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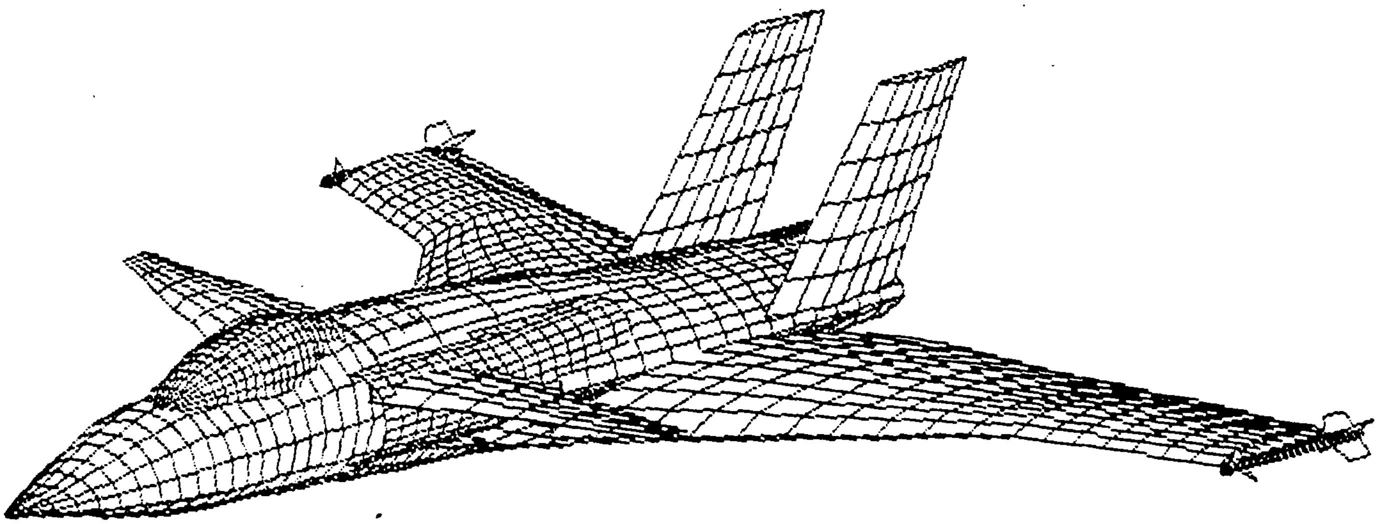
Proposal for a Low Cost Close Air Support Aircraft for the Year 2000

The Raptor



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PROPOSAL FOR A

LOW COST CLOSE AIR SUPPORT AIRCRAFT

THE RAPTOR

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ABSTRACT

The Raptor is a proposed low cost Close Air Support (CAS) aircraft for the United States Military. The Raptor incorporates a "cranked arrow" wing planform, and employs canards instead of a traditional horizontal tail. The Raptor is designed to be capable of responsive delivery of effective ordnance in close proximity to friendly ground forces during the day, night, and under-the-weather conditions. This report presents details of the Raptor's mission, configuration, performance, stability and control, ground support, manufacturing, and overall cost to permit engineering evaluation of the proposed design. A description of the design process and analysis methods used is also provided.

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List of Symbols and Abbreviations

AEP	Airplane Estimated Price
AMAD	Airframe Mounted Accessory Drive
APU	Auxiliary Power Unit
AR	Aspect Ratio
b	Span
BAI	Battlefield Air Interdiction
c	Chord
C^3I	Command, Control, Communication, Intelligence
CAS	Close Air Support
C_D	Drag Coefficient
C_{D0}	Zero-Lift Drag Coefficient
ΔC_D	Drag Coefficient Increment
cg	Center of Gravity
C_L	Lift Coefficient
$C_{L\alpha}$	Lift Curve Slope
C_m	Moment Coefficient
$C_{N_{max}}$	Maximum Aerodynamic Load Factor
e	wing efficiency
ECCM	Electronic Counter Countermeasures
FLIR	Forward Looking InfraRed
FLOT	Forward Line of Own Troops
HUD	Head Up Display
INS	Inertial Navigation System
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
L/D	Lift to Drag Ratio
M	Mach Number
M_{DD}	Drag Divergence Mach Number
n	Load Factor
P_s	Specific Excess Power
q	Dynamic Pressure
Q	Dynamic Pressure Limit
S	Wing Planform Area
T_a	Thrust Available
T_r	Thrust Required
TACAN	Tactical Air Navigation
t/c	Thickness Ratio
T/W	Thrust to Weight Ratio
V-n	Velocity--Load Factor
V_{stall}	Stall Speed
W	Weight
W/S	Wing Loading
α	angle of attack

1. INTRODUCTION

As the United States Military enters into the 21st century the need for a dedicated close air support aircraft will become evident. With the continuing, but declining threat from the Soviet Union, as well as the increasing frequency of low intensity conflicts, any new airplane design will need to combine the requirements for both combat arenas. Such an aircraft will need to have advanced technology to survive and conduct effective operations on the high threat battlefield of Europe while requiring minimal ground support and facilities when deployed to crisis spots around the world. Low cost is also an essential characteristic of any new aircraft because of the shrinking military budget and Congress's unwillingness to fund such projects. The Raptor is this airplane.

1.1 Background

Close air support is defined by the Dictionary of Military and Associated Terms as "air action against hostile targets which are in close proximity to friendly forces and which require detailed integration of each air mission with the fire and movement of those forces."[1] However, CAS is responsive, but not necessarily effective or decisive. "It is a reactive rather than a pro-active force."[2] Battlefield Air Interdiction (BAI), on the other hand, is an offensive rather than a defensive tactic, involving deep strikes beyond the Forward Line of Own Troops (FLOT) against enemy rear echelon units.[3]

Since the "battlefield of the future will be fluid and nonlinear,"[2] the Army and the Air Force have developed the AirLand Battle doctrine. This doctrine is envisioned as encompassing "operations by mobile forces on both sides. It predicts a high operational tempo, increased lethality, and intense use of electronic measures and countermeasures (with fighting continuing) at night and in bad weather."[2]

Since AirLand is a combined forces doctrine, both the Army and the Air Force have stressed certain requirements that are vital to the successful implementation of such a plan. The Army requirements stress flexibility, availability, and survivability. Flexibility is the ability to support Army operations both at the FLOT and in deep strike operations. Availability is simply the capacity to operate day or night, and during adverse weather. Survivability is the capability to operate in a dense and lethal battlefield environment.[4]

Since close air support is the province of the Air Force, the means by which these requirements can best be met have been determined by the Air Force to be speed and maneuverability, coupled with unparalleled command, control, communications, and intelligence (C^3I) capability.[4]

1.2 The Raptor

The Raptor incorporates high thrust engines and highly swept wings to meet the Air Forces speed requirement, while the cranked arrow wing planform and canards give a good combination of high and low speed maneuverability. The LANTIRN and Pave Penny systems allow for targeting coordination between the Raptor and other ground and air assets; the LANTIRN system also allows low-level navigation at night and in bad weather. The Raptor's large planform area accommodates a high payload weight while the targeting systems allow a large variety of weapons to be employed effectively. The internal Auxiliary Power Unit (APU) and Airframe Mounted Auxiliary Drive (AMAD) reduce ground support requirements which allow the Raptor to deploy to forward air fields, increasing aircraft availability by reducing response time. The major advantage that the Raptor has, however, is its low cost: $12.6 million per aircraft.

The Raptor proposal is presented in the following manner. Section 2 describes the Raptor's mission requirements. Sections 3 and 4 discuss design results and preliminary sizing; the fifth section presents overall configuration selection and justification while individual components are described in Section 6. The seventh and eighth sections present the structural layout and mass properties. Aerodynamics and stability are discussed in Section 9 and Section 10; Sections 11 and 12 show the Raptor's avionics philosophy and the layout of the major systems. Weapons integration is presented in the thirteenth section and ground support requirements are discussed in the following section, Section 14. Cost analysis and manufacturing breakdown are presented in Sections 15 and 16. Finally, Section 17 presents a summary of the Raptor's features and a discussion of its future.

2. Mission Description

There are two attack missions that the Raptor is required to perform. Each of these missions involves the attacking of ground targets 250 nautical miles from the takeoff point; also both missions require the aircraft to carry 20 Mk 82 bombs, two AIM-9L Sidewinder missiles, and the GAU-8 30 mm Avenger cannon with 1,350 rounds of ammunition.

The primary mission takes place entirely at low level. The first phase of this mission is warm-up, taxi, takeoff, and acceleration to cruise speed during which fuel consumption is based upon five minutes at military power. The aircraft then accelerates to maximum speed at military power (required to be 500 knots minimum) and flies to the target where two combat passes are made at maximum military power minus 50 knots. Each combat pass encompasses a 360 degree sustained turn along with a 4,000 feet energy increase and afterwards it is assumed that all bombs are dropped and approximately 950 rounds of 30 mm ammunition is expended. After combat the aircraft dashes back to base, at low level and with the same speed requirements as the dash to the target, where the plane must land with enough fuel for 20 minutes endurance at sea level. The primary mission is summarized in Table 2.1 and shown in Figure 2.1.

As can be seen from the description the primary mission is a low-level and high-speed penetration to the mission target. No mention of the target location (at the FLOT or beyond it) is made. In accordance with the AirLand Battle concept of a fluid battlefield a worst case situation was assumed in which the Raptor was called upon to provide CAS for friendly troops involved in combat operations deep within enemy territory or was required to perform BAI deep within hostile airspace. Low level and high speed flight would be necessary for such a mission to lower the chance of detection.

Phase	Mission Phase	Altitude	Speed (knots)
1	Engine Start, Warm-up	Sea Level	-
2	Takeoff, Accelerate	Sea Level	-
3	Dash Out	Sea Level	500
4	Combat	Sea Level	500
5	Dash In	Sea Level	500
6	Land (20 min reserve)	Sea Level	-

Table 2.1 Primary Mission

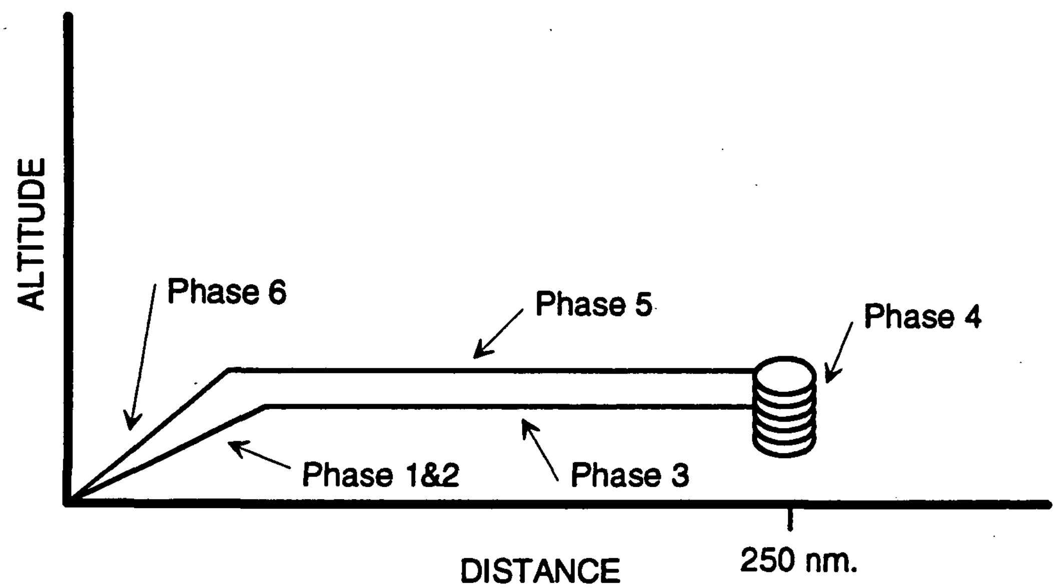


Figure 2.1 Primary Mission

The secondary mission requires the same combat radius of 250 nautical miles but does not take place entirely at low level. The takeoff and acceleration phase is the same as in the primary mission, but instead of staying at sea level the aircraft climbs at intermediate power to its best cruise altitude and speed. After cruising 150 nautical miles at this condition the aircraft descends to sea level during which time it is assumed that no time, distance, or fuel is used. At this point the aircraft loiters at maximum endurance for as long as possible and then dashes 100 nautical miles at low level to the target. Combat at this phase of the mission has the same combat pass requirements and ordnance expenditure. The return to base is a mirror image of the flight to the target with the exception of the loiter; a 100 nautical mile dash out is followed by a 150 nautical mile cruise at best altitude and speed. After descending to sea level the aircraft must land with fuel reserves sufficient for 20 minutes endurance at sea level. Table 2.2 and Figure 2.2 summarize the secondary mission.

The secondary mission is very similar to the primary mission in that target location and type are not described. Accordingly the same worst case of the target being behind enemy lines is assumed just as in the primary mission. However, a major distinguishing characteristic of the secondary mission is the loiter phase prior to the dash to the target. This phase indicates a mission in which an aircraft was launched to a staging area where it is held in readiness until suitable targets are located. In order to effectively perform this mission the aircraft would have to be able to loiter for a long enough time to be useful while carrying a variety of ordnance to enable it to deal with whatever situation arises.

Phase	Mission Phase	Altitude (ft)	Speed (knots)
1	Engine Start, Warm-up	Sea Level	-
2	Takeoff, Accelerate	-	-
3	Cruise Out	25,000	480
4	Loiter	25,000	480
5	Dash Out	Sea Level	500
6	Combat	Sea Level	500
7	Dash In	Sea Level	500
8	Cruise In	25,000	480
9	Land (20 min reserves)	Sea Level	-

Table 2.2 Secondary Mission

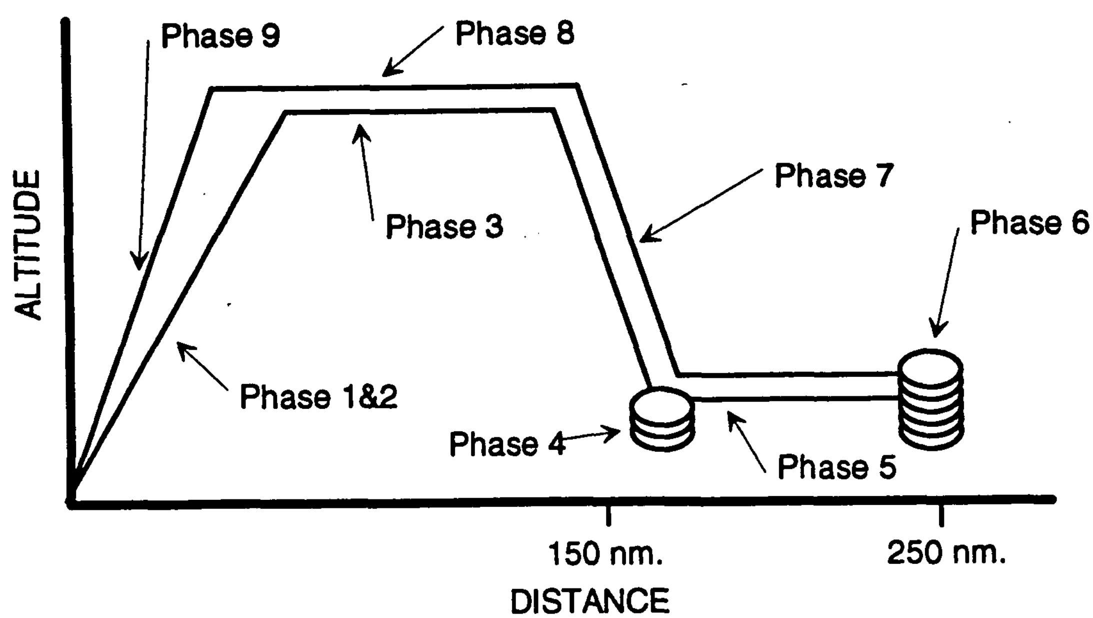


Figure 2.2 Secondary Mission

An additional mission requirement is that the aircraft must have a ferry range of 1,500 nautical miles. For this mission the payload is replaced with fuel and air-to-air refueling is not permitted. The takeoff and acceleration phase is the same as in the primary and secondary missions. After takeoff the aircraft climbs to its best cruise altitude and speed and cruises at least 1,500 nautical miles to its destination where it descends to sea level. Upon landing the aircraft must still retain sufficient fuel for 20 minutes endurance at sea level.

3. DESIGN RESULTS

3.1 Geometry

The results of the Raptor design are illustrated in the 3-view drawing presented in Figure 3.1; important dimensions are listed in Table 3.1.

Raptor Data	
Overall Length	61.5 ft
Overall Width	45 ft
Overall Height	17 ft
Wing Area	500 ft^2
Canard Area	95 ft^2
Vertical Tail Area	160 ft^2

Table 3.1 Raptor Geometry

3.2 Performance

In addition to the performance requirements set forth in the mission description, the design aircraft must be able to accelerate from Mach 0.3 to Mach 0.5 at sea level in under 20 seconds. Also, it must be capable of sea level sustained turns at maximum military speed minus 50 knots with a g-loading of 4.5 as well as instantaneous g's up to 6.0 at combat speed. The aircraft must have a re-attack time of less than 25 seconds. This is measured from the time of first pass weapons release to second pass weapons release, and the airplane is assumed to be carrying half of the bomb load, half of the fuel, and all of the self defense stores which consists of Sidewinders and the cannon with its ammunition. Finally, the aircraft must be capable of takeoff and landing ground roll distances of less than 2,000 feet on a standard day from a hard, dry strip.[5]

The Raptor exceeds all of these performance requirements. The acceleration requirement is met in only 7.7 seconds, substantially less than the 20 second requirement. As can be seen in the excess power curves of

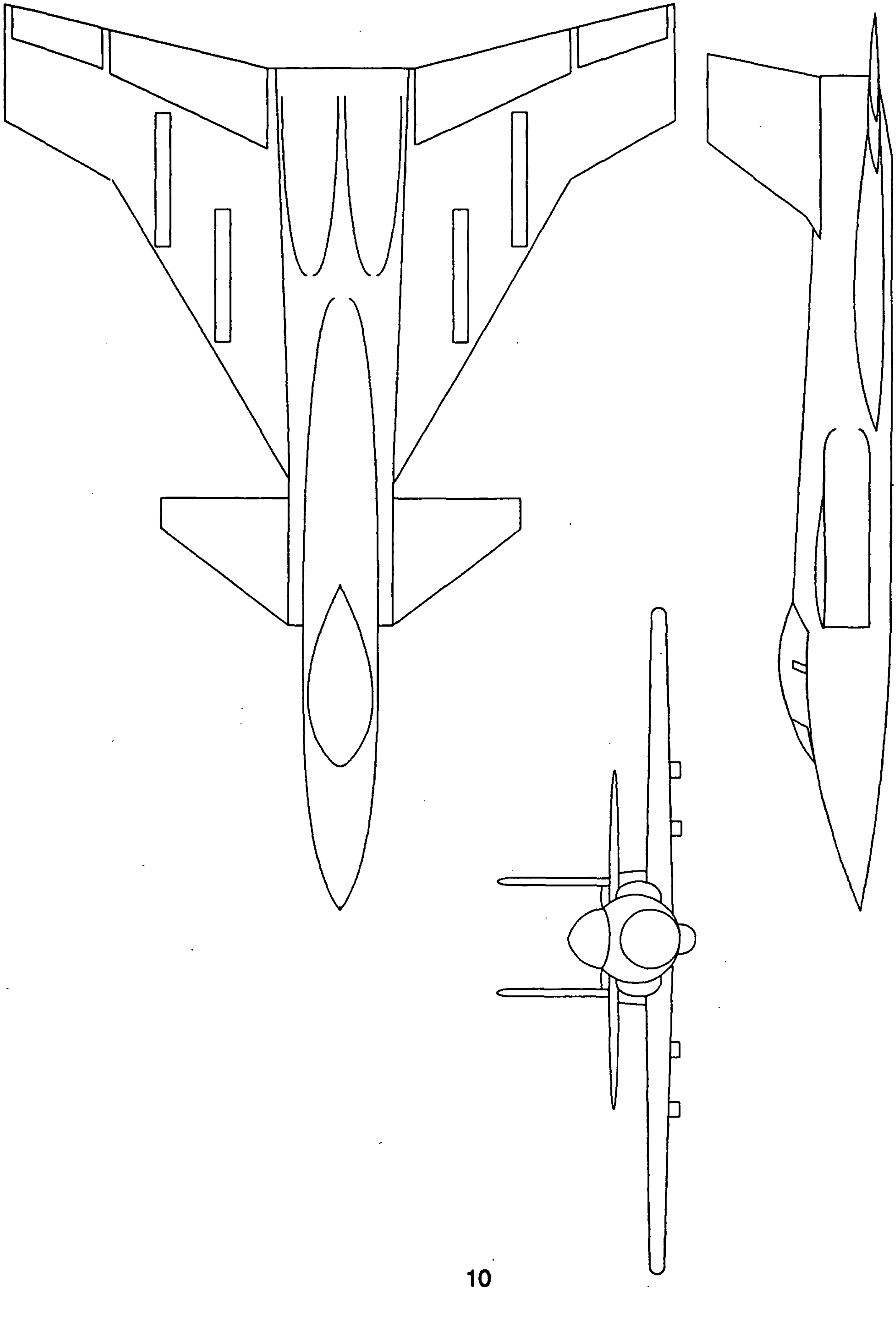


Figure 3.1 Raptor 3-View

Figure 3.2 and 3.3, the Raptor has ample thrust in reserve to accommodate sudden demands from the pilot. This thrust availability allows the Raptor to exceed the turn requirements, as shown in Figure 3.4, giving the pilot a distinct advantage over his opponent. The re-attack time is 24 seconds, with the turn completed at Mach 0.6.

