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THE ALUMINUM FALCON

A Low Cost Modern Commercial Transport

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Undergraduate Team Aircraft Design Competition

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ABSTRACT

The American Institute of Aeronautics and Astronautics (AIAA) released a Request For Proposal (RFP) in the form of an undergraduate design competition for a 153 passenger jet transport with a range of 3,000 nautical miles. The primary requirement for this aircraft was low cost, both in acquisition and operation, with a technology availability date of the year 2000. This report presents the Non-Solo Design Group's response to the RFP, the Aluminum Falcon (AF-1). Non-Solo's approach to development was to take the best elements of seven individual preliminary designs, then combine and refine them. The resulting aircraft meets or exceeds all requirements of both the RFP and the Federal Aviation Administration (FAA). Highlights include a revolutionary wing planform, known as an M-wing, which offers many advantages over a conventional aft swept wing. For example, the M-wing lessens the travel in the aircraft center of gravity caused by fuel being stored in the wing. It also reduces the amount of torque imposed on the center wing box because more of the lifting load acts near the fuselage joint, rather than behind it. In essence, the M-wing offers the best of both worlds: using a forward swept wing root places the aerodynamic center of the wing further forward and allows the landing gear to be placed without the use of a yahudi. At the same time, with the outboard section swept backward the tip retains an amount of aeroelastic dampening that is lost on a completely forward swept wing. The result is a wing which has many advantages of a straight, unswept wings without the severe compressibility effects at high Mach numbers. Other highlights include judicious use of composites, giving recognition to the importance of weight and its effect on aircraft cost and performance, and an advanced passenger entertainment system which can be used as a source of revenue for the airlines. This aircraft meets the low-cost doctrine with an acquisition cost of $29 million and a direct operating cost of 3.5 cents per seat mile. The AF-1 incorporates new ideas with existing technology to result in an aircraft that will retain market viability well into the next century.

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NOMENCLATURE

C_{Da}	Variation of drag coefficient due to angle of attack
C_{Du}	Variation of drag coefficient due to aircraft speed
C_{DdelE}	Variation of drag coefficient due to elevator deflection
CG	Center of gravity
C_{L1}	Steady state lift coefficient
C_{La}	Variation of lift coefficient due to angle of attack
C_{La} dot	Variation of lift coefficient due to change in angle of attack
C_{LdelE}	Variation of lift coefficient due to elevator deflection
C_{Lmax}	Maximum lift coefficient
C_{Lq}	Variation of lift coefficient due to pitch rate
C_{Lu}	Variation of lift coefficient due to aircraft speed
C_{Txu}	Variation of X-thrust coefficient due to aircraft speed
C_{lb}	Variation of rolling moment coefficient due to sideslip
C_{ldelA}	Variation of rolling moment coefficient due to aileron deflection
C_{ldelR}	Variation of rolling moment coefficient due to rudder deflection
C_{lp}	Variation of rolling moment coefficient due to roll rate
C_{lr}	Variation of rolling moment coefficient due to yaw rate
C_{m1}	Steady state pitching moment coefficient
C_{mT1}	Steady state thrust pitching moment coefficient
C_{mTa}	Variation of thrust pitching moment coefficient due to angle of attack
C_{mTu}	Variation of thrust pitching moment coefficient due to aircraft speed
C_{ma}	Variation of pitching moment coefficient due to angle of attack
C_{ma} dot	Variation of pitching moment coefficient due to change in angle of attack
C_{mdelE}	Variation of pitching moment coefficient due to elevator deflection
C_{mq}	Variation of pitching moment coefficient due to pitch rate
C_{mu}	Variation of pitching moment coefficient due to aircraft speed
C_{nb}	Variation of yawing moment coefficient due to sideslip
C_{ndelA}	Variation of yawing moment coefficient due to aileron deflection
C_{ndelR}	Variation of yawing moment coefficient due to rudder deflection
C_{np}	Variation of yawing moment coefficient due to roll rate
C_{nr}	Variation of yawing moment coefficient due to yaw rate
C_{yb}	Variation of side force coefficient due to sideslip
C_{ydelA}	Variation of side force coefficient due to aileron deflection

C_{ydelR}	Variation of side force coefficient due to rudder deflection
C_{yp}	Variation of side force coefficient due to roll rate
C_{yr}	Variation of side force coefficient due to yaw rate
I_{xx}	Moment of inertia of the x-plane
I_{yy}	Moment of inertia of the y-plane
I_{zx}	Moment of inertia of the x-y plane
I_{zz}	Moment of inertia of the z-plane
L/D	Lift to drag ratio
M	Mach number
M_{br}	Mach number for best range
R/C	Rate of climb
S_{fl}	Landing field length
T	Thrust
V_{br}	Velocity for best range
V_{max}	Maximum velocity
W/S	Wing loading
W_l	Landing weight
W_{to}	Takeoff weight

LIST OF ACRONYMS

AC	Alternating Current
ACE	Actuator Control Electronics
ACMP	Alternating Current Motor Pump
ADP	Air Driven Pumps
AERO	Aeronautical Engineering
AF-1	Aluminum Falcon-1
AIAA	American Institute of Aeronautics and Astronautics
AOA	Angle of Attack
APU	Auxiliary Power Unit
BFL	Balanced Field Length
CFD	Computational Fluid Dynamics
CFRP	Carbon Fiber Reinforced Plastics
CG	Center of Gravity
DC	Direct Current
DFMA	Design For Manufacturing and Assembly
DOC	Direct Operating Cost
EDP	Engine Driven Pump
EFIS	Electronic Flight Instrumentation System
ETOPS	Extended Twin Engine-Operations Over Water
FAA	Federal Aviation Administration
FAR	Federal Air worthiness Regulation
FCU	Flush Control Unit
GE	General Electric
GFRP	Graphite Fiber Reinforced Plastics
GLA	Gust Load Alleviation
GPS	Global Positioning System
HDM	Hydrodynamics Machining
IAE	International Aero Engine
IDG	Integrated Drive Generator
ILS	Instrument Landing System
INS	Inertial Navigation System
IOC	Indirect Operating Cost
LCN	Load Classification Number

MAC	Mean Aerodynamic Chord
MD	McDonnell/Douglas
MLA	Maneuver Load Alleviation
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NMI	Nautical Mile
OBA	Required Trim Triangle
OEI	One Engine Inoperative
PAX	Passenger
PCU	Power Control Unit
PFC	Primary Flight Computer
PFCS	Primary Flight Control System
RDTE	Research, Development, Testing, and Evaluation
RFP	Request For Proposal
SFC	Specific Fuel Consumption
TAI	Thermal Anti-Icing System
TAT	Total Air Temperature
VCK	Variable Camber Kruger

CHARACTERISTICS DATA			
ITEM	WING	HORIZ. TAIL	VERV. TAIL
AREA (FT^2)	1069	210	200
ASPECT RATIO	10	4.5	1.6
DIHEDRAL (°)	3	6	~
SWEEP (° C/4)	27	33	33
TAPER RATIO	.3	.4	.4
t/c (%)	.16	.12	.12
b (IN.)	1241	372	215
CR "	191	112	192
CT "	57	47	77
AIRFOIL	E555	"	"

PAYLOAD CAPACITY

- MIXED CLASS

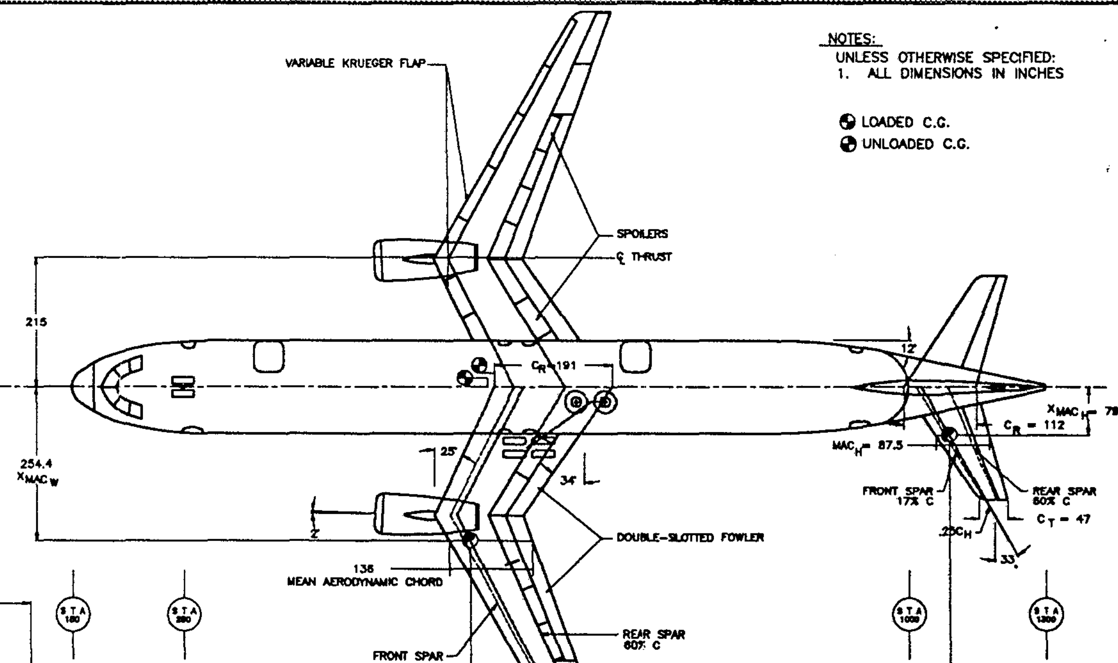
FIRST CLASS = 4 ABREAST @ 42 IN. PITCH = 8
BUSINESS CLASS = 4 ABREAST @ 36 IN. PITCH = 16
ECONOMY CLASS = 6 ABREAST @ 32 IN. PITCH = 130
TOTAL = 154 SEATS

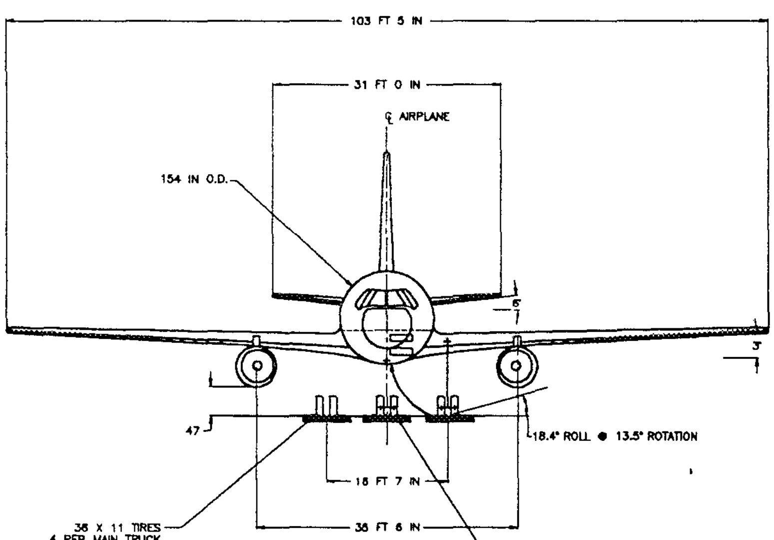
- BELLY COMPARTMENT

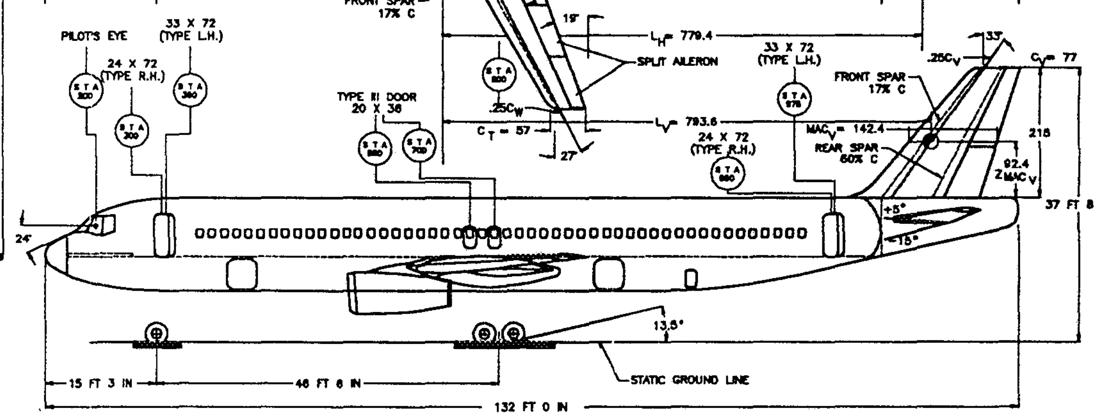
FORWARD BAY = 8 LD-W @ 78 FT^3 = 624 FT^3
AFT BAY = 2 LD-W @ 78 FT^3 = 156 FT^3
AFT BAY = BULK = 400 FT^3
TOTAL = 1180 FT^3

NOTES:
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES

LOADED C.G.
UNLOADED C.G.







NONSOLO

CAL POLY

GENERAL ARRANGEMENT

AF-1

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1. THE ALUMINUM FALCON - A TRANSPORT FOR THE FUTURE

1.1 Statement of Purpose

Even in the age of fax machines, the information super highway, video phones, and teleconferencing, nothing takes the place of actually being there in person. As a result, people still need to travel. Air travel continues to be a quick, convenient, and economical option for today's commuters, but sustaining this service is proving to be a difficult chore for the airlines and airframers. With minuscule profit margins and rapidly changing technology, making the right choices at the right times on even seemingly minor issues can make the difference between success and failure for the companies involved. The AIAA acknowledged the severity of this problem by issuing a Request For Proposal for an aircraft that emphasizes low cost and profitability.

Non-Solo's answer to the RFP addresses the issues of simplicity and economy that were specifically mandated. While meeting all of the AIAA requirements, the AF-1 uses many currently available technologies and an innovative wing design to give it the edge over the competition that will be critical in the saturated transport market of the next decade. Non-Solo uses this approach along with an emphasis on efficiency in design to speed up manufacturing, minimize dependence on untested technology, and decrease the costs to both the airline and the airframer. This approach will allow airline passengers to continue receiving the service they expect at prices they can afford.

When initially approaching this design, Non-Solo focused on areas which would directly lower the aircraft purchase price and the direct operating cost. Research proved that manufacturing far outweighed all other contributors to the aircraft purchase price and that maintenance and the cost of flying the airplane were the biggest drivers when determining the direct operating cost (refer to section 3). This meant that Non-Solo targeted efficient manufacturing, low maintenance engines and aircraft systems, and decreased fuel burn by low weight and drag to directly lower the cost of the AF-1 as compared to its competitors.

1.2 The M-wing

Although the AF-1 looks unlike any aircraft produced today, the bent wing concept, known commonly as the M-wing, was extensively studied by both the British and the Germans in the years around the Second World War. During this time, German engineers investigated many radical ideas, several of which had great promise and were further developed by other countries. At the time, the M-wing concept presented little in the way of advantages over conventional design because aircraft flew slower and required more inherent stability to be flyable without computer assitance. Simple sweep in the wings provided sufficient aerodynamic benefits. An M-wing structure was also much more difficult to analyze with the limited computational power available. Consequently, the design of commercial aircraft took the path of least resistance along the lines of the swept-wing conventional tail format so prevalent today. The M-wing offers many advantages of the familiar aft-swept wing as well as the more recently studied forward-sept wing without many of the disadvantages of either. It essentially offers the advantages of a straight wing without the compressibility problems at high speed. This is fully detailed in Section 7.

The thought of embracing a notion as revolutionary as the M-wing could meet considerable resistance in an established corporation such as Boeing or McDonnell/Douglas. Not only would it be a problem to throw out much of the empirical database available to the designers and start anew, but it would be a chore in itself to convince those with decision making power to commit to such a change in company philosophy. These problems are not faced to the same degree by the Non-Solo Design Group, which is unfettered and willing to take the bold steps necessary to usher in a new age in air transport. The risk involved in using an unconventional configuration such as the M-wing lies mainly in the reasearch and development costs of the aircraft. Non-Solo estimates that by incorporating the M-wing into the design of the AF-1 rather than a conventional aft swept wing, the research, development, test, and evaluation (RDTE) cost increases 42%. However, the portion of the total purchase price of the airplane dependent of RDTE cost is only 2%. So, by targeting an area of improvement that has the smallest effect on the total acquistion cost, Non-Solo is maximizing the benefits with minimal cost.

1.3 Summary of Design

1.3.1 Configuration

Aside from the M-wing, the configuration of the AF-1 is conventional. Non-Solo focused on making all components of the aircraft as small as possible while still maintaining competitive passenger comfort. Important geometric parameters are summarized in Table 1.1.

Table 1.1 AF-1 Configuration Summary

Fuselage Length	132 ft
Fuselage Diameter	12.8 ft
Wing Span	103 ft
Wing Planform Area	1,069 sq ft
Wing Aspect Ratio	10
Wing Taper Ratio	0.3
Wing Dihedral	3 deg
Wing Quarter Chord Sweep	27 deg
Horizontal Tail Area	210 sq ft
Vertical Tail Area	200 sq ft
Cargo Capacity	1180 cubic ft
Fuel Volume	

1.3.2 Cost

During the life of the AF-1 program, Non-Solo estimates a total production of 2005 aircraft, including five that will be used for static and flight testing. At this number of units produced, the AF-1 total acquisition cost, not including spares, is approximately $29 million. Analyzing the aircraft operating cost using a stage length of 2000 nmi, Non-Solo estimates the direct operating cost of the AF-1 to be $5.37 per nmi or 3.5 cents per available seat mile (Refer to Section 3 for detail).

1.3.3 Performance

The AF-1 meets all performance requirements of the RFP without exceeding them due to unnecessary over-design. Table 1.2 contains a complete performance summary of the AF-1 (Refer to Section 6 for detail).

Table 1.2 AF-1 Performance Summary

	AF-1	Requirement
TAKEOFF		
Balanced Field Length	7000 ft	7000 ft
C_{Lmax}	2.1	
Thrust-to-Weight Ratio	0.35	
Wing Loading	131 psf	
Maximum Takeoff Weight	140,000 lb	
CLIMB		
Rate of Climb	Maximum	Best
Time to Climb	18 minutes	
CRUISE		
Range	3000 nmi	3000 nmi
Altitude	35,000 ft	Best
Mach Number	0.8 (.99 Vbr)	.99 Vbr (>0.7)
L/D	18.4	
LANDING		
Field Length	4940 ft	5000 ft
C_{Lmax}	3.1	
Maximum Landing Weight	126,000 lb	

2. ORIGINS OF THE ALUMINUM FALCON

2.1 The AIAA Request for Proposal

The AIAA provided a specific mission profile with special design requirements. The aircraft was to be designed for domestic routes and to conform to all applicable FAR sections for a technology availability date of the year 2000. The special design requirements of the RFP include a mixed class passenger capacity of 153 and a minimum range of 3,000 nmi. The design weight of each passenger including baggage was given as 200 lbs. Front and rear galleys as well as overhead stowage were to be provided. The aircraft must also meet all proposed environmental regulations.

2.2 Mission Profile

The design mission profile for the AF-1 was completely fixed by the RFP and is outlined below:

- Warm up and taxi for 15 minutes
- Take off within a FAA field length of 7000 feet
- Climb at best rate of climb to best cruising altitude
- Cruise for 3000 nmi at .99 V_{br}
- Descend to sea level (no range credit)
- Land within a FAA landing field length of 5000 feet
- Taxi to gate for 10 minutes

To account for the necessary domestic fuel reserves specified by the RFP, the following segments were added to the mission profile:

- Climb to 10,000 feet
- Cruise for 150 nmi
- Descend from 10,000 feet to sea level
- Additional 45 minutes of flight at cruise conditions

The additional 45 minutes were added for possible time in holding patterns or adverse head winds. This method for estimating necessary fuel reserves is similar to that used by Douglas Aircraft Company.

It is important to acknowledge that as air traffic control becomes more and more efficient hold times will diminish and this method for estimating fuel reserves may become overly pessimistic. However, Non-Solo decided that without a definite guarantee that this would happen there was no reason to deviate from the current practices of other airframe manufacturers.

Figure 2.1 graphically depicts the Aluminum Falcon's complete design mission profile.

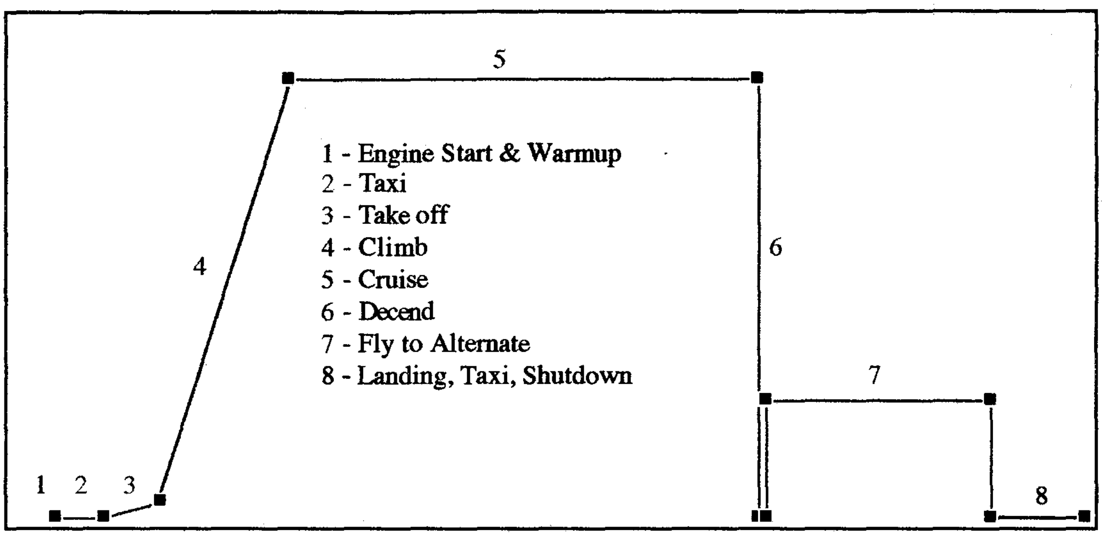


Figure 2.1 AF-1 Mission Profile

2.3 Design Process Outline

The AF-1 evolved through the team approach to design. Non-Solo used a very flat corporate structure and emphasized the equal importance of all team members (Figure 2.2). For the design phase, each member had a specialty or emphasis and no member was chosen as a "team leader." Using Total Quality Management (TQM) techniques, team members were held accountable to each other and to the team as a whole.

Figure 2.2 Non-Solo Organizational Structure

A single design database was used for the AF-1. At bi-weekly team meetings, team members gave input and discussed possible design changes. Discussion encompassed the impact of changes on other aircraft components, cost, and design goals. Using this Concurrent Engineering (CE) approach, the team agreed on the changes which were then implemented in the design database. This provided consistency and expediency while maintaining the flexibility necessary to produce a winning design.

The process for Non-Solo's design followed the AERO Senior Flight Vehicle Design Course series at Cal Poly, San Luis Obispo. During the fall quarter of 1993, team members assembled individual design proposals to satisfy the RFP. This facilitated creativity and individualism as well as developed an understanding of the balance required in designing a complete aircraft. Also during this time, team members built up an interest in a specific area which carried over into a specialty within the team. Once the team was assembled, the group evaluated the individual concepts and chose the best qualities of each aircraft for implementation in the final design. From this process, the AF-1 evolved.

2.4 Final Concept Selection

The design concept evolution is shown below in Figure 2.3. The individual designs included two conventional designs, a three-surface concept and an M-wing. Two or three engines were used, mounted on the wings or on the fuselage.

The use of a canard was not chosen because of control complications and airport compatibility. The center structural box of the canard also takes up valuable space at the front of the aircraft.

The conventional design seemed appropriate for the low-cost requirement, and its single aisle was the final selection for the interior. Another component adopted from the conventional design was the wing-mounted engines, which were better for noise and accessibility considerations as well as center of gravity (CG) travel characteristics. However, the Non-Solo design still needed a technology that could beat the competition, so the M-wing concept was explored.

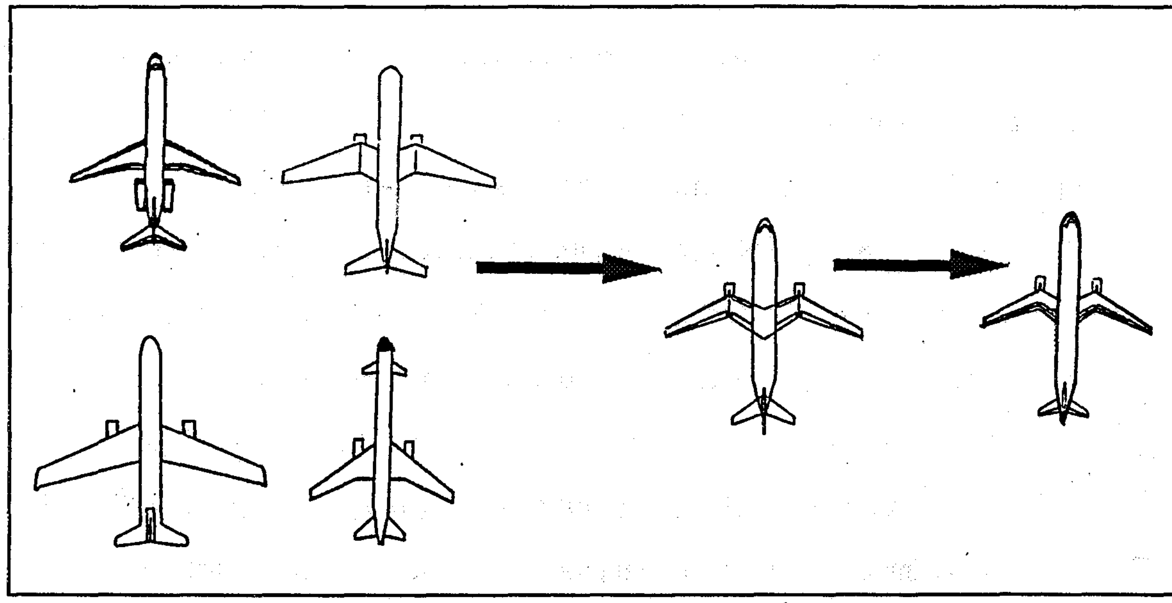


Figure 2.3 Concept Evolution

When the M-wing was first considered, the team had certain intuitive ideas about the benefits of that particular design. Most of these have been verified thorough analysis and inspection, with varying levels of success. These include landing gear placement, minimized CG travel, and increased inboard lift capablitiy.

Other design considerations changed at different times in the evolution, even alternating between two configurations, such as single or double aisle. After consulting with industry professionals, Non-Solo reemphasized the low-cost precept and held this as the driving factor in the final concept selection.

2.5 Comparison of Competitors

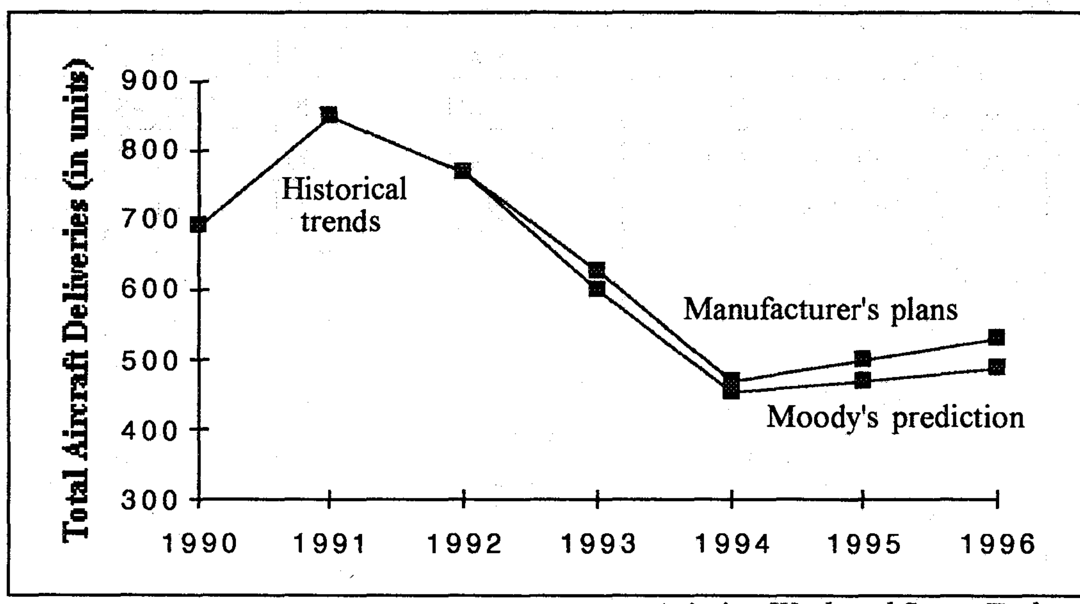
Unfortunately, the market for a passenger aircraft in this class is not an opportunity waiting to be exploited. On the contrary, it is quite saturated with planes from many airframers, including the Airbus 320/321, the Boeing 757, and the McDonnell/Douglas MD-80/90. Requiring the plane to fly 3000 nautical miles with a full load of passengers when most of its business will be in stage lengths of under 1000 could be considered another disadvantage. In order to break into the market it is not feasible to solely change the size and shape of an existing concept for a new mission. Succeeding with this aircraft calls for innovation to place it far enough ahead of the competition to justify its purchase and the difficulties of changing the support structure for a new airplane. The advantages of the M-wing are slight, but given the state of the business, a slight advantage will make a big difference.

Three aircraft currently have a similar range and passenger capacity to the AF-1. A comparison is shown in Table 2.1.

Table 2.1 Comparison of Similar Aircraft

	B737-400	MD-83	A320-200	AF-1
Number of Passengers	146	155	150	154
Range (nmi)	2500	2501	2990	3000
Max Landing Weight (lb)	124,000	139,500	142,195	126,000
Max Take-Off Weight (lb)	150,000	160,000	162,040	140,000
Take-Off Field Length (ft)	8,200	8,375	7,680	7,000
Landing Field Length (ft)	6,070	5,200	5,040	4,940
Wing Span	94 ft. 9 in.	107 ft 10 in	111 ft 3 in	103 ft
AR	7	9	9.4	10
1st Class Seat Pitch (in)	38	36	36	42
Economy Class Seat Pitch (in)	32	31-33	32	32
Wing Loading (lbf/ft^2)	127	126	123	131
Cruise Mach Number	0.73	0.76	0.80	0.80
Circular X-Section?	No	No	No	Yes
Wing Sweep Angle (deg)	25	24.5	25	27

Currently, there is some debate about the future of the global commercial aircraft market. Airframers have an optimistic view of projected aircraft deliveries compared to others, such as Moody's Investors Service. Moody's is generally in line with Standard & Poor's forecast and is "gloomier than aircraft builders' predictions." (ref. 6) Previous upturns in the industry have shown significant growth in deliveries, but this may not be the case now. Moody's claims that in the 1980's, airlines all over the world expanded their capacity. International Air Transport Assn. Members grew by 93% while traffic only grew by 78%. Consequently, many commercial transports parked in storage are waiting to be returned to service when the market recovers. Restructuring among the major airlines will cause a lag in ability to finance purchases of new aircraft. New competitors from the Russian aerospace industry, as well as Non-Solo, are bound to drive prices down. Also according to Moody's, traffic growth will be lower than the expected 5% annual increase through the year 2002. This means that demand for new aircraft will be lower and aircraft manufacturers will have a difficult time generating a return on their investment and financing new aircraft development. Figure 2.4 shows manufacturer's plans and Moody's Projections for aircraft deliveries through 1996.



source: Aviation Week and Space Technology

Figure 2.4 Projected Aircraft Deliveries

The M-wing offers several benefits over a conventional design. The unique shape helps reduce shift in the center of gravity, thus allowing the control surfaces and tail to be smaller. Smaller control surfaces mean less structural weight. This shape will also show a decreased nose-down pitching moment due to wing sweep, allowing a decrease in structural weight in the center wing box. The joint in the wing will need more structure; however, engine placement at the joint also necessitates extensive structure. The M-wing may be slightly heavier, but the reduction in aircraft drag makes it advantageous. This along with fly-by-wire flight optimization will result in reduced fuel consumption and commensurate reduction in direct operating cost.

All of the competitors have very conventional designs that are nearly optimized and can only achieve slight performance benefits at great cost, known economically as diminishing margin of return on investment. The AF-1, uses a totally new concept that will attract passengers with high tech services and attract airlines with lower DOC. Even as the aircraft market grows tight, a new entry such as the Aluminum Falcon has the potential to acquire a significant market share.

3. THE LOW COST CONCEPT

3.1 Economic Philosophy

The key to a healthy and expedient return on investment is to reduce the design time and move quickly to produce aircraft. Non-Solo is capable of a much shorter design phase due to its flat corporate organization and concurrent engineering. Using a team approach and increased responsibility and accountability for all team members, Non-Solo expects to shorten the design phase by up to ten percent.

The low cost approach to designing the AF-1 included focusing on the areas which are the biggest contributors to the aircraft acquisition cost and direct operating cost. This meant that Non-Solo concentrated on efficient manufacturing, low maintenance engines and aircraft systems, and decreased fuel burn by low weight and drag to directly minimize the cost of the AF-1.

3.2 Research, Development, Test and Evaluation Cost

The major factors in Research, Development, Test and Evaluation (RDTE) costs are the test airplanes, development and support testing costs, airframe engineering and design cost, flight test operations, and profit and financing for the RDTE phase. With the team design approach and Computer Aided Design (CAD), Non-Solo can reduce typical engineering and design costs. For research, development, test and evaluation costs, extensive M-wing wind tunnel tests will have to be done, but this is true of any new wing or aircraft design. Well tested, reliable engines can reduce the flight test requirements and lower costs. Assuming that Non-Solo is an established airframer with a large current facility, the AF-1 will need no special facilities for assembly. The total cost of the RDTE phase is $1.26 billion as shown in Table 3.1. However, there is some risk associated with new technology, such as an M-wing. It is possible that wind tunnel and structural testing will prove the M-wing concept unfeasible. If the M-wing were abandoned and the configuration changed to a straight aft-swept wing, the expected loss would be $0.013 billion. The breakdown of RDTE cost components is shown in Figure 3.1.

