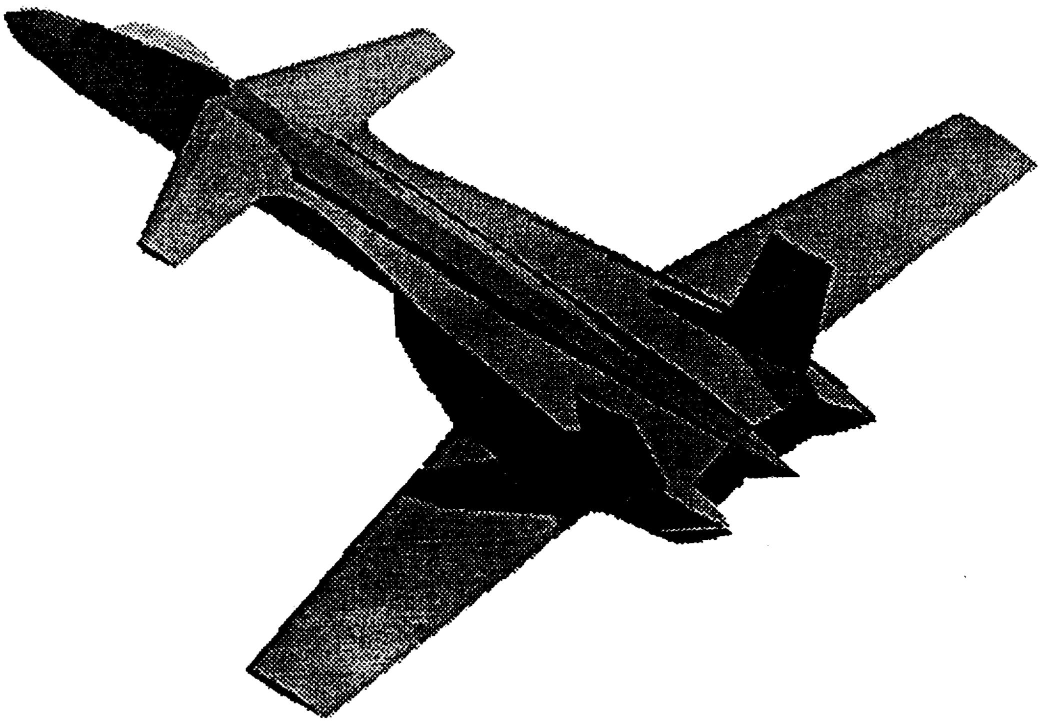
NASW-4435

THE ELIMINATOR



A Design of a Close Air Support Aircraft
California Polytechnic State University, San Luis Obispo
1990 / 1991

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Sincerely,

Barbara Rumbaugh

Barbara Rumbaugh
Senior Project Administrator

ABSTRACT

The Eliminator is the answer to the need for an affordable, maintainable, survivable, high performance close air support aircraft primarily for the United States, but with possible export sales to foreign customers. The
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LIST OF SYMBOLS

Symbol	Description	Units
A	Aspect Ratio, b^2/S	
b	Span (from tip to tip)	ft
c	mean chord, S/b	ft
C_D	Total drag coefficient for the aircraft	
C_{D_α}	Change in coefficient of drag with respect to angle of attack	rad^{-1}
$C_{D_{\dot{\alpha}}}$	Change in coefficient of drag with respect to rate of change in angle of attack	rad^{-1}
$C_{D_{\delta c}}$	Change in coefficient of drag with respect to deflection of aileron on the canard	
C_{d_o}	Profile drag coefficient	
C_{D_q}	Change in coefficient of drag with respect to pitch rate	rad^{-1}
C_{D_u}	Change in coefficient of drag with respect to velocity in the x direction	
CGR	Climb gradient	radians
C_{L_α}	Change in coefficient of lift with respect to angle of attack	rad^{-1}
$C_{L_{\dot{\alpha}}}$	Change in coefficient of lift with respect to rate of change in angle of attack	rad^{-1}
C_{l_β}	Change in coefficient of rolling moment with respect to sideslip angle	rad^{-1}
$C_{l_{\dot{\beta}}}$	Change in coefficient of rolling moment with respect to rate of change in sideslip angle	rad^{-1}
$C_{L_{\delta c}}$	Change in coefficient of lift with respect to deflection of aileron on the canard	rad^{-1}
$C_{l_{\delta r}}$	Change in coefficient of rolling moment with respect to deflection of the vertical tail (rudder)	
$C_{l_{\delta s}}$	Change in coefficient of rolling moment with respect to deflection of the spoilers	
$C_{L_{max}}$	Maximum coefficient of lift for the aircraft	
C_{l_p}	Change in coefficient of rolling moment with roll rate	rad^{-1}
C_{L_q}	Change in coefficient of lift with respect to pitch rate	rad^{-1}
C_{l_r}	Change in coefficient of rolling moment with respect to yaw rate	rad^{-1}

Symbol	Description	Units
C_{L_u}	Change in coefficient of lift with respect to velocity in the x direction	
C_{M_α}	Change in coefficient of pitching moment with respect to angle of attack	rad^{-1}
$C_{M_{\dot{\alpha}}}$	Change in coefficient of pitching moment with respect to rate of change in angle of attack	rad^{-1}
$C_{M_{\delta c}}$	Change in coefficient of pitching moment with respect to deflection of aileron on the canard	
C_{M_q}	Change in coefficient of pitching moment with respect to pitch rate	rad^{-1}
C_{M_u}	Change in coefficient of pitching moment with respect to velocity in the x direction	
C_{n_β}	Change in coefficient of yawing moment with respect to sideslip angle	rad^{-1}
$C_{n_{\dot{\beta}}}$	Change in coefficient of yawing moment with respect to rate of change in sideslip angle	rad^{-1}
$C_{n_{\delta r}}$	Change in coefficient of yawing moment with respect to deflection of the vertical tail (rudder)	
$C_{n_{\delta s}}$	Change in coefficient of yawing moment with respect to deflection of the spoilers	
C_{n_p}	Change in coefficient of yawing moment with respect to roll rate	rad^{-1}
C_{n_r}	Change in coefficient of yawing moment with respect to yaw rate	rad^{-1}
C_{Y_β}	Change in coefficient of side force with respect to sideslip angle	rad^{-1}
$C_{Y_{\dot{\beta}}}$	Change in coefficient of side force with respect to rate of change in sideslip angle	rad^{-1}
$C_{Y_{\delta r}}$	Change in coefficient of side force with respect to deflection of the vertical tail (rudder)	
$C_{Y_{\delta s}}$	Change in coefficient of side force with respect to deflection of the spoilers	
C_{Y_p}	Change in coefficient of side force with respect to roll rate	rad^{-1}
C_{Y_r}	Change in coefficient of side force with respect to yaw rate	rad^{-1}

Symbol	Description	Units
D	Drag of aircraft, $0.5 r V^2 C_D S$	lb
dh	Incremental change in altitude	ft
dt	Incremental change in time	s
e	Oswald efficiency factor	
g	local gravitational acceleration	ft/s^2
L	Lift of aircraft	lb
M	Mach number - max.	
P_s	Specific Power, Thrust/Weight	ft/s
S	Planform area, including area through the fuselage	ft^2
SFC	specific fuel consumption	
S_{lg}	Landing ground roll distance	ft
S_{tog}	Take-off ground roll distance	ft
T	total engine thrust	lb
T/W	Power loading	
V_s	Stall speed, $V_s = V_a / 1.2$	kts
W	Weight of Aircraft	lb
W/S	Wing loading	lb/ft^2
	Subscripts	
clean	Flaps and Landing Gear Up	
l	Landing values	
max	Maximum values	
to	Take-off values	

1.0 INTRODUCTION

Since the conflict in Europe and the South Pacific during the Second World War, the need for communication and support between air and ground forces has been evident and critical. Many lives of U.S. Marines were saved on the Japanese held islands of the Pacific when aircraft of the Marine Corps were used to bomb and strafe heavily defended and fortified enemy positions. The same can be said for the conflicts in Korea, Vietnam, Grenada and Panama.

Perhaps at no other time was the value of close air support more evident than in the conflict in the deserts of the Middle East, however. Even before ground forces were committed to battle, ground attack aircraft were pounding Iraqi positions relentlessly from the air, dealing out major damage and casualties while suffering little in return. When ground forces finally went on the offensive, the ease with which they swept through the enemy positions was a testament to the value and power of close air support and ground attack missions.

As important as close air support is, the United States is facing a desperate need for a new aircraft to fill this role. Its current ground attack aircraft are aging, like the A-10, A-6 and A-7, many of which are left over from the Vietnam era, almost 20 years ago. At the same time, defense spending is shrinking to an all-time low, with less money being spent on new technologies and new aircraft, tending to rely instead on proven abilities and hardware.

The challenge for the future will be to produce a close air support, ground attack aircraft that will be able to stand up to a high-tech, fast moving, incredibly deadly and possibly even nuclear battlefield. The war in the Persian Gulf demonstrated that an aircraft must be able to perform high sortie rates in a hostile environment, operating from dispersed or unimproved landing strips, without major maintenance or service.

The aircraft must be able to mesh with the operations of other branches of the armed forces, the essence of close air support, and maintain communications with its controllers under possible electronic warfare and jamming that has reached new heights in sophistication. Modern aircraft must overcome a more dangerous threat posed by radar and IR homing missiles that are unmatched in their accuracy.

In addition, the aircraft must be versatile enough to adapt to any possible mission it might be called upon to perform during war or peacetime. This would include limited conventional response, anti-terrorist, counter-insurgency, anti-drug or any number of possibilities. The aircraft must be at home in any of these environments.

Most importantly, the aircraft must be affordable. It must combine the best existing technologies with those that are new or almost completed to provide a blend that gives high performance and survivability while remaining affordable. This is the challenge facing the designers of the next close air support aircraft.

The Eliminator is the answer to this problem. It combines high performance with versatility and ease of maintenance to produce a very potent aircraft that is capable of performing any task asked of it. It performs best in the high subsonic region, but is capable of limited supersonic flight. Redundant controls and features provide safety for the pilot and high survivability for the aircraft. It can land and takeoff on fields of less than 2000 ft in length and deliver its ordnance accurately using the latest targeting and navigation systems while incorporating sufficient design and manufacturing techniques to ensure the lowest production and acquisition costs. The Eliminator is the attack aircraft of the future.

2.0 MISSION DESCRIPTION

The AIAA/ General Dynamics RFP[1] specifies three distinct missions, the first of which is designated as the design mission. Additional performance requirements to be met by the aircraft were also given in the RFP. What follows is a brief outline of the design mission and additional requirements.

The requirements of the design mission are shown in Figure 2.1. It begins with warm-up and taxi. The aircraft then takes off and accelerates to dash speed (either 500 knots or maximum speed at military power). The aircraft dashes 250 nautical miles at sea level, at which point it engages in two combat passes. Each combat pass consists of a 360-degree sustained turn plus a 4000 ft energy increase. The aircraft drops its air to ground weapons, but retains the pylons, racks and ammunition. It then returns at dash speed to base, and lands with enough fuel for 20 minutes endurance at sea level

The aircraft should also be able to accomplish a ferry mission, in which it must be capable of cruising a total accumulated range of 1500 nautical miles at best altitude and speed, and again land with enough fuel for 20 minutes endurance at sea level.

Lastly, the aircraft should be able to: (1) Accelerate from Mach 0.3 to 0.5 at sea level in less than 20 seconds; (2) Sustain 4.5 g's at combat speed (maximum speed at military power minus 50 knots) at sea level; and (3) Be capable of a re-attack time (from first pass weapons release to second pass weapons release) of less than 25 seconds. It should be able to accomplish these last three performance requirements while carrying self-defense stores (2 AIM9-L sidewinders, gun and ammo), and 50% of internal fuel.

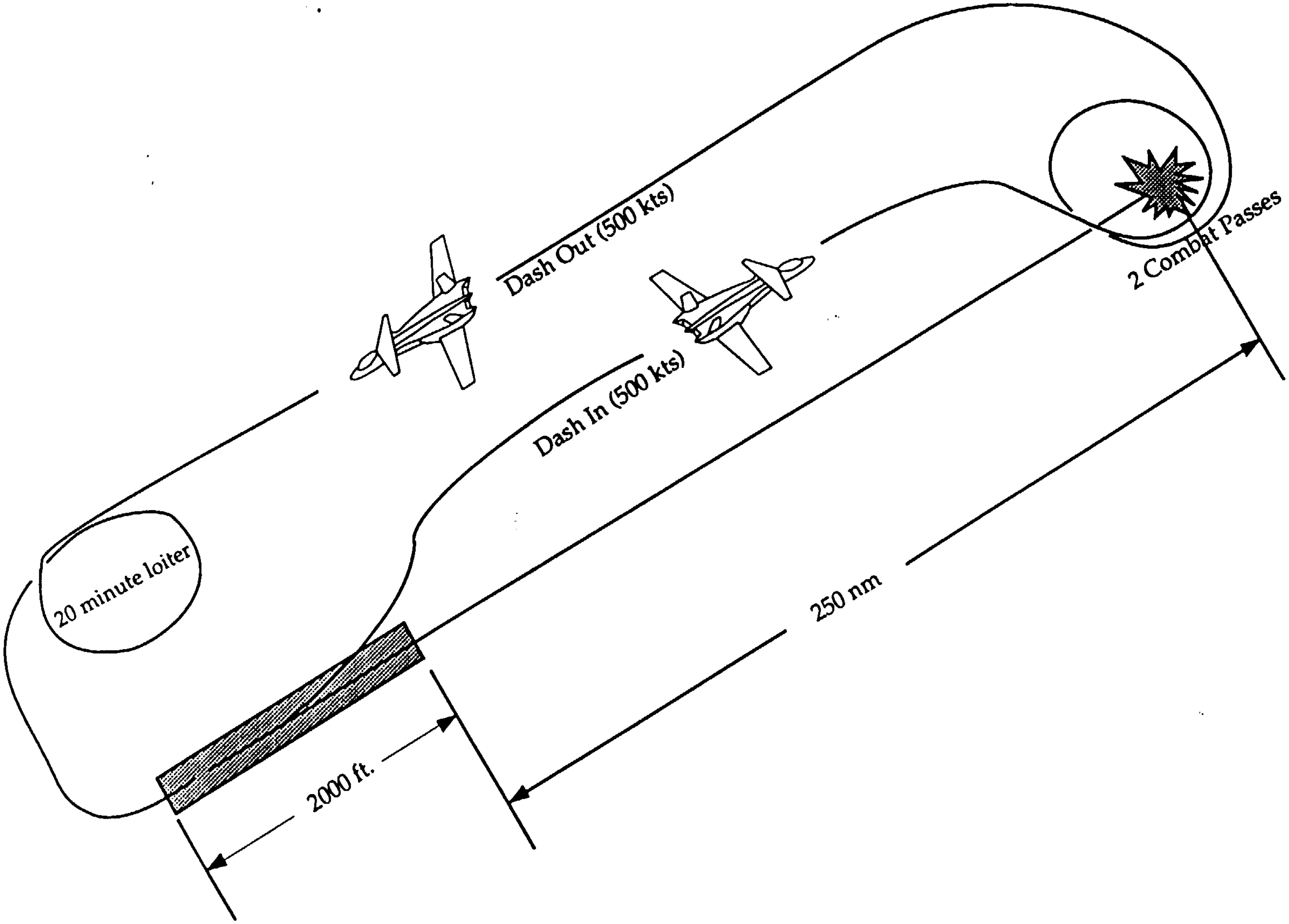


Figure 2.1 Design Mission Profile

3.0 DESIGN RESULTS

3.1 GEOMETRY OF THE ELIMINATOR

The Eliminator is a fixed wing aircraft, with two turbofan engines, and a high canard, low wing, twin tail configuration (Figures 3.1 to 3.3, Table 3.1). The total length of the aircraft is 55 feet, with a wingspan of 53 feet, and a total planform area of 517 ft^2. Since the take-off weight is 55,000 lb, the maximum wing loading is 110 psf. The maximum thrust from the two engines, with afterburners, is 30,000 lb, therefore the maximum power loading at take-off is 0.55.

Table 3.1 Configuration Summary of the Eliminator

Total Length	55 ft	Empty Weight	27,000 lb
Total Height	17.58 ft	Payload Weight	13,000 lb
Total Span	53 ft	Fuel Weight	14,700 lb
Ground Clearance	3 ft w/ bombs	Take-Off Weight	55,000 lb
Total Planform Area	517 ft^2	W/S_{to}	110 psf

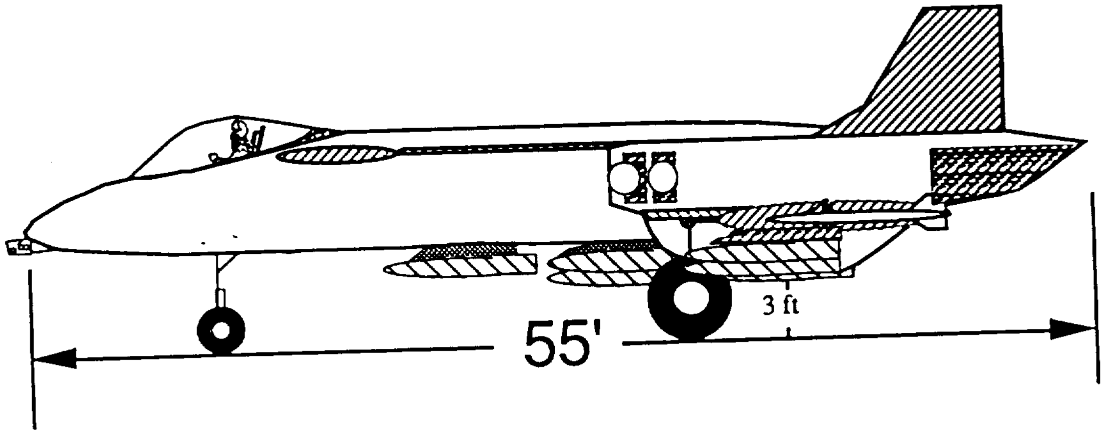


Figure 3.1 Side View of the Eliminator

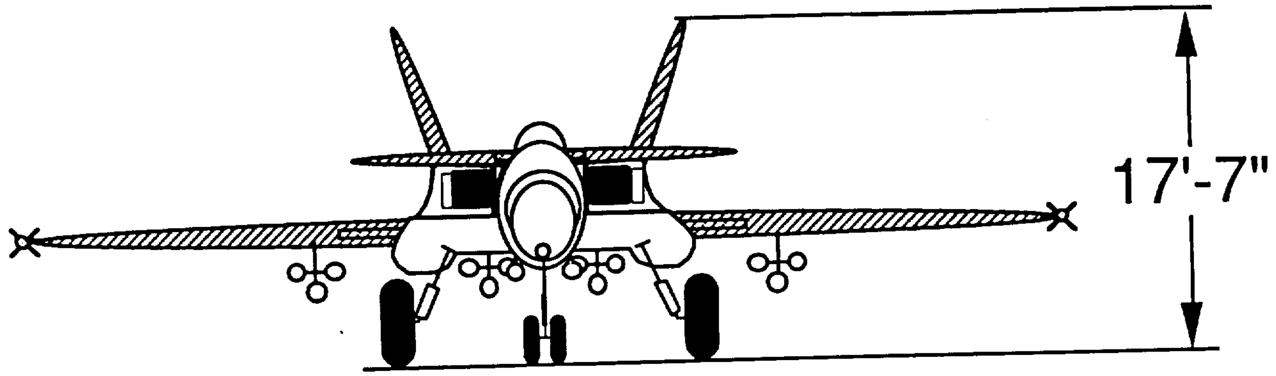


Figure 3.2 Front View of the Eliminator

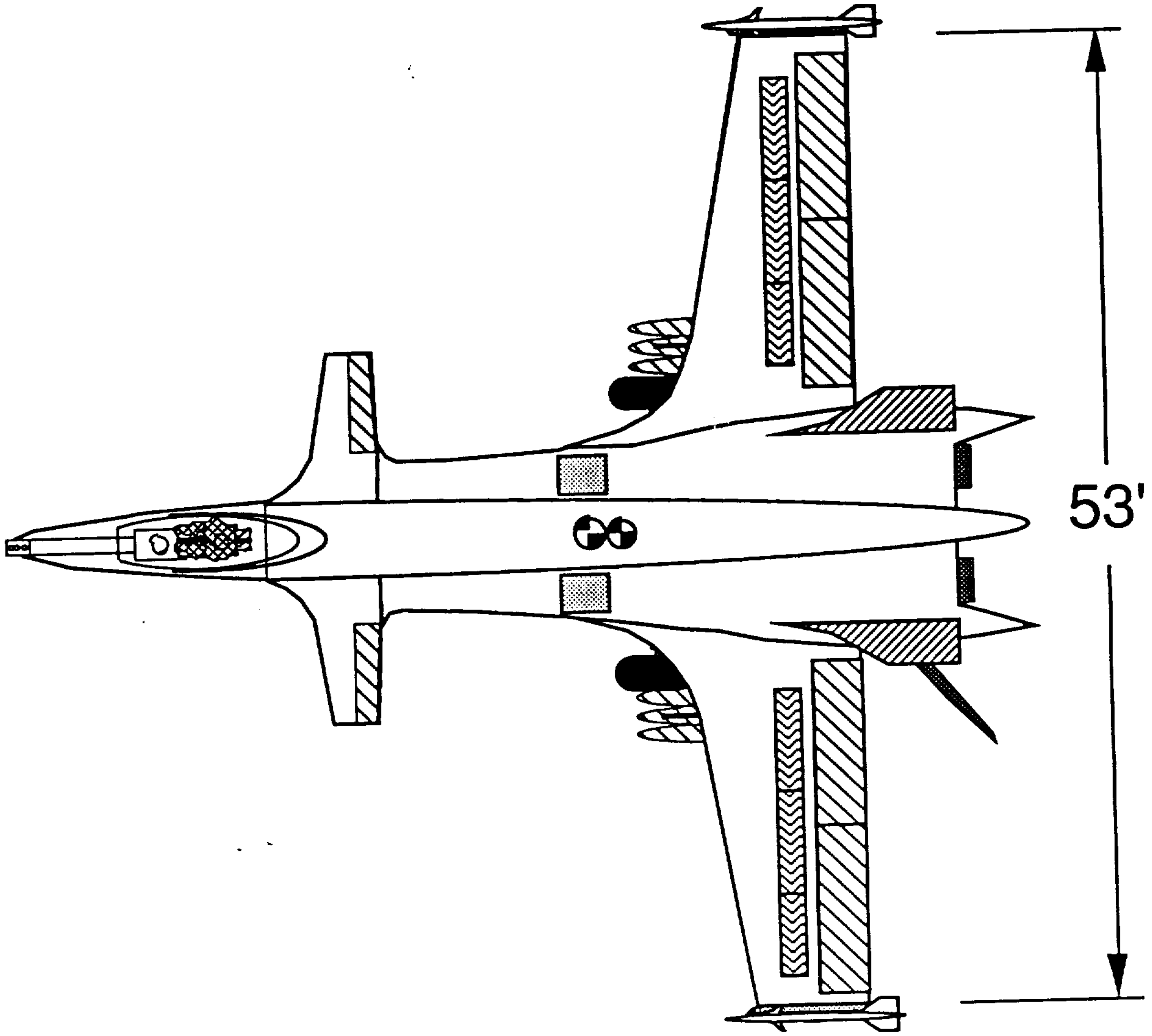


Figure 3.3 Top View of the Eliminator

3.2 PERFORMANCE

The Eliminator has excess power in normal flight conditions due to the take off requirement of a 2000 foot ground roll. This allows for greater maneuverability. Table 3.2 is a summary of the performance characteristics of the Eliminator. The maximum thrust of the engines is 30,000 lb with afterburners, and 22,000 lb without afterburners. This relates to an excess power of 300 ft/s with afterburner or 150 ft/s without afterburner. The take off and landing ground roll distances are under 1810 ft. for maximum weight conditions, which is under the 2000 ft requirement.