The outstanding performance of the Raptor does not impair its range capabilities. With external fuel tanks replacing ordnance, the Raptor is required to have a ferry range of at least 1,500 nautical miles. The range of the Raptor in this configuration, with external fuel tanks retained throughout the duration of the flight, is 2,420 nautical miles. This is attained by climbing to its best cruise altitude of 25,000 feet and flying at Mach 0.8, where the Raptor's L/D is 7.15 and c_j is 0.766. However, without the additional drag of external fuel tanks the Raptor can cruise at a L/D of 9.34 enabling the aircraft to ferry 3,000 nautical miles. The airplane's clean configuration and large internal fuel capacity, approximately 20,150 lbs, actually allows a greater ferry range than with external fuel carried.

Using data from the design engine, T_{avail} and c_j were tabulated for altitudes from sea level to 40,000 feet, and Mach numbers from 0.0 to 1.0. The range was determined using a standard range equation[6]. With the full design bomb load retained throughout the entire flight, the Raptor may fly 920 nautical miles on internal fuel.

The design mission requires less fuel than the Raptor can carry internally. The internal fuel capacity is 20,150 lbs This capacity allows a longer range than called for in the mission specifications while still retaining the use of all external hardpoints for weapons. It should be noted, however, that the aircraft would be 7,090 lbs over the maximum allowable weight (51,400 lbs) for a 2,000 feet takeoff. The takeoff ground roll for this case is 2,655 feet which is still a very

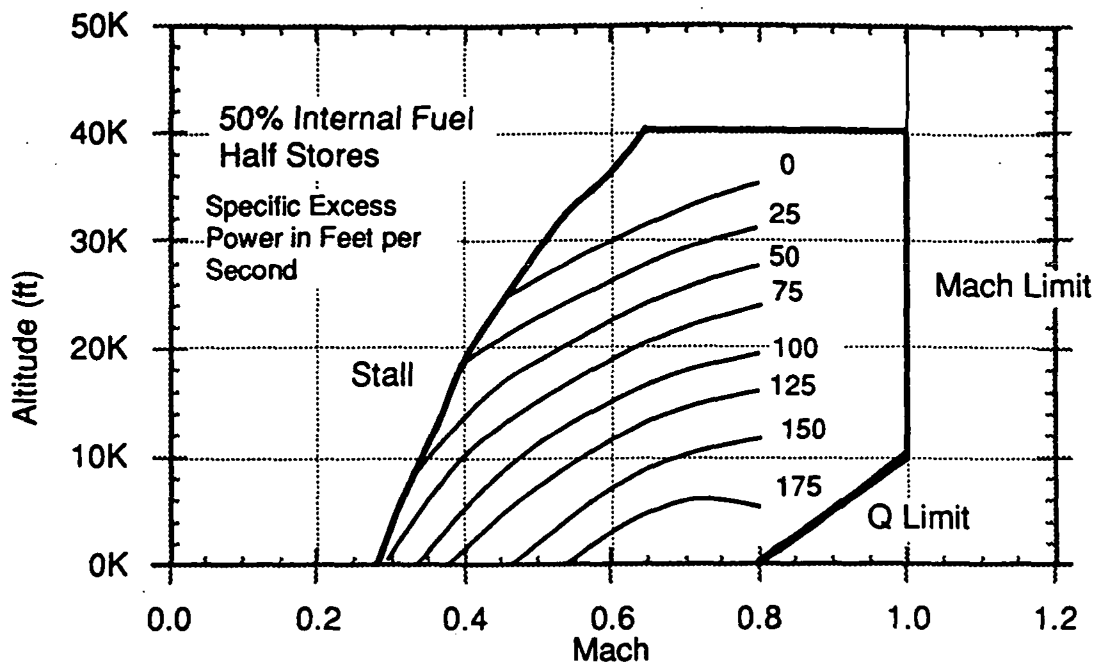


Figure 3.2 Specific Excess Power at Full Military Power

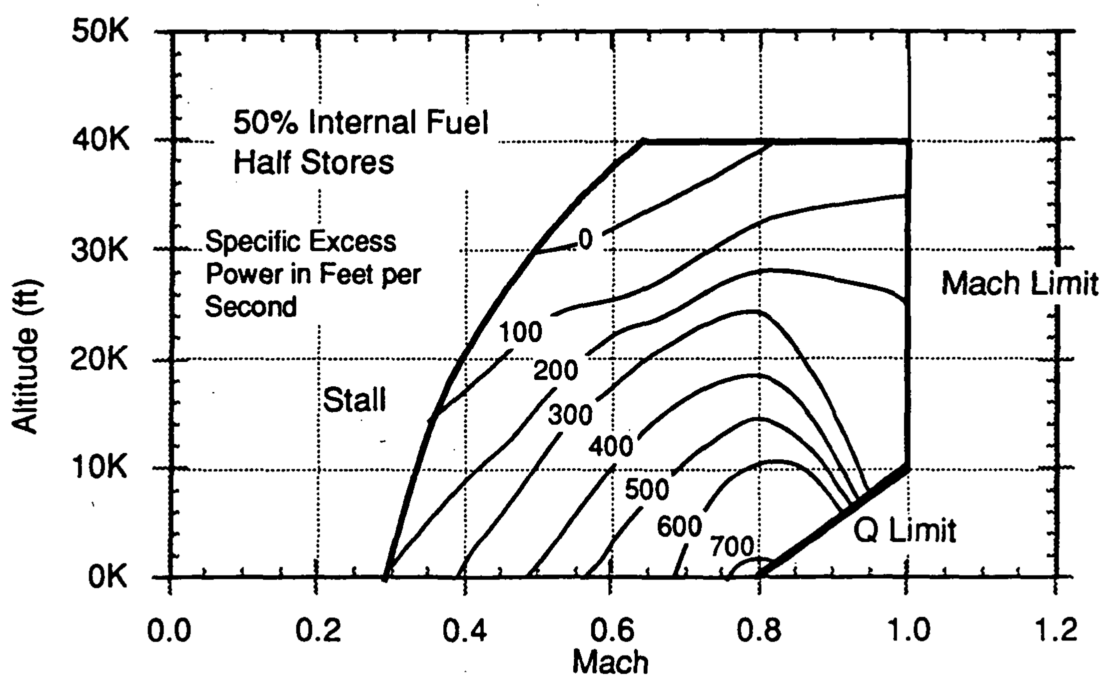


Figure 3.3 Specific Excess Power with Full Augmentation

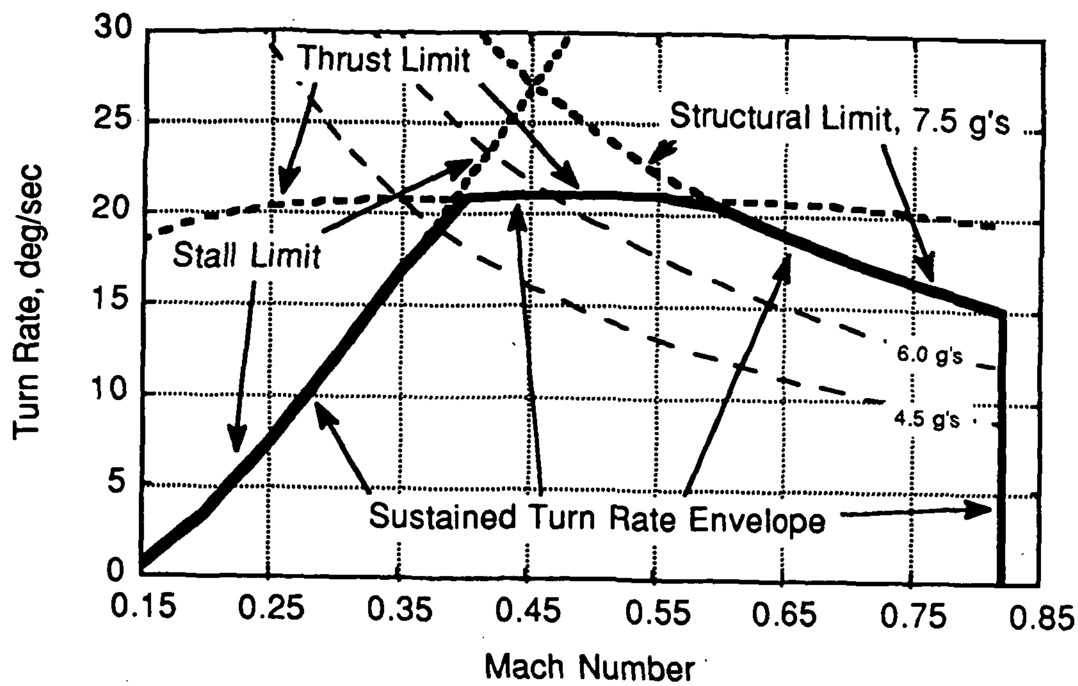


Figure 3.4 Turn Rate vs. Mach Number

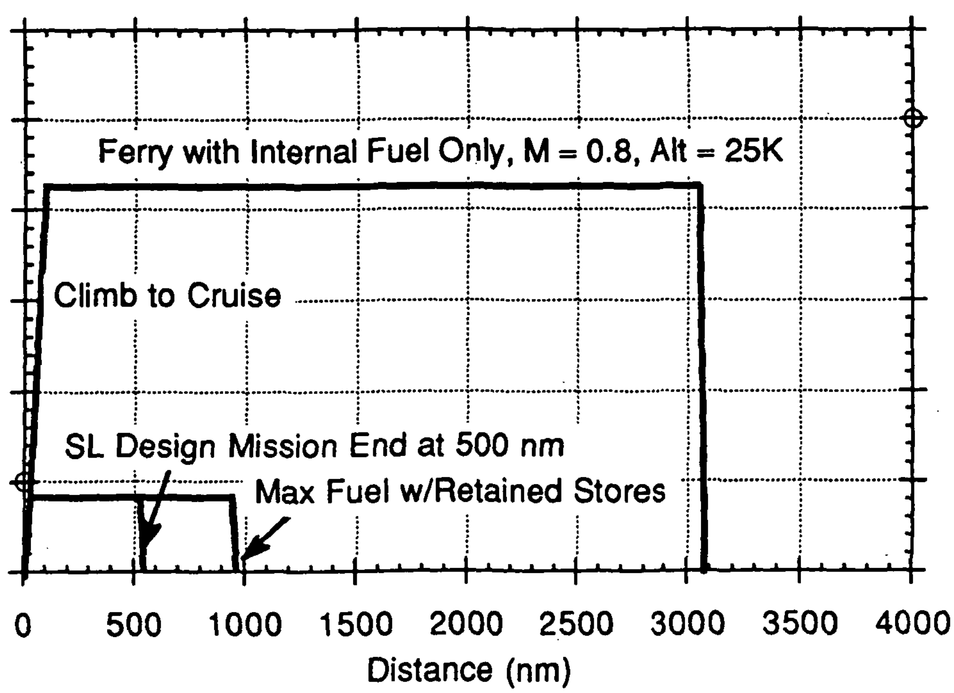


Figure 3.5 Range versus Payload

good ground roll considering the large payload being carried; although, the aircraft would be very stable in this configuration.

The range capabilities of the Raptor are illustrated in Figure 3.4.

Integral to the design of the Raptor is the ability to takeoff and land on very short runways (2,000 feet). Table 3.2 lists the distances achieved by the Raptor. For the primary mission the Raptor can takeoff in 1,605 feet which is almost 400 feet shorter than required. An additional 4,900 lbs of ordnance may be carried while still meeting the takeoff requirement; this is equivalent to ten more Mk 82 bombs.

Takeoff	**Design Load**	**Clean**
Ground Roll	1605 ft	942 ft
50' Obstacle	1742 ft	1038 ft
Landing		
Ground Roll	1800 ft	1410 ft
50' Obstacle	3130 ft	2558 ft

Table 3.2 Takeoff and Landing Performance

The fuel consumption calculations utilized a combination of mission specification fuel allowances and theory, with design engine data supplied.

For the engine start/taxi/takeoff sequence, the mission specifies five minutes at intermediate power. Using the engine data, scaled to meet the Raptor's thrust requirements, fuel consumption was calculated.

For cruising and loiter portions of the flight, the drag polar for the configuration was used in conjunction with the average weight of the aircraft during this phase. This is an iterative process, as the fuel consumption directly affects the weight. For the primary design mission, the engine/aircraft performance is given in Table 3.3.

	c_j	L/D
Takeoff	2.20	-
Dash Out, V=500 kts	0.75	6.31
Combat	2.33	-
Dash In, V=500 kts	0.75	5.33
Loiter	0.80	9.27

Table 3.3 Design Mission Fuel Consumption Data

4. Sizing Analysis

4.1 Weight Sizing

The weight of the Raptor was estimated using two methods. For initial weight sizing the methods of reference 7 were used. First the method of fuel fractions was used to determine an initial fuel weight. This was accomplished by dividing the mission into phases such as takeoff, cruise, combat, etc. and determining the amount of fuel used during each phase by subtracting the initial mission phase weight from the final one. These weights were determined from standard equations such as the Breguet range and endurance equations; in cases where formulas were unavailable weight ratios were taken from tables and graphs of similar aircraft. Values for such things as specific fuel consumption, lift to drag ratios, etc. were chosen on the basis of experience and similarity to aircraft in the same class as the Raptor. After calculation of the fuel weight, the aircraft empty and takeoff weights were determined using an iterative process. This iterative process was based on the linear relationship between the logarithms of empty weight and takeoff weight as shown in reference 7.

After the initial weight sizing and performance sizing had been done the weight of the Raptor was refined using a second method. The second method involved the calculation of the weights of all of the aircraft components. The weights of some individual components such as the AMAD and LANTIRN were known and the exact values were used; however, the weights of such components as the fuselage and electrical system were calculated using empirical equations based on the aircraft weight.[8] The weight of the Raptor was continously updated as the design evolved; for example the weight of the wing could be obtained directly once the structural layout had been determined. The final aircraft weight for the Raptor is shown in Table 4.1.

Empty Weight	22708 lbs
Fuel Weight	8400 lbs
Fixed Payload Weight	4902 lbs
2 AIM-9L's Weight	390 lbs
20 Mk-82's Weight	10100 lbs
Gross Takeoff Weight	46500 lbs

Table 4.1 Preliminary Weight Sizing Results for Primary Mission

4.2 Performance Sizing

In order to determine the necessary wing area and required thrust for preliminary design purposes, various performance requirements were calculated as a function of wing loading and thrust-to-weight ratio. These constraints included takeoff, landing, and cruise performance. Figure 4.1 is a plot of these constraints and illustrates the preliminary design area. This resulted in a wing area of 500 square feet and a thrust to weight ratio of 0.7.

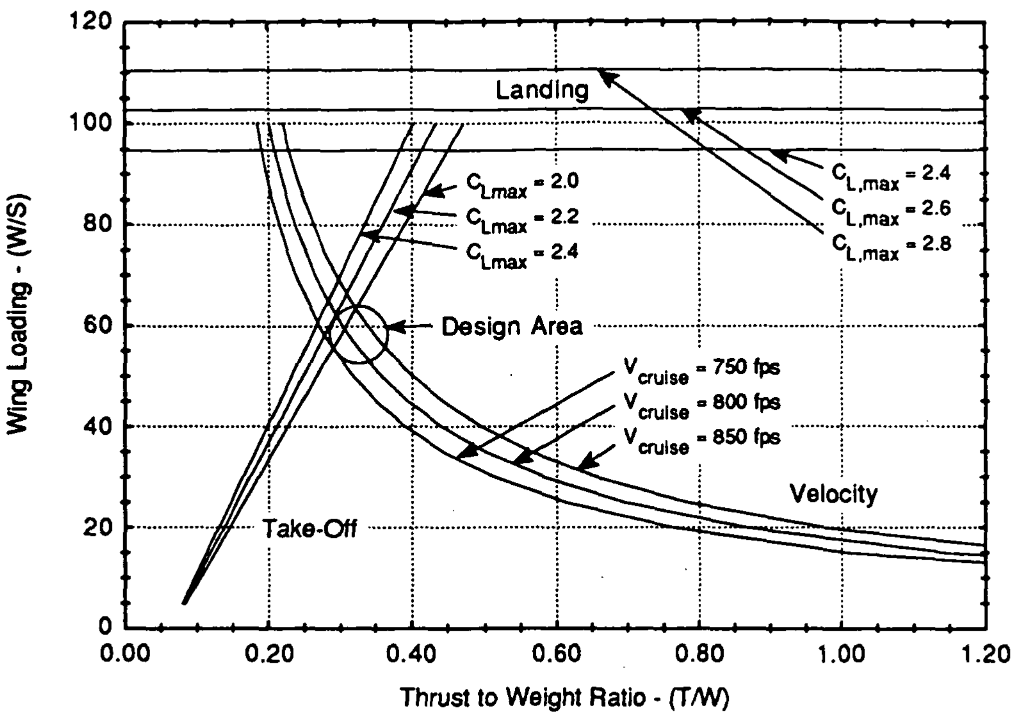


Figure 4.1 Matching Preliminary Sizing Results for the Raptor

5. CONFIGURATION

5.1 Propulsion System

The propulsion system chosen for the Raptor is an advanced turbofan design engine (rubber engine) whose specifications are shown in Appendix A. This system was chosen over other propulsion systems, such as existing engines, vertical lift engines, and propeller/rotor driven systems, for the reasons delineated below.

Since short takeoff performance is a crucial element of the Raptor, a high engine thrust-to-weight ratio is preferred. While existing engines may rival the proposed engine in performance, sufficient data for these state of the art systems is not available for determination of performance in all flight regimes. This lack of concrete information lead to the elimination of existing engines as a viable alternative. Additionally, the ability to scale the provided engine allowed the system to be sized to fit the exact performance requirements, unlike existing engines, which are understandably fixed in size and performance.

Vertical lift engines were ruled out due to the increased complexity, weight, and cost inherent in their design and implementation. Furthermore, the thrust needed to lift such a heavy aircraft would necessitate the use of very high thrust engines, since a thrust-to-weight ratio in excess of 1.0 is required for such a maneuver. The weight and size of such engines alone would be prohibitive due to the necessary addition of flow deflection nozzles and their corresponding ducting, not to mention the high fuel consumption rates which result in reduced range. All of these additions as well as the additional engine and control systems complexity would incur a large cost increase over a conventional propulsion system.

Propeller and rotor driven aircraft were discarded because of their inefficiency at the high cruise speeds envisioned for the Raptor.

Although vectored thrust would have enhanced takeoff performance and improved maneuverability, the increased complexity and weight offset any advantages that might have been gained.

5.2 Configuration

Several possible wing configurations were considered, and are shown in Table 5.1, along with their advantages and disadvantages.

CONFIGURATION	ADVANTAGES	DISADVANTAGES
Straight Wing	• Simple, low cost construction • High lift coefficient • Good low speed maneuverability	• Low drag divergence Mach number • Heavier structural requirements
Aft-Swept Wing	• High drag divergence Mach number • Improved stability • Good high speed maneuverability	• Poor low speed maneuverability • Poor stall characteristics
Forward Swept Wing	• Good high alpha performance • High drag divergence Mach number	• High structural complexity
Joined Wing	• Efficient long range cruise • Lower structural weight	• Poor aft visibility • Susceptibility to catastrophic damage
Variable Sweep Wing	• Good performance at high and low speeds	• High complexity, weight, and cost
Cranked Arrow	• High drag divergence Mach number • Low wing weight • Large internal and external capacity • Good performance at high and low speeds	• Reduced lift coefficient • Reduced downward visibility

Table 5.1 Wing Planform Comparison

The cranked arrow configuration offers a good combination of the low speed performance found in straight wings and the high speed characteristics of an aft-swept wing. The high sweep angle helps delay drag divergence, allowing a higher cruising speed, while the large root chord reduces structural weight and increases wing internal fuel capacity. Also, the large planform area allows a large amount of external stores to be carried.

As with the wing planform configuration, a similar comparison was conducted to determine horizontal and vertical stabilizer disposition, and are presented in Table 5.2

CONFIGURATION	ADVANTAGES	DISADVANTAGES
Horizontal Tail	•Proven design • Large moment arm	• Download during takeoff rotation
No Horizontal Tail	• No added weight • Reduced drag	• Less efficient pitch control
Canard	• Good stall characteristics • Upload during takeoff rotation • Vortex lift contribution	• Could contribute to aircraft instability • May cause reduced downward visibility
Single Vertical Tail	• Simple design • Low weight • Reduced cost	• Large single surface • Possibility of catastrophic damage
Twin Tails	• Redundancy for survivability • Reduced height • Higher angle of attack flight	• Added weight and complexity • Added skin drag • Higher cost

Table 5.2 Control Surface Comparison

Canards were chosen over a horizontal tail because of the uplift during takeoff rotation, which helps reduce takeoff distance, the good stall characteristics, and vortex lift contribution. The canards were sized so that the Raptor is stable during all phases of flight. Twin vertical tails were implemented mainly due to the added survivability factor of a redundant system.

