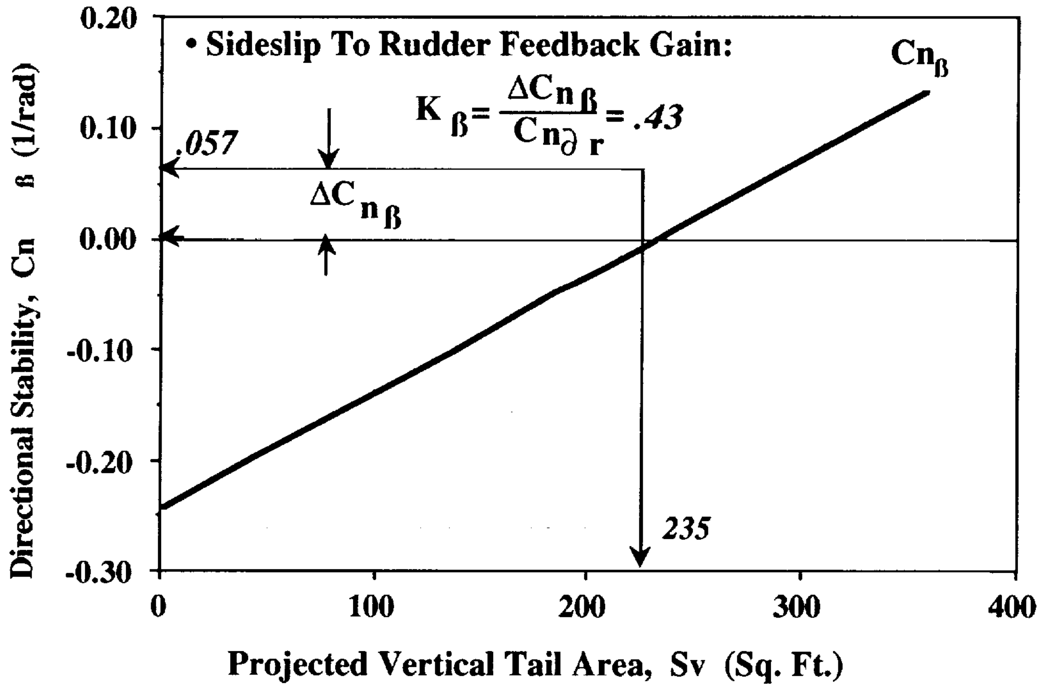


Figure 6.2b SA-150 Directional X-Plot

Since de facto static stability is achieved through the SCAS, control power was the critical factor in tail sizing. Thus, the final tail areas are larger than what is required just for stability. The final sizing was determined by control power requirements for the conditions of trimmed flight with full landing flaps extended and a forward CG location for the horizontal area, and OEI yaw control at $1.2V_{stall}$ for vertical area.

6.3 Empennage Geometry

The "V" tail is shown in Figure 6.3. It consists of two identical tail structures whose planes intersect on a line 1.5 feet above the fuselage centerline. The control surfaces on the tail, called "ruddervators", are double hinged and extend across 90% of the span and have a width equal to 35% of the local chord. The double hinged surfaces were chosen to obtain the maximum control power from the available surface area.

Important tail dimensions are given in Table 6.3. Historical jet transport aircraft data was used as a guide in selecting the geometry of the

empennage. Typically, sweep at quarter-chord has ranged from 18° to 37° for horizontal tails and from 33° to 53° for vertical tails. Taper ratio has ranged from .27 to .67 for horizontal tails and from .26 to .73 for vertical tails. The airfoil chosen is symmetrical, which allows for adequate maximum positive and negative tail lift, and also makes the two tail structures identical and interchangeable. A 12% thick airfoil is in the typical range for small jet transports. These geometry parameters insure that the tails have a higher critical Mach number than the wing. The 48° dihedral angle is a result of the effective S_V and S_h requirements previously determined; i.e., 48° is the angle required in order to achieve the proper ratio of S_V to S_h.

Table 6.3 SA-150 Tail Dimensions

Tail Geometry

S	186 sq. ft.	Taper Ratio	0.34
b	23.6 ft.	Thickness	0.12
AR	3	Root Chord	11.75 ft.
Sweep, LE	40°	Tip chord	4 ft.
Sweep, c/4	35°	Airfoil	NACA 0012
Sweep, TE	20°		

Total Empennage

Dihedral	48°
Sv	235 sq. ft.
Sh	249 sq. ft.
Swet	638 sq. ft.

- **Double Hinged Control Surface**
- **Chord Fraction: 0.35**
- **Maximum Deflection: 40 Degrees**

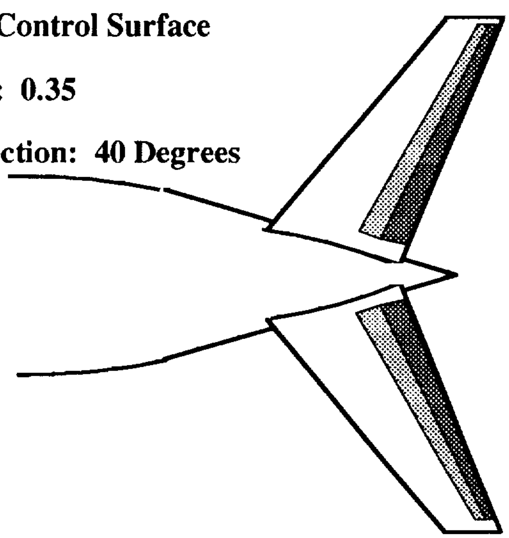


Figure 6.3 SA-150 "V" tail

6.4 Empennage Aerodynamics

Several empennage configurations were considered for the SA-150. The final "V" tail configuration was chosen, in part, because initial research seemed to indicate that a slight reduction in surface area and interference drag could be realized with this design.[11,12] The initial prediction of significant drag reduction, however, was not realized with this configuration.

Due to stability and control reasons the initial sizing of the projected wetted area had to be increased. This resulted in more parasitic drag than calculated for the initial configuration. This increase in parasite drag almost exactly offsets the reduction in interference drag derived from the two surface design.

During the drag build up analysis of the SA-150 it was noticed that as the MAC of the empennage surfaces increased, parasitic drag decreased by three percent over an equivalent conventional tail layout in the cruise configuration. This effect is primarily a result of the coefficient of friction declining as the Reynolds number increased for the longer chord of the "V" tail. These results are questionable and extensive wind tunnel testing will have to be conducted to either verify or disprove these empirical results.

7.0 FUSELAGE DESIGN

7.1 Fuselage Configuration

In a departure from traditionally narrow fuselage dimensions, the SA-150 has been designed with a maximum external diameter of 13 ft 2 in. With a three inch wide wall section to allow for structure, insulation and liner material, the internal cabin diameter is 12 ft 8 in. Figure 7.1 provides a comparison of the SA-150's diameter to that of current aircraft with similar capabilities.[1,13,14]

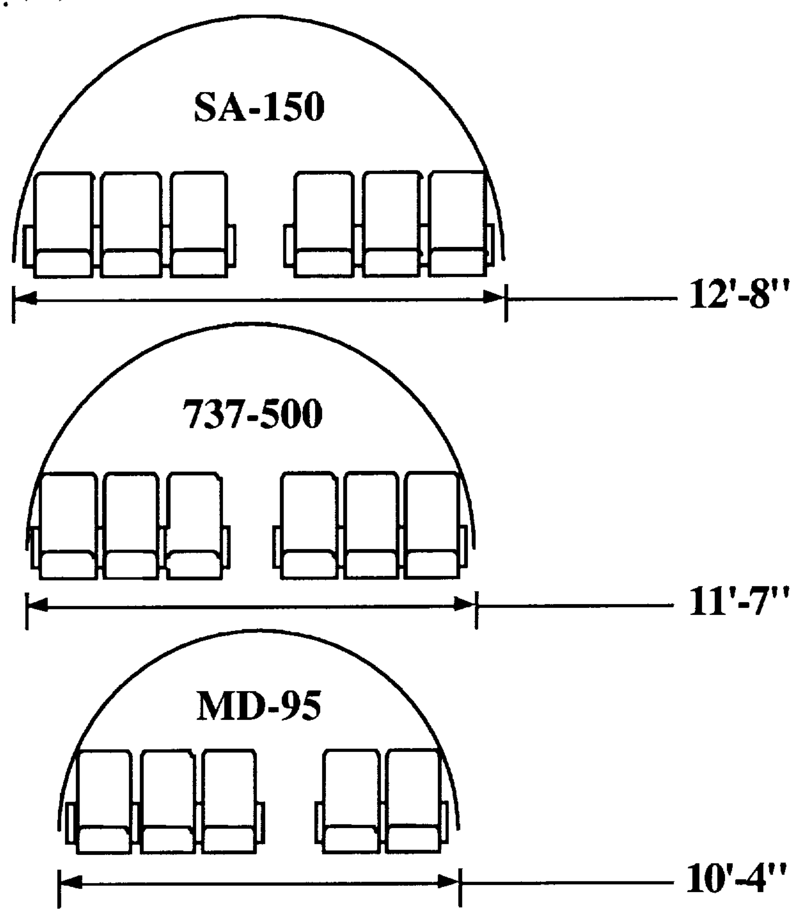


Figure 7.1 SA-150 Aircraft Cabin Diameter Comparison

Passenger comfort and container capability were the primary design criteria for the selection of this dimension. In order to provide the passengers with more shoulder and elbow room it was necessary to design a fuselage with this relatively wide diameter.

The SA-150 fuselage also features a circular cross section. This geometry allows for a simple loads analysis and a less complex design when compared to a double bubble configuration. Associated benefits include lighter weight, reduced engineering analysis and lower design costs. The uniform cross section design also has fewer large structural joints so it will be easier and less expensive to manufacture. A double bubble fuselage would offer a smaller frontal area and less exposed surface area than a circular cross section. The cost to design and produce such a structure however, was deemed prohibitive for the SA-150 in comparison to the advantages it would provide.

7.2 Fuselage Aerodynamics

With a total aircraft length of 107 feet, the SA-150 has a fineness ratio of 8.12. A fineness ratio of around 8 has been determined to be optimum for overall friction drag concerns at subsonic speeds.[15] Further reducing drag is the ability to retract the main landing gear into the wide circular body of the aircraft so that only very small fairings are required. A trade study was conducted to determine what total aircraft drag penalty would be incurred in comparison to a more conventional fuselage diameter of 12 feet. The initial calculation indicated a 2.5% increase in total aircraft drag for the cruise condition.[16] When the effects of fineness ratio on the coefficient of drag and the need for larger gear fairings were factored into the equation, the drag penalty dropped substantially and was considered a small price to pay for the increased level of passenger comfort.

Attention to design and manufacturing detail in certain critical areas will also help to reduce the fuselage contribution to total aircraft drag. The attachment points for the wing have been blended into the fuselage to help reduce interference drag and countersink rivets in the forward sections will be shaved flush to help maintain laminar flow for as long as possible. In areas where the boundary layer has become so thick that minor surface imperfections no longer contribute to a drag increase, fine detail will not be required. By restricting detailed attention to the areas from which benefits can be obtained, the SA-150 strikes a balance between aerodynamic efficiency and cost effectiveness.

Aft fuselage upsweep is 15° toward the boat tail and down sweep is 3°. The upsweep angle was chosen to provide ample takeoff rotation clearance without causing a significant increase in base drag. The blending of the fuselage to the boat tail starts just forward of the rear cabin doors and will help transition the airflow from around the aircraft body to the free stream. By starting the fuselage blending at this location, it is possible to maintain a constant three by three seating arrangement throughout the length of the cabin. No attempt to area rule the fuselage was made because the cruise speed of the SA-150 is not high enough to necessitate it.[11]

7.3 Cabin Layout

One reason for designing the SA-150 was to provide the airline passenger with a higher level of comfort and convenience than is currently available in the small commercial aircraft category. To address this goal, features of current aircraft that were considered restrictive, annoying or inconvenient were targeted for redesign. These features include such items as narrow seating, small overhead storage compartments, awkward seat back trays and cramped lavatory doorways. Throughout this process, the business traveler was considered to be the core of the airlines' business. As frequent flyers, business travelers know what level of service different airlines can provide. It was imperative, especially in today's competitive market place, to create a cabin design that presents the business traveler with the highest level of convenience possible. With the SA-150, an airline can build a reputation around passenger comfort and service to keep the frequent flyer coming back again and again.

The SA-150's standard class features a three by three seating arrangement and an 18 inch central aisle with a seven foot, two inch ceiling height. Seat widths are 18 inches and the arm rests between the seats and along the fuselage wall have been expanded from the industry standard of 2.25 inches to 3.5 inches.[11] A number of important benefits are derived from this design approach. By widening the armrests and using a conventional, yet comfortable seat width, the passengers are afforded a substantial increase in shoulder and elbow room, while seat weight is kept to a minimum. Meal trays are removed from the seat back location and stored in the armrests and ample space is available for light, radio and other electronic controls. The overall effect is to create a spacious and comfortable environment where the traveler can either work or relax.

In addition to the standard class seating arrangement, the option to convert the SA-150 into a high density configuration is also available. For this arrangement, the seat pitch in standard class is reduced from 33 to 31 inches to allow for the installation of an additional row of seats. All other seating dimensions in the main cabin will remain the same. Figure 7.3a illustrates the cross section of the main cabin of the SA-150.

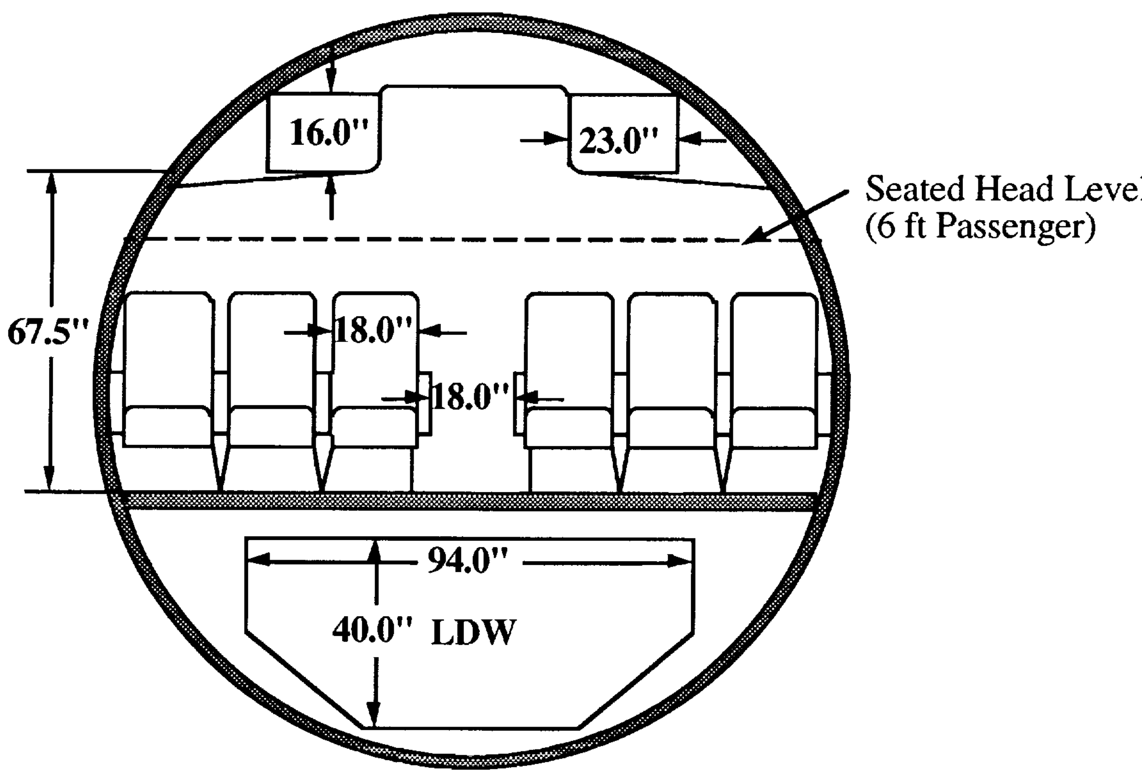


Figure 7.3a SA-150 Main Cabin Cross Section

Another feature designed into the cabin of the SA-150 is the large overhead bins, sized to handle standard carry on baggage in combination with a large briefcase. The increased storage space will provide the option to carry on luggage instead of checking it at the ticket counter. Since the fold down trays have been removed, the option to install an airphone and video screen on each seat back is also available. Other conveniences to be provided at the airlines request can include an on board FAX machine and E-mail hook-ups for lap top computers. The extra room, illustrated in Figure 7.3b, and cabin features of the SA-150 can make a business travelers on board time more productive and allow them to avoid spending additional time in the airport waiting for their luggage.[13,14]

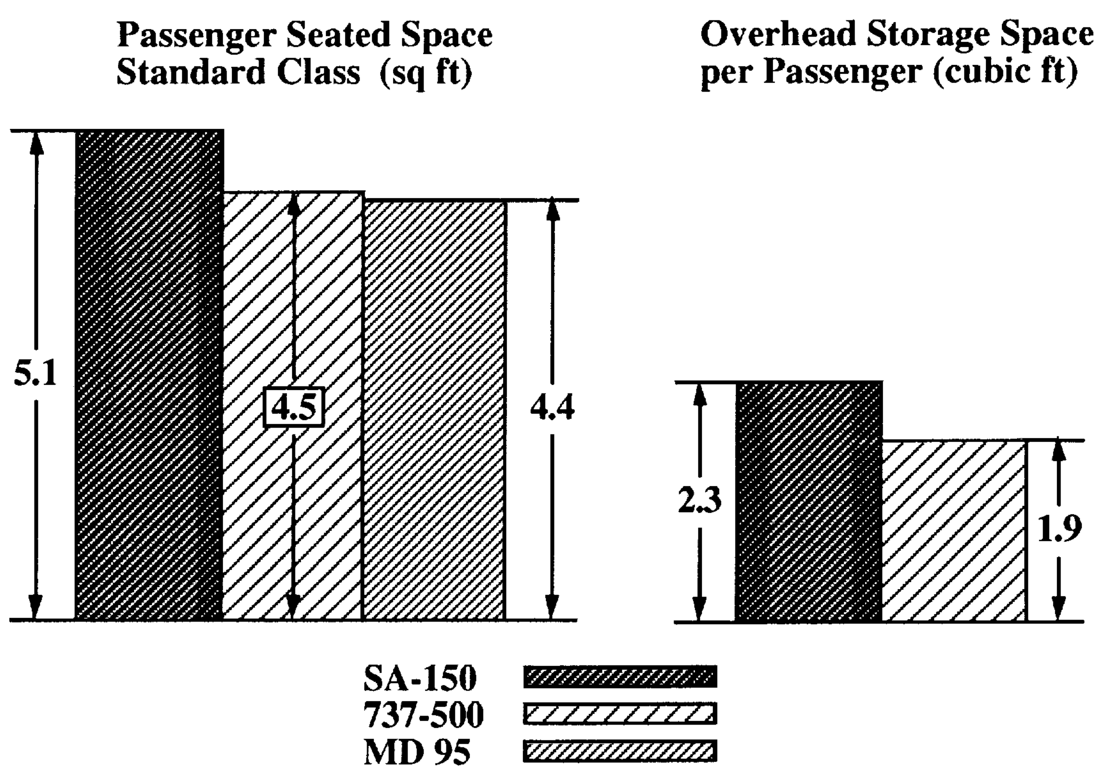


Figure 7.3b Aircraft Cabin Comparisons

First Class seating is also available on the SA-150 and is offered with a generous 44 inch seat pitch. Once again the emphasis was placed on providing an open, comfortable environment, plenty of elbow room and large overhead storage capacity. Figure 7.3c illustrates the first class seating arrangement, and Table 7.3 lists the critical cabin dimensions for all three classes.

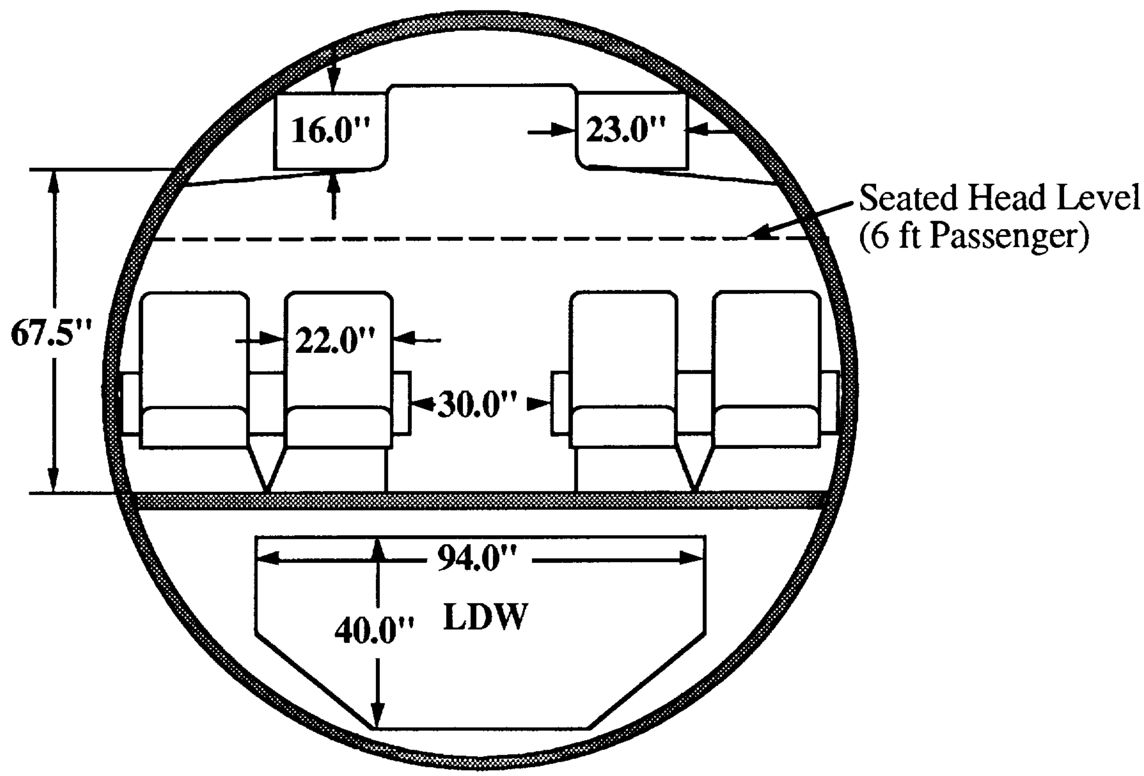


Figure 7.3c SA-150 First Class Cabin Cross Section

Table 7.3 SA-150 Cabin Dimensions

	First Class	Standard Class	High Density
Seat Pitch	42"	31"	31"
Seat Width	22"	18"	18"
Mid-Seat Arm Rest Width	8"	3.5"	3.5"
Aisle Side Arm Rest Width	4"	2.5"	2.5"
Aisle Width	30"	18"	18"
Overhead Storage per PAX (ft^3)	5.6	2.3	2.2
Galley Volume per PAX (ft^3)	6.4	1.8	1.7

The SA-150's interior layout has three different variations. These configurations are illustrated in Figure 7.3d and were designed to facilitate rapid conversion, keeping unprofitable ground time to a minimum. A number of concerns specific to several European countries have also been

1.

