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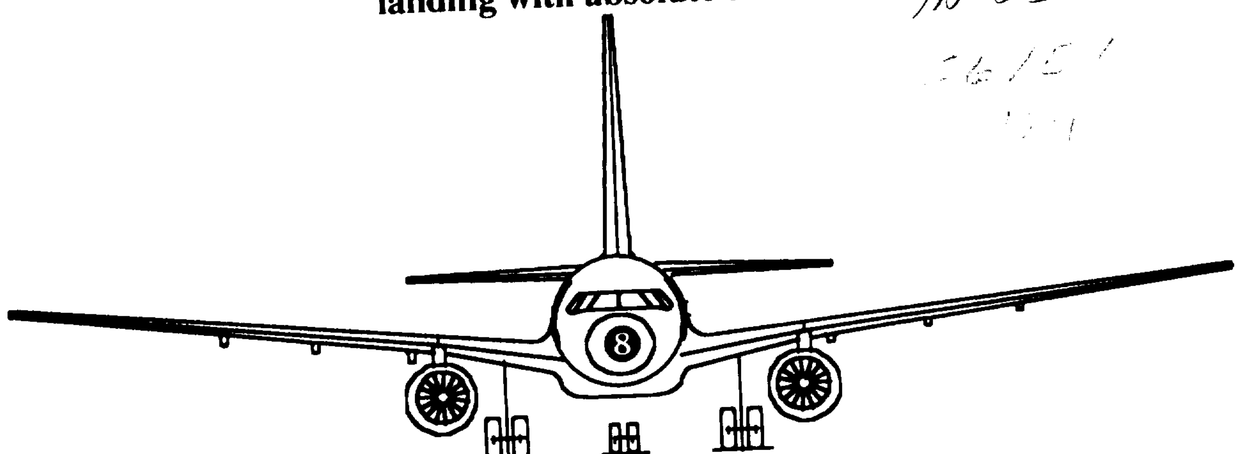
Central Coast Designs

The Eightball Express

Taking off with convention, cruising with improvements and landing with absolute success

IN-05-CR



1993/1994 AIAA/Lockheed Corporation
Undergraduate Team Aircraft Design Competition

California Polytechnic State University, San Luis Obispo

June 1, 1994

A Low Cost Commercial Transport For Domestic Routes

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NOMENCLATURE

Symbols

C_D	Total drag coefficient
C_{Do}	Zero lift drag coefficient
C_{Di}	Induced drag coefficient
C_L	Total lift coefficient
C_{Lmax}	Maximum total lift coefficient
FEPS	Flight Envelope Protection System
HIRF	High Intensity Radiant Fields
HLCS	High Lift Control System
I_{xx}	Moment of Inertia is the x-stability axis(slg-ft^2)
I_{yy}	Moment of Inertia is the y-body axis(slg-ft^2)
I_{zz}	Moment of Inertia is the z-stability axis(slg-ft^2)
I_{xz}	Moment of Inertia with respect to the x&z-stability axis(slg-ft^2)
$(L/D)_{max}$	Maximum lift to drag ratio
MAC	Mean aerodynamic chord (ft)
M_{be}	Mach - best endurance
M_{br}	Mach - best range
MSL	Mean sea level (ft)
M_x	Moment about x-axis (ft-lbf)
M_y	Moment about y-axis (ft-lbf)
M_z	Moment about z-axis (ft-lbf)
n	Load factor (g's)
OWE	Operating empty weight
PFCS	Primary Flight Control System
S	Wing area (ft^2)
S_{wet}	Wetted area (ft^2)
T/W	Thrust to weight ratio
$\dot{u}$	Acceleration in flight path direction (ft/sec^2)
V_A	Approach speed (kts)
V_A	Maneuver speed (keas)
V_{be}	Velocity - best endurance (ft/sec)
V_{br}	Velocity - best range (ft/sec)
V_C	Cruise speed (keas)

V_D	Dive speed (keas)
V_{LOF}	Lift off speed (kts)
V_S	Stall speed (kts or keas)
V_x	Shear in x-direction (psf)
V_y	Shear in y-direction (psf)
V_2	Obstacle clearance speed (kts)
W_E	Empty weight (lbs)
W/S	Wing loading (psf)
W_{to}	Takeoff weight (lbs)
X_{cg}	Position of CG along x-axis (ft)
X_{mg}	Position of main landing gear along x-axis (ft)
X_{ng}	Position of nose landing gear along x-axis (ft)
Y_{mg}	Lateral position of main landing gear (ft)
$\dot{\alpha}$	Rate of change of angle of attack (rad/sec)
δ_a	Aileron deflection (rad)
δ_e	Elevator deflection (rad)
δ_r	Rudder deflection (rad)
$\dot{\phi}$	Roll rate (rad/sec)
$\dot{\theta}$	Pitch rate (rad/sec)
ω_n	Natural frequency (rad/sec)
$\dot{\psi}$	Yaw rate (rad/sec)
ζ	Damping ratio
$/nm.	Dollars per nautical mile
¢/nm.	Cents per nautical mile

Acronyms

ACN	Aircraft Classification Number
AIAA	American Institute of Aeronautics and Astronautics
APU	Auxiliary Power Unit
AR	Aspect Ratio
ASM	Available Seat Mile
BITE	Built In Test Equipment
CBR	California Bearing Ratio
CCD	Central Coast Designs
CG	Center of Gravity

DOC	Direct Operating Cost
ECS	Environmental Control System
EDDS	Engine Data Display System
EFIS	Electronic Flight Instrumentation System
ETOPS	Extended Twin Operations
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Regulation
FCS	Flight Control System
GPS	Global Positioning System
HIRF	High Intensity Radiated Fields
HMU	Hydraulic Motor Generator
HMV	Heavy Maintenance Visit
HUD	Head Up Display
IDG	Integrated Drive Generator
IOC	Indirect Operating Cost
L/D	Lift/Drag ratio
LFC	Laminar Flow Control
LND	Landing
MAC	Mean Aerodynamic Chord
NASA	National Aeronautics and Space Administration
PTU	Power Transfer Unit
RAT	Ram Air Turbine
RDTE	Research, Development, Test, and Evaluation
RFP	Request For Proposal
SAS	Stability Augmentation System
T/O	Takeoff
TOC	Total Operating Cost
TRU	Transformer Rectifier Unit
USD	United States Dollars

ABSTRACT

The airline industry is very competitive, resulting in most U.S. and many international airlines being unprofitable. Because of this competition, the airlines have been engaging in fare wars (which reduces revenue generated by transporting passengers) while inflation has increased. This situation of course is not developing revenue for the airlines. To revive the airlines to profitability, the difference between revenue received and airline operational cost must be improved. To solve these extreme conditions, the Eightball Express was designed with the main philosophy of developing an aircraft with a low direct operating cost and acquisition cost. Central Coast Designs' (CCD) aircraft utilizes primarily aluminum in the structure to minimize manufacturing cost, supercritical airfoil sections to minimize drag, and fuel efficient engines to minimize fuel burn. Furthermore, the aircraft was designed using Total Quality Management and Integrated Product Development to minimize development and manufacture cost. Using these primary cost reduction techniques, the Eightball Express was designed to meet the Lockheed/AIAA Request for Proposal (RFP) requirements of a low cost, 153 passenger, 3,000 nm. range transport. The Eightball Express is able to takeoff in less than a 7,000 ft. runway, cruise at Mach 0.82 at an altitude of 36,000 ft. for a range of 3,000 nm. and lands on a 5,000 ft runway. It is able to perform this mission at a Direct Operating Cost of 3.51 ¢/asm (cents/available seat mile in 1992 dollars) while the acquisition cost is only $28 million (in 1992 dollars). By utilizing and improving on proven technologies, CCD has produced an efficient low cost commerical transport for the future.

1. INTRODUCTION

Recent global economic conditions have forced the airline industry to struggle in order to stay afloat and merely survive a trend in bankruptcies and corporate devastation. One major factor in their demise has been the implementation of the policy known as deregulation. This policy resulted in an industry-wide approach: the so-called 'fare wars'. These fare wars produced ticket fares so low that the airlines barely made any profit or actually lost money with each flight. For example, during a 'fare war', one of TWA's Boeing 767 flights required that the aircraft operate with full capacity in order to break even.[48] A solution to this problem could be found with the aid of the airframe manufacturers. In order to be able to fight this trend, airframe manufacturers must design and build airliners that cost less, both in purchase price and total operating cost. This prompted the current Request For Proposal (RFP), by the Lockheed Corporation in their co-sponsored Undergraduate Team Aircraft Design Competition along with the American Institute of Aeronautics and Astronautics (AIAA) search for a low cost commercial aircraft (see Appendix I). The basic requirements consist of 153 passenger capacity with 3,000 nautical mile range allowing for a sufficient supply of domestic fuel reserves. The aircraft must be able to take off from a 7,000 ft. runway on a standard day plus 27° F and land on a 5,000 ft. runway. In addition, it must fly at a Mach number larger than 0.7 at 99% of the best range velocity (V_{br}). To optimize this aircraft, it must be designed and built with the most efficient methods available. A necessary requirement underlying this RFP is that of a low cost maintenance and operation capability which defines the design parameters investigated under severe analysis of the market and the factors that govern the respective industry.

To reduce development and manufacturing costs, the Central Coast Designs (CCD) has implemented TQM (Total Quality Management). Considering the nature of this philosophy, a revolutionary approach was applied in the conceptualization and design of the Eightball Express. Improved management techniques along with a brand new way of problem solving, provided great incentive to CCD to perform with a realistic sense of motivation, always keeping the low cost philosophy of this design in mind. The CCD concluded that the best answer to the need at hand was most feasibly obtained through an intensive and realistic look at the balance between engineering and marketability. This attitude will also follow over into the manufacturing of the aircraft. It is projected that with an efficient work force, quality control, and an efficient manufacturing process, the construction costs of the aircraft will decrease. Furthermore, final assembly time can be decreased by utilizing precision manufacturing techniques so that the parts will fit correctly the first time. To further reduce manufacturing costs, the aircraft must be designed so that it can grow without re-tooling a factory. This will effectively increase the service life of the series and spread out the tooling costs over many more aircraft. The CCD team believes that with an Integrated Product Design (IPD) system, these goals can be accomplished.

In order to lower total operating costs, the aircraft will be very efficient in the air as well as on the ground. With modern technology applied throughout the aircraft it will be designed with a realistic, but low maximum gross takeoff weight, fuel consumption, and drag. New design techniques and materials can lower the structural weight by applying more efficient structural design. New engines are more efficient than the engines in service on current aircraft. Modern airfoil design has made breakthroughs in lowering drag at high Mach numbers. By lowering the drag and increasing the cruise speed, the aircraft will save considerable amounts of fuel and is able to make more flights in a given time span. Furthermore, costs on the ground can be lowered by utilizing improved maintenance and reducing turnaround time. This requires that maintenance procedures be simple and quick. To obtain a maintenance friendly aircraft, it will be designed with adequate access panels and use present technology which will not require new training. This design principle will be inexpensive and not take a lot of time on the ground to maintain. By meeting these criteria, the Eightball Express will be able to perform more efficiently for the operators, providing them a considerable Return On Investment (ROI).

2. CONCEPT DEVELOPMENT

2.1 Current Commercial Aircraft

The Eightball Express will be able to carry 153 passengers and their baggage over a 3,000 nautical mile range. Currently there are many aircraft carrying approximately 150 passengers placing the Eightball Express in direct competition with regards to passenger capacity. These include the McDonnell Douglas MD-90-30 (153 passengers and bags), the Boeing 737-400 (135-172 passengers and bags), and the Airbus A320-200 (150 passengers and bags). The Eightball Express will be competing against all three of these aircraft for the passenger load, but will have a longer range.

Table 2.1. Comparison of Current Aircraft

	Boeing 737-400	McDonnell Douglas MD-90-30	Airbus A320-200	***Eightball Express***	RFP Requirements
Passengers	146	153	150	***153***	153
Range (nm.)	2,500	2,396	2,900	***3,000***	3,000
$W_{t.o.max}$ (lbs.)	150,000	156,000	162,000	***149,000***	-
T/O Field Length (ft.)	8,200	6,880	7,680	***6,990***	7,000
Landing Field Length (ft.)	6,070	5,090	5,040	***4,512***	5,000
Cruise Mach Number	0.73	0.76	0.80	***0.82***	> 0.70

Source: Jane's All the World's Aircraft

Table 2.1 shows several important areas of performance madated by the RFP which current aircraft cannot achieve. In order to attain the goal of a low cost transport, an airframe must be designed to obtain lower manufacturing cost and operating than the current aircraft in service. The RFP requirements can be seen in Appendix I.

2.2 Concept Development

At the beginning of the project, each member of the Central Coast Designs (CCD) team submitted a design subject to preliminary review by the other members of the team. Each of these were evaluated based on ease of construction, technology cost, performance, and marketability. These categories were chosen because of the low cost requirement. The different configurations included two and three engine concepts, under wing mounted as well as tail mounted engines, single aisle and twin aisle interiors. There different designs were then eliminated or combined to find the best possible solution for the RFP challenge and the airline industry. Figure 2.1 depicts the various configurations examined and the final configuration chosen.

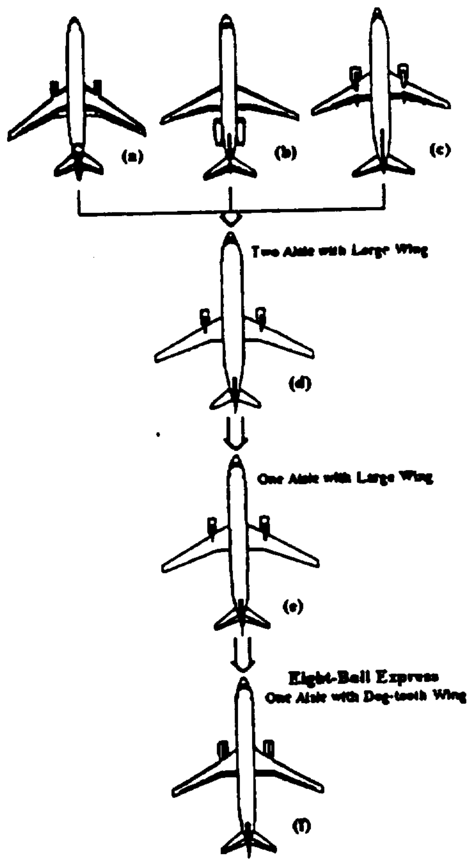

Figure 2.1. Eightball Express Concept Development

Tri-Engine Configuration

This configuration had three engines with one mounted in the tail (Figure 2.1a). This configuration had better one engine out (OEI) characteristics and the advantage of not being required to meet Extended Twin Overwater Operations (ETOPS). However, the third engine increases the total cost of the aircraft by increasing purchase price and maintenance hours. The location of the engine in the tail makes the engine difficult to access requiring special cranes or lifts. The location also increases the vertical tail weight because of the need to transmit the structural loads from the tail around the engine. Since, all of the above limitations affected the low cost issue in a negative way, the CCD team eliminated this concept as an unviable choice.

Twin Engine, Tail Mounted Configuration

The positioning of the two engines on the tail in this configuration would allow the aircraft to have shorter landing gear, thus reducing the weight of the landing gear and takeoff weight (Figure 2.1b). However, the engines' performance is degraded a little because the inlet flow is disturbed by the fuselage. Also, the engines are more difficult to access than if the engines were located under wing which will increase maintenance cost. Engine noise propagation into the fuselage becomes another dilemma to handle. To solve this dilemma an added cost would be encountered to isolate the aft section of the fuselage. Furthermore, the location of the engines would require a 'T-tail' configuration which would increase the structural weight of the vertical tail making direct operating cost increase. More problems occur at high angles of attack because the engines would act as bluff bodies in the flow impinging the tail and create tail stall, known as "deep stall." This would require added modifications or design constraints. Most important, the added weight at the tail would cause a larger Center of Gravity (CG) excursion resulting in poor cruise performance For these reasons, this configuration was eliminated.

Twin Engine, Twin Aisle

After eliminating the above configurations, an aircraft with two engines mounted under the wing was considered (Figures 2.1c through 2.1f). This aircraft had a small CG excursion and optimum engine performance. This results in the most efficient flight operations possible because of minimized trim drag and ideal fuel consumption. In order to produce the lowest cost aircraft, the preliminary design used a twin aisle cabin seating six abreast in tourist class. It was believed that the two aisles would allow a lower turnaround time. However, after further research, the twin aisle did not actually affect the turnaround time. It was discovered that the aircraft servicing and baggage handling took a longer amount of time. Furthermore, a single aisle configuration would yield 20% less drag on the fuselage at a Mach number of .82 at 36,000 ft then a two aisle configuration (see Figure 2.2). The fuselage drag reduction results in a 3% overall drag reduction of the Eightball Express which translates to a lower fuel consumption and decreased takeoff weight. In turn this resulted in a lower operating cost.[44]

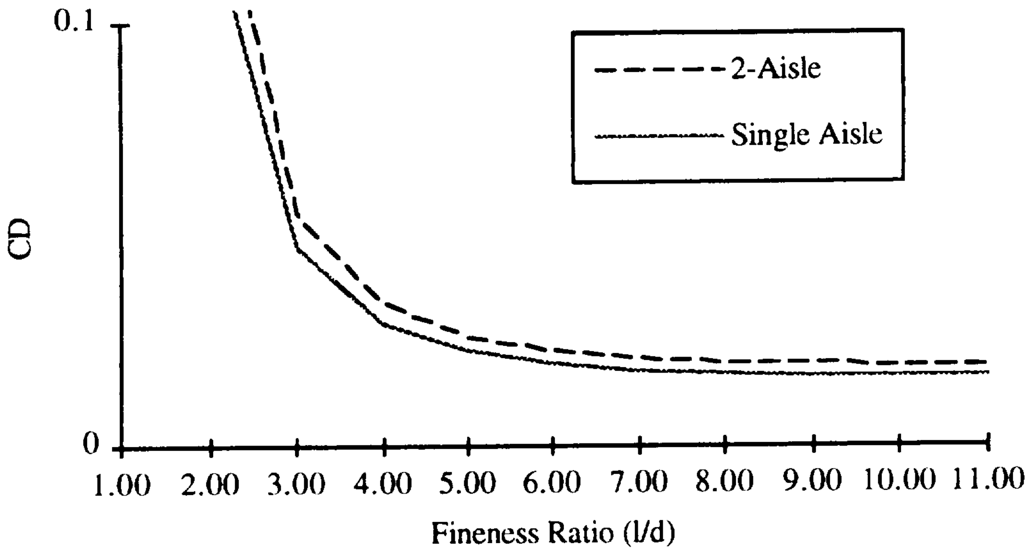

Figure 2.2. Eightball Express Fuselage Drag Comparison

This analysis resulted in a single aisle configuration. The Eightball Express' external fuselage diameter of 13 ft is optimized for minimum drag, while still maintaining passenger comfort. This aircraft is shown in Figure 2.1f. The aircraft was designed for growth which resulted in a low wing loading (approximately 100 psf). The low wing loading resulted in an excessively large wing, which in turn increased manufacturing cost and drag. To optimize for a low cost, CCD redesigned for optimal use at the current requirements of 153 passengers and bags over 3,000 nm. range. The final design resulted in the current Eightball Express which can be seen in Figures 2.1f and 2.3.

2.3 General Arrangement

The three-view drawing of the Eightball Express can be seen in Figure 2.3 which shows the conventionality of the Eightball Express. The driving design philosophy was for low cost which was accomplished by using conventional geometry and technology. Since new technology will take longer to develop and certify, it would result in a longer development time and higher cost. By maintaining the conventional configuration, the airlines' ground and flight crews would not have to be trained on an excessively different aircraft. The low wing design allows for the wing box to be designed simply, as light as possible and located underneath the passenger compartment. The tail saves weight because it has a low horizontal variable incidence tail plane which allows the angle of attack of the horizontal tail to be changed in flight. This saves weight as compared to a 'T' - tail configuration. Since it is capable of variable incidence, the trim drag will be lower than a fixed stabilizer with an elevator. The Eightball Express also has a smaller vertical tail than usual. The aircraft has a digital fly by wire flight control system with relaxed lateral static stability. These features use the flight control system to counteract the smaller size. Again, the smaller size will save weight and also lower the wetted area, thus decreasing the drag. The specific sizes of the tail can be found in the stability and control section. In order to obtain the best possible performance from the engines and for center of gravity reasons, the engines are mounted on the wing which ensures that the airflow into the engines will not be disturbed by another portion of the aircraft. This also reduces the center of gravity movement as compared to a configuration with the engines mounted on the aft section of the fuselage.

Figure 2.3 shows that the Eightball Express has an aspect ratio of 10. The aspect ratio is large in order to reduce the induced drag, thus saving fuel weight and money. The aspect ratio and area of the wing sets the span at 114 ft. This span is smaller than what airports can currently handle, which is 156 ft for narrow body aircraft.[22] Furthermore, the wing has a sweep of 27° at the quarter chord line which will allow the Eightball Express to cruise at M = 0.82 without experiencing the large drag rise associated with high Mach numbers. Also, the tail surfaces have a higher sweep angle than the wing so that they will still have authority if the aircraft should attain an excessive speed where the wing will lose it's control power. The wings are at a 6° dihedral to give more clearance for the engines and wing tips.

1.

FOLDOUT FRAME

CHARACTERISTICS DATA			
ITEM	WING (BASIC)	HORIZ. TAIL	VERT. TAIL
AREA,FT~2	1296	323	259
ASPECT RATIO	10	5	2
TAPER RATIO	0.30	0.32	0.32
SWEEP,DEG. c/4	27	35	41
DIHEDRAL,DEG	6	0	0

PAYLOAD CAPACITY
- BUSINESS CLASS 12 SEATS ● 38-IN. PITCH
- TOURIST CLASS 141 SEATS ● 32-IN. PITCH

TOTAL SEATS = 153

CARGO CAPACITY
- FORWARD CARGO BAY = 675 CUBIC FEET
- AFT CARGO BAY = 525 CUBIC FEET

TOTAL CARGO VOLUME = 1200 CUBIC FEET

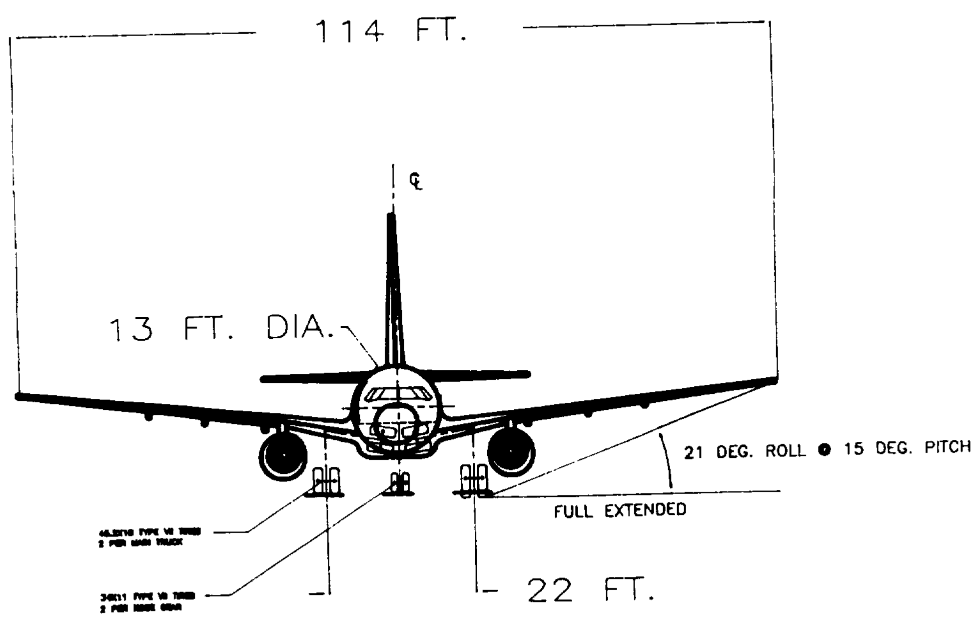

FIGURE 2.3 Eightball Ex

2.

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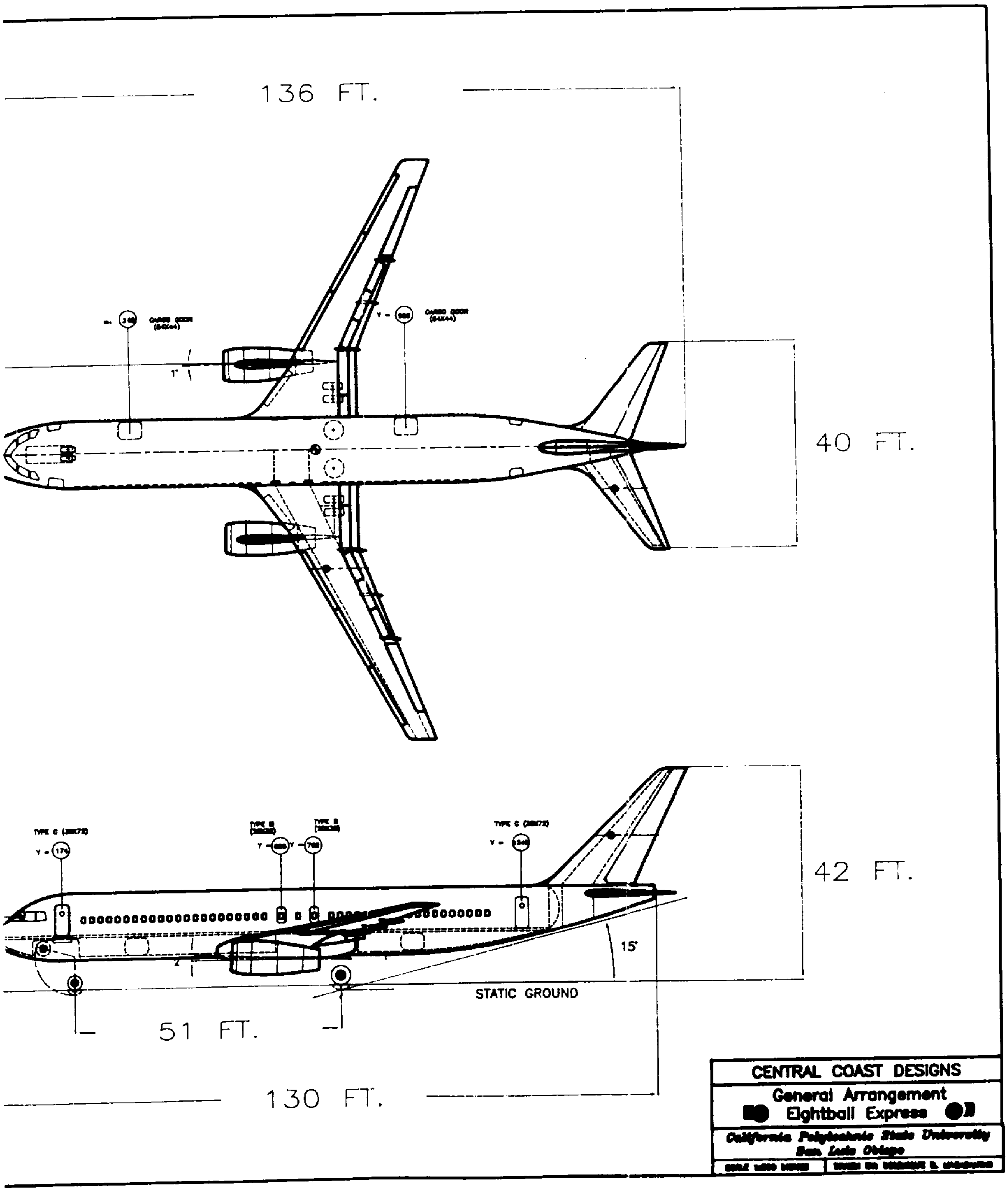


ɔress General Arrangement

3. INTERIOR LAYOUT

3.1 Layout Philosophy

The interior of the Eightball Express was designed to maximize use and minimize cost. By maximizing use of space, the aircraft will be lighter saving fuel weight and cost. Furthermore, in order to create the most productive aircraft, the interior layout has features to maintain passenger satisfaction and allow for growth.

3.2 Cabin Layout

The interior configuration can be seen in Figure 3.1. The aircraft has two classes: Business and Tourist. Since there is a growing number of business travelers, the Business Class was designed slightly "roomier" to meet the business need while eliminating the need for a First Class. The interior cross-sections of the two classes can be seen in Figure 3.2. Table 3.1 shows the important dimension of the interior. The Eightball Express was designed for maximum space usage and passenger comfort. The flight attendant seats are located so that they are able to see 80% of the passengers. The aft attendant seats are mounted on a rotating fixture. This allows the seats to be rotated into the floor when not in use. Figure 3.3 shows a comparison of the Eightball Express overhead storage space to the competition.

Table 3.1. Eightball Express Interior Dimensions

	Business Class	Tourist Class
Number of Seats	12	141
Pitch (in)	38	32
Seat Width (in)	24	17.5
Center Seat Width (in)	-	19.5
Shared Armrest Width (in)	6	2
Single Armrest Width (in)	3	1.5
Aisle Width (in)	24	19
Overhead Storage (ft^3/passenger)	6.6	3.6

In order to handle the passengers over the long range, 3,000 nm., the Eightball Express has two galleys and four lavatories (Figure 3.1). The aircraft will be able to provide the passengers with at least one meal and snacks for the flight. By having one smaller galley forward and a single large galley aft, the attendants can efficiently provide food service from the front and back. This will reduce the amount of time required for the

1.

