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The FC-1D: The Profitable Alternative
Flying Circus Commercial Aviation Group

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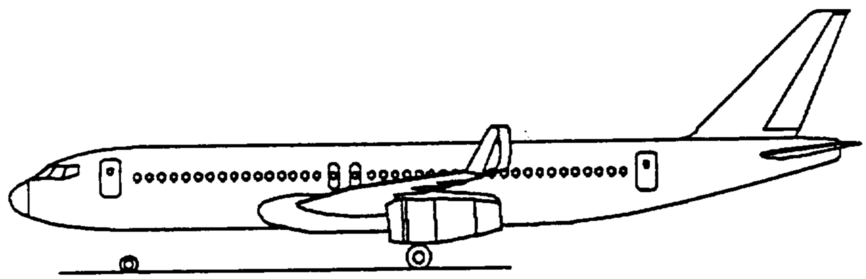

1993/1994 AIAA/Lockheed Corporation Team Aircraft Design Competition
California Polytechnic State University, San Luis Obispo
A Low Cost Commercial Transport
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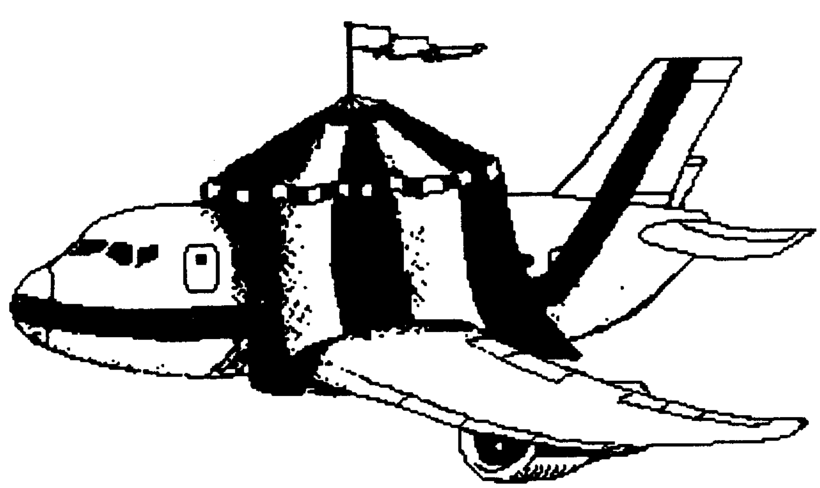
EXECUTIVE SUMMARY

The Flying Circus Commercial Aviation Group is proud to present the FC-1D in response to the AIAA/Lockheed Corporation Design Competition. The FC-1D was designed as an advanced solution for a low cost commercial transport meeting or exceeding all of the 1993/1994 AIAA/Lockheed request for proposal (RFP) requirements. The driving philosophy behind the design of the FC-1D was the reduction of airline direct operating cost (DOC). Every effort was made during the design process to have the customer in mind. The Flying Circus Commercial Aviation Group targeted reductions in drag, fuel consumption, manufacturing costs, and maintenance costs.

Flying Circus emphasized DOC reduction throughout the entire design program. Drag reduction was initiated with the implementation of the aft nacelle wing configuration to reduce cruise drag and increase cruise speeds. To reduce induced drag, rather than increasing the wing span of the FC-1D, spiroids were included in the efficient wing design. Profile and friction drag are reduced by utilizing riblets in place of paint around the fuselage and empennage of the FC-1D. Choosing a single aisle configuration enabled the Flying Circus to optimize the fuselage diameter. Thus, reducing fuselage drag while gaining high structural efficiency. To further reduce fuel consumption a weight reduction program was conducted through the use of composite materials. An additional quality of the FC-1D is its design for low cost manufacturing and assembly. As a result of this design attribute, the FC-1D will have fewer parts which reduces weight as well as maintenance and assembly costs.

The FC-1D is affordable and effective, the apex of commercial transport design.



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ACN	Aircraft Classification Number	
AIAA	American Institute of Aeronautics and Astronautics	
APU	Auxiliary Power Unit	
AR	Aspect Ratio	
ASHRAE	American Society of Heating Refrigeration and Air Conditioning	
AWN	Aft Wing Nacelle	
b	Wingspan	feet
CG	Center of Gravity	
DOC	Direct Operating Cost	
EPNL	Effective Perceived Noise Level	decibels
ETOPS	Extended Operations	
FAA	Federal Aviation Administration	
FAR	Federal Aviation Regulation	
FLIR	Forward Looking Infrared	
HF	High Frequency	
LCN	Load Classification Number	
IAE	International Aero Engines	
ICAO	International Civil Aviation Organization	
IOC	Indirect Operating Cost	
MAC	Mean Aerodynamic Chord	
MTOW	Maximum Take-Off Weight	lbs
PNL	Perceived Noise Level	decibels
RAT	Ram Air Turbine	
RFP	Request for Proposal	
ROI	Return on Investment	
SFC	Specific Fuel Consumption	lbm/hr/lb
UHF	Ultra High Frequency	
VCSF	Variable Speed Constant Frequency	
VHF	Very High Frequency	
V_A	Maneuver Speed	KEAS

V_B	Maximum Gust Intensity Speed	KEAS
V_C	Design Cruise Speed	KEAS
V_{MO}	Maximum Operating Speed	KEAS
V_D	Dive Speed	KEAS
V_{LO}	Landing Operating Speed	KEAS
V_{FE}	Flaps Extend Speed	KEAS
δ_T	Wing Tip Deflection	ft
M	Moment	ft-lbs
E	Young' Modulus of elasticity	lbs/in^2
b	Wing Span	ft
r_f	Fuselage Radius	ft
I	Moment of Inertia	ft^4 or in^4
$\Lambda_{0.5}$	Half Chord Sweep Angle	deg
$Cl\beta$	Rolling moment derivative due to sideslip	
$Cl\delta_a$	Rolling moment derivative due to aileron deflection	
$Cl\delta_r$	Rolling moment derivative due to rudder deflection	
C_{lp}	Rolling moment derivative due to roll rate	
C_{lr}	Rolling moment derivative due to roll rate	
$C_{m\alpha}$	Pitching moment derivative due to angle of attack	
$C_{m\alpha}$	Pitching moment derivative due change angle of attack	
$C_{m\delta e}$	Pitching moment derivative due to elevator deflection	
C_{mq}	Pitching moment derivative due to pitch rate	
$C_{n\beta}$	Yaw moment derivative due to sideslip	
$Cn\delta_a$	Yaw moment derivative due to aileron deflection	
$Cn\delta_r$	Yaw moment derivative due to rudder deflection	
C_{np}	Yaw moment derivative due to roll rate	
C_{nr}	Yaw moment derivative due to yaw rate	
$C_y\delta_a$	Side force derivative due to aileron deflection	
$C_y\delta_r$	Side force derivative due to rudder deflection	
C_{yp}	Side force derivative due to roll rate	
C_{yr}	Side force derivative due to yaw rate	
C_D	Drag coefficient	
C_{D1}	Steady state drag coefficient	
$C_{D\delta e}$	Drag coefficient derivative due to elevator deflection	
C_{Di}	Induced drag coefficient	

C_{Do}	Induced drag coefficient
C_L	Lift coefficient
C_{L1}	Steady state lift coefficient
$C_{L\alpha}$	Lift coefficient derivative due to angle of attack
$C_{L\alpha}$	Lift coefficient derivative due to change in angle of
attack	
$C_{L\delta e}$	Lift coefficient derivative due to elevator deflection
C_{Di}	Induced drag coefficient
C_{Do}	Induced drag coefficient
C_{Lq}	Lift coefficient derivative due to pitch rate
C_{Lu}	Lift coefficient derivative due to aircraft velocity

1. INTRODUCTION

In the American airline industry of the 1990's, some changes were instated that changed the current way airlines choose to do business. The increased competition created by airline market. A number of airlines went out of business in this tough economic environment, including Pan Am, Eastern, and Midway, while former giants Continental, TWA, and America West faced bankruptcy (Ref. 1-1). Even today, domestic airlines have been forced to streamline their operations and reduce their overhead, while still sustaining heavy losses. The only carriers still maintaining profits are regional carriers such as Southwest Airlines, who has broken from the hub-and-spoke system of transportation, and runs shuttle-like, no-frills service between city pairs (Ref. 1-2). In order for other airlines to survive, a new market is being created similar to this direct flight model. To exploit this situation, a new plane must emerge that has a longer range than current planes, but is still small enough for airlines to fill.

The Flying Circus Commercial Aviation Group was presented with the challenge of designing a jet transport that fulfilled this criteria, as laid out in the 1994 AIAA/Lockheed Corporation Undergraduate Team Aviation Design Competition. The Request For Proposal (RFP) for the competition was for a low cost commercial transport that will significantly reduce the direct operating cost for domestic airlines. In addition, it must also meet current and proposed Federal Aviation Regulation (FAR) requirements (Reference 1-3). The complete design requirements are laid out in Table 1.1. The Flying Circus Commercial Aircraft Group met this challenge with their design of the FC-1D. Because the FC-1D intends to compete in a market that is already inundated with aircraft, its performance characteristics must be comparable. A sample of the other aircraft that currently have a similar range and passenger capabilities include the Boeing 737 series, the Airbus A320-200, and the McDonnell Douglas MD90 class airplanes. Table 1.2 shows some of the main specifications of the FC-1D, and how they compare with its competition.

TABLE 1.1: AIAA/Lockheed Aircraft Design Competition RFP

DESIGN REQUIREMENTS	FC-1D RFP Compliance
Mixed class aircraft that accommodates 153 and bags, at 200 pounds apiece	√
Design must meet future FAR noise regulations	√
Space provided for overhead storage	√
Interior must have front and rear galleys	√
MISSION PROFILE	
Plane must warm up and taxi for 15 minutes at a sea level airport, ISA +27 degree, day	√
Take off within a FAA field length of 7000 feet with full passenger and baggage load	√
Climb at best rate of climb to best cruising altitude	√
Cruise at 99 percent of best range velocity for 3000 nautical miles	√
Descend, earning no range credit, to sea level	√
Land, with domestic fuel reserves, within a FAA landing field length of 5000 feet	√
Taxi to gate for 10 minutes	√

TABLE 1.2: FC-1D Specification Comparisons

	FC-1D	MD90-30	A320-200	Boeing 737-400
Empty Weight	60,700 lbs	86,900 lbs	88,141 lbs	73,570 lbs
Takeoff Weight	135,200 lbs	156,000 lbs	162,040 lbs	138,500 lbs
Wing Span	109.3 feet	107.8 feet	111.25 feet	94.75 feet
Wing Area	1150 square feet	1209 square feet	1317.5 square feet	1135 square feet
Cruise Speed	.80	.76	.80	.73
Altitude	39.000 feet	35.000 feet	35.000 feet	33.000 feet
Aspect Ratio	10.0	9.6	9.4	8.8
Max Thrust	50,000 lbs	50,000 lbs	50,000 lbs	50,000 lbs
Range	3000 NM	2396 NM	2870 NM	2500 NM
Passengers	153	153	150	146
Wing Loading	117.5 lbs/ft^2	129 lbs/ft^2	123 lbs/ft^2	117.9 lbs/ft^2
Landing Distance	5000 feet	5090 feet	4725 feet	5650 feet
Take-off Distance	7000 feet	5880 feet	7645 feet	7600 feet

2.1 Design Philosophy

When the design of the FC-1D was initiated, Flying Circus considered their design goals. While all the RFP requirements needed to be addressed, the low cost issue was singled out as a main design goal. When the direct operating costs of the current airline industry were then evaluated, Flying Circus realized that the only cost factors that they could effect were fuel and maintenance costs. In order to achieve this, the design of the FC-1D evolved in order to optimize four main critical factors: drag, weight, maintenance cost and production cost.

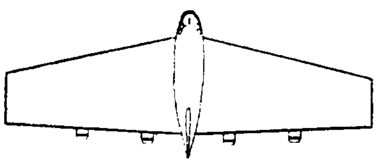
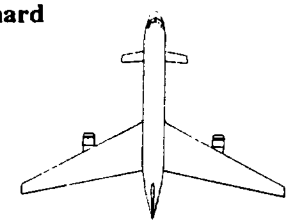
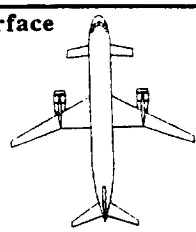
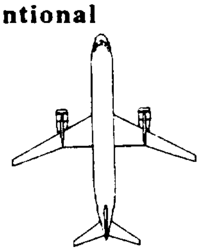
Drag and weight reduction schemes were enacted in order to reduce the amount of fuel that was burned during flight. By reducing these key factors, the thrust required for flight was lowered, which reduced the fuel required for flight. This is a critical factor because fuel burned during flight directly affects airline DOC.

The final criteria targeted for reduction was production and maintenance costs. Materials that were relatively inexpensive and easy to manufacture were used to build the FC-1D when more advanced technologies were not sufficiently justified. With a decrease in its manufacturing costs, the FC-1D could be sold at a more competitive price. The direct operating cost of the airplane was also minimized by using proven technologies, which helped lower maintenance costs.

The evolution of the FC-1D came in two major phases. The first phase was the basic selection of the initial airplane configuration. The decision to begin with a conventional airplane configuration ushered the end of the first phase of the FC-1D evolution. The second phase was the evolution of the FC-1A to the FC-1D.

Phase one involved the careful consideration of the four different configurations, as shown in Table 2.1. The configuration selected by Flying Circus was the conventional airplane. It was selected because its proven technology fulfilled Flying Circus' low cost goal.

TABLE 2.1 FC-1D Configuration Considerations

Configuration	Strengths	Weaknesses
Flying Wing 	- Complete lifting body - Maximum L/D for any configuration	-Stability and control problems associated with lack of tails -Airport compatibility problems -Unique design creates passenger psychological barrier
Canard 	-Two lifting surfaces create a higher trimmed max lift coefficient -Gives good achievable trimmed L/D -Would not suffer passenger prejudice due to popularity of Canard business jets	- Canard must stall, but not reach drag divergence Mach, before wing -Folding canards would be needed to clear airport walkways -Design shows large CG shift -High loads on the canard during landing and takeoff create structural problems
Three Surface 	-Forward lifting surface reduces aft tail size by balancing the aircraft moment -Has similar benefits of canard, without a large CG shift, extreme canard wing load, or stall problems -Reduced trim drag	-Creates extra aircraft weight and structure with two horizontal stabilizers -Forward lifting surface creates extra manufacturing costs -Small gains in trim and induced drag offset by extra skin friction and interference drag
Conventional 	-Proven design -Easier to certify -Much easier to implement technology base currently available -Easier to manufacture -Would not suffer from airport compatibility problems or passenger prejudice	-An aft tail provides down loads for inherent airplane stability

Phase II of the FC-1D design evolution was to take the chosen basic configuration and optimize it for lowest DOC. This evolution is illustrated in Figure 2.1. The first design, the FC-1A, was a twin aisle transport with wing mounted engines. Its large cross-section was designed mainly to offer twin aisles for easier unloading and a double bubble fuselage cross-section that could fit LDW cargo containers. These factors were viewed as a major selling point to airlines. However, with a drag coefficient (C_D) of .032, and a takeoff weight of 159,000 pounds, this design was unsatisfactory. In order to reduce the DOC for this plane, Flying Circus decided to change the design in order to reduce the plane's weight and drag. As shown in Figure 2.2, a trade study was conducted to find the optimum fuselage diameter, as a

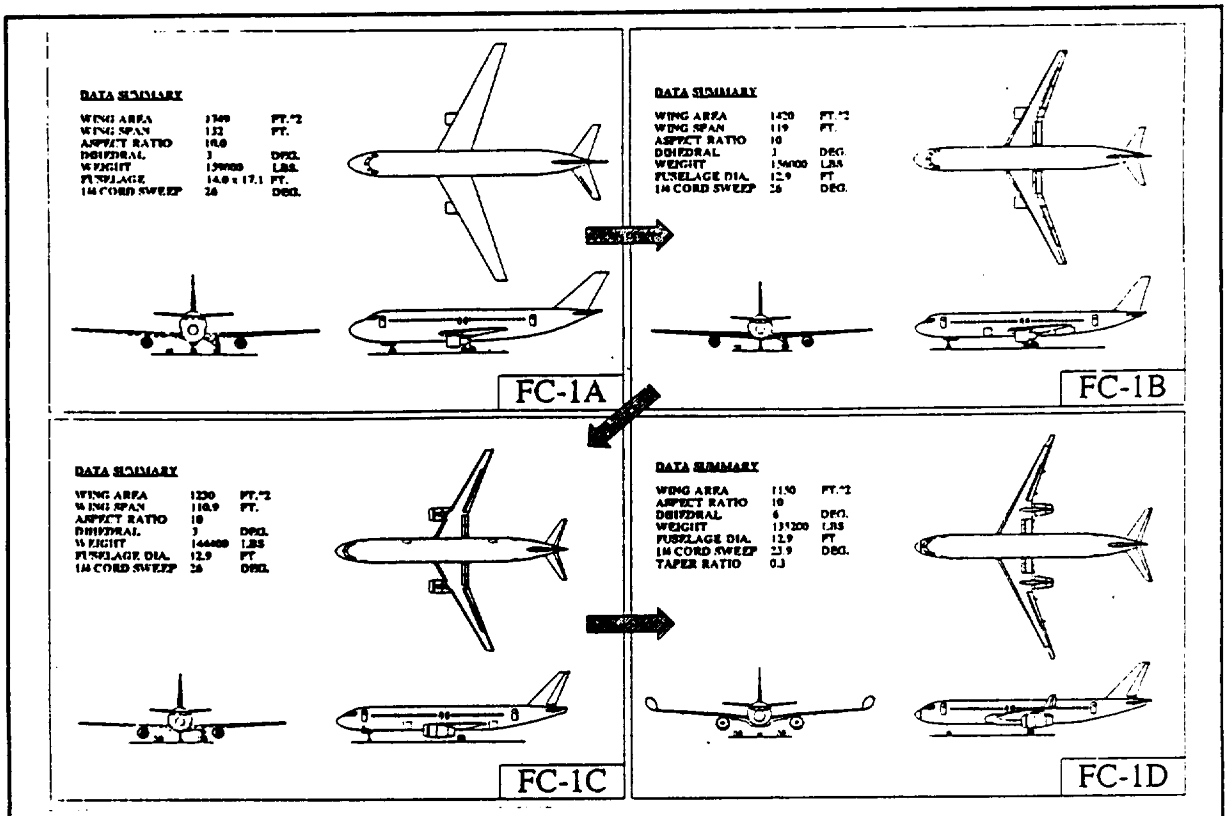


FIGURE 2.2 FC-1D Evolution as a Conventional Aircraft

function of fuselage drag and weight. This trade study showed how the coefficient of drag and empty weight were reduced, as the fuselage diameter was reduced. At a fuselage diameter of approximately 12.7 feet, the fuselage was too narrow to have five-across seating. To accommodate the same amount of passengers the fuselage needed to be extended, which created more drag. In addition to these results, a study was done to show that the twin-aisle configuration did not give the FC-1A better turnaround time. Figure 2.3 shows statistical data for the average turnaround time for single bridge operation, normalized to a 153 passenger 3000 nautical mile airplane. The chart shows that ground time was found to be more a function of plane servicing than passenger deplaning. The change from twin to single aisle increased the FC-1D efficiency by eliminating the weight penalty incurred from the double bubble. This created a jump in drag and weight, making the optimum fuselage width close to 12.7 feet. The sleeker FC-1B evolved from these trade studies with a single aisle cabin and a

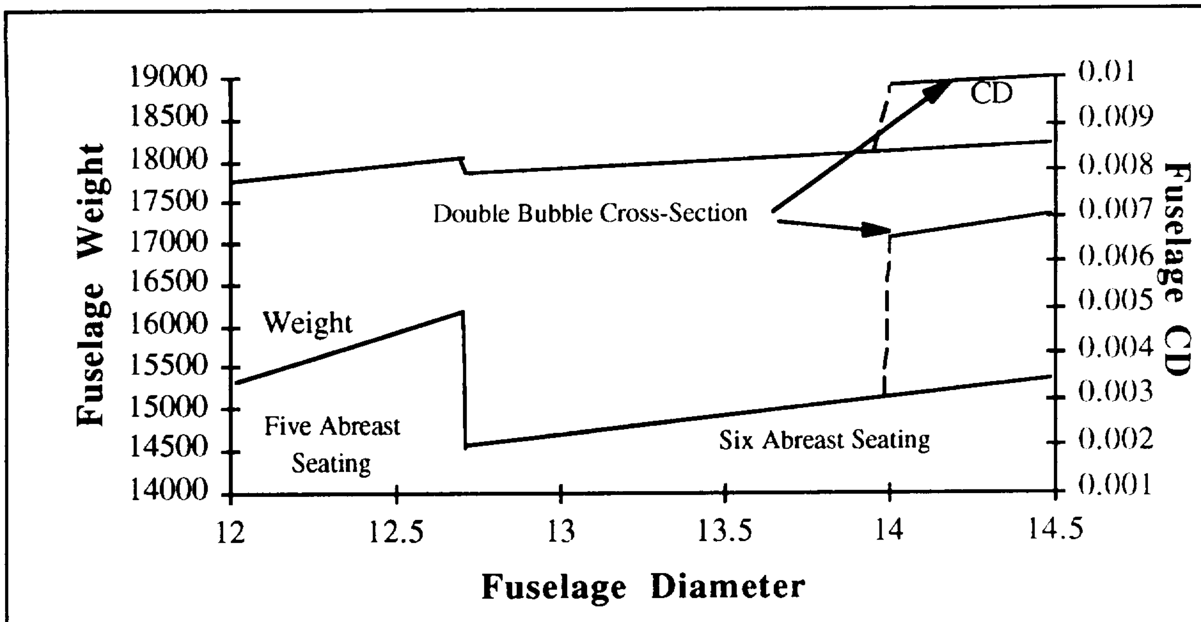


FIGURE 2.3: Fuselage Trade Study

circular cross-section. While this design was an improvement over the FC-1A, the weight and drag of the FC-1B still made it non-competitive with current planes on the market. In response to this, aerodynamic performance was targeted. Airfoil thickness was reduced in order to reduce wing weight and parasite drag. In order to get a more efficient total wing lift distribution, three different airfoils were used throughout the wingspan. All these factors ended up dropping the drag coefficient to 0.027 and the weight to 144,400 pounds.

It was decided that at this point in the design stage that the FC-1C would be a baseline aircraft. Since the it was similar in performance to current aircraft on the market, it would make a good comparison model for future reference. Flying Circus realized that to be cost competitive, the baseline aircraft had to reduce its weight and drag by implementing more advanced, higher risk technologies. This evolved the baseline aircraft to the FC-1D. The engines were placed on the aft edge of the wing in order to keep the lift distribution of the wing intact, and reduce drag. The trailing edge extension was increased in order to add structural strength for the landing gear and the aft-wing nacelle (AWN). The wings were placed to give a negative stability margin (which reduced trim drag), a lower CG shift, and still maintain proper landing gear loads. Spiroids were attached to the wing tips to reduce the

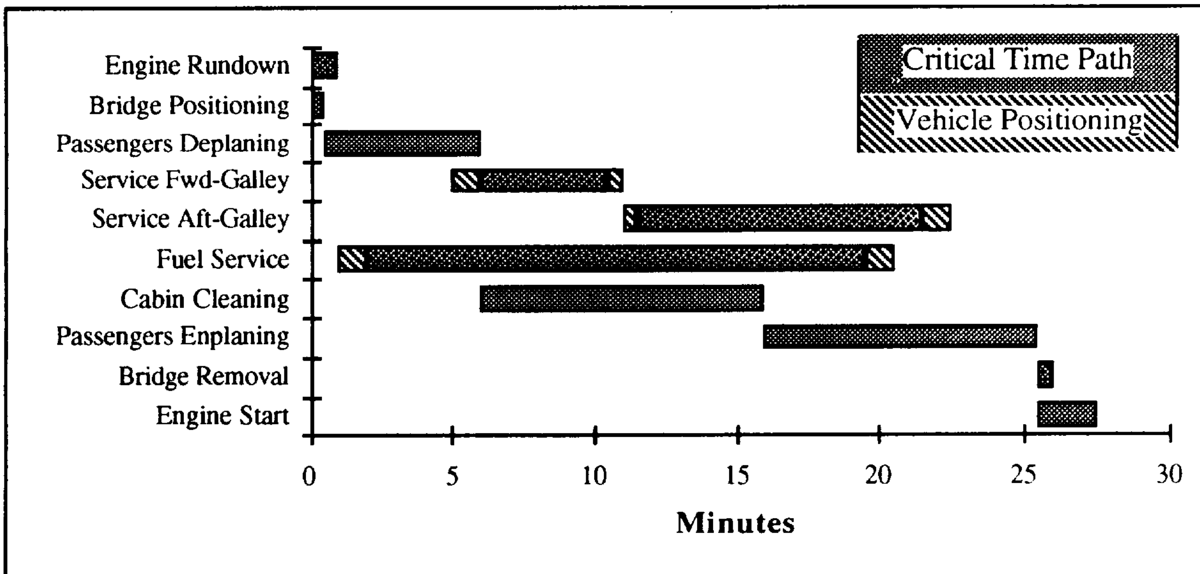


FIGURE 2.4: Average Turnaround Time for Single Bridge Operation

induced drag on the FC-1D. In addition, a methodical weight component analysis was undertaken to reduce the individual weights, substituting composites and other lightweight products where applicable.

The results of this design evolution were a takeoff weight reduction by 9200 pounds and a fuel burn reduction of about 5000 pounds (see Figure 2.4).

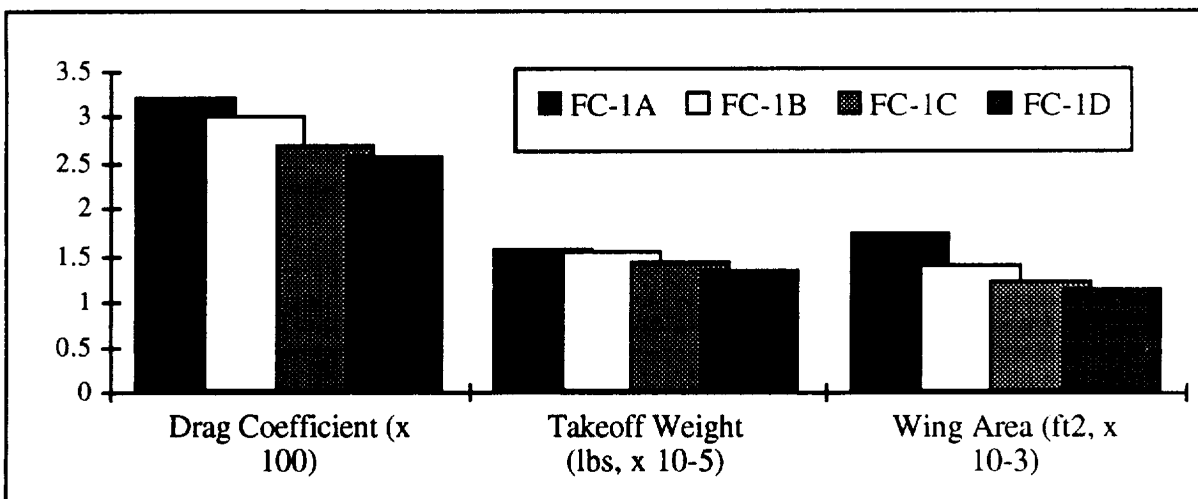


FIGURE 2.5: Performance Evolution of the FC-1D

3.1 Mission Profile Analysis

The most crucial part of the FC-1D's performance is the efficient completion of the mission profile outlined by the RFP. The typical mission is outlined in Figure 3.1 below.

1. Warm-up and taxi with a full load of 153 passengers and bags, and 42,000 pounds of fuel.
2. Take-off from a sea level airport on a 76 degree temperature day, + or - 27 degrees. The FC-1D builds up a takeoff velocity of 117 feet per second, before rotating and lifting off in a 7000 ft runway.
3. The FC-1D climbs at its fastest rate of climb to an altitude of 39000 feet, flying 112 nautical miles in the process, and taking 26 minutes.
4. Cruise for the required 3000 nautical miles (minus climb credit) at an altitude of 39,000 feet, at a velocity of 793 feet per second, or a Mach number of .82.
5. Upon reaching its destination, the FC-1D has the capability at loiter above the airport for 45 minutes before beginning descent.
6. Descent is enacted to the runway, maintaining FAR cabin depressurization rules and appropriate glide slope.
7. Landing gear, flaps, and spoilers are deployed for the landing in a 5000 ft runway at a sea level airport on a 76 degree day.
8. Taxi to a standard airport unloading chute, and cool down.
9. Have fuel remaining for emergencies.

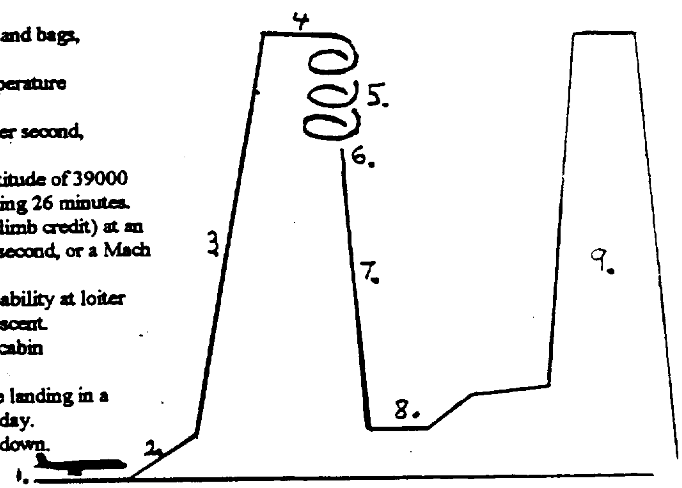


FIGURE 3.1: FC-1D Mission Profile

From the requirements given by the mission profile, the preliminary sizing of the FC-1D was initiated. The factors that affected the FC-1D sizing included the FAR one-engine out criteria, take-off field length, and the maximum lift coefficients (C_{Lmax}) at take-off and landing (Figure 3.2). The FC-1D C_{Lmax} at takeoff of 2.4 mandated a thrust-to-weight ratio of 0.37, which in turn created a required take-off thrust of 50,000 pounds. A wing loading of 117.5 lbs/ft^2 was dictated by a landing C_{Lmax} of 3.0 coupled with a landing field length of 5,000 ft. Because the required FAA landing field length of 5000 ft. is shorter than typical aircraft landing distances, the FC-1D's wing loading is lower than other planes in its category (See Table 1.2).