FOLDOUT FRAME

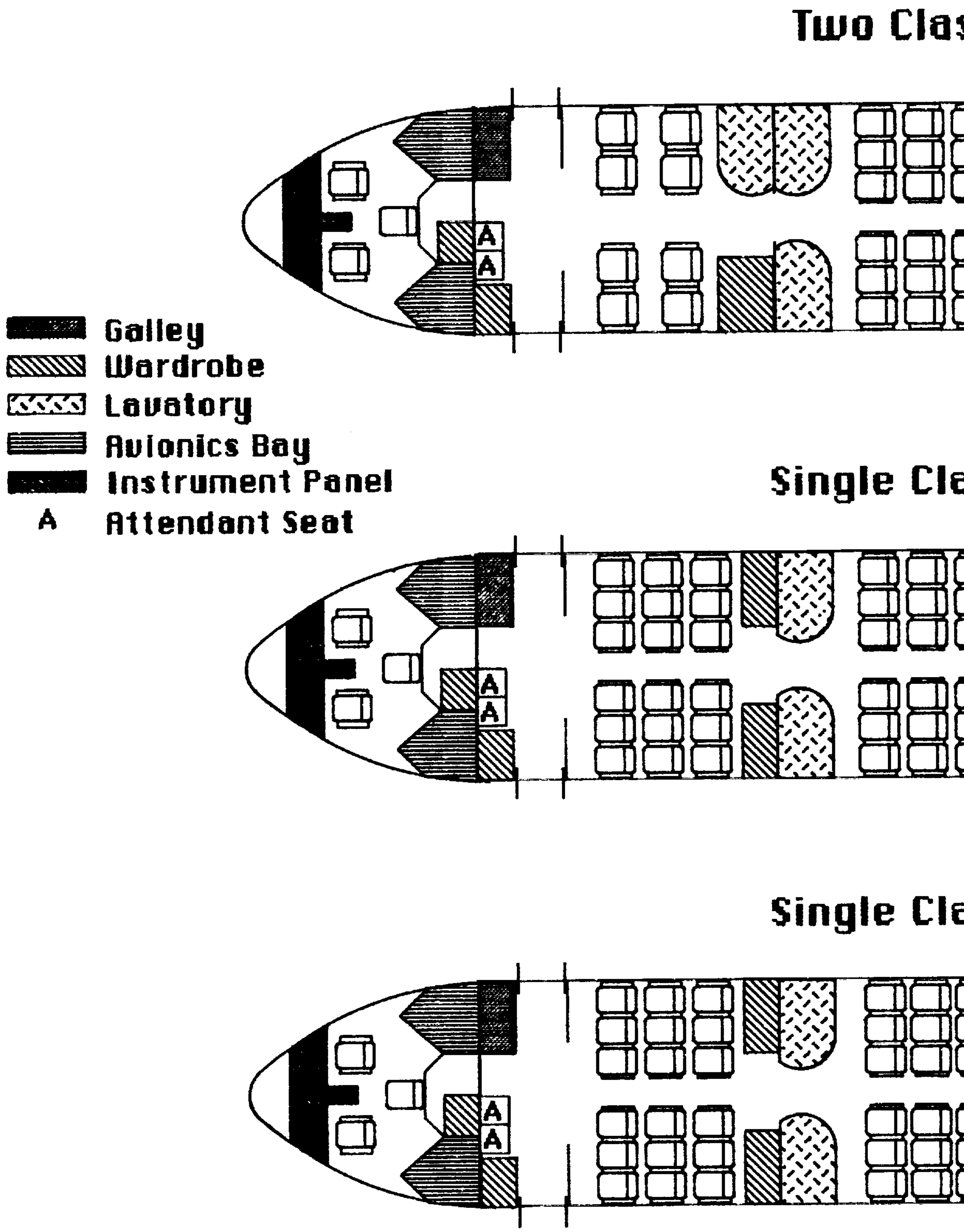
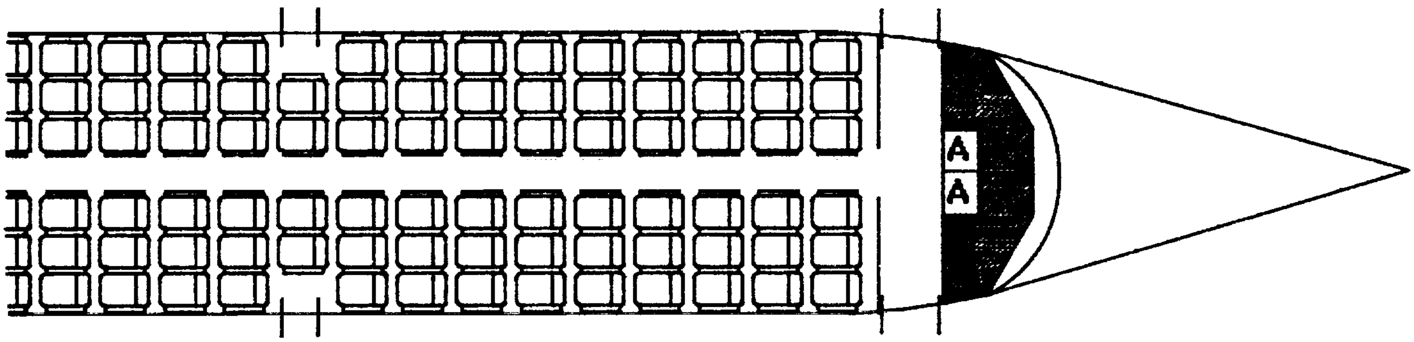


Figure 7.3d SA-150 Cabin Configurations

2.

FOLDOUT FRAME

;s Case - 108 PAX



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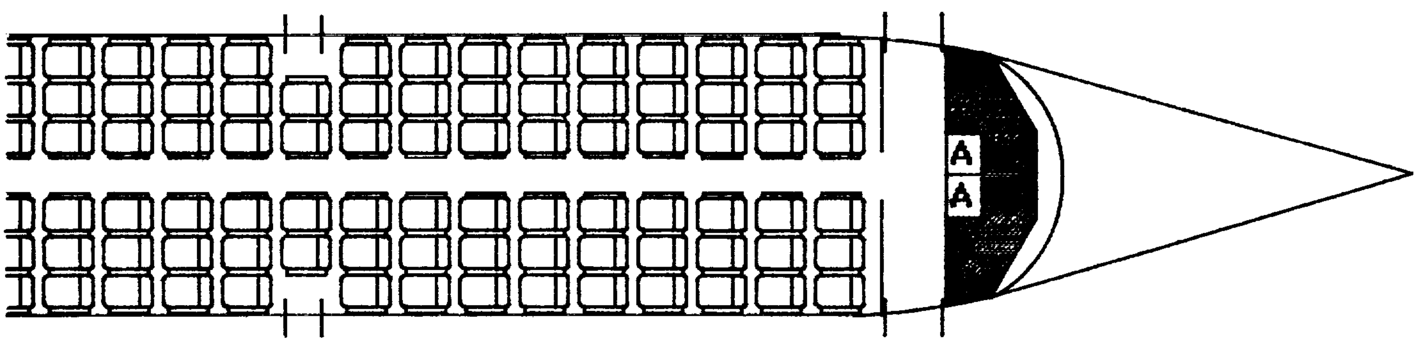

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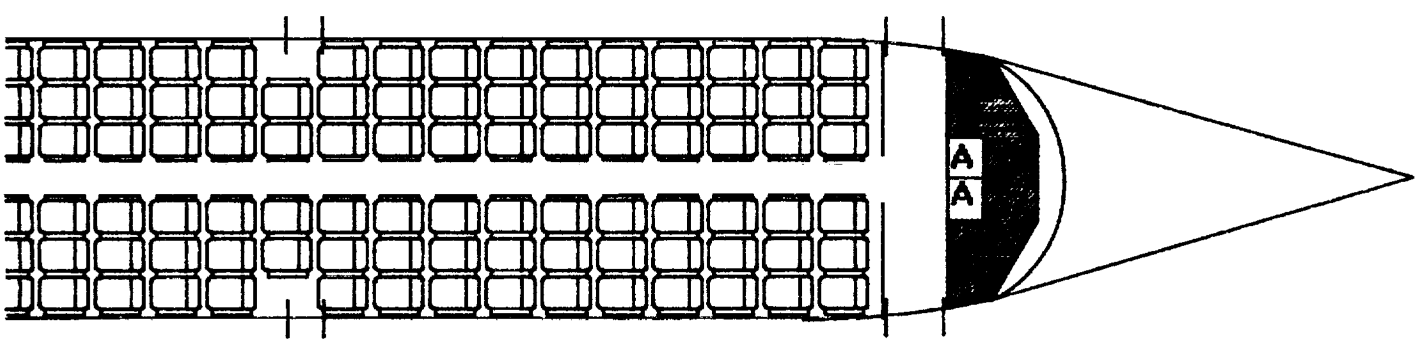

addressed, such as appropriate lavatory placement and emergency exits designed to meet ICAO regulations. By dealing with these items in the design phase, costly conversions later on can be avoided and the SA-150 will be ready for immediate overseas marketing.

All three layouts feature lavatories located together at the separation between the main and forward cabin and away from the galleys at either end. This will reduce congestion at the galley locations and satisfy international regulations regarding the separation of these facilities for sanitary reasons. The central location also allows for rapid conversion between configurations. By removing only one modular lavatory and the mid-plane wardrobe, three rows of standard class seats and two smaller wardrobes can be installed. The reduction of seat pitch in the main cabin by two inches will permit the installation of an additional row of seats. In all three configurations, the over-wing Type III emergency exits meet FAR and ICAO clearance regulations and the removal of an additional seat will not be required.[3] The removal of the lavatory, even with the high density configuration, provides a satisfactory PAX to lavatory ratio of 62 to 1. Industry standards for short haul aircraft range between ratios of 35 to 74 PAX per lavatory. In the high density configuration, the SA-150 will be flying the short hop routes, so for this case a large PAX to lavatory ratio was not considered critical.

Flight attendant seating is located at both ends of the aircraft, near the main exits, and provides adequate visibility of the entire cabin. Four attendant seats have been installed so an additional crew member can dead head, or an increased level of service can be provided. The port side entrances are 72 inches tall by 36 inches wide and the starboard exits (galley service doors) are both 60 inches tall by 30 inches wide. All four doors use a plug design for insured cabin sealing under pressurization, and exceed the minimum required dimensions for Type I emergency exits. The traditional swinging style doors on the lavatories have been replaced by constant radius, sliding doors to ease accessibility. All three lavatories have a generous dimension of 15.5 square feet of floor space compared to industry standards which range between 11 and 16 square feet.

7.4 Flight Deck

The SA-150 has a modern, two person flight deck, complete with a state of the art, fly-by-wire, flight control system. Side and top view configurations are presented in Figures 7.4a and 7.4b. A limited travel, traditionally mounted stick and conventional throttles located between the seats will help ease pilot transition to this new aircraft and reduce training costs. Visibility from the flight deck is good and meets all federal and international requirements.[3] An observers seat has also been provided with the capability to fold and store it to the left side of the flight deck

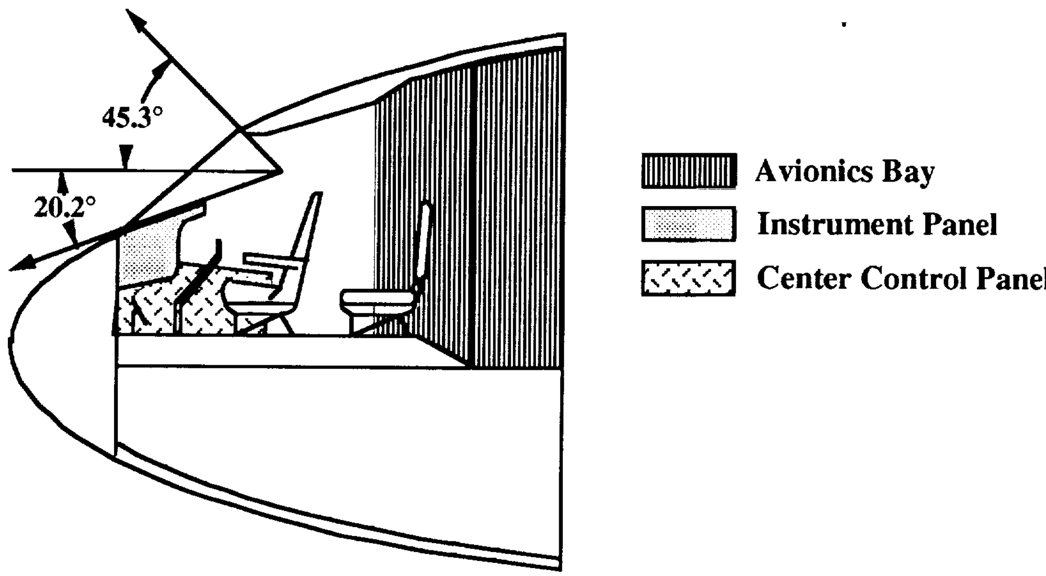

Figure 7.4a SA-150 Flight Deck Side View

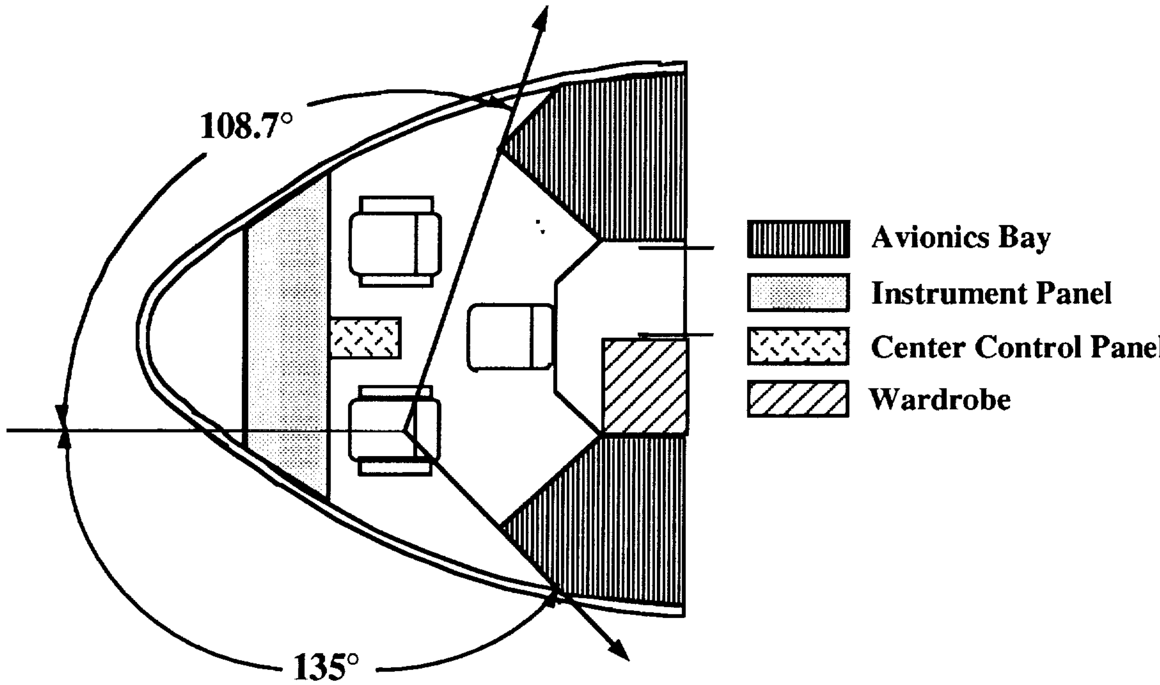

Figure 7.4b SA-150 Flight Deck Top View

8.0 PROPULSION SYSTEM

8.1 Thrust Requirements

Initial required thrust levels were determined by the number of engines, wing loading and maximum aircraft weight. For the SA-150, a minimum usable thrust of 14,700 lbs. per engine was calculated. This value was modified after completing an intensive aerodynamic analysis and increased to 16,000 lbs. per engine.[17] The increase in thrust is needed to meet the 4,000 ft step climb and direct climb to 35,000 ft requirements stated in the RFP. The 16,000 lb rating per engine is the usable thrust required, so losses for installation and bleed air were taken into account when selecting the engine.

Since a number of engines already exist that can meet the thrust requirements of the SA-150, the additional expense of designing a new engine could not be justified. Engine availability is also a consideration. With an entry into service date of the year 2000, trying to design, test and certify a new engine could delay production of the SA-150. Among the possible engine selections, there are also several candidates that could possibly meet the proposed Stage IV noise and emission requirements. Table 8.1 lists a number of turbine engines that were considered for use on the SA-150. For all these reasons, the search for an appropriate power plant was limited to designs in development or already in service.

Table 8.1 Engine Data Comparison

	Pratt & Whitney	Rolls-Royce	Rolls-Royce	CFM International
	JT8D - 209	TAY650	BR700 - 17	CFM56 - 3
Thrust (lbs)	17, 580	14, 345	18, 600	19, 000
SFC (lb/lb/hr)	0.724	0.707	0.62	0.664
Diameter (inches)	49.2	45	53	60
Weight (lbs)	4435	3340	3600	4275

8.2 Engine Selection

Thrust for the SA-150 will be provided by two high-bypass Rolls-Royce BR-700 turbofan engines mounted under the wings. With this arrangement, the fan diameter becomes a critical design constraint. The redesign of the Boeing 737 encountered problems when trying to mount the CFM-56 engine under a wing which was originally configured to have a narrow, low-bypass JT-8D engine beneath it. The increased diameter of the new engine required a special inlet and extensive wind tunnel testing to develop an acceptable pylon design.[18] In order to avoid similar design and development costs, the BR-700 was selected, in part, because it has a relatively small fan diameter of 53 inches in comparison to the 60 inch diameter of the CFM-56. The small diameter of the BR-700 will permit the fuselage of the SA-150 to remain within easy reach of the ground for servicing, and still provide adequate engine ground clearance. A side cutaway view of the BR-700 is shown in Figure 8.2.

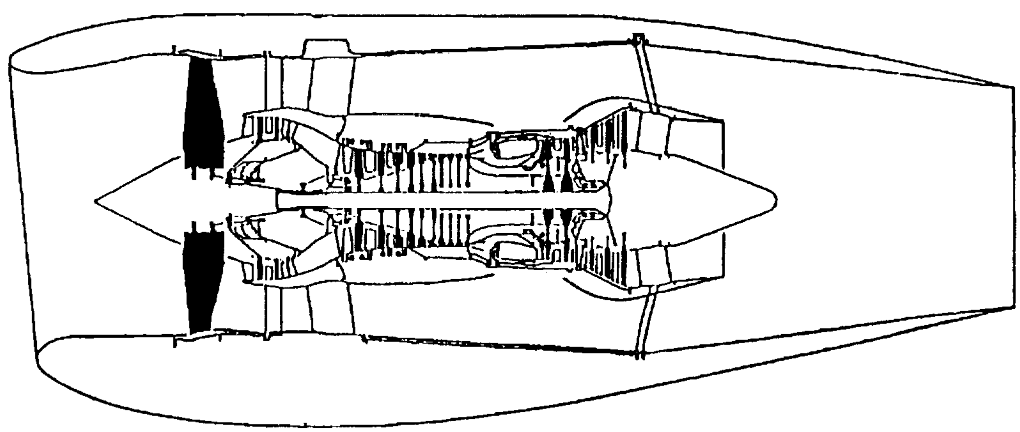

Figure 8.2 BR-700 Side Cutaway

Another concern for proper engine selection is the specific fuel consumption of the power plant. SFC is a measure of engine efficiency and a low SFC results in less fuel burned to complete a mission. Even with it's relatively small fan diameter, the BR-700 has the lowest SFC of all the available engine selections. As can be seen in Table 8.1, the BR-700 has a smaller fan than the CFM-56 but a better SFC value.[1,19] Generally, a smaller fan diameter translates into a decreased by-pass ratio and higher values of

SFC, but this is not the case for the BR-700. The engineers at BMW and Rolls-Royce have found ways to improve SFC without drastically increasing the fan diameter. This technology helps to make the BR-700 the best engine for use on the SA-150.

Engine weight is also a point of concern when selecting an appropriate power plant for the aircraft. Weight translates directly into fuel burn required to complete a mission, and will increase direct operating costs for the airlines. Once again, as illustrated in Table 8.1, the BR-700 proves to be one of the best options available.

In today's world of increased environmental awareness, the effects of noise and gaseous emissions such as NO_X cannot be overlooked. The BR-700 has been engineered to be one of the quietest and cleanest burning engines in its class. An example of this is that the engine has been guaranteed to generate noise levels 30% lower than are required to meet current Stage 3 criteria.[20] This would imply that the engine will also be able to meet proposed Stage 4 noise requirements.

All of these factors, along with purchase price, availability and maintainability were considered when selecting the power plant. Of all the engine options available, only the BR-700 has the combination of a low SFC, an acceptable fan diameter, low weight and the ability to meet the proposed Stage 4 noise and emission requirements. While the BR-700 series is not currently in production, it has been selected to power the new Gulfstream 5 and Canadair Global Express business jets, so no availability problems are projected for a year 2000 entry into service date.[20]

9.0 LANDING GEAR

9.1 Basic Configuration

A standard tricycle landing gear arrangement was chosen for the SA-150. The advantages associated with this design are good visibility over the nose during ground operation, stability against ground loops, good steering characteristics, and a level floor while on the ground.[21] Both the nose gear and the main gear consist of a single strut with one wheel mounted on either side.