Table 3.2 Performance Summary of the Eliminator

$C_{L_{max_{to}}} = C_{L_{max_{l}}} =$	2.6	W/S_{to}	110 psf
$C_{L_{max_{clean}}}$	1.6	T/W_{max} w/ afterburners	0.55
Dash Velocity	500 kts	T_{max} w/ afterburners	30,000 lb
Stall Speed	115 kts	$P_{s_{max}}$ w/ afterburner	300 ft/s
Take-Off Ground Roll - max	1760 ft.	T_{max} w/o afterburners	22,000 ft/s
Landing Ground Roll -max	1810 ft.	$P_{s_{max}}$ w/o afterburner	150 ft/s

3.2.1 EXCESS POWER

Excess power for the Eliminator was generated on specific energy plots shown in Figures 3.4 and 3.5 The maximum non-augmented and fully augmented flight regimes for the Eliminator were plotted respectively. Both plots showed a ceiling limit of 57,000 feet. The Eliminator does not expect to exceed this ceiling limit, even during cruise. The plots were generated for the following flight condition: a maximum gross take-off weight of 55,000 lb (with full armament and fuel), and load factor of one. For the non-augmented condition, the installed thrust was assumed to be 22,000 lb (11,000 lb per engine) and 30,000 lb for the augmented condition.

Figure 3.4 shows two of the specific energy flight envelopes (at Ps=0 and 100 ft/s) that the Eliminator can operate in. The Eliminator cannot reach a Ps=200 ft/s for this flight condition without afterburners. At sea level, the Eliminator can approach a Mach of 0.98. While this surpasses the RFP's requirement, it shows the potential performance capability of the Eliminator. In addition, at 45,000 feet, the Eliminator can reach Mach 1.3. At the other extreme, the Eliminator's take-off and landing maneuvers can be performed within the Ps=0 ft/s envelope and therefore have excess power for climbing. The take-off stall speed of the Eliminator is 195 ft/s or Mach 0.176. Figure 3.4 shows that this is indeed within the excess power envelope.

With afterburners engaged, the specific energy envelope of the Eliminator is greatly enhanced (Figure 3.5). The Eliminator can now operate within higher specific energy envelopes. At sea level and at Mach 0.75 (dash speed), the Eliminator operates within the 300 ft/s specific energy range, allowing for a more maneuverable aircraft. The Eliminator is capable of approaching Mach 1.32 at sea level, again exceeding the RFP's criteria. This excess power during take-off is capable of propelling the Eliminator off the 2,000 ft. runway. The maximum speed the Eliminator could reach will be Mach 1.54 at an altitude of 47,500 ft. Like the non-augmented case, the stall speed during take-off is well within the flight envelope. The figures show that the propulsion unit is well able to handle the Eliminator's maneuvering needs.

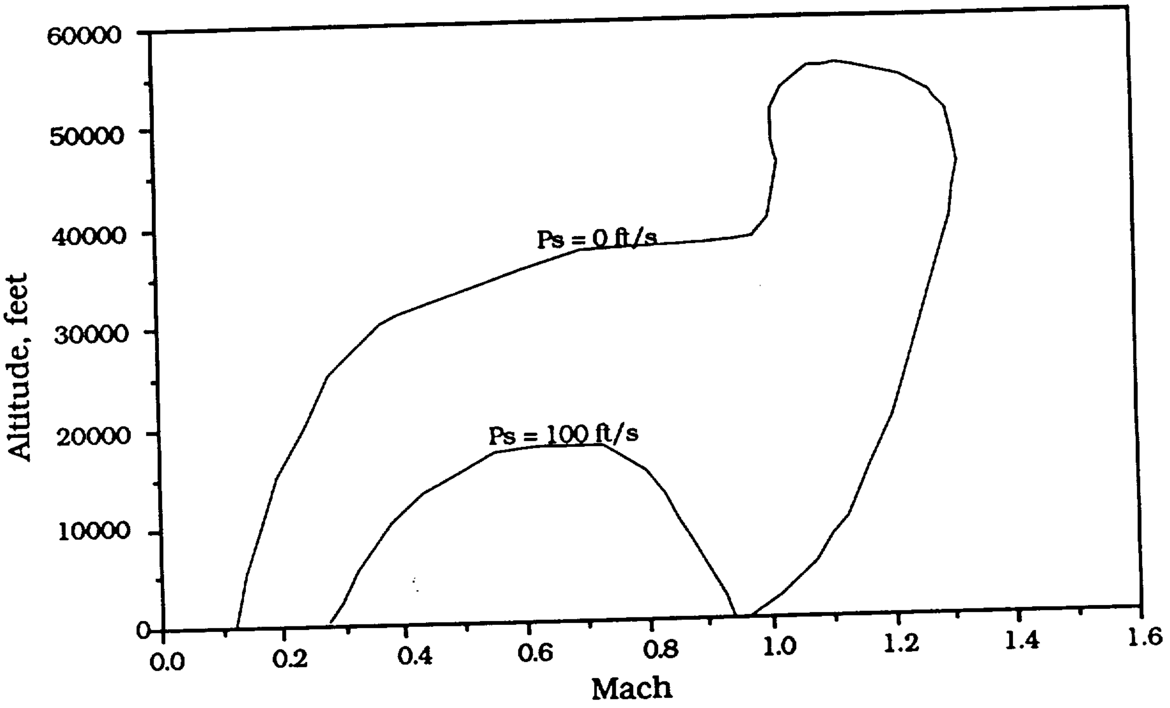


Figure 3.4 Specific Energy for a Non-Augmented Flight Regime

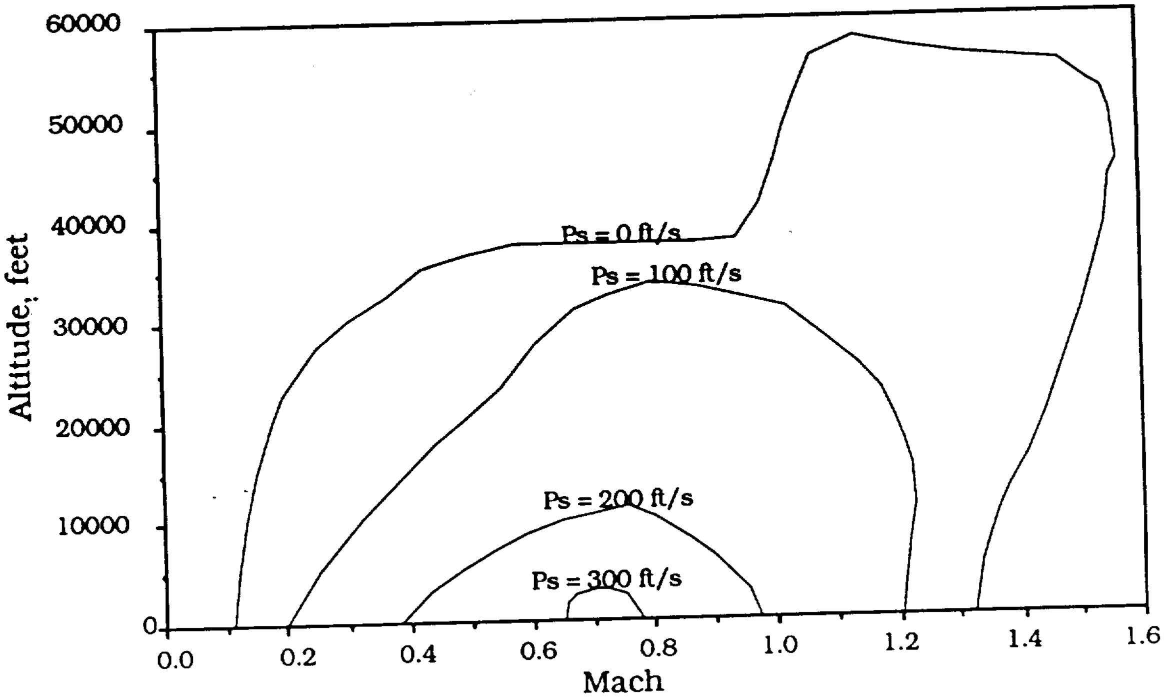


Figure 3.5 Specific Energy for an Augmented Flight Regime

In both figures, a sharp rise in excess power occurs at a Mach of 1.0 and creates a bulge in the flight envelope. Two factors influence this behavior. In the analysis of the power available versus power required curve (Appendix E), a compressibility factor for Cd was used for Mach greater than 0.3. This however, means that as Mach reaches one, Cd would go to infinity, making it absurd. Knowing this, values at Mach of 1.0 +/- 0.10, were left out of the analysis. However after Mach of 1.1, the flight envelop developed into a smooth and continuous curve. This section of the envelope may have been caused by the engine itself. Although the F404-400 is classified as a turbofan, it has a bypass ratio of only 0.34, this suggests that it should behave more like a turbojet engine. If this is the case, then performance would improve at higher altitudes and speeds. The flight envelope was later curve fitted after both the right side (Mach greater than 1.1) and left side (Mach less than 0.9) of the excess power envelope was generated.

3.2.2 RANGE VS PAYLOAD

As presented in Table 3.3., the Eliminator is able to perform the primary mission requirements, achieving a maximum range of 617 nm with an endurance of 2.2 hours. The range was calculated using the fuel fraction method from preliminary design sequence one and the primary mission profile. It was assumed that the fuel consumption during each flight regime was constant. Only the weight before and after each flight regime was used Fuel consumption was corrected for the RB-199 engine, as explained in Section 3.2.4.

The Eliminator's ferry mission range is over 2,000 nautical miles (Table 3.3), easily exceeding the performance requirement of 1,500 nm, set forth by the RFP The Eliminator is also capable of performing several other missions, including maritime patrol and anti-radiation (See Weapons Integration Section, Fig. 13.1). Its ranges for these missions are 975 nm and 906 nm respectively. Endurances for these two mission are both over six hours.

Table 3.3 Mission Ranges and Endurances

MISSION PROFILE	RANGE(nm)	ENDURANCE(hrs)
Design Mission	617.1	2.21
Ferry Mission	2211.5	9.71
Maritime Patrol	973.7	6.62
Anti-Radiation	906.6	6.03

3.2.3 TAKE-OFF AND LANDING PERFORMANCE

The specifications laid out in the RFP[1], call for the candidate aircraft to be able to take-off and land from a 2000 ft. runway for short field operations. While this capability could prove very valuable and probably indispensable, it is nevertheless, a very difficult requirement to meet.

The Eliminator is powered by two large turbofan engines that provide over 30,000 lbs of thrust with afterburner. The afterburner, combined with single-stage Fowler flaps to provide a high boost to the lift coefficient at take-off, enable the Eliminator to meet and exceed the runway length requirement. Using standard equations for take-off ground roll[2], it was calculated that the Eliminator is able to take-off with a mere 1760 ft. ground roll.

The landing distance was determined using a similar method. This ground roll distance was determined to be 1810 ft, with no stopping apparatus other than brakes. However, the Eliminator is equipped with airbrakes that begin at the trailing edge and extend to the rear of the fuselage, mounted directly on the side of the aircraft. These can be used to further decrease the landing distance and avoid brake wear, and can also be used during maneuvering to bleed speed or for low speed, high lift flight.

The landing distance was determined first by determining stall speed for the Eliminator based on wing loading and maximum lift coefficient, which is with flaps. The approach speed can be approximated as 1.2 times the stall speed, for safety reasons. Knowing the approach speed, and applying empirical relations, the landing ground roll can be determined.[2]

The Eliminator is designed to meet the landing requirements enforced on its design, and does so with ease and a significant margin for error. When operating from standard fields of larger length, the Eliminator will be able to take-off without afterburner, using a longer ground roll, and increase its range and possibly even payload.

3.2.4 FUEL CONSUMPTION

To decrease production cost, the Eliminator uses production engines. The major disadvantage of using a production engine is lack of specification. Since the engines are in operation, performance specifications are still classified. Two options were available to overcome this problem. The first option is to use the rubber engine's data and hence its SFC values. The draw back with this method is that the SFC values do not change when scaling the engine up or down. The other option is to use SFC data from another production engine. Since information for a RB-199 engine was available, the latter option was used. A reproduction of the SFC data for the RB-199 engine is shown in Figure 3.6.

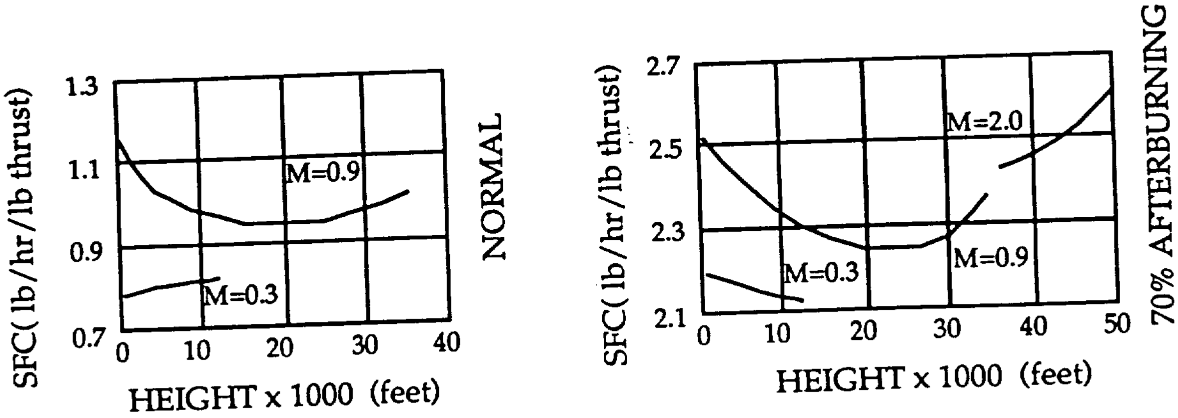


Figure 3.6 Specific Fuel Consumption for the RB-199 (Reference 13)

The RB-199 is a smaller engine than the F404, hence produces less thrust. To account for the F404's greater thrust and weight, a correction factor was used. A factor of 1.05 was used to calculate the SFC for the Eliminator during non augmented conditions. And a factor of 1.10 was used during afterburner conditions.

The SFC's for the F404 at military power is 0.85 lb/hr/lb thrust.[16] For the RB-199, its SFC is 1.2 (at M=0.9 and sea level). Assuming that the F404's SFC of 0.85[16] is for sea level at Mach of 0.9 and comparing this to the RB-199, this shows that the RB-199's SFC is 5% greater than the F404. The RB-199 is a less efficient engine, it was assumed that this is so because the RB-199 is an older engine. However, to be on the conservative side, this 5% was applied to the F404's engine instead. Unfortunately, there was no SFC values to compare for the afterburner case. To calculate SFC for the Eliminator during afterburner, a correction factor of 10% was added to the RB-199's augmented SFC. To be conservative, the correction factor was chosen to double that of the non-augmented condition.

4.0 CONFIGURATION - SELECTION / JUSTIFICATION

4.1 BASIC CONFIGURATION

There are two basic configurations possible for an aircraft, fixed wing or rotary wing. A rotary wing aircraft appears to be a very good choice, as it is maneuverable and can operate with little or no landing field. The reasons a rotary wing craft was not chosen were high maintenance requirements and an inability to obtain a speed of 500 knots. High speed rotary wing aircraft are still in the developmental stage, and will not be available for production for 15 to 20 years. Also, for the design mission, a rotary wing aircraft would be inefficient, due to a large size necessary to satisfy the payload and range requirements.

A fixed wing aircraft can obtain speeds of 500 knots and more, depending on the specific geometry and propulsion system. The take off and landing requirements are greater than for an airship or rotary wing aircraft, but these distances can be minimized through proper design techniques. Since the fixed wing aircraft can meet the design requirements, this is the configuration chosen for the Eliminator.

4.2 FIXED WING OPTIONS

A fixed wing aircraft can cover a wide range of possibilities. The empennage can consist of a canard-vertical tail, horizontal-vertical tail, or V-tail. For a close air support aircraft, maneuverability is very important. A canard configuration offers more inherent maneuverability than a horizontal tail or V-tail configuration. Also a canard configuration can be more efficient than a horizontal tail configuration, because the canard provides lift, although this increases the bending of the fuselage. A canard configuration was chosen, primarily for the increased maneuverability.

The main wing of the aircraft can be a swing wing, oblique wing or stationary wing. The advantages of a swing wing is that a higher Mach number is obtainable, as the wing can increase its sweep as the speed increases. The disadvantages of a swing wing are the increased expense, weight, construction complexity and high maintenance requirements. Since the operating range of the close air support aircraft is high subsonic, approximately Mach 0.75, a swing wing was not necessary, and therefore was not chosen. An oblique wing was not chosen for similar reasons to the swing wing in addition to the increased stability and control complexity due to the unsymmetrical design. A stationary wing is limited to a smaller operating range than the swing or oblique wings, nevertheless this wing type was chosen because the operating range is sufficient for the close air support role, and it is easier to build and control and therefore less expensive.

A stationary wing can have several different configurations, for example straight wing, aft swept wing, forward swept wing and delta wing. A delta wing performs well at high Mach numbers, but is inefficient at lower speeds, and has a low Clmax. A straight wing is the simplest to design and build, but the Mach divergence number is lower than that of a swept wing. A forward swept wing, much like an aft swept wing, has a higher Mach divergence number than a straight wing, but is more difficult structurally due to wing twist. An aft swept wing was chosen for its high Mach divergence number, as well as its relative simple structures, compared to a forward swept wing.

4.3 PROPULSION SELECTION

There are three main engine types to consider for an aircraft. These are turbofan, turbojet and turboprop. A turboprop engine is the most efficient of the three, but it can not operate at speeds approaching the speed of sound, such as Mach 0.75. Both turbofans and turbojets can provide enough power for the design mission, so a decision was based upon engine efficiency. A turbofan engine is more efficient than a turbojet engine at lower altitudes and subsonic to low supersonic speeds. Since this is the operating range of the design mission, a turbofan engine was chosen for our aircraft.[1]

The possibility of a tilt engine or tilt wing aircraft was considered. But these configurations have the same limitations of a turboprop, and therefore were not chosen. Thrust vectoring was examined, but was determined to be too expensive and complicated, and unnecessary. The benefits of thrust vectoring are a decrease in the take off distance, and increase in maneuverability. Since the Eliminator has enough maneuverability with afterburners, which are cheaper and simpler, and with afterburners the Eliminator can meet the take off restrictions, thrust vectoring was not used.

4.4 LANDING GEAR SELECTION

A tricycle landing gear was selected. This type of landing gear permits a large degree of rotation upon take-off and landing. Other possible types of landing gear are tail draggers, quadricycle, bicycle and multi-bogey. The bicycle, quadricycle and multi-bogey are too heavy and do not allow sufficient rotation for take-off and landing, and therefore are not used. A tail dragger is inherently unstable, and thus was not used.[7]

A track mechanism, similar in concept to that used by tanks, was considered, as such a mechanism would greatly increase the flexibility of the Eliminator. With such a landing gear, operation could occur from almost any type of field, without significant difficulty. Unfortunately, the weight and size increase was determined to be too large, making this mechanism impractical for this size of an aircraft. Therefore conventional wheels were selected.

5.0 COMPONENT DESIGN SUMMARY

5.1 WING CHARACTERISTICS

Sweep

Advantages

- Reduces compressibility effects because normal component of velocity is less than free stream velocity, and can be less than the M_{cr} [5]

Disadvantages

- spanwise component of V_∞ produces a thickening of the boundary layer in the tip region, therefore more likely to stall at tip[6]
- increased loading at the tips, unless compensated for by washout [6]
- nose pitch up caused by tip stall [6]
- Low lift curve slope, especially for high sweep [5]
- Increased wing weight and manufacturing complexity

Comments

- Amount of sweep needed is dependent on the airfoil shape [6]

Thickness Ratio

Advantages

- Increases C_l especially when going from 10% to 16% [5]

Disadvantages

- Increases C_d , and decreases M_{cr} , especially for large thickness ratios [5,6]

Low wing

Advantages

- Good position relative to canard, to maximize energy flow over wing [18]

Disadvantages

- interference drag w/fuselage is poor ($e \approx 0.6$ low ; $e \approx 0.6$ high) [6]
- Possible visibility problems from cabin [2]

Fowler Flaps

Advantages

- Very efficient in increasing C_{lmax} compared to slats and slotted flaps

Disadvantages

- More complex to manufacture and maintain than slotted flaps
- More complex structurally, due to the retraction mechanism

Since the Eliminator is required to fly at 500 knots at sea-level, which is approximately Mach 0.75, a 10° leading edge sweep was selected. This gives a drag divergence Mach number of 0.85 for our airfoil, a NACA 63-412, chosen for it's high C_{lmax}, and relatively low thickness. A low thickness ratio was chosen to increase the critical Mach number, and decrease the profile drag coefficient. The main wing is mounted low so the canards would be most effective in increasing the maximum angle of attack, as well as energizing the flow over the wing.[18] In mounting the wing low, a slight penalty is paid in increased drag due to fuselage interference, as well as lateral stability. These disadvantages were judged to be outweighed by the significant advantages due to the canard/wing interaction (Figure 5.1, Table 5.1). Winglets were considered, but were determined to be too structurally complex and expensive for the relative small increase in performance. The high lift devices selected were simple fowler flaps, to increase the maximum lift coefficient from 1.6, without flaps, to 2.6 for take-off and landing. Fowler flaps were chosen for their high effectiveness in increasing lift, compared to simple flaps. A one stage flap was chosen to ease manufacturing difficulties, and because one was sufficient. For wing mounted control surfaces, spoilers were selected, combined with the rudder for lateral control. Longitudinal control is provided by the canards (see Section 6) (Table 5.2).

