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FOWL ENTERPRISES

LCX

Proposal for a Low-Cost Commercial Transport

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ABSTRACT

The LCX has been developed in response to a request for proposal for an aircraft with 153 passenger capacity and a range of 3000 nautical miles. The goals of the LCX are to provide an aircraft which will achieve the stated mission requirements at the lowest cost possible, both for the manufacturer and the operator. Low cost in this request is defined as short and long term profitability. To achieve this objective, modern technologies attributing to low-cost operation without greatly increasing the cost of manufacturing were employed. These technologies include hybrid laminar flow control and the use of developing new manufacturing processes and philosophies. The LCX will provide a competitive alternative to the use of the Airbus A319/320/321 and the Boeing 737 series of aircraft. The LCX has a maximum weight of 150,000 lb. carried by a wing of 1140 ft^2 and an aspect ratio of 10. The selling price of the LCX is 31 million in 1994 US dollars.

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NOMENCLATURE

C_D	Drag Coefficient
C_L	Lift Coefficient
PAX	Passengers and Baggage
SFC	Specific Fuel Consumption
V-n	Velocity Load Factor
LCX	Liquid Chicken Express
nm.	Nautical Miles
lb.	Pounds
HLFC	Hybrid Laminar Flow Control
ETOPS	Extended Twin Operations
sfc	Specific Fuel Consumption
c.g.	Center of Gravity
FAR	Federal Aviation Rules
(T/W)	Thrust to Weight Ratio
(W/S)	Thrust to Weight Ratio
Cl	Coefficient of Lift
Cd	Coefficient of Drag
HP	Horse Power
ECU	Enviromental Control Unit
EDP	Engine Driven Pump
PTU	Power Transfer Unit
RAT	Ram Air Turbine
AC	Alternating Current
DC	Direct Current
APU	Auxillary Power Unit
IDG	Integrated Drive Generators
HMG	Hydraulic Motor Generator

1.0 INTRODUCTION

1.1 Purpose of Proposed Design

Currently, the airline industry is struggling through one of the most difficult periods in history due to the market competition brought on by a current recession, rising fuel prices, and the deregulation act of 1979. This deregulation lifted all restrictions on fares and allowed intensified pricing competition between airlines. In order to continue to make profits from the low fares and reduced income, the airline industry is forced to cut operational and service costs of their fleets. One of the many methods being tried by the airlines to lower operational costs is to reduce the use of some hubs they are currently operating. The LCX will facilitate this transition by allowing the airlines to move moderate amounts of people over a medium range in an economically efficient manner.

Traditionally the airlines have not found it economically practical to consistently fly 150 passengers 3000 nm. in the US domestic market. Instead of direct transportation of passengers from a medium market locale to their destination, airlines route these passengers to large city hub airports via regional carriers. Passengers are then carried to other large hubs via wide-body aircraft for mass transportation at low cost. With the LCX, airlines will be able to connect more secondary airports with direct flights where wide-body jets are unable to service due to size restrictions. The LCX can compete as a midsize medium range carrier because it has reduced fuel burn (approximately 14%) during cruise reducing its trip cost. The fuel savings comes from incorporating Hybrid

Laminar Flow Control (HLFC) technology. HLFC lowers the parasite drag over the wing and thus the fuel burn required.

Another use of the LCX is its utilization as a replacement on normal widebody routes when they can not be filled. Examples would be during early morning and late night flights and during the slow travel periods of the year. The LCX will be able to accomplish the mission with a lower trip cost than a widebody aircraft. The low per passenger seat mile cost of the widebody is only effective when the aircraft is filled to at least half capacity with passengers.

1.2 Investigation of Similar Aircraft

In comparing the LCX to other aircraft, two aircraft were found to be capable of meeting the requirements of the RFP with minor revisions. These two aircraft are the Airbus A320/A321 and the Boeing 737. Although the maximum capabilities of these aircraft are similar to that of the LCX, they are designed for optimum operating ranges at much shorter distances than the LCX. This is one of the major capabilities that sets the LCX apart from its competition. The A320 and Boeing 737 must reduce passenger load to achieve the range the LCX is capable of with a full load of passengers and bags.

One of the most recent additions to short-medium range class of aircraft is the Airbus A320 series of aircraft. The A320 uses advanced technologies such as composite materials, fly-by-wire flight control systems, and computer central monitoring of all systems and functions. The A320 uses either CFM-56 or IAE V2500 series turbofan engines. The A320 has a maximum takeoff weight of 158,000 pounds with a range of 2,600 miles at an altitude of 37,000 feet.

The Boeing Company, based in Seattle, Washington, is the manufacturer of the second aircraft researched concurrently with the preliminary design of the LCX: the 737. Boeing has sold more 737's than any other civilian commercial transport aircraft type in the history of aviation. Powered by CFM56 engines, the 737 has become the fleet mainstay of carriers such as Southwest Airlines. The 737 is available in 3 versions: the -300, -400, and -500. Boeing has now launched new versions of the 737 called the 737-X, a new generation of 737 capable of meeting the current design RFP. The LCX was designed to out perform the 737-X at ranges larger then 1000 nm. The current version 737-300 has a maximum take-off weight of 135,000 pounds with a range of 2,350 miles at 35,000 feet.

1.3 Design Requirements of the LCX

The LCX is designed to meet all proposed requirements and enable the airline industry to carry 153 passengers with a profit at medium range. Using technologies available by the year 2000, the proposed aircraft has to accomplish this at low cost. A summary of the given requirements follows and the complete requirements are provided in Appendix A.

-Warm up and taxi for 15 min., SL,ISA+27° day

- Take-off within a field length of 7000 ft

- Climb at best rate of climb to best cruising altitude at best altitude

- Cruise at 0.99Vbr

- Land, with domestic fuel reserves, within a landing field of 5000 ft

- Taxi to gate for 10 minutes

After reviewing the RFP, Fowl Enterprises concluded that two approaches are possible;

(1) A lightweight, simple aircraft that would be very economical at short range, or

(2) A very efficient aircraft that could operate effective at short range, but would provide outstanding economics at longer ranges.

There are numerous aircraft competing in the short range market, therefore it was decided to design for the longer range market niche.

2.0 CONCEPT EVOLUTION

2.1 Final Design Shape and Concept Philosophy

The final basic design of the LCX can be found in Figure 2.1.1 on the following page. This figure displays the outer design parameters and basic geometry of the LCX. As can be seen, the aircraft is very conventional in its basic layout. The basic design layout of the aircraft available in today's market is the result of an evolutionary process which is based upon a tremendous amount of work and experience. This evolution has refined the design to the point that it provides near optimum performance. For this reason the LCX in most respects was designed as a similar aircraft to this optimum configuration. Of all the other configurations studied, none presented any significant improvements over what is currently being used. There may be opportunities in the future, through technological improvements in materials or manufacturing techniques, to radically change the design from the current basic shape. Other improvements may come in engine performance and further electronic control and can be applied to the conventional layout of the LCX. However, no significant shape modifications are expected to be developed for a commercial transport in the near future that would significantly reduce overall cost.

2.2 Design Evolution in its Beginning Stages

Each member of Fowl Enterprises initially designed an individual aircraft to meet the RFP. In this process, the weight, wings, engines, interior layout, and basic configuration were the main focus of the design. The individual results can be seen in

FOLDOUT FRAME

	WING	HTAIL	VTAIL
AREA FT^2	1140	347	281
SPAN FT^2	107	41.7	20.5
C/4 SWEEP(DEG)	28	34	45
ASPECT RATIO	10	5	1.5
TAPER RATIO	0.3	0.33	0.3
DIHEDRAL (DEG)	6	5	
ROOT CHORD IN	198	151.2	217.8
TIP CHORD IN	58.8	49.2	64.8
M. A. CHORD IN	140.4	108	154.8

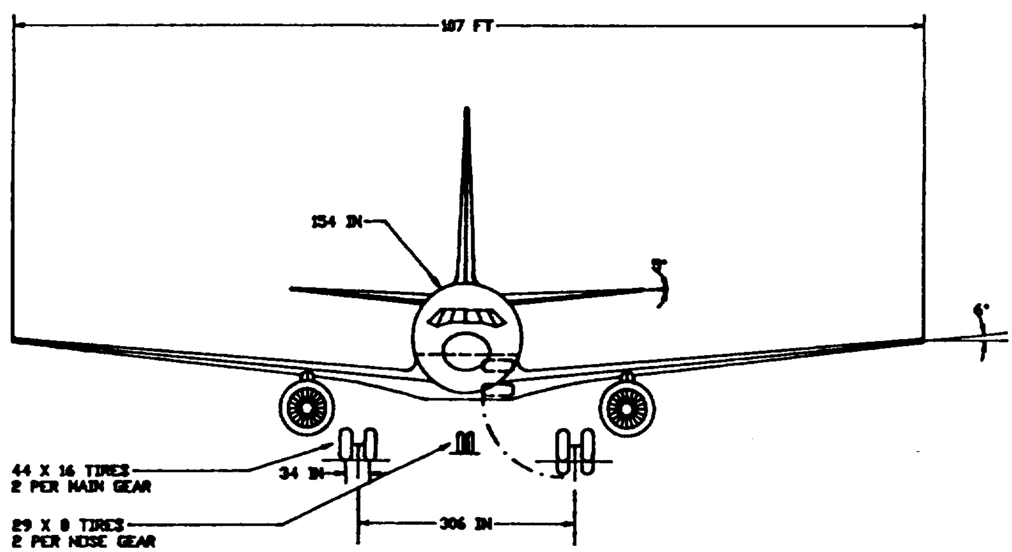
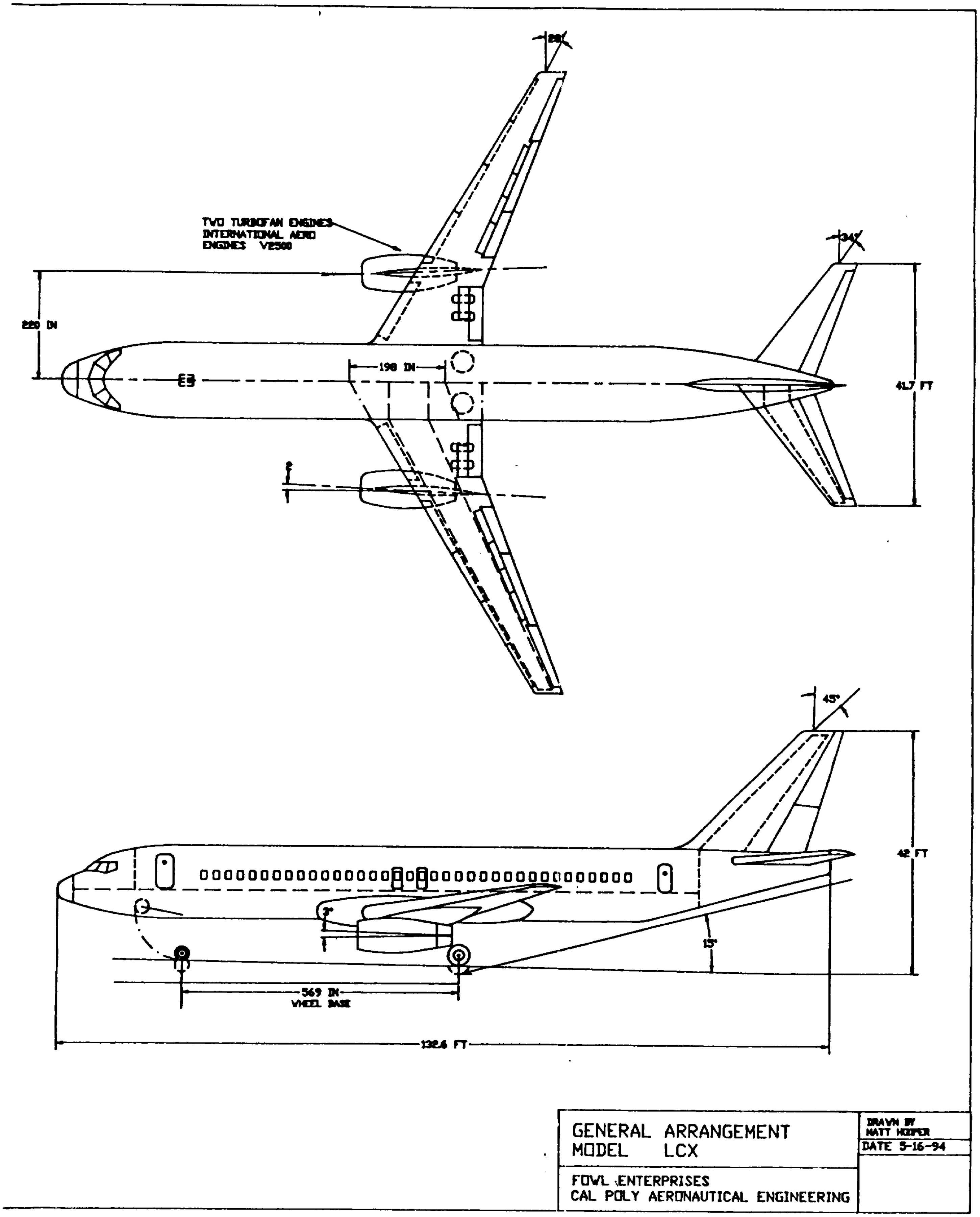


Figure 2.1.1: L


28°
TWO TURBOFAN ENGINES
INTERNATIONAL AERO
ENGINES V2500
34°
220 IN
198 IN
41.7 FT
45°
42 FT
3°
15°
569 IN
WHEEL BASE
132.6 FT
GENERAL ARRANGEMENT
MODEL LCX
DRAWN BY
MATT HOOPER
DATE 5-16-94
FOWL ENTERPRISES
CAL POLY AERONAUTICAL ENGINEERING

X Three View

Figure 2.2.1 found on the following page. From these ideas and research, a team design was born. It started as a composite of the five different aircraft and developed from there. Strong points of each design were explored and considered as to how it would help or hurt the composite design.

The joined wing, upon initial investigation, displayed many advantages. These include structural weight savings in the wing and the possible elimination of the empennage by incorporating the split wing as a V-tail. The disadvantages that prevented the use of this technology were flow interference effects of one wing to the other causing added drag and the added expense involved in production and R&D cost due to a lack of research data.

A three engine layout would eliminate the need for Extended Twin Engine - Operations (ETOPS) certification and was examined for this reason. But as further information was gathered in the subject, it was seen that ETOPS is becoming more of a standard certification procedure. The majority of new transports are twin engine. The cost of maintaining and accessing the third engine would add significantly to the initial cost of the aircraft and the cost of keeping extra spares available for the third engine. The smaller engines used for a three engine layout would also have higher specific fuel consumption (sfc) then the larger engines of a two engine layout. Therefore a cost concern eliminated the use of a three engine configuration.

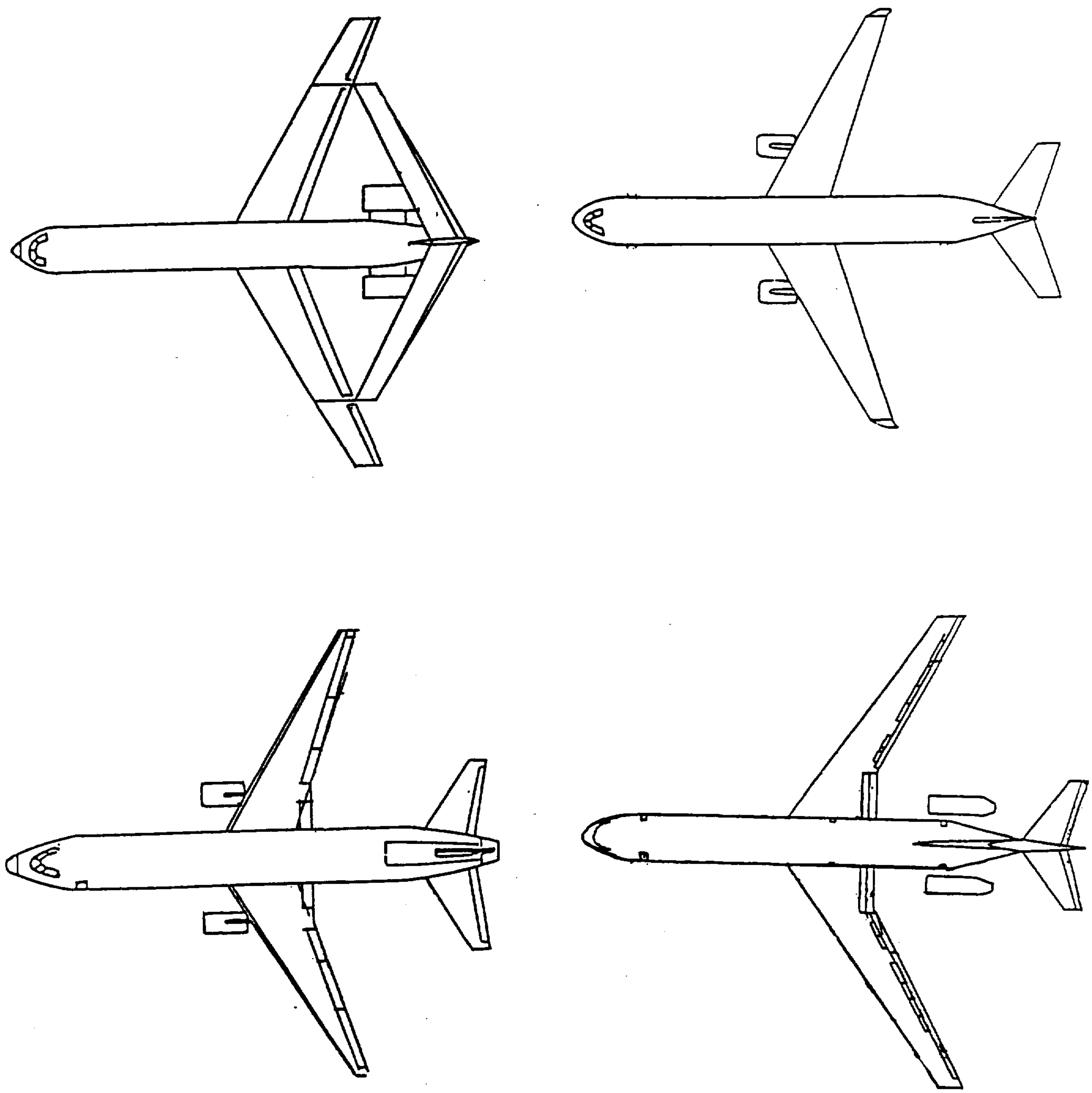


Figure 2.2.1: Individual Designs

2.3 Design Evolution from Initial Composite form to Maturity

Several new ideas entered into the design as Fowl Enterprises began to work with a single aircraft. The use of a twin aisle to add comfort, provide expansion possibilities, and increase utilization through shorter turn around time was examined. The benefits were appealing since less than two feet were being added to the diameter of the fuselage. The design carried this interior for several weeks. The RFP gave little consideration to comfort or expandability but stressed a low cost aircraft. Since drag and weight cost money, the fuselage diameter was cut and only a single aisle was incorporated.

Along the same lines, the LCX was designed with a three class configuration. The three class configuration was designed with a large first and business class to force a large cabin area. At 153 passengers the mixed class could provide more revenue to the airlines if the first and business class seats were filled. When the aircraft flew routes where these seats could not be filled, they would be replaced with economy seats. The reduction in the revenue of each seat would be offset by the increase in the number of seats. This is based on the assumption that the LCX could fill these seats when flying competing routes with an aircraft like the A320. An intermediate interior configuration was created where half of the first and business class could be replaced with economy seating. The speed at which this change could be performed was increased using expandable seat frames that could slide out from first to business to economy size with little effort. The full economy class configuration would carry over 180 passengers at a range of around 2400 nm.

The three class configuration offered airlines a great deal of flexibility in interior layout but was eliminated due to the weight and drag the longer fuselage added. Another driving factor leading to the removal of the three class configuration was the effect it had on range. Laminar flow control is only effective in reducing operating cost when utilized over long ranges. The reduction in range of the larger fuselage diminished this savings so a shorter fuselage with a smaller business first class was used.

The LCX wing loading was increased during the design process also. It was increased from 95 to 130 lb./ft.^2. The initial low value occurred for two basic reasons. Initially it was assumed that the normal value was between 90 and 120 lb./ft^2 and that a low value was needed to allow for expansion. When the decision was made not to design for expansion, the wing loading was raised to lower wing size and the cost of the LCX. The second reason for an increase came from the discovery that the current industry trend is for increased wing loading. The current standard varies from 110 at the low end, up to 160 at the high end. By changing the wing loading, the size and weight of the wing was decreased.

In order to lower the parasite drag, a new technology system was added to the LCX. Hybrid Laminar Flow Control (HLFC) is used to lower the parasite drag over the wing. This is accomplished by maintaining laminar flow over significant portions of the wing through the use of suction through a porous surface. This technology has been researched by NASA and industry. The first extensive research occurred during the oil crisis of the 1970's and has regained interest due to advances in manufacturing technology

(Ref. 7). The use of HLFC is incorporated into the LCX to reduce fuel burn and thus increase maximum range capabilities. The complications and complexities of incorporating HLFC into the LCX are addressed in section 6, HLFC Systems. The effect of HLFC on the overall design evolution of the LCX was not as extensive as initially thought. Fuselage mounted engines were again examined to lower vibration on the wing, but further research showed this was not necessary (ref. 11). HLFC had the greatest effect on the wing layout by changing the high lift devices and spar location. Overall, HLFC blended well into the aircraft design.

2.4 Design Point Analysis

The determination of the design point of the LCX has been an iterative process. The design point analysis used one engine inoperative Federal Aviation Regulations (FAR) and ceiling limitations to establish a range of possible design point values. Further limitations on the design point include maximum landing and takeoff lift coefficients, wing size, and available engine thrust.