Table 3.1 AF-1 RDTE Cost Breakdown

Airframe engineering and design	225 million
Development, support and testing	27 million
Flight test airplanes	771 million
Flight test operations	26 million
RDTE Profit	125 million
Finance for RDTE	117 million
Total RDTE cost	1,280 million

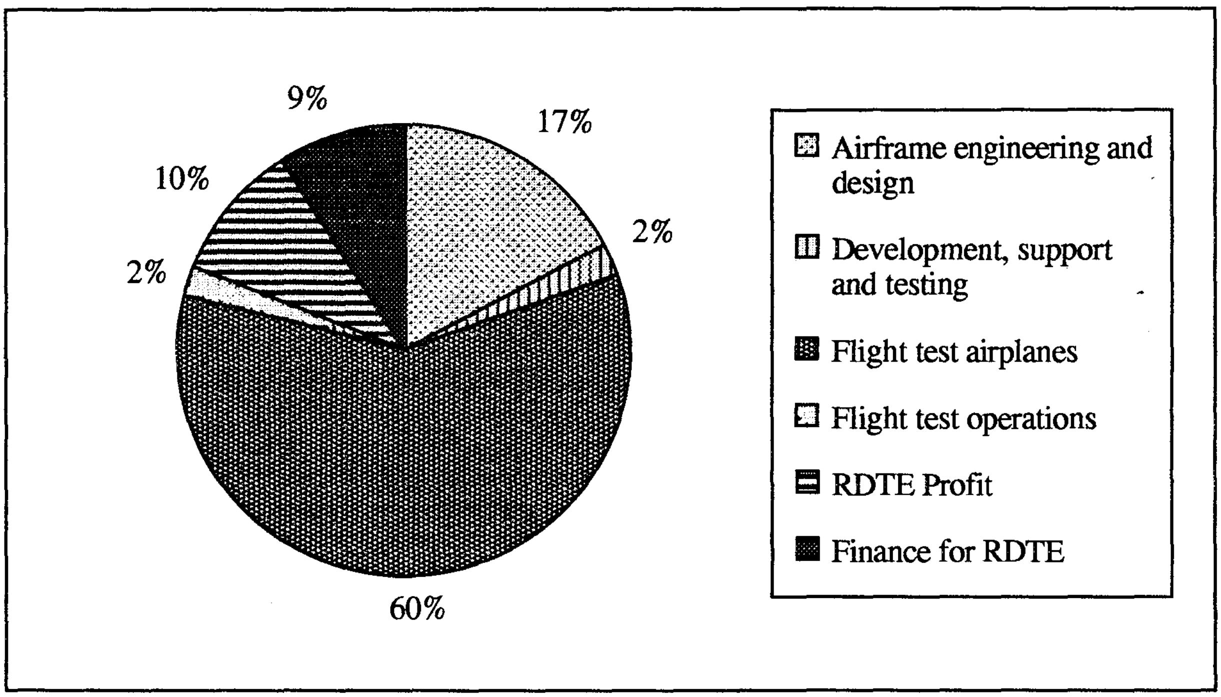


Figure 3.1 Research, Design, Test and Evaluation Breakdown for the AF-1

3.3 Production Costs

The number of aircraft produced can greatly affect costs. The Boeing Company plans to produce 2,000 of their 737-X aircraft by the year 2010 (ref. 9). For the purpose of analysis, Non-Solo assumed equal marketability for the similar AF-1. When analyzing the effect of the number of aircraft produced on cost factors, it is clear that the more aircraft a company can produce and sell, the lower the costs to airlines. As production increases there is a significant decrease in both Airplane Estimated Price and Direct Operating Costs, as shown in Figures 3.2. The estimated price goes down due to the decrease in RDTE costs per airplane. The direct operating cost is reduced due to a lower airplane cost, which reduces the cost of spares and insurance. During the life of the program, Non-Solo estimates a total production of 2005 aircraft, including the five used for static and flight testing. As demand increases for travel to third world countries, Non-Solo plans an aggressive marketing style to acquire a solid market share.

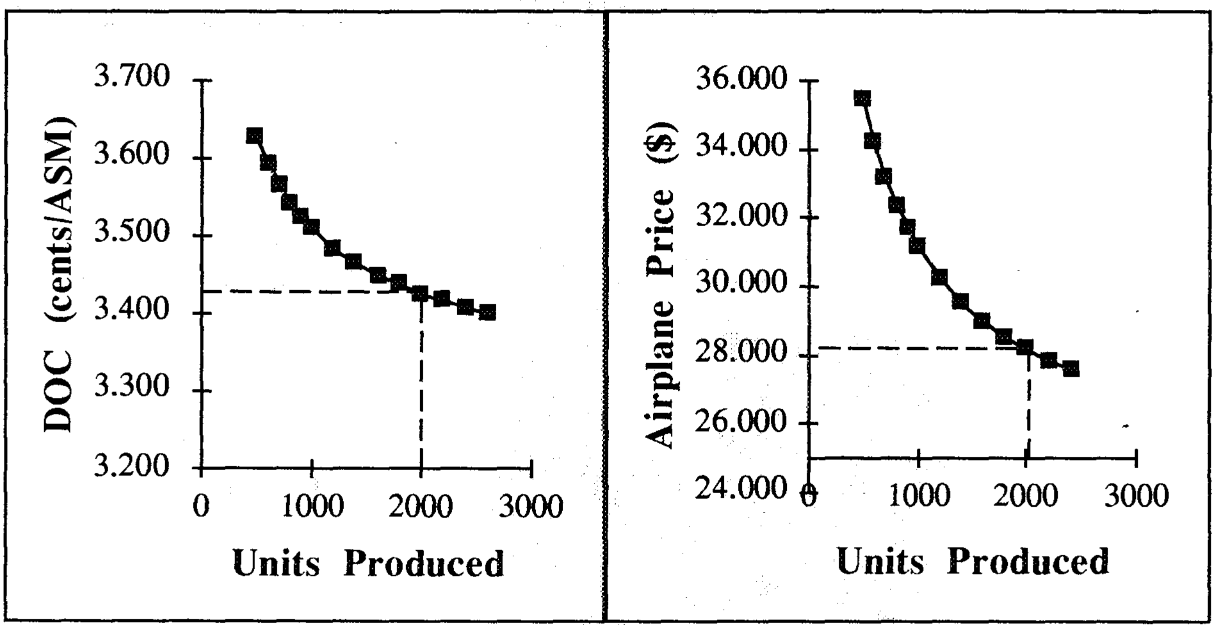


Figure 3.2 Effect of AF-1 Production on Airplane Estimated Price and DOC

Non-Solo has performed a cost estimation for the AF-1 program, based on production of 2005 aircraft in 1994 U.S. dollars. The production costs, shown in Table 3.2, depend on the price of engines, avionics, manufacturing labor, tooling, materials, and quality control. The Aluminum Falcon is designed for simple manufacturing, using currently available facilities. When the program goes into production, standardized composites and aluminum materials will compose the structure. The estimated average production rate was 6 aircraft per month. The estimated engine price is $6 million and the estimated avionics price is $5 million.

Table 3.2 AF-1 Production Costs

Engines and Avionics Cost	41,860 million
Interiors Cost	822 million
Manufacturing Labor Cost	7,672 million
Manufacturing Materials Cost	3,930 million
Tooling Cost	767 million
Quality Control Cost	997 million
Total Production Cost	**56,049 million**

The airplane program costs are the total costs to the manufacturer, including production, engineering and design, flight tests, financing and profit as shown in Table 3.3. According to Non-Solo estimations, the price of the AF-1 is competitive at approximately $29 million each without spares. Figure 3.3 is a comparison of the AF-1 and similar aircraft in airplane price per available seat.

Table 3.3 AF-1 Total Program Costs

Production Cost	$56,049 million
Airframe Engineering and Design Costs	$483 million
Flight Test Costs	$208 million
Financing Cost	$5,674 million
Airframe Manufacturer Profit	$7,490 million
Total Program Cost	**$69,903 million**

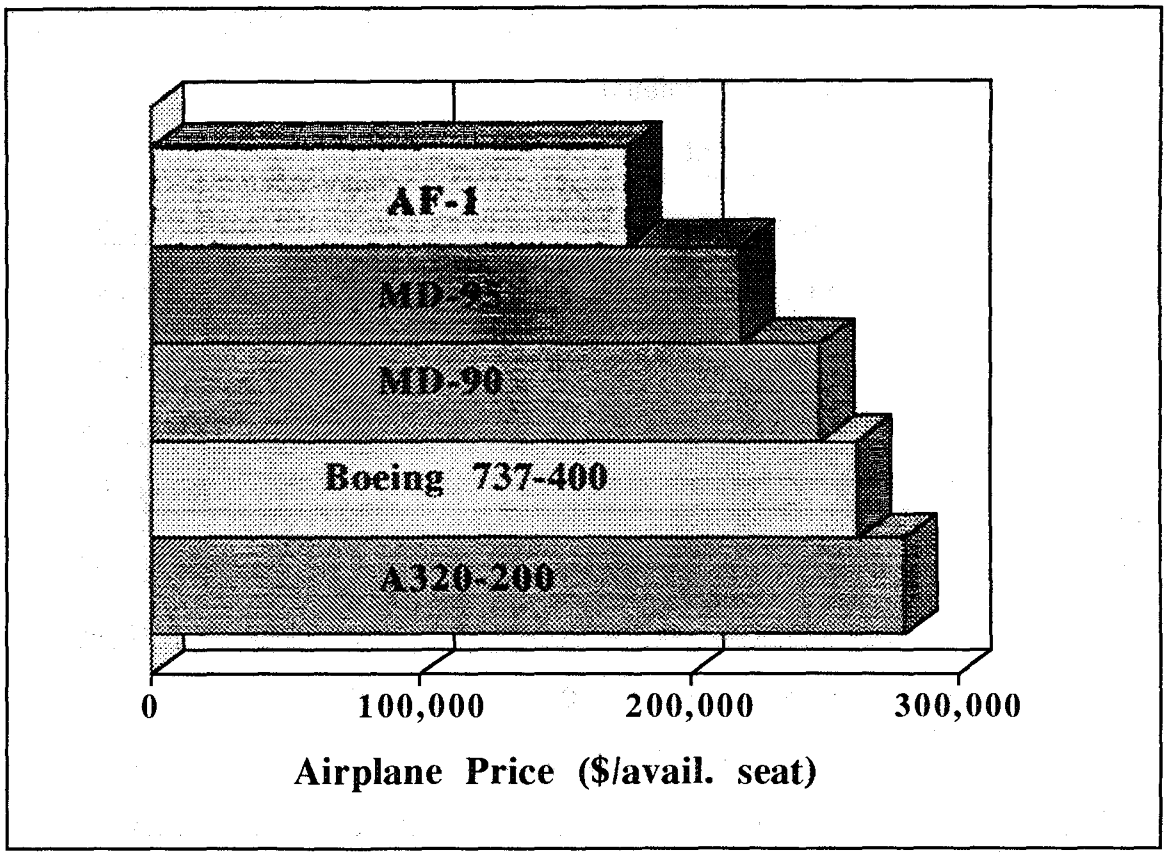


Figure 3.3 Airplane Price Comparison

3.4 Operating Costs

Operating costs incurred by airlines consist of direct operating costs and indirect operating costs. DOC depends largely on design choices; however, airplane designers have little or no control over IOC. There are five major components of DOC, calculated for the AF-1 in 1994 U.S. dollars per nautical mile and based on a 2,000 nmi. stage length (Table 3.4). When an aircraft is out in the fleet, it rarely flies the maximum range on a regular basis. With a range of 3,000 nmi., the AF-1 can easily be used for cross-country domestic flights. Non-Solo chose a stage length of 2,000 nmi. to model this type of use. Many flights from coast to coast in the United States fall into this range. Common city pairs include Los Angeles or San Francisco to international travel centers such as Dulles and John F. Kennedy Airports. If an airline chooses to use the AF-1 on a shorter stage length, the DOC can be expected to increase, as with any other aircraft. Table 3.4 below are the components of DOC for the AF-1 using the 2,000 nmi. stage length.

Table 3.4 Breakdown of AF-1 Direct Operating Costs

Direct Operating Cost of Flying	$1.95
Direct Operating Cost of Maintenance	$1.27
Direct Operating Cost of Depreciation	$1.73
Direct Operating Cost of Fees	$0.05
Direct Operating Cost of Financing	$0.37
Total estimated DOC	**$5.37**
Total estimated IOC	$3.49

A quick conversion gives a total estimated DOC of 3.49 cents per seat mile.

To fly the airplane, airlines must pay for the crew, insurance, fuel, and oil. Crew costs depend on current salaries and insurance depends on the purchase price of the airplane. By choosing an engine with low specific fuel consumption (SFC), Non-Solo was able to decrease the required fuel for its mission and lower both weight and DOC. Improved sealants and finishes on the airframe that have a longer useful life will also lower both fuel consumption and maintenance costs.

Maintenance is the biggest area for designers to affect costs. While labor rates fluctuate beyond airframer's control, Non-Solo can reduce the number of man-hours required. Strict quality control and reliable components on the AF-1 will help keep costs low. Reliable engines will keep the engine maintenance down, and conventional materials including aluminum and some standard composites will keep maintenance material cost low. Maintenance costs were calculated with labor on both airframe and engines, maintenance materials, and maintenance burden.

Depreciation is a fact of life, but Non-Solo keeps the airplane price low to minimize acquisition cost for airlines. The computing of depreciation breaks down into airframe, engine, avionics, airplane spares, and engine spares. Airlines use different depreciation periods, so this cost may vary.

Landing fees have recently been on the rise, but they are usually based on the aircraft weight which will give this plane an advantage. The AF-1 has the lowest aircraft weight per passenger seat of the three major competitors, as shown in Figure 3.4.

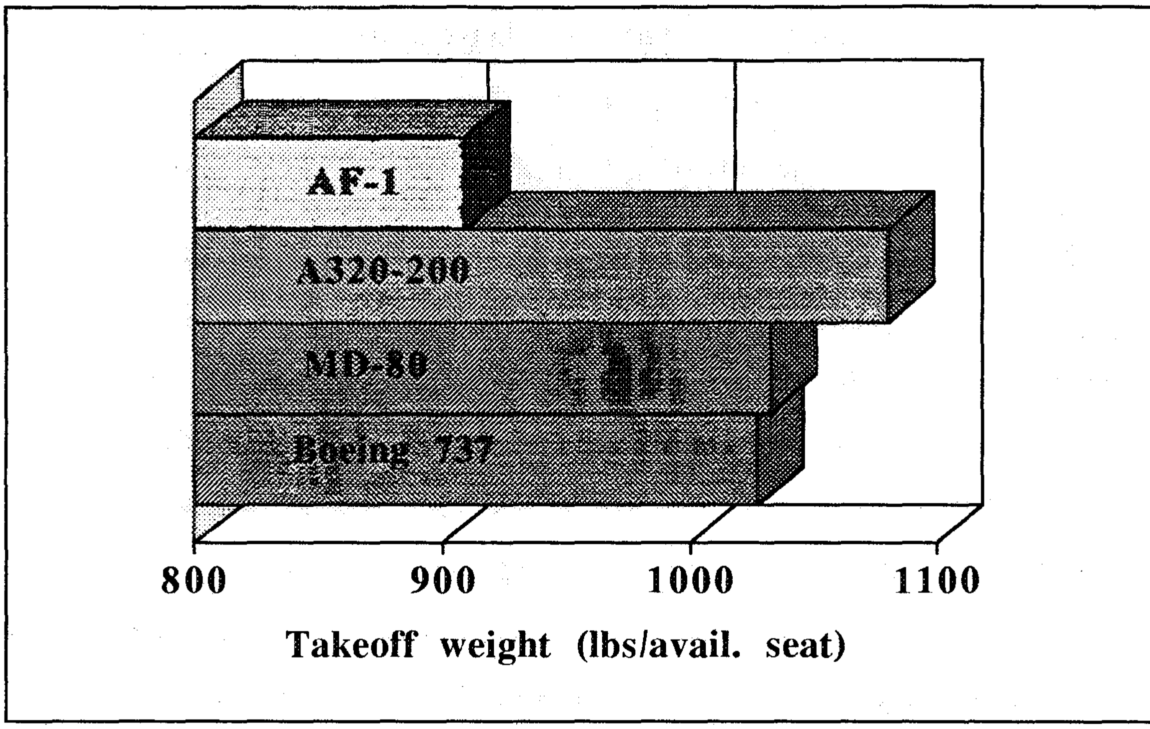


Figure 3.4 Comparison of Aircraft Max Take-off Weight in lbs per Available Seat

Financing depends on interest rates and total DOC. Non-Solo used a financing annual percentage rate of 7% .

Non-Solo cost estimates result in very competitive Direct Operating Costs. Figure 3.5 shows the significant savings the AF-1 can give airlines in dollars per flight hour. The other aircraft estimates (ref. 24) are converted from 1989 dollars to 1994 dollars. These numbers may vary according to route structure, pay scales, depreciation strategies, and the age of the airplanes.

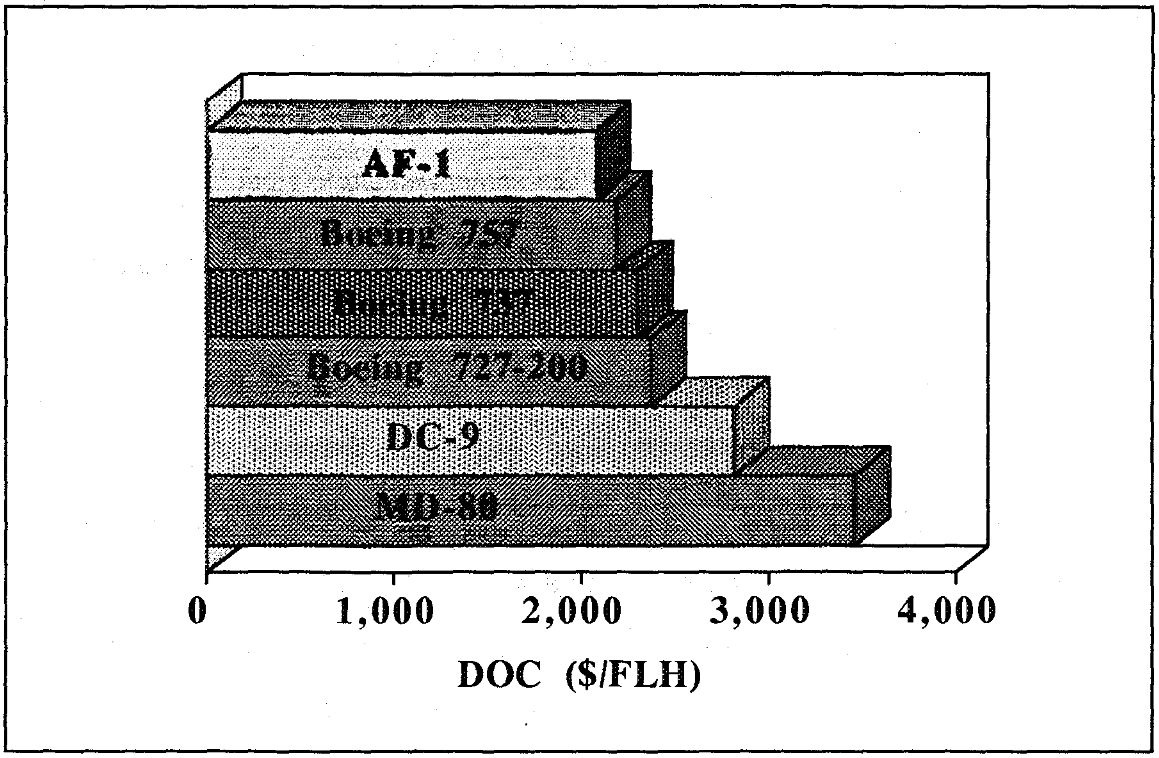


Figure 3.5 Comparison of DOC in $/FLH

Because IOC varies among airlines, Non-Solo used a conservative average of 65% of DOC for the 2,000 nmi. stage length. IOC includes passenger services, ground equipment and facilities, servicing, control, freight, promotion, sales, entertainment and administrative expenses. While in-flight entertainment costs are included in IOC, it is important to consider them on the AF-1. There is a cost associated with the entertainment system and tech center on board, but airlines can expect to make a significant profit from their captive audience. Modular units that can be quickly and easily replaced will keep maintenance costs down for these extra items.

The design emphasis on low cost has made the AF-1 a serious contender in the market for low cost aircraft. Lower purchase price as well as lower DOC make the AF-1 the first choice of airlines looking to improve profits.

4. AIRPORT OPERATION AND MAINTENANCE

4.1 Airport Requirements

The AF-1 is conventional in the sense that it will have the same service requirements and capabilities of current aircraft in service. From a configuration standpoint, the aircraft is small enough to fit in any gate capable of serving a 737. More importantly, the Falcon lacks canards or other unconventional surfaces that might pose a problem to jetway access or other maintenance. Air-conditioning, power, and other ground feed hookups are all located on the right side of the aircraft, but the systems are designed to run off APU power should these not be available. The AF-1 is not equipped with extendible stairways for passenger access at rural airports because the weight penalty could not be justified when most airports serviced by this type of aircraft will provide passenger loading capability.

4.2 Maintenance Schedule

Following the low cost doctrine, Non-Solo avoided implementing any system or technology that would have extraordinary maintenance requirements. The wing joint and associated structure may require more frequent inspection for fatigue due to its unorthodox and unfamiliar nature, but this procedure will be similar to inspections already being performed. The engines, being a major factor in service costs, are already in use and will follow the same maintenance schedule already in place for the Airbus 320. Other intervals will be similar, with A, B, C, and D checks occurring at normal periods in aircraft service life.

4.3 Inspection and Access Panels

Inspection panels and access doors are located where necessary and ergonomically designed to facilitate quick and easy examination of critical aircraft systems. Close attention was paid to placement of panels and related parts to minimize the time spent in accessing parts needing inspection. This will help keep labor costs low. Composites were also used in panel construction for weight reduction.

4.4 Ground Support

As mentioned above, ground support for the Falcon will be virtually identical to current practices. Figure 4.1 illustrates how the ground support equipment will be able to access the aircraft. Fueling can be done solely from the right side or from both sides if desired. All galleys are right-side serviceable as well with cabin cleaning service accessing the aircraft from the left rear door. It can be seen in the figure how the non-swept nature of the M-wing may be a possible benefit to ground crews since it leaves a greater percentage of the fuselage directly accessible.

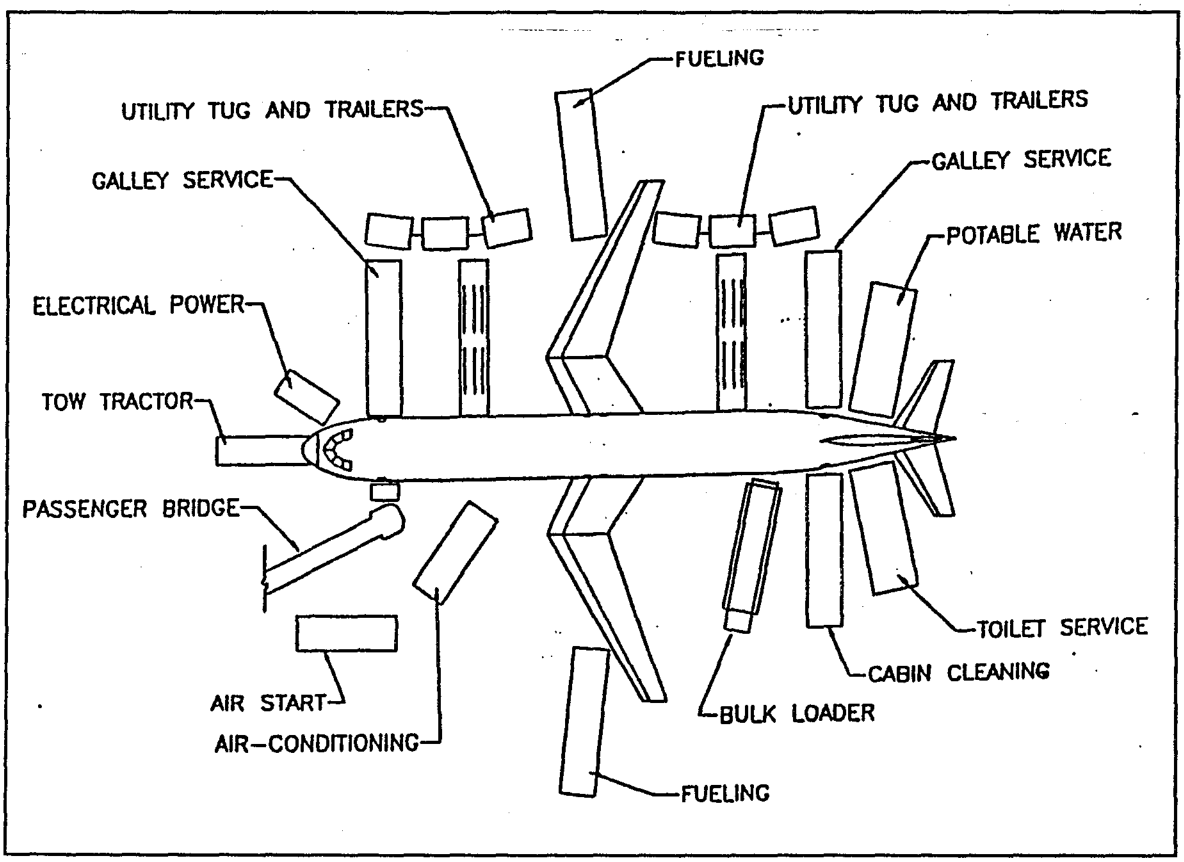


Figure 4.1 Aircraft Ground Support

5. WEIGHTS

5.1 Weight Breakdown

The AF-1's major component weight breakdown was evaluated by Reference 18 is shown in Table 5.1.

Table 5.1 AF-1 Weight Breakdown (lbs)

Structural Weight	
Wing	10,400
Empennage	1,460
Fuselage	17,900
Nose Gear	849
Main Gear	4,640
Total	**35,300**
Powerplant Weight	
Engines	15,400
Fuel System	438
Propulsion System	317
Total	**16,200**

Fixed Equipment	
Flight Controls	2,340
HPS	280
Electrical	1,730
IAE	1,750
API	2,870
APU	700
Oxygen System	268
Furnishings	7,770
Auxiliary	1,400
Paint	560
Total	**19,700**

Fuel Weight	35,800
Crew Weight	1,200
Payload Weight	30,600
Total Empty Weight	71,100
Total Takeoff Weight	**140,000**

All of the component weights add up to the total empty weight. This, along with the weight of fuel, crew and payload make up the total design takeoff weight.

5.2 Weight Reduction Strategy

To minimize the takeoff weight of the AF-1 Non-Solo concentrated on the two biggest contributors to the weight of the aircraft: the structure and the fuel needed to fly the required range. To attack the structural weight Non-Solo incorporated a definite philosophy: "The smaller, the better." Every design decision from the number of aisles in the passenger cabin to the static margin selection followed this philosophy. The result of this was the smallest possible aircraft capable of comfortably transporting 154 passengers a range of 3000 nmi.

In order to reduce fuel burn Non-Solo did two things - selected engines with high performance and low fuel consumption (Section 9) and concentrated on lower drag for lower required thrust (Section 7).

5.3 Center of Gravity

The center of gravity (CG) was determined according to the weight breakdown. As shown from Figure 5.1 the center of gravity is shown at different stages of the aircraft's flight; from the empty aircraft with addition of fuel and loading passengers and bags to a fully loaded aircraft, then burning fuel and unloading passengers and bags back to the empty aircraft. Careful attention was paid to properly locating heavy items in order to minimize CG travel, however Figure 5.1 includes the uncertainty of the positioning of these heavy items. Analysis determined that the forward CG location was 57.6 ft and the aft CG of 56.6 ft. from the nose of the aircraft. The cruising CG location was determined to be 56 ft from the nose. One of the characteristics of the M-wing is the minimal CG travel of 1 foot. One of the advantages of a small center of gravity travel is a reduction in wetted area of the tail due to less trim control power required.

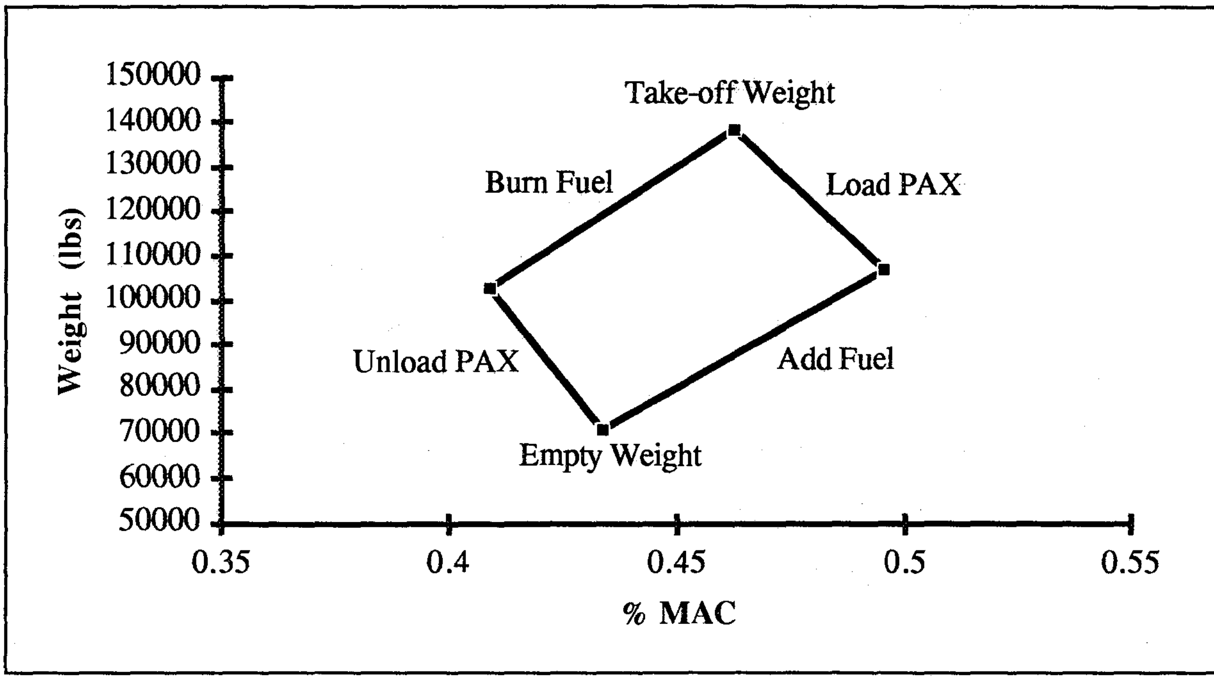


Figure 5.1 AF-1 Center of Gravity Excursion

Once the component weight breakdown and the center of gravity were determined the moments of inertia at takeoff and at the empty weight were calculated according to the methods in Reference 21.

Table 5.2 AF-1 Moments of Inertia (Slug ft^2)

	Ixx	Iyy	Izz	Izx
Takeoff Weight	720,000	2,600,000	3,000,000	14,000
Empty Weight	380,000	1,980,000	2,160,000	8,000

6. PERFORMANCE

6.1 Preliminary Sizing

In the beginning of the design phase a matching plot was constructed to establish important design parameters. Figure 6.1 contains this matching plot and the design point that was selected. Shown on the matching plot are the climb and cruise requirements for selecting a design point, the most restrictive being the climb requirement.

The takeoff wing loading of 131 psf corresponds to a C_{Lmax} at landing of 3.1. This requires a fairly sophisticated high lift system. However, the consequences of a lower wing loading include a larger wing structure and a less comfortable ride for the passengers. At an earlier design phase, the AF-1 had a lower wing loading of 110 psf, and consequently a much large wing planform area. Increasing the wing loading and shrinking the wing size resulted in a decrease of approximately 8,000 lbs in total takeoff weight.

With two engines, each rated at 23,000 lbs static thrust, the AF-1 has a takeoff thrust-to-weight ratio of approximately 0.32.

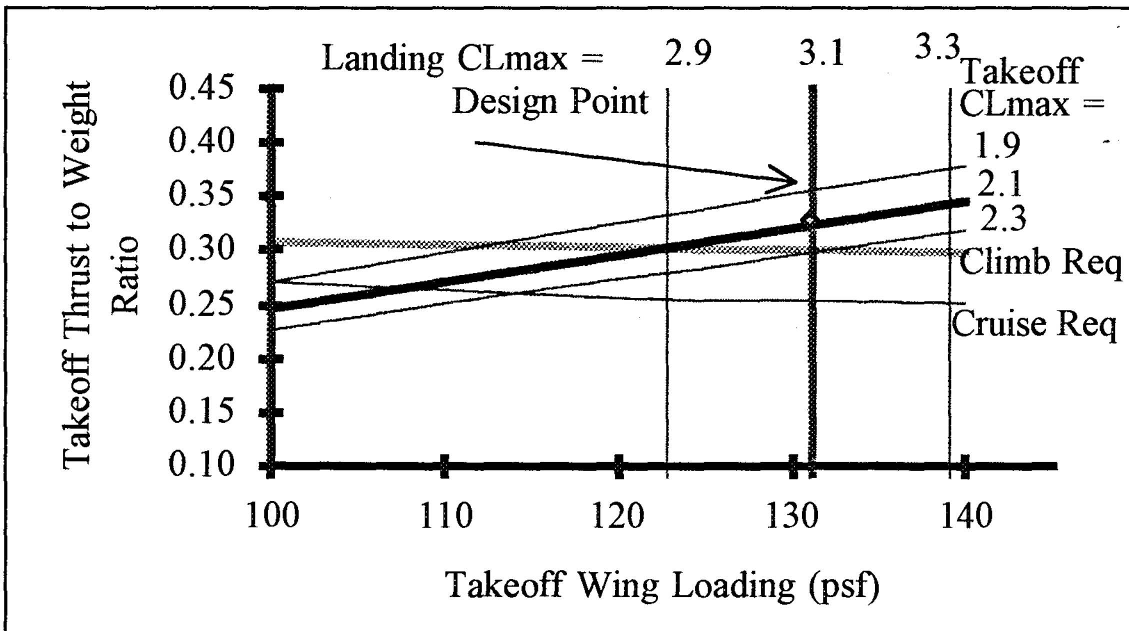


Figure 6.1 AF-1 Design Point Plot

6.2 Field Performance

6.2.1 Takeoff Performance

The RFP specifies that the AF-1 must be able to takeoff within a FAA field length of 7,000 feet. The AF-1 meets this requirement with a balanced field length of exactly 7,000 feet. This was calculated using methods from Reference 23. In takeoff configuration with one engine inoperative, the AF-1 has a thrust-to-weight ratio of 0.16 and an L/D of 10.1. The takeoff L/D with both engines operative is approximately 10.3. The additional drag with OEI is due to wind milling effects and was calculated using Reference 22. Figure 6.2 shows how the balanced field length varies with takeoff weight.

