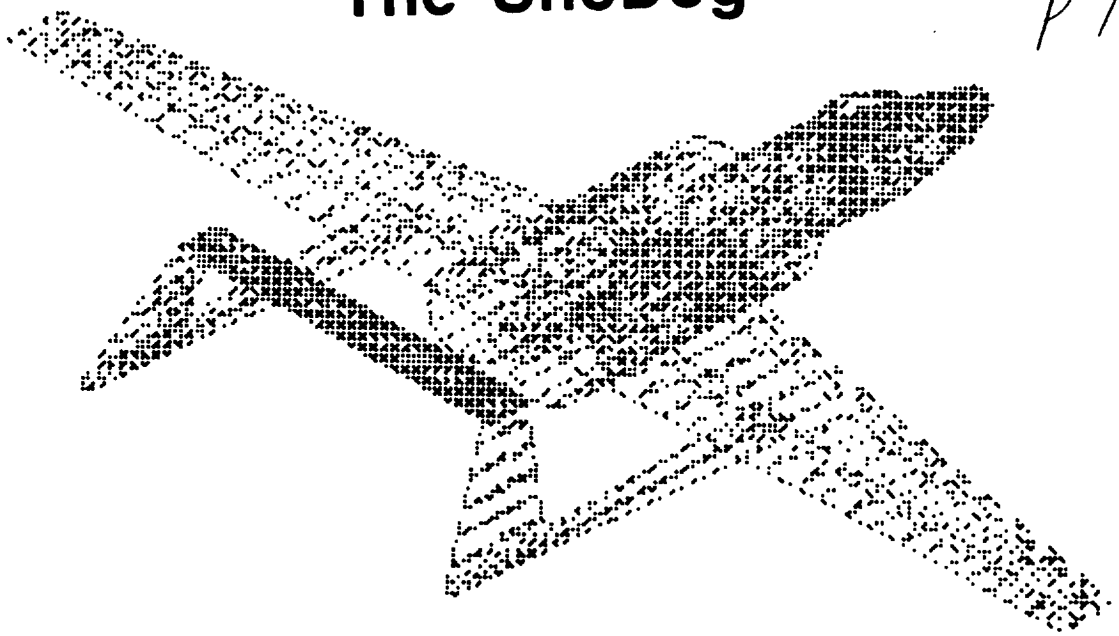
NASW4435

The SnoDog



**PRELIMINARY DESIGN OF A
CLOSE AIR SUPPORT
AIRCRAFT**

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(NASA-CR-1[illegible]) THE SNODOG: PRELIMINARY DESIGN OF A CLOSE AIR SUPPORT AIRCRAFT (California Polytechnic State Univ.) 110 p CSCL 01C
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PREFACE

By-Tor And The Snow Dog

The Tobes of Hades, Lit by flickering torchLight
The netherworld is gathered in the glare
Prince By-Tor takes the cavern to the north Light
The sign of Eth is rising in the air.
By-Tor, knight of darkness,
Centurion of evil, devil's prince.

Across the River Styx, out of the LampLight
His nemesis is waiting at the gate
The Snow Dog, ermine glowing in the damp night
Coal-black eyes shimmering with hate.
By-Tor and the Snow Dog
Square for the battle, Let the fray begin...

The battle's over the dust is clearing
Disciples of the Snow Dog sound the knell
Rejoicing echoes as the dawn is nearing
By-Tor in defeat retreats to Hell
Snow Dog is victorious
The Land of the Overworld is saved again.

Neil Peart

The SnoDog design team would like to give thanks to Faculty Advisors Dr. D. Sandlin and Dr. R. Cummings and Teaching Assistances Brent Baur and John Duino for their instruction and guidance throughtout the 1990-91 academic year. We would also like to extend special thanks to Willis Hawkins of Lockheed and Jim Alberf of NASA Ames Research Center for taking a moment from their busy schedule to read this report and critique the SnoDog design.