Further investigation was conducted to determine the wing vertical placement, and is presented in Table 5.3.

CONFIGURATION	ADVANTAGES	DISADVANTAGES
High Wing	• Good downward visibility • Good ground clearance	• Generally results in poor interference drag
Mid Wing	• Low interference drag	• Complex and heavy structure
Low Wing	• Easiest weapons installation • Best aft visibility	• Generally results in poor interference drag • Poor lateral stability

Table 5.3 Wing Placement Comparison

A low wing was selected because the structure is less complex, it protects the engines, and facilitates ordnance loading.

6. COMPONENT DESIGN

6.1 Fuselage

The overall length of the Raptor's fuselage is 57 feet which gives the fuselage a fineness ratio of 6.13. All of the major systems are enclosed in the fuselage except for the payload which is carried externally on both the wings and the fuselage; Figure 6.1 shows the placement of these systems.

The Avenger cannon is carried internally under the nose; the large size of the cannon and the ammo drum as well as the necessary separation distance for ammo feed between them presented a major design consideration. Maintenance of the gun is a simple matter because the entire system can be removed from the fuselage through the access doors on the bottom of the plane.

Engine removal is accomplished by pulling the engines out from the rear. Avionics access is a very simple matter. The nose cone is hinged just aft of the LANTIRN system's terrain following radar for easy access to that system; furthermore the avionics bay which is installed on runners can be slid forward for easier access to individual avionic modules.

The two main factors that have to be taken into account for the design of the cockpit area are good visibility and ejection seat clearance. Some of the more important dimensions of the cockpit are shown in Table 6.1.

Dimension	
Over-the-Nose Visibility	16°
Over-the-Side Visibility	41°
Seat Tip-Back Angle	17°
Head Clearance	3"
Maximum Canopy Width	40"

Table 6.1 Cockpit Dimensions

In order to ensure pilot safety the next generation of ejection systems in the form of Boeing's CREST ejection seat is employed in the Raptor.

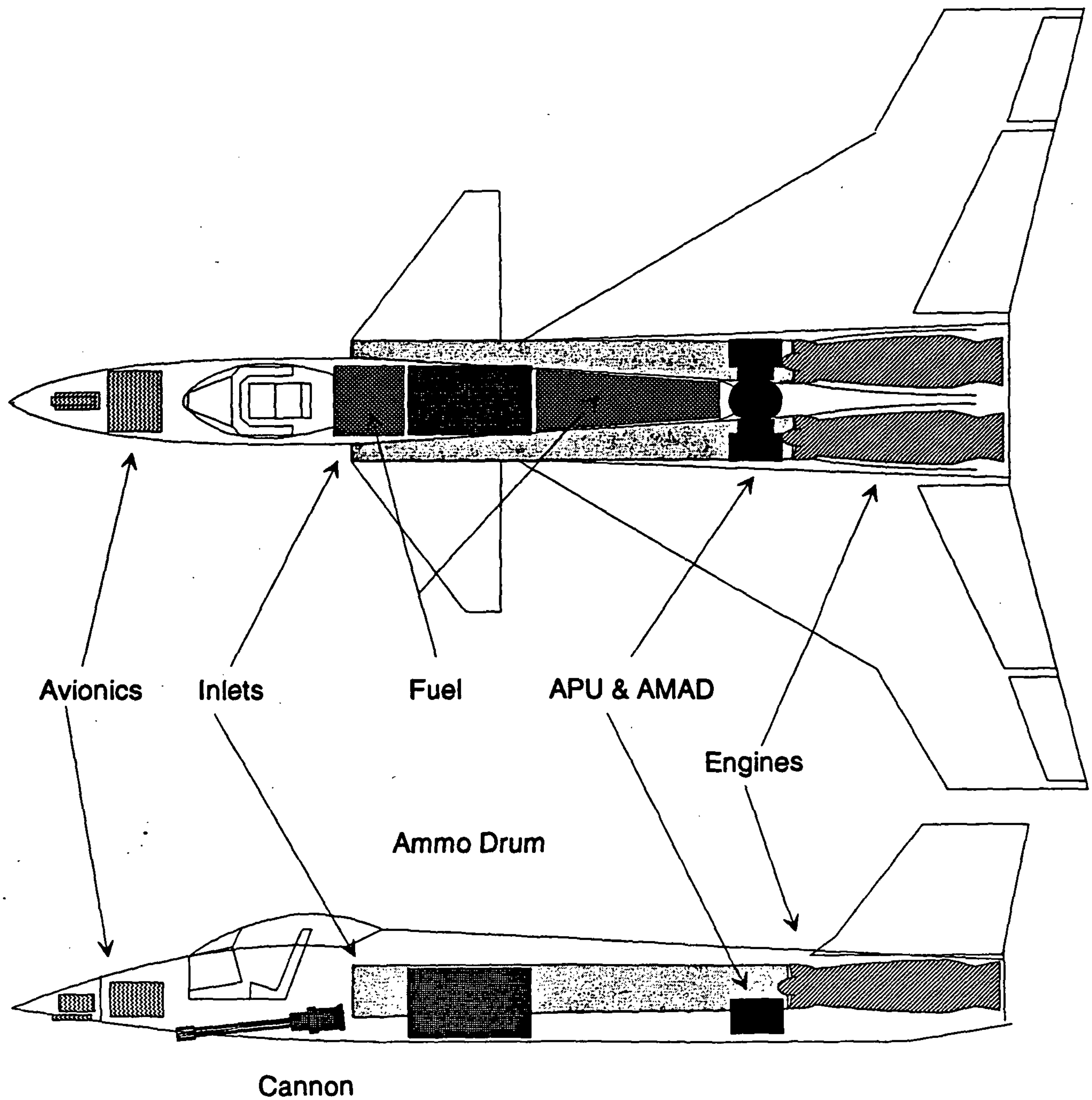


Figure 6.1 Fuselage Layout

Information about aircraft attitude is fed to the ejection system so that upon ejection reaction control jets roll the ejection seat into an upright position before the main rockets fire. With the CREST ejection system the pilot can safely eject in a thirty-degree dive, with ninety degrees of bank, seventy-five feet off the ground with only three tenths of a second until impact.[9]

6.2 Wing

The Raptor employs a cranked arrow wing configuration. Since the Raptor cruises at a very high subsonic Mach number, drag divergence had to be delayed. In order to accomplish this a large sweepback angle is employed and a moderate thickness ratio is used. Geometric data on the wing is provided in Table 6.2.

Geometry	
Planform Area (exposed)	500 ft^2
Span	45 ft
Root Chord	25 ft
Tip Chord	8 ft
Mean Aerodynamic Chord	16.15 ft
Taper Ratio	0.32
Leading Edge Sweep	60° (inner wing) 30° (outer wing)
Quarter Chord Sweep	53° (inner wing) 26° (outer wing)
Anhedral	0°
Twist	0°
Aspect Ratio	2.56

Table 6.2 Wing Geometry

While the high sweepback of the Raptor's wing delays the drag divergence Mach number to .96, it seriously reduces the maximum lift coefficient. Since a high maximum lift coefficient is needed for good takeoff and landing performance an airfoil with a high C_{Lmax} is required that still has a thickness ratio as low as possible. The airfoil selected is the NACA 64A410; data for this airfoil is presented in Table 6.3 and Figure 6.2 shows the airfoil.[10]

c_{lmax}	1.6
c_{do}	.0043
α_{stall}	14°
$c_{l\alpha}$	6.21

Table 6.3 Airfoil Data

The Raptor employs single-slotted flaps on the inboard section of the wing. To further increase the lift capability, flaperons are employed on the outer wing section instead of traditional ailerons. The inboard flaps have an average length of 25% of the wing chord and are used along 57% of the exposed wing span; likewise, the flaperons are approximately 25% of the chord and 34% of the exposed wing span. Figure 6.3 depicts the planform layout.

6.3 Empennage

The Raptor's canards are located just aft of the canopy and are mounted above the inlets. The canards are designed so that the entire surface rotates to provide pitch control; there are no control surfaces built into the canard. Also each canard is capable of independent rotation so that the canards can also provide roll control. The NACA 0006 airfoil is used for the canard. A symmetric airfoil is advantageous in that the canards are interchangeable from side to side; this makes battlefield repairs simpler and lowers manufacturing costs because one machine can manufacture both left and right canards. Table 6.4 lists the important geometric parameters of the canard.[10]

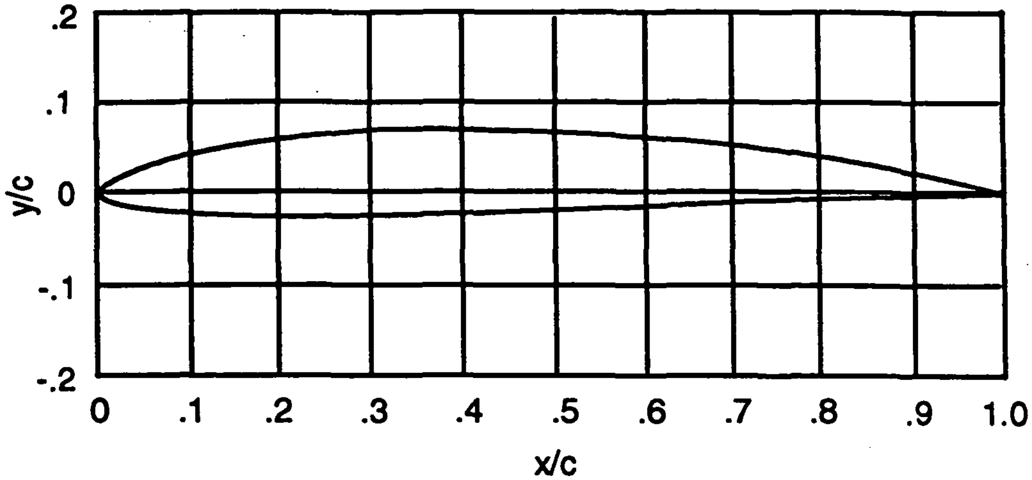


Figure 6.2 NACA 64A410 Airfoil

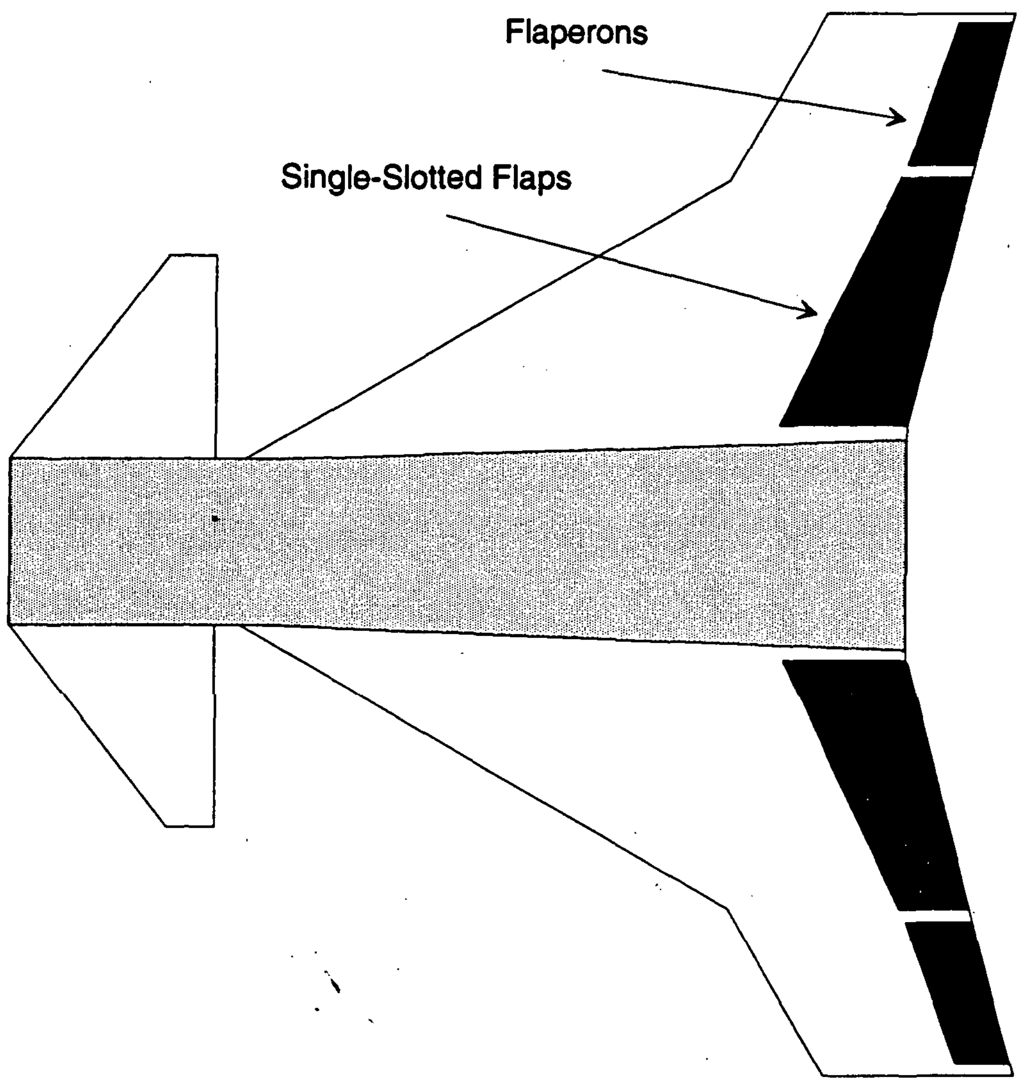


Figure 6.3 Wing Planform

Area (each)	47 ft^2
Leading Edge Sweep	34°
Root Chord	8.5 ft
Tip Chord	2.0 ft
Taper Ratio	0.24

Table 6.4 Canard Geometry

The Raptor employs twin vertical tails. The NACA 0006 has also been selected as the airfoil for the vertical tails. Since the vertical tails are not canted, they enjoy the same manufacturing and battlefield replacement benefits as the canards due to their interchangeable nature. Table 6.5 summarizes the geometry of the vertical tails.

Planform Area (each)	80 ft^2
Leading Edge Sweep	43°
Root Chord	13.0 ft
Tip Chord	9.5 ft
Taper Ratio	0.73
Height	8.5 ft

Table 6.5 Vertical Tail Geometry

6.4 Propulsion Integration

As stated previously, the turbofan design engine was chosen for the Raptor. The thrust required of the engine was determined from the performance analysis, with turning performance being the driving factor. It was determined that 37,000 lbs of thrust was necessary to achieve the required turning performance. A non-augmented engine sized to this requirement proved to be very inefficient at cruise speeds, due to the low throttle setting. Therefore, an augmented engine was chosen because the thrust required at all other aspects of the mission were significantly less than at takeoff, and specific fuel consumption was near optimum at cruise conditions. The thrust-to-weight ratio of the engine by itself is 8.8 at sea level, M=.8.

Two engines were employed instead of one because the weight and complexity of the engine increase dramatically as thrust goes up, thereby increasing the cost. Furthermore, two engines increases survivability in a hostile environment, preventing the loss of an aircraft and possibly its pilot due to engine failure or damage. The engines are placed slightly above the wing carry-through structure to further increase survivability, and are separated from each other by a firewall to decrease the chance of damage to one engine affecting the other.

Fixed inlets are mounted along the side of the fuselage. Variable geometry inlets were not chosen because of complexity and the Raptor's subsonic operational environment. Since the Raptor employs canards, care had to be taken to prevent flow off the canards from disturbing the smooth flow of air into the inlets. Chin-mounted and top-mounted inlets were considered as possible solutions to this problem, but were rejected for the following reasons. Chin-mounted inlets would be subject to foreign object digestion (FOD) and hot-gas ingestion from the Avenger cannon mounted on the bottom of the forward fuselage. Top-mounted inlets could be blanked by the fuselage at higher angles of attack, and greatly reduce visibility to the rear. To ensure that smooth flow entered the inlets the canards were mounted on the inlets. This inlet/canard placement necessitated an overly long inlet length of 25 ft, which increases pressure losses in the inlet. It was felt that these pressure losses, which are approximately 5 to 8%, would be offset by the insurance of relatively smooth airflow into the inlets. An inlet capture area of 3.53 ft^2 each was calculated for optimum performance at cruise conditions, with the addition of spillage and blow in doors of 3 ft^2 for use at other flight conditions such as takeoff. A boundary layer diverter was used to prevent the development of a boundary layer in the inlet, which would present a definite problem in inlets of this length.

6.5 Landing Gear

The Raptor employs a conventional hydraulic actuated tricycle landing gear configuration. The nose gear, consisting of two wheels connected to a single strut, is mounted to the aft cockpit bulkhead and retracted forward. Since the Avenger cannon is mounted in the same space, the nose gear is slightly off-center, in much the same configuration as the Fairchild A-10. Emergency extension would be performed by gravity drop and free stream airflow locking. Figure 6.4 depicts the location in the fuselage, while Figure 6.5a illustrates the retraction sequence. Data for the nose wheels are shown in Table 6.6.[11]

Maximum Static Load	6200 lbs
Tire Size	18" x 5.5"
Ply Rating	14
Inflation Pressure	215 psi
Maximum Speed	275 mph
Tire Weight	15 lbs

Table 6.6 Nose Gear Tire Data

The main gear for the Raptor are similar in nature to the wide-stance gear of the F/A-18 Hornet. Placement of the main gear is shown in Figure 6.4, while retraction sequence and a descriptive picture are shown in Figure 6.5b. The retraction kinematics, while appearing complex at first glance, are deceptively simple. An upward retracting, floating link scheme is used, with the wheel rotating 90 degrees about the strut to reduce stowage depth. Emergency extension is performed in the same manner as the nose gear.

The main gear configuration was chosen in order to keep the landing gear out of the wing, where it would have interfered with the wing structure and external loads, but still maintain the desired lateral tip-over angle of 55 degrees.

Distance from the underside of the fuselage to the center of the wheel is 42 inches, providing a longitudinal tip-over angle of 15 degrees and a tail-scrape angle of 15 degrees. Data for the main landing gear are listed below in Table 6.7.[11]

Maximum Static Load	33500 lbs
Tire Size	40" x 14"
Ply Rating	28
Inflation Pressure	200 psi
Maximum Speed	200 mph
Tire Weight	127 lbs

Table 6.7 Main Gear Tire Data

As noted previously the Raptor is able to carry the equivalent of ten additional Mk 82 bombs for the primary design mission. Because of this the tires were sized to 55,000 lbs (with a 1.25 safety margin) since it would be pointless to have this additional performance but not be able to use it.