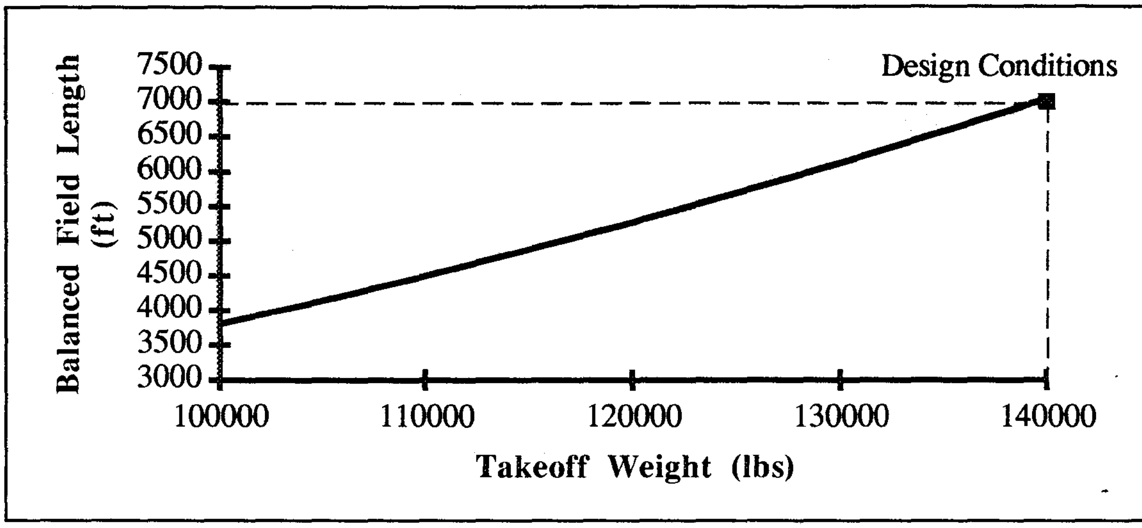


Figure 6.2 AF-1 BFL Versus Takeoff Field Length

6.2.2 Landing Performance

The FAA landing field length required by the RFP is 5,000 feet. Figure 6.3 shows how the Aluminum Falcon's landing field length increases with landing weight. At a maximum landing weight of 126,000 lbs, the AF-1 meets the requirement with a landing field length of 4,940 feet. The AF-1 can therefore land within the required field length at 90 percent of its design takeoff weight. This is competitive with other aircraft of the same class. The MD-90 lands at 88 percent of its takeoff weight and the Boeing 737 lands at 87 percent. These percentages were obtained from Reference 13.

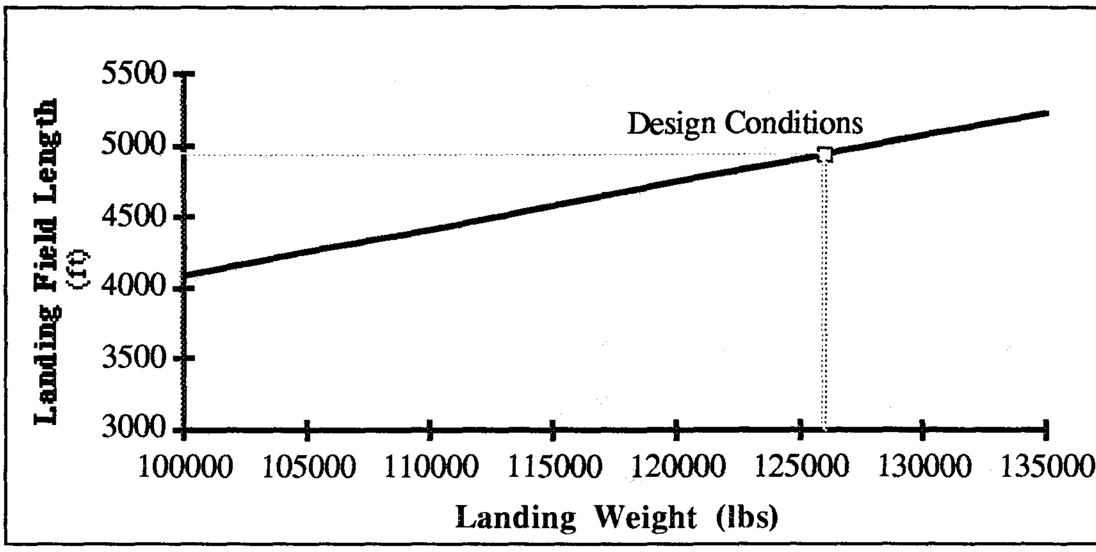


Figure 6.3 AF-1 Landing Field Length vs. Landing Weight

6.3 Climb Performance

The climb requirement of the RFP specifies that the AF-1 must climb at its best rate of climb directly to its best cruising altitude. The designers of the AF-1 interpreted the best rate of climb to mean the fastest possible climb to cruising altitude because the RFP was unclear about whether range credit should be taken for climb. Reference 10 stated that the fastest climb is nearly the most economical climb . The best cruising altitude was interpreted as the optimum compromise between the altitude where the engines are most fuel efficient and the altitude where the wing is most aerodynamically efficient.

Climb ceilings for the AF-1 were calculated and are summarized below in Table 6.1. The service ceiling is at an altitude of 36,000 feet and the absolute ceiling is at an altitude of 39,000 feet.

Table 6.1 AF-1 Climb Ceilings

	Altitude (feet)
Cruise Altitude	35,000
Service Ceiling	36,000
Absolute Ceiling	39,000

Figure 6.4 contains the complete schedule for the climb phase of the design mission. The total time to climb from sea level to the cruising altitude of 35,000 feet is

approximately 18 minutes. Below 10,000 feet the velocity is limited to 250 knots due to FAA regulations. Throughout the climb phase, it is necessary to monitor the cabin pressurization to ensure that the pressure differential does not exceed the maximum that the fuselage skin can accommodate. Figure 6.4 also includes a cabin pressurization schedule. This shows that at all times during the climb phase the pressure differential imposed on the fuselage skin is less than the maximum which occurs at cruise. The cabin reaches a pressure equivalent to that at 8000 feet approximately two minutes prior to the aircraft reaching its final cruising altitude.

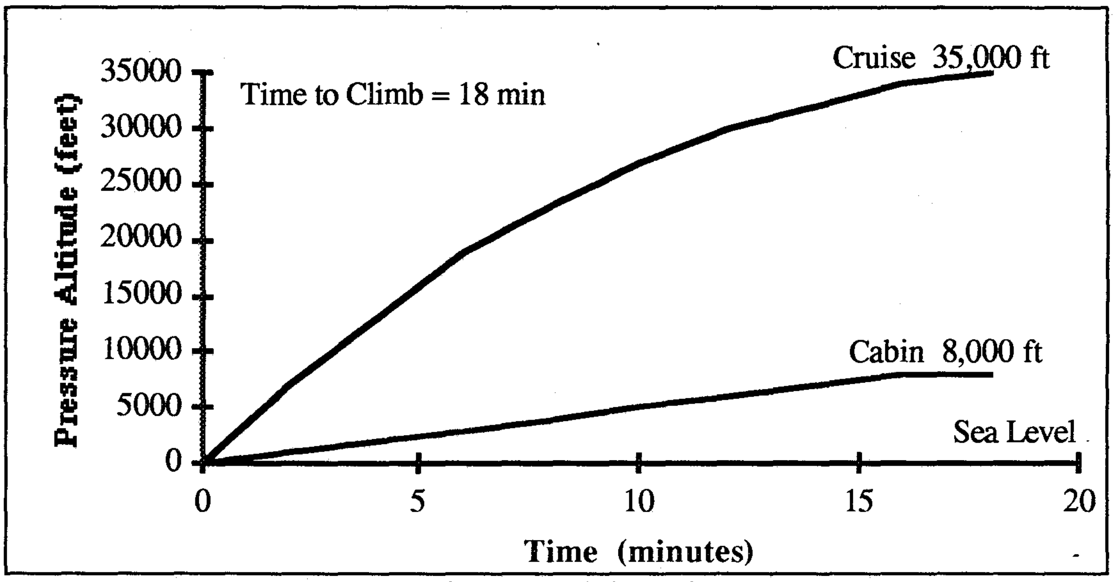


Figure 6.4 AF-1 Climb Schedule

6.4 Range and Endurance

6.4.1 Cruise Velocity

The AF-1 cruises at 99 percent of its velocity for best range as required by the RFP. This velocity was determined by the information presented in Figure 6.5. The velocity for best range occurs where the square root of the lift coefficient divided by the drag coefficient ($C_L{}^{1/2}/C_D$) is at a maximum. Accounting for an increase in wave drag at higher Mach numbers, Figure 6.5 shows that this curve peaks at a Mach number of 0.81. Therefore the Aluminum Falcon's design cruise speed at .99 Vbr is Mach 0.80. This cruise Mach number is also at the maximum ML/D which is the ultimate optimization of cruise velocity versus L/D.

Also included in Figure 6.5 is the lift to drag ratio (L/D) as a function of Mach number. This shows that the AF-1 has a maximum L/D of 19.5 which occurs at Mach 0.69 which would be the desired Mach number for maximum endurance. This Mach number for maximum endurance would provide minimum fuel consumption on a per hour basis and consequently the maximum time in the air for a given amount of fuel. However, on a per trip basis, the velocity for best range will provide lower fuel consumption because the fuel burned per mile is lower. Overall, the most economical velocity is that for best range. The L/D ratio at the design cruise speed is 18.4 which is 94 percent of the maximum L/D. Reference 16 indicates that a typical value for this is 86 percent.

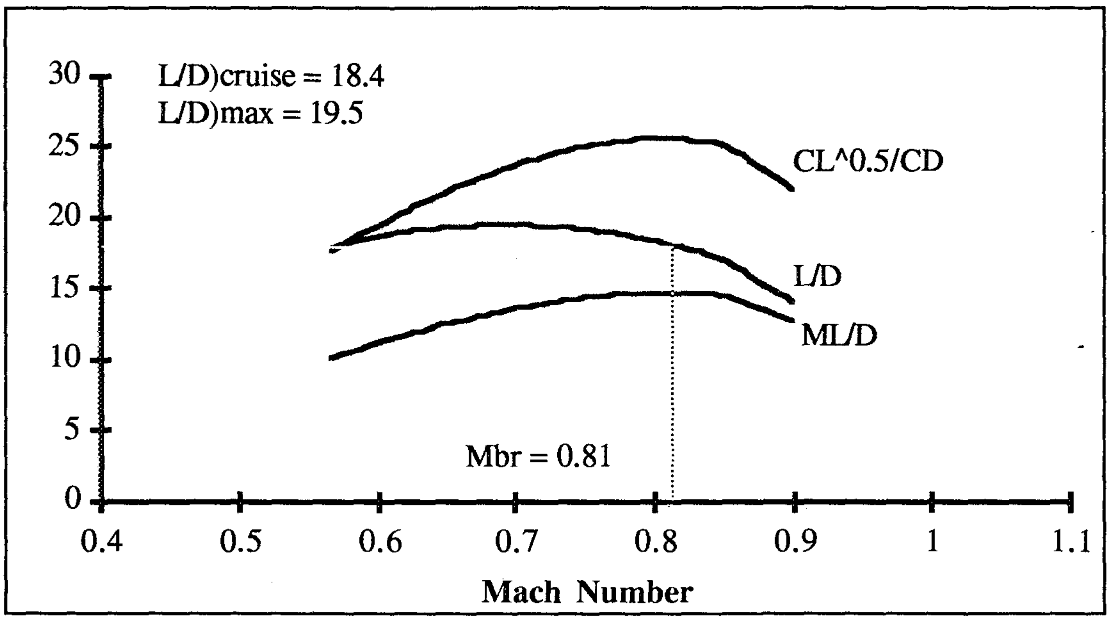


Figure 6.5 AF-1 Velocity for Best Range

Figure 6.6 shows how the Falcon's required thrust varies with Mach number. The maximum thrust available from the engines and the necessary thrust needed at cruise are also labeled on the graph. These thrust levels are shown as constant; however, it must be noted that in reality there is a slight variation with Mach number which would require a slightly higher thrust at lower Mach numbers. The bucket of the thrust required curve is the point of maximum endurance while the cruise condition is at the point of maximum range. Table 6.2 is a summary of critical velocities at cruising altitude.

Table 6.2 AF-1 Critical Velocities at Cruise Altitude

	Velocity (knots)	Mach Number
Speed for Maximum Endurance	252	0.69
Cruise Speed	457	0.80
Maximum Level Flight Speed	539	0.92

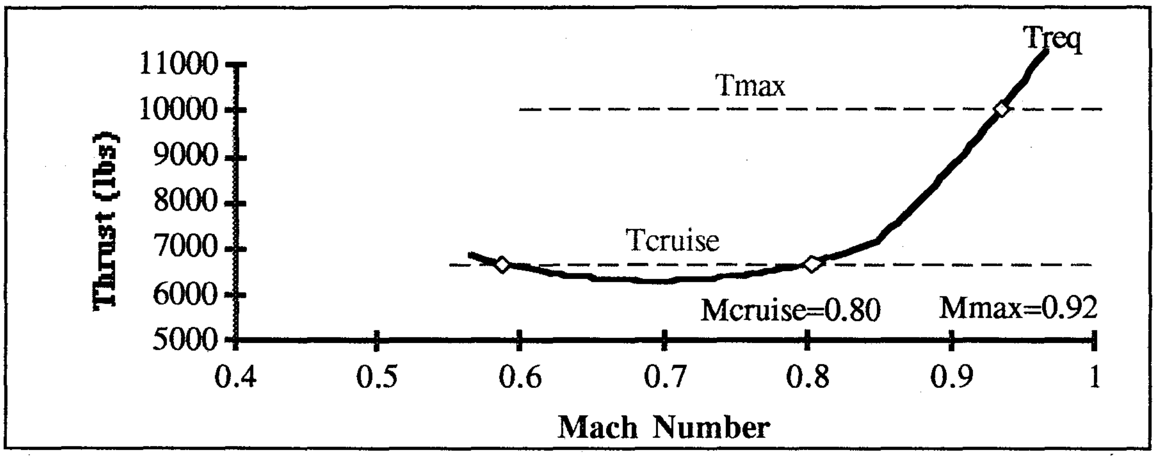


Figure 6.6 AF-1 Thrust vs. Mach Number at Cruise Altitude

6.4.2 Payload Versus Range

Figure 6.7 is the payload range relationship for the Aluminum Falcon. As indicated, at the design payload of 154 passengers plus bags the AF-1 is capable of a range of 3,000 nmi which meets the RFP requirement. If the aircraft is loaded to its maximum capacity of 178 passengers the AF-1 can cruise for 2,500 nmi. If the AF-1 carries no passengers and the fuel tanks are filled to maximum capacity the range capability increases to 5,750 nmi.

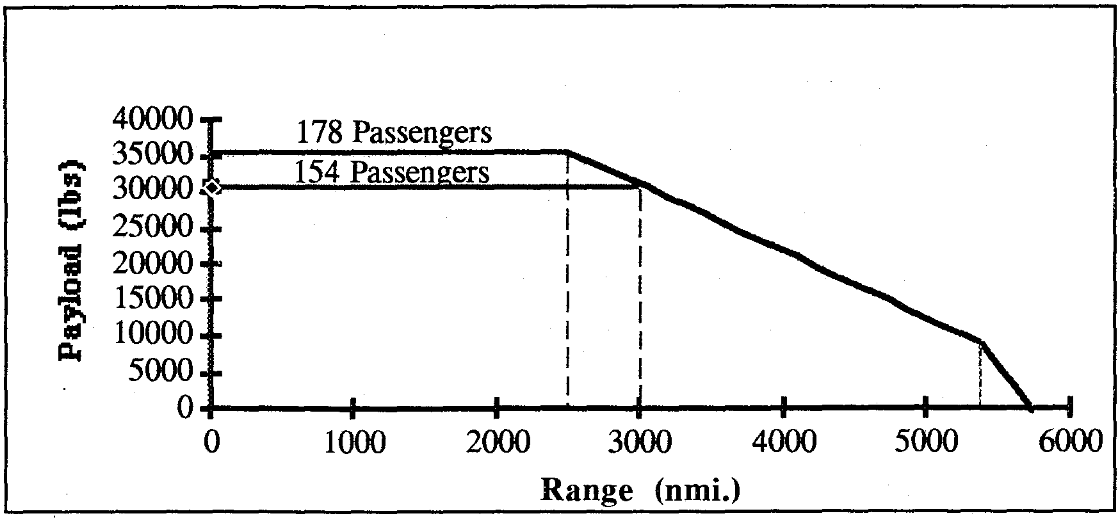


Figure 6.7 AF-1 Payload Versus Range

6.4.3 Flight Path Optimization

The two major aspects of the flight path that were not determined by the RFP and were left to be optimized by the designers were the rate of climb and the cruising altitude. The designers attacked the rate of climb with the following philosophy. Range credit is not being taken for the climb phase because from the specifics in the RFP it was difficult to interpret whether this was allowed. Therefore, in order to begin traveling the required 3000 nmi, the AF-1 needs to climb to cruising altitude as quickly as possible. For this reason, the AF-1 climb flight path is such that the rate of climb is maximized. In support of this, Reference 10 states that for preliminary design purposes, it is safe to assume that the fastest rate of climb is close to the most economical rate of climb.

The cruising altitude of 35,000 feet is optimum for the engines and wing geometry of the AF-1. This compromise was a challenge because higher aspect ratio wings tend to have optimum performance at higher altitude while above 35,000 feet the engines tend to decrease in performance. However, by not exceeding an aspect ratio of 10 and by selecting high performance engines, the designers of the AF-1 were able to meet this challenge and optimize the cruising altitude at 35,000 feet. The isothermal layer begins at this altitude and engine performance decays at a faster rate since the air density is decreasing more rapidly.

6.5 Stall Performance

Figure 6.8 contains the operational flight envelope for the AF-1. The stall locus segment of this curve was determined for power-off stall with the aircraft center of gravity in the least favorable position producing the lowest maximum lift coefficient. These stall characteristics meet all requirements FAR 25.

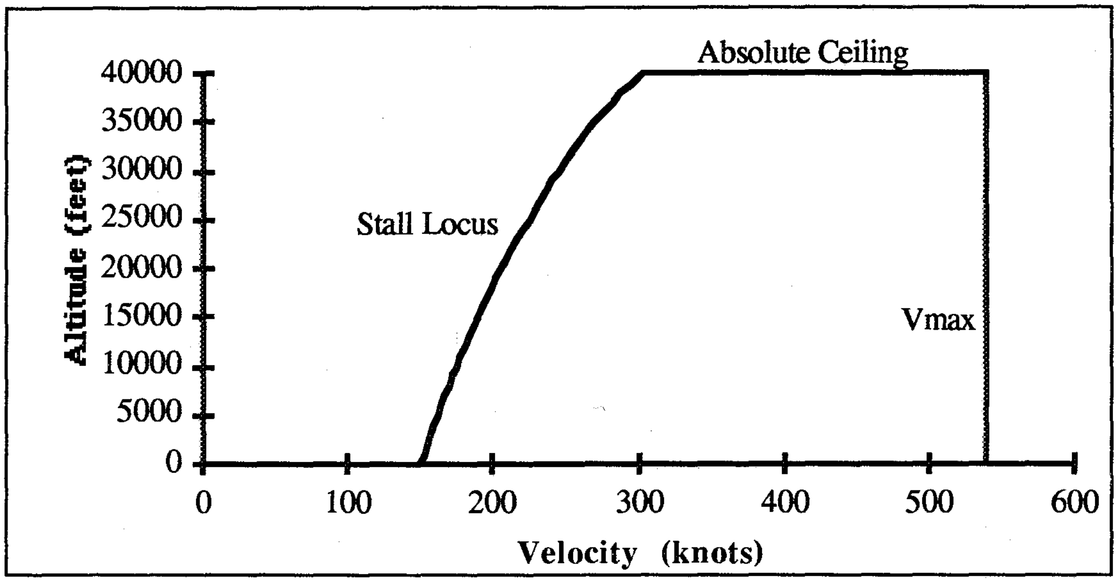


Figure 6.8 AF-1 Operating Envelope

Stall performance was taken a step further and the load factor was calculated at various flight conditions and is represented as the flight envelope in Figure 6.9. The AF-1 is designed to withstand 2.5 g's positively and 1 g negatively plus a safety factor of an additional 50%. Gust lines were also analyzed and fell within the static loading requirements set for FAR 25 aircraft (Figure 6.10).

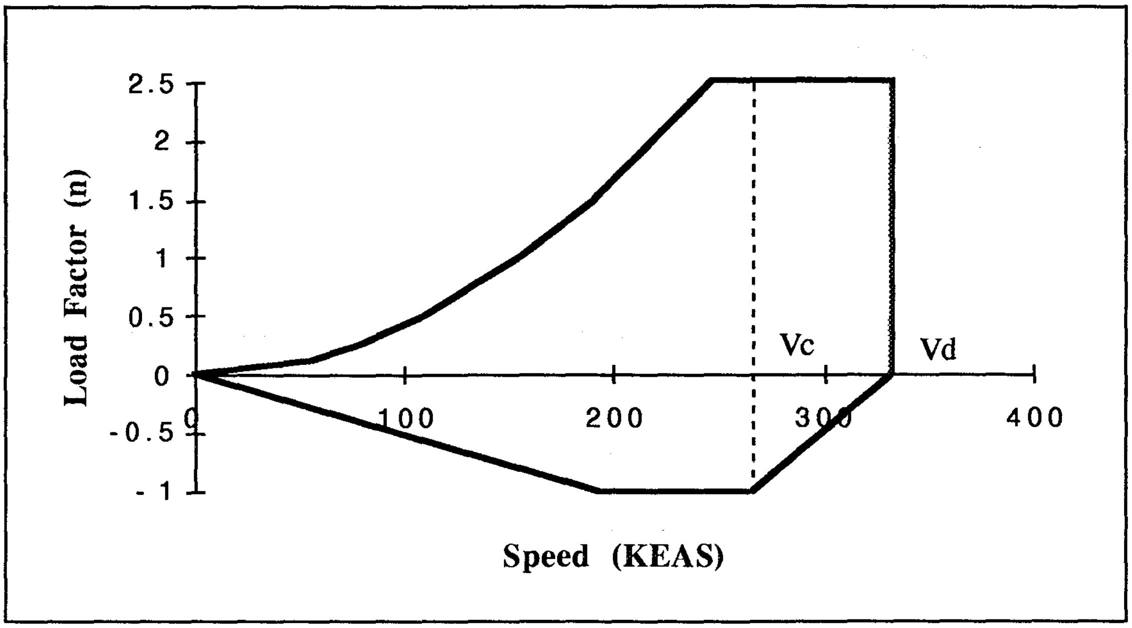


Figure 6.9 AF-1 V-n Diagram

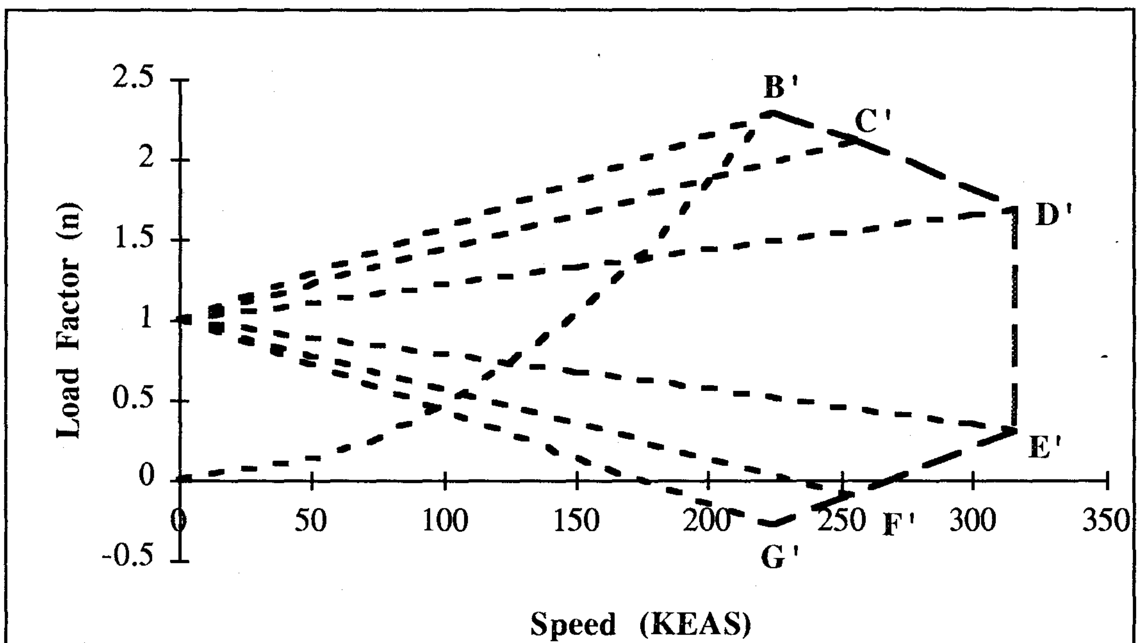


Figure 6.10 AF-1 Gust Loading Chart

7. AERODYNAMICS

7.1 Wing Geometry

7.1.1 M-Wing Concept

Immediately apparent to even the casual observer is the unusual shape of the wing on the AF-1. Referred to in many texts as an "M-wing" for obvious reasons, this wing design was chosen for the aircraft based on careful analysis and meticulous attention to the compromises that came along with it. Initially, the concept was researched as a possible solution to the landing gear placement difficulties that seem to be getting more severe. As performance dictates smaller static margins, the wing wants to move forward on the fuselage. Unfortunately, this places the main landing gear too close to the center of gravity of the aircraft and causes the aircraft to tip over onto the tail. Using a forward-swept wing root places the overall aerodynamic center of the wing farther forward without the use of an otherwise unwanted yahudi. The yahudi unsweeps the wing at the root, creating compressibility problems and is only necessary for proper landing gear placement in an aft-swept wing. Sweeping the outboard section of the wing backward also has substantial benefits. One is that the tip then retains an amount of aeroelastic dampening that is lost on a forward swept wing. Flexing an aft-swept wing up causes a reduction in local angle of attack, decreasing lift and stabilizing the disturbance. On the contrary, if the wing were completely forward swept, tip divergence would be a major stability and structures problem, requiring much stiffer composites and flight control computers.

In essence, the M-wing has many of the advantages of a straight, unswept wing without the severe compressibility problems at high Mach numbers. Stall of the outboard section no longer causes unstable pitch-up, so the inboard section can be optimized without having to stall first. Having the lift located near the fuselage joint rather than behind it, as with a conventional swept wing, also reduces the torque load on that structure significantly (see figure 7.1).

Ultimately, the M-wing assists notably in achieving one of the major design goals of the AF-1, reduced CG travel. Comparison studies show a reduction of about 50% (see figure 7.2) compared to a standard wing.

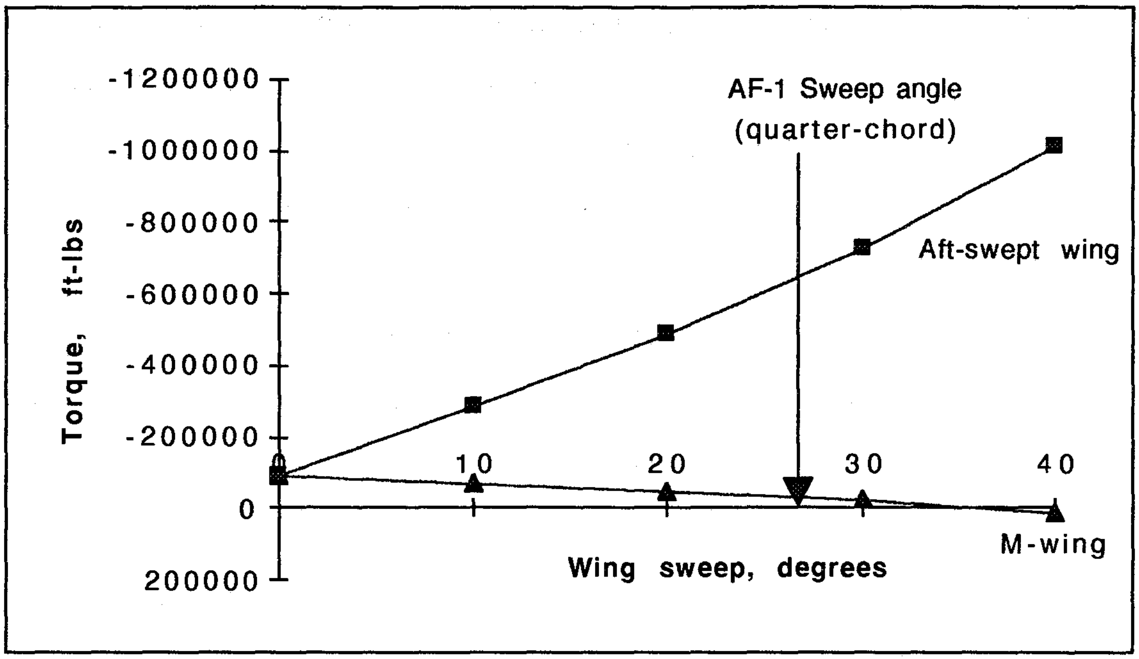


Figure 7.1 Wing Torque at Fuselage due to Sweep, M-wing vs. Standard

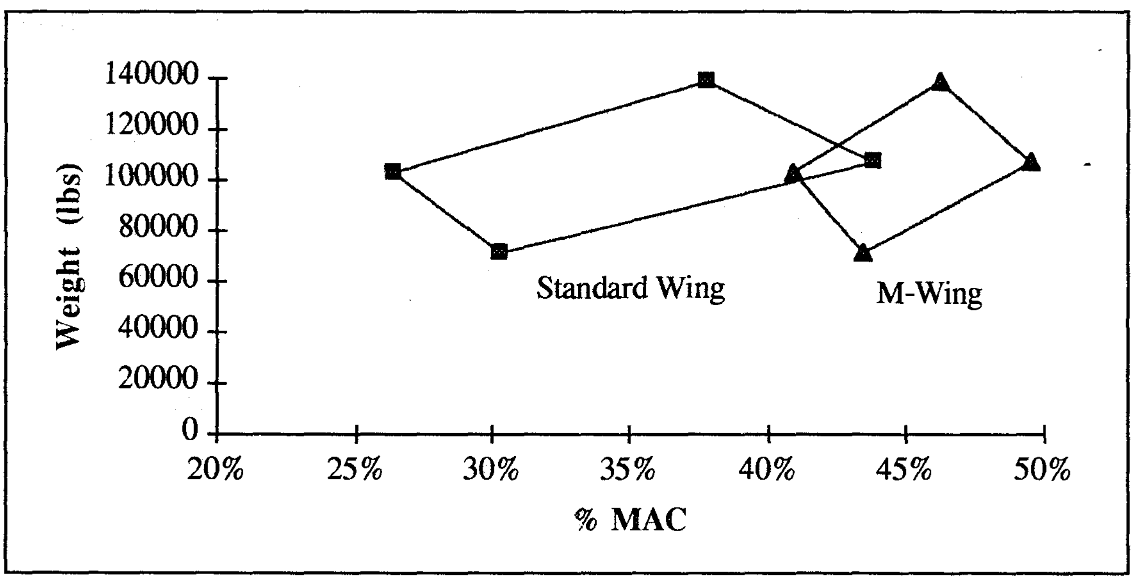


Figure 7.2 CG Shift Comparison Between M-Wing and Standard Wing

Difficulties with this wing design include increased drag and additional structure and weight for the wing joint. Advanced CFD and complicated wind tunnel testing will be required to investigate these areas completely, but preliminary research reveals only minor consolations in both areas. For example, the engine pylon can be utilized to add sweep to the unswept joint section and reduce Mach effects. Furthermore, once this development work is completed, manufacturing costs for the wing will be similar to a conventional wing and maintenance costs will remain unchanged. The low-cost doctrine is again upheld while still presenting the customer with an advanced concept and lower operating costs.

7.1.2 Preliminary Potential Flow Analysis

To obtain a basic comparison between possible aerodynamic differences between a conventional wing and the M-wing, Non-Solo utilized computational fluid dynamics. By inputting to the program parameters from both the M-wing and an aft-swept wing with similar characteristics, inherent variations in lift could be compared between the two.

Keeping under consideration that the straight wing is being used as a control and for comparison purposes, the results are only being interpreted qualitatively. Many other variables, including influence of the fuselage, will affect the actual performance of the wing on the aircraft, so strict interpretation of the numbers at this stage has been avoided. Furthermore, to account for possible complications with the program analyzing a two-segment wing, this trait was also reproduced in the control wing by using two panels, as shown in Figure 7.3. The graph shows only a slight anomaly in section lift between the two panels, allowing the assumption that sweeping the inboard section of the wing forward will have no unwarranted effects on the analysis. Figure 7.4 shows the results from this case, the M-wing configuration.

From the graph, it is apparent that the lift over the outboard section of the wing is relatively unchanged. The root section, however, shows a remarkable increase in section C_l away from the joint. The trends show that lift tends to increase on aft portions of a swept wing, and the M-wing has two such sections on each side as opposed to one, at the tip, with a conventional wing.