ABSTRACT

U.S. Military forces are currently searching for the next generation Close Air Support aircraft for the year 2000 and beyond. The following report presents the SnoDog, a low-cost ($14.8 million) aircraft capable of operating from remote battlefields and unimproved airstrips. The configuration consists of a conventional, low aspect-ratio wing, twin booms, twin canted vertical stabilizers along with a high-mounted joined horizontal tail. A supercritical airfoil for the wing enhances aerodynamic performance, while the SnoDog's instability increases maneuverability over current close air support aircraft. Survivability was incorporated into the design by the use of a titanium tub to protect the cockpit from anti-aircraft artillery, as well as, the twin booms and retracted gear disposition. The booms aid survivability by supplying separated, redundant controls, and the landing gear are slightly exposed when retracted to enable a belly landing in emergencies. Designed to fly at Mach 0.76, the SnoDog is powered by two low-bypass turbofan engines. Engine accessibility and interchangeable parts make the SnoDog highly maintainable. The SnoDog is adaptable to many different missions, as it is capable of carrying advanced avionics pods, carrying external fuel tanks or refueling in-air, and carrying various types of munitions. This makes the SnoDog a multi-role aircraft capable of air-to-air and air-to-ground combat. This combination of features make the SnoDog unique as a close air support aircraft, capable of meeting the U.S. military's future needs.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The role of the Close Air Support (CAS) aircraft is to provide assistance and protection to friendly forces in close proximity to enemy troops. The aircraft must be capable of delivering ordnance effectively and accurately as well as be able to slow or halt advancing forces (Reference 1).

In order to successfully fulfill mission requirements, the CAS aircraft must have the following characteristics: extended, around-the-clock mission capability; high sortie rates; day or night operation; and the ability to operate in all weather conditions. The high threat environment necessitates that a high level of survivability be obtained, and that the aircraft be easily maintained with little or no ground support. Finally, as in any aircraft, low cost is a primary objective.

With these objectives in mind, we would like to present the future of Close Air Support: the SnoDog (Figure 1.1). This highly maneuverable aircraft has a low aspect ratio, 20° aft swept wing incorporating a supercritical airfoil for low weight and larger fuel volume. The SnoDog has twin low-bypass turbofan engines, twin booms, two canted vertical stabilizers, a high horizontal tail, and minimal avionics. The cost per aircraft is $14.8 million.

The basic philosophy governing the design of the SnoDog was simplicity. The aircraft uses conventional, proven technology, with little use of composites or advanced avionics. This helps maintain the SnoDog's low cost. The aircraft is rugged, incorporating redundant systems and strong structural strength. Combined with its great maneuverability, this makes the SnoDog highly survivable. Finally, interchangeable parts and strategically placed accessibility panels make the aircraft easily maintainable.