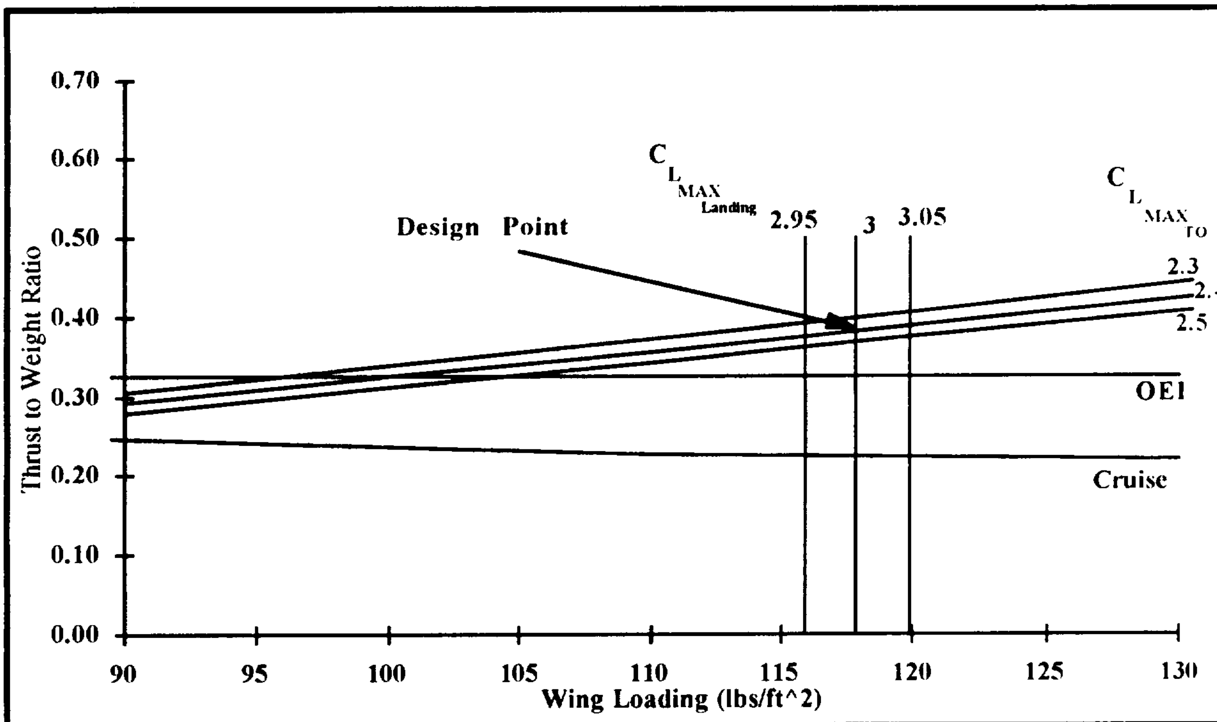


FIGURE 3.2: FC-1D Design Point

3.2 Range Performance

The RFP requires that the FC-1D cruise at 99% best Mach number as well as the best altitude corresponding to that Mach number. To determine the best cruise Mach number for the FC-1D, the specific range was maximized for efficiency. The specific range is defined as the miles flown per pound of fuel used and is calculated using Equation 3.1.

$$mi/lb = \frac{V}{c}\frac{L}{D}\frac{1}{W} \qquad (3.1)$$

Here V is the aircraft velocity, c is the specific fuel consumption, W is the average cruise weight, and L/D is the lift to drag ratio. As seen from Equation 3.1, to maximize the specific range, Flying Circus sought not only a high L/D in their design, but also a high cruise velocity. The maximum specific range was found by plotting specific range versus Mach number for various altitudes (Figure 3.3) according to the method outlined in Reference 3-1. Figure 3.3 shows that the specific range is maximized at a Mach number of 0.77 at an altitude of 39,000 feet. At these conditions the specific range was found to be 0.103 nautical miles

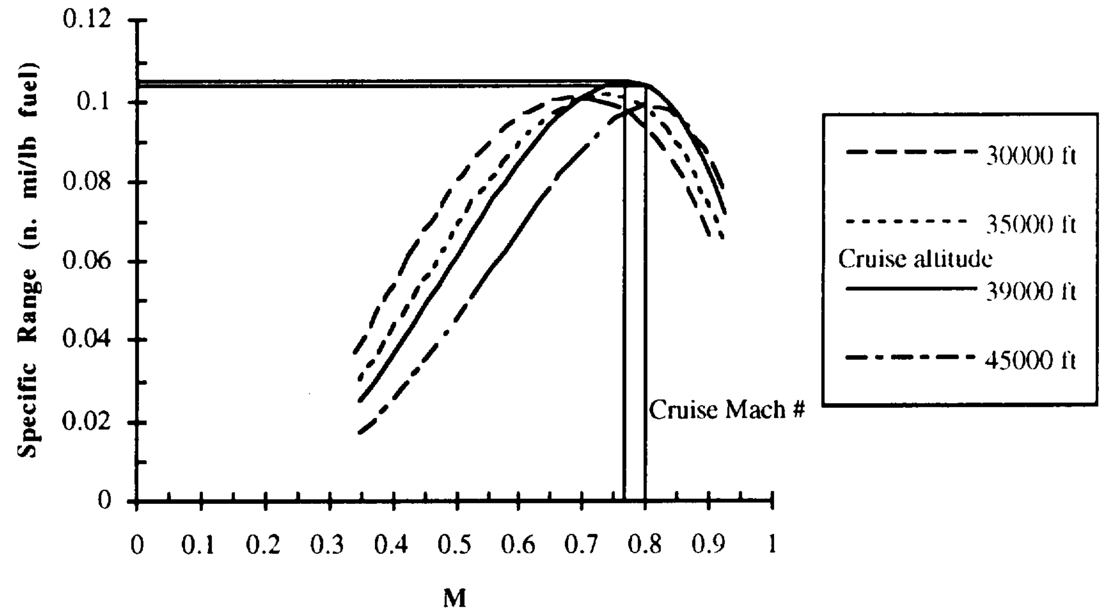


FIGURE 3.3: FC-1D Best Cruise Altitude, Mach Number Chart

flown per pound of fuel burned. At 99% velocity best range, a specific range of 0.102 was obtained at a corresponding cruise Mach number of 0.80. With knowledge of the cruise conditions for the FC-1D, the payload range curve was determined using the method outlined in Reference 3-2. Figure 3.4 shows the payload range curve for the FC-1D. As seen in the payload range diagram, the range for the FC-1D with 153 passengers is 3,000 nmi. To fly farther requires more fuel, which can be carried only by reducing the payload. When the fuel

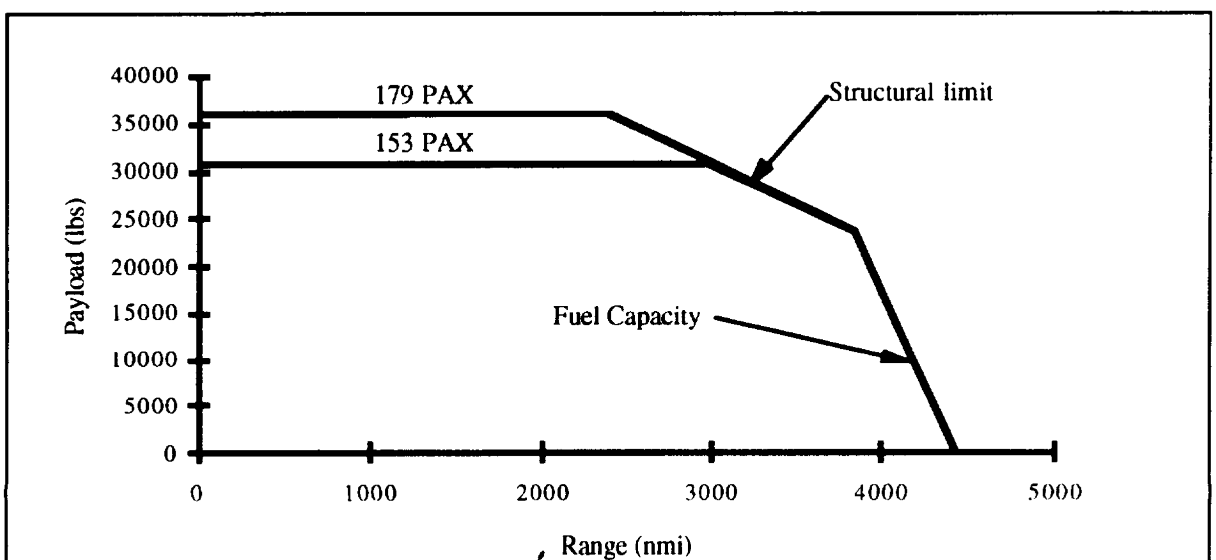


FIGURE 3.4: Payload Range Diagram for the FC-1D

tanks are full, range can be increased only by further decreasing payload. In the ferry condition (no payload) the FC-1D can travel a range of 4,430 nmi. For the maximum payload configuration of 179 passengers the FC-1D travels a distance of 2,400 nmi.

3.3 Best Rate of Climb

The RFP requires that the FC-1D reach its best cruising altitude at the best rate of climb. According to Reference 3-3, the best rate of climb is the maximum rate of climb. Since the aircraft was designed for maximum efficiency and speed at the cruise condition, it is desirable to reach the cruising altitude as fast as possible, to reduce flight time. The resulting decrease in block time will help in reducing the direct operating costs of the airline.

The maximum rate of climb for the FC-1D was determined using the method outlined in Reference 3-4. For passenger comfort the FC-1D will climb at an angle no greater than 20°. Based on this method, the maximum rate of climb was found by determining the maximum excess power from the engines. The excess power is defined as the power available to the engines minus the power required to overcome drag and weight. Before the maximum rate of climb can be found several limitations must be met. Some of these are summarized below.

- The power available from the engines.
- From 0 to 10,000 feet the velocity of the aircraft cannot exceed 250 knots, in accordance to FAA regulations.
- The cabin pressure cannot exceed an equivalent rate of climb of 500 feet per minute for passenger comfort up to 8,000 ft.
- The pressure difference between the cabin and ambient cannot exceed the pressure difference between 8,000 ft to 43,000 feet, due to structural limitations.
- The velocity of the aircraft cannot exceed the critical Mach number of 0.80 due to excess drag penalties.

Based on these restrictions and the procedure outlined in Reference 3-4, the maximum rate of climb for the FC-1D was estimated. The specific fuel consumption and thrust at different altitudes were obtained from the engine cycle analysis (Ref. 3-5). Figure 3.5 shows

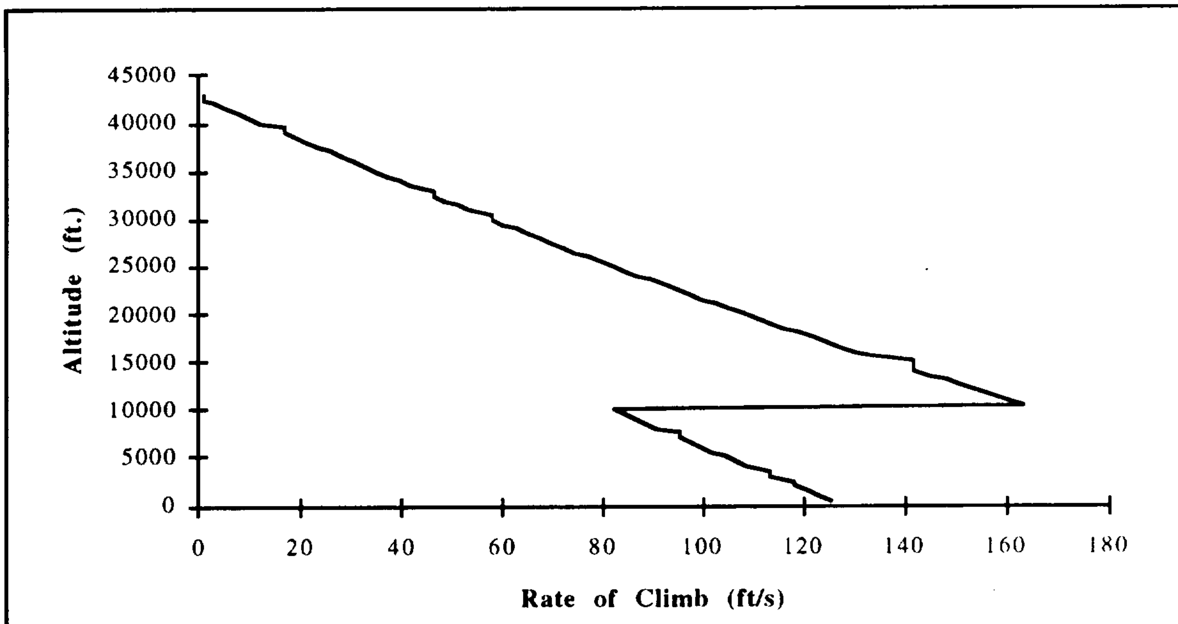


FIGURE 3.5 FC-1D Rate of Climb vs. Altitude

the FC-1D maximum rate of climb versus altitude. The total time to climb was found to be 19 minutes with a fuel burn of 2,600 lb. The total distance traveled in climb was found to be 137 nmi.

3.4 Field Performance

Field performance for the FC-1D was determined using FAR Part 25 rules (Ref. 3-6 and Ref. 3-7). The RFP specifies that the aircraft must take off at a maximum field length of 7,000 feet at sea level and a temperature of 27°F above International Standard Atmosphere (ISA). Figure 3.6 shows the takeoff performance for the FC-1D. This figure shows that the FC-1D meets the takeoff requirements specified by the RFP for all the possible takeoff weights up to an altitude of 5,000 ft. A take-off field length of 5,570 ft. was obtained at the maximum takeoff weight of 135,200 lbs and sea level conditions. Landing distances are also well within requirements. The use of high lift devices gives the FC-1D an approach speed of about 120 knots at maximum landing weight of 121,700 lbs. This speed gives a required FAR landing distance of 4,987 ft. based on Reference 3-8.

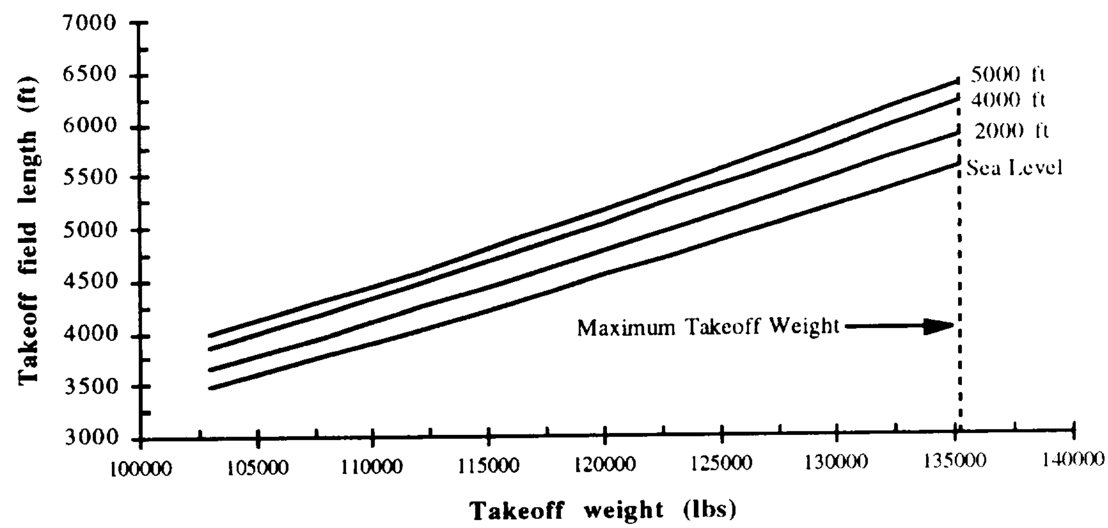


FIGURE 3.6: FC-1D Takeoff Performance

3.5 Operating Envelope

The FC-1D operating envelope was determined using the method outlined in Reference 3-9, and is shown in Figure 3.7. The operating envelope defines the flight speed and altitude limits for the aircraft. Stalling speed is the minimum speed with power off, encountered in the stalling maneuver. The stalling speed is indirectly proportional to the square root of the density. Therefore, the stalling speed increases with altitude as shown in Figure 3.7. The stalling speed varies from 96 knots at sea level to 200 knots at 43,000 ft.

The maximum operating speed (V_{MO}) should never be exceeded in any flight regime. The FC-1D was designed for a V_{MO} corresponding to M=0.84. V_{MO} defines the limiting airspeed so that the aircraft remains free from buffeting or undesirable flying qualities associated with compressibility. Figure 3.7 shows that V_{MO} varies from 240 knots at sea level to 460 knots at the maximum cabin altitude of 43,000 ft.

The diving speed, V_D, is the maximum speed in level flight at which the structure is designed to withstand particular loads set by the airworthiness regulations. The dive speed is approximately 1.07 times the maximum operating speed.

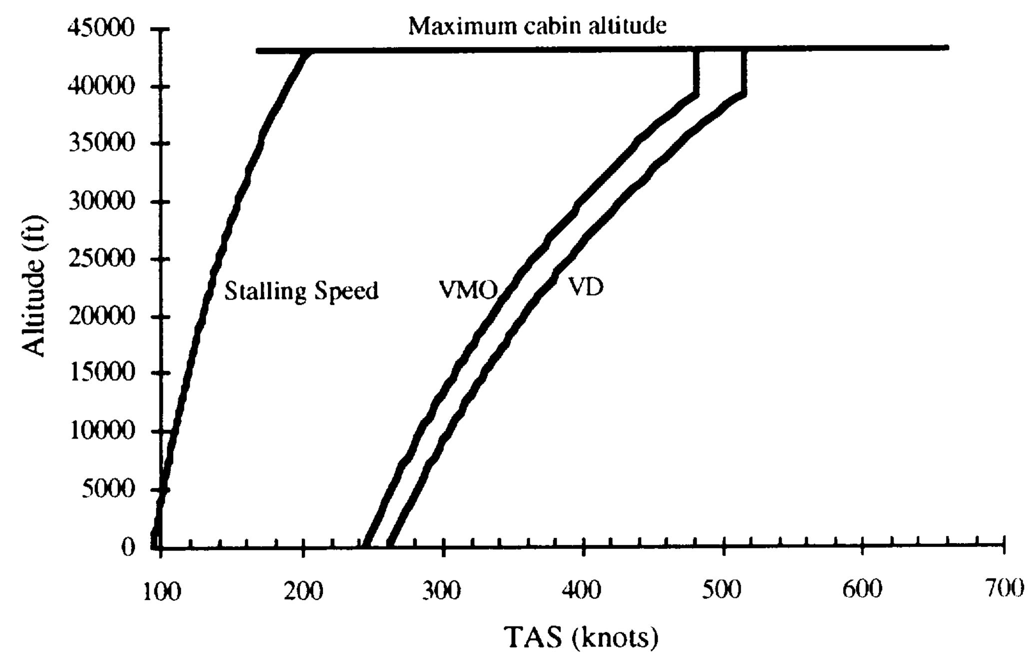


FIGURE 3.7: FC-1D Operating Envelope

4.1 Interior Layout Philosophy

The main design objectives in laying out the interior of the FC-1D was to reduce exterior size and weight, while maintaining a low cost aircraft. This allowed Flying Circus to achieve better DOC savings for the FC-1D. In addition, the interior layout had to meet RFP and FAR 25 requirements, all while providing passenger comfort.

The first consideration was to design for 153 passengers in a mixed class configuration, as required by the RFP. However, because airlines are often faced with different passenger ferrying needs, Flying Circus will present two configurations as possible interior layouts (See *Cabin Layout*). In addition to the required 153 passenger mixed configuration, 179 passengers can be seated in a single class configuration with the seat pitch reduced to 29 inches. This configuration is the maximum allowed by FAR 25.807 door requirements. A summary of the cabin dimensions for the FC-1D is shown in Table 4.1, with other comparable aircraft (Ref. 4-1). The FC-1D aisle width and seat pitches not only meet FAR requirements (Ref. 4-2), but it gives the passenger much more room than most competing aircraft. This wider aisle also facilitates quicker loading and unloading of passengers, and it adds to the illusion of a larger interior. Passenger comfort over the long flight was another benefit of increasing seat dimensions (Figure 4.1). From Table 4.2, it can also be shown that the FC-1D surpasses FAR 25.815 seat requirements, to give the passenger greater comfort. This is shown in Figure 4.1, which illustrates volume/passenger versus trip duration for different configurations. This shows that passengers onboard the FC-1D will not

TABLE 4.1: Seat Dimensions for Various Aircraft

	Aisle Width	Pitch		Galley	Overhead
		First Class	Economy	Dimensions	Containers
FC-1D	22 inches	40 inches	32 inches	12.2 ft x 88.2 ft	3.13 ft^2/pass
MD 90-30	15 inches	36 inches	31 inches	10.1 ft x 101 ft	2.4 ft^2/pass
Boeing 737	18 inches	38.3 inches	32 inches	11.3 ft x 77.2 ft	1.7 ft^2/pass
A320	19 inches	36 inches	32 inches	12.1 ft x 89.8 ft	2.0 ft^2/pass

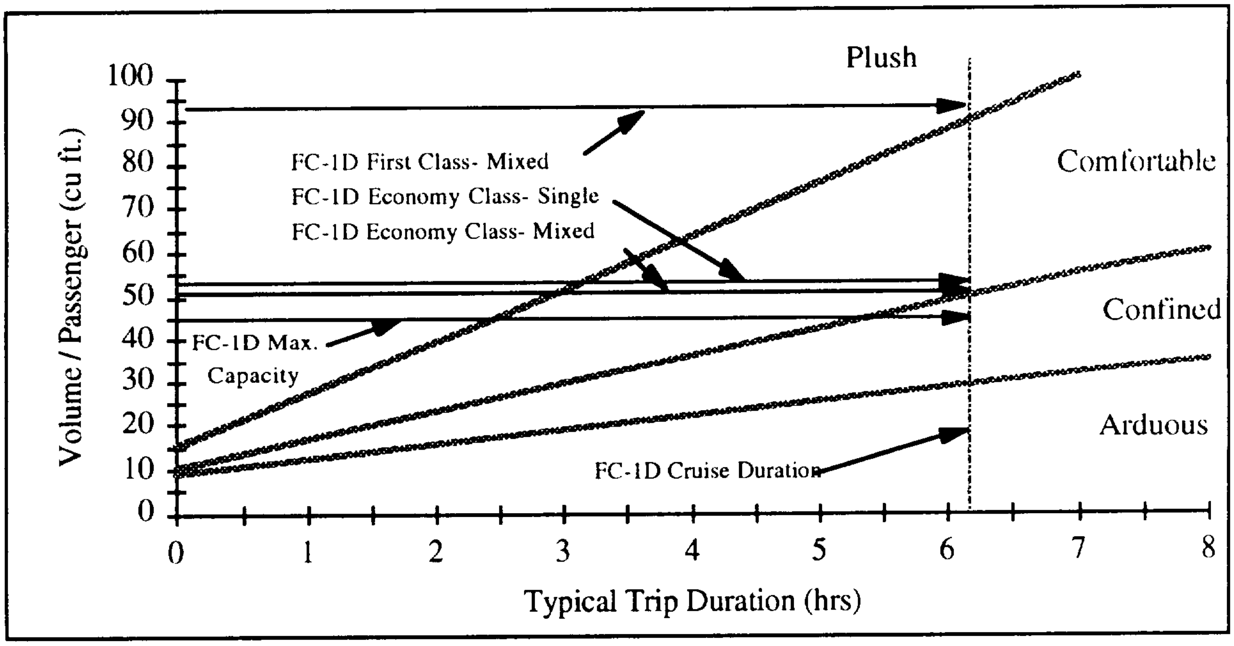


FIGURE 4.1 Passenger Comfort on the FC-1D

feel discomfort, even in the maximum capacity configuration, through the trip duration of 6 hour. Flying Circus will offer to airlines seats constructed by Keiper Recaro of Germany that conform to FAR 25.561 and 25.562 minimum g-force requirements.

Once the seating arrangement was laid out, the door, aisle, crew, galley and lavatory requirements were considered. The passenger doors and emergency exit requirements were laid out as specified by FAR 85.807 requirements (Table 4.2). For passenger convenience, four vacuum flush lavatories, equipped with a toilet, sink and amenities were provided. With the exception of the lavatory next to the forward galley, all of these lavatories are modular and attach to the seat guides. This allows airlines more versatility on its interior layout. To meet RFP requirements, two galleys (Figure 4.2) are built into the interior layout of the FC-1D. The aft galley has space for 8 food carts, 4 ovens, a small refrigerator, coffee makers, and miscellaneous storage, while the front galley has space for 4 food carts. These galleys are easily serviced by the Type I doors. Flight attendant seating was designed so seating is near the larger emergency exits and to accommodate a view of 80 percent of the passenger seating area in all configurations (Figure 4.5). Overhead baggage compartments have been installed in the FC-1D in compliance with the RFP. The total overhead storage is 480.5 cubic feet.

TABLE 4.2 Meeting FAR 25 Requirements

FAR 25.807-c1	Doors/153 pax	2 type I and 2 type III one each side
FAR 25.807-a1	Type I doors	4, 2 fore and 2 aft, 72"x36", at floor level
FAR 25.807-a3	Type III doors	4 over wing exits ,20"x 48" step up inside< 20" step down outside < 27"
FAR 25.815	Aisle width requirements	more than 18" @ less than 25" from floor more than 20" @ more than 25" from floor
FAR 25.855	Cargo & baggage compartments	No cargo or baggage compartment can contain controls, wiring, lines, equipment or accessories whose damage would effect safe operation of the plane.
FAR 25.561, 562	seat requirements	Seats and supporting structure will meet all requirements.

Space is provided in the panels underneath the overhead luggage, or in the armrests, for optional passenger entertainment. The cargo compartment accommodates eleven 727-200c or LD-W containers and has room for bulk storage at the rear of the cargo compartment. The minimum necessary requirements for 179 passengers is about 500 cubic feet of cargo area, which the FC-1D easily meets. An optional sliding carpet baggage option or telescoping bin system is also available, which is convenient for airlines that do not use LD-W or 727-200c cargo containers.

4.2 Flight Deck Panels

Standardization of flight decks is being demanded by airlines to reduce training time and cost. Therefore, the flight deck of the FC-1D is designed to be compatible with existing flight decks. Six eight-inch-square interchangeable, multicolor, and multi-functional display units will be within fingertip reach of the pilots. The use of flat CRT's will reduce the weight of these parts compared to traditional types of displays. The flight deck plans also include a two pilot configuration with an optional third seat for an observer. A list of the flight deck components is listed in Figure 4.2.

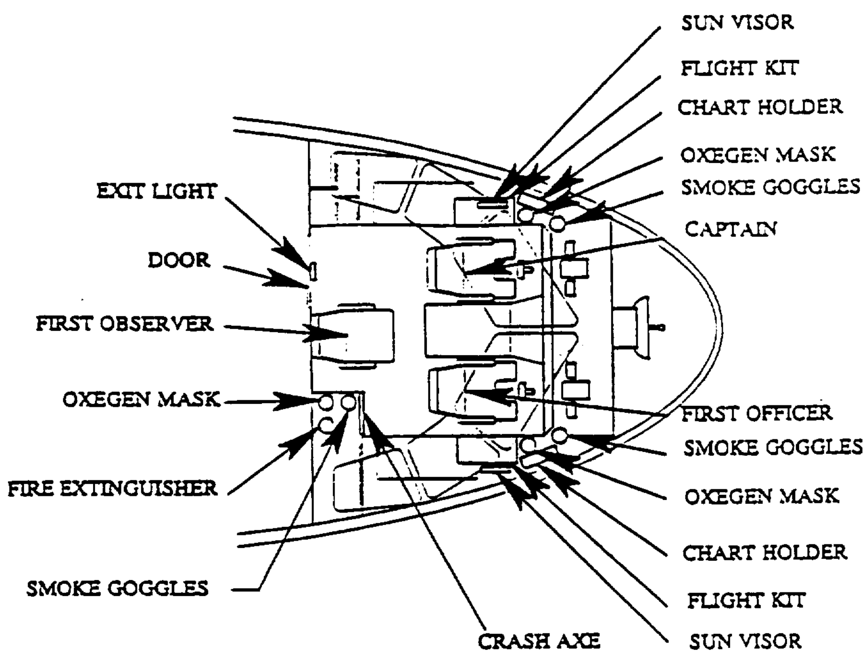


FIGURE 4.2: FC-1D Flight Deck

5. AERODYNAMICS

The main aerodynamic design goal of the FC-1D was to achieve good aerodynamic and stability characteristics, while fulfilling the RFP requirements. This was done by designing the FC-1D for optimum efficiency in range, endurance, rate of climb, cruising speed, and drag. To accomplish this task while maintaining a low cost profile, the Flying Circus approached each component of the aerodynamic performance as a function of cost, weight and drag.

5.1 Airfoil Selection

One of the major considerations in the design of a wing is the airfoil selection. Based on the performance requirements set by the RFP and the results from preliminary sizing the following aerodynamics requirements were obtained for a 3-D wing. Taking into account the effect of a 3-D swept wing, the following 2-D section characteristics were obtained using simple wing sweep theory (Reference 5-1).

TABLE 5.1: Airfoil Requirements

3-D	2-D
Cruise C_L = .545 Reynolds Number = 17 million M cruise = 0.8 t/c = 11% Leading Edge Sweep = 24^o	Cruise C_L = .7189 Reynolds Number = 17 million M cruise = .75 t/c = 12%

Due to the high cruise Mach number, compressibility effects will be important. Therefore, airfoils with a high Mach drag divergence will be required. To meet the performance requirements listed above in Table 5.1, supercritical airfoils were selected to make up the wing. Supercritical airfoils provide a higher drag divergence Mach number than conventional airfoils.

In selecting the airfoils, a proper variation of c_{lmax} and the local lift coefficient across the wing span was considered in order to avoid tip stall. Thus giving the wing an aerodynamic twist rather than a geometric twist. When the wing reaches initial stall, the wing should stall inboard first. Considering the 2-D wing section parameters listed in Table 5.1 as well as the aircraft performance requirements, the airfoils on Figure 5.1 were employed along the span of the wing. Figure 5.2 shows the c_l vs α curves for the inboard, midspan, and outboard airfoils at their designed Mach number of 0.76. A thick airfoil at the inboard was chosen because of the high structural bending loads and to accommodate more wing fuel volume. Also, the aft camber of this airfoil creates a large negative pitching moment that acts to counter the large positive pitching moment produced by the aft wing nacelle configuration.

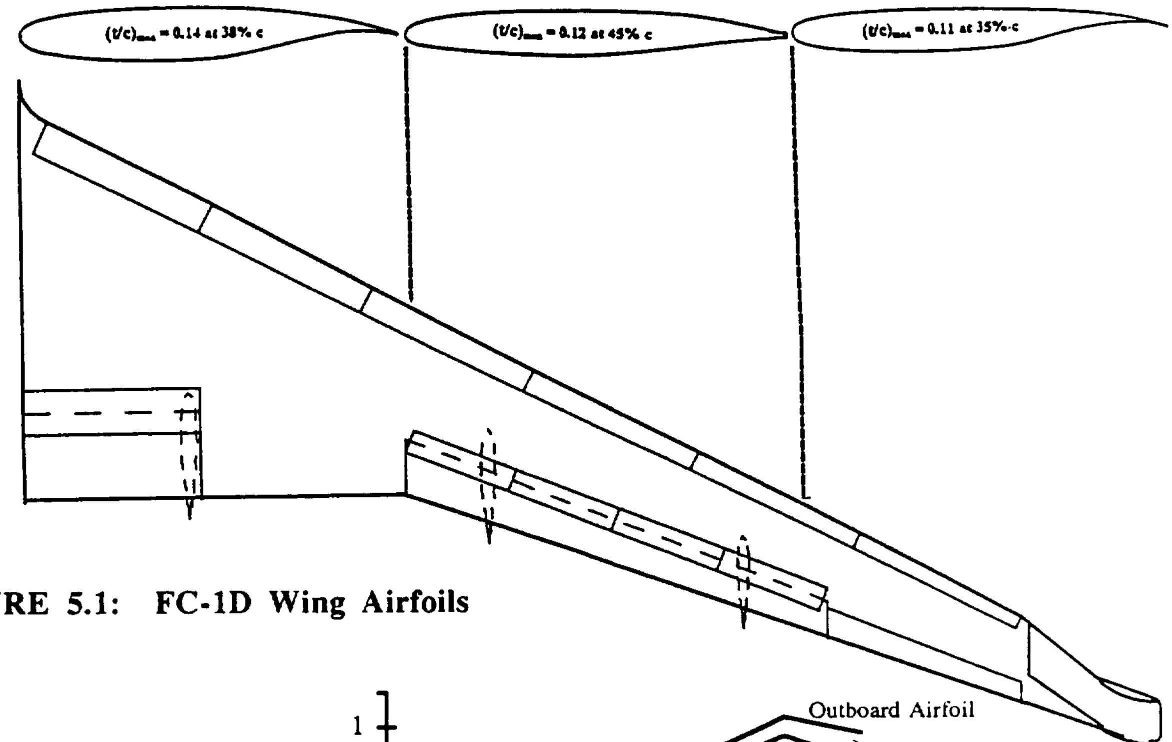


FIGURE 5.1: FC-1D Wing Airfoils

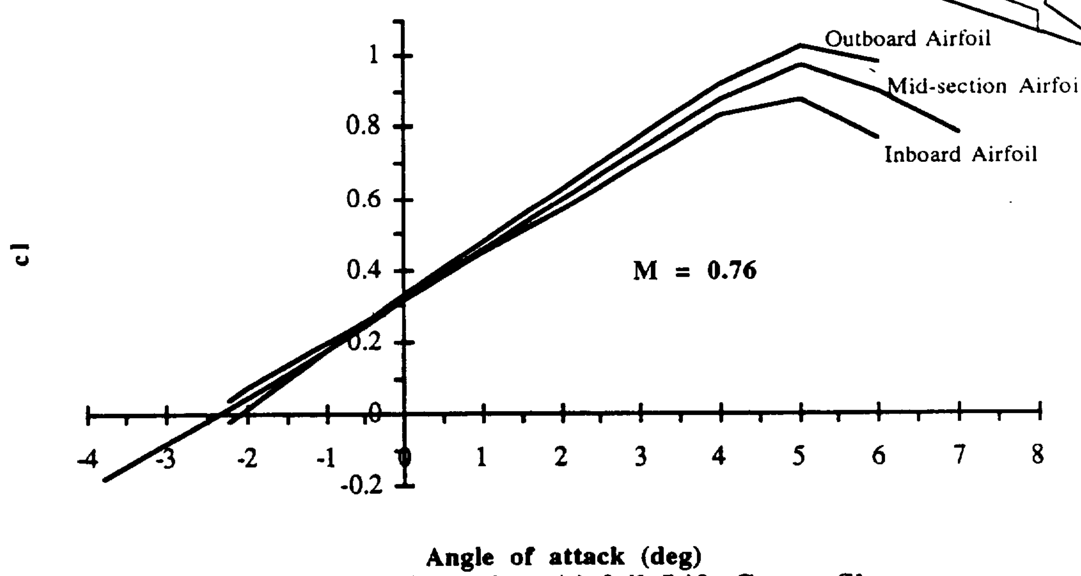


FIGURE 5.2: Inboard And Midsection Airfoil Lift Curve Slopes

The airfoil at the mid span was chosen to help vary the c_{lmax} across the span as required to avoid tip stall. A thin wing section was chosen at the outboard to raise the local c_{lmax} and minimize pressure drag caused by thickness.