As an additional test of the simulation's validity in comparing these two wings, an engine pylon was modeled. Although it seems likely that the engine may have some

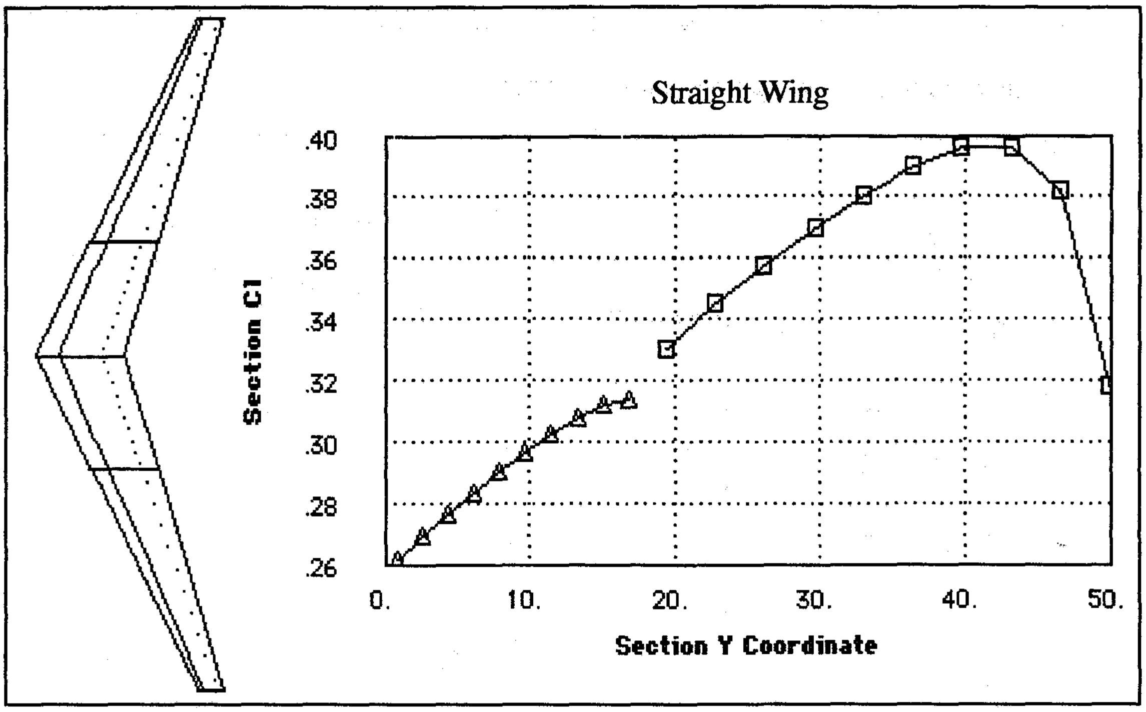


Figure 7.3 Section C_l versus Span Location, Standard Wing

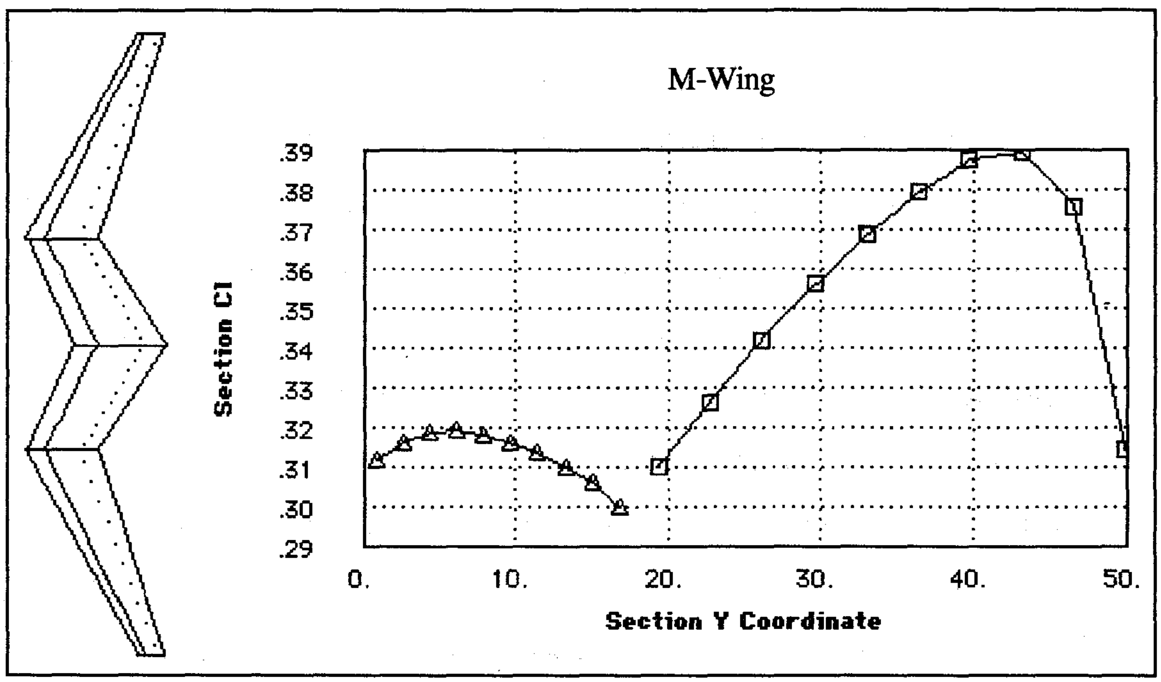


Figure 7.4 Section C_l versus Span Location, M-wing

influence on the spanwise flow patterns across the wing, especially on a conventional wing, the results showed no difference on either wing due to the simulated pylon installation. The results for the M-wing are shown below in Figure 7.5, with only a local change in lift about the pylon. Note the change in scale.

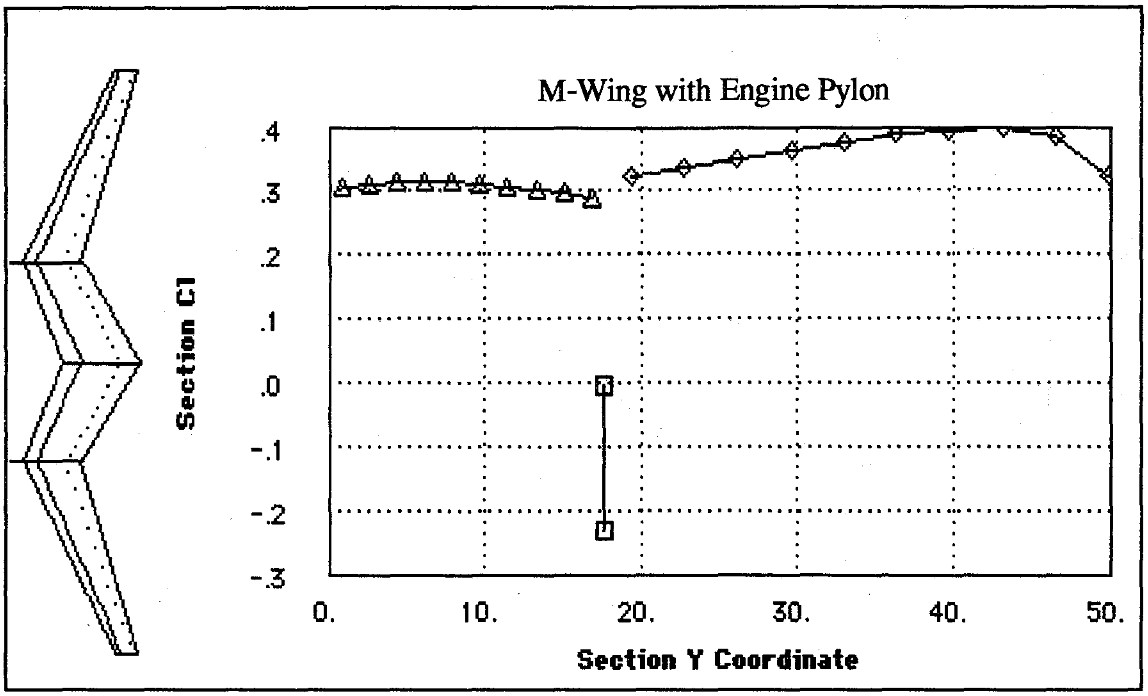


Figure 7.5 Section C_l versus Span Location, M-wing with Engine Pylon

Finally, for a more illustrative depiction of the advantages of the M-wing, the section lift is plotted versus wing span in Figures 7.6 and 7.7. This takes into account section chord length and thereby shows the greater lift generated at the root sections of the wing where there is more wing area. As the figures show, the enhanced aerodynamic effectiveness of the inboard section on the M-wing translates to approximately a 10% increase in lift over the standard wing in that same region. This does not factor in the additional compromises inherent to a standard wing after installation of a glove and yahudi.

Since the program used shows that a standard wing produces the desired elliptical lift distribution for minimum induced drag with no twist, it was apparent that the model was insufficient for furthur analysis. However, by twisting the inboard section 2 degrees, from an angle of incidence of one at the fuselage to 3 at the joint, it was possible to reproduce the elliptical lift pattern. The benifits of this include easier wing fuselage placement, lower compressibility drag on the inboard section, and better stall performance.

Even from this preliminary analysis, it is safe to assume that there is no compromise in lift capability for the M-wing, if not some added benefits. This will lower the moment loads on the wing, mitigating structural concerns where they are of utmost concern.

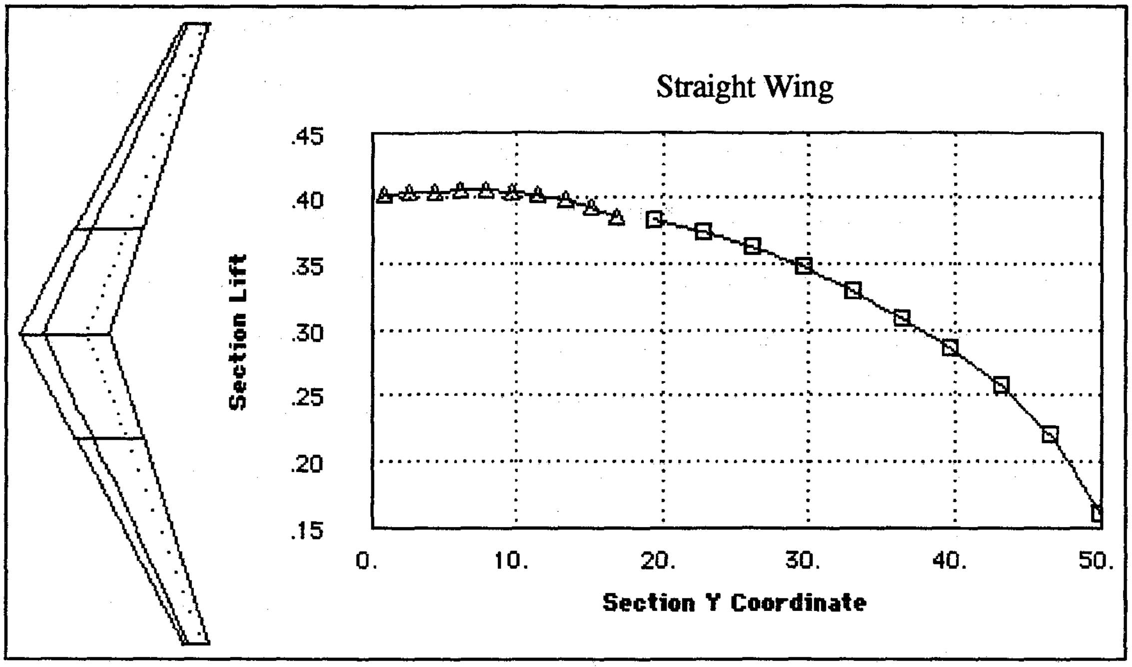


Figure 7.6 Section Lift versus Span Location, Standard Wing

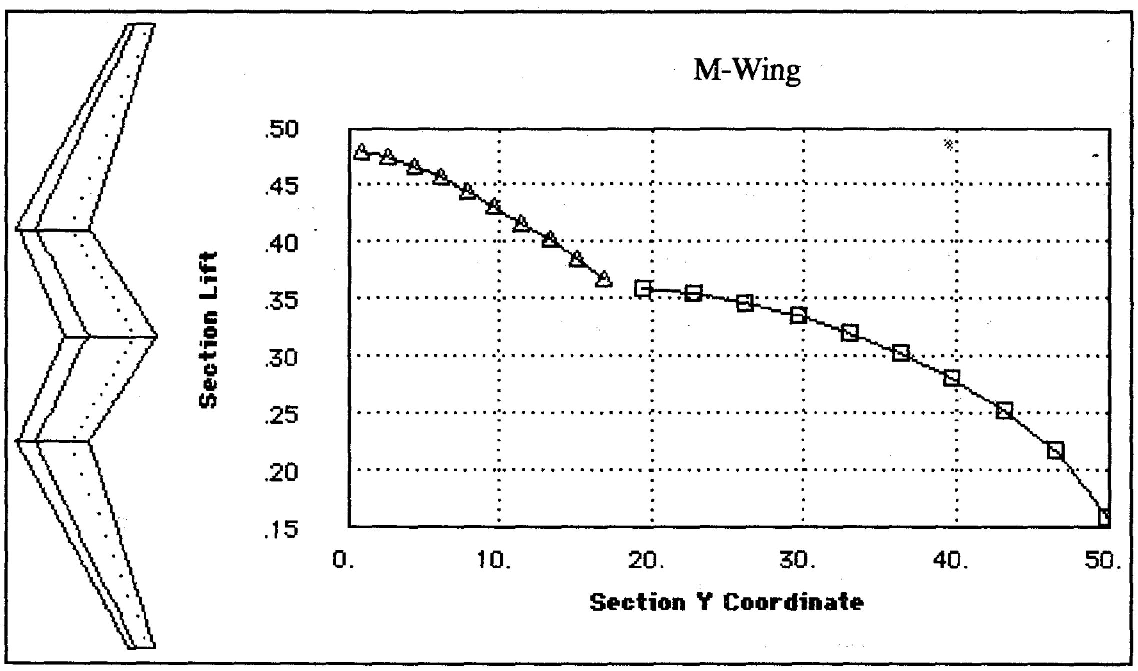


Figure 7.7 Section Lift versus Span Location, M-wing

7.1.3 Wing Placement

One of the first decisions to be made was the vertical positioning of the wing on the fuselage. Aerodynamically, for minimum interference drag, a mid-wing configuration would be optimum. This configuration was briefly investigated and definite complications between the center wing box and the passenger cabin were discovered. For this reason, the mid-wing placement possibility was eliminated.

The decision was then between the high and low wing configurations. The high-wing generally has lower interference drag characteristics; however, this presents landing gear retraction complications. Attaching the gear to the wing presents a substantial weight penalty. Retracting the gear into the fuselage would require the use of a bump fairing which would cause additional drag that would offset the savings in interference drag.

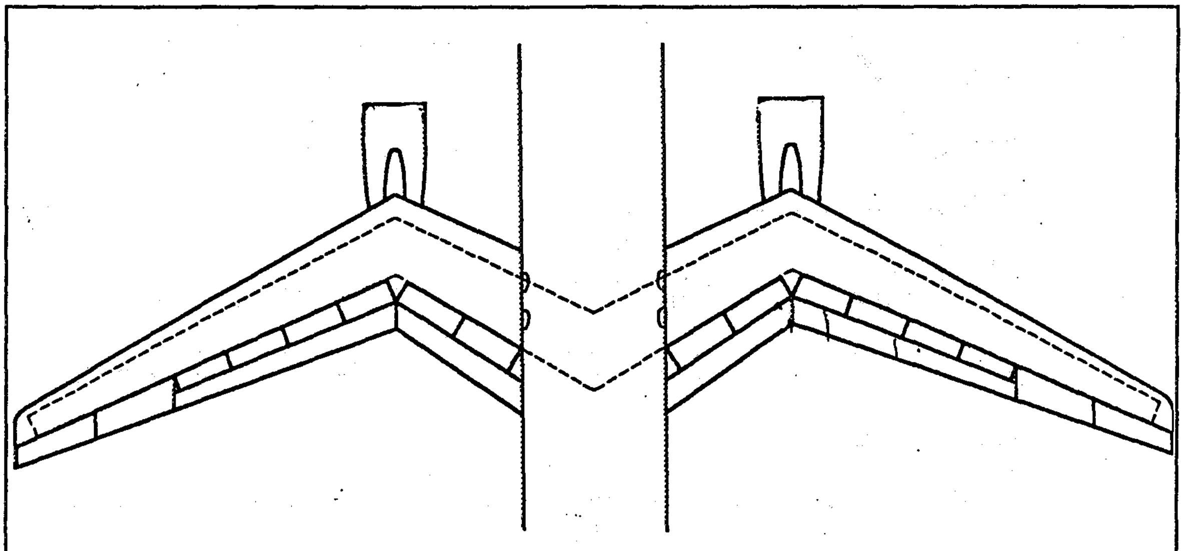
With these considerations, the designers of the AF-1 opted for the low wing configuration, not only because of the easier landing gear placement, but for safety reasons as well. The AF-1 has a design range of 3000 nmi which means many of its flights could be over water. The low wing configuration is the safest for emergency water landings because the passenger cabin will remain above the water. This provides for passenger evacuation onto the wing, if necessary, under these circumstances.

Longitudinal placement of the wing was a compromise between obtaining the desired static margin, which dictates that the wing be as far forward as possible, and landing gear placement, which dictates the wing be further back to obtain a reasonable tip-over angle. However, because of the nature of the M-wing, its aerodynamic center is further forward than for a conventional aft swept wing. Therefore, desired negative static margin for lower trim drag and decreased tail area was possible without creating a severe landing gear placement problem.

7.1.4 Wing Planform

7.1.4.1 Planform Area

The AF-1 has a wing planform area of 1069 square feet. With the design takeoff weight being 140,000 lbs, the maximum wing loading is 131 psf. This wing loading is comparable to other aircraft in this class (ref. 13) and is high enough to provide a smooth, comfortable ride for the passengers. It does, however, call for a fairly sophisticated high lift system to provide a maximum lift coefficient at landing of 3.1. The planform is shown in Figure 7.8.



Planform Area = 1069 square feet	Aspect Ratio = 10
Span = 103 feet	Taper Ratio = 0.3
Quarter Chord Sweep = 27 degrees	Mean Aerodynamic Chord = 11.3 feet

Figure 7.8 AF-1 Wing Planform Geometry

7.1.4.2 Aspect Ratio

The aspect ratio of 10 was selected with weight and cost in mind. A higher aspect ratio will provide low induced drag requiring less thrust, and therefore, less fuel. However, it will increase the structural weight of the wing. Figure 7.9 graphically shows the relationship between aspect ratio with wing weight and thrust required during cruise. Reference 21 and Reference 2 were used for these calculations.

The effects of aspect ratio on wing weight and thrust required were combined and referenced back to the total takeoff weight of the airplane. This relationship is shown in Figure 7.10 and shows that the takeoff weight starts to level off at an aspect ratio of about

10. The curve actually reaches an absolute minimum at an aspect ratio of approximately 12. However, it flattens out so much that the difference in takeoff weight between in

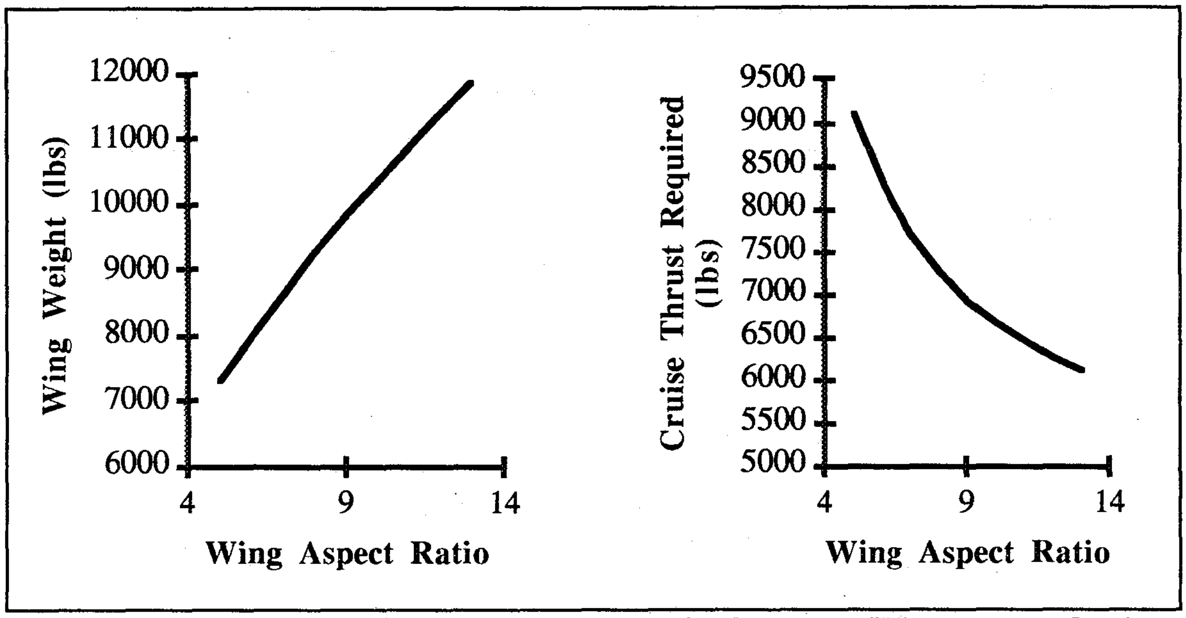


Figure 7.9 Wing Weight and Thrust Required Versus Wing Aspect Ratio

aspect ratio of 10 and one of 12 is minimal. Therefore, the designers of the AF-1 opted for an aspect ratio of 10 to avoid structural complication of the wing especially because the structure of the M-wing is more complex than that of a straight wing. In addition, a higher aspect ratio leads to a larger span which may cause airport compatibility problems. With an aspect ratio of 10, the AF-1 has a wing span of 103 feet.

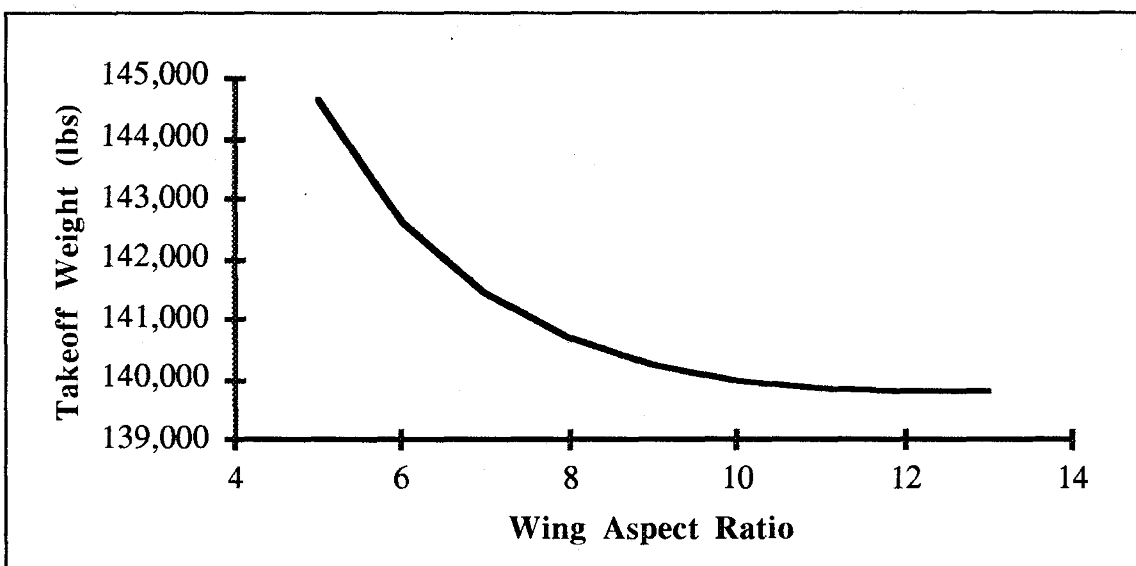


Figure 7.10 AF-1 Effect of Aspect Ratio on Takeoff Weight

7.1.4.3 Taper Ratio

The M-wing of the AF-1 has a taper ratio of 0.3. According to Reference 2, for an aspect ratio of 10, this is the taper ratio that provides the most elliptical lift distribution for a straight tapered wing and hence produces the lowest amount of induced drag.

7.1.4.4 Sweep Angle

The wing sweep angle was directly determined by the airfoil drag divergence Mach number and the desired cruise Mach number. It is necessary that the wing be swept enough to stay out of the drag rise at cruise conditions. Using C_p data for the airfoil chosen from Reference 8, a method outlined in Reference 3 was used to find the drag divergence Mach number at the cruise incidence angle. Figure 7.11 shows that the critical Mach number is approximately 0.70. Using historical data as a guide, the AF-1 designers estimated from this the drag divergence Mach number to approximately 0.72. Taking flow acceleration due to the fuselage into account, the required sweep angle is 27 degrees at a cruise Mach number of 0.8.

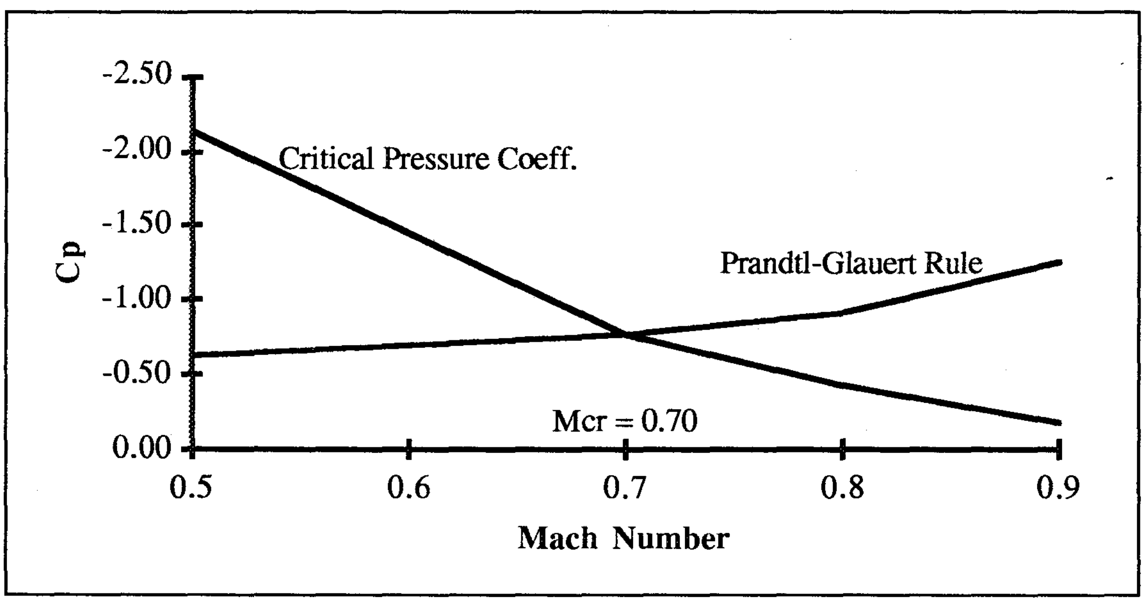


Figure 7.11 AF-1 Wing Section Critical Mach Number

7.1.4.5 Dihedral Angle

The Aluminum Falcon's dihedral angle was originally chosen by examining other aircraft in its class. Dihedral angles generally range from 2 to 6 degrees. A large dihedral angle is generally undesirable due to its unfavorable Dutch roll characteristics which must be compensated by an oversized vertical stabilizer. Because designing a small empennage was a priority to the designers of the AF-1, as small as possible dihedral was pursued. However, as the design phase continued, it was found that the minimum allowable dihedral angle was dictated by engine ground clearance rather than stability and control characteristics. The AF-1, therefore, has a dihedral angle of 3 degrees.

7.1.4.6 Wing Twist

The optimum amount of twist in a configuration such as the M-wing most easily be obtained through wind tunnel testing procedures. The designers of the AF-1 have chosen to optimize washout to obtain the most favorable lift distribution during cruise rather than for stall characteristics, because wing tip stall of the M-wing is not as much of a concern as it is for a standard aft swept wing. However, a potential flow analysis of the M-wing compared to a standard aft swept wing showed that the lift distribution for the M-wing was essentially similar outboard of the pylon. With the inboard section of the wing operating at a slightly higher C_l value and since it is not required to stall first, washout should be able to be reduced. Preliminary studies set the AF-1 with a washout angle of 1 degree.

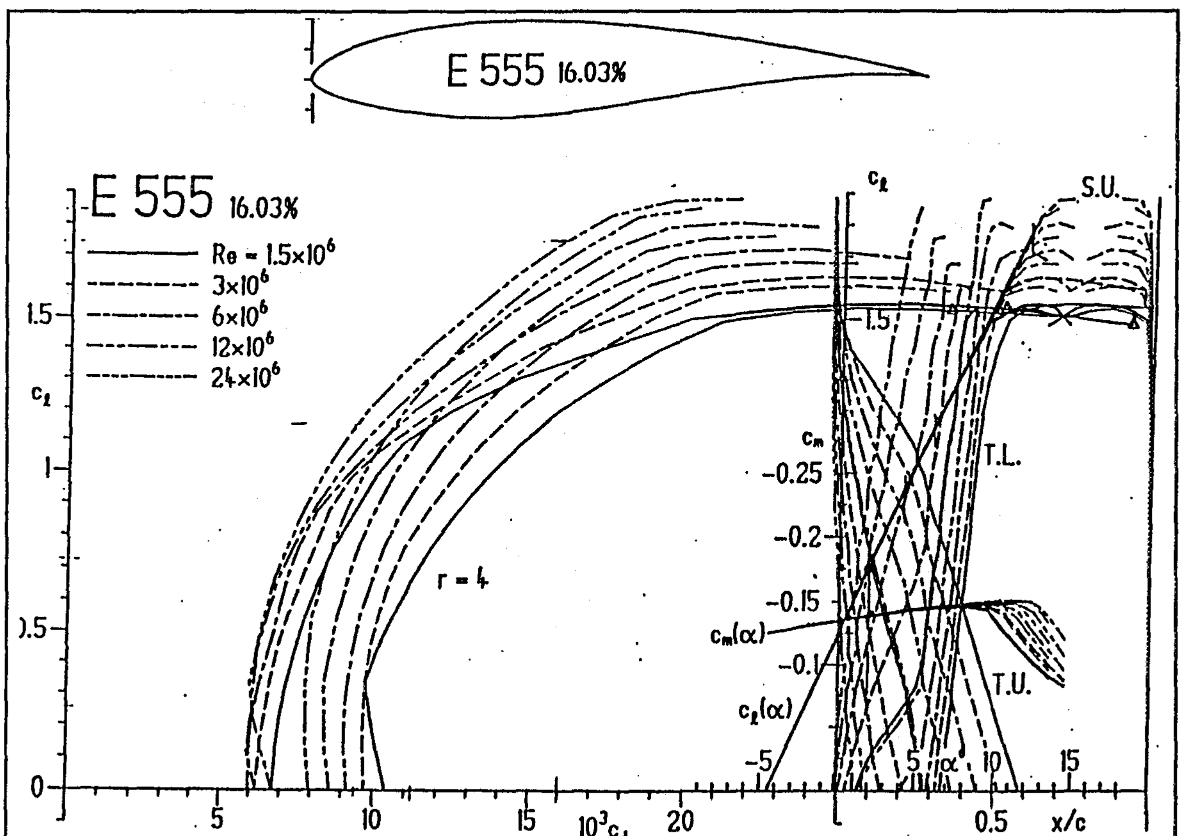
7.2 Airfoil Selection

With today's commercial aircraft flying at high subsonic Mach numbers, it is important that airfoils are capable of sustaining minimal drag with minimal wing sweep under these conditions. For this reason, the designers of the AF-1 first turned to supercritical technology when selecting an airfoil. However, supercritical airfoils have low lift capabilities at low speed due to early stall. Because a high maximum lift coefficient is needed to meet the landing field requirement, it was crucial to find an airfoil with favorable lift characteristics under low speed conditions. So other families of airfoils were researched and compared to find the optimum trade between high speed drag divergence Mach number and low speed lift capability. Table 7.1 contains a comparison among the three airfoils most seriously considered for use on the Aluminum Falcon.

Table 7.1 Airfoil Comparison

	NACA 65-415	NASA SC(2)-0714	E555 (16% Thick)
C_{lmax}	1.6	1.15	1.83
C_{Lmax}	1.38	0.88	1.54
Stall Angle	16 degrees	5 degrees	14 degrees
Mdd	0.71	0.77	0.72
Cruise C_D	~0.011	~0.012	~0.015
Cm@ac	-0.075	-0.175	-0.13

The E555 airfoil is an experimental airfoil that was found in Reference 8. This airfoil was chosen for the AF-1 because maximum lift coefficient was the most important criterion. The drag divergence Mach number is lower than desired; however the reduced torque characteristics of the M-wing make wing sweep angle a less crucial design consideration. Figure 7.12 shows the E555 airfoil shape as well as its lift, drag, and moment characteristics.



Source: Reference 8

Figure 7.12 Airfoil E555 Shape and Aerodynamic Characteristics

7.3 High Lift Devices

Obtaining the flight performance and weight requirements for the aircraft necessitated a small wing and consequently a high average wing loading. In turn, a sophisticated high lift system was inevitable to achieve the landing field performance dictated in the RFP. The trailing edge is fitted with a standard double-slotted Fowler flap along the entire wing with the leading edge employing a variable-camber Kruger (VCK) flap. The VCK was chosen for many reasons, the most important being the large increase in maximum lift coefficient that it offers compared to standard Kruger flaps or slats. Also, having no gaps on the upper surface of the wing will improve cruise drag slightly by eliminating leakage. The installed area of the Kruger is substantially less than the retractable slat and generates fewer complications around the wing joint. As was mentioned above, the Kruger is used full span, optimizing lift and stall performance at all sections of the wing. Figure 7.13 shows the mechanical structure of the VCK.

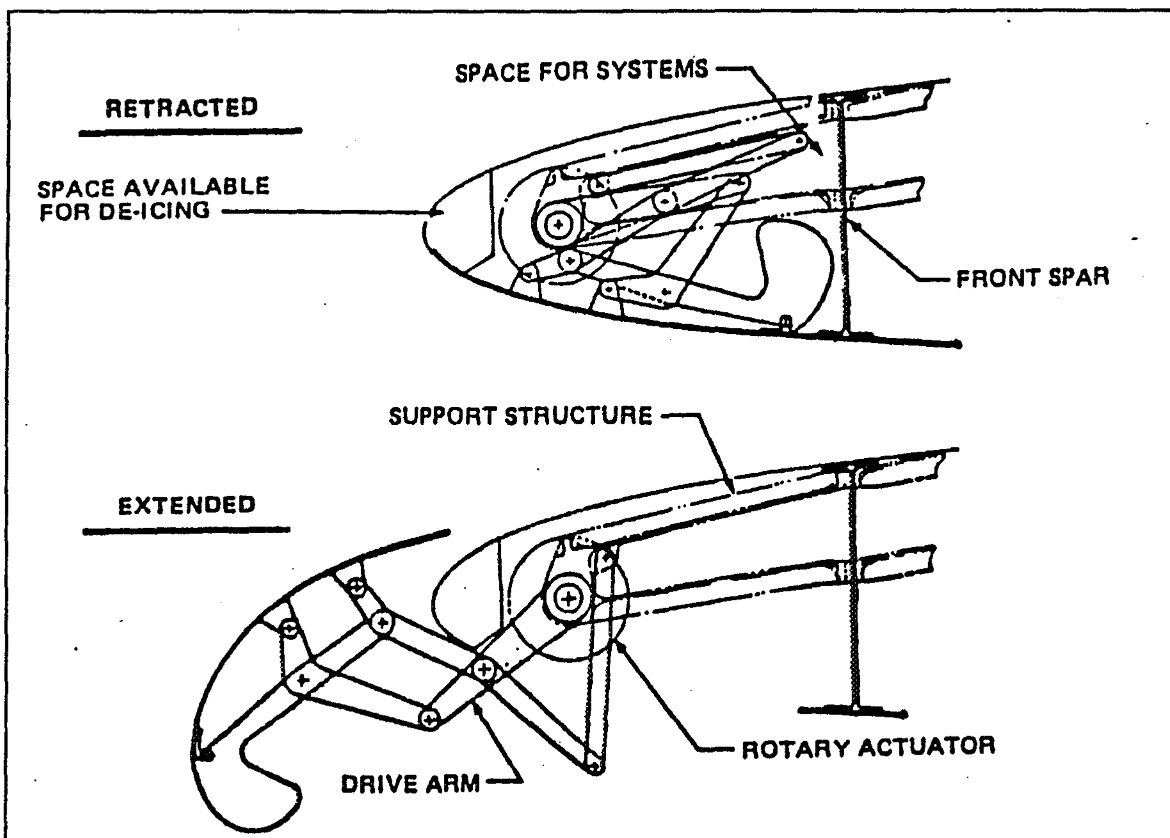


Figure 7.13 Variable Camber Kruger Flap

Because the AF-1 has a sufficient thrust-to-weight ratio at takeoff, the required maximum lift coefficient at takeoff can be obtained without the deployment of the leading edge devices. The trailing edge flaps will be extended to 15 degrees with all surfaces sealed to prevent excess drag. In the landing configuration, the trailing edge flaps will be fully extended to 30 degrees with the leading edge flaps also deployed.