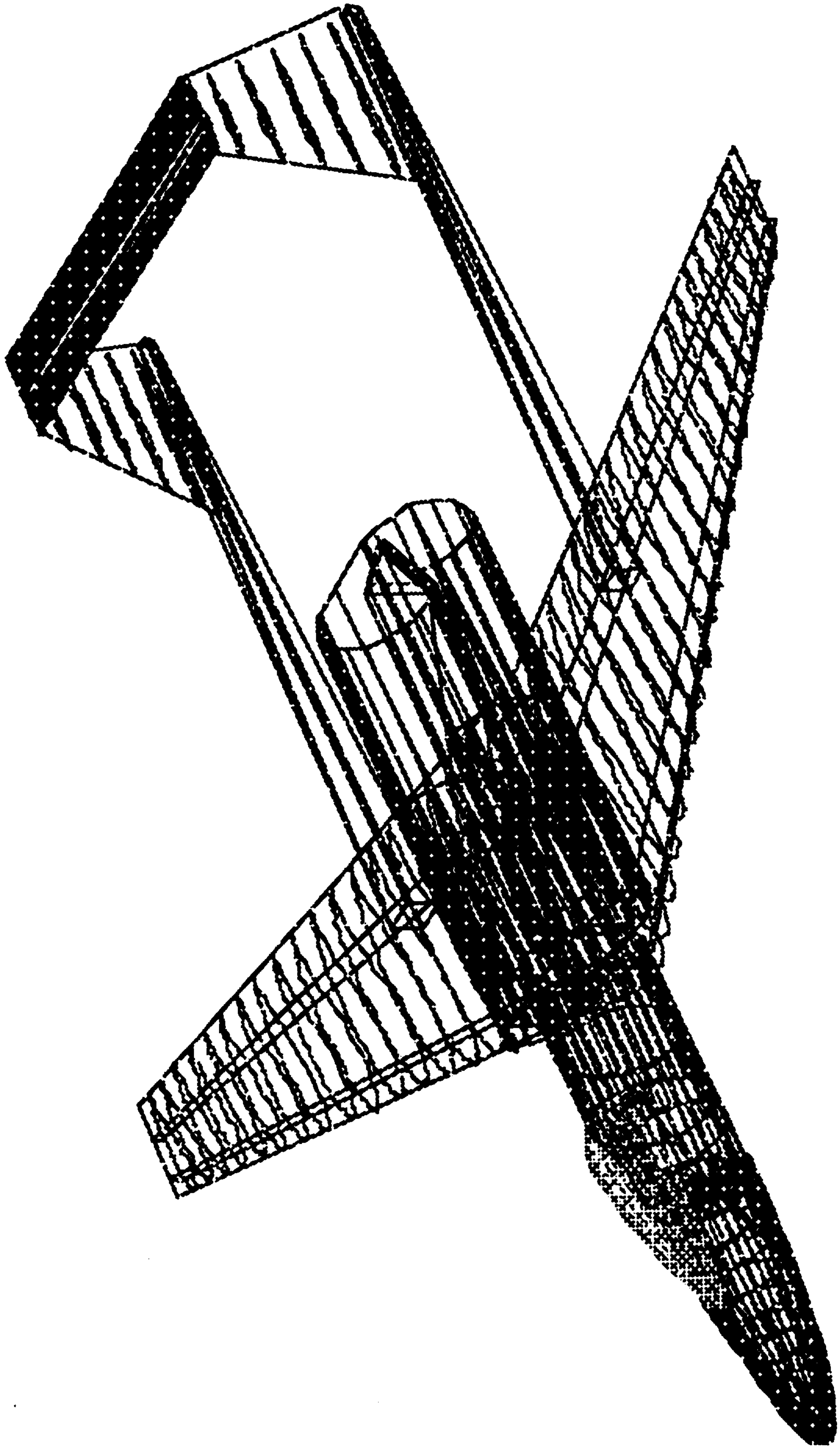


Figure 1.1 SnoDog Isometric.

2.0 MISSION DESCRIPTION

2.1 MISSION PROFILES

The SnoDog has been designed to meet requirements for the following three missions: low level mission, high-low-low-high mission, and ferry mission. The aircraft must meet Mil-Spec requirements for standard, sea level conditions (Reference 1). Figure 2.1 illustrates the Low Level Mission (Design Mission):

A. Warm-up, taxi, takeoff, and accelerate to cruise speed.
B. Dash at sea level at lower of 500 knots or maximum speed at military power to a point 250 nautical miles.
C. Combat: two combat passes at maximum speed minus 50 knots each, with a 360° sustained turn plus a 4000 foot energy increase. Drop air-to-ground weapons.
D. Dash at sea level at lower of 500 knots or maximum speed 250 nautical miles return to base.
E. Land with 20 minutes of fuel.

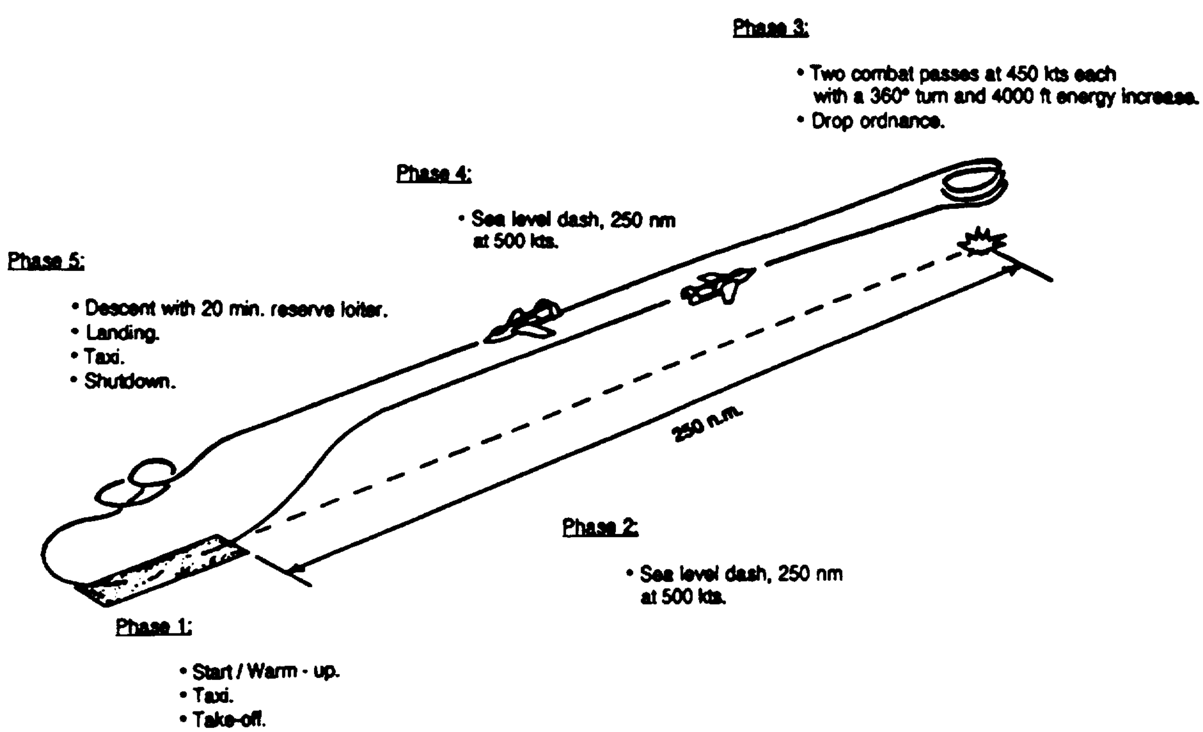


Figure 2.1 Design Mission Profile.