Airfoil section selection was also performed for the other control surfaces. The resulting section chosen for the horizontal tail was the NACA-0012 airfoil. The NACA-0015 airfoil was chosen for the vertical tail (see *Empennage Sizing*).

5.2 Wing Design

Selecting airfoils is only part of the overall wing design. The wing design also comprises several other aspects in order to optimize the wing for the cruise conditions and to meet the takeoff and landing requirements.

The wing geometry was determined based on the sizing and performance parameters obtained from the design point plot (Figure 3.1) and the demands imposed by the RFP. The wing area, S, was determined from the wing loading obtained from the design point, as shown in Figure 3.1. From the wing loading of 117 pounds per square foot, the wing area was found to be 1150 square feet. A quarter chord sweep angle of 24° was obtained based on the critical Mach number of the airfoils and the cruise Mach number. A taper ratio of 0.3 was chosen to obtain the most efficient lift distribution across the wing.

To obtain the optimum aspect ratio for the FC-1D, a DOC vs AR chart was generated. Figure 5.3 shows this aspect ratio optimization chart. The aspect ratio affects DOC through Reference 5-2. Note from Figure 5.3 that the DOC is minimized at an aspect ratio of 10. At

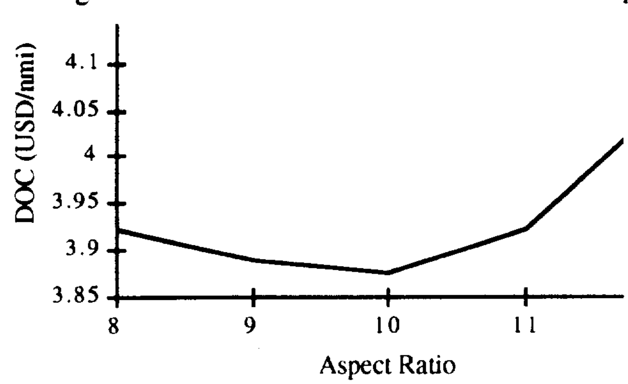


Figure 5.3: Aspect Ratio Optimization Plot

that point the benefits for induced drag and weight are maximized for DOC. For this reason the aspect ratio was chosen to be 10. With an aspect ratio aircraft weight and drag. The weight of the wing was varied based on an equation found in

of 10, the wing span, b, was found to be 110 ft.

A trailing edge extension was added to the inboard part of the wing to accommodate the landing gear and to provide a strong structural support for the aft wing mounted engine. Lateral control will be provided by an outboard aileron for low speeds and inboard spoilers for high speeds. The control surface sizing will be discussed in the *Stability and Control* section of this report.

5.3 High Lift Devices

To attain the high lift necessary for take-off and landing, high lift devices were added to the trailing edge and the leading edge of the wing. These high lift devices were sized using the method outlined in Reference 5-3. Due to the high lift requirements and the large flap cutout from the aft engine nacelle placement, double slotted Fowler flaps were employed at the trailing edge. Although double slotted Fowler flaps increase cost and complexity, it was the only way that the required high lift could be achieved given the wing airfoils and wing design.

To increase the stall angle of attack, high lift devices were employed at the leading edge of the wing. Leading edge slats were added to the outboard of the wing. Less effective Krueger flaps were added at the inboard section of the wing to obtain positive longitudinal stability in the stall. Table 5.2 summarizes the high lift devices employed on the FC-1D.

TABLE 5.2: High Lift Devices Summary

High Lift Device Type	Location	% Chord	Deflection		Max. Def.
			Takeoff	Landing	
Double Slotted Fowler Flap	Trailing Edge	30	20	30	30
Slat	Leading Edge	15	25	25	25
Krueger Flap	Leading Edge	15	15	15	10

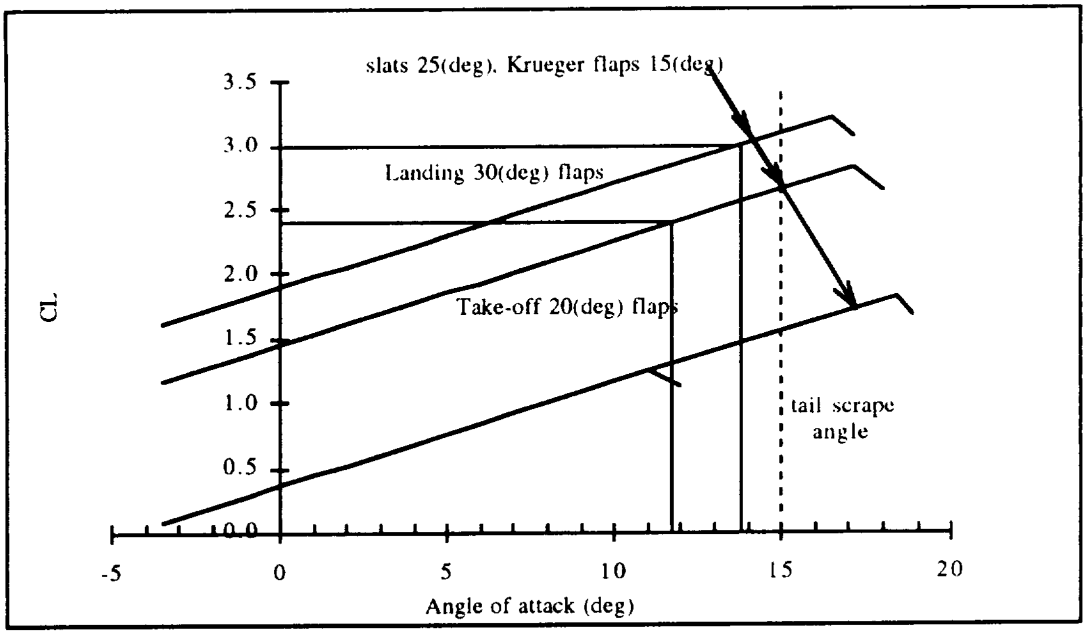


FIGURE 5.4: FC-1D Takeoff and Landing Lift Curves

From the sizing of the high lift devices, lift curve slopes were obtained with high lift devices deployed. Figure 5.4 shows the lift curve slope for the clean, clean with slats and Krueger flaps, takeoff, and landing configurations. From Figure 5.4 it can be seen that the required C_{Lmax} for takeoff of 2.4 is achieved at an angle of attack of 12°. In order to meet the high C_L of 3.0 for landing, all the high lift devices are deployed. The lift curve slope for the landing configuration (Figure 5.4), shows that the required C_{Lmax} of 3.0 is achieved at an angle of attack of 13.8° in the landing configuration.

5.4 Fuselage Aerodynamics

The main concerns in the design of the fuselage were the structural weight of the fuselage as well as the aerodynamic efficiency. In order to get the minimum drag, the skin surface area was minimized, as shown in Figure 2.3. Another major driver for good aerodynamic design during fuselage layout was the use of smooth longitudinal contours, such as the wing fuselage integration, the fuselage empennage integration, and the nearly elliptical nose shape. This was done to minimize wave drag by getting a smooth area ruling.

In order to minimize interference drag, the wing-fuselage intersection was fitted with fairings. The tail was designed for minimum interference drag, while maintaining good structural qualities. A circular cross-section was chosen to minimize weight because a cylinder is an ideal pressure vessel. To prevent flow separation, the aft-fuselage deviation from the freestream direction was set at 7.5°.

5.5 Drag Reduction Program

As was mentioned in the concept considerations section, the FC-1D evolved from the baseline aircraft through the implementation of advanced technologies. The baseline aircraft was found to have a higher DOC than the industry average. To reduce the DOC of the baseline aircraft, the Flying Circus implemented a drag reduction program. Through the evolution of the FC-1D from the baseline aircraft, drag was reduced from a total cruise drag coefficient of 0.0293 to 0.0257, a reduction of 12.2 percent. This translates into a direct reduction in fuel burned during cruise, which, in turn, translates into DOC savings for the airlines.

In order to target the main components of drag acting on the baseline aircraft, the drag was broken down into its components as shown in Table 5.3 and Figure 5.5. In order to reduce drag acting on the baseline aircraft, Flying Circus targeted the areas of drag that were most critical. Notice that the main components to the drag are wing drag, induced drag, skin friction drag, nacelle interference drag, and nacelle drag. Therefore, these areas of drag were targeted for reduction.

5.5.1 Riblets

Since skin friction drag was such a large part of the total drag acting on the FC-1D, riblets were employed as a passive reduction method to reduce skin viscosity. Developed by 3M Corporation, in conjunction with NASA Langley, riblets are streamwise surface fabrics that are applied to the surface of the airplane so they are aligned with the direction of the flow. The optimum riblets have sharp valleys and sharp peaks with an aspect ratio, H/S of 1 (Figure 5.6). The height, H, on the riblet is approximately 0.003 in. Data obtained by NASA Langley indicates a fuselage drag reduction of 16 percent. By placing riblets over 75 percent

TABLE 5.3: FC-1D Drag Breakdown

Zero Lift Drag		**Comments**	
Cdo Wing	0.005984	Riblets reduce skin friction by 10 percent	
Cdo Fuselage	0.006821	Riblets on 90 percent of fuselage reduce drag by 16 percent	
Cdo Horizontal Tail	0.000782	Riblets provide minor drag reduction on horizontal and	
Cdo Vertical Tail	0.000509	vertical tails; tail size reduced by dynamic controls	
Windmill Drag (OEI)	0.009217	Only applicable for one-engine out conditions	
Windshield Drag	0.000227	Area ruling used to minimize wave drag	
Cdo Nacelle	0.001961	Riblets, local area ruling reduce drag by 10 percent	
Drag due to Lift			
Cdl Wing	0.006979	Spiroids reduce induced drag by 10 percent	
Trim Drag	0.000380	Negative stability margin, fly-by-wire creates little tail lift	
Base Drag Fuselage	0.000068	Optimum 15 degree taper for fuselage tail cone	
Cdl Fuselage	0.000008	Maximum cruise fuselage angle of attack is one degree	
Nacelle Interference	0.001961	Reduced by placing engines aft	
Landing And Takeoff Drag			
Landing - 25 deg. flaps	0.020118	**Flap Interf. - Landing**	0.005029
Take-off - 10 deg. flaps	0.006218	**Flap Interf. - Take-off**	0.001554
Slats	0.007392	**Landing Gear**	0.018661

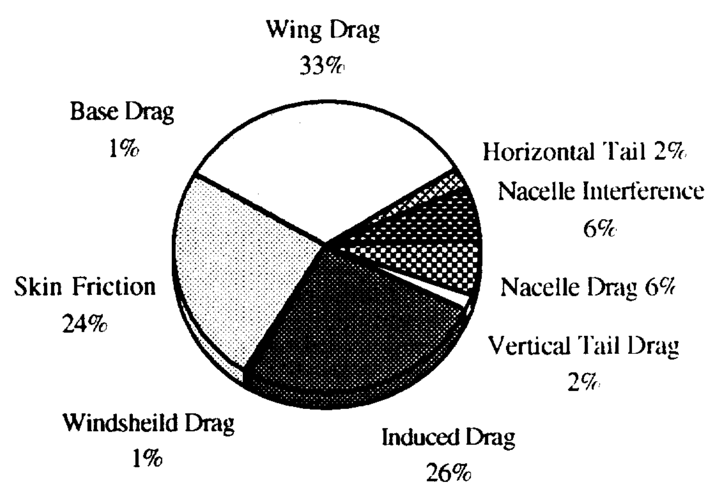


FIGURE 5.5: FC-1D Drag Breakdown

of the FC-1D's wetted surface area, an 8 percent fuselage drag reduction was credited (Reference 5-4). Riblets move air fluctuations away from the wall, reducing the magnitude of turbulence production (Reference 5-4). Aerodynamically, riblets work by creating turbulence in their "valleys" that tends to push viscous flow away from its surface. In general, they are a passive method that creates a slip layer at the surface.

Riblets have already been tried by some airframe manufacturers, including the Airbus A320, which was flight tested with riblets on November 9, 1989 (Reference 5-5). However,

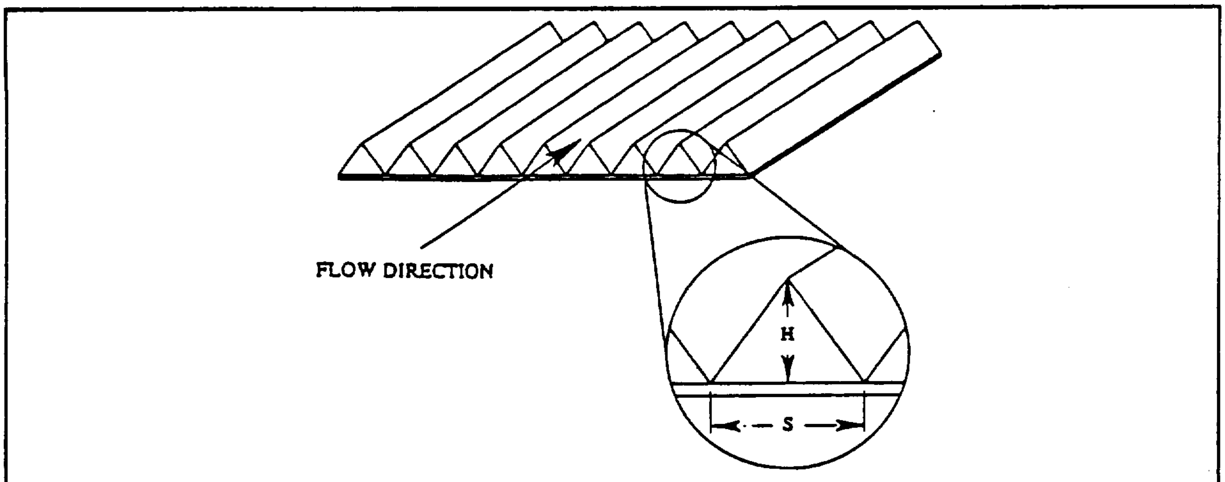


FIGURE 5.6: Riblet Cross-section

the current problem with ultraviolet sensitivity has caused some airlines to take them off. However, the problems are known and, by the year the FC-1D goes into service, the new and improved riblets should be developed and widely used (Reference 5-6).

5.5.2 Spiroids

With the reduction taken in fuselage drag, the next major drag area targeted was the induced drag acting on the wing. To accomplish this, spiroids were placed on the wing tips (see Three-View). Developed by Seattle Aviation Partners Inc., spiroids are looped winglets made from fiberglass and weighing approximately 100 pounds apiece. The key to spiroid performance is its closed loop design that eliminates the concentrated wing tip vortex, which represents almost 50% of aircraft induced drag generated during cruise flight. By reducing the induced drag, their implementation is expected to yield induced drag reductions of 10% at cruise relative to the baseline aircraft (Reference 5-7). An added benefit from the spiroid is associated with reduced cross stream velocity levels (i.e., vorticity) in the wing wake. Because the wake intensity is reduced, the separation distance between the aircraft can be decreased. This is illustrated in Figure 5.7 which shows estimated separation distances between following and lead aircraft equipped with spiroids as a function of the span of the following aircraft. The pilots conducting the flight tests of spiroid equipped aircraft reported that the use of spiroids also enhanced the planes stability (Reference 5-7). These added benefits improve operational efficiency while increasing flight safety.

To design the optimum spiroid geometry for the FC-1D, several considerations will be taken into account. Selecting appropriate airfoils along the span of the spiroid will be important to optimize the aerodynamic surface loading on the spiroid, and to avoid shock waves and flow separation. The added weight and skin friction drag due to the spiroid will also have to be minimized in the design of the spiroid. There are many ways to exploit the tradeoffs between drag, structural margins and wing weight. However, these tradeoffs can only be explored through extensive wind tunnel and flight tests. The design of the spiroids themselves is proprietary to Aviation Partners. They will be manufactured from foam-filled

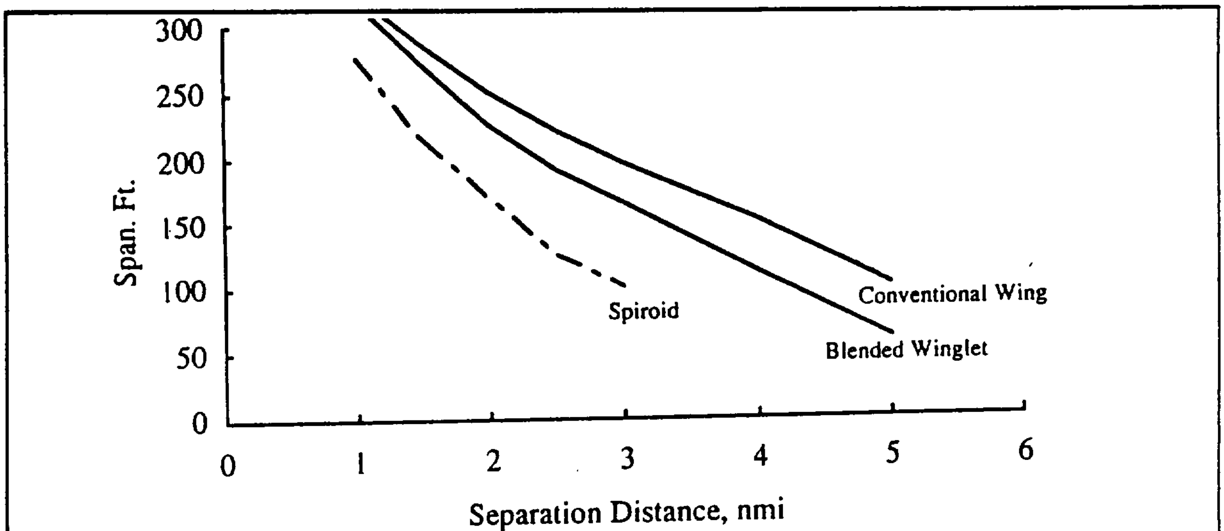


FIGURE 5.7: Separation Distances between Aircraft Equipped with Spiroids *(Courtesy Aviation Partners, Inc.)*

fiberglass using cold, hand lay-up techniques to the most efficient form (Reference 5-7). The spiroids would then be purchased separately by Flying Circus and transferred to the FC-1D assembly plant, where it would then be bolted onto the ends of the wings with steel attachment fittings.

Spiroids were introduced to the aviation world in 1990. For this reason the spiroids will not be ready for market for about three to five years from now. By the year 2000, when the FC-1D will be ready for service, spiroids will be a proven technology and be ready to be placed on the FC-1D.

5.5.3 Aft Wing Nacelle

The most radical drag-reduction scheme implemented on the FC-1D is the aft-wing nacelle. Reports indicate that for forward wing mounted engines, it is a major task to reduce interference drag. In addition, by placing the engine forward of the wing, turbulence created by the engines, pylons, and nacelles disturb the lift distribution over the wing. To solve this problem, the Flying Circus placed the engines aft of the wing, in order to obtain a better lift distribution over the wing. In addition, due to a more favorable cross sectional area distribution of the aft wing nacelle configuration, lower wave drag and a higher drag divergence Mach number are obtained. Preliminary data suggests that this would create a decrease in interference drag and profile drag of approximately five percent of the total airplane drag, which creates an excellent drag reduction (Reference 5-8). However, this design does have some structural drawbacks, including flutter and thrust reverser impingement. These will be addressed in detail in the *Flutter* and *Nacelle Integration* sections of this report.

After the drag credits were summed for the FC-1D, data showed that the FC-1D achieved a total cruise drag coefficient of .0257, which is five percent lower than other aircraft in this class. Using the methods of Reference 5-9, the drag polar for the FC-1D could be generated, showing the drag characteristics at all phases of flight.

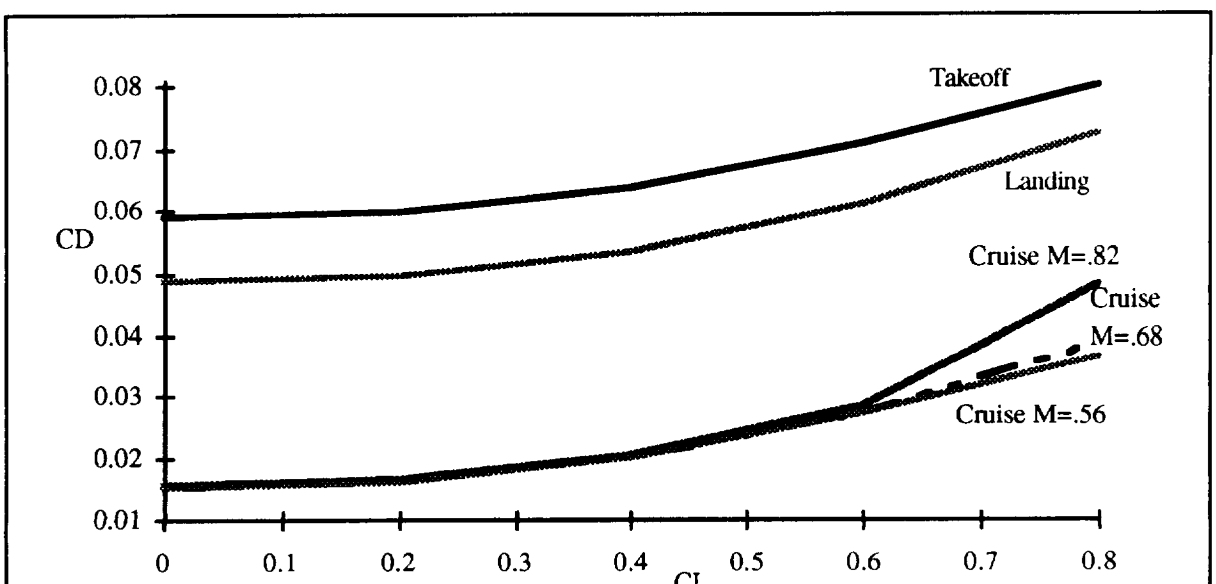


FIGURE 5.8: FC-1D Cruise Drag Polar

6. ENGINE SELECTION

Early in the FC-1D design process, the selection and integration of a propulsion system was required. Flying Circus had to select an engine that would not only provide the FC-1D's thrust requirements, but was also quiet, environmentally friendly, and cost effective. To select the size range of the engine, it was necessary to meet the design point requirement of a thrust to weight ratio of .37 (see Figure 3.1). With a take-off weight of 135,200 pounds, a propulsion system was required that delivered a minimum of 51,000 pounds of thrust at sea level for takeoff, and 5,000 pounds of thrust at a 39,000 foot altitude. In order to meet this requirement, Flying Circus went through a selection process of available commercial engines in this size range. Through this process, the engine choice was narrowed down to the International Aero Engines (IAE) AG V2527 and the CFM 56-3XS. It is the intention of Flying Circus to present both engines as possible alternatives for the propulsion needs of the FC-1D. Since each airline has its own engine repair and maintenance set-up, they could choose their own engine. This would reduce airline DOC by lowering their engine maintenance costs (See Figure 14.7, *Cost Estimates*).

A chart listing the main attributes of each engine is illustrated on the following page (Table 6.1, 6.2, and 6.3). The V2527 (Figure 6.1), which delivers 26,500 lbs of thrust at sea level, is an offshoot of the IAE family of engines. As a derated version of the V2530 (30,000 lbs thrust), the V2527 operates at lower temperatures (about 130 °F cooler), which reduces engine wear and maintenance costs (Ref. 6-1). Also, the IAE V2527 boasts an extremely low specific fuel consumption (SFC) of 0.570 lb/hr/lb (at a cruise altitude of 35,000 feet and a cruise Mach of 0.8). The 27,000 pound thrust CFM 56-3XS is a derivative of the highly successful family of CFM engines, and was initially developed for the Boeing 737-X (Figure 6.2).

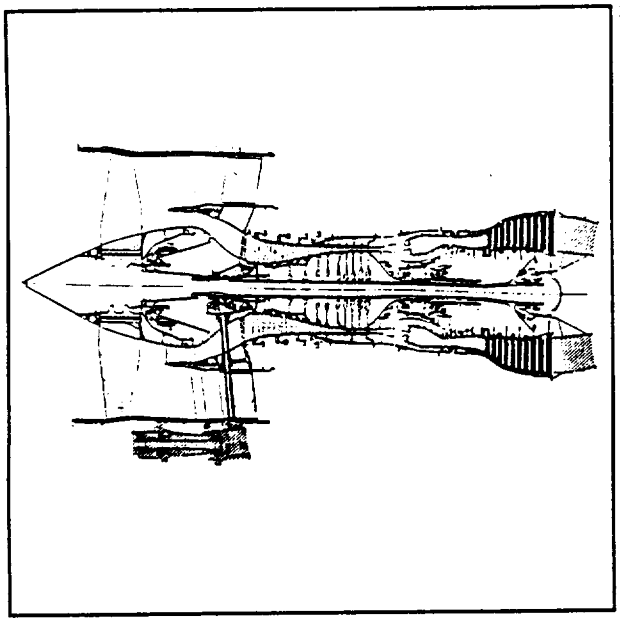


FIGURE 6.1 IAE Engine
(Courtesy IAE, Inc.)

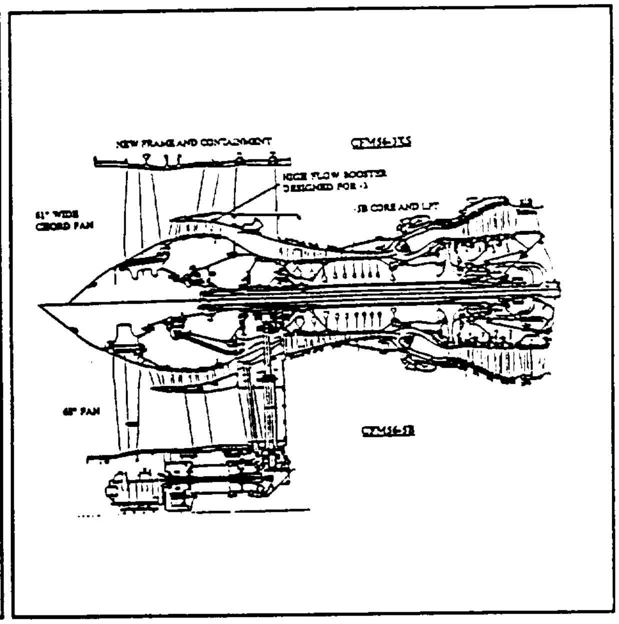


FIGURE 6.2 CFM 56-3XS
(Courtesy CFM)

TABLE 6.1: FC-1D Engine Selection Criteria

	Inter. Aero Engine V2527	CFM 56-3XS
Thrust (Sea Level)	26500 lbs	27000 lbs
Specific Fuel Consumption (Mach=.8, Alt.=35,000 ft)	.570 lb/hr/lb	.622 lb/hr/lb
Dry Weight	4942 lbs	4241 lbs
Bypass Ratio	4.8	5
Diameter	5.5 feet	5.1 feet
Noise	15 EPNdB lower FAA Stage 3	12 EPNdB lower FAA Stage 3
Thrust at 35,000 ft, M=.8	5200 lbs	5370 lbs

TABLE 6.2: Engine Component Characteristics

1.Low pressure compressor	4 stages	3 axial stages, high flow booster
2.High pressure compressor	10 stage, inlet guide,variable stator vanes	9 stage rotor with first 4 variable
3.Combustor	Annular segmented construction	Double dome combustor
4.High pressure turbine	2 Stages, air cooled with bleed air	Single stage, air-cooled stator and rotor airfoils
5.Low pressure turbine	5 stages of uncooled blading	Five stage
6.Fan	Transmits 848 lbm/second	Shroudless, solid titanium fan.

TABLE 6.3: FC-1D Engine Comparison Characteristics

	IAE V2527	CFM 56-3XS	Comments
Noise	+		IAE engine is 3 EPNdB quieter than CFM56 (Ref. 6-2)
SFC	+		CFM burns eight percent more fuel
Reliability	-	+	CFM baseline engine better maintenance record
Emissions	+		IAE has lower NOX emissions

The CFM 56-3XS has design changes that give it lower noise, reduced maintenance, better performance, and lower emissions (Ref. 6-2). It was certified in late 1993. Because many airline companies are already suited for CFM56 maintenance, and the CFM56-3XS has interchangeable parts with the CFM56-3 and the CFM56-5, it was the decision of the Flying Circus that the CFM56-3XS would be an option for these airlines. However, because the FC-1D performance can only be evaluated for one engine, Flying Circus selected the IAE V2527 for its engine recommendation. The reason that the IAE engine was chosen for the FC-1D is due to its lower fuel consumption. The updated CFM56-3XS is expected to have a SFC of 0.620 lbm/hr/lbm, which is eight percent higher than the SFC of the IAE V2527. Because of the FC-1D's long mission range, this translates into a 1887 lb increase in fuel burned in flight. This, in turn, created a DOC increase of 1.7 percent (Figure 6.3), making the CFM56 prohibitive.