7.4 Fuselage Geometry

The fuselage of the AF-1 was designed using other aircraft as a guide. One aspect is that the cross-section is circular with a diameter of 154 inches. This geometry is structurally ideal for cabin pressurization as well as aerodynamically optimum for minimum surface area. This cross-section was accomplished without sacrificing comfort for the passenger sitting next to the cabin wall while still providing sufficient cargo space.

The upsweep on the underside of the tail cone is 13.5 degrees, which will not induce flow separation but still allows adequate angle for rotation. The top of the tail cone has no downsweep to maximize headroom in the aft galley. There is a small base at the tip of the tail cone with a diameter of approximately 8 inches. According to industry professionals, this is the maximum base area that can be maintained without encountering a significant amount of base drag. Keeping this base reduces the surface area of the tail cone slightly and provides a location for the APU exhaust duct.

7.5 Empennage Geometry

7.5.1 Horizontal Tail

The design philosophy incorporated by Non-Solo was, "Make it as small as possible", since suface area is a major contributor to parasite drag. Therefore, the Aluminum Falcon's horizontal tail was sized to maintain the desired cruise static margin of -5% (see section 8.1) and it is, therefore, slightly undersized for rotation capability at takeoff. To obtain the necessary down force on the tail required to rotate, the horizontal stabilizer is equipped with a slotted elevator rather than a plain flap elevator.

Table 7.2 contains geometric data for the Aluminum Falcon's horizontal tail. All characteristics are similar to other aircraft in the same class. The sweep angle and dihedral angle were driven by characteristics of the wing. The sweep was chosen such that the drag divergence Mach number of the tail is 0.05 above that of the wing.

Table 7.2 AF-1 Horizontal Tail Geometry

Planform Area	210 sq. ft.
Aspect Ratio	4.5
Span	31 ft.
Taper Ratio	0.4
Thickness Ratio	0.12
Quarter Chord Sweep	33 deg
Dihedral Angle	6 deg

7.5.2 Vertical Tail

The size of the vertical tail was driven by the one engine inoperative condition rather than by lateral stability considerations. Table 7.3 summarizes the dimensions of the Aluminum Falcon's vertical tail.

Table 7.3 AF-1 Vertical Tail Geometry

Planform Area	200 sq. ft.
Aspect Ratio	1.6
Span	17.9 ft.
Taper Ratio	0.4
Thickness Ratio	0.12
Quarter Chord Sweep	33 deg.

7.6 Drag Analysis

In this preliminary design phase, the Non-Solo had the following philosophy when approaching a component drag breakdown: Concentrate on the biggest drag contributors and those that are unique to the AF-1 design. In this manner, research and development cost and effort are focused where they will deliver the greatest return on investment.

7.6.1 Parasite Drag

Methods outlined in Reference 14 were used to estimate the Aluminum Falcon's parasite drag coefficient. Parasite drag coefficients for the major components (wing, fuselage, and nacelles) were each calculated and then added to produce an approximate total parasite drag coefficient of 0.0175. Figure 7.15 shows how much each component specifically contributes to the parasite drag.

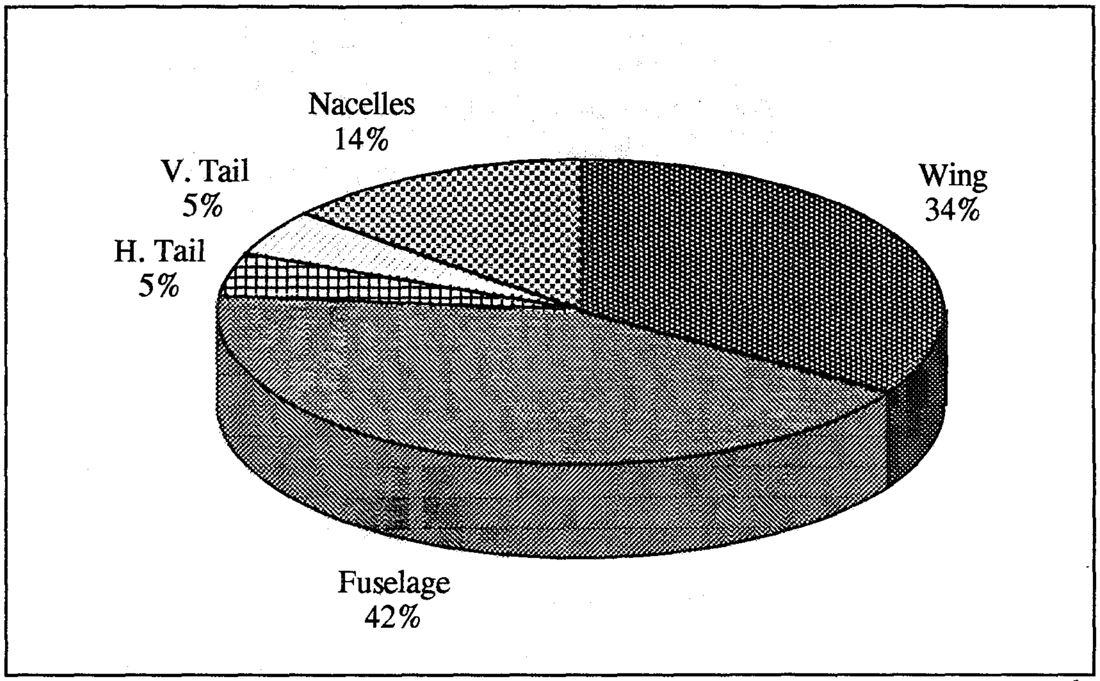


Figure 7.14 AF-1 Parasite Drag Coefficient Breakdown

7.6.2 Cruise Drag

Figure 7.15 contains a percentage breakdown of the cruise drag coefficient which was calculated to be approximately 0.029. As shown, the parasite drag is the biggest contributor to total drag at cruise conditions.

Wave drag was a serious concern to the designers of the AF-1 because it was expected that the wave drag of the M-wing would be significantly higher than that of a standard aft swept wing. Three-dimensional Mach effects emanating from the unswept region at the wing joint could create serious complications in the flow patterns around the wing and increase drag significantly. M-wing drag data was obtained from Reference 11 and is shown in Figure 7.16. This graph shows a drag comparison between an M-wing and an aft swept wing with all other geometric parameters being identical. In order to

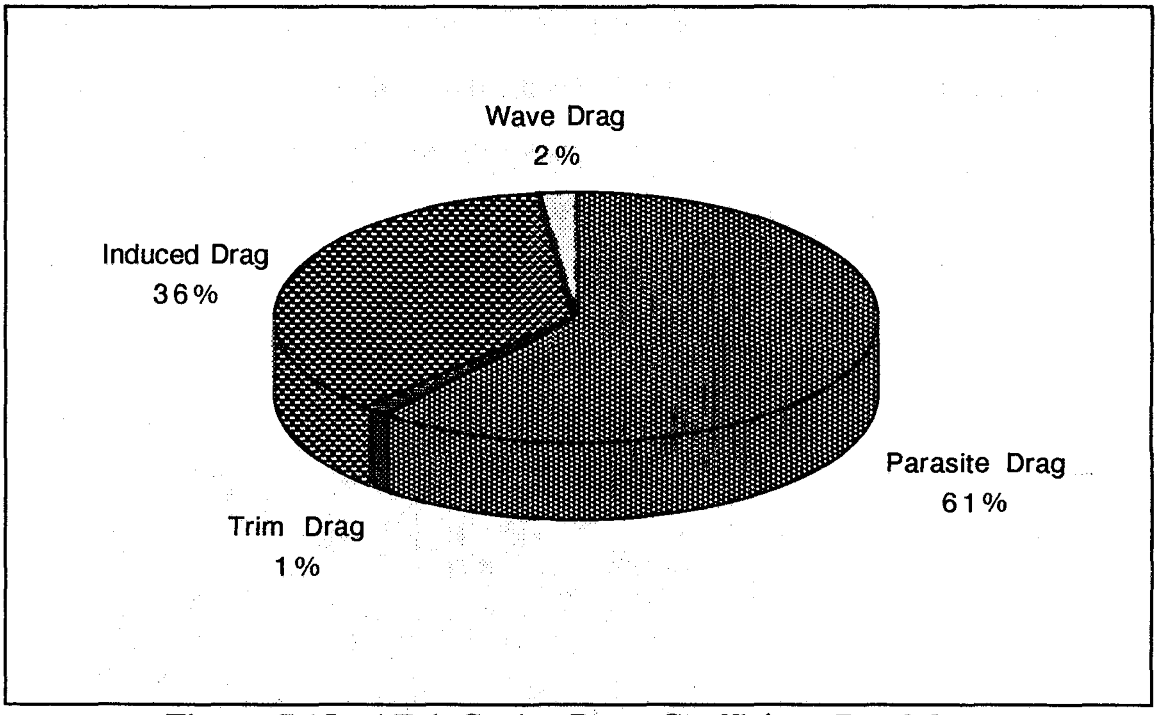


Figure 7.15 AF-1 Cruise Drag Coefficient Breakdown

predict the wave drag of the AF-1, an initial prediction for an aft swept wing was made from Reference 17 and then a percentage increase obtained from Figure 7.16 was applied. As indicated by Figure 7.16, the wave drag is approximately 2 percent of the total cruise drag coefficient. The trim drag of the AF-1 was estimated using methods outlined in Reference 22 and is approximately 1 percent of the total cruise drag coefficient. Wave drag was not as critical as Non-Solo designers had feared.

Local tailoring of the wing joint / pylon area will be accomplished after wind tunnel studies can be performed. Integrating the pylon to reduce the local thickness ratio at the unswept joint could be accomplished therefore lowering the negative wave drag effects. Considering the recent accomplishments in pylon design which have resulted in the pylons moving closer to the leading edge of the wing, Non-Solo believes that it will not be difficult to incorporate this trend with the M-wing.

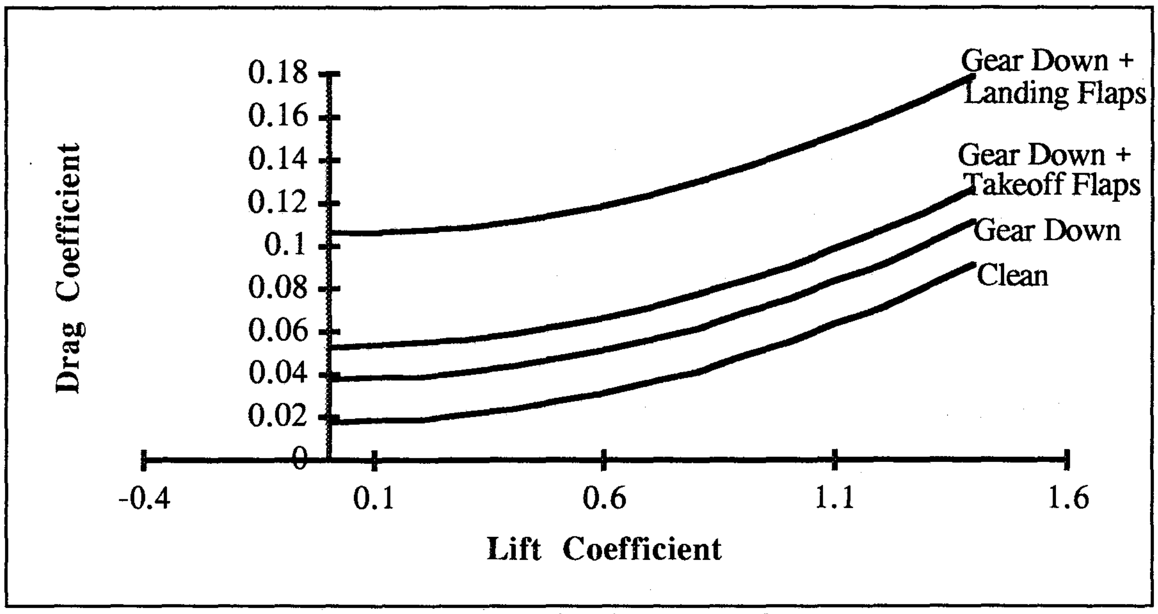


Figure 7.17 AF-1 Drag Polars

7.7 Drag Reduction Strategy

Low drag is key to lowering fuel burn and therefore imperative to lowering the direct operating cost of the aircraft. Fuel costs are already a major contributor to operating cost and will only get worse as prices increase. When approaching the task of drag reduction Non-Solo targeted the biggest contributor to total cruise drag which is parasite drag. Non-Solo took a passive approach to reducing the parasite drag, strictly abiding by the philosophy of "the smaller, the better." Lower surface area on the aircraft will reduce drag proportionately. Static instability yielded a small empennage, opting for a single aisle rather than double aisle interior configuration saved 9% in parasite drag, and using double bogey main landing gear rather than single made it possible to stow the landing gear without the use of a bubble fairing, saving another 5% in parasite drag. Induced drag was minimized by choosing the proper aspect and taper ratios for the wing and proper wing twist tailoring will provide the proper elliptical lift distribution. Compressibility drag may be a concern at the wing joint, but engine pylon integration can be used to ameliorate this effect and the rest of the wing will actually have better near-Mach performance than a standard wing. Overall, significant reductions in major drag areas will result in a total drag reduction and commensurate reductions in operating cost.

8. STABILITY AND CONTROL

The AF-1 uses a conventional forward main wing with an aft tail. This simplifies the process of designing control surfaces and analyzing the stability of the aircraft. The most important stability derivatives of the AF-1 are summarized in Table 8.1 below, as evaluated using Advanced Aircraft Analysis (AAA). Due to the M-wing, certain derivatives are significantly different than those for conventional aircraft. Some calculations were based on wing sweep angle, and therefore estimations had to be made to analyze the M-wing.

Table 8.1 AF-1 Stability Derivatives

C_{L1}	0.643	C_{DdelE}	0
C_{m1}	0	C_{mdelE}	-1.135
C_{mT1}	0	C_{lB}	-0.116
C_{mu}	-0.028	C_{lp}	-0.300
C_{ma}	0.274	C_{lr}	0.257
$C_{ma\ dot}$	-1.335	C_{ldelA}	0.063
C_{mq}	-7.727	C_{ldelR}	0.007
C_{mTu}	0	C_{nB}	0.153
C_{mTa}	0	C_{np}	-0.068
C_{Lu}	0.521	C_{nr}	-0.239
C_{La}	5.493	C_{ndelA}	-0.005
$C_{La\ dot}$	0.283	C_{ndelR}	-0.054
C_{Lq}	2.904	C_{yB}	-0.474
C_{Da}	0.219	C_{yp}	-0.068
C_{Du}	0.016	C_{yr}	0.526
C_{Txu}	0	C_{ydelA}	0
C_{LdelE}	0.240	C_{ydelR}	0.120

The control surfaces include two split ailerons and 12 spoilers for lateral control, two elevators for longitudinal control, and a rudder for directional control. In high speed flight, the outboard section of the split ailerons becomes locked in place with the inboard sections being used for control. This eliminates the possibility of aileron roll reversal, a phenomenon caused by elasticity in the wing and adverse yaw that usually occurs in high aspect ratio wings. Inboard spoilers are added for additional lateral control power and also to dump lift on landing. The AF-1 has successfully used relatively small control surfaces yielding an additional drag reduction and in turn reducing the overall weight of the aircraft.

8.1 Longitudinal Stability and Static Margin Selection

Longitudinal placement of the main wing on the AF-1 was optimized for landing gear placement and also for the desired static margin of -5%. Static instability causes the tail to generate positive lift during cruise rather than the negative lift generated when the aircraft is stable. Consequently, the main wing no longer needs to overcome this adverse lift and induced drag is decreased. The AF-1's horizontal tail was sized to maintain this desired cruise static margin, and is slightly undersized for rotation capability at takeoff. This was desirable in order to reduce the weight as well as the wetted area of the tail, which again reduces the total drag of the aircraft. The resulting horizontal tail area is 210 square feet. To gain rotation power for takeoff, slotted elevators are utilized (see Section 7.5.1).

Figure 8.1 shows the longitudinal X-Plot for the AF-1. The graph shows that as the horizontal tail area increases, the CG of the aircraft travels aft more rapidly than does the AC. Fixing the static margin at -5%, the designers of the AF-1 had two degrees of freedom: wing placement and tail size. Landing gear placement was an important consideration in determining how far forward on the aircraft the wing could be placed. Due to the nature of the M-wing, its aerodynamic center is further forward than that of a standard aft swept wing, therefore the wing did not have to be placed so far forward to create static tip over problems. Because of this forward limit on wing placement dictated by the landing gear, using a standard aft-swept wing would have made it difficult to obtain the desired static margin without an unacceptably small tail. As indicated by Figure 8.1, the aircraft would need a horizontal tail area of 680 square feet to be neutrally stable.

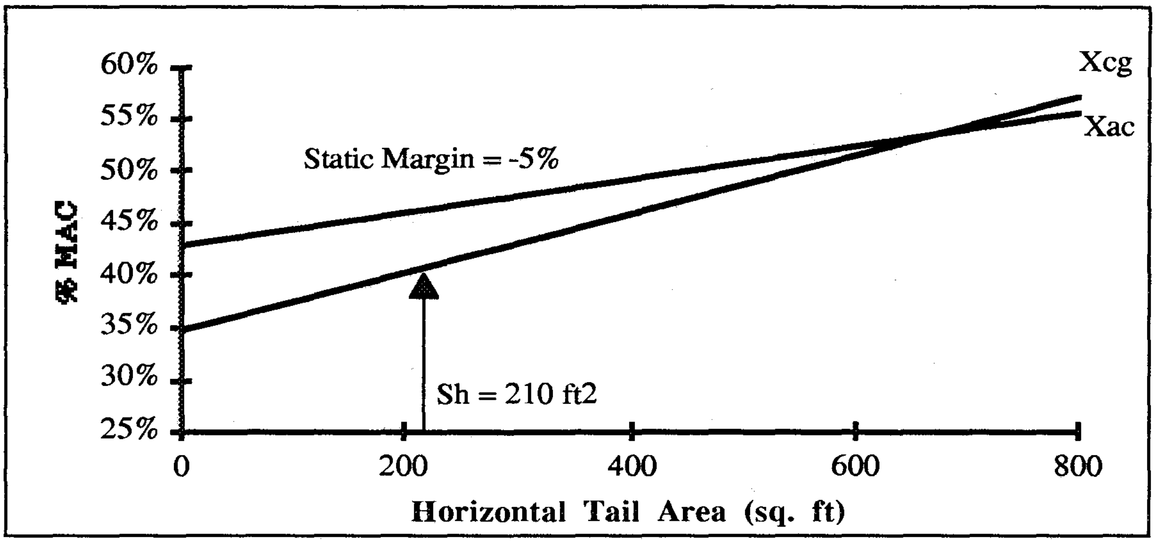


Figure 8.1 AF-1 Longitudinal X-Plot

Due to the stability margin of the AF-1 being -5%, the stability of the aircraft must be augmented. This is corrected by using a fly-by-wire system which connects the control surfaces to the pilot inputs (Section 14.3). Preliminary dynamic stability calculations show with an open loop, unaugmented system, the AF-1 is divergent along the pitch axis. By closing the loop, however, the system responds properly with opposite elevator input and quickly dampens any unwanted divergence or oscillation. This flight control system will also allow for gust and maneuver load alleviation. In operation, certain control surfaces are deflected in response to gusts or maneuvers to shift or dampen wing loading. This reduces the stress on the airplane structures as well as providing a smoother ride for the passengers.

8.2 Lateral Stability and Vertical Tail Sizing

The lateral control system consists of a vertical tail with a standard double hinge-line rudder. The size of the vertical tail was driven by the one engine inoperative (OEI) condition rather than by lateral stability consideration. For the one engine inoperative condition, directional control must be maintained while correcting for the yawing moment due to asymmetrical thrust. To counteract this yawing moment with OEI, the rudder must be deflected to an angle of approximately 24 degrees. As seen in Figure 8.2, the vertical tail area is 200 square feet which gives adequate lateral stability (positive $C_{n\beta}$). Compared to other aircraft in the class, the area of the AF-1 tail is slightly smaller, again contributing to the reduction in parasite drag and reduced direct operation cost.

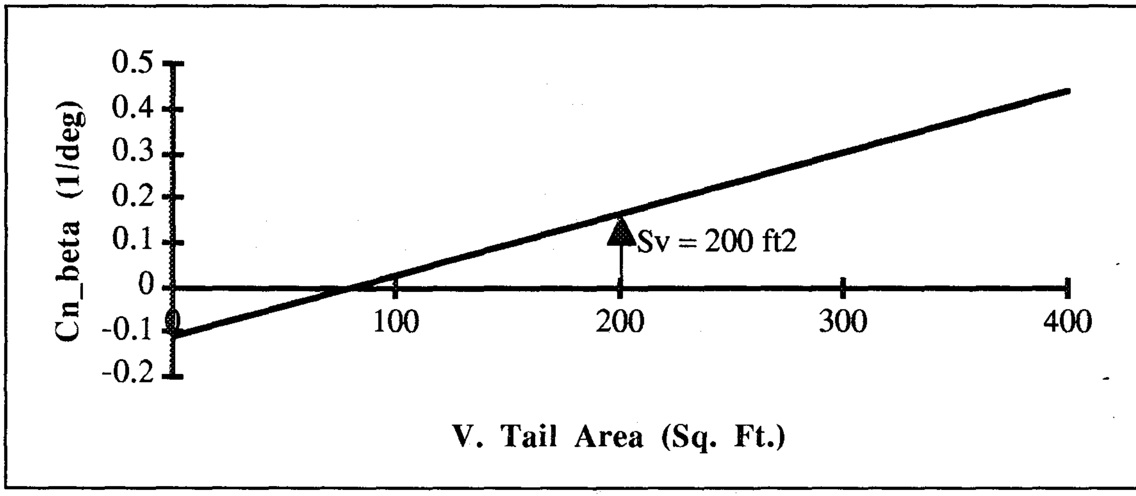


Figure 8.4 AF-1 Directional X-Plot

8.3 Trim Diagram

The driving forces for the trim diagram are the stabilizer incidence and elevator deflection. The control surface deflections effects on the aircraft lift versus angle of attack curve can be seen in Figure 8.3. The aircraft must be within the aft and forward pitching moment coefficient, known as the trim triangle OBA. The AF-1 meets this in all flight conditions.

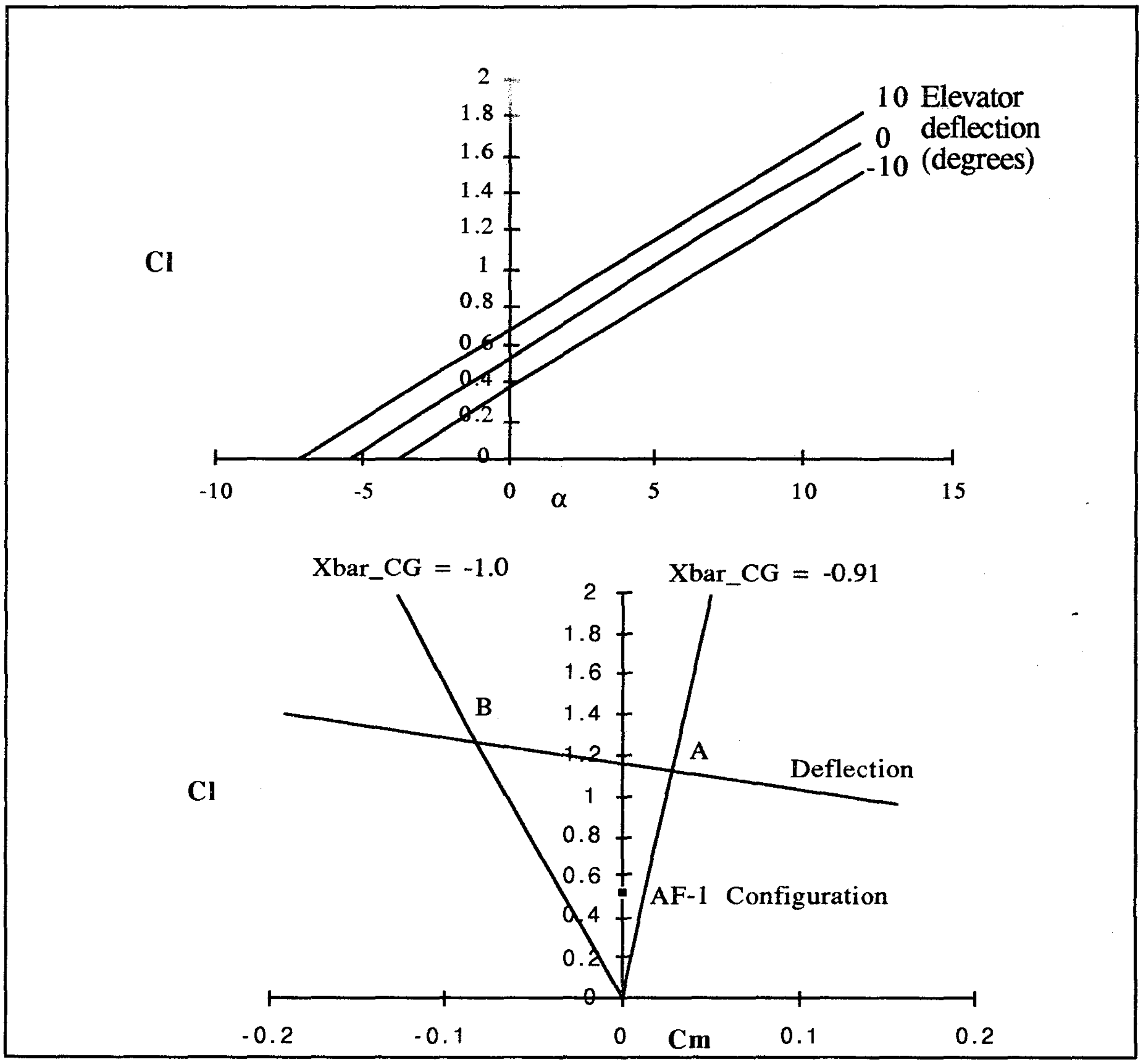


Figure 8.5 AF-1 Trim Diagram

9. PROPULSION

9.1 Engine Selection

The initial concern for engine selection was the number to install on the AF-1. Many factors, including fuel economy, maintenance cost, and weight, promote fewer engines. One transport aircraft in this size range, the BAE-146, uses four engines but it is optimized for short hops into small fields with noise restrictions and to have good OEI performance. These traits are unnecessary for this RFP and therefore reduce the candidates to a tri-jet or a twin. Using three engines would eliminate the AF-1 from the complications of extended-twin-engine-operations-over-water (ETOPS) certification and allow better OEI performance. However, given the trend of increasing engine reliability, ETOPS certification is a minor concern, evident in Boeing's choice to use two engines on the 777. More important to the RFP is low cost, a result of the lower specific fuel consumption of two large engines versus three smaller ones and the corresponding reduction of the engine maintenance costs which are such a large percentage of direct operating cost. Finally, research showed that most manufacturers do not even produce an engine in the thrust class that would be required for this aircraft if it were equipped with three turbofans.

The two possibilities that did surface were the IAE V2500 and the CFM56 engine families. To our advantage, both families are new product lines with a variety of thrust ratings in the 22,000 to 30,000 lb range and environmental considerations to make them viable for many years into the next century. They have also been in use for many years on the MD-90 and Airbus 320/321. Hence, they are a perfect balance between advanced modern technology and proven reliability, the two traditionally opposing determinants that define a low-cost engine. The V2500 was selected as the primary engine because of its better specific fuel consumption, but the CFM56 is a close second alternative. The advantages of the V2500 engine are shown in Figure 9.1.

The noise and pollutant levels are well below international requirements that are forecast for the year 2000 and beyond. As shown above, the baseline V2500 is currently

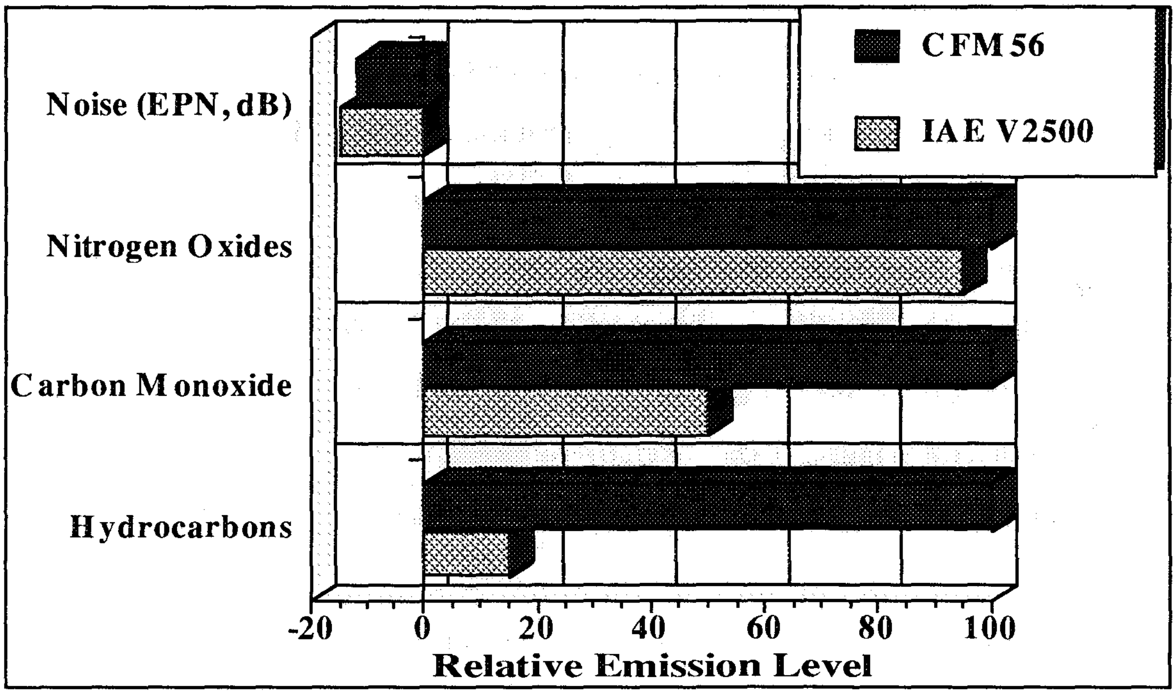


Figure 9.1 V2500 versus CFM56, Noise and Pollutant Emissions

15 decibels below Stage 3 noise regulations. Nitrogen oxide emissions are 40% below current limits and, with the installation of a new burner, are planned to drop another 60%. Overall, IAE claims that the V2500 family emits 20% of currently acceptable levels of pollutants.

The thrust ratio selected for the AF-1 is the reduced thrust model at 23,000 pounds of thrust. The major benefit in derating the baseline 25,000 lb engine is a reduction in the stress levels on the engine and a corresponding decrease in maintenance requirements. In addition, the purchase price of the engine is lower as engine price is generally determined by dollars per pound of thrust. Also, using a derated version significantly reduces engine noise at takeoff. With the noise level of the engine being proportional to the exhaust gas velocity to the eighth power, this small change in thrust level will reduce noise emissions by nearly 50%!