Figure 2.2 illustrates the High-low-low-high Mission:

A. Warm-up, taxi, takeoff and accelerate to cruise speed.
B. Climb on course at intermediate power to best cruise altitude and speed.
C. Cruise outbound at best altitude and speed to a total accumulated range of 150 nautical miles.
D. Descend to sea level; no time, distance or fuel used.
E. Loiter at sea level at best speed for maximum endurance for a time as determined by fuel and payload.
F. Dash 100 nautical miles at sea level.
G. Combat: two sea level combat passes at speed maximum speed minus 50 knots each, with a 360° sustained turn plus a 4000 foot energy increase. Drop air-to-ground weapons.
H. Dash 100 nautical miles at sea level.
I. Climb to best cruise altitude and speed.
J. Cruise at best altitude and speed for 150 n.m.
K. Land with 20 minutes reserve fuel.

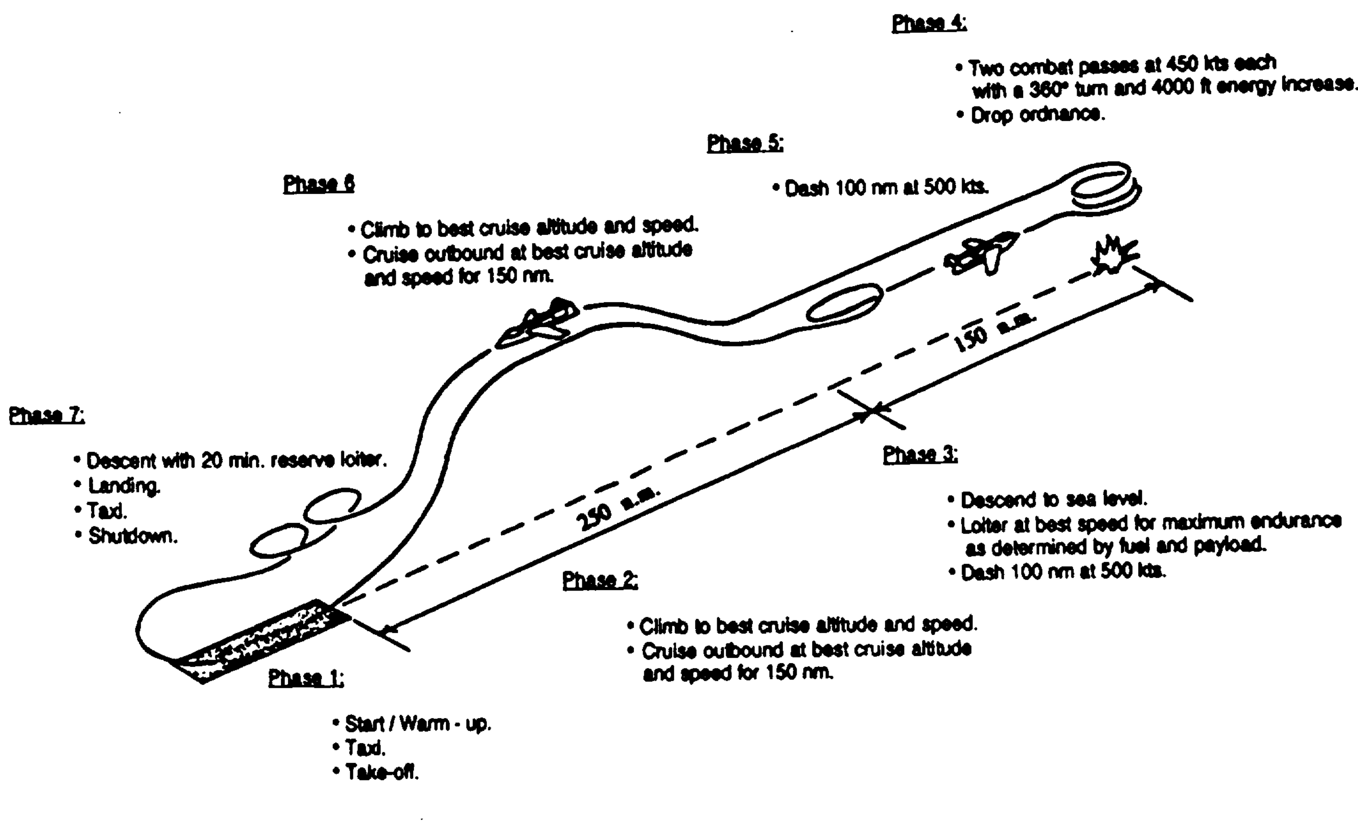


Figure 2.2 High - Low - High Mission Profile.