9.2 Nose Gear

Figure 9.2a shows the positioning of the nose gear. At this location the minimum and maximum nose gear loads will be within normal parameters. Static nose gear loads generally vary about 6-20%, but these are usually considered extremes. Accepted ranges for nose gear loads are 8% with the CG aft, increasing to 15% with the CG forward.[22] As can be seen from Table 9.2, the minimum nose gear load is equal to the normal 8%. The maximum nose gear load of 15% will be difficult to obtain because of the CG excursion that exists. This is not a concern, since weight is normally needed on the nose gear to maximize stability and ensure adequate steering control. With 8-10% of the total aircraft weight on the nose gear, adequate steering control should exist.

Table 9.2 SA-150 Nose Gear Data

Per Strut:		Per Tire:	
Max static load	10,923 lbs	Size	24" x 7.7"
Max dynamic load	15,526 lbs	Max loading	8,200 lbs
Max % of Wto	10.50%	Max speed	200 mph
Min % of Wto	8.00%	Pressure	135 psi
		Footprint Area	19 sq. ins.

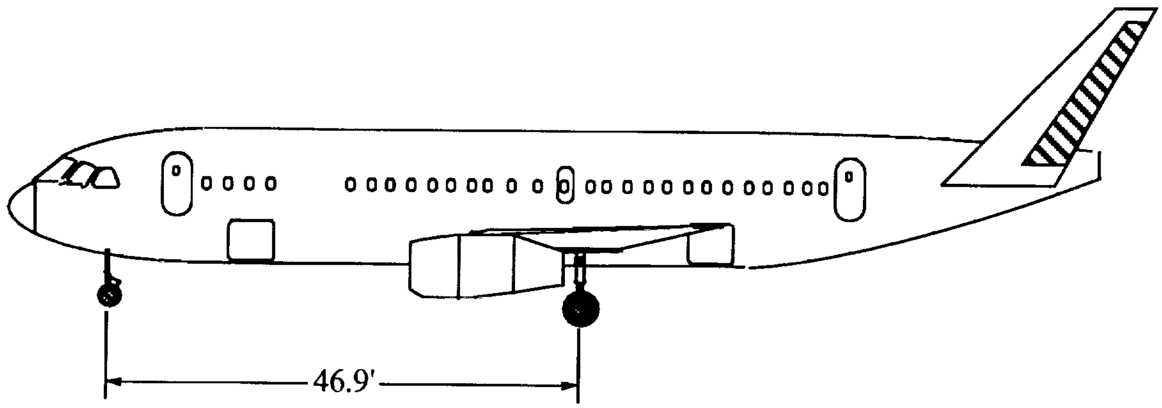

Figure 9.2a SA-150 Side View with Gear Deployed

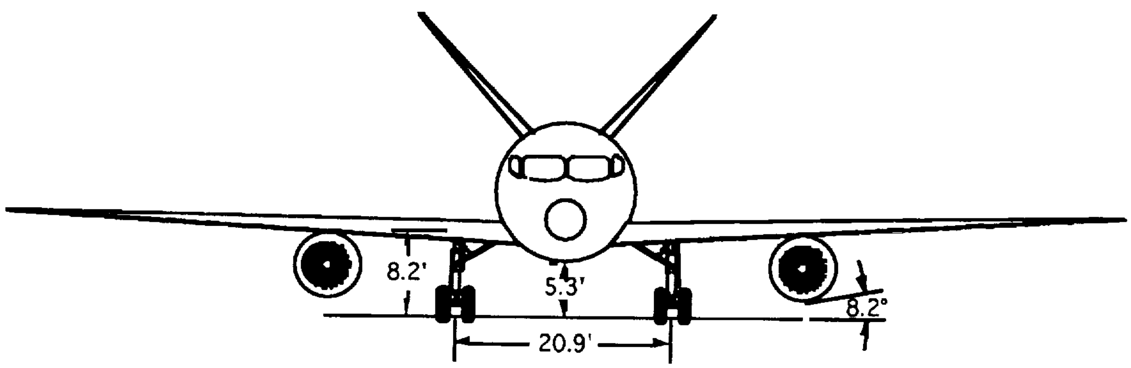

Figure 9.2b SA-150 Front View with Gear Deployed

9.3 Main Gear

Figures 9.2a and 9.2b show the location of the main landing gear. The main landing gear has been sized such that it can easily accept the total weight of the plane. Most commercial aircraft have this feature, since growth potential would have been incorporated into the landing gears. Provisions for future stretching of the SA-150 was incorporated into the landing gear sizing, so that the gear would not have to be replaced or strengthened. As can be seen in Figure 9.3, the main gear can fully retract into the fuselage. This will minimize the size of the gear fairings required and reduce the airplane's drag. However, a suitable height was required to address FOD problems of the BR-700 engines. These engines have large turbofans that require large inlet areas, which would tend to ingest debris off the runway. At the same time, the gear length could not be made so long that it would hamper the ability of ground crews to service the plane. A fuselage height of 5.3 ft off the ground, as in Figure 9.2b, should not hinder the loading and unloading of cargo. This gear design results in an LCN value of 49 which will not limit operations at any primary airport facility. For comparison, the 737-300 also has an LCN of 49.[21] Table 9.3 summarizes the important data for the main gear. The main landing gear will normally be required to accept 93% of the aircraft's takeoff weight. Tires were chosen that could handle these weights, yet still be able to take additional weight should the plane grow. This is accomplished by increasing tire pressures.

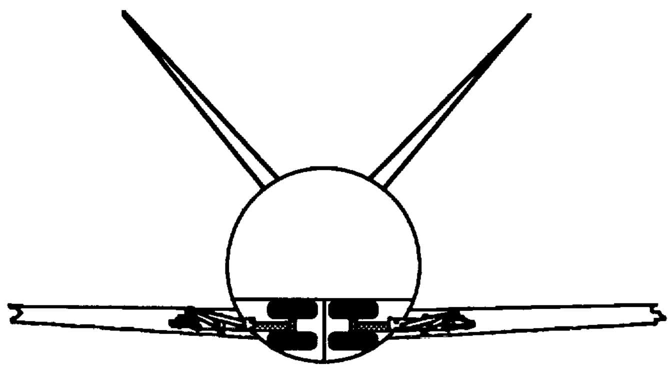

Figure 9.3 SA-150 Main Landing Gear in Stowed Location

Table 9.3 SA-150 Main Gear Data

Per Strut:		Per Tire:	
Max static load	47,863 lbs	Size	40" x 14"
Percentage of		Max loading	25,000 lbs
total Weight	46.02%	Max speed	210 mph
LCN	49	Pressure	155 psi
		Footprint Area	116 sq. ins.

9.4 Landing Gear Compliance

There were several requirements that dictated the landing gear disposition. The lateral and longitudinal ground clearance criterion and the lateral tip-over criterion must all be met. In addition, engine placement had to be considered to be sure all FOD angle requirements were satisfied.[21] The main gear placement allows a maximum rotation angle of 15.5°, with the most aft CG located 15.7° ahead of the main landing gear. With this configuration, the aircraft can fully rotate on take-off without the danger of over-rotation. Figures 9.2b and 9.4a show the associated angles for the SA-150. As can be seen, the lateral ground clearance angle is 8.3° with the tires deflated. The critical FOD angles are satisfied based on comparison with existing aircraft. For reference, the Boeing 737-300 has a FOD angle of 10° and the DC-10-30 has a FOD angle of 12° as compared to the 13.5° associated with the SA-150. The lateral tip-over angle for the SA-150 is 49°, which is less than the maximum allowable angle of 63°, as illustrated in Figure 9.4b.[22] This small angle insures that the SA-150 will be stable while maneuvering on the ground and will not turn over. With this landing gear configuration, the SA-150 will not have any steerage problems. The SA-150 will be able to turn around on a 103 ft runway, when most runways are 150 ft wide.

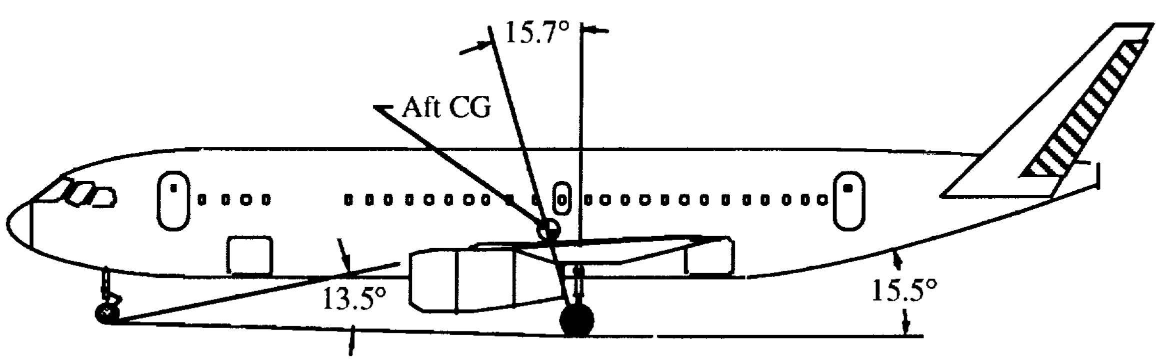

Figure 9.4a SA-150 Angle Requirements

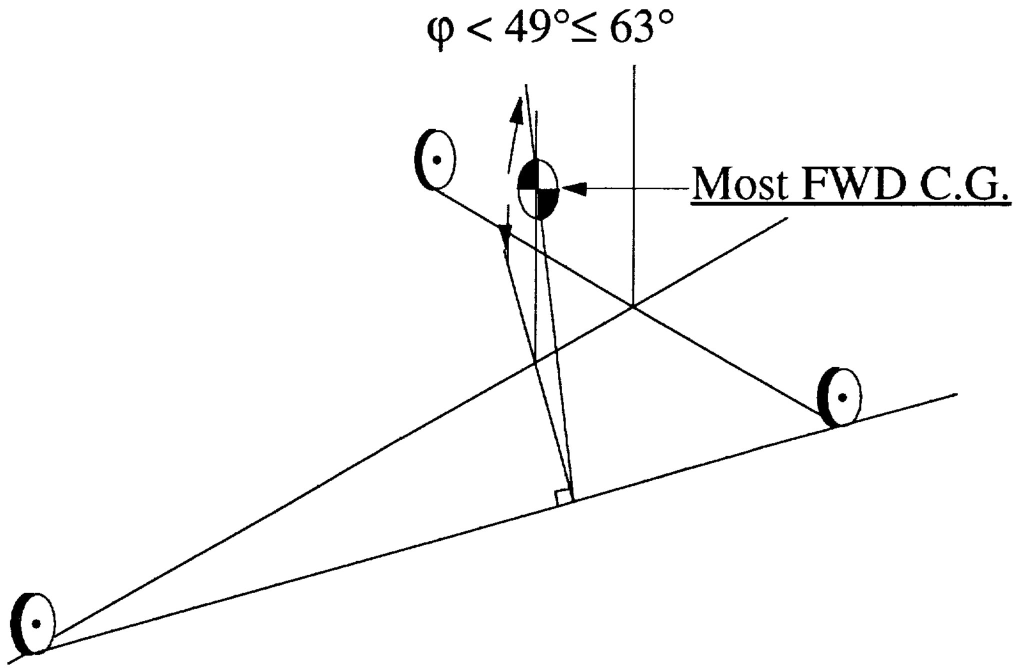

Figure 9.4b SA-150 Tip-Over Diagram

10.0 PERFORMANCE

10.1 Take-off Performance

The SA-150 will have a total take-off distance of 6000 ft at 95° F sea level. This is a deviation from the RFP requirement of 5000 ft at the same temperature.[4] The deviation was considered an acceptable trade after an analysis of the flap requirements to generate take-off CLs was completed and after the take-off performance was analyzed for competing aircraft. The extension of 1000 ft to the runway length will not be a detriment to the SA-150 for several reasons. The SA-150 will still have a shorter take-off distance than all of its major competitors. The flap system will be less complex and therefore more cost effective for the aircraft. Finally, the SA-150 will still be able to operate out of all the airports that the competition operates out of and possibly some that they are may not be able to operate from. The aircraft will clear the specified, end of take-off run, 35 ft obstacle at a velocity of approximately 170 knots. For standard day, sea level conditions, the SA-150's required balanced field length is 5,500 ft.[17] Table 10.1 compares the take-off performance of the SA-150 with current operational aircraft and shows that it will exceed the take-off performance of all of them.[1]

Table 10.1 SA-150 Runway Length Comparison

Aircraft	SA-150	MD-90	737-300	F-100
Runway Length (ft)	6000	6900	6650	6037
Altitude	S/L	S/L	S/L	S/L
Temperature (°F)	95	58	84	58

For maximum performance take-off runs, the flaps will have an initial deflection angle of 20° and the leading edge slats will be deflected 15°. Under normal conditions, when the aircraft is not under take-off length restrictions, the take-off settings for flaps and slats will be 10° and 15° respectively.

10.2 Climb Performance

The SA-150 is required to climb to an initial altitude of 35,000 ft and be able to make step climbs in 4,000 ft increments. The SA-150 will be able to meet these requirements. The climb segment for the 1500 nmi. mission will start immediately after clearing the 35 ft take-off obstacle. The aircraft will then accelerate from 170 knots to 250 knots through 10,000 ft. Past 10,000 ft the SA-150 will accelerate up to cruising speed while climbing to the prescribed cruise altitude and 4,000 ft step climbs can be accomplished up through a maximum altitude of 40,000 ft.[17] The rate of climb for the SA-150 is 8,000 ft per minute at sea level and decreases to 4,000 ft per minute at altitude. The engines were increased in thrust to 16,000 lb each when the initial T/W estimation proved too low for the aircraft to meet these criterion.

10.3 Cruise Performance

The wing of the SA-150 was designed to allow the aircraft to cruise at the required Mach number of 0.76 and at an altitude of 35,000 ft. The SA-150 has no significant drag rise up to this cruise speed. The L/D for this speed and altitude is 18.2. If the need arises, the cruise speed can be increased to Mach 0.80 but the L/D ratio will deteriorate from 18.2 to 9.5. For the 500 nmi. mission the optimum cruise altitude will be 30,000 ft. Since the SA-150 is designed to operate in this range, the L/D ratio decreases to approximately 17, due to the increased friction drag on the aircraft, which will not degrade fuel savings by a substantial amount.[16,17] The Boeing 737-200 has a L/D of 14 at cruise and is at a higher altitude so the SA-150 outperforms the competition.

10.4 Landing Performance

Landing is the one of the most demanding tasks that a jet transport is called on to perform. The SA-150 can obtain a maximum glide slope angle of 6°, so descending to, and holding a 3° approach angle will not be a problem. At the prescribed glide path angle, the aircraft will have a minimum AOA of 4°, so pilot visibility of the runway will be excellent.[23,24,317] The deflection angles of 30° for both slats and flaps on

landing will keep noise to a minimum, and help the SA-150 to meet the proposed Stage 4 requirements. This flap deflection angle is less than the flap deflections on most current aircraft, which run as high as 45°.

The approach and landing noise cannot be estimated at this time. Realistic noise readings can only be generated once the aircraft is in fight testing and noise readings are taken directly. However, throughout the whole design of the SA-150 efforts were made to reduce the possibilities of having a noise restricted aircraft. The flap system also allows the SA-150 to have an approach speed of approximately 180 knots with a final touchdown speed of 130 knots.

10.5 Drag Determination

The overall drag of the aircraft was calculated through a component build-up method.[16] This was done for both parasite and induced drag. An additional drag analysis was performed with ACSYNT to verify the aerodynamics of the SA-150.

The drag polars, illustrated in Figure 10.5a, are from this analysis and indicate the aerodynamic performance of the SA-150 for take-off, landing, and cruise configurations. The initial sizing of the aircraft predicted an L/D ratio of approximately 17 for the cruise configuration.[5] After the SA-150 drag build up was completed using both analysis methods, a final cruise L/D ratio of 18.2 was obtained for the aircraft (Mach 0.76 at 35,000 ft).[16,17] Final L/D ratios for various flight conditions are listed in Table 10.5. The L/D ratio in the loiter configuration was optimized by ACSYNT. The altitude for the loiter was fixed at 20,000 ft while Mach number was varied. Figure 10.5b illustrates the L/D ratios for the SA-150 for various Mach numbers vs. CLs of the aircraft.

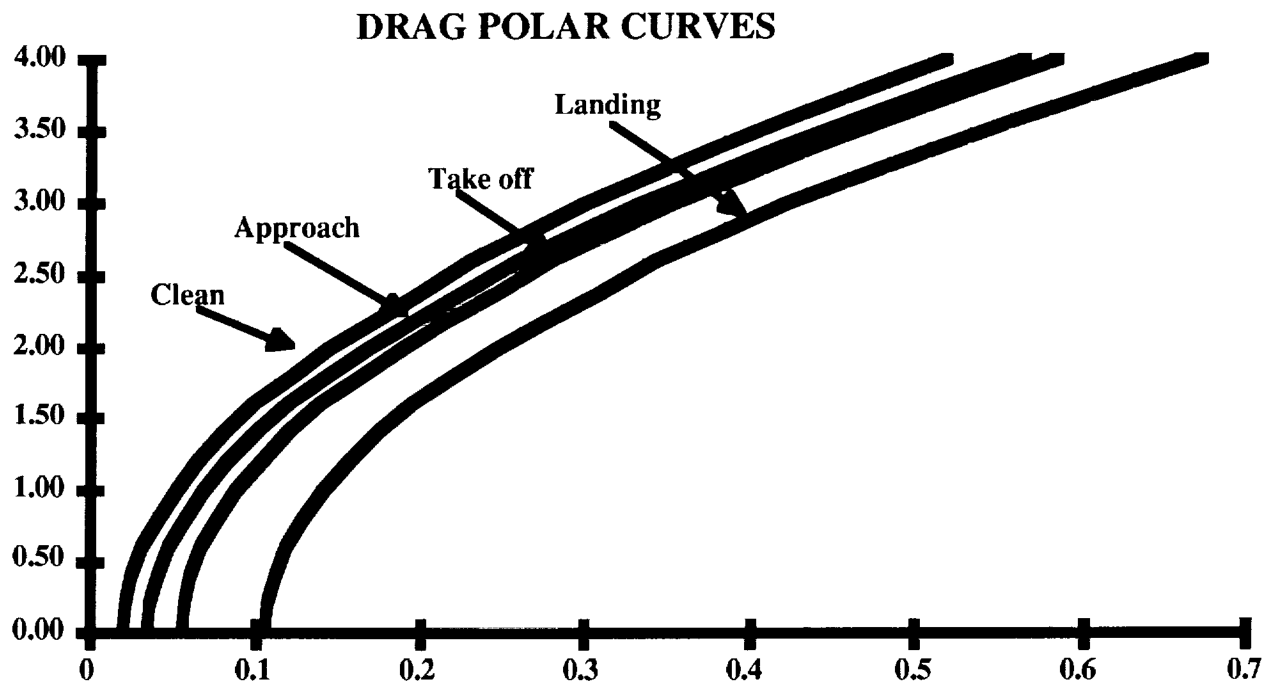

Figure 10.5a SA-150 Drag Polar Curves for Primary Configurations

Table 10.5 SA-150 L/D Ratios (Flight Segments of 1500 nmi Mission)

Flight Segment	L/D
Take-off	8.19
Second Segment Climb	11.45
Climb	17.3
Cruise(M=.76 @ 35,000ft.)	18.17
Secondary Climb	21.48
Cruise(M=.76 @ 40,000ft.)	19.20
Loiter(M=.22 @ 20,000ft.)	20.77
Landing	4.40

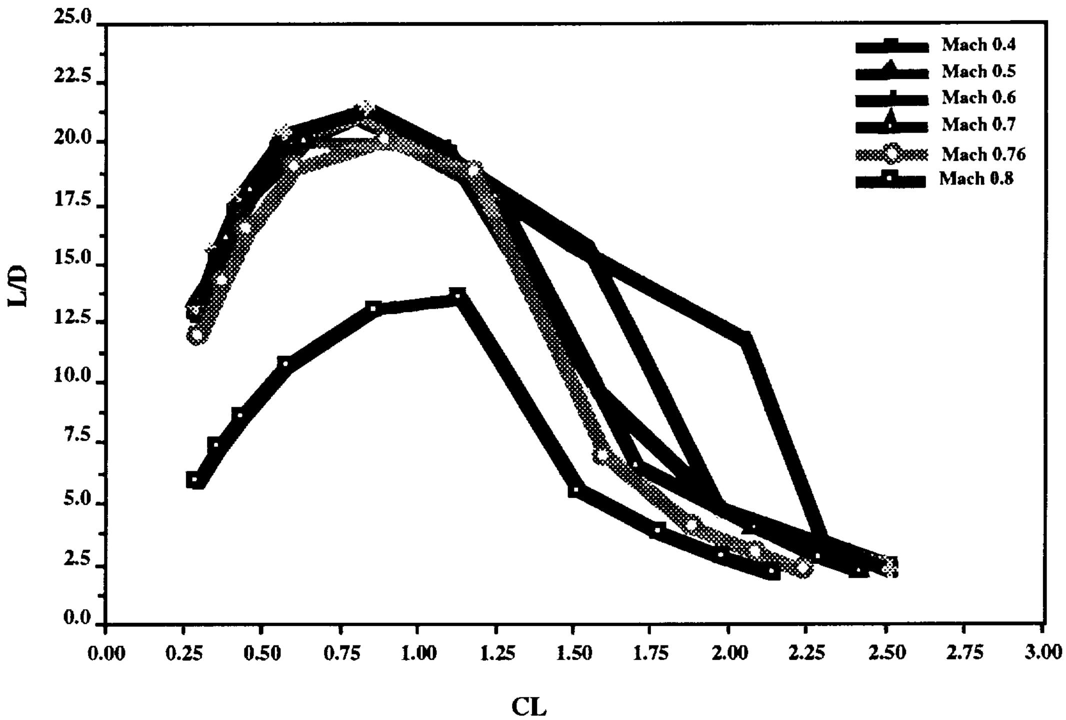

Figure 10.5b L/D Ratios for SA-150 in Cruise Configuration

10.6 Parasite Drag

Wetted surface areas of the SA-150 were calculated with the methods referenced above, and three of the major component areas are listed in Table 10.6a. For these calculations, the fuselage was assumed to be a perfect cylinder. To compensate for the increased surface area caused by this modeling, the length of the structure used for the calculations was decreased by five percent. The "V" tail and wing surface areas were found by doubling the planform area and multiplying the result by 1.02 to account for curvature of the surfaces[16]. Wing planform area was used as the reference area for all calculations and engine frontal areas were neglected. For the empennage and engine nacelle interference drag, values were calculated using empirical equations.[23,16] A 5% parasite drag factor was included in the calculations to account for protrusions from the airframe, leaks between control surfaces and any other miscellaneous drag that may occur.[16] The major drag contributions for the SA-150 are listed in Table 10.6b.