9.2 Engine Performance and Analysis

Information available about the V2500 was generally limited to cruise thrust conditions and sea-level static thrust conditions. Therefore, the thrust and fuel consumption data for various altitudes and flight velocities from an AIAA example high-bypass turbofan was used as a baseline and modified to approximate the V2500 using equations that were provided with the data.. The thrust rating of the AIAA engine was 25,000 lbs, so adjustment ratios were applied to pertinent data fields to normalize the values. Also, the cruise thrust specific fuel consumption was higher for the AIAA engine than the V2500; therefore, a 90% correction was multiplied to all given fuel values. This gave thrust available and fuel consumption throughout the climb phase, allowing climb performance to be calculated as well as the fuel fraction for this portion of the flight. Graphs were also produced showing engine performance versus altitude and Mach number to help determine the most efficient cruise altitude and velocity for best range. These plots are shown in Figures 9.2 through 9.4

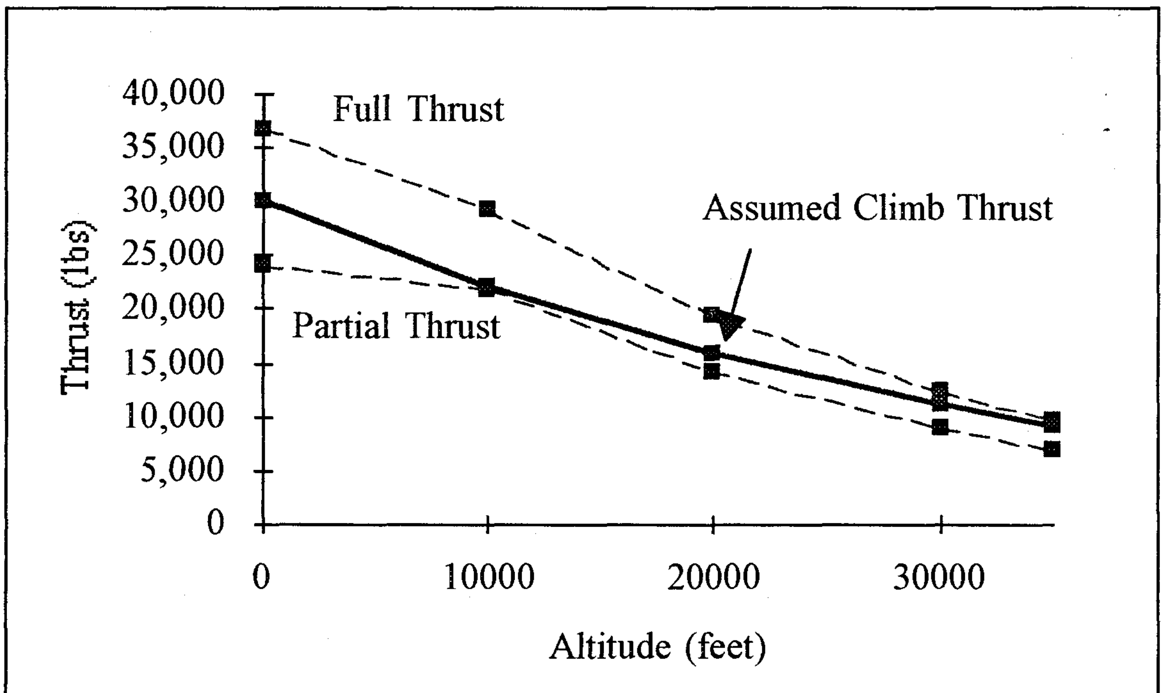


Figure 9.2 AF-1 Engine Thrust, climb phase

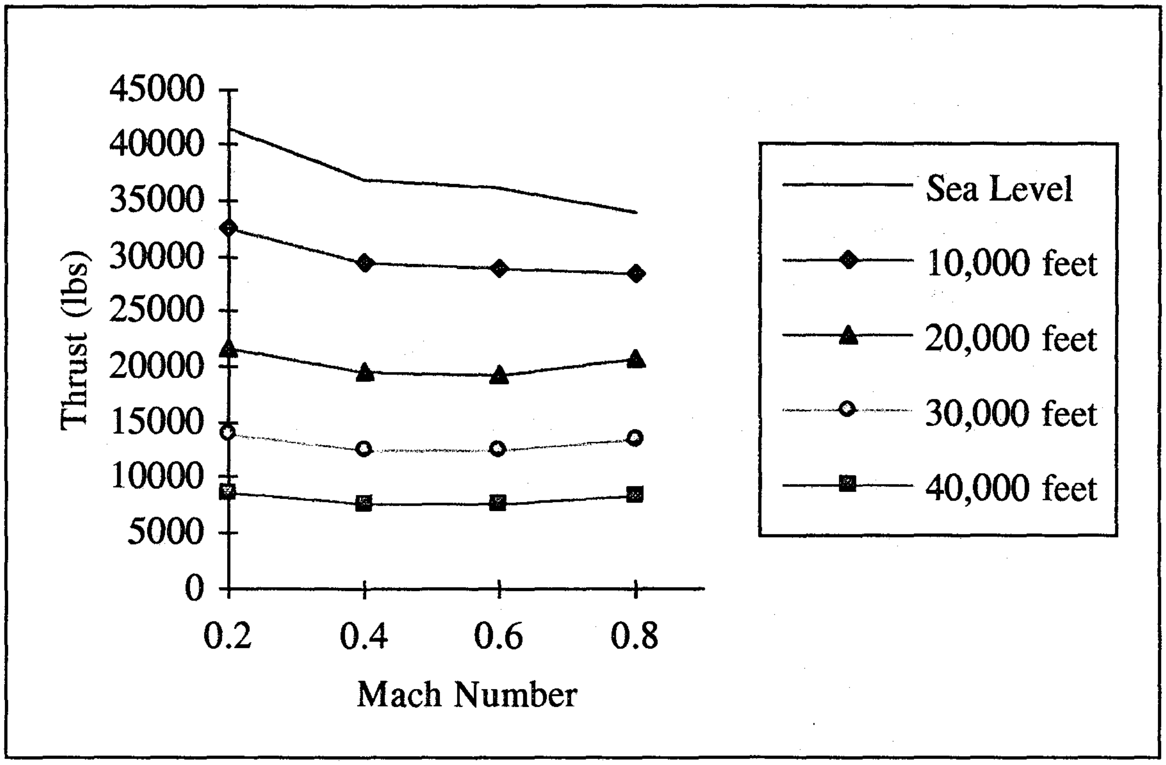


Figure 9.3 AF-1 Engine Thrust versus Altitude and Mach Number

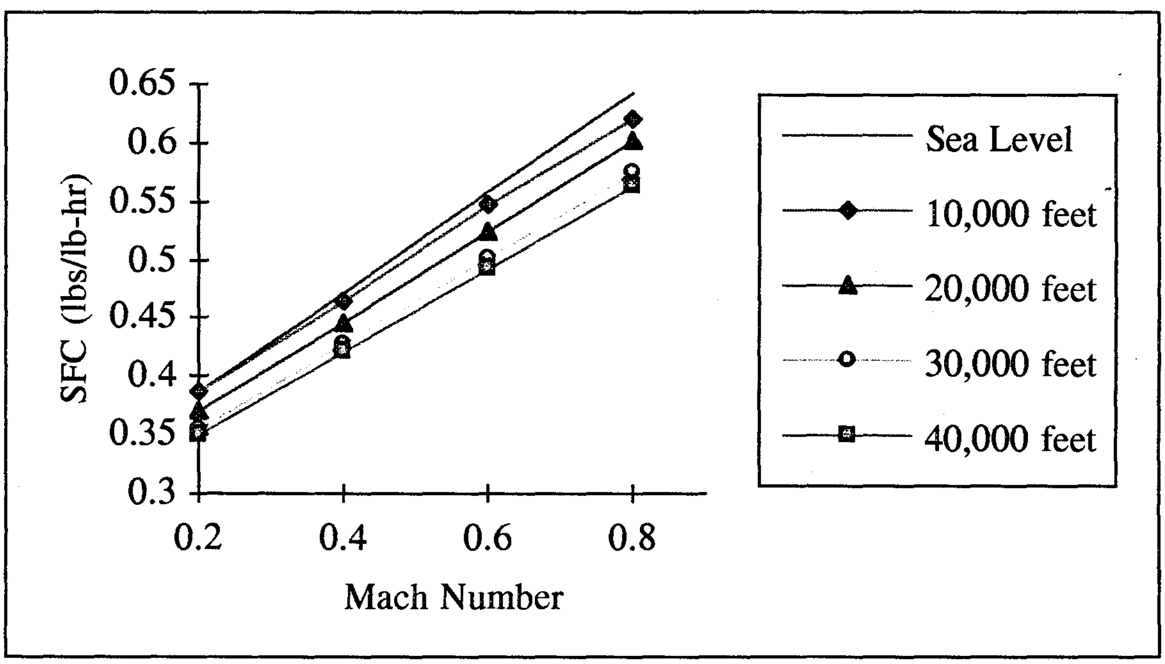


Figure 9.4 AF-1 Engine SFC versus Altitude and Mach Number

9.3 Propulsion System Integration

Another important factor in engine selection was whether to place the engines on the fuselage or under the wings. Again, current trends were followed in this selection process. Placing the engines on the fuselage produces a cleaner wing and less chance of foreign object damage, but also complicates maintenance, necessitates the implementation of a T-tail, and, most importantly, adversely affects the center of gravity. One of the major design tenets of the AF-1 was to minimize CG travel and thereby reduce trim drag during cruise. This is best accomplished by placing the CG of individual components as close together as possible. Since the CG of the wing, fuel, and passengers are all located near the center of the fuselage, it follows then to put the engines on the wing. This also places a greater percentage of the aircraft weight out on the wings, providing load relief. The structure necessary to mount the engine is located with the joint structure at the bend in the M-wing, supplying synergistic benefits as well. The air-conditioning packs, which draw significantly on engine power and bleed air, are placed as close as possible to the engines to minimize the weight and complexity of piping hot, high-pressure air through long sections of the fuselage. Non-Solo was also concerned with passenger comforts. Putting the engine on the wing instead of the fuselage decreases the noise in the cabin. By following the Non-Solo design philosophy, designers found that the obvious placement for the engines was under the wing.

10. STRUCTURES AND MATERIALS

10.1 Wing Structure

The structure involved in the M-wing posed several challenges to Non-Solo designers. First of all, the joint in the wing made structural design more complicated. Keeping this structure as simple and light as possible was achieved by careful modeling of the M-wing with finite element analysis. As a comparison, the modeling of a conventional wing under the same loading conditions was also completed.

The material used for the first cut analysis was an improved aluminum alloy, with both ribs and intermediate spars being omitted from the model (front and rear spars only). In this simplified analysis, it was first determined that the critical loading condition would occur when subjected to a gust with little fuel, which normally provides load relief. As anticipated, a stress concentration was found to exist at the leading edge of the inboard section on the M-wing as shown in the pullout, Figure 10.1. This stress concentration was absent in the conventional wing under the same loading conditions. As a result, the structure in the inboard section needs to be reinforced with thicker spars and thicker skins. Also, there is a stress concentration at the M-wing joint, which again calls for additonal structure. Fortunately, the latter case is not as critical from a weight standpoint, when a well designed rib is placed at the M-wing joint.

Peak stress levels in the M-wing are approximately twice that of a conventional wing with similar dimensions. However, this is not true of stress levels throughout the wing. An estimate of the additional structural weight required indicates an increase of approximately 10% (1000 lbs) in the weight of the wing is adequate to allieviate this problem.

10.2 Empennage Structure

Owing to the success of both Boeing and Airbus in developing and fabricating all composite empennage primary structures, Non-Solo opted to do the same (Figure 7.2) The

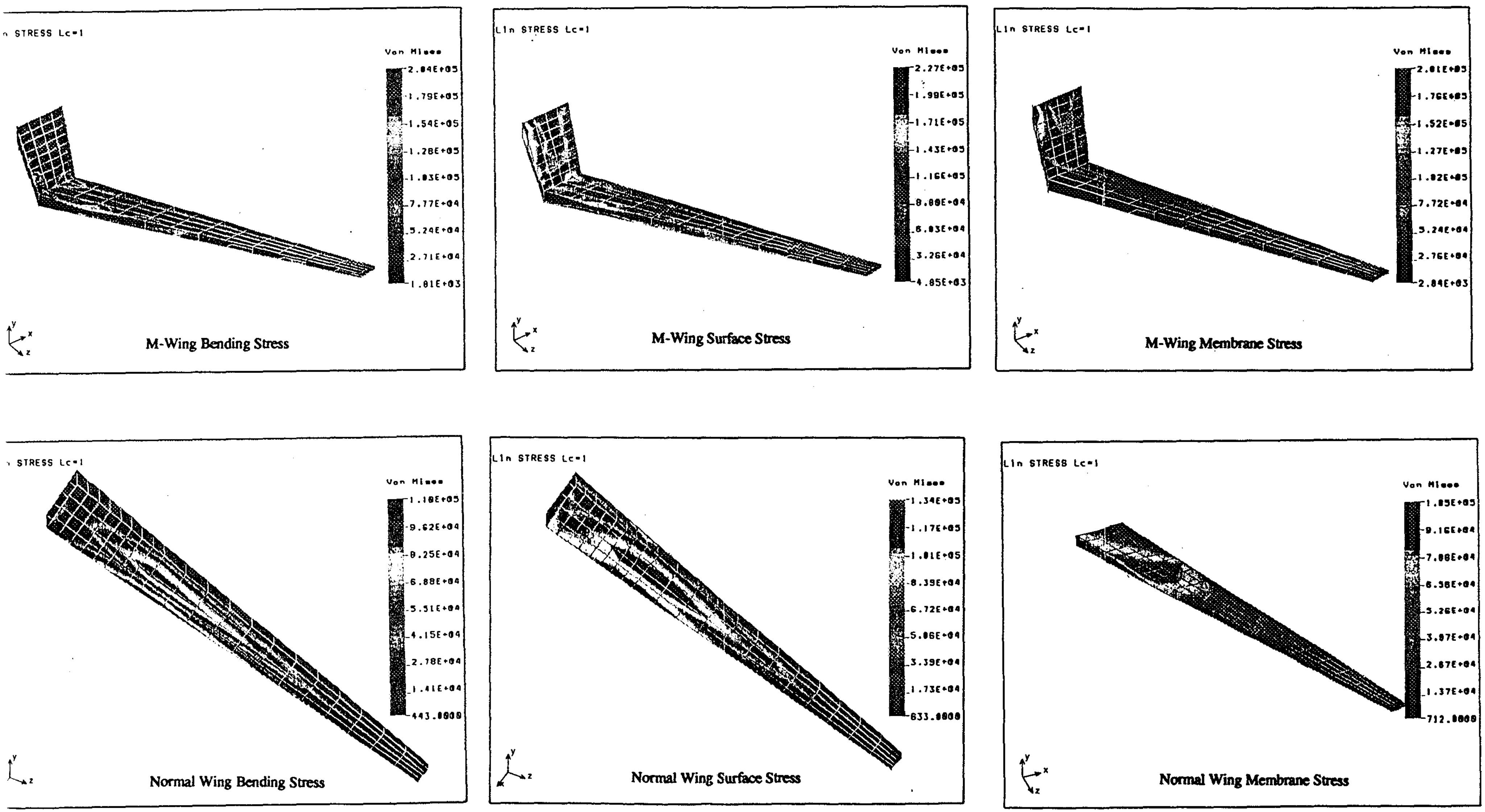


Figure 7.1 Finite Element Analysis Results

advantages in weight are considerable, and possible damage to the structure is minimal. Aircraft exposed to hail showed more extensive damage to the aluminum structure than the composite. The AF-1 has no third engine requiring maintenance near the tail. This was cited by McDonnell/Douglas as a major cost issue on the MD-11 when the elevator was damaged by incidental contact during ground service.

10.3 Fuselage Structure

The fuselage structure, as can be seen in the structural pullout Figure 10.3, is primarily constructed of aluminum alloy, with the exception of the floor panels and nose radome. The radome, as indicated in Fig 10.2, is fabricated out of a hybrid composite (kevlar / carbon), and the floor panels are constructed out of graphite fiber reinforced plastics. This material was chosen for the radome because it needs to be transparent to electromagnetic waves while retaining its durability. The floor panels were chosen mainly for reduced weight and improved corrosion resistance, which has been a major problem with aluminum panels. Floor components are also well suited for composite fabrication. There are many duplicate pieces, they have a relatively simple in design and they are well isolated from damage.

10.4 Structural Materials and Construction

The use of composites in the AF-1, including carbon fiber reinforced plastics (CFRP), graphite fiber reinforced plastics (GFRP), and hybrids is illustrated in Fig 10.2. The key to making these materials work in aircraft construction is improved design. Although composites typically offer a 10-20% decrease in weight over conventional aluminum parts, they have also been 10-15% more expensive in material cost. Since the weight savings is highly desirable and composites offer improved corrosion resistance, Non-Solo, like the other major airframers, has decided the benefits outweigh the costs.

There is a growing trend to design for manufacturing and assembly (DFMA), which emphasizes simplicity and durability. Composite structures can be more easily designed with fewer fasteners, reducing the number of parts and providing a savings in assembly and production. For example, the rudder on the A310, which is all composite, reduced the weight by 20%, the number of parts from 17,015 to 4,800 and the overall cost by 10% over the metal design, even though the materials cost rose by 13%! The use of manufacturing cells has grown extensively at both Boeing and McDonnell/Douglas, helping to speed up the process of fabrication. High speed machining of parts has also greatly improved efficiency. These advantages, along with the growing standardization of composites, will allow airlines to rely on the next generation of aircraft for reduced cost and reduced cost of operation. The key here is "on time, on weight, on performance, on cost". These goals for composite fabrication and construction are quickly becoming a reality.

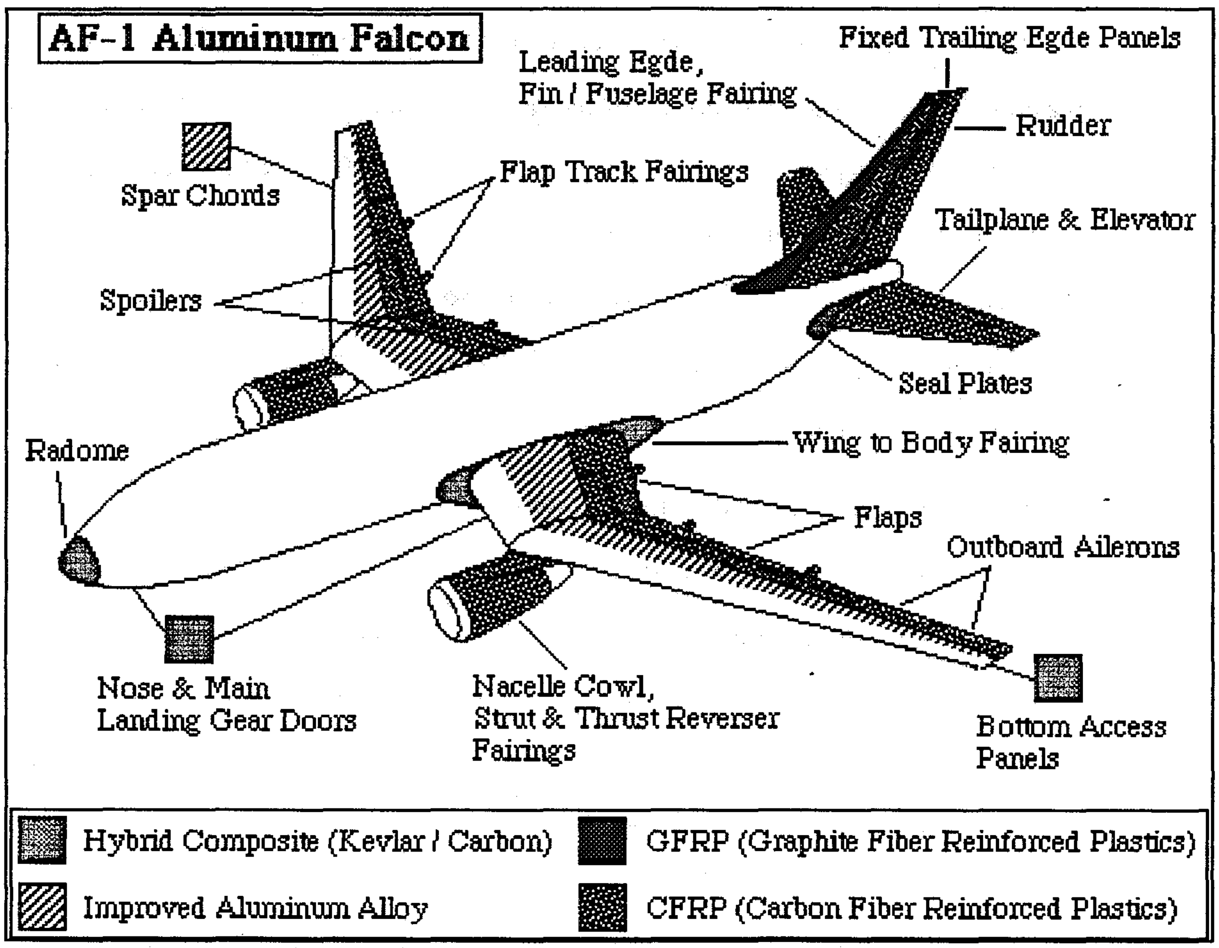


Figure 10.2 AF-1 Composite Materials

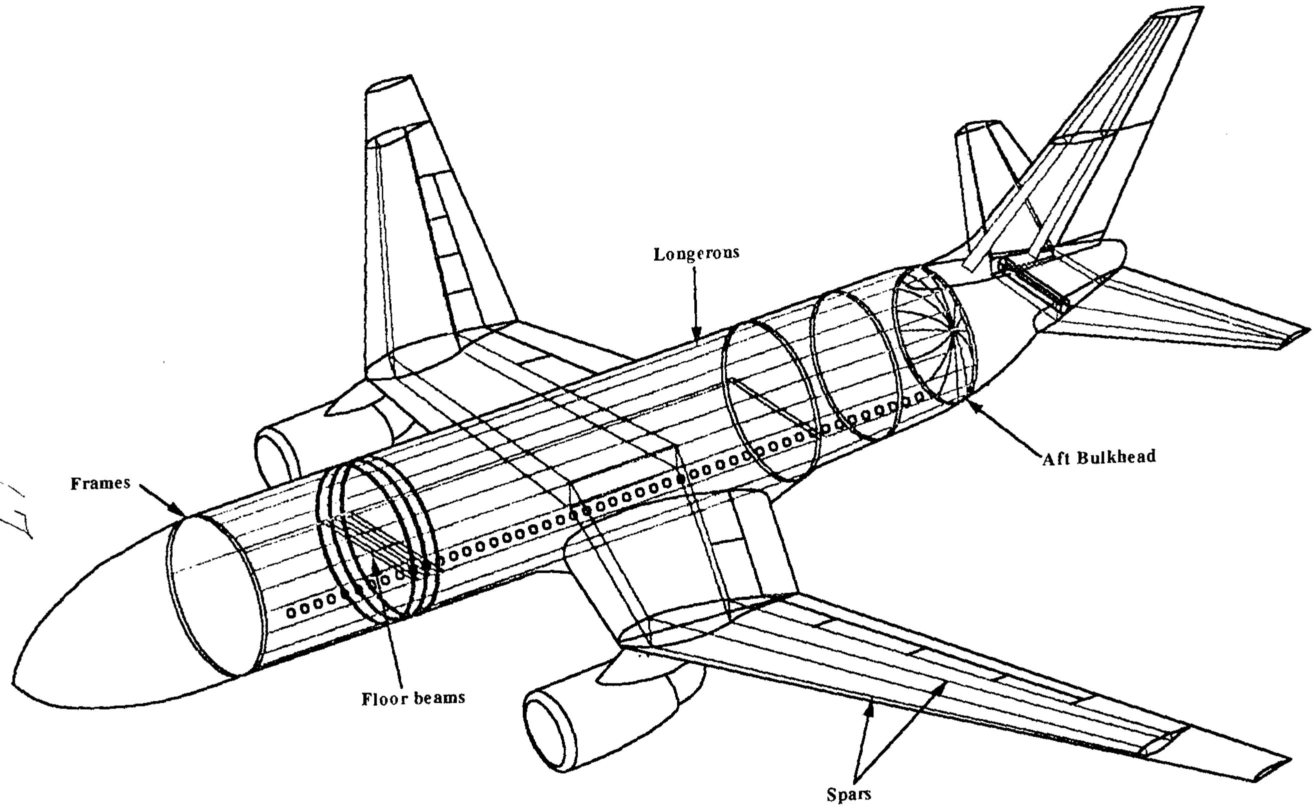


Figure 7.3 Structural Pullout

11. MANUFACTURING

11.1 Component Manufacture

Component sub-assemblies on the AF-1 will be similar to other aircraft being produced today. Long shapes with various constant profiles, such as stringers, are produced using the pultrusion process. In this process each component is fabricated continuously. Hydrodynamics machining (HDM), also called water-jet machining, is used to trim each component to the desired size and smoothness.

Honeycomb structures will be fabricated using corrugation process. The sheet passes through a pair of specially designed rollers, which produce textured sheets that are then cut into desired lengths. The material is finally sandwiched together to provide the honeycomb structure.

All composite structures will be produced using a lay-up process. Die molding and forging will be used to produce all metal component structures.

11.2 Final Assembly

After components are manufactured, they are shifted to the assembly station. Here, the main wing, horizontal tail and vertical tail are assembled. Next, the main wing and the center of the fuselage are joined together. Then they are moved to the final assembly station, where the remaining aft and forward fuselage components are added to form the complete Aluminum Falcon. Figure 11.1 illustrates the schematic of this assembly process.

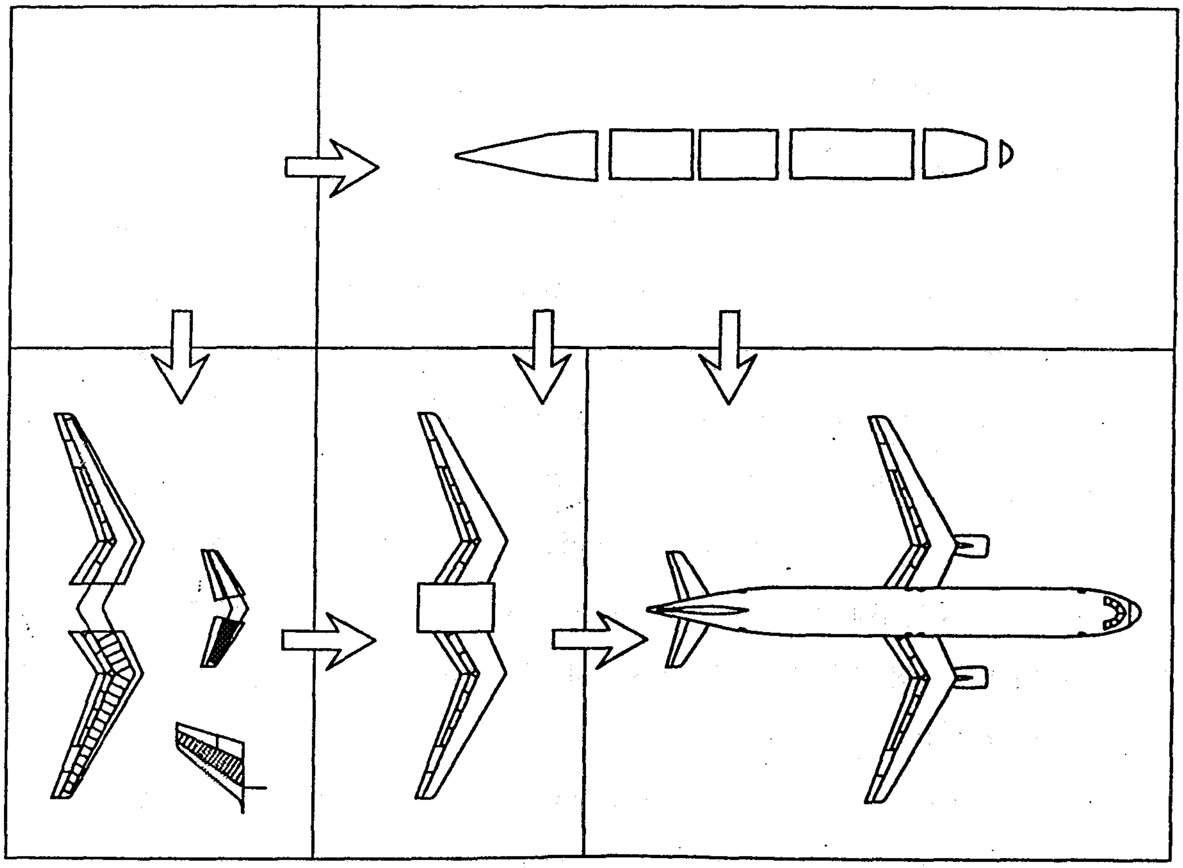


Figure 11.1 Manufacturing Assembly

12. LANDING GEAR

12.1 Gear Placement

From the historical data available, it was predicted that a tricycle gear configuration with two main gear and a nose gear would be the best choice. After researching other options, Non-Solo found no substantial reason to deviate from this common layout. Most aircraft in this weight range use two wheels on each gear. However, after performing a detailed analysis, it was discovered that an extensive fairing for the twin main gear was required to fit the wheels in the fuselage. The alternative was to use a double bogey configuration with four tires on each main strut, but the penalty was an increase in weight. This increase in weight of 1250 lbs was approximately equal to the increase in fuel weight due to the increase in drag of 5% caused by the fairing. So although there is no direct weight benefit, there is the added cost per flight of the additional fuel burned. Other factors in the comparison are listed below in Table 12.1

Table 12.1 AF-1 Twin Vs. Double Bogey Tradeoff

Type	Advantages	Disadvantages
Twin	• Reduced maintenance cost • Reduced number of parts	• Fairing required, causing additional drag fuel consumption
Double Bogey	• Extended Tire / Brake Life for operation at less than max. rated load • All ten tires same size - reduced complexity • Reduced maintenance cost (longer life increased time between service)	• Increased chance of tire failure • Reduced braking effectiveness on rear tires • Increased production cost

Considering this, a double bogey was chosen for the AF-1.

Due to the shape of the M-wing, it was necessary to retract the main gear into the fuselage at an angle and have the truck pivot slightly for final stowage. (Figures 12.1 -

12.2) This system will require a blow down system to deploy the gear in the event of hydraulic failure.

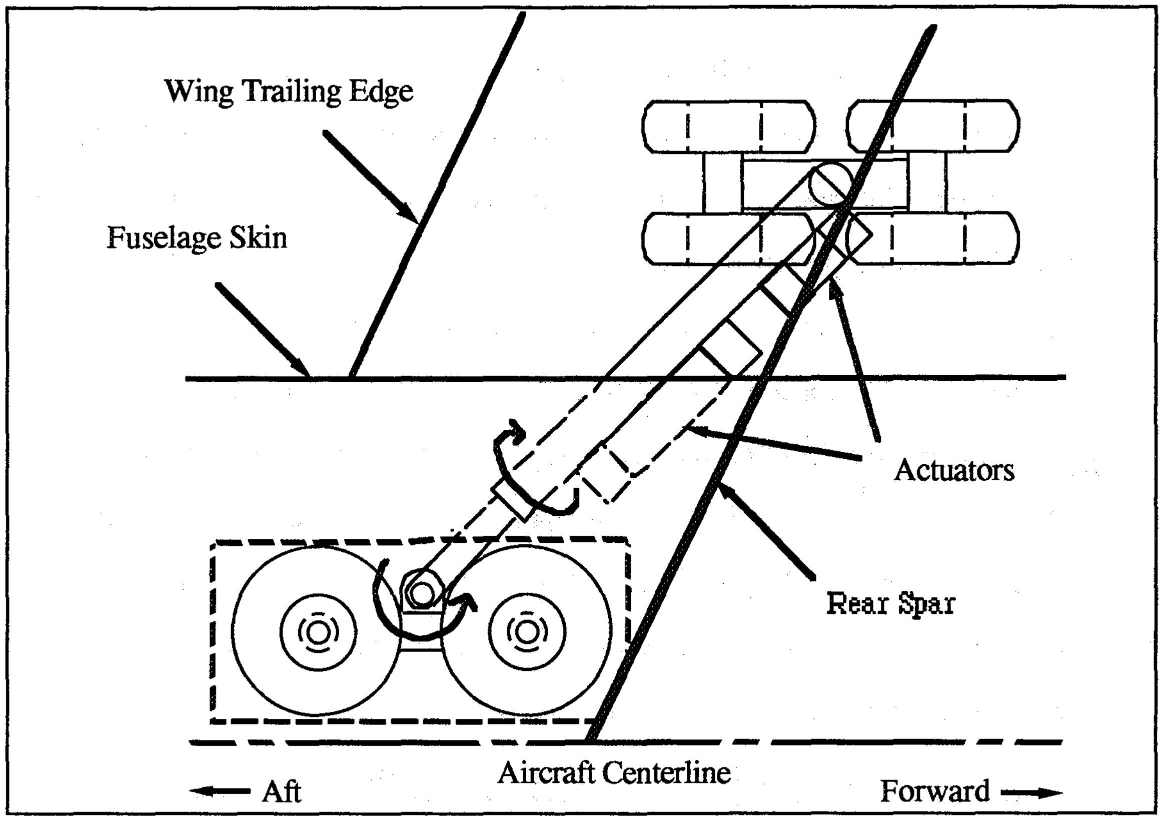


Figure 12.1 AF-1 Main Landing Gear Kinematics (Top View)

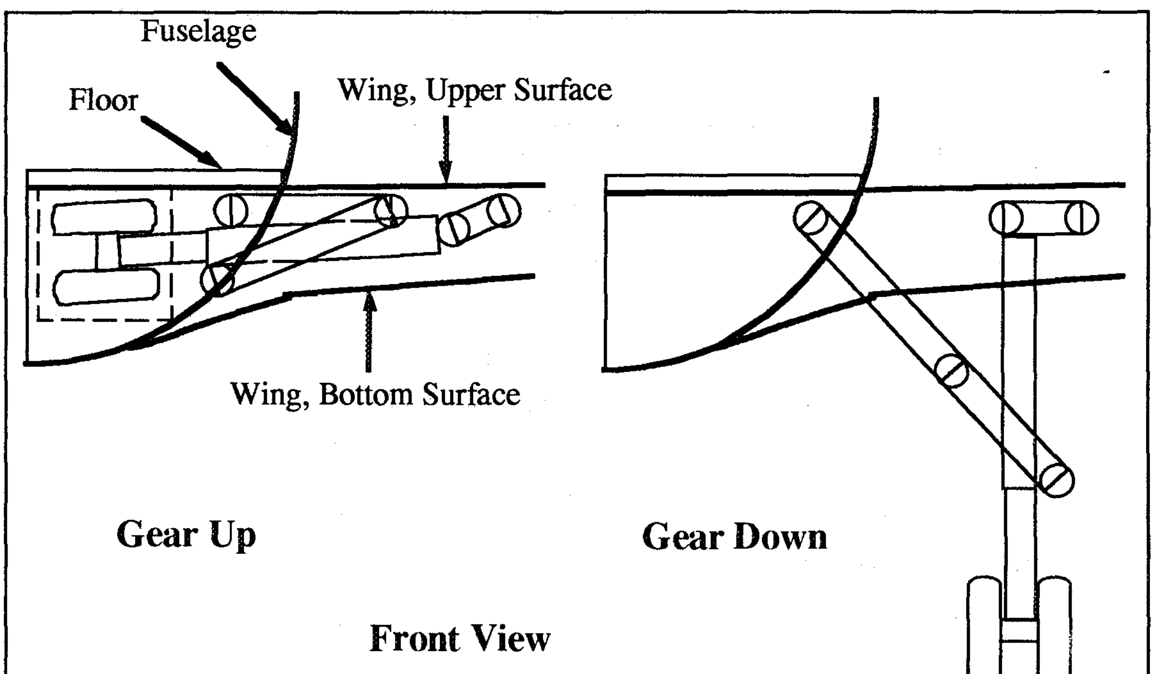


Figure 12.2 AF-1 Main Gear Retraction Mechanism (Front View)

12.2 Tire Selection

For both the main and nose landing gear, Non-Solo chose the Type VII tire in all positions. Again, this allows for a smaller parts inventory and reduced cost. A brief analysis indicated that the wheel diameters were sufficient to absorb the kinetic energy of landing. Tire specifications are shown in Table 12.2. The selection was also driven by the necessity that the load classification number not exceed 80, the maximum allowable for major airport runways.

There is also one additional advantage of using the double bogey. According to Reference 16, a tire that is operated at half its rated load increases its lifetime by a factor of six. Relating this information mathematically, the following equation was developed:

$$\% \text{ increase in life} = [(L_{max} / L)^{2.6} - 1.0] * 100.0$$

where L_{max} is the maximum rated load and L is the operating load. With this tire choice, it was possible to extend the main gear tire life by 32%, and the nose gear tire life by 128% over the average tire life span on current aircraft.

Table 12.2 AF-1 Tire Selection

	Type	Do (in)	W (in)	Load Rating (lb)	Inflation Pressure (psi)	Weight (lb)	LCN
Nose	VII	36	11	23300	143	85	45
Main	VII	36	11	23300	176	85	60

12.3 Brakes

The main gear brakes were chosen to be standard anti-skid design with discs and pads. The brake rotors are manufactured from carbon for several reasons. The weight reduction is significant, which tends to offset the added installation cost. Carbon brakes can withstand greater thermal stress and are therefore safer under extreme use, such as aborted takeoff. This larger heat capacity will also allow faster turnaround times on short stage lengths since time will not have to be spent allowing the brakes to cool before takeoff.

In general, carbon brakes are becoming the standard in the industry, so costs will continue to decrease.

12.4 Strut Design

For the main gear, which uses a metered oleo-pneumatic shock absorber with an efficiency of 0.75, the strut diameter was determined to be 9.2". Additionally, the stroke length was found to be 15.9". For the nose gear, the stroke length was found at 7.9" with a strut diameter of 6.5". Both were designed for a touchdown rate of 10 fps.

12.5 Steering Mechanism

The nose gear steering mechanism, driven by the requirement for the aircraft to perform a 180° degree turn on a 150 ft wide runway, was chosen to be similar to the Boeing 727 or 737 mechanism. This system has been proven reliable and the data was readily available. The minimum steering angle was found to be 63.5°, well within the 58 - 78° steering angle of a linear actuator system. (See section 14.2 Steering System)

12.6 Landing Gear Data Summary

A summary of all pertinent landing gear data is shown below in Table 12.3.