Figure 2.3 illustrates the Ferry Mission:

A. Warm-up, taxi, takeoff, and accelerate to cruise speed.
B. Climb on course at intermediate power to best cruise altitude and speed.
C. Cruise outbound at best altitude and speed to a total accumulated range of at least 1,500 nautical miles.
D. Descend to sea level.
E. Land with 20 minutes of reserved fuel.

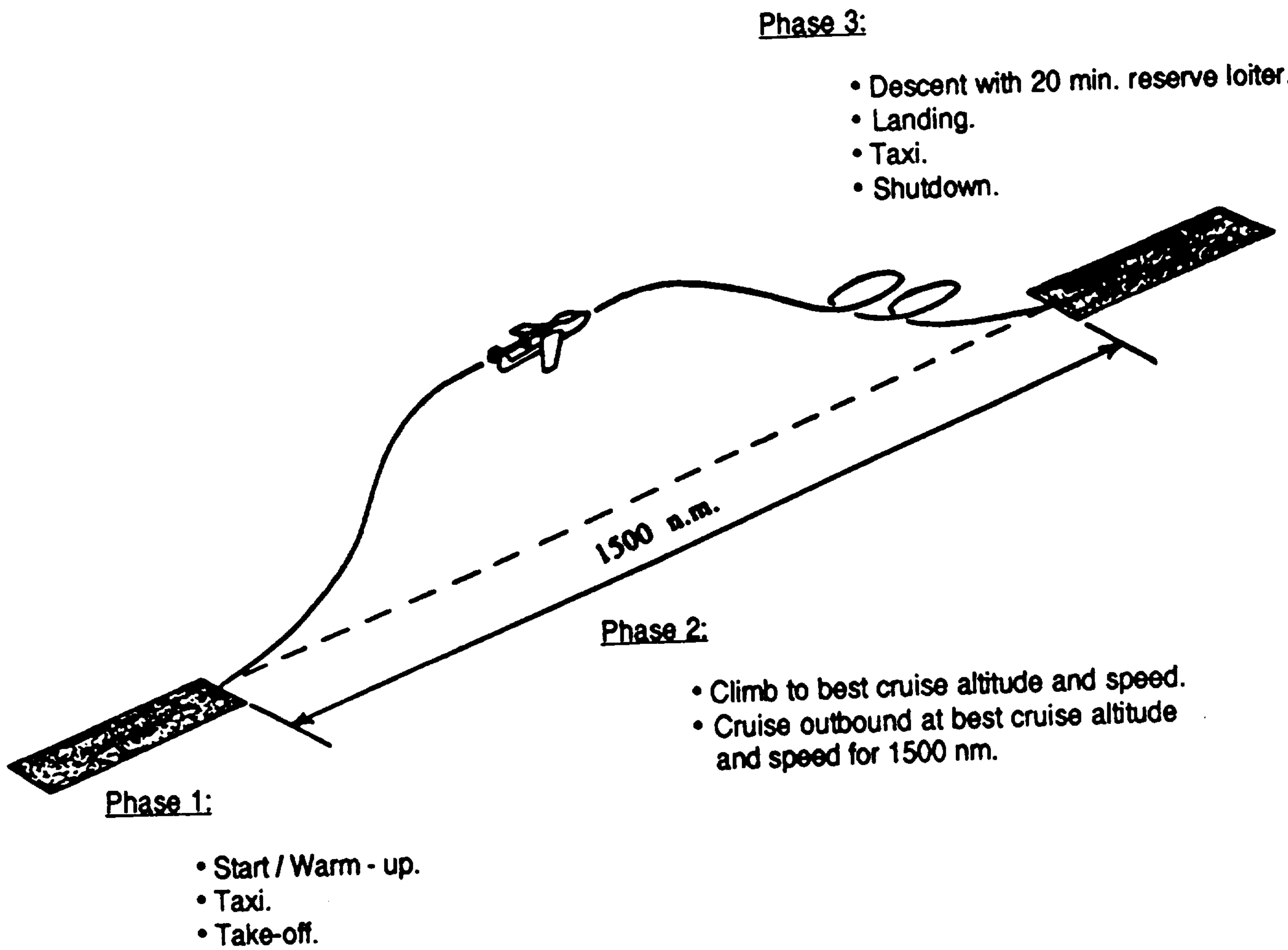


Figure 2.3 Ferry Mission Profile.