The final results of the design point analysis can be seen in Figure 2.4.1 found on the following page. The selected thrust to weight ratio (T/W) of the LCX had to be equal to or higher than a value of 0.33 to meet the required climb gradient during takeoff. The wing loading (W/S) value of 130 lb./ft^2 was balanced between wing size and the cost of incorporating a complex high lift system to achieve a landing lift coefficient of 3.2. Furthermore, a takeoff lift coefficient of 2.0 was obtained after the selection of the design point was accomplished.

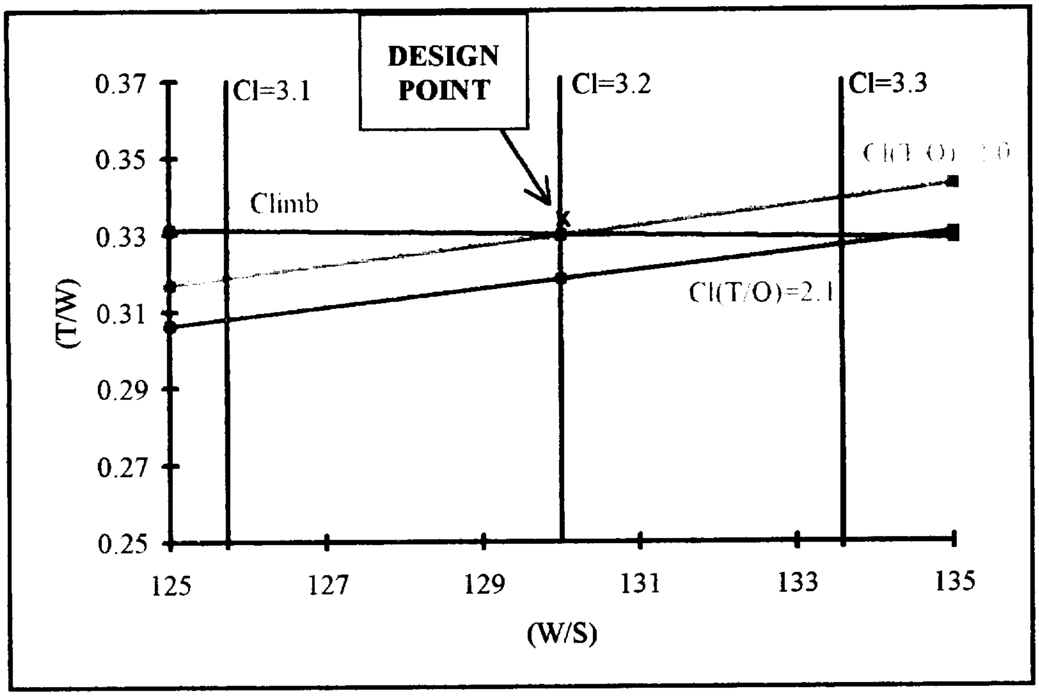


Figure 2.4.1: LCX Design Point

3.0 PERFORMANCE

3.1 Mission Profile

The LCX was designed for two basic states of HLFC parasite drag reduction technology, operational and failed. Failure of HLFC can occur due to adverse weather or system failure. The LCX was designed to meet the RFP requirements under the most pessimistic state of system failure throughout the entire mission. The mission profiles for both states is shown in Table 3.1.1.

	No HLFC lb. Fuel	HLFC lb. Fuel
warm-up	321	321
takeoff	656	643
climb	3,905	3,827
cruise	24,090	21,681
loiter	752	744
decent	396	396
landing	178	178
reserves	25,000	25,000

Table 3.1.1: LXC Mission Profile and Fuel Burn

Fuel use was calculated for each segment of the mission. During the climb phase no credit was taken for range. The use of HLFC will begin at 10,000 ft. as the speed of the LCX increases and density decreases. The LCX will then continue climbing to its cruising altitude of 36,000 ft. During cruise 3000 nm. can be covered. No range credit is taken during descent. The reserves for the LCX include fuel for an hour added to cruise, a missed approach, and travel to an alternate airport 100 nm. distant. The reserve requirements were determined using both McDonnell Douglas and Boeing definitions of domestic reserves (Ref. 16 and Ref. 25). The reserve fuel calculations were all made without taking credit for HLFC drag reduction or penalty for HLFC power requirements.

3.2 Climb

The best rate of climb for the LCX was interpreted as the most economic rate of climb. For the LCX, the faster altitude is obtained, the sooner LFC can be utilized. Therefore the drag on the LCX can be reduced sooner if the LCX climbs at its highest rate. Also when the sfc and thrust can be assumed to vary linearly with altitude, the most economical rate of climb is found to be the fastest rate of climb to cruising altitude (Ref. 27).

The rate of climb of the LCX is constrained under an altitude of 10,000 ft. by the FAR velocity limit of 250 kts. The LCX then accelerates to the velocity of maximum climb rate. The maximum rate of climb with altitude is shown in Figure 3.2.1 below. The maximum climb rate at altitudes above 27000 ft. is limited to allow time for the cabin pressure to decrease to its minimum level. As the pressure in the cabin decreases at the maximum allowable rate, the LCX can increase altitude without putting additional strain on the fuselage from the pressure gradient between the cabin and outer air. At the slower climb rate the cabin pressure reaches its minimum level at the same time the LCX reaches altitude. The LCX climbs to altitude in 20 minutes. The total fuel burned during the climb phase is 3200 pounds.

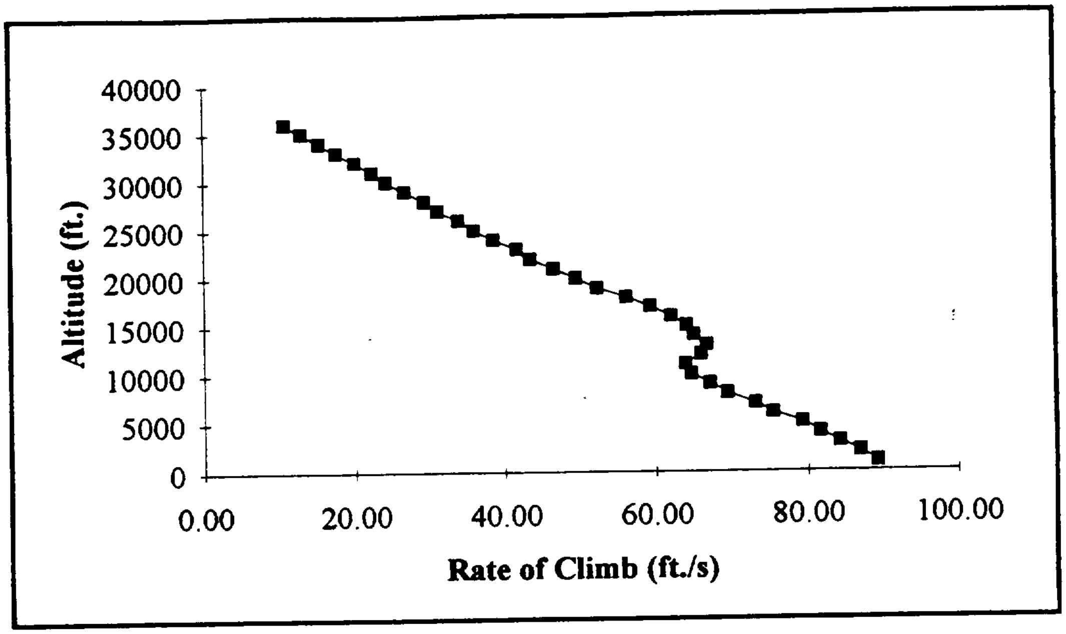


Figure 3.2.1: LCX Rate of Climb

3.3 Range and Endurance

The range and endurance curves were calculated using equations from Reference 27. As a result the curves in Figure 3.3.1 were produced.

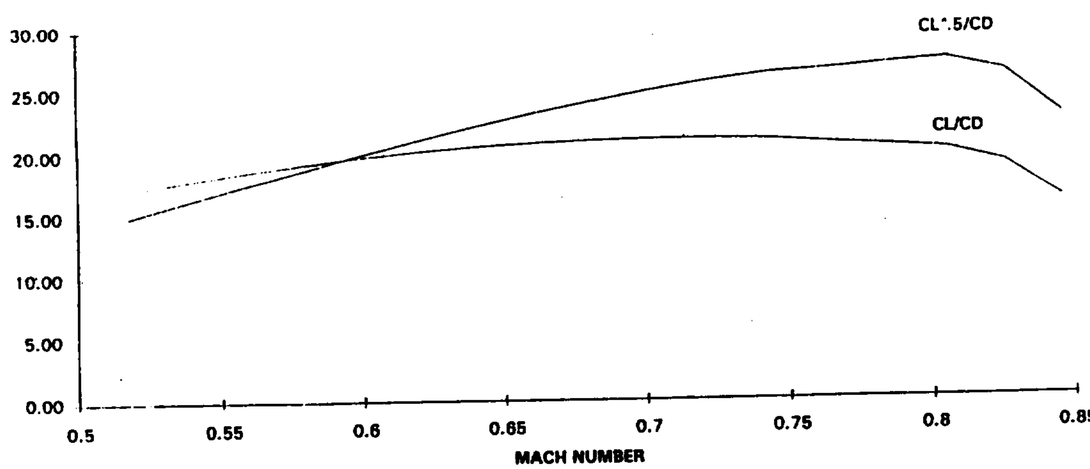


Figure 3.3.1: LCX Range and Endurance

The endurance curve is labeled as C_L/C_D and the range curve is labeled as the C_L^.5/C_D. The best range velocity is at Mach 0.8. The best endurance velocity is at Mach 0.72, were L/D is a maximum. The LCX is designed for flight at a Mach number of .8 to obtain best range and a competitive flight time.

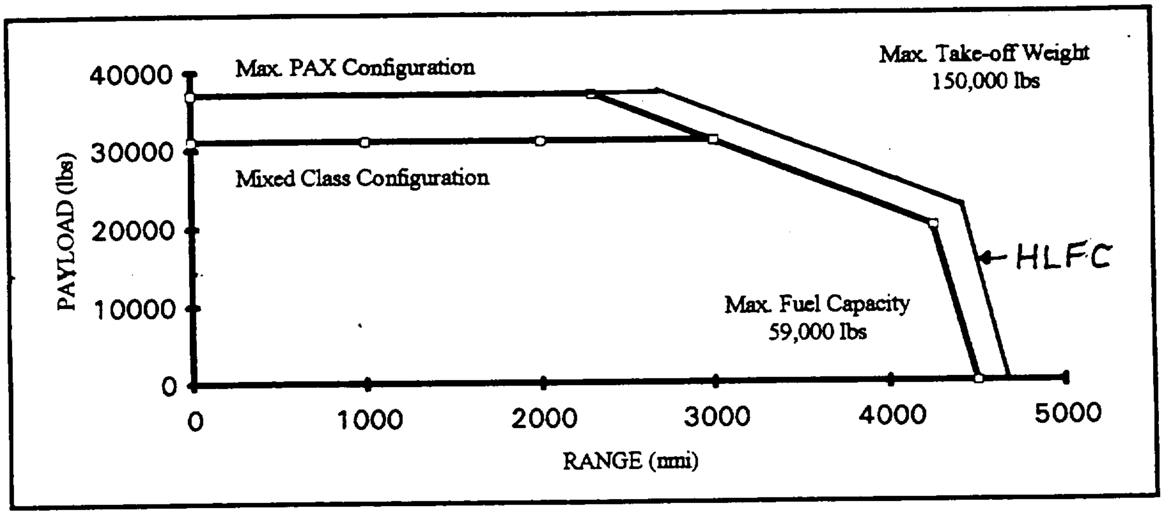


Figure 3.3.1: LCX Payload Range

The range for the maximum PAX configuration (165 passengers) without HLFC suction operating over the wing is 2400 nm. The range for the mixed class (153 passengers) is 3000 nm. When laminar flow is achieved over the wing these values increase to 2650 nm. and 3350 nm. respectively.

3.4 Take-off and Landing

The takeoff and landing capabilities of the LCX allow it to operate in smaller airports. This coincides with its mission of extending the use of direct flights to and from regional airports. The landing field requirement is easily met through the use of a fairly complicated flap system that includes double slotted Fowler flaps at the trailing edge and a variable camber Krueger flap at the leading edge. The calculated takeoff and landing distances meet the RFP requirements of 7000 ft. and 5000 ft.

4.0 INTERIOR LAYOUT

The LCX cabin design process was driven by the need to seat passengers in the most efficient, space-saving manner. As required a minimum of 153 passengers in a mixed class was used for interior spacing analysis. The interior layout is also designed for a satisfactory compromise between passenger comfort and aerodynamic efficiency. The final layout includes a comfortable business-first class and an economy class.

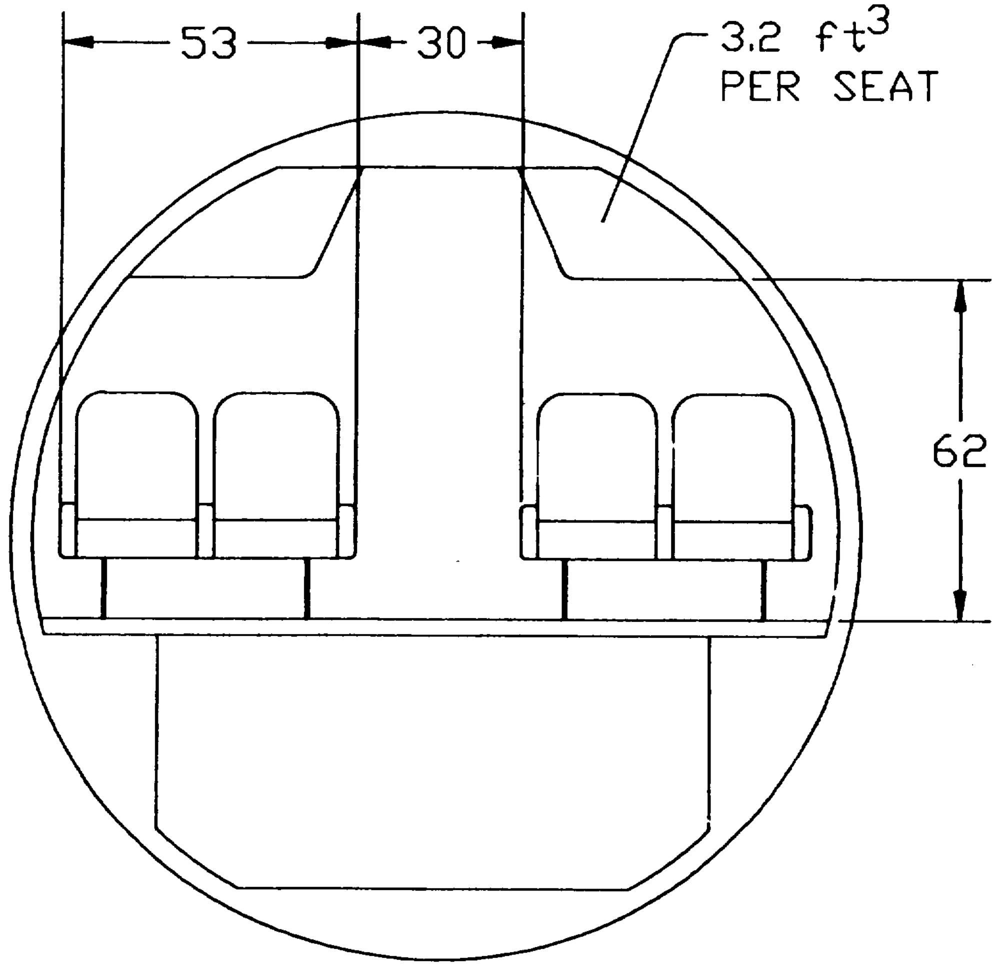
4.1 Seating Layout

The optimum seating arrangement for the economy class is six across. If the number were increased to seven or decreased to five, it would result in a less efficient fuselage. The larger number of seats would increase the fuselage diameter and require the use of two aisles. This would result in the increase of drag, weight, and operating cost. Decreasing the number seats to five abreast would lengthen the aircraft and increase the surface area, drag, weight, and operating cost.

To enhance passenger comfort, the center seat width of the LCX is increased by an inch to a total of 18 in. The outer seats have a width of 17 in. and a seat pitch of 32 in. The cross section shows the placement of the seats as seen in Figure 4.1.1.

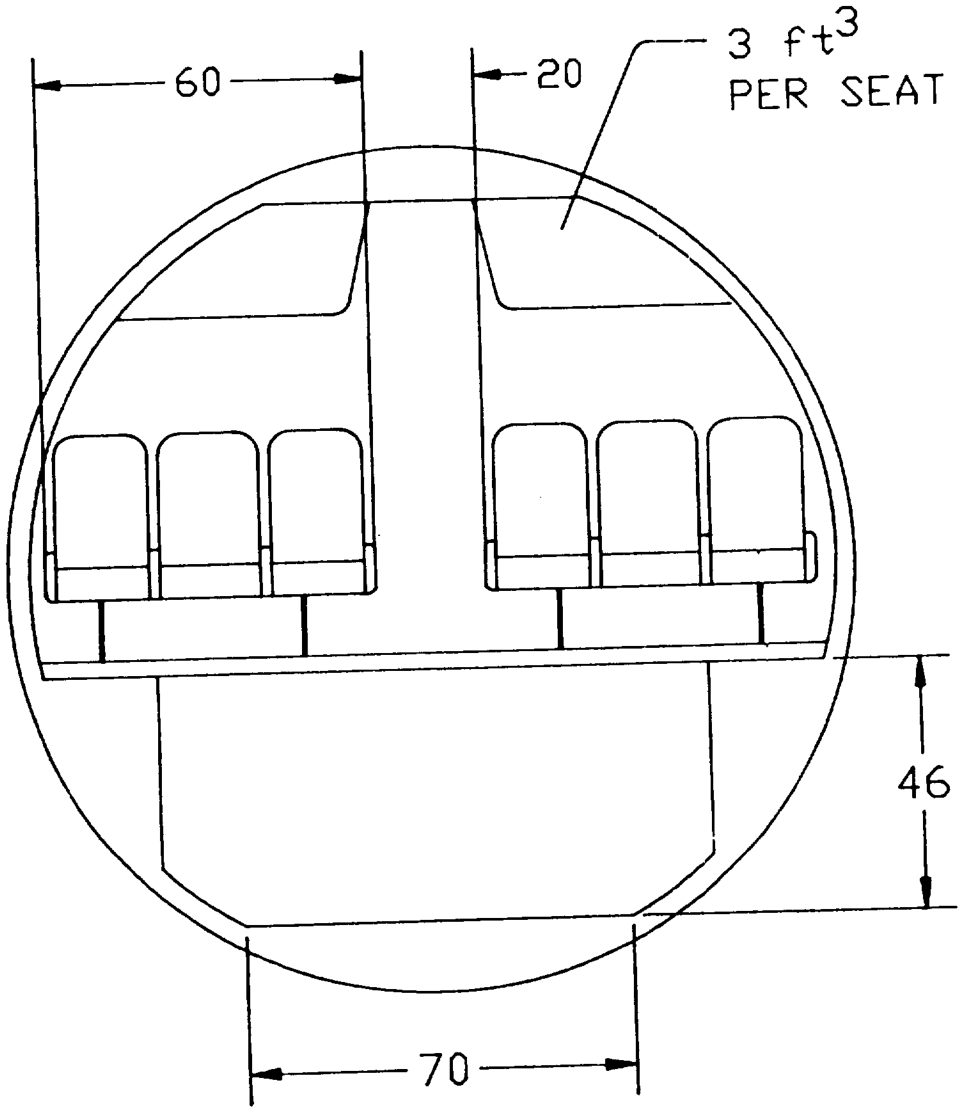
The business-first class, with larger seats than found in most business classes, are sized with comfort in mind. This is important to maintain the patronage of both the first class and business travelers used to flying separately on widebody flights. Seat arrangement and dimensions are shown in Table 4.1.1 found on the following pages.

FOLDOUT FRAME



BUSINESS CLASS

Figure 4.1.1: LCX Int



ECONOMY CLASS

ior Cross Section

	Business		Economy	
Seat Pitch	38	in.	32	in.
Seat Width	21	in.	17,18(Center Seat)	in.
Armrest Width	3	in.	2	in.
Height	42	in.	39	in.

Table 4.1.1: LCX Seating Arrangement

The over head storage was designed so that a traveler can bring compact carry-on luggage into the aircraft cabin. The economy class has 3 ft^2 and the business first class has 3.2 ft^2 of over head storage.

4.2 Galley, Lavatories, and Closet

Provided for the traveler is one closet at the entrance to the aircraft. There is one galley located in front of the cabin and one galley located in the rear. The forward and rear galleys were placed in compliance with RFP requirements. The galleys are sized to allow one meal and snack to be provided to each of the 165 passengers in the full economy layout.

The LCX is also designed to have 4 lavatories which provides one lavatory per 41 passengers in the all economy configuration. One lavatory is located in the front of the aircraft, sized for accessibility by disabled people. Three lavatories are located in the rear of the cabin for the economy class. The closet is able to house a wheel chair and the wardrobe for the business first class. The placement of the above galleys, lavatories, and closet are shown in Figure 4.2.1 and Table 4.2.1.

Forward Galley	43 in. x 60 in.
Rear Galley	55 in. x 120 in.
Front Lavatory	43 in. x 60 in.
Rear Lavatories	37 in. x 40 in.
Closet	25 in. x 50 in.

Table 4.2.1: LCX Interior Dimensions

4.3 Layout of the Exits

FAR 25 requires that there be two Type I and two Type III doors on each side of the aircraft for 140 to 179 passengers. The forward left side loading door (type I) is designed to allow passengers to comfortably load and unload the LCX. The loading door dimensions are 32x72 inches. The three other type I doors are sized to allow for easy servicing of the galleys and emergency exits. The dimensions of these doors are 27x60 inches. Two exit doors (type III) are placed over the wings. This enables the LCX to meet the FAR's and allows passengers to egress quickly in case of a emergency landing.