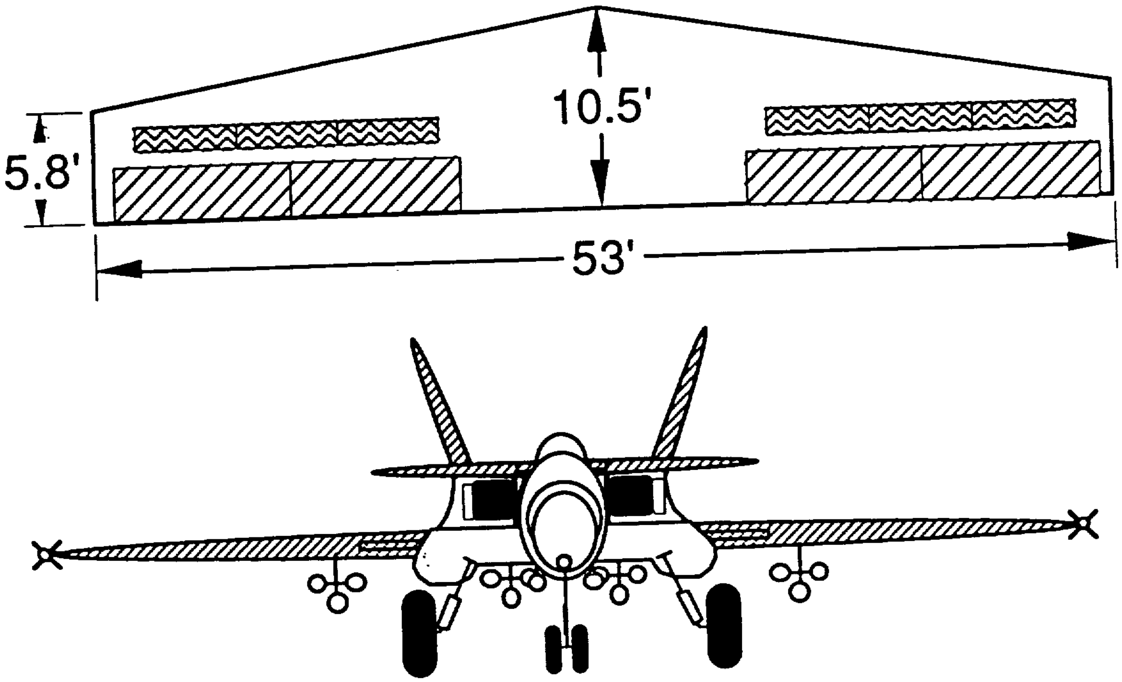


Figure 5.1 Main Wing of the Eliminator

Table 5.1 Main Wing Configuration

Airfoil Type	NACA 63-412	Planform Area	432 ft^2
Span	53.0 ft	Wetted Area	665 ft^2
Aspect Ratio	6.5	Leading Edge Sweep	10°
Taper Ratio	0.55	Trailing Edge Sweep	0°

Table 5.2 Configuration of High Lift Devices / Control Surfaces

High Lift Device	Single Stage Fowler Flap	Control Surface	Spoiler
Span	36 ft	Span	35 ft
% MAC	30%	% MAC	16%
Surface Area	90 ft^2	Surface Area	50 ft^2

5.2 FUSELAGE

The fuselage was designed in a streamlined shape to reduce aerodynamic drag. The ammunition drum, located near the front of the fuselage, determined the minimum width of the fuselage (Figure 5.2). The fuselage was kept as narrow as possible, to reduce the target area exposed to ground fire. The length of the fuselage was determined by the equipment within the fuselage, for example, the fuel, ammunition, and engines. Pods are constructed underneath the fuselage for the retraction of the main landing gear. This was necessary due to the location of the main landing gear as well as the bombs and main wing.

A trailing edge extension (TEX) was chosen to inhibit the canard downwash from entering the inlets. Pressure relief doors were added to the TEX, just behind the inlets, to release the air trapped by the TEX at high angles of attack, and thus reduce the pressure build up in front of the inlet. The doors should also act as vortex generators, producing vorticies over the fuselage, thus increasing the lift of the fuselage slightly.

The fuel is located completely within the fuselage, in tanks C1 to C4 (Figure 5.3). This protects the fuel from ground fire by offering a smaller target area. To minimize potential losses, the fuel tanks are resealable bladders. Locating all of the fuel in the fuselage simplifies the construction of the wing, as an open space is no longer necessary within the wing. The disadvantages to having all of the fuel in the fuselage is the increased fuselage area, and the increased central bending moment of the wing. The advantages of survivability were determined to outweigh the disadvantages of structures. The fuel is separated into four tanks, and the order in which they are used is controlled, in order to limit the travel of the center of gravity (see Section 11).

The ammunition drum is located close to the cannon to simplify the loading of the cannon. The cannon, located in the nose, is canted so that the cannon line of fire is lined up with the center of gravity of the aircraft, so no moment is created when the gun is fired (Figure 5.2).

Fourteen of the twenty bombs carried by the aircraft are located under the fuselage. This allows greater flexibility and carrying capacity of ordnance than would be available if the wings were the only surfaces with hardpoints. Additionally, placing the bombs under the fuselage keeps them close to the center of gravity, thus reducing the travel of the center of gravity when the bombs are dropped. The disadvantage to this bomb placement is that the landing gear must be long enough to ensure adequate ground clearance with the bombs attached. To ensure adequate clearance, the Eliminator has a three foot ground clearance fully loaded.

The engines are buried in the fuselage, and separated with a kevlar shield, to protect one engine if the other is destroyed. The APU and chaff and flare dispensers are located between the engines (Figure 5.3). The airbrakes, located at the trailing edge of the fuselage, are designed to open 30° to slow the aircraft upon landing, thus enabling the Eliminator to land with a ground roll less than 1810 feet.

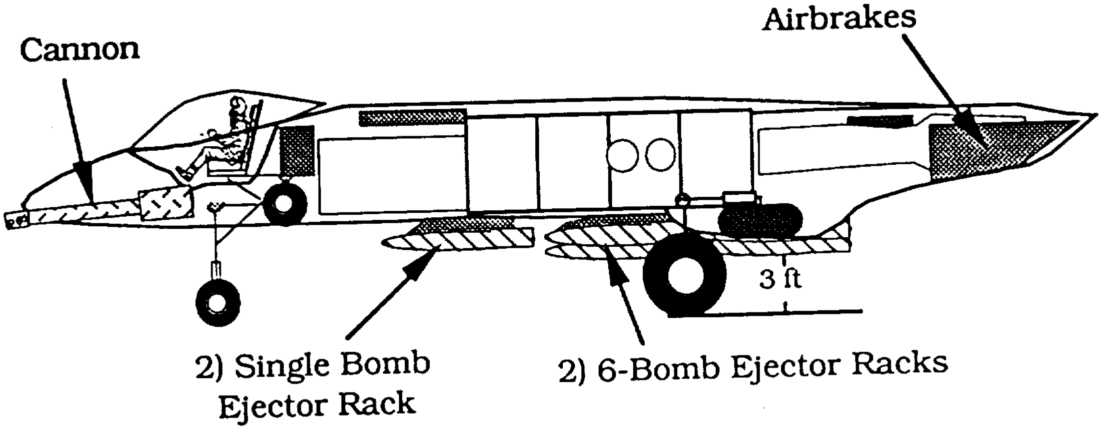


Figure 5.2 Side View of the Fuselage for the Eliminator

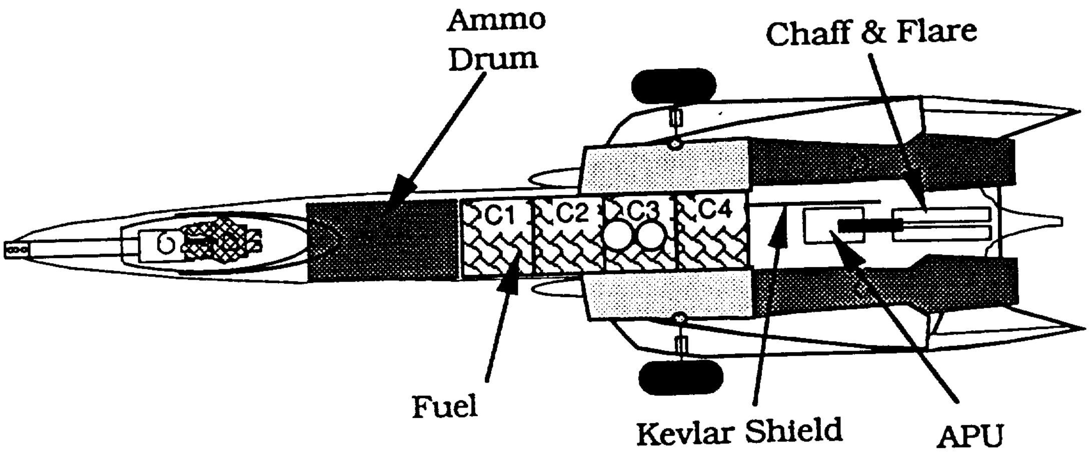


Figure 5.3 Top View of the Fuselage for the Eliminator

5.3 EMPENNAGE DESIGN

5.3.1 CANARD DESIGN

A canard configuration was chosen to increase the inherent maneuverability of the aircraft, as well as to increase the performance of the aircraft. A canard can increase the maximum angle of attack for the aircraft by generating vortices over the main wing, thus keeping the flow attached for higher angles of attack. A canard also reduces the induced drag of the airplane, because it produces lift. And finally, the canard can be made to stall first, creating a large pitch down moment, thus making stall recovery much easier. The disadvantages of a canard are the downwash which could flow into the engine inlets. As well as the increased bending of the fuselage due to lift generated in front of as well as behind the center of gravity. It was judged that these disadvantages were outweighed by the benefits.

Like the main wing, a low thickness ratio was desirable, thus a NACA 63-412 airfoil was selected (Table 5.3). To increase the Mach divergence number, the canard has a 10° leading edge sweep, and is mounted high to maximize the efficiency of the canard-wing interaction.[18] For longitudinal control, the canard has elevators (Figure 5.4). Since the plane is unstable, small deflections are sufficient for good longitudinal control, thus small trim drag penalties are induced.

Table 5.3 Canard Configuration

Airfoil Type	NACA 63-412	Leading Edge Sweep	10°
Span	20.25 ft	Trailing Edge Sweep	-5°
Aspect Ratio	4.82	Position on fuselage	High
Taper Ratio	0.39	Height above Wing	3 ft = 0.4 $\mathrm{MAC}_{\mathrm{wing}}$
Planform Area	85 ft^2	Distance in Front of Wing	24 ft = 3 $\mathrm{MAC}_{\mathrm{wing}}$
Wetted Area	114 ft^2	Canard Elevator Area	13 ft^2

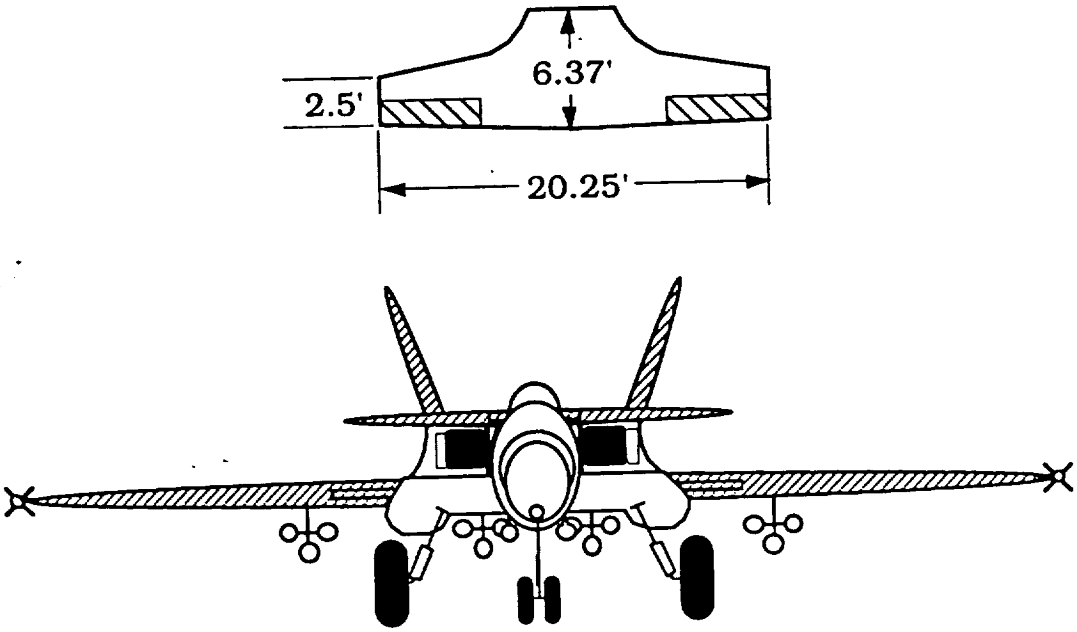


Figure 5.4 Canard Configuration for the Eliminator

5.3.2 VERTICAL TAILS

A symmetric airfoil was chosen for the vertical tail because it is a fully moving surface, as well as for ease in manufacturing and interchangeability. A low thickness ratio was chosen for the same reason mentioned for the canard, mainly for a high critical Mach number. Twin vertical tails were chosen for survivability, as well as a smaller radar cross section. They are canted outwards 20° to decrease fuselage interference at high angles of attack, as well as radar cross section (Table 5.4, Figure 5.5). To further decrease the radar cross section, they are constructed of composites. The disadvantages of twin vertical tails are the increased structures and weight compared to one large tail, but these are readily outweighed by the significant safety features. Some of these features are survivability, and smaller radar cross section. To simplify manufacturing and possible maintenance, the vertical tails will be interchangeable. To increase the control surface area, the vertical tails are fully moving surfaces, therefore smaller deflections for lateral control will be required.

Table 5.4 Vertical Tail Configuration

Airfoil Type	NACA 0006	Canted Outwards	20°
Span	7.0 ft	Planform Area	85 ft^2
Aspect Ratio	1.2	Effective Area	80 ft^2
Taper Ratio	0.41	Distance from Centerline	3.5 ft
Leading Edge Sweep	30°	Distance from Ave. CG	16.5 ft

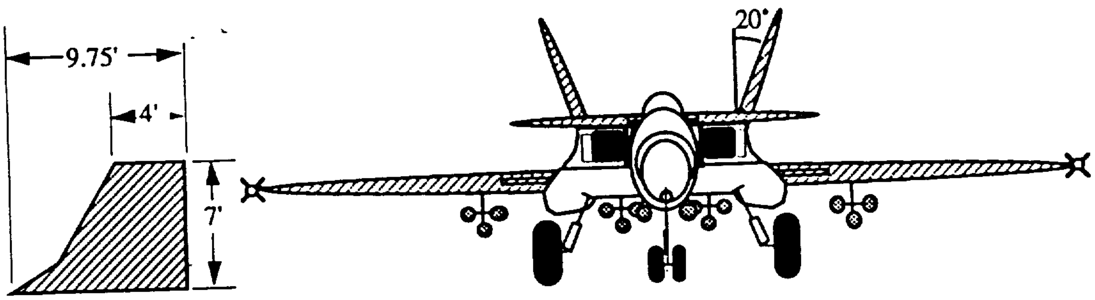


Figure 5.5 Vertical Tail Configuration for the Eliminator

5.4 PROPULSION SYSTEM

5.4.1 INLET DESIGN

In designing an appropriate inlet, several considerations were made. The pressure loss in an inlet can directly affect engine performance, thus the lower the pressure loss, the better the design. Square inlets were found to have an intermediate pressure loss compared to circular and semi-circular inlets. These results seem startling, but the change from a semi-circular inlet to a circular shape is more complex than the rounding of corners necessary to change a square inlet into a circular shape. As expected the circular inlet has the lowest pressure loss (see Section 9.2). Along with pressure loss, interference drag with the fuselage must be considered. Semicircular inlets were found to have the least interference drag, with circular inlets generating the most. Finally, side auxiliary inlets are added to the inlets to increase air flow at low speeds thus increasing engine efficiency. It is easier to add side auxiliary doors to square inlets than to circular or semicircular inlets (see Section 9). Square inlets were chosen for their reasonable pressure loss, and interference drag, as well as for the ease in design and manufacture of the auxiliary inlets (Figure 5.6).

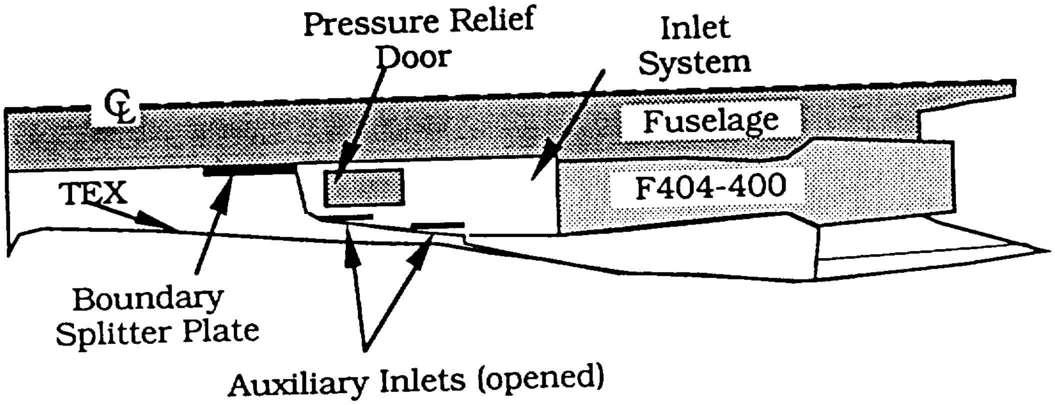


Figure 5.6 Inlet Design for the Eliminator

5.4.2 ENGINE SELECTION

Two engines were selected for several reasons. Two smaller engines are more fuel efficient than one large one. Survivability is increased, as power remains with one engine out. Also, no single engine was found to produce 30,000 lb of thrust and yet remain small enough to fit within the current fuselage. The increased complexity and weight of two engines was not significant enough to counteract the benefits, of survivability and size.

An off-the-shelf engine was chosen for several reasons. Although a new engine model can be designed for the aircraft's requirements, manufacturing delays of the engine can cause manufacturing delays of the aircraft. Also, an off-the-shelf engine has been tested and used on other aircraft, so it's performance characteristics are known. Finally, a production engine has the required parts and personnel readily available for maintenance and repair. For the required thrust, a General Electric turbofan engine, model F404-400 was chosen (Figure 5.7).

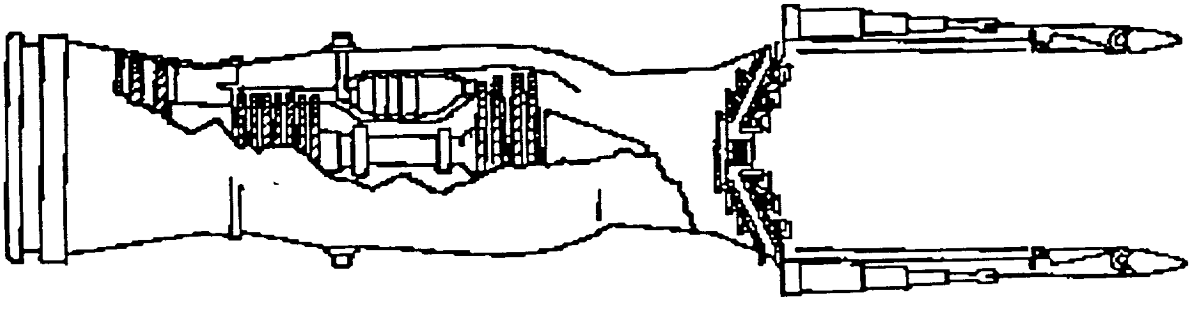


Figure 5.7 General Electric F404-400 Engine, for use in the Eliminator

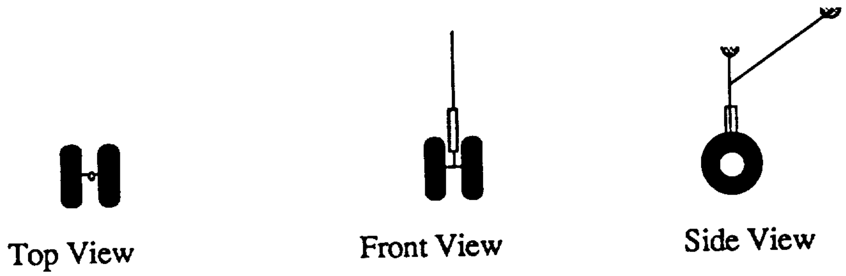
5.5 LANDING GEAR

For the Eliminator, the tires are oversized to permit landing and takeoff from hard, dry dirt runways (Table 5.5). If the landing field is soft grass or sand, a portable metal runway must be used, as the tires on the Eliminator are not large enough for such a landing. The reason such tires were not used was the size and weight penalty. It was felt that a portable runway was a reasonable limitation to the close air support aircraft. A simple landing gear was desired, to reduce maintenance and cost, so the nose gear is designed with a simple retraction system (Figure 5.8). The main gear must retract in a more complex manner due to the location of the main wing and ordinance. The retraction method is a combination of rear retraction and a 90° tire rotation (Figure 5.9). This method was chosen because it is relatively simple, and it results in the best position for the main gear given the design space limitations.

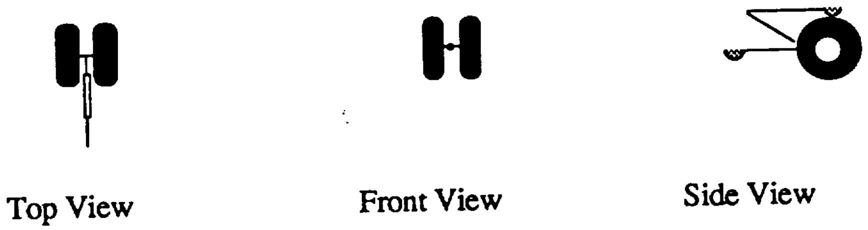
Table 5.5 Landing Gear Disposition

Type	Tricycle	% W_{to} on Nose gear	13 %
Wheel Base	25 ft	Maximum ø (Lateral Tip)	55°
Track	8 ft	Minimum Tip Back Angle	15°

	Nose Gear	Main Gear
Distance from Nose	10 ft	35 ft
Length of gear	9.4 ft	8.8 ft
Retraction	Simple rotation	Complex rotation
Maximum Load / Tire	5,000 lb	24,000 lb
# Tires / Strut	2	1
Tire Size	28 x 9.0-12	52 x 20.5-23
Tire Diameter	27.60 in.	39.80 in.
Tire Pressure	63 psi	67 psi

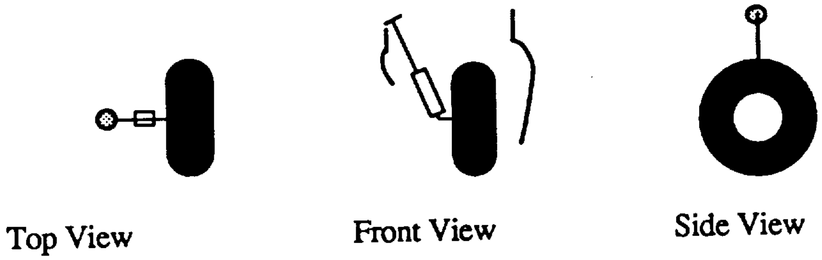


(a) Extended

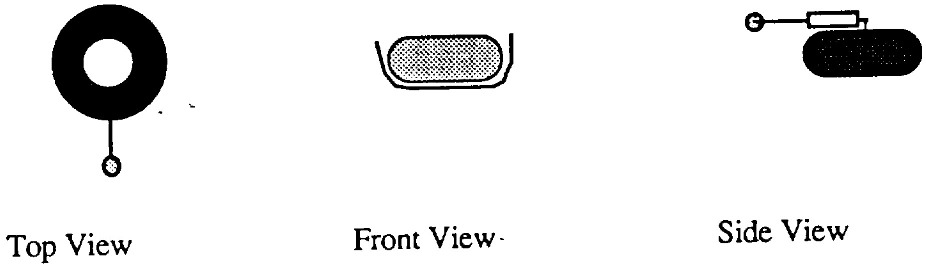


(b) Retracted

Figure 5.8 Nose Gear Retraction System for the Eliminator



(a) Extended



(b) Retracted

Figure 5.9 Main Gear Retraction System for the Eliminator

6.0 SIZING ANALYSIS

6.1 TAKE-OFF WEIGHT ESTIMATION

To estimate the take-off weight for the Eliminator, a method was used which determines the amount of weight left after a mission leg. This method, called the fuel fraction method, is based upon existing aircraft of a similar type. For the Eliminator, this was fighters with jet engines. For the stages of take off, accelerate to dash, dash in, combat and dash out, additional parameters, such as L/D and c_j were used in calculating the fuel fraction. The L/D values were originally based upon existing aircraft, then later based upon the aerodynamics of the Eliminator. The c_j values were based upon the engine selected for the Eliminator. A summary of the results is shown in Table 6.1 (also Appendix B). The weight found from this method was used to generate the general size of the Eliminator. When the actual weight of the aircraft was found (see Section 11), that weight was used in this table to determine the exact fuel weight required for the design mission.