The above design missions emphasize the characteristics necessary for a successful CAS aircraft. The constantly and quickly changing status of the battlefield necessitates that the CAS aircraft have the capability to take-off from a base and arrive as soon as possible to provide effective support for friendly troops. Thus, the aircraft must be capable of extended dashes. Maneuverability and the ability to fly at low speeds at tree-top level are crucial to the effective delivery of ordnance and to the survivability of the aircraft. Finally, the aircraft must be able to structurally withstand evasive maneuvers.

2.2 PERFORMANCE REQUIREMENTS

In addition to fulfilling the mission requirements outlined above, the aircraft must meet the additional requirements listed below, with fifty percent fuel and self-defense stores:

1. Accelerate from M=0.3 to M=0.5 at sea level in less than 20 seconds
2. 4.5 sustained g's at combat speed, sea level
3. 6.0 instantaneous g's at combat speed, sea level
4. Re-attack time of less than 25 seconds
5. Take-off/landing ground roll distances of less than 2000 feet
6. Maximum and minimum normal loads of +7.5 and -3.0 g's with a safety factor of 1.5 for the aircraft with full low level mission, weapons and 60% internal fuel. Maximum dynamic pressure to be 1,000 psf.

These performance requirements are designed to provide the SnoDog with both maneuverability and survivability, resulting in an effective CAS aircraft.

2.3 PAYLOAD REQUIREMENTS

The aircraft must be capable of carrying the following armament:

1. 1 GAU-8 30mm cannon with 1,350 rounds of ammunition
2. 2 AIM-9L Sidewinder Missiles
3. 20 Mk 82 bombs

This payload corresponds with the typical payload capabilities of the Fairchild A-10, the current U.S. choice for the close air support mission. The cannon, although quite heavy, is a very effective anti-tank weapon. Alternative ordnance capabilities are discussed in Section 10.8.

3.0 CONFIGURATION SELECTION AND DESIGN RESULTS

A three-view of the SnoDog is shown in Figure 3.1. The configuration selected was based on the following design drivers:

1. Survivability
2. Maneuverability
3. Maintainability
4. Low Cost

3.1 WING SELECTION

Tables 3.1 and 3.2 show the relative merits of various wing configurations. For the SnoDog, a low, conventional wing with a supercritical airfoil was chosen. The placement of the wing was made to facilitate ordnance accessibility, to enhance maintainability, and to reduce the length of the landing gear struts. Structurally, a low wing allowed for spar carry-through to occur with minimal internal interference. In addition, the wing spars are used to help support the engines. Although visibility is not as good as with a high wing position, the SnoDog's wing is placed as far aft as possible to maximize visibility. An aspect ratio of 6 was selected as a compromise between the better aerodynamic performance of a high aspect ratio wing; and the low cost, simplicity, and desirable ride qualities of a low aspect ratio wing. The wing is swept aft 20° to increase the critical Mach number. This allowed the wing to be thicker, thus reducing the wing weight and creating ample space to store most of the SnoDog's fuel.