Table 10.6a Major Component Wetted Areas

Fuselage (sq. ft.)	4052
Wing (sq. ft.)	1922
"V" Tail (sq. ft.)	432

Table 10.6b SA-50 Component Drag Breakdown (m=0.76 @ 35,000ft.)

Component	Drag(lbs.)
Friction	732
Fuselage	425
Wing	239
V-Tail	68
Interference	95
Induced	1216

10.7 Drag Due To Lift

The induced drag of the aircraft was developed using the method described in Reference 17. The assumed efficiency factors were 0.85 for cruise, 0.80 for approach, and 0.75 for the take-off and landing configurations.[5] An efficiency factor of 0.85 was held constant for the "V" tail for all flight conditions and an additional induced drag component was calculated for the flaps.[23] Figure 10.7 shows that even in the cruise configuration that induced drag is the largest part of the SA-150's drag. The 12 AR wing helps minimize this drag and the cruise L/D is approximately 4 above the Boeing 737. ACSYNT was also used to develop the induced drag of the SA-150, as well a complete drag build up for the entire aircraft which was less than one percent different than component build up method.

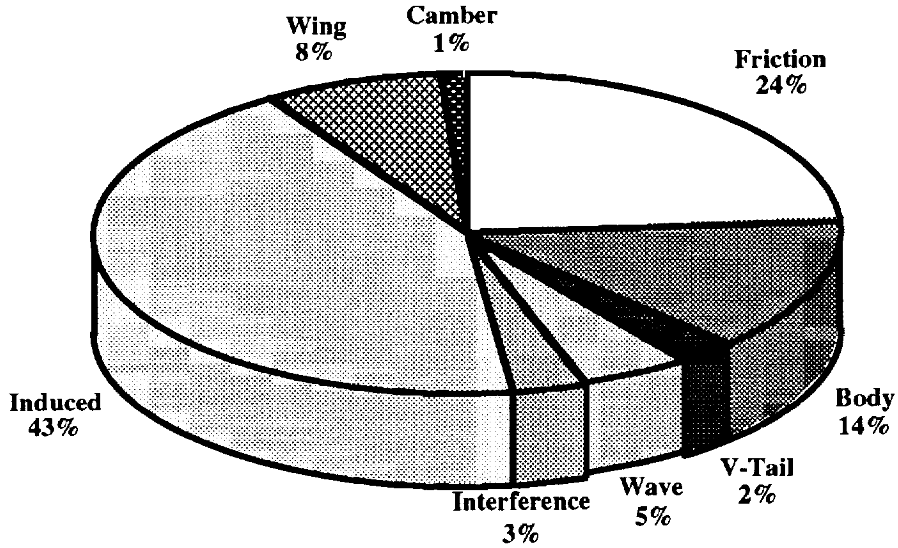

Figure 10.7 SA-150 Total Aircraft Drag Breakdown (M 0.76 @ 35,000 ft)

11.0 STABILITY AND CONTROL

11.1 Flight Condition Definitions

In the following analyses, stability and control derivatives and other parameters will be calculated for several flight conditions. These conditions will be called takeoff (T/O), climb, cruise, and landing, and are defined in Table 11.1.

Table 11.1 Definition of Analyzed Flight Conditions

Flight Condition	T/O	Climb	Cruise	Landing
Altitude, ft (std. MSL)	0	10,000	35,000	0
Mach Number	.20	.39	.76	.16
Weight, lbs.	104,000	100,000	94,000	85,000
Xcg, fraction MAC	.30	.28	.26	.21
C_L	1.9	.7	.49	2.65
Flaps	15°	up	up	30°

11.2 Balance and CG Excursion

Total aircraft weights and CG locations are illustrated in the CG excursion diagram of Figure 11.2 The total CG travel is 0.15 of the MAC, which compares well to the 0.12 to 0.32 range typical of jet transports. CG travel during a typical mission is even smaller, making the aircraft more easily trimable.

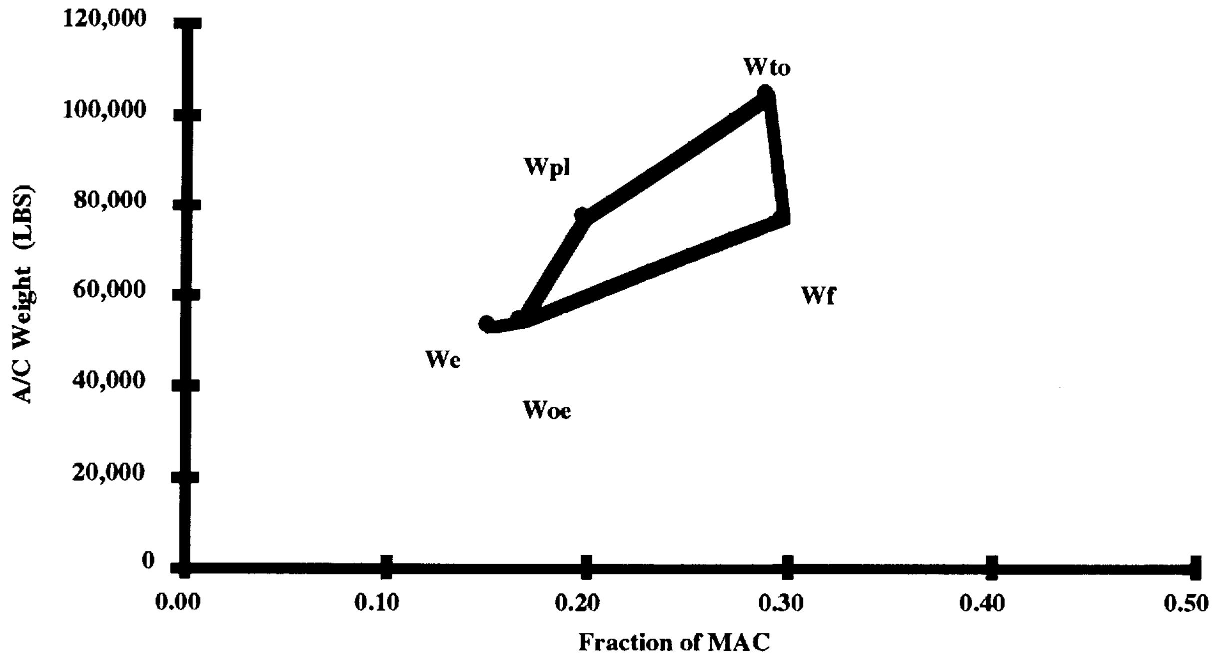

Figure 11.2 SA-150 CG Excursion Diagram

11.3 Static Stability

The SA-150 uses a digital electronic fly-by-wire flight control system (FCS) with feedback stability and control augmentation system (SCAS) in order to allow negative static stability in the longitudinal axis and approximately neutral static directional stability.

The SA-150 was designed to have its neutral point ahead of the CG, creating a positive value of C_m/C_L. The resulting C_m reduces the tail down-force required for trim and allows trim in cruise conditions to be accomplished by fuel distribution alone. This will be more fully discussed in the section on aircraft trim. The longitudinal static instability of the SA-150 necessitates the use of a SCAS which will be implemented through the software of the flight control system. Table 11.3 shows the static margin for several flight conditions.

Table 11.3 SA-150 Longitudinal Static Stability

Flight Condition	Neutral Point	CG	Static Margin
T/O	0.25	0.30	-0.05
Climb	0.20	0.28	-0.08
Cruise	0.21	0.26	-0.05
Landing	0.28	0.21	0.08

As discussed in the empennage sizing section, the static directional stability is conservatively estimated to be zero. Some methods have indicated C_{n_β} values in the range of 0.02 to 0.06 depending on the flight condition.[25] However, the SCAS will be able to provide sufficient sideslip-to-rudder feedback in order to achieve an effective margin of stability of C_{n_β} = 0.057. For an unaugmented value of C_{n_β} = 0.0, the required sideslip-to-rudder feedback gain is $K_\beta = \Delta C_{n_\beta}/C_{n_{d_r}} = 0.43$, which is a relatively small and easily achievable amount of gain.[24]

11.4 Stability and Control Derivatives

Stability and control derivatives for the SA-150 have been evaluated for several flight conditions.[25,23,26] These derivatives are presented in Table 11.4.

Table 11.4 SA-150 Stability and Control Derivatives

Longitudinal

	T/O	Climb	Cruise	Landing
C_{L_u}	.067	.10	.47	.093
C_{m_u}	.05	.018	.013	.07
C_{L_α}	8.5	5.0	4.5	9.5
C_{m_α}	.39	.42	.23	-.71
C_{L_α}-dot	2.1	2.2	3.1	2.1
C_{m_α}-dot	-9.5	-10.3	-14.5	-9.8
C_{L_q}	-3.5	-3.7	-4.0	-3.4
C_{m_q}	-12.5	-13.4	-14.5	-12.4

Lateral/Directional

	T/O	Climb	Cruise	Landing
$C_{l\beta}$	-.13	-.079	-.226	-.14
$C_{n\beta}$	.043	.038	.023	.058
$C_{y\beta}$	-.59	-.59	-.59	-.59
$C_{l\beta\text{-dot}}$	.0027	.0033	.0027	-.0011
$C_{n\beta\text{-dot}}$	.016	.018	.016	-.019
$C_{y\beta\text{-dot}}$	.039	.043	.040	.046
C_{lr}	.46	.15	.14	.44
C_{nr}	-.19	-.19	-.20	-.20
C_{yr}	.45	.46	.45	.47
C_{lp}	-.57	-.52	-.48	-.58
C_{np}	-.27	-.11	-.08	-.29
C_{yp}	-.05	-.058	-.05	-.001

Control Derivatives

	T/O	Climb	Cruise	Landing
$C_{l\delta a}$	.12	.13	.15	.12
$C_{n\delta a}$	-.064	-.018	-.030	-.066
$C_{l\delta r}$	.006	.007	.005	.000
$C_{n\delta r}$	-.12	-.11	-.10	-.12
$C_{y\delta r}$	.13	.13	.10	.13
$C_{l\delta s}$	.024	.024	.029	.024
$C_{n\delta s}$	.038	.038	.038	.038
$C_{L\delta e}$	.53	.48	.37	.49
$C_{m\delta e}$	-1.9	-2.2	-1.7	-2.32

11.5 Aircraft Trim

The SA-150 uses its ruddervators for longitudinal control and trim. Trim is also accomplished by pumping fuel within the aircraft to shift the CG. In addition to fuel distribution within the wing, fuel can be pumped to a 40 gallon tank located in the aft fuselage area near the APU. In the cruise flight condition fuel pumping alone is sufficient to trim the aircraft, thus eliminating control surface trim drag. Figures 11.5a through 11.5d present trim diagrams for four flight conditions. These diagrams show plots of C_L vs angle of attack and C_L vs C_m. Lines of constant control deflection are drawn on the C_L vs C_m curve. A positive deflection is one that produces positive lift. Since the SA-150 has a negative static margin in most flight regimes, the required control deflections for trim are often opposite to those which would be required in a conventional aircraft. This would be highly undesirable in a conventional airplane since it would be very unnatural to

pilots, so the SCAS is necessary to provide control while giving the pilot the illusion of a conventional aircraft.

Figure 11.5a is the trim diagram for the takeoff flight condition. It is evident from the C_L vs C_m curve that the ruddervators must produce a negative pitching moment (positive lift) for trimmed flight in this condition. This is due to a relatively large negative value of static margin (-.11) in this situation. This makes takeoff rotation easy and increases the maximum available trimmed lift. As noted above, it also means that the aircraft requires a control deflection opposite to that of a stable one in the same situation. Figure 11.5b is for the climb condition. It can be seen that a small positive ruddervator deflection is required for trim. Figure 11.5c is for the cruise condition. As can be seen, the SA-150 has been designed to cruise with no ruddervator deflection. As mentioned previously, the CG can be shifted slightly by means of fuel distribution in order to compensate for variations in pitching moment during cruise. Figure 11.5d is for the landing condition. As can be seen from Table 11.3 and the value of $c_{m\alpha}$ in Table 11.4, the SA-150 has positive longitudinal static stability in this regime, so that a negative ruddervator deflection is required for trim.

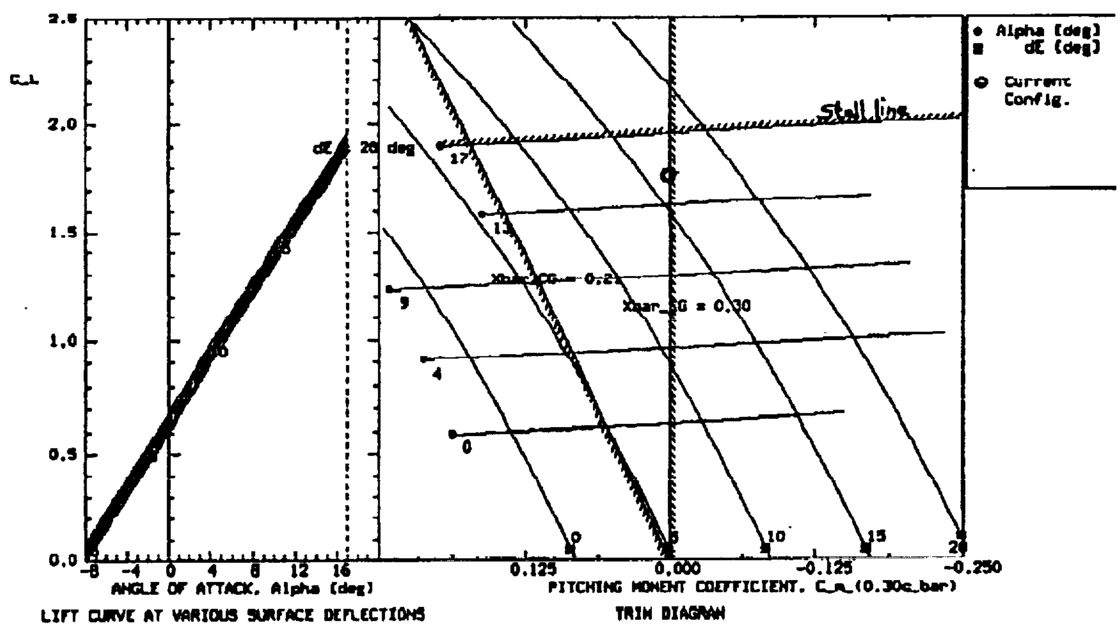

Figure 11.5a Trim Diagram for SA-150 (Takeoff)

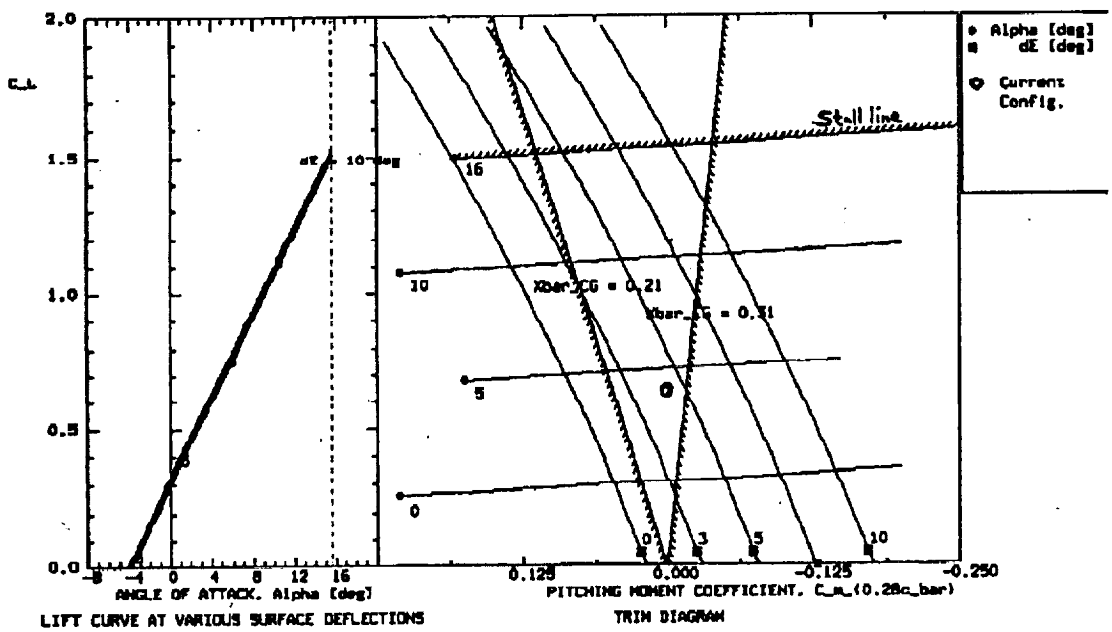

Figure 11.5b Trim Diagram for SA-150 (Climb)

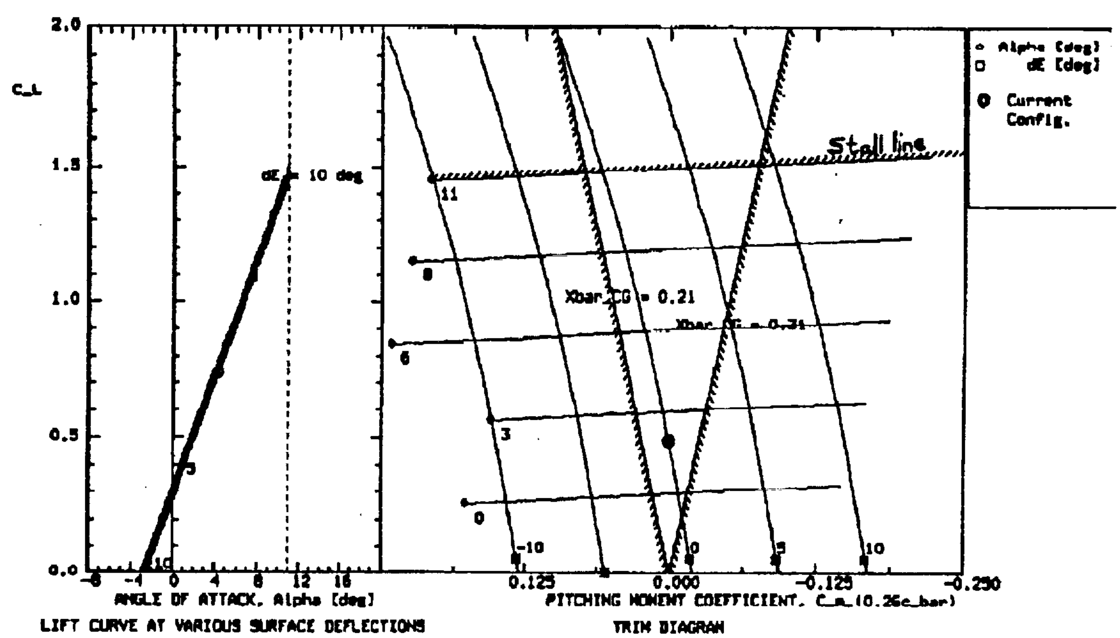

Figure 11.5c SA-150 Trim Diagram (Cruise)

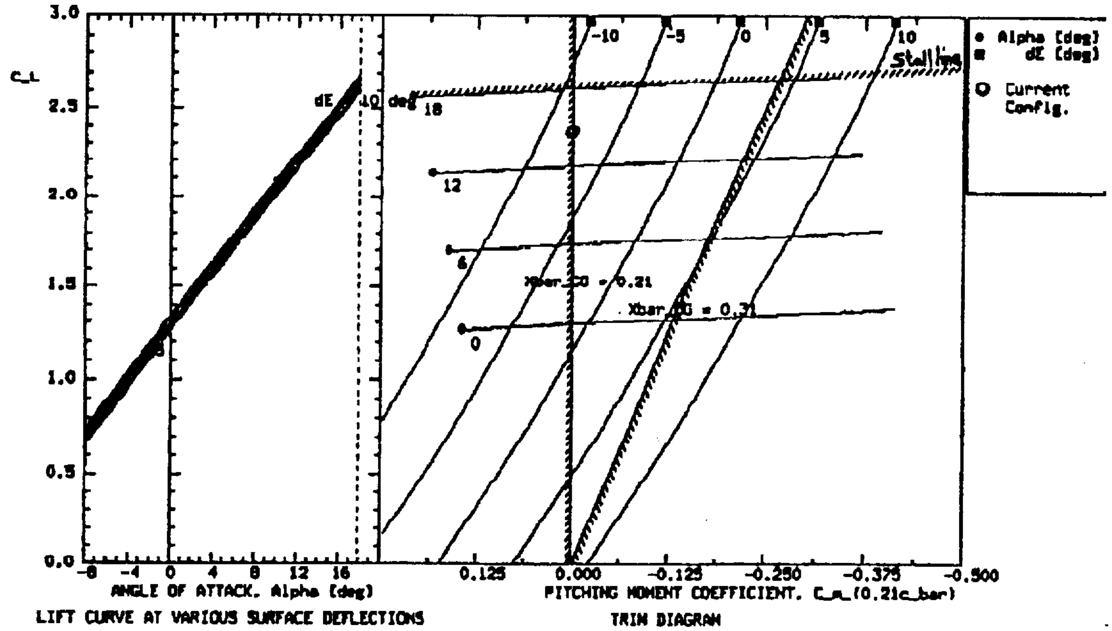

Figure 11.5d SA-150 Trim Diagram (Landing)

11.6 Flying Qualities

A literal factors analysis was performed to evaluate dynamic stability and flying qualities of the SA-150.[27,28] For each of the flight conditions analyzed, natural frequencies and damping ratios were calculated for phugoid and Dutch roll modes. In addition, the time constant was calculated for the roll mode. The results were compared to flying qualities levels as defined in MIL-F-8785B. A summary of the results of this analysis is shown in Table 11.6.

Table 11.6 Evaluation of SA-150 Flying Qualities

	T/O	Climb	Cruise	Landing
Phugoid				
damping ratio	.064	.035	.039	.18
nat. freq., rad/sec	.21	.11	.054	.26
Predicted Level	1	2	2	1
Dutch Roll				
damping ratio	.40	.43	.59	.37
nat. freq., rad/sec	.64	1.0	.88	.6
Predicted Level	1	1	1	1
Roll				
time const., sec	.19	.12	.10	.19
Predicted Level	1	1	1	1

It can be seen from Table 11.6 that acceptable flying qualities are predicted in most cases. The exception is the Phugoid mode which is predicted to be Level 1 only for takeoff and landing. For this mode, the requirement for Level 1 is a minimum damping ratio of 0.04. The predicted values of 0.035 and 0.039 for climb and cruise, respectively, put the SA-150 slightly within Level 2. Due to the approximate nature of the analysis and the uncertain correlation of literal factors to actual pilot-in-the-loop handling qualities, flight testing must be the ultimate judge of the acceptability of the SA-150's handling qualities. If the Phugoid or another mode proved unacceptable, compensation would be implemented through the SCAS in order to provide Level 1 handling.