Table 6.1 Fuel Fraction Summary for Low Level Mission

W_{to} (lb)	55,000
W_F (total) (lb)	14,707
W_{Pay} (lb)	13,000
W_{Crew} (lb)	225
Empty weight - estimate (lb)	27,068
Empty weight log equation (lb)	28,289
% difference in Empty weights	-4.316%

6.2 TAKE-OFF AND LANDING DISTANCE REQUIREMENTS

For similar aircraft operating under ideal conditions, no wind, level runway, all engines operating and jet engines, an equation was developed relating the power loading to the wing loading for take-off conditions.[2] This equation relates the wing loading as a function of power loading, ground roll, profile drag coefficient, lift coefficient and runway type. For the Eliminator, only the power loading and the lift coefficient can be varied for the design mission. Figure 6.1 shows the results of this requirement for two different maximum lift coefficient's.

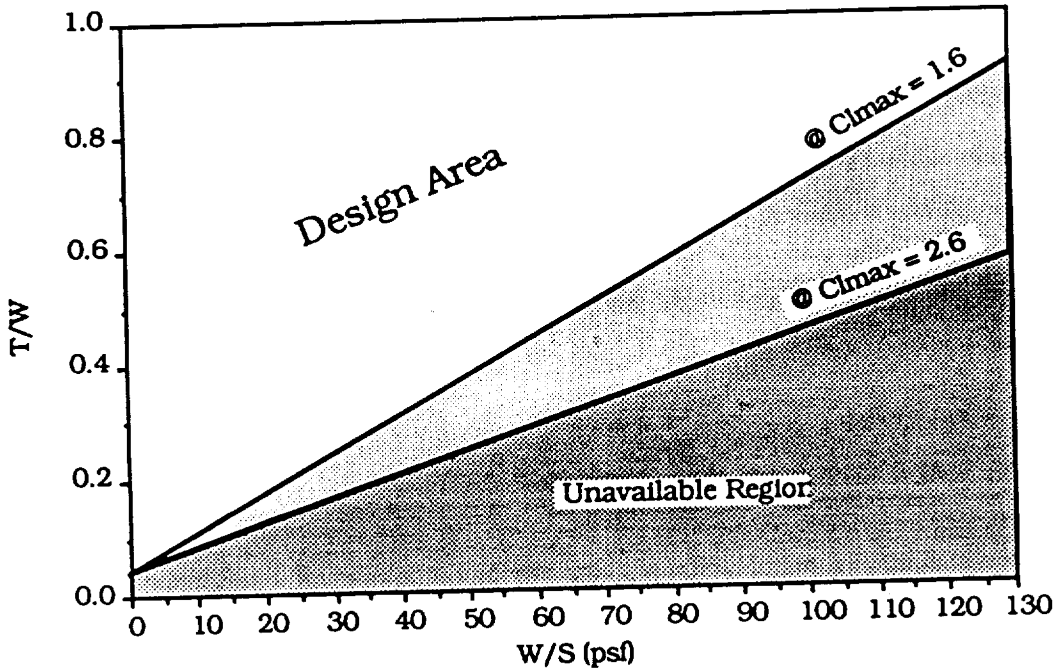


Figure 6.1 Take-Off Distance Constraint for the Eliminator

The landing constraint is based upon the ground roll requirements, which was given in the RFP.[1], and the maximum lift coefficient during landing. Table 6.2 summarizes the wing loading constraints for several lift coefficients and a maximum ground roll of 2000 feet.

Table 6.2 Landing Distance Constraint for the Eliminator, Assuming a 2000 ft Ground Roll

	Vstall =	122 kts =	207 ft/s		
C_{LmaxL}	1.4	1.6	1.8	2.0	2.6
W/S_{maxL} (psf)	71	81	91	102	132

6.3 MANEUVERING REQUIREMENT

For the Eliminator a maneuvering requirement of 4.5 g's sustained load factor and 6.0 g's instantaneous load factor is imposed upon the aircraft during the alternate self-defense mission.[1] This requirement provides further power and wing loading parameters to be integrated into the design. By applying Newton's Law to steady turning flight condition in the radial direction, an equation is derived relating power loading to wing loading for a given load factor. Given the velocity at which the maneuvering must occur a constraint line of power loading versus wing loading is obtained (Figure 6.2). The velocity for this case was 450 knots, based upon the RFP requirements.[1]

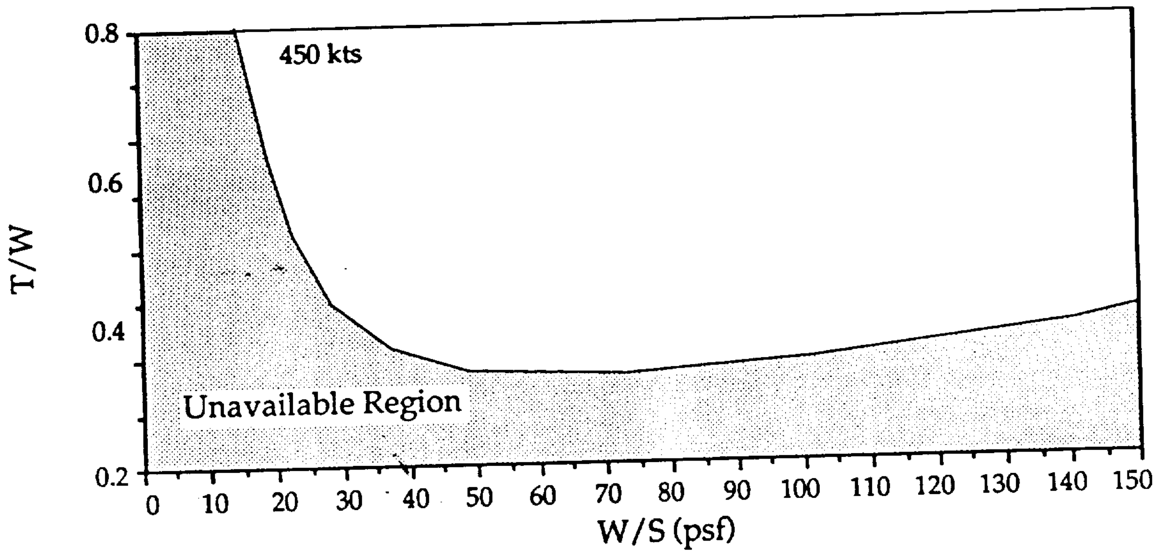


Figure 6.2 Maneuvering Constraint on T/W versus W/S

A design area for the Eliminator was found by combining the constraints from the take-off, landing and maneuvering requirements, and maximum engine thrust of 30,000 lb (Figure 6.3).

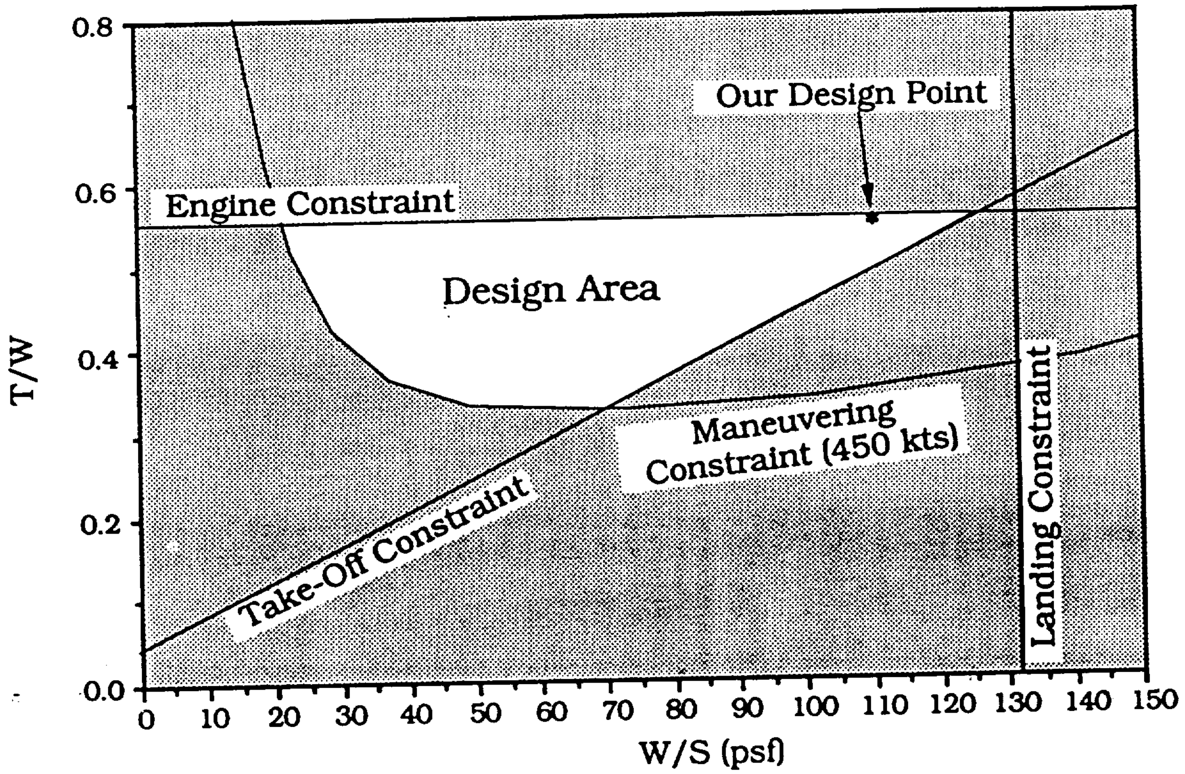


Figure 6.3 Design Area For the Eliminator, for a $C_{Lmax} = 2.6$

6.4 CLIMB REQUIREMENTS

Although the RFP contains no explicit climb requirements, general military specifications give minimum requirements that are applicable to all military aircraft. These requirements are in the form of climb gradients, where the climb gradient is given by the relation

$$CGR = (dh/dt) / V$$

There are three different climb requirements that must be satisfied by the aircraft's performance. Two of those conditions are for takeoff. At takeoff speed, which is approximated as 1.1 times the takeoff stall speed, the climb gradient must be at least 0.005. The aircraft configuration for this is gear down, flaps down and maximum power. The climb gradient over the 50 ft obstacle must be at least 0.025. The configuration here is gear up, flaps down and maximum power. There is also a climb gradient requirement of no less than 0.025 for landing with the configuration being gear up, flaps down for approach and maximum dry power applied. All of these climb gradients are assumed for the case of a single engine aircraft or a multi-engine aircraft with the most critical engine inoperative. These are the only climb related requirements and were therefore the only climb parameters considered in the Eliminator's preliminary design. Other capabilities such as rate of climb and absolute ceiling will be discussed at a later point in this report.

A relation between lift to drag ratio and thrust to weight ratio was found as a function of the climb gradient.[2] For the preliminary sizing and design a range of L/D values was used to find a range of T/W, but as the design matured, calculated values of L/D were used to obtain a more accurate value for the required thrust to weight ratio. This value was used in the decision for required thrust and in determining other engine parameters (see Appendix B).

6.5 ENERGY CLIMB

The RFP[1] calls for two 4,000 ft. energy increases during the combat phase of the mission. By evaluating the potential energy equation for a change in height of 4,000 ft., the total required energy increase is obtained. This can be obtained by any combination of altitude and velocity. By setting the sum of kinetic energy and potential energy equal to the total energy increase, a relationship is established between velocity change and altitude change. For a value of initial velocity and altitude increase, a value for the final velocity can be obtained. This was done for altitude changes of 0 to 4,000 ft. in 1,000 ft.

intervals and initial velocities of 200 to 500 knots. The results were then plotted with the initial velocity as the abscissa, the final velocity as the ordinate and the altitude change as a parameter (Figure 6.4). This gives a quick and easy reference for the 4,000 ft. energy increase called for in the RFP.[1] For example, with an initial velocity of 400 knots and a planned climb of 2000 ft, the final velocity required would be approximately 455 knots.

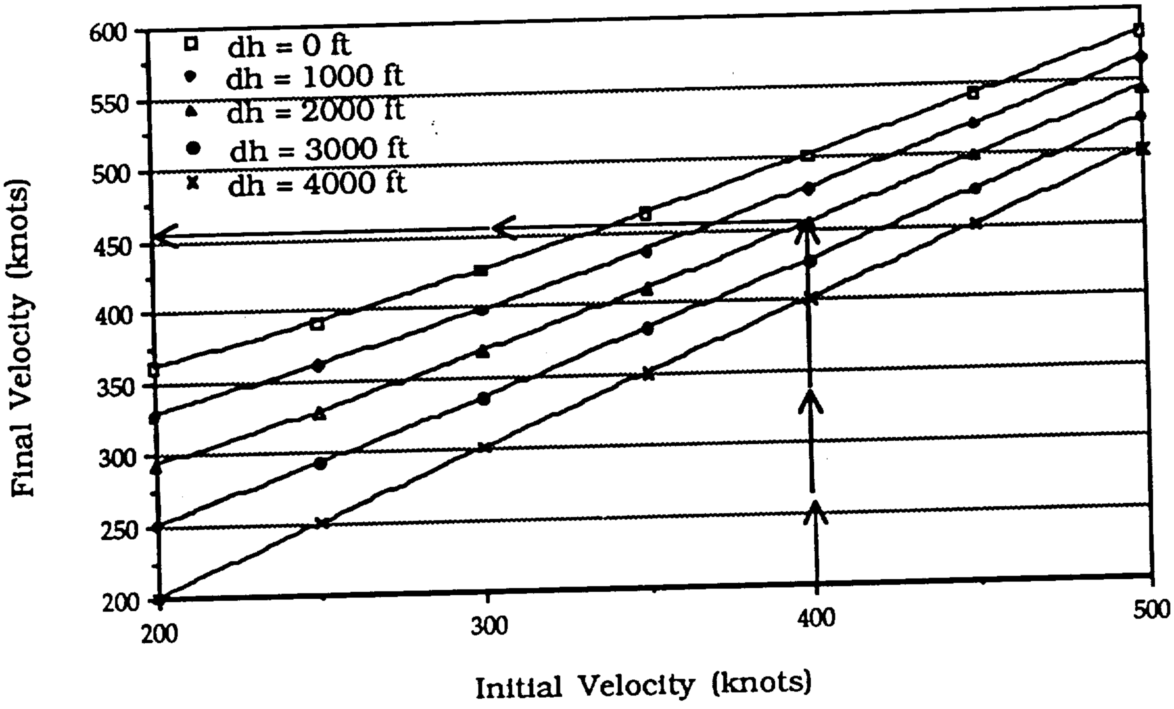


Figure 6.4 4000 ft Energy Increase

6.6 WING AND CANARD SIZING

The wing loading for the Eliminator was determined from the design area (Figure 6.3). A wing loading of 110 psf was determined to be sufficient from a buffeting standpoint, as well as within the constraint area due to landing, takeoff, maneuvering requirements and the thrust available. Using this wing loading and the take-off weight of the aircraft, a total planform area was required of 515 ft^2. This is the total area of the wing and canard, as the canard is a lifting surface. A comparison was made between canard sizing and static margin. We decided on an approximately 20% unstable aircraft, to increase maneuverability. Thus the canard area was determined to be 85 ft^2, and the wing area 432 ft^2 (Figure 6.5). For the main wing, an aspect ratio of 6.5 was desired, with a leading edge sweep of 10°, thus the exact wing size was determined. The canard size was determined in a similar manner, with an aspect ratio of 4.8, and a leading edge sweep of 10° (see section 5.0).

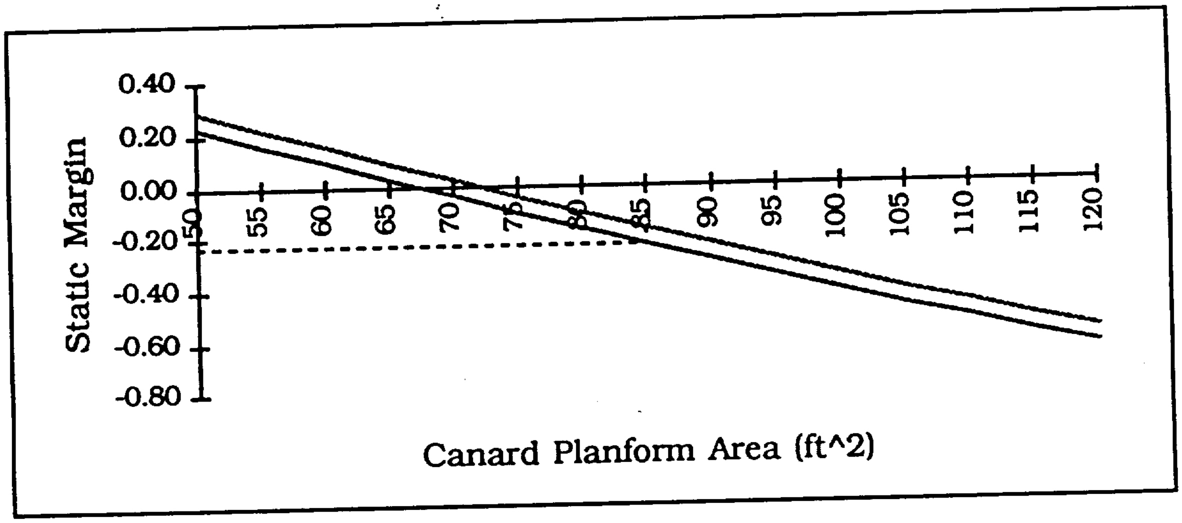


Figure 6.5 Static Margin for the Eliminator as a Function of Canard Size

6.7 EMPENNAGE SIZING

The size of the vertical tail was determined by the relationship between lateral stability and the size of the vertical tail. A slightly negative lateral stability was chosen for the Eliminator, for maneuverability (Figure 6.6). Thus the size of the vertical tail is 75 ft^2. Since the vertical tail is canted outward 20°, to reduce radar cross-section, the planform area is 85 ft^2 or 42.5 ft^2 each. Since this sizing was performed, the lateral stability has changed to 0.04 (see Section

8), due to changes in the wing sizing. This positive stability was determined to be acceptable, therefore the tail was not resized.

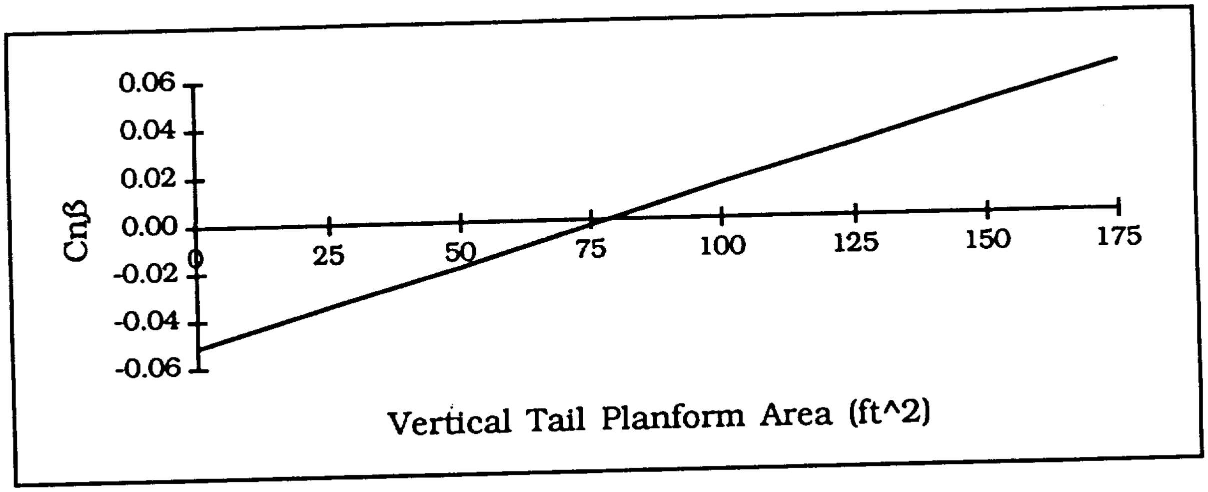


Figure 6.6 Lateral Stability for the Eliminator as a Function of Tail Size

6.8 LANDING GEAR DESIGN

In designing a landing gear system several constraints must be considered. The first is the tip back angle which must be no less than 15° for a tricycle landing gear to allow sufficient clearance for take-off and landing rotations (Figure 6.7). For this reason, the landing gear was designed so that at the most aft CG the tip back angle was 15°, thus fixing the main gear location for any height. The second constraint is the lateral tip over angle. If this angle is more than 55°, the aircraft will not be stable on the ground, and may tip over during taxiing (Figure 6.7). Also, the weight on the nose gear, at take-off, should be between 8 and 15% of the weight. This allows enough control of the aircraft on the ground, and yet not so much that it would hamper the rotation about the main wheels during take-off. The final constraint on the landing gear placement was the necessary ground clearance to allow attachment of the payload under the fuselage and wings, as well as to allow clearance for rotation of the aircraft during take-off and landing. We judged a three foot clearance, after the bombs were loaded to be the minimum allowable clearance for accessibility to the payload. Typically, a 15° clearance angle with flat tires is judged as the minimum allowable. This is to ensure adequate clearance for take-off rotations. Thus the nose gear was located by the above constraints. The location of the landing gear is summarized in Table 6.3, and Figure 6.8.