FOLDOUT FRAME

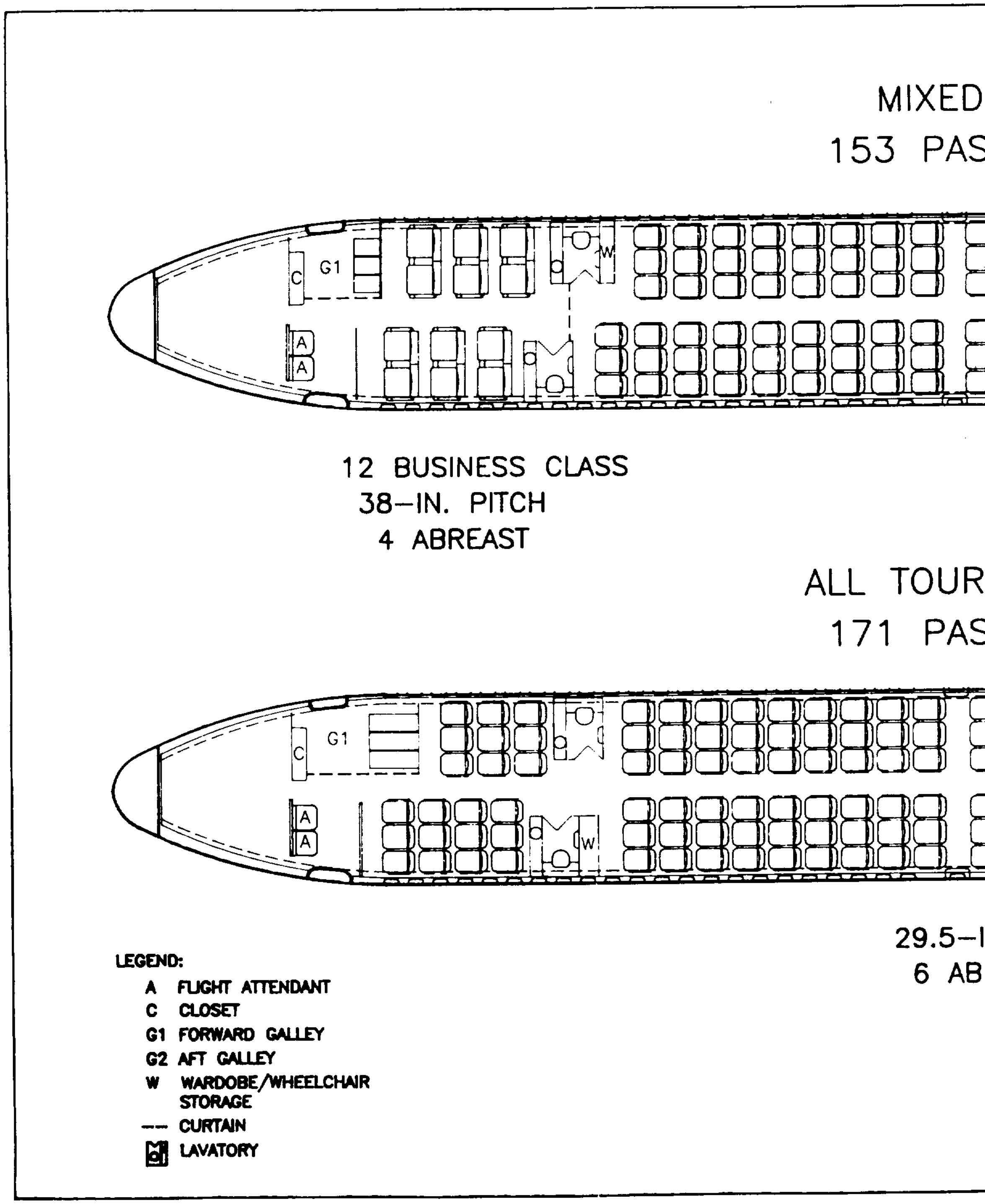
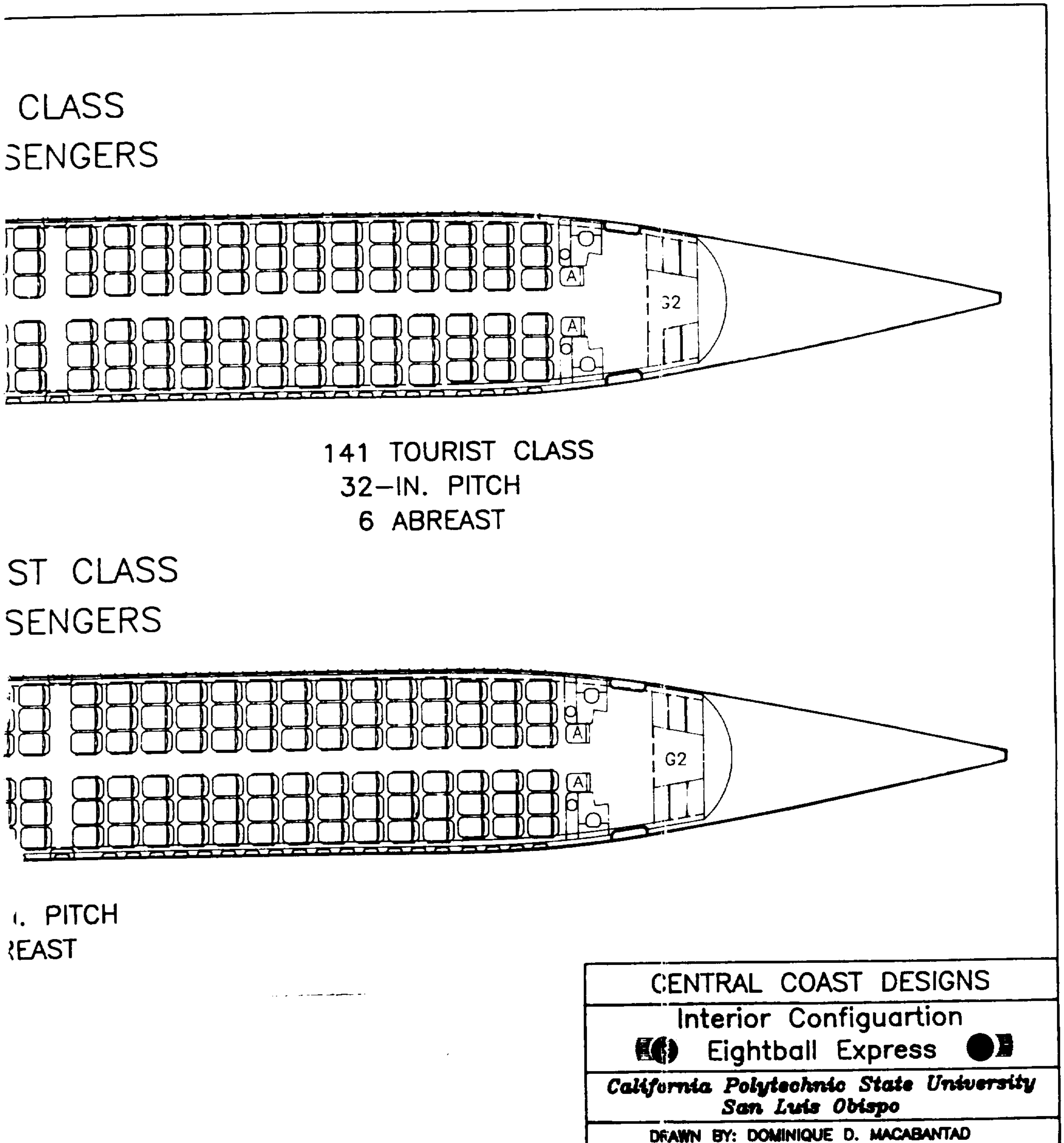


FIGURE 3.1 Eightball Ex

2

FOLDOUT FRAME



press Interior Configuration

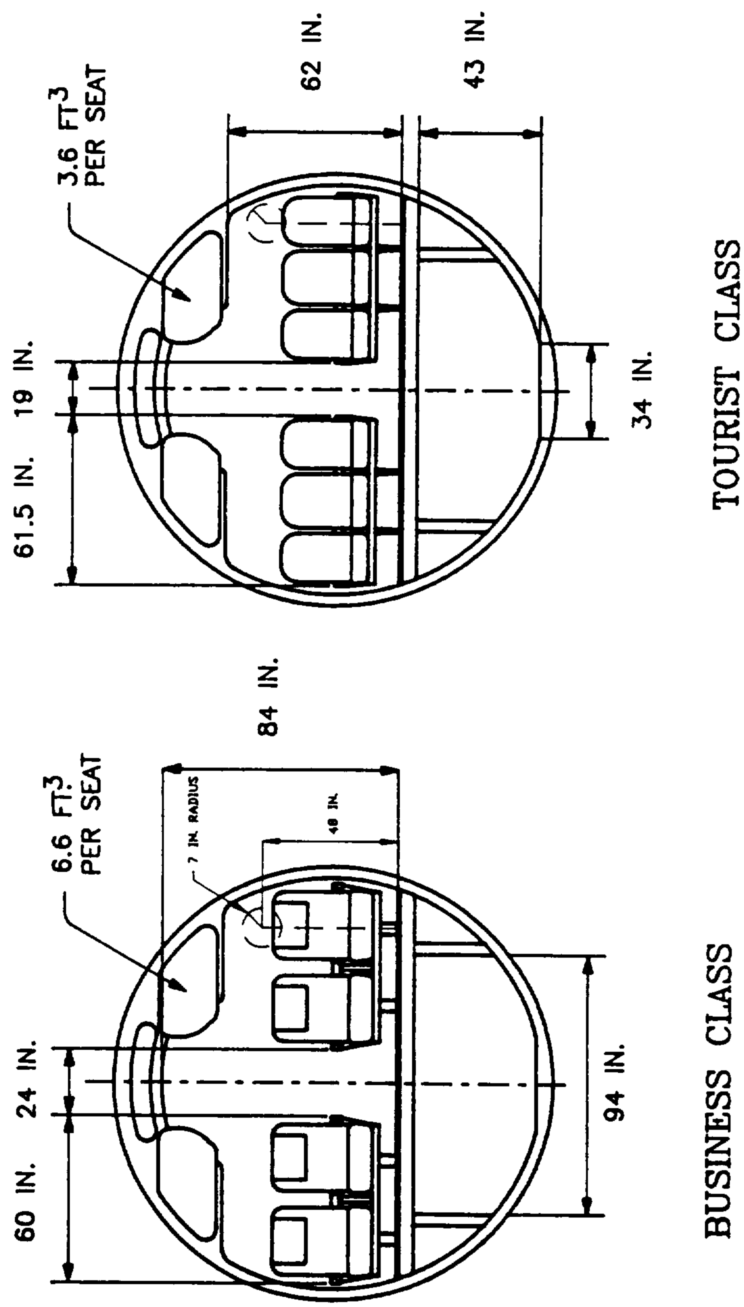


FIGURE 3.2 Eightball Express Interior Cross Section

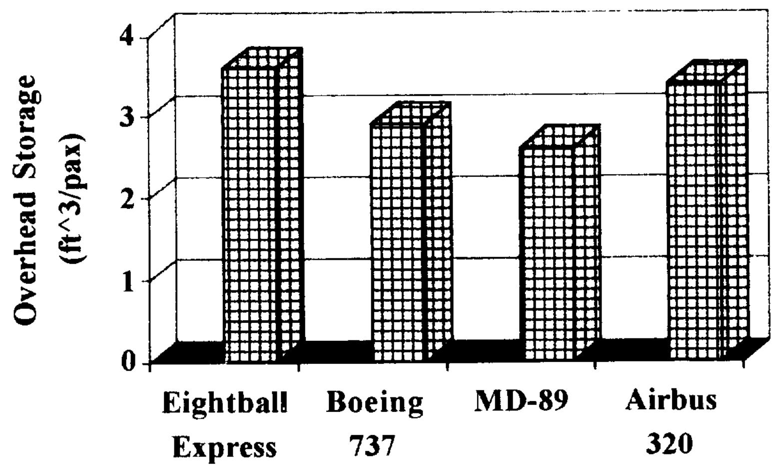


Figure 3.3. Eightball Express Overhead Storage Comparison

service, reducing attendant work load and improving passenger satisfaction with the prompt food service. Furthermore, the large aft galley utilizes the space in the tail cone which minimizes the length added to the fuselage by the galley and it has been measured to fit the food carts. Also, the aircraft has two lavatories between the classes which are accessible to disabled persons. There are also two lavatories aft. Also, the Tourist Class aisle is slightly wider than usual (19 in.) so that the passengers will be able to pass a food service cart when they are in use. Both galleys are easily serviced through the large Type C doors immediately adjacent to them. The access ways for these doors also provides room for maneuvering the food carts into and out of the galleys and gives passengers room to wait for a lavatory if need be without disturbing passengers in the last rows. The Eightball Express also has ample closet space for the odd carry-on items and a wardrobe for hanging travel bags. These features make the Eightball Express a comfortable aircraft to fly in.

The Business Class will also have an option for phone and modem jacks. These items will be subcontracted with a phone corporation for maintenance . The data-jacks for the modem will be installed in seat armrests where users of laptop computers will have digital communications capability at a rate of 9600-baud/sec. Users will pay a service charge per minute of use.[5] This feature in the Business Class gives the customer an opportunity they do not have on other aircraft of doing their job while they're traveling.

Furthermore, there is an option for all classes to have a Hughes-Avicom video system[6] which can be used to watch films and play video games.

The large pieces of fixed equipment can be seen on the inboard profile of Figure 3.4. The air-conditioning packs are located in the forward portion of the wing fillet which provides adequate maintenance accessibility and minimal effect on the CG. The location of the avionics bay allows for air conditioned air to be received to maintain safe operating temperature, while still allowing adequate access to the avionics. The Auxiliary Power Unit (APU) is located in the tail cone of the fuselage to isolate it from the passenger compartment and fuel tanks. This also allows for a minimal drag increase from the inlet and exhaust ports.

The inboard profile of the Eightball Express shows an abundance of cargo space. These values can be found in Table 3.2. Since passenger baggage does not fill the cargo volume, extra cargo can be carried. Assuming typical cargo densities of 10 lb/ft^3, a maximum of 8,000 lbs of extra cargo can be carried. This bulk cargo space should increase the revenue of the airline due to the increase in freight carriers around the world. The Eightball Express utilizes class C compartments with a telescoping bulk cargo system. These compartments contain fire extinguishers in case of fire within the cargo area refer to Figure 3.5. The lower cargo compartment meets the standards of the FAR §25.857.

Table 3.2. Eightball Express Cargo Capacity

Total Cargo Volume (ft^3)	1200
Cargo Volume per Passenger (ft^3/passenger)	7.85
Forward Compartment Volume (ft^3)	675
Aft Compartment Volume (ft^3)	525
Passenger Baggage Volume (ft^3)	382
Extra Cargo Volume (ft^3)	818

FOLDOUT FRAME 1.

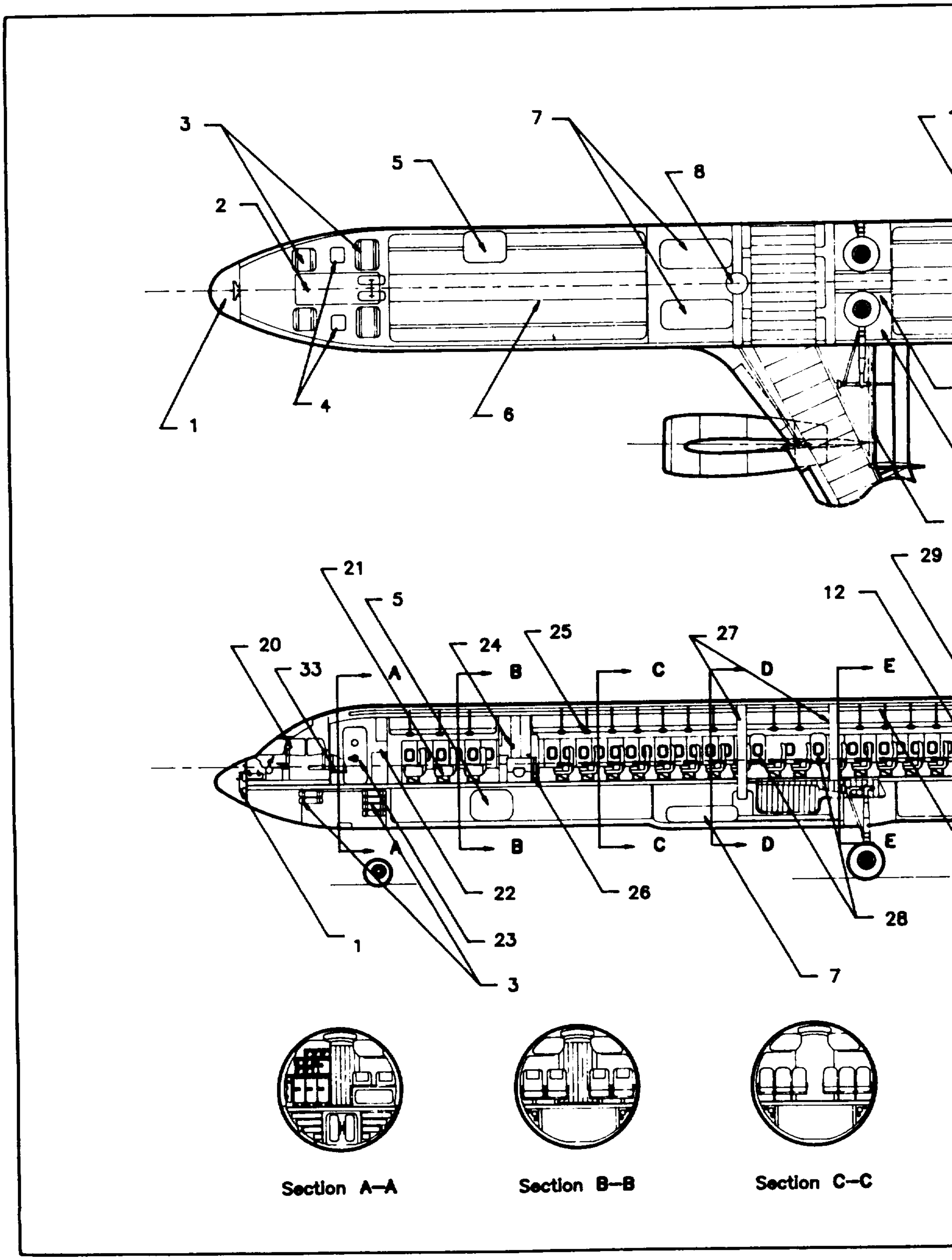


FIGURE 3.4 Eightball Expres

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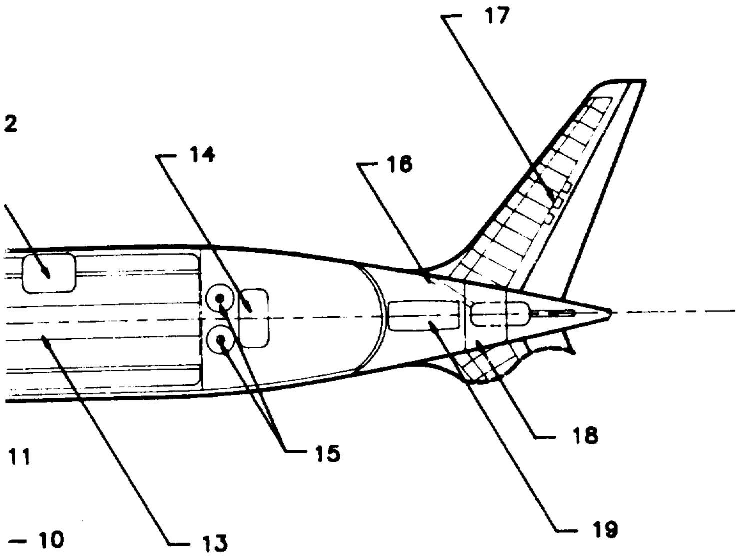
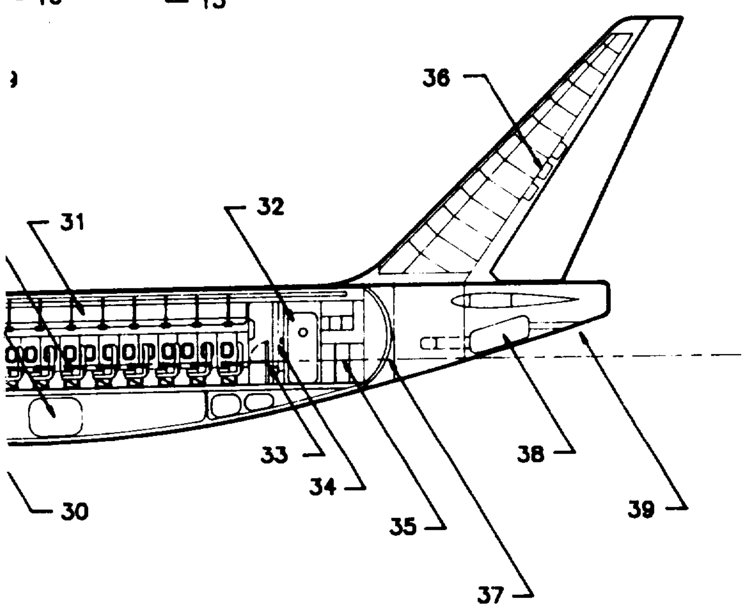
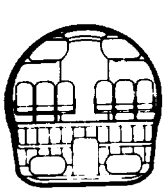


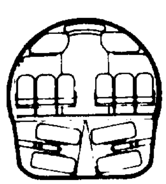


SYSTEM CALLOUT

1. Weather Radar Antenna
2. Nose Gear Well
3. Electronics Rack
4. Electronics Bay Access Hatch
5. Forward Cargo Door (RH)
6. Forward Cargo Bay
7. Air Conditioning Packs
8. Environmental Control System Mix Bay
9. Auxiliary Spar
10. Main Gear Well
11. Wheel Well Seal
12. Aft Cargo Door (RH)
13. Aft Cargo Bay
14. Potable Water Tank
15. Waste System Vacuum Tanks
16. Auxiliary Power Unit Inlet
17. Elevator Actuators
18. Horizontal Tail Box
19. Vertical Tail Box
20. Flight Deck
21. Business Passenger Seat
22. Forward Galley
23. Forward Service Door
24. Forward Lavatory (Disabled Accessable)
25. Passenger Service Unit
26. Wheelchair/Wardrobe Stowage
27. Air Conditioning Risers
28. Overwing Emergency Exits
29. Tourist Passenger Seat
30. Air Conditioning Duct
31. Overhead Stowage
32. Aft Service Door
33. Flight Attendant Seat
34. Aft Lavatory
35. Aft Galley
36. Rudder Actuators
37. Pressure Bulkhead
38. Auxiliary Power Unit
39. Auxiliary Power Unit Exhaust



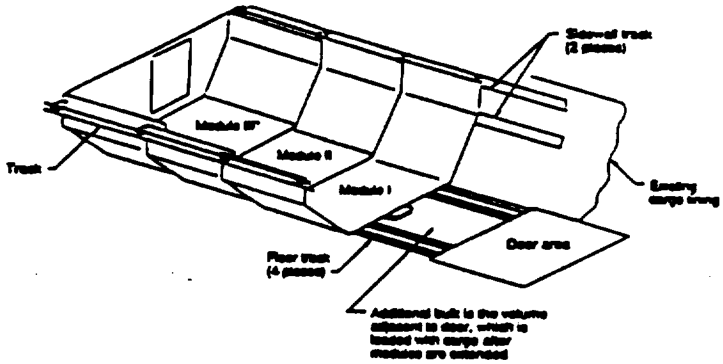
Section D–D



Section E–E

CENTRAL COAST DESIGNS
Below Floor and Inboard Profile Eightball Express
California Polytechnic State University *San Luis Obispo*
DRAWN BY: DOMINIQUE D. MACABANTAD

ss Below Floor and Inboard Profile



Picture of Cargo Handling equipment here.

Figure 3.5. Eightball Express Bulk Cargo
Source: Boeing 727

The flight deck of the Eightball Express can be seen in Figure 3.6. The cockpit has a fully digital, automated avionics system which provides the flight crew with critical information in a easily accessible manner.

Finally, Figure 3.7 shows the exterior lighting of the Eightball Express. This includes landing, taxi, anti-collision, and logo lights.

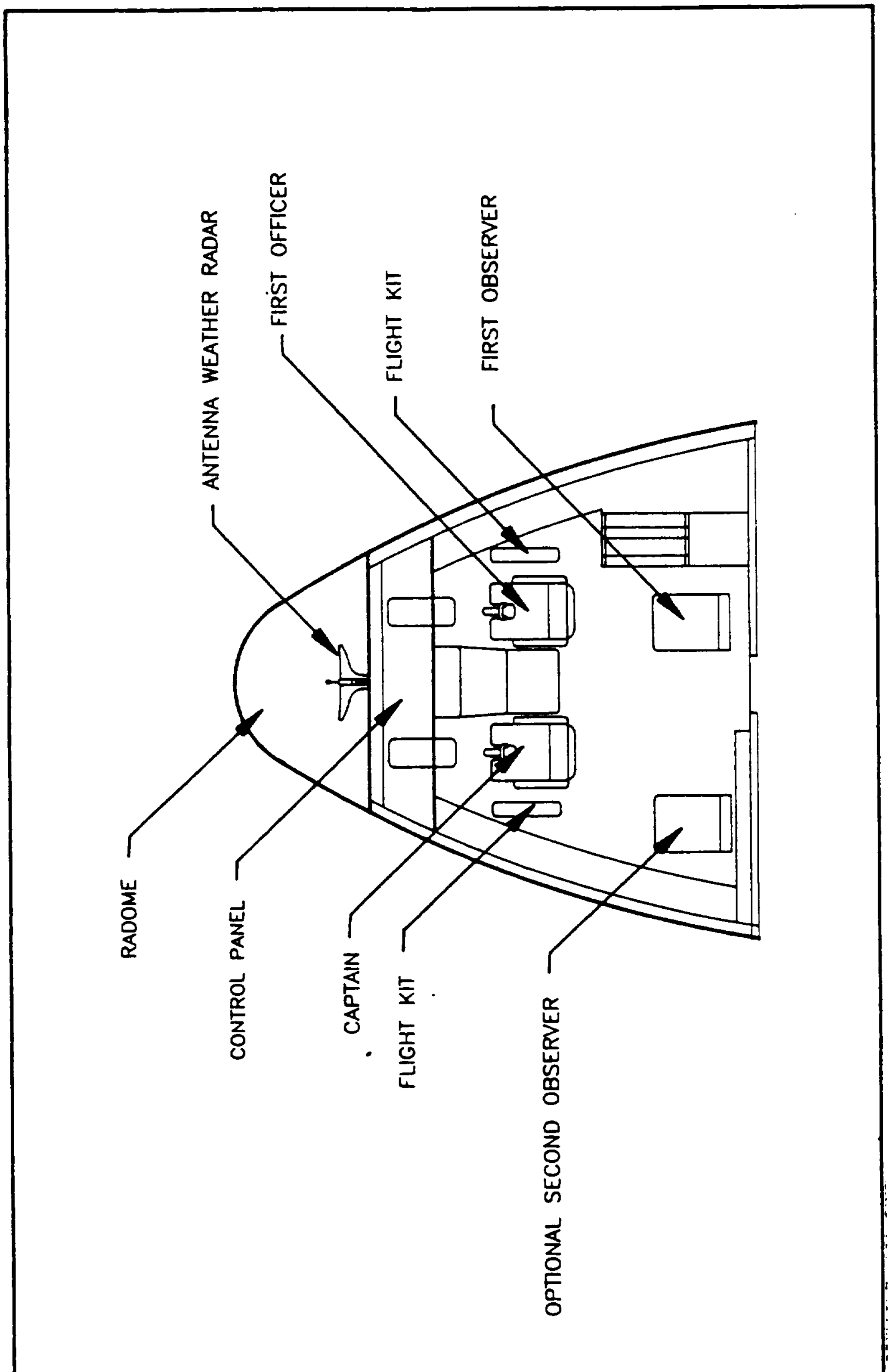


FIGURE 3.6 Eightball Express Flight Deck Top View

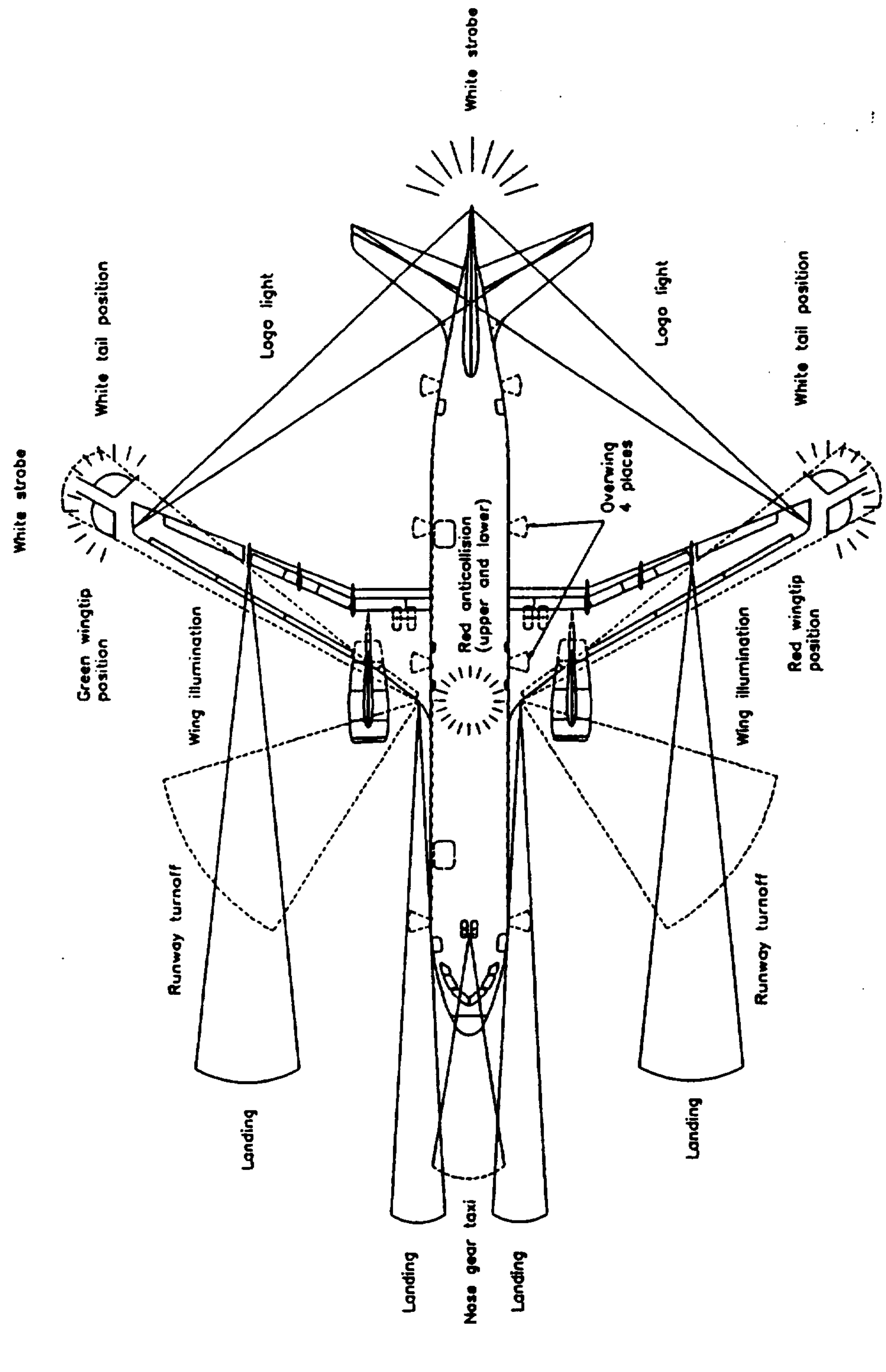


FIGURE 3.7 Eightball Express Exterior Lighting

4. PERFORMANCE

4.1 Mission Profile

The mission of the Eightball Express is shown in Figure 4.1 and is defined by the RFP as shown in Appendix I. The aircraft will climb to 36,000 ft, then cruise for 3,000 nm and will have a 45 minute reserve at a Mach of 0.82. At this point, the aircraft will loiter for 15 minutes then begin it's descent and be able to perform a balked landing. After performing the balk landing, the aircraft will climb up to 10,000 ft and cruise for 150 nm at a Mach of 0.7. Finally it will begin its descent and land.

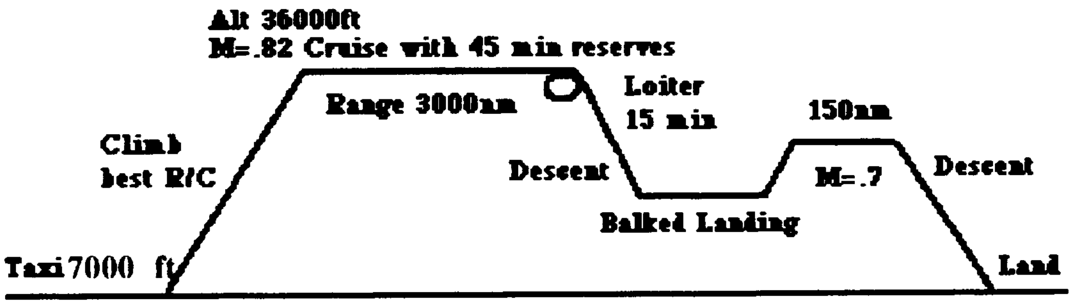


Figure 4.1. Eightball Express Mission Profile

4.2 Aircraft Sizing

The design point plot of the Eightball Express shown in Figure 4.2 shows the optimal combination of wing loading and thrust to weight ratio. From these values the required take-off and landing coefficients of lift were determined. The design point meets the critical OEI requirement. The thrust loading and wing loading were determined to be .31 and 118 psf, respectively. A mid range wing loading was chosen to help alleviate gust effects on the wing. Table 4.1 shows the resulting parameters.