12.0

STRUCTURES

12.1 Structural Design Loads

A number of different criteria determined the loads to which the structures of the aircraft had to be designed. In order to determine the worst case scenario for the aircraft, a series of V-n diagrams were generated for different altitudes and load conditions.[29,30] An altitude of 20,000 feet and maximum gross takeoff weight was the critical design condition for the wing structure. At altitudes between sea level and 20,000 feet, gust intensity is considered the same. Since all calculations are made using equivalent airspeed, the V-n diagram for 20,000 ft and MGTOW will be identical to a V-n diagram generated for sea level conditions and the same aircraft weight. The V-n diagram for this case is shown in Figure 12.1a.

The aircraft is slightly gust load sensitive for this condition and to be flown at an unrestricted Mach number of 0.76, the wing structure must be designed to a 2.6 g-load factor. This structure will be heavier and more expensive to build because it must be stronger than a wing designed for a maneuvering g-load factor of 2.5. This penalty was considered an acceptable trade to give the airlines a plane that has no structural design restrictions on its cruise speed.

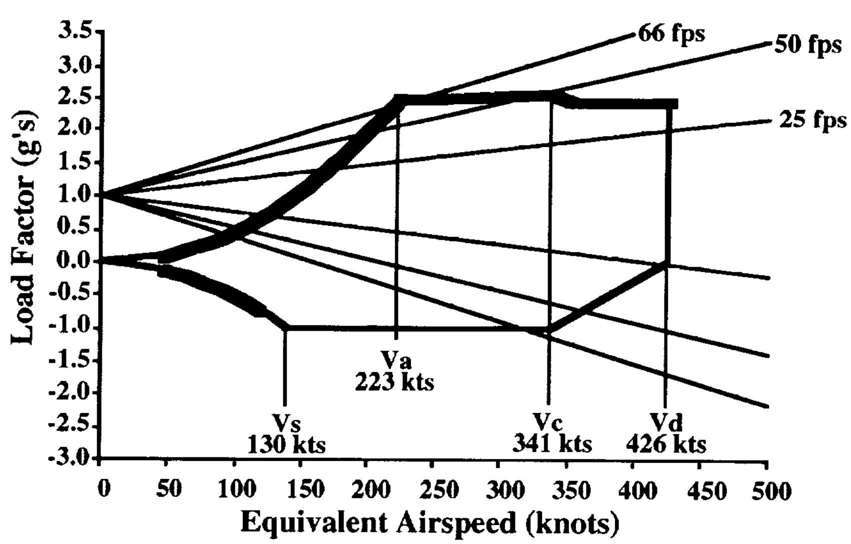

Figure 12.1a V-n Diagram, Max. Gross Weight at 20,000 ft

The V-n diagram for Woe and minimum fuel at 20,000 feet, as illustrated in Figure 12.1b, indicates that gusts can place a maximum g-load factor of 3.7 on the aircraft. This effect is due to the decreased wing loading of the aircraft when all the payload is removed and the mission fuel is burned off down to the reserve level. Such a situation could occur when ferrying the aircraft for initial delivery or maintenance requirements.

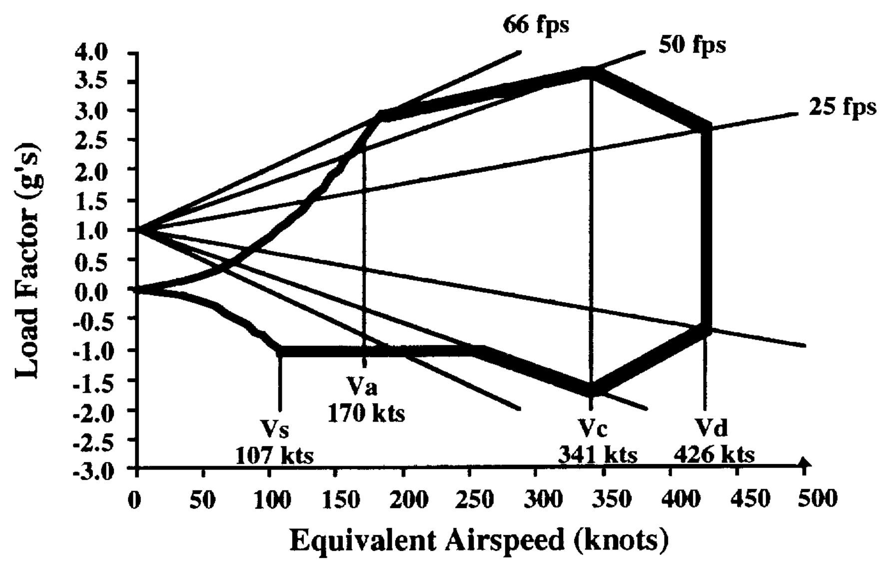

Figure 12.1b SA-150 V-n Diagram, Woe and Reserve Fuel at 20,000 ft

Even though this g-load factor is 40% greater than the value determined from Figure 12.1a, the aircraft weight reduction, due to fuel and cargo being removed, results in lower stresses at the wing root. Calculations for the bending and twisting moments at the wing root were completed using the maximum g-loads indicated in Figures 12.1a and 12.1b as well as for the case of maximum PAX and bags in combination with reserve fuel only. It was determined that stresses were higher for the MGTOW loading at 20,000 ft than for any other case tested. Even though the g-load experienced by the aircraft is increasing as weight is removed, the total amount of weight that the wing has to support decreases. The net result is that the wing has to generate more lifting force for the case indicated in Figure 12.1a than it does for any other condition.

A similar case study was completed for the design of the fuselage structure to determine its critical condition. Maximum stresses in the fuselage structure were calculated at a g-load factor of 2.9 as determined by the V-n diagram for 20,000 feet, maximum PAX and bags with reserve fuel only. The V-n diagram for this case is not shown.

Lift distribution over the span of the wing was found by applying the Shrenk method.[26] The magnitude of this lift distribution was set equal to the product of the maximum gross take-off weight, the 2.6 g-load factor and a safety factor of 1.8 to account for the unknowns of composite construction. Shear force, bending moment and twisting moment diagrams for the wing were generated after accounting for the weight distribution of structure, fuel, engines, landing gear and control surfaces, When determining the twisting moment it was assumed that the lift forces were acting at the quarter chord location.

The distribution diagrams for the half span of the wing are illustrated in Figures 12.1c and 12.1d. The dip in the shear force distribution plot is the result of the engine weight focused at that point. Shear force relief due to the weight of wing structure, fuel and control surfaces is more evenly distributed over the span of the wing so it does not show up to the extent that the engine weight does. Twisting effects due to engine placement and weight along with the uneven distribution of fuel and structural weight of the wing account for the irregularities of the twisting moment plot in Figure 12.1d. The effect of the yehudi on the lift distribution of the wing can also be noticed starting about 15 feet outboard of the wing root in Figure 12.1c.

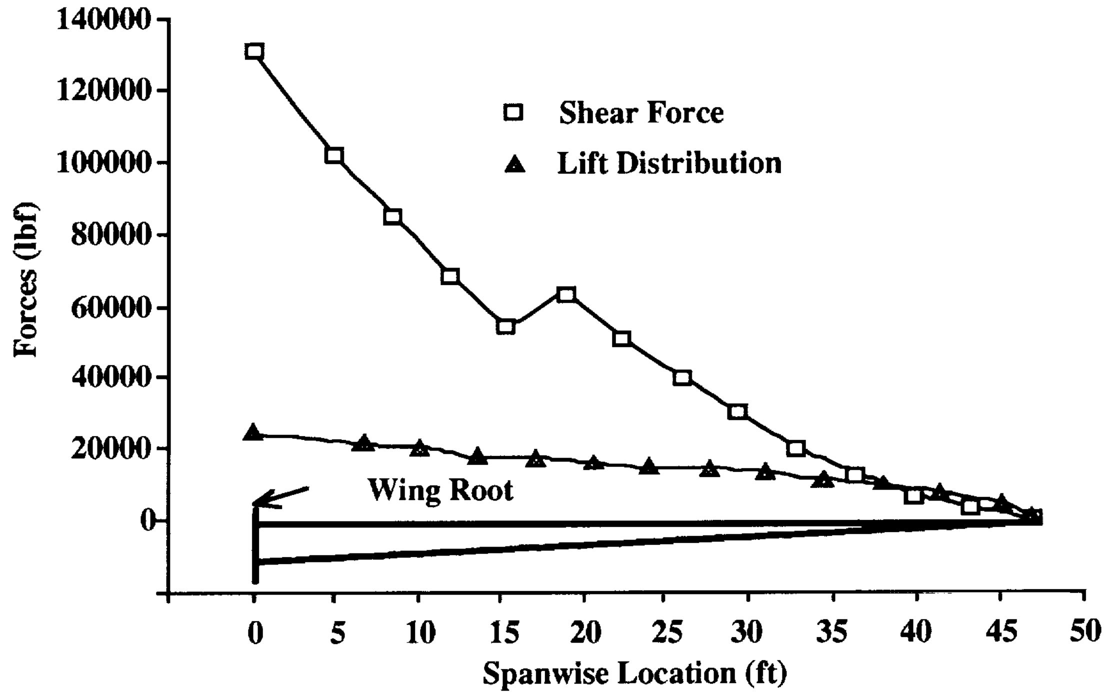

Figure 12.1c SA-150 Wing Lift and Shear Distribution

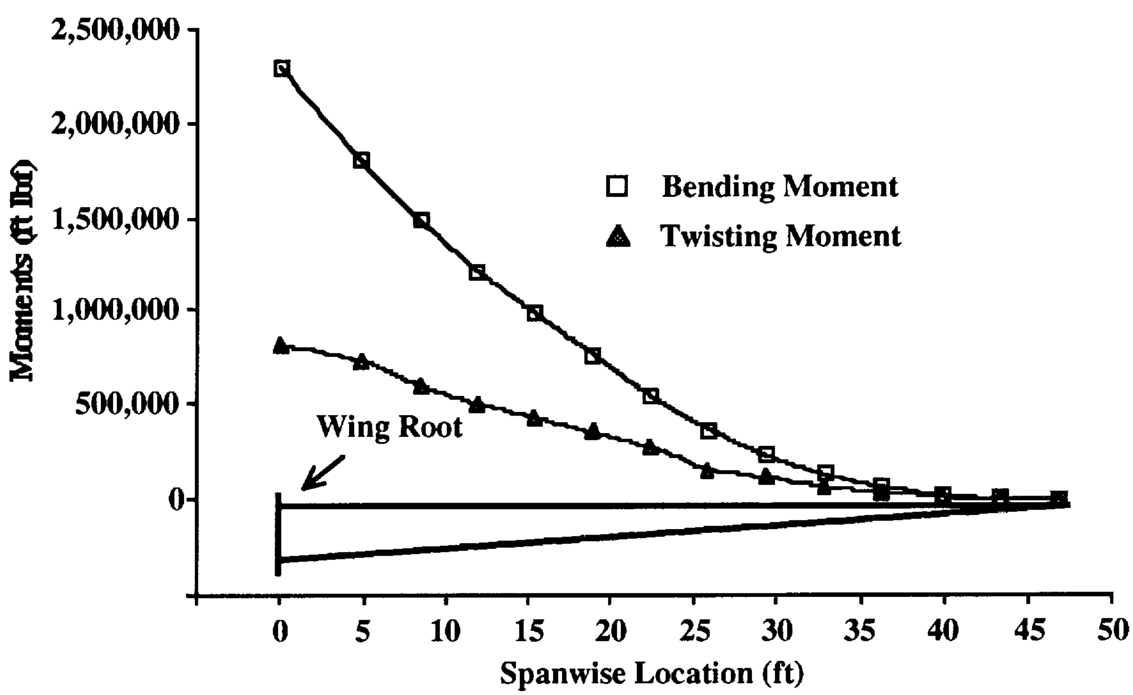

Figure 12.1d SA-150 Wing Twist and Bending Moment Distribution

Structures for the tail were sized by the control power needed to counter the maximum pitching moment of the aircraft at approach speed and one engine out, cross wind conditions. After maximum load conditions were determined, lift distribution, shear force, bending moment and twisting moment diagrams for the tail were constructed. These diagrams were generated using the same methods as described for the wing analysis except that a safety factor of 1.5 instead of 1.8 was used because conventional aluminum materials will be used in the tail. From the diagrams, the maximum moments and shear forces at the tail root location were obtained.

The forces accounted for in the fuselage design include down and side loads generated by the tail, weight of the structure during maneuvers and pressure differentials between the cabin and atmosphere. A complete listing of design bending moments, twisting moments and shear values is given in Table 12.1.

Table 12.1 SA-150 Calculated Structural Design Loads

Design Loads	Wing Root	Tail Root	Fuselage Joint @ Aft Side of the Wing Box
Shear Force (lbf)	130,000	26,600	159,952
Bending Moment (ft lbf)	2,300,000	227,270	4,465,452
Twisting Moment ft lbf)	889,000	141,800	172,800
Pressure Force (lbf / in^2)	N/A	N/A	8.2

12.2 Wing Structures

The wing of the SA-150 is the most unique structural component of the aircraft. With an aspect ratio of 12, it becomes a serious challenge to design a structure that can withstand not only bending and twisting moments, but aeroelastic flutter effects as well. For this reason, the decision was made to build a composite wing structure. The stiffness provided by the material and the ability to tailor the structure as necessary, will allow flutter effects to be compensated for. This approach has been successfully applied on experimental aircraft such as the Grumman X-29. A detailed analysis of aeroelastic flutter and the tailoring needed to compensate for it is beyond the

scope of this report and will need to be addressed with extensive wind tunnel testing.

A primary wing structure made out of composites necessitates a different design and manufacturing technique than used for conventional aluminum structures. Unlike metals, composites are not easily joined together by common fasteners such as rivets and bolts.[31] The use of these devices detract from the inherent advantages of a composite structure and are costly, since expensive titanium fasteners must be used to avoid corrosion.[31] In addition, the design of numerous small parts neglects the ability to form one piece, complex geometries out of composite material. For these reasons, a one piece elliptical wing box was designed as shown in Figure 12.2a.

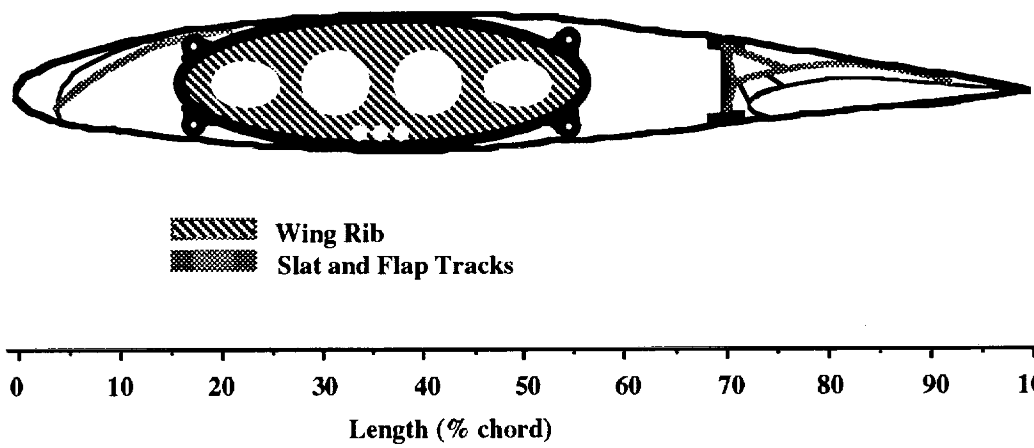

Figure 12.2a SA-150 Side View of Wing Structures at Root

The elliptical shape of the box was chosen for a number of practical reasons. An ellipsoid will provide the second largest cross sectional area that can fit within the confines of the aerodynamic shape of the wing. A more traditional rectangular shape would provide a larger area but its design would create large stress concentrations at the corners and it would be more difficult to filament wind. A large area not only allows for a more efficient structural use of material, but it provides a place to store fuel. Calculations of the space available for fuel storage in the wing box of the SA-150 were completed to verify that a larger cross section would not be needed. With the current design, taking dry bay space behind the engines and at the wing tips into account, there is enough space in the wing to hold up to 29,000 lbs. of fuel. For the 1500 nmi. mission, only 23,000 lbs of fuel storage space is required.

Initial calculations, using AS4-8552 carbon graphite epoxy and a weave pattern of 0°,-45°, 45°, 90° result in a structure that is 0.4 inches thick at the wing root.[32,33,34] AS4-8552 was chosen because the fibers are widely used in the industry and are not as expensive as IM7 or IM8 fibers. The IM fibers have a higher tensile strength and modulus, but the increase in material strength was not considered to be cost effective. The initial weave directions were chosen so the material would have nearly uniform stiffness and its reaction to different loading directions would be more easily calculated. The size and thickness of the structure will taper in a nearly linear fashion out towards the tip of the wing as seen in Figure 12.2b.

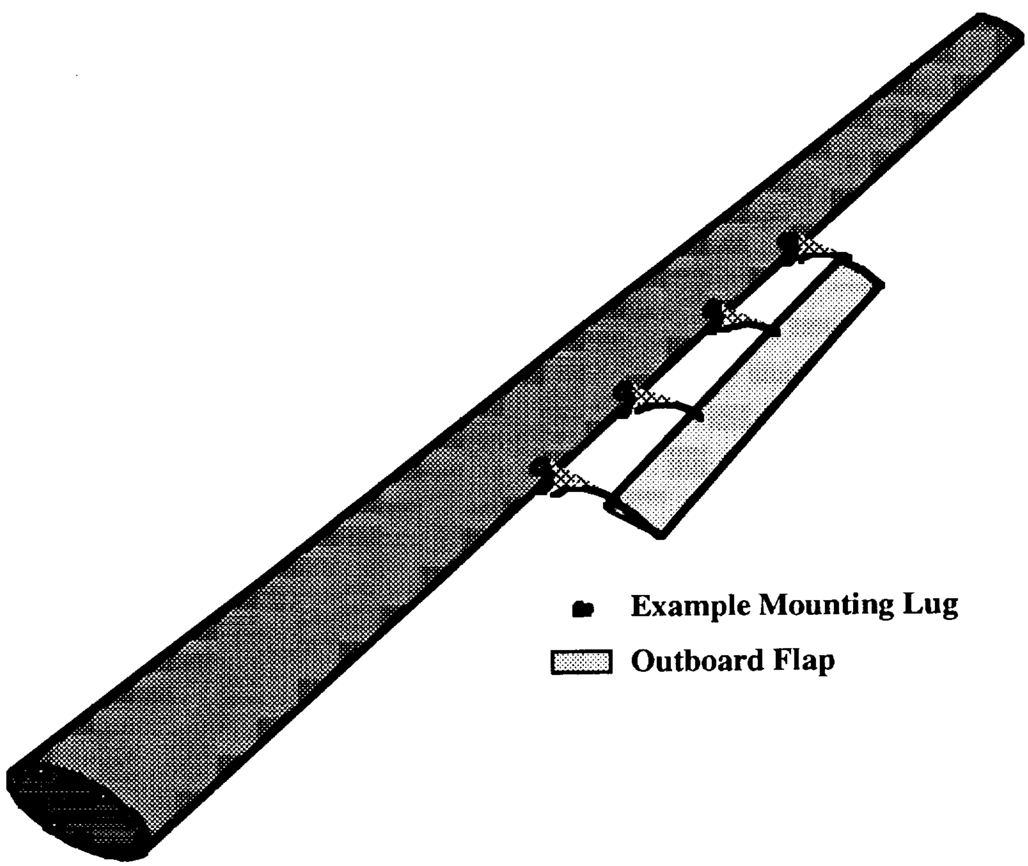

Figure 12.2b SA-150 Wing Box

The example lugs shown will be partially preformed and then wound into the structure to provide adequate strength for the attachment of flaps, control surfaces, landing gear and engine pylons to the structure. Internal members, such as the rib shown in Figure 12.2a, will also be preformed and laid up as part of the spinning mold. The internal members can be stitched into the windings to increase their strength and avoid delamination. Once the wing box has been spun and cured, the foam winding mold can be dissolved and removed from the internal gas tank areas which can then be sealed and treated as necessary. This manufacturing process has the benefit of being almost entirely automated so that long term production costs are reduced and consistent quality is assured.

Careful examination of Figure 12.2a shows that leading edge slat tracks have adequate room to be stowed between the wing skin and the wing box. With this arrangement, there is no need to provide space in the wing box, which would be more complex and degrade the strength of the structure. A trailing spar of extruded composite material is provided for the attachment of the inboard flaps and main landing gear. A stowed slat and flap are also illustrated in Figure 12.2a. The flap extension and retraction system, and the track structures were modeled after systems found on Lockheed and Hawker Siddeley aircraft.[31] In the areas where the wing skins do not directly contact the wing box, light weight ribs will be formed and bonded to the structure. Wing skins can then be bonded to these ribs to transmit the aerodynamic loads to the primary structure.[35]

Figure 12.2c illustrates the top view of the same structure. This view indicates the location of the dry bay behind the engine and the spacing of the internal structure in the wing box. Spacing between the ribs will be a fairly conventional 24 inches to help maintain the shape of the structure and to help limit the movement of the fuel in the tanks. The main gear will have multiple attach points at the wing box and trailing spar to decrease point loads and possible shock damage incurred as a result of hard landings. Wing box mounting to the torque box will be accomplished through a series of attach points aligned with the major cross members of the torque box as indicated in Figure 12.2c. This multi-point attach system was chosen to take advantage of the distributed load throughout the wing box instead of concentrating it back down to only a few points.