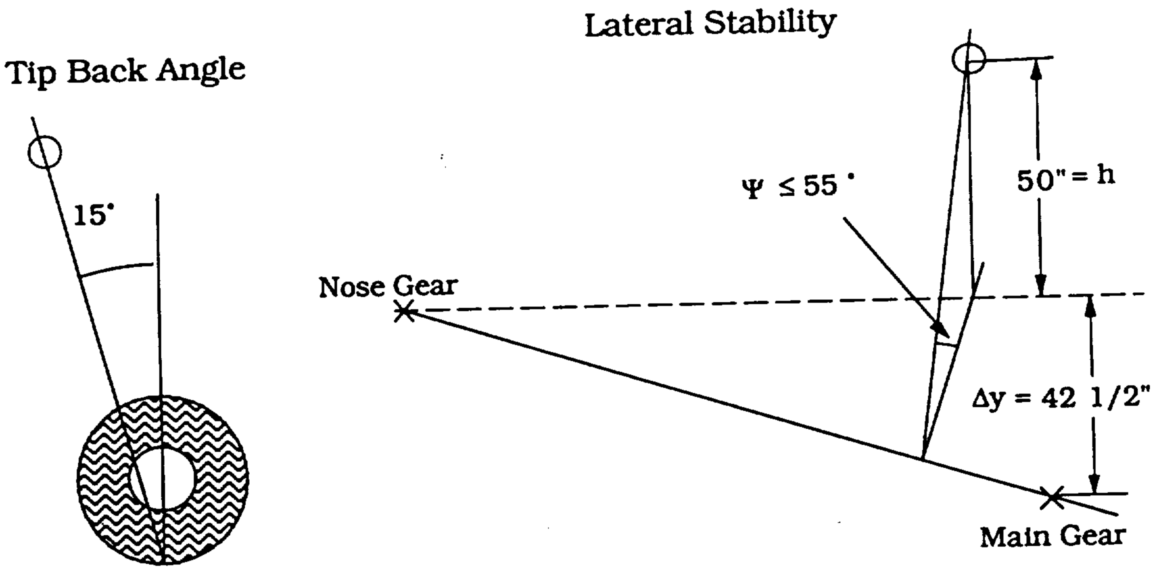


Figure 6.7 Tip Back and Lateral Tip Angle for Tricycle Landing Gear

Table 6.3 Landing Gear for the Eliminator

	Nose Gear	Main Gear
Distance From nose	10 ft	34.4 ft
Length of gear	9.4 ft	8.8 ft
Distance from centerline	0 ft	4 ft

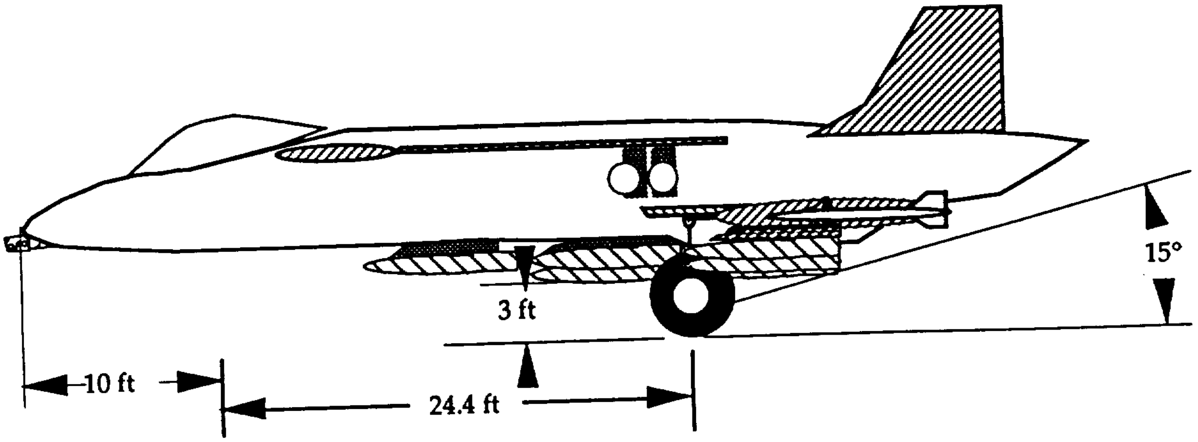


Figure 6.8 Landing Gear Location for the Eliminator

In sizing the tires, several decisions must be made. What kind of field will the aircraft be able to land on, and how many tires per strut for the nose gear and main gear. The design requirement for the Eliminator is for a smooth, hard surface, but operation from a dirt runway or unimproved field may be required. Several different options were examined, such as two wheels per strut and oversized tires. For the nose gear, two tires were chosen. This was to decrease the load carried by each tire, so that landing on a dirt field, or metal runway is possible. One large tire could have been used, but the space available to the nose gear is relatively wide and short. Therefore a large tire would require a more complex retraction mechanism. The wheel specifications for the nose and main gear are listed in Table 6.4. Figure 6.9 illustrates the landing gear configuration for the Eliminator. For the main gear, one tire per strut was chosen. Again the deciding factor was space. Due to the space available for the main gear, a larger tire would be easier to retract than two smaller tires (see Appendix B). A complex retraction method is still necessary for the main gear, but it was determined that a larger diameter would be easier to accommodate than the increased width caused by two tires.

Because the tires were sized so that they have a low internal pressure, under 70 psi, the tires should last longer than they would if they were inflated at 200 psi.

Table 6.4 Wheel Specifications for the Eliminator

	Nose Gear	Main Gear
Maximum Load / Tire	5,000 lb	24,000 lb
# Tires / Strut	2	1
Tire Size	28 x 9.0-12	52 x 20.5-23
Wheel Diameter	12.00 in.	23.00 in.
Tire Diameter	27.60 in.	39.80 in.
Tire Width	8.85 in.	20.50 in.
Tire Pressure	63 psi	67 psi

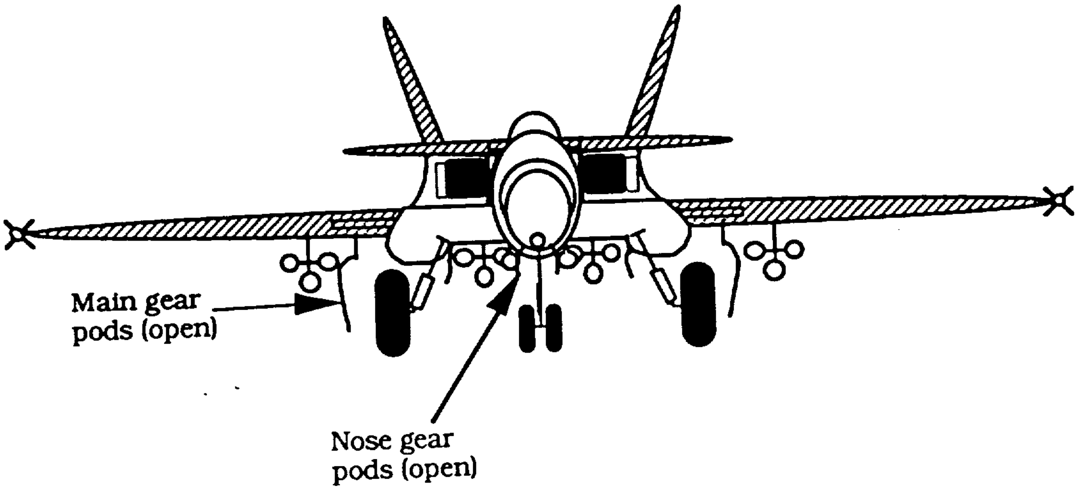


Figure 6.9 Front View of the Eliminator

7.0 AERODYNAMICS

The driving force behind the aerodynamic design of the Eliminator was good performance at moderate subsonic Mach numbers, around 0.75 for the majority of the primary mission. This performance is achieved by designing the wing with a 10° leading edge sweep and 12% thickness to dictate a critical Mach number of 0.77 and a drag divergence Mach number of 0.85. Both of these values are greater than the maximum Mach number for the primary design mission. The Eliminator is capable of speeds in excess of these values, however, due to its high thrust-to-weight ratio, and so the effects of compressibility and drag divergence are evaluated.

7.1 DRAG POLAR

Figure 7.1 shows a plot of lift coefficient versus drag coefficient for the Eliminator for the configuration with bombs but with gear and flaps stowed, and also superimposes the drag polars for landing and for take-off on the same figure. Both include flaps and landing gear deployed as well as full weapons stores. This would be the worst case for the landing situation, assuming an aborted mission with unused munitions.

Naturally, the drag is much higher for the latter two cases than for the clean with payload case, because of the higher angles of attack involved and the larger frontal and surface area.

From the figure, it can be determined that C_{d_o}, the profile drag coefficient, is approximately 0.025 for the standard configuration and 0.04 and 0.11 for take-off and landing respectively.

Every effort has been made in the design of the Eliminator to locate the external ordnance so as to minimize as much as possible the projected frontal area. Research has also been done on the best bomb arrangements to limit drag.

The primary payload configuration calls for the bombs to be aligned so as to shield some bombs with others located in front of them and thus reduce frontal area. This is done under the fuselage where the majority of the ordnance is carried.

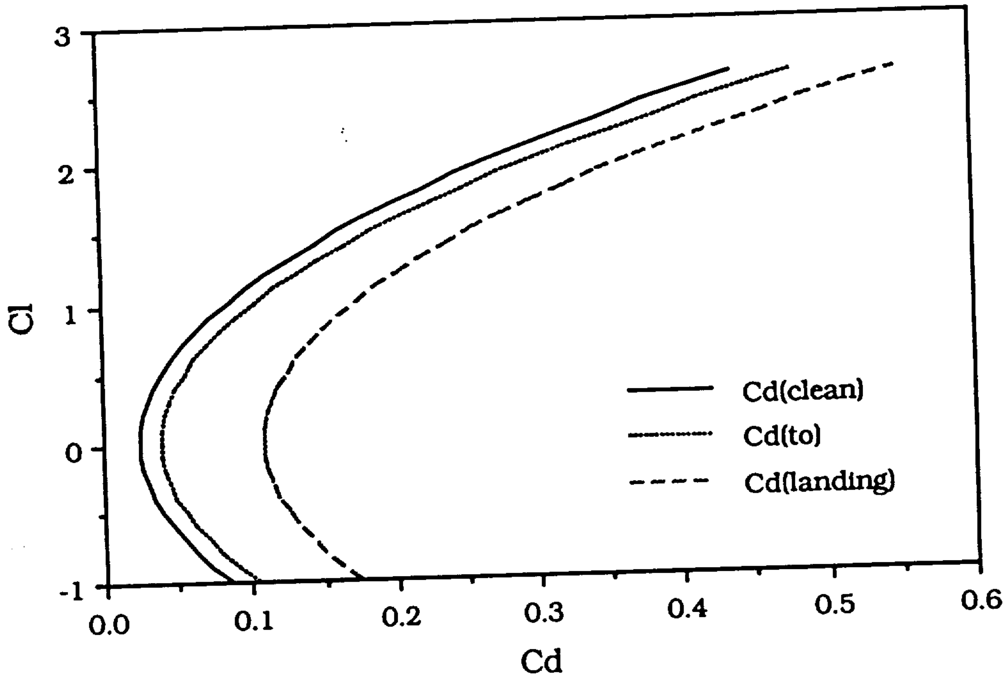


Figure 7.1 Comparison of Drag Polars for the Eliminator

7.2 LIFT-CURVE

Figure 7.2 shows the basic lift curve for the Eliminator. Superimposed upon this curve is the lift curve when flaps are deployed, such as during landing and take-off.

This curve was determined by applying lifting-line theory to a simplified model of the proposed Eliminator design. The model consisted of the canards, the main wing and the vertical tails. These components were estimated to be the major contributor to the overall lift of the aircraft.

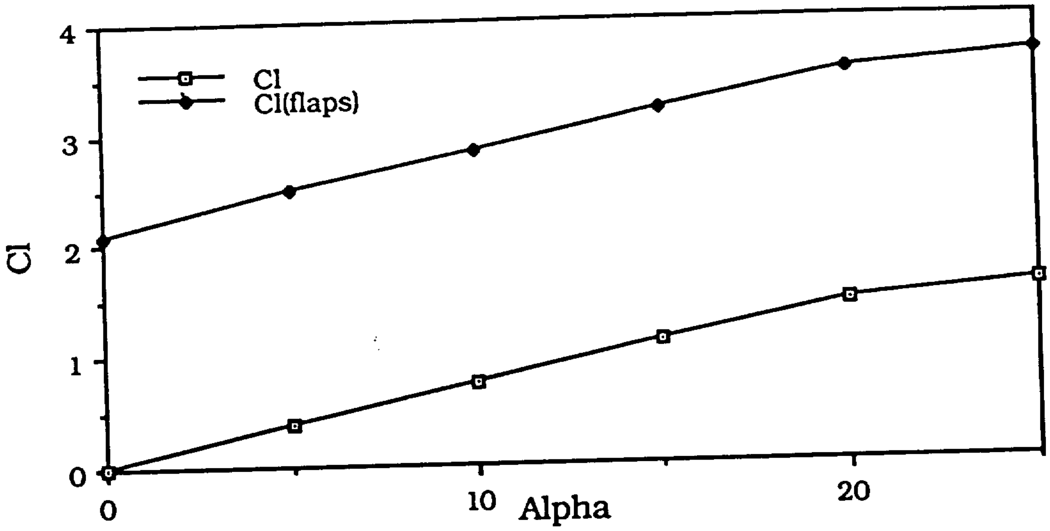


Figure 7.2 Lift Curve for the Eliminator, with bombs

Although, undoubtedly, the fuselage does contribute to the lift, it was felt that the contribution would be small in relation to the wings and the canards.

The vertical tails were included because they are canted outward at 20 degrees and thus will have some force upward that would contribute at certain flight attitudes and angles. The magnitude of this contribution was unknown, and that was another reason for including the tails. Upon examination of the results, it was observed that their contribution is also small, but by no means negligible.

Figure 7.2 gives a good, though certainly not perfect, estimate of the overall lift curve for the Eliminator. This can be used in determining performance characteristics that can not be determined by airfoil data alone.

Because this figure does take into account other contributors to lift, canards and vertical tails, it is more accurate.

Because of the canard configuration utilized on the Eliminator, there is no downward component of lift, or negative force, generated by the empennage. The canards generate a positive, or upward, lift force for stability and control purposes and for this reason are more efficient than a comparable conventional configuration with a horizontal tail.

The lift to drag ratio, L/D, during the dash in or out portion of the flight was found to be 4.5. However this was not the maximum due to the high speed required for this part of the mission. The maximum L/D was found to be 11.0 which occurs at a much lower velocity than the dash and this velocity would be used for the ferry and loiter missions when endurance is to be maximized.

7.3 COMPRESSIBILITY EFFECTS

7.3.1 ON LIFT

Flow can be considered to be incompressible as long as the freestream Mach number is below 0.3. For the Eliminator, this is basically during landing and take-off as the majority of its mission will be conducted at Mach numbers of approximately 0.75.

Figure 7.3 plots lift coefficient versus Mach number at various angles of attack to show the variation of lift generated taking compressibility into effect. The Prandtl-Glauert correction factor was used to make the adjustment for compressibility. Although this is not the best method for evaluating compressibility, it is the simplest to apply and gives a good estimate.

Values for angle of attack were limited to between 1 and 9 degrees because these values give a good indication of the overall behavior of lift coefficient without unnecessary clutter.

7.3.2 ON DRAG

Just as compressibility affects lift adversely, it affects drag by causing higher drag than for incompressible flow. Figure 7.4 shows a drag polar for the clean with ordnance configuration at a Mach number of 0.9, during the dash in portion of the flight.

The compressibility corrections were found by applying empirically derived factors relating the correction to the difference between the Mach number of interest and the drag divergence Mach number.[8] By applying this relational graph to existing drag relations, a figure relating drag coefficient to Mach number can be found.

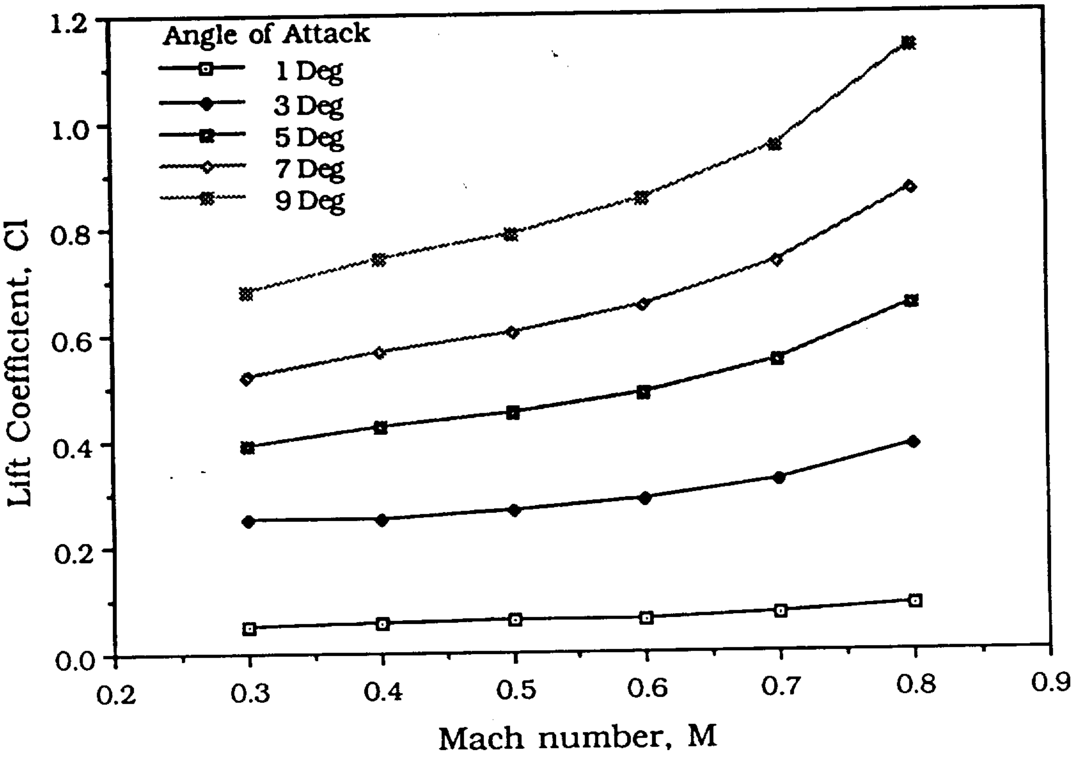


Figure 7.3 Variation of lift coefficient versus Mach number

Due to the compressibility effects, this drag is much higher than that at low Mach numbers. As mentioned previously, wing sweep is present in an attempt to minimize the adverse drag effects and raise the critical Mach number.

Fortunately, these high drag rises do not occur until the very high subsonic Mach numbers, and so are not a consideration for the majority of the primary mission. While the dash in and out does comprise the largest portion of the design mission, this is at Mach numbers that are still below the critical Mach number. Good design has made this a factor only during performance above and beyond the requirements.[1]

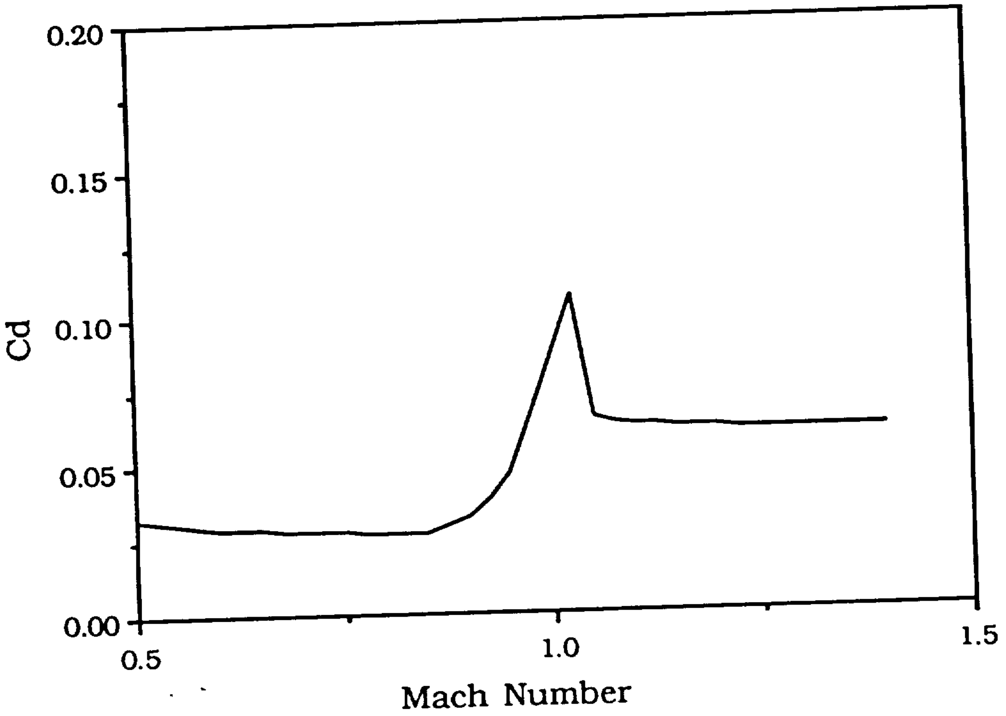


Figure 7.4 Drag Coefficient versus Mach number

8.0 STABILITY AND CONTROL

The discussion of stability and control of the Eliminator is divided into four main areas: 1) Static stability, 2) Stability derivatives, 3) Handling qualities, and 4) Control systems. The above three stability areas were investigated for the three different flight conditions shown in Table 8.1, namely combat dash in, combat dash out, and approach. These flight conditions will be referred to as Case A, Case B, and Case C for the remainder of this discussion. These three conditions were chosen because it was felt that these were the most critical conditions during flight.

Table 8.1 Stability Derivative Flight Conditions

	Case A	Case B	Case C
Phase	Combat Dash in	Combat Dash out	Approach
Altitude	Sea level	Sea level	Sea level
Mach #	0.76	0.76	0.175
Configuration	Full Munitions	Missiles & Ammo	Missiles & Ammo
Fuel	75%	50%	12.5%
Static Margin	-23%	-17%	-15%
Weight (lb)	51,090	37,315	29,966

8.1 STATIC STABILITY

The Eliminator was designed to be unstable both laterally and longitudinally as reflected by the static margins in Table 8.1. An unstable configuration was chosen so that an extremely maneuverable aircraft would result. It was felt that, in the CAS role, maneuverability is of the utmost importance so that the aircraft is able to evade the abundant hazards from shoulder launched and ground based surface to air missiles.

The level of longitudinal instability varies from a maximum of -23% at the most aft center of gravity to a minimum of -15% at the most forward center of gravity. This level of instability would, with a conventional flight control system, be too much for any pilot to handle; but the Eliminator's fly by wire flight control system makes this instability invisible to the pilot. While the cost of developing a fly by wire flight control system is more than that for a conventional system it was felt that the additional maneuverability outweighs the cost.