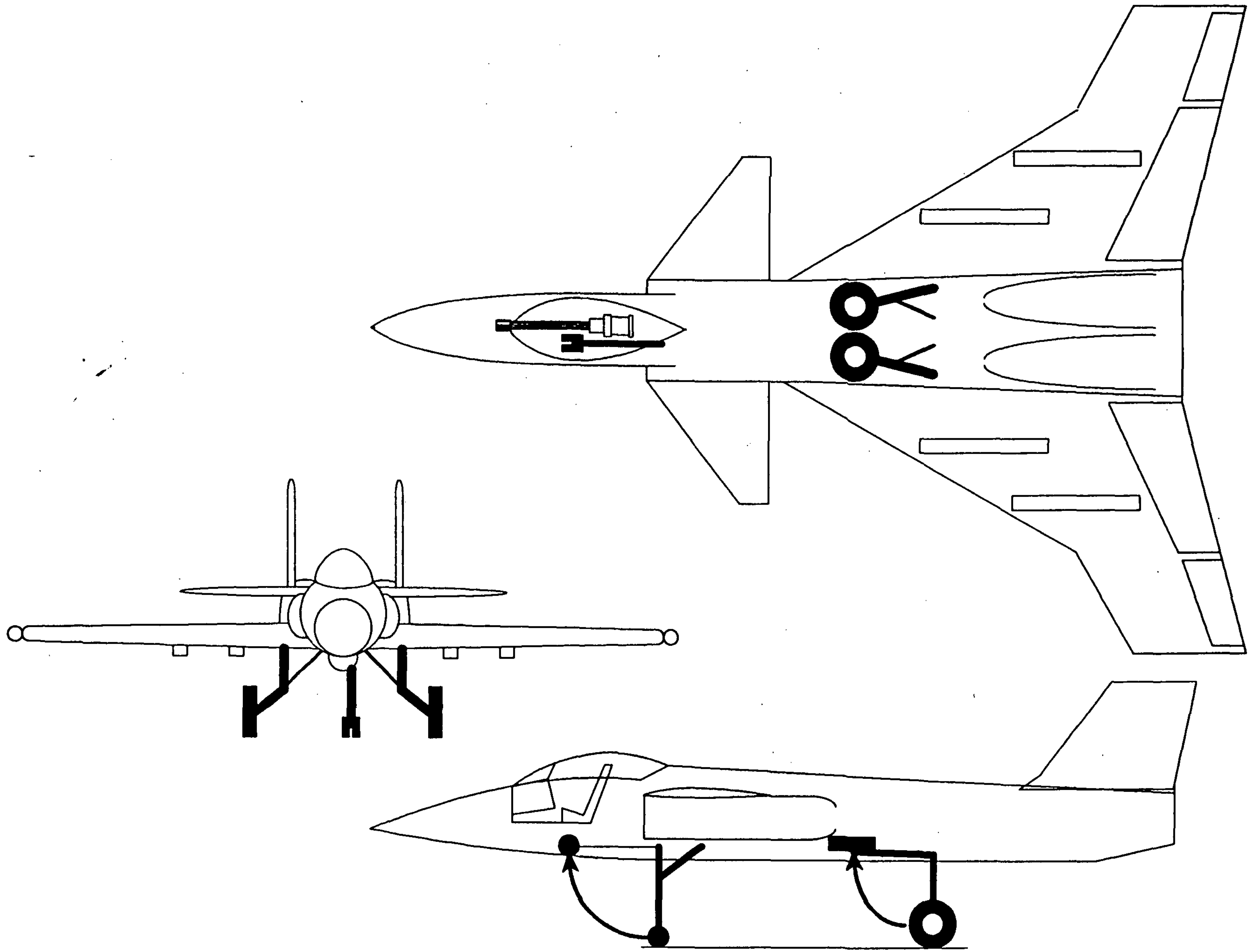


Figure 6.4 Landing Gear Layout

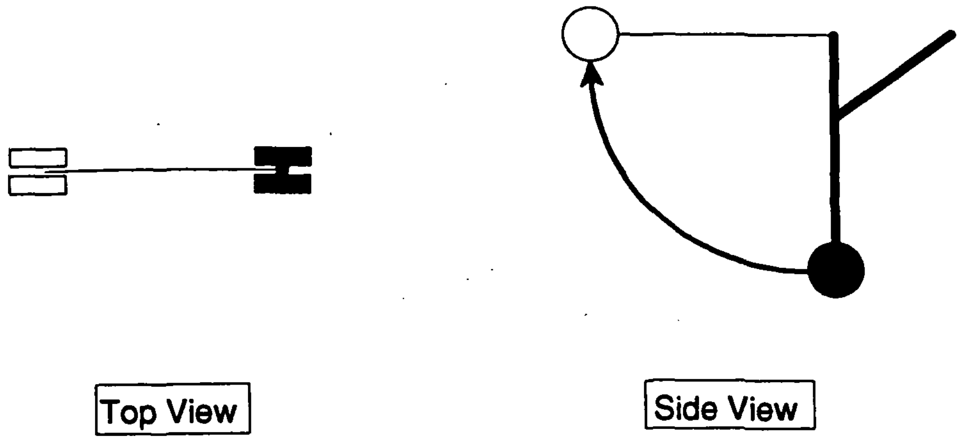


Figure 6.5a Nose Gear Retraction Scheme

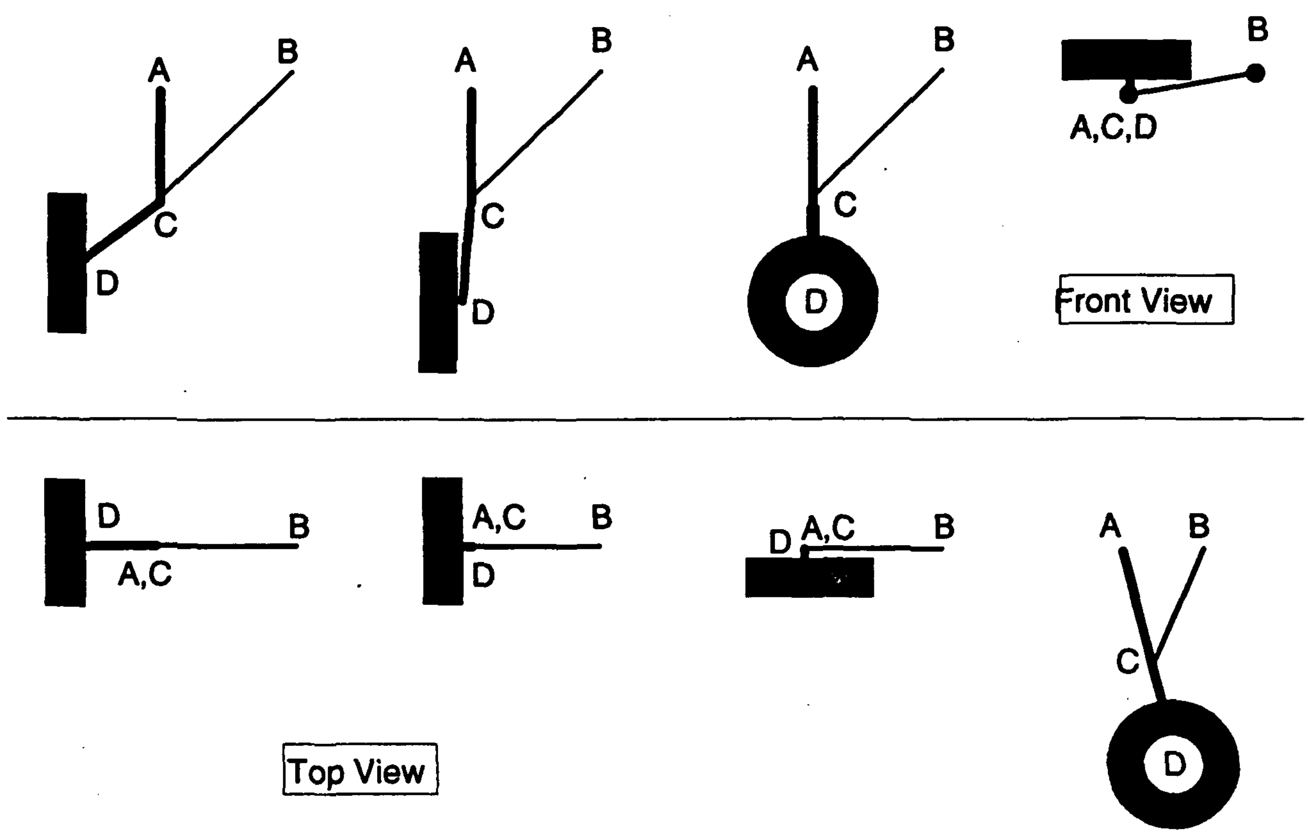


Figure 6.5b Main Gear Retraction Scheme

7. STRUCTURES/MATERIALS

The following section describes the structural layout, material selection, and methodology used to size the structures. The requirements for structural design considerations were maximum and minimum normal loads of +7.5 and -3.0 g's, with a safety factor of 1.5, for the aircraft flying the primary mission with full weapons load, 60 percent internal fuel, and a maximum dynamic pressure of 1000 psf.[5]

7.1 Structural Layout

The frame spacing for the fuselage was based upon standard values for military aircraft taken from reference 12; the frame spacing for the Raptor is 15-20 inches. Longeron spacing is 8-12 inches, and was determined in the same manner. There are two bulkheads in front of the cockpit to support the avionics bay, with two more aft of the cockpit bracketing the ammo drum and supporting the nose gear, inlets, and canards. A spar runs between the two bulkheads immediately fore and aft of the cockpit which supports the GAU-8A Avenger cannon.

The wing and engines are both supported by the aft half of the fuselage. The wing has six primary load carrying spars which taper linearly from root to tip. The taper is the same for all six spars, although overall dimensions vary to minimize weight and yield maximum allowable stress, which is 40 ksi for *aluminum 2014-T6. The dimensions of the spars are given in Table 7.1.*

	Spar 1	Spar 2	Spar 3	Spar 4	Spar 5	Spar 6
Location (% chord)	15.30	28.60	40.00	51.40	62.00	70.50
Root Height (in)	14.00	17.10	18.00	16.56	14.00	12.24
Tip Height (in)	7.47	9.12	9.60	8.83	7.47	6.53
Root Web Thickness (in)	0.59	0.74	0.80	0.74	0.59	0.52
Tip Web Thickness (in)	0.32	0.40	0.43	0.39	0.32	0.28
Root Flange Thickness (in)	0.47	0.62	0.67	0.62	0.51	0.43
Tip Flange Thickness (in)	0.25	0.33	0.35	0.33	0.27	0.23
Root Flange Width (in)	5.71	7.55	8.15	7.50	6.18	5.26
Tip Flange Width (in)	3.04	4.03	4.35	4.00	3.30	2.81
% allowable	77.80	95.00	100.00	92.00	77.80	68.00

Table 7.1 Wing Spar Data

Figure 7.1a shows the internal structure of a wing cross-section, while Figure 7.1b illustrates the wing spar dimensions. The spars run spanwise through the main wing, and then run perpendicular through the fuselage, connecting directly to the engine support frames. There are also ten ribs in the wing, three of which support hardpoints. The skin thickness of the wing is 0.015 inches for torsional resistance. Figure 7.2 illustrates the internal structural layout of the fuselage and wing.

The canards and vertical tails, since they carry lighter loads and are smaller in size, only required two spars each.

7.2 Materials

The primary material used in the construction of the Raptor is Aluminum 2014-T6 alloy, since it is lightweight and easy to obtain and manufacture, while still possessing the necessary strength. Because it is so readily available, acquisition costs are reduced, and its ease of manufacture reduces machining costs and the need to create new manufacturing processes. Aluminum is used

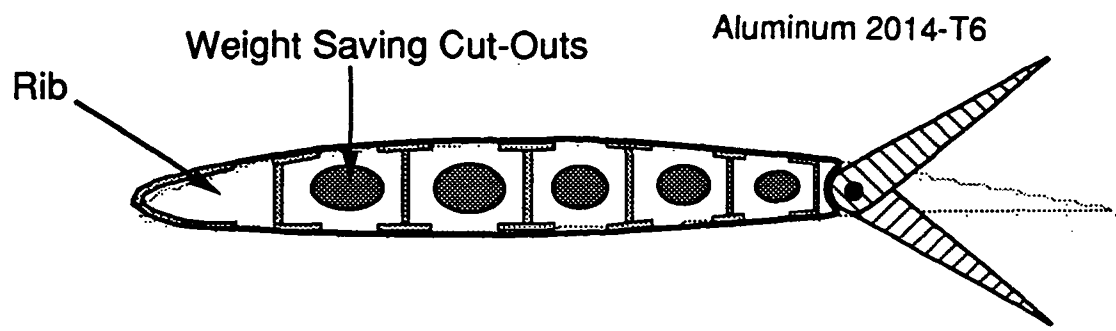


Figure 7.1a Internal Layout of Wing (not to scale)

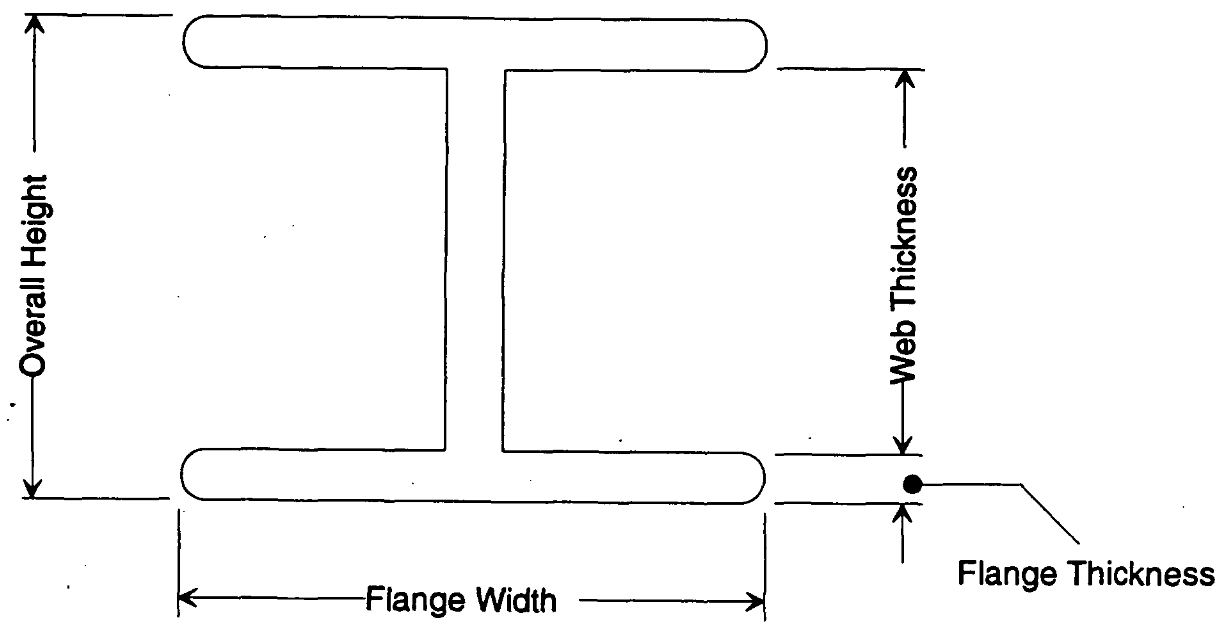


Figure 7.1b Wing Spar Dimensions

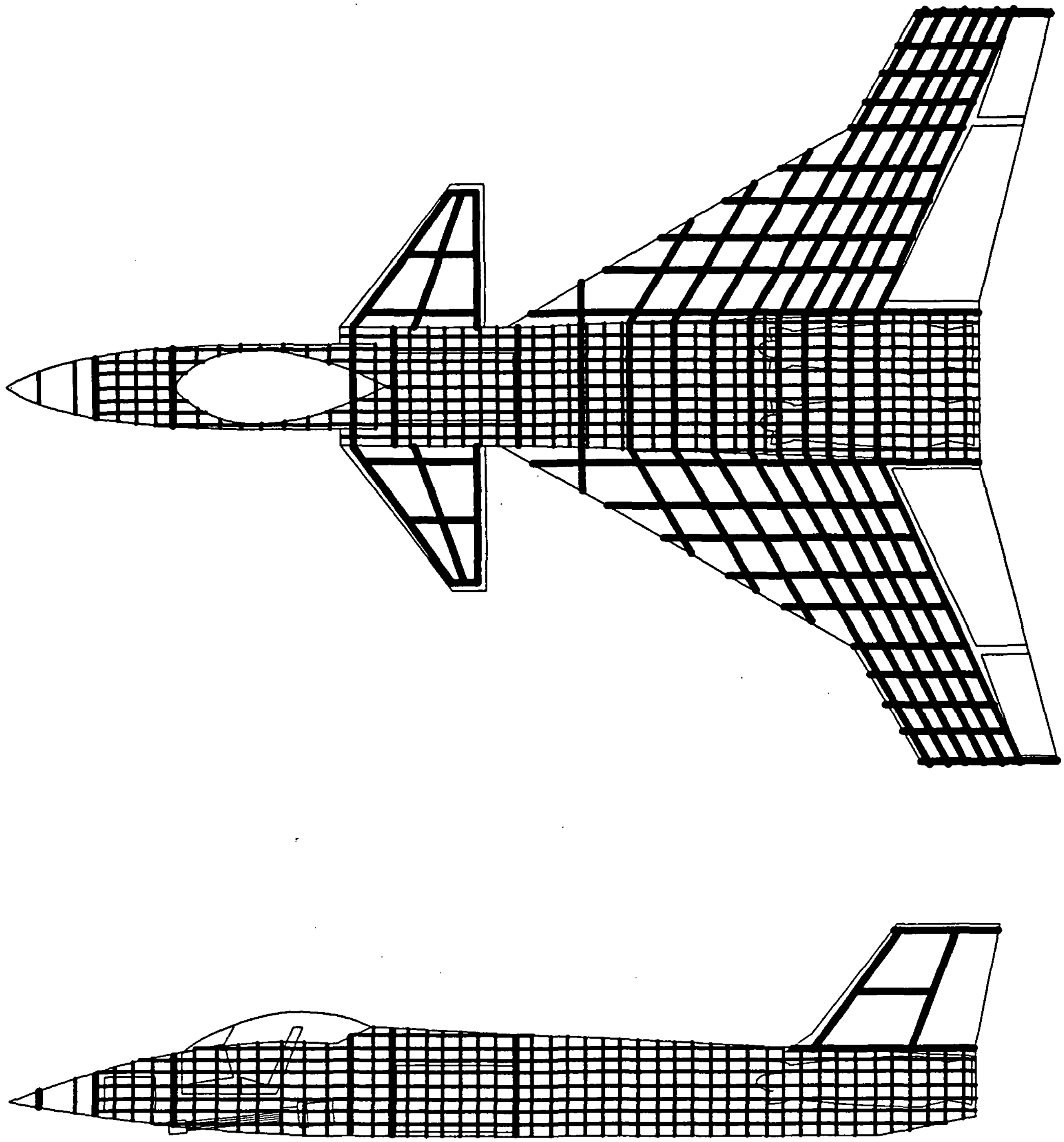


Figure 7.2 Structural Layout

throughout the aircraft structure, except in the landing gear, vertical tails, canards, and nose cone.

The landing gear is constructed from steel, due to its high strength and fatigue resistance.

The skin of the canards and twin vertical tails is fabricated from a graphite/epoxy composite because of its increased strength, necessary for resistance to buffeting fatigue. Composite materials were not used in other structural members because of the higher cost of manufacture; the canards and tails are relatively simple structures, however, and would require very little in the way of extra manufacturing costs.

Figure 7.3 shows the overall materials layout of the Raptor.

7.3 Methodology

The structural arrangement of the wing was calculated in the following manner. First, the lifting load for maximum lift on the wing was determined using lifting line theory. The fuselage weight was distributed evenly across its width, which puts maximum bending stresses at the wing/fuselage junction. The wing weight was distributed spanwise along the wing according to the wing area at each station, while wing fuel is distributed over the inboard wing section. Finally, ordnance loads were applied as point loads at their respective hardpoint locations. The weight of the fuel in the wing and the wing mounted bombs decreases the bending moment, allowing for a lighter wing structure. All loads were considered constant along the chord. In order to generate a shear versus wing station plot, incremental shear distributions were summed using Riemann sums. The moment versus wing station plot was determined in the same manner. These plots are presented in Figures 7.4 and 7.5. Spar sizes were calculated by taking the maximum loading, with a margin of safety of 1.5, so that