Table 4.1. Eightball Express Design Point Parameters

T/W	0.31
W/S (psf)	118
$C_{Lmaxt/o}$	2.2
$C_{Lmaxlanding}$	2.9

4.3 Velocity Best Range

The velocity best range for the Eightball Express was found using methods from reference 2 based on maximum lift over drag curves. Figure 4.3

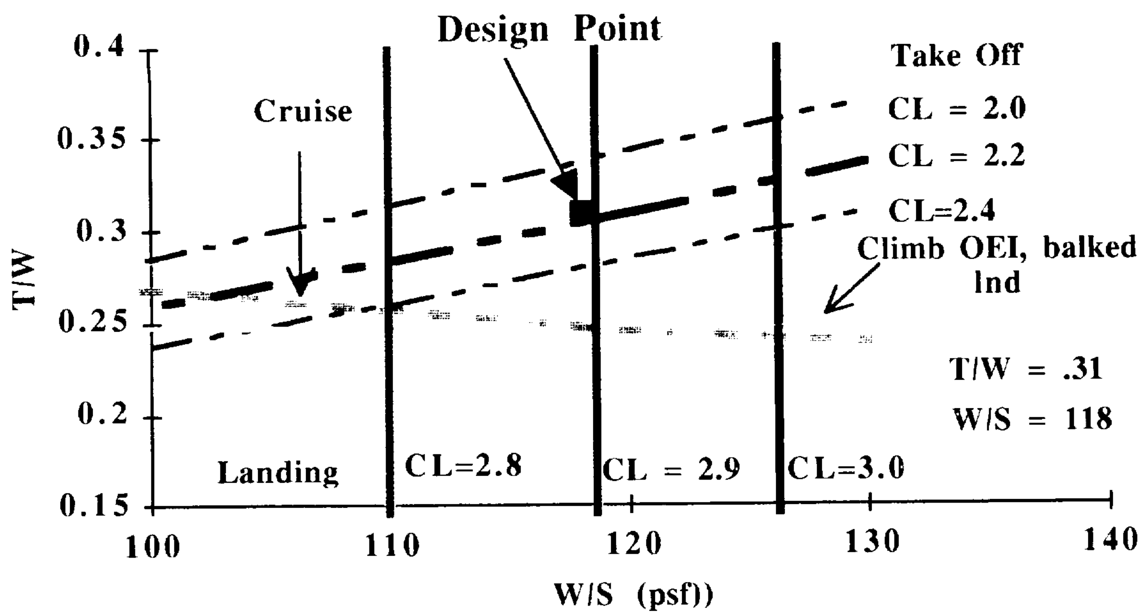


Figure 4.2. Eightball Express Design Point

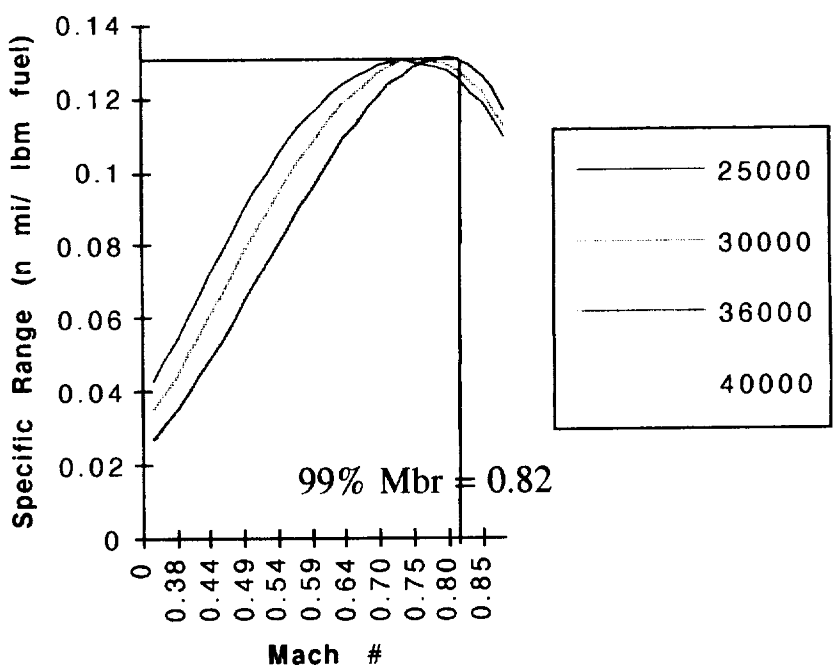


Figure 4.3. Eightball Express Velocity Best Range Diagram

shows the best range and endurance in terms of Mach number. At a cruise altitude of 36,000 ft., the sectional lift and drag coefficients were 0.5 and 0.01, respectively. As seen in the graph, the best cruise velocity for the Eightball Express is at Mach 0.83. The

Eightball Express cruising at Mach 0.82 complies with the RFP requirement of 99% of V_{br}. The L/D ratio required for this cruise speed is 17.7

4.4 Takeoff

The Eightball Express was designed to meet the takeoff and landing requirements specified by the RFP. As can be seen in Figure 4.4, FAR Part 25 requires that the aircraft accelerate to a required lift off speed, climb, and clear a 35 foot obstacle. This distance is based on a critical engine failure during the take off roll or the distance obtained with AEO plus 15%, whichever is longer. Using reference 44, the Eightball Express, using an installed thrust 12% lower than the rated thrust can take-off from a FAR field length of 6,900 feet. A ground run of 5,520 feet is required to reach a liftoff speed, V_{LOF}, of 139 kts. The minimum speed required at the obstacle height V_2 is 145 kts.

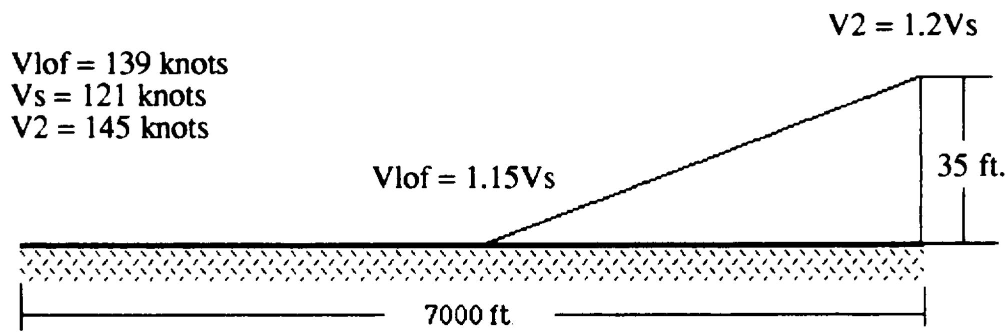


Figure 4.4. FAR Takeoff Distance Requirement over 35 ft Obstacle

4.5 Landing

The landing field length specified by the FAR's includes a safety factor of 1.67 and does not allow the use of thrust reversers. The landing distance requirements are shown in Figure 4.5. From methods in reference 44, the Eightball Express flying at an approach speed, V_A, of 127 kts on a standard day requires an FAR landing field length of 4512 ft. In order to minimize the ground roll of the Eightball Express, automatic spoilers and brakes with anti-skid systems are used to increase the effective friction coefficient of the aircraft. This is more desirable than decreasing the air run by increasing flap deflection and/or power to limit landing noise. Table 4.2 summarizes the takeoff and landing performance criteria.

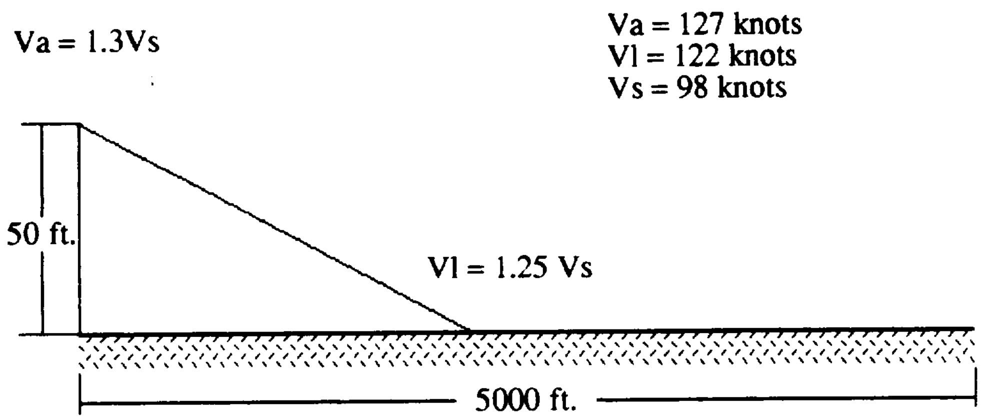


Figure 4.5. FAR Landing Distance Requirements Over a 50 ft Obstacle.

Table 4.2. Eightball Express Take off and Landing Performance Requirements.

	RFP Requirement	Eightball Express	FAR Requirement
FAR Takeoff Distance	7,000 ft	6,900 ft	Met
FAR Landing Distance	5,000 ft	4512 ft	Met

4.6 Payload Range

The Eightball Express was designed for a 3,000 nm. range carrying 153 passengers and baggage. However, the aircraft can achieve longer ranges with fewer passengers by replacing passenger weight with fuel. The extreme case of this is the ferry mission of the Eightball Express which does not carry any payload. Figure 4.6 shows the payload range diagram. The figure includes the condition for the all Tourist Class configuration which can carry 176 passengers.

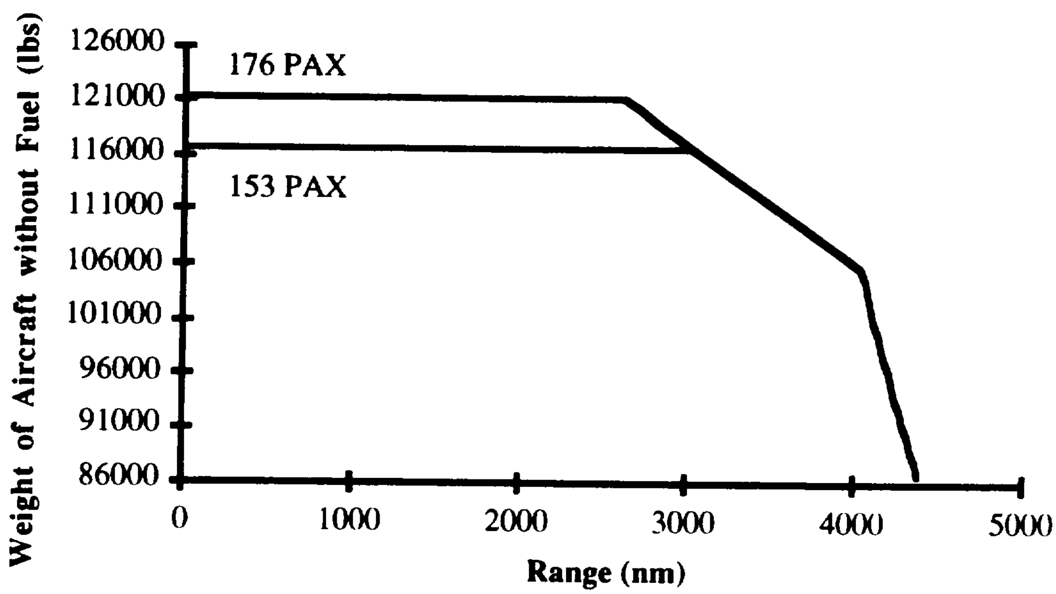


Figure 4.6. Eightball Express Payload Range Diagram

4.7 Rate of Climb and Aircraft Ceilings

The rate of climb for the Eightball Express is broken up into two sections. First, the aircraft will begin takeoff at a maximum rate of climb of 250 knots (422 ft/s). The primary reason for this is to meet the FAR requirement pertaining to cabin pressurization up to an altitude of 10,000 ft. Having done so, the Eightball Express accelerates to its cruise altitude of 36,000 ft. at its maximum rate of climb maintaining a cabin pressure at all times of 8,000 ft. This is done to minimize the amount of time in the air. Since most of the fuel savings occurs under cruise conditions, the initial loss in fuel is acceptable in light of the savings at cruise. As can be seen from Figure 4.7, the rate of climb begins at sea level and gradually progresses to altitude in increments of 500 ft.

The rate of climb program was also used calculate the service and absolute ceilings of the Eightball Express. From the Rate of Climb program it was determined that the point at which the R/C = 0 ft/min, occurs at approximately 42,700 ft. This point is known as the Absolute ceiling and is appropriately the point at which the aircraft can operate at level and steady state conditions. The next point consists of the service ceiling. At this point the R/C = 100 ft/min and occurs at an altitude of 42,300 ft as can be seen by Figure 4.7.

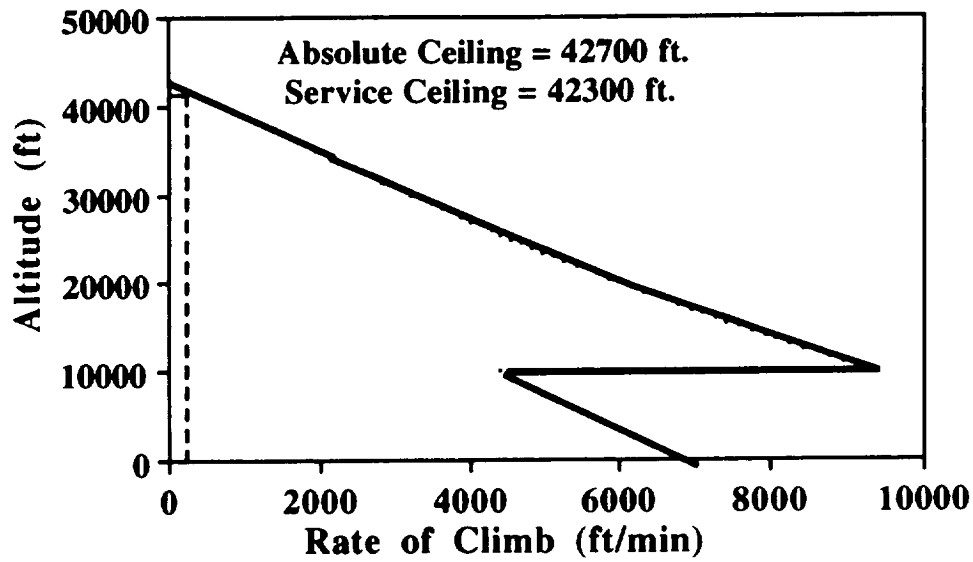


Figure 4.7. Eightball Express Altitude vs Rate of Climb.

4.8 Engine Performance

Performance data for the V2500 was obtained from the AIAA gas turbine engine library. This data was compiled for the 25,000 lb thrust class aircraft. From this data, the thrust requirements were scaled to meet the needs of the Eightball Express. The thrust requirement of 22500 lb was calculated by scaling the reference data. The thrust at full power relative to altitude is shown in Figure 4.8. This data indicates the thrust at different altitudes for the power plant. This data gives a general view of thrust variations as the power plant changes in altitude.

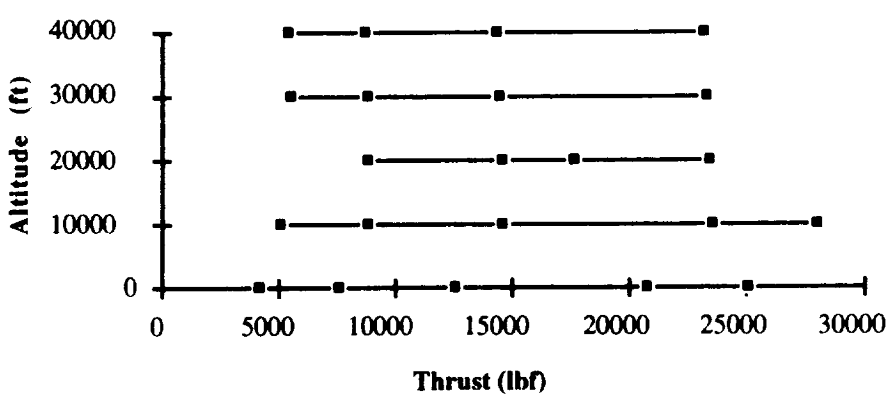


Figure 4.8. Eightball Express Altitude vs Thrust.

5. AERODYNAMICS

5.1 Wing Sizing

The Eightball Express was designed to meet a 3,000 nm cruise range requirement. Figure 5.1 represents the effects of adjusted aspect ratio (includes glove and yehudi sections) on fuel burned during cruise. As can be seen, fuel burn, hence airline DOC, is reduced by choosing an aspect ratio between 10 and 10.5. Increasing the aspect ratio past 10.5 an increase in fuel burn results due to aeroelastic effects. A large aspect ratio is also beneficial on the induced drag produced by the wing. Figure 5.2 shows how the induced drag at the cruise lift coefficient can be decreased by increasing the aspect ratio of the wing. Thus, for low fuel burn, and low induced drag, an aspect ratio of 10 was chosen.

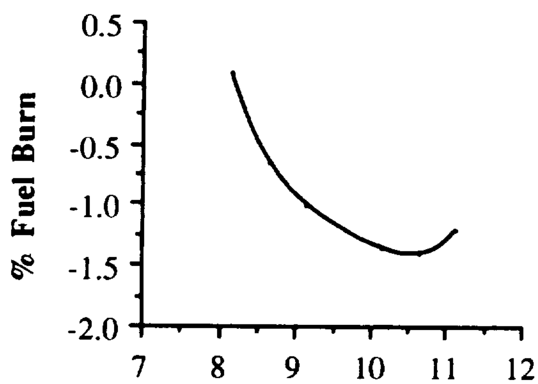


Figure 5.1. Effect of Adjusted Aspect Ratio on Fuel Burned
Source: NASA CR 3254

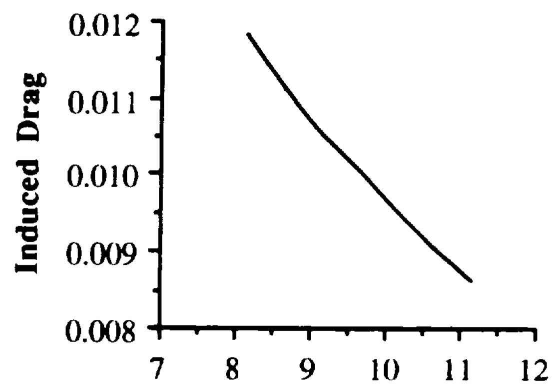


Figure 5.2. Effect of Adjusted Aspect Ratio on Induced Drag

The effects of the aircraft fuselage on the local Mach number encountered by the wing also had an influence on the wing design. As can be seen by the trend in Figure 5.3, the Mach number encountered by the inboard portion of the wing can be as much as two tenths higher than the free stream Mach number.[19] To account for these effects, the quarter chord sweep angle was established at 27°.

In Figure 5.4, the plan view of the wing can be seen. The inboard wing has a leading edge sweep of 37° to counteract the negative effects of the yehudi on the effective sweep of the wing. The chord lengths of the outboard wing have been extended to improve the stalling characteristics of the high aspect ratio wing. The wing dihedral was set at 6° to allow for engine clearance and an acceptable landing gear height and weight. The wing also has a 1.5° angle of incidence so that the fuselage is level during cruise. A taper ratio of 0.3 was chosen to minimize structural weight and increase torsional rigidity of the wing.[44]

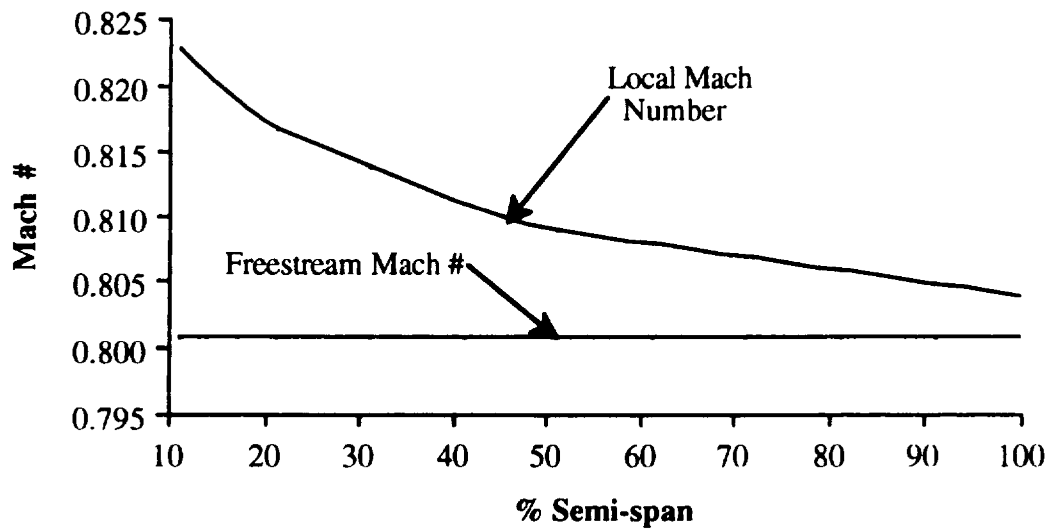


Figure 5.3. Fuselage Effects on Local Mach Number Trend
Source: NASA CR 3524

The wing span of the Eightball Express is 114 feet and the wing area was computed to be 1,300 square feet which is comparable to other aircraft of its size.[22] Calculations have verified that there is adequate room in the wing for fuel, landing gear, and control systems. The root chord of the wing is 25 ft, including wing glove and yehudi, and provides enough depth for the wing box and associated wing attachment points. A low cantilever wing was chosen because it will keep the fuselage at a practical height above the ground which will provide for efficient use of the under floor cargo space without resorting to tall landing gear.[44] It also allows for the fuselage to be stretched while maintaining acceptable geometric pitch angle. The wing dimensions are summarized in Table 5.1.

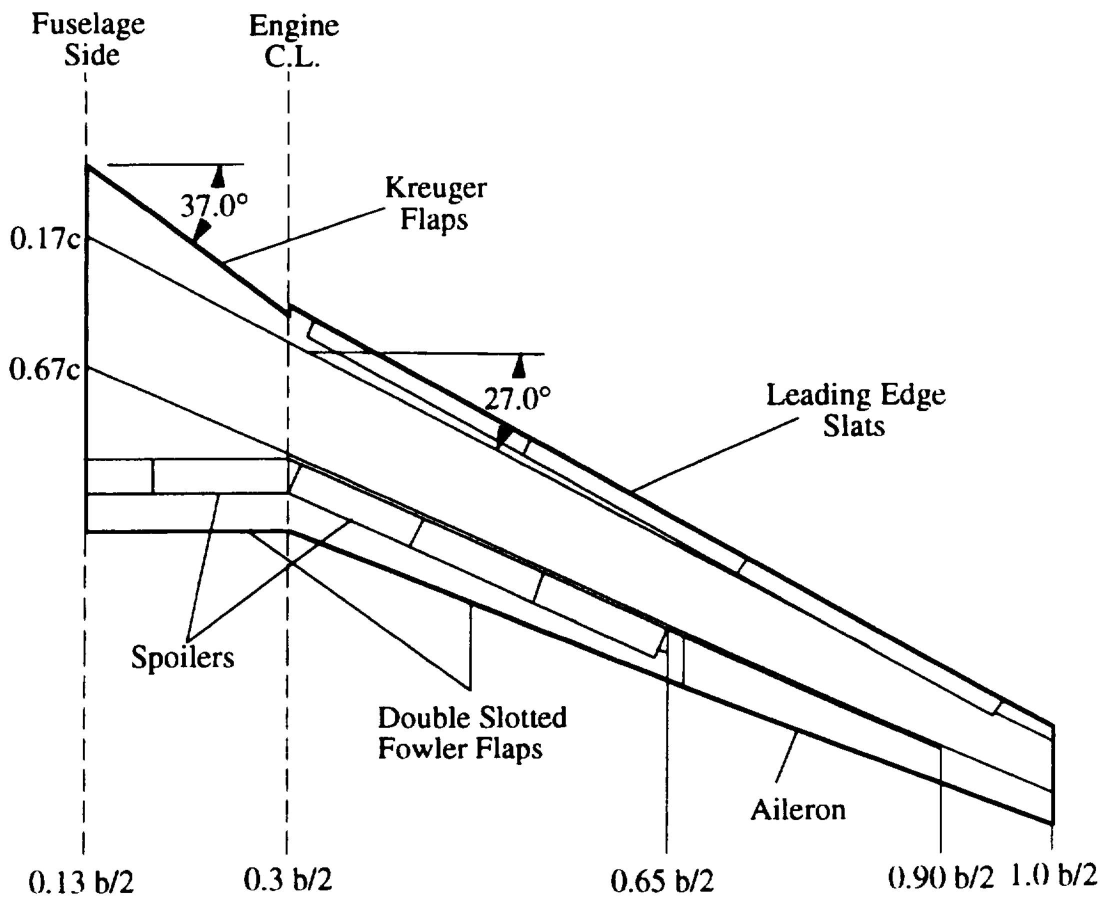


Figure 5.4. Eightball Express Wing Layout and High Lift Devices.

Table 5.1. Eightball Express Wing dimensions

Span (ft)	114
Wing Area (ft^2)	1,300
Aspect Ratio	10
Quarter Chord sweep	27°
Taper Ratio	0.3

5.2 Airfoil Selection

The wing of the Eightball Express incorporates supercritical airfoil technology. In order to optimize the cruise performance, supercritical airfoil sections were chosen to obtain a higher drag divergence Mach number, thus increasing cruise speed. As a result of the aircraft sizing process, the aerodynamic requirements for a finite, swept wing were converted to the equivalent airfoil section parameters using simple wing sweep theory at about the 1/2 chord of the wing. These parameters are summarized in Table 5.2. It was decided to use the 1/2 chord instead of the 1/4 chord because upon investigating the calculated isobars for a similarly shaped supercritical wing, it was found that the shock formation on the outer panel of the wing occurs near the half chord.[19] A 1/2 chord sweep of 25° results in the corresponding 1/4 chord sweep of 27° mentioned earlier.

Table 5.2. Eightball Airfoil Section Aerodynamic Requirements.

Finite Swept Wing Requirements	Equivalent Airfoil Section Requirements
$C_{Lcruise} = 0.5$	$C_{lcruise} = 0.61$
Re = 30 million	Re = 30 million
1/2 Chord Sweep = 25°	
$M_{cruise} = 0.82$	$M_{cruise} = 0.74$
$(t/c)_{aver} = 12.0\%$	$(t/c)_{aver} = 13.3\%$

As can be seen, an airfoil capable of producing a C_l of 0.61 at a Reynolds number of 30 million was required. A large leading edge radius R4 airfoil designed by Deutsche Forschungs - und Versuchsanstalt fuer Luft - und Raumfahrt e.v. (DFVLR) was chosen (the airfoil cross section can be seen in Figure 5.7). Figure 5.5 shows that the airfoil easily meets the requirements mentioned in Table 5.2. In Figure 5.6, the drag rise curve for the R4 airfoil at a constant C_l of 0.5 can be seen. From this figure the drag divergence Mach number was found to be 0.76, which resulted in a wing drag divergence Mach number of 0.84.

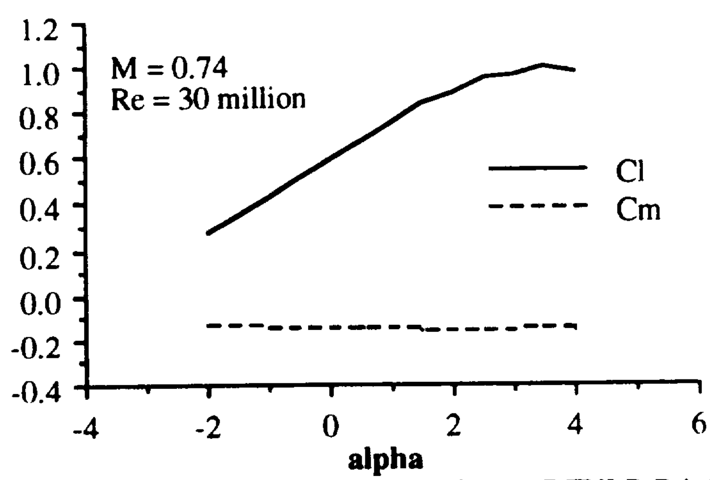


Figure 5.5. Section Lift Coefficient versus Alpha for the DFVLR R4 Airfoil.
Source: NASA TM 85739

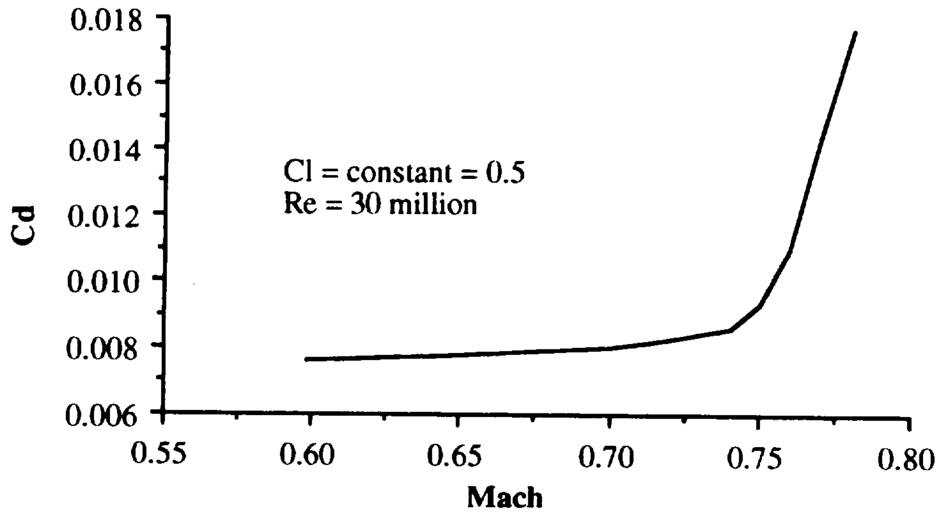


Figure 5.6. Drag Rise Curve for the DFVLR R4 Airfoil.
Source: NASA TM 85739

In order to obtain an ideal elliptical lift distribution on the Eightball Express' swept tapered wing (to increase efficiency) it was necessary to modify the R4 airfoil and adjust the taper ratio such that the maximum section lift coefficients occur at approximately 60-70 percent span.[31] Since this airfoil section is aft loading and generates large negative pitching moments, the inboard sections of the wing need to be a front loading type airfoil with a small moment coefficient. This will minimize wing deformation at various lift configurations and minimize trim drag.[31] For the outboard portion of the wing, the R4 supercritical airfoil will be used. This type of airfoil is aft loading and its trailing edge stall behavior results in improved stall characteristics. Moving inboard towards the mean geometric chord, the airfoil section is modified to a small leading edge radius supercritical airfoil. This type of airfoil is also aft loading but exhibits leading edge stall behavior and results in abrupt stalling and lower maximum lift coefficients. To counteract the large negative pitching moments these airfoils generate, front loading NASA symmetrical supercritical airfoil is used on the root section of the wing. The various airfoil sections can be seen in Figure 5.7.

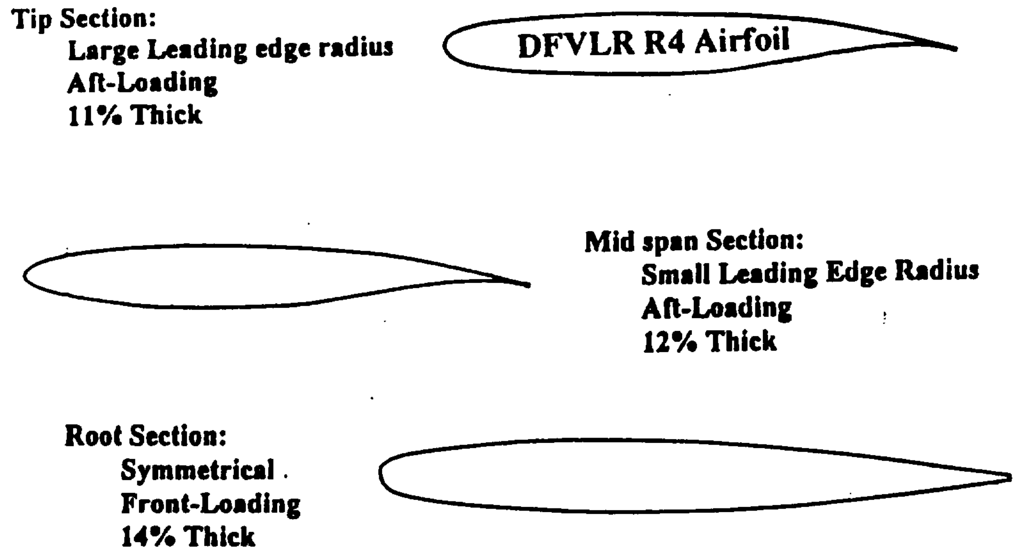


Figure 5.7. Eightball Express Supercritical Airfoil Selection

5.3 High Lift Devices

High lift devices were selected based on the landing and takeoff requirements found in the design point graph in Figure 4.2. Although it added complexity and expense, it was found that a double slotted Fowler flap arrangement and leading edge slats were necessary because it was found that single slotted Fowler flaps would require the entire span of the wing. In Figure 5.8, it can be seen that the maximum section lift coefficient of a supercritical type airfoil at M = 0.2 can be increased to approximately 4.7 through the use of leading edge slats and trailing edge double slotted flaps. Less efficient Krueger flaps are installed on the inboard portion of the wing to promote initial stall in this region. Initial flap surface area estimations were calculated using this data and the methods found in reference 43. This resulted in a required flap span of 60 percent. Flap deflections of 15° and 30° are required to obtain the required take off and landing lift coefficients of 2.2 and 2.9, respectively. Because there is no room for inboard ailerons, lateral control for the aircraft will be provided by an outboard aileron and inboard spoilers. The high lift and lateral control devices can be seen in Figure 5.4.