8.2 STABILITY DERIVATIVES

Semiempirical methods were used to calculate the stability derivatives of the Eliminator, see appendix D for sample calculations.[2,9] All of the derivatives assume a rigid airplane in steady subsonic flight. The results of the calculations are shown in Tables 8.2 and 8.3. Of particular interest is the sign of CM_{α}. The static longitudinal stability (CM_{α}) is positive indicating an unstable configuration. All of the rest of the derivatives fall within expected ranges.[12]

The control derivatives are shown in Table 8.4 for all cases. All of the derivatives fall within an acceptable range except for the rolling moment due to spoiler deflection ($C_{l_{\delta s}}$). This derivative is very small and further investigation should be done to change it to a value that is at least two orders of magnitude larger. This could be accomplished by increasing the chord of the spoilers and/or moving the spoilers forward on the wing. By increasing the chord of the spoilers they would be deflected into a larger area of flow making them more effective in producing a rolling moment. Moving the spoilers forward on the wing would have the effect of spoiling a larger portion of the lift on the wing and also spoiling the lift at a point closer to the maximum pressure differential point on the wing. If these two methods fail to increase

$C_{l_{\delta s}}$ by the required amount some differential canard elevator deflection should be tried to increase roll rates.

Table 8.2 Longitudinal Derivatives

	Case A	Case B	Case C
C_{L_u}	0.1366	0.1366	0.05398
C_{M_u}	0.0	0.0	0.0
C_{D_u}	0.0	0.0	0.0
C_{L_α} rad^{-1}	5.2724	5.2724	5.0030
C_{M_α} rad^{-1}	1.2358	0.9051	0.7505
C_{D_α} rad^{-1}	0.08590	0.06194	1.1305
$C_{L_{\dot\alpha}}$ rad^{-1}	0.4668	0.4487	0.4279
$C_{M_{\dot\alpha}}$ rad^{-1}	-0.8591	-0.7937	-0.7220
$C_{D_{\dot\alpha}}$ rad^{-1}	0.0	0.0	0.0
C_{L_q} rad^{-1}	10.527	11.482	7.0644
C_{M_q} rad^{-1}	-13.733	-14.3565	-10.995
C_{D_q} rad^{-1}	0.0	0.0	0.0

Table 8.3 Lateral Stability Derivatives

	Case A	Case B	Case C
C_{l_β} rad^{-1}	-0.04157	-0.03890	-0.13858
C_{n_β} rad^{-1}	0.03962	0.03962	0.04769
C_{Y_β} rad^{-1}	-0.1247	-0.1247	-0.1247
$C_{l_{\dot\beta}}$ rad^{-1}	-0.001932	-0.001932	-0.001720
$C_{n_{\dot\beta}}$ rad^{-1}	-0.002107	-0.002107	-0.001876
$C_{Y_{\dot\beta}}$ rad^{-1}	-0.01489	-0.01489	-0.01326
C_{l_r} rad^{-1}	0.06646	0.05299	0.4575
C_{n_r} rad^{-1}	-0.06349	-0.06332	-0.1533
C_{Y_r} rad^{-1}	0.1922	0.1922	0.1922
C_{l_p} rad^{-1}	-0.5347	-0.5324	-0.5053
C_{n_p} rad^{-1}	0.01313	0.009468	0.2033
C_{Y_p} rad^{-1}	-0.006405	-0.006405	-0.006405

Table 8.4 Control Derivatives

	Case A	Case B	Case C
$C_{L_{\delta c}}$ rad^{-1}	0.001162	0.001162	0.001162
$C_{M_{\delta c}}$ rad^{-1}	0.4616	0.4616	0.4616
$C_{D_{\delta c}}$ rad^{-1}	-0.1062	-0.07847	-0.06924
$C_{l_{\delta s}}$ rad^{-1}	0.0004035	0.0004035	0.0004995
$C_{n_{\delta s}}$ rad^{-1}	0.001141	0.001141	0.001141
$C_{Y_{\delta s}}$ rad^{-1}	0	0	0
$C_{l_{\delta r}}$ rad^{-1}	0.2029	0.2029	0.2010
$C_{n_{\delta r}}$ rad^{-1}	-0.6087	-0.6087	-0.6030
$C_{Y_{\delta r}}$ rad^{-1}	2.151	2.151	2.131

8.3 HANDLING QUALITIES

The Eliminators handling qualities, with its stability augmentation system and inherent instability, will be quite good. The natural frequencies and dampening ratios for the short period, phugoid, and Dutch roll modes were approximated without solving the characteristic equations for each mode, see sample calculations in appendix D.

The short period mode had complex numbers for the natural frequencies and dampening ratio, indicating a diverging motion in this mode. This mode will require considerable feedback to insure that the airplane is flyable. The reason for these complex numbers is the designed instability in Alpha ; creating a sign change in these stability derivatives. These derivatives are the main driving factors in the short period mode; and the approximations used to calculate the natural frequencies of this modes requires that the square root of these derivatives be taken, producing a complex number.

The phugoid mode has level 1 flying qualities with a dampening ratio (z) greater than 0.04 for all three cases. This may change with the stability augmentation system feedback necessary for the short period and Dutch roll modes but good flying qualities are still expected.

The Dutch Roll mode has level 2 flying qualities with all parameters falling within this level. As with the phugoid mode this may change with the stability augmentation system necessary for the short period mode, but again good handling qualities are expected.

8.4 CONTROLS

The Eliminator employs a highly reliable controls system, pictured in Figure 8.1. The primary system uses the quick-responding fly-by-wire (FBW) controls, thereby employing electrical signals instead of mechanical links, which have a greater chance of failing. However, electrical systems do fail, and since the Eliminator may be required to operate in remote areas with no access to electrical repair, the secondary system (also fly-by-wire) may be used. The primary FBW system is operated by the engine generators. The secondary FBW system is run by the battery in the nose of the aircraft and by the APU generator.

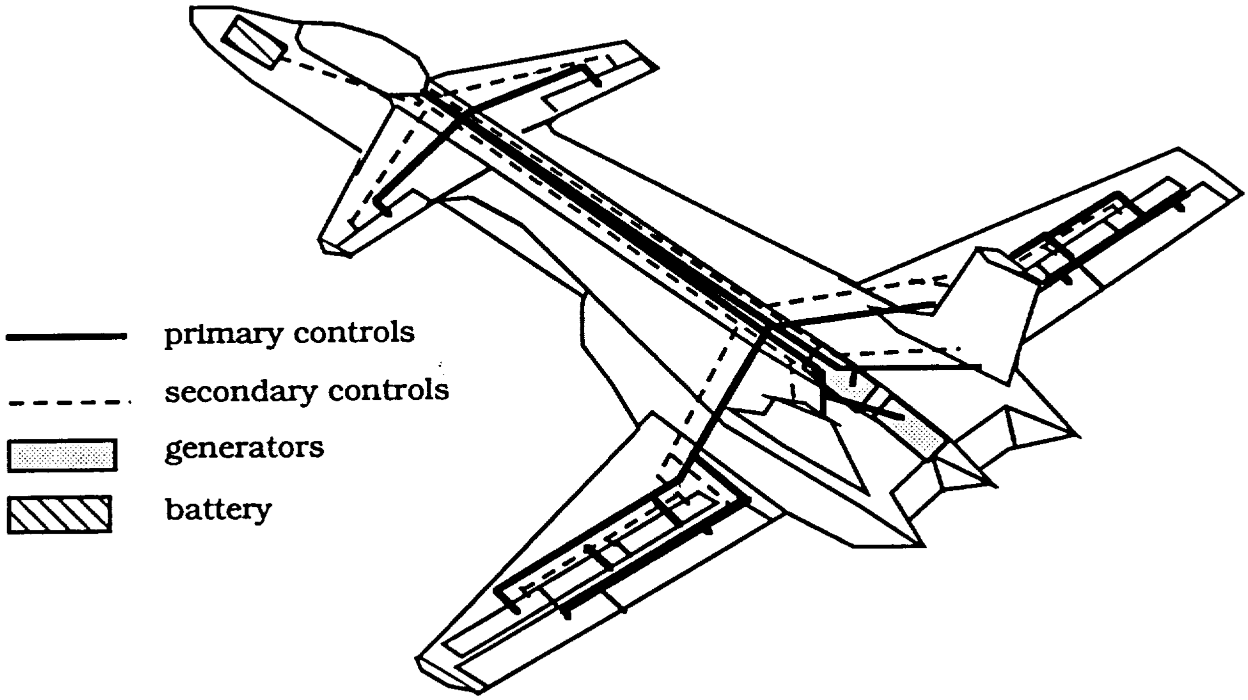


Figure 8.1 Control Systems Layout for the Eliminator

9.0 PROPULSION SYSTEM

9.1 PROPULSION AND APU SELECTION

For the selection of the propulsion unit, it was decided that a production or "off-the-shelf" unit would power the Eliminator. Since an important criteria of the program is to provide a low cost aircraft, the production engine offers this by eliminating research and development cost. In addition to availability, a production engine eliminates start up production. Spare parts are readily available as well as service and representative networks. These are some of the reasons why a production unit will reduce the overall cost of the project.

The propulsion unit chose for the Eliminator is the General Electric F404-400. This engine is currently being used in the F/A-18 Hornet. With afterburners, it produces 15,000 lb of thrust The engine was also selected for its upgrade capability. Currently, the family of F404 engine upgrade includes the F404-402, which can produce up to 17,000 lb of thrust. Should the Eliminator need to have an upgraded engine, the F404-402 would be a suitable candidate due to its similar dimensions and improved thrust.

The team's first choice engine was the Rolls-Royce RB-199 engine. It is smaller and lighter then the F404-400 and would have been a good candidate. With afterburners engaged, it produces 13,000 lb of thrust each, giving the Eliminator a total of 26,000 lb of thrust. This, however, was not able to propel the 55,000 lb aircraft within the take-off requirement of a 2000 ft ground roll. This was the primary reason in not selecting the Rolls-Royce engine. The RB-199 is a turbofan engine and therefore more efficient than the F404 low-bypass turbofan engine, at the altitudes and speeds at which the Eliminator is operating

To decrease development cost further, the same auxiliary power unit that operates in the F/A-18 will be used in the Eliminator. The Garrett AiResearch auxiliary unit will power the Eliminator.

9.2 INLET SIZING

Since the primary flight regime of the Eliminator is at low level and subsonic speeds, selection of the inlet system was relatively simple. The subsonic flight regime allows for a simpler design than would be necessary at supersonic speeds, since no shock wave is produced.

Three inlet designs were considered: a square to circular, a semicircular to circular, and a circular to circular inlet system. Of the three designs, the semicircular to circular design had the most pressure loss while the circular to circular design had the least pressure loss. A summary of the maximum pressure loss achieved by the three designs is presented in Table 9.1. The pressure loss is shown to vary with velocity.

Table 9.1 Maximum Pressure loss for Different Inlet Design

Velocity (ft/s)	Semicircular ΔP_{total} (psi)	Square ΔP_{total} (psi)	Circular ΔP_{total} (psi)
100	0.001	0.000	0.000
200	0.005	0.003	0.002
300	0.011	0.008	0.005
400	0.020	0.014	0.008
500	0.031	0.022	0.013
600	0.045	0.032	0.019
700	0.061	0.044	0.026
800	0.080	0.057	0.034
900	0.102	0.073	0.043

In order to calculate pressure loss, the inlet's shape had to be generated (see Appendix E). Each inlet is eight feet long and appropriate dimensions were taken at every 0.2 feet to arrive at the results in Table 9.1. The Eliminator uses boundary layer splitters, otherwise inlet pressure loss will be greater than those in Table 9.1. In addition, the pressure relief door, although part of the TEX, relieves high pressure in front of the inlet, thereby preventing pressure surges into the fan stage.

Although the circular inlet offers the best pressure recovery, the square inlet was chosen instead. There are two reasons: first, a square inlet offers reasonable pressure loss, and second, with a square inlet, it is easier to mount side auxiliary inlets, since it offers a relatively smooth surface panel to work with (as on the SEPECAT Jaguar). The integration of side auxiliary inlet doors for a square and circular inlet system are shown in Figure 9.1. Clearly, manufacturing and maintenance of a square inlet system is less complex. The airflow into the square auxiliary inlet is more straight forward than the circular system, thereby decreasing turbulent airflow into the fan section.

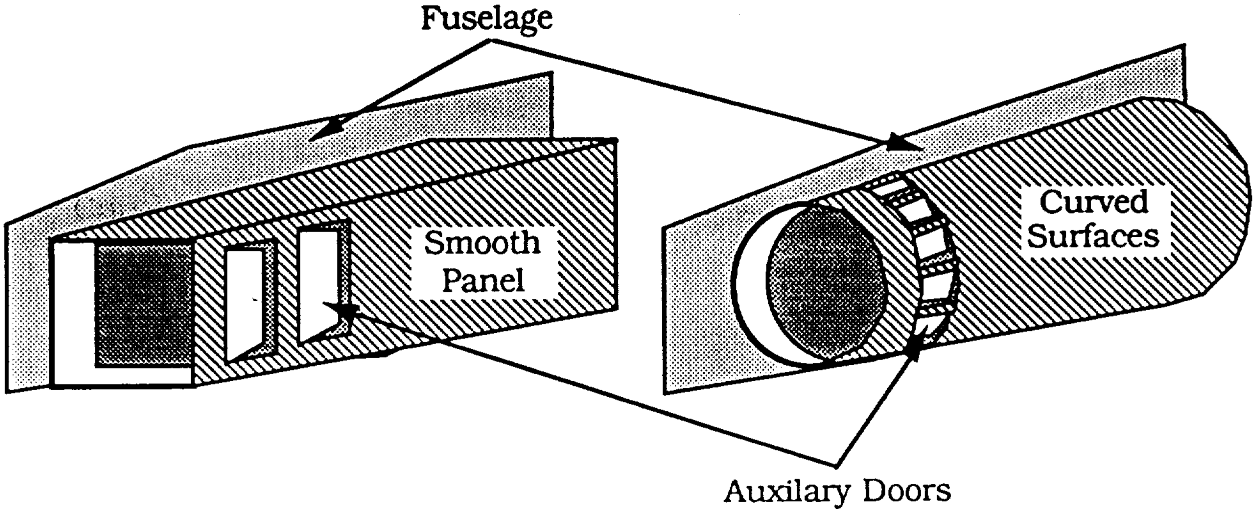


Figure 9.1 Typical Auxiliary Doors on a Smooth and Curved Surface

The side auxiliary doors are spring loaded. They open when the ambient pressure is greater than inlet pressure, which usually occurs at low speeds. Opened, they increase airflow to improve fuel efficiency.

At take-off, the required inlet area for proper airflow was calculated to be 9.55 ft^2. It was calculated to be 2.33 ft^2 for dash speed of Mach 0.75. The inlet area was compromised and an inlet size of 4 ft^2 at Mach 0.5 was chosen. The inlet size of 4 ft^2 is not an average area between take-off and dash speed. Instead, it was scaled toward the higher Mach number. The inlets are designed for subsonic speed, but the Eliminator is capable of reaching supersonic speed. In the supersonic regime, subsonic inlet performance is expected to degrade sharply. Hence, thrust output would decrease. No attempt was made to analyze the square inlet system at supersonic flight regime. At lower speed, the side auxiliary inlet will provide greater intake area to improve engine performance.

9.3 ENGINE, INLET AND FUSELAGE INTEGRATION

The total length of the Eliminator's inlet and propulsion system is twenty one feet, eight feet for the inlet system and thirteen feet for the F404 engine. The inlet diffuses from 4.00 to 7.06 square feet, where it meets the fan stage of the engine. A top view of the engine/inlet system is shown in Figure 9.2 The side auxiliary inlet is shown as well as the aft panel that camouflages the engine's infrared heat signature from the side.

As shown in Figure 9.2, on the outer side of the aft panel is the airbrake. Airbrakes are placed as far aft as possible so as not to disturb air flow over any control surfaces when deployed. The Eliminator is equipped with a boundary layer splitter plate in front of the inlet to prevent low energy boundary layer ingestion. The pressure relief door is located just aft of and on top of the inlet.

This door relieves high pressure air trapped by the TEX during high angle of attack, allowing for a more continuous and steady flow stream to enter the inlet, and reducing pressure drag.

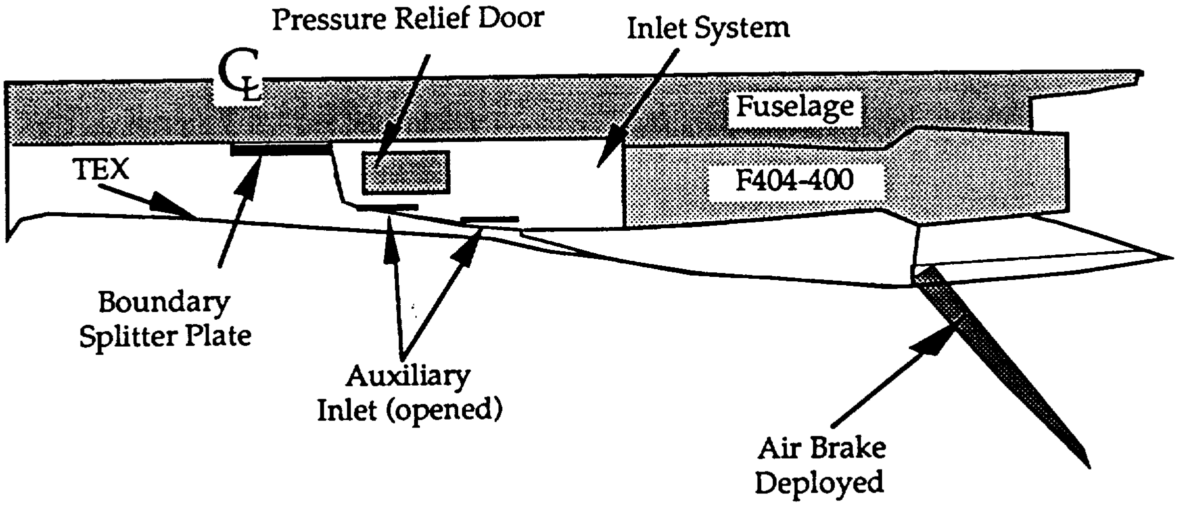


Figure 9.2 Top View of Engine, Inlet and Fuselage Integration

10.0 STRUCTURES

10.1 MATERIAL SELECTION

A listing of the material selection for the Eliminator is given below:

Wing:

Skin: Aluminum 7075-T6

Wing Box (Frames, Ribs, Stiffeners): Aluminum 2124-T8

Fuselage:

Skin: Aluminum 7075-T6

Frames, Bulkheads, Longerons: Aluminum 2124-T8

Vertical Tails:

Post: Stainless Steel

Skin: Graphite Epoxy Composite stiffened by aluminum honeycomb core

Canard:

Frames: Aluminum 2124-T8

Skin: Graphite Epoxy Composite

Protective Tub Surrounding Pilot: Kevlar

Landing Gear: Steel 4130

Canopy: One piece polycarbonate wraparound protected with transparent coatings.

10.2 WING STRUCTURE

The structural layout for the wing is shown if Figure 10.1. The wing is a cantilever low-wing, employing a three spar design. A fourth spar is added near the root to accommodate the large shear and bending moments developing near the root of the wing, as seen from Figure 10.2. Note that the wing will not house the landing gear, nor will it store any internal fuel. Accommodations in the form of "beefed up" ribs inside the wing will allow for the placement of hardpoints along the wing, to allow for the carrying of ordnance for added firepower as well as external fuel tanks to increase the range and endurance of the Eliminator. The two forward wing spars will also act as the forward engine mounts.

The leading edge sweep of the wing is 10 degrees, to offset drag divergence. The wing is composed of a NACA 63-412 airfoil section. Large Fowler flaps, covering 60% of the wing span with a chord of 30% MAC are utilized to meet the takeoff and landing requirements. Three spoilers are located at the rear edge of the fixed wing structure, just forward of the flaps. Spoilers will be constructed of aluminum allow honeycomb with aluminum alloy skin. No leading edge devices nor anti-icing systems are utilized.

10.3 FUSELAGE STRUCTURAL LAYOUT

The fuselage is a conventional semi-monocoque structure, composed of aluminum alloys. The forward section of the aircraft has been designed fairly rigidly to accommodate the placement of the GAU-8 gun. Speed brakes on the aft section of the fuselage are constructed of aluminum honeycomb and aluminum alloy skin. Note also the forward and aft pressure bulkheads to allow for cockpit pressurization, as shown in Figure 10.1. The main landing gear is housed in pods located below the wing, just outside of the engine nacelles.

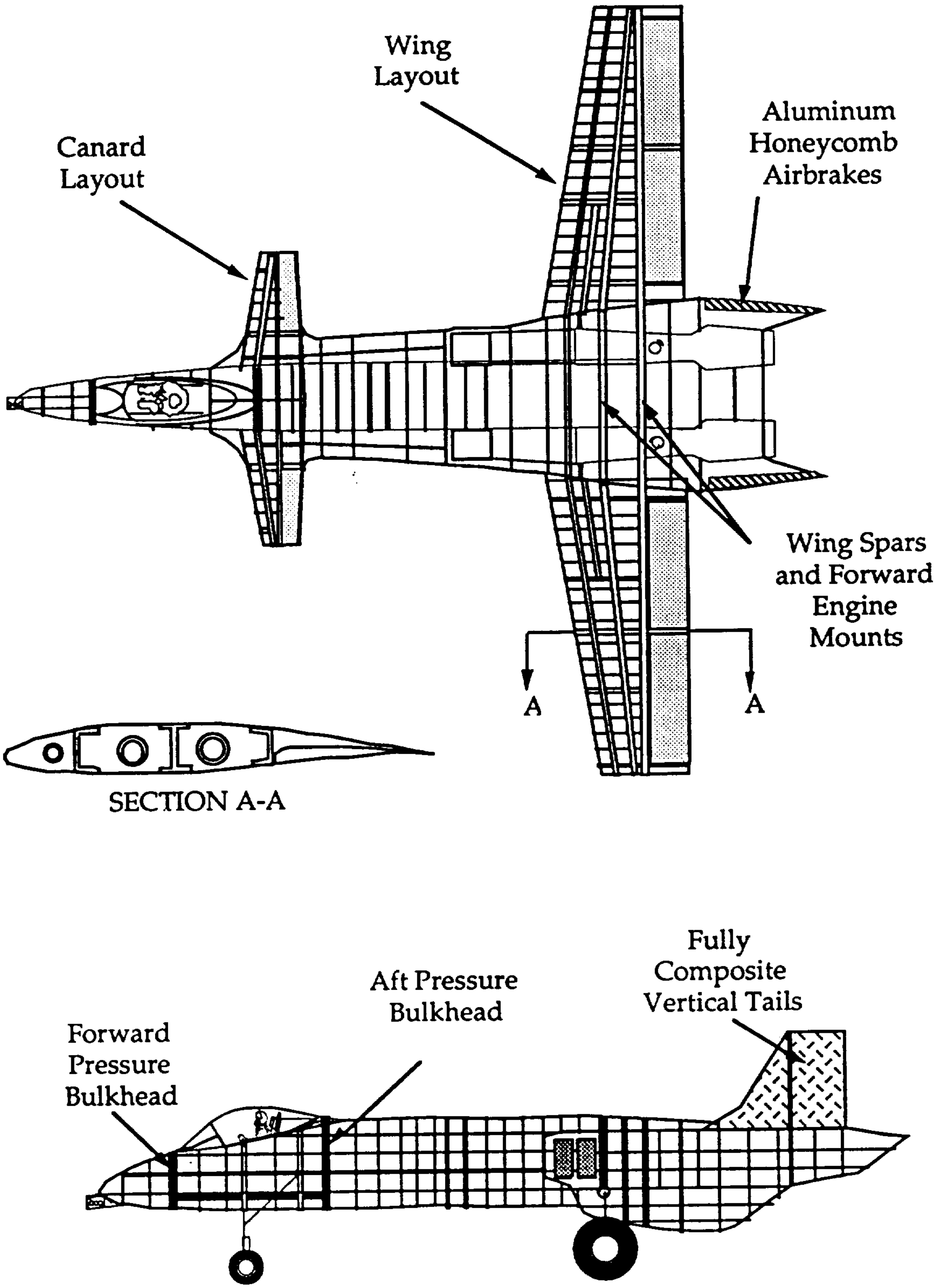


Figure 10.1 Structural Layout of the Wing and Fuselage of the Eliminator

10.4 CANARDS

The canard spars and ribs are composed of aluminum alloy. The skin is composed of graphite-epoxy, in the interest of saving weight. The elevators are constructed of aluminum alloy.