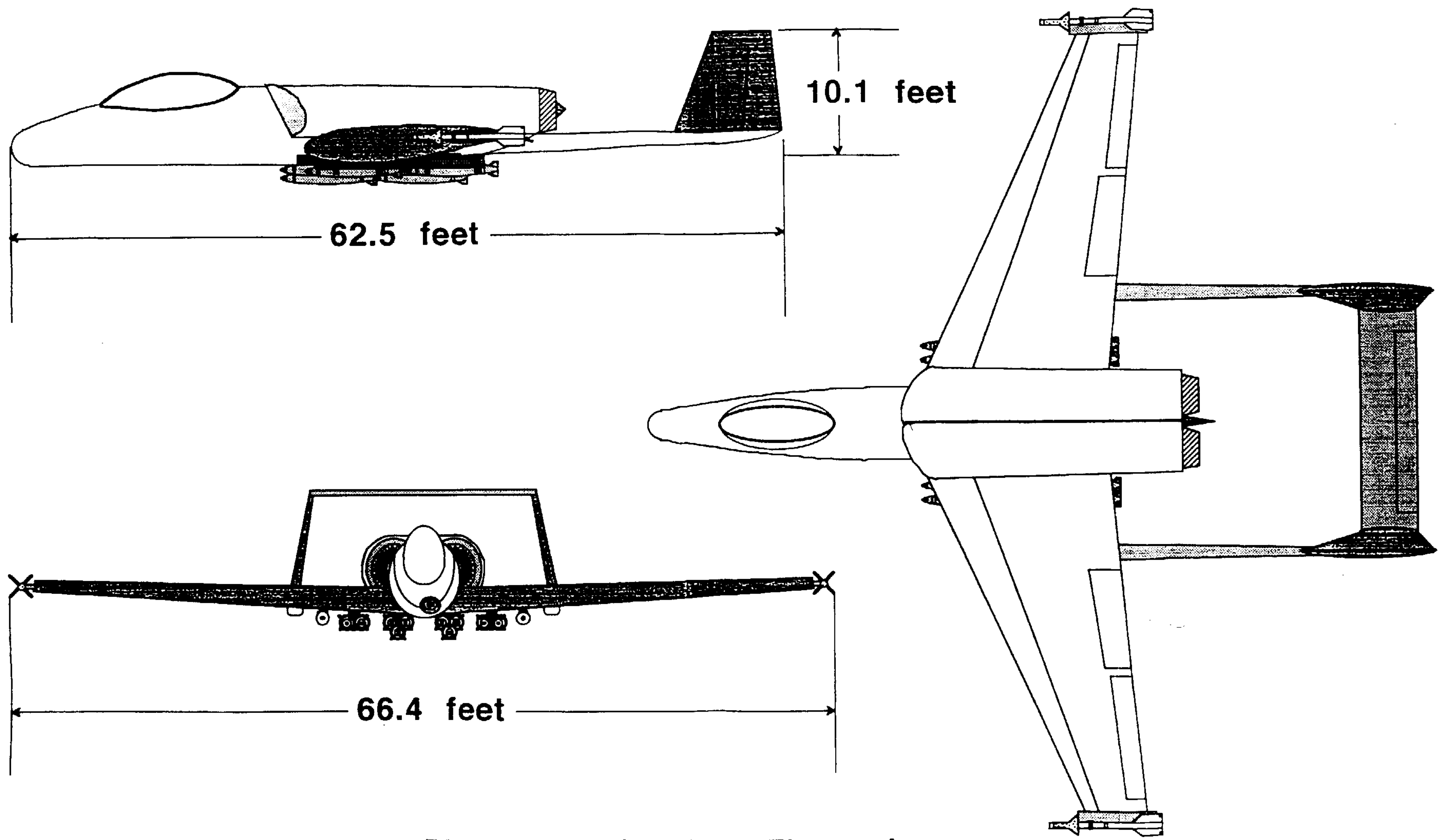


Figure 3.1 SnoDog Three-view.

Table 3.1 Wing Configuration Selection (a)

Configuration	Advantages	Disadvantages
Straight, Low Aspect Ratio Wing	•High Wing Loading •Low Cost	•High Strength Must Be Built Into Thin Wing •Inadequate Space For Stores
Conventional Aft-Swept Wing	•Higher M_{cr}, M_{dd} For Same Wing Thickness	•Aeroelastic Deformation From Control Surface Deflections •Poor Stall Characteristics
Forward-Swept Wing	•Same M_{cr}, M_{dd} As Aft Swept Wing •Stalls Near Root First Keeping Ailerons Effective	•Wing Tip Divergence Increases Structural Weight
Delta / Cranked Delta	•Lowest Wing Weight •High Angle-of-Attack attainable	•Tailless Delta Requires Long Takeoff Run •Lateral Controllability Problems From Pointed Wingtips
Joined Wing	•Efficient Long-Range Cruise •Structural Synergism with Horizontal Tail •Low Structure Weight	•Eliminates All-Moving Horizontal Tail Surface
Variable Geometry	•Wing Position Optimized For Flight Condition	•Weight Penalty For Sweep Mechanism •Complexity
Oblique Wing	•Wing Position Optimized For Flight Condition	•Weight Penalty For Sweep Mechanism •Complex Control Laws For Asymmetric Configuration •Weapons Placement Difficult

Table 3.2 Wing Configuration Selection (b)		
Position	**Advantages**	**Disadvantages**
High Wing	•Good Downward Visibility	•Wing Stores May Be To High Above Ground •Poor Interference Drag Characteristics
Low Wing	•Easy Wing Store Access	•Poor Interference Drag Characteristics
Mid-Wing	•Best Drag Characteristics from Clean Wing/Fuselage Joint	•Spar Carry-Through Must Be Replaced By Heavy Frames

3.2 FUSELAGE SELECTION

The cockpit and engines for the SnoDog are contained in a conventional fuselage. The empennage, however, is supported by twin booms. This configuration was selected for several reasons. A conventional fuselage was needed to provide the internal area necessary for the pilot, internal systems, and cannon. Twin booms, however, are lighter structurally than a conventional fuselage (although a slight drag penalty is paid). Having twin booms allowed complete separation of the redundant control systems, a survivability feature. Finally, engine accessibility is greatly enhanced. The engines can be pulled straight out the back without any empennage interference.