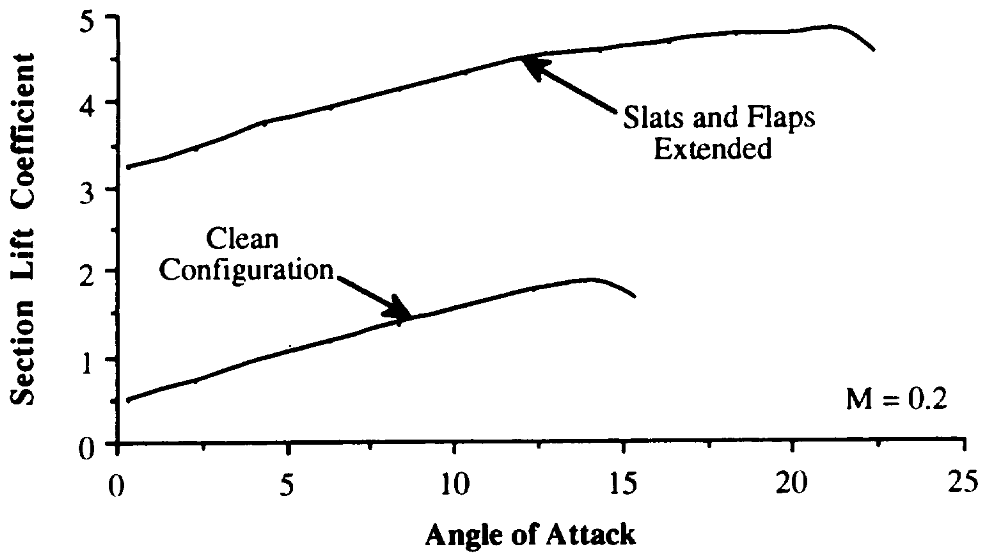


Figure 5.8. Effects of Slats and Flaps on Airfoil Section Lift Coefficient.
Source: NASA TM 89125

5.4 Why No Winglets

By optimizing the wing to a higher aspect ratio rather than using winglets a lower structural weight can be achieved and hence lower cost.[36] Since the Eightball Express is easily accessible at airports, winglets are not needed to reduce the wing span. Also, winglets are an expensive addition to the aircraft increasing parts and adding to the initial cost and the service cost of the aircraft since they subjected to damage from ground personnel and vehicles.[14]

5.5 Why No Laminar Flow Control (LFC)

Although LFC has been successfully tested on wings with sweeps of up to 30° at cruise conditions, maintaining laminar flow in these conditions is very difficult.[8] Some of the major problems are as follows:

- Leading edge roughness caused by insects, dirt, and ice crystals is highly effective in destroyinglaminar flow on 3-D swept wings.
- Boundary layer cross flow instability is inherent with 3-D swept wings.

For a laminar flow control wing to be beneficial it will be necessary for the airlines to ensure the wing is constantly kept clean. Since the aircraft is flown many times a day, airlines will need to incorporate wing cleaning in their maintenance procedures or else the LFC would only be most effective during the first flight after an aircraft wash. Structural weight of the wing must also be considered because LFC is best suited on wings with thickness ratios on the order of 10%.[8] For the Eightball Express a thin wing would require fuel to be stored in the center wing box, adding complexity to the fuel system. Until effective LFC can be implemented at a low initial cost and have low maintenance costs during its lifetime, it will not be considered for use on the Eightball Express.

5.6 Drag Analysis

The drag analysis was a very important factor in determining the performance and fuel burn of our aircraft. These two factors were very important in determining the direct operating cost of the Eightball Express. The first analysis was to determine all the causes of drag in the cruise portion of our mission profile. The different contributors to drag can be seen in Figure 5.9. From this figure induced drag and parasite drag played a large role in drag production.[23]

A further, more detailed analysis was done to determine what components of the aircraft affected drag. Figures 5.10 and 5.11 show a total component drag breakdown for the trimmed aircraft at takeoff/landing and at cruise respectively[23,39]. In Figure 5.10, the main contributors to drag were found to be the landing gear and the flaps, which are deployed during takeoff and landing. However, a more important analysis consisted of what causes drag at the cruise condition, since the Eightball Express will spend most of its flight time in the cruise portion of the mission profile. The majority of the drag at cruise was found to be produced by the wing and the fuselage. The nacelles also contribute a significant amount of drag due to the fineness ratio.

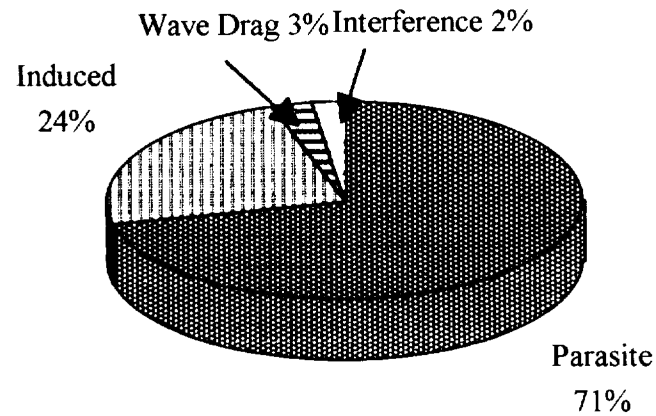


Figure 5.9. Eightball Express Total Drag Breakdown

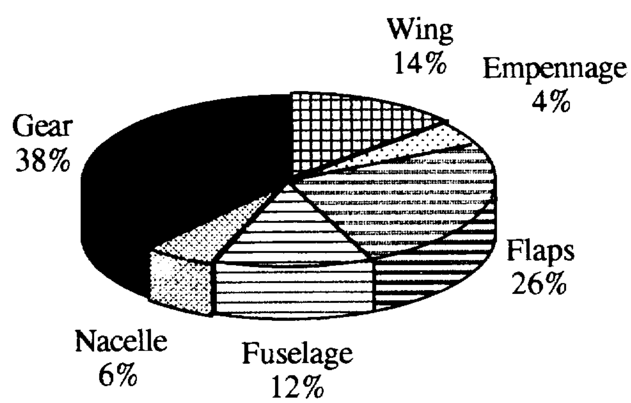


Figure 5.10. Eightball Express Drag Breakdown for Takeoff & Landing

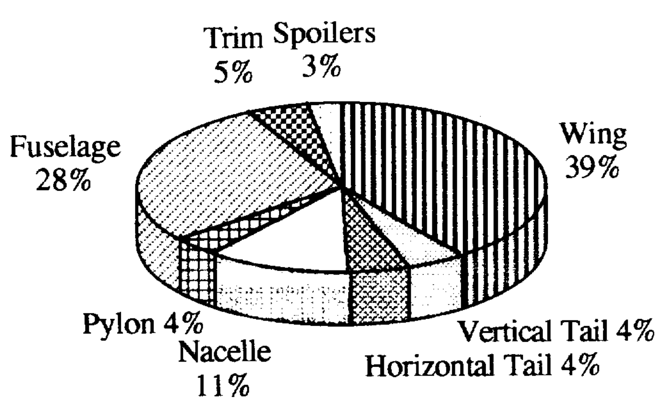


Figure 5.11. Eightball Express Drag Breakdown at Cruise

Estimates of C_{Do} for the Eightball Express were performed by calculating the parasite drag given the wetted areas of the aircraft[23,39]. The total parasite drag of the

Eightball Express was found to be .0173 using the wetted areas of the different components. Results for the aircraft at takeoff, landing and cruise conditions are given in Table 5.3.

Table 5.3. Eightball Express C_{Do}

Mach #	Altitude (ft)	C_{Do}
0.2	0	0.0210
0.82	36,000	0.0173

Many drag reduction schemes were investigated for drag reduction benefits, reliability, and cost. To try to reduce the induced drag from the wing, laminar flow control and winglets were researched. As mentioned in an earlier section, these two applications seemed unreliable and economically unviable, especially since the design philosophy is for a low cost aircraft. The next drag reduction scheme analyzed was riblets. Riblets are an adhesive film with 0.001 to 0.006 inch deep grooves. Riblets would be applied to the fuselage of the aircraft to reduce the parasite drag. They were expected to reduce the parasite drag by 4% to 6%.[33] Table 5.4 shows the parasite drag reduction if riblets were applied.

Table 5.4 Eightball Express Drag Reduction

	C_{Do}	% change
Without Drag Reduction	0.0173	--
Riblets	0.0171	1.15

5.7 Why No Riblets

If riblets perform as expected in service, our aircraft would experience an overall drag reduction of 1% and it would be a beneficial tool to use to reduce fuel burn, in turn allowing a reduction in takeoff weight and a noticeable reduction in direct operating cost. The CCD team realized that the grooves of the riblets could become clogged with dirt or ice which would require more maintenance time to keep the riblets clean. The life of the riblets were also in question. With all these possible consequences occurring, CCD decided that the drag reduction was not worth the unreliability and cost of riblets. However, if they continue to show promise there would be no problem in applying them later to the fuselage of our aircraft. At this time the Eightball Express has been optimized for drag reduction and performs fine without riblets.

5.8 Drag Polars

Low C_{Do} numbers were determined without using any drag reduction schemes. The drag polars were constructed using the C_{Do} values for takeoff and landing with gear down and low speed clean condition and shown in Figure 5.12. The estimates for the C_{Do} for the Eightball Express were performed by using references 23 & 39 and a overall drag calculation of the aircraft using the wetted area of the aircraft.

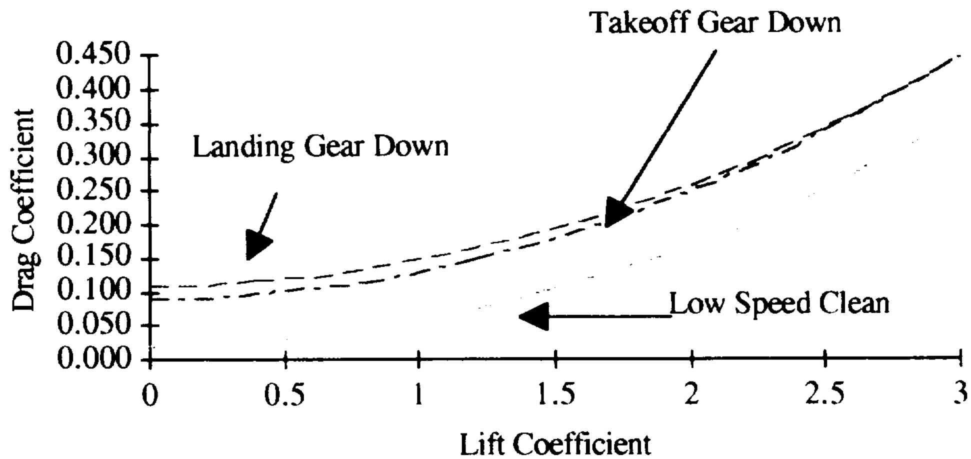


Figure 5.12. Eightball Express Drag Polars

6. PROPULSION

6.1 Engine Development

Meeting future needs of the airlines is an important aspect to consider when choosing an affordable engine. As engine costs continue to grow because of the advanced materials used, complexity of the systems and inflation, the need for engines that are environmentally and economically sound, simple, streamline and reliable are key to the design process of building a cost-effective engine. The key advantage to a cost effective engine is the low cost of aircraft ownership.[25] The majority of the costs stem from the maintenance programs and maintenance costs that are applied to the engines involved. The maintenance programs are run under the supervision of FAA regulations and run on the principle of "on -condition maintenance" (only fixed when broken) or under "hard time " conditions such that components are removed at set intervals. Under these conditions, the success of an engine program is now measured on its ability to achieve ETOPS (Extended Range Operations) certification.[25] Maintenance costs continue to grow as new technology is introduced. Typical maintenance costs vary in the range of $50-$100 per flying hour[25] for every engine and as new technology is applied to powerplants, the cost, number of maintenance stations, and skill level of mechanics will change, thereby creating an increase in maintenance costs.

Airlines are in the business to transport people from point A to point B safely, on time, and to make a profit. Airlines of today are not concerned with making adjustments to schedules to maintain engines, but are rather interested in safe, reliable and maintainable engines. Some key guidelines are: easy access to components, designed and built to last, commonality with existing systems, over-design for performance, fuel efficiency, and higher life limit on disks.[25]

Since the decrease in initial cost is important, the use of an existing engine is very profitable. This was very convenient because of the fact that engine designs of the nineties meet all the existing FAA requirements for noise, emissions, and safety and will continue to meet the needs of the 21^{st} century through upgrades and improvements. Therefore the V2500 was chosen to meet the needs of the Eightball Express and the competing airlines. The main advantage of the V2500 is the reliability and its ability to be versatile. This was visible in the ability of the power plant to be mounted into a common nacelle with the ability to upgrade in thrust to facilitate growth. Table 6.1 shows some of the characteristics of the V2500. Table 6.2 shows a comparison between the V2500 and the CFM56. These variables are very important, since the cost of operating an engine for long periods of time can be expensive if maintainability costs rise. The V2500 was chosen for reasons of reliability and maintainability over extended periods of time, the efficiency in component design and flexibility in power plant thrust growth.

Table 6.1. Engine Comparison Chart

	V2500	CFM56-3C
OPR	24.9	22.6
Bypass ratio	4.9	5
Installed Thrust (lbf)	22500	23500
Mach	.8	.8
Altitude (ft)	35000	35000
SFC (lb/lb/hr)	.575	.655
Installed Thrust (lbf)	4850	5370
Engine Wt.(bare, lbf)	4942	4301

The following information specifies details that are important for reliability and maintainability in the aircraft world.

ETOPS

By satisfying Extended Range Operations (ETOPS) requirements, the Eightball Express meets the stringent reliability checks that all airlines require. The V2500 meets 120 minutes ETOPS certification. Under these conditions, time delays and shutdowns are less likely to occur since ETOPS certification decreases the possibility of inflight shutdowns which can create time delays and cancellations[9] As can be seen from Figure 6.1, the world map representation of 120 minutes ETOPS certification, flight destinations are greatly increased and travel times made shorter with fewer stops. The use of the twin engine configuration provides for consumer safety and provides the airline with operating reliability and lower operating costs and lower maintenance costs.

Figure 6.1. 120 minutes ETOPS Representation
Source: Boeing CAG

6.2 NOISE REGULATIONS

FAR 36 stipulates noise levels for all conditions of flight. According to FAA proposed rules on noise, 25% of stage two airplanes will be phased out by 1994; 50% by 1996 and 100% by the year 2000.[32] A cumulative effective perceived decibel reading of zero must exist to certify that Stage III requirements are met. At present, Stage IV requirements for noise levels have not been confirmed, but a -4 dB level is to be maintained at all levels of flight (sideline, takeoff and landing) for stage III requirements. From Figure 6.2 below it can be seen that the V2500 meets the needs of the Stage III requirements and surpasses its competitors by approximately -10 dB. These standards in noise will propel the V2500 to be an excellent choice as a cost effective engine because noise requirements will already be met up to the year 2000 and beyond.

Airworthiness certification under FAR part 36 requires that the airplane be certified for takeoff, sideline and approach. Since effective percieved noise levels (EPNL) for approach are the highest, it is important that these noise levels are met. Under these conditions, the allowable noise level is approximately 98 EPNL dB. Based on a maximum gross weight approximation, the Eightball Express was able to fall within the estimated requiremnts obtained from noise levl test data.

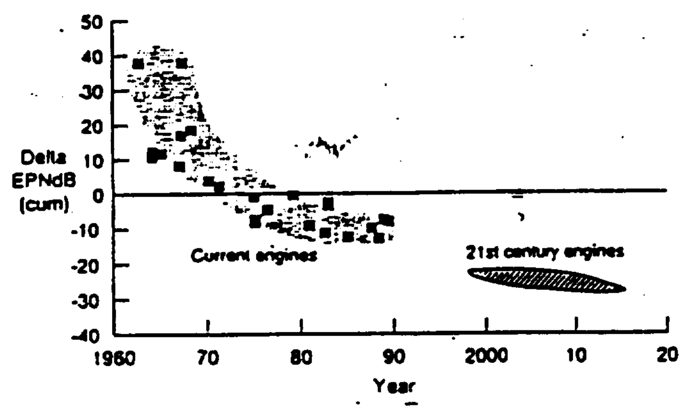


Figure 6.2. Noise Reduction Progress
Source: Koff

6.3 NOx Emissions

Figure 6.3 shows the comparison between the conventional and the two stage burner. In the V2500, the configuration has an estimated efficiency of 99.95% at design and off-design conditions with the two stage burner. As an upgrade from the conventional machined ring combustors, the two stage burner was proven to be durable and reliable. The two stage burner is broken up into two stages, or zones as it were, where there is a pilot zone and a main zone. In the low power regime, the pilot zone's prime objective is to minimize emissions of carbon monoxide and unburned hydrocarbons. When high levels of power are required, the main zone or second stage is activated to minimize oxides of nitrogen and smoke emissions. With this system of emission reduction, the aircraft can fly at its optimum during cruise and handle emissions and fuel efficiency better during takeoff and climb.

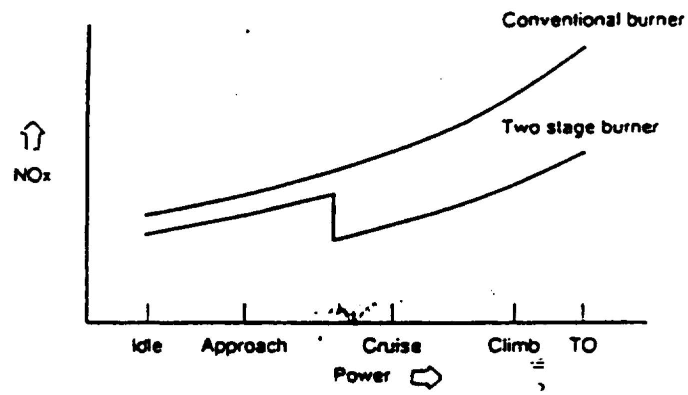


Figure 6.3. NOx Emissions vs. Flight Conditions
Source: Koff

6.4 Special Characteristics Of V2500

Active Clearance Control

The Active Clearance Control concept has improved the thermal losses that occur with increased pressures and temperatures. As unequal thermal heating and cooling occurs in the rotor and stator blades of the turbine, there is an increase in radial build-up clearances to avoid excessive rubbing during transients. The use of the Active Clearance Control system as shown on Figure 6.4 clearly shows the improved performance of the turbines.

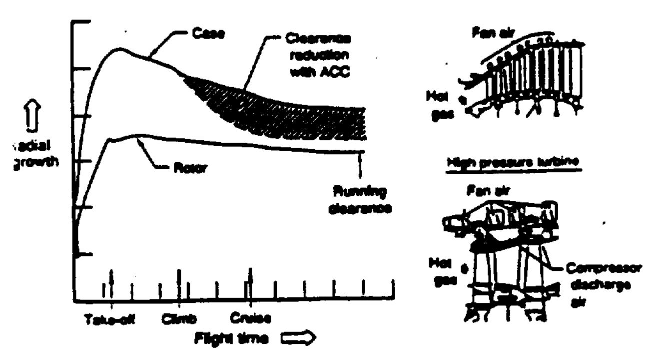


Figure 6.4. Active Clearance Control (ACC) on V2500
Source: Koff

Single Crystal Blading

The performance of the V2500 is also enhanced by the use of single crystal blading of powder metallurgy discs. This greatly increases the allowable turbine cooling temperatures resulting in less engine cooling air loss. The "cooling effectiveness" of the turbine blades is a measure of how well the blades are cooled relative to the amount of heated gas that exists. From Figure 6.5, it can be seen that the family of single crystal blading, on the upper right hand side, greatly improves the cooling allowing for higher rotor gas inlet temperatures. This aspect of engine design is very important since aircraft shutdowns or delays are caused by the life that the disks have. Moreover, the higher rotor temperature will increase the cycle efficiency and leads to fewer " on-condition " maintenance checks which results in lower shop costs and lower overall maintenance costs.[25]

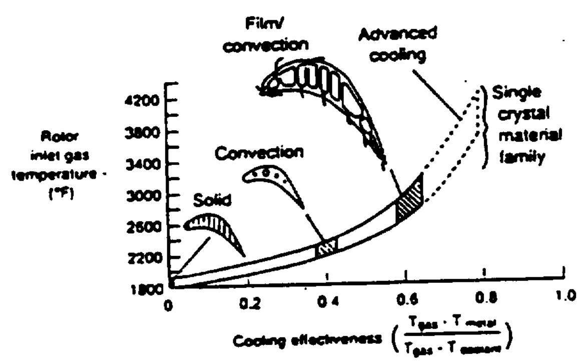


Figure 6.5. Effectiveness of Single Crystal Blading on the V2500
Source: Koff

FADEC

The Full Authority Digital Electronic Control system or similarly hydromechanical control systems are being used to meet the needs of the multifunctional engines. Figure 6.6 indicates the amount of commands that current engines require for such jobs as fluctuations in nacelle temperatures due to both air and fuel cooling. Moreover, these systems are an attempt to accomplish better reliability and service needs are what make the V2500 a very profitable choice for low cost design.

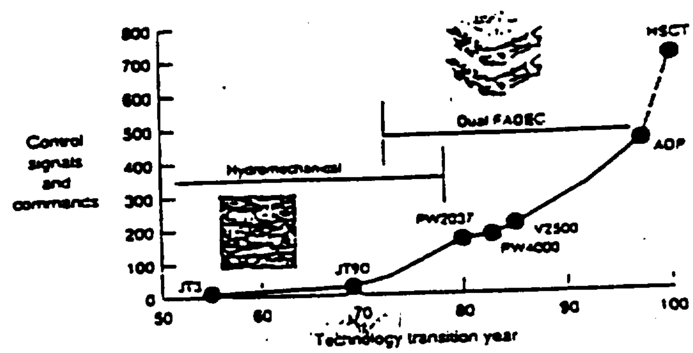


Figure 6.6. Reliability with Dual FADEC Systems
Source: Koff

As a whole the choice of the V2500 turbofan engine shows itself to be a profitable investment that can meet the needs of the airline and the FAA. The V2500 is the engine to propel the Eightball Express to a clear future. Cost effective engine design revolves around maintenance costs, reliability, and maintainability. The V2500 considers the needs of the airlines by implementing existing engineering technology to achieve environmental requirements and the needs of reliability and maintainability.

6.5 Wing/Nacelle Integration

In order to reduce the effects of interference drag, the wing/nacelle junction must be optimized for minimum configuration drag. The primary factors that affect configuration drag are the longitudinal and vertical location of the engine nacelle and pylon with respect to the wing. Wind tunnel data from reference 21 was used to justify the estimates of configuration drag.

In Figure 6.7, pylons P_{1C}, P_{2A}, and P_{3A} represent engine/pylon configurations that have the center of gravity at 25%, 10%, and 0% of the local wing chord ahead of the wing leading edge respectively. Investigation of the longitudinal location of the engine on drag increment at 0.8 Mach number can be seen in Figure 6.7.

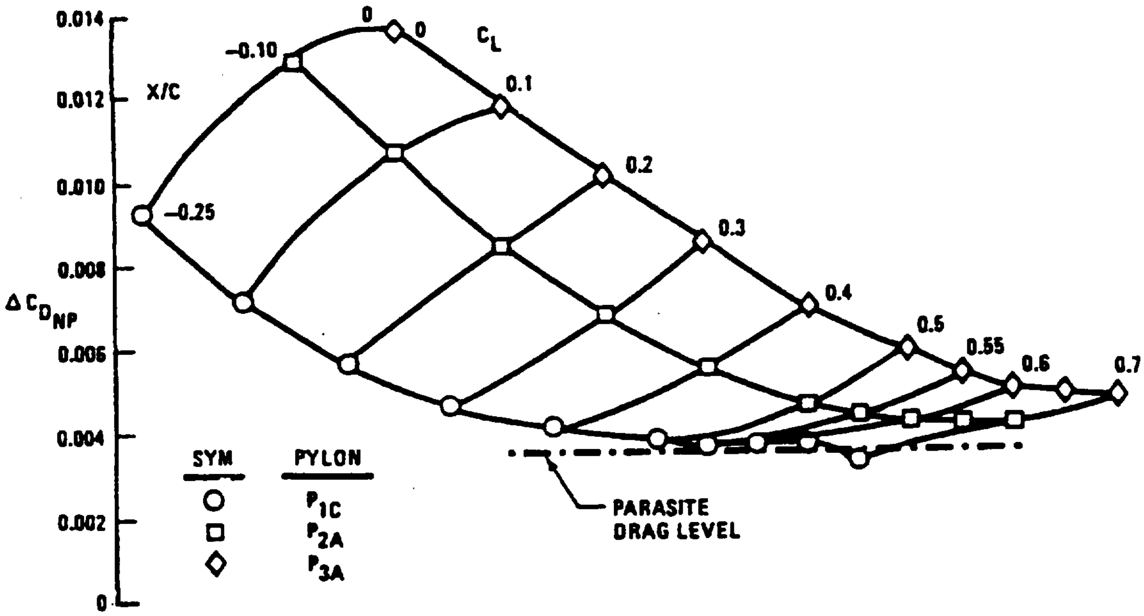


Figure 6.7. Effects of Nacelle Longitudinal Position on Nacelle/Pylon Incremental Drag. Source: NASA CR 3524

For lift coefficients greater than 0.4, the drag increment for pylon P_{1C} is very close to calculated parasite drag. As the engine is moved closer to the wing leading edge a significant increase in interference drag is experienced at lift coefficients associated with the cruise condition. Thus, for forward mounted engines, it is safe to assume that very little interference drag occurs at cruise. Figure 6.8 shows the Eightball Express nacelle/pylon configuration which incorporates the previous concept in order to minimize interference drag at cruise, yet provide adequate engine clearance with minimum landing gear weight.

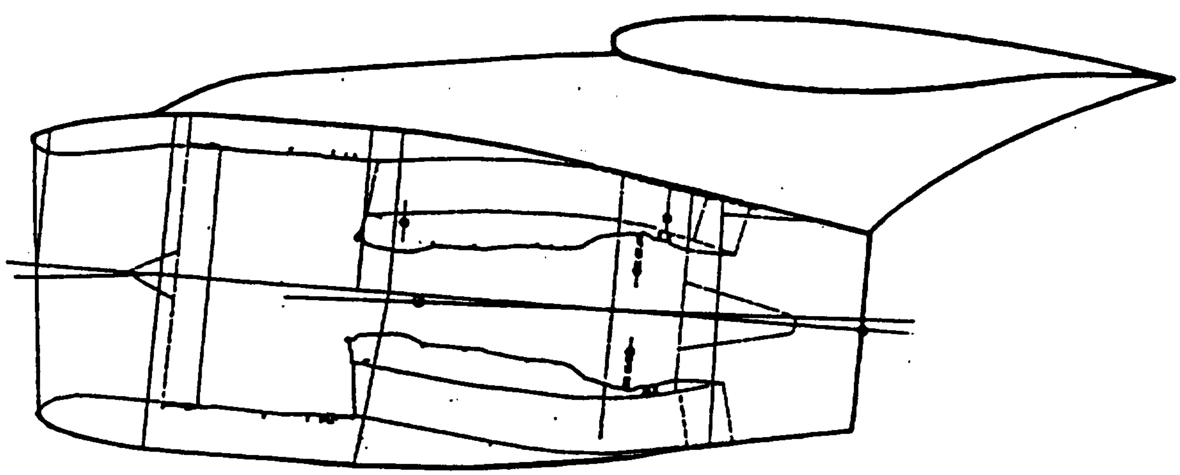


Figure 6.8. Eightball Express Nacelle/Pylon Configuration

7. STRUCTURES AND MATERIALS

7.1 Flight Envelopes

When considering the weight and performance of an aircraft, the structural loads that it experiences are very important. From the weight, the Eightball Express' structural limits were determined with the use of the V-n diagram shown in Figure 7.1. The structural loads and velocities encountered by the aircraft at a critical gust situation are shown in Figure 7.2. This critical situation was analyzed at an altitude of 36,000 feet and a weight of 120,000 lbs (the total weight minus the fuel weight). The important values of the V-n diagrams can also be seen in Table 7.1.[38] The flight envelopes were developed to determine the critical speeds at which the aircraft is capable of. From these flight envelopes, velocities and loads were known and then the exact materials and structural layout of the wing, wing box and fuselage were determined. Analyzing the critical gust situation we developed our aircraft structure to handle any critical gust problem. Therefore, the Eightball Express is not gust sensitive. The flight envelopes were done in accordance with FAR §25.301-§25.341.

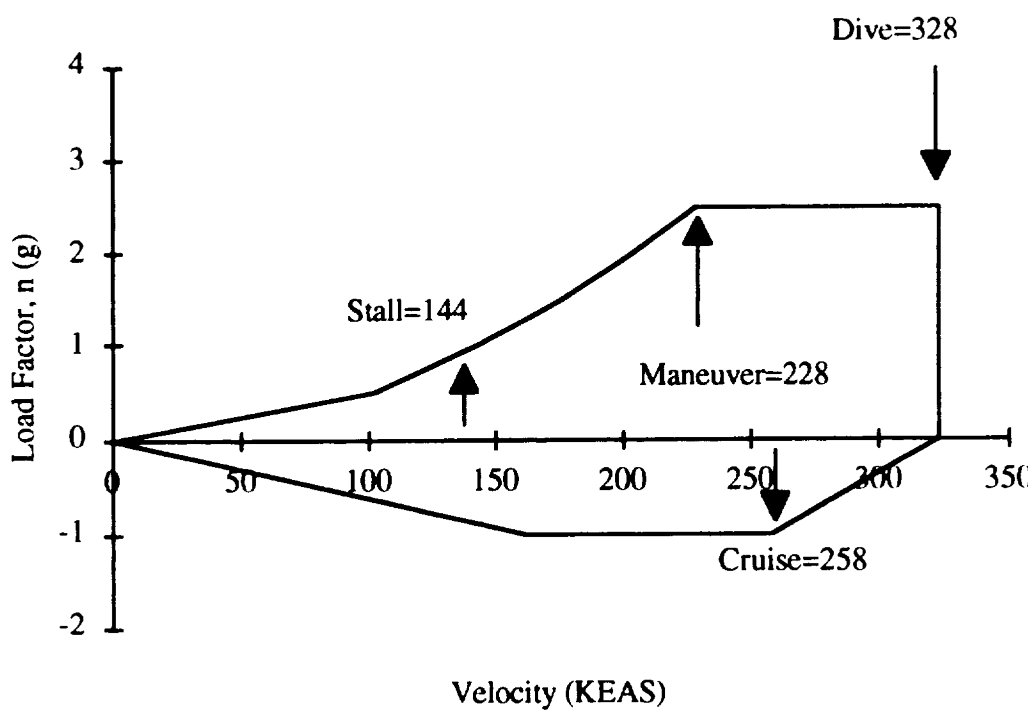


Figure 7.1. Eightball Express V-n Maneuver Diagram

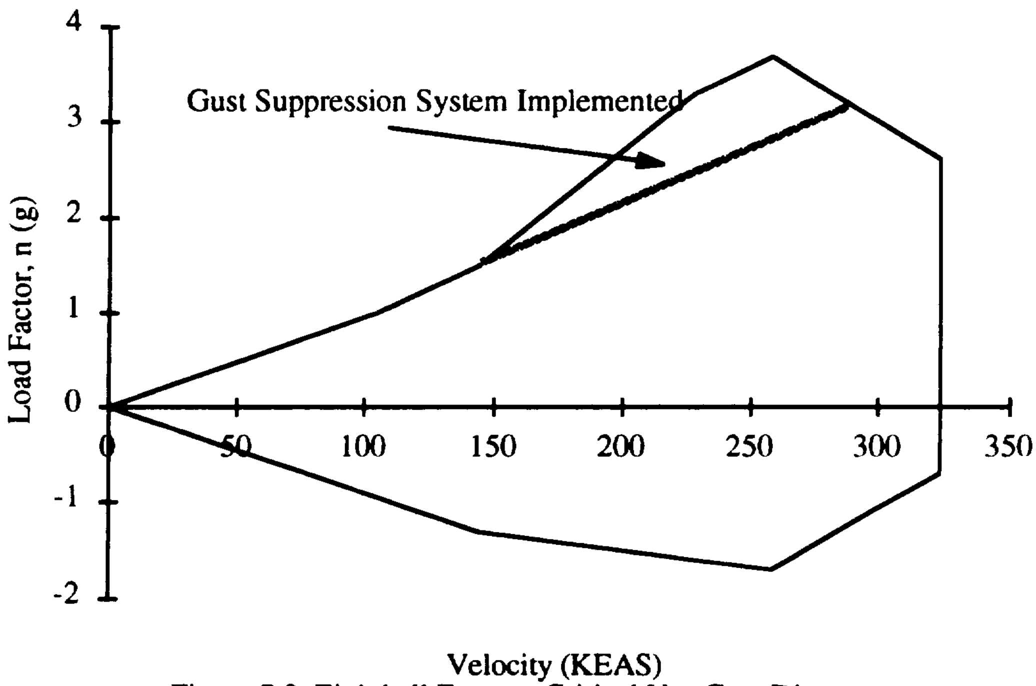


Figure 7.2. Eightball Express Critical V-n Gust Diagram

Table 7.1. Eightball Express Critical Loads

Limits	Speed (keas)	Load, n (g's)
V_A	228	2.5
V_C	258	-1.0
V_D	328	2.5
V_S	144	1.0
V_{gust}	250	3.7
V_{gust}	260	-1.7

7.2 Structure

For the design of the wing box, the wing loadings were examined at landing and cruise. The load that resulted in the most shear on the wing box occurred at cruise with minimum fuel to provide load relief as shown in Table 7.2 and Figures 7.3 & 7.4 (during a ferry mission). All loads include the effects of engine, wing, and fuel weight and the effects of engine thrust.