10.5 VERTICAL TAILS

The vertical tails of the Eliminator are fully composite, similar to those employed by the F-117 Stealth Fighter. This will be advantageous from the standpoint of reducing the overall aircraft weight as well as decreasing the overall radar cross-section of the aircraft. the only non-composite component will be the post, which will be composed of stainless steel. The vertical tails are canted outward and are interchangeable from left to right.

10.6 CANOPY

Polycarbonate was chosen for its superior toughness and ductility, thus giving it the ability to form into complex shapes and contours. The protective coatings are used to protect the polycarbonate from solvents and other chemicals.[11]

10.7 FLIGHT ENVELOPE

The V-n diagram for the Eliminator is shown at sea level and at 20,000 ft altitude in Fig. 10.3. The structural limits indicated (7.5 and -3.0 g's) are in accordance with the RFP. The maximum airspeed given on the graph refers to the maximum performance capable by the aircraft, and is not a structural limit. More detailed analysis is necessary to ensure that the aircraft could withstand the loads created by these flight conditions.

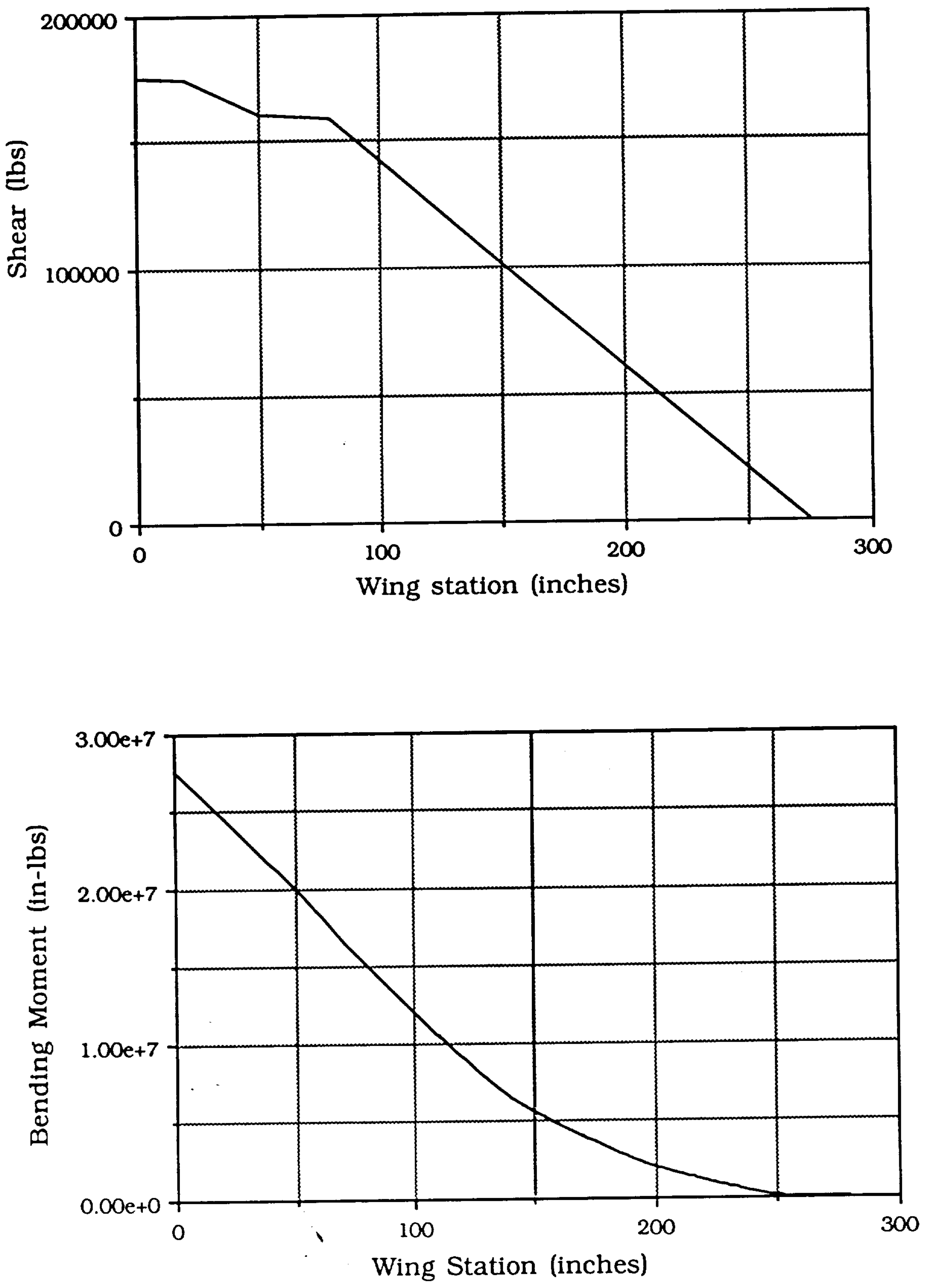
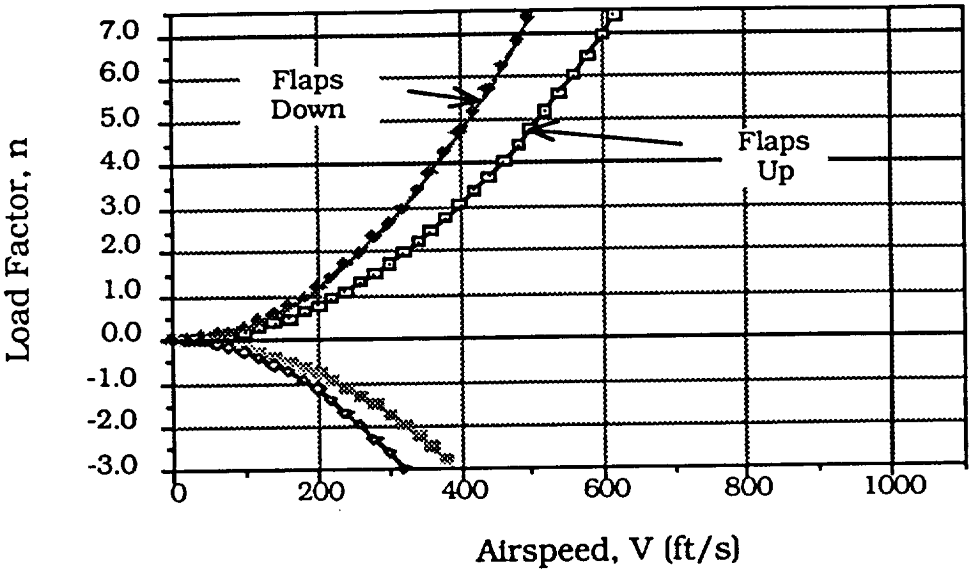


Figure 10.2 Wing Shear and Bending Moment Diagrams



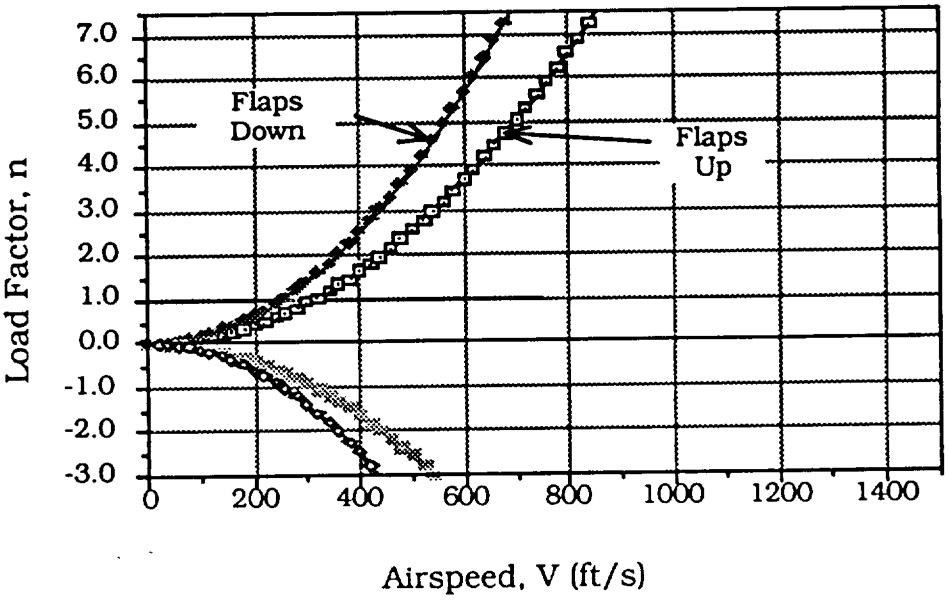


Figure 10.3 V-n diagram at sea level (top) and at 20,000 ft altitude (bottom)

11.0 CENTER OF GRAVITY AND MOMENT OF INERTIA ANALYSIS

11.1 CENTER OF GRAVITY

In order to determine the center of gravity of the Eliminator, the weight and location of each item was found. For the weight and balance calculations, the steps outlined below were followed.

1. All the major aircraft components were listed and divided into groups, such as Structures, Propulsion, Equipment, and Removable Load

2. Weights were determined for each component (Appendix G)
   - Wing, canard, vertical tail, fuselage, landing gear, etc. - from equations developed from similar aircraft
   - Engine's - from the specifications for General Electric's F404-400
   - Fuel - from the amount required as determined from the mission requirements (see Section 6.1)
   - Gun, bombs, missiles, pylons & racks, ammo, and pilot - from mission specs.

3. CG locations for each component were found
   - Bombs, missiles, pylons & racks, ammo, fuel, titanium tub - center of object
   - From CG locations for similar components on current fighters

4. Origin was set 100" in front of the Eliminator's nose, 100" below ground level, to allow for growth during the design process, and along the center line in the Y direction.

5. Distance from origin to each component was found

6. The center of gravity was found by taking the moment about the origin, and dividing by the total weight.

7. The CG locations were found during the following conditions: Design mission, most forward loading, and most aft loading. The loading conditions were found in order to determine the for the landing gear placement, but do not affect the flight conditions. In order to minimize CG travel, a specified order was generated for burning fuel and dropping bombs (Table 11.2 and Figure 11.1).

Table 11.1 Component Weight Breakdown for the Eliminator

EQUIPMENT GROUP	WEIGHT (LB)
STRUCTURES	12,014
PROPULSION	7,453
EQUIPMENT	7,301
<u>EMPTY WEIGHT</u>	<u>26.768</u>
REMOVABLE LOAD	27.816
<u>TAKE-OFF WEIGHT</u>	<u>54,584</u>

Table 11.2 CG travel in the X direction for the Design Mission

Most Forward Location, on the ground (Ammunition drum loaded, all else empty)	458 in
Most Aft Location, on the ground (Ammunition drum, missiles and bombs loaded)	478 in
Maximum CG travel, on the ground	20 in. = 0.20 MAC
Most Forward Location, during flight (0.5 Fuel burned, all bombs dropped)	463 in.
Most Aft Location, during flight (0.5 Fuel burned)	475 in.
Maximum CG travel, during flight	12 in. = 0.13 MAC

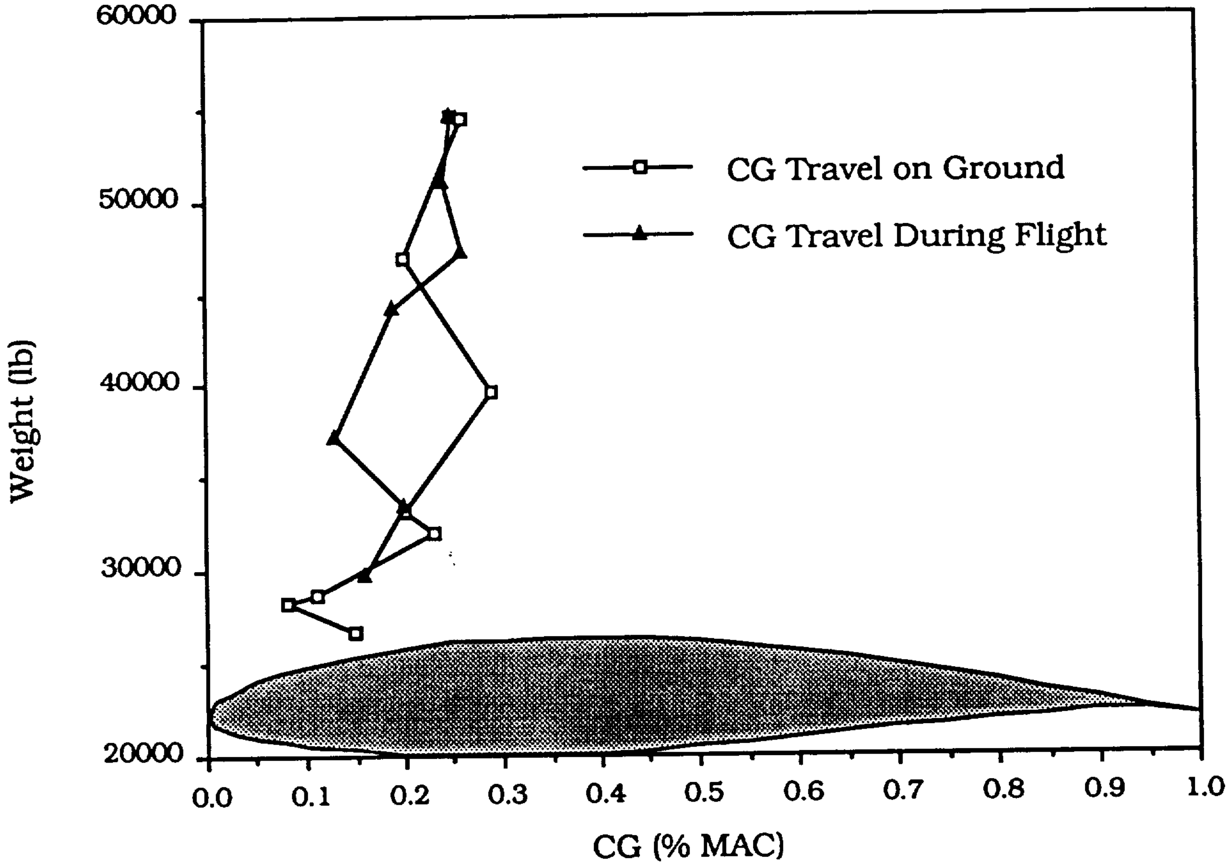


Figure 11.1 CG Excursion in the X Direction for the Design Mission

The order for the CG travel in Figure 11.1 is as follows for loading: ammunition, missiles, 6 bombs on the wing, 2 forward bombs on the fuselage, 12 bombs on the fuselage, 2 forward fuel tanks, 2 aft fuel tanks, and the pilot. During flight, the order is as follows: burn fuel from the 2 middle tanks, drop the 6 bombs from the wing, drop the 14 bombs from the fuselage, burn the fuel from the forward tank, and begin burning the fuel from the aft tank.

For fighters, the typical CG travel is about 15 inches, or 20% of the mean aerodynamic chord. The CG travel for the Eliminator is 12 inches or 13% of the mean aerodynamic chord. Therefore, the order in which fuel is burned and bombs are dropped minimizes the CG travel significantly, which results in a consistent aircraft. For the Eliminator, this means that the instability is nearly constant, varying from 15% to 23%. The CG travel on the ground is only for landing gear placement, and does not affect the stability of the aircraft in flight.

11.2 MOMENTS OF INERTIA

The moments of inertia were calculated using the information derived for the center of gravity calculations. The moments of inertia were found for the following conditions, (1) Dash out to the target, (2) Dash back after the mission with half of the fuel remaining, and (3) Landing at the mission end (Table 11.3). These were used in calculating some of the stability and control derivatives.

Table 11.3 Moments of Inertia for the Eliminator

	I_{xx} / I_{xy}	I_{yy} / I_{yz}	I_{zz} / I_{zx}
Dash Out to Target	209,952,907	761,497,781	924,655,321
SL, M = 0.72, fully armed	0	0	-14,627,423
CG in inches (473, 0, 125)			
Dash Back from Target	212,678,341	771,821,459	932,253,565
SL, M = 0.72, no bombs, 0.5 fuel	0	0	-19,290,405
CG in inches (463, 0, 133)			
Landing (Mission End)	212,070,666	767,914,645	928,954,425
no bombs, 0.125 fuel left	0	0	-17,756,176
CG in inches (466, 0, 132)			

12.0 AVIONICS

12.1 AVIONICS

The following avionics systems are employed by the Eliminator:

- Pave Penny laser target-identification unit
- radar warning system
- chaff/flare system
- inertial navigation system
- LANTIRN
- IFF Transponder
- UHF/VHF links

The Eliminator's avionics systems were chosen with usefulness and low cost in mind. Precise weapons delivery is vital for the close air support aircraft to eliminate fratricide and collateral damage. However, it was deemed unnecessary for the Eliminator to employ a radar system. Other, less costly units were chosen for the same purposes and are explained here. A Pave Penny laser target-identification unit is used for targeting during the daytime. This is located under the center of the fuselage, as shown in Figure 12.1. For defense, a radar warning receiver will be employed, in order to inform the pilot when to employ the internal chaff and flare system for electronic countermeasures protection. The chaff/flare system is internally located at the aft section of the fuselage, on the ventral side.

For navigation purposes, an inertial navigation system (INS) will be used in coordination with the heads-up display (HUD). Although an INS is more expensive than other forms of navigation systems, it was felt that it would be vital for the Eliminator, which is required to fly in low-level terrain.

LANTIRN (Low Altitude Navigation and Targeting by Infra-Red at Night) will be implemented for nighttime targeting as well as for navigation purposes. The two pods are located at hardpoints, one under each wing. An IFF Transponder will be used by the Eliminator to identify itself to other aircraft, and VHF/UHF links will be used for communication. The essential structures and wiring provisions will be built into the airframe of the Eliminator to allow for the integration of future avionics systems, should they be necessary.

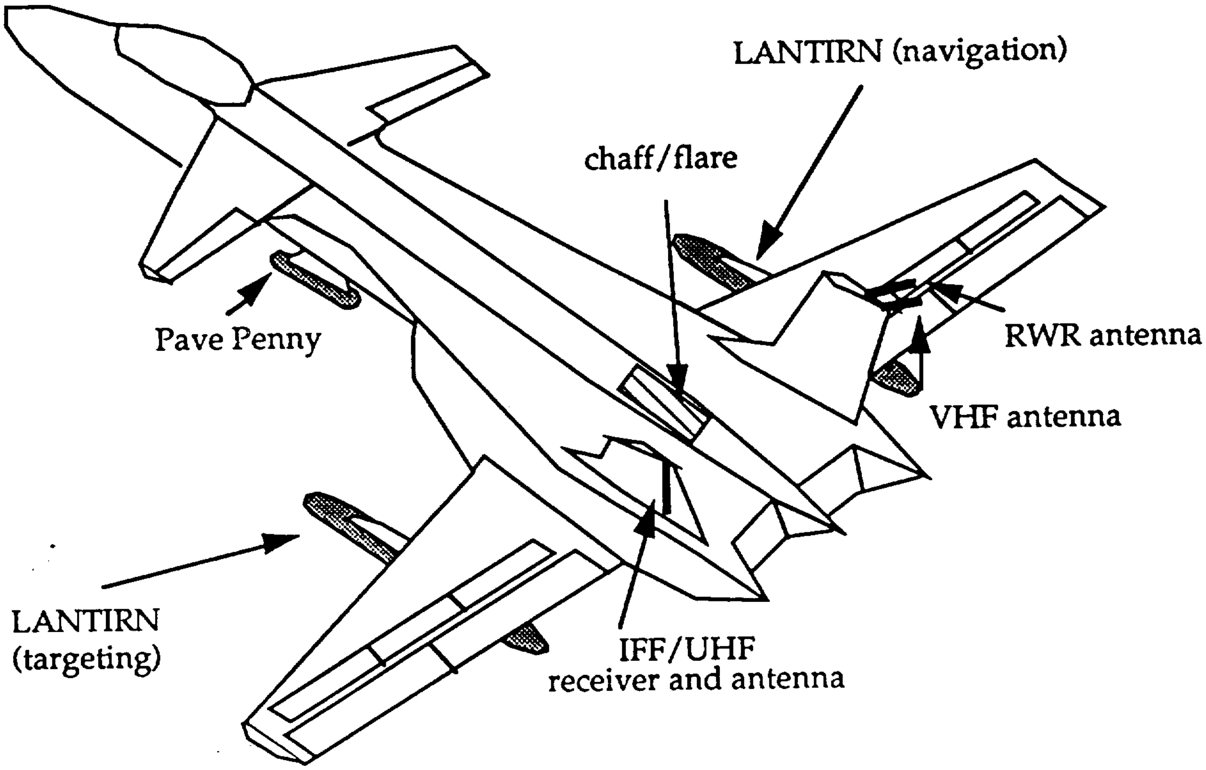


Figure 12.1 Avionics Layout for the Eliminator

12.2 COCKPIT LAYOUT

The Eliminator's cockpit has been designed with ease and accessibility in mind. The layout of the cockpit is shown in Figure 12.2. Pilot visibility is a primary factor for the close air support aircraft. The Eliminator's slender fuselage aids in this area, as the over-the-nose visibility is 22° and the over-the-side visibility is a generous 64°. The pilot is provided with a high-g ejection seat for emergency situations, such as engine failure or if the aircraft is hit. Since small arms fire is of primary concern to CAS aircraft, the ejection seat controls are carefully designed and located for quick triggering in the case of such an emergency, and so that it is also impossible for the seat to be ejected by accident.

The instrument panel is dominated by the head-up display (HUD). This device provides information concerning target range and weapons supply, enabling the pilot to maintain visual contact with the target. Also, the HUD displays information during take-off, landing and weapons launch. As shown in Figure 12.3., the panel directly to the left of the HUD is used primarily by instruments displaying flight information such as airspeed and angle of attack. Directly to the right of the HUD are located the instruments displaying aircraft status information such as fuel levels. The area on the lower right side of the cockpit consists mainly of the defensive controls, such as the chaff/flare and radar warning receiver (RWR) controls. Also on this side of the cockpit are the radio transmission controls and airbrake. On the left-hand side of the cockpit is located the secondary flight controls, as well as the ejection seat handle (well marked), and lighting controls. The control stick operates the weapon selection and deployment controls, as well as the target selection and trim controls.