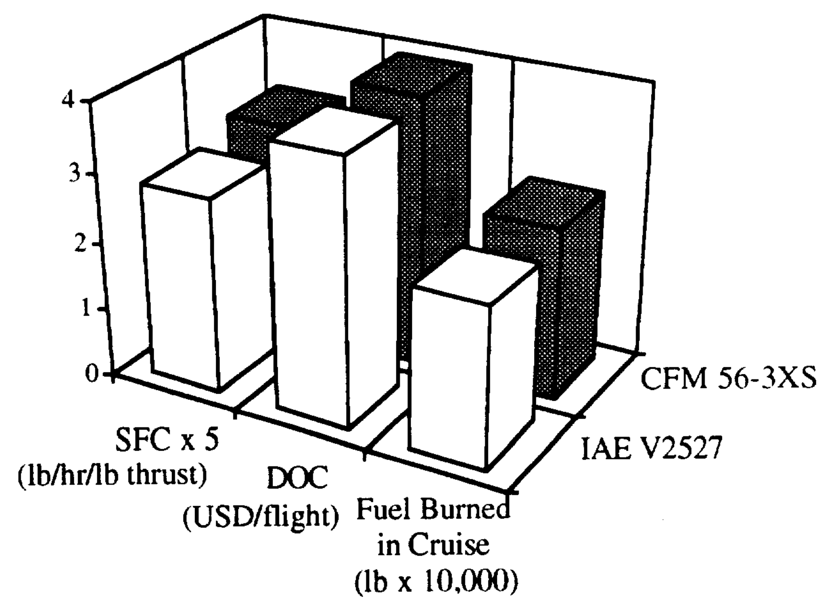


FIGURE 6.3 Engine Comparison

6.2 Engine Placement

The engine placement for the FC-1D was the subject of intense scrutinization by the Flying Circus. The final placement of the engine was considered for two main designs: wing mounted and tail mounted (Figure 6.4). Flying Circus opted for wing mounted engines. With fuselage or tail mounted engines, there are problems with turbulence disrupting the inlet flow

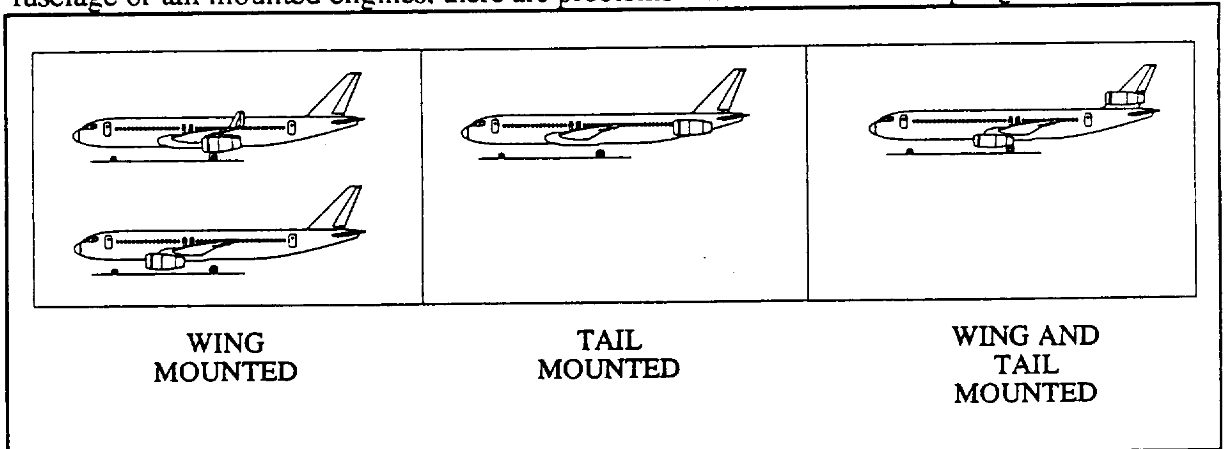


Figure 6.4 FC-1D Engine Mounting Considerations

of the engines, especially at takeoff. Another problem with placing the engines on the fuselage is the increased structure required to mount the engines. Besides an increase in aircraft weight, this also tends to shift the CG of the empty aircraft aft. This forces the wing to be placed further aft to get desirable stability margin and CG shift characteristics (see *Center of Gravity*). In order to keep the tail volumes constant, the aft horizontal and vertical tail size would have to increase. Another major drawback to tail mounted engines is its interference with the movement of the variable incidence tail. Conventional aft-mounted engine planes, such as the DC-9, are forced to go with a T-tail. This would be impractical for the FC-1D, because of the structural loads associated with putting the horizontal stabilizer's hydraulic screw jack inside the vertical tail.

By placing the engine on the wing, there is also a weight penalty created by the increased wing structure needed to support the engine. However, this engine weight helps to alleviate the upward bending moment on the wing during flight conditions. In addition, maintenance of wing-mounted engines is improved, since they would be hanging down for easy access, and there would be few obstructions for maintenance personnel. As explained earlier, this reduced maintenance is beneficial.

From this, Flying Circus determined that the aft-wing nacelle configuration best suited their requirements for lowered drag. By placing the engine aft of the wing, a number of benefits were gained, including a sustained lift distribution over the wing's surface and reduced skin friction drag (see *Drag Analysis*).

6.3 Nacelle Integration

The basic engine pylon structural arrangement for the IAE V2527 can be seen in Figure 7.5. By placing the engines aft of the wing, some structural problems need to be addressed. Flutter was the main concern of the Flying Circus, because of the inherent instability of placing the engine aft of the wing. This problem will be addressed in more detail in the *Structures* section of this report. Another problem faced by placing the engine aft on the wing concerns engine exhaust impingement on the wing and flaps during landing. The FC-1D solved this problem by employing four-way cascade thrust reversers, which are a modified version of the thrust reversers that are currently used on the IAE engine nacelles, and designed by Rohr Industries (Ref. 6-3). The design of the thrust reversers minimizes foreign object damage (FOD) by diverting the lower half of the flow away from the centerline of the engine at 45 degree angles. The upper half of the flow is diverted up and forward to minimize interference with the flaps, as seen in Figure 6.5.

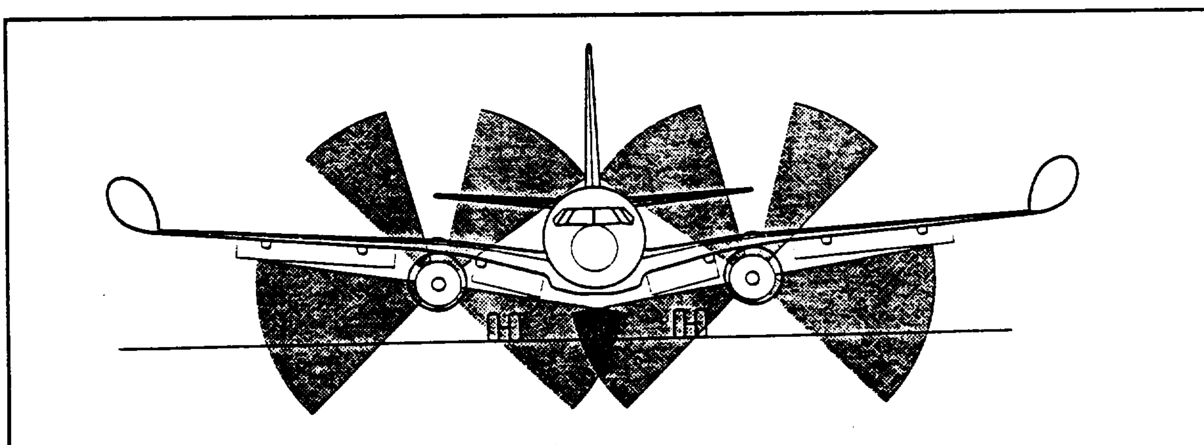


FIGURE 6.5 FC-1D Thrust Reversers

6.4 Environmental Considerations

With the choice of engines, the FC-1D had to meet noise and emissions requirements.

For the year 2000, the FC-1D must meet FAR Part 36 Stage 3 and expected Stage 4 noise requirements. A summary of the Stage 3 requirements is listed in Table 6.4 for the FC-1D and other aircraft employing IAE engines (Ref. 6-4). The expected FC-1D takeoff and sideline noise can be found by comparing them to IAE engine noise data. These extrapolated numbers suggest the FC-1D is within 4 Effective Perceived Noise decibels (EPNdB) of Stage 3 requirements (Ref. 6-5). However, approach noise is dominated by thrust reversers and flow on the wing. Because the engine inlet is placed under the wing for the AWN, the approach noise can only be roughly estimated (Ref. 6-6). It should be noted that the four-way cascade thrust reversers and engine inlet placement will probably create approach noise problems. To help alleviate this, Flying Circus will install noise absorbing material in the nacelles. The nacelle manufacturers recently completed implementation of a noise absorbing cowling (Ref. 6-7). This was done to reduce the fan noise that is a major part of the current IAE noise problem. Because it only affects the area directly in front of the engine, it has only been a problem for first-class passengers on other aircraft. However, the FC-1D, with its aft-wing engine placement, will use this nacelle in order to reduce passenger discomfort over the majority of the plane.

TABLE 6.4 Noise Considerations

	FC-1D		Airbus A319	Airbus A320	Airbus A321
	FAR Stage 3	Estimated	FAR Stage 3	FAR Stage 3	Far Stage 3
Approach	99.9 EPNdB	94-98 EPNdB	100 EPNdB	100.5 EPNdB	101 EPNdB
Sideline	96 EPNdB	91 EPNdB	96.5 EPNdB	96.8 EPNdB	97 EPNdB
Takeoff	90.4 EPNdB	95 EPNdB	91 EPNdB	91.5 EPNdB	92.5 EPNdB

Emissions of the FC-1D was found from IAE engine data for Oxides of Nitrogen, Smoke, Carbon Monoxide and Carbon Dioxide (Ref. 6-8). The data shows that the IAE engine has considerably less emissions than current engines (Figure 6.6), and easily meets limits imposed by the Environmental Protection Agency (EPA) and the International Civil Aviation Organization (ICAO) (Ref. 6-9). However, IAE is in the process of developing an axially-staged combustor that will reduce NOx emissions another 20 percent (Ref. 6-10).

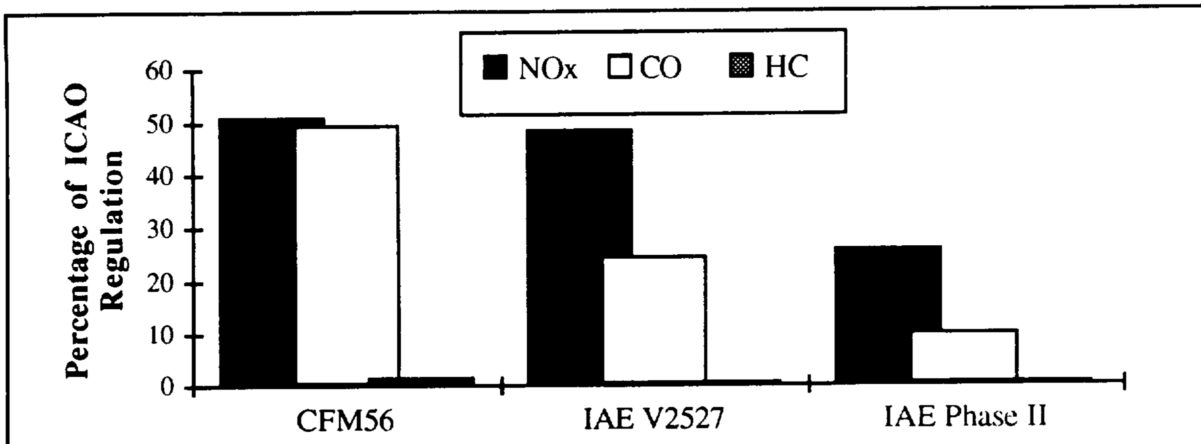


FIGURE 6.6 Engine Emissions for ICAO Regulations *(courtesy IAE)*

This would be offered as an option to airlines that are required to operate in areas with stricter emissions requirements, such as the Scandinavian countries. It should be pointed out, though, that these low NOx burners are heavier, more complex, and increase engine cost by another 5 percent (Ref. 6-11).

6.5 Future Propulsion Considerations

More advanced engines were considered for the FC-1D, including very high bypass ratio engines and unducted propeller engines. The benefits of these larger bypass engines lie in their low fuel consumptions. Evidence suggests that for a bypass ratio of 10, there is an approximate 10 percent SFC savings, and for advanced ducted propfans, with bypass ratios in the 20 to 30 range, there is a 20 percent SFC reduction (Ref. 6-12). Ultrabypass engines boast increased SFC savings of 25 percent over conventional engines. Of these, ultrabypass and advanced ducted engines represent technology that is in its initial testing stages and did not represent a feasible choice for the FC-1D. High bypass ratio engines with a bypass ratio of more than six show an improvement in SFC burn, but also show a projected four to five percent increase in maintenance costs (Ref. 6-13). At a bypass ratio of 10, the engine would then need a gearbox to accommodate the optimum efficiency of the fan without building in excessive low-pressure turbine stages. This excess machinery adds to the complexity, overhead, and maintenance of this type of engine. However, the main disadvantage of implementing a high bypass ratio engine on the FC-1D is the basic question of reliability of any high bypass ratio engine which could be developed by the year 2000. Two likely candidates include the Pratt&Whitney Advanced Ducted Propulsor (ADP) and the Rolls-Royce Aft Ducted Fan, neither of which are scheduled to be certified before the turn of the century. For future considerations, however, the ADP program has the ability to be implemented on IAE V2500 engine cores when it enters production around the turn of the century (Ref. 6-14). But until the characteristics of the ADP can be evaluated at that time, these concepts represent a poor technological risk for the cost-conscious FC-1D.

7.1 Basic Structural Description

The FC-1D is primarily a metal low-wing aircraft, with full cantilevered wing and tail surfaces, semi-monocoque fuselage and fully retractable landing gear. Its two power plants are located under the wings on short struts in a non-conventional aft wing nacelle (AWN) configuration.

7.1 Design Philosophy

The structural design of a low cost commercial transport required that a number of guidelines be met. The aircraft had to have fail safe design and be structurally efficient. The structure must also have a high-fatigue design life and comply to industry regulations. In addition, the aircraft must be designed for ease of manufacture and maintainability. The Flying Circus utilized these guidelines as the primary structural design philosophy for the FC-1D.

The Flying Circus feels that passenger and aircraft safety is of the utmost importance and the main drivers of a fail-safe design. Redundant structural load paths and scheduled aircraft structural inspections are the basis for the fail-safe design philosophy. To maintain a fail-safe design and still retain a highly efficient aircraft, the use of composite materials will be incorporated as a lightweight replacement for aluminum in some primary and secondary aircraft components. These composites will be used specifically in the vertical and horizontal tail, empennage, floor beams, high lift devices and control surfaces To give the customer a larger return on investment the FC-1D will be designed with a service life goal of thirty years or more.

The FC-1D will utilize the latest technology and inservice experience to create advanced corrosion prevention methods. High fatigue life materials will be selected on the basis of long life, high toughness, workability, and maintainability.

The manufacture and design of the FC-1D structure will utilize the most advanced design and manufacturing processes to ensure reduced parts rework and cut quality control work load by minimizing the number of parts required to be manufactured. Customer input and the most advanced computer-aided design systems will be utilized to ensure manufacturing and maintainability requirements during pre-assembly.

7.3 Structural Design Criteria

The structural design criteria defines the types of maneuvers, speeds, useful loads, and gross weights which are to be considered for the FC-1D. In addition, the structural criteria must consider inadvertent maneuvers, effects of turbulent air, and severity of ground contact during landing. This analysis showed that the FC-1D loads were typical of those encountered by civil transport aircraft.

The first consideration in the structural design criteria of the FC-1D was the V-n (velocity vs. load factor) diagram. The V-n diagram presents the operating flight strength limitations of the FC-1D see Tables 7.1 & 7.2 Flying Circus analyzed the aircraft loads and flight weight combinations that would yield the largest aircraft loads, including the loads on the wings. An example of this was found to be at the end of a ferry cruise condition on a steep descent, shown in Figure 7.1.

The weight of the FC-1D was modeled as the aircraft operating empty weight plus fuel and reserves. The altitude was chosen on the basis of the highest equivalent gust intensities.

Due to its light weight in this flight condition, the FC-1D is susceptible to high vertical accelerations caused by vertical gusts. The V-n diagram shows that the maximum and minimum load factors of +3.1 and -1.1 occur below the design cruise speed (V_c).

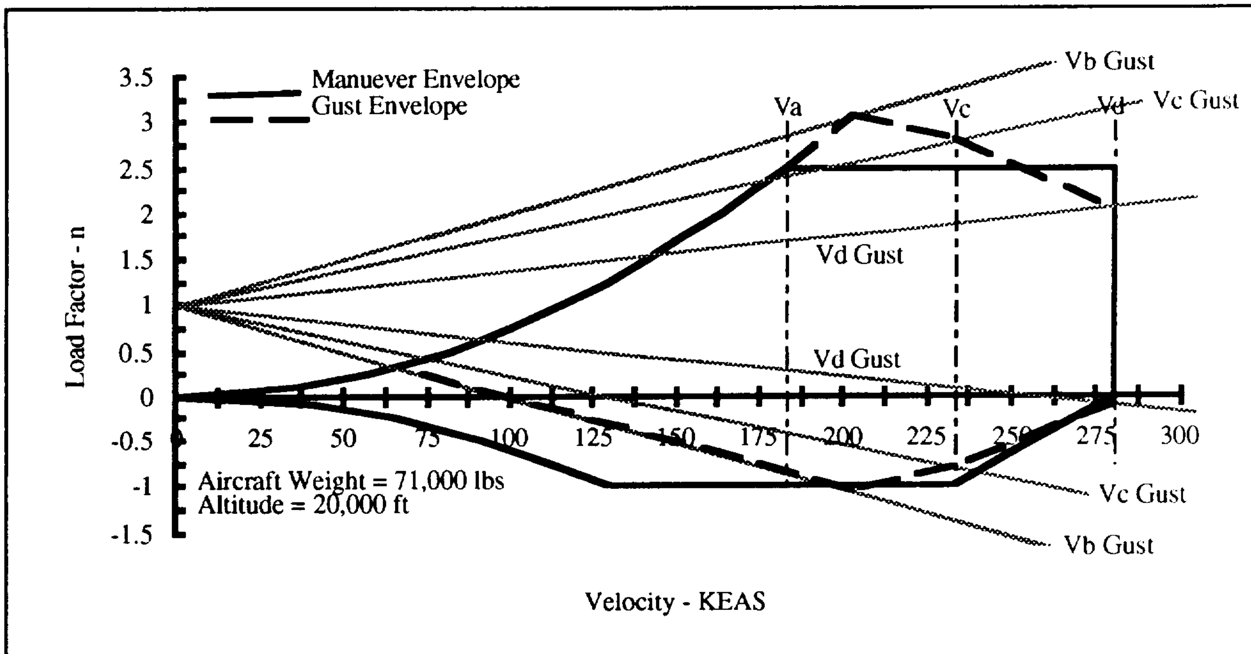


FIGURE 7.1 : Composite V-n Diagram for the FC-1D

The design and certificate limitation speeds for the FC-1D are obtained from the V-n diagram, using procedures in FAR 25, (Tables 7.1 and 7.2).

Table 7.1: FC-1D Certificate Limitation Airspeeds

Component	Speed	Position	KEAS
Landing Gear	V_{LO}	Retract Extend Extended	156
Flaps	V_{FE}	1° 5° 15° 20° 25°	165 155 150 144 131

Component structural sizing for the FC-1D was defined by the ultimate loads encountered. For each component the highest limit load conditions were sought and multiplied by a factor of safety of 1.5. The resulting ultimate load and material characteristics

Table 7.2: Design Airspeeds for the FC-1D

Velocity	Definition	KEAS
V_A	Maneuver Speed	183
V_B	Maximum gust Intensity Speed	203
V_C	Design Cruise Speed	234
V_D	Dive Speed	280
V_{MO}	Maximum Operating Speed	245

were then used to size major structural components.

7.4 Fuselage Structure

The fuselage is a pressurized semi-monocoque structure formed from circumferential frames and longitudinal stringers. Pressure bulkheads at the forward and aft ends of the fuselage form a pressure vessel. The fuselage is divided horizontally by the floor, which is built up from beams and panels.

The primary fuselage structural requirements consist of pressure and flight loads. The fuselage of the FC-1D is designed for atmospheric environments up to 43,000 ft and flight velocities up to Mach 0.84 at 39,000 ft. The primary flight loads applied to the fuselage are lift, thrust, and pitching moment applied by the wing, and maneuvering tail loads from the empennage.

7.5 Bulkheads and Frames

Bulkheads are provided at points of concentrated forces from the wings, tail surfaces, and landing gear. Bulkheads distribute the applied loads into the fuselage skins. The FC-1D has 10 major bulkheads. The function and location of each bulkhead is listed in Table 7.3 and are shown in the *Structural Layout.*

Frames primarily serve to maintain the shape of the fuselage and to reduce the column length of the stringers. The FC-1D has approximately 60 frames located at 24 inch intervals. Frames were sized using the methods in References 7-1 and 7-2. Frames have a depth of

TABLE 7.3: Bulkhead Functions and Locations

Bulkhead	Function	Fuselage Stat.(in)
1	Forward pressure bulkhead	340
2	Nose landing gear strut	536
3	Wing front spar attachment	968
4	Wing rear spar attachment	1013
5	Main landing gear support beam	1088
6	Aft pressure bulkhead	1600
7	Front vertical tail spar	1644
8	Rear vertical tail spar	1700
9	Horizontal tail jackscrew support	1732
10	Horizontal tail pivot attachment and APU firewall	1792

approximately 4.5 inches and a width of 1.5 inches and are constructed of 7075-T73 aluminum alloy.

7.5.1 Keelbeams

The FC-1D has two keelbeams underneath the fuselage wing box that run along its length to the trailing edge extension. Measured horizontally, the keels are located ± 9 inches from aircraft vertical centerline. Because it must withstand front and rear fuselage forces and moments, the keelbeam is the most highly loaded structure in the fuselage. This structure takes the place of the lower half of the skin/stringer system that is missing underneath the wing center section due to the presence of the main gear wheel well.

7.5.2 Skin/Stringers

The primary design requirements considered for the fuselage skin was the pressure differential and the number of GAG (Ground-Air-Ground) cycles. In a thirty year service life it was assumed that the FC-1D would accumulate approximately 60,000 cycles and a maximum pressure differential of 1240 psf. As a result of the methods in Reference 7-3, hoop stress analysis predicted that a skin needed a thickness of 0.06 inches. The fuselage skin is made of 2024-T3 aluminum alloy.

A typical skin-stringer panel is shown in Figure 7-2. Stringers are made of 7075-T6 aluminum alloy and are spaced approximately 9 inches apart around the circumference of the fuselage, to prevent fuselage bucking.

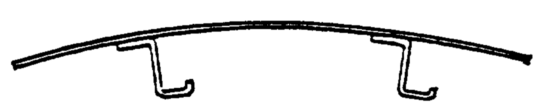


FIGURE 7.2: Skin-Stringer Panel

7.5.3 Flooring

The primary function of the floor beams is to absorb passenger and cabin pressure loads. Floor beams act as an attachment base for the cabin floor and seat tracks. Floor beams are attached to every frame in the fuselage and act as tension ties to resist cabin pressure loads. The floor beams are made of carbon fiber reinforced plastic C-channels and have cutouts to allow cabling. The floor beams are braced by struts that help form the side walls of the cargo hold.

7.6 Wing Structure

The basic FC-1D wing structure consists of left, center and right wing boxes. These are built up from front spar, rear spar, ribs, top and bottom skins and stringers. The thickness of the spars, wing skin, and the size of the spar caps were calculated by setting the wing tip deflection at cruise conditions to be no greater than 1.5 ft. This was chosen to keep the wing from deflecting too far from its designed aerodynamic shape. The wing structure was modeled as a swept tapered box beam and then theoretically loaded with structure weight, engine, and fuel weights with lift and drag forces at a specified load factor. At the root of the spar, the spar thickness is required to be 1.3 inches. The skin and spar caps have a thickness of 0.13 inches and cross sectional area of 8.5 square inches.

The dimensions of the wing structural members were optimized to reduce total wing weight. Wing ribs were placed perpendicular to the rear spar in 24 inch intervals along the wing. This was done to keep total rib length to a minimum which reduces structural weight.

The wing of the FC-1D was theoretically loaded through the aircraft weights and load factors that result from maneuver and gust conditions. Tensile, compressive, and shear forces were then computed to ensure that the resulting stresses were below the allowable stresses of the material. The highest wing load condition was found to be a 2.5g maximum maneuver at MTOW (Maximum Take-Off Weight). This is a condition that may be encountered in an emergency situation after or during take-off . The resulting wing shear and moments are shown in Figure 7.3 and 7.4

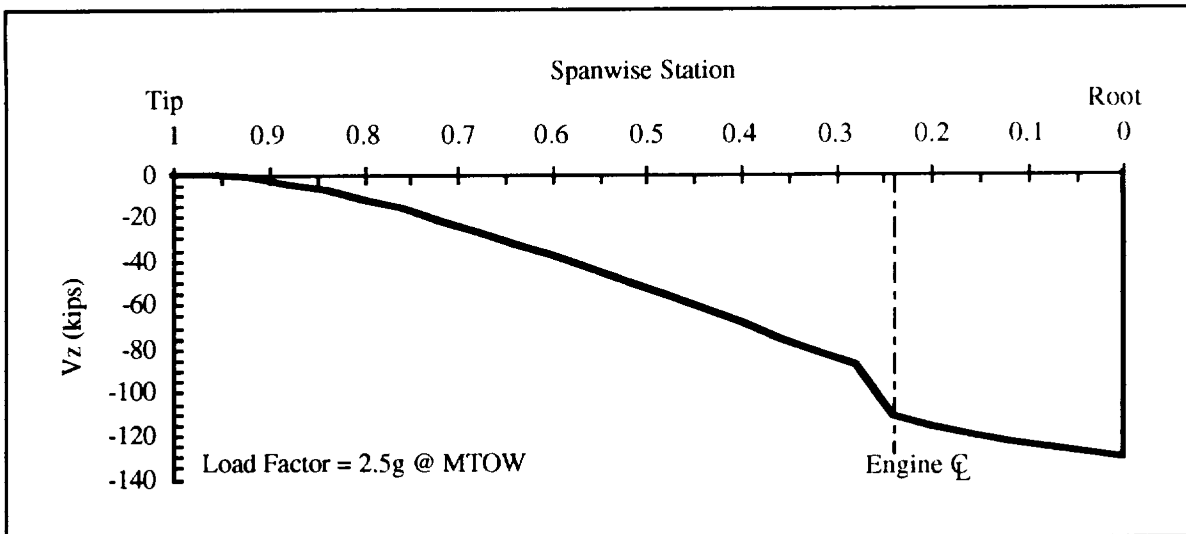


Figure 7.3: FC-1D Wing Shear Diagram

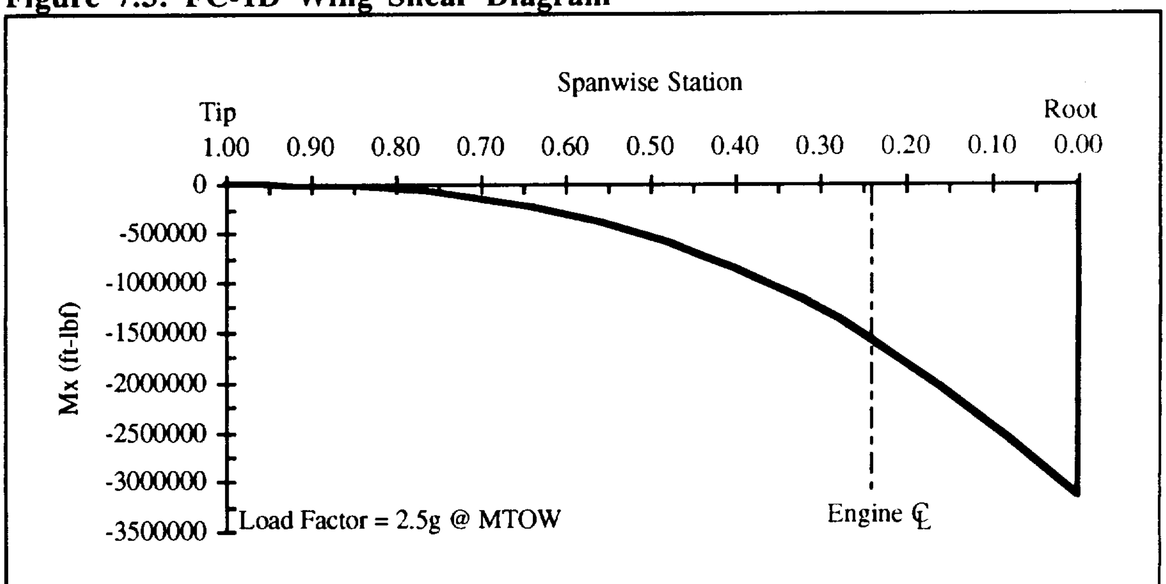


Figure 7.4: FC-1D Wing Moment Diagram

Swept wings have an associated increased torsional moment due to lift. The AWN configuration gave the FC-1D some inherent wing torsional relief benefits, shown in Figure 7.5. This shows the effect of the AWN configuration for different flight conditions, aircraft load factors and flight weights. The AWN configuration relieves approximately 35 percent of the wing torsional moment when compared to the baseline aircraft with the conventional engine-forward of wing arrangement. The fluctuations in torsion relief are due to changes in fuel weight and landing gear load path geometry.

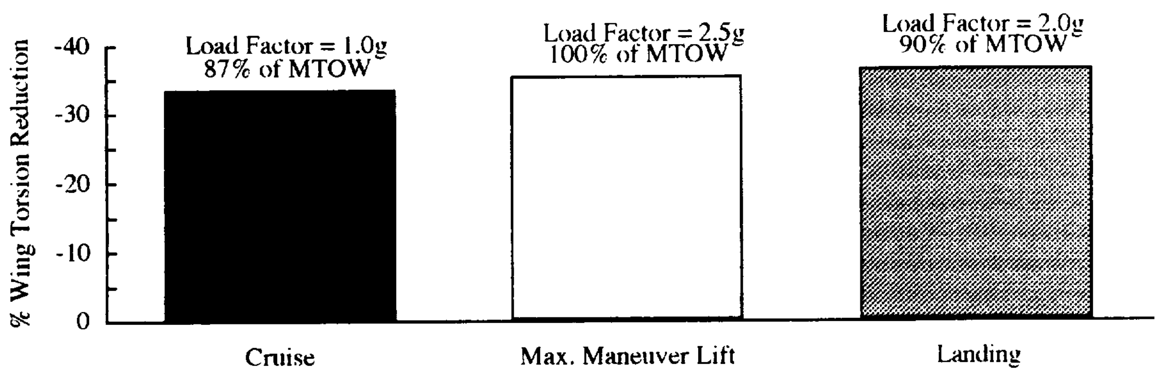


FIGURE 7.5: Effect of AWN Configuration on Wing Torsional Relief Relative to Baseline Aircraft

Wing tip deflections for key loading conditions were calculated by numerically integrating the following equation from (Ref. 7-4)

$$\delta_T = \int_0^{\frac{(b/2 - r_f)}{\cos\Lambda_{0.5}}} \frac{yM(y)}{EI(y)}\, dy$$

Where d_T is the tip deflection, M(y) is the moment curve acting on the wing (Figure 7.5), E is the Young's modulus, I(y) is the moment of inertia of the beam, b is the wing span, r_f is the fuselage radius, and $\Lambda_{0.5}$ the half chord sweep angle. The resulting deflections are shown in Table 7.3

TABLE 7.4: Wing Tip Deflections

Flight Condition	Weight (% of MTOW)	Load factor	Deflection (ft)
Max. Maneuver Lift	100	2.5	4.7
Landing	90	2.0	0.8
Cruise	87	1.0	1.5
Taxi	100	1.0	-0.6

7.7 Engine Pylon

Due to the unique nature of the AWN configuration the engine pylon design required a special approach (Figure 7.6). The pylon is attached to a fixed torque box that is incorporated between the rear and auxiliary spars. This torque box allows a load path between the auxiliary and the rear spar and acts as a firewall. The interface between the pylon and the torque box is made of titanium. The pylon is attached to the torque box by shear-fuse pins to allow breakaway for loads in the vertical and horizontal directions. It should be noted that no attempt is made to bolt directly through the auxiliary spar, the attachment is around the auxiliary spar. This scheme prevents weakening of the auxiliary spar as it passes through the pylon to tie into its own attachment point on the rear spar. This pylon scheme also allows the auxiliary spar to increase the torsional stiffness of the wing.