Table 7.2. Eightball Express Wing Loads @ Cruise

	Shear (lbs)	Moment (ft-lb)
x direction	-0.97×10^5	-2.58×10^6
y direction	-0.56×10^5	-0.33×10^6
z direction	------------	0.29×10^6

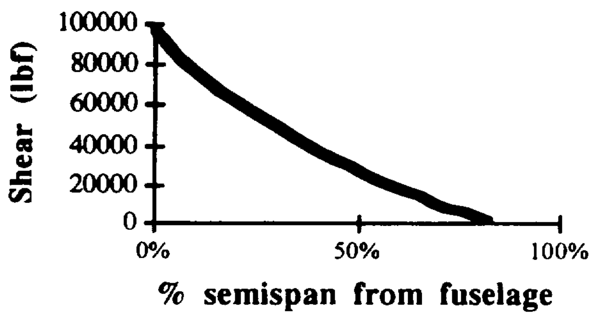


Figure 7.3. Eightball Express Shear Diagram

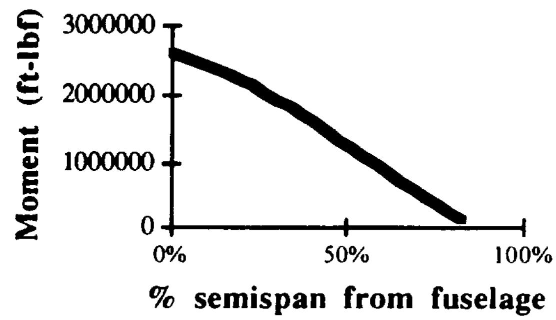


Figure 7.4. Eightball Express Moment Diagram

For the design of the wing box, consideration FAR §25.301a, future wing loadings resulting from aircraft growth, and weight from additional cargo were accounted for in the wing box's design. Thus the Eightball Express can be modified (either for growth or converted to a cargo aircraft) without major modifications to the wing box. A load factor of 3.7g's, obtained from the V-n diagram, and a factor of safety of 1.5 were assumed in the calculation. The spar caps were assumed to take shear and bending loads resulting from drag. The criteria for failure was assumed to be yielding stress (to comply with FAR §25.305). A sketch of the wing box is shown below in figure 7.5. The wing box consists of two I beam spars one inch thick at the fuselage root, spaced 50% chord apart, with six skin fasteners in between (extruded I stringer type). The ribs are space 24 inches apart and placed perpendicular to the spars. Preliminary analysis showed the above configuration produced a satisfactory wing structure with the least weight. The stiffeners are placed parallel to the spars 6 in. apart. Figure 7.6 shows the internal wing structure.

The empennage internal design was similar to the wing.. The critical loads for the vertical tail was at maximum rudder deflection with one engine inoperative., while the horizontal tail critical loads were at maximum elevator deflection during cruise. Table 7.3 displays the characteristic of the empennage.

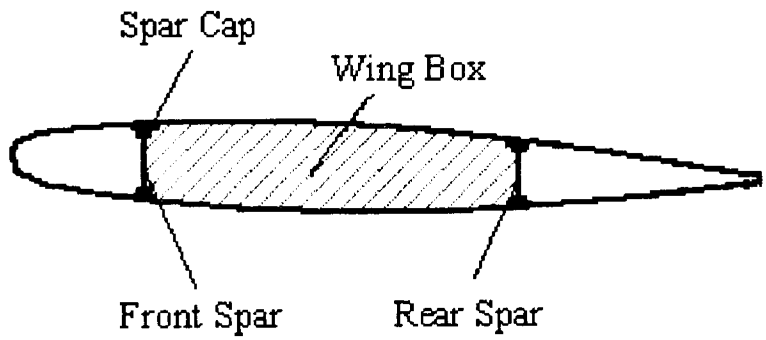


Figure 7.5. Eightball Express Sketch of Wing Box

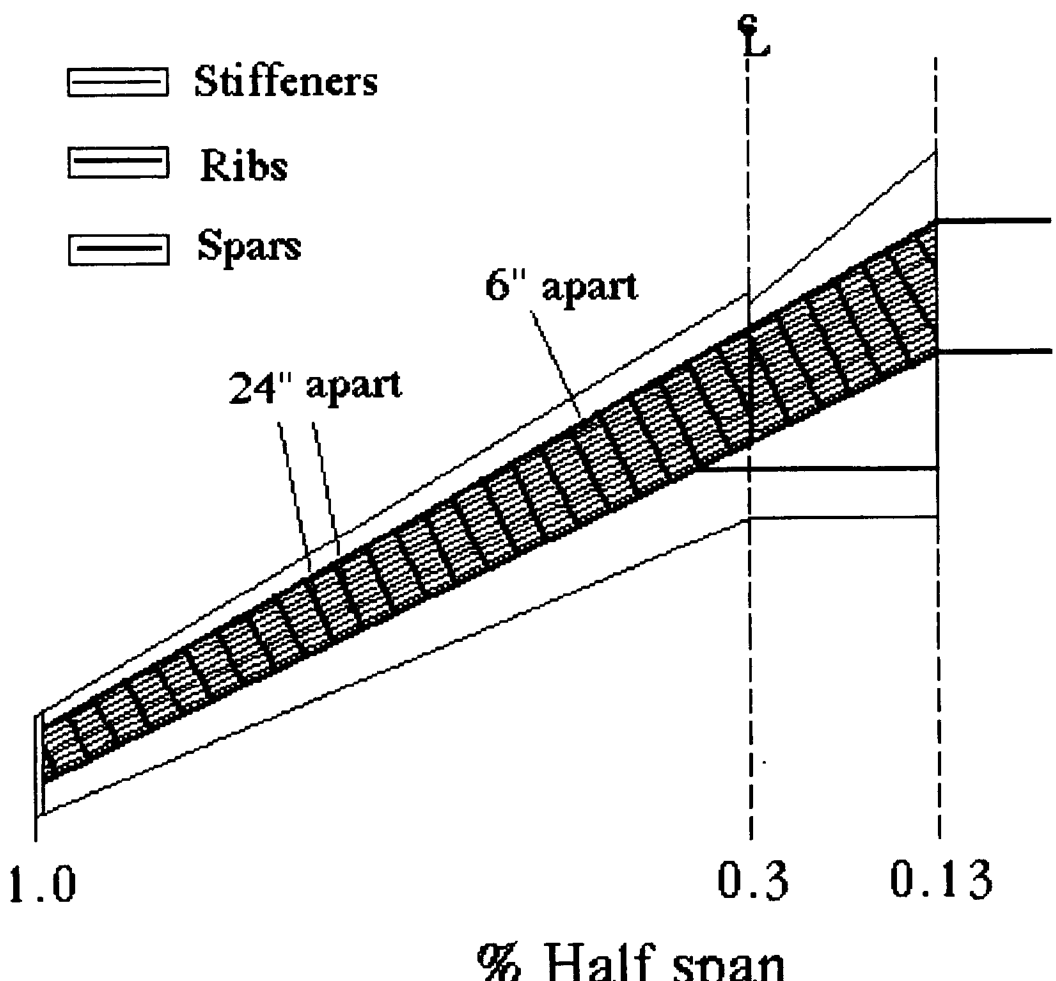


Figure 7.6. Eightball Express Internal Wing Structure

Table 7.3. Eightball Express Empennage Structure Characteristics

	Spar width apart	Spar thickness	Rib Spacing	Rib placement
Horizontal Tail	50% chord	0.7 in. @ root	24.0 in.	normal to spar
Vertical Tail	50 % chord	0.5 in. @ root	24.0 in.	normal to spar

The fuselage structure consists of 12 longerons place 14 inches apart with 70 frames spaced 20 inches apart. The fuselage skin was calculated at an altitude of 44,000 ft and Mach 0.82. The skin thickness is 0.06 inches using a factor of safety of 1.5 in the hoop stress calculation (surpassing the 1.33 required by FAR §25.365). This allows the fuselage to withstand greater pressure differentials, which would be encountered when flying at higher altitudes, provides additional fatigue resistance, and account for rivet sizes. To integrate the wing box into the fuselage, the main frames will be bolted to the front and aft spars using high tensile steel links. This allows the wing box and fuselage section to function as an integral unit which saves structural weight.[30] Figure 7.7 illustrates the basic internal structure of the Eightball Express.

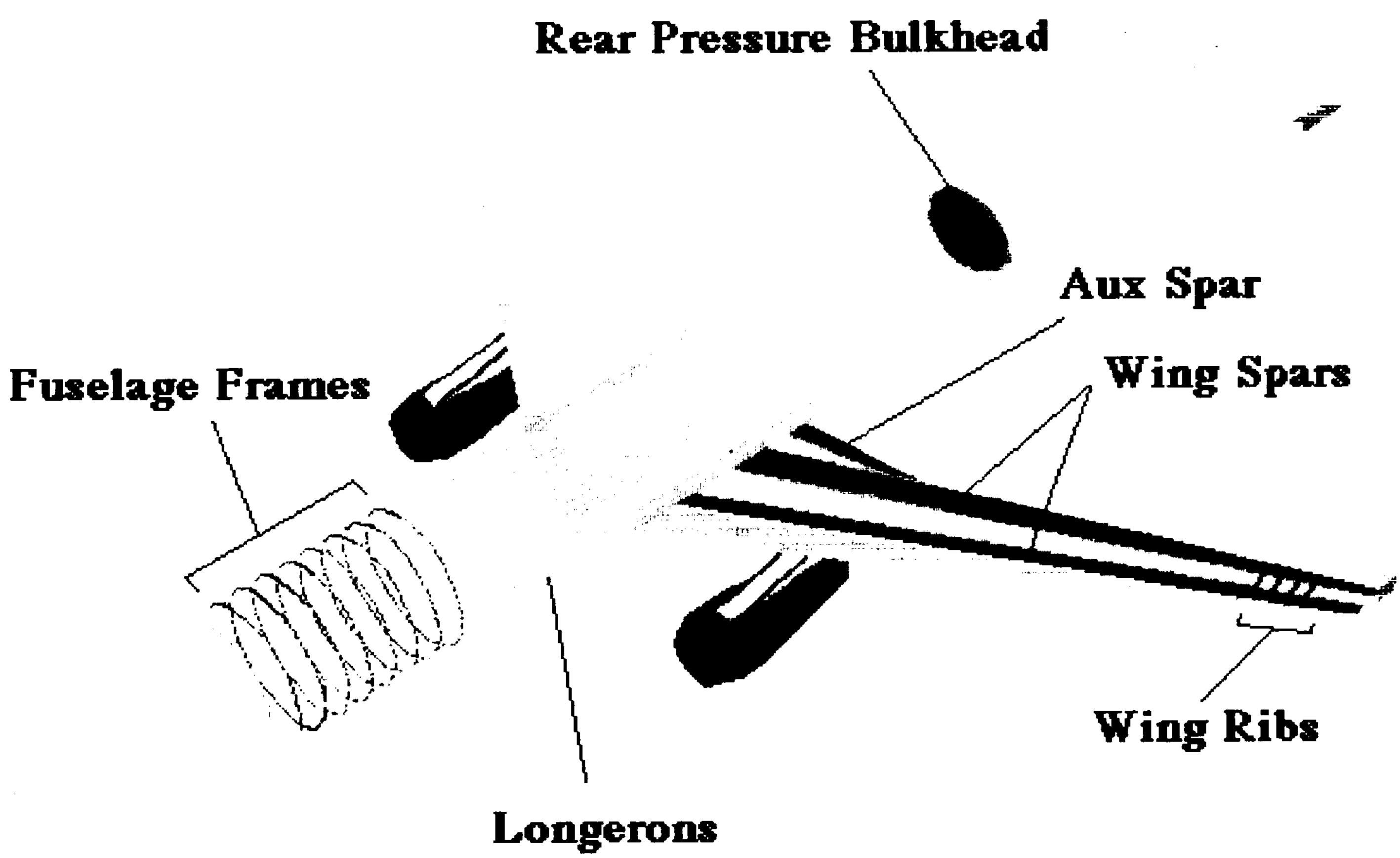


Figure 7.7. Eightball Express Basic Internal Structure

7.3 Materials

The materials being used in constructing Eightball Express were chosen based on several criteria. These criteria included fatigue, corrosion resistance, resistance to foreign object damage and wear, weight savings, ability to manufacture, and total cost. The three materials considered for Eightball Express' construction were aluminum-lithium alloy, composites, and standard aluminum alloys (2000 and 7000 series), .

Aluminum-lithium alloys (such as C155) are stiffer than current aluminum (thus being more fatigue resistant) can be machined with existing manufacturing facilities, requiring no additional tooling. These alloys are also 8% lighter than current aluminum alloys.[47] However, aluminum-lithium alloys possess several flaws. Theses alloys tend to be hazardous to handle, toxic, and unrecyclable. Special care and safety precautions must be made when dealing with aluminum-lithium. This raises environmental issues of how to dispose of waste material resulting in the base cost of this alloy being three time more than conventional aluminum. It is believed that in the future, environmental restrictions will become more severe. As a result, the disposal cost of aluminum-lithium alloys will increase. This will result in a greater base cost than present. It is due to these environmental and cost reasons that the Eightball Express will not use aluminum-lithium alloys.

Another set of materials examined for use on the Eightball Express were composites. The problem with composite materials is their high cost. Certain composites cost $40/ sq ft (92 US dollars).[14] If an airframe manufacturer does not possess adequate facilities for composite manufacturing, the material must be purchased from outside sources, hence increasing acquisition cost. Airlines also dislike composites because they are very difficult to inventory and maintain.[13] Currently there is no standardization of composite materials. Thus, if an airline uses aircraft from several airframe manufacturers (such as Airbus, Boeing, Douglas), repair materials from each company much be purchased. Another problem with composite resins is that they are time-limited to about six months with "minimum order quantity being much more than an average airline would require" in that time span.[14] All of these factors combine to increase the IOC of the airplane. A solution to offset these costs is to set a standard by which all related areas concerned with composites are regulated. Currently the Boeing and Douglas corporations are developing an American standard that would simplify the problem. A major advantage of using composites is their high structural efficiency. Kevlar composites have structural efficiencies in the ranges of 3200 (10^3in.).[30] Composites are also stiffer, more fatigue resistant, and more corrosion resistant than aluminum. Central Coast Designs projects that by the time the Eightball Express reaches production, better standardization of composites for airlines will be introduced. Even though composites are costly, their structural value should not be overlooked. Based on this rationale the Eightball Express uses composites for some non critical structures. These areas include the radome, engine nacelles, and control surfaces. To save on manufacturing cost, these composite pieces will be contracted out to other manufacturers specializing in composite production. In the Eightball Express, the control surfaces will be made out of carbon with an epoxy resin. Because composite control surfaces retard electrical current flow, which presents a problem with lighting strikes, a 0.003" aluminum foil will cover the control surfaces. The radome and engine nacelles will be constructed out of a hybrid carbon-kevlar/epoxy composite. The epoxy resin was chosen for both composites because it is relatively easy to process, possesses excellent mechanical properties, good delamination resistance, and is relatively inexpensive compared to other resins.[30]

Because the airlines are driven by profit, low cost materials that are relatively environmentally safe are used in the Eightball Express. For this reason, standard aluminum alloys are going to be used for the primary structures of the Eightball Express. The majority of these structures will be composed of 2324-T3 series aluminum. This material is fatigue resistant, has good fracture toughness, and possesses slow crack propagation characteristics.[30] This material will be used in area structures that undergo high fatigue levels. These areas include the wing spars, empennage spars, lower wing skin, floor beams, and fuselage skin.

For the upper skin of the wing, high compressive strength is needed resulting in the use of 7075 - T351. This alloy was chosen over the other 7000 series because of its ability to resist corrosion. The lower wing skins are constructed from 2324-T3 aluminum. The skin will be attached to the fuselage using 7075-T3 aluminum stringers.

The undercarriage will be made of 300M steel because of the high impact loading it undergoes. The 300M series possesses yield stresses of 230 ksi in tension and 247 ksi in compression. To protect from corrosion, cadmium plating and primer are used. The oblique view (Figure 7.8) of the Eightball Express gives the general arrangement of the materials.

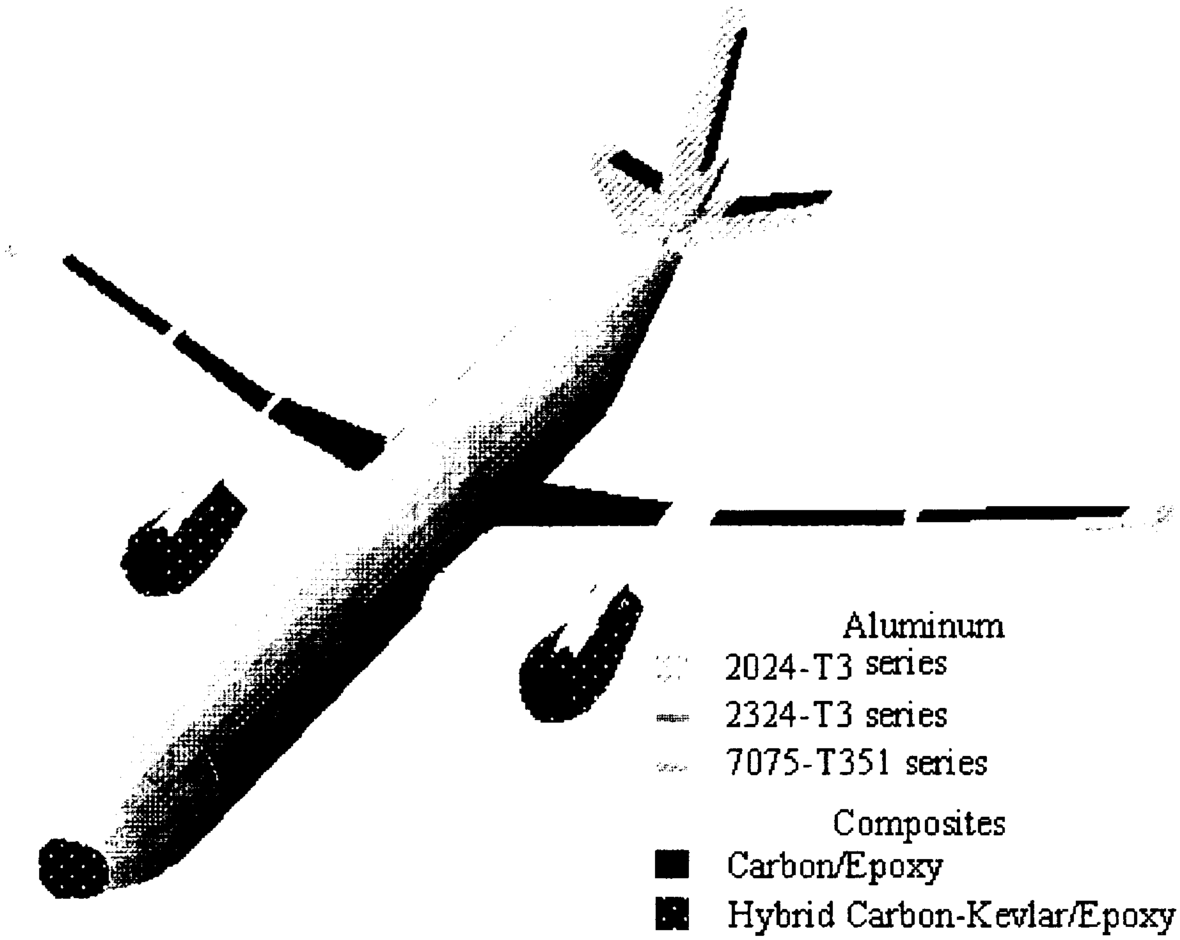


Figure 7.8. Eightball Express External Materials

8. WEIGHTS

8.1 Weight Breakdown

The weight of the Eightball Express was analyzed in three major categories: structure, which includes the empennage, wing, and fuselage; the power plant; and the fixed equipment which includes the interior cabin compartment and systems. When determining the aircraft's empty and takeoff weights, the aircraft's geometry, flight conditions, and the loads encountered from the V-n diagram were taken into account.[38]

Throughout the analysis, methods of saving weight on the Eightball Express were researched in an effort to reduce drag and fuel consumption, which would lead to a lower direct operating cost. In order to reduce the structural weight of the Eightball Express, the use of composite materials and a new alloy (C155) were researched.[47] From a weight savings standpoint these modern technologies seemed beneficial in reducing the takeoff weight, fuel weight and operating cost. However, the new technologies seemed too expensive, unreliable, not maintenance friendly and toxic to the environment. Thus, CCD engineers decided to go mainly with an aluminum structure which has proven reliability, is easy to manufacture, is maintenance friendly and very cost effective. This decision was in accordance with FAR §25.603. From these criteria, the structural weight was determined and includes the wing assembly, fuselage, empennage assembly, and landing gear.

The second major component weight was the power plant. This included the weight of the engine, the air induction system, the fuel system and the propulsion system. Next, methods of power plant weight reduction were analyzed. However, the weight of the engine was fixed by the manufacturer of the V2500 engine.

Finally, an analysis of the weight of the fixed equipment was performed. This included the flight control system, the hydraulic and pneumatic system, electrical system, state of the art instrumentation, avionics, electronics, air conditioning system, pressurization and anti-icing system, oxygen system, auxiliary power unit, furnishings of the cabin, baggage and cargo area, operational items, and finally paint for the aircraft. The total of the above weights determined the final take-off weight of the aircraft. Figure 8.1 and Table 8.1 show a detailed breakdown of the component weights of the Eightball Express.[30]

There were many opportunities to reduce the weight of the furnishings of the Eightball Express. Since the technology of polymers and plastics keep improving each year, it is safe to assume that, by the twenty first century, the seats, lavatories, galleys, floor, storage areas, interior walls, piping systems, and air ducts will be lighter weight and less expensive to manufacture. Thus, it is fair to assume a 10% reduction in the weight of the furnishings. With these weight savings, the take-off weight was finally determined to be 141,532 lbs with a payload of only passengers and baggage. However, the large cargo volume (1200 ft^3) of the Eightball Express allowed an additional 8,000 lbs. of extra cargo to be carried. The added cargo capacity makes the Eightball Express more cost effective for the airlines by being able to haul cargo as well as passengers. For this reason, the Eightball Express' mission profile and performance were analyzed at a take-off weight of 149,532 lbs.

8.2 CG Excursion and Balance

One of the most important characteristics of an airplane's performance is the movement of the center of gravity (CG) as a function of different loading configurations. The decision to design the Eightball Express as a statically stable aircraft was based on the need for a simple set of control laws that would enhance the controllability during the most significant phases of flight. The CG locations and the corresponding weights are given in Table 8.2 and the CG excursion for the Eightball Express is given in Figure 8.2.

Table 8.1. Eightball Express Component Weights

STRUCTURE		POWER PLANT	
Compt.	W(lbs)	Compt.	W(lbs)
Wing	12794	Engines	9884
VertTail	1195	apsi	108
Hor. Tail	1350	Fuel Sy	963
Fuselage	16150	Eng.Cont.	143
Nacelle	2266	Electrical	110
Ldg. Gear	3881	ThrustRev	1779
Total	**37,638**	**Total**	**12,987**
FIXED EQUIPMENT			
Compt	W(lbs)	Comt	W(lbs)
Flt Cont	1771	Hyd Syst	1124
ElecSyst	3236	AvioSyst	1862
AC/Press.	3630	Oxygen	230
APU	899	Furnish	7748
Cargo handl	1350	Operational	5576
Paint	674		
Fixed Equipment	**28,100**		
Empty Weight	78,725 (lbs)		
Payload Weight	30,600 (lbs)		
Crew Weight	1,400 (lbs)		
Trapped Fuel Weight	807 (lbs)		
Cargo	8,000 (lbs)		
Fuel Weight	30,000 (lbs)		
TAKEOFF WEIGHT	**149,532 (lbs) with cargo**		
TAKEOFF WEIGHT	**141,532 (lbs) without cargo**		

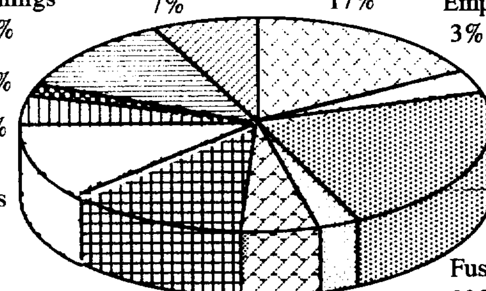


Figure 8.1. Eightball Express Weight Breakdown

.c.Table 8.2. Eightball Express CG Locations

CONFIGURATION	Xcg %MAC	WEIGHT(lbs)
WE	27.13	89000
OWE	45	90000
Fuel	33	130400
PAX& Luggage	26	109600
Fuel	42	139600
PAX& Luggage	45	109600

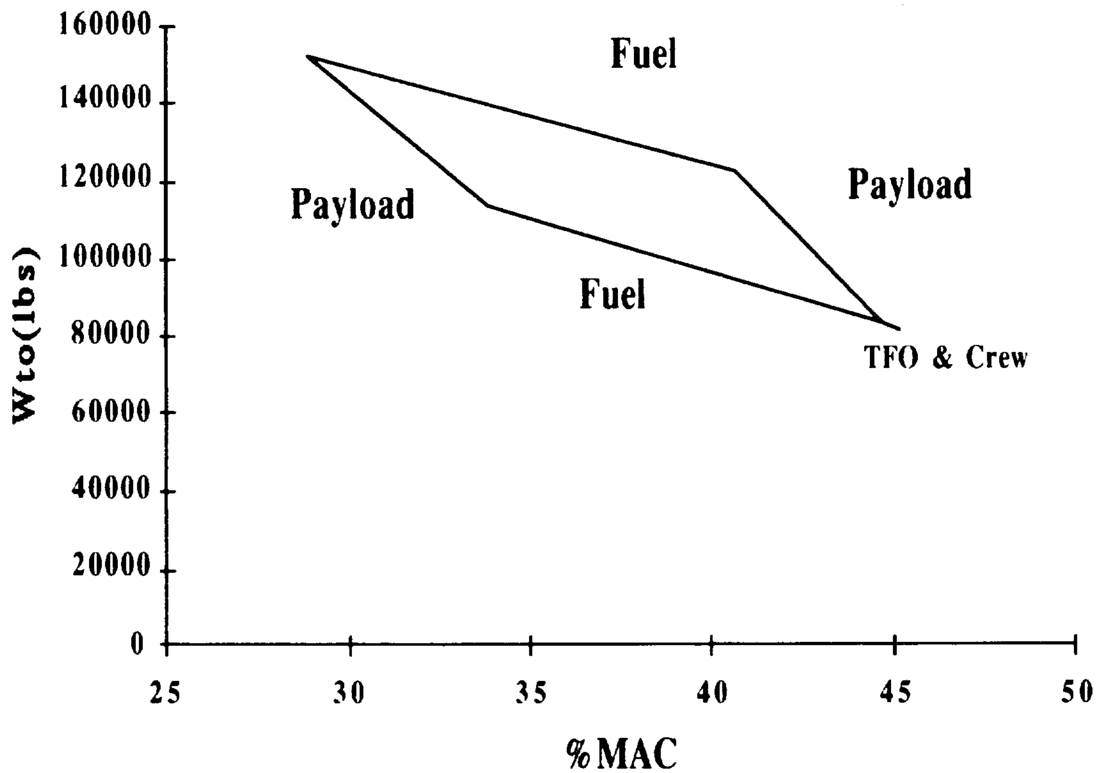


Figure 8.2. Eightball Express CG Excursion Diagram

9. STABILITY AND CONTROL

9.1 Flight Conditions for the Eightball Express

The following analysis in this section takes the geometrical parameters of the Eightball Express and calculates the stability and control derivatives for four different flight conditions. These four flight conditions are the take-off, climb, cruise and landing phases.

.c.Table 9.1. Eightball Express Flight Conditions

FLIGHT CONDITIONS	Take-Off	Climb	Cruise	Landing
Altitude (std MSL,ft)	0	10,000	36,000	0
Mach Number	0.2	0.4	0.82	0.2
Weight (lbs)	149,000	145,000	139,000	111,000
X_{cg} fraction MAC	28	27	26	25
C_L	2.4	0.8	0.45	2.8
Flaps (degrees)	15	0	0	30
Landing Gear	down	up	up	down

9.2 Empennage Sizing

In determining the size and configuration of the Eightball Express tail section, several considerations were initiated and investigated. Due to overall conventional design of the Eightball Express, the engineers at Central Coast Designs chose to proceed with a familiar tail section configuration, similar to that of the Boeing design of the 737 series. This process was begun by choosing tail volume coefficients for the vertical and horizontal sections.[36] In order to provide an increase in passenger comfort, safety and excellent flying qualities, the Central Coast Designs engineers chose to proceed with a digital fly-by-wire control system; which resulted in a reduction in size for the vertical and horizontal tail areas This is due to the modern feed-back control theory which enables the pilot to have a relatively easy task bandwidth allowing excellent controllability to be achieved.[31] A nagative static margin of -2% was chosen to yield a relaxed statically stable aircraft. Table 9.2 lists the tail volume coefficients and the corresponding surface areas.

.c.Table 9.2. Eightball Express Empennage Sizing

	Volume Coefficient	Surface Area (ft^2)
Vertical Tail	1.15	259
Horizontal Tail	0.09	323

After analyzing the desired static margin and the relationship between the location of the center of gravity and the aerodynamic center of the Eightball Express, the horizontal tail area was conveniently chosen at 254 ft^2. A plot of horizontal tail area versus X_{ac} and X_{cg} can be seen in Figure 9.1. Consequently, this area along with the choosing of the area ratio of the control surface to total area, it was observed that enough control power was available for take off and the One Engine Inoperative criterion which is mandated by the FAR §25. These values are represented in Table 9.2. The empennage surface areas and the corresponding control surfaces are presented in Figure 9.3.

Table 9.3. Eightball Express Tail Control Surface Areas

	Area Ratio(S_x/S)	Criterion
Elevator / Horizontal Tail	0.4	Take Off
Rudder / Vertical Tail	0.35	OEI

As a result of the control surface and area sizing, the Eightball Express was found to be able to achieve takeoff rotation with ease. Also the thrust offset criterion of the aircraft was satisfied as the components of thrust were calculated in the flight path axis meeting the minimum requirements for this category of FAR §25.121.