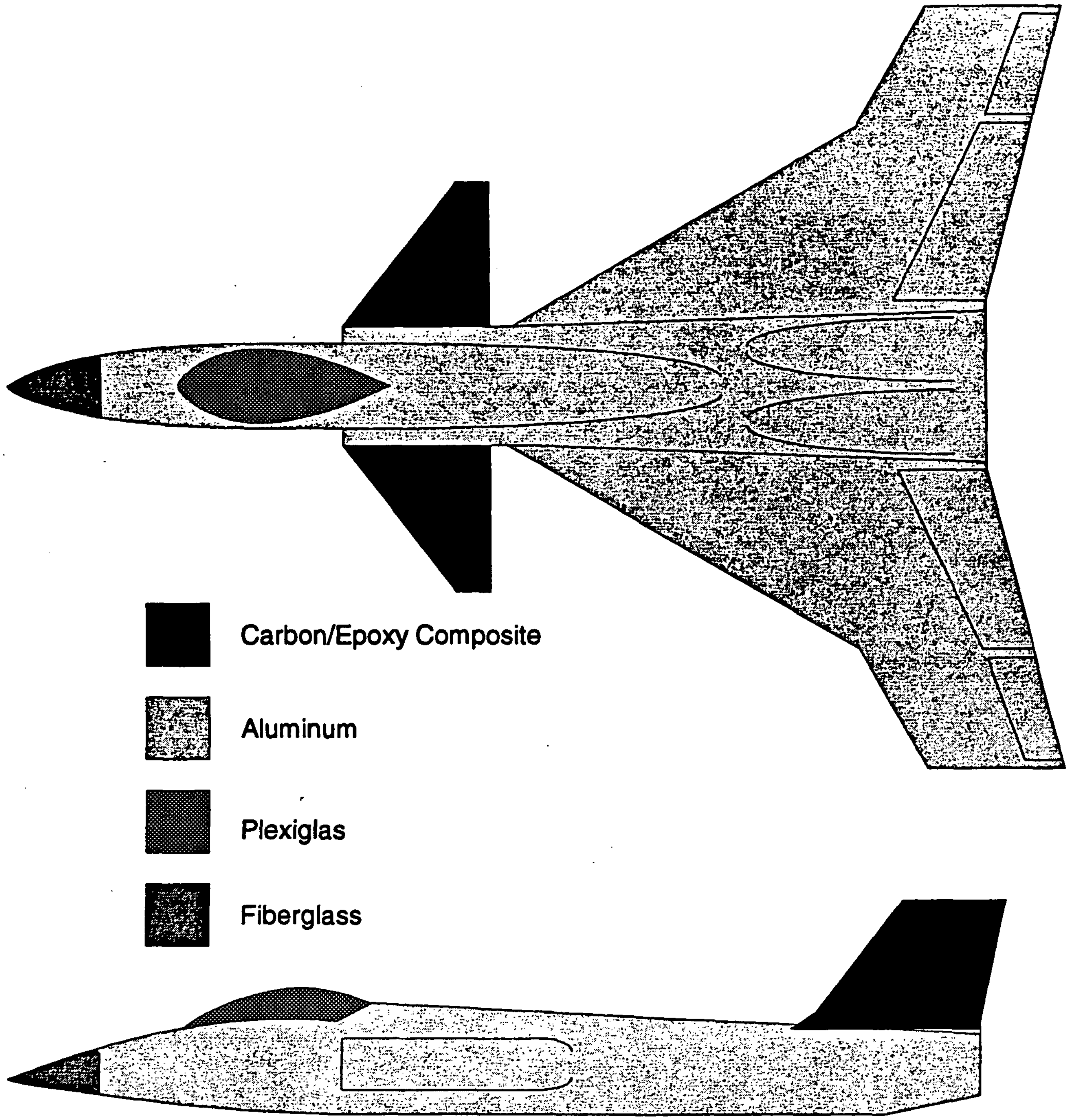


Figure 7.3 Materials Composition

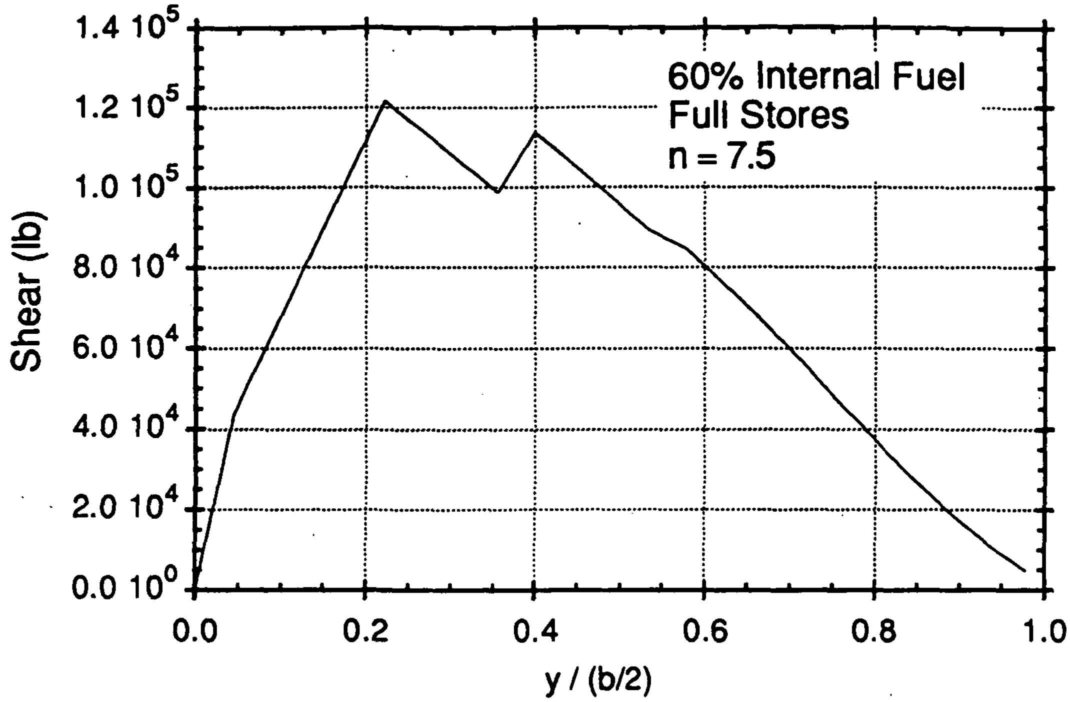


Figure 7.4 Shear Diagram

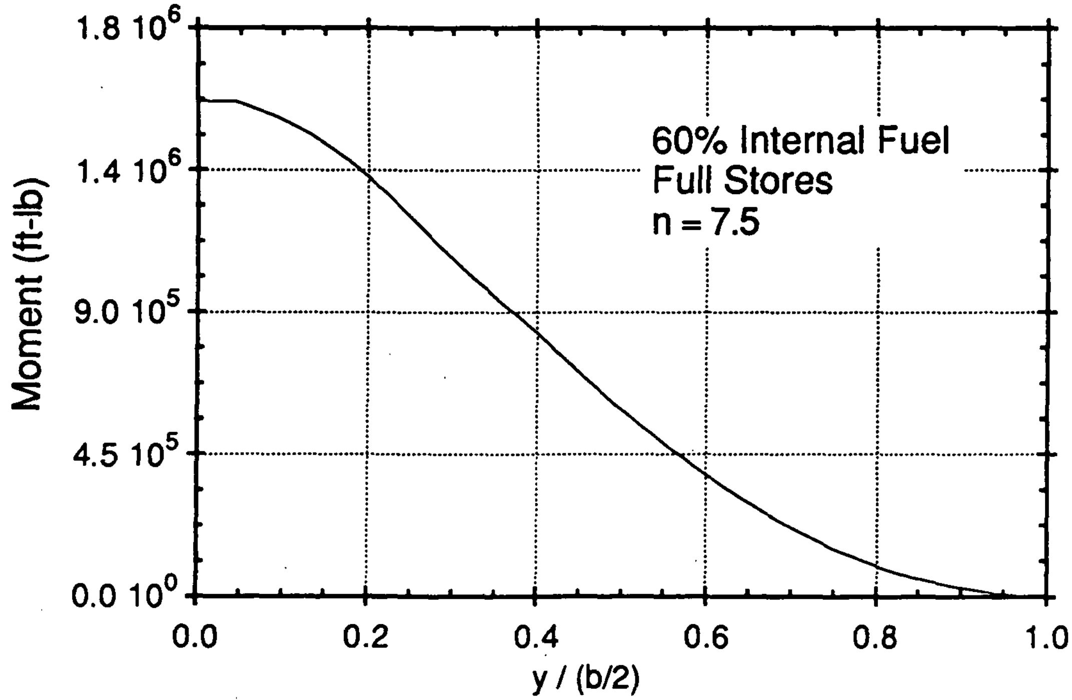


Figure 7.5 Moment Diagram

the spar size yielded the maximum allowable stress for that spar size. Under this loading, the spar located at maximum thickness is at maximum allowable stress, but the remaining spars are subjected to a lower stress. The moment each spar supported was proportional to the stiffness of each spar relative to their combined stiffnesses. This assumed a constant chordwise deflection at any particular span. Figure 7.6 shows the stress loading relative to the maximum allowed as a function of span. The wing/fuselage junction stress level is at 100% of the allowable stress. Shear stress was also determined, but was not a limiting factor.

The Raptor's flight envelope is shown as a V-n diagram in Figure 7.7; the flight envelope is constrained by the maximum structural load factor (specified by the mission description) and by the maximum aerodynamic load factor. The 1,000 psf maximum dynamic pressure specified in the mission description translates into a maximum level velocity at sea level. The design dive velocity was calculated to be 120% of the maximum level velocity.[8] The aerodynamic load factors, both positive and negative, are dependent upon $C_{L_{max}}$ and the corresponding C_D. Table 7.2 lists the data that pertains to the positive and negative structural load factor limits. The gust induced load factors are not critical for the Raptor and were not included for that reason.

Structural Load Factor	+7.5	-3.0
Aerodynamic Load Factor	1.96	-0.73
$C_{L_{max}}$	1.74	-0.71
Stall Velocity (knots)	118.7	197.4
Maximum Level Velocity (knots)	543.5	543.5
Design Dive Velocity (knots)	652.1	652.1

Table 7.2 V-n Data

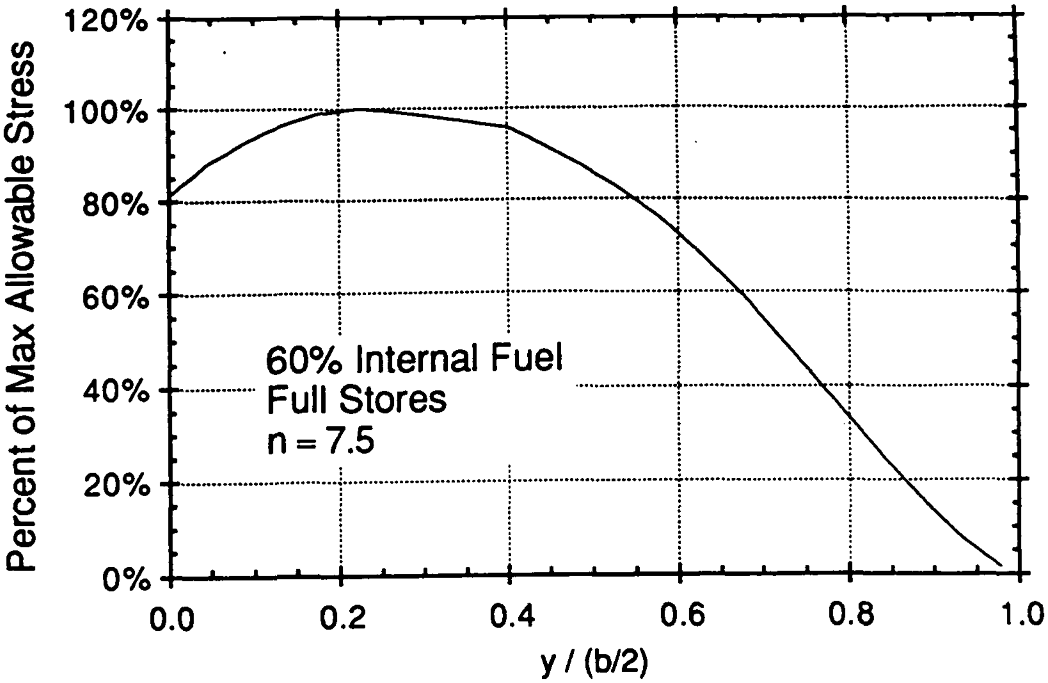


Figure 7.6 Maximum Loading of 40% Chord Spar

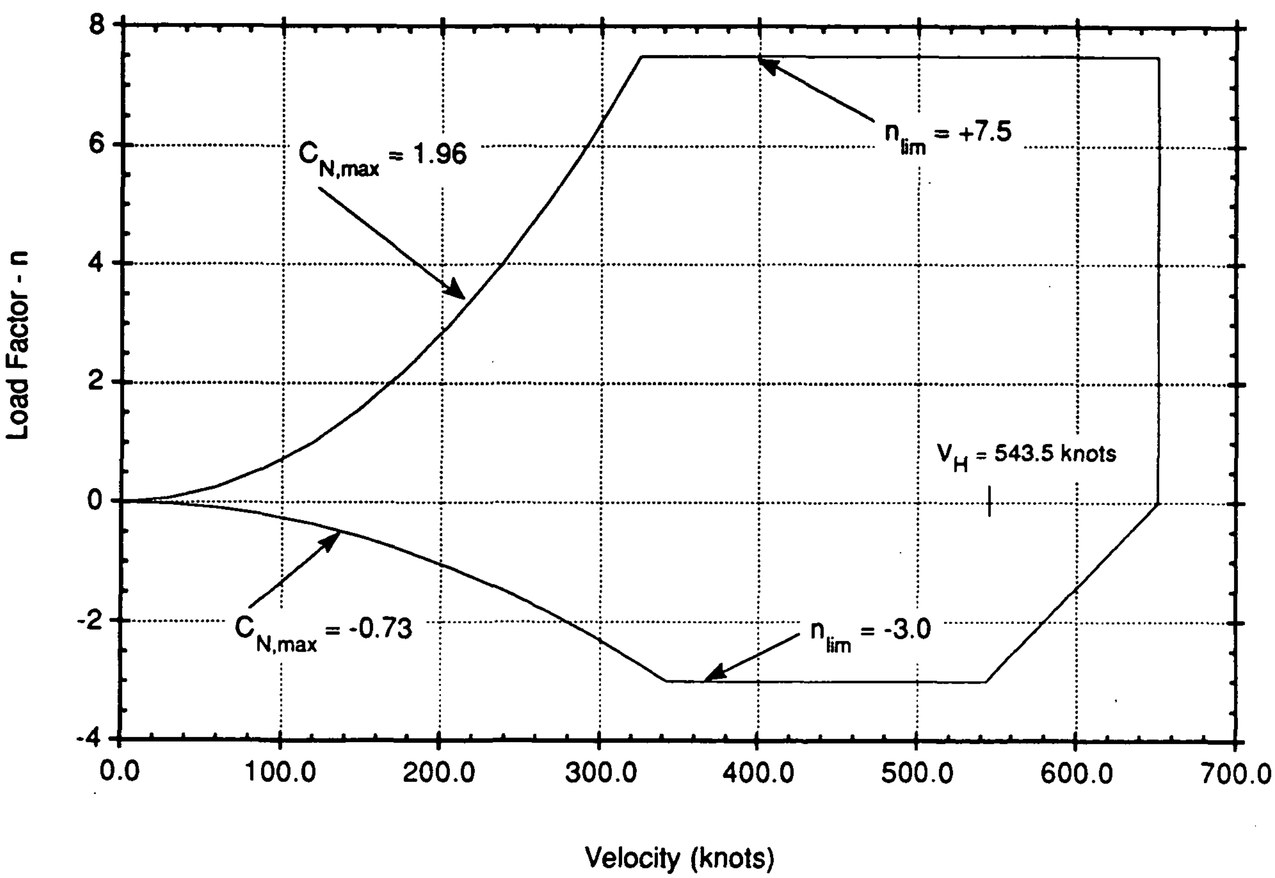


Figure 7.7 V-n Diagram at Sea Level

8. CENTER OF GRAVITY/MOMENT OF INERTIA ANALYSIS

8.1 Center of Gravity

Center of gravity (cg) was calculated by determining component weights and positions, summing the subsequent moments, and dividing by total weight. Wherever possible, actual component weights were used. Otherwise, empirical equations from reference 8 were used to obtain estimates.

The moment contribution of all component were summed and divided by the corresponding total weight, giving center of gravity positions. This was done for the configuration encountered during the design mission. A cg excursion diagram was then generated, showing the longitudinal position and travel of the cg during a typical design mission. This is presented in Figure 8.1. The cg travel is quite low, giving nearly constant longitudinal stability ranging from 2.2 to 5.6%.

8.2 Moment of Inertia

The moments of inertia were determined for the fully loaded aircraft at takeoff. The moment arm of each component is the distance from the aircraft's fully loaded center of gravity location to the component's own cg location. Values for these moments of inertia are presented in Table 8.1.

I_{xx}	41683 slug ft^2
I_{yy}	173167 slug ft^2
I_{zz}	206989 slug ft^2
I_{xy}	0 slug ft^2
I_{xz}	4594 slug ft^2
I_{yz}	0 slug ft^2

Table 8.1 Moments of Inertia

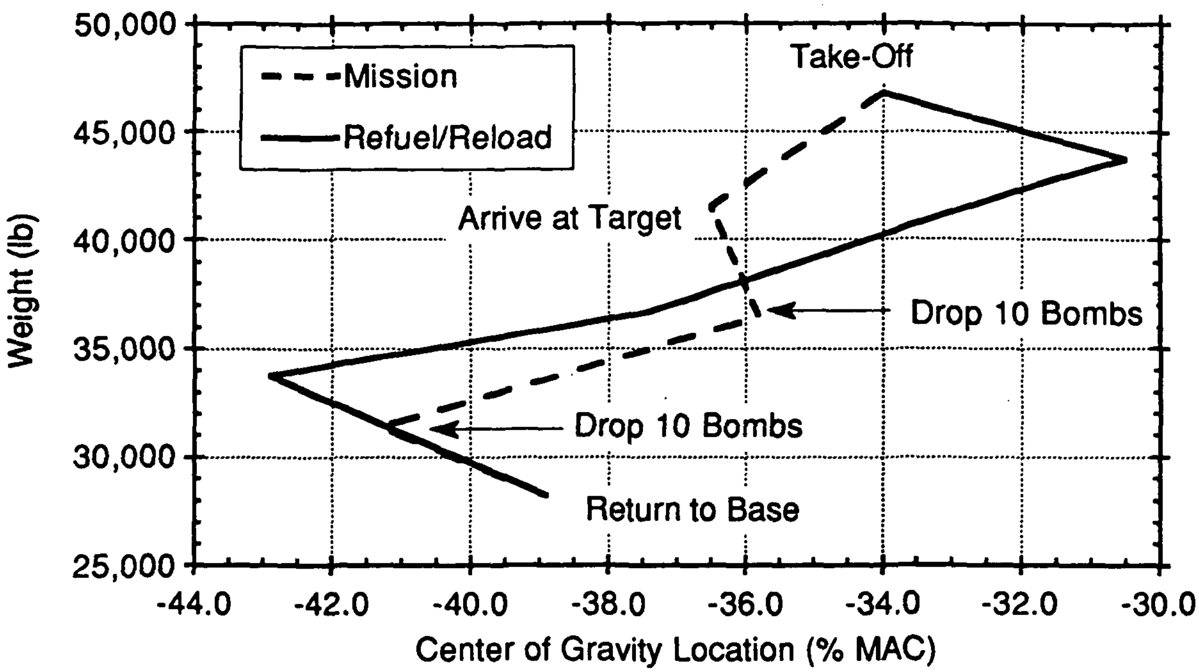


Figure 8.1 Center of Gravity and Weight Excursion

9. AERODYNAMICS

9.1 Lift Predictions

The theoretical lift curve slope and C_m/C_L relationship were determined using lifting line theory. These values are plotted in Figures 9.1 and 9.2. The wing is modeled by creating a number of panels that approximate the shape of the wing at each span position; canards can be modeled in the same way with three dimensional distances from the wing to examine downwash and vortex effects. Samples of the results obtained are shown in Figures 9.3 and 9.4. These figures indicate that the canard tends to reduce the lift on the wing when the canard is at a higher angle of attack than the wing, but actually increases the lift over the wing when the canard is at a lower positive angle of attack relative to the wing. In other words, the most effective lifting condition occurs when both the wing and the canard are at positive angles of attack, but the canard is at a lower angle than the wing. This flight condition is optimal for various flight regimes, including low-speed maneuvering and landing.

9.2 Drag Predictions

Drag predictions for the Raptor were determined for different flight conditions by breaking the total drag into four components: induced drag due to lift, zero-lift drag due to interference and skin friction, profile drag due to flaps and trim surfaces, and wave drag for transonic flight. The wetted area of the wing, canards, and tails were found using an integration technique described in Appendix B. Pertinent data is listed in Table 9.1.