Table 12.3 AF-1 Landing Gear Data

Main Gear Type	Double Bogey
Nose Gear Type	Twin
Load Gear Factor	1.52
Main Gear Weight (lb)	6400
Nose Gear Weight (lb)	900
Take off Angle (12-15°)	14°
Tip over Angle (<63°)	60°
Lateral Ground Clearance Angle (>5°)	23°
% Nose Gear Load - CG aft	10%
% Nose Gear Load - CG forward	12%

13. INSIDE THE ALUMINUM FALCON

13.1 Interior Layout Philosophy

The internal layout philosophy incorporated in the design of the AF-1 is based on the best possible compromise between efficiency and comfort. It is extremely important in today's market to minimize costs while providing service and convenience that will attract passengers.

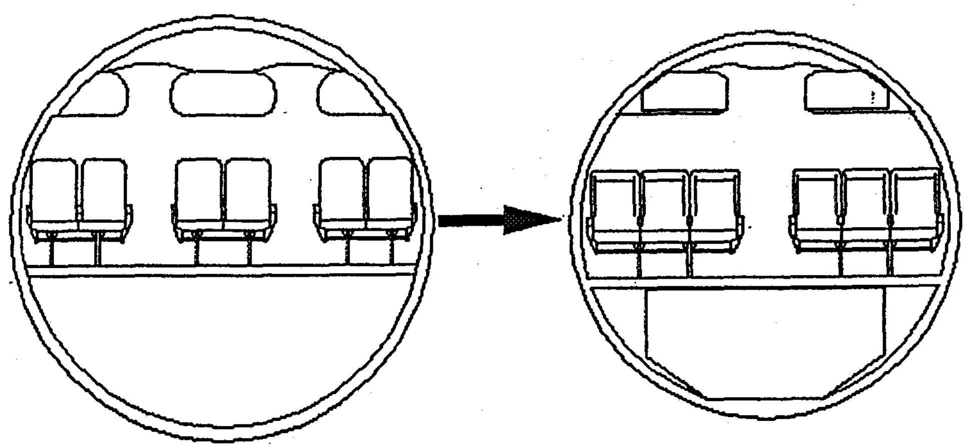
The RFP included several design requirements as stated in section 2.1. Incorporating the layout philosophy with the design requirements resulted in the following compact yet comfortable interior configuration. Non-Solo strives to provide these comforts while minimizing size, cost, and drag penalties.

13.2 Interior Configuration

The original layout of the AF-1 interior consisted of a twin aisle configuration (see Figure 4.1). It was originally thought that with a larger interior, turnaround time would be improved. Also, the passengers would be given added comfort with better aesthetics and no middle seating. However, the penalties incurred with this design included an increase of 3.5% in total cruise drag an increase of 4% in structural weight for the larger fuselage. Also, turnaround time is a negligible factor considering the time involved in flying the full 3000 nmi range. With a flight time as long as six hours, shortening the turnaround time will not allow for one more flight per day. Passenger loading time is not usually the deciding factor when the aircraft needs to be cleaned and other services performed before takeoff.

A comparison between twin and single aisle configurations proved that the single aisle is more economical. The twin aisle configuration utilizes a larger diameter which results in a 5.5% total cruise drag penalty. This means that 1100 extra lbs of fuel is needed to complete the design mission. In addition to the increase in drag, there is a weight penalty to be paid with the double aisle configuration. The increase in fuselage diameter yielded a 6% increase in its the structural weight. This combined with the increased fuel weight increased the takeoff weight of the aircraft by 2000 lb. For these reasons, Non-Solo opted for a single aisle design in the AF-1, holding to the low-cost philosophy.

The AF-1 incorporates a three class configuration consisting of 8 First Class seats, 16 Business Class seats, and 130 Tourist Class seats (total of 154 PAX). The aircraft is separated into two cabins with the forward containing First and Business Class.



Double Aisle Configuration Diameter: 14.5 ft

Single Aisle Configuration Diameter: 12.8 ft

Figure 13.1 AF-1 Cross Section Evolution

Given the long range demanded in the RFP, Non-Solo felt justified implementing three classes to meet the 154 passenger limit. Should an airline desire to maximize occupancy, the Falcon is expandable to 178 passengers with an all tourist, 32" seat pitch configuration.

There are four lavatories in the passenger cabin. Two are in the front with the First/Business Class and two are located in the rear with the Tourist Class. All of these lavatories are handicap accessible.

A small galley is located in front to service the forward cabin and the larger galley is at the rear of the aircraft to service the aft cabin. Separate galleys will improve the efficiency and service of the flight attendants, giving them a shorter distance to travel to access all passengers. Both galleys are separated from the lavatories by exits. This feature is important to Scandinavian buyers who prefer the lavatories away from the galleys.

Figure 13.2 is a pull-out showing the interior configuration.

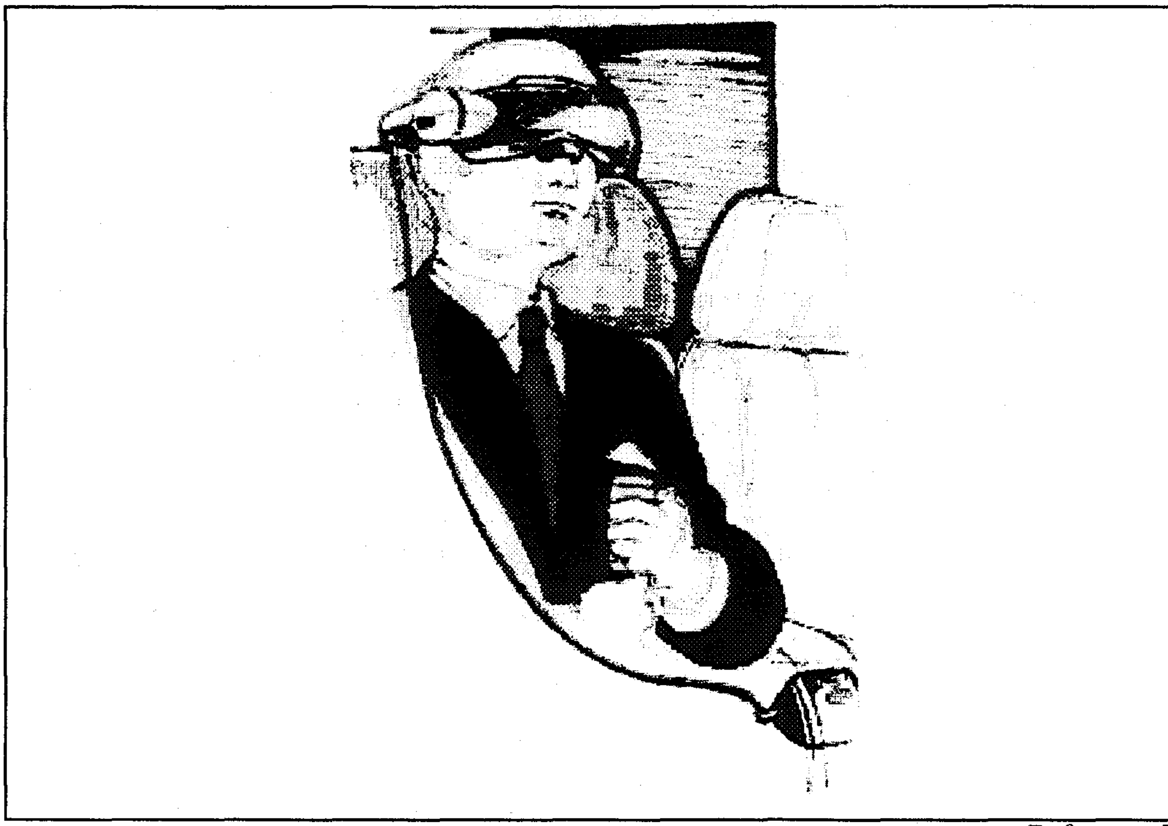
13.3 The Tech Center

Person-to-person contact is vital to business communications, therefore corporate passengers will continue travel by air for meetings, presentations and office visits. This decade has already seen the advent of a business class seating, and the next step is using technology to cater to the business traveler's needs. The Aluminum Falcon's special attraction for the business community is the Tech Center.

The Tech Center on the AF-1 is a station in the business class containing modern office equipment for passenger use. First-class or business class travelers with lap-top computers can connect through a pre-wired plug in the armrest. Compatible to both Macintosh and IBM computers, the tech center can help travelers finish last minute reports, memos, and presentations. Facsimile machines and color printers provide immediate access to documents while modem connections offer remote access to personal accounts or Internet, the information superhighway. Business travelers will have everything necessary to be productive while in flight. These services can be billed to a credit card and later reimbursed as a travel expense. This is an excellent source of revenue for airlines, as well as an incentive for busy passengers to fly the AF-1.

13.4 High-Tech Entertainment

The AF-1 will be equipped with personal headset entertainment systems that offer three dimensional video and stereo audio, depicted in Figure 13.3. Varying visor opacity will allow the passenger to keep an eye on children or the cabin environment while enjoying a movie, a three-dimensional video game, music videos, and popular television shows. Individual headsets allow passengers to choose their entertainment from computerized menus of programs. Each particular airline can choose the level of service they wish to offer.



source: Reference 7

Figure 13.3 AF-1 Passenger Entertainment System

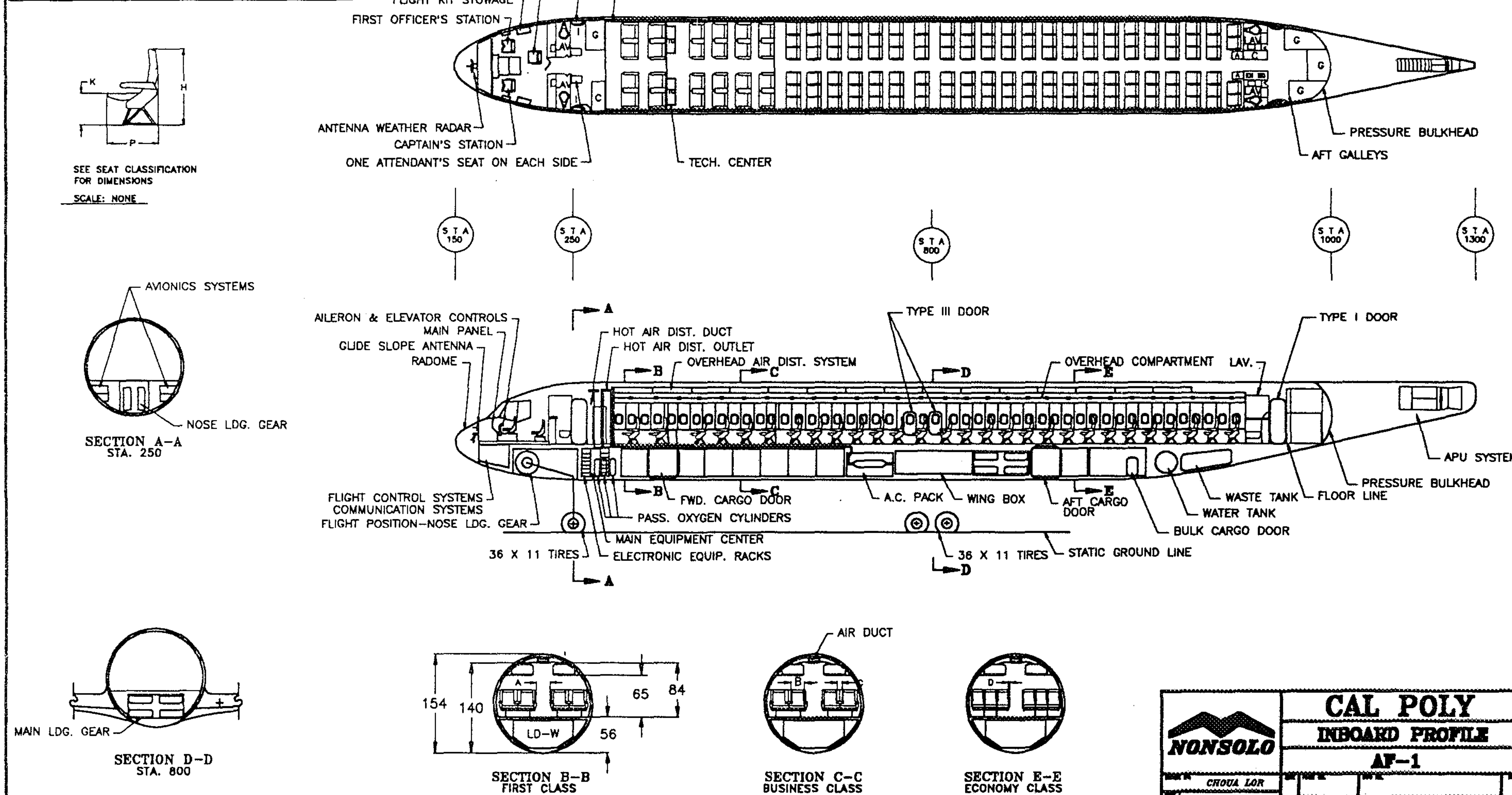
With the present in-flight television systems, if one system goes out most of a cabin can be without entertainment. This may create some agitated passengers. Private plug in headsets allow malfunctioning units to be quickly replaced and avoid the expensive alternative, installation and maintenance of systems located in seat backs. With personal units, all that is needed for replacement is a new headset instead of a new seat.

These entertainment systems can be easily rented on flights the same way airlines currently rent audio headsets. Another option for airlines is a credit card payment system, with the headset attached to the seat, similar to the way the in-flight phone is billed. Using this system, entertainment could be charged by the minute and would also provide theft

FOLDOUT FRAME 1

FOLDOUT FRAME 2

SEAT CLASSIFICATION				
SYMBOLS	UNIT	FIRST CLASS	BUSINESS CLASS	ECONOMY CLASS
A	INCH	22	22	19
B	"	21	21	17.5
C	"	8	8	2
D	"	4	4	2
K	"	18	17.75	17.75
H	"	42	42	39
P	"	27	25	22



security. Both arrangements give passengers the option of entertainment while adding profitability for the airline.

13.5 Flight Deck Layout

The AF-1 flight deck, shown in Figure 13.4, is based on the Boeing 767 and 777 cockpit and control panels (ref 4 and 5). Therefore, pilots of Boeing aircraft will find the AF-1 flight deck very familiar and will have few problems with the transition. This layout improves flight crew operations with easy access to system controls. There are six main control panels which will be discussed in Section 14.1.

The AF-1 flight deck is designed to be operated by a two member flight crew. In addition, one observer seat is provided and is stowable. This seat is necessary for FAA certification and observers, but is otherwise seldom used. Providing stowage capability allows the flight deck to be shortened.

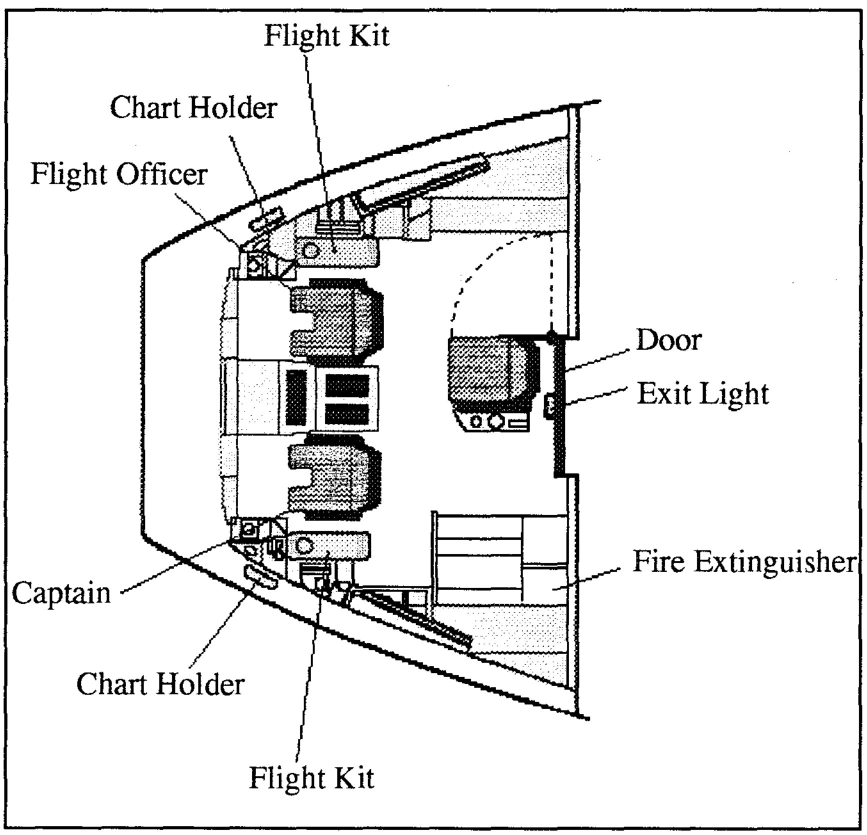


Figure 13.4 AF-1 Flight Deck Layout (Modified from Boeing 767)

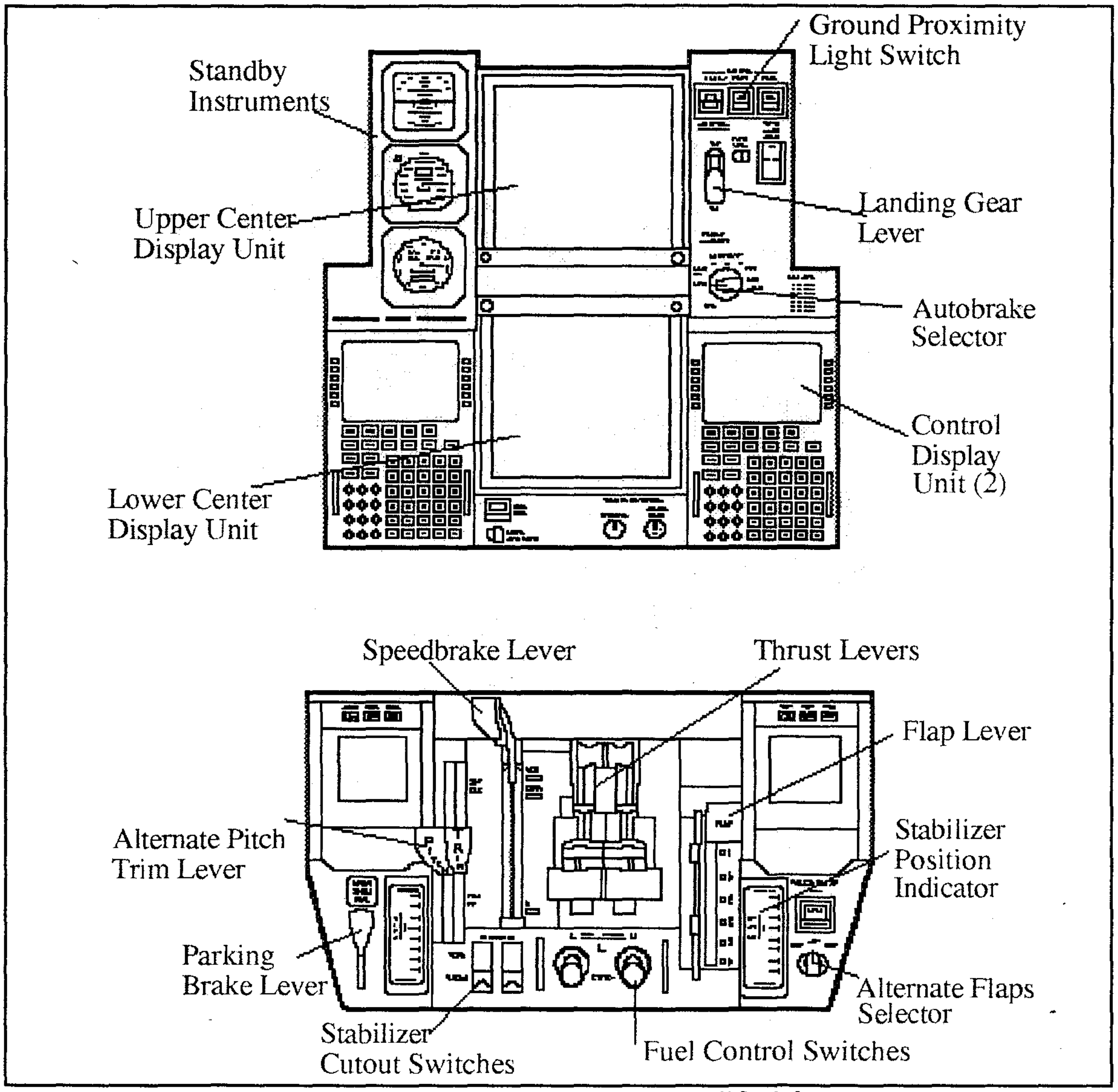
14. SYSTEMS FOR THE ALUMINUM FALCON

The systems found within the Aluminum Falcon are not unusual in today's commercial transports. Systems ranging from the advanced control panels down to the anti-icing system are all proven and are currently being used in Boeing, McDonnell Douglas, and Airbus aircraft. Therefore, the costs of such systems are reasonable and conforms to Non-Solo's low cost philosophy. In fact, using such proven systems will actually lower operating costs because pilots and airline maintenance personnel will already be familiar with them.

14.1 Avionics System

The Non-Solo advanced design philosophy continues into the cockpit layout. Traditional analog instruments are replaced by Multi-Functional Displays with visual mode selection controls. The result is an all glass cockpit that displays a greater amount of information to the flight crew while maintaining upgrade capability. Figures 14.1 to 14.3 show the six primary instrument panels found in the AF-1 flight deck.

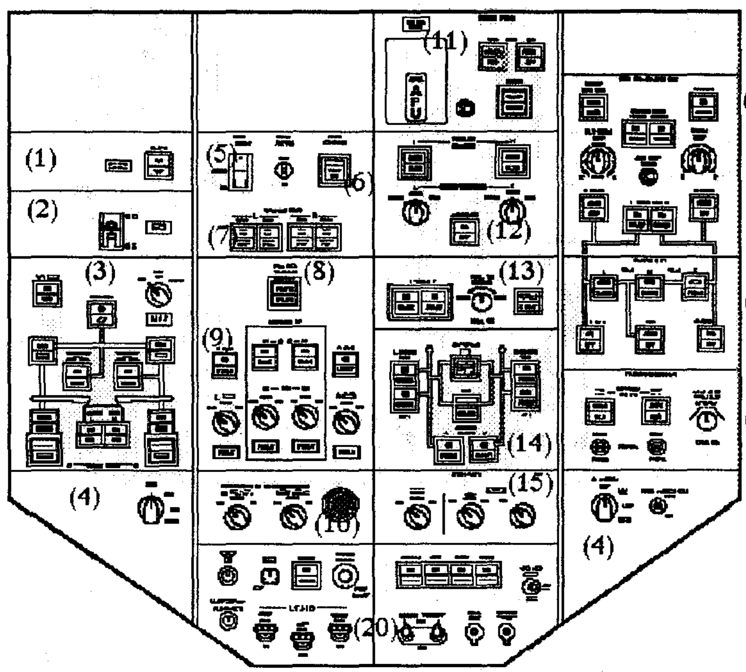
The AF-1 is also equipped with both a differential global positioning system (GPS) and an inertial navigation system (INS). The GPS can link up to 8 satellites at a time and can pin-point the aircraft location with three-meter accuracy. Differential GPS will also replace or augment standard ILS landing systems.



modified from: Boeing 777 Systems

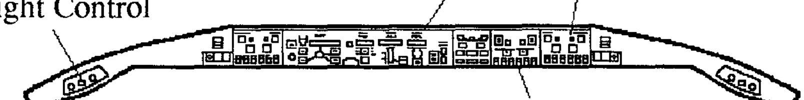
Figure 14.1 Forward Aisle Stand Panel and Control Stand

C-2



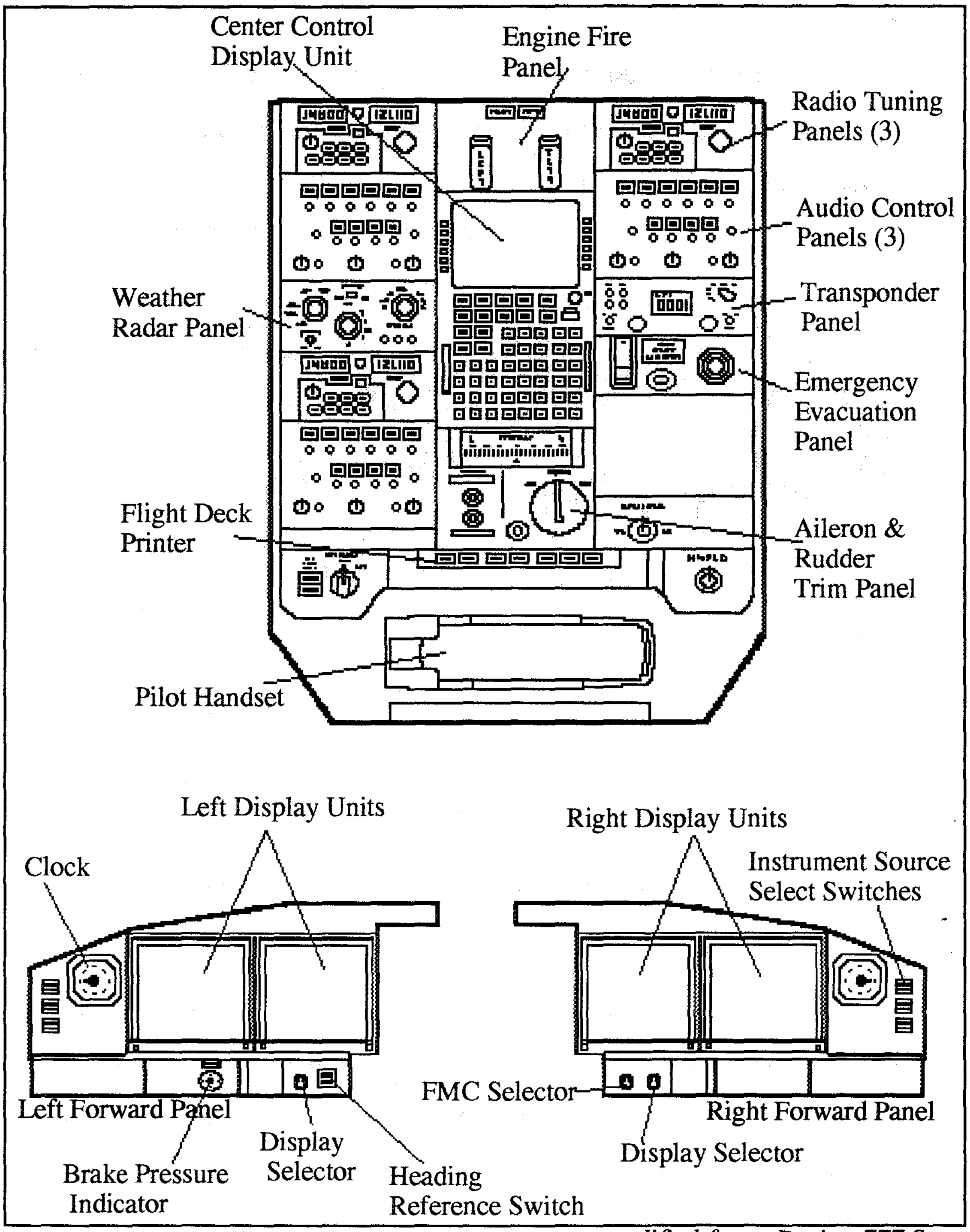
(1) Air Data Inertial Reference System Contro
(2) Primary Flight Computers Disconnect
(3) Electrical System / APU
(4) Wiper Control
(5) Emergency Lighting
(6) Passenger Oxygen
(7) Window Heat
(8) Ram Air Turbine Switch
(9) Hydraulic System
(10) Passenger Signs

(11) APU and Cargo Fire Contro
(12) Engine Start
(13) Fuel Jettison
(14) Fuel Management
(15) Anti-ice System
(16) Air Conditioning Controls
(17) Temperature Controls
(18) Bleed Air System
(19) Pressurization Control
(20) LIghting



modified from: Boeing 777 Systems

Figure 14.2 AF-1 Overhead and Glareshield Panels



modified from: Boeing 777 Systems

Figure 14.3 AF-1 Aft Aisle Stand Panel and Main Instrument Panels

14.2 Steering System

For steering, the nose gear is hydraulically powered with two linear actuators. It is controllable by either rudder pedals or a backup cockpit hand wheel. A schematic diagram is shown below in Figure 14.4.

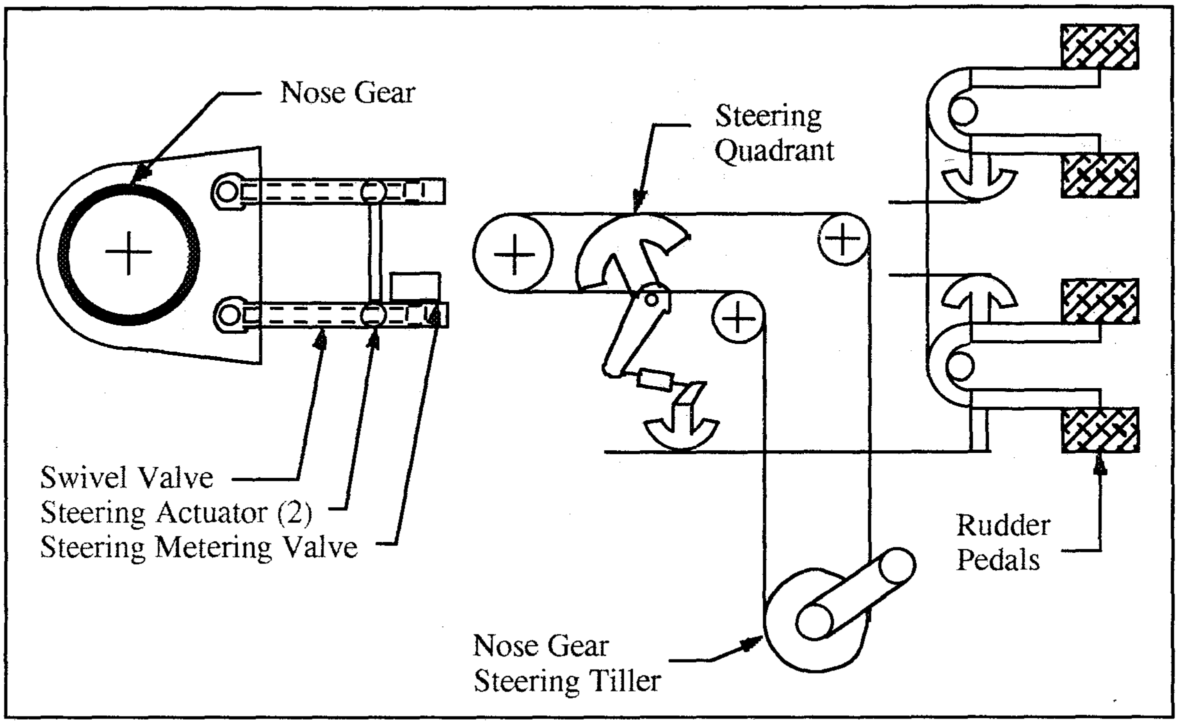


Figure 14.4 AF-1 Steering System

14.3 Flight Control System

The primary flight control system (PFCS) is a three axis, electronic fly-by-wire system. Because the AF-1 is statically unstable, it requires the use of fly-by-wire for rapid control surface actuation. Benefits include increased fuel economy, smaller vertical tail size, and easier adaptation to level I flying quality. This design also allows for a more efficient structural design by facilitating maneuver load and gust load alleviation, where the computer alters control inputs to shift load patterns away from sensitive areas during certain maneuvers and wind gusts. With both GPS and INS, the AF-1 can more easily interface with autopilot and auto landing. This technology also allows the AF-1 to meet strict safety requirements while decreasing weight.

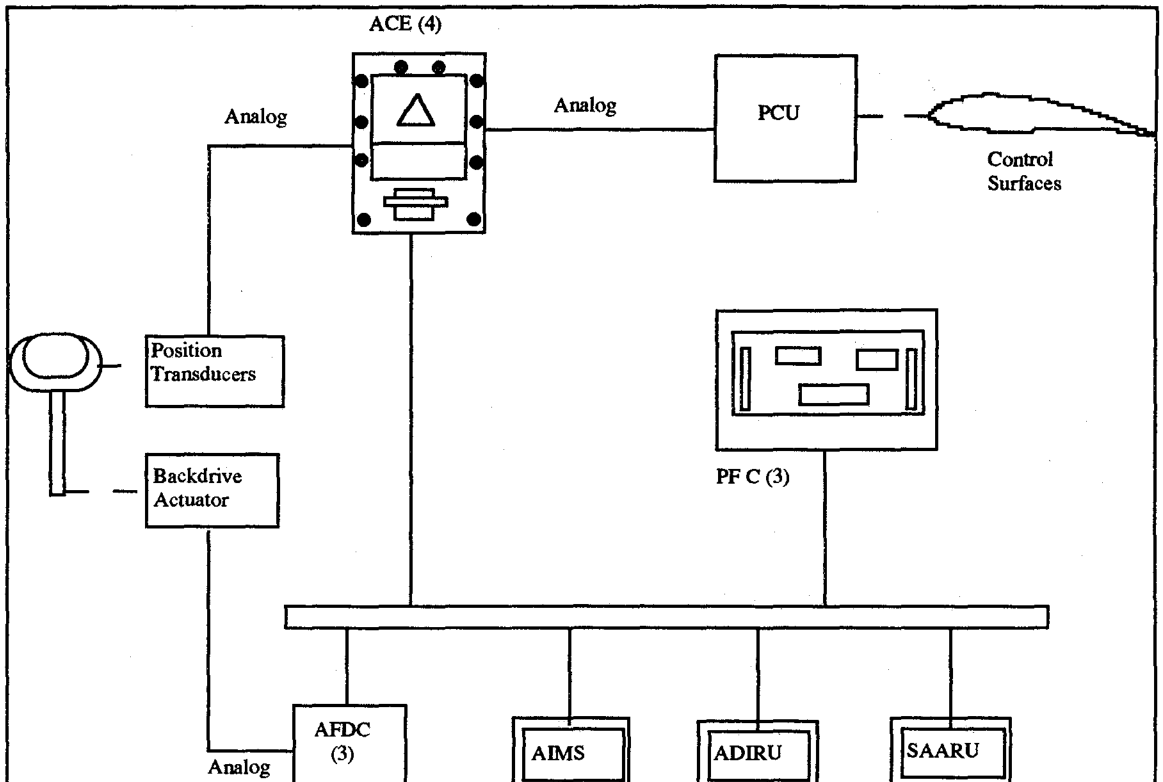
The control surfaces include two split ailerons and 12 spoilers for lateral control, two elevators for longitudinal control, and a rudder for directional control.

The PFCS supplies manual and automatic airplane control and envelope protection in the roll, pitch, and yaw axes. There is stability augmentation in the pitch axis to accomodate the inherent unstable characteristics of the aircraft.