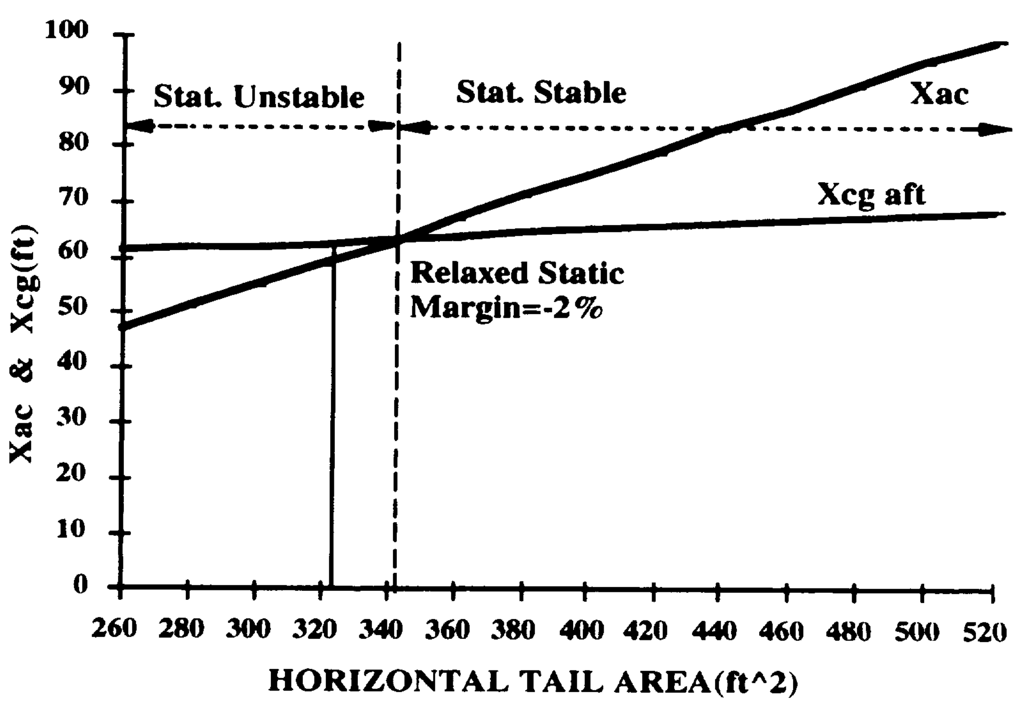
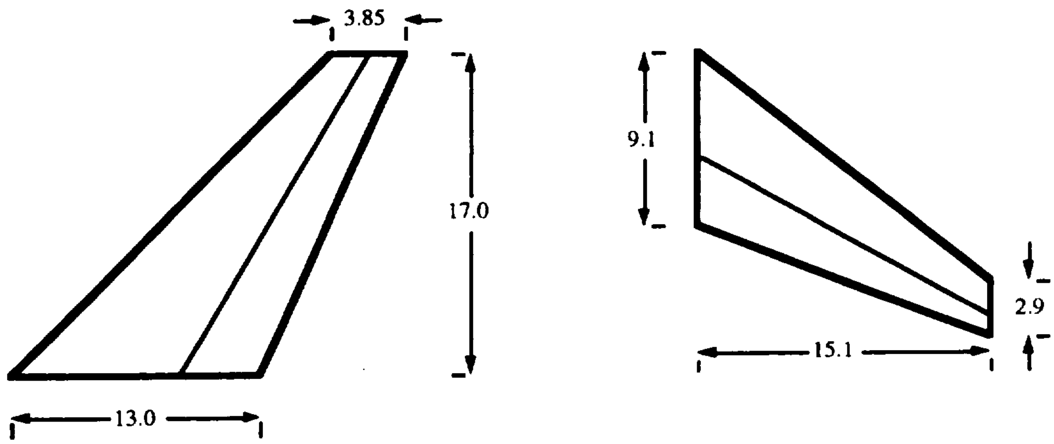


Figure 9.1. Eightball Express Horizontal Tail Sizing



Vertical Tail

Total Area=254sqft
Rudder Area=104sqft

Horizontal Tail

Total Area=162sqft
Elev. Area= 57sqft

Figure 9.2. Eightball Express Control Surface Sizing for the Horizontal and Vertical Tails

9.3 Calculation of the Moments of Inertia and Stability Derivatives

The moments of inertia for the Eightball Express were calculated using Class II methods. The results of this calculation is listed in the Table 9.2.

Table 9.4. Eightball Express Moments of Inertia

I_{xx}	1.35E6 slg-ft^2
I_{yy}	2.90E6 slg-ft^2
I_{zz}	4.20E6 slg-ft^2
I_{xz}	-8.50E5 slg-ft^2

Using the above results, the stability derivatives in the longitudinal, directional and lateral axis were obtained. These values are listed in Tables 9.3 and 9.4.

Table 9.5. Eightball Express Longitudinal Stability Derivatives

	T/O	Climb	Cruise	Landing
CL_u	0.082	0.160	0.417	0.103
Cm_u	0.076	0.025	0.197	0.091
CL_α	9.600	6.650	6.400	10.700
CL_α-dot	1.790	1.770	2.680	1.860
Cm_α-dot	- 10.70	- 12.10	- 15.20	- 10.10
CL_q	- 4.70	- 5.10	- 5.67	- 4.82
Cm_q	- 13.80	- 15.20	- 19.2	- 14.30

Table 9.6. Eightball Express Lateral/Directional Stability Derivatives

	Take-Off	Climb	Cruise	Landing
Cl_{β}	- 0.250	- 0.093	- 0.420	- 0.210
Cn_{β}	0.057	0.046	0.037	0.071
Cy_{β}	- 0.630	- 0.630	- 0.630	- 0.630
Cl_{β}-dot	0.0041	0.0032	0.0024	- 0.0015
Cn_{β}-dot	0.021	0.026	0.032	- 0.037
Cy_{β}-dot	0.045	0.056	0.061	0.067
Cl_r	0.530	0.240	0.210	0.560
Cn_r	- 0.220	- 0.220	- 0.240	- 0.240
Cy_r	0.540	0.560	0.540	0.570
Cl_p	- 0.600	- 0.570	- 0.550	- 0.630
Cn_p	- 0.320	- 0.170	- 0.110	- 0.340
Cy_p	- 0.080	- 0.062	- 0.080	- 0.002

9.4 Trim Drag Diagram

The purpose of determining the trim drag diagram was to determine if the Eightball Express would be trim during cruise. The driving factors for the trim drag diagram were the stabilizer incidence and elevator deflection. The control surface deflections which effected the aircraft lift versus angle of attack curve can be seen in Figure 9.3. The Eightball Express was within the forward and aft pitching moment coefficient. Therefore, the Eightball Express is trimmed during cruise between 0° and 1° deflection of the elevator.

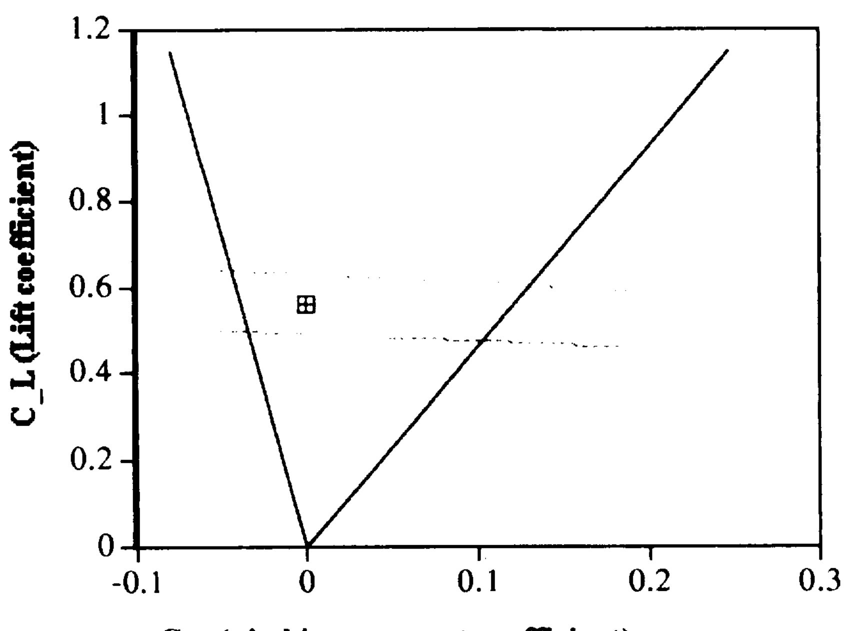


Figure 9.3. Eightball Express Trim Diagram for the Horizontal Tail

9.5 Stability and Handling Qualities

The Eightball Express utilizes a digital fly-by-wire control system (FCS) with a modern feedback dynamic stability augmentation system(SAS) to provide for static stability in the longitudinal and lateral axes.[28] In order to provide for safety, passenger comfort and smoother ride characteristics, the FCS is implemented with triple redundancy. The triple redundancy of the FCS was chosen for reliability reasons as it places the Eightball Express well above the FAR requirements for safety and system dependability. These criterion along with the ease of maintenance and accessibility enhance the logic in using a digital fly-by-wire system. The dynamic stability augmentation of the Eightball Express, along with the use of the digital fly-by-wire control system, yielded favorable handling qualities for the aircraft as performed through the Cooper-Harper rating scale. The thrust offset criterion was satisfied since the thrust components were calculated and found sufficient in the flight path axis. The stability and handling qualities in the longitudinal were analyzed through the use of the time and frequency response and the root locus of the rate of change of angle of attack, pitch rate, flight path angle and forward acceleration in the stability axis in relation to elevator deflection. The lateral and directional handling qualities were investigated without compensation for the system, by using the roll rate and yaw rate in relation to aileron and rudder deflection respectively. The short period and phugoid natural frequencies and damping ratios were obtained and the results are listed in Table 9.7.

Table 9.7. Eightball Express Mode Characteristics

	ω_n	ζ	ζ Short Period	ω_n Short Period
Phugoid	0.107 r/s	0.33	II	II
Short Period	0.825 r/s	0.73	I	II

The following transfer functions were used in order to perform the system analysis on the Eightball Express:

$$\frac{\dot{\alpha}}{\delta_e} = \frac{-10s(s+82.9)(s^2+0.0834s+0.0075)}{796.4(s+1.2s+0.68)(s^2+0.0696s+0.011)}$$

$$\frac{\dot{u}}{\delta_e} = \frac{-308s(s-7.6)(s+5.6)}{796.4(s+1.2s+0.68)(s^2+0.0696s+0.011)}$$

$$\frac{\dot{\theta}}{\delta_e} = \frac{-822s(s+0.483)(s+0.102)}{796.4(s+1.2s+0.68)(s^2+0.0696s+0.011)}$$

$$\frac{\dot{\phi}}{\delta_a} = \frac{-1313s(s^2+0.215s+1.412)}{(s-0.004)(s+0.3)(s^2+0.339s+4.15)}$$

$$\frac{\dot{\psi}}{\delta_r} = \frac{-505s(s^2+0.215s+1.412)}{700(s-0.004)(s+0.3)(s^2+0.339s+4.15)}$$

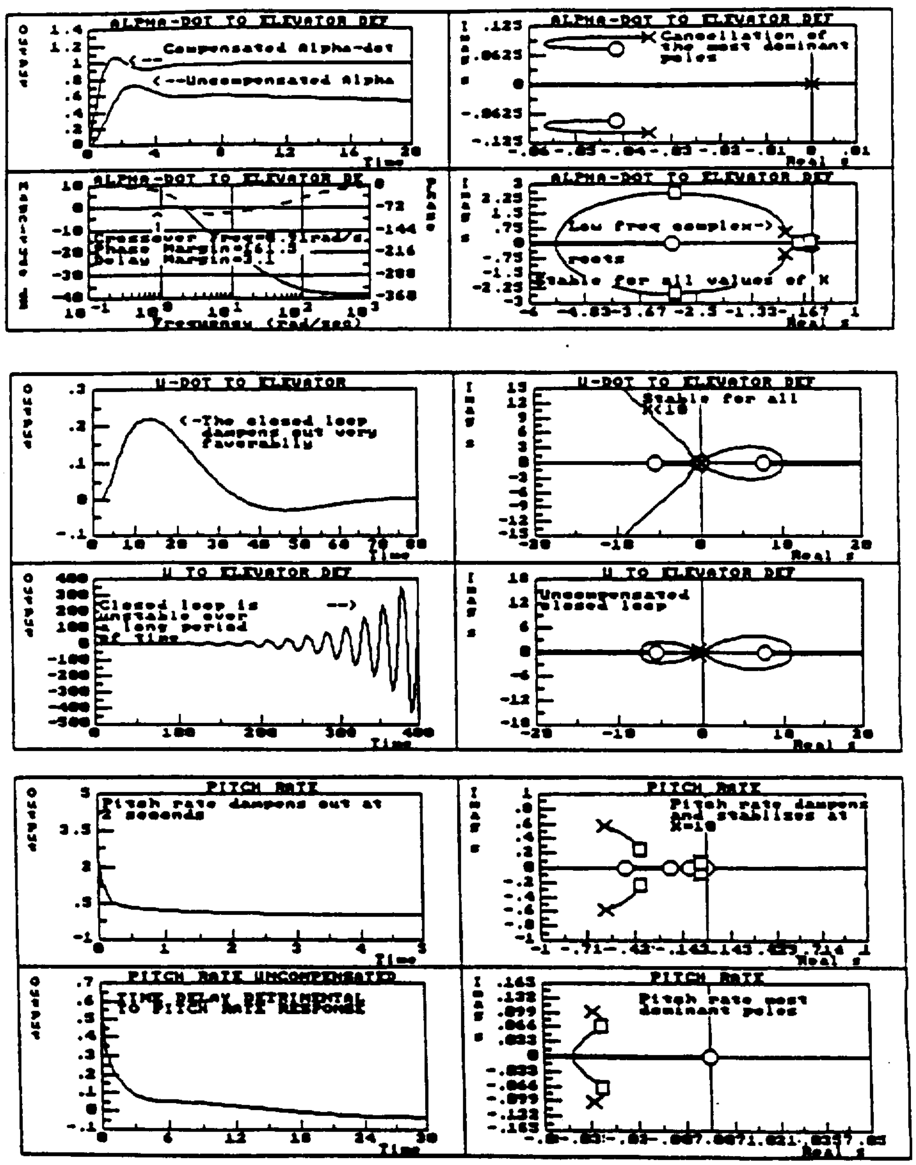


Figure 9.4. Longitudinal Axis System Analysis for the Eightball Express

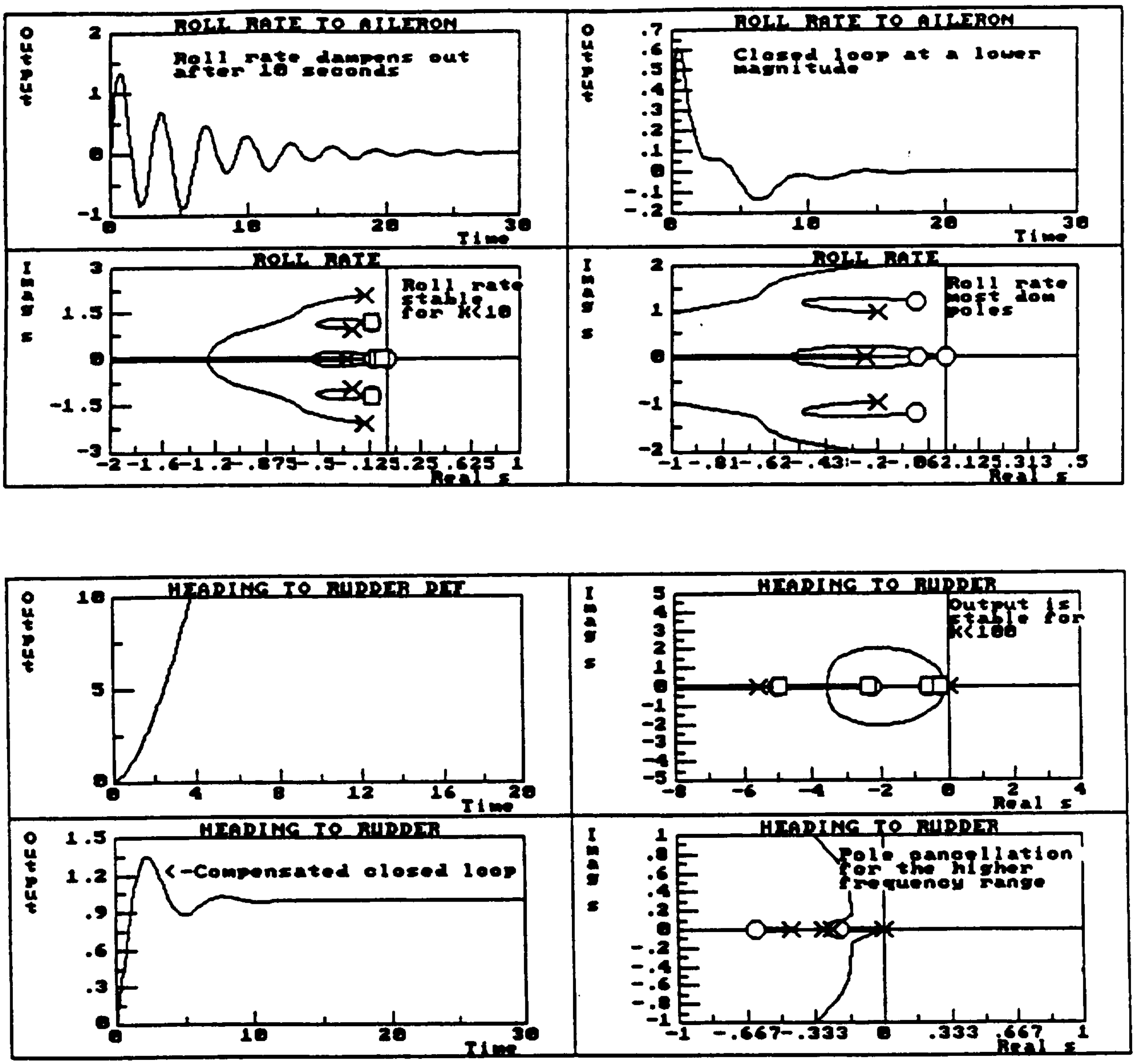


Figure 9.5. Lateral / Directional Axis System Analysis for the Eightball Express

The system analysis forced an iterative process in which compensation was needed in order to provide for favorable airplane response to a given set of inputs. Although thorough analysis of the aircraft's handling qualities is only possible through flight test data acquisition, a mathematical modeling process was chosen to closely estimate the trends and investigate any possible "cliffs" in the airplane's controllability.[10] Table 9.8 summarizes the compensated handling qualities of the Eightball Express in conjuction with the implementation of the digital fly-by-wire control system.

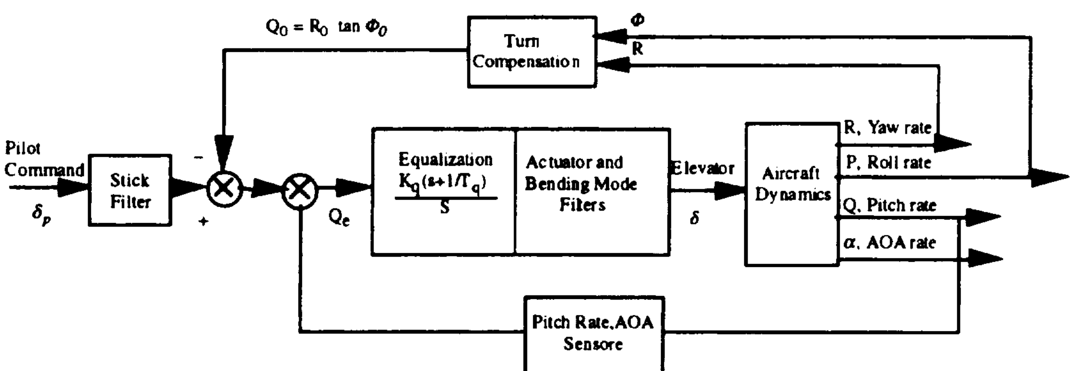


Figure 9.6. Eightball Express CAS Block Diagram

Table 9.8. Eightball Express Handling Qualities

	T/O	Climb	Cruise	Landing
Phugoid ζ	.070	.040	.045	.190
Phugoid ω_n (rad/sec)	.210	.130	.140	.210
Dutch Roll ζ	.080	.050	.050	.080
Dutch Roll ω_n (rad/sec)	.500	1.040	1.020	1.200
Roll time constant	0.2	0.13	0.11	0.2
Cooper-Harper Rating	1	1	1	1

10. SYSTEMS

For civil transport aircraft, the primary objectives of an aircraft system are that it must be simple and adequate enough to perform the task required. The system must also be reliable, sufficiently redundant, and cost effective for the airlines. These objectives are first addressed in the preliminary layout and design sequence. For the Eightball Express, the following systems will be required:

- Avionics System

10. SYSTEMS

For civil transport aircraft, the primary objectives of an aircraft system are that it must be simple and adequate enough to perform the task required. The system must also be reliable, sufficiently redundant, and cost effective for the airlines. These objectives are first addressed in the preliminary layout and design sequence. For the Eightball Express, the following systems will be required:

- Avionics System
- Flight Control System
- Electrical System and Auxiliary Power Unit (APU)
- Pneumatic and Environmental Control System (ECS)
- Hydraulic System
- Fuel System
- Anti-icing System

Although new emerging technologies will be investigated for use on this aircraft, airlines have expressed that technology must pay its way on board a new aircraft. As a result, present day techniques were primarily used to determine system requirements.

10.1 Avionics System

Preliminary research in the area of high tech avionics systems revealed that the airlines find that the costs of incorporating new technology avionics are not counteracted by an equal increase in overall system reliability.[14] Often, the costs of these systems can be attributed to maintenance and inventory costs for stocking the line-replaceable units associated with these systems.

The following systems will provide adequate performance with minimum cost for the Eightball Express beyond the year 2000. Cockpit equipment for communications and navigation will be similar to the ARINC 700 system, which has proven to be cost effective.[14] A cost effective Electronic Flight Instrumentation System (EFIS) will also be incorporated. To compliment the EFIS, a full-authority digital engine control (FADEC) and an engine data display system (EDDS) will also be installed. A global positioning system (GPS) will also be provided as standard equipment. As an option, Cat. IIIB landing capability will be offered through the use of a head up display (HUD).

10.2 Flight Control System

The flight control system for the Eightball Express is a triple redundant digital fly-by-wire system which provides a smooth ride, excellent flying qualities and considerable easy maintainability. The aircraft control is governed by two separate systems: a Primary Flight Control System (PFCS) and the High Lift Control System (HICS) supplying roll, pitch and yaw control using ailerons, spoilers, elevators, rudders and inboard and outboard trailing edge flaps, leading edge slats and Krueger flaps, respectively. The PFCS and HLCS utilize the ARINC-700 series Digital Data Bus to communicate their functions to the control surfaces. The Flight Envelope Protection System (FEPS) of the PFCS accounts for the following: bank angle, over-yaw, aileron lockout, droop, yaw damping, gust suppression, rudder ratio control, elevator off-load and flare compensation. FEPS for the HLCS takes control over the flap and slat load relief, auto slat extension and flap/slat sequencing during all phases of flight. The safety issue of the FCS's wiring is addressed by the presence of insulating material offsetting the effects of lightning and high intensity radiated fields (HIRF). Provisions are made for mechanical control during non-normal flight conditions using the control surfaces on the tail section. Figure 10.1 represents the schematic for the FCS with primary electrical connections and assuming a triple redundant routing for the reliability criterion. Figure 10.2 shows the control surfaces of the Eightball Express.

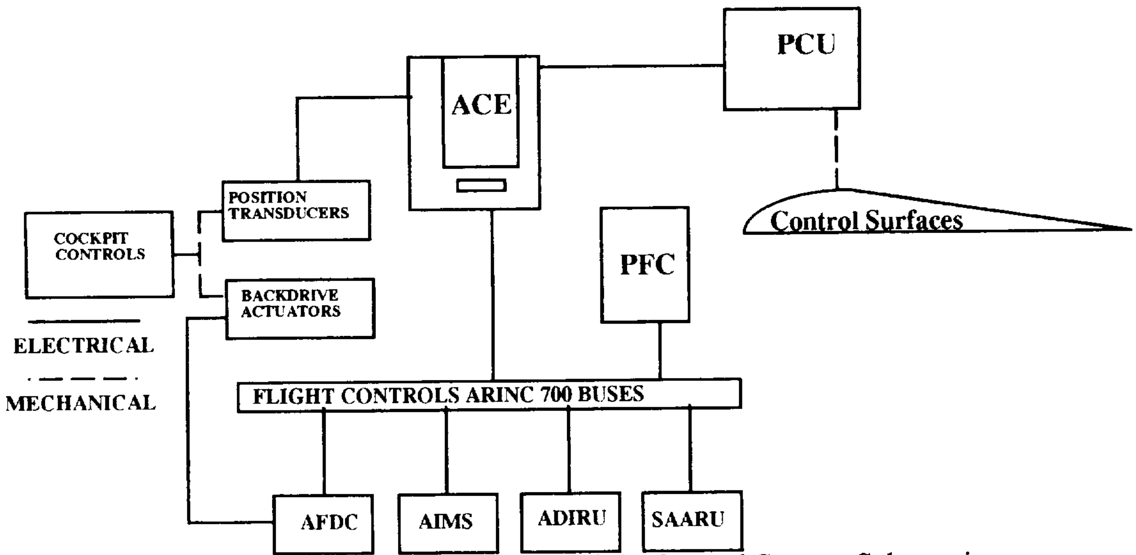


Figure 10.1. Eightball Express Flight Control System Schematic

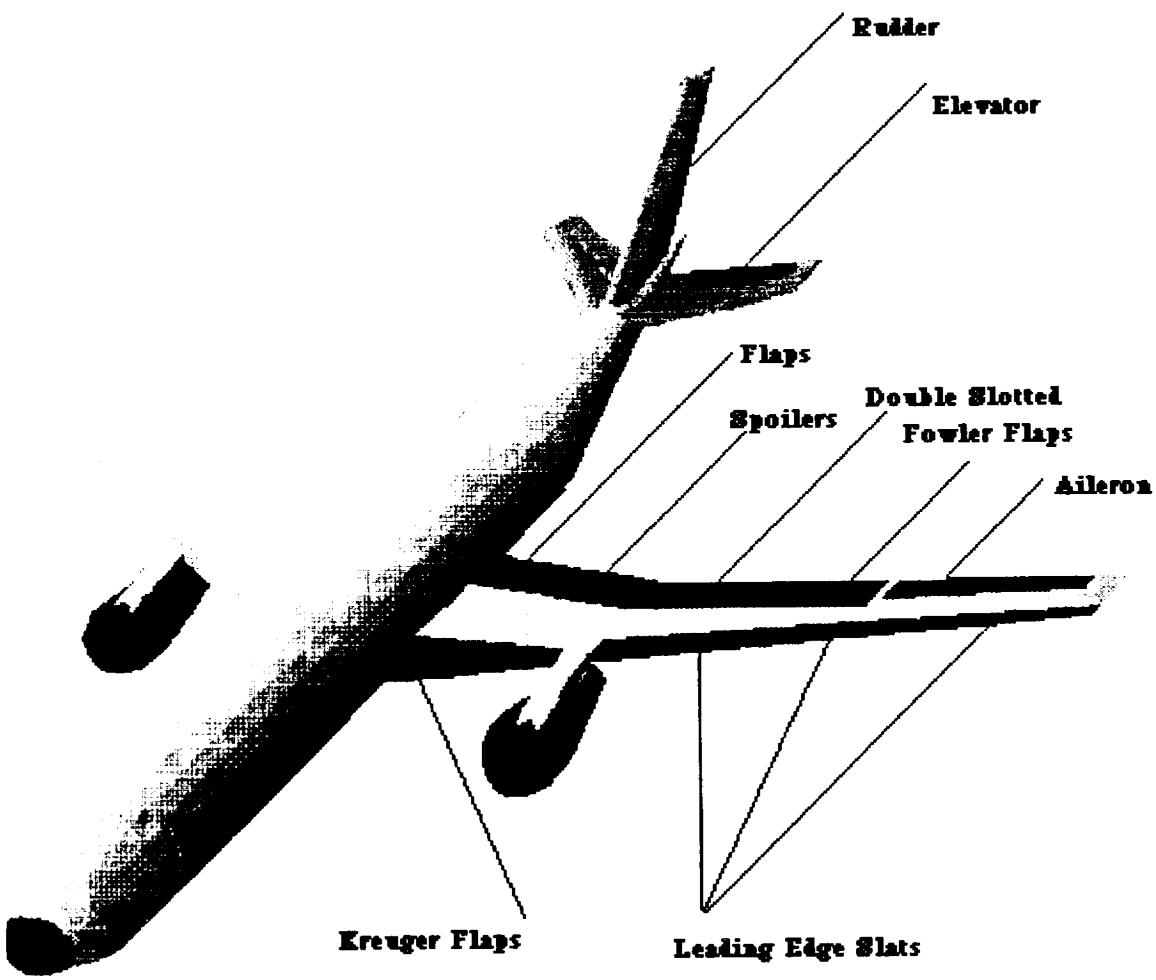


Figure 10.2. Eightball Express Flight Control Surfaces

10.3 Electrical System And Auxiliary Power Unit

Primary power for the aircraft electrical system is provided by two 90-kVA Integrated Drive Generators (IDG) mounted on the accessory gearbox of each engine which produce three phase, 115/200 VAC at a constant frequency of 400 Hz. Each IDG has its own independent oil system to provide cooling and hydraulic control for maintaining constant generator output regardless of engine RPM.

Sizing of the electrical system was based on an estimated maximum electrical demand which normally occurs during the takeoff and decent portions of flight.[37] Each IDG is capable of carrying all the essential loads required for safe operation of the aircraft. The primary electrical power is distributed to the various electrical components via the left and right AC busses. Two Transformer Rectifier Units (TRU's) are used to convert the primary AC power to 28V DC for use in aircraft lighting and control circuits. In the case of an engine failure, the APU is capable of being started and operated in flight through the use of a high pressure recovery inlet and battery to provide secondary power. External electrical power can be connected through a standard electrical plug located on the forward right side of the aircraft.

Over current protection of the electrical system is provided to protect electrical components in the event of any single failure. Aircraft grounding receptacles are located in each wheel well and in the tail and are easily replaceable. In order to reduce cost standardized electrical components and micro integrate circuits are used. The wire bundles have been number coded and have been designed for prevent wire chafing through holes and allow for easy removal modifications thus improving reliability and ease of maintenance of the system.

As was previously mentioned, an APU is installed to provide secondary electrical power for emergency (battery start) and ground operations. For the Eightball Express, a next generation Garrett 131-9 series APU with a bleed airflow capacity of 155 lb/min. and 90 shaft horsepower was chosen based on the following qualities:

- Capable of inflight starting and operation up to 37,000 ft.
- Provide electrical power for ground and emergency inflight operations.
- Provide bleed air for engine starting as well as Environmental Control Systems (ECS), anti-ice, and heating operations.
- It is automatic in operation and maintenance friendly.

The APU drives a 90-kVA generator to provide secondary electrical power should an engine fail in flight.

As in most aircraft, the APU is installed in the tail of the fuselage so that special adaptations (such as firewall installation) to isolate the APU from the rest of the aircraft can be done with a minimum increase in weight.[43] To reduce noise, the APU inlet is located on the top portion of the fuselage and incorporates a muffler. Exhaust gases are vented to the atmosphere via a small exhaust duct at an upward angle of 30 degrees with respect to the ground to help minimize interference with ground crews. The accessibility of the APU for maintenance is very good in this location and the airframe hard points and access doors are designed to allow for its quick removal and replacement. For ground operation and checkout, a small quick release access panel located by the aft cargo door allows for ground operation and checkout of the APU using Built In Test Equipment (BITE). In order to further reduce weight and cost of the APU, special attention will be made towards designing the APU configuration in order to reduce the number of parts by eliminating the APU shroud.[16]

10.4 Pneumatic And Environmental Control Systems

The primary purpose of the Eightball's pneumatic system is to supply air for the ECS used for cabin pressurization, aircraft anti-icing systems, and for cross engine starting. Source air is tapped from each engine and routed through a precooler before it is piped to each respective system. ECS, anti-ice and heating operations can be accomplished on the ground using the 155 lb/min. of bleed air available from the APU. Bleed air for engine starting can be obtained from either the APU or a running engine.