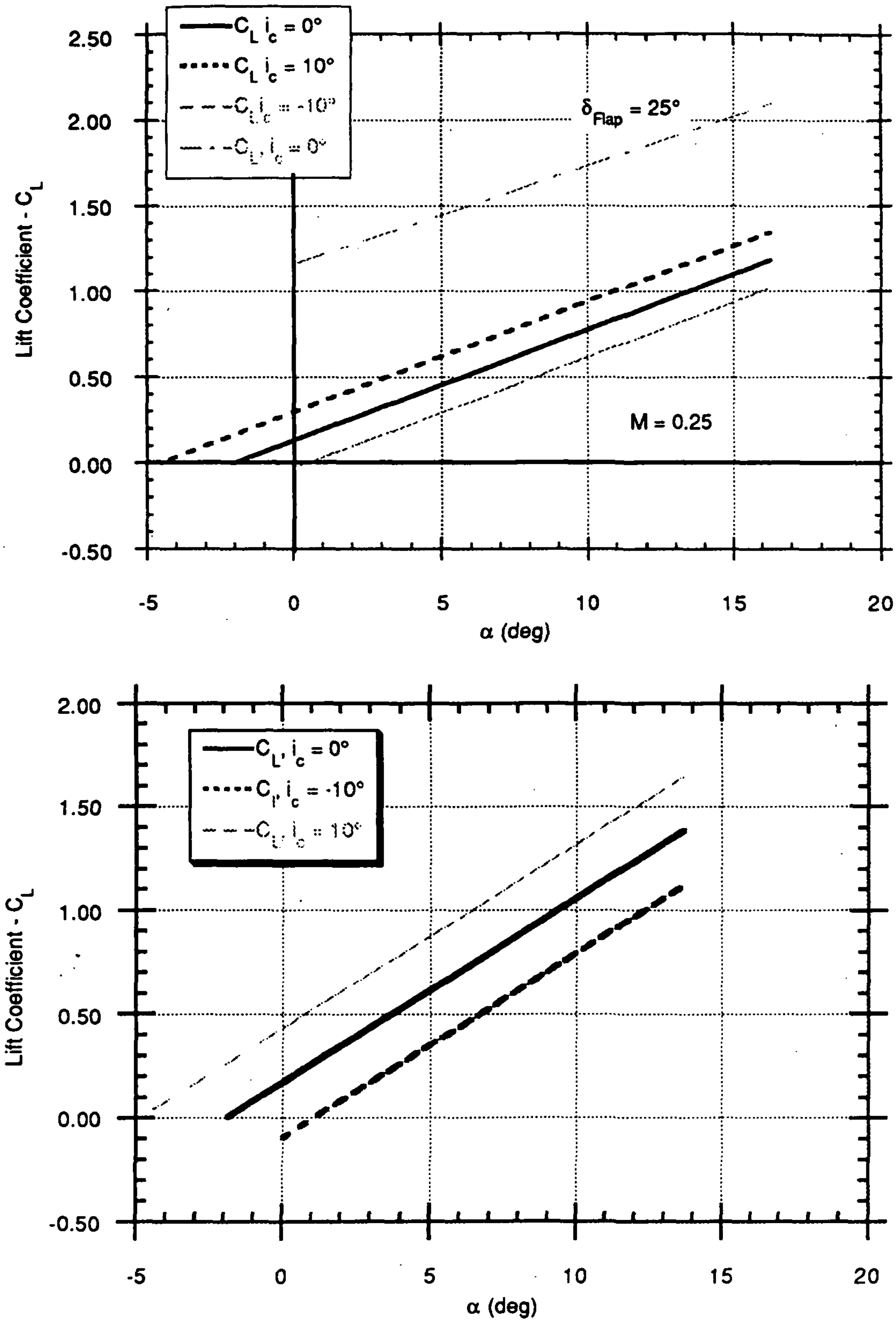


Figure 9.1 C_L versus α Curves

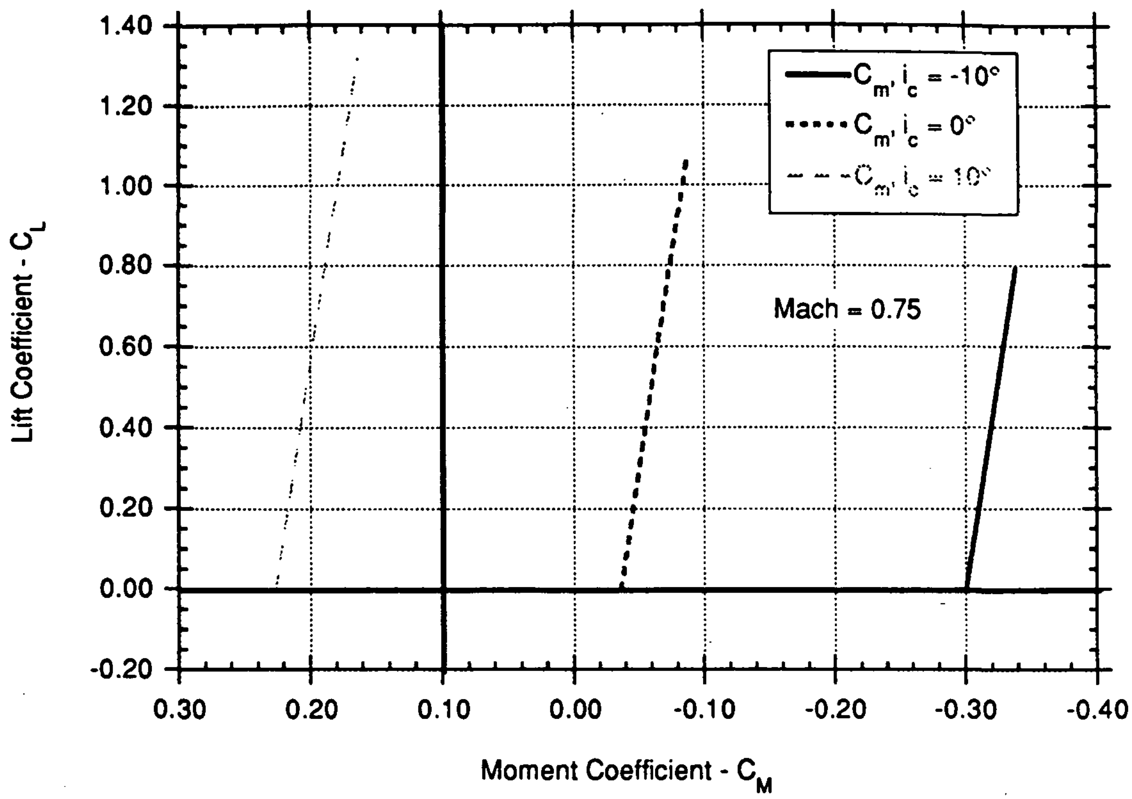


Figure 9.2 C_L versus C_M Curves

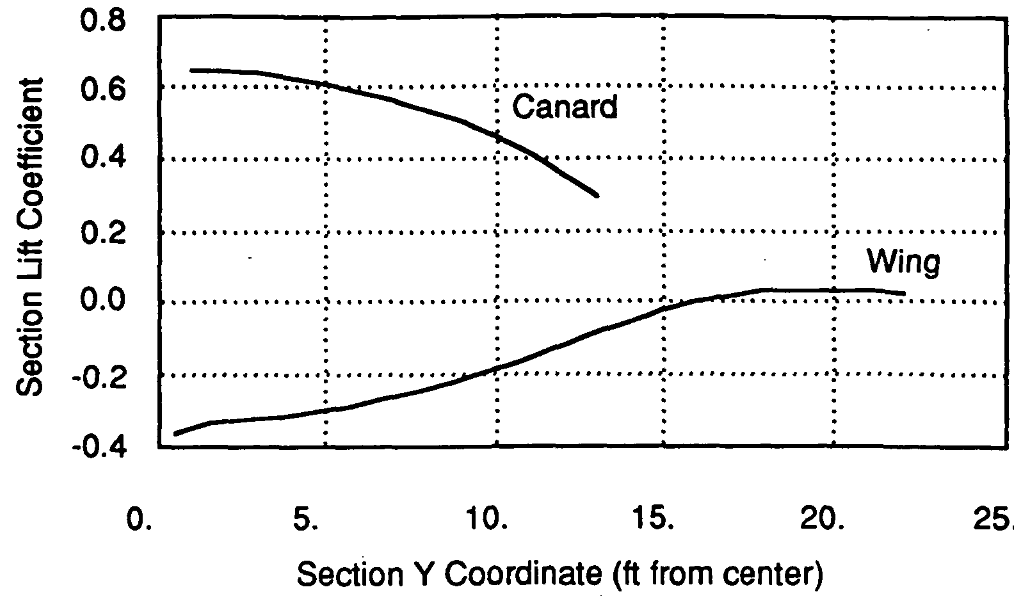


Figure 9.3 Lift Distribution at $\alpha = 0.8°$ and Canard Deflection = -12°

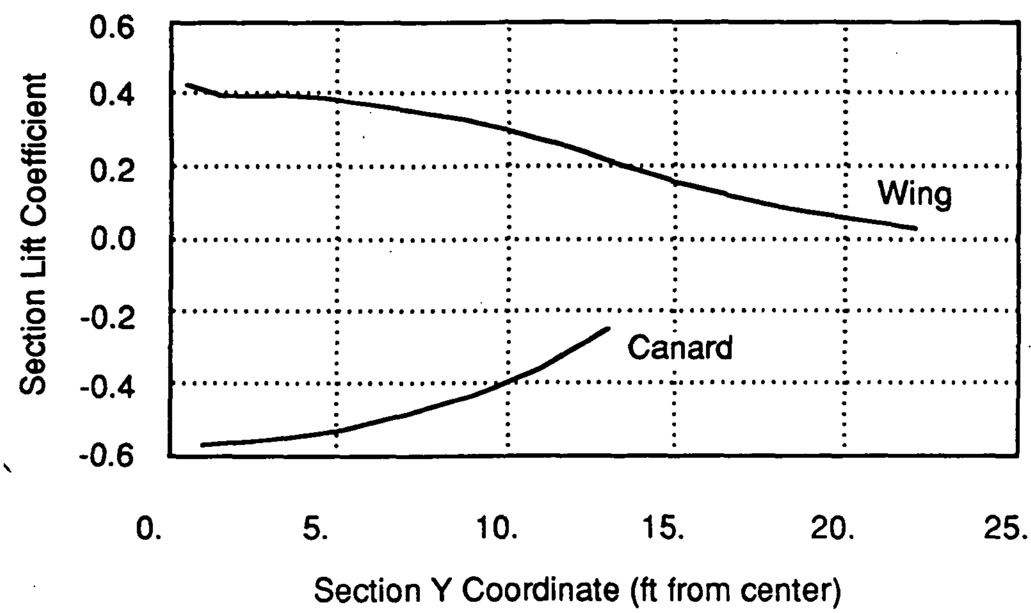


Figure 9.4 Lift Distribution at $\alpha = 0.8°$ and Canard Deflection = 12°

Component	Wetted Area
Wing	2384.3 ft^2
Fuselage	1201.2 ft^2
Canard	202.2 ft^2
Vertical Tail	145.6 ft^2
Bombs	20.5 ft^2
Fuel Tanks	45.3 ft^2

Table 9.1 Component Wetted Areas

The wing drag coefficient due to lift is found from the following equation:

$$C_{D_{L_H}} = (C_L{}^2/\pi eAR)(S_H/S)$$

where: $e = (1.1C_{L_{\alpha H}}/\pi AR) = 0.56$ for wing

This method is used for both canards and wings. The fuselage drag coefficient due to lift is found from

$$C_{D_{Lfus}} = \eta\alpha^3 c_{dc}(S_{plffus}/S)$$

where: $\alpha = [(W/qs)-C_{L_0}]/C_{L_\alpha}$

η = data taken from Roskam[13]

c_{dc} = data taken from Roskam[13]

S_{plffus} = fuselage planform area

For the horizontal lifting surfaces, the zero-lift drag coefficient was found from:

$$C_{D0_H} = (R_{HF})(R_{LS})(C_{f_H})[1+L'(t/c)+100(t/c)^4](S_{wet_H}/S)$$

where: L' = airfoil thickness location parameter = 1.2

t/c = thickness ratio

R_{HF}, R_{LS}, and C_{f_H} were all found in Roskam[13] graphs using sweep angles and Reynolds numbers.

The fuselage and stores zero-lift drag coefficients were found from

$$C_{D0fus} = R_{wf}C_{ffus}[1+60(l_f/d_f)^3+0.0025(l_f/d_f)](S_{wetfus}/S)$$

where: l_f/d_f = body fineness ratio

Again, R_{wf} and $C_{f_{fus}}$ were found in Roskam[13] graphs using Reynolds numbers.

The drag caused by the deployment of the Raptor's flaps was determined by calculating drag increments. The drag increments for the flaps was broken into three components, profile, induced, and interference drag. Equations for these three components are given below.

$$\Delta C_{D_{profflap}} = \Delta C_{D_{prof_{\Lambda c/4}}} \cos\Lambda_{c/4}$$

$$\Delta C_{D_{indflap}} = K^2 \Delta C_{L_{flap}}{}^2 \cos\Lambda_{c/4}$$

$$\Delta C_{D_{intflap}} = K_{int} \Delta C_{D_{profflap}}$$

where: $\Delta C_{D_{prof_{\Lambda c/4}}}$, K, and K_{int} are constants found in reference 13

Landing gear drag increments were calculated from the equation shown below.

$$\Delta C_{D_{gear}} = \Sigma(C_{D_{gear_{C_L=0}}} + kC_{D_{gear_{C_L=0}}} C_L)(S_{gear}/S)$$

where: k is a constant from reference 13

Using graphs found in Roskam[13] and the methods described there, a plot of wave drag versus drag-divergence Mach number was created, and is shown in Figure 9.5. From this graph the wave drag coefficient can be found for the outboard and inboard portions of the wing for high Mach numbers. They can then be totalled according to the following:

$$C_{D_{wave}} = C_{D_{wave_{in}}}(S_{in}/S) + C_{D_{wave_{out}}}(S_{out}/S)$$

The separate drag coefficients can then be summed to obtain the total drag and construct drag polars for the different flight conditions. These drag polars are presented in Figures 9.6-9.13.