4.4 Attendant Seats

FAR 25 requirements state that the attendants must be able to see 80 percent of the passengers during takeoff and landing phases of flight. To meet this criteria, two of the attendants are placed on the side of the rear lavatories and face forward. This enables them to see over 80 percent of the passengers in both configurations. The other two attendant seats are placed on the forward lavatory facing aft. The placement of the attendant seats can be seen in Figure 4.2.1.

FOLDOUT FRAME

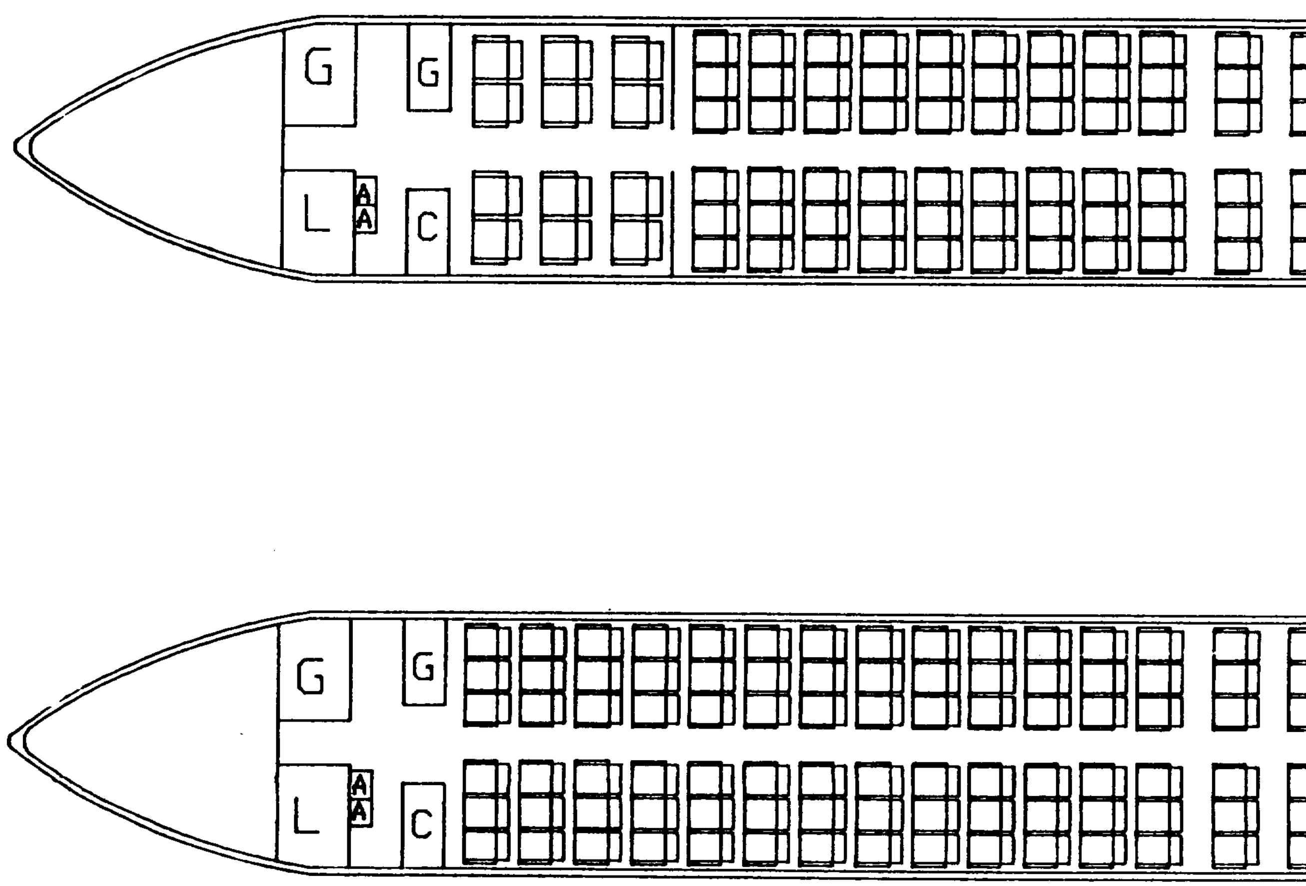
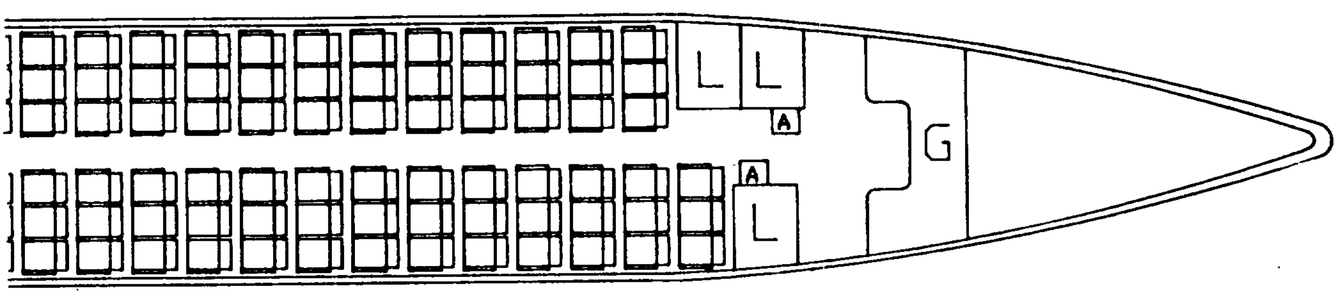
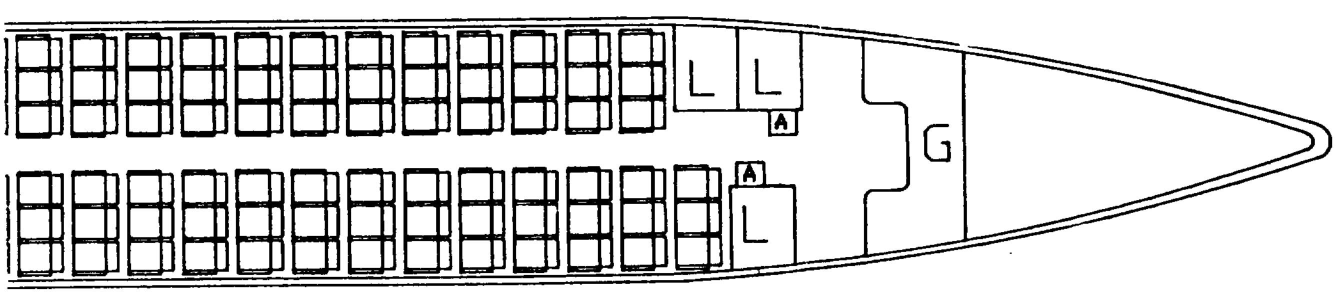


Figure 4.2.1: LCX Interio

FOLDOUT FRAME 2





Layout

4.5 Flight Deck

The LCX flight deck is designed for two-member crew operations featuring digital electronic systems and instruments, flat panel displays, automatic navigation and landing systems, and built-in test equipment. Goals to be attained in this design include safety, reduced workload, reliability, maintainability, and low operation costs.

Some of the more modern design enhancements in the LCX cockpit include uncluttered instrument panels, simplified caution and warning systems, low-noise windows, and better crew comfort. This can be seen in Figure 4.5.1.

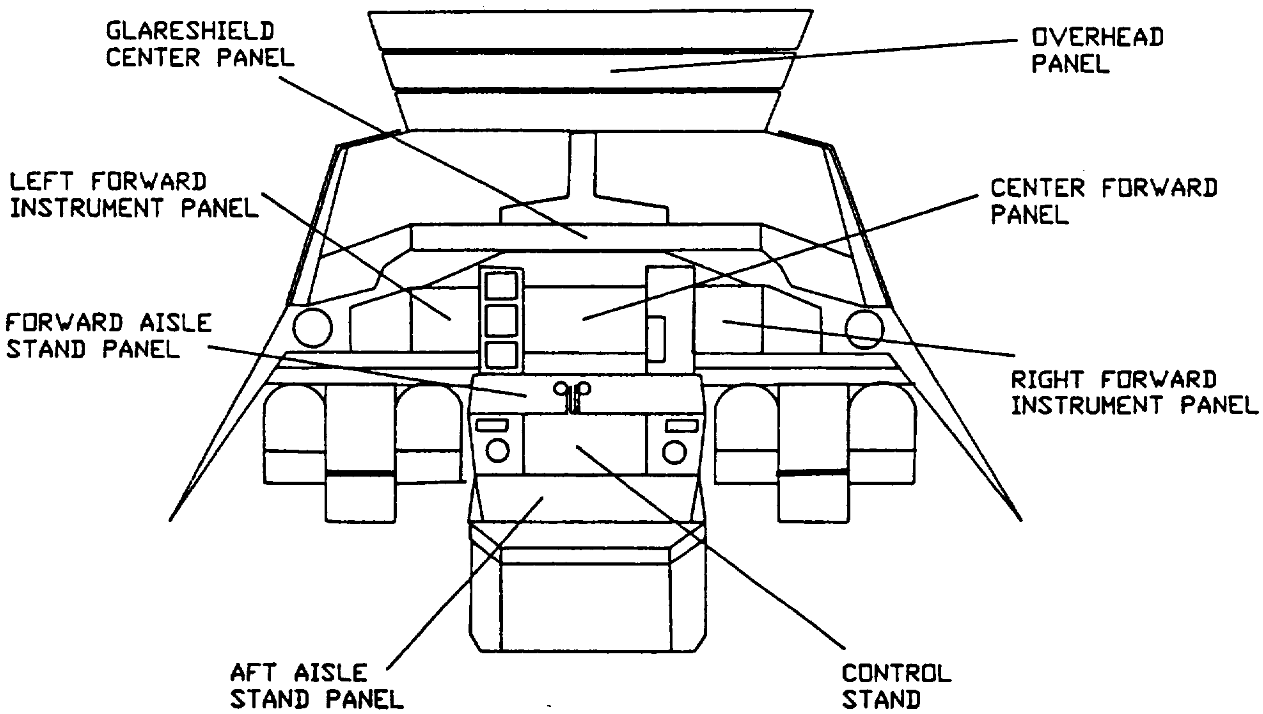


Figure 4.5.1: LCX Cockpit Layout

An uncluttered instrument panel was achieved through the "layer" philosophy. The layer philosophy incorporates flat panel displays where each instrument, instead of having only one or two functions, allow many levels of information to be readily displayed for the pilot. This cleaned up the cockpit environment significantly. The alert system is simplified by having a minimum number of different aural alerts, which are grouped according to the level of action required, thus reducing nuisance alerts. Finally, crew comfort is enhanced by the provisions of more comfortable and durable seats, lower noise levels, more efficient air-conditioning, and better internal and external vision. Typical stowage space under the observer's seat (centered behind crew seats) is provided as well as a coat closet and flight kits.

5.0 AERODYNAMICS

5.1 Airfoil Characteristics

The LCX is designed to travel at a high subsonic velocity to lower the block time of each flight. This allows the LCX to be competitive with similar sized aircraft. It is also designed with a high aspect ratio wing to lower induced drag. The supercritical airfoil used on the LCX helps to achieve both a high velocity and a high aspect ratio wing. The higher drag divergence Mach number of a supercritical airfoil requires less sweep in the wing and allows for a greater thickness ratio at the same cruise Mach number. The additional thickness of the airfoil provides room for a larger structure with higher stiffness and moment of inertia. With the lower sweep and larger thickness, a high aspect ratio can be achieved without incurring large structural weight penalties.

In addition to shaping the airfoil with supercritical technology, the design of the airfoil must also incorporate a flat contour over the upper surface to maintain the laminar flow stabilized with suction applied at the leading edge of the wing (Ref. 10,13,26). Since a supercritical airfoil already has a flat contour the modification necessary to stabilize laminar flow will not be extensive. The disadvantage of the supercritical airfoil is an increase in the pitching moment characteristics due to the aft loading characteristics of the airfoil. One problem encountered in design modification to the airfoil is the effects it has on the airfoil characteristics when laminar flow control is inactive. The change in airfoil characteristics can not be significant when hybrid laminar flow control is lost.

The design of the actual airfoil was not chosen or accomplished by Fowl Enterprises. The airfoil designs studied were created in the early 1980's. Current designs were not discovered. In order to attain airfoil characteristics that would represent the capabilities of current design trends an educated engineering analysis was performed using the data available and the LCX airfoil characteristics were chosen. The results that Fowl Enterprises believes it can achieve are found in Figure 5.1.1 (Ref. 2,10,13,24,26).

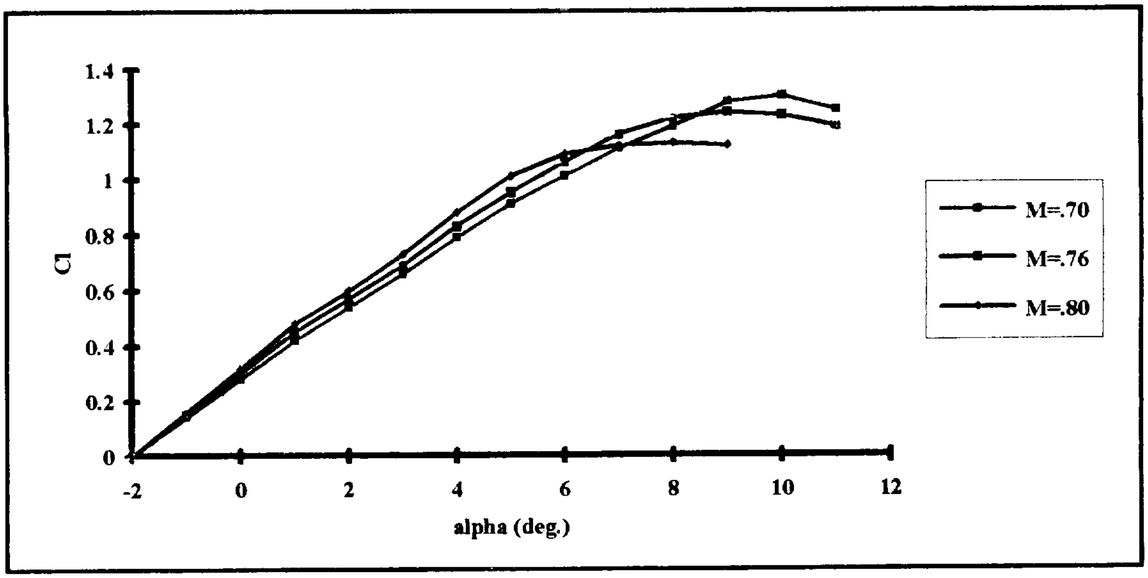


Figure 5.1.1: LCX Cl vs. Alpha

5.2 Wing Layout

The overall wing layout of the LCX is found in Figure 5.2.1. The basic characteristics include a span of 107 ft with an aspect ratio of 10. A high aspect ratio is necessary on the LCX to balance the reduction in parasite drag accomplished with HLFC with a subsequent reduction in induced drag. A high aspect ratio also lowers the wing chord allowing for laminar flow over a greater percentage of the wing and thus a greater percentage of parasite drag is reduced. The cost of a high aspect ratio wing comes from the weight added by the necessary structure of a larger wing span. For this size aircraft the span is within the capabilities of current maintenance facilities and airports. A higher aspect ratio was not used because the structural weight penalty incurred was larger then the benefits gained in drag.

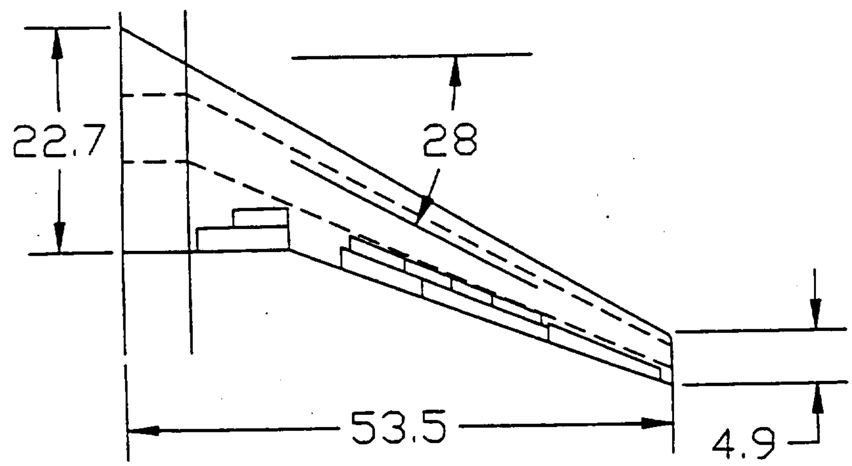


Figure 5.2.1: LCX Wing Layout

The taper ratio of .3 was chosen to coincide with current trends in industry. The sweep was calculated using the supercritical airfoil data generated with a drag divergence Mach number of .76. At this drag divergence Mach number the half chord sweep of 26° was calculated. The half chord sweep was used to accommodate for 3-D effects and the effect of the body on the flow over the wing. The resulting quarter chord sweep is 28°. The thickness ratio of the wing is reduced from 13.5% at the chord to 9% at the tip. A dihedral angle of 6° was added in order to allow for ground clearance of the large turbofan engines used on the LCX. This resulted in a large vertical tail as discussed in the stability section. The wing also houses the fuel used by the LCX. All of the fuel is located in the wing with enough volume to contain 46,000 lb. of fuel.

5.3 Fuselage and Empenage Layout

The LCX has a circular cross section to reduce the structural weight necessary to contain the pressure at altitude inside the fuselage. This form of the fuselage doesn't adversely effect the aerodynamics of the LCX since it doesn't add much length or diameter to the LCX layout. The nose was designed to limit the acceleration of the flow around it without adding significantly to the wetted area and skin friction or limiting the pilot view below the FAR requirements.

The tail of the aircraft was designed to allow for the limits of incidence of the horizontal stabilizer and for the structure needed to support the horizontal tail. The size was limited to minimize the chance of tail strike on rotation and to keep the adverse pressure gradient experienced at the tail low enough to not induce separation. The tail is designed to satisfy these criterion and to provide room for the APU.

5.4 Drag Components

The drag of the LCX is composed of both parasite and induced drag. The use of laminar flow provides a reduction of the parasite drag. The suction applied at the leading edge section and the shaping of the airfoil over the upper surface establish laminar flow to over 50% of the chord on the upper surface. Beyond this point the flow is supersonic causing the flow density to drop with the rise in temperature reducing the parasite drag also. With laminar flow being added to the upper surface of the wing parasite drag is reduced by approximately 50% (Ref. 2,7,14,16). The total wing drag then drops by approximately 36%. This equates to approximately a 11% reduction in aircraft drag for an aircraft in the LCX size range. The approximate parasite drag breakdown can be seen in Figure 5.4.1.

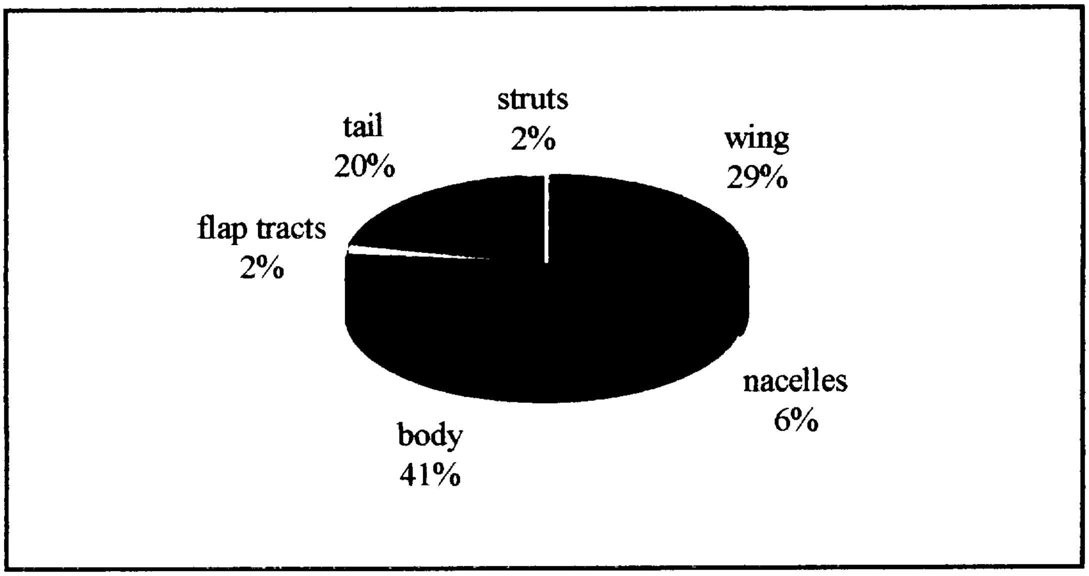


Figure 5.4.1: LCX Drag Breakdown with HLFC

An accurate prediction of the overall reduction would take extensive airfoil and wind tunnel analysis not possible within the scope of a 9 month report. The reduction used was determined from various sources. The main sources included Boeing and McDonnell Douglas studies performed in the early 80's and a few discussions with engineers at the companies who were familiar with the HLFC projects being performed (Ref. 7,14,16).

The reduction in drag on the nacelles with the application of HLFC to them was found in NASA reports also (Ref. 5).