The ECS diagram can be found in Figure 10.3. Air from the pneumatic system is ducted into two air conditioning packs located in front of the wing box where it is cooled and sent to a mixing unit where it is mixed with recirculated air. The conditioned air is then distributed up the sides of the fuselage and down the top centerline of the fuselage through acoustically designed ducts to reduce cabin noise. The Eightball's ECS is capable of providing up to 20 cubic feet per minute per passenger during the critical flight condition of decent at flight idle.[37] There is also a separate line for electronic equipment cooling and an aft cargo heating system. The cabin pressurization system is designed to maintain cabin altitude up to 8,000 ft above sea level and incorporates both positive and negative pressure relief. Pressurization scheduling with altitude is automatic in order to reduce the pilot's workload. In the event of pressurization failure, a dry oxygen system is deployed and distributed with face masks to every passenger. The flight crew uses a small source of gaseous oxygen located in the cockpit.

10.5 Hydraulic System

In order to power aircraft systems such as the flight controls, landing gear, wheel brakes, thrust reversers, and landing gear steering, a 3,000 psi. hydraulic system is used by the Eightball Express. New technologies in hydraulics, such as electrohydrostatic and 8,000 psi. systems will be looked at to reduce weight and installed volume should the airlines show interest in incorporating these systems in their fleets. Sizing of the hydraulic system was based on an estimated amount of hydraulic fluid flow required during landing (highest operating demand) and with comparisons of other aircraft.[37] As a result, there are three separate, independent systems used on the Eightball Express. The left and right systems are powered by an engine driven pump and an AC motor pump while the central system is powered by two AC motor pumps. Most aircraft systems, such as the flight controls and auto pilot are distributed over all three systems while other systems, such as the spoilers and speed brakes are distributed evenly over all three systems. For systems operating on the left system only (flaps, slats, and landing gear), a power transfer unit

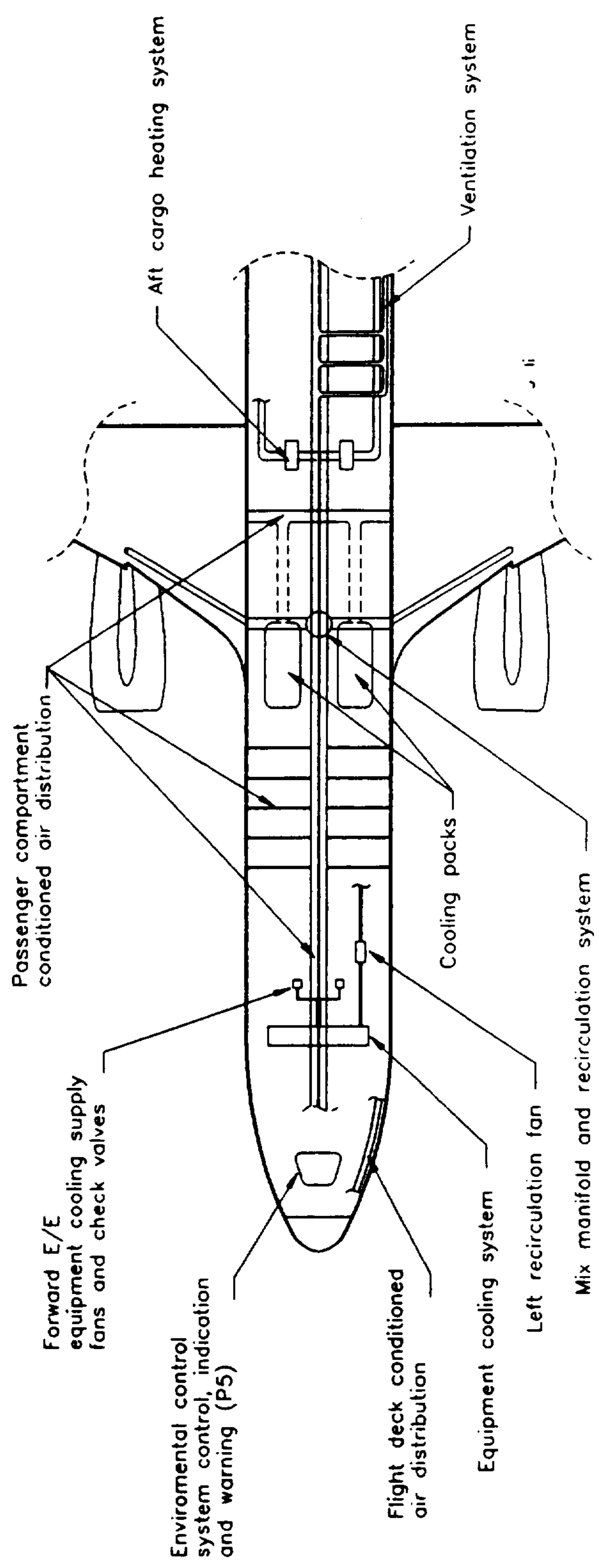


FIGURE 10.3 Eightball Express Environmental Control System

(PTU) is used to transfer power from the right system in the event failure. A hand pump for the landing gear and reserve accumulators for each system and the brakes are also provided. A ram air turbine (RAT) can also be deployed in the event of a hydraulic failure. For airlines wishing to qualify for ETOPS, a hydraulic motor generator can be added as an option to provide power for essential electrical loads in the case of total electrical power loss. To simplify ground servicing, The reservoirs have been located in their respective MLG wheel well and are easily accessible. For ground maintenance operations, an easily accessible quick disconnect fitting is located in each engine nacelle for a ground cart. A summary of hydraulic needs and sources can be seen in Figure 10.4.

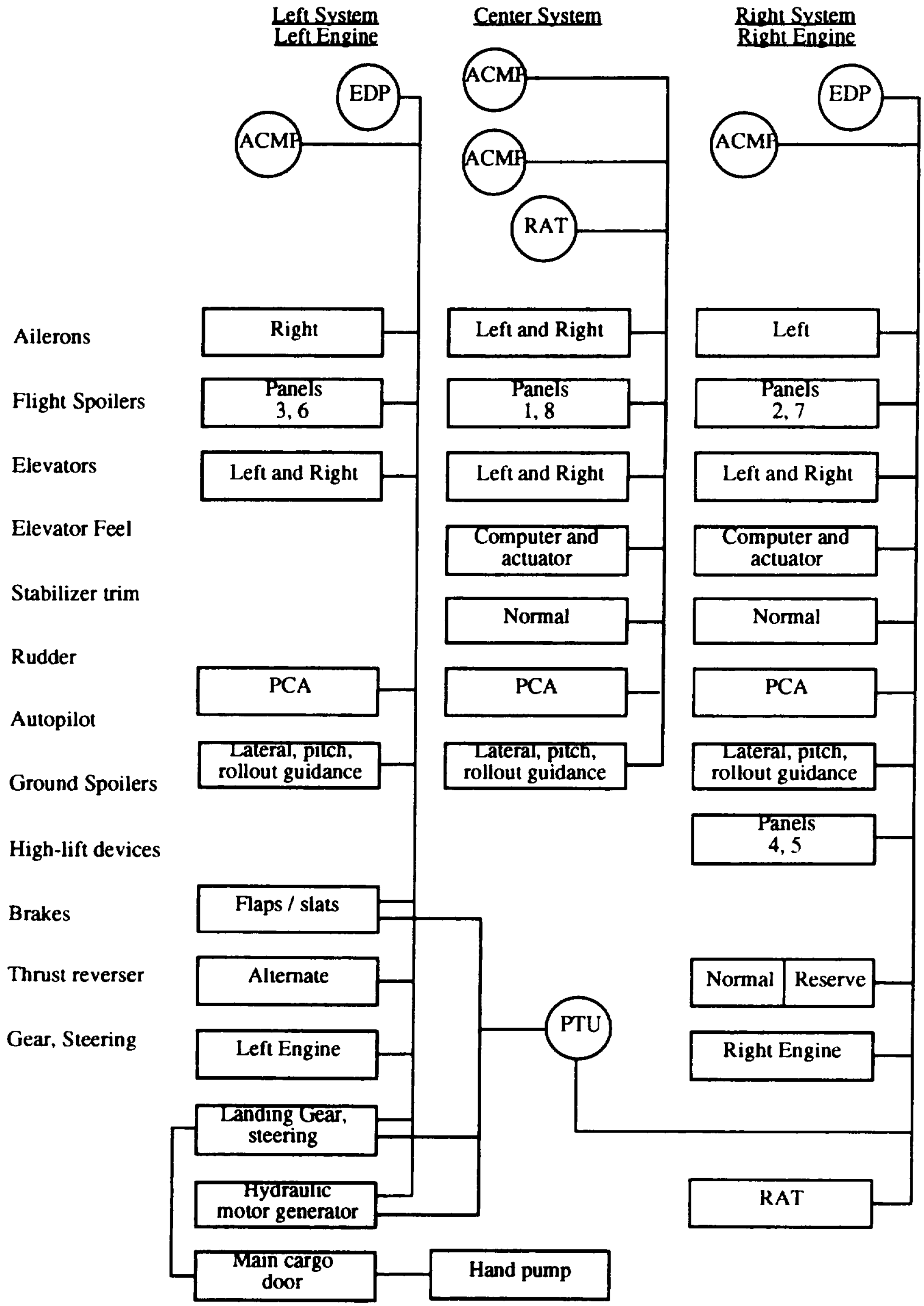


Figure 10.4. Eightball Express Hydraulic System

10.6 Fuel System

Two main integral fuel tanks are located in the wings which provide enough volume for the design range of the Eightball Express. The fuel supply system incorporates dual element fuel boost pumps and associated plumbing sized to provide up to 1.5 times the maximum required fuel flow required during takeoff. A fuel transfer system is not required on the Eightball Express because any imbalance condition can be corrected by manipulating the boost pumps and crossfeed valves. A single point refueling receptacle and control panel is located outboard of the left engine to allow for quick refueling. Overwing ports are also provided in case single point services are unavailable. In order to prevent pressure buildup in the fuel tanks and provide positive tank pressure during flight, a fuel vent system is used. The Eightball Express is also equipped with an automatic sumping system to remove water and other contaminants from the fuel. There is also a surge tank and associated flame arrestor located in each wing to collect and condense any excess fuel vapor. Figure 10.5 shows the fuel system.

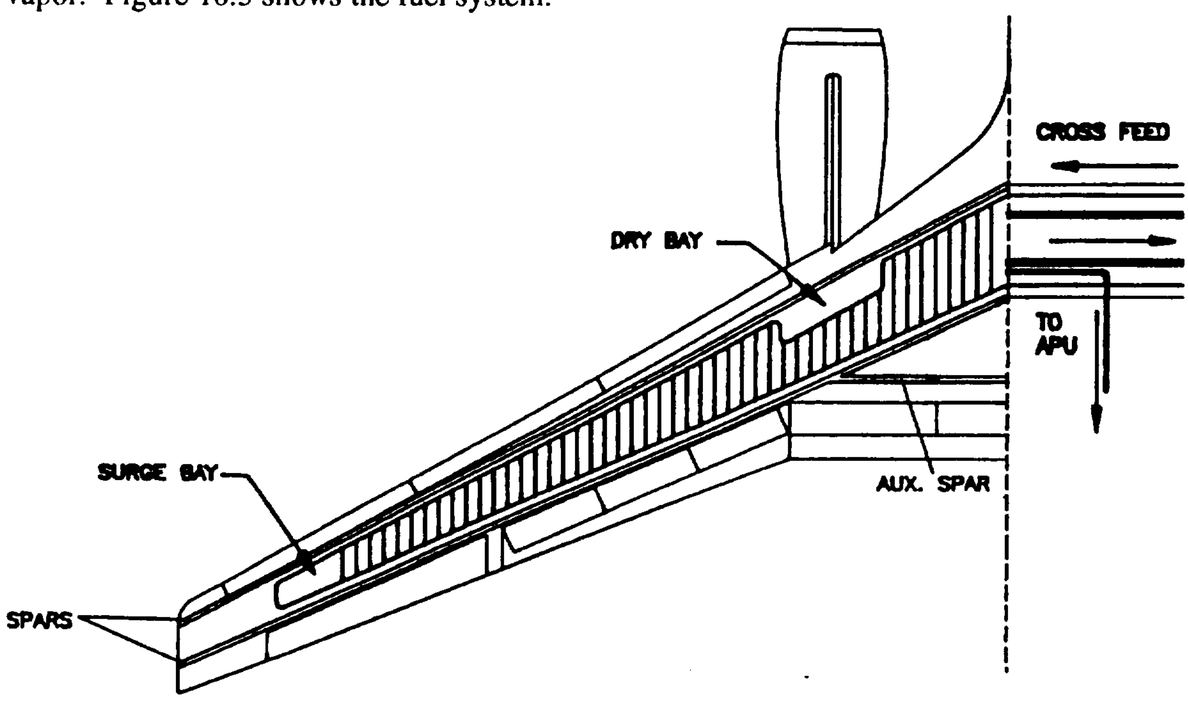


Figure 10.5. Eight-ball Express Integral Fuel System Schematic.

In the case of severe in flight failure or an emergency landing, the engine and landing gear mounts have been designed to separate from the aircraft without rupturing a fuel tank. The engines are isolated from the fuel tanks through the use of dry bays. The wet portion of the wing ends six feet short of each wing tip in order to meet FAR lightning strike requirements. A shrouded fuel line is used to deliver fuel to the APU from the left #1 main tank.

By using a two tank fuel system, fuel system components and associated plumbing are reduced resulting in a less complex system. Common vales and pumps are incorporated in both the left and right systems are also used to reduce cost. Most of the components such as valves and plumbing are located outside of the tank so that they may be removed without draining the fuel tanks.

11. LANDING GEAR

11.1 Layout And Loading

The landing gear of the Eightball Express was designed for low weight, reliability, and stability. A conventional tricycle type undercarriage was chosen because it provides a level aircraft on the ground which is desirable for loading and unloading as well as passenger comfort on the ground. The undercarriage was designed in accordance with FAR §25.471 - .511 and §25.721 - 735.[7] The landing gear was situated such the longitudinal tip-over and lateral tip-over angles of 15° and 55° were met.[12] Figure 11.1 shows the general arrangement of the gear and the tip-over requirements.

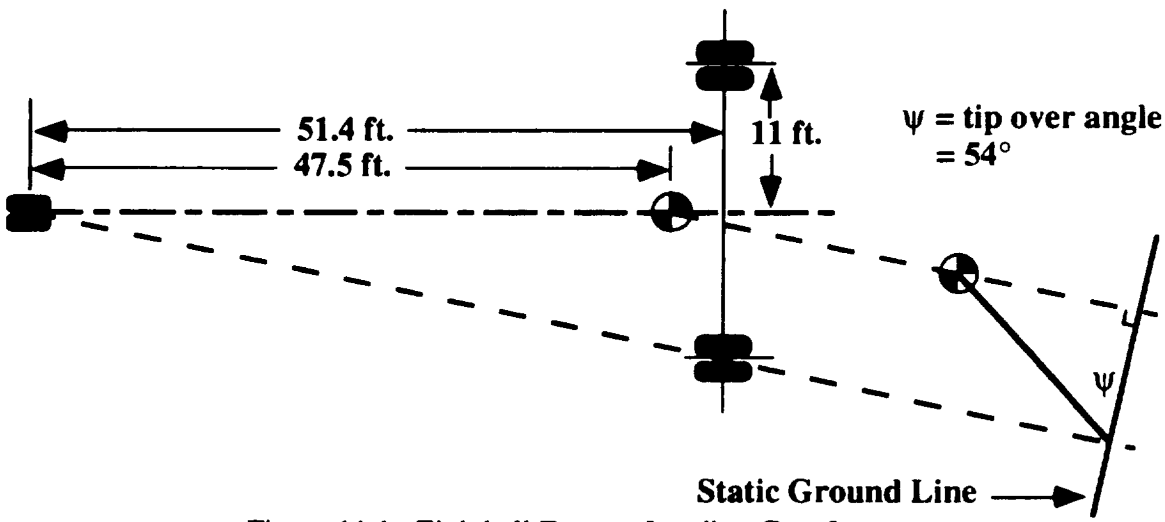


Figure 11.1. Eightball Express Landing Gear Layout

The figure shows the specific locations of the landing gear group. These locations in relation to the center of gravity determine the weight on each strut. The main gear will be carrying 74,800 lbs on each strut while the nose strut will be carrying 17,900 lbs. statically. Figure 2.3 shows the longitudinal tipover criteria. A summary of the landing gear geometry and loading can be seen in Table 11.1.

Table 11.1. Eightball Express Landing Gear Geometry and Loading

	Dist from nose (ft.)	Dist from cent (ft.)	Load/strut (lbs.)
Nose Gear	17.0	0	17854
Main Gear	68.4	11.0	74784

The weight percentage on the nose gear was ascertained to be within the 6 - 15% range to minimize structural weight of the nose while maintaining steerability.[12]

From the given strut loadings, the tires required were determined for both the nose and main gear. These were calculated using two nose gear tires and two main gear tires per strut as well as four tires per strut. A preliminary Aircraft Classification Number (ACN) calculation determined that four tires would not be required. The ACN classifies aircraft according to the loads placed on the runway by the aircraft which depend on the geometry of the undercarriage. This resulted in Type VII tires for both the nose and main gear. The tire data can be seen in Table 11.2. These tires are acceptable both for size considerations for retraction and pavement loading as will be shown later and for inflation pressure in that it is not overly high.

Table 11.2. Eightball Express Tire Data

	Outside Dia. (in)	Rim Dia. (in.)	Width (in.)	Load Rating (lbs)	Inflation Pressure (psi)
Nose Gear	34	14	16	38300	192
Main Gear	45.25	20	11	20500	192

A final ACN calculation was performed using the above tire data which produced values within current airport requirements based on current aircraft data found in reference 12. The ACN's were calculated using the Newflex2 computer program provided by McDonnell Douglas. The ACN's are shown in Table 11.3 for different CBR values.

Table 11.3. Eightball Express ACN Values

CBR	Required Runway Thickness (in.)	ACN
15.0	15.6	34.2
10.0	20.8	37.0
6.0	29.7	42.4
3.0	46.1	48.9

11.2 Steering

The steering of the Eightball Express on the ground is controlled by both pedal steering and a hand wheel. The pedals are used for take-off and landing corrections and can only provide about 5° of rotation of the nose wheel. The hand wheel is used for slow maneuvering such as on taxi ways and near the gate. The steering is controlled by two opposed linear actuators similar to the Boeing 727.[12] This mechanism is capable of approximately 78° of rotation from straight ahead. Using only 58° of steering, the Eightball Express has a turning radius of 43 ft. (see Figure 11.2). This will allow the aircraft to perform a 180° turn easily within a 150 ft. wide runway. Furthermore, the steering system on the nose gear is connected to a wheel spin-up sensor so that as soon as the nose gear leaves the ground, the steering system will center itself for retraction and the controllers are disconnected so that the wheel will not rotate in flight. When the gear touchdown again, the steering system is re-connected for steering control on the ground.

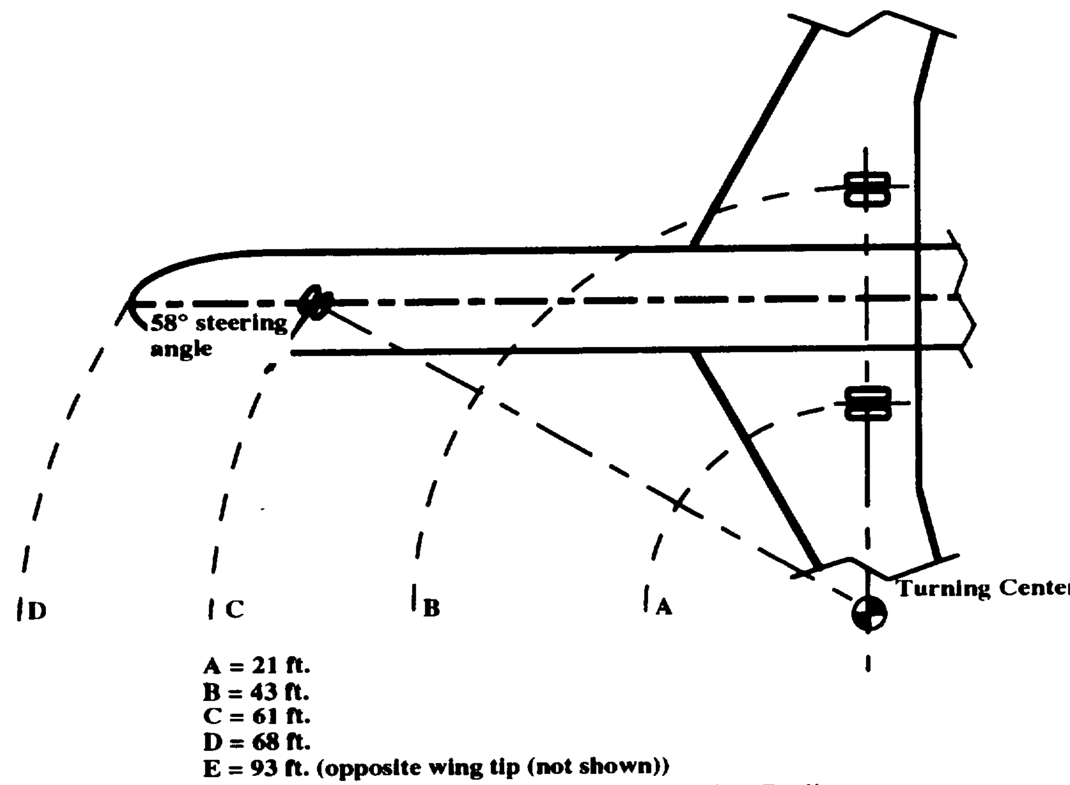


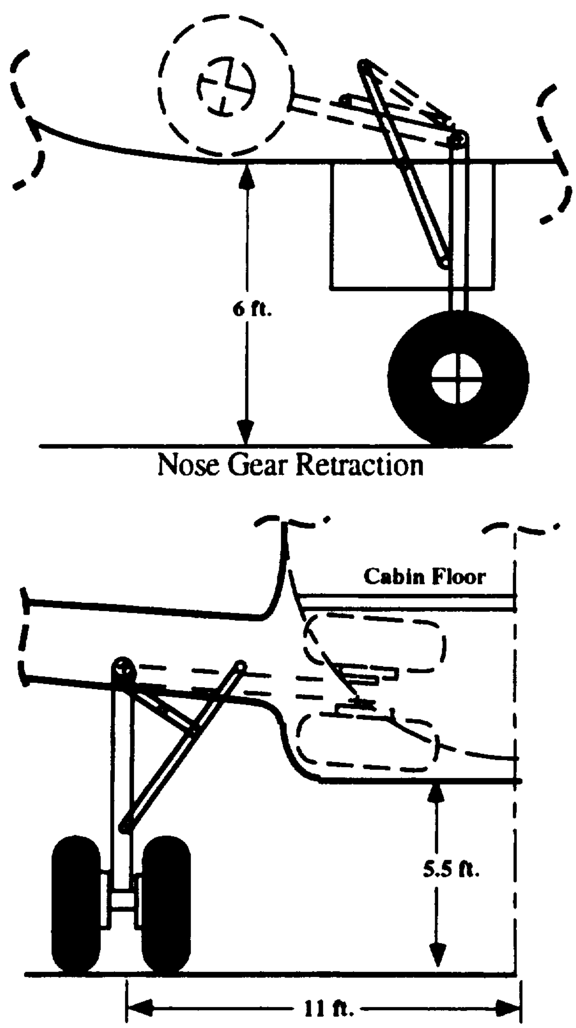
Figure 11.2. Eightball Express Turning Radius

11.3 Brakes

The Eightball Express will utilize carbon brakes as opposed to steel brakes. Carbon was chosen because of its higher thermal conductivity and better efficiency. Because carbon has a high thermal conductivity, the heat transfer occurs more rapidly and more uniformly through the entire brake disk stack than steel. Reference 12 cited that carbon brakes allow five to six times as many landings between brake refurbishment on the Concorde. The carbon brakes are also lighter, which either save fuel or allow more cargo weight.

11.4 Gear Retraction

The landing gear of the Eightball Express are hydraulically extended and retracted. When retracting, the left main gear retracts first, followed by the right main gear and finally the nose gear. A simple retraction diagram can be seen in Figure 11.3. The gear are capable of free-fall to the down and locked position should a hydraulic failure occur.



Nose Gear Retraction

Main Gear Retraction

Figure 11.3. Eightball Express Retraction Diagrams

12. MANUFACTURING

12.1 Manufacturing Philosophy

The Central Coast Designs (CCD) manufacturing philosophy is design-to-cost. The main goal is to make the assembly and parts simple, with minimal misalignment and interference. CCD is approaching this by using modular design, interactive computer design, and simplification of parts.

The modular design enables the final assembly to be carried out quickly. Modular design puts together the wings torque box and the fuselage quickly with minimal error. With modular design, CCD believes that final assembly time will be reduced 5% from the original time estimated without modular design.[26]

The CCD used a high powered three-dimensional, interactive computer in the design of the Eightball Express. This computer was connected to workstations all over CCDs' facilities. These workstations enabled engineers to design parts of the aircraft and then assemble these parts in a three-dimensional model that will place this part with the thousands of others in the aircraft.[10] This ability to see parts on the computer screen assembled enabled engineers to minimize the misalignment and interference problems that typically comes with final assembly of the aircraft.

The simplification of parts is a philosophy adopted by many of the large airframers of today.[26] The process is simply taking a part that has hundred separate subparts and designing it so it has 20% to 30% less subparts without reducing the efficiency of that final part. The design of these new subparts is limited to the parts that will make a return in investment within three to four years. The simplification of parts from one hundred to five will enable time and cost of construction to be significantly reduced.

12.2 Management Structure

Central Coast Design uses a Team Quality Management approach in its design and management of the company.[41] CCD philosophy is "Team Work". Engineers work with maintenance personnel, marketing works with the engineers, and engineers work with the cost division, to ensure that the Eightball Express is a quality product that the customer wants and that is competitive in today's market. Finally, CCD believes every employee is important and has a say in the final product. This structure is shown in Figure 12.1.

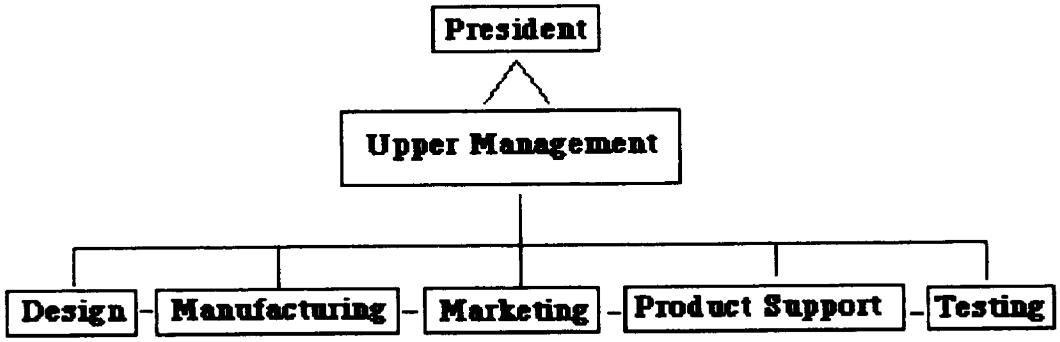


Figure 12.1 Management Structure

12.3 Manufacturing Facilities

The Eightball Express required minimal retooling of existing production assembly lines because of its conventional shape and aluminum structure. The conventional design required minimal retooling by using existing equipment in the manufacturing facility. Another way CCD saved costs was by subcontracting the parts that required retooling. The ailerons and other control surfaces of the aircraft were subcontracted with a composite manufacturing company. With this company CCD has a repair contract that repairs all ailerons and other control surfaces. This contract is offered to all airlines at the purchase of the Eightball Express but is not required for that purchase.

12.4 Production Schedule

The production schedule for the Eightball Express is shown in Figure 12.2. The schedule shows a total production run of 800 aircraft with 250 produced in a six year period. This assumption is from the production schedule of the Boeing 737.[40]

12.5 Production Assembly

The major aircraft assembly sequence of the Eightball Express was shown in Figure 12.3. The main assembly was done by Central Coast Designs. The aircraft's major sub-assemblies were subcontracted for possible labor savings. The assembly took place in the Central Coast Design main factory.

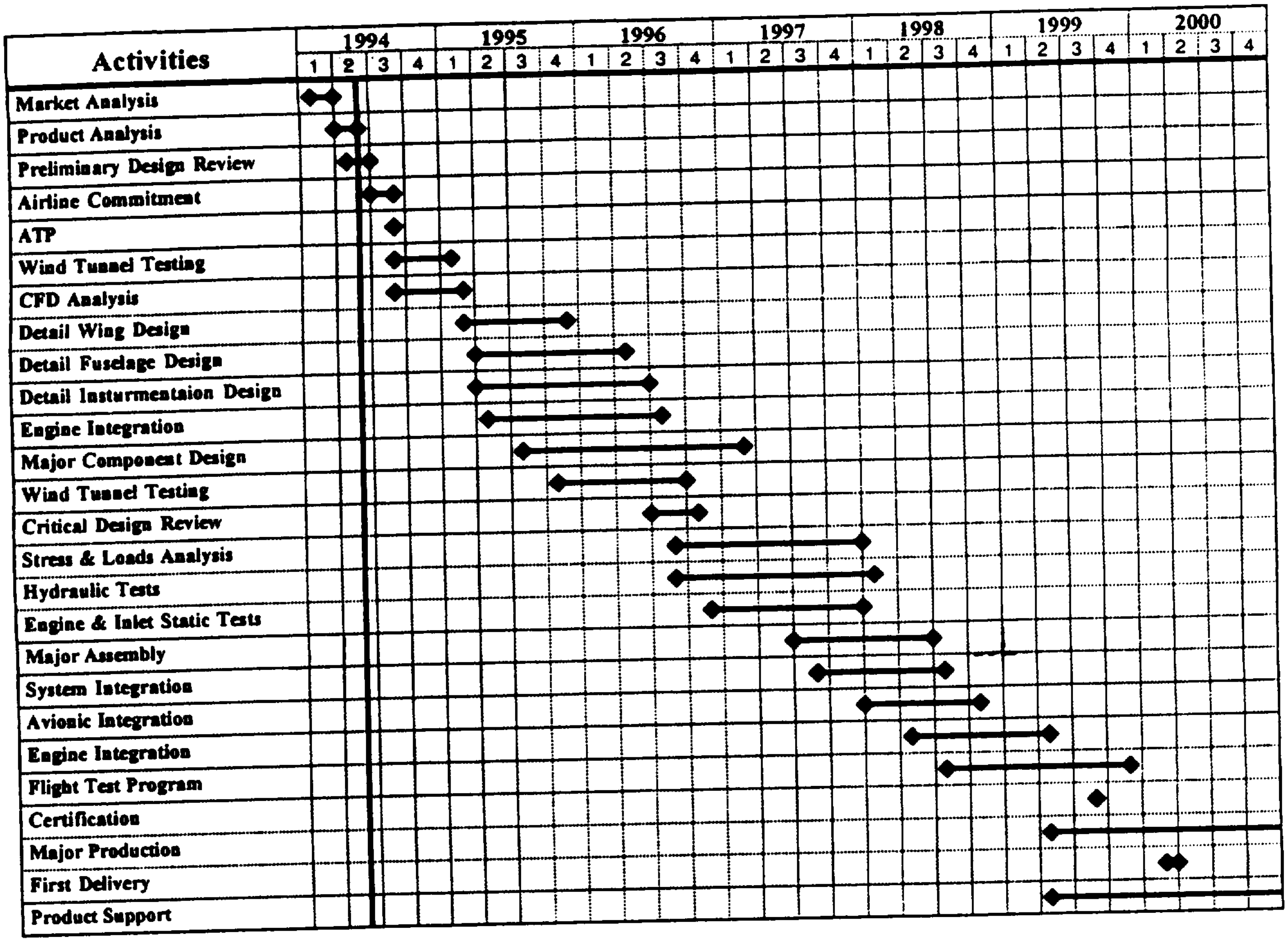


Figure 12.2. Eightball Express Production Schedule

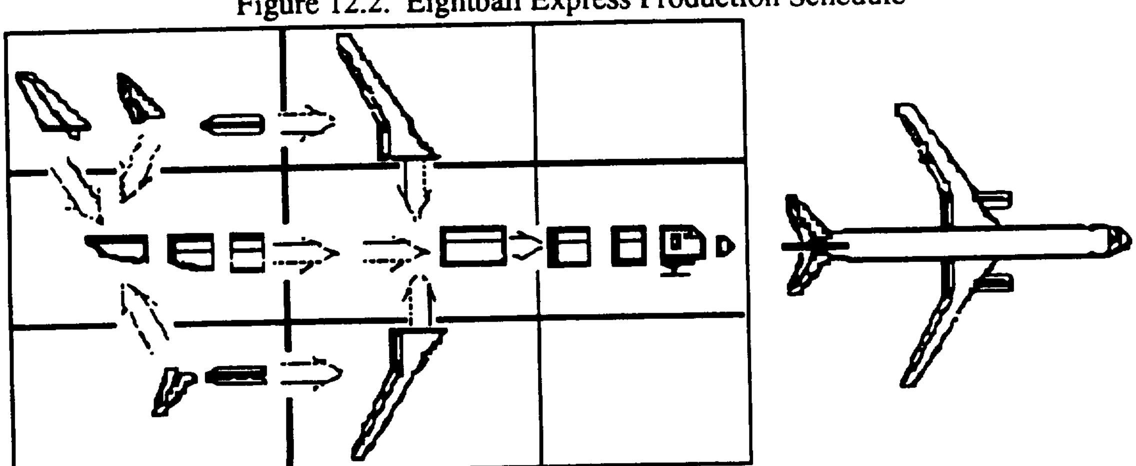


Figure 12.3. Eightball Express Assembly

12.6 Environmental Considerations

The environmental impact of manufacturing the Eightball Express have been considered by CCD. The usage of a primarily aluminum body instead of composites or aluminum lithium gave the Eightball Express a cleaner manufacturing process. CCD is also using new paints and painting processes that reduce the solvent and particulate emissions from aircraft painting by approximately 50%.[10] The environmental impact of the manufacturing of the Eightball Express has been lowered by these manufacturing processes.