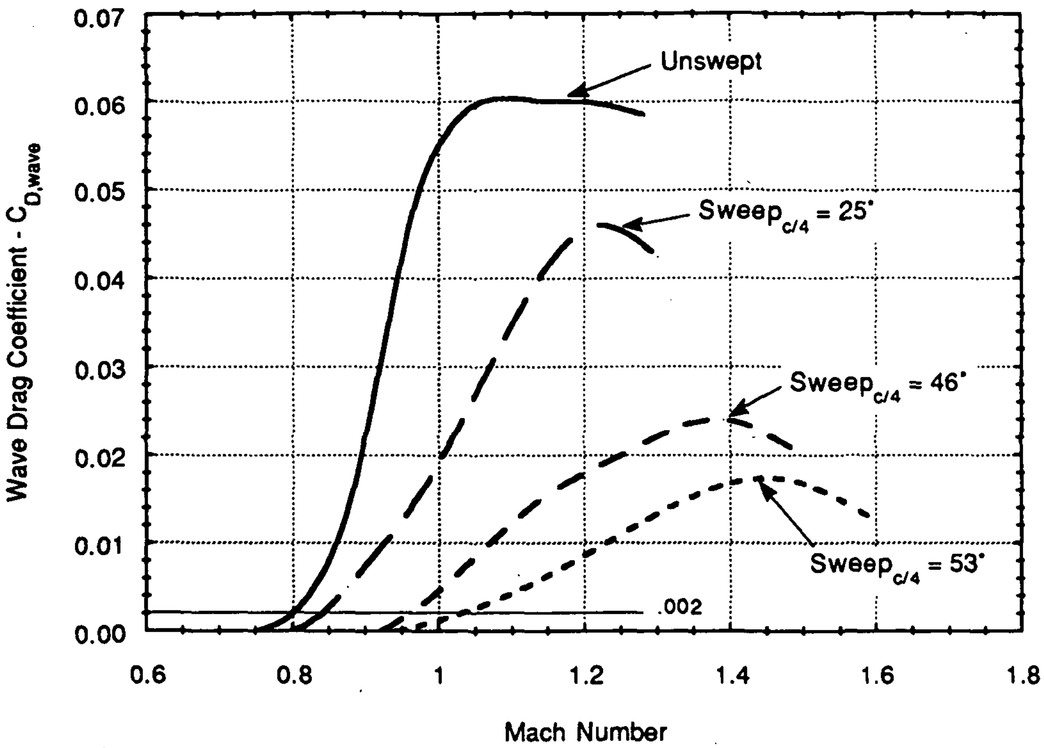


Figure 9.5 Wave Drag and Drag Divergence Mach Number Estimation

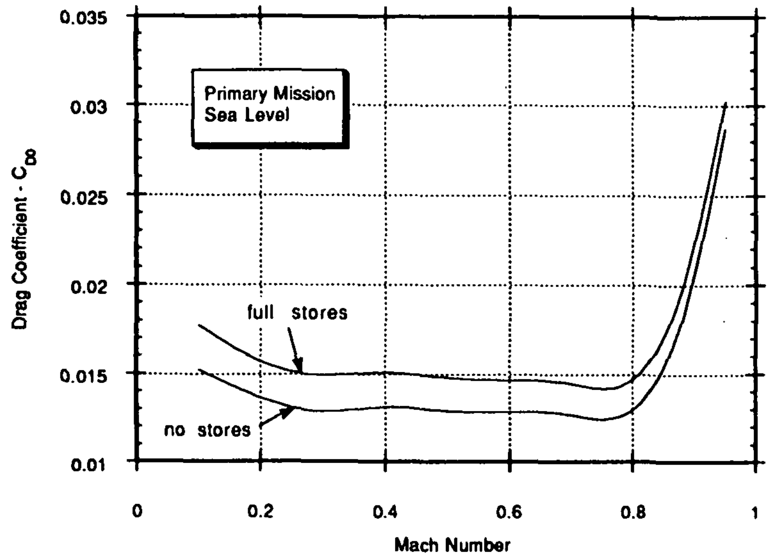


Figure 9.6 C_{D0} vs. Mach Number

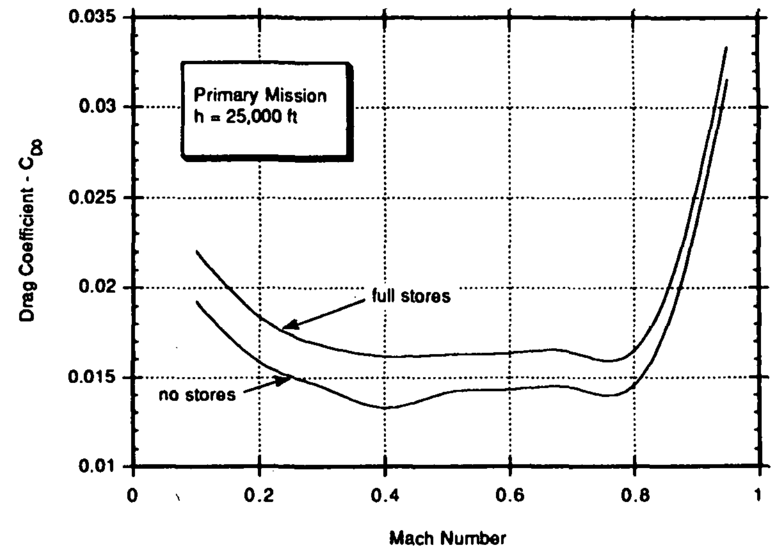


Figure 9.7 C_{D0} vs. Mach Number

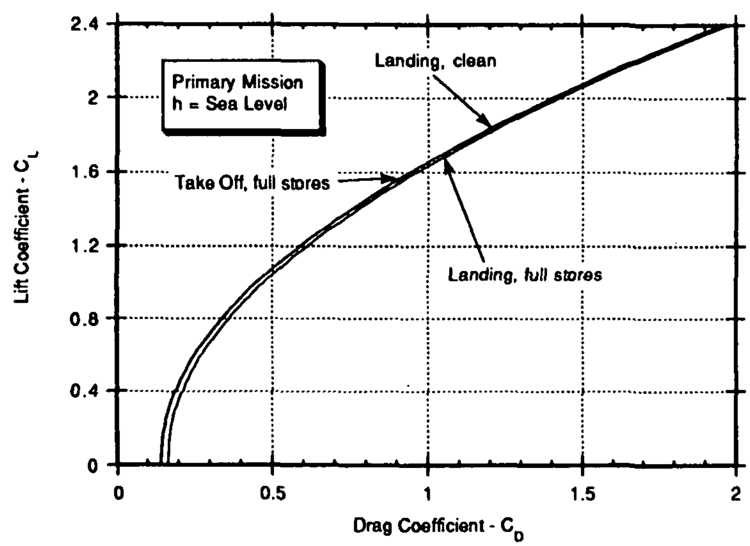


Figure 9.8 C_L vs. C_D for Primary Mission

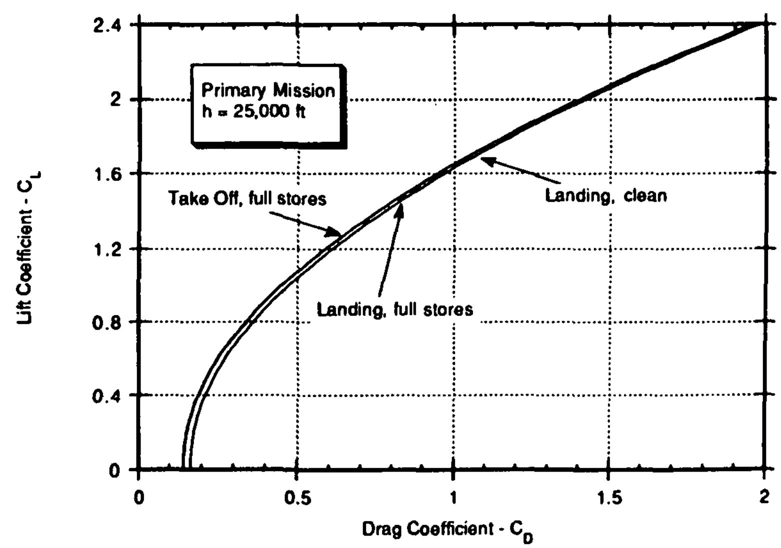


Figure 9.9 C_L vs. C_D

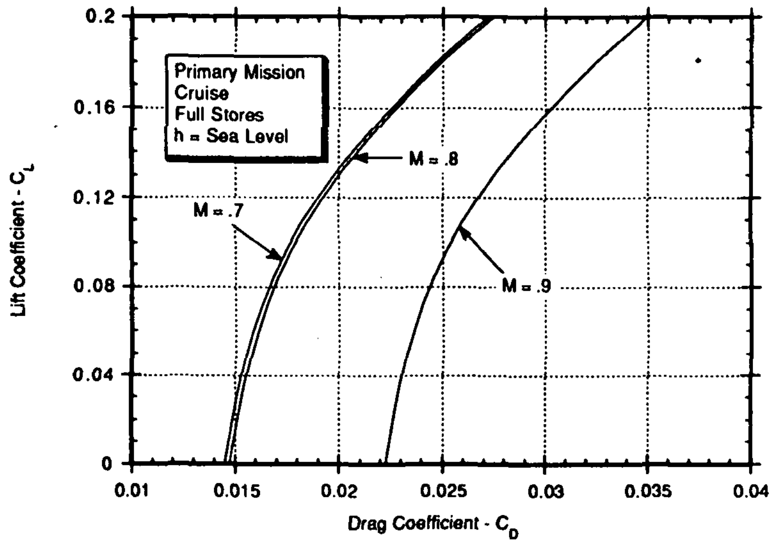


Figure 9.10 C_L vs. C_D

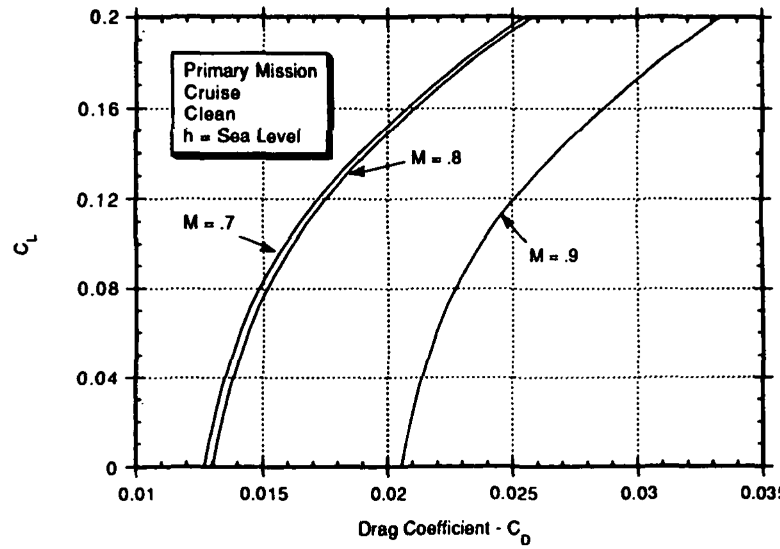


Figure 9.11 C_L vs. C_D

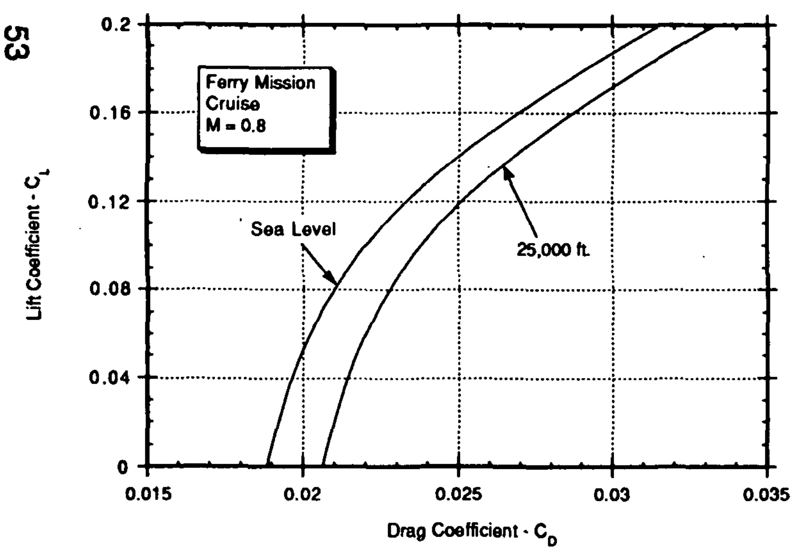


Figure 9.12 C_L vs. C_D

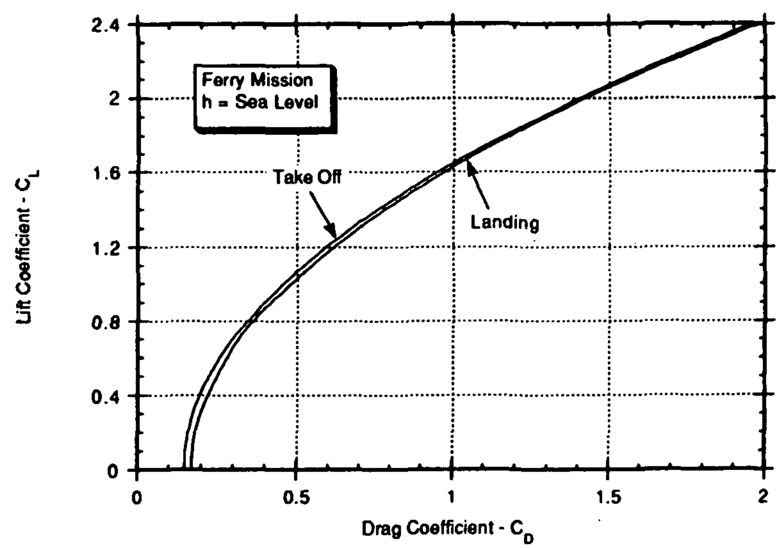


Figure 9.13 C_L vs. C_D

10. Stability and Control/Handling Qualities

The stability derivatives were calculated for the flight conditions listed in Table 10.1. The methods used are described in reference 13 and 22. Table 10.2 shows the final stability derivative results, the calculations for which can be found in the appendix. The handling qualities are then presented in Table 10.3.

Flight Condition	Take-Off	Landing	Cruise	Combat
Mach Number	0.25	0.25	0.755	0.80
Altitude (ft.)	Sea Level	Sea Level	Sea Level	Sea Level
Center of Gravity (X_{bar})	0.339	0.388	0.351	0.376
Weight (lbs)	46759	28240	44128	37457

Table 10.1 Flight Conditions for Stability Analysis

	TAKEOFF	LANDING	SL CRUISE	COMBAT PASS
C_{D1}	0.479	0.249	0.018	0.017
C_{L1}	1.009	0.610	0.104	0.079
C_{m1}	0.000	0.000	0.000	0.000
C_{Tx1}	0.479	0.249	0.018	0.017
C_{mT1}	0.000	0.000	0.000	0.000
C_{Du}	0.000	0.000	0.000	0.000
C_{mu}	0.000	0.000	0.000	0.000
C_{Lu}	0.032	0.019	0.048	0.044
C_{Txu}	-0.931	-0.472	-0.027	-0.032
C_{mTu}	-0.086	-0.044	-0.002	-0.003
$C_{D\alpha}$	1.159	0.700	0.165	0.132
$C_{m\alpha}$	-0.177	-0.177	-0.244	-0.258
$C_{L\alpha}$	3.695	3.695	5.089	5.372
$C_{D\alpha}$*	0.000	0.000	0.000	0.000
$C_{L\alpha}$*	0.792	0.815	1.294	1.428
$C_{m\alpha}$*	-0.809	-0.792	-1.306	-1.406
$C_{y\beta}$	-0.3105	-0.3105	-0.3105	-0.3105
$C_{l\beta}$	-0.347	-0.210	-0.036	-0.028
$C_{n\beta}$	0.124	0.124	0.1235	0.1234
$C_{y\beta}$*	-0.00029	-0.00029	-0.00029	-0.00029
$C_{l\beta}$*	-0.00005	-0.00005	-0.00005	-0.00005
$C_{n\beta}$*	-0.00005	-0.00005	-0.00005	-0.00005
C_{yp}	-0.0101	-0.0101	-0.0101	-0.0101
C_{lp}	0.2676	0.1581	0.0280	0.0192
C_{np}	-0.5377	-0.3132	-0.0868	-0.0585
C_{Dq}	0.0000	0.0000	0.0000	0.0000
C_{Lq}	-3.04864	-3.13247	-5.02879	-5.55607
C_{mq}	-7.220	-7.928	-11.492	-12.927
C_{yr}	0.029	0.029	0.029	0.029
C_{nr}	-0.006	-0.013	-0.017	-0.017
C_{lr}	0.189	0.189	0.190	0.190
C_{Lic}	0.288	0.288	0.490	0.537
C_{mic}	0.325	0.325	0.528	0.574
C_{Dic}	0.06012	0.06012	0.15833	0.18746
$C_{y\delta r}$	0.02650	0.02650	0.02637	0.02636
$C_{l\delta r}$	0.00383	0.00383	0.00381	0.00381
$C_{n\delta r}$	-0.01078	-0.01078	-0.01072	-0.01072

Table 10.2 Steady State Derivatives

The stability derivatives all fall within a reasonable range when compared to aircraft of the same category and class. The Raptor is designated as Class IV and Category A. For the longitudinal flying qualities, the phugoid mode and short-period mode are at Level 1. The dutch roll qualitie, however, is designated as Level 2. These classifications are not unexpected due to the low stable static margin of the Raptor providing the high level for longitudinal handling. The Raptor's unconventional design could also account for the Level 2 status for dutch roll.

Longitudinal Derivatives				
X_u	-0.1093	-0.0942	-0.0129	-0.0156
X_{Tu}	0.00306	0.00507	0.00316	0.00103
X_α	-4.7745	-4.7742	-18.7138	-21.5360
Z_u	-0.23409	-0.2340	-0.0936	-0.0920
Z_α	-132.963	-208.029	-1572.368	-2194.499
$Z_{\alpha dot}$	-0.72972	-1.24340	-3.81696	-5.25952
Z_q	2.810	4.780	14.832	20.456
M_u	0	0	0	0
M_{Tu}	-0.00133	-0.000677	-0.000116	-0.000147
M_α	-0.7656	-0.7656	-9.6189	-11.3985
$M_{\alpha dot}$	-0.1009	-0.0988	-0.4925	-0.5619
M_q	-0.9018	-0.9902	-4.3349	-5.1668
Lateral Directional Derivatives				
Y_β	-9.8919	-16.3776	-95.5976	-126.440
Y_p	-0.02604	-0.04311	-0.08333	-0.1040
Y_r	0.07331	0.1213	0.2346	0.2928
$Y_{\partial R}$	0.8442	1.3978	8.1191	10.7351
L_β	-17.3403	-10.4726	-16.5671	-14.1474
L_p	1.0780	0.6370	0.3405	0.2471
L_r	0.7609	0.7609	2.3084	2.4472
$L_{\partial R}$	0.1912	0.1912	1.7362	1.9485
N_β	1.2452	1.2452	11.3314	12.7203
N_p	-0.4362	-0.2541	-0.2127	-0.1517
N_r	-0.00519	-0.0104	-0.0407	-0.0433
$N_{\partial R}$	-0.1084	-0.1084	-0.9843	-1.1047
Short Period Mode				
$\omega_{n,sp}$	1.0932	1.2262	4.2077	4.9085
ζ_{sp}	0.6765	0.7480	0.7952	0.8338

Dutch Roll Flying Qualities				
λ_{dr}	.057±1.11i	.072±1.11i	.189±3.36i	.211±3.56i
$\omega_{n,dr}$	1.1158	1.1159	3.36641	3.5668
ζ_{dr}	0.0182	0.03091	0.02290	0.02592
Phugoid Mode				
ω_{fug}	1.115984	1.1159	3.3662	3.5665
ζ_{fug}	0.04	0.04	0.04	0.04

Table 10.3 Handling Qualities

The Raptor's canard configuration provides a long moment arm between the longitudinal control surface and the center of gravity. The canard was sized to yield a low positive static margin of between +2.6 and +7.2%. These static margins still allow for ample maneuverability, although a sophisticated flight system is still necessary.

The vertical tail was sized to provide adquate lateral stability in the case of one engine failing. The rudder deflection angle for one engine-out is 9 degrees. For survivability and redundancy, the vertical tails are slightly oversized.

11. AVIONICS

The avionics selection for the Raptor was driven by three main goals: minimal cost, minimal pilot workload, and the ability to deliver a wide variety of ordnance with pinpoint accuracy at any time. This was not an easy task, since the sophisticated systems necessary to meet the second and third requirements are often quite expensive.

The decision to utilize the LANTIRN targeting and navigation systems eliminated the need for an expensive ground-attack radar, while still providing the necessary targeting functions. The LANTIRN system combines the use of terrain-following radar, forward looking infra-red (FLIR) for all-weather navigation and target acquisition, and laser target designation. Through the use of this single integrated system instead of several separate systems, the overall cost is reduced. Furthermore, LANTIRN is an existing system that has been proven in use; also, acquiring an existing system will cost less and guarantee the availability of spare parts.

Unlike the conventional LANTIRN system which is mounted in an externally mounted pod, the Raptor would employ an internally mounted variant. Some cost would be incurred in order to redesign the system for internal mounting, but some money would also be saved because the need for separate environmental control systems and external casings would be eliminated. Since the Raptor's system would be assembled from the same components as the pod mounted version, no additional manufacturing or design costs would be introduced. Furthermore, a similar system is believed to be employed by the F-117A, which demonstrates the feasibility of such a configuration, and would even further reduce any additional costs of integration.

The radar dish for LANTIRN has been placed in the Raptor's radome which allows a broader "view" than the pod mounted system; the FLIR system is placed just below the radar so that it protrudes from the radome. The laser designator has been mounted on the under surface of the nose on a swivel mount so that it can track targets to the rear of the aircraft; this allows the plane to overfly or turn away from the target while still maintaining a lock for the inbound weaponry.

The Raptor also employs a Pave Penny sensor which allows the aircraft to launch smart weapons against targets that have been illuminated by friendly ground forces or by other aircraft.

Avionics costs were further kept to a minimum by not including an internal electronic jamming device in the Raptor. Since the Raptor has such a large ordnance carrying capability an externally mounted jammer pod could be employed when the mission called for one without subtracting from the weapons loadout. However, a chaff and flare countermeasures system was installed internally; such a system is a cheap but very effective self-defense tool. The dispenser is placed above and between the engines and has a carrying capacity of any combination of ninety chaff, flare, and/or jammer cartridges. Threat warning is accomplished by three radar warning receivers placed on the leading edge of each wing and on the trailing edge of the left vertical tail. Additionally an infrared warning system is employed because of the large threat presented by both surface-to-air and air-to-air infrared missiles.

An inertial navigation system was chosen over a TACAN system because of the latter's susceptibility to jamming. Also the high accuracy of the inertial navigation system is necessary for the Raptor's navigation through hostile airspace.

The systems mentioned above and other standard avionic systems are listed in Table 11.1. Specific brand names have not been chosen for most systems because of the rapidly changing nature of electronics; since improvements and innovations are almost certain to be made in the next several years, it would be unwise to limit the aircraft by selecting specific systems at this early stage. Specific types are mentioned only when that system has a certain feature that was considered important to the Raptor's design.

A proposed cockpit instrumentation layout is shown in Figure 11.1, but as indicated above this layout is for illustrative purposes only; the details are expected to change to best fit the concept layed forth here. The main consideration for the design of the cockpit is ease of use in order to reduce the pilot's workload. The three large multi-function displays dominate the panel and are the primary interface device within the cockpit; their large size and placement near the top of the panel enables the data presented to be understood at a glance so the pilot's scan can remain outside of the cockpit. The displays are able to present computer-generated maps, flight attitude information, weapon management data, and target acquisition data from LANTIRN and other smart weapons, and a variety of other useful information.

The up-front control panel, located just below the wide-angle HUD, allows the pilot to enter data into the system; it also displays the radio frequencies for the Collins AN/ARC-210 interoperable ECCM (electronic counter-countermeasures) communications system. This system incorporates VHF-FM, VHF-AM, and UHF radios into one system; the pilot simply inputs the frequency that he wants and the system automatically chooses the appropriate radio band. The system also features its own anti-jamming modes as well as being easily reconfigurable for advances in ECCM wave forms.

Figure 11.2 shows the layout of the main avionics systems.

Main Systems	
LANTIRN	Chaff and Flare Dispenser
Pave Penny	Infrared Warning Receiver
HUD	Autopilot
Radar Warning Receivers	IFF Transponder
Miscellaneous Systems	
Environmental Control System	Collins AN/ARC-210 Radio System
Electrical System	Hydraulic System
Boeing CREST Ejection System	Fire Control System

Table 11.1 Aircraft Systems

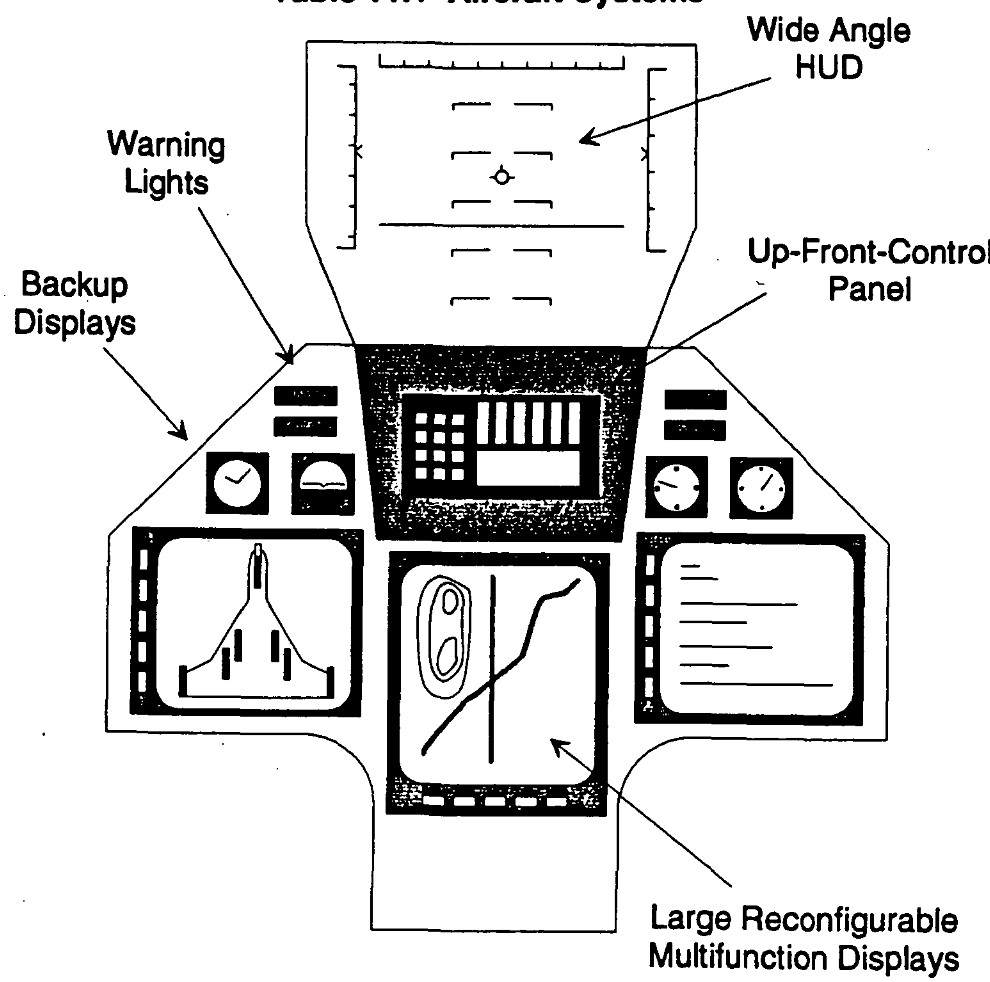


Figure 11.1 Cockpit Instrumentation

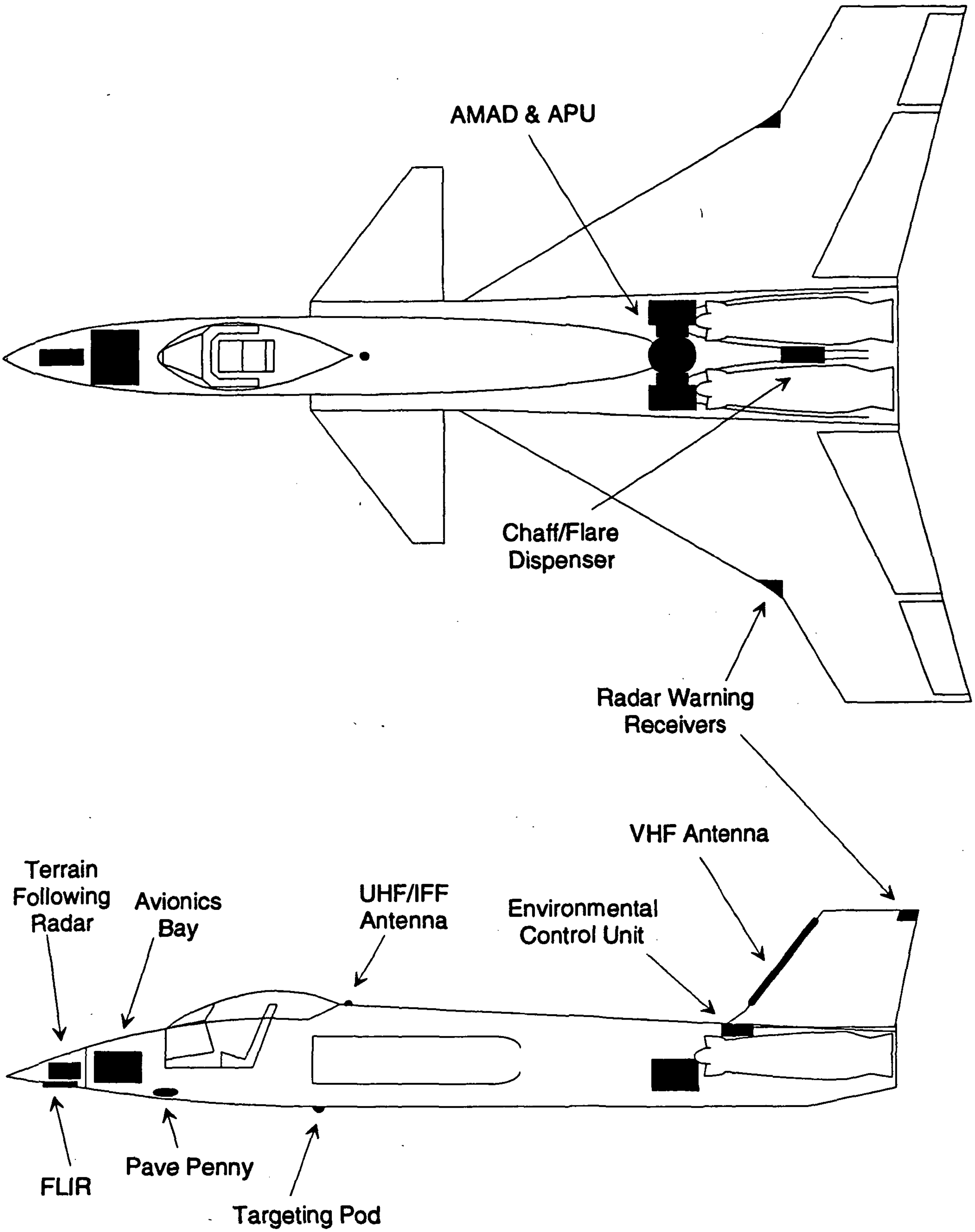


Figure 11.2 Avionics Layout

12. SYSTEMS LAYOUT

A schematic of the Raptor's major systems is shown in Figure 12.1 and the hydraulic, electrical, and ejection systems are discussed in detail below. Wherever possible lines are run along each side of the plane and then cross-linked so that loss of one line will not incapacitate the system. If battle damage causes the destruction of one line, control inputs would be rerouted through a different node.