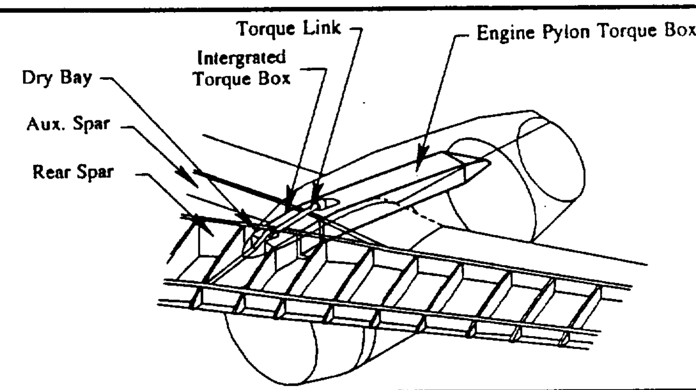


FIGURE 7.6: FC-1D Engine Pylon

7.7.1 Fuel Volume

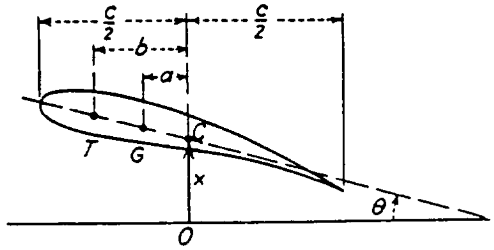
The fuel mission requirement of 42,000 lbs is accommodated with the use of integral wing fuel tanks. The FC-1D uses three fuel tanks in each wing, with a five percent allowance for fuel expansion. Fuel is burned from the inboard to the outboard tanks to provide wing bending moment relief.

7.8 Empennage Structure

The horizontal stabilizer consists of a front spar, rear spar, ribs, skins, and center section truss that forms a structural beam. The beam allows for attachment points for a jack screw and pivot attachments. The vertical stabilizer consists of a front spar, rear spar, ribs skins, and also forms a structural beam. The structure aft of the rear vertical tail spar consists of ribs that incorporate hinge bearings for the rudder. The empennage is constructed of carbon reinforced plastic to help reduce weight.

7.9 Flutter

One of the possible problems with the AWN was flutter. The reason flutter should be considered as a possible problem can be seen more clearly in Figure 7.7.



$$m\ddot{y} + 2m\xi y + S_x\theta + k_y y = F_u$$

$$J_\theta\theta + 2\,J_\theta\xi\theta + S_x\ddot{y} + k_\theta\theta = F_\theta$$

FIGURE 7.7: Free Body Diagram of Forward Wing Nacelle Case

For the forward engine case, the engine-wing center of gravity is forward of the aerodynamic center. As lift increases, through gusts and/or maneuvering, it creates a moment around the center of gravity (point G). This extra inertial force causes a rotation around the wing center of twist (point T), which tends to reduce the angle of attack, thus dumping the excess lift. However, for the aft wing nacelle case, the wing-engine CG moves aft of the aerodynamic center. If the wing experiences a sharp gust or increased lift, the extra lift would create a moment in the opposite direction, that would create a higher angle of attack. The only dynamic moment counteracting this instability is the torsional stiffness in the wing, which will bounce the wing back and could possibly create a flutter condition. FAR 25.629 requires that the FC-1D must be free from flutter and divergence for all combinations of altitude and speed encompassed by the V_D verses altitude envelope, enlarged by 20 percent (see Figure 3.7).

If there proves to be a significant degree of flutter caused by the aft wing nacelle configuration the Flying Circus has a number of options available to alleviate this flutter condition. One option involves increasing the torsional stiffness in the wing. Extra structure will help torsionly stiffen the trailing edge extension and wing box. For this option there is an increase in structure that would add approximately ten percent structural weight to the wing.

A second option may be the use of an Active Flutter Control System (AFCS) system which will be used to dampen the flutter with the use of existing or auxiliary control surfaces. This system will be able to demonstrate high reliability in the field. The AFCS system will be implemented in conjunction with the fly-by-wire flight control system (see Ref. 7-5 & 7-6).

A third option may be the incorporation of both of the previously mentioned approaches to reduce any draw backs that might be found in each of the previous solutions.

7.10 Materials

The selection of materials has a major impact on the economics, and service performance of the FC-1D. Careful consideration was made for material selection as to keep maintenance costs down. If a material is selected primarily on the basis of its weight characteristics, the benefits gained by lower fuel consumption may be diminished or negated by higher maintenance costs. The selection of materials also has a major impact on manufacturing costs. Inappropriate selection of materials could increase manufacturing costs by requiring expensive tooling. This could make the FC-1D relatively expensive in a competitive market.

The use of composites in the FC-1D were kept at a level that was consistent with the projected trends of the commercial aircraft fleet in the year 2000 (Ref. 7-7). The use of composites above this trend was avoided to keep the customer from incurring additional costs for increased training of airframe servicing mechanics, and as not to test the bounds of certification requirements.

The fail-safe philosophy that is incorporated in the design of the FC-1D has placed an emphasis on material selection criteria. The FC-1D must be able to perform safely in a hostile day-to-day service environment in any region, anywhere in the world. To accomplish this goal, an emphasis has been placed on material fracture toughness, fatigue characteristics, and environmental stability.

7.11 Structural Materials

Most of the primary structure of the FC-1D will be constructed of aluminum alloys. This will include the main structure of the wings and the fuselage. The horizontal and vertical tail will be constructed of carbon reinforced plastic and graphite. The primary movable control surfaces such as the ailerons, elevators, rudder, spoilers, and aft flaps will be constructed of carbon fiber. Faring structures will be constructed of fiberglass and carbon reinforced fiberglass hybrid and firewalls of titanium.

The proven field performance of aluminum alloys makes them an attractive choice of materials. The aluminum alloys used in the FC-1D are common to what is used in today's modern commercial air transports. To meet all fail-safe criteria the Flying Circus not only chooses materials on the basis of its strength qualities, but on its proven ability to withstand minor damage in service without compromising the safety of the aircraft. This concept was used throughout material selection of the FC-1D. The fuselage skin, pressure bulkheads, and lower wing skins are made of 2024-T3 aluminum alloy. The Flying Circus chose 2024-T3 aluminum alloy for high strength tension applications, this material has good fracture toughness, slow crack growth rate, and a good fatigue life. The wing spar webs are constructed of 2224 and 2324 aluminum alloys which have been proven an excellent choice in other aircraft. The wing spar caps, landing gear fittings, fuselage frames and bulkheads are made of 7075-T73 aluminum alloy, this material has higher strength than 2024, a slightly lower fracture toughness, and a good stress corrosion resistance. The upper wing skin will be made of 7075-T76 aluminum alloy, which has properties comparable to 7075-T73 and is used extensively by the Flying Circus in compression applications.

To improve the overall structural efficiency, the fuselage floor beams are constructed of graphite and floor panels are made of carbon fiber reinforced plastic with a nomex core. Graphite has a proven performance record in tension applications and suits itself well to floor beams, which act as tension ties.

To further improve the overall structural efficiency, the horizontal tail, vertical tail, and torque box will be constructed of carbon fiber reinforced plastic. A secondary beneficial effect was achieved by constructing the empennage out of composite materials which improved CG effects of the AWN, as explained in weights.

One of the main factors that drove the design of the FC-1D was the analysis and reduction of the aircraft weight. As explained in *Concept Evolution*, weight reduction lowered induced drag, reducing fuel burn and airline DOC. To accomplish this, the component weight of the baseline aircraft was broken down into its components to target key areas for reduction.

A detailed weight component breakdown, shown in Tables 8.1 through 8.3, shows that the FC-1D has an empty weight of 60,660 pounds and a takeoff weight of 135,200 pounds. In order to reduce the takeoff weight of the FC-1D, the Flying Circus concentrated on the aircraft components that were a large fraction of the weight breakdown (see Figure 8.1). These areas included parts of the wing structure, the interior flooring, and the horizontal and vertical tail. These weights were reduced by the incorporation of composite materials. In order to justify the use of composites, the manufacturing, material, and repair costs had to be considered (see *Materials Selection*). These and other empty weight reductions resulted in an empty weight reduction of 4000 pounds (as shown in Table 8.2).

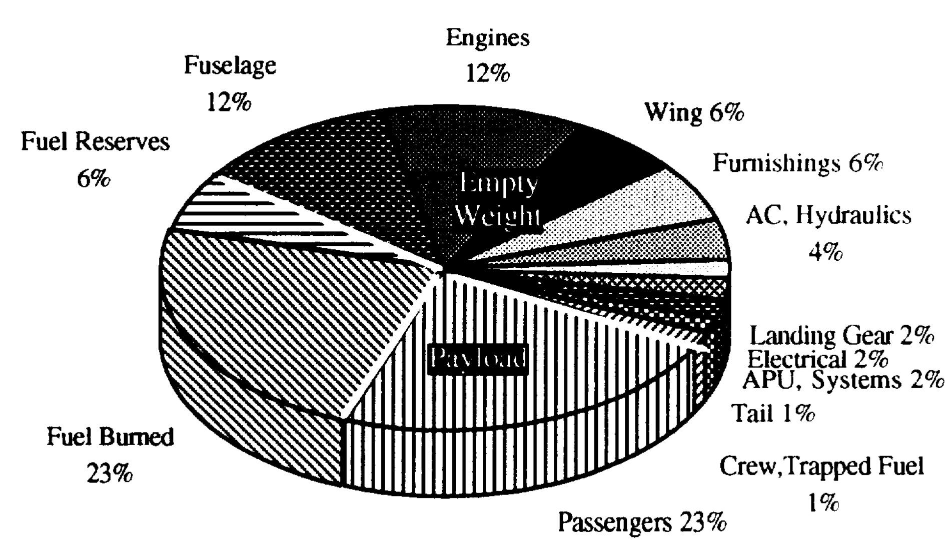


FIGURE 8.1: FC-1D Takeoff Weight Breakdown

TABLE 8.1 Fuselage Weight Breakdown

Components	Weight (lbs) Reduced		Reduced
Skin Weight	4060	Speedbrakes	10
Stringers	2210	Flooring	1280
Frames	2010	Pressure Bulkheads	170
Gross Shell	8280	Wheelbays (Main Gear)	730
Gross Shell Modifications		Wheelbay (Nose Gear)	390
Passenger and Crew Doors	780	Support Structures	
Cargo Hold Doors	320	Wing Fuselage Connection	350
Escape Hatches	290	Tail Support	340
Cockpit Window Glazing	210	Wing Fuselage Fairings	320
Windows and Ports	930	Sealant, joints	330
Access Doors	70	**Fuselage**	**14790**

TABLE 8.2: FC-1D Component Empty Weight Breakdown

Components	Weight (lbs) max.	reduced	Comments
Fuselage	15800	14800	
Basic Wing Struc.	6550	6550	Ten percent extra wing weight taken for added stiffness
Trail Edge Flaps	490	440	Weight of flaps and spoilers were reduced with the
Lead Edge Flaps	370	340	application of carbon fiber, epoxy matrix composites,
Spoilers	63	56	formed from pre-preg sheets and baked in an autoclave
Spiroids	200	200	Fiberglass; weights estimated from Reference 8.1
Wing Group	7650	7540	
Horizontal Tail	1170	880	Carbon-epoxy composites reduce weight by 25 percent
Engines+Nacelle	14900	14000	Composites on the nacelles and pylons
Engine Support	870	870	
Landing Gear -front	2690	2690	Weight penalty incurred because of FOD protection needed
-main	220	220	to protect aft-wing nacelle (see *Landing Gear*)
Flight Control Sys.	1690	1690	Weight penalty for AFCS
Hydraulics	950	950	
Electrical Sys.	2580	2580	
Inst. and Avionics	2300	2300	
AC, Pressurization	2090	2090	
Oxygen	400	400	
Auxiliary Power	860	860	
Furnishings	7900	6150	Weights reduced with selection of Keiper Recaro seats
Cargo Handling Eq.	480	480	Same for cargo containers and carpet baggage loading option
Auxiliary Gear	820	820	
Paint	400	400	Includes weight of riblets
Vertical Tail	820	610	Carbon-epoxy composites reduce weight by 25 percent
Empty Weight	**64700**	**60700**	

TABLE 8.3: FC-1D Component Take-off Weight Breakdown

Components	Weight (lbs) Maximum	Weight (lbs) Reduced	Comments
Empty Weight	**64700**	**60700**	**See Table 8.1**
Stewards	680	680	Four flight attendants
Crew	340	340	Two crew members
Trapped Fuel, Oil	680	680	
Oper.Empty Weight	**66400**	**62400**	
Passenger	26000	26000	One hundred fifty three passengers at 170 pounds apiece
Baggage- Front	2170	2170	Five cargo containers in front part of hold
Baggage- Aft	2800	2800	Six cargo containers in aft part of hold
Payload Weight	**97200**	**93200**	
Warm up	1270	1270	
Taxi	1280	1280	
Take-off	640	640	
Climb	2600	2600	Climb to 39,000 foot altitude
Cruise	22600	22600	3000 nautical mile cruise
Loiter	3530	3530	Forty five minute loiter
Descent	1280	1280	
Cool Down	1020	1020	
Cruise	34200	34200	
Minute Takeoff	970	970	
45 Min Cruise	2280	2280	Enough to reach next available airport
Climb	2600	2600	
Cruise 150 NM	940	940	Enough to reach next available airport
Descent	970	970	
Reserves	7760	7760	
Fuel Weight	42000	42000	
Take-off Weight	**139200**	**135200**	
OEW+Fuel	**107800**	**103700**	

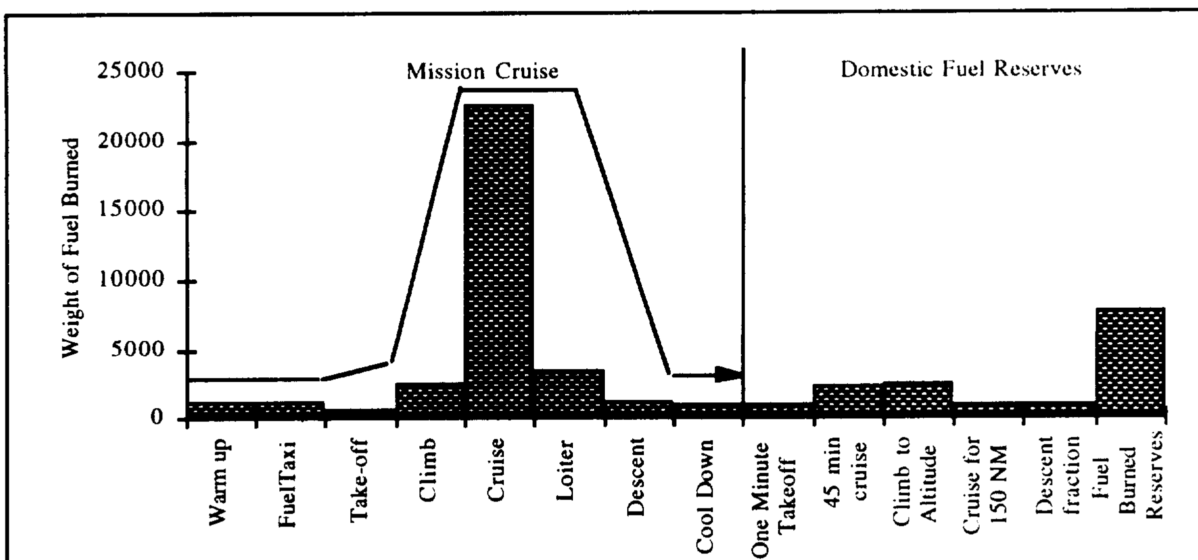


FIGURE 8.2: FC-1D Mission Fuel Burn

The next step was a reduction in the amount of fuel carried. This weight was crucial because it is a quarter of the FC-1D's total take-off weight. To further analyze this problem, a mission profile fuel burn is shown in Figure 8.2. This figure illustrates how the fuel is burned in each phase of the mission specified by the RFP. From this chart it can be seen that in order to reduce the fuel burned, it was particularly important to concentrate on the cruise conditions. This is where approximately 66 percent of the fuel carried is burned. In order to decrease the amount of fuel burned in cruise, two main factors were considered. First, incorporating engines with a lower specific fuel consumption, and second, reducing the drag acting on the aircraft. For the first case, the Flying Circus went through an extensive engine selection process (see *Engine Selection*) in order to acquire the most fuel efficient engine available that could show proven, reliable technology. For the next case, the Flying Circus performed a detailed drag reduction analysis, which is shown in great detail in the *Drag* section of this report.

8.2 Center of Gravity Excursion

The following Table (Table 8.4) and plane section (Figure 8.3) shows the X- and Z-axis center of gravity (CG) locations of major components of the FC-1D. The X-axis CG locations are listed comparing the most aft, most forward and average case. This range stems from the relative uncertainty in locating the exact CG location of many of the structural components of the FC-1D. Because CG location is so important for aircraft stability and control, landing gear loads, and structures, this CG range had to be considered in the ultimate analysis of the FC-1D, as shown in the CG excursion chart (Figure 8.4). However, for standard analysis consideration, the CG loction value used in calculations was an average between the two extreme cases. The takeoff weight and OEW CG average was found to be at 47 and 46 percent MAC, respectively. This shows a CG difference of one percent of the MAC as fuel is burned during flight, which is essentially negligible.

TABLE 8.4: Component Center of Gravity Locations

Components		X-Axis Center of Gravity Maximum	X-Axis Center of Gravity Minimum	X-Axis Center of Gravity Average	Y-Axis CG
Fuselage	A	54.6	58.4	56.5	0.0
Wing Group	B	59.8	60.5	60.2	-3.2
Horizontal Tail	C	113.2	113.2	113.2	0.0
Engines+Nacelles	D	65.6	65.6	65.6	-5.4
Engine Support	B	59.8	60.5	60.2	-2.5
Landing Gear -front	E	20.0	20.0	20.0	-11.7
Landing Gear -main	F	60.7	60.7	60.7	-11.7
Flight Control Systems	G	8.0	8.0	8.0	-.8
Hydraulics	B	60.2	60.2	60.2	-1.5
Electrical Systems	H	63.5	63.5	63.5	0
Instruments and Avionics	I	6.4	6.4	6.4	0
AC, Pressurization	J	53.9	53.9	53.9	-6.4
Oxygen		58.1	58.1	58.1	3.0
Auxiliary Power Unit	L	121.0	121.0	121.0	5.2
Furnishings		58.1	58.1	58.1	.75
Cargo Handling Equipment		48.9	48.9	48.9	-3.0
Auxiliary Gear	H	63.5	63.5	63.5	-1.2
Paint	A	56.5	56.5	56.5	0
Vertical Tail	N	116.0	116.0	116.0	12.2
Empty Weight	**O**	**58.8**	**59.8**	**58.76**	**-1.8**
Stewards		58.1	58.1	58.1	0.4
Crew	G	7.0	9.0	8.0	0.4
Trapped Fuel and Oil		60.3	60.3	60.3	-3.2
Oper. Empty Weight	**T**	**58.5**	**59.5**	**58.5**	**-1.8**
Passenger		58.1	58.1	58.1	0.4
Baggage- Front	P	29.5	29.5	29.5	-3.4
Baggage- Aft	Q	72.3	72.3	72.3	-3.4
Payload Weight	**S**	**57.9**	**58.6**	**57.9**	**-1.2**
Fuel Weight		60.3	60.3	60.3	-3.2
Take-off Weight		**58.7**	**59.1**	**58.66**	**-1.8**
OEW+Fuel		**59.6**	**60.2**	**59.62**	**-2.3**

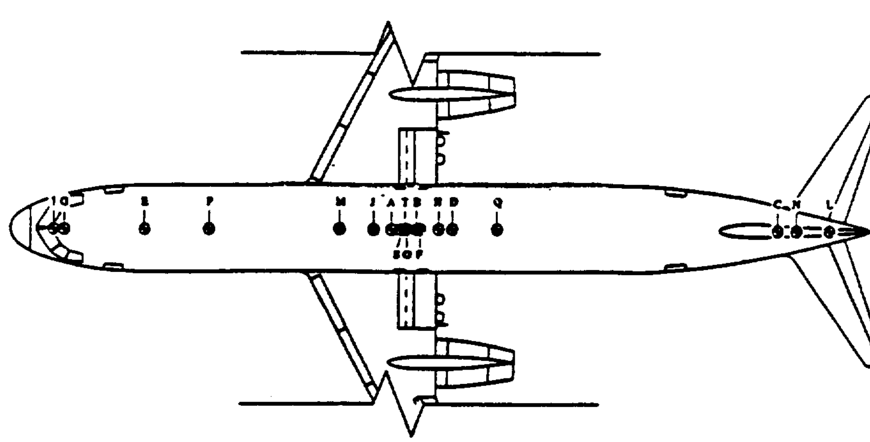


FIGURE 8.3: FC-1D Component CG Locations

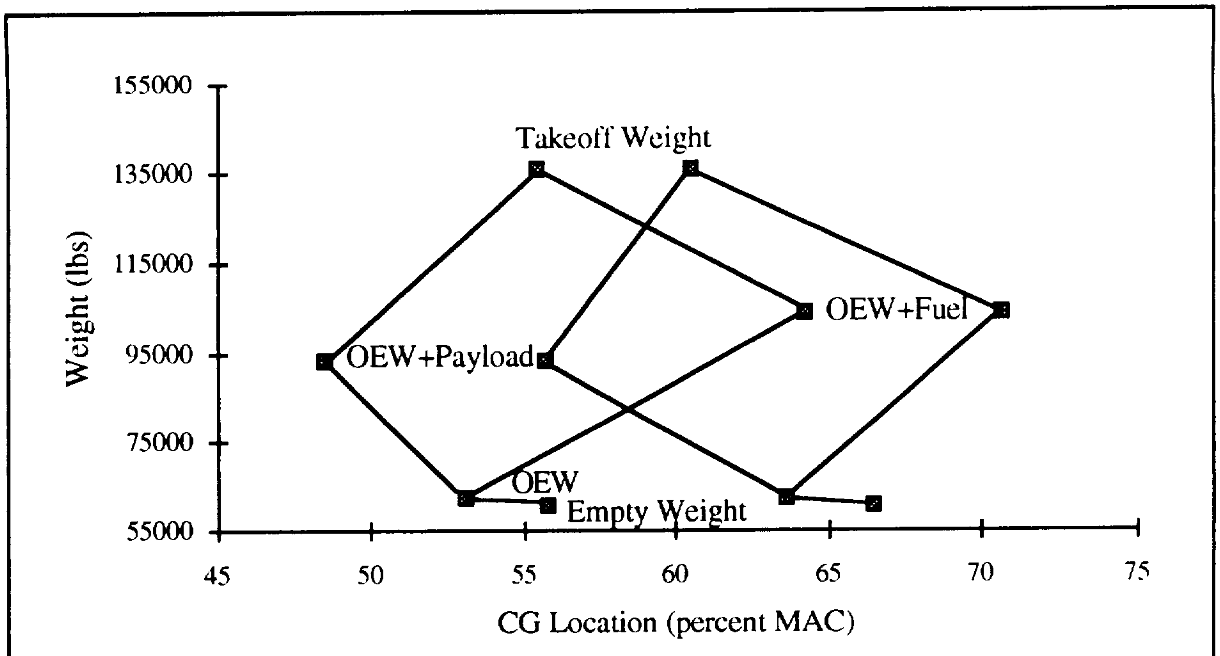


FIGURE 8.4: FC-1D Center of Gravity Excursion

In order to obtain a minimum CG shift, wing placement was considered (Figure 8.5). However, CG shift was not the only factor that relied on the wing location. The stability margin, landing gear tip-over criteria, landing gear loads, and inherent stability of the FC-1D were all strongly affected by the selection of the wing placement. Figure 8.5 shows how the aerodynamic center and the take-off weight CG both travel aft as the wings are placed further back from the nose of the FC-1D. When the wing is placed at approximately 41 feet, the CG moves ahead of the aerodynamic center, creating static stability (see *Stability and Control*). Notice that the FC-1D has its wings placed about 40 feet aft, causing the plane to have a slightly negative stability margin. This was found to create an upload on the tail, which reduced trim drag and induced drag. In addition, this gave the FC-1D a small CG shift.

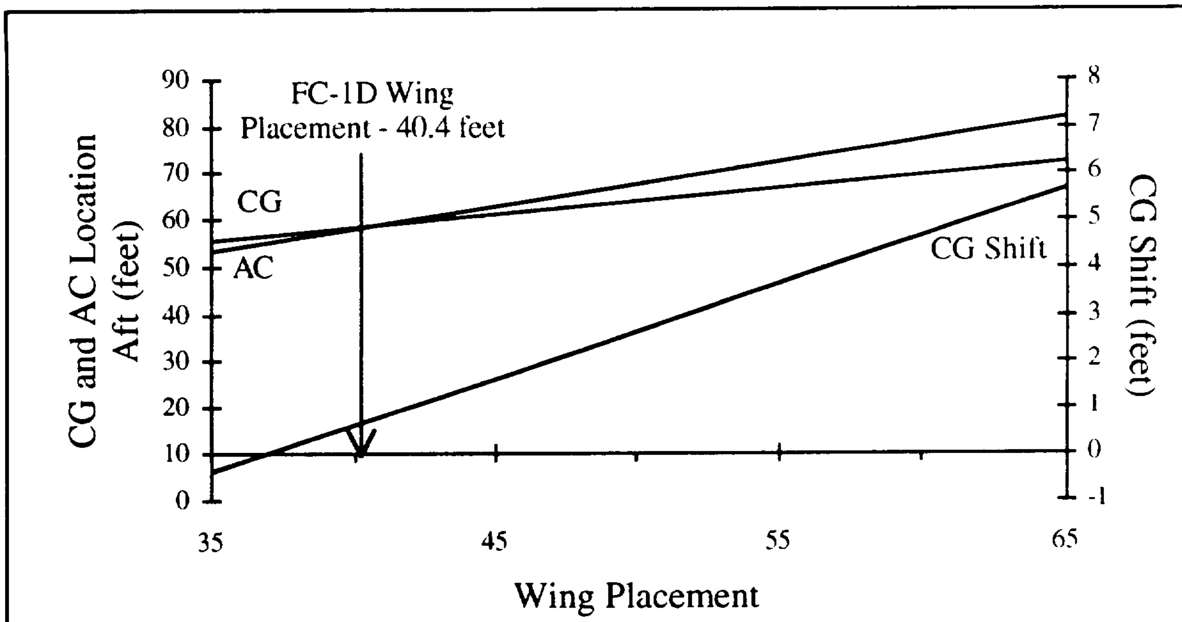


FIGURE 8.5 FC-1D Wing Location Considerations

8.3 Moments of Inertia

The moment of inertia for takeoff and empty weight were calculated by treating the individual components of the aircraft as point masses. In the case where actual CG locations of particular components were not readily available, the geometry of the component was simplified and the CG location was assessed. The following general equation was then used:

$$Ixx = \sum_{i=1}^{n} m_i[(Yi - Ycg)^2 + (Zi - Zcg)^2] \qquad \text{(Equation 8-1)}$$

The moments of inertias that were found (see Table 8.5) were used in stability and control analysis. They play an important role in the calculation of maneuverability, pitch rate, and roll rate of the aircraft.

TABLE 8.5: FC-1D Moments of Inertia

	Ixx	Iyy	Izz	Izx
Wto	806745	2369240	3026238	-605059
We	363512	1519356	1834654	-385037

9. *STABILITY & CONTROL*

9.1 Design Philosophy

When considering flight control systems, Flying Circus was primarily concerned with safety. The control system of choice was required to safely and inexpensively provide the best possible control of the aircraft while keeping minimum weight and maintenance. In addition the flight controls had to be a low risk, proven technology system. After evaluating classic mechanical systems, futuristic fly-by-light systems and modern fly-by-wire systems, the Flying Circus determined that fly-by-wire technology would meet these requirements. Even though Fly-by-Light is the lightest weight control system, it is an unproven technology that has not yet been developed or implemented in commercial air transports. The Flying Circus believes that this technology does not have the potential to mature by the FC-1D's planned entrance into the commercial aviation service fleet. The classic mechanical flight control system has proven itself to be safe and effective, and is implemented on most of the commercial fleet of today. However, this older technology incurs a substantial weight penalty, as well as higher maintenance costs. Fly-by-wire was chosen because it is a technology that is currently proving itself in commercial transport fleet. This modern light weight technology is used as the flight control system of many of the Airbus Industries' commercial aviation transports. The Flying Circus feels that fly-by-wire is a mature technology that can be efficiently implemented on the FC-1D with a minimum of expense and maintenance cost.

9.2 Control Surface Sizing

The size of the control surfaces are directly related to the handling qualities of an aircraft. Therefore, extreme care needs to be taken so that adequate control power is available for the FC-1D, particularly for rotation at take-off, roll control at low and high speeds and, most important of all, the one-engine-out situation. For this emergency situation, rudder sizing was given careful consideration. Keeping the governing parameters in mind, the following control surfaces were sized using reference 9-1 in conjunction with statistical data from reference 9-2:

- The rudder area of 64 ft^2 and a deflection of 13.4°, provided adequate control for the one-engine-out criterion.
- The outboard ailerons with an area of 49.8 ft^2 were sized for high speed control. For low speed control, ailerons with an area of 24.2 ft^2 are used simultaneously with inboard spoilers that have an area of 18.9 ft^2 (see High Lift Devices).
- The elevators with an area of 66.2 ft^2, and a deflection of 30 degrees provided adequate control for rotation. This deflection corresponds to the max. rotation, just prior to scrapping the tail. (rotation will be discussed in detail in *take-off rotation*).

9.3 Flight Control System

The inherent stability characteristics of the FC-1D depend directly upon its aerodynamic stability derivatives. The magnitude of the derivatives affect both the damping and frequency of the longitudinal and lateral motions of the airplane. Since the geometric characteristics and FC-1D's aerodynamics are fixed, the stability derivatives were be fixed. Using the method discussed in Reference 9-3, these stability derivatives were calculated and are listed in (Table 9.1).

TABLE 9.1: Stability Derivatives of the FC-1D

Longitudinal	C_{mu}	C_{ma}	C_{ma}	C_{mq}	C_{mTu}	C_{mTa}	C_{Lu}	C_{La}	C_{La}	C_{Lq}	C_{Da}	C_{Du}	C_{Txu}	C_{Lde}	C_{Dde}	C_{mde}
M=.8; 39000 ft	.161	-3.85	-28.91	-76.06	.021	0.0	.758	8.680	5.630	23.33	.395	.0002	-.060	.3794	.005	-1.950
M=.20 Sea-level	.059	-3.347	-16.094	-57.414	.021	0.0	.067	6.534	3.140	17.315	1.198	.0001	-.060	.499	*.004	-2.559
Lateral	c_{lb}	c_{lp}	c_{lr}	c_{ldA}	c_{ldR}	c_{nb}	c_{np}	c_{nr}	c_{nda}	cn_{dR}	c_{yb}	c_{yp}	c_{yr}	c_{ydA}	c_{ydR}	
M=.8; 39000 ft	-.265	-1.192	.391	.090	.026	.329	-.068	-.404	.090	-0.86	-.994	-.224	.758	0.000	.164	
M=.20 Sea-level	-.274	-1.359	.776	.064	.015	.287	-.068	-.397	-.023	-.133	-.888	-.076	.670	0.000	.243	
Steady State	C_l	C_D	C_{Tx}	C_m	C_{mT}											
M=.8; 39000 ft	.550	.029	.022	-.040	.000											
M=.20 Sea-level	2.44	.054	.929	-.584	.000											

Note, that for a particular flight regime it is possible to design an airplane to posses desirable flying qualities. For example, knowing that $C_{m\alpha}$ and C_{mq} are a function of horizontal tail volume ratio, one can select a tail size so that $C_{m\alpha}$ and C_{mq} provide the proper damping and frequency for one particular mode of flight. However, the FC-1D operates through an extended flight envelope, and stability derivatives can vary significantly by changing speed, lowering flaps, etc. Therefore, the handling qualities will also change.

Table 9.2 shows the handling qualities for the longitudinal and lateral modes. The handling qualities were determined using approximations for the varying modes of flight. (Ref. 9-4).

TABLE 9.2: Handling Qualities of the FC-1D

Aircraft Stability Mode	Take-Off (CAT C)	Cruise (CAT B)	Landing (CAT C)
Phugoid	LEVEL II	LEVEL II	LEVEL II
Short Period	LEVEL I	LEVEL I	LEVEL I
Dutch Roll	LEVEL I	LEVEL I	LEVEL I
Spiral	LEVEL I	LEVEL I	LEVEL I
Roll	LEVEL I	LEVEL I	LEVEL I

To provide the pilot with an airplane that has desirable handling qualities over its entire range of operation, the FC-1D will employ a Stability Augmentation System (SAS).