CCD is a company looking towards the future and the environment is a big part of that future. We use recycling policies in all levels of the company to lower waste. We also use recycled paper in all the offices. In addition, there is a ride-share program for all employees. CCD continues to look for new ways to improve the environmental impact of its operations.

13. AIRPORT OPERATION AND MAINTENANCE

13.1 Airport Requirements

The Eightball Express meets the pavement loading, noise control, ground support, and gate access requirements for all major airports. There will be no need to purchase extra equipment for the Eightball Express because existing equipment can be used. Examples of this equipment are the gate access and the ground support vehicles.[36] All access vehicles can approach the Eightball Express without waiting for a turn, as can be seen in Figure 13.1.[36] Furthermore, the fueling of the Eightball Express can be accomplished through a single point system with the receptacle located on the right wing. This positioning maintains safe clearance between the fueling truck and all other operations going on around the aircraft.

13.2 Turnaround Time

Design features that helped speed ground servicing are the centrally located lavatories and good planning of servicing access. Galley crews can enter from the rear and front port doors immediately after engine shutdown. Refueling, water and lavatory servicing can be completed concurrently with the cleaning of the cabin. These factors make the Eightball Express have a faster turnaround time.

13.3 Maintenance

The main goal of the Eightball Express was low cost The maintenance cost was a major component of this concept. Special attention has been made to reduce maintenance man-hours associated with the engine. In older designs, engine services such as fuel and hydraulic lines passed through the strut structure. In the Eightball Express design, all services come down the top of the strut. The services can be disconnected where they come into the nacelle at a single disconnect point that is easily accessible when the nacelle is open. Other design ideas will be explored in the future in order to reduce the time for most major maintenance tasks such as engine replacements to under six hours.

C-2.

The wings, empennage, and fuselage have been made to reduce maintenance cost. All service doors are easily accessible with either ground access or service ladder access. The systems and components which need servicing more frequently are located to provide easier access.

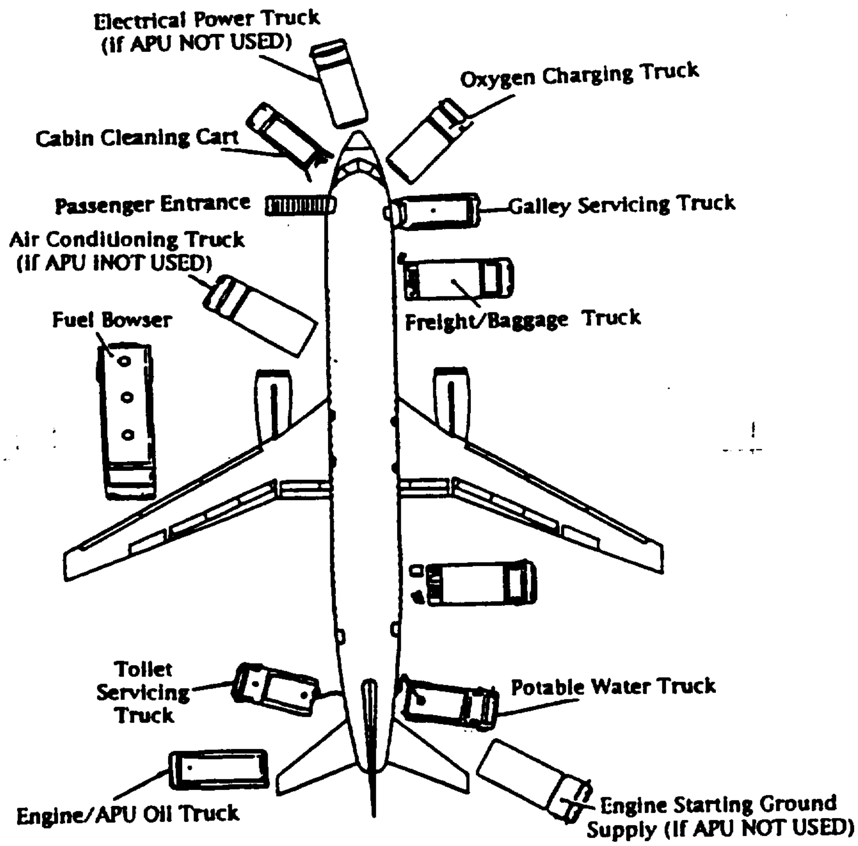


Figure 13.1. Eightball Express Ground Operations

13.4 Maintenance Schedule

The Eightball Express maintenance schedule was designed to minimize cost and time. The maintenance schedule has the following checklists which explain when a maintenance should occur and how often they should occur. It was broken down into the following:[45]

- 1-Service Performed whenever a flight passes through or terminates at a station approved for this work unless higher level of service or check is performed.

- 2-Service Performed at a time in service not exceed 45 hours since completion of last Number 2-Service.
- A-Check Performed at a time in service not to exceed 350 hours since completion of last A-Check.
- C-Check Performed after an interval not to exceed 456 days or 3000 hours, whichever comes first, since completion of last C-Check.
- HMV Performed after an interval not to exceed 1460 days since completion of last HMV (Heavy Maintenance Visit).

This breakdown will help ease the load of the service technicians and make the maintenance of the Eightball Express less time consuming. Tables 13.1 and 13.2 are abbreviated task lists, which show briefly what is needed to be done on the Eightball Express for maintenance. The A-Check list, C-Check list, and the HMV lists were not added due to their length.

Table 13.1. Eightball Express #1 Service Task List (Abbreviated)

Task	Man-hours Required
Visual Inspection of Fuselage from the ground	.17
Visual Inspection of Wing from the ground	.01
Visual Inspection of Fuselage Doors from the ground	.01
Visual Inspection of the entire Aircraft from the ground	.01
Accomplish a Flight Log Review	.01
Various other checks not mentioned in Abbreviated schedule	.32
Routine MH/VISIT	**.54**
Cycle Time	**.54**

Table 13.2. Eightball Express #2 Service Task List (Abbreviated)

Task	Man-hours
OP Test Emergency Generation System	0.51
General Visual Inspection of Main Landing Gear	0.06
General Visual Inspection of Nose Gear Well and MG	0.10
Cargo Pit Lining and Debris Check	0.10
Cockpit check/service	0.05
Drain Water From Fuel Tanks Sumps	0.30
Exterior Light Check	0.05
Various other checks not mentioned in Abbreviated schedule	1.93
Routine MH/VISIT	**3.10**
Cycle Time	**3.00**

Source: United Airlines

14. COST ANALYSIS

The Eightball Express meets the RFP as a low cost commercial transport. It meets the requirements with a low cost in research, development, testing, evaluation, tooling, manufacturing, and a competitive DOC. This cost analysis was done in 1992 U.S. dollars. One of the reasons that the Eightball Express is a low cost transport is its purely aluminum primary structure which lowers the cost of tooling, manufacturing and maintenance of the aircraft. The cargo capability of the Eightball Express allows the aircraft to add additional revenue for the airline that purchases it which lowers the aircraft's operational cost. The aircraft is low cost also because it has efficient engines with a low specific fuel consumption. The engines are very reliable which lowers fuel cost and maintenance cost (see Engine data).

The method used to perform the cost analysis for the Eightball Express is shown in reference 40. The numbers generated were compared with existing data of similar aircraft to ensure that the numbers were reasonable. Results were given in the following three categories of Life Cycle Cost:[40]

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

The Research, Development, Test, and Evaluation (RDTE) showed that the flight test airplanes were the greatest cost in the RDTE. The airframe engineering and design, which was the second highest cost in RDTE, was lowered by using a completely aluminum aircraft. To lower cost, an integrated design system was used that would connect all factors of design and engineering on the same main frame computer which enables the engineers and designers to see how the design and problems of each portion of the aircraft would affect the rest of the aircraft engineers and designers. This is shown in Figure 14.1.

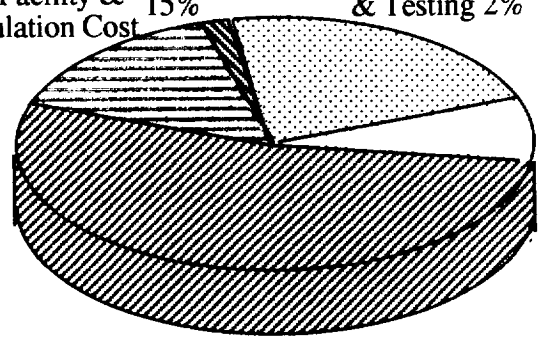


Figure 14.1 Eightball Express Cost of RDTE

The purchase cost was low in comparison to the other aircraft in its class this is shown in Table 14.1. The main reason for its competitiveness was the fully aluminum airframe and the use of common technology. The disposal cost was difficult to influence. However, in order to lower the disposal cost, the aircraft has a longer life.

Table 14.1. Eightball Express Purchase Cost Comparison in 1992 U.S. dollars

Eightball Express	$ 28-30 million
MD-90	$ 36-40 million
737-400	$ 35-39 million
A320-2000	$ 38-42 million

The operating cost was based on the entire life of the aircraft. The assumption was that the Eightball Express will last 20 years.[17] This is from the assumption that the aircraft has better quality parts. The operating cost includes the Direct Operating Cost and the Indirect Operating Cost. These subjects will be looked at in further depth at a later time. The total operating cost broken down into DOC and IOC is shown in Table 14.2.

Table 14.2. Eightball Express Operating Cost in 1992 U.S. dollars

IOC TOTAL	2.96 $/NM
DOC TOTAL	5.38 $/NM
DOC	3.51 ¢/ASM
TOC TOTAL	8.34 $/NM

($/NM = cost per nautical mile, ¢/ASM = cost per seat nautical mile)

The life cycle cost analysis uses 1992 dollars as a baseline so that a dollar comparison to other aircraft can be made. Assumptions for this analysis were a production of 800 aircraft with a 20 year life cycle before the aircraft is considered for disposal.[39] The breakdown of the Life Cycle Cost and the percentages of this breakdown are shown Table 14.3 and Figure 14.2.

Table 14.3. Eightball Express Life Cycle Cost Breakdown in US dollars Base Year 1992

Disposal Cost	$	3,750,000
Operating cost	$	204,000,000
RDTE	$	2,500,000
Purchase Cost	$	28,000,000

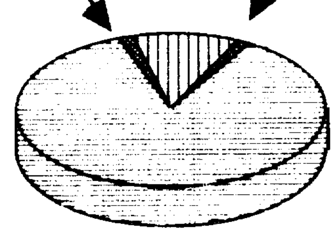


Figure 14.2. Eightball Express Life Cycle Cost Breakdown

Both Table 14.3 and Figure 14.2 show that the operational cost was a large portion of the life cycle cost. The main factor that greatly influences life cycle costs was the number of aircraft produced. For the Eightball Express, a production run of 800 aircraft was envisioned, The production run of 800 aircraft seems large but is justifiable. The fleet of Boeing 737-100's and 737-200's is already close to 20 years old, which is the age when airlines typically phase those aircraft out of service. Currently, these aircraft only meet Stage II noise requirements and it would not be economical to upgrade such old airframes to meet Stage III or, in the near future, Stage IV requirements.[3] The Stage III requirements will be 15 years old when the Eightball Express goes into service in the year 2000. The airlines are faced with a decision of refitting 15 year old or older airframes or purchasing a new aircraft that will easily meet the future requirements of Stage IV. The cost of the refitting versus the buying of a new aircraft will be an easy decision. The Eightball

Express has better fuel efficiency and meets all the requirements without having to take the aircraft out of commission for several months for the refitting.

14.1 Operational Cost

The total aircraft operational cost was broken down into direct and indirect operating cost. Direct operating cost (DOC) can be broken down into several categories. These categories are Flying Costs, Maintenance Costs, and Depreciation Costs.

One of the assumptions that was used for this calculation was a difficulty factor of production of 1. The difficulty factor was a factor used in Cost Analysis to determine the difficulty of the manufacturing and tooling of the particular aircraft. A difficulty factor of 1 corresponds to the simplest aircraft for manufacturing (i.e., conventional aircraft), while 2 and 3 correspond to a non-conventional aircraft, such as one with a full composite structure.[40] The prices of fuel and oil per gallon are $0.52 and $6.0, respectively, in 1992.[17] The component breakdown of the DOC was shown in Table 14.4 while Figure 14.3 shows the percentage breakdown, in 1992 dollars.

Table 14.4. Eightball Express DOC
Dollars per Nautical Mile

FLIGHT	1.94 $/NM
MAINTENANCE	1.72 $/NM
DEPRECIATION	1.34 $/NM
LANDING	0.10 $/NM
FINANCE	0.27 $/NM
TOTAL	5.38 $/NM

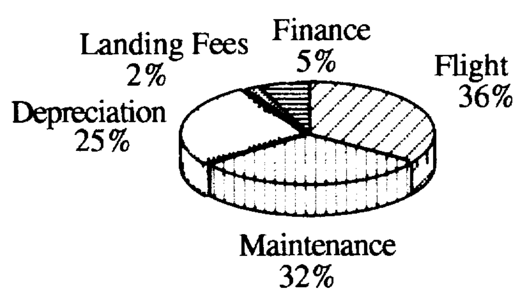


Figure 14.3. Eightball Express Total DOC

Figure 14.3 shows that the main influence in the DOC was maintenance and flight. The maintenance includes airframe, engines, and maintenance overhead which was called "burden." The flight cost includes the cost of crew, fuel and oil. The IOC was mainly influenced by the airline that purchases the aircraft. Providing for passenger services (meals, cabin attendants, baggage handling, etc.), maintenance of ground equipment and facilities, aircraft and traffic servicing, promotional and entertainment activities, and administrative costs result in the IOC.[17] This varies so greatly between one airline to another that it was not approached in this analysis.

The Eightball Express compares very well with the aircraft of today, beating most aircraft in its class and beyond. Because of this, the Eightball Express will be drawing business away from the competition, and when these aircraft become 15 years old and older, the Eightball Express will sweep the competition. Table 14.5 and Figure 14.4 show that the Eightball Express is very competitive in the market, the comparison is in DOC per available seat mile.

Table 14.5. Direct Operating Cost
US Domestic Rules, 1000 nm range 1992 U.S. dollars

Eightball Express	4.41 ¢/ASM
737-1/200	4.67 ¢/ASM
737-300	4.45 ¢/ASM
767-200	4.345 ¢/ASM
757-200	4.18 ¢/ASM

Source: Boeing Analysis

The previous table and following figure was given for 1000 nm which was a third of the distance given in the RFP which was what the Eightball Express was designed to cruise for.[46] There were assumptions for this table that the fuel used was lower and therefore the weight takeoff was lower. This table also uses of the Per Seat Price versus the Per Trip Price and basing this on the Eightball Express's Per Seat Price and the Per Trip Pice and showing the difference in Percentages. This table also used 1992 US dollars. Finally the DOC versus Range was plotted in Figure 14.5 and shows that the Eightball Express is more efficient when cruising for a longer mission range. The DOC of this figure was calculated by using different ranges while changing the weight of fuel used which would show that the Eightball Express would have better DOC for lower ranges.

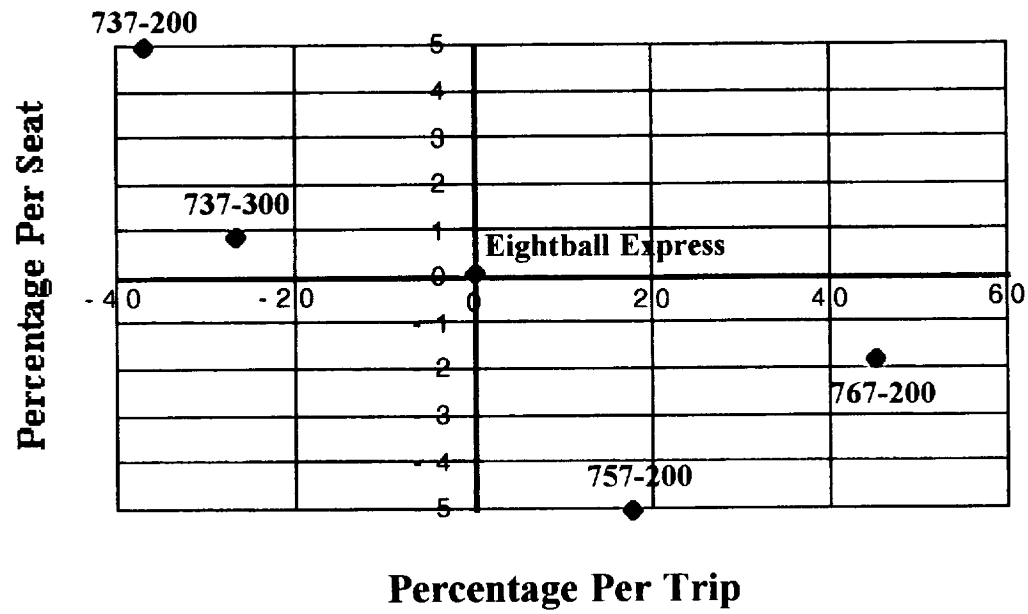


Figure 14.4: DOC for Various Aircraft
Source: Boeing Analysis

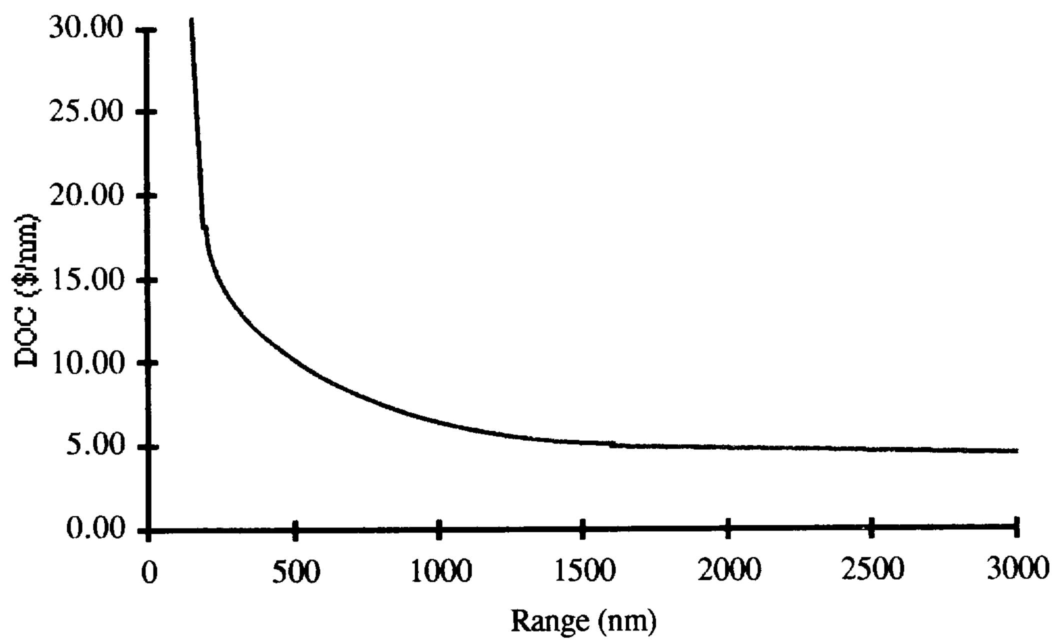


Figure 14.5. Eightball Express DOC vs. Range

15. CONCLUSIONS AND RECOMMENDATIONS

Central Coast Designs feels that the Eightball Express is the answer to the RFP requirement of a low cost commercial transport. Through the use of concurrent engineering and digital design a low cost transport has been designed with the most cost saving features such as low manufacturing cost and fuel consumption. In order to reduce the cost of today's aircraft, airframer must be able to manufacture aircraft in the most efficient way possible, which is exactly how the Eightball Express will be built. The aircraft which are built must be more efficient than aircraft of the past both in the air and on the ground. The Eightball Express has excellent fuel consumption in the air and very efficient maintenance operations on the ground. By designing the aircraft for the airlines who are the ultimate users, the maintenance and operation cost of the aircraft will be less than other aircraft because it is easier to maintain.

The primary use of aluminum throughout the aircraft lowers both the cost of manufacture and maintenance since composite materials are difficult to repair and require costly materials to be kept in stock. Since Central Coast Designs is a fledgling company, this is the best way to lower costs. However, in the future, composite material will be considered as an upgrade option should manufacturing and repair procedures become less expensive and standardized.

A helpful recommendation to modify the RFP in order to reduce cost is to relax the restriction on the takeoff field length. Currently, the takeoff field length mandated by the RFP is at 7000ft. It is the contention of the CCD that this requirement should be laxed. Presently, the existing runways at majority of the airports operating such aircraft are at approximately 11000ft. Furthermore, the decision to operate the aircraft at certain conditions is the choice of the airlines themselves. CCD believes that such easing of restriction on the takeoff field length will enable the customer to purchase the aircraft at a lower acquisition cost. Figure 15.1 demonstrates the mony saving capability of the Eighball Express. As the takeoff field length is increased, the thrust requirement for the takeoff roll is decreased to a point where at 8000ft takeoff field length, an estimated savings in powerplant price of $1.16 million is attainable.

The Eightball Express is clearly the choice for the airlines. As the profit margin for the airlines becomes smaller, they must put greater emphasis on reducing overhead and operational cost. The lower purchase price of the Eightball Express offered by the CCD team is a great incentive for the airlines to use this aircraft for their future upgrades and additions to their fleets. Furthermore, the Eightball Express is an extremely versatile aircraft which is competitive in the shorter domestic routes as well as the international segment.

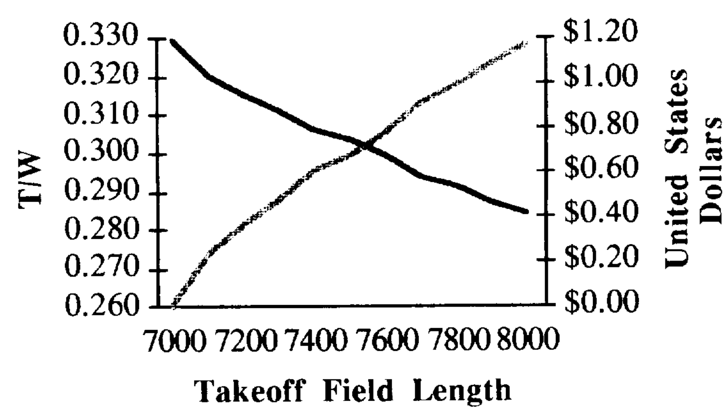


Figure 15.1. Eightball Express Reduction in Acquisition Cost with Increased Take-off Field Length

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1993/1994
AIAA/LOCKHEED CORPORATION
Undergraduate Team Aircraft Design Competition

Release 6/4/93

I. RULES

1. All groups of three to ten ***undergraduate*** AIAA branch or at-large Student Members are eligible and encouraged to participate.

2. ***Five copies*** of the design will be submitted; each must bear the signatures, names and student numbers of the project leader and the AIAA Student Members who are participating. Designs that are submitted must be the work of the students, but guidance may come from the Faculty Advisor and should be accurately referenced and acknowledged.

3. *Design projects that are used as part of organized classroom requirement are eligible and encouraged for competition.*

4. The prizes shall be: First place-$1,000; Second place-$500; Third place-$250; with the awards for the students submitting the winning designs. Certificates will be presented to the winning design team for display at their university and a certificate will also be presented to each team member and the faculty project advisor.

5. More than one design may be submitted from student groups at any one school. Projects should be ***no more than 100 double-spaced typewritten pages*** (including graphs, drawings, photographs, and appendix) on 8.5" x 11.0" paper. Up to five of the 100 pages may be foldouts (11" x 22" max).

6. If a design group withdraws their project from the competition, the team chairman must notify the AIAA National Office immediately!

II. SCHEDULE AND ACTIVITY SEQUENCES

Significant activities, dates and addresses for submission of proposal and related materials are as follows:

A. Letter of Intent — March 14, 1994
B. Receipt of Proposal — June 6, 1994
C. Announcement of Winners — September 12, 1994

Groups intending to submit a proposal must submit a letter of intent (Item A), with a maximum length of one page to be received with the attached form on or before the date specified above, at the following address:

Mr. Patrick Gouhin
AIAA Student Programs, 10th Floor
370 L'Enfant Promenade S.W.
Washington, D.C. 20024-2518

The finished proposal must be submitted (postmarked) to the same address, on or before the date specified for the Receipt of Proposal (Item B).

III. PROPOSAL REQUIREMENTS

The technical proposal is the most important factor in the award of a contract. It should be specific and complete. While it is realized that all of the technical factors cannot be included in advance, the following should be included and keyed accordingly:

1. Demonstrate a thorough understanding of the Request for Proposal (RFP) requirements.

2. Describe the proposed technical approaches to comply with each of the requirements specified in the RFP, including phasing of tasks. Legibility, clarity, and completeness of the technical approach are primary factors in evaluation of the proposals.

3. Particular emphasis should be directed at identification of critical, technical problem areas. Descriptions, sketches, drawings, systems analysis, method of attack, and discussions of new techniques should be presented in sufficient detail to permit engineering evaluation of the proposal. Exceptions to proposed technical requirements should be identified and explained.

4. Include tradeoff studies performed to arrive at the final design.

5. Provide a description of automated design tools used to develop the design.

IV. BASIS FOR JUDGING

1. *Technical Content (35 points)*

This concerns the correctness of theory, validity of reasoning used, apparent understanding and grasp of the subject, etc. Are all major factors considered and a reasonably accurate evaluation of these factors presented?

2. *Organization and Presentation (20 points)*

The description of the design as an instrument of communication is a strong factor on judging. Organization of written design, clarity, and inclusion of pertinent information are major factors.

3. *Originality (20 points)*

If possible, the design proposal should avoid standard textbook inforıtion, and should show the independence of thinking or a fresh proach to the project. Does the method and treatment of the problem ɔw imagination? Does the method show an adaptation or creation automated design tools.

Practical Application and Feasibility (25 points)

e proposal should present conclusions or recommendations that are ısible and practical, and not merely lead the evaluators into further ficult or insolvable problems.

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esign Objectives and Requirements

EQUEST FOR PROPOSAL:

Low Cost Commercial Transport

OPPORTUNITY DESCRIPTION

l the major airlines continue to face financial difficulties due to npetition brought on by deregulation. Deregulation has caused the ines to offer increasing low fares in order to maintain market share many lucrative domestic routes. The low fares result in costs ceeding revenues and lead to unprofitable operations almost across board. Indeed, several of the major carriers are currently operating ler provisions of Chapter 11 bankruptcy laws, while several others ve actually ceased operations. The implications to the aerospace lustry are immense. Without profits, the airlines have difficulty esting in new aircraft, which affects all segments of the aerospace ıustry. This affects development of new aircraft. Noting that nsport aircraft exports make up a large portion o f the total goods orted, they make a significant impact in the balance of trade for the ;.

is problem is not unique to the current economics. A similar ıation existed in the mid 1930's when airlines were subsidized by government for carrying mail in addition to paying passengers. hile the problem was slightly different, the result was that the airlines ıld not make a profit solely from carrying passengers. The intro- ction of the DC-2/3 changed that by incorporating advanced tech- logy of the day to enable the airlines to carry enough passengers, at easonable price, to offset the operating costs.

lay, the competition for passengers will keep ticket prices low. The lines must reduce operation costs in order to be profitable. The time s come to incorporate emerging technologies to develop a modern y DC-3 that reduces the operating costs to a point that allows the lines to operate profitably.

. PROJECT OBJECTIVE

ıe objective of the project is to design a domestic commercial nsport aircraft that will significantly reduce direct operating costs OC) for the airlines, while meeting current and proposed FAR for s type of aircraft. The project should identify the major operating st drivers on current aircraft in use on the majority of domestic routes l identify technology options to incorporate that reduce these costs. ıerging technology should be considered but technology maturity, k and implementation practicality must be assessed in the design ɔcess. Finally, a comparison of the operating costs of the new design that of a current technology transport will demonstrate the design's fectiveness.

III. REQUIREMENTS AND CONSTRAINTS

The design shall be of a commercial transport aircraft for use on domestic routes. It shall conform to all applicable FAR for this type of aircraft.

All performance requirements shall be standard day and atmosphere unless noted otherwise. Technology availability date is 2000.

Design Mission Profile

1. Warm up and taxi for 15 min., SL, ISA + 27° day.
2. Take off within a FAA field length of 7000 ft, SL, ISA + 27° day with full passenger and baggage load.
3. Climb at best rate of climb to best cruising altitude.
4. Cruise at .99 Vbr for 3000 nmi. (M>.7)
5. Descend (no credit for range) to SL.
6. Land, with domestic fuel reserves, within a FAA landing field length of 5000 feet.
7. Taxi to gate for 10 minutes.

Special Design Requirements

1. Passenger capacity—mixed class, 153.
2. Weight of each passenger and baggage—200 lbs.
3. Design shall meet proposed noise regulations.
4. Overhead stowage space shall be provided.
5. Front and rear galleys required.

IV. DATA REQUIREMENTS

The final proposal, based on the previously stated objectives, requirements and constraints, should include sections and data on the following:

1. Identify the major direct operating cost drivers of the current fleet of domestic commercial transport aircraft. Based on these results, identify candidate technologies/design concepts that could potentially reduce the impact of the major direct operating cost drivers. Identification must include an assessment of technology maturity, risk, and implementation practicality and any assumptions made.
2. Justify the final design that uses some or all of the technologies previously identified. Describe why the configuration was selected. Present results of design tradeoffs, and criteria used for selection of technologies and other design options. Show carpet plots used to optimize the final selected design.
3. Include a dimensional 3-view general arrangement drawing.
4. Include an inboard profile showing the general internal

rangement.

Include an illustrated description of the primary load bearing rframe structure and state rational for material selection.

Show an estimated drag build up for both cruise and landing nfigurations.

Show a weight breakdown of major components and systems, d location of center of gravity.

Provide performance estimates and demonstrate aircraft ability for all flight and loading conditions.

Estimate the direct operating costs of the new design and mpare these with the current fleet average to demonstrate the impact advanced technology. Assume fuel costs remain constant in 1992 llars.

'. ENGINE DATA

aseline high bypass ratio turbofan engine data is available upon quest by contacting:

Mr. Patrick Gouhin
AIAA Student Programs
370 L'Enfant Promenade, SW
Washington, DC 20024-2518

udents are encouraged to investigate other developing propulsion chnology with potential for availability by the technology date for e in the design. If other propulsion technology or propulsion systems e used, the system characteristics must be provided.