12.1 Hydraulic System

The Raptor incorporates a non-traditional hydraulic system. Instead of using a single hydraulic reservoir connected to all of the separate actuators and pumps by hydraulic lines, the Raptor employs an electrohydrostatic system. An electrohydrostatic actuator which contains its own fluid reservoir, pump, and manifold is placed at each aircraft station that requires hydraulic actuation. Control inputs are sent to the actuators by electronic signalling instead of hydraulic pressure; this is beneficial in that it easier to run electrical wire than hydraulic piping through the plane. While a single hit to the hydraulic reservoir on a traditional system would put the entire hydraulic system out of commission, the same hit to the Raptor's system would only damage one part of the system and leave the remainder unaffected.

12.2 Electrical System

The Raptor uses the Airframe Mounted Auxiliary Drive system to provide power to all electrical systems (including the power for the electrohydrostatic actuators). Backup power is provided by a ram-air turbine and batteries for critical systems.

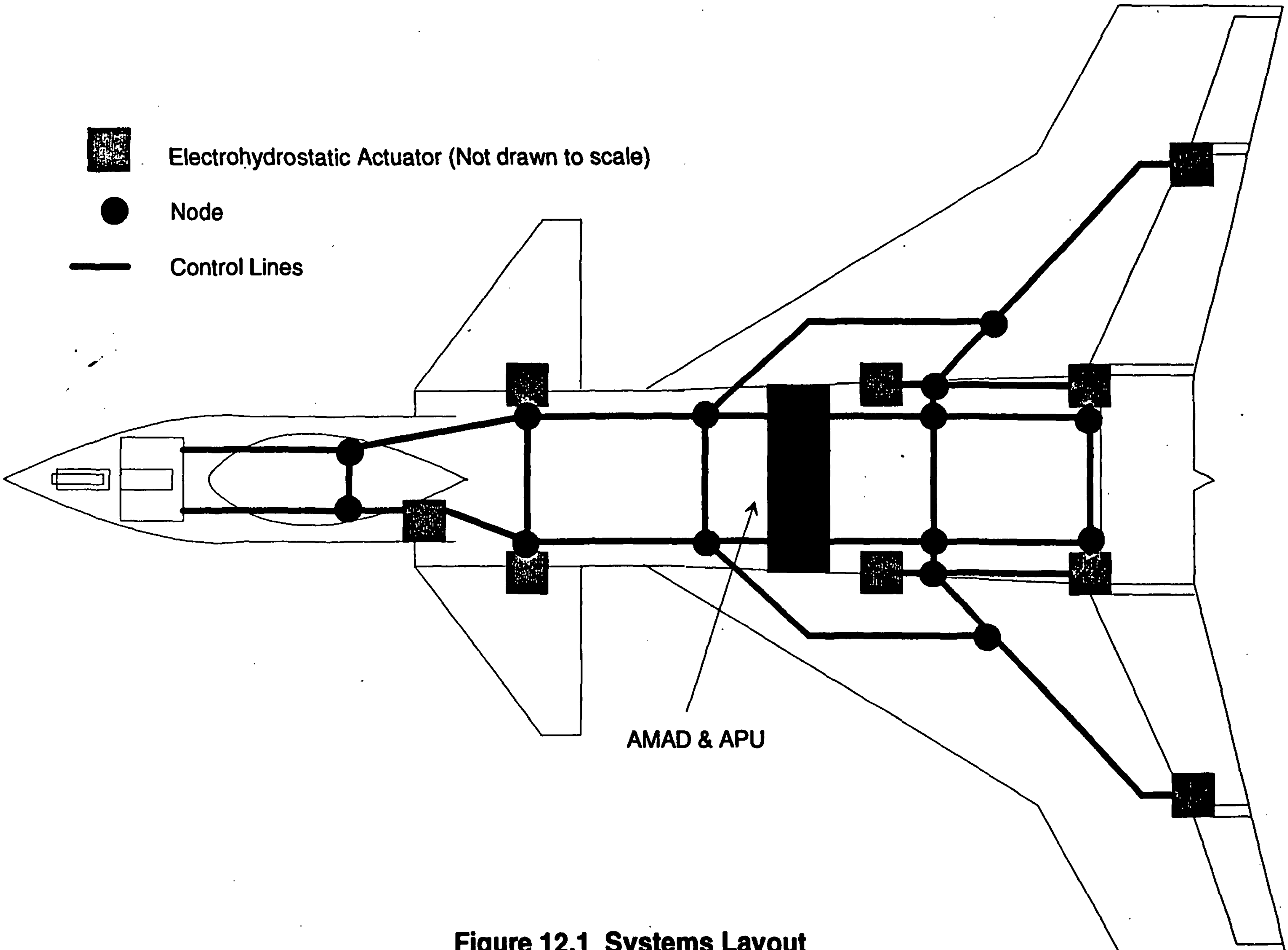


Figure 12.1 Systems Layout

13. WEAPONS INTEGRATION

The primary and secondary design missions for the Raptor require twenty Mk 82 free-fall bombs, 2 AIM-9L Sidewinder missiles, and the GAU-8/A Avenger cannon with 1,350 rounds of ammunition. This combination of weapons gives a wide range of combat capability, combining general air-to-ground, excellent anti-armor, and anti-air defense.

The Avenger cannon is housed internally below the cockpit with the ammo drum placed behind it. The entire system is easily accessible through the bottom of the fuselage as can be seen in Figure 13.1. The cannon is placed slightly off of center to allow room for the nose gear, but the firing barrel is aligned on the centerplane of the aircraft and inclined at a -6° angle so that the recoil force acts through the Raptor's center of gravity thus causing no pitching moments. Vibrational dampers are utilized in key areas where sensitive electronics would be affected by the firing of the cannon.

Wingtip launch rails carry the Sidewinder missiles, providing them with a good field of view for acquiring targets as well as ease of mounting.

The majority of the Raptor's ordnance carrying capacity is provided by seven hardpoints, three located on each wing and one on the fuselage centerline. Due to the Raptor's large planform two of the hardpoints on each wing can accommodate multiple ejector racks instead of triple ejector racks which doubles the bomb carrying capacity of that station.

The Raptor has been designed to be capable of carrying a large variety of air-to-ground weaponry. The combination of the Raptor's LANTIRN targeting system and large carrying capacity make it a very lethal and versatile delivery system. A few of the possible mission loadouts for the Raptor are shown in Figure 13.2.

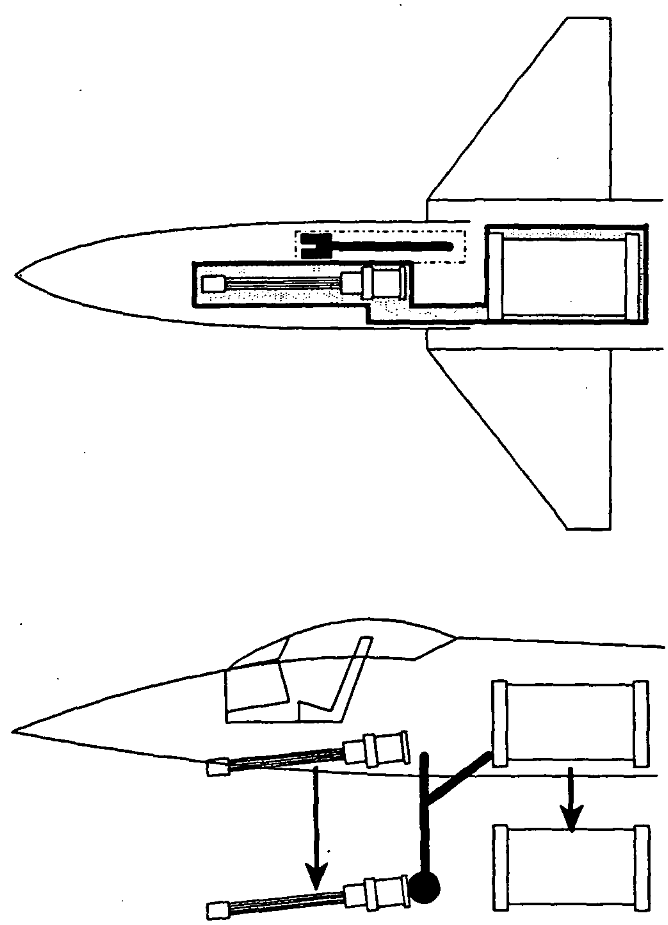


Figure 13.1 Avenger Cannon Access

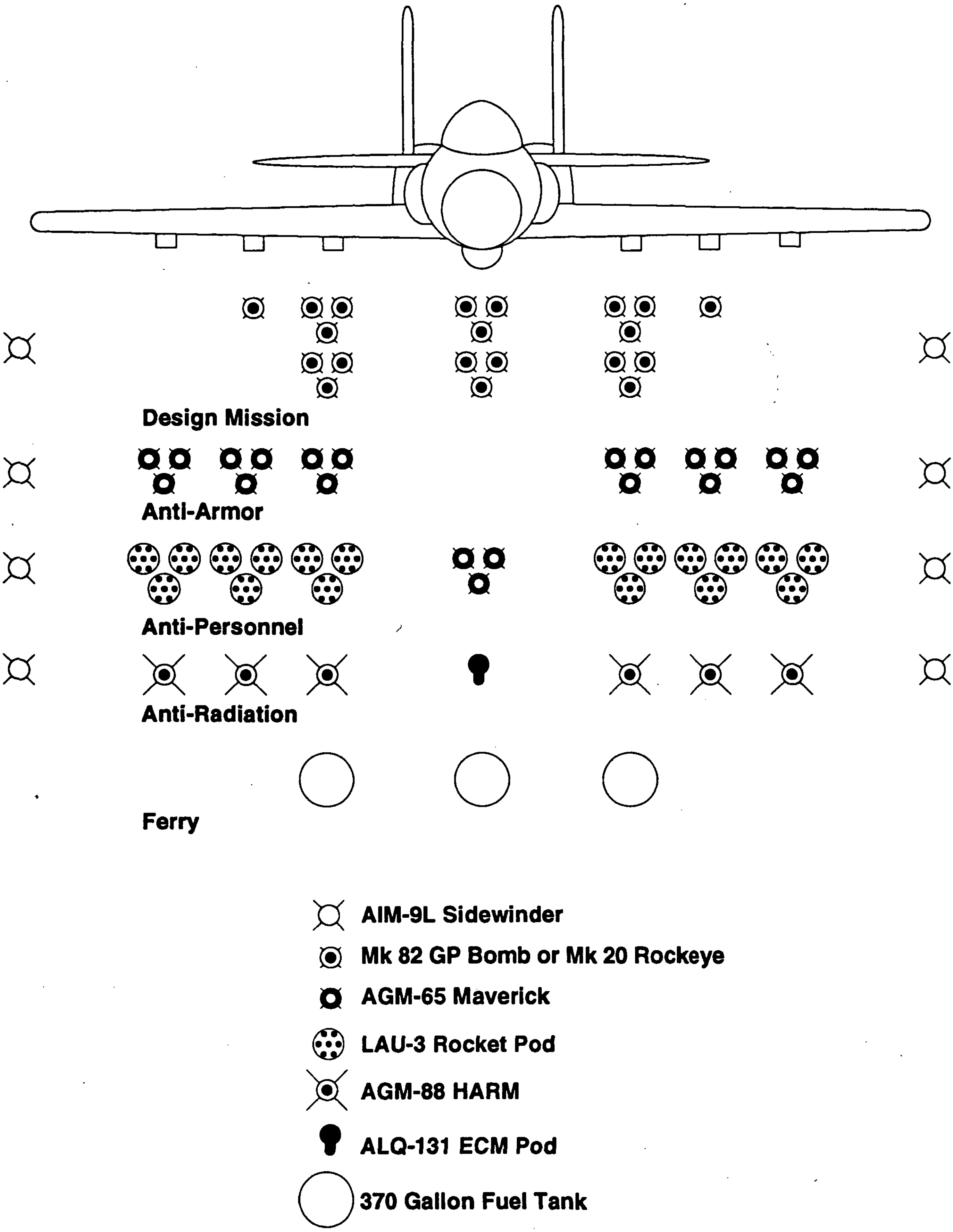


Figure 13.2 Weapons Loadout

14. GROUND SUPPORT REQUIREMENTS

The Raptor requires minimal ground support. Ground support requirements are greatly reduced due to the internal installation of an APU as well as the AMAD system. No external equipment besides the pilot is required to start the engines. The APU is started from the cockpit by battery power, and then supplies high-pressure air to the turbine starter to start the engine. Once one engine has been started, a power-shaft drives the AMAD, and thereby the pumps and generator, so that cross-bleed air can be used to start the second engine.[14] Another valuable function of the AMAD system is that by disengaging the accessory drive from the engines, all of the aircraft systems can be run independently of the engines; this enables a full ground checkout to be made of all systems that require electric power, hydraulic power, or fuel pressure from the Raptor's own resources. Additionally, the Raptor's low wing facilitates weapon mounting, further reducing down-time.

15. Cost Analysis

The overall cost of the Raptor was estimated by dividing the cost of the aircraft into acquisition and operating costs.[15] The acquisition cost includes both research, development, test, and evaluation (RDTE) costs and manufacturing costs, while the operating cost includes fuel costs, crew salaries, and basic maintenance costs. These costs were estimated in 1991 dollars for a production run of 500 aircraft, with an average of ten aircraft built per month. The acquisition cost of the Raptor is $12.6 million, making it extremely competitive in both domestic and foreign markets.

The cost estimation method employed was based largely on statistical data, with a number of variables which were judgement factors based on characteristics of the airplane. These values were chosen from a range of values in an attempt to accurately reflect the anticipated difficulties in design and manufacture. The following is an explanation of some of the more important variables and justifications for the values chosen.

One of the major factors involved in the acquisition cost is the difficulty factor, F_d, which is a reflection of the level of advanced technology utilized in the aircraft. This value ranged from 1.0 to 2.0, with 1.0 being typical of a conventional, non-sophisticated aircraft, and 2.0 represented by such aggressive users of advanced technology as the X-29 and the National AeroSpace Plane. A value of 1.3 was chosen for the Raptor, as only a simple flight control system is required, while the engines are currently in the research and development phase.

Another major factor in acquisition cost is the materials factor, F_{mat}, which reflects the degree of difficulty associated with the use of advanced materials. This value ranges from 1.0 to 3.0; the lower number applies to airframes made primarily of conventional aluminum alloys, 1.5 applies to stainless steel airframes, and higher values correspond to airframes made of composites. A value of 1.3 was chosen for the Raptor, since the vast majority of the airframe is constructed from standard aluminum alloys, with only a very small percentage of the overall airframe employing composites.

One value in particular required extensive deliberation, namely the maximum speed of the aircraft. Since aircraft are subjected to greater stresses at higher speeds, the cost goes up as speed increases. While the design mission calls for an aircraft capable of reaching a speed of 500 knots, the Raptor was envisioned as achieving even greater speeds, due to the design philosophy described in the Introduction. It seemed unreasonable to use 500 knots for the cost analysis when it would be a waste of the Raptor's capabilities never to exceed that speed, and would in fact downgrade its performance. Therefore, a compromise value of 660 knots (approximately Mach 1.0) was used instead. This seemed a reasonable assumption for the Raptor's maximum speed, although detailed analysis of transonic performance would have to be carried out in order to determine the exact value; however, the mission specifications made no requirements for supersonic performance, and nowhere was it assumed that the Raptor would achieve these speeds.

The profit margin chosen was ten percent, while a finance rate of fifteen percent was chosen. These percentages represent average values that might be expected during production. Obviously, changes in these values cannot be controlled, and could affect overall cost tremendously.

The operating cost includes a wide variety of expenses, including fuel, oil and lubricants, direct and indirect personnel, consumable materials, spares, etc. These values were all suggested in reference 15, and are therefore open to question. No other data was available, however, so these values were used.

A breakdown of the RDTE and production costs used to determine acquisition cost are shown below in Table 15.1, while operating costs are presented in Table 15.2.

RDTE Cost	1991 Dollars (in millions)
Airframe Engineering and Design	103.78
Development, Support, and Testing	39.96
Flight Test (based on 2 flight test aircraft)	271.65
Flight Test Operations	9.18
Profit and Finance	141.53
Total RDTE	566.10
Manufacturing Cost	
Airframe Engineering and Design	129.88
Avionics and Engine Production	2095.90
Manufacturing	962.53
Materials	666.35
Tooling	205.65
Quality Control	125.13
Production Flight Operations	269.79
Profit and Finance	1304.52
Total Manufacturing	5218.07
Total Acquisition	5739.87
Unit Cost	12.61

Table 15.1 Raptor Acquisition Cost Breakdown

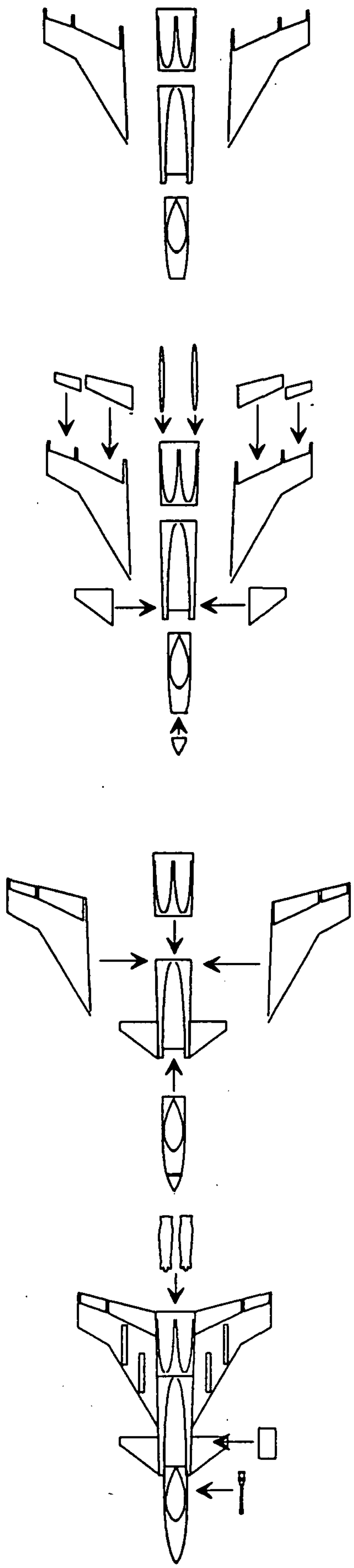
Operating Cost	1991 Dollars (in millions)
Fuel, Oil, and Lubricants	2559.41
Direct Personnel	4213.82
Indirect Personnel	3513.66
Consumable Materials	429.78
Spares	2810.93
Depot	2810.93
Miscellaneous	1229.78
Total Operating Cost (20 year life cycle)	17568.31
Unit Operating Cost (20 years)	35.14
Unit Operating Cost per year	1.76

Table 15.2 Raptor Operating Cost Breakdown

16. MANUFACTURING BREAKDOWN

The Raptor was designed to be as simple to manufacture and inexpensive as possible. Due to its almost entirely aluminum structure, tooling, manufacturing, and material costs are kept to a minimum. Only a few relatively small sections of the airframe are non-aluminum, allowing them to be constructed at separate facilities more suited to their production. These components, which include the canards, tails, nose cone, and engine exhaust shield, can easily be mass produced and then integrated into the airframe at the appropriate stage on the assembly line.

For manufacturing purposes, the Raptor is divided into four main parts: the aft fuselage, the mid fuselage, the forward fuselage, and the wings. During the first stage of production, the four main sections are constructed in parallel. The next phase consists of the addition of the vertical tails, canards, cockpit, nose cone, landing gear, control surfaces, etc. to their respective sections. In the third phase, the aft and mid sections of the fuselage are mated, so that in the fourth stage the wings may be joined to the body. Next, the forward part of the fuselage is added, thus completing the airframe. Finally, any remaining systems, such as the engines and the Avenger cannon, are installed and the entire aircraft is painted. This order of assembly is illustrated in Figure 16.1.



Phase 1: Construction of wings and aft, mid, and forward fuselage

Phase 2: Addition of control surfaces and other components to main sections

Phase 3: Joining of mid and aft fuselage

Phase 4: Addition of wings and forward fuselage

Phase 5: Addition of final components

Figure 16.1 Order of Assembly

17. CONCLUSIONS

The Raptor is a low cost, high performance close air support aircraft. The ability to take off and land from short fields with heavy payloads increases the Raptor's availability, while the interchangeability of parts and simple avionics suite reduces maintenance time.

The three main strong points of the Raptor are its low cost, outstanding performance, and versatility. At $12.6 million, the Raptor offers high performance at a very low cost. The short ground rolls allow a much broader theater of operation, while the availability of excess power at nearly all flight regimes increase the pilot's chances for success. Furthermore, with the large internal fuel capacity, a wide variety of ordnance may be carried over extended ranges, at night or in bad weather.

The Raptor's low cost and weight makes alternate versions an enticing prospect. With a few simple modifications, the Raptor could be outfitted for practically any conceivable mission. Its large combat radius and short takeoff requirement make it suitable for deployment to crisis spots around the globe.

Future plans for the Raptor include: detailed stability and control analysis, incorporation of low-pressure tires for rough-field performance, integration of HIDEC (Highly Integrated Digital Engine Control) to improve engine performance, and a more detailed trade-off investigation of vectored thrust.

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