Flying Circus decided that a pitch rate feedback system will be implemented to improve damping. In the case of yawing motion following a side gust, the airplane experiences Dutch roll. In order to alleviate this problem, a yaw damper will be used, which basically consists of a rate gyro transmitting a signal to a servomechanism. The yaw damper also functions as yaw a suppresser in case of an engine failure. For the longitudinal part of the SAS, an alpha limiter will be implemented. This will cause the control in the cockpit to shake, reducing the possibility of unintentional stalling of the aircraft (see Figure 9.1).

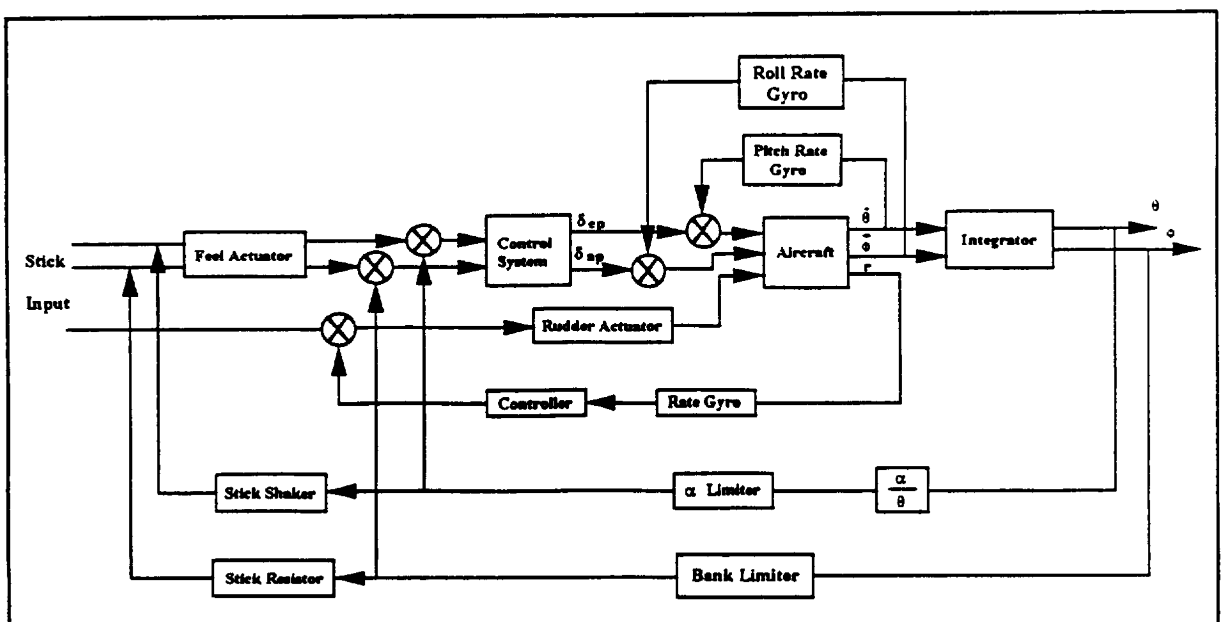


FIGURE 9.1: FC-1D Flight Control System Block Diagram

The FC-1D's control system consists of a triple redundancy hydraulic and flight computer system. Triple redundancy ensures that the plane will be fully controllable in the event of a system failure. The three flight computers are linked to the control surfaces via three control runs; one runs through the overhead of the fuselage and two run through the cabin floor beams. Each control run can has the capability of carrying full control commands for the FC-1D. The control runs are placed with consideration to the turbine and compressor failure zones of the engines and the APU of the aircraft. The placement ensures that all three control runs can never be severed simultaneously by a turbine or compressor failure. Also, three flight computers insures accurate inflight operation of the fly-by-wire system by eliminating erroneous signals. If one computer is sending a signal that disagrees with the other two computers' signals, the dissenting computer is shut down.

Lateral control of the FC-1D is achieved through the use of ailerons, spoilers, and the rudder. Each wing has four inflight spoilers and an aileron for lateral (roll) control. These control surfaces can be operated by either control wheel in the flight deck. Each spoiler is powered by one hydraulic actuator, is powerful enough to provide full-range surface control. In addition, the aileron is powered by two hydraulic actuators that each have enough power to give full-range control of the aileron. The rudder has three hydraulic actuators that each have enough power to give full control capability to the rudder. The arrangement of these systems insure that in the event that one or two of the three hydraulic systems fail, the aircraft will continue to respond to commands from the pilot in a safe and stable way.

Longitudinal control of the FC-1D is provided by the elevators. Each elevator is powered by three actuators. Each hydraulic actuator is capable of providing full control power for the elevator. The elevators are controlled with inputs from either control wheel in the flight deck.

Three flight computers insures accurate inflight operation of the fly-by-wire system by eliminating erroneous signals.

9.4 Empennage Sizing

A simple design for the empennage was chosen in order to minimize cost as well as weight. Deciding to employ 'relaxed static stability' combined with a digital fly-by-wire flight control system, allowed the use of a smaller tail volume coefficient resulting in a small tail, this also lowers the trim drag and the weight of the aircraft. The benefit associated with this decision is a trimmed lift-to-drag-ratio.

The sizing of the empennage was governed by the following parameters : first, it should be insured that the wing of the aircraft stalls before the tail; second, the vertical and horizontal tails must provide adequate lateral and longitudinal stability in critical conditions such as one engine out; and the final governing parameter is governed by the results obtained from stability and control analysis. However, the last parameter was not of great concern, due to the implementation of the SAS.

For the horizontal and vertical tail, NACA airfoils were selected. Both airfoils were swept back to increase the critical Mach number, to guarantee airplane stall after the stalling of the wing and meet the transonic cruise requirement. Using the method in Reference 9-3 resulted in the geometry of the empennage listed in Table 9.2.

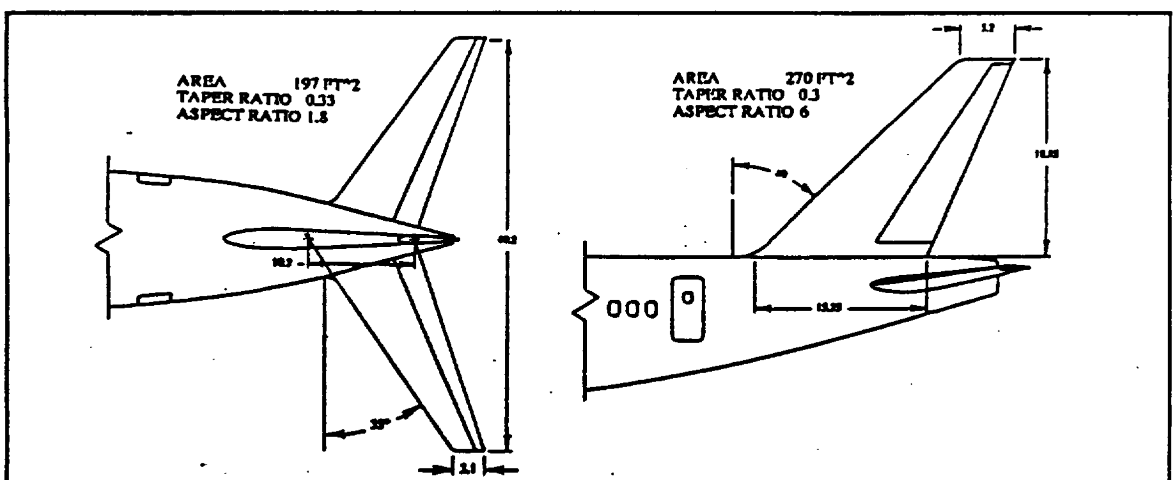


FIGURE 9.2: Empennage Geometry

9.5 Takeoff Rotation

In the analysis of take-off rotation, the following two areas were investigated: first, the maximum angle the airplane could physically rotate before it scrapes on the ground; secondly, whether or not there is adequate control power available to make that rotation. To determine whether adequate control power is available, a simplified engineering method was applied as follows:

(1) $\Sigma M_{main\ gear}$ = Moment (required for a certain degree of rotation)

(2) $Work_{total} = 0$: (Force)*(Distance) = (Moment)*(Theta)

Applying the two principals above results in two equations and two unknowns, where the unknowns are tail lift and the moment required for rotation. From the lift of the tail, the corresponding C_L can be calculated. This was then compared to the C_L available (This is given in the airfoil characteristics).

Upon investigation, it was found that FC-1D was limited to 15° of rotation. At 15° rotation angle, the lift required on the tail was calculated to be 13,100 lbs. This lift corresponded to a C_L of 1.07, which could be achieved several different ways. Figure (9.3), shows different incidence angles of the horizontal tail with corresponding elevator deflection which provide the required C_L.

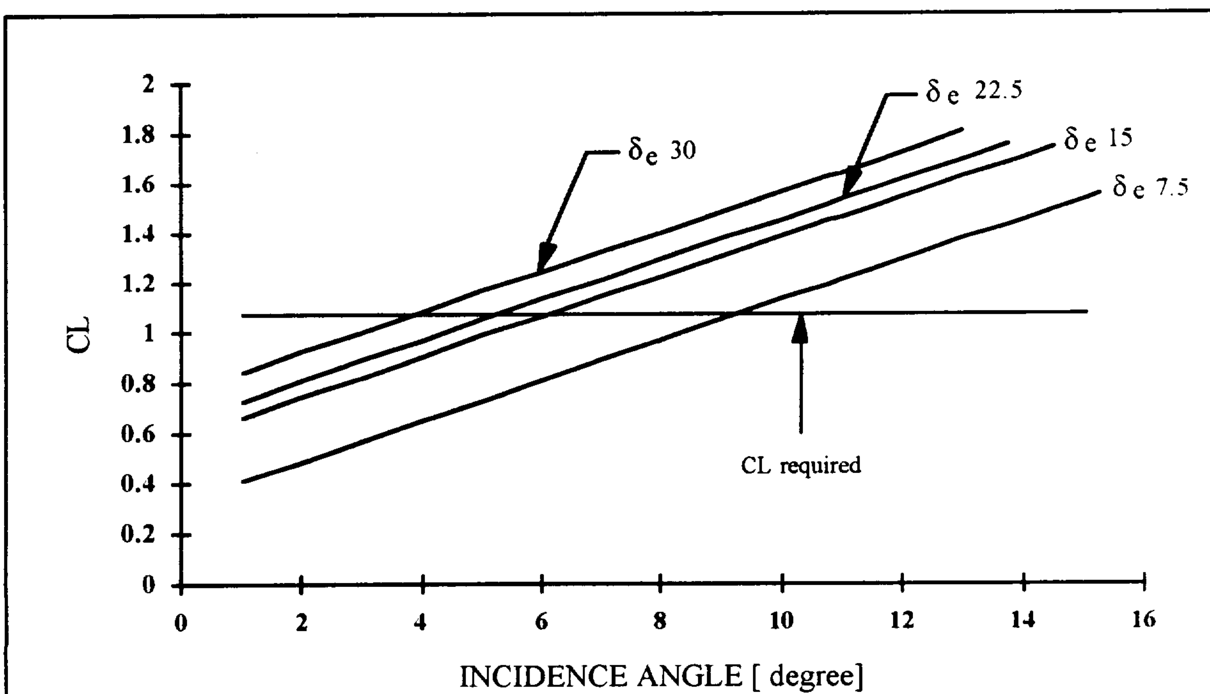


FIGURE 9.3: Lift Coefficient vs. Incidence Angle

The heart of any airplane is its internal systems, and the systems found in the FC-1D play an important part in the airplane cost. The philosophy implemented by Flying Circus kept the systems as simple as possible in order to reduce airplane weight and costs, while increasing safety and passenger comfort.

10.1 Electrical

The electrical system of the FC-1D provides passenger comfort, control of vital systems, and powers feedback sensors that are important for stability and control. Sizing of the FC-1D's electrical system was accomplished by comparing its requirements to other aircraft of the same size. The power needs of the FC-1D were assumed to be approximately 5% less than existing aircraft, taking into account the anticipated efficiency of future equipment. Also, because of the crucial nature that electricity plays in the fly-by-wire control systems, backup systems are essential (See Figure 10.1). With this in mind, the FC-1D can be provided with power from six different sources: two engine mounted generators, two APU mounted generators, a battery set, and a ram air turbine (RAT).

To produce the main inflight electrical power for the FC-1D, a 65 kVA variable speed constant frequency (VSCF) generators will be mounted on each engine. The benefits of VSCF generators compared to ordinary integrated drive generators are weight reduction, efficiency, and reduced cooling requirements. These generators will produce 115/200 volts AC at a frequency of 1600 Hz. Transformers are used to provide single phase, 28 volt, AC power to the aircraft's electronics. Transformer / Rectifiers are used to provide 28 volts DC power by converting 115 volts AC to 28 volts DC.

Another generator that can provide 65 kVA inflight power will be mounted on the auxiliary power unit (APU). This generator can also provide 65 kVA when the plane is on the ground during servicing, making it possible for the FC-1D to be independent of external power sources. However, the FC-1D is also equipped with external power adaptability, in the event that the APU is temporarily removed during maintenance.

A set of batteries are used as a power source for communications, fire protection control, and ignition during pneumatic engine start. These batteries are fully recharged during flight by a battery recharger. In case of a power failure in the FC-1D, the battery recharger will automatically disconnect, preventing battery drain. In case of a primary generator failure, the batteries can provide up to 30 minutes of inflight power to the controls and communications systems, enabling the plane to land.

In addition, the APU generator can be started at cruise altitude and be used for inflight power if an engine fails to provide power. Flying Circus offers the airlines a choice of APU's that will be compatible with their existing APU maintenance set-ups. This will enhance the marketability of the FC-1D, since the airline's maintenance operating costs would be minimized (See *Maintenance Schedule* section). Three APU options have been provided for airlines to choose, all at an approximate weight of 840 lbs each: the Garret 85-129, Garret 36-280, and Sunstrand APS-2000.

In case of an extreme emergency, a RAT has been placed beside the front landing gear of the FC-1D. If there is complete electrical failure it is capable of being deployed in two to three seconds by a manual cable linkage, and can provide 5 kVA for inflight control power.

10.2 Avionics

The avionics package for the FC-1D has been designed by Flying Circus in order to maintain the complex communications, controls, and navigation systems that are required. It is the intention of the Flying Circus to implement the most state-of-the-art equipment available. Although this contradicts the FC-1D low-cost philosophy, it was felt that these systems were important to the efficient operation of the FC-1D and that the use of lower quality components was unacceptable. Table 10.1 is an outline of the major avionics systems that are implemented on the FC-1D.

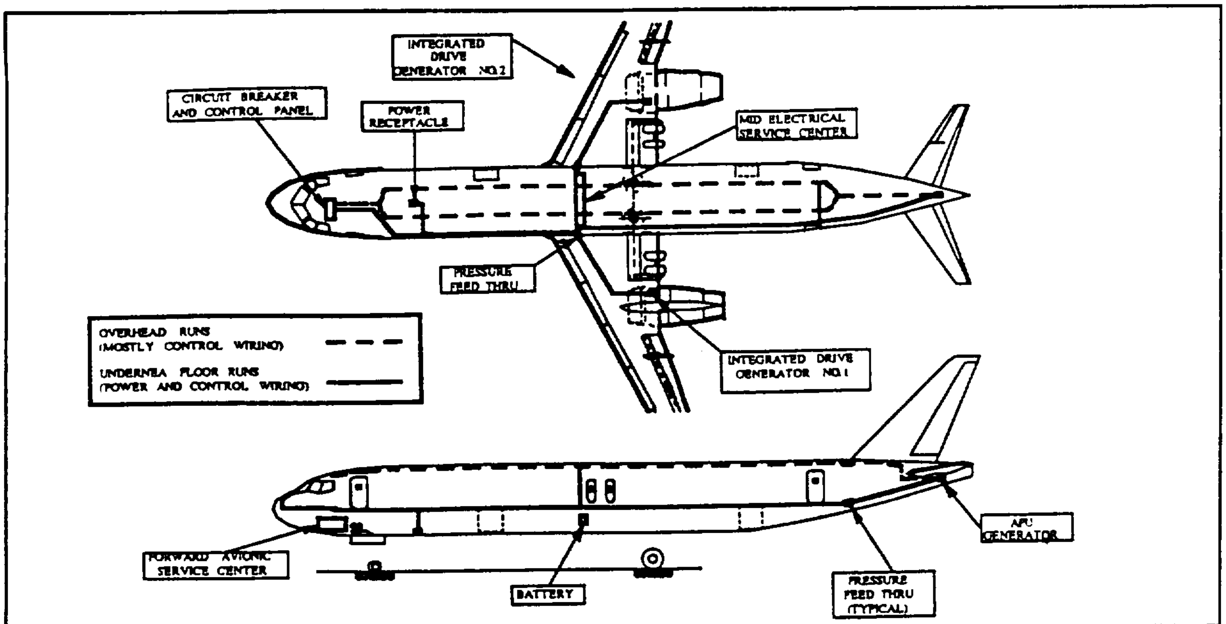


FIGURE 10.1: FC-1D Electrical Routing

TABLE 10.1: FC-1D Avionics Systems

Communications	
UHF Line of Sight & Satcom	FLIR vision enhancement system
VHF - AM/FM	UHF Direction Finding
HF	Pilot operable color Weather(WX) RADAR
Intercom System	Instrument/Control/Display Avionics
Navigation	Full color Multi Function Displays
Inertial reference units	Mission Computers
GPS Global Positioning System	Warning and caution system
VHF Omni Range/ Distance Measuring Equipment	Central Aural Warning System
Collision Avoidance Navigation	Stand by navigation and performance indicators
Instrument Landing System	Digital autopilot system
Millimeter band RADAR vision enhancement system	
Miscellaneous Avionics	
Ground proximity warning systems	Performance Data Computer System
RADAR altimeter	Fuel Savings Advisory System
Cockpit voice recorder	Performance Navigation Computer System
Standard flight data recorder	Electronic Braking System
Aircraft Diagnostics and integrated Test system	Anti-Lock/Anti Skid
Computer access panels at service ports , avionics bays, cargo bays etc.	Tire temperature monitoring
Airborne integrated data system recorder	Control Column controls
Flight Management Computer System	Pitch/Roll/yaw trim control
Flight path optimization continually adjusts throttle and flight path at constant speed as part of auto pilot to minimize fuel burn.	Autopilot disconnect
Electronic flight system mode selector	Microphone toggle switch

10.3 Hydraulics

The FC-1D relies on hydraulics for all aspects of its flight control and landing systems. This is especially important to the active flutter control system (AFCS), variable incidence tail, and dynamic tail swing systems of the FC-1D. In order to ensure these controls, the hydraulic system installed on the FC-1D is a triple redundant system that takes advantage of fuselage and wing structures for protection against possible damage. The routing of the left, center, and right hydraulic lines is shown in Figure 10.2. In the event that any two of these systems are disabled, the FC-1D can still maintain controlled flight with control power from the remaining system

In addition to providing power to the flight control surfaces, the hydraulic system also provides power to raise and lower landing gear, apply wheel brakes, steer the nose wheel, and open and close the thrust reversers. The hydraulic system schematic, shown in Figure 10.3, illustrates the triple redundant system and shows which system supplies power to each integral part of the plane. The 8000 psi hydraulic pressure is maintained by two engine driven pumps and two electronic pumps during flight. There is also a pneumatic pump driven by the APU for ground service needs or emergency backup. The pump on the APU is similar to the pump driven by the RAT, and both pumps can supply long duration standby hydraulic power to

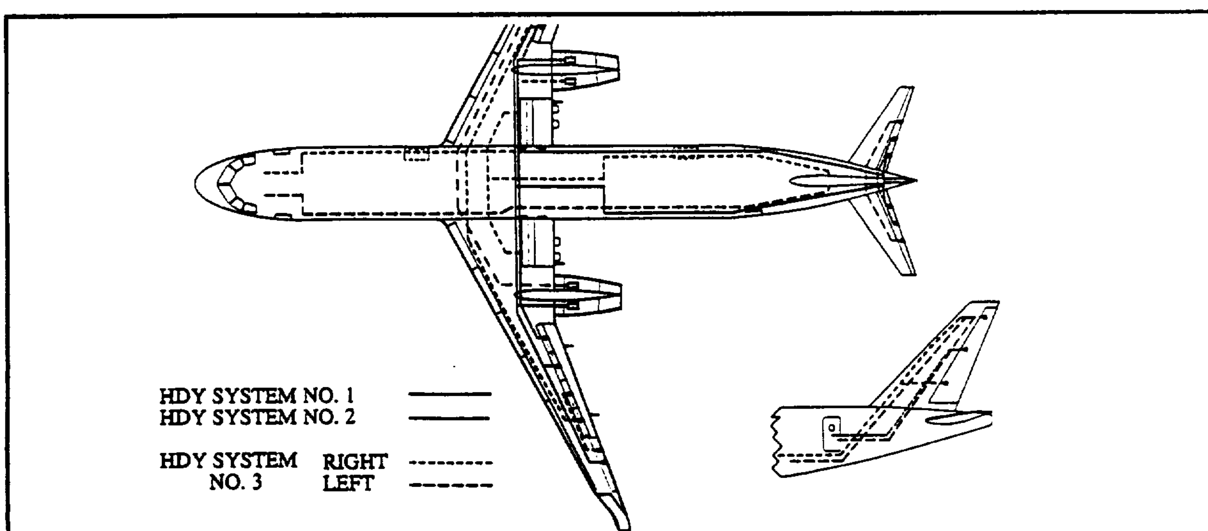


FIGURE 10.3 FC-1D Hydraulics Layout

operate flight controls. Some short duration hydraulic power for lowering landing gear is produced using hydraulic accumulators.

Methods incorporated by the Flying Circus to reduce the cost of the hydraulic system include reducing the amount of parts used in current systems, and implement the 8000 psi system which reduces weight and installed volume of the actuators.

10.4 Fuel System

Because of its range, the FC-1D is required to have a large fraction of its weight in fuel. To accommodate this there are two main tanks located in each wing (See Figure 10.3), which hold 42,000 pounds of fuel and also have 5% extra volume for fuel expansion. To service the FC-1D there are overwing and underwing fueling ports, and defueling ports. During cruise, fuel is first burned from the inboard tanks, in order to keep fuel weight in the outboard tanks for wing bending relief. Provisions have also been made for emergency fuel dumping and fuel tank venting. Also, baffles are employed in the tanks to reduce fuel slosh. Fuel slosh causes increase moments and deflections of the wings.

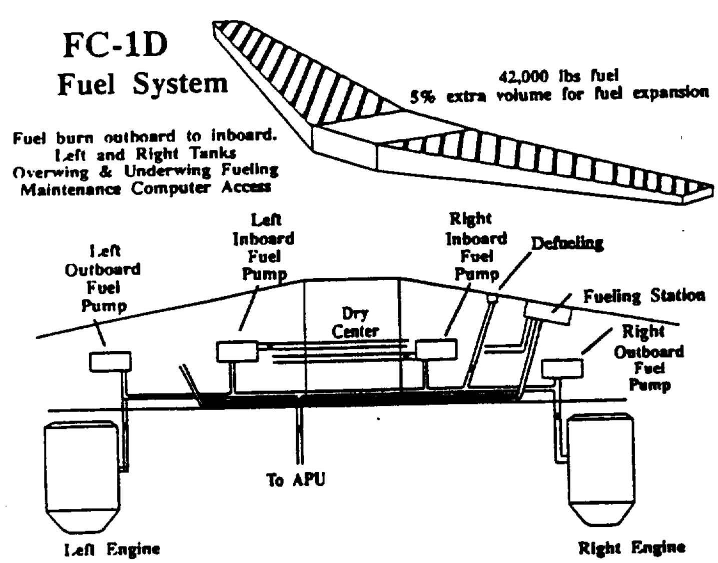


FIGURE 10.4: FC-1D Fuel System

10.5 Lightning Protection

Making an aircraft durable in terms of resistance to lightning strikes is important for a commercial transport. To protect the fuel tanks from lightning strikes, the fuel tank vents are located well inboard from the furthest outboard metallic part of the wing. The Flying Circus was required to conform with FAA Advisory Circular AC20-53 (Ref. 10-1), which states that fuel tank vents must be at least 3 feet inboard from the furthest outboard metallic part of the wing. To further decrease the possibility of fuel ignition at the vents, flame arrestors are implemented. To reduce the possibility of wingtip strikes in general, lightning attachments are used in nonconducting skins. Flying Circus also took into consideration other potential problem areas, such as: joints and interfaces in hinges and fittings; access doors and filler caps, wing tips, and antennas. To reduce lightning damage in these places, non conducting primers or sealants will be implemented. In addition, diverter straps and wires were also used to reduce any sparks between joints.

10.6 Environmental/Pneumatics

The FC-1D has a fairly high cruise altitude, this makes the design of the pneumatic systems significant. The pneumatic system supplies compressed air for cabin pressurization environmental control, anti-icing, engine start-up and pneumatic hydraulic pumps. To maintain passenger comfort, the cabin will be maintained at a pressure altitude of 8000 feet during cruise. A control and metering system will control positive and negative pressure relief and temperature of the environment inside the FC-1D cabin and cargo bay. Cooled air will be provided to the cockpit, cabin, cargo bay, and avionics bay (Figure 10.4).

In 1981, the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) mandated a minimum of 5 cfm/passenger flow of air to keep CO_2 concentrations at a minimum limit of 2,500 ppm (Ref. 10-2). In 1989 ASHRAE mandated 15 cfm/passenger for surrogate odor and other contaminants. The FC-1D surpasses these mandates with 20 cfm/passenger, 50% fresh air and 50% recirculated air. The air movement is accomplished by two Allied Signal Aerospace Co., large air conditioning packs (the second

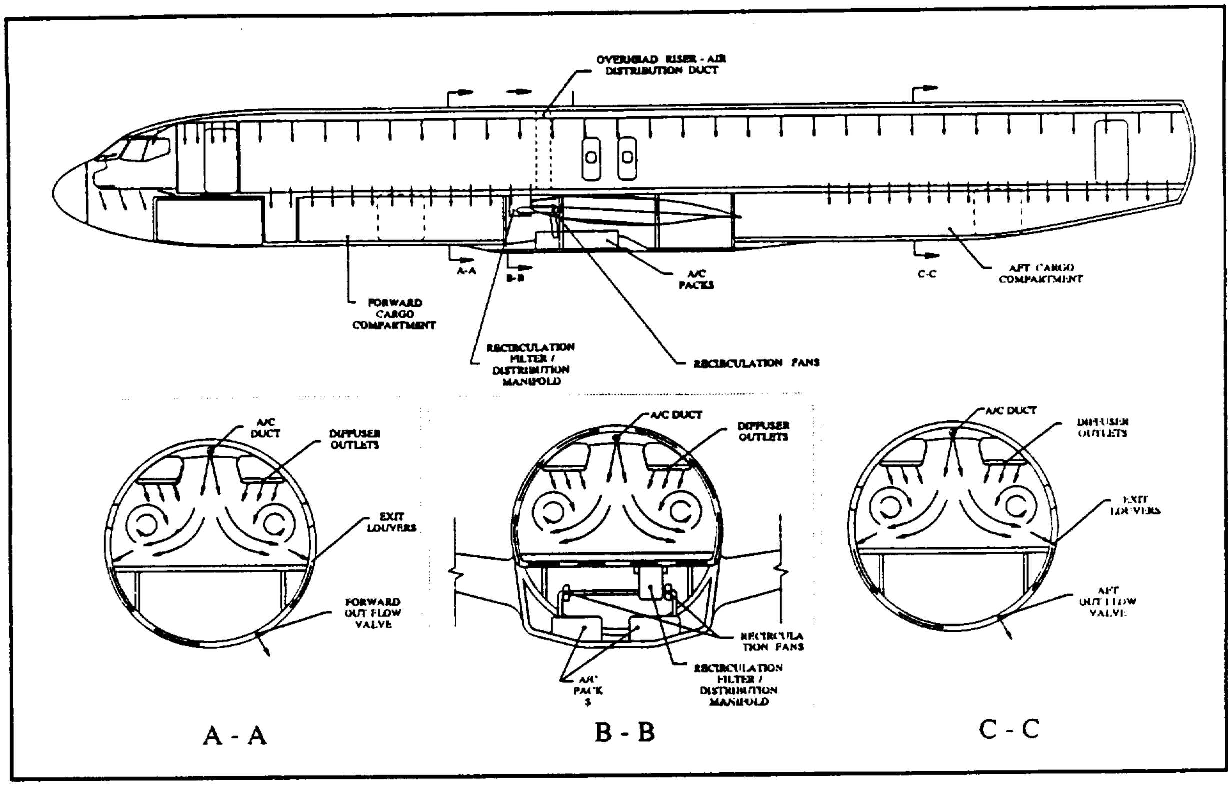


FIGURE 10.5: FC-1D Air Conditioning and Circulation

pack is used for redundancy). Each of these air packs can supply 4945 cfm at the 39,000 foot cruise altitude. These AC packs have a combined weight and volume of 460 pounds and 34.4 cubic feet. Locations for these air conditioning packs are shown in Figure 10.4.

10.7 Anti-Icing

In order for the FC-1D to be certified for domestic use, regulations require that an anti-icing system be in place (Ref. 10-3). Ice that forms on wings or tail can cause distortion to aerodynamic contours, which increases drag and may result in loss of climbing ability. To counteract this problem, Flying Circus designed an anti-icing system for the leading edges of the wing, horizontal and vertical tail, front windshield, and leading edges of the engine nacelle. This system consists mainly of pneumatic lines carrying engine bleed air in flight. Air from the APU is used for ground service, and can also be used during flight. Small instruments, such as Pitot tubes, are electronically anti-iced by resistively heating the metallic bodies of the instruments themselves.

10.8 Oxygen System

In the event of depressurization during flight, cabin passengers will be supplied with oxygen from the overhead compartments (See *Inboard Profile*). The oxygen system will come from nitrogen chlorate chemical oxygen generators. Chemical type oxygen was chosen by the Flying Circus over oxygen bottles because it reduces cost, weight, and the associated risk in servicing bottles. A gaseous bottled oxygen system is used, however, for the cabin and cockpit crews. Two smaller portable oxygen bottles are stored in an overhead compartment, for emergency use by the cabin attendants.

10.9 Fire Suppression

The control and sensing of onboard fires was an important safety consideration for the FC-1D. The fire suppression systems must be able to extinguish any fires that may occur in all phases of flight. For this reason, Flying Circus placed Halatron I extinguishing systems in the avionics bay, battery compartment, pneumatics bay, engines, landing gear bays, and the APU compartment. Because pressurized areas cannot have extinguishing agents that are toxic, class A-B-C carbon dioxide extinguishers will be located in the cockpit, fore and aft galley locations, and in compartments near the emergency over-wing doors. The cargo bays will also have carbon dioxide bottles distributed throughout it, so that a fire at any location in the cargo bays can be extinguished. In order to detect stray fires, temperature sensors on engines and landing gear brakes will be used. This information is relayed to caution lights, warning lights and the extinguishing system controls in the overhead cockpit panels and aisle control panels.

10.10 Escape/Emergency Evacuation

For emergencies, the FAA mandates strict rules for the design of proper evacuation capabilities, as detailed in Table 4.2 outlining FAR requirements. Type III doors over the wings allow emergency evacuation to passengers in the mid-section of the aircraft. To maintain an egress platform, these doors are placed directly over the wing box. The Flying

Circus also placed non-slip surfaces on the wing near the overwing exit to facilitate smoother evacuations. The overwing evacuation from the FC-1D meets the FAR 25.810-(d) 6 ft requirement and does not require slides to aid egress off of the wings. For evacuation of the forward and aft fuselage, slides are stowed in each of the type I doors. Emergency placards and lighting are also placed in strategic positions for the safe evacuation of passengers from the aircraft.

10.11 Lighting Systems

Flight deck lighting is accomplished with the use of background lights, floodlights, dome lights and map lights. Integral instrument lights are used for all instrument panels. Cabin lighting is provided by florescent lights in the overhead ceiling panels and in window panels. Incandescent night lights are mounted in select ceiling panels to provide low level illumination. Each passenger also has individual adjustable reading lights (Figure 10.5).