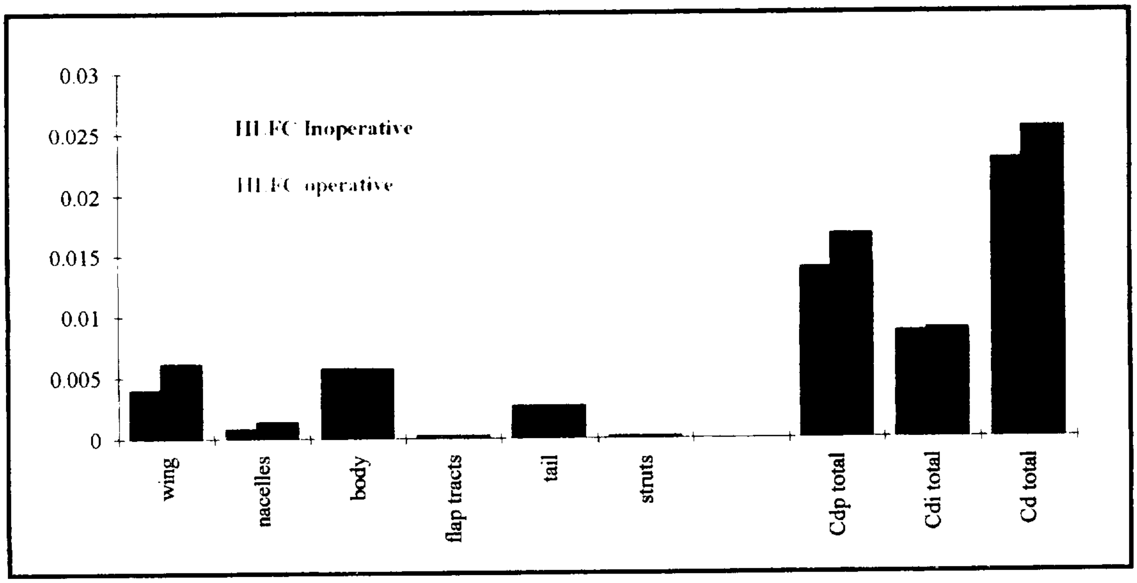


Figure 5.4.2: LCX Coefficient of Drag Comparison

The values of drag that were found for the LCX can be found in Figure 5.4.2. The L/D value that corresponds to the turbulent flow aircraft reaches a maximum value of 19.5 at its optimum condition. With the use of HLFC this value increases to a value of 21.5. These values include drag reduction techniques being incorporated into most modern aircraft in terms of minimizing the drag of the nose and cockpit glass, better fairings, and reduction of drag in the engine pylon design. With all these factors accounted for a modern transport can obtain L/D values in the 20 range.

5.5 High Lift Devices

The LCX will incorporate the use of a three flap system. The two main flaps will be slotted Fowler flaps and the third will be a Krueger flap at the leading edge. The aft-most flap will also be used to control pressure distribution in the aid of laminar flow. It will accomplish pressure distribution control through small deflections during cruise and climb.

The leading edge Krueger flap also serves as an insect shield for the leading edge of the wing. It is necessary to protect the upper wing surface from insect contamination which would disrupt the laminar flow. To serve as insect protection for the entire wing it covers the full leading edge span. It will need to be deployed until the aircraft climbs out past 500 feet of altitude. It has been determined that the large majority of the insect population exist under 500 feet of altitude and once beyond this altitude insect contamination is no longer a concern to laminar flow on the wing. The problem encountered with the Krueger flap being used at takeoff is that it can not seal to the wing and thus tends to be a high drag device that lowers the overall lift to drag ratio. At V_1 and one engine inoperative climb this situation becomes critical and would end up requiring additional thrust. For this reason a variable camber Krueger is utilized to control the drag penalties while still allowing the flap to act as an insect shield. The additional lift obtained at landing, by the variable Krueger flap, allows for simplification of the Fowler flaps at the trailing edge.

To provide for short field access as prescribed by the RFP, double slotted Fowler flaps are incorporated as the final addition to the high lift system. With the use of these flaps and the addition of the Krueger flaps on the leading edge a maximum lift coefficient of 3.2 is obtained at landing. The high drag of variable camber Krueger flaps in their landing configuration help to slow the aircraft down at landing. With the lift coefficient obtained from the LCX high lift systems, the LCX can land in 4,890 ft. at 90% of its maximum takeoff weight.

6.0 HLFC SYSTEMS

6.1 Reasons for the use of HLFC

The chief benefit of HLFC comes in the form of savings in fuel burn. The fuel savings offered by HLFC ends up to be about 12% of that of a modern turbulent flow aircraft, but only during cruise at altitude. The reduction in fuel burn can be used in two ways. The first would be to reduce the maximum gross takeoff weight while maintaining the same range. The other option is to increase the range of the aircraft while maintaining the same maximum gross takeoff weight. The LCX is designed to the second option. The reason for this decision was to increase the capabilities of the LCX to fill in for widebody aircraft at longer ranges and expand the marketability of the aircraft. The other reason is that if the system is inoperable for any reason the LCX can still complete the RFP.

HLFC also reduces the impact of fuel price on the airlines. It does increase the effect of range though. The combination of these give the LFC an advantage if it is flown according to the RFP as Fowl Enterprises has interpreted it. HLFC helps the LCX create a new market niche that was not as economically profitable before its use.

6.2 HLFC Performance

Since HLFC has not been implemented on a production aircraft before, there exists questions as to its reliability and performance. The airframe manufacturers have been completing studies in this area under the sponsorship of NASA. The first wave of studies occurred in the early 80's. These tests gave real data into the areas where laminar flow research needs to be expanded and where solutions have been accomplished. The latest tests in HLFC have just been completed but the printed results are not available to the general public. A brief discussion of Boeing's results with a Boeing engineer revealed that HLFC was shown to be feasible, but the actual improvements to economics depend on the individual application.

Joint testing performed by McDonnell Douglas and Lockheed in the early 80's gave an initial look into HLFC and two methods of achieving significant laminar flow regions over the upper surface (Ref. 36). These tests showed the conditions where suction could sustain laminar flow and the conditions where the flow would become turbulent despite suction.

The major causes found to effect laminar flow are chord Reynolds Number and surface contamination on the upper surface. Reynolds Number has the greatest effect at low altitude where the density is high. The large value of Reynolds Number at low altitude causes the flow to transition to turbulent, in spite of suction. At 10,000 ft. suction starts to have a significant effect allowing for the benefits of laminar flow control to be realized. The amount of laminar flow over the upper surface of the wing increases as altitude increases and Reynolds Number decreases (Ref. 16).

Surface contamination effects laminar flow in the local region of the contamination. The contamination can occur from various sources. The first would be in the manufacture of the upper surface of the wing. It has been shown through NASA and

Douglas Aircraft experiments that a titanium skin can be manufactured with tight enough tolerances to eliminate the surface waves that would cause loss of laminar flow.

Another type of contamination occurs while operating the aircraft during regular flights. The most critical type is from ice crystals formed in clouds bombarding the wing. When flying through clouds, these crystals cause laminar flow to be lost. No method of regaining laminar flow inside a cloud exists, but upon exiting the clouds laminar flow is regained. One benefit of travel through clouds is that it tends to act as a washing mechanism for the wing. Any particles stuck to the wing will be washed off and upon exiting the cloud laminar flow is regained in that area. From average weather studies it was found that most aircraft need to fly through the clouds 6% of the time. This was confirmed by three years of flight test of HLFC gloves flown in a NASA simulated airline scenario (Ref. 25).

A second source of contamination that can occur while the aircraft is in service is to have insects stick to the wing surface causing the flow to trip to turbulent. The solution to this problem was to implement a insect shield to deflect insects. The shield acts similar to what is found on the front of a truck. The shield takes the form of a Krueger flap to maximize its use. Since the insect population is mainly located below 500 feet of altitude this solution works extremely well.

The final form of surface contamination comes from ice forming on the wing while purging water from the system. This generally occurs when water has collected in the system after sitting for a long period of time in the rain. The solution to this problem could occur through heating of the entire leading edge or by mixing an anti-icing fluid with the water being ejected. The LCX uses the second option and carries this fluid only when water has collected and needs to be purged from the system. As the LCX climbs, the fluid is pumped out with the water and the weight penalty of carrying extra fluid diminishes to nothing.

6.3 HLFC Systems

The HLFC systems are concentrated in the leading edge of the wing, forward of the front spar. This section of the wing is made of a .025 in. thick titanium skin that has been drilled with .0025 in. diameter holes used for suction. The holes are drilled in a .025 in. square grid using laser drilling technology. This technology is used because it allows the holes to be drilled at an angle, banking inward, making clogging of the holes less likely. A reverse flow purge is also incorporated into the system to clear blockages in the porous surface and to purge water that might be collected in the system due to rain or washing. When the reverse flow is used to purge the system of water an anti-icing fluid is added to prevent freezing of the extracted water.

The flow through the leading edge porous surface is controlled through the use of ducts running spanwise along the leading edge of the wing. The system is run by electric pumps located in the fuselage that are powered by the engines. The engines are used as the power supply since they are the most efficient source of power on the aircraft. The system will be patterned after that used by Boeing in its latest flight tests. The estimated weight, added by the entire system, totals 1,500 pounds.

7.0 PROPULSION SYSTEMS

7.1 Considerations

There are several concerns addressed when integrating the propulsion system with the aircraft. These concerns include fuel efficiency, thrust available, foreign object damage, maintenance, interference drag, and environmental concerns for noise and emission pollution.

7.2 Thrust Requirements

From the sizing program the thrust to weight ratio(T/W) was selected to be .33. The required thrust for the LCX is therefore 49,500 lb. To supply this thrust, the V2527 and CFM56-5A3 engines were investigated. The main reason for their selection is that they are currently available and are being made quite reliable. The engine chosen for the basic installation was the V2527, but the LCX also has the option to use the CFM56-5A3.

Both engines have a low sfc, which will reduce the cost of operating the LCX. The engines also have the advantage of being over four years old. As a result, maintenance problems have been reduced and maintenance personal have a better understand of the engine. Table 7.2.1 compares the two engines before installation which were attained from Reference 17. One noticeable difference between the two is the fan diameter, which means that the landing gear will have to be modified to accommodate the different engines.

	CFM56-5A3	V2527-A5
Fan Diameter	68.3 in.	63.0 in.
Dry Weight	4995 lb.	4942 lb.
Cruise Conditions		
Altitude	35,000 ft.	35,000 ft.
Speed	Mach 0.8	Mach 0.8
Thrust	5000 lb.	5250 lb.
SFC	0.596 lb./hr/lb.	0.58 lb./hr/lb.
Sea Level Conditions		
Thrust	26,500 lb.	26,500 lb.
SFC	0.45 lb./hr/lb.	0.45 lb./hr/lb.

Table 7.2.1: LCX Engine Data

When the engine is installed on the aircraft the thrust is effected by engine bleed and power extraction. The losses are caused by high-pressure air being bled from the engine. Bleeding results in a loss of between 2 to 5 percent of the uninstalled thrust. The power extraction for each engine of a 150,000 lb. aircraft under normal operation is 200 lb. (Reference 27). The power for the LFC is 150 HP for each engine. Total horsepower extraction is 350 HP for each engine. The thrust loss was estimated to be 1750 lb. for a 26,500 lb. engine. Since the thrust required is 49,500 lb. it was determine that a 26,500 lb. engine is required.

7.3 Environmental Issues

Two environmental concerns for propulsion are noise and emissions. The noise produced by the engines are caused by exhaust gas on takeoff and fan noise when landing. The noise on takeoff has been reduced by the engine manufactures who redesigned the engine to have a higher by-pass-ratio. Increasing the by-pass-ratio decreases the exit velocity and therefore reduces the takeoff noise. The noise on landing has been reduced by using an advanced broad-band acoustical liner. The position of the liner from reference 15 can be seen in Figure 7.3.1.

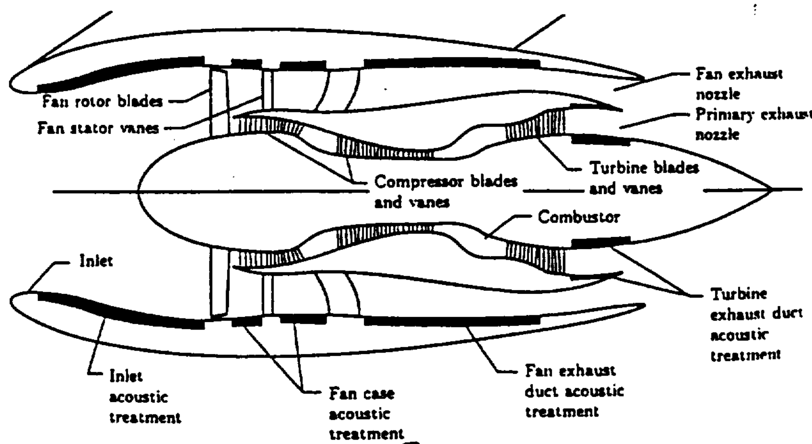


Figure 7.3.1: LCX Acoustical Liner

Both engines meet the FAR stage three requirement of less than 100 dB for approach, 91 dB for takeoff, and 97 dB for sideline. Since it meets these requirement the LCX will be able to operate efficiently into and out of noise sensitive airports.

Both engines have reduced the emission by using a two stage burner. The two stage burner greatly reduces the NO_x emissions. It also reduces other pollutants, such as carbon monoxide, unburned hydrocarbons, and smoke. At this time the V2500 is 40% below and the CFM56 is 35% below the legislative limit for NO_x emissions. The NO_x emissions for both engines are expected to drop in the upcoming years. This is very important for the aircraft industry since countries are starting to tax planes for NO_x emissions.

7.4 Nacelle and Pylon

As stated before, the engines are placed on the wing of the LCX. Placing the engine on the wing requires the nacelle be placed in a position to reduce the drag and interference with the wing. This is done by looking at historical data. The data used to scale is from the Lockheed L1011 (Reference 41). The data for the L1011 was used since the size of the of the engines are in the same class as the LCX. Even though the L1011 has three engines, the placement of the wing mounted engines is equivalent to that of a two engine aircraft. From this data it was determined that $\varepsilon=3^\circ$, $\phi=2^\circ$, X=1.85D and Z=.9D for the LCX. Where ε is the angle of the inlet relative to wing canted down and ϕ is the angle of the inlet angled towards the fuselage. By doing this the flow into the inlet will be local to the wind velocity. X is the distance from the leading edge of the wing to the front of the inlet. Z is the distance from the chord line to the center of wing. This can be seen in Figure 7.4.1.

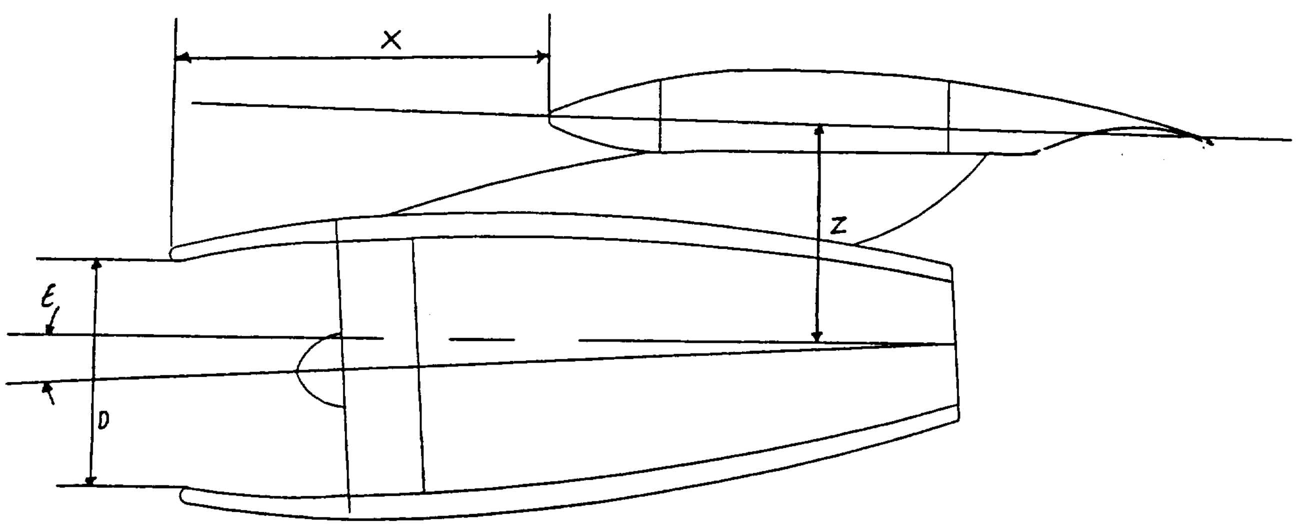


Figure 7.4.1: LCX Nacelle Placement

For the preliminary design this is a good estimate, but more research needs to be completed to optimize the nacelle placement. This is due to the HLFC being used on the nacelle and wing.

The nacelle has also been modified for HLFC. The main goals are the reduction of the skin friction drag and prevention of laminar separation on the nacelle. By using HLFC the skin friction will be reduced and the laminar flow will be present to 60% of the length of the nacelle. This reduces the nacelle skin friction drag by as much as 50% and the total aircraft drag by 2%. Using the existing V2500 nacelle, the following modifications were made. The position of the maximum radius was moved from 35% of the length to 47% of the length. The radius was increased by 1.5 inches. This increased the maximum radius of the nacelle from 3.125 to 3.25 ft.

The pylon is designed to carry the loads of the nacelle and engine. It is determined from historical data that the width of the pylon will be 18 in. The pylon attaches to the front spar at 20% chord and the rear spar at 65% chord.

7.5 Inlet Design

The inlet of the nacelle is designed to reduce the velocity of air before it comes in contact with the fan. A diffuser must be used to increase the pressure and reduce the velocity. The velocity is reduced from Mach .8 to Mach .6 before it enters the inlet. The diffuser must reduce the velocity to Mach .4 in order for the engine to run efficiently. As a result the cowl is designed to increase the pressure and to reduce the drag on the nacelle. The cowl is designed to be as short as possible, reducing the skin fiction drag. The capture area is 2743 in^2 compared to a fan area of 3117 in^2. This gives a diameter ratio of 0.88 which will reduced the Mach number to 0.4.

7.6 Engine Performance and Analysis

The performance curves for a 26,500 lb. engine were scaled using the data provided by the AIAA. It can be seen in Figure 7.6.1 that the uninstalled thrust is greater than the installed thrust and as altitude increases the thrust available decreases. At altitudes above 30,000 ft the thrust no longer varies with the Mach number. In Figure 7.6.2 it can be seen that the sfc is reduced as the altitude is increased and the sfc increases as the mach number is increased.

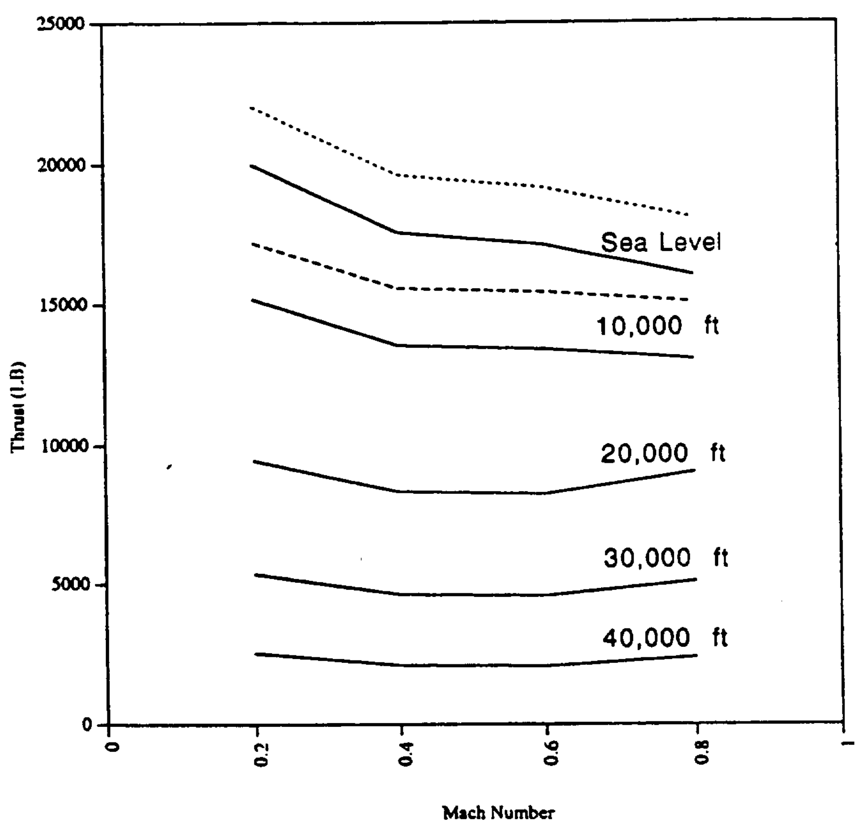


Figure 7.6.1: LCX Installed Thrust

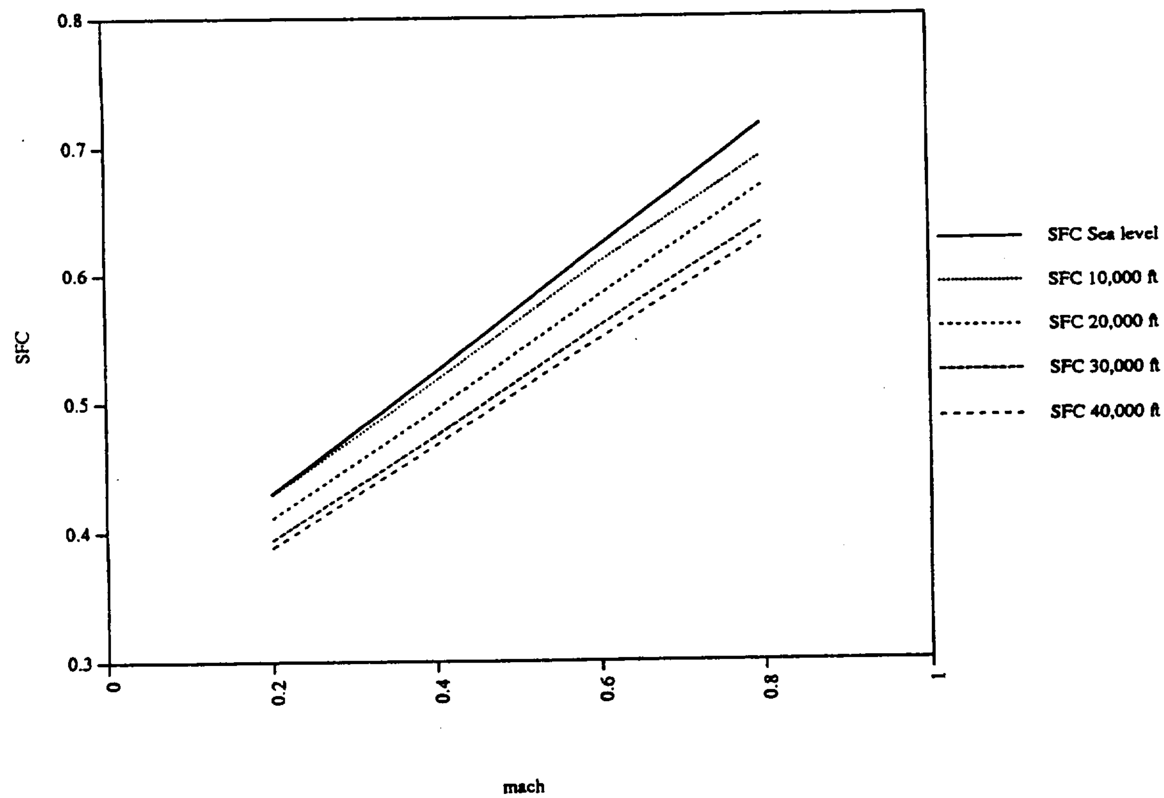


Figure 7.6.2: LCX Specific Fuel Consumption

8.0 STRUCTURES

8.1 Materials

With the goal of keeping the manufacturing and direct operating costs low for the LCX, simplicity in structure was attained through a conventional design configuration. The use of aluminum alloys is emphasized in the majority of structural components as a proven low-cost, lightweight material. It was important to keep focused on simplicity, yet not let this design theme detract from the effort to produce a stronger, lighter, and aerodynamically superior aircraft.