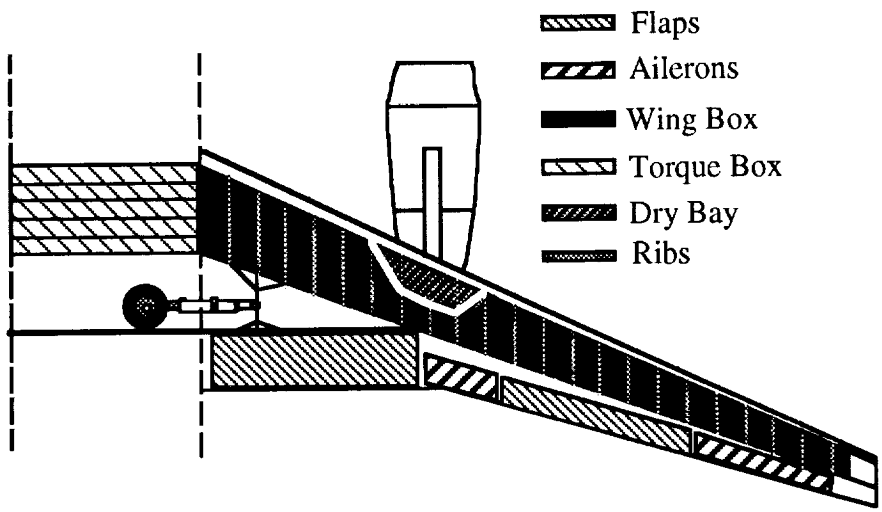

Figure 12.2c SA-150 Top View of Wing Structures

Since this skin does not need to have the same strength and rigidity as the primary structure, a material with improved durability characteristics can be used in these areas. These more durable skins will resist foreign object damage better than the material of the primary structure to help keep maintenance costs low. In addition, fuel pumps will be located outside of the tanks so maintenance procedures on these items will be quick, and the number of inspection and access panels in the primary structure can be kept to a minimum. A composite structure also has the advantage of not being susceptible to common corrosion or fatigue problems, so required inspections will be quick and few repairs due to these effects will be required.

The high lift and control systems, with the exception of the inboard flap, will need to be attached to the wing box at specially designed attach points because simple bonding procedures will not provide adequate strength. Examples of these attach lugs are illustrated in Figure 12.2b. Figure 12.2c shows that the wing box is close enough to these surfaces so that an extensive secondary mounting structure will not be required.

12.3 Fuselage

In comparison to the wing, the fuselage is a relatively conventional structure. Traditional semi-monocoque construction techniques are used

with frames, stringers and stressed skin. This design approach was chosen because there was no structural requirement to apply a more advanced and expensive composite structure.

In an attempt to reduce the number of fasteners required, the skin in the pressure vessel area is 0.070 inches thick. This increase in skin thickness will allow the use of 3/32 inch countersink rivets instead of smaller and more numerous 1/16 inch diameter rivets.[31,36] The thicker skin also results in lower stress levels in the pressure critical areas.[37] These low levels will allow the fail safe tear straps to be removed, which will further simplify the construction. Since a separate structure to support the pressure loads in the event of a failure will no longer be present, additional testing for crack propagation rates will need to be conducted to verify the safety of the design. Skin material will be 2324-T3 aluminum which has an 8% improvement in strength over 2024-T3, better fatigue and toughness characteristics while still retaining its favorable ductile qualities. The 2324 alloy, like 2024, is a aluminum-copper mix with a 24% purity content. The only difference between the two is a processing modification. For this reason, weights will be identical and cost should be close to the same.[31]

In addition to the larger diameter rivets, the thicker skins will allow frame spacing to be increased to 24 inches and stringer spacing will be 12 inches. A trade study conducted found that this structural layout decreased fuselage material weight by 4% in comparison to a structural configuration of 0.050 inch thick skins, 20 inch frame spacing and 10 inch stringer spacing. This comparison did not take into account the weight to be saved by having fewer windows and a reduced number of rivets.

Figures 12.3a and 12.3b illustrate the top and side views of the aircraft structure. A narrower frame spacing of 15 inches at the wing is provided to transmit loads to the fuselage with the exception of a 20 inch frame spacing for the over wing emergency exit. Frame spacing also deviates from normal around the cabin doors and in the aft fuselage sections.

Additional structure has been provided around the cabin door frames to distribute the pressure shear loads.[14] The cargo doors will latch firmly to the fuselage and be stress carrying members so additional surrounding structure can be kept to a minimum. Cargo door locations shown in Figure 12.8 will actually be installed on the right side of the fuselage. Passenger cabin windows are placed between all of the frames with the exception of

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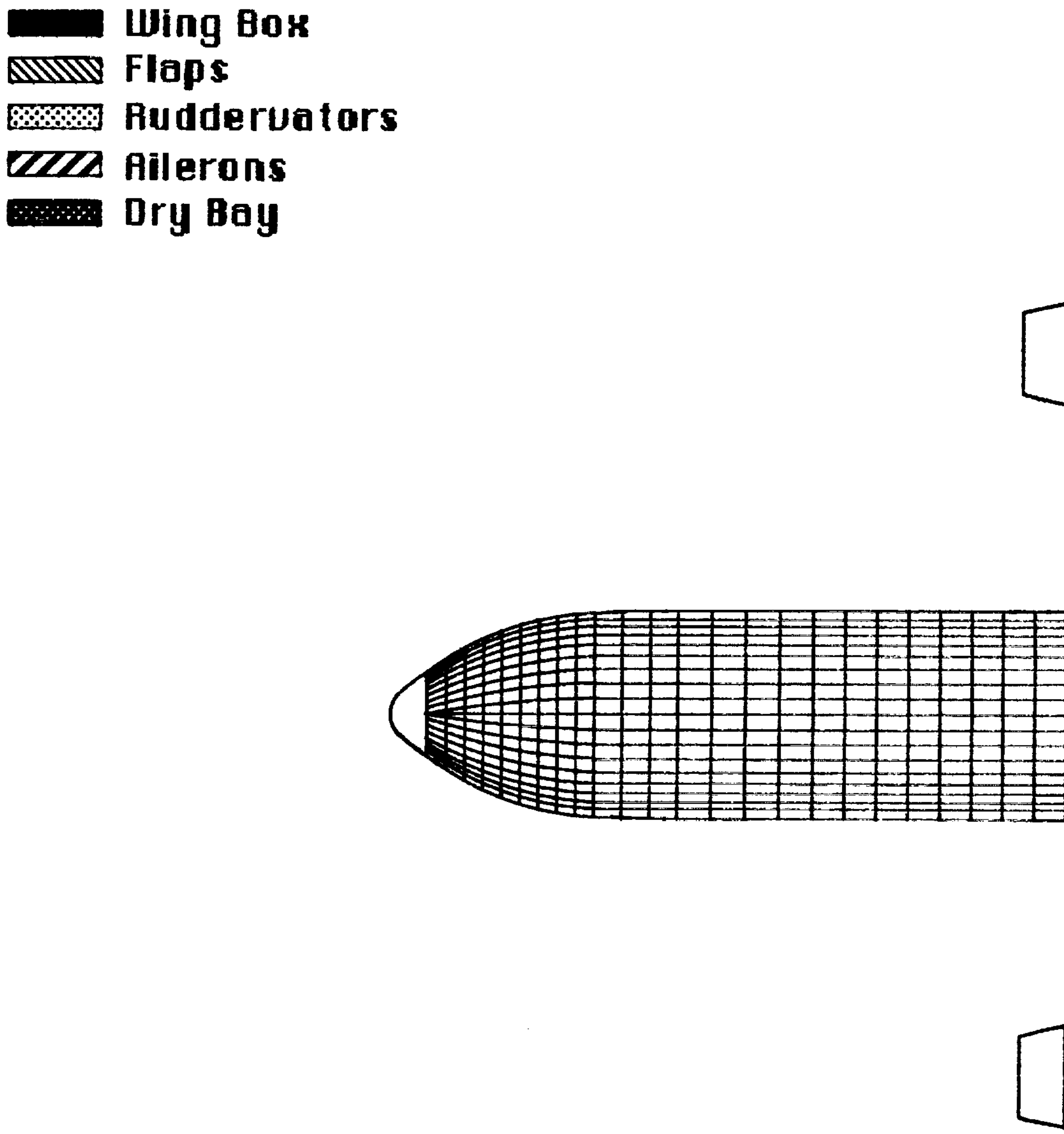

Figure 12.3a SA-150 Top View of Aircraft Structure

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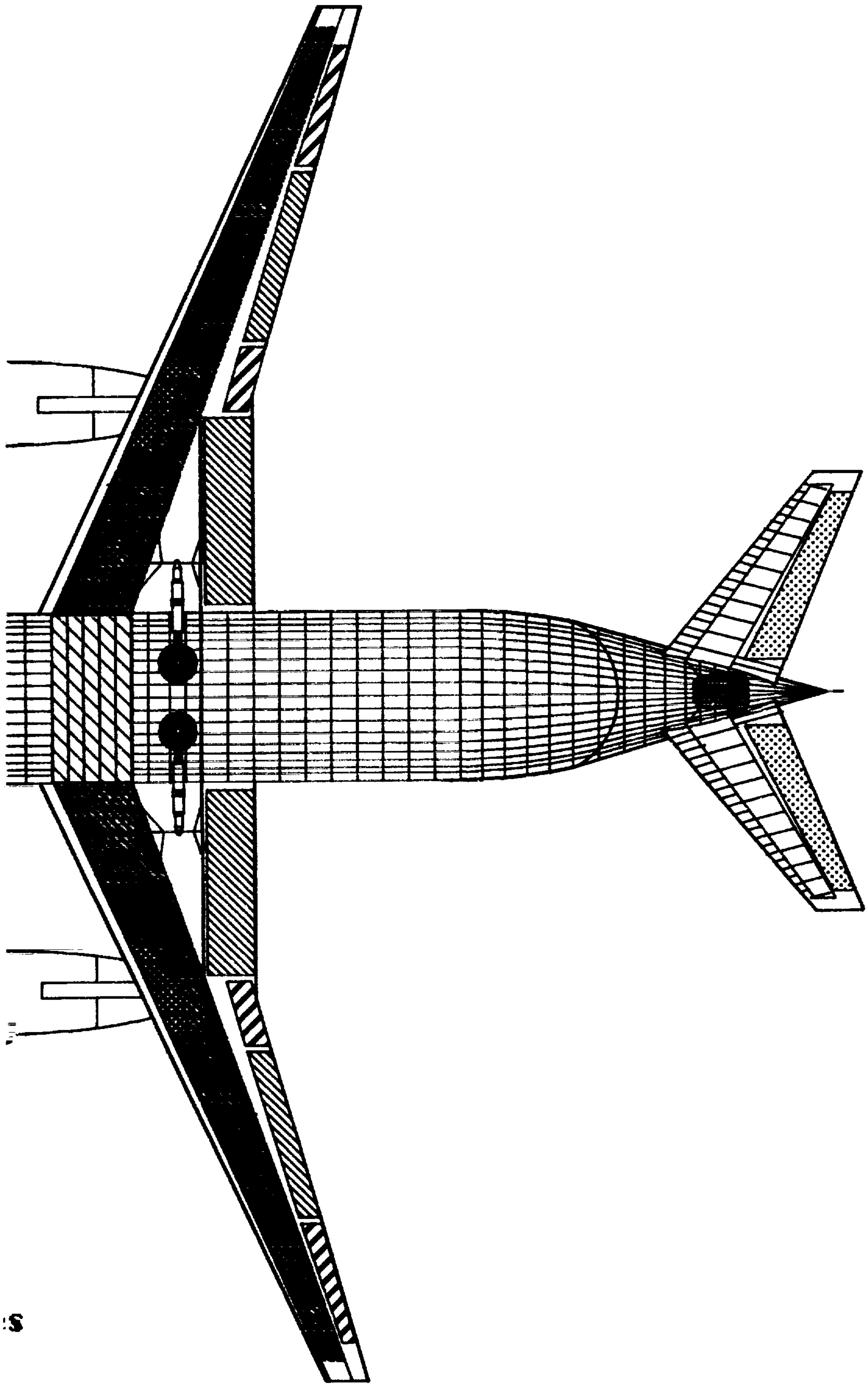

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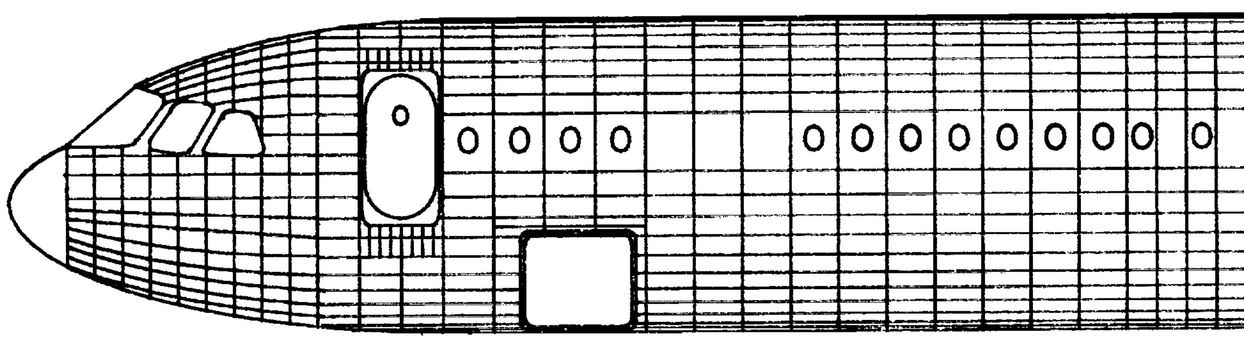

Figure 12.3b SA-150 Side View of Aircraft Structu

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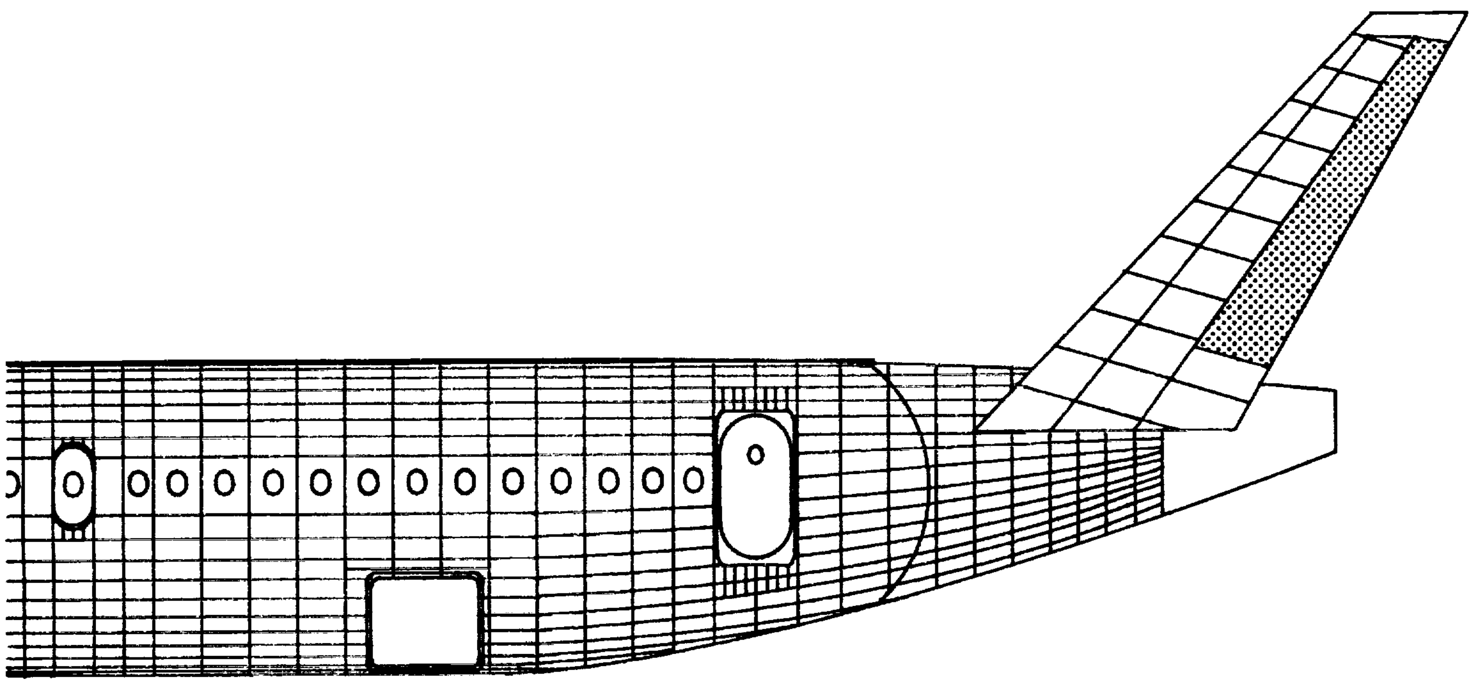

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areas where lavatories, wardrobes and galleys are located. Due to the narrow spacing between the frames over the wing, windows have been omitted at every other location. Distances between window edges reaches a maximum of 20 inches in this area which is considered adequate to provide an open and comfortable cabin atmosphere.

12.4 Empennage

A conventional twin spar, stressed aluminum skin construction was used for the "V" tail. Skin material is 0.070 inch thick 2324-T3 aluminum riveted to extruded and machined spars of the same material.[38] Since the "V" tail will experience large loads in both directions, none of the surfaces are in constant compression and there is no advantage in using 7075 aluminum in the structure.[31] The slight increase in thickness over standard 0.064 inch thick stock will allow for the use of fewer, larger diameter rivets.

Double hinged control surfaces have been designed for the tail of the SA-150 to increase control power. Instead of having an independent actuator for each control surface, only one actuator and a special control linkage is required to have both surfaces act in harmony. A cross section view of the tail structures is shown in Figure 12.4a.

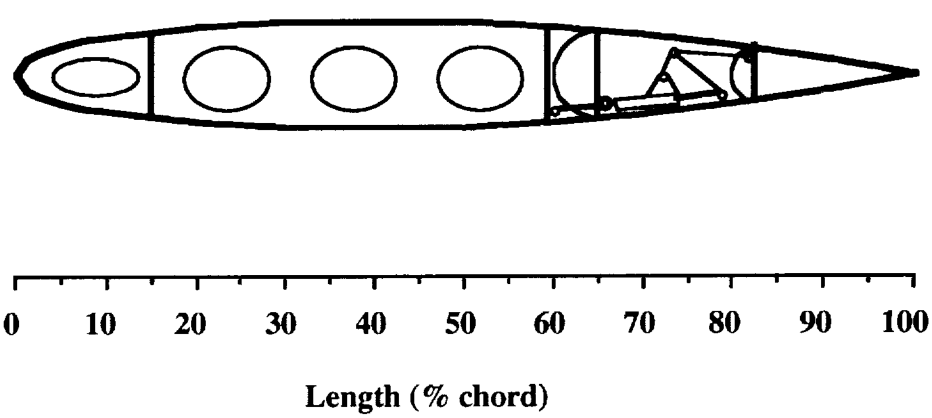


Figure 12.4a SA-150 Cross Section View of Tail Structures

Figure 12.4b is the top view of the tail section. Rib spacing between the spars is set at a conventional dimension of 24 inches.[31] Since the SA-150 will not be trimmed by varying the angle of attack of the tail, the mounting of the surfaces becomes relatively simple. A conventional torque box would be an inefficient structure considering the angle at which the two surfaces are incident upon each other. For this reason, and because there is ample room, a triangular truss type structure can be used to take advantage of the tension and compression capabilities of the material and the inherent rigidity of the geometry.

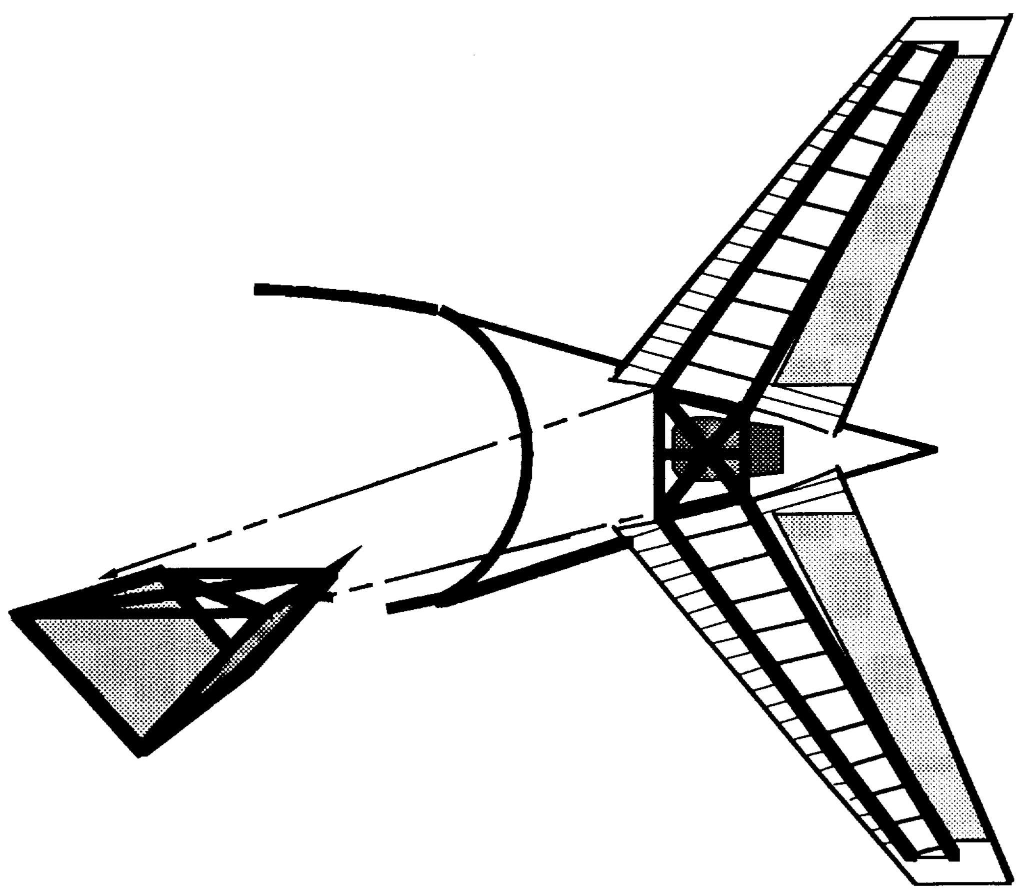


Figure 12.4b SA-150 Top View of Tail Structures

Torsion and bending moments aft of the pressure bulkhead were not critical to skin thickness. Since there are also no pressure forces on the

structure in this area, a skin thickness of 0.040 inches thick can be used and will be attached to the frames and stringers with brazier or mushroom head rivets.[36] At this aft location, the boundary layer is very thick and skin friction drag will not be increased by using these types of rivets. This selection will also reduce the manufacturing costs of building the structure.