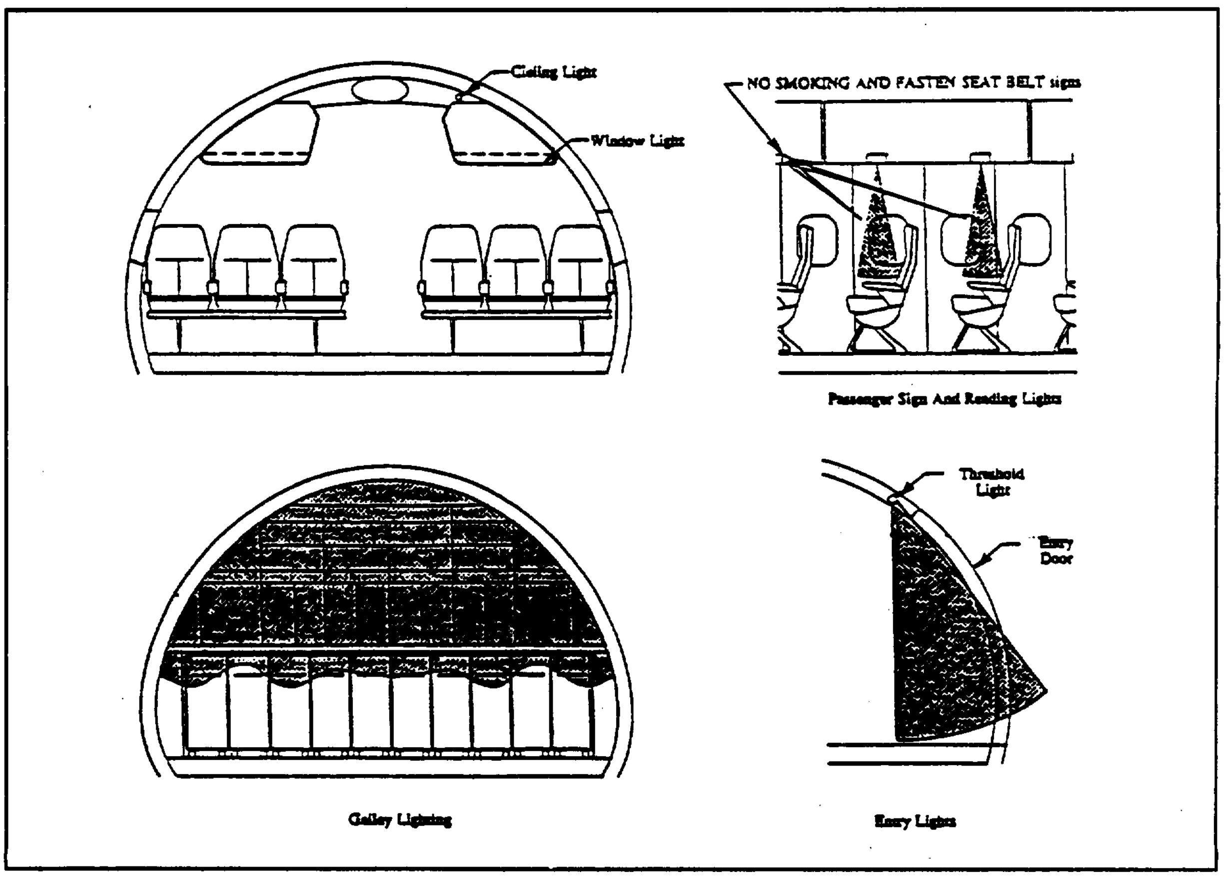


FIGURE 10.6: FC-1D Interior Lighting Arrangement

High intensity strobe beacon lights are mounted on the top and bottom of the fuselage, and aft of the wing leading edge (Figure 10.6). Additional strobes are mounted at each wing tip and in the tailcone.

Emergency lighting includes illuminated exit signs, lights in the ceiling above all emergency exits, and exterior escape path lighting. Emergency lighting is provided through the battery packs which are kept recharged at all times.

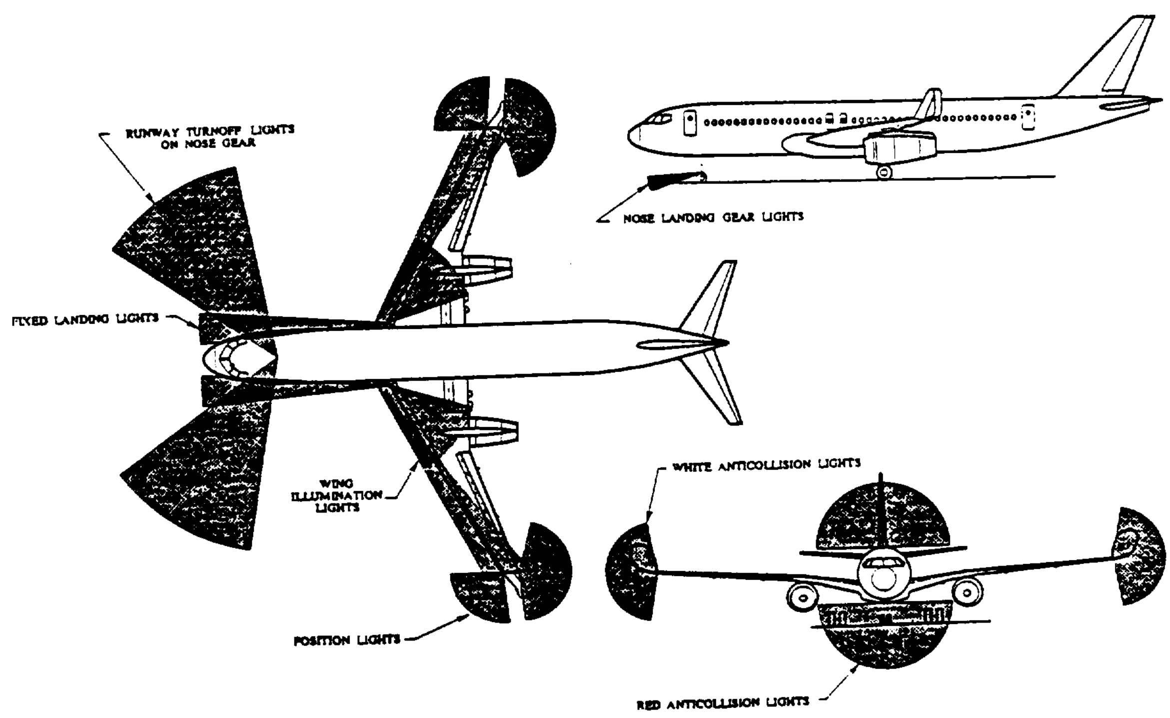


FIGURE 10.7: FC-1D Landing and Anti Collision Lights

11.1 Requirements

The main design requirement for the landing gear and brakes of the FC-1D is that it must be able to stop the aircraft within a FAR landing field length of 5000 feet as specified by the RFP. The gear is also required to support the aircraft weight and loads taxi and landing. On the ground, the landing gear must also be able to steer the aircraft safely while maintaining ground stability.

11.2 Gear Placement and Critical Angles

The unique configuration of the FC-1D greatly influenced the landing gear configuration. To assist the Flying Circus in its landing gear design, methods in Ref. 11-1 were used.

The first area of interest was the location of the aft and forward most CG locations of the aircraft (take-off CG and payload-added CG, respectively) with respect to the longitudinal load distribution on both the main and nose gear. In order to maintain proper steering control throughout the entire CG shift of the aircraft, the nose gear was placed to carry approximately 7% of the static load in the aft most CG position. In the forward most CG position, the nose gear carries approximately 9% of the static load. As a result, the main gear carries approximately 93% (aft most CG position) and 91% (forward most CG position) of the static load. This has been deemed within an acceptable range to ensure that the nose gear is not too great in complexity and size while maintaining adequate nose load to steer (Ref. 11-1). The narrow nose load shift is attributed to the small CG shift of the aircraft.

Stability, while maneuvering on the ground as well as on takeoff, was taken into account in the landing gear design. The main landing gear strut was angled back slightly more than 6° to ensure enough nose load for steering and the tail cone allowed a maximum rotation of 15° upon takeoff.

Lateral main gear placement was decided with considerations to turn over criteria. The recommended turn over angle had to be less than 63° to ensure ground stability during turning (Ref. 11-1). The main gear configuration yielded 43° to ensure a large safety margin in turn maneuvers (see Figure 11.1) as well as allowing sufficient engine clearance upon takeoff rotation.

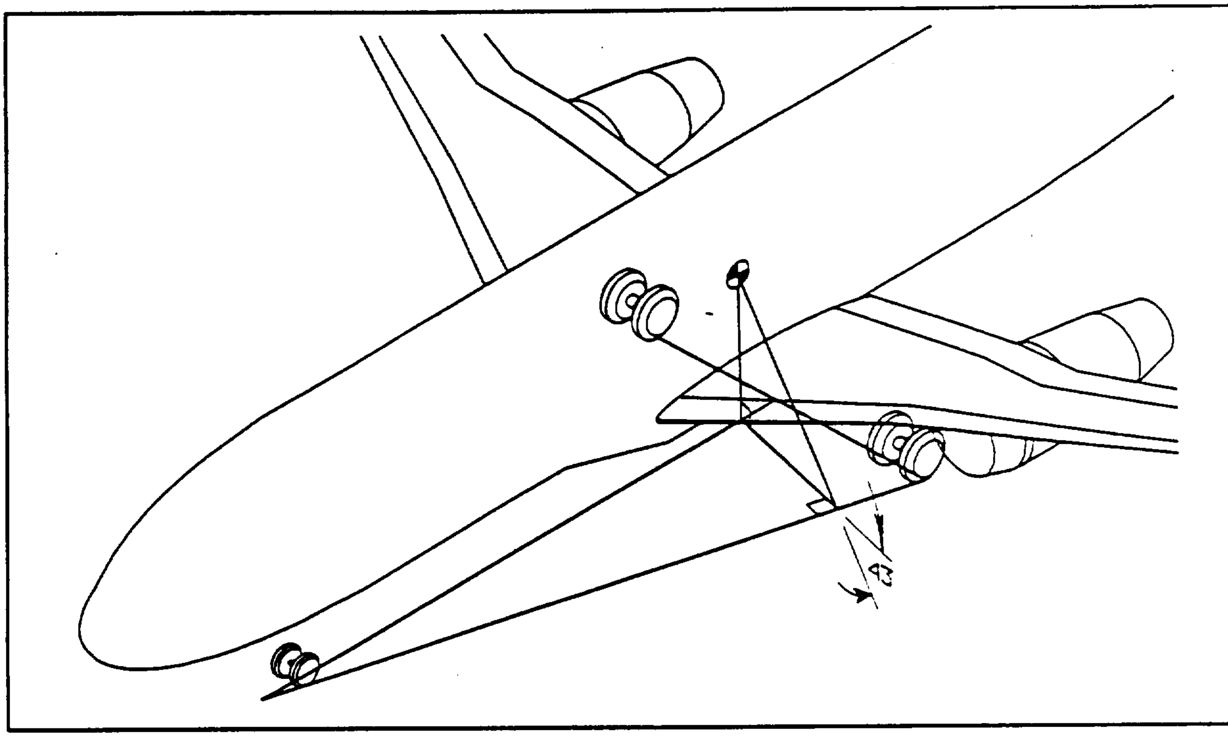


Figure 11.1: FC-1D Turnover Angle

The main gear lateral placement was also designed to provide a adequate pitch/roll envelope upon takeoff in which the FC-1D has approximately 14° pitch and 15° roll before wingtip strike.

11.3 Landing Gear Retraction

Landing gear retraction methods are unconventional, given the structural & ground stability restraints of the FC-1D. The main gear strut was angled back slightly while adding extra trail through a strut casting (see Figure 11.2). The strut casting became necessary due to the structural space limitation between the rear spar and auxiliary spar which were required for structural attachment areas for flaps as well as the trunion. The strut casting also minimized

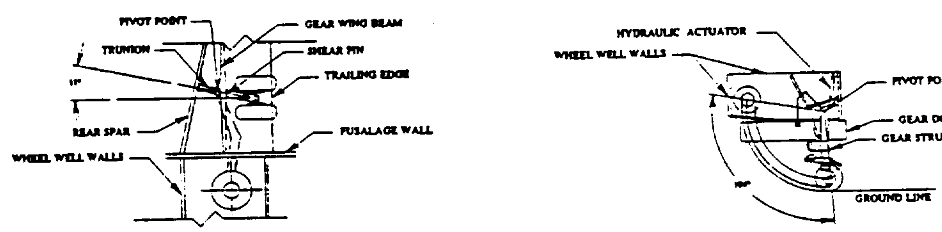


FIGURE 11.2 FC-1D Main Landing Gear

the amount of gear strut trail required to ensure adequate nose load and rotation capability; consequently, a total gear trail of 20° was designed.

Upon retraction, the main gear was required to move forward to allow enough space for aft cargo containers while maintaining enough required clearance with the wheel well walls due to expected tire growth. Tire growth is due to expansion of rubber tires under high angular velocities and moments of inertia experienced while a tire is spinning after take-off. To accomplish this, the trunion attachment was offset from the pivot point by 11° (See Figure 11.2). The pivot point is defined as the rotation point of the trunion about the shear pin.

When retracted, the landing gear must fit within the fuselage fairing along the gull of the wing (See Figure 11.2). The strut retracts 19 inches from the 21 inch strut stroke(See *Load Analysis & Strut Design*) through the use of an accumulator. The accumulator acts as a reservoir that is placed within the main gear bay and connected to the shock strut through a flexible pressure hose. A cable attachment at the gear axle and fixed to the airframe provides strut compression upon retraction. A sequential release valve opens that enables pressurized fluid to pass into the accumulator during retraction. Upon retraction, the pressure is shut off, the valve closed, and the precharge pressure in the accumulator is sufficient to extend the gear.

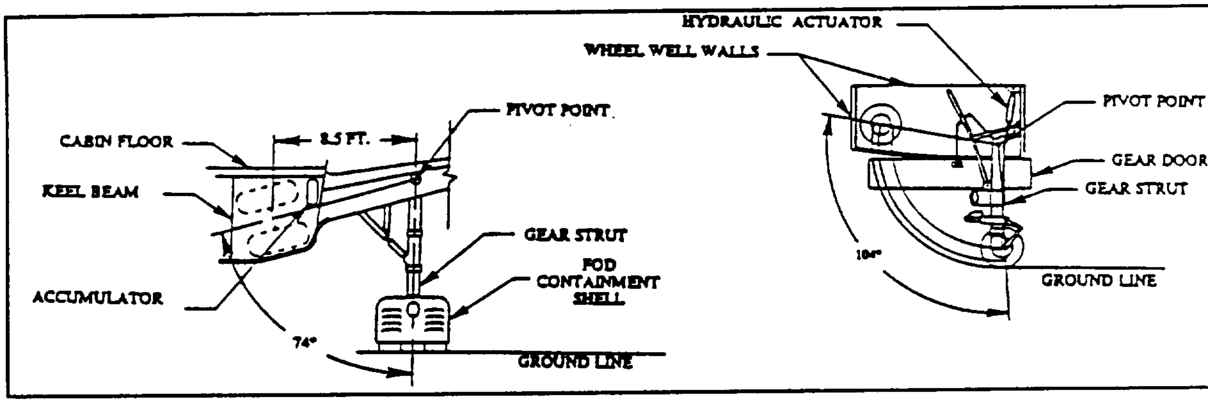


FIGURE 11.3: FC-1D Main and Nose Landing Gear

Nose gear retraction is very simple and conventional. A hydraulic actuator rotates the gear about the pivot point, while the strut extends 10 inches, (see Figure 11.3), into the wheel well permitting tire growth clearance.

The emergency gear extension system is operated by a control panel switch that is connected to an electric motor. The electric motor drives a hydraulic pump that provides pressure to the actuator for the nose gear. The actuator also operates a door safety valve to clear the door actuator of hydraulic fluid and mechanically unlock door actuator and gear uplocks. This allows both the doors and landing gear to open freely by gravity and into the locked position. The main gear uses the precharge pressure in the accumulator for alternate extension by a valve release switch that allows hydraulic fluid to travel back into the strut. The main gear doors are opened through the same system as the nose doors.

11.4 Load Analysis & Strut Design

The critical loads that the shock strut must absorb are the maximum static landing weight (90% of MTOW) for the main gear and the combined maximum static & dynamic braking loads for the nose gear. For this task, the Oleo-pneumatic shock absorber was used for its high efficiency (typically 80 to 90 %) and good energy dissipation (Ref. 11-1). The maximum static load applied to the nose strut is 11,000 lbs and 22,000 lbs of dynamic braking load for a combined total of 32,000 lbs of maximum load on the nose strut. The main gear struts have a maximum applied load of 58,000 lbs each on landing, using a calculated 1g landing gear load factor. These loads yielded the shock strut characteristics shown in Table 11.1.

TABLE 11.1: FC-1D Shock Strut Characteristics

	Strut Diameter	Strut Stroke	Efficiency
Nose	5.4 "	10 "	87 %
Main	7 "	21 "	87 %

The shock strut characteristic were calculated assuming a 10 ft/s sink speed and 1g landing gear load factor and a comparison of similar aircraft, such as the Airbus A320, to provide a comfortable landing and taxi (see Ref. 11-1 and Figure 11.4).

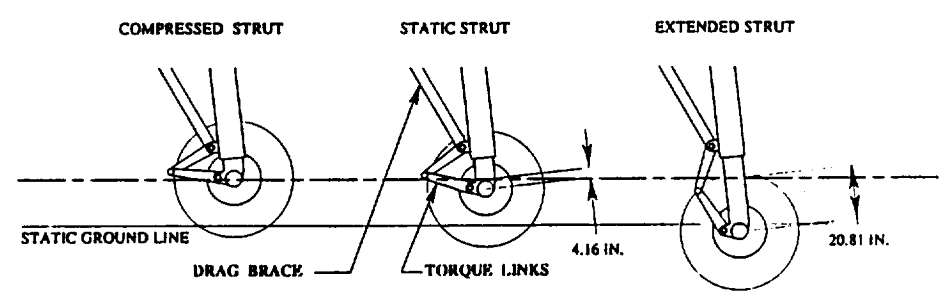


FIGURE 11.4 FC-1D Landing Gear Stroke Diagram

11.5 Configuration & Tire Selection

The configuration chosen for the landing gear was a twin landing gear arrangement. This decision was based on the space availability in the fuselage and the braking characteristics between the twin and twin tandem configurations. The twin arrangement occupied less volume in the fuselage upon retraction as compared to the twin tandem configuration. Room for 11 727-200 or LD-W cargo containers, (See *Inboard Profile*), was another benefit of the twin's smaller volume occupancy. Also, empirical data from the McDonnell Douglas Corporation (Ref. 11-2), shows that the twin arrangement landing gear brakes in shorter runway distances than the twin tandem arrangement.

Tire selection was based on size, loaded radius, required psi, and the equivalent single wheel load upon tire blow out. The main criteria in the tire selection was the static applied loads to each tire. The tire blowout condition was considered and the equivalent single wheel load was calculated for the remaining tire: 9,000 lbs for the nose and 42,500 lbs for the main tires. This load determined the tire type and size to be used. The tire type that met these requirements was the B.F. Goodrich radial tires. The tire characteristics are given in Table 11.2.

TABLE 11.2: Critical tire characteristics

	Tire Dimension	Max Load	InflationPressure	Loaded Radius	Ply Rating
Nose Tire	28" x 7.7"	11,000	195 psi	11.7"	14
Main Tire	44" x 16"	45,000	225 psi	17.9"	32

The required psi for both the nose and main tires are less than the recommend psi which is beneficial in that it extends the life of the tires under normal operation. From the tire dimensions and the applied loads, the footprint area of the nose and main tires is found to be 78 and 250 square inches respectively. From here, the Load Classification Number (LCN), as established by the ICAO (Ref. 11-1), is found to be 15 for the nose and 64 for the main gear tires. As the aircraft burns fuel, the weight decreases and so does LCN to 11 for the nose and 54 for the main. This aids in the determination of how the FC-1D operates on a specified surface and how compatible it is with airport runways in terms of its landing loads and the runway deflection it causes.

Another classification system uses a characteristic number of an aircraft that is based on aircraft weight, tire pressure, and type of surface is called the aircraft classification number or ACN. The ACN is used to describe an aircraft's capability to use a given runway. The FC-1D has an ACN of 27 on takeoff and 19.5 upon landing at its operating empty weight as calculated using Reference 11-3. Subgrade B surface strength is a measure of the pavement strength at given tire pressures. It is based on a flexible pavement with a working stress of 300 psi/in which is similar to 17 inch thick asphalt.

11.6 Steering Systems

The FC-1D's steering will be accomplished through two push/pull type hydraulic actuators. The captain's side panel steering wheel provides 78° of nose wheel steering while

7° is provided by the rudder pedals. The rudder pedal steering will be used during taxi, takeoff and landing so as to restrict the maximum angle for turnover safety considerations. Disconnect valves will be provided to release the actuators from powered control to allow the aircraft to be towed. Shimmy damping is provided by canting the nose gear forward 5° to give 2 inches of mechanical trail which ensures that the wheel leads the load and is not behind it. The gear is centered on retraction through the use of centering cams to ensure that the nose wheel is straight upon landing. Nose gear doors are mechanically actuated through the same system as the retraction actuators and automatically open and close as the gear is extended and retracted. The maximum steering angle provides the FC-1D with a tight turning radius of just over 88 ft (see Figure 11-4).

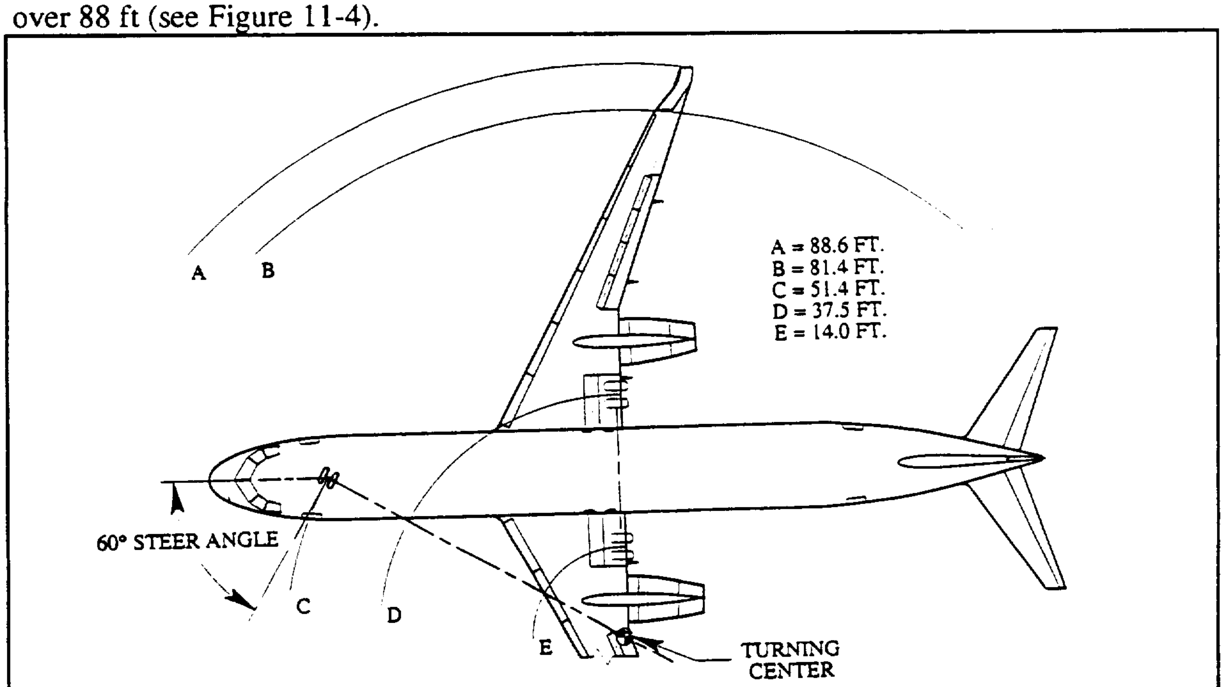


FIGURE 11.6 FC-1D Turn Radius

11.7 Antiskid System

The antiskid system monitors wheel velocity continuously and compares it to the hydroplaning velocity of the FC-1D (Ref. 11-4). When the wheel is decelerating faster than the reference velocity, it is detected as a skid. The system then provides brake releases to achieve optimum braking action under varying braking conditions.

11.8 Brakes

Carbon brakes were chosen for the FC-1D due to their high reliably, reduced weight and high heat sink characteristics. Carbon brake spares are a high cost and subsequently so is the maintenance cost, however, the high reliability coupled with the weight savings of carbon brakes is found to be a good tradeoff. Also, carbon brakes are less likely to cause damage to the landing gear on a rejected takeoff. This is because steel brakes usually fuse at rejected takeoff temperatures whereas carbon brakes fuse at much higher temperatures.

12. MANUFACTURING

12.1 Manufacturing & Assembly Philosophy

In keeping with Flying Circus' low cost philosophy, the FC-1D will be constructed and assembled using as many cost saving manufacturing processes as possible. Integrated Product Development (IPD) will be implemented into the manufacturing of the FC-1D. The IPD designers consist of cross functioning teams which are made up of engineering, mechanical, maintenance, manufacturing, and contractor personnel. IPD designs and redesigns new and existing parts, respectively, so as to minimize part numbers in the component. This reduces overall aircraft weight, which translates into increased assembler productivity, due to reduced assembly parts which results in reduced manufacturing man-hours. Additional benefits are less required fuel due to reduced operating empty weight, less tooling, tooling costs, and tooling man-hours.

Use of a common graphics oriented data base will also be instrumental in the manufacturing design of the FC-1D. A system such as CATIA will assist cross functional development teams in identifying manufacturing, maintainability, and part interference problem areas. Subcontractor use of the common data base will also assist in accurate part production. This translates into a large savings through reduced redesign engineering hours and reduced assembly time due to accurate part integration.

The use of aluminum on a majority of the aircraft structures allows for diversity in manufacturing location. Production of major aluminum parts, such as fuselage sections, would take place with either a domestic or foreign contractor, depending on the international trade climate. This would help lower overhead costs for FC-1D production.

Composites use on the horizontal and vertical tails, control surfaces, raydome, and engine nacelles benefits weight and operating cost (See *Weight Breakdown*). Composite manufacturing will be done in house using automated lay-up machines that are set to standardized production methods for accuracy, quality, and reliability. Standardized methods are currently being established by several companies in an effort to reduce the production and repair cost of composites (Ref. 12-2). Increased industry demand for composites will lead to lower cost and standardized techniques for fabrication as well as repair of composites. It is expected that these standards will be implemented by the year 2000 technology date and will be adopted by the Flying Circus in the production of the FC-1D.

12.2 Final Assembly

In order to meet expected market demands the manufacturing facility of the FC-1D is equipped for duel production lines. Figure 12.1 shows the FC-1D production and assembly facility. Fuselage manufacturing of the FC-1D is broken up in to five assembly sections. These are summarized in table 12.1

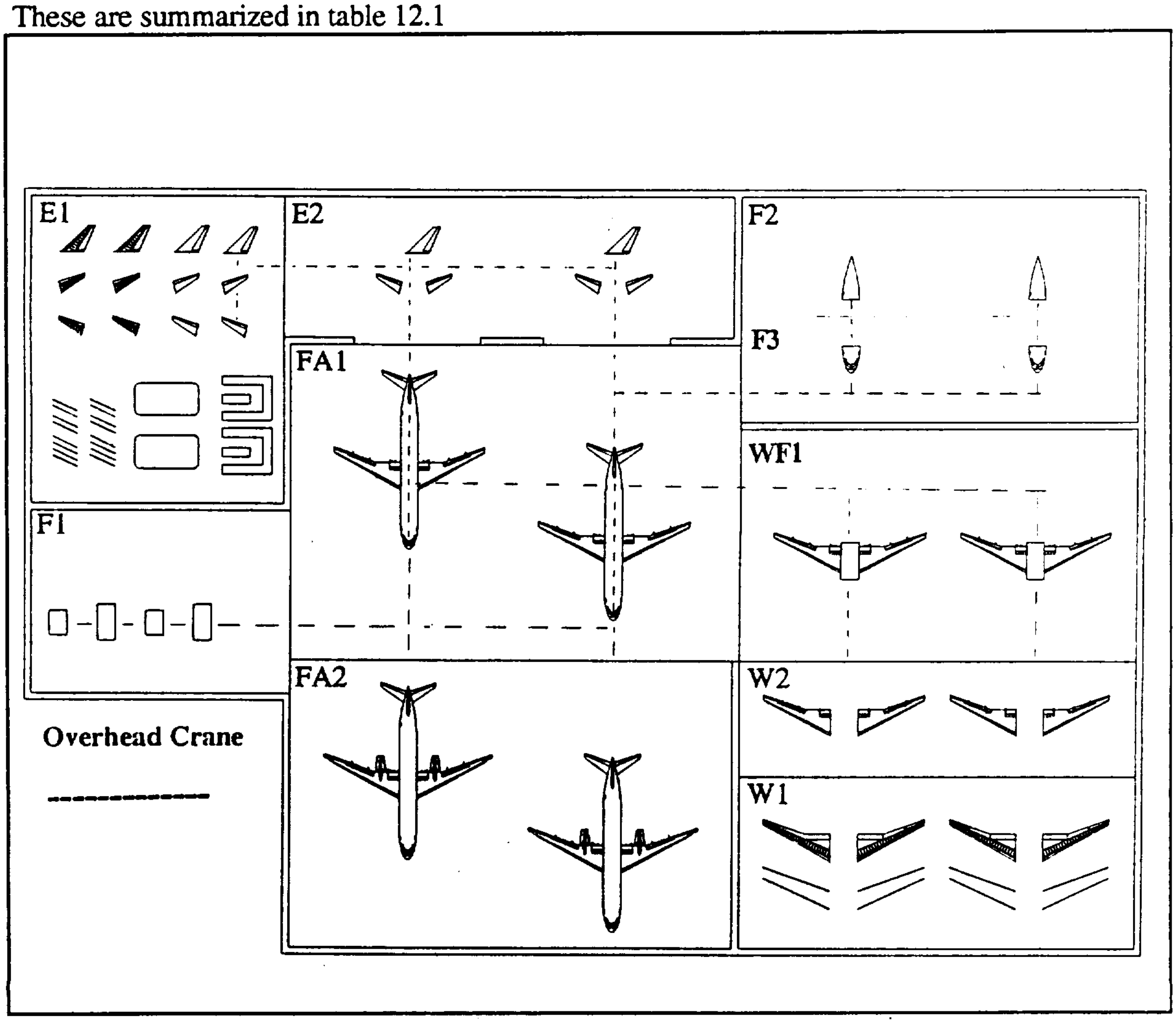


FIGURE 12.1: FC-1D Final Assembly

TABLE 12.1: Fuselage Manufacturing Sections

Fuselage Section	Fuselage Station (in)
31	300-464
32	464-948
33	948-1172
34	1172-1456
35	1456-1820

The FC-1D manufacturing and assembly facility is divided into separate areas where specific assembly and manufacturing tasks are accomplished. Table 12.2 describes the task and function of each area.

TABLE 12.2: FC-1D Manufacturing and Assembly Task Areas

Area	Task
F1	Section 32 and 34 Prep for Final Assembly
F2	Section 35 Manufacture/Assembly
F3	Section 31 Manufacture/Assembly
W1	Wing Manufacture/Assembly
W2	Wing/Fuel Tank Sealing
WF1	Wing/Section 33 Assembly and Prep
E1	Empennage Manufacture/Assembly
E2	Empennage Prep for Final Assembly
FA1 and FA2	Final Assembly Areas

Area F1 is the receiving and preparation area for final assembly of sections 32 and 34. Sections 32 and 34 are manufactured and assembled by contract partners and shipped to the FC-1D manufacturing facility. Contractors will chemically mill and machine fuselage skins and extrude frames for fuselage panel sections. Fuselage sections are then built up from panels and assembled on a rotating jig. Areas F2 and F3 are manufacture and assembly areas for sections 31 and 35. The manufacture and assembly is similar to that of F1.