The materials used in the LCX construction are aluminum alloys 2024-T3 and 7075-T3, titanium, steel 300M, and graphite-epoxy composite (Gr-Ep). Aluminum material accounts for approximately 80% of the structural makeup. Its high strength characteristics and ability to withstand minor damage without compromising the safety of the aircraft are driving factors behind this decision.

Aluminum alloy material 2024-T3 was used for areas subjected to fatigue due to extended application and relaxation of tension stresses. Regions prone to such stresses include the pressurized cabin shell and lower wing skin.

Titanium is a suitable alternative to light alloys in regions of prolonged operating temperatures in excess of 150°C, where aluminum would deform. Other desirable features of titanium include minimal creep deformation and a greater strength-to-weight ratio. Titanium alloys comprise up to 5% of the structural weight of the LCX. Titanium panels are also used on the upper wing surface because of their machining properties and strength.

LCX structures that perform duties under high compression, such as the landing gear, are composed primarily of steel alloys. The use of such steel components was kept to a minimum since these alloys have fairly undesirable weight characteristics.

8.2 Wing Design

With the exception of the laminar flow control technology, the LCX basic wing structural skeleton is typical of that found on a similar class commercial transport. An initial investigation into stress concentrations yielded the results found in Table 8.2.1.

Moments		
Mx	1,453,400	lb. in.
My	86,000	lb. in.
Mz	61,000	lb. in.
Shear Forces		
Sz	123,000	lb. in.
Sx	2600	lb. in.

Table 8.2.1: LCX Wing Forces

The materials and dimensions of the wing components are specified to withstand these loads. The LCX wing primary structure is aluminum and comprised of front and rear spars, webs, stringers, ribs, and upper and lower spars. Figure 8.2.1 shows that the wing ribs are built parallel to the flight path in order to ensure a smooth aerodynamic shape between the spars.

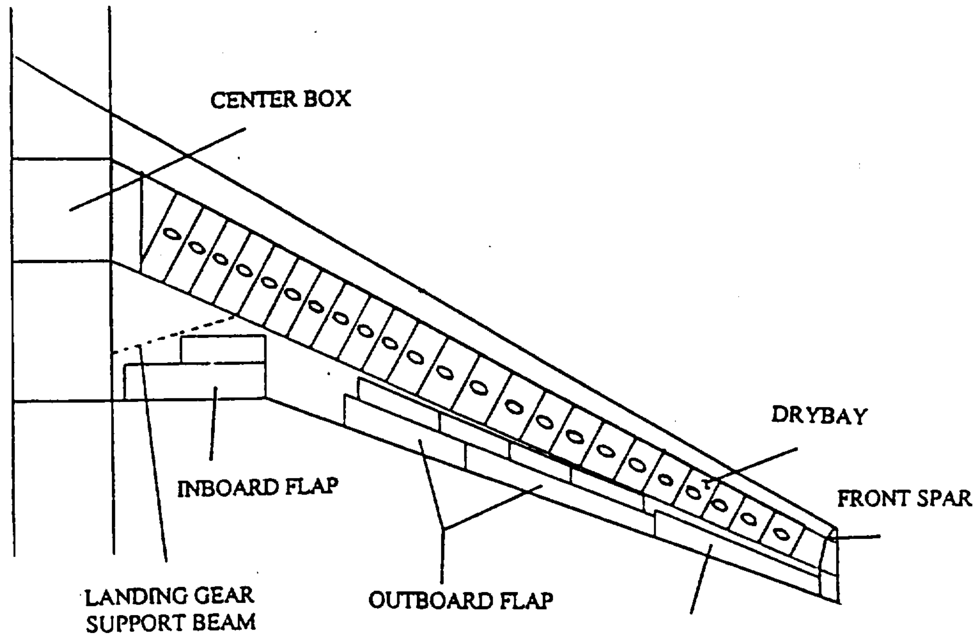


Figure 8.2.1: LCX Wing Layout

The wing rib spacing is a factor of the wing loads, and it is desirable to get hinge-rib locations to coincide with the rib station. Reinforced ribs are also used for engine-mount attachments and landing gear attachments. Spars are constructed by making caps in the wing box a different thickness. The forward lower, and rearward upper sparcaps need to be structurally reinforced to withstand high tensile stresses.

Spanwise stiffeners are closely spaced in order to keep the buckling of the material to a minimum. Since the LCX wing utilizes laminar flow control, the front spar is located at 20% chord, and the rear spar is located at 60% chord leaving adequate space for the appropriate high lift devices (Figure 8.2.1).

8.3 Wing Covers

The LCX wing cross section is built such that the skin is distributed around the periphery of the profile. The distributed bending material consists of stiffening elements running in the spanwise direction. The wing bending loads which cause compression at the upper surface of the wing are generally higher than those causing compression at the lower surface. This requires that the stiffening elements along the upper surface be more efficient and closely spaced than those on the lower surface. The torsional moments are subjected to resistance primarily by the skin and front and rear spars.

8.4 Fuselage Structure

The LCX fuselage structure was designed through semi-monocoque construction using stiffening members such as frames, bulkheads, stringers, and longerons to stabilize the tube of thin skins under compression and shear. The fuselage itself is comprised entirely of aluminum alloys. The skin is a sheet of 2024-T3 with a thickness of 0.035 in. Attached to the shell are stringers and spars running 6 inches deep. Since the upper part of the fuselage is under greater concentrated compressive force, stringer spacing is closer than the bottom half of the fuselage. Longerons are spaced at one foot and run from the front fuselage to the aft fuselage.

8.5 Skin and Stringers

Skin and stringers are the most critical structure since they carry all of the primary loads due to fuselage bending, shear, torsion and cabin pressure. These primary loads are carried by the fuselage skin and stiffeners with frame spacing at regular intervals to prevent buckling and maintain cross-section. The most efficient structure will have the least number of joints or splices; therefore the LCX skin panels are large, limited only by available mill sizes. Stringers, being rolled from strip stock, are limited in length by manufacturing techniques. The LCX also uses single splices for the longitudinal skin joints.

8.6 Frame and Floor Beam

The LCX frame and floor beam support the fuselage skin-stringers panel, hold the fuselage cross-section to contour shape, and limit the column length of the longerons and stringers. In addition, this structure distributes externally and internally applied loads onto the shell, redistributes shear around structural discontinuities, and transfers loads at major joints. The LCX is also designed to support heavy conventional bulkheads and frames, which preserve the circular shape against elastic instability under compressive longitudinal loads.

8.7 Fatigue Life of Materials

The LCX was designed to withstand a variety of fatigue loading conditions, including: ground load, taxiing, takeoff, maneuvering, gust loads, and pressurization. The most critical part of the LCX structure are the wings, which carry the most important loading cases that arise from ground loads and gust loads. Since the magnitudes and respective frequencies of positive and negative gust loads are the same, the fatigue life of the LCX wing materials are estimated using a method based on the Linear Cumulative Damage Hypothesis (Introduced and Tested by Aeronautical Research Laboratories in Melbourne

8.8 Empennage Structure and Layout

The basic structure layout of the LCX horizontal and vertical tails is the similar to that of the wing. A conventional horizontal tail is used to minimize the manufacturing and material costs. This tail basically consists of left and right outboard sessions attached to the center box within the aft fuselage. The LCX stabilizer is designed to pivot on two self-aligning bashing type hinge joints attached to the bulkhead in the fuselage. The angle of attack is adjusted by an electrically driven jackscrew. The center box is designed with titanium distributed in sparcaps and cover skins for greater bending strength. The vertical tail is designed in a similar manner, utilizing a multi-spar structure with cover panels. The structural design for both the elevator and rudder are similar in construction. Front and rear spars and the skin form a box beam which is the primary structural member of the elevator and rudder. Due to the high torsional load and local aerodynamic pressure, ribs are located in close proximity with each other to withstand these loads.

8.9 V-n / Gust Diagrams

The LCX envelopes were created as a function of gross takeoff weight, wing area, flight altitude conditions, and structural load limits. The resulting V-n diagram is typical for a commercial transport aircraft. The initial curves running from the origin of the graph are the positive and negative stall limit borders. The horizontal straight lines represent the positive and negative structural load limits. A positive load factor limit of 2.5 g's and negative limit of -1 g correspond to historical values for the same class of aircraft. If these values are exceeded in flight, the aircraft structure may fail. The vertical straight line designates the never exceed design dive speed, which is 313 knots equivalent airspeed. Exceeding this airspeed limitation also may cause structural failure.

Other important airspeeds found in the flight envelope include Vs1, Va, and Vc. These are the 1-g stall airspeed, maneuver speed, and design cruise speed, respectively. The airspeed at which the LCX will stall in a 1 g loaded condition is 143 knots equivalent airspeed. The maneuver speed for the LCX is 227 knots equivalent. This can be seen in Figure 8.9.1 found on the following page. This is also known as the "turbulent air penetration speed." At this airspeed, if the aircraft experiences a sudden gust, it will stall before experiencing structural failure. This airspeed is very important to pilots for obvious reasons. Finally, the design cruise speed for the LCX is 250 knots equivalent, which is simply the conversion of the most efficient cruise mach (.8) with altitude conditions taken into consideration.

A gust diagram was created for the LCX to investigate the possibilities of exceeding the structural loading limitations should the aircraft encounter a strong gust. Factors that contributed to this analysis included the wing lift curve slope and geometry and the aircraft weight at the most critical condition and airspeeds. The most critical weight condition used is at landing weight.

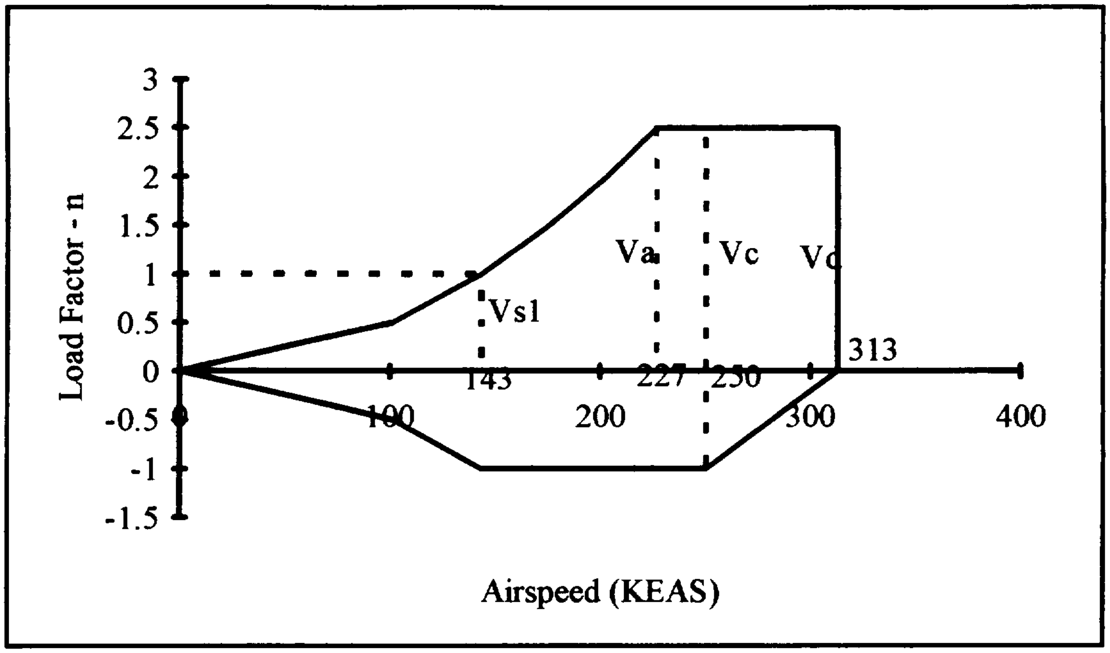


Figure 8.9.1: LCX V-n Diagram

The original positive stall limit line was plotted with three gust lines- cruise (Vc), maximum gust intensity (Vb) and maneuver speed (Va) as seen in Figure 8.9.2 found on the following page. It was important to find out the maximum possible loading due to a gust. This point is found where the positive stall limit line intersected the maximum intensity gust line. The speed where this occurs is at 232 knots equivalent airspeed, producing a gust loading of 2.12. Fortunately, this value falls within the maneuver envelope positive limit of 2.5 g's. The negative gust limits were not investigated since this is not the critical case. The positive load limits are the critical case that may be exceeded since a gust will produce a positive g load, not negative.

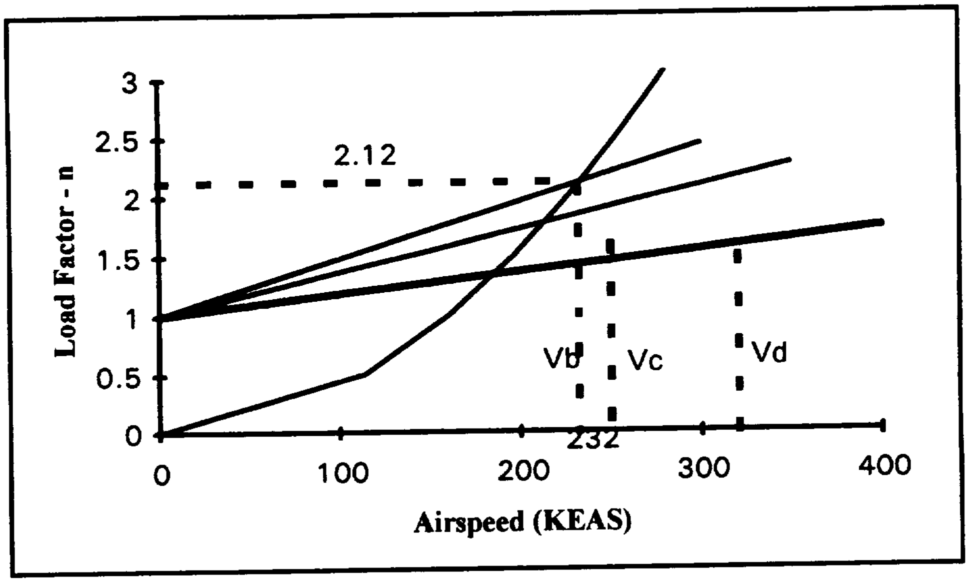


Figure 8.9.2: LCX Gust Loading

9.0 WEIGHT / C.G. EXCURSION

Weight analysis was done on the LCX through two methods and results were compared. The initial method used aircraft fuselage, wing, and empannage sizes and geometry for component weight estimations. The second method was to use the aircraft synthesis software (ACSYNT), which made weight estimations through the use of historical trends of weight fractions of aircraft gross weight. It was difficult to determine which method was more accurate for the LCX. It was decided that both analysis methods would have to be incorporated into the weight calculations. The fuselage and empannage geometry is fairly standard, thus the weights provided by ACSYNT were used for these areas. However, due to the incorporation of the hybrid laminar flow control as a key design feature of the LCX wing, the ACSYNT wing weights were scaled to account for the changes. Geometric analysis and correction factors were used for the wing and wing control surface weights. Manufacturer-published weights were used for the engines, auxiliary power unit, and air-conditioning packs. The resulting weight breakdown is shown in Figure 9.1 found below.

Some of the key design configurations were decided with weight considerations well before the weight analysis was actually carried out. It was not certain whether the engines should be located under the wings or on the aft portion of the fuselage. One important consideration was that of the critical one-engine inoperative situation that would subject the LCX to a large adverse yaw. When initial weight estimations were made, it was found that with wing mounted engines the vertical tail would increase in weight by

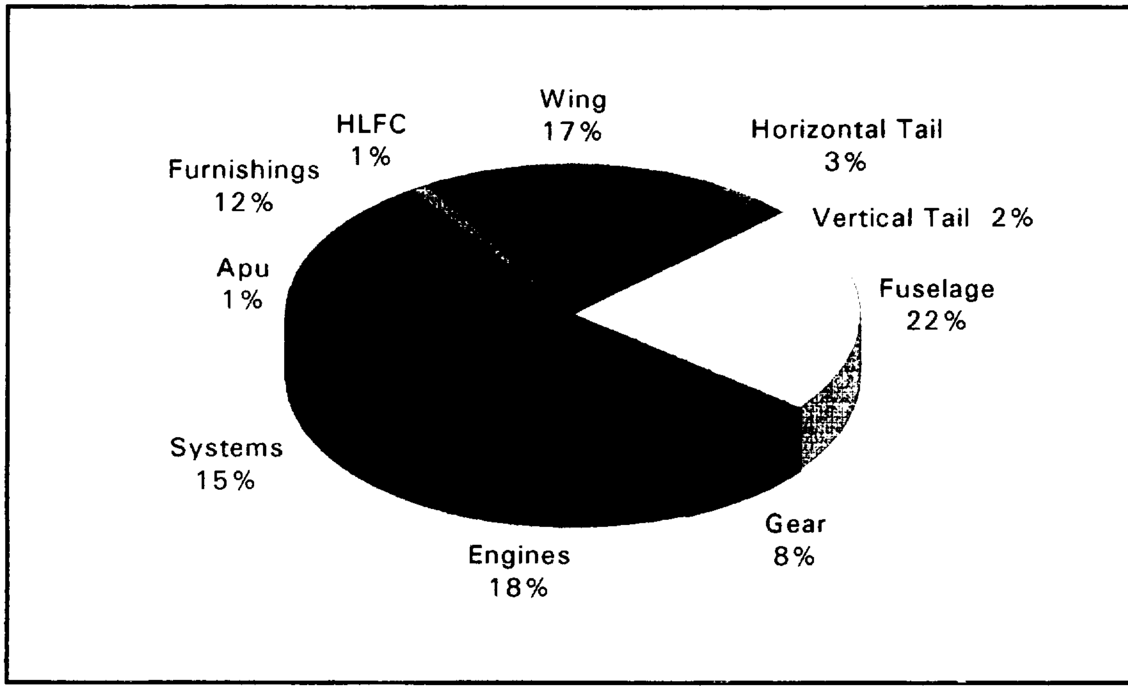


Figure 9.1: LCX Weight Breakdown

about 20% due to the necessity for a large vertical tail surface to compensate for this critical condition. Also it was found that landing gear weight would increase due to the necessity for longer struts to clear the engine intakes of potential foreign object damage (FOD). With the engines mounted aft, the major weight concern comes from the lack of a negative lifting force by the engines to counteract the bowing tendency by the wings in flight. Major structural "beefing-up" would need to be done to compensate for this loss. This would be difficult with the incorporation of the hybrid laminar flow control. In addition, since the laminar flow control system operates dependent upon the engines, it would be more efficient to have these power sources close to the system.

Finally, a c.g. excursion analysis was performed to see the different effects of both configurations. This was where the final decision was made clear. The c.g. travel envelopes were created for both engine mounting locations and were then compared. Due to the large moment created by the heavy engines so far aft, this configuration produced an envelope that was two times as wide as that of the wing-mounted engine configuration. With the decision to incorporate the engines into the wing structure, final calculations showed the c.g. to land approximately 2 feet in front of the aerodynamic center, with a maximum travel of 20% of mean geometric chord.