13.0

SYSTEMS LAYOUT

Systems layout involved the careful placement of each component for ease of maintenance, CG location manipulation, and safety considerations. The major systems of the SA-150 have been described in the following sections and are shown in Figures 13.0a and 13.0b. Table 13.0 shows the basic weight, based on curved fit data from historical data based on aircraft size,[26,29,39] and location of each system.

Table 13.0 SA-150 Component/System Weights & Locations

	Weight (lbs)	Xcg (in.)	Ycg (in.)	Zcg (in.)
Structure				
Wing	8,200	670	224	103
Empennage	1,720	1,205	90	242
Fuselage	10,800	560	30	151
Main Gear	3,300	680	120	47
Nose Gear	615	119	6	40
Power Plant				
Engine + Nacelle	8,280	555	280	60
Pylon	1,000	575	280	86
Fuel System	900	640	285	105
Fixed Equipment				
Flight Controls	1,725	730	185	154
Hydraulics	730	670	185	107
Electrical	1,560	770	27	142
Abionics	1,000	180	20	162
Air + Anti Ice	1,600	430	224	116
Ox	180	375	30	162
APU	850	1,182	5	192
Furnishings	6,050	650	35	166
Baggage Handling Equip.	1,000	500	30	70
Operational Items	2,640	500	40	142
Auxilliary	600	850	30	170
Paint	425	650	30	120

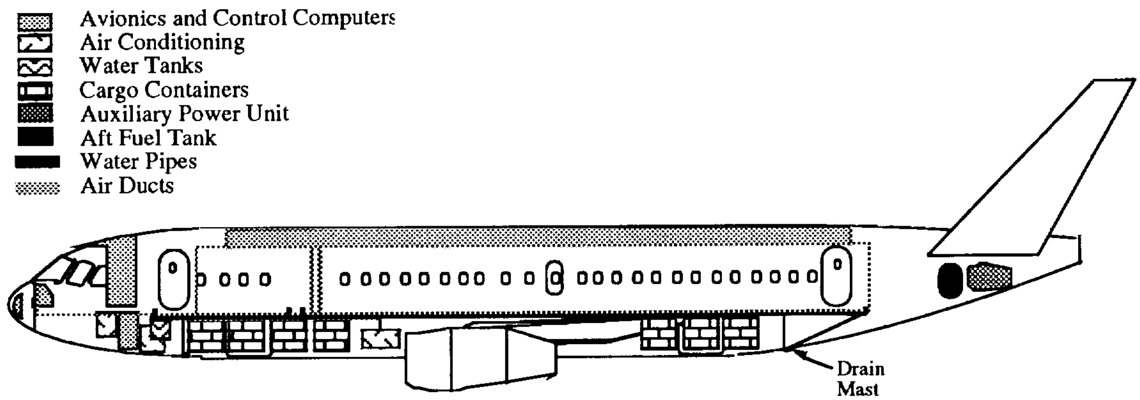


Figure 13.0a SA-150 Side View of Systems Layout

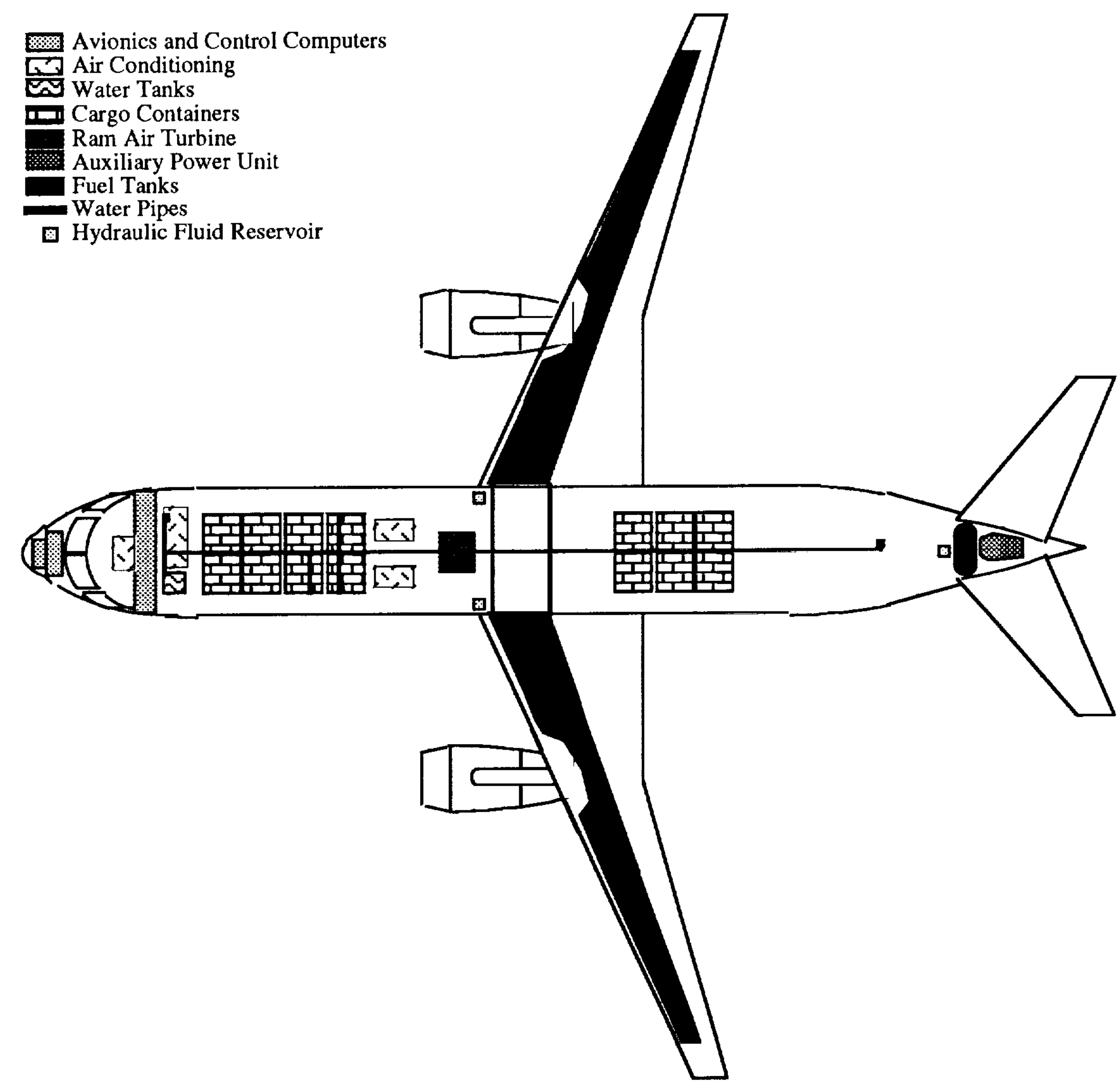


Figure 13.0b SA-150 Top View of Systems Layout

13.1 Anti-Icing System

The cockpit windows and leading edges of the wing are heated with high pressure air from the engines to prevent the formation of ice. Pitot tubes and other sensitive measurement devices are heated electrically to maintain accuracy.

13.2 Avionics Systems

Communications, data processing/data display, and navigation are controlled by the SA-150's avionics package. Optional passenger communications equipment (controlling E-MAIL, FAX, etc.) is located beside the central wardrobe.

A glass flight deck layout displays all information to the crew with backup speed, altitude, and heading indicators in case of power loss. A limited travel stick is used to simulate the dynamics of a conventional stick in order to gain pilot acceptance.[40]

With the exception of the optional passenger conveniences, communications onboard the SA-150 are standard. However, navigation will include an inertial navigation system (INS) with triple redundant calculations. A TACtical Air Navigation system (TACAN) will also be used to provide compatibility with other future aircraft capabilities. Wiring and slots to include a global positioning system (GPS) will be made, but the actual package will not be included until the option decreases in cost.

13.3 Electrical System

The fly-by-wire control system, required to maintain stability of the SA-150, makes the electrical system critical for safe operation. Main power is supplied by two engine driven generators (one off each engine) each producing 90 kVA. Wiring for each system is independent and apart from one another to assure safety and conduits are used to facilitate ease of maintenance.

The Auxiliary Power Unit (APU) or Ram Air Turbine (RAT) can provide backup power in the case of an emergency for critical systems. The APU produces 90 kVA which is enough to run the aircraft systems during stationary ground operations. The RAT is deployed automatically when power drops below a specified level. In the case of an extreme emergency, only the flight control actuators are powered by the RAT, producing 18 kVA, and the flight control computers are powered by batteries.

13.4 Environmental Control System

Hot bleed air is drawn from both engines into two air conditioning packs located just in front of the wing box. The air is then cooled (or heated), pressurized and sent to a mixing unit to be mixed with recirculated air. Distribution to the cabin is accomplished through ducts down the center of the aircraft and out vents along the upper walls and down the center aisle. Air is circulated from the front and rear of the aircraft to the lavatory section. The air is then drawn in from this area and reprocessed. The SA-150's larger diameter fuselage provides more headroom allowing the elimination of gaspers (they would be difficult to manipulate from a seated position) since the regular ventilation system will have adequate power to provide a comfortable environment, even on the ground. This precedent has been set on the McDonnell Douglas MD-11. Figure 13.4 illustrates the cabin ventilation system.

Since the SA-150 uses many sensitive electronic devices, cool air is also piped and distributed to the instrument panel and electrical equipment (which has its own small cooling bay). The FAX will be cooled with excess airflow in the lavatory region.

In the case of pressurization failure, oxygen masks deploy to each passenger providing dry chemical oxygen. A small source of gaseous oxygen located near the cockpit supplies the crew in emergency situations.

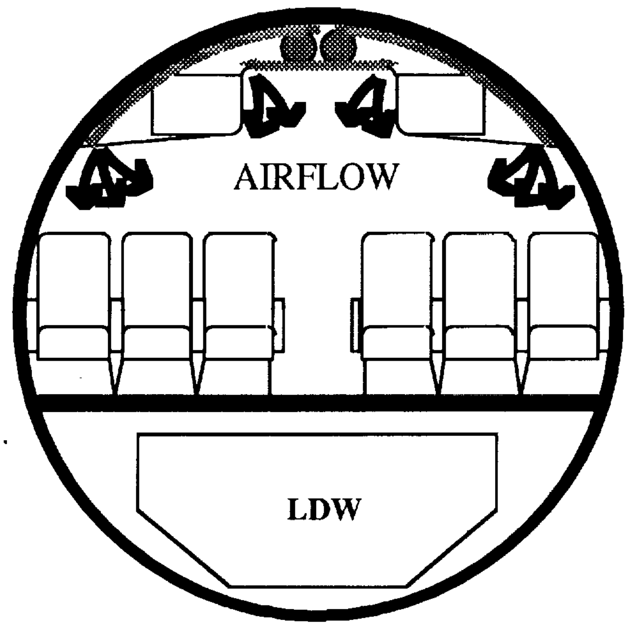


Figure 13.4 SA-150 Passenger Ventilation System

13.5 Flight Control System

Static instability and cross-coupling of the "V" tail necessitates the use of a digital flight computer. Three redundant flight control computers, each capable of controlling the SA-150, will be used. These computers will maintain level flight and stable conditions as well as provide suggestions and warnings to the flight crew. In addition, the flight control computers will manage fuel flow to the engines and between tanks to optimize CG location.

The fly-by-wire flight control system replaces the need for a conventional cable and pulley system with triple redundant wiring to the actuators. This arrangement will decrease both weight and maintenance requirements of the system.[41]

13.6 Fuel System

Fuel tanks for the SA-150 are all located in the wing with the exception of a tank in the tail. Behind and above the APU, separated by a firewall, lies the tail fuel tank which provides capacity to trim the aircraft during cruise operations. A single point refueling receptacle is located outboard of the right engine and a back-up overwing port is positioned on each wing. Normal fuel management, with the exception of pumping for

trim, will move fuel to the outboard tanks for maximum stress relief and ride comfort. Surge tanks are located at the tips of each wing and the ribs act as baffles in the tanks to reduce fuel sloshing. The wing box has been sealed and treated to serve as fuel tanks.

In the case of a severe in flight failure or emergency landing, the engine and landing gear mounting systems have been designed to break away with minimum damage and without rupturing a tank. Dry bays behind the engines and fire walls near the APU serve as precautionary measures and fuel transfer to the aft body tank will be accomplished through a fail safe line.[21]

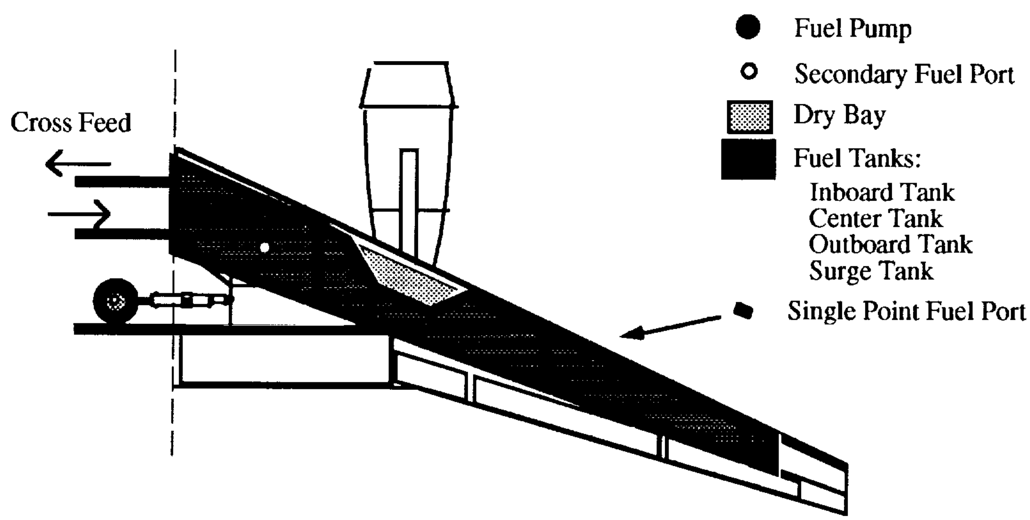


Figure 13.6 SA-150 Fuel System Layout

13.7 Hydraulic System

The SA-150 requires hydraulic power to operate the brakes, landing gear, and control surfaces. Two independent sources, one powered off each engine, operate at 3000 psi and are each capable of moving the control surfaces. Each control surface has two actuators to safeguard against failure. An independent system provides power to the landing gear, and brakes with accumulators to provide emergency hydraulic power in the event of a failure.

13.8 Water System

The SA-150 requires 40 gallons of water to service the galleys and lavatories. Two tanks are used, one which holds potable water and one which collects gray water to be disposed of during ground servicing. Warm water is provided by running the cold water through electrical heat exchangers.

The drain mast is heated to prevent any collection of ice that might break off and damage the aircraft. In case of an emergency where the heaters have failed, the drain masts have been located away from the engines so that ingestion does not occur.

Overall, the systems for the SA-150 are standard, safe, and economical. The only exception is the fly-by-wire control system which is required to achieve desired handling qualities.

14.0 AIRPORT OPERATIONS

14.1 Airport Compatibility

The SA-150 has been design to be completely compatible with current airport facilities. With a wing span of 107 feet and a cabin floor level of 10 feet above the ground, the aircraft can utilize any gate space designed to handle Boeing 737 or McDonnell Douglas DC-9 series aircraft.[1] As illustrated in Figure 14.1, there is adequate space around the SA-150 to complete all the indicated critical ground servicing operations simultaneously.

The potable water tank and service port are located far forward on the fuselage to keep space open for baggage loading operations at the forward cargo hold. At the aft cargo hold, the "V" tail configuration assures that ground crews loading baggage cannot accidentally damage any of the control surfaces.

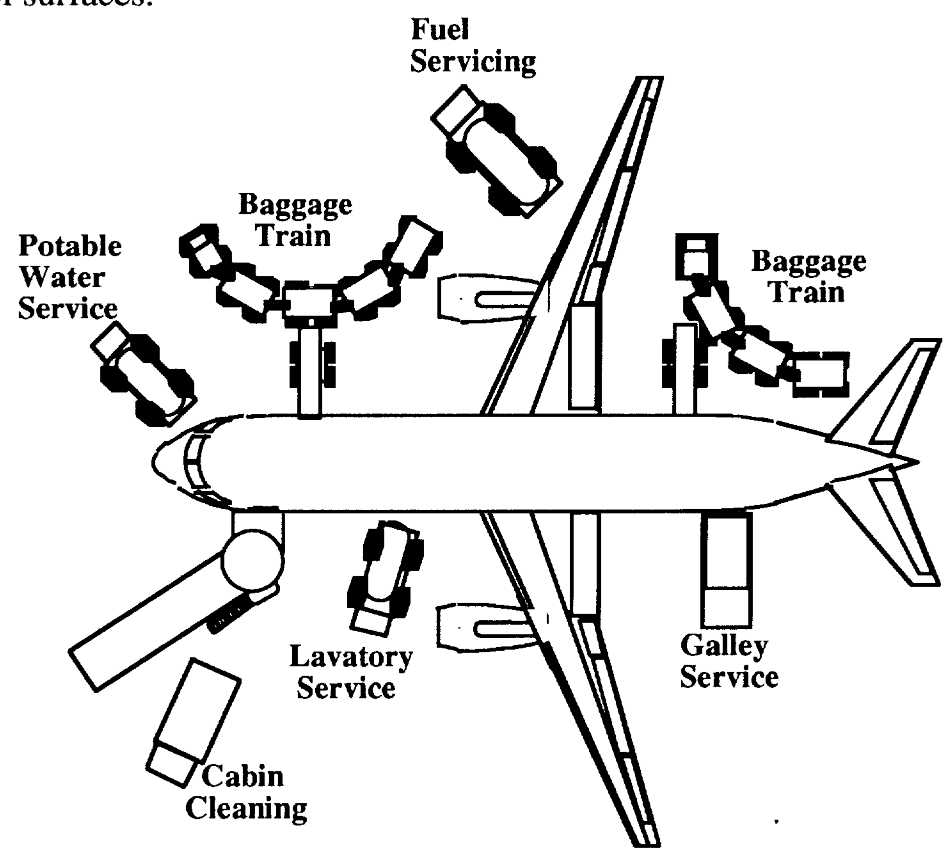


Figure 14.1 SA-150 Ground Service Vehicle Positioning

Fueling the SA-150 can be accomplished through a single point system. The receptacle is located outboard of the starboard engine. This positioning maintains safe clearance between the fueling truck and all other operations going on around the aircraft. The underwing height at this location is approximately 8 feet so that special equipment to access the port will not be required.

14.2 Turnaround Time

Design features that help speed ground servicing are the centrally located lavatories that require only one port and vehicle for servicing. Galley crews can enter the SA-150 through the large rear cabin door on the port side of the aircraft as soon as engine shut down is completed and cleaning crews will have access to the aircraft through the main boarding door after the passengers have departed. A turnaround timeline and critical time path are illustrated in Figure 14.2.[14]

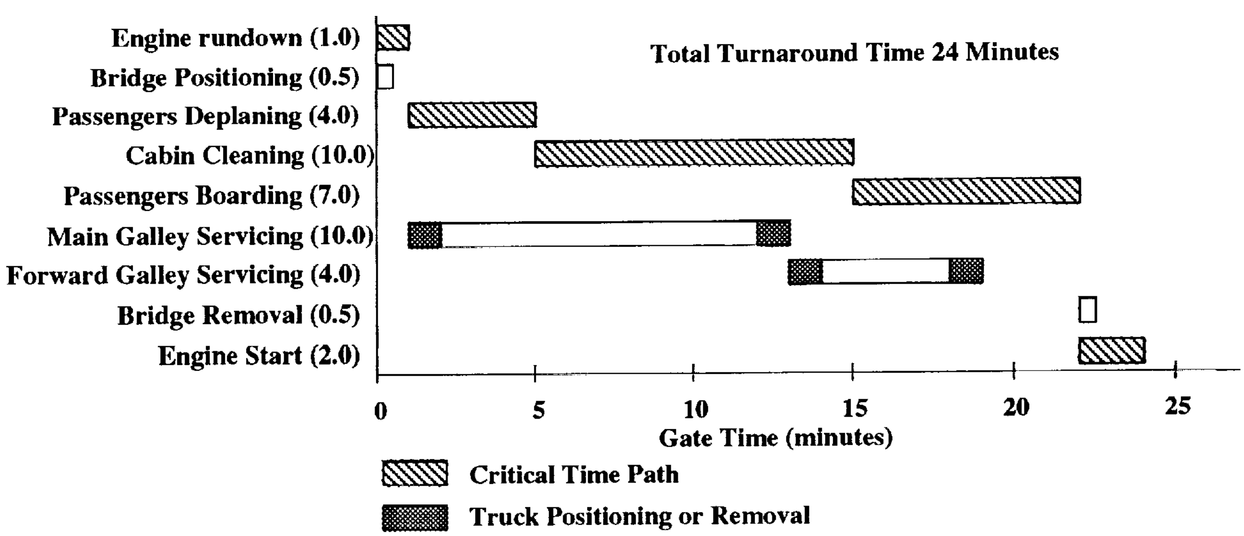
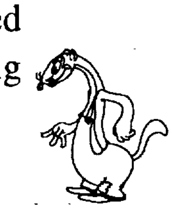


Figure 14.2 SA-150 Turnaround Timeline

Refueling, baggage, water and lavatory servicing can be completed concurrently with the operations shown in Figure 14.2. The resulting



turnaround time of the SA-150 is 0.1 minutes quicker than for the Boeing 737-500 and a full 1.1 minutes quicker than for the MD-87-105. This factor will help the SA-150 meet its scheduled departure times and keep costly delays and unprofitable ground time to a minimum.

15.0 MANUFACTURING

15.1 Manufacturing Breakdown

The SA-150 final assembly has four major divisions: fuselage, tail, wing, and engines. Each of these sections can be easily transported, since even the largest of them, the wing, will fit in a 50 x 10 x 8 ft tractor trailer container. The breakdown is shown in Figure 15.1.

The fuselage is broken down into five subsections for ease of construction. The mid section has been separated because of its odd rib spacing and unique structural requirements for attachment to the wing box. The separation points, at either end of this section, will also act as a locations for the insertion of plugs, so future capacity of the SA-150 can be easily expanded. The other two cylindrical sections have even rib spacings to promote quick and easy manufacture. The more complex curvature of the nose and tail sections will require that they be built separately.