Area W1 is the manufacture and assembly area for the wings of the FC-1D. Wing skins and ribs are integrally machined and wing spar webs are extruded. All other control surfaces are contracted out and shipped to the plant. After assembly on jigs the wings are rolled into Area W2, where fuel tanks are sealed. Area WF1 receives section 33 from contract partners and is prepared for final assembly. Wings are then rolled from sealing and attached to the center wing box and engine pylons are mounted.

Area E1 is the manufacturing and assembly areas for the horizontal and vertical tail.

Area E1 focuses on flow through processing. At the head of the production line are freezers containing epoxy pre-preg materials. These materials are laid-up on an automated tape lay-up machines. The empennage structures are then loaded into a double ended autoclave. At the far side of the autoclave the empennage structure us unloaded and given a nondestructive inspection. The structures are then assembled and craned to area E2 and placed on jigs for torque box attachment.

Final assembly of the FC-1D will be performed in assembly sections FA1 and FA2 and will be a staggered dual production assembly line. Fuselage section 33 is joined to the main wing in section WF1 and carried by the overhead crane to assembly area FA1 and placed on a final assembly jig. The locations of wing-body sections will be staggered so as to allow for maximum usage of floor area and to facilitate the dual production line. However, the wing locations will not overlap so as to allow movement of one aircraft past the other. After final assembly preparation in F1, fuselage sections 32 and 34 are carried by the crane, , to FA1 to be joined with the wing-body on the final assembly jig. Fuselage sections 31 and 35 are equipped for final assembly in F3 and F2 respectively and transported by crane to FA1 to complete fuselage final assembly. Laser alignment is used to ensure that assembly falls within acceptable tolerances. The overhead crane will then carry the completed empennage sections from E1 to E2 for final assembly preparation. Following empennage preparation, the overhead crane transports empennage sections from E2 to FA1 for fuselage attachment. The staggered arrangement also allows for non-interference with the vertical tail, once it is joined to the fuselage, during transportation of fuselage sections 31 and 35. Once completed, the assembled airframe is moved to assembly station FA2 for engine and spiroid integration as well as electrical, avionics, and major system checks. The completed aircraft is then ready for roll out and certification testing.

12.3 Management Structure

Flying Circus follows the team philosophy of design. The aircraft is concurrently engineered as much as possible. This is done through cross functioning teams of engineers, common data base systems, and up to date information on aircraft status. Clear and concise goals are established by the team leader as well as inspiration and leadership. The Flying Circus Commercial Aviation Group is committed to providing accurately engineered products at the lowest possible cost to its customers.

13. AIRPORT REQUIREMENTS

Part of the requirements for the FC-1D was that it be compatible with current airport facilities and be easily maintained. Certain areas of the fuselage were designed to be readily accessible to maintenance personnel for inspection, replacement of parts or repairs. In addition, all access panels are of a size and placement that allows mechanics to work in that area efficiently.

The FC-1D was also designed so that many services can occur simultaneously, including: loading and unloading passengers; refueling and re-oiling; replenishing potable water, lavatory service and baggage; cabin cleaning; and servicing the galley. Figure 13.1 shows that the required trucks and service vehicles do not interfere with each other, loading ramps or any protruding component of the FC-1D.

Many ports are needed around the plane in order for the maintenance personnel to be able to work on a piece of equipment. The FC-1D Three-View show locations of the many ports which are necessary in the design. Figure 13.2 illustrates the compatibility of heights for some of the service locations of the FC-1D compared to the DC-10 and the Boeing 737-400. Some of the access ports will have control panels with links to the main computer system

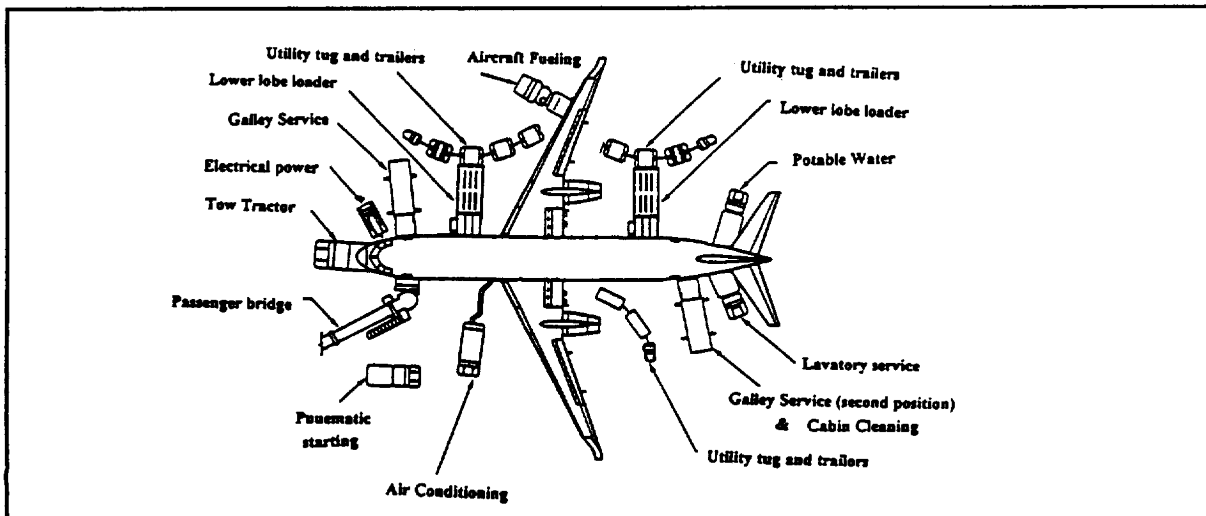


FIGURE 13.1: FC-1D Airport Compatibility

C-2.

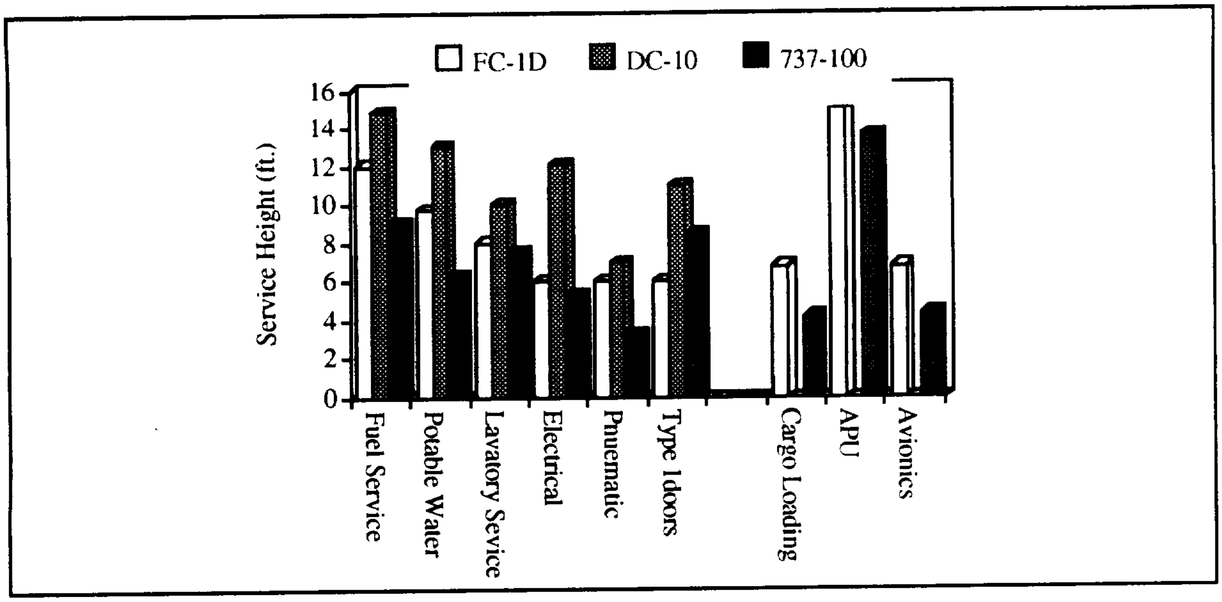


FIGURE 13.2: FC-1D Service Height Compatibility

onboard the aircraft, so that maintenance personnel can analyze the equipment right at the port. Aircraft maintenance personnel will have access panels or these important stations on the FC-1D:

Avionics centers	Radome	Lavatory Service
Overhead Wiring	Electrical bay	Potable Water Service,
Auxiliary power unit	Air Conditioning packs	Landing gear Bays
Pneumatic and engine starting	Pneumatic	Over and under wing Fueling/defueling centers

Flying Circus also had to design for a regular maintenance schedule for the FC-1D. A breakdown of the required maintenance checks is listed in Table 13.1.

TABLE 13.1: FC-1D Maintenance Checks

Type of Check	Intervals	Checkpoints
Class 1	Every flight	visual inspection of the fuselage, both vertical and horizontal tails, engines and pylons, wings, landing gear, tires and wheels, and any areas that have a high frequency of leaks
Class 2	45 hours	Class 1 in addition to galley equipment maintenance, check of all major fluids, cargo hold inspections, gear doors, emergency systems, and other visual inspections
Class A	350 hours	lass 2 check, however, it also includes testing of the avionics, emergency fire suppression systems, major hydraulic reservoirs, rudder and elevator actuators, and other detailed sensor equipment
Class C	456 days or 3000 hours	comprehensive inspection and testing on all the systems and subsystems of the aircraft
HMV	4 years and 35 days	complete servicing of the aircraft and inspections of the aircraft's structural integrity and airworthiness

14.1 Market Analysis

In justifying the construction of the FC-1D, Flying Circus researched the current and future market needs for the narrow body aircraft. According to Reference 14-1, an approximate market size of 4100 narrow body aircraft exists between now and the year 2000. Assuming that initial FC-1D deliveries start in the year 2000 and that Flying Circus obtains an 18% total market share, Flying Circus expects to have demands for approximately 750 aircraft. (Ref. 14-1)

The FC-1D is very restrained in its overall cost, both by the RFP requirements and the reality of today's market needs. The cost of the FC-1D is made up of research & development and test & evaluation (RDTE), acquisition, operating, and the disposal cost. The calculation of these costs was done with the help of Reference 14-2 and actual airline data (Ref. 14-3), all dollars are normalized to 1994 dollars.

Costs of RDTE are estimated for 5 aircraft; 3 for flight and 2 for static testing. Engineering, tooling, and manufacturing labor rates are all in house and include overhead costs. The engine price used is $6 million and $2.75 million is used for the avionics and flight management systems (see Ref. 14-3). After conducting quality control and adding financing expenses for RDTE, total expenses amount to $597 million. A tabular breakdown of RDTE is given in Table 14.1.

TABLE 14.1: Research, Development, Test, and Evaluation Cost Breakdown

Engineering & Design	$53 million
Development support & Testing	$20.5 million
Flight Test Airplane	$378 million
Flight Test Operation	$1.5 million
Profit Margin of RDTE (10%)	$59.8 million
Financing of RDTE (12%)	$71 million
RDTE Phase Total Cost	$597 million

Manufacturing is an extremely important cost parameter, since it is a component of the acquisition cost. Methods for curtailing manufacturing cost were addressed in the *Manufacturing* section. Estimated manufacturing costs will determine the amount of investment capital required for start up, types of materials and production philosophies used, and ultimately, the aircraft production and market prices. The largest contributors to manufacturing cost are the airplane production cost and airframe design and engineering (see Table 14.2).

TABLE 14.2: FC-1D Acquisition Cost Breakdown and Production Costs

Airframe Design & Engineering	$110 million
Aircraft Production	$7.1 billion
Flight test operations	$31.8 million
Total Manufacturing Cost	$9.2 billion
Total Acquisition Cost	$10.2 billion
Aircraft Acquisition per unit	$48 million

Manufacturing Assumption
750 aircraft produced
6.94 avg. unit/month Prod. rate
10 year Prod. life
8 % financing
19 % profit margin

The acquisition cost of the FC-1D was calculated to give the manufacturer an adequate return on investment (ROI) while remaining at a competitive aircraft price (See Figure 14.1 and Table 14.3). Choosing a $48 million acquisition cost gives a 4.40% ROI and aircraft number 612 is the breakeven unit.

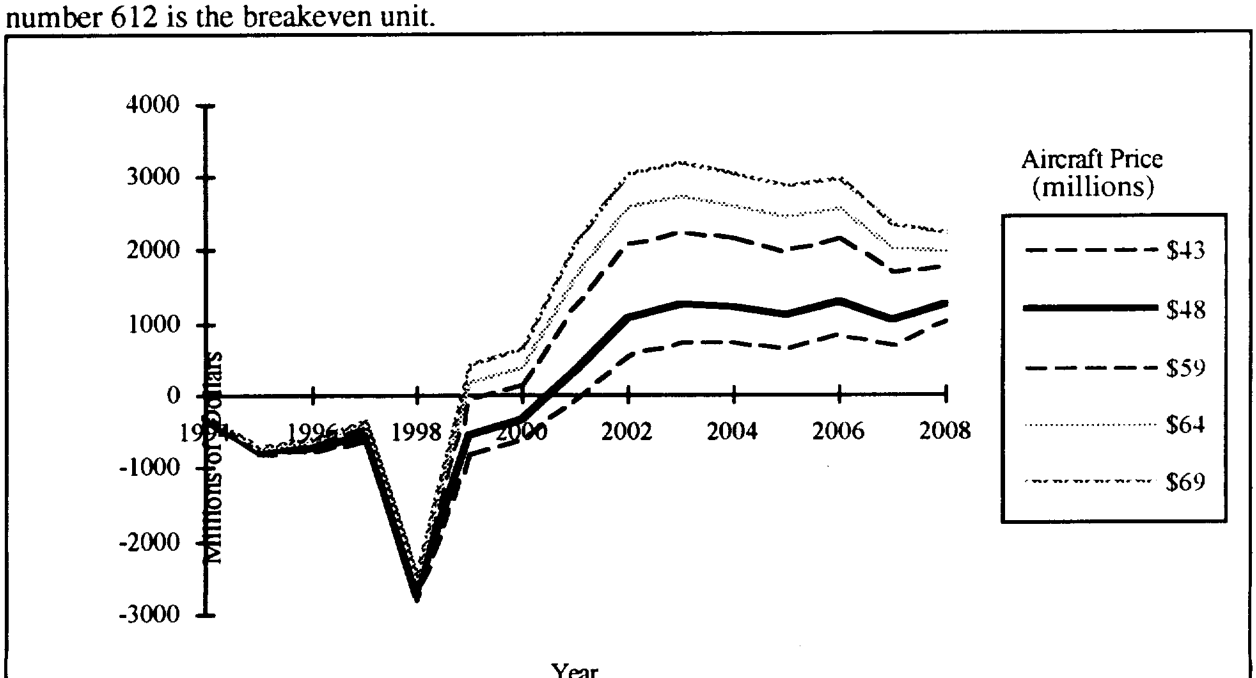


Figure 14.1: Manufacturer's Cumulative Cash flows for Varying Aircraft Price

TABLE 14.3: Acquisition Cost Comparison

737-X	A320-200	FC -1D
$45 million	$42 million	$48 million

source: Aviation Week & Space Technology

The operating costs of the FC-1D and the ways in which to reduce them were the paramount concern for Flying Circus. The total operating cost is composed of the IOC and the DOC. Indirect operating costs are generally not controllable by the airframer and are left as a percentage of the DOC. In this case it is found to be approximately 55% (Ref. 14-4). DOC reduction was done by establishing a baseline aircraft and improving upon it.

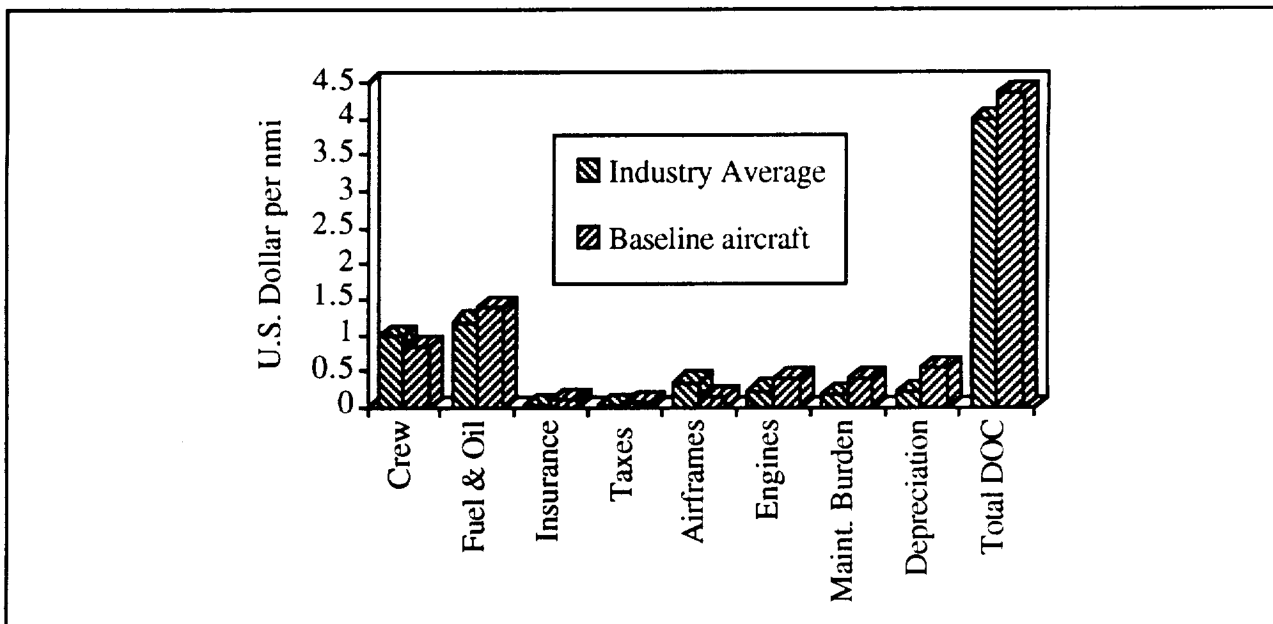


FIGURE 14.2: Industry average vs Baseline aircraft

The current fleet of domestic aircraft shows that the key areas to reduce the direct operating costs are in fuel consumption, crew costs, airframe and engine maintenance, and depreciation of the aircraft (see Figure 14.3 & Reference 14.5). Crew costs are mainly controlled by the airline selection of pilots. However, the FC-1D assists in reducing cost by providing an advanced two crew cockpit. Fuel consumption was addressed through drag and weight reduction schemes. Airframe and engine maintenance data obtained from actual industry sources (Ref. 14-3), was used for maintenance man-hour data and material cost.

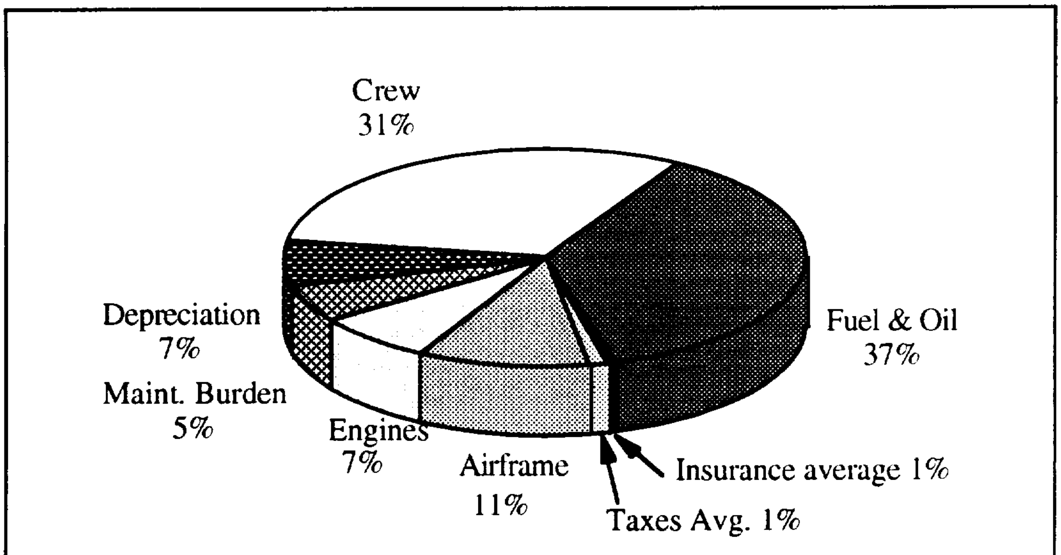


FIGURE 14.3 Industry DOC Averages

This was deemed acceptable due to the industry proven engines the FC-1D employs, as well as the mechanic familiarity associated with them. The assumption that composites will be relatively inexpensive to repair by year 2000 was mentioned in the *Manufacturing section* (Ref. 12.1).

In order to reduce drag, Flying Circus adopted the aft wing nacelle. A parasite drag decrease of 5% was obtained with a corresponding 10% structural weight penalty. The net effect was a 4.53% decrease in DOC due to the fact that reduction in required fuel adequately compensated for the structural weight penalty. Maintenance was not complicated due to the use of existing engines and their close proximity to the ground as opposed to an aft nacelle configuration such as the MD-80.

Riblets were also used to reduce the drag and subsequently, the fuel burn of the baseline model. Riblets are a very low risk technology that reduces the overall drag of the aircraft by 4% (Ref. 5-4) while replacing aircraft paint. Application of riblets to 75% of the fuselage resulted in a 4.26% DOC reduction. The maintainability of riblets is relatively light when damage occurs to small sections. They are applied in strip sections and require minimal time to both apply and adhere. Their projected life is 5 years, which corresponds with aircraft heavy maintenance visits for ease of total reapplication.

Spiroids are another technology that was utilized for drag reduction. Available data provided a 10% induced drag reduction with a slight weight penalty. This resulted in a net weight drop due to less required fuel. Net DOC reduction from the baseline came to be 3.69%. It is expected that pilots will be accustomed to them from experience with winglets.

Composite use by Flying Circus was prompted by their growing use in industry and research being done to improve their repair methods (Ref. 12-1). Composite use yielded a 6% in structural weight reduction. This in turn reduced operating empty weight and gave a 4.36% DOC reduction as compared to baseline. The net benefit and ramifications on DOC of these modifications are shown in Table 14.4.

TABLE 14.4: FC-1D Drag & Weight reduction program summary

Modification	% Decrease Drag or Weight	% Decrease DOC
Aft nacelle	5% drag dec. 10% wing weight inc.	4.53%
Spiroids	10% induced drag reduction	3.69%
Riblets	4% drag reduction	4.26%
Composites	6% weight reduction	4.36%
FC-1D vs. Baseline	6.3% weight & 13.8 % drag	12.20%

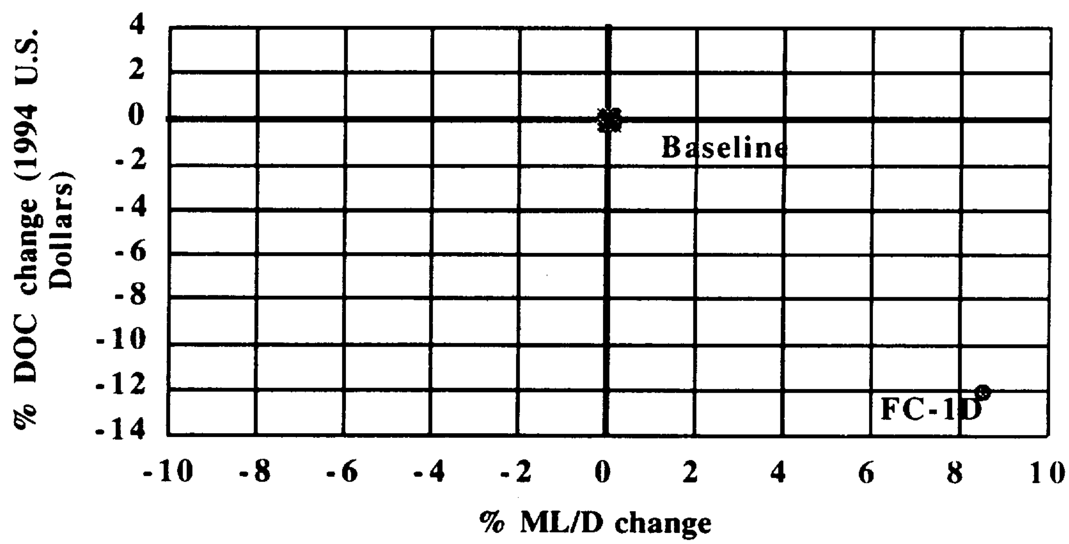


Figure 14.4 Cumulative Effect of Advanced Technology on FC-1D

Table 14.4 and Figure 14.4 illustrates how implementation of low risk, high technology enhancements make the FC-1D a more cost effective aircraft when compared to the average, and the baseline. The DOC of the FC-1D was calculated using a stage length of 3000 nmi, annual utilization of 3262 hours per year, and a block time of 7.05 hours. Reduction factors of 3% and 2% were taken for engine and airframe maintenance respectively. These were at taken due to the use of proven engines and simplified airframe systems and diagnostic computers that extend time between maintenance cycles and thus reduce maintenance cost.

TABLE 14.5: FC-1D DOC comparison

Aircraft	DOC (US. Dollars/nmi)
Baseline	4.40
Industry average	4.15
FC-1D	3.86

However, the most effective method to illustrate the FC-1D's cost efficiency is shown in Figure 14.5, which shows current fleet aircraft of similar size normalized to a 3000 nmi trip. In Figure 14.5 the FC-1D operates below the competition on a cost/seat basis with its maximum density configuration and competitively at its mixed class configuration. This shows that the FC-1D uses its given volume very effectively to generate revenues, it is also

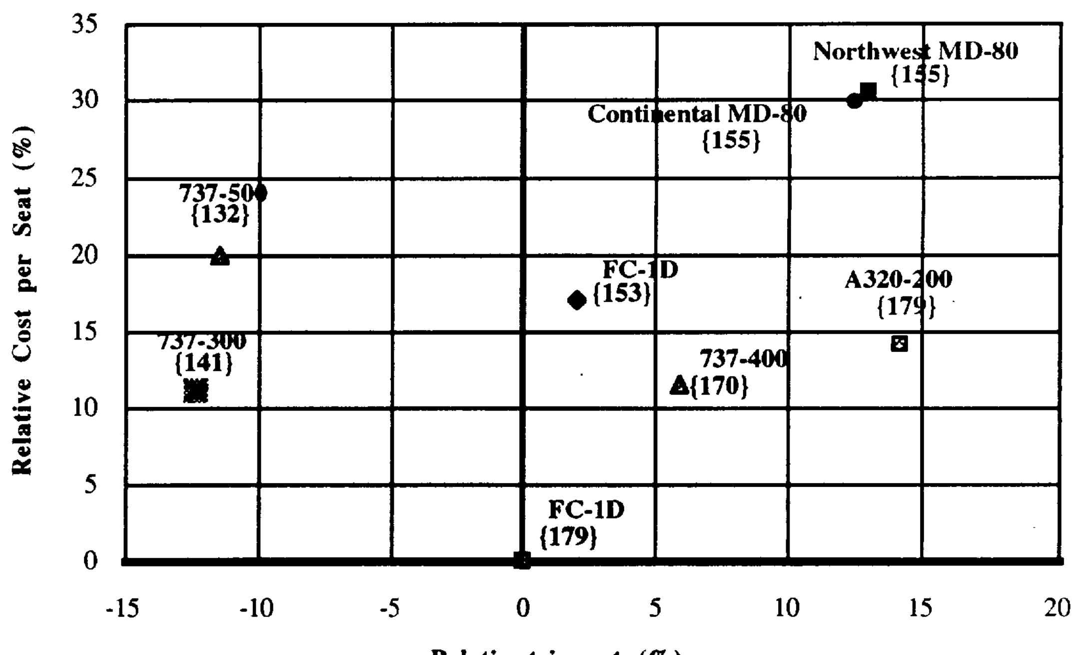


FIGURE 14.5: DOC Comparison of FC-1D Chart with Competition

very competitive on a per trip basis.

Summing the costs of the FC-1D over the estimated 30 year life yields a life cycle cost of $477 million as can be seen in Figure 14.6. It should be noted that the greatest contributor is the operating cost, which is where Flying Circus concentrated its cost reduction efforts as per the RFP. RDTE is also sizable portion of cost due to intensive certification requirements warranted by the FC-1D's unique configuration. Acquisition cost were reduced through the use of advanced manufacturing processes see *Manufacturing* section..

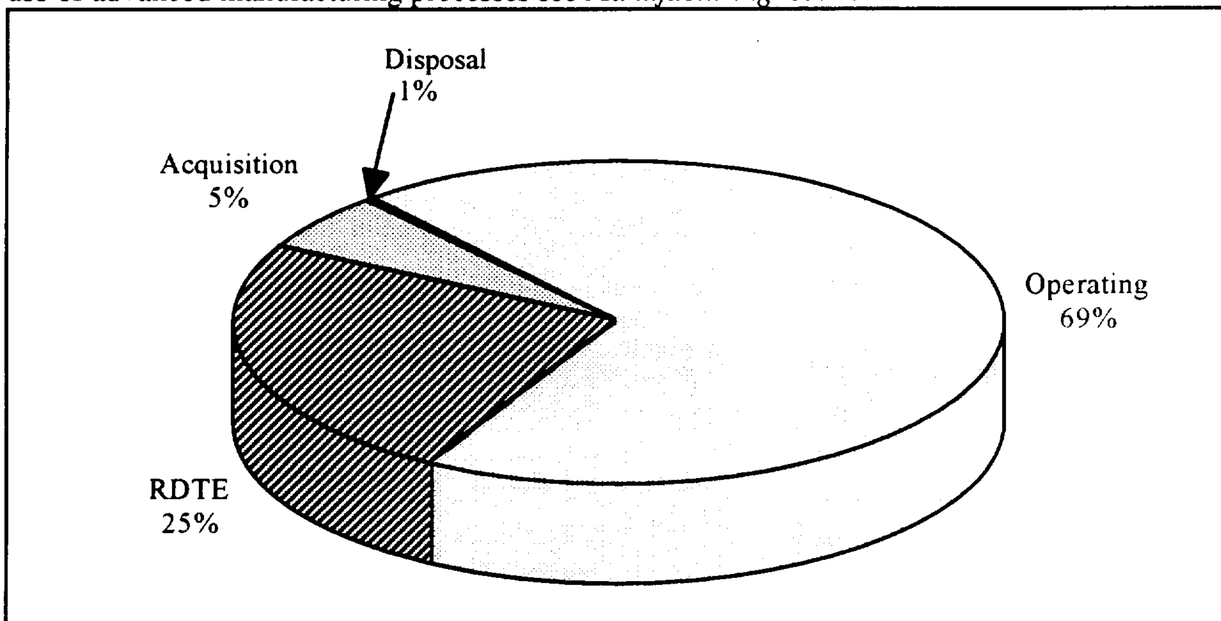


FIGURE 14.6 FC-1D Life Cycle Costs

15. CONCLUSIONS AND RECOMMENDATIONS

The next decade will see harsh economic times for the airlines as well as airframers due to slow global economic growth and a slumping market. For the airlines to survive in the tough economic times of the next decade they will need an aircraft that significantly lowers their DOC.

The Flying Circus' response to the airlines needs was the FC-1D. The FC-1D evolved from a baseline aircraft that was modeled after a conventional transport flying today. It was found that the DOC of the baseline aircraft was greater than the industry average. To reduce the DOC of the baseline aircraft drag ,weight, and cost reduction methods were implemented. Through the use of low risk, advanced technologies, Flying Circus was able to reduce the DOC of the baseline aircraft by 12%. This is a significant reduction in DOC, which makes the FC-1D highly competitive in the world market for the year 2000.

The FC-1D shows itself as the outstanding new leader in air travel by maximizing its performance for a new, medium sized, longer range market, that is more compatible to airline's needs. The FC-1D has achieved maximum performance in this category while maintaining low direct operating costs for the airlines. The future for the FC-1D is not limited to the plane it is now, but in its inherent ability to change and adapt to fit the new demands and benefits that will come in the future.

On recommendation for airlines to reduce crew and maintenance costs is through an employee profit sharing program similar to Southwest's philosophy. This allows the airline to pay their employees less and increase their productivity, by increasing pay benefits through profit sharing. Also adoption of a single pilot cockpit that is acceptable to the FAA would greatly reduce crew costs.

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