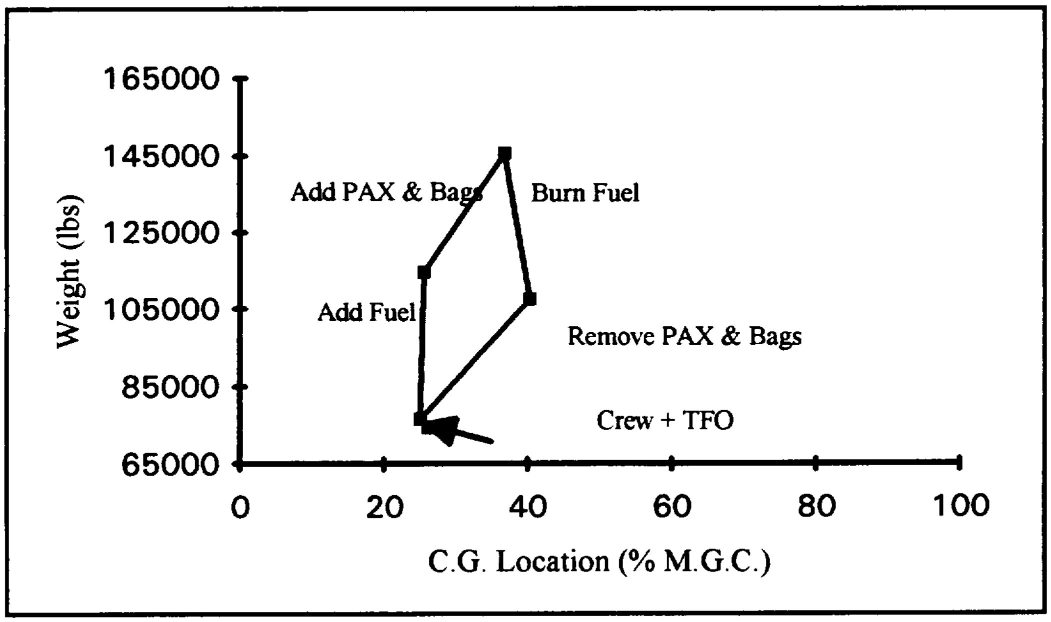


Figure 9.1.1: LCX C.G. Excursion

10.0 STABILITY AND CONTROL

10.1 Empennage and Control Surface Sizing

The empennage and control surface sizing was completed using ACSYNT 2.0 from NASA. The initial inputs into ACSYNT were obtained using the horizontal and tail volume coefficients from similar aircraft. The first cut areas for the empennage where calculated from these coefficients. The results were compared to the results obtained from the stability module of ACSYNT and thus the empennage was sized.

The control surfaces are sized to provide the largest amount of control power without adding to much complexity. The control surfaces extend from the trailing edge to just aft of the rear spar. Hinged control surfaces were not used because they would increase the complexity and maintenance of the empennage. The vertical tail is sized by engine out and Dutch roll characteristics while the horizontal tail is sized for rotation.

10.2 Fly-by-wire Control System

Fly-by-wire is implemented in the LCX for several reasons. Computers will be used to control the pressure distribution over the wing by changing the deflection of the aft flap. The engines are under digital control also. Electronic control of all parts of the aircraft allows for the systems to communicate between themselves. This requires electronic control of the flight control systems and thus fly-by-wire technology. It is likely that in the future there will be digital control of all systems in the aircraft with all systems being optimized as a group adding to the overall efficiency of the aircraft.

11.0 SYSTEMS

11.1 Pneumatic/Environmental System

The LCX pneumatic system supplies compressed air to many vital aircraft systems. The air-conditioning system, hydraulic reservoir, engine starters, anti-icing system, and potable water tanks all demand pressurized air for efficient operations. Each engine has a low/intermediate port as well as a high pressure port as sources of pressurized air. Additionally, there is an APU bleed source for ground operations. From each of these ports, the air runs through a check valve to prevent reverse flow, followed by a precooler. Temperature and pressure of the air supply is automatically regulated by the system. Low pressure air is used during climb, cruise, and holding conditions. High pressure air is used during descent and low power settings. The high pressure system is regulated at approximately 55 psi.

The LCX environmental control system (ECS) is designed to be energy-efficient in providing passengers and crew with conditioned air. This efficiency lies in the fact that only about 50% of all conditioned air comes from engine bleed, while the rest of the air is provided by filtered, recirculated air. Lavatory and galley ventilation, forward cargo compartment heating (the aft compartment uses electrical heating), and electrical equipment bay cooling systems also rely upon the air-conditioning system.

The ECS has a high-pressure water separation component, consisting of a condenser, water extractor, and reheater. Water that is extracted from the air is ducted and sprayed into the ram air upstream of the heat exchangers, which increases the efficiency of the air cooling system.

Odors and smoke are vented from the lavatories and galleys through overhead ducting, forced out by vent fans. Both the forward and aft cargo compartments have independent, closed-loop systems that are self-regulating. Air from the forward cargo compartment is drawn from the aft end by a compartment fan and is warmed by heat transfer from fan motor. The aft compartment system is similar except that it uses electrical air heating. The flight deck is provided with conditioned air through sidewall, windshield, and individual crew outlets.

The cabin pressurization system is regulated by controllers in the main equipment center. Air data computers provide actual airplane altitude information to these controllers. Microswitches in the throttle quadrant automatically set controllers to pre-takeoff mode when appropriate. The pressurization system utilizes air discharge via an outflow valve that is driven by either of two separate alternating current motors. A dc system is also utilized for manual operation. Pressure sensors will trigger an altitude warning switch and alarm to alert the crew of excessive cabin altitude (>10,000 ft.). The system will go through an automatic shutoff at cabin altitudes in excess of 11,000 ft. The system layout can be found in Figure 11.1.1.

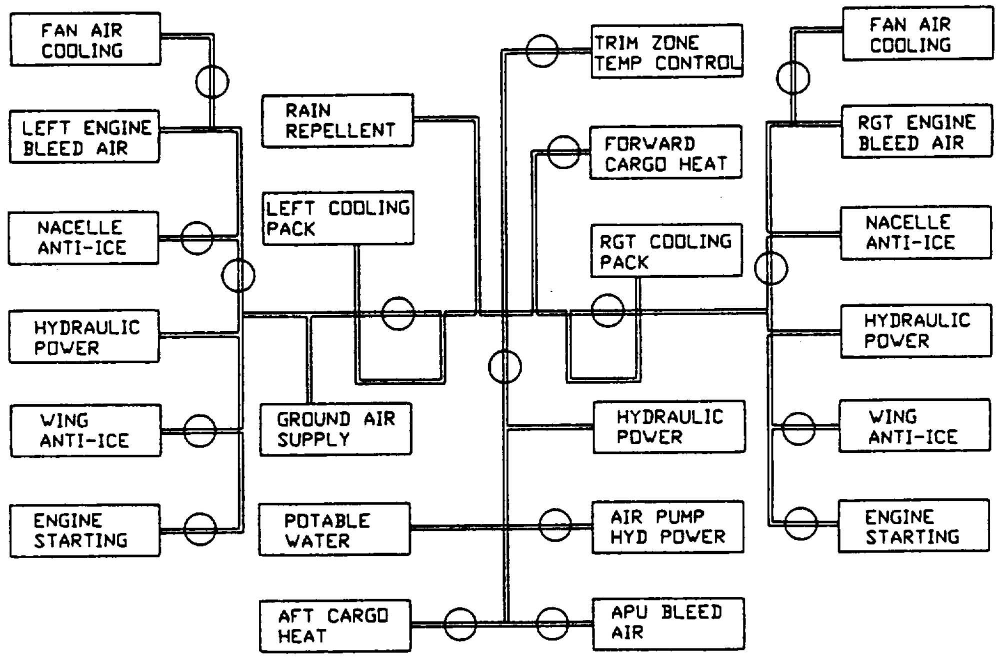


Figure 11.1.1: LCX Pneumatic System

11.2 Hydraulic System

The LCX has hydraulic power distributed through three systems- left, right, and center. There are also three pumps in each system to provide reliability. Primary flight controls have three separate systems supplying power to power control actuators for the control surfaces and autopilot servos. The stabilizer trim unit and brake systems all have dual redundancy. Only one hydraulic power source is used for the thrust reverser and landing gear systems. The philosophy used is to provide more redundancy for the critical systems, where no redundancy is typically deemed critical for other systems.

The left and right systems are very similar, each powered by one engine-driven pump (EDP) and one alternating current motor pump (ACMP). These two systems are mechanically connected by a power transfer unit (PTU). In the event of a loss of the left engine or left EDP, a hydraulic motor in the right system powers a hydraulic pump in the left system to provide sufficient flow to retract the landing gear and operate the flaps and slats. The ram air turbine (RAT) retract actuator is powered by the right system. The RAT is installed in the right aft wing-to-body fairing to automatically provide emergency hydraulic power to the center system flight controls in the event both engines become inoperable. The pilot has the authority for manual deployment through an override switch. Retraction can only be accomplished on the ground. When the RAT is extended in flight, airflow drives the turbine, which drives the hydraulic pump.

The center system is smaller than the left and right systems. It is powered by two ACMPs and is responsible for only the flight controls. The RAT powers the center system to provide hydraulic power for emergency operation of the flight controls.

All three systems can be serviced through a central fill point. The LCX pneumatic system provides reservoir pressurization, which is available whenever the pneumatic ducts are pressurized. External hydraulic power can be connected to each system. The hydraulic system layout is given in Figure 11.2.1 found on the following page.

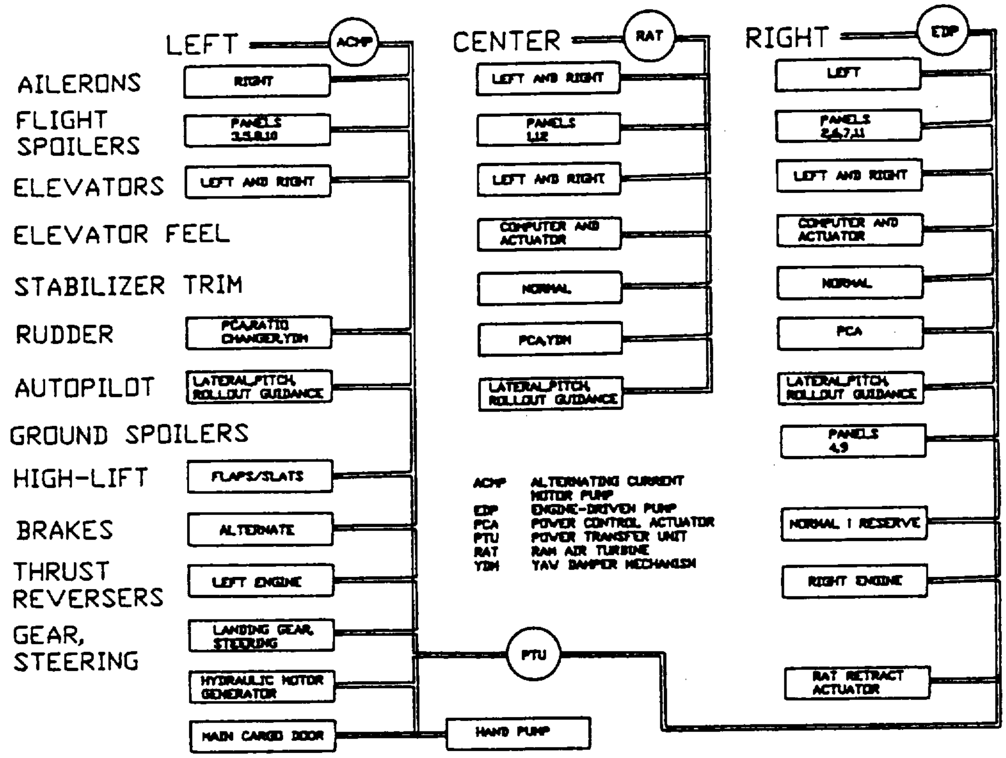


Figure 11.2.1: LCX Hydraulic Systems

11.3 Electrical Power

The LCX electrical system includes provisions for both alternating current (AC) and direct current (DC) operations. On the ground, ac power is provided from either the external power panel or the auxiliary power unit (APU). In-flight operations use power provided by the integrated drive generators (IDG) mounted on each engine. Power can also be supplied in flight from the APU-driven generator. For ETOPS certification, an optional hydraulic motor generator (HMG) is used. This generator would operate as a one-time-limited backup source in the event of loss of all main electrical power. Normal dc power is produced in the LCX by ac/dc conversion. This battery system is used to provide alternate dc and standby power.

Ground service supplies power for interior lights, battery chargers, cooling fans, and cargo handling equipment. DC batteries also provide power for ground equipment. A main battery and battery charger system provide critical power for the autoland system. A separate APU battery and charger system provide power for APU starting.

All generated power in the LCX is distributed among the three equipment racks-front, main, and rear. The main equipment rack includes such components as the airplane information management system, window heat control unit, cabin temperature controller, traffic alert/collision avoidance, audio entertainment, flight director system, flap/slat electronics unit, and PAX address cabin interphone. The forward rack includes the fuel quantity processor unit and forward cargo controller, while the rear rack houses the brake system control unit, brake temperature monitor unit, aft axle steering control unit, and tire pressure monitor unit. The electrical system layout is found in Figure 11.3.1.

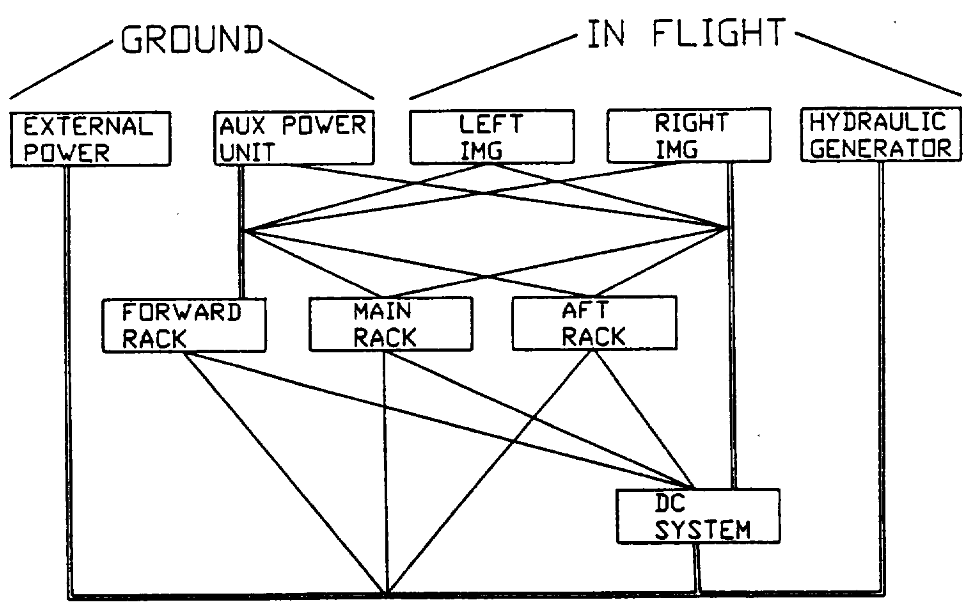


Figure 11.3.1: LCX Electrical System

12.0 LANDING GEAR

Layout

The LCX will incorporate a double main gear and single nose gear assembly. Gear arrangement on the LCX is a tricycle configuration. The main gear will be a dual twin gear with two wheels per main strut. Each of the two main gear struts, attached to the wing underside, will retract into the undercarriage area of the fuselage to be fully encased by the wheel well. The nose gear will have two wheels attached to its strut and will retract fully into the forward fuselage underside of the LCX. Retraction control for the landing gear will be a lever placed in the cockpit accessible to both the captain and first officer.

The length of the landing gear have been determined for a combination of desired qualities. The landing gear on the LCX allows for a fairly low engine ground clearance for the special engine pylon placement needed for the LCX Laminar Flow Control while allowing for minimal FOD (Foreign Object Damage). For weight considerations, the nose gear on the LCX will create a slope of 3 degrees while on level ground due to its shorter length. For the LCX, the main landing gear have been placed 15 degrees behind the aft C.G. to allow for a adequate rotation angle without tail scraping. The fuselage will be fitted, however, with a skid pad in case of over-rotation. Additionally, as a factor of the aircraft center of gravity, the tip over angle for the LCX was determined to be 56 degrees, less than the critical 63 degree limit therefore minimizing the possibility of tipping over.

12.1 Main Gear

The LCX main gear will incorporate an oleo-pneumatic strut to support the landing shock as well as to provide a means of ground mobility. The main gear of the LCX will support approximately 91% of the weight of the aircraft. The diameter of the main gear shock strut is 8.5 inches. Using an equation from (Ref. 27), the total stroke of the main landing gear was calculated to be 18.5 inches. This calculation allows the LCX to undergo 18.5 inches of gear travel in the vertical direction upon landing of the aircraft. Spray deflectors will be installed on the main landing gear of the LCX to deflect water away from engine intakes. Also incorporated on the landing gear is a system to retract the wheel well door to help act as a debris shield for wheel well protection from object damage.

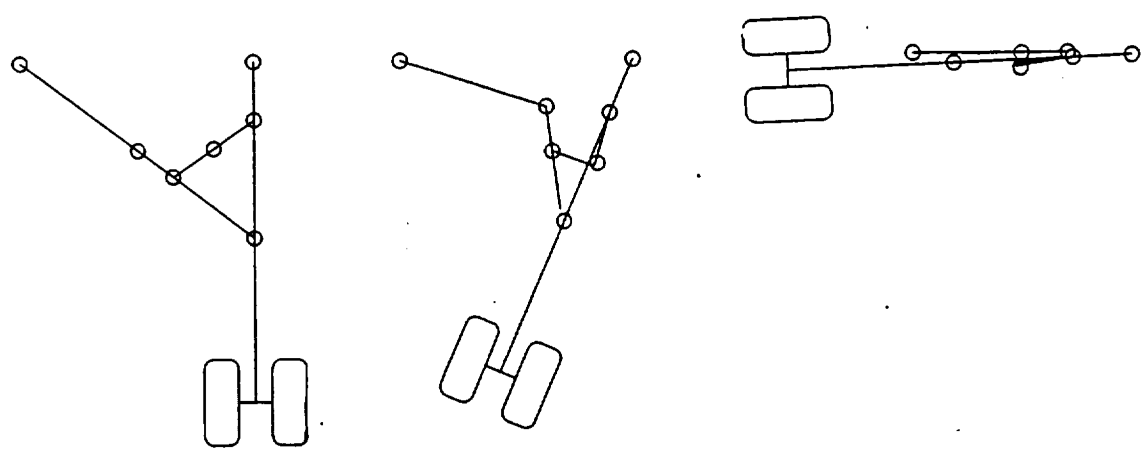


Figure 12.1.1: LCX Main Gear Kinematics Retraction Scheme

The main gear will have side struts as well as drag braces attached to the main strut. As seen in Figure 12.1.1, the side brace assembly is attached to provide lateral support to the main gear. During retraction, the side braces, using links, will fold up along the main gear strut. Torque links will insure that the main gear is held in an irrotational position in both the extended and retracted configurations..

12.2 Doors for Main Gear

On the LCX, each of the main gear is equipped with a retractable door. One of the main functions of the doors is to act as a barrier to protect the wheel wells from debris accumulation. When the gear is extended, the doors will still be in a closed position. The doors will open long enough for the gear to retract into the wheel well and then shut therefore enclosing the entire wheel well. If for any reason the doors should fail to shut during landing, skids attached to the edges of the doors will act as a protective shield to prevent damage. In case of lock failure in the gear retracted position, the wheel well doors will also be strong enough to support the gear.

Doors for the main gear will be directly linked to the gear strut via a mechanical assembly in order to open and close with the gear movement to the extended and retracted position. In the extended position, the gear doors will be closed. The door will then open to allow the main gear to enter the wheel well. The door will then shut again upon retraction. For landing gear extension, the same operation will occur. Manual bypass levers will be placed so that they are accessible by ground maintenance personnel. All locks and pressurization equipment in the wheel wells as well as the hydraulically locked doors will be relaxed or depressurized when the manual bypass is used.

12.3 Nose Gear

On the LCX, a two wheeled nose gear will be used for landing shock support, weight support, and steering of the aircraft. The nose gear supports approximately 9% of the weight of the aircraft. Nose gear on the LCX is retractable and located in the forward section of the aircraft. The diameter of the nose gear shock strut is approximately 5 inches. Hydraulically actuated cylinders will be used for the extending and retracting process. The nose gear is positioned so that in the retracted or extended position, the wheel is clear of the cockpit area.

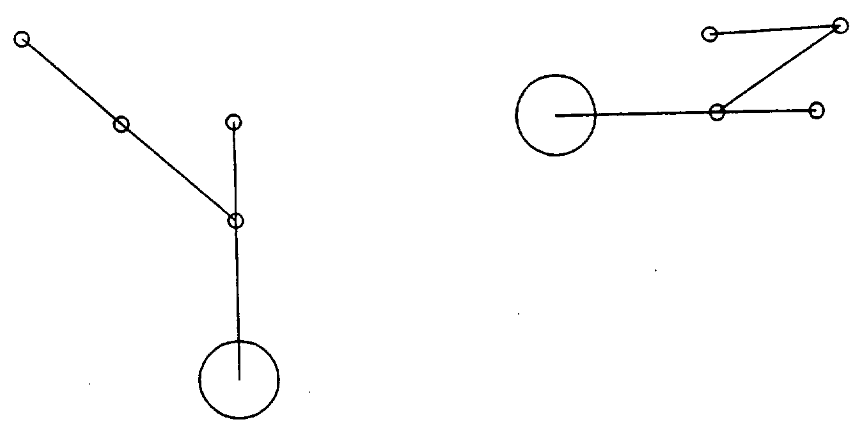


Figure 12.3.2: LCX Nose Gear Kinematics Retraction Scheme

As with the main gear, the nose gear will utilize an oleo-pneumatic shock strut to absorb the weight of the aircraft and landing shock. Drag links will support the nose strut in both the fore and aft position. Lock links will lock and secure the drag braces while in the extended and retracted positions (Figure 12.1.1). On the LCX, two doors will act as an aerodynamic seal to enclose the nose gear wheel well. These doors will be mechanically linked to the gear strut so that the doors move to the open and closed position based on position of the nose gear assembly.

The nose gear on the LCX will be equipped with ground sensing mechanisms to provide a mechanical system to switch aircraft control systems from a flight mode of operation to a ground mode. The system also switches the aircraft from ground to flight mode. Sensors will engage a lock mechanism on the landing gear lever in the cockpit. This lock will prevent the unintentional retraction of the landing gear while on the ground. If desired, the nose gear can be retracted using a override switch while on the ground. Spray deflectors will be attached to the nose gear at the lower end of the nose shock strut. These spray deflectors will help minimize water and FOD to the engines placed on the wings of the LCX. In addition, debris deflectors will be attached to the spray deflectors to also help with FOD.