Each wing will have its composite “spar / fuel tank”, filament wound and completely treated before flaps, fuel pumps, leading edge devices and skins are connected. Facilities for the production of large scale composites, like the unique SA-150 wing box, already exist (Beechcraft, Boeing, LTV, and McDonnell Douglas all have large autoclaves) so new technology will not have to be developed. Even before these components are attached, the primary structure will be shipped to the final assembly point and attached to the torque box. This method of assembly will help ensure that sensitive portions of the wing will not be damaged during transport. Landing gear and engine installations will not be completed until the wing has been joined with the fuselage.

The tail surfaces are symmetrical and will require only one assembly line and set of tooling for their construction. This feature will help reduce both fixed overhead and labor costs. Both the engines and nacelles are built by Rolls-Royce & BMW, attaching them to the wing last.

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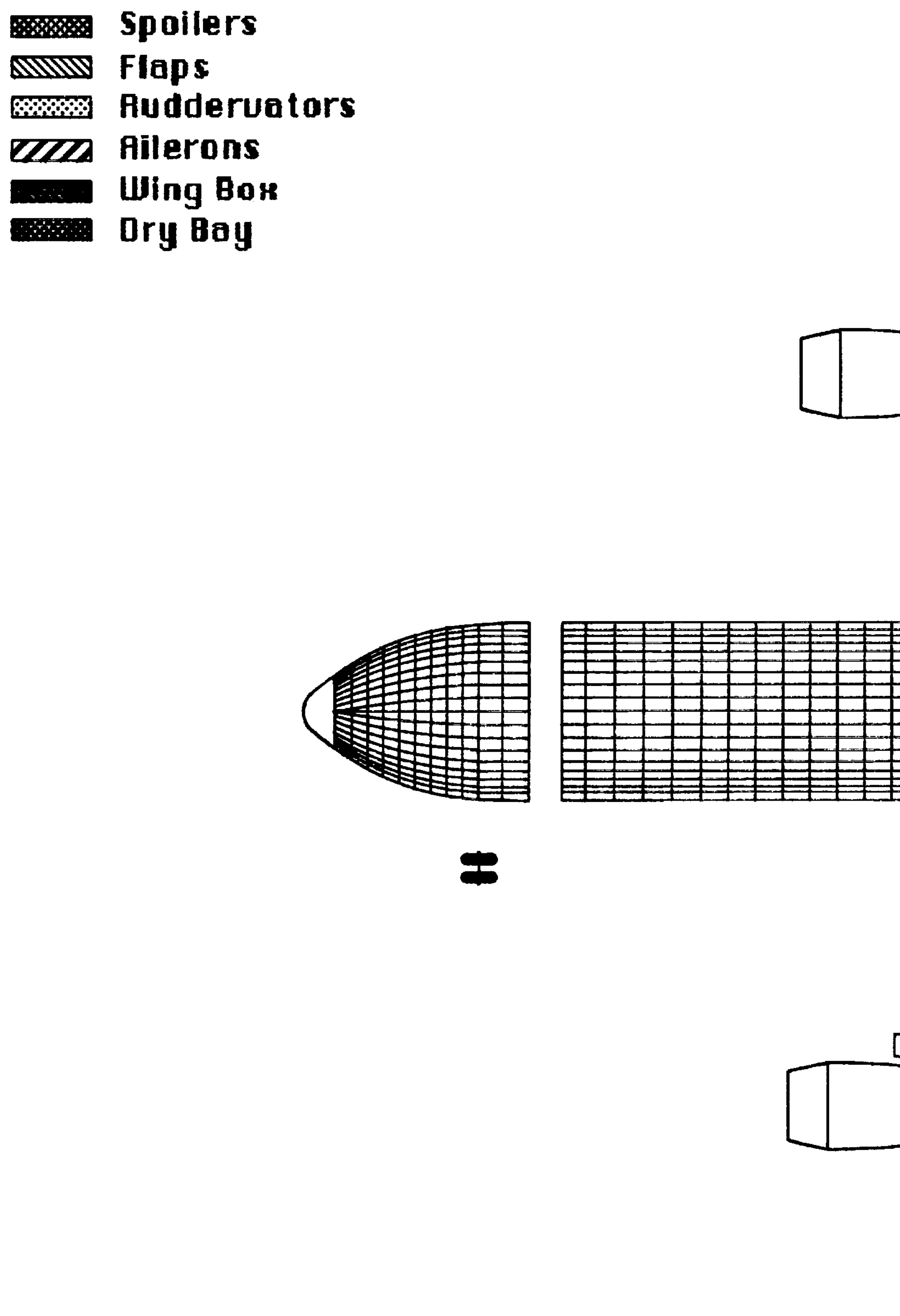

Figure 15.1 SA-150 Manufacturing Breakdown

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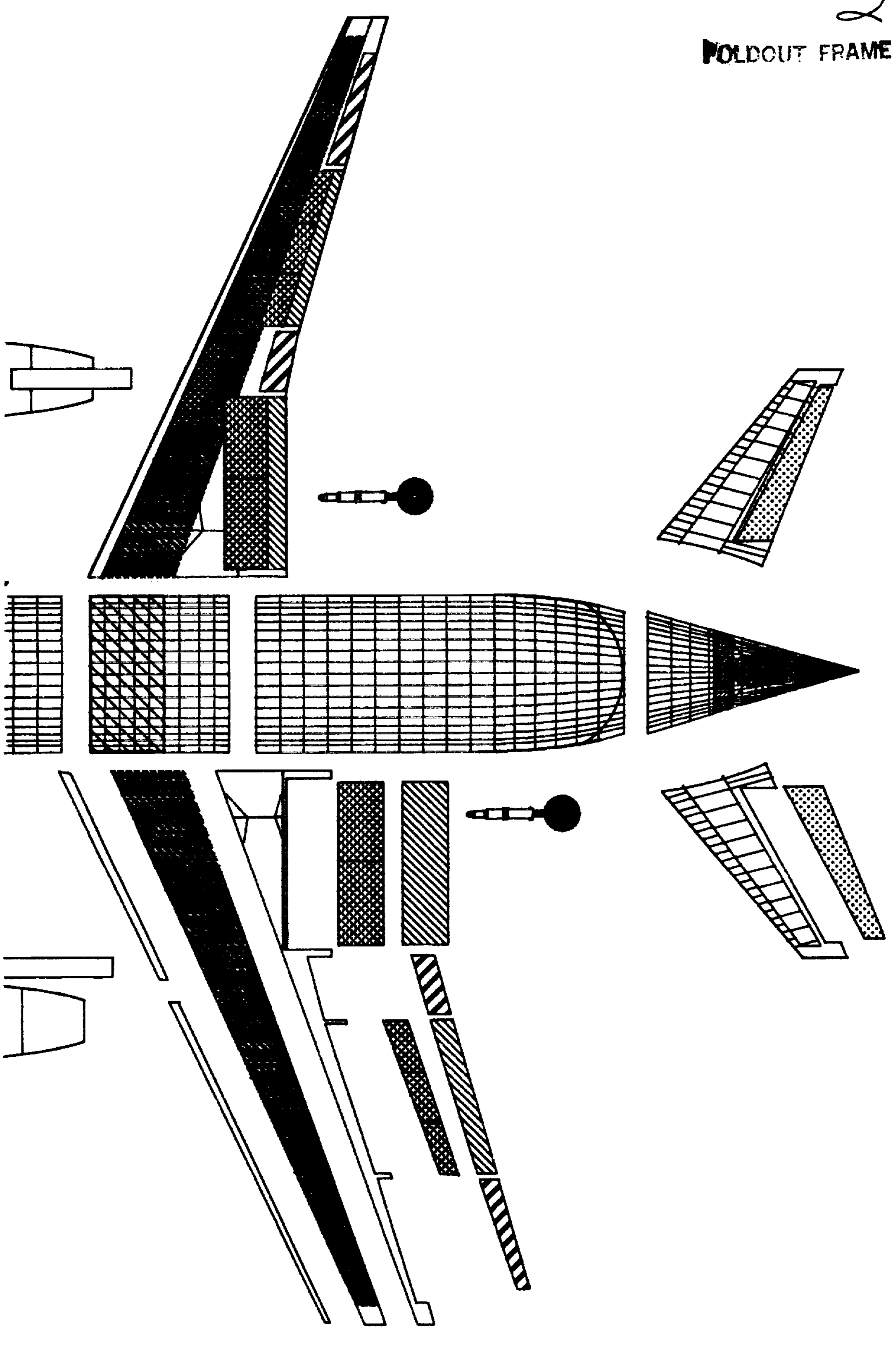

15.2 Economic Considerations

It has been deemed important to keep the majority of the airframe production of the SA-150 within the boarders of the continental United States. Though an increase in the cost of production will probably occur, this choice has been made to help improve the U.S. foreign trade balance and to increase the morale and team spirit of the people responsible for assembling the aircraft. With a higher morale, employees will produce a higher quality product with less defects reducing future maintenance costs. Thus, production of the major airframe components will be in an area with an economic status similar to that of Texas (as of 1993). The fuselage sections, and even the composite wing structure, can be subcontracted out to companies such as LTV Aerospace Corporation.

16.0 COST ANALYSIS

16.1 Life Cycle Cost

Three methods were used to perform a cost analysis on the SA-150, as provided in References 7, 13 and 37. The numbers generated were evaluated by comparing the results to known cost numbers of current aircraft, and it was determined that ACSYNT[37] provided the most detailed and reasonable results. Based on these results, a total life cycle cost was determined and is broken down into four categories:[42]

- Research, Development, Test, and Evaluation (RDTE)
- Manufacturing and Acquisition
- Operational Cost
- Disposal

The life cycle cost analysis uses 1993 dollars as a baseline so a dollar comparison to other aircraft can be made. Assumptions made for the analysis were, an 800 airplane production run and a 15 year life cycle before the airplanes are considered disposable. A large production run is needed for the SA-150 due to the use of composites in the wing. By increasing the amount of aircraft produced, the acquisition cost per aircraft can be lowered. It was found that a reasonable cost could be achieved if 800 aircraft were produced. A 10% manufacturer's profit margin was also incorporated into the cost analysis method. Table 16.1 shows the life cycle cost (LCC) breakdown for the SA-150, and a percentage breakdown of subtotal costs to total cost is shown in Figure 16.1a. As can be seen from Table 16.1, the acquisition cost of the SA-150 is approximately $38 million. This compares reasonably well with a Boeing 737-500 estimated sales price of $30 million.[43] As will be indicated later, the SA-150 has a lower direct operating cost than the competition, about 4 cents per available seat mile versus 4.3 cents per available seat mile. Thus, over the life cycle of the aircraft, the SA-150 will prove to be the less expensive alternative.

Table 16.1 SA-150 LCC Breakdown ($ millions)
Base Year : 1993

	Per Aircraft	Total
RDTE	4.66	3,725.18
Manufacturing and Acquisition	37.92	30,334.98
Operational Cost	150.46	120,366.96
Disposal	1.95	1,559.87
Total	194.98	155,986.99

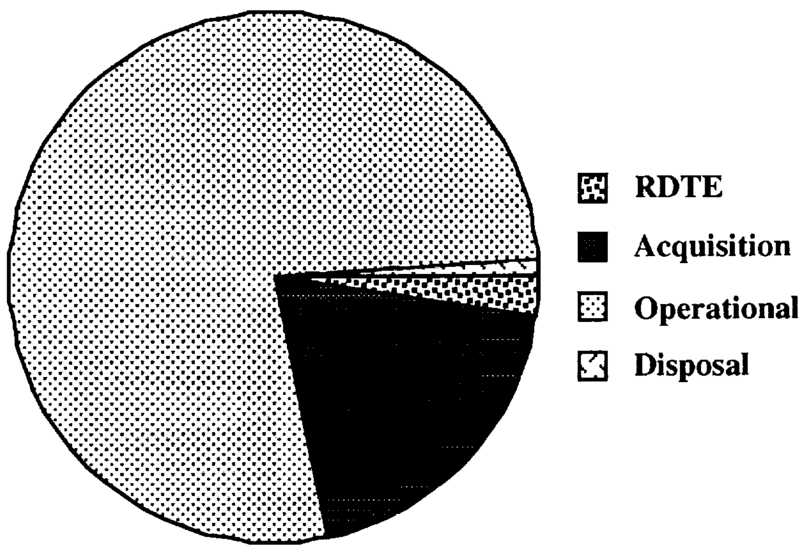

Figure 16.1a SA-150 LCC Percentage Distribution

From Figure 16.1a, it can readily be seen that operational costs constitute a large portion of the life cycle cost. Two factors that greatly influence life cycle costs are the number of aircraft produced and the length of the production run.[42,44] For the SA-150, a production run of 800 airplanes over a 9 year period is envisioned. This is justifiable if the Boeing 737 and the McDonnell Douglas MD-80 aircraft production trends continue. Figure 16.1b shows the production rates of these two aircraft families.[38] Prior to 1982, 524 Boeing 737's had already been delivered along with 66 MD-80's.[38] Figure 16.1c shows the number and age of 737's and DC-9-30's already in service with major U.S. airlines.[45]

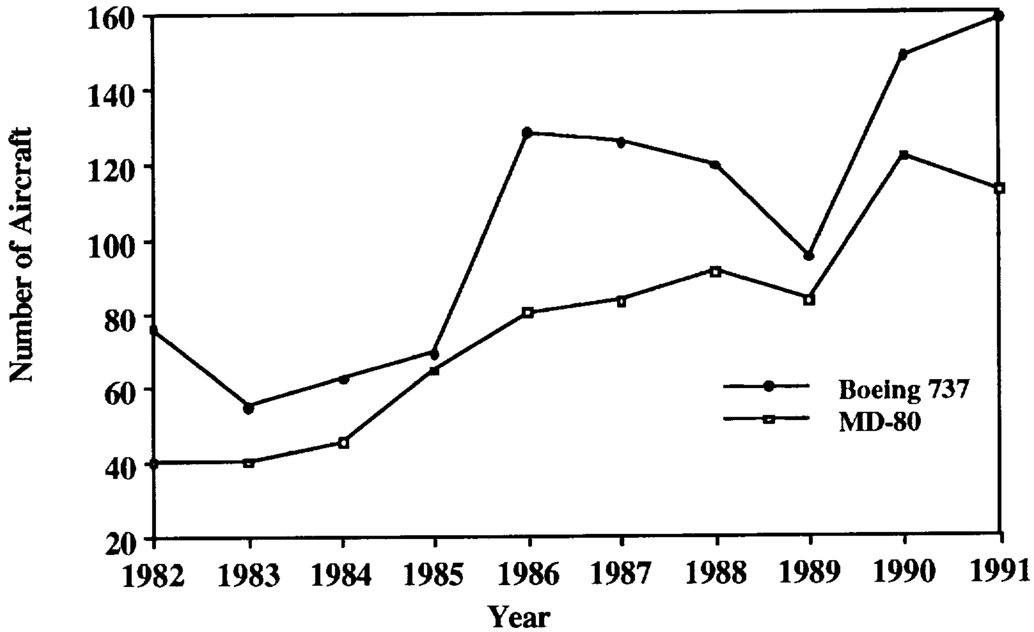

Figure 16.1b Boeing 737 and MD-80 Production Rates

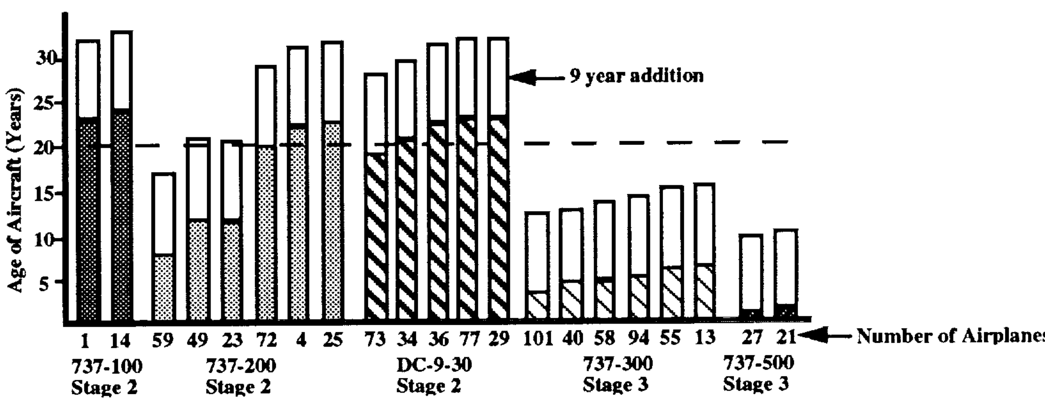

Figure 16.1c Age Comparison of Major U.S. Carrier Aircraft in 1992

From Figure 16.1c, the 737-100, 737-200, and DC-9-30 aircraft are generally over 20 years old, and will be close to 30 years old by the year 2000. These aircraft represent 500 planes that are now in use by major U.S. carriers and will begin to be phased out of service. These aircraft are currently certified to Stage 2 requirements and it would not be economical to upgrade such old airframes to meet Stage 3 or proposed Stage 4 requirements.

Even current Stage 3 aircraft will be close to 15 years old when the SA-150 begins its entry into service. By the year 2000, the airlines will be faced with the decision of upgrading a 15 year old airframe or purchasing a new aircraft. Since it is likely that Stage 4 requirements will be in effect, the available options are: hush kit the engines at $1.5-3 million per aircraft, re-engine at $10-12 million, or purchase a new aircraft for about $30 million.[46,43] Only the later choice allows the airlines to meet tighter environmental restraints with improved fuel efficiency and zero life on the airframe. While the SA-150 will be competing with the Boeing 737 family of aircraft and the McDonnell Douglas MD-80 and MD-90 families, it is believed that SA-150 will be competitive in this sales market. Figure 16.1c only shows the major U.S. carrier's aircraft in service. While it shows that 500 aircraft will definitely need to be replaced and another 100 should be considered for replacement, it does not show how many aircraft the smaller U.S. carriers or the foreign carriers need to replace. It is believed that a large number of aircraft will begin to be replaced as the SA-150 comes into service in the year 2000. Considering the number of aircraft that need replacing, a production run of at least 800 airplanes is justifiable.

16.2 Operational Cost

Total aircraft operational costs are a result of both direct and indirect sources. Direct operating cost (DOC) can be broken down into:[42]

- Flying Costs
    - Crew Cost
    - Fuel Cost
    - Rental Cost
    - Insurance
    - Taxes
- Maintenance Cost
- Depreciation
- Other

Some assumptions made to analyze the direct operating cost of the SA-150 were an increased difficulty factor of 2.0, for the use of composites in the wing, and a fuel price of 63 cents per gallon.[17] DOC for the SA-150 and comparable aircraft are given in Table 16.2a, in 1991 dollars. This DOC data was obtained from Reference 37 for the SA-150 and from Reference 50 for the current aircraft.

Table 16.2a DOC Comparison Per Aircraft ($ per block hr.)

	737-100/200	737-300	737-500	DC-9-30	SA-150
Crew Cost	442	420	326	472	485
Fuel Cost	515	477	611	528	450
Insurance	4	9	9	2	17
Maintenance Cost	363	353	306	489	400
Depreciation	91	91	181	78	285
Other	265	455	337	143	73
Total	1,680	1,805	1,770	1,712	1,710

By comparing the data in Table 16.2a, it can be seen that the SA -150 will have lower fuel costs than current aircraft, but this is partially offset by increased maintenance and ownership costs. The net result is that a lower DOC is still obtained for the SA-150.

Another way to look at DOC is on a cost per seat mile basis. Table 16.2b shows a comparison of the SA-150 with other aircraft on this basis.[37] These numbers are all based on fuel price set at a 1993 dollar value of 63 cents per gallon. Since the SA-150 is a very fuel efficient aircraft, a 5% reduction in direct operating cost per seat mile is possible.

Table 16.2b DOC Comparison Per Seat Mile

	(cents/ASM)
SA-150	4.0
737-1/200	4.2
737-300	4.3
737-500	4.3
DC-9-30	4.2

The indirect operating cost (IOC) results as a consequence of providing for passenger services (meals, cabin attendants, baggage handling, etc.), maintenance of ground equipment and facilities, aircraft and traffic

servicing, promotional and entertainment activities, and administrative costs.[42] A quick estimate is to set IOC and DOC equal to one another. The DOC and the IOC are calculated assuming a load factor of 0.67 in first class and 0.80 in normal class and a 10% profit margin.[17] The load factor chosen may seem high, but it is representative of the design philosophy to provide increased passenger comfort and convenience to achieve this result. Typical load factors range between 60 and 66 percent. Major U.S. airline break-even load factors of 60 to as high as 79 percent were found.[45] In many cases, current information listed a negative percent margin between actual load factor and break-even load factor.[45] This means that the current aircraft like the Boeing 737 may be able to obtain 4.3 cents per seat mile, but the airlines would need to charge, say, 6.0 cents per seat mile just to break-even. Therefore, as load factors increase for the SA-150, drawing business away from other aircraft, lower fares can be provided by the SA-150 at a profitable margin for the operator.

17.0 CONCLUSION

The SA-150 has been designed to meet the changing needs of the airlines at the beginning of the twenty first century. Throughout the design process, a great deal of emphasis was placed on providing a quality aircraft at a reasonable cost. The SA-150 has been able to meet all of its design goals and RFP requirements with the exception of the takeoff field length requirement which was extended to allow for a less complicated high lift system.

The SA-150 reflects the design team philosophy of incorporating new designs and technology only in the areas that can return economically justified performance. The "V" tail did provide some drag savings, however they were not as great as was initially anticipated, There are other advantages associated with the configuration. It provides the aircraft with a unique look that aircraft operators can use to help market their services. Production costs for the "V" tail will also be slightly less than for a comparable three surface design due to the utilization of identical airfoils for both surfaces.

Other aircraft features, indicative of the design philosophy, include the wide fuselage to increase passenger comfort and load factors for the airlines. The SA-150 is an aircraft that carriers can market to the business traveler by providing the comfort and amenities that are important to these travelers. The aspect ratio 12 wing of the aircraft was chosen to improve aerodynamic performance with the intended result of lowering direct operating costs. The wing could have been manufactured with aluminum and standard construction techniques if not for the possibility of flutter effects. Construction of the wing with composite material will provide weight savings and help to offset the increased initial purchase price of the aircraft through lower direct operating costs.

The SA-150 has a direct operating cost lower than the Boeing 737 and MD-80 series aircraft 4.0 ASM vs. 4.2 ASM and 4.3 ASM for our direct competition. The initial purchase price of the SA-150 will be higher, $37.7 million per aircraft, than for these aircraft, but if fuel prices begin to rise and the load factor estimates for the aircraft are correct, the total operating cost for the SA-150 will be lower than for the competition.

18.0

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