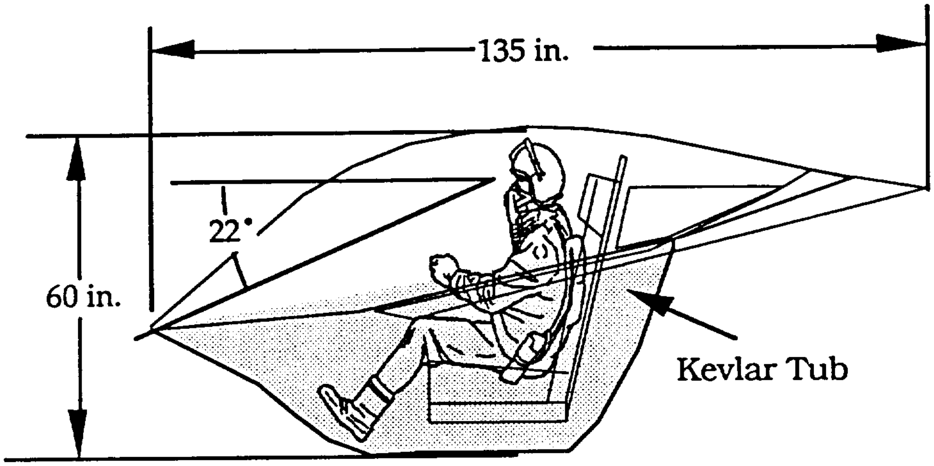
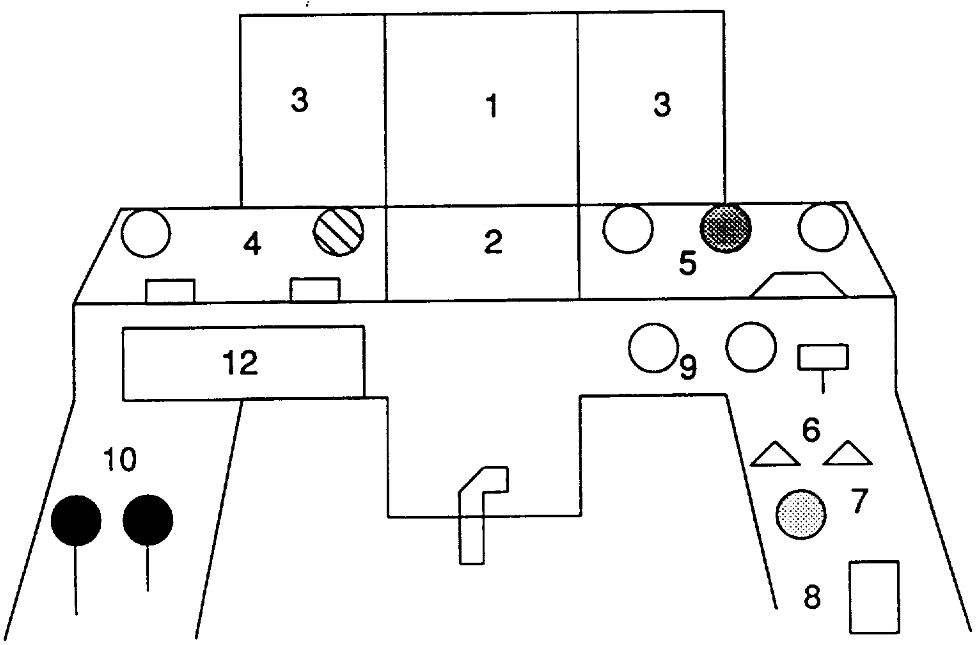


Figure 12.2 Cockpit Layout for the Eliminator



1. HUD
2. INS
3. HUD Messages
4. Flight Information
5. Aircraft Status Information
6. ECM
7. RWR
8. Airbrake
9. Radio Transmission
10. Secondary Flight Controls
11. Ejection Control
12. Lighting Controls

Figure 12.3 Cockpit Instrumentation

13.0 WEAPONS INTEGRATION

The Eliminator is capable of carrying a load of 13,500 lbs. This load consists of the RFP's munition. In addition to satisfying the RFP's ordnance requirement, the Eliminator's load can vary extensively. The Eliminator is designed to be flexible to accept new weapon systems. Currently, the Eliminator is a passive aircraft without any radar system. However, there exists enough space in the nose cone to accept a radar system if the Eliminator's role is redefined. The two inner wing pylons have piping capability to accept external fuel tanks. Different ordinance combinations that the Eliminator can carry is shown in Figure 13.1

Figure 13.1 shows five different mission sorties that the Eliminator may be asked to carry out. The Eliminator's primary mission is close air support, but it can easily be converted to carry 20 Mavericks for anti-armor duty. In addition, the Eliminator can do maritime patrols, anti-radiation missions and interdiction missions. In maritime patrol, it would be equipped with four Harpoons, two general purpose torpedoes, and two external fuel tanks to increase range. It also has nuclear capability, by replacing the Harpoons under the fuselage with two Tomahawks, at stations 5 and 9. The anti-radiation configuration will be equipped with four HARM missiles, two ECM pods and external fuel tanks. When used in the suppression role, the Eliminator is armed with Rockeye cluster bombs to maximize damage on enemy fortifications. To aid in night missions, Eliminators will be equipped with LANTIRN systems. These different roles make the Eliminator a flexible and capable aircraft for all services.

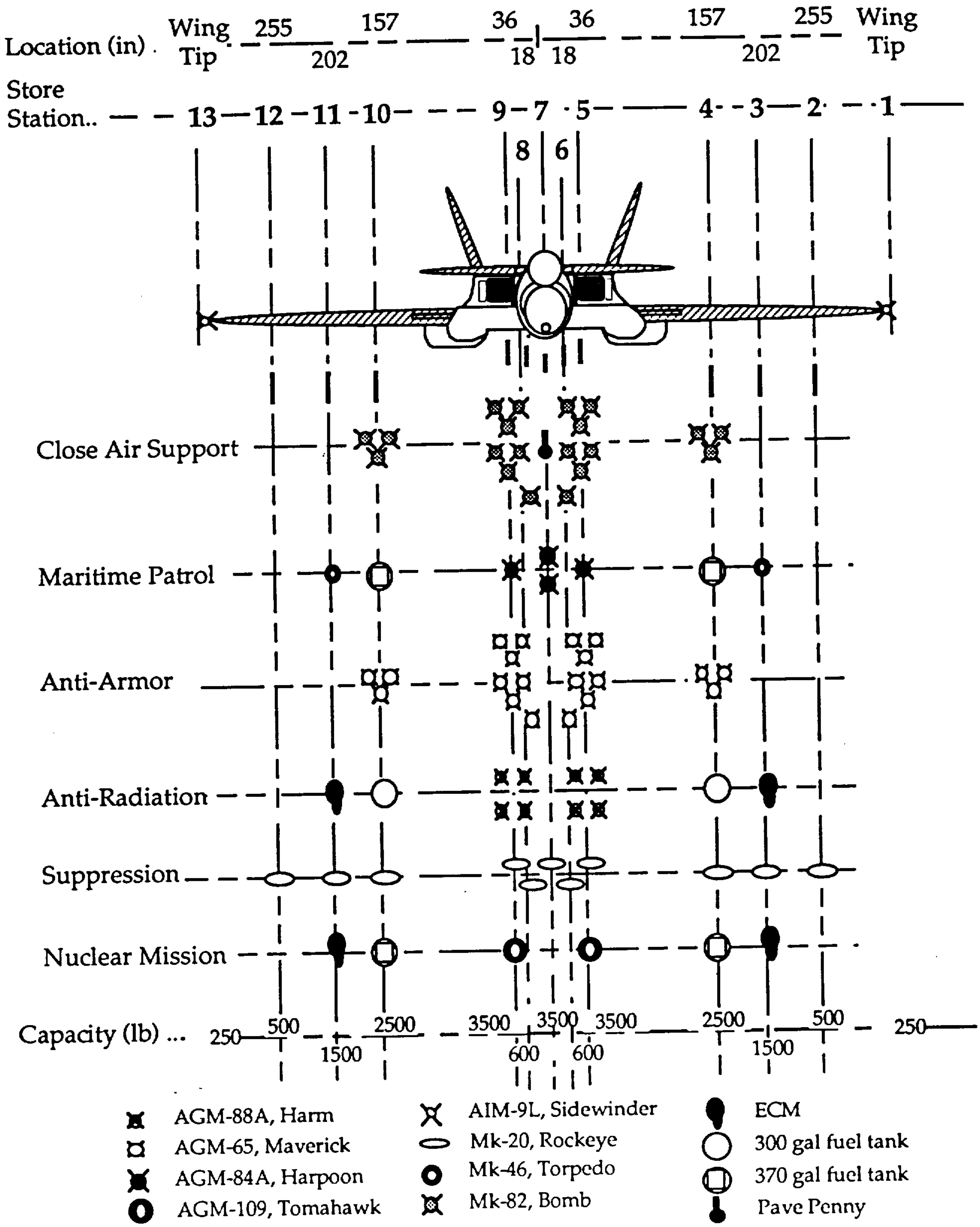


Figure 13.1 Ordnance Placement

14.0 GROUND SUPPORT

To make the Eliminator readily deployable from a forward and/or remote base of operations, the need for extensive ground support equipment is eliminated through the use of an on board auxiliary power unit (APU). The APU supplies electrical power to all essential and non-essential equipment, making an electrical power cart unnecessary. The APU also supplies bleed air to the engine starters so that self contained engine starters can be accomplished. All of the hydraulics in the Eliminator are enclosed in self contained units with their own separate reservoirs; by doing this the need for a hydraulic ground cart is eliminated.

The weapons placement on the Eliminator also makes for very little need of extra equipment for arming the aircraft. Because of the bombs placement on the low wing and under the fuselage there is not a large distance that the bombs must be raised to attach them to their hard points. The missiles are also attached to the wing so that special equipment is not needed to arm the aircraft.

The only necessary service equipment that will be needed for forward and/or remote deployment of the Eliminator will be one or two vehicles that can service the fuel and oxygen systems. All the rest of the Eliminators systems are independent of needs from ground support equipment. This makes for a readily deployable aircraft to remote locations without the need for sending along extra support equipment.

The Eliminator is designed to operate from military airfields to hard, dry dirt airfields. This allows for flexibility in mission capabilities. But soft field operation requires a temporary metal runway, as the tire pressure is too high without this runway. It was felt that this was a reasonable design compromise with size and weight versus mission flexibility.

15.0 COST ANALYSIS

The total cost of the Eliminator may be divided into four parts: 1) Research, Development, Test and Evaluation (RDTE), 2) Acquisition, 3) Operation, and 4) Disposal. A summary of these costs is presented in Table 15.1. The total life cycle cost is the sum of the costs of the four phases. The acquisition cost for one aircraft is a reasonable $14,652,403. Many considerations have been made to keep the Eliminator's cost as low as possible, and the goal to design an effective, yet low cost, close support aircraft has truly been achieved. The costs were determined according to the methods and calculations as shown in Appendix H. Because the acquisition cost is generally considered to be the most significant in determining the value of an aircraft, Figure 15.1., which shows a percentage breakdown for the components of the acquisition cost, has been included in this section. As is clear from this figure, the majority of the acquisition cost is accounted for by production. This cost includes the actual manufacturing of the 500 program aircraft as well as the engines and avionics.

Each component of the cost of the Eliminator is based on its take-off weight and the number of aircraft to be produced, which is 500. The two engines were approximated at $2.2 million each. The avionics systems were assumed to account for 25% of the acquisition cost, or $3.7 million. The RDTE costs assume that seven aircraft will be built for testing during these phases of the life cycle, which was thought to be an appropriate amount for this type of aircraft. A "difficulty factor" was used to account for the Eliminator's fairly aggressive use of advanced technology. It is assumed that CAD will be used extensively in the design and research phases, and that the manufacturers will be experienced in the use of CAD; an appropriate judgement factor accounting for this was also incorporated into the costs. A judgement factor was used to account for the fact that the Eliminator has been designed such that a fair amount of the structure is built of conventional composite materials. Because the Eliminator is not employing stealth capabilities, an appropriate "observance" factor was used to display this in the cost outcome. Profit during the RDTE and acquisition phases was approximated at 10%, and interest was assumed to be 15%. The operation cost was based on such factors as fuel costs and personnel pay, as well as the number of aircraft expected to be lost over its service life, which was approximated at 21 years. The disposal cost accounts for 1% of the total life cycle cost.

Table 15.1 Summary of Costs for the Eliminator

Phase of Aircraft Life Cycle	Cost Per Aircraft
RDTE	$ 2,642,657
Acquisition	$ 14,652,403
Operation	$ 111,321,904
Disposal	$ 1,299,161
Total Life Cycle Cost	**$ 129,916,125**

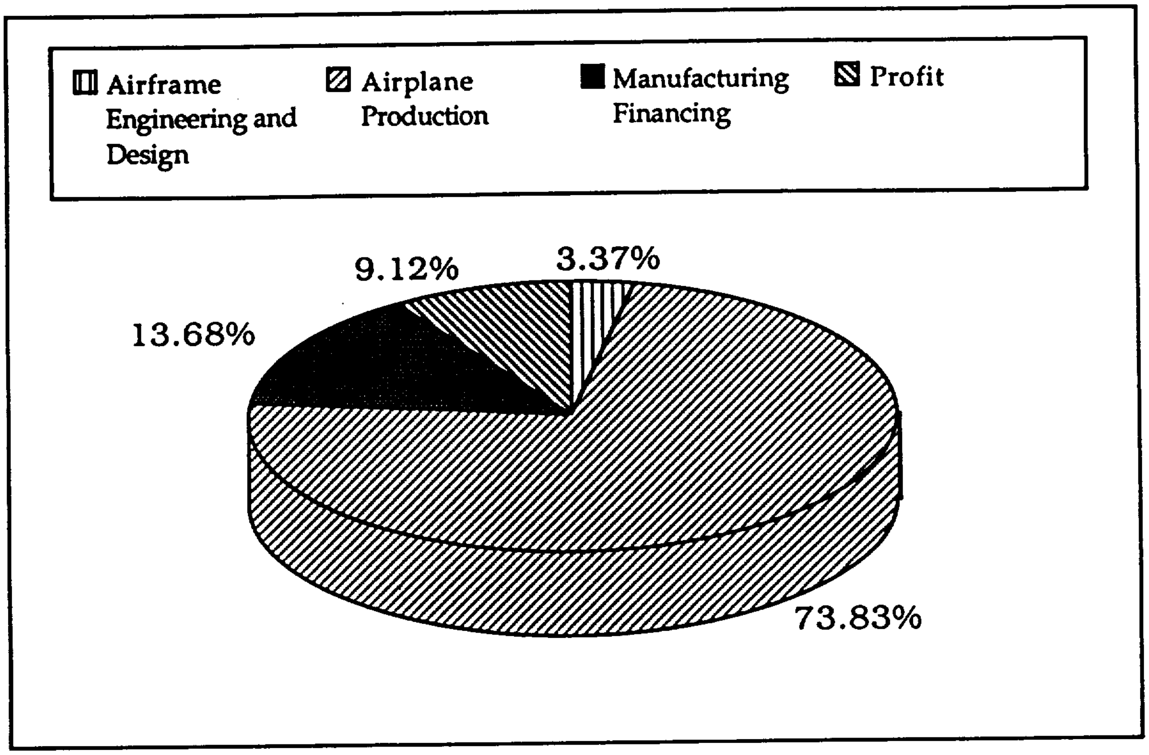


Figure 15.1 Breakdown of Acquisition Costs for the Eliminator

15.1 MANUFACTURING PROGRAM FOR THE ELIMINATOR

A suggested time frame for the research and production of the Eliminator is shown in Figure 15.2. Five years is thought to be sufficient time for the continued research of this aircraft, as well as for design, testing and evaluation of the prototypes. During the first decade of the 21st century, the manufacturing of the Eliminator will begin. Ten years is thought to be an appropriate amount of time for the production of 500 aircraft, as follows: During the first year, approximately four aircraft are built. During the next seven years of production 420 will be built, with the remaining 76 produced in the final two years of manufacturing. The costs of the Eliminator were based upon a service life of 21 years, during which maintenance of the Eliminator will be necessary.

Because of the simplicity of the Eliminator, in design as well as in control and avionics systems, it is anticipated that its manufacturing will be relatively easy. For example, the same airfoil is used for the canard and vertical tails, which will add to the ease with which the Eliminator is produced. In addition, the vertical tails are exchangeable, left for right. Also, the fuel system is simple, being contained entirely within the fuselage. This makes construction of the wing simpler, since no fuel cells must be incorporated into it.

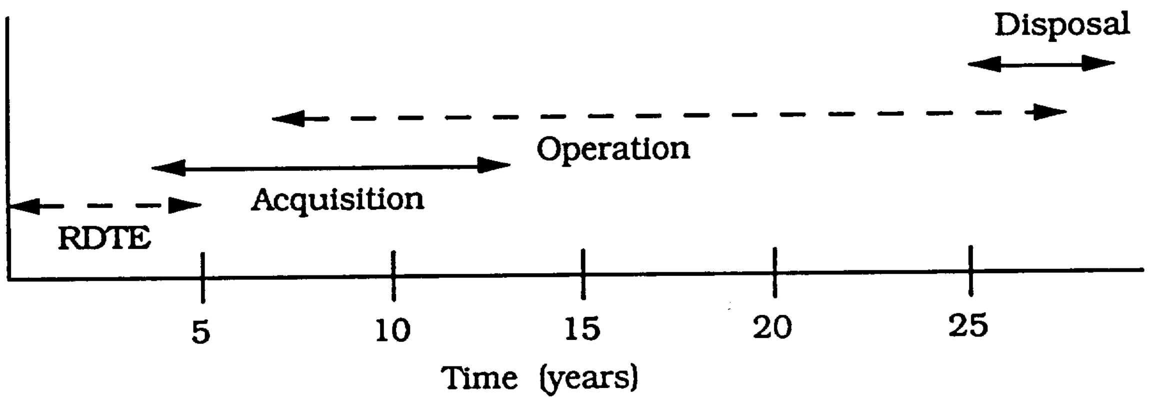


Figure 15.2 Life Cycle Time Line for the Eliminator

16.0 CONCLUSIONS AND RECOMMENDATIONS

As experience has proven, no aircraft is ever complete. Long after production has begun, modifications and changes are often made. For example, many models of the same basic design and designation are often made, for instance the F15-C and E. These changes are made after use and hindsight have cast light upon flaws and shortcomings. Though the Eliminator does not have the luxury of such techniques for discovery, there are some design considerations that should and would have been considered had time permitted.

16.1 PERFORMANCE

Performance calculations were some of the most difficult that had to be made, with many assumptions and approximations for key values in several places. Although large discrepancies are not expected, these calculations could use further refinement.

Specific fuel consumption values for the F404 engine were fewer than desirable and had to be approximated from limited available data. More complete information on the capabilities of this engine would allow the performance calculations to be more accurate and complete.

The specific power curves also revealed an error in the power required equations resulting in a sharp jump in the specific power in the transonic flight regime. The source of the error, and it is only speculation that it is indeed an error, is unknown, and further study in this area is warranted.

Upon examination of the performance results, it became evident that the Eliminator was capable of much higher speeds than had been anticipated or planned for. With this apparent capability, it would be wise to reevaluate the design to take advantage of the high speeds and to make the aircraft more efficient at these velocities. More in depth performance calculations at these speeds should also be made.

16.2 LANDING GEAR

The landing gear retraction system on the Eliminator must be able to fold and rotate the main gear alongside of the external ordnance and still fit inside the fuselage below the low mounted wing. Currently, an external pod is used to house the gear alongside the fuselage.

Further consideration should be made into how to redesign this system. A larger tire diameter would allow for landings on soft fields, but could not be accommodated into the current design. A redesigned system, with the gear folding either into the wing with the tire rotated parallel or into a smaller fairing on the wing, would allow the larger tire size.

Another option would be to move the fuselage mounted ordnance forward to allow the main gear to fold into bays on the underside of the fuselage. This would also allow for the larger tire size and would result in lower profile drag.

16.3 AERODYNAMICS

The drag calculations for the aircraft were made purposely conservative to insure that the aircraft's capabilities were not overestimated, and most likely caused just the opposite. Because so many of the performance and stability calculations rely on drag estimates, this may have caused these values also to err on the conservative side. More detailed calculations should be made into the drag at different altitudes and flight regimes. Trim drag could also be an important factor that has not been considered and should be added if possible.

16.4 STABILITY AND CONTROL

The rolling moment due to spoiler deflection derivative needs to be increased by at least two orders of magnitude. This can be accomplished in a number of ways: by increasing the chord of the spoilers, by moving the spoilers forward on the wing, and including some differential canard elevator deflection.

The first two methods would be fairly easy methods to implement due to the absence of other systems in the wing such as fuel and hydraulic lines. the third method would require some additional software development costs in the stability augmentation system.

An effort should also be made to utilize higher order methods to estimate the values for the stability derivatives to provide greater accuracy.

16.5 Structures

The overall structural layout of the Eliminator is relatively simple and should lend itself to inexpensive methods and modes of manufacture. All composite components used on the aircraft have already been proven to work on other aircraft of similar types (i.e. the all composite vertical tail has already been utilized by the F-117). Though more exotic and lighter materials could have been used in some cases, it was felt that cost and maintainability were more overwhelming criteria in the choice of materials.

It is recommended that further structural analysis be completed on the aircraft in the form of finite element analysis. Of particular interest are those regions most critical to the survival of the aircraft, and those regions on the aircraft experiencing the highest stresses. This would include the wing-fuselage joints, the canard-fuselage joints, and the engine mounts. The relatively simple wing and canard configuration of the Eliminator should lend itself to a relatively simple finite element model.

Further study is necessary to determine if it would be advantageous to place internal fuel in the wing of the aircraft. It is possible that placement of fuel in the wing would have allowed for a lighter wing structure, as the added weight would have relieved some of the large bending moment that exists at the wing root and made for a lighter wing-box. No fuel was placed in the wing, in an effort to reduce the target area of fuel apparent from the ground and susceptible to ground fire.

16.6 COST ANALYSIS

The costs of the Eliminator have been calculated in terms of 2010 dollars and there is a possibility that the factor used to account for the escalation in costs is too low.. It is truly difficult to attempt to determine how much an aircraft will cost in 20 years. If a more certain cost estimate is desired, it is recommended that an alternate method be used. However, even if the acquisition cost determined is for 1991 dollars, this is still a reasonable price for an aircraft with such qualities and capabilities as the Eliminator.

16.7 FINAL COMMENTS

Although this is only a preliminary design, and much work and analysis would need to be done before the Eliminator could be considered a finished concept, there is a great deal of cause for enthusiasm.

The Eliminator meets or surpasses all the requirements that drove its design[1] and has emerged as a capable aircraft that can be used to fulfill many missions. Although designed for close air support, it has become evident that the Eliminator could fill many roles, and could be acquired as a single plane air force. This fact alone makes it a remarkable aircraft. The Eliminator, it's not a threat; it's a promise.

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