12.4 Steering

Steering of the LCX will be provided by using the nose gear as well as differential braking of the main gear. Two hydraulic cylinders will be placed on both the right and left of the nose gear landing strut. These cylinders will provide steering control and direction by pulling or pushing in the desired direction of travel. The LCX will use two steering mechanisms. The rudder pedals an the LCX will provide 7° of directional control to the left and right of the center line of the aircraft. Table 12.4.1 on the following page shows the steering clearance distances for the LCX.

Wingtip Clearance	75.6	ft.
Nose Clearance	70.4	ft.
Wing Gear Clearance	33.9	ft
Nosegear Clearance	49.1	ft.
Minimum Width for 180 deg. turn	121	ft.
Nose Gear Steering Angle	68	deg.

Table 12.4.1: LCX Steering Clearance Around Turning Center

The LCX will also be equipped with a steering tiller located on the captain's side of the cockpit. The steering tiller will provide a 68° steering angle to the left and right of the center line. The nose gear can be turned only when ground sensing mechanisms in the nose gear have switched the aircraft to ground mode of flight.

12.5 Wheels and Tires

The LCX will use four forged aluminum, split type wheels on the main landing gear, two per gear. The wheels have been tested and certified to an equivalency of 50,000 miles before delivery. Tire data can be found in Table 12.5.1.

The tires used on the main gear are manufactured by the B.F. Goodrich Corporation. Tires for the gear will be two 44 x 16 size tubeless radial tires with a ply rating of 32. Maximum unloaded tire inflation of these tires will be 225 psi and the maximum speed rating will be 225 miles per hour. With an inflation pressure of 156 psi and a tire deflection of 7.45 inches upon landing, the footprint, or area of tire contact, while on the ground will be approximately 1.6 square feet. To prevent blow-out from excessive pressure build-up from heat, thermal fuse plugs will be incorporated into the tire to prevent this occurrence. The calculated LCN was found to be 65.

Main gear					
Tire Selected for Main Gear	44x16		Tire Inflation	225	psi
Loaded Radius	17.9	in.	Max Operating Tire Speed	225	mph
Max loading	45000	lb.	Max Actual Width	16.00	in.
Rolling Radius	17.9	in.	Max Actual Diameter	43.25	in.
Ply Rating	32		Tire Deflection	7.45	in.
Tube Type	tubeless		Footprint Area	225	sq. in.
Required Inflation Pressure	156	psi.			

Nose gear					
Tire Selected for Nose Gear	29x7.7	in.	Tire Inflation	230	psi.
Loaded Radius	12.2	in.	Max Tire Operating Speed	200	mph
Max Loading	13800	lb.	Max Actual Width	7.85	in
Rolling Radius	12.2	in.	Max Actual Diameter	28.4	in
Ply Rating	32		Tire Deflection	4.00	in.
Tube Type	tubeless		Footprint Area	69	sq. in.
Required Inflation Pressure	102	psi.			

Table 12.5.1: LCX Tire Data

The nose gear of the LCX will use two forged aluminum, split type wheels, one for each side of the strut and be equipped with tires manufactured by B.F. Goodrich. The tire size is a 29 x 7.7 tubeless radial tire with a 16 ply rating. Maximum unloaded tire inflation of the nose gear tires is 230 psi with a maximum speed rating of 200 miles per hour. The nose tire will have a maximum deflection of 4 inches upon landing of the aircraft. With maximum loading, this tire deflection, and a footprint of .5 square feet, the tire inflation pressure will be around 100 psi.

12.6 Brakes

The brakes on the LCX are an important and integral part of the entire gear assembly. On the main landing gear, hydraulically operated, multiple disk brakes will be installed for each wheel of the main gear. Carbon brakes will be used to provide braking for the LCX. Carbon brakes have high thermal conductivity, low thermal expansion, high thermal shock resistance, and a high temperature limit. These properties are desirable for a braking system. With carbon brakes capable of maintaining strength at high temperatures, overhaul time could be reduced drastically over new beryllium and conventional steel brakes. Brake wear will be monitored using sensors allowing for wear determination without the need for disassembly. Manual braking can be accomplished using brake pedals in the cockpit. The parking brake on the LCX, used in cases of prolonged non-use, will be capable of maintaining sufficient and adequate brake pressure for a period of time no less than eight hours.

Automatic braking is incorporated into the LCX. Using a selected rate of deceleration determined by the flight crew, the brakes will automatically engage upon landing with the thrusters in the idle position. The system will compensate for any delay in the nose gear touching down after the main gear during landing. The autobraking system will work in conjunction with the other devices such as thrust reversers and speed brakes to allow a constant deceleration of the aircraft. In a rejected take-off condition, the brakes will apply maximum pressure to the brakes if the throttles are moved to the idle position with RTO (Rejected Take-Off) switch applied and the aircraft speed being greater than 85 knots. Automatic disengaging of the autobrake system will occur if the thruster is moved, manual braking is applied, or the system disarm switch is flipped.

The LCX will be equipped with an anti-skid braking control unit connected to each of the main gear assemblies. The anti-skid system will prevent the wheels of the main gear from locking up therefore eliminating skidding during application of the brakes. The anti-skid unit, located in the electronics bay, will monitor skidding with sensors in the wheels. Wheel speed is compared to the speed of the other wheel. If a discrepancy occurs between the wheel velocities, skidding is compensated and corrected for. The anti-skid device can be armed or disarmed with a switch located in the cockpit. Automatic arming or disarming will occur when the gear is extended or retracted, respectively.

12.7 Indicators

Status and sensor information regarding the landing gear will be reported and displayed on the EICAS display in the cockpit of the aircraft. Tire temperature, tire pressure, gear position, brake temperature and anti-skid control indications will be displayed. In addition, green, amber, and red lights for each of the main gear and the nose gear will be used as indicators. If there is disagreement between actual and indicated gear position, warning lights will illuminate and an aural warning horn will sound. Red lights will turn on if there is any major malfunction with the landing gear systems. If a problem should arise that is not detrimental to flight operations, amber warning lights will illuminate. Green status lights will indicate that operations are normal.

13.0 MANUFACTURING

Existing technology will be used for the efficient production of the different aircraft components. The modern method of pre-design and fit testing with computer aided design (as developed by Boeing), will be utilized to insure part compatibility before production. Die molding will be used for the production of metal components such as the landing gear struts and cargo decking.

The wing of the LCX will consist of the typical spar and rib structural skeleton. The spars will consist of laid-up C-channels that will form an I-beam when joined back to back. Many of these small I-beam components will be assembled to form a full length spar. All wing inner systems (fuel, flight controls, engine controls) will be incorporated, followed by installation of the control surfaces. The attachment of the upper wing skin is the final step in the wing manufacturing process.

The fuselage is broken down at this stage into three sections: nose, tail, and fuselage skin. Each of these sections is split into a left and right half. These components, as well as the three main bulkheads, will be set in place using a jig and overhead crane system and joined. The cargo bay floor and major systems can be added at this point.

Final assembly of the LCX is prepared by the movement of the fuselage, wing sections, horizontal tail, and vertical tail on rails to the final assembly room. Silicone protectant is applied at this stage to all subassemblies to ensure complete, uniform coverage. At this point, engines and avionics are installed followed by testing for proper operation. Then the LCX is ready for roll-out and the final paint coating, as per the customer's desire.

Each LCX must go through a specific number of ground and flight test hours as required by the Federal Aviation Administration. Upon successful completion of many testing exercises, each aircraft will be issued an Airworthiness Certificate from the FAA. This will certify the aircraft for commercial operations and is the final step before the LCX will be sold.

14.0 AIRPORT OPERATION AND MAINTENANCE

14.1 Operation

The LCX is a versatile aircraft in that it can be operated from airfields ranging from international airports in metropolitan areas to regional and municipal airports in less populated areas of the country.

14.2 Servicing

International airports have major facilities and equipment to service the aircraft during ground operations. For this reason, the LCX can accommodate ground service equipment and personnel with minimum congestion. An airport equipped with a passenger bridge or jetway can use the bridge for loading and unloading of passengers. The arrangement of ground support equipment can be seen in Figure 14.2.1. The LCX is fitted with tow accessories on the nose landing gear for use by the ground tow vehicle. The tow vehicle will be used to back the aircraft on to the ramp without the use of main engine power for acceleration. By-pass valves located on the nose gear will allow the tow vehicle to provide directional guidance to the aircraft during the tow.

A galley service truck will have access to the aircraft in both the aft and forward sections of the aircraft. The forward truck will provide galley service and restocking of supplies and amenities for the forward galley which serves the first class and forward economy section of the aircraft.

Next to the forward galley service vehicle, space is provided for an external electrical power generator. This mobile generator will provide electrical power for all electricity needs during the loading and unloading of the aircraft. While on the ground, this generator will have priority over the APU or direct current system in providing power.

Loading of baggage onto the LCX will be faster and easier with a bulk cargo loader used in the loading area of the aircraft. The loader is a mobile vehicle with a conveyor belt to load baggage and light cargo onto the aircraft. Baggage is delivered from the terminal area to the aircraft via baggage cargo tractor and trailers. The LCX can accommodate two of these cargo tractors for baggage loading in the forward and aft holds of the aircraft.

Fuel for the LCX can be delivered by either the use of a fuel truck or by direct connection to underground fuel supplies at the airport. The use of a fuel truck is positioned in such a way that it will not add to the congestion surrounding the aircraft during servicing. The fuel truck will load fuel on the right side of the aircraft and park underneath the wing or as close to the aircraft as possible.

Lavatory servicing on the LCX can be accomplished using two lavatory service vehicles. One of these vehicles will service the forward lavatory while the other services the remaining lavatories on board. The trucks will remove waste water or raw sewage from drainage piping incorporated into the LCX for such purpose. The system is a single point system designed for speed, ease, and efficiency. During servicing, the toilets will be recharged for additional usage on subsequent flights. In addition to a non-potable water truck, a potable water truck will service the aircraft to replenish fresh water used by the galley and sinks in the lavatories.

In the rear of the aircraft, the cabin cleaning service vehicle will park and utilize the aft starboard door to access the aircraft. Due to this location, any work needed to be done on the aircraft can be accomplished with minimal interference from other maintenance and service groups and personnel.

While being serviced on the ground, an air conditioning unit will be hooked up to ports on the aircraft to provide ventilation through heating or cooling as dictated by climate. The air conditioning unit will be placed near the forward lavatory service station.

14.3 Minimum Servicing

Since the LCX is capable of landing at smaller municipal and regional airports, provisions had to be made to allow for a minimum required number of service vehicles to provide adequate and sufficient servicing for another flight. As seen in figure 14.3.1, the LCX can be serviced with a single lavatory truck, a fuel truck or fuel delivery system, potable water supply truck, and baggage trains. The aircraft is equipped with an ample potable water supply, a reservoir for non-potable water, and supply of additional beverage and snack items to allow the absence of one or two servicings at destinations. The LCX is also available with an optional air stair for use at airports not equipped with a passenger bridge, at airports which use shuttles for transporting passengers to the terminal area, or at airports without mobile aircraft stairs.

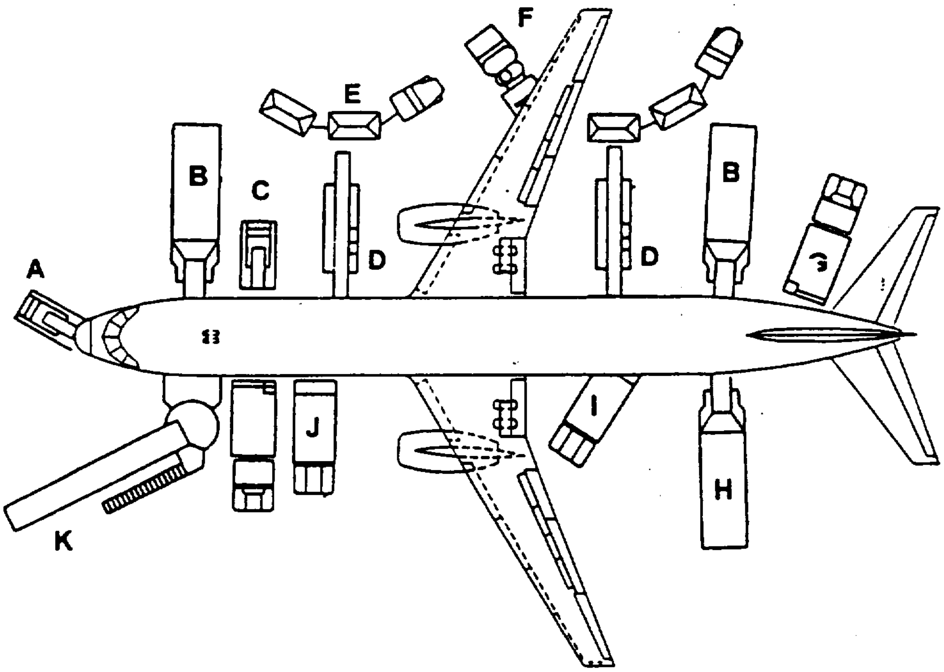


Figure 14.2.1: Ground Operations For Airport With All Servicing Options

Service Vehicle Locations

A	Tow Tug	G	Lavatory Service Vehicle
B	Galley Service Vehicle	H	Cabin Cleaning Vehicle
C	Electrical Power Generator	I	Potable Water
D	Bulk Cargo Loader	J	Air Conditioning
E	Bulk Cargo Train	K	Passenger Bridge
F	Fuel Train		

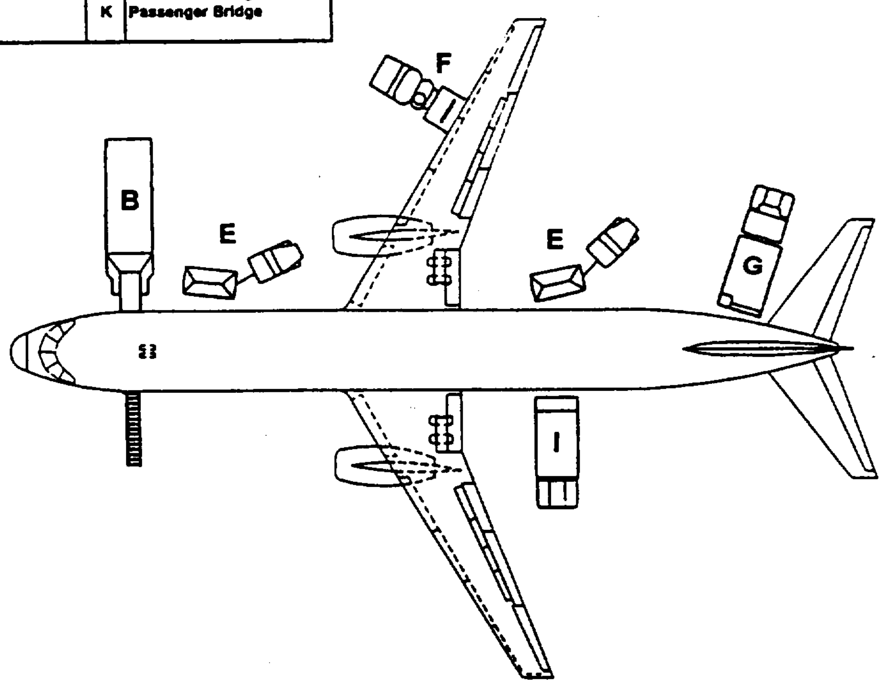


Figure 14.3.1: Ground Operations For Airport With Minimal Servicing Options

14.4 Maintenance Scheduling

The LCX has been developed with a maintenance program suggested for use by operators of the aircraft. The LCX will be required to go through different levels of maintenance according to operation time since the last required service.

Class 1

The first level of service for the LCX is the Class 1 service. This service is required after each termination of a flight segment at the destination unless a higher class check is scheduled for the aircraft at that time. Class 1 servicing includes visual inspection of the fuselage, tail and empennage, engines, wings, landing gear, tires and wheels, and leak prone areas.

Class 2

Class 2 service should be performed no later than 50 flight hours since the last Class 2 check. Class 2 service includes inspections similar to a class 1 service with the addition of galley equipment maintenance, checks of major fluids, cargo hold inspections, gear doors, emergency systems, and other general visual inspections.

Class A

The next level of maintenance recommended for the LCX is a Class A service and check. This check should be performed no later than 400 hours since the last Class A check. A Class A check includes all of the items in the Class 2 check as well as testing of avionics, emergency fire suppression systems, egress systems, hydraulic reservoirs, rudder and elevator actuators, and other more detailed sensor equipment.

Class C and Heavy Maintenance Visit

Two additional checks are the Class C and Heavy Maintenance Visit. The Class C check is a complete inspection of all the systems and subsystems of the aircraft. Class C checks should be performed no later than 450 days or 3000 hours since the last Class C check. The Heavy Maintenance Visit is the most thorough of all the inspections. In addition to all the servicing, the structural integrity and airworthiness of the aircraft is inspected. This inspection should take place no later than 1450 days from the last Heavy Maintenance Visit.

15.0 COST ANALYSIS

15.1 Fowl Enterprises Cost Philosophy

One of the design requirements of the LCX program is that the aircraft must be low cost . Since this is one of the major reasons for the creation of this aircraft, it is imperative that, throughout the entire design phase, a cost philosophy be kept clearly in mind. A theme was determined from the start in order to simplify the process and eliminate any unnecessary variables. The LCX cost philosophy has been to achieve the lowest possible direct operating costs (DOC) through the integration of modern technologies and conventional design. The incorporation of HLFC as a tool implies that there will be a rise in production costs per aircraft. This increase in production costs will be mostly attributed to a slight increase in tooling and quality control costs required for the HLFC system. Yet this is an accepted tradeoff by Fowl Enterprises with the understanding that long-term costs will be significantly reduced due to long-range operations and an assumption of rising fuel costs that will deem other aircraft less economically fit than the LCX.

Initial investigations into the different costs incurred in aircraft design have shown satisfactory results. The results of our investigation are seen in the Life Cycle Cost (LCC), Acquisition Cost, and the Direct Operating Cost (DOC) of the aircraft with a assumed production run of approximately 800 aircraft, and a service life of twenty years.

One of the components of the Life Cycle Cost of the LCX program is the Research, Development, Test and Evaluation cost (RDTE). The RDTE cost of the LCX is comprised of different areas such as development support and testing, airframe and engineering, test facility and simulation, and the test aircraft cost.

Aircraft Selling Price	$31 mil.	RDT&E Cost	$2.5 mil
Direct Operating Cost	.038 $US/PAX/nm	Acquisition Costs	$28.5 mil.
Indirect Operating Cost	.022 $US/PAX/nm.	Operating Costs	$386 mil.
Life Cycle Cost	$422 mil.	Disposal Costs	$3.3 mil.
Production Costs	$24 mil.		

Table 15.1.1: LCX Major Costs for the Program Per Airplane

Due to extensive research already done in the field of Hybrid Laminar Flow Control, any increase in development support and testing cost is attributed only to the application of HLFC to this particular aircraft program. Airframe engineering and design cost is one area where new design philosophies are making an impact in lowering the cost of RDTE. Integrated Product Development (IPD) and cross-functional organizations are scaling back the needed man-hours and labor costs for each phase of development. The use of the CATIA computer-aided drafting software allows for proper pre-development of parts and components such that the potential for post-production discrepancies is significantly reduced. Use of cross-functional organizations reduces the number of individuals working on one project and increases the effective productivity of each design group. RDTE costs for the LCX are reduced by the incorporation of these two management philosophies. With this management style, the Flight Test program, which is a significant percentage of the total RDTE cost of the program, will require minimal time and expense . This is due to the aforementioned reduction in post-production problems or discrepancies in produced test aircraft. The acquisition and disposal cost of the LCX takes in to account the minimal use of composites and other materials as well as aluminum. The operating cost, including direct and indirect operating cost, is the most significant segment of the Life Cycle Cost as seen in Figure 15.1.1.

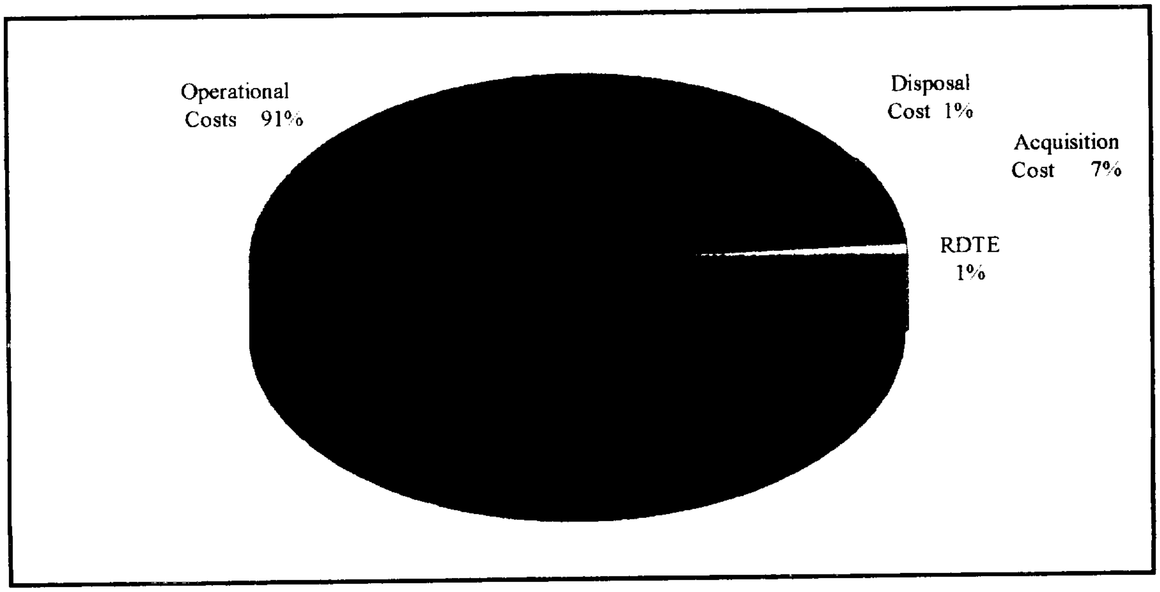


Figure 15.1.1: LCX Life Cycle Cost Breakdown

Many of today's aircraft operators are still operating older aircraft, many of them well beyond their projected service lives. These aircraft utilize outdated technologies and have relatively high operating costs. Since direct operating costs are an important area of cost reduction for the operator a large amount of study was dedicated to this area. The LCX boasts a significant reduction in DOC through the use of HLFC. An investigation was conducted in this area to see how effective this technology will be. Flight range is the driving factor in the effectiveness of the drag reduction promoted by laminar flow control over the LCX wing. For low range flights, the cost of operating the LCX with the HLFC system is higher than the reduction in cost from fuel saved. For this reason, the LCX is clearly defined as a medium/long range transport. However, Figure 15.2.1 demonstrates that as the LCX flight range exceeds 1500 nm., cost reductions compared to conventional aircraft with no HLFC begin to take effect. The operating cost in dollars per available seat mile continues to decrease as the range is increased. For flight ranges over 1750 nm., the DOC could be reduced by as much as 3%.