Redundancy is built into the system, both with the computer control system and with the control surface actuators. Not only does the AF-1 contain multiple control surfaces and three flight computers, but the aircraft also has two sets of wiring for the transfer of signals to each control surface. If the primary set of wiring does not transfer the digital signals properly, the system will automatically switch to the second set of wires. This redundancy guarantees that surfaces will be controllable even if one or more computers, wiring, or surface is damaged or fails to receive signals.

The system works by position transducers converting the flight crew commands from the control wheels, the control columns, the rudder pedals, and the speed brake lever to analog electronic signals. These signals go to the actuator control electronics (ACEs). The ACEs convert the signals to digital format and send them to the primary flight computers (PFCs) and the power control units (PCU). A schematic representation of the flight control system is shown in Figure 14.5.

Between one and three PCUs operate each control surface. Each PCU contains a hydraulic actuator, an electro-hydraulic servo-valve, and position feedback transducers. The servos cause the hydraulic actuators to move the control surfaces. The PFC stops the PCU command when the position feedback signal equals the command position.



source: Boeing 767 Systems

Figure 14.5 AF-1 Flight Control System

14.4 Hydraulic System

The AF-1's hydraulics system actually consists of three independent systems. Each system has two or more pumps operating from different pneumatic, mechanical, or electrical power sources. Each hydraulic system can independently operate the necessary flight controls for safe flight and landing. There are built-in redundancies in case one or possibly two systems malfunction. Figure 14.6 contains the system diagram.

The three systems are the left, center, and right in reference to the location of their main components. Each system has its own reservoir, pump, and filters.

The left system has an engine driven pump (EDP) and an alternating current motor pump (ACMP). The left engine drives the EDP and the right AC bus powers the ACMP. The left system powers flight controls and the left thrust reverser. A similar system is based on the right engine.

The center system has two ACMPs, two air driven pumps (ADPs) and a ram air turbine-driven pump. The left and right AC buses power both ACMPs. Pneumatic power from either of the two engines or the APU drives the ADPs. The ram air turbine deploys when either both engines are shut down, both AC buses are not powered, or all three hydraulic system pressures are low.

14.5 Pneumatic System

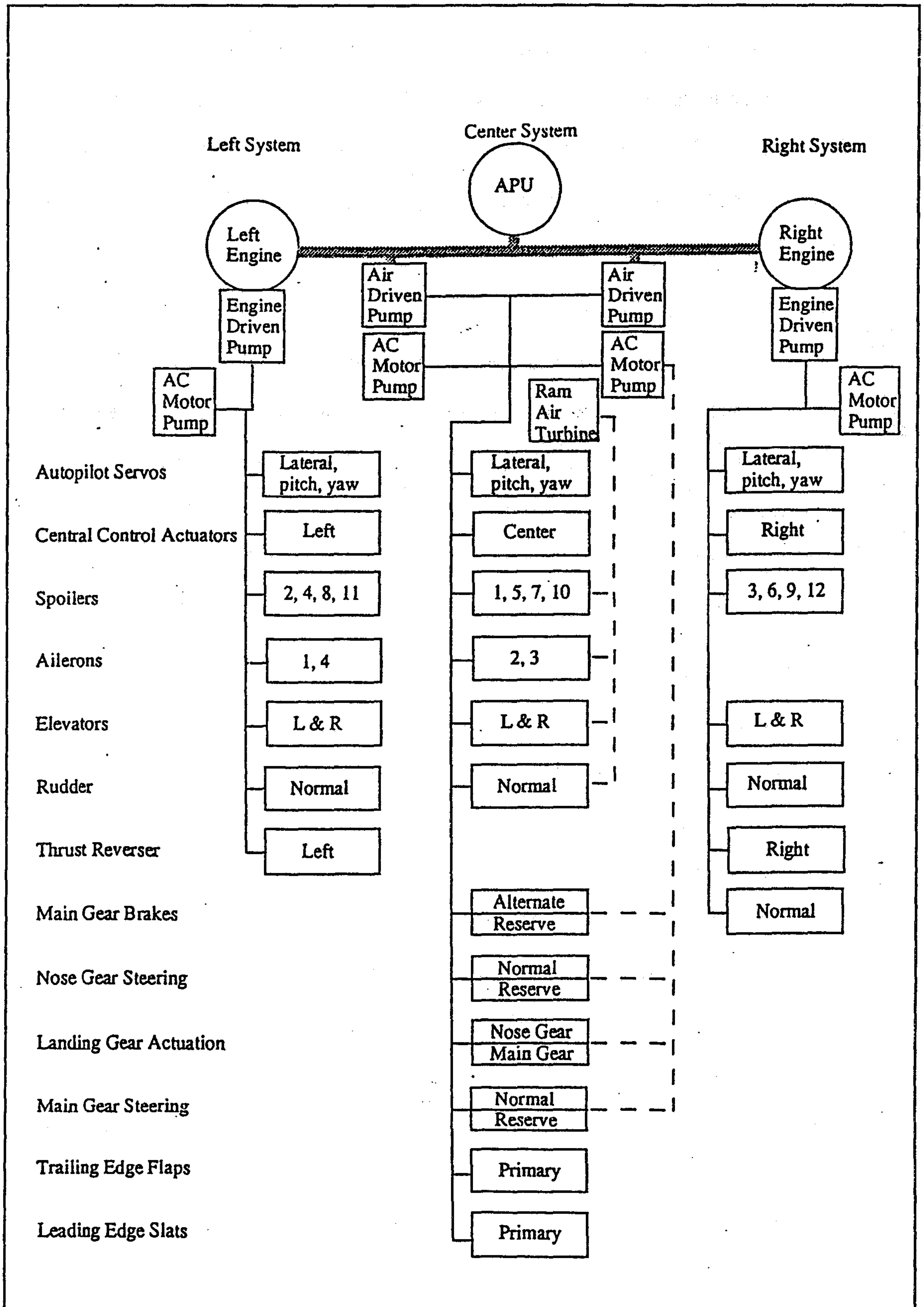
This pneumatic system is used to supply air (temperature and pressure regulated) for engine starts, cabin pressurization, air conditioning, and anti-icing. The pneumatic distribution system is located throughout the aircraft and is divided into three parts - left, right, and center. Each part contains ducting and valves to control the distribution from the supplier to user systems. The air for the system is obtained from the two engines, the APU, and an external source. The pneumatic system diagram is shown in Figure 14.7.

14.6 Electrical System

The electrical system, shown in Figure 14.8, is designed to reduce flight crew operations prior to, during, and after flight. This system also incorporate automatic features such as on-line power during engine start and standby power operation.

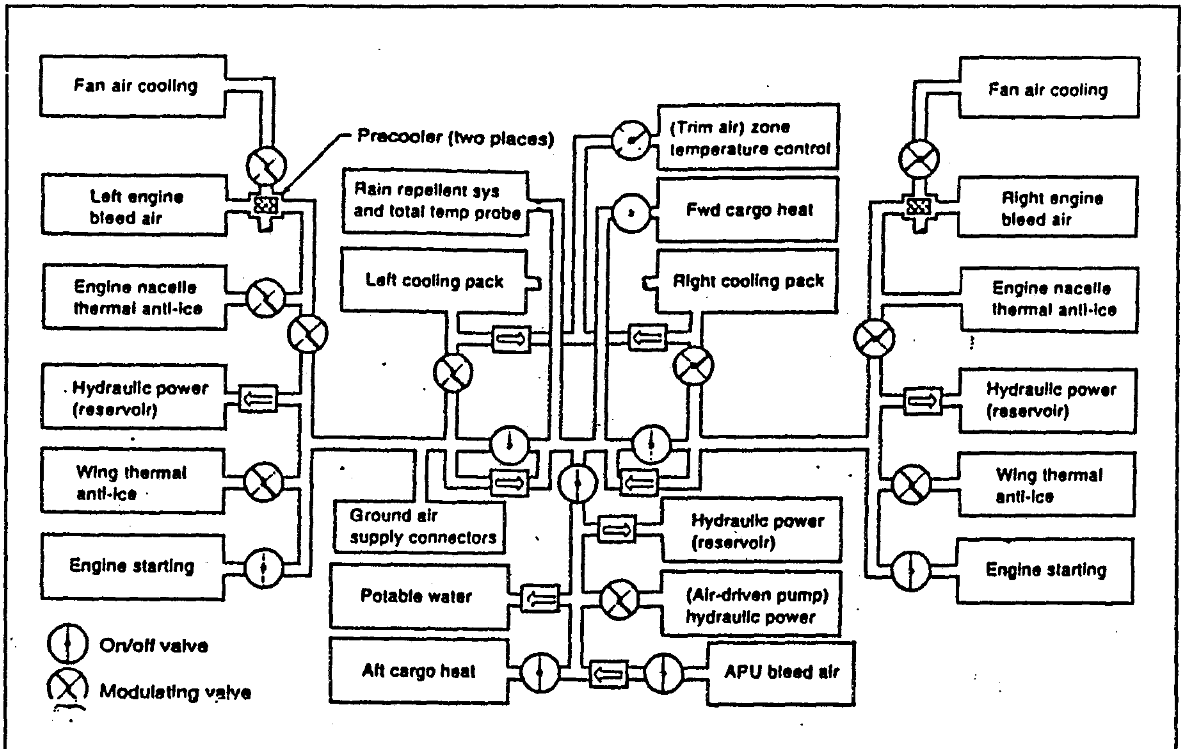
The primary AC power is produced by the right and left engine mounted integrated drive generators (IDG). With the loss of either IDG, the APU automatically powers up. During ground operations, the APU driven generator or an external power source can be used to handle all servicing and loading operations.

The left and right main AC buses provide power for various lights, instruments, and other loads. In case the electrical system fails, the standby system can provide both AC and DC power for up to 30 minutes from the main battery. Also, the ram air turbine can provide limited power to the AF-1.



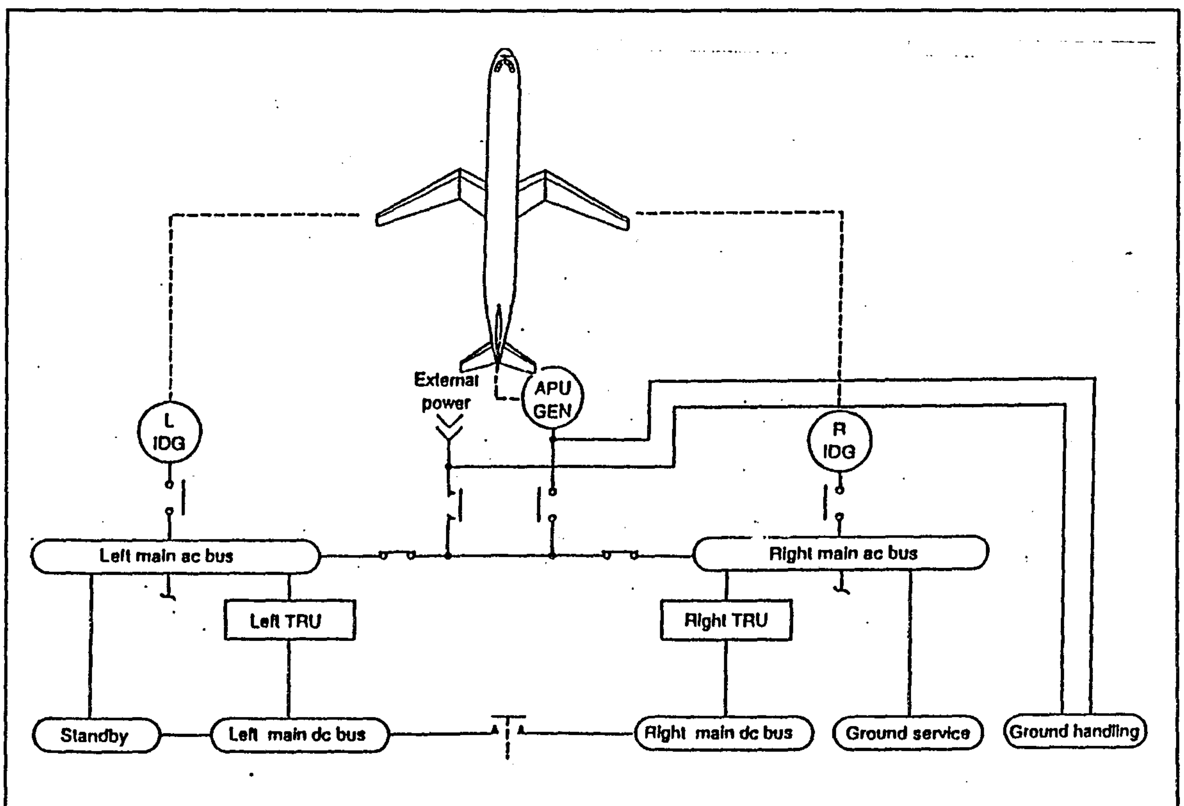
modified from Boeing 767 Systems

Figure 14.6 AF-1 Hydraulic System Schematic



source: Boeing 767 Systems

Figure 14.7 AF-1 Pneumatic System



source: Boeing 767 Systems

Figure 14.8 AF-1 Electrical System (From Boeing 767)

14.7 Fuel System

The fuel system for the AF-1 is fairly conventional and is shown in Figure 14.9. The 3000 nautical mile stage length requires approximately 5500 gallons of fuel. This amount of fuel can be stored in the two main wing tanks and a center tank with the refueling ports on the underside of the wings. The fuel system provides storage, fueling, venting, auxiliary power unit and engine fuel feed.

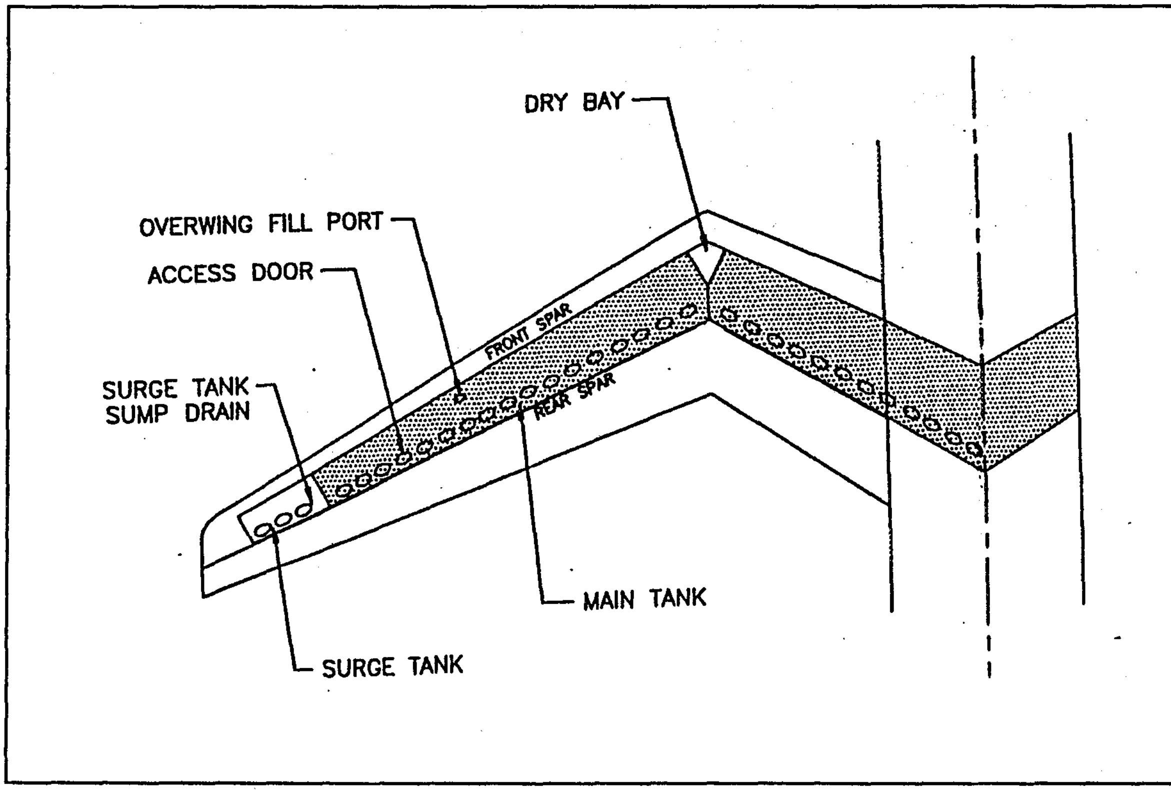


Figure 14.9 AF-1 Fuel System

14.8 Environmental Control System

Environmental controls for passenger comfort are powered by the pneumatic system. The supply air is delivered to the two cooling packs located near the main wheel well where it is cooled and properly humidified. The conditioned air is then brought forward to the front of the aircraft where it is channeled to the top of the passenger compartment and distributed through the cabins via ceiling ducts. A similar process provides air with a higher oxygen content to the cockpit. A fraction of the cabin air will then be filtered and mixed with conditioned air from the packs for redistribution, thus decreasing the load on the system. Figures 14.10 illustrates the system layout.

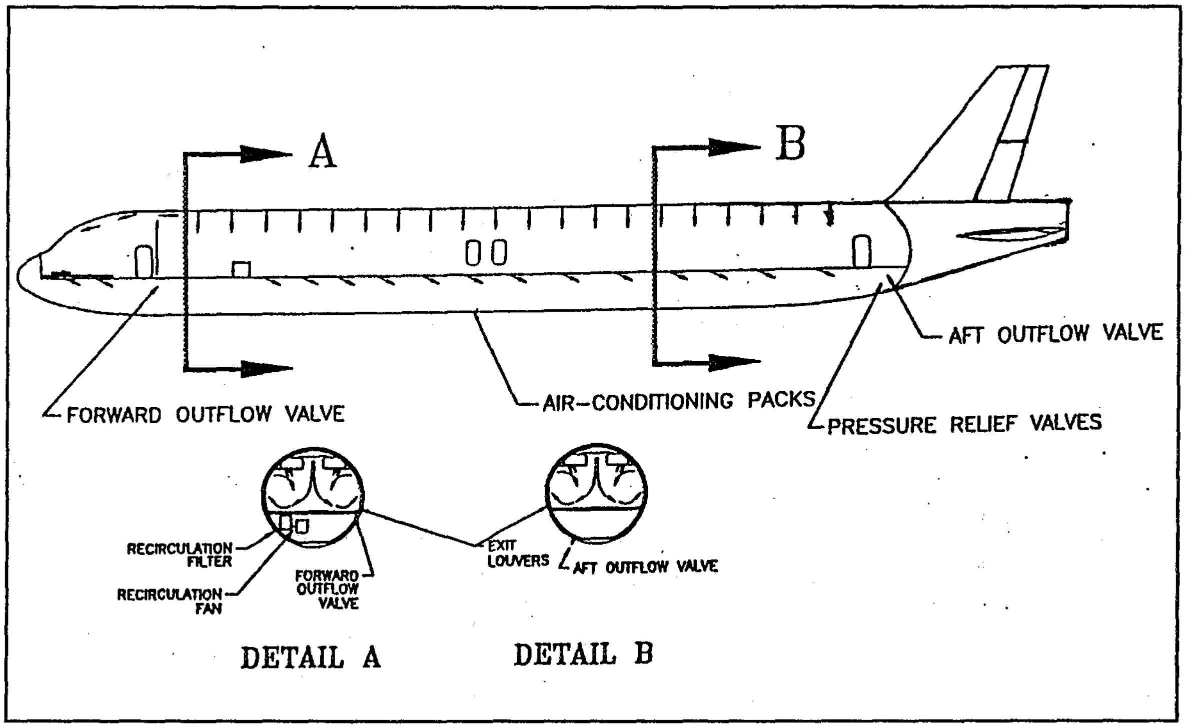


Figure 14.10 AF-1 Environmental Control System

In case of an emergency, the oxygen system, depicted in Figure 14.11, can be activated in one of two ways. First, the pilot can activate the system by switching the system on manually. Second, the system automatically activates should the cabin pressure altitude exceed 13,000 feet.

Once the system is activated, control units will produce pressure surges to release the mask stowage doors and chemical generators will start providing oxygen to passengers, laboratories, and flight attendant stations.

14.9 Emergency Evacuation System

Figure 14.12 shows the evacuation system of the AF-1. Single slides open up to allow passengers to exit from the forward and aft type I doors. Over the wing, a twin slide deploys off the back of the wing to allow passengers from both type III doors on either side to evacuate.

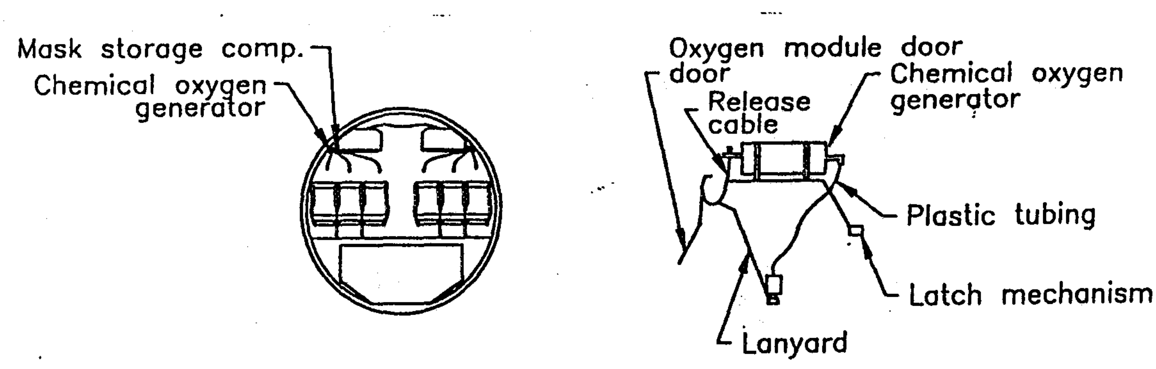


Figure 14.11 AF-1 Passenger Oxygen System

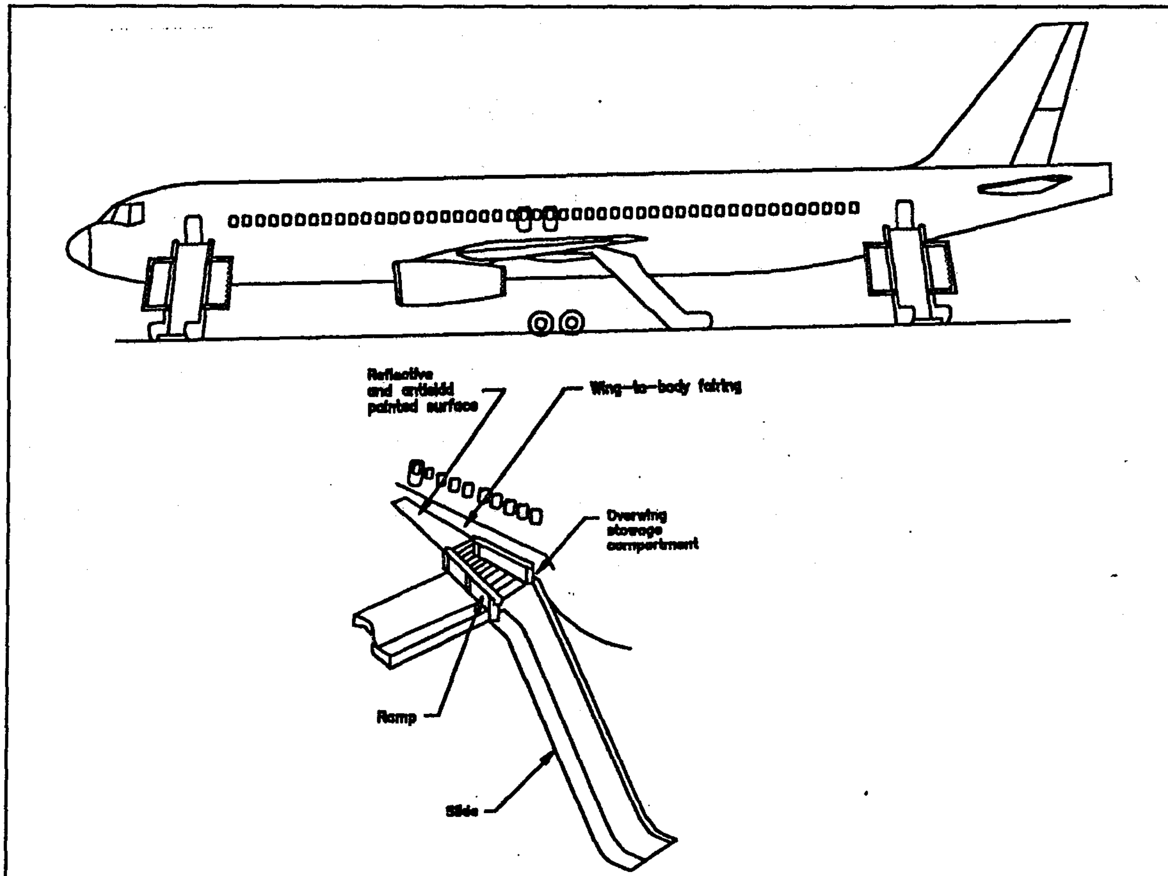
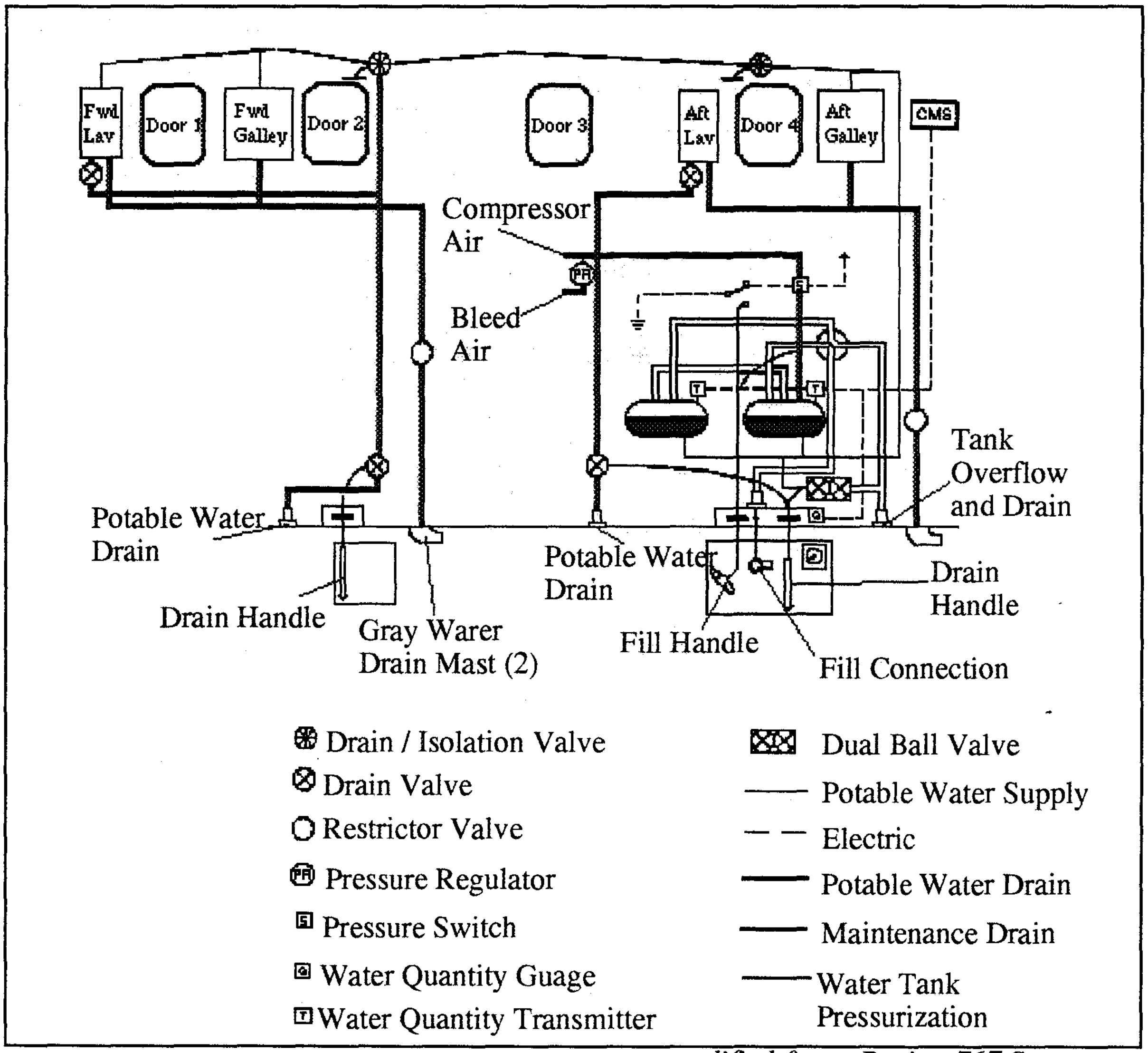


Figure 14.12 AF-1 Emergency Evacuation System

14.10 Potable and Gray Water System

The potable water system supplies over 100 gallons of clean water to the galleys and lavatories. There are two potable water tanks located behind the bulk cargo compartment. Air pressure from the pneumatic system pushes the potable water from the tanks through distribution lines to the lavatories and galleys.

There is also a gray water system to drain used water from the sinks in the galleys and lavatories. Two gray water drain masts located on the bottom of the fuselage are used for this purpose. A schematic is shown in Figure 14.13.



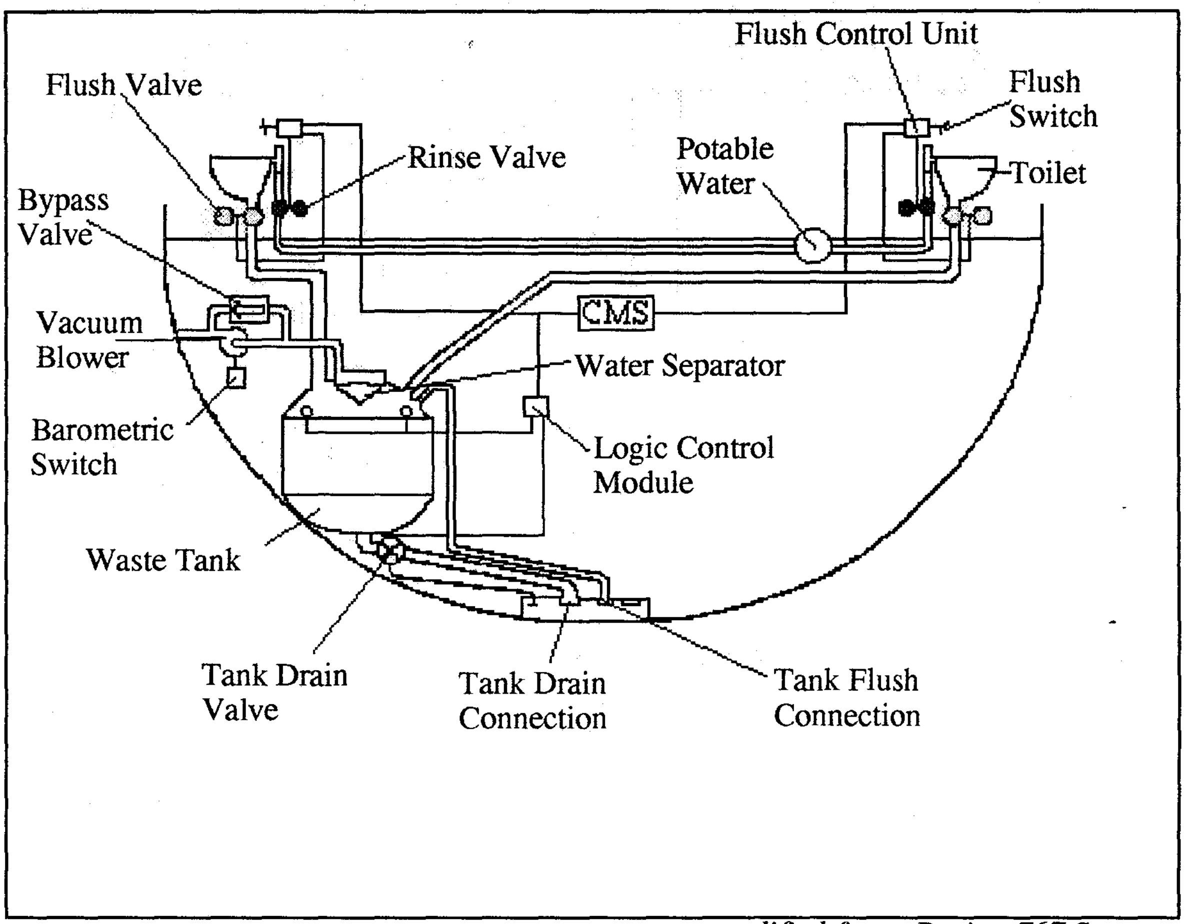
modified from: Boeing 767 Systems

Figure 14.13 AF-1 Potable Water System

14.11 Lavatory Waste System

There are four lavatories on the AF-1. Each lavatory is equipped with a vacuum toilet. Each toilet has a flush switch connected to a flush control unit (FCU). When a person pushes the flush switch, the FCU starts the flush cycle which includes moving the waste to one of two waste tanks, either forward or aft, and potable water flushing the toilet. These waste tanks are located on the left side of the fuselage adjacent to the bulk cargo compartment. The system is shown in Figure 14.14.

The waste is evacuated from the toilet by vacuum. Above 16,000 feet, the ambient atmosphere causes the vacuum. However, below 16,000 feet vacuum pumps are necessary, with one installed on each tank.



modified from: Boeing 767 Systems

Figure 14.14 AF-1 Lavatory Waste System

14.12 Anti-Icing System

The thermal anti-icing (TAI) uses engine bleed air and electrical power to provide protection from ice buildup. The engine bleed air is used for heating the leading edge of the wing and for the engine inlet cowls. Electric anti-icing is used to protect water and waste lines, drain and waste masts, cockpit windshields, angle of attack (AOA) sensors, Pitot-static probes, and total air temperature (TAT) probes.

Ice detectors are installed on either side of the fuselage. When ice starts to develop, an icing signal is sent to the cockpit. The flight crew can then turn on the system with a switch located on the overhead panel.

15. CONCLUSION

The AF-1 takes a radical jump in design philosophy, leaping ahead of the competition. It meets all the requirements of the RFP, which is a notable achievement. Using an innovative wing, discerning use of composites and other advanced materials, and close attention to every other detail from engines to entertainment, the AF-1 stands out as an advanced concept designed specifically for the demands of the future air transport market. Proceeding forward with the development will entail wind tunnel work on the wing joint, to determine both the aerodynamic and structural complexities of this new conception. The rest of the aircraft, however, will require little advanced testing and development time and money can be better spent refining and optimizing the various aircraft systems, assisting in the goal of delivering a certifiable, profitable aircraft from the very first unit out of the hangar. Close attention will be paid to keeping acquisition cost down while also minimizing direct operating cost. Just as the airline market begins to cycle upward before the turn of the century, the AF-1 will make its debut, leading the way into the new millennium.

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