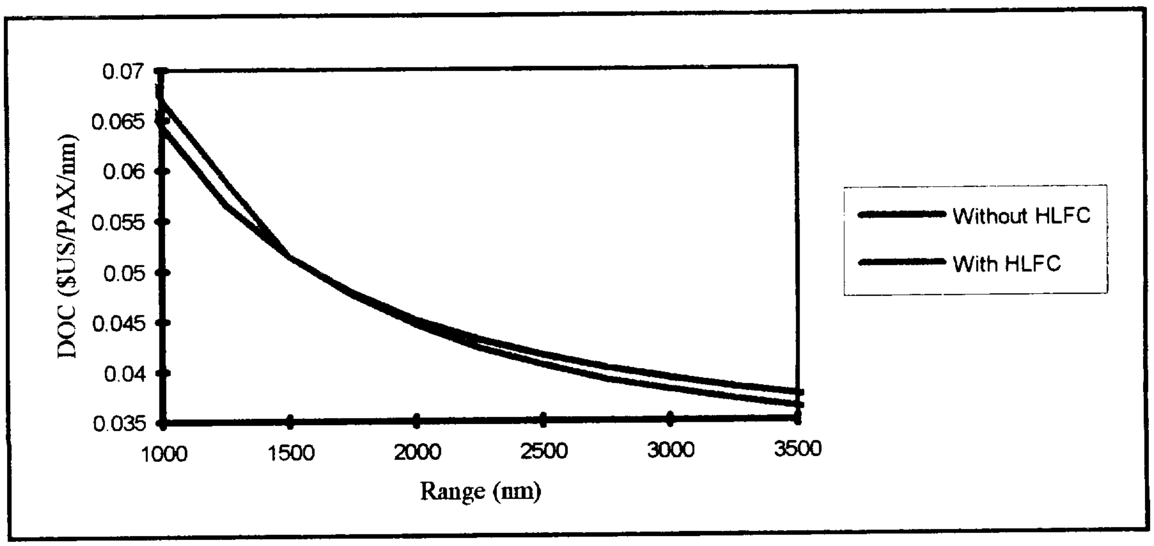


Figure 15.2.1: LCX Cost vs. Range

15.2 The Effect of Fuel Prices

Another aspect that was investigated was the effect of fuel price on the DOC of the LCX. Current fuel prices have been at an artificially deflated level for some time. Fowl Enterprises presumes that these prices will increase significantly through the course of the next ten years. To protect operators from experiencing extreme cost rises in direct operating costs from rising fuel costs, the LCX has been equipped with HLFC. In Figure 15.2.1. it can noted that the current fuel price is approximately

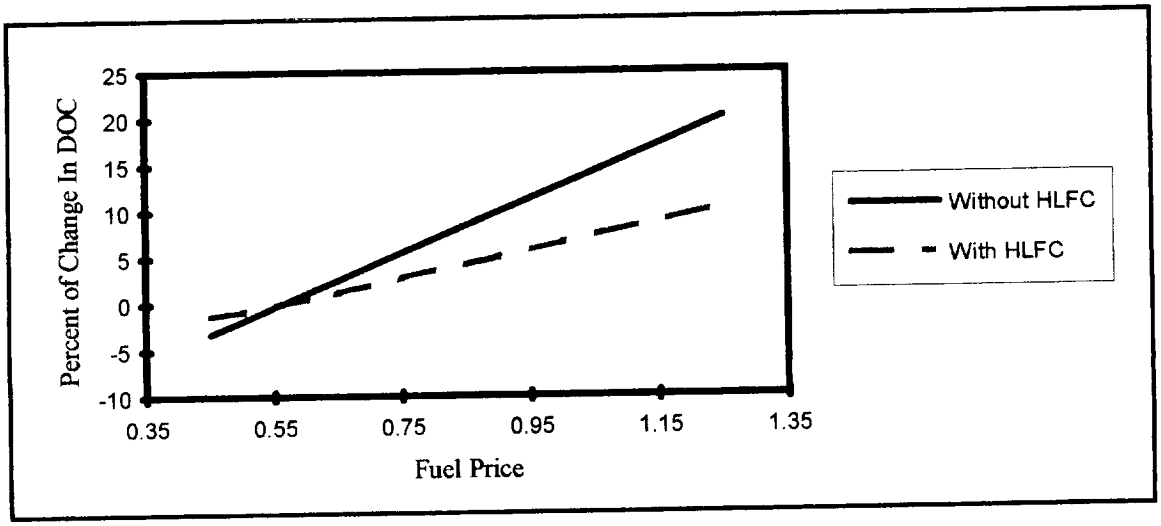


Figure 15.2.2: LCX Percent Change in DOC vs. Fuel Price at $ 0.56/gal.

$ .56/gallon at the time of this printing. This is the point where the DOC for a HLFC equipped and non-equipped LCX are fairly equal. As fuel price increases, the amount of DOC increase is less dramatic with the HLFC, making the LCX a more cost efficient aircraft. At a fuel price of $ .80/gallon, savings in DOC are predicted to be 4%. However, if fuel price happens to decrease, the LCX direct operating costs will increase relative to other aircraft. As seen in the DOC breakdown in Figure 15.2.3, fuel costs are part of the flying category, which represents 28% of all DOC costs. The ability of LCX to minimize the impact of fuel prices on the DOC would make the LCX an invaluable asset to any aircraft fleet of any operator.

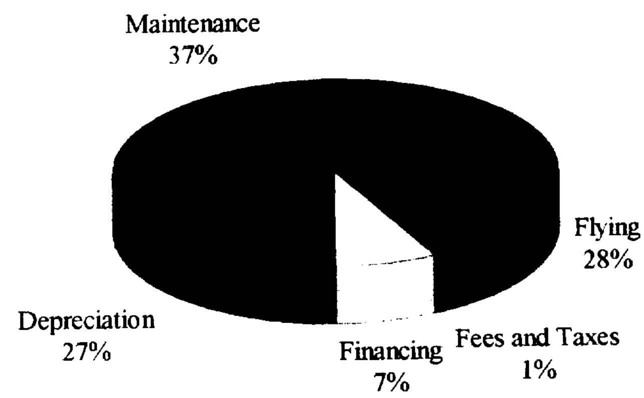


Figure 15.2.3: LCX Direct Operating Cost Breakdown

15.3 Production and Price

The projected selling price of the LCX with HLFC is approximately \$31 million. Since this is derived from the predicted production of 800 aircraft, any increase in the

Selling Price	\$31 mil.	Break-even Unit	570
Production Run	800	Return on Investment	7.5%

Table 15.3.1: LCX Cost Data

number of orders for the LCX will bring the cost of the aircraft down Figure 15.3.1. As more aircraft are produced, the costs of engineering, tooling, and RDTE are divided mong more units. Thus, the LCX unit price decreases as more aircraft are produced. Another area of interest for Fowl Enterprises is determining when the LCX will become a profitable venture. Using an analysis program with an economics module, a projected net cash flow curve was created from the costs and found to show that the LCX program

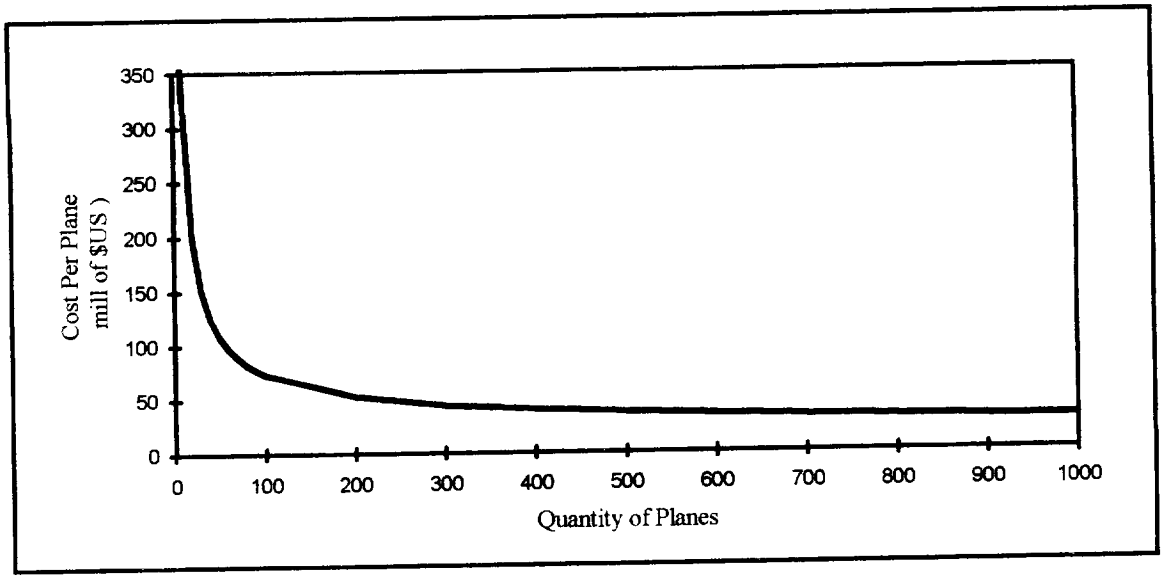


Figure 15.3.1: LCX Cost vs. Quantity Produced

will take approximately 13 years to break even Figure 15.3.2. The number of aircraft required to reach the break even point is around 570 aircraft. Fowl Enterprises expects not only to meet this production number, but produce over one thousand of the series. The return on investment of the LCX at the $31 million price is nearly 7%.

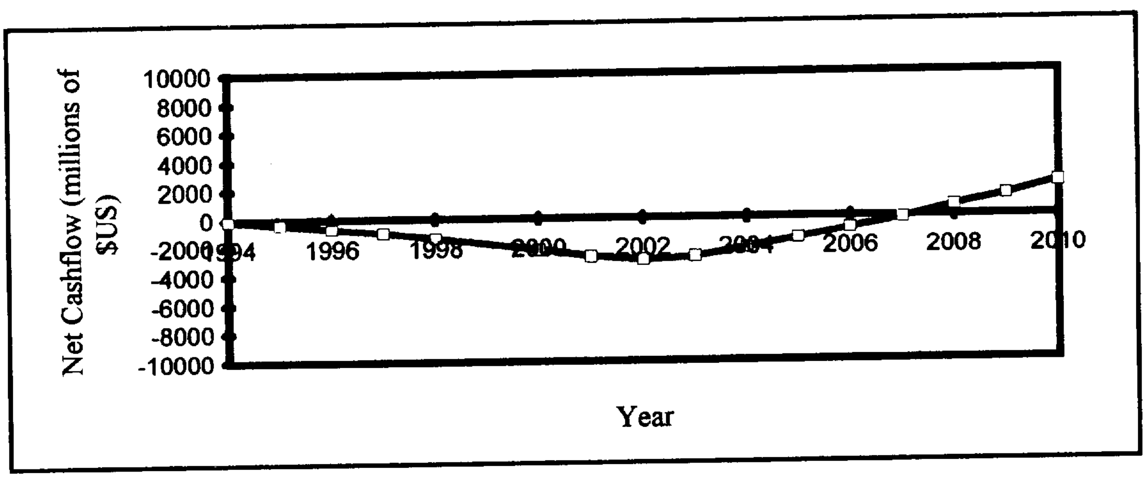


Figure 15.3.2: LCX Program Net Cash Flow

C-2.

16.0 CONCLUSION AND RECOMMENDATIONS

Based on the design skills gained through research in the process of creating this solution to the proposed design the following recommendations are made. First and foremost the design must be optimized at a lower weight. The LCX in its current state has not taken full advantage of all possible means of saving weight. With one more full iteration of the aircraft, the weight could be optimized while still retaining the current range of the aircraft. ACSYNT would have been useful for this purpose but no enough time was available to fully learn the system so much of the time spent using the system was wasted.

Composites were not extensively used on the LCX to retain the designs simplicity and ease in its maintenance. The use of composites does offer many benefits not only in weight savings but also in environmental and manufacturing advantages. Fowl Enterprises now believes that composites will need to be implemented more extensively in the next iteration of design to lower its weight.

The LCX should also use a stability augmentation system to lower trim drag by having a static margin. Stability augmentation was not used because there was no time to perform the analysis needed to implement the system.

Finally the decision to use HLFC was found to be a good one. HLFC has been proven possible and will help the LCX to capture a new part of the airline market.

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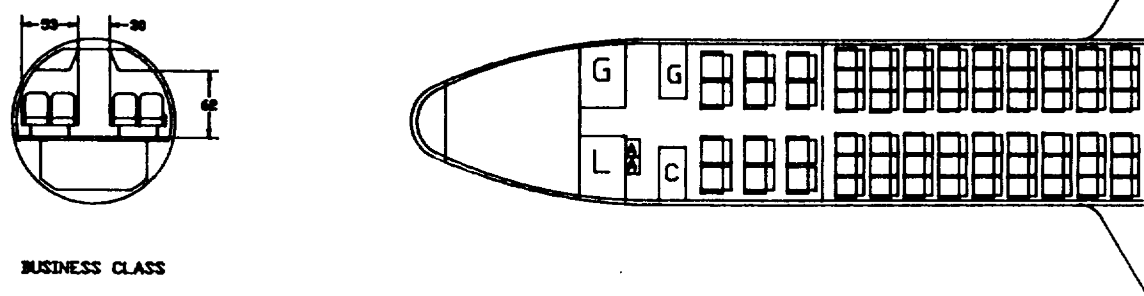
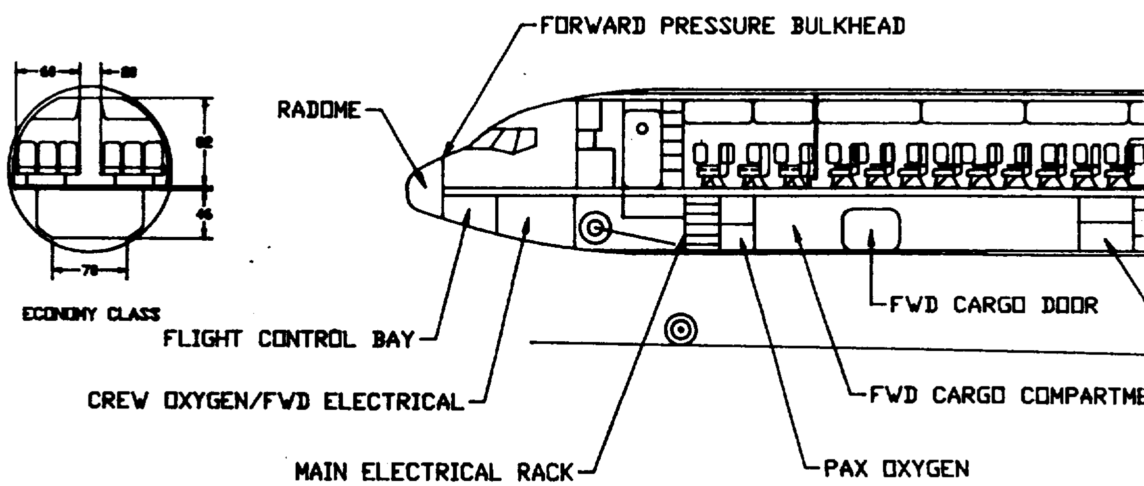
18.0 APPENDICES

FOLDOUT FRAME



BUSINESS CLASS



ECONOMY CLASS

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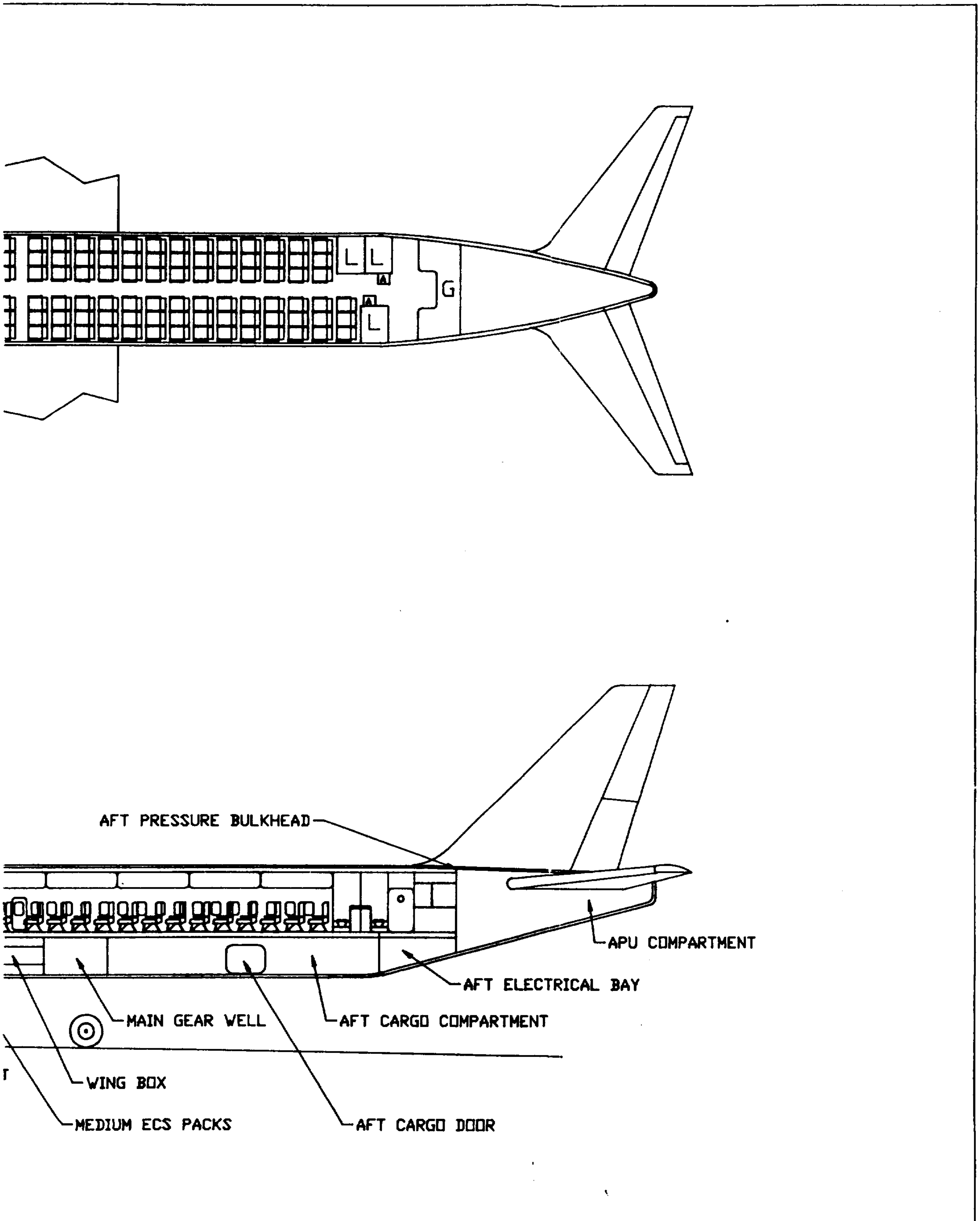

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1993/1994
AIAA/LOCKHEED CORPORATION
Undergraduate Team Aircraft Design Competition

#523

Release 6/4/93

JAE: 546: 8347

CLEMM: 545: 8983

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 information, and should show the independence of thinking or a fresh approach to the project. Does the method and treatment of the problem show imagination? Does the method show an adaptation or creation of automated design tools.

4. *Practical Application and Feasibility (25 points)*

The proposal should present conclusions or recommendations that are feasible and practical, and not merely lead the evaluators into further difficult or insolvable problems.

Design Objectives and Requirements

REQUEST FOR PROPOSAL:

A Low Cost Commercial Transport

I. OPPORTUNITY DESCRIPTION

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

This problem is not unique to the current economics. A similar situation existed in the mid 1930's when airlines were subsidized by the government for carrying mail in addition to paying passengers. While the problem was slightly different, the result was that the airlines could not make a profit solely from carrying passengers. The introduction of the DC-2/3 changed that by incorporating advanced technology of the day to enable the airlines to carry enough passengers, at a reasonable price, to offset the operating costs.

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

II. PROJECT OBJECTIVE

The objective of the project is to design a domestic commercial transport aircraft that will significantly reduce direct operating costs (DOC) for the airlines, while meeting current and proposed FAR for this type of aircraft. The project should identify the major operating cost drivers on current aircraft in use on the majority of domestic routes and identify technology options to incorporate that reduce these costs. Emerging technology should be considered but technology maturity, risk and implementation practicality must be assessed in the design process. Finally, a comparison of the operating costs of the new design to that of a current technology transport will demonstrate the design's effectiveness.

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. .998

2. Take off within a FAA field length of 7000 ft, SL, ISA + 27° day with full passenger and baggage load. 59° std

3. Climb at best rate of climb to best cruising altitude.
   - inter to flt

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.

3000 nmi
153 mix
Takeoff 7k
[illegible]
Low Cost

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. FAR - 3db

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

arrangement.

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

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

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

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

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

V. ENGINE DATA

Baseline high bypass ratio turbofan engine data is available upon request by contacting:

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

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