3.3 EMPENNAGE SELECTION

Table 3.3 compares different empennage selections. For the SnoDog, two vertical stabilizers were used, canted inward 12°, coupled with a high horizontal stabilizer. The location of the horizontal tail was selected for three reasons. First, the high position of the horizontal tail kept it out of the hot jet exhaust of the engines. Second, at high angles of attack the horizontal surface remains in the freestream flow. Finally, the high location of the horizontal tail facilitated engine removal. The twin vertical stabilizers are a survivability feature; the control system is redundant and the SnoDog can fly with one stabilizer severely damaged. The stabilizers are canted in for two reasons. First, they are canted to reduce their radar signature. Second, for a given horizontal tail area, canting the vertical tails inward increases the chord of the horizontal tail, thus increasing the structural integrity of the empennage.

3.4 ENGINE PLACEMENT

The SnoDog employs twin engines located above the wing and to the rear of the fuselage. Each engine has its own inlet located above the wing and surrounding the fuselage. This inlet placement minimizes foreign object damage (FOD) and reduces the amount of cannon exhaust gases ingested. Possible pilot visibility problems are reduced by placing the inlets as far back as possible, but they still ingest relatively undisturbed airflow since they are placed at the leading edge of the wing. Two engines were selected to increase survivability (the SnoDog is capable of flying with one engine out) and to achieve the thrust needed with minimum engine size. The engines are placed

Table 3.3 Empennage Selection

Empennage	Advantages	Disadvantages
Tail Aft	•Upload For Trim For Subsonic Unstable Configuration •Upload For Trim For Supersonic Unstable Configuration	•Download Required For Takeoff Rotation •Must Be Carefully Positioned With Respect To Wing Wake
Canard	•Upload For Trim For Subsonic Stable Configuration •Upload For Trim For Supersonic Stable Configuration	•Canard Contributes To Aircraft Instability •Forward Position May Block Pilot Downward Visibility
Three-Surface	•Drag Can Be Minimized For Trim State With A Balance Between Forward and Aft Control Surface Deflections	•Complex Flight Controls •Additional Structure Needed For Additional Set Of Horizontal Surfaces
Single Vertical Tail	•Simple System •Low Weight •Reduced Cost	•Large Tail May Be Required •High Angle Of Attack Stability May Require Large Span
Twin Vertical Tail	•Smaller Tail Surfaces •Increased Directional Stability At High Angle Of Attack	•More Complex System •Must Have Sufficient Lateral Separation For Effectiveness •Higher Cost And Weight

close together to minimize differential thrust in an engine-out situation, and are separated by a Kevlar™ shield to help contain a catastrophic engine failure.

3.5 DESIGN RESULTS

The SnoDog exceeds all of the performance requirements specified in the RFP and meets all applicable military specifications. The SnoDog's low cost of $14.8 million and versatile performance make it a competitive candidate for the future of close air support. Some of the major results are presented in Table 3.4 and the SnoDog three-view is shown in Figure 3.1.

Table 3.4 Configuration Results
(all values for sea level unless noted)

W_{TO}	51642 lbs	Airfoil	75-07-15
W_{stores}	12596 lbs	$C_{L_{TO}}$	1.8
W_f	11845 lbs	$C_{L_{landing}}$	1.95
A.C.	0.298 MAC	$C_{L_{clean}}$	1.8
Static $Margin_{TO}$	-0.0437 MAC	L/D_{max}	14.2
$Thrust_{TO}$	24979 lbs	e	0.77
V_{TO}	211.68 ft/sec	V_{stall}	142.24 ft/sec
V_{max}	916 ft/sec	Abs. Ceiling	42826 ft
Cost	$14.8 million	Max g's	-3.0 to 7.5
Turn $radius_{min}$	2415 ft	Turn $rate_{max}$	18.02 °/sec
Range (internal fuel)	1566 n.m.	ROC_{stores}	12794 ft/min

4.0 PRELIMINARY SIZING

The preliminary sizing determined the region from which the initial design point was selected to begin the iterative design process. It was found that the take-off and landing distance requirements provided the most constraining segments of the design mission profile, and they are shown in Figure 4.1. This section outlines the assumptions and procedures that were used to determine the thrust loadings and wing loadings for the various performance requirements. These include take-off and landing, maneuvering, engine-out, and balked landing requirements. For each of these flight conditions the methods of Reference (2) were used to calculate the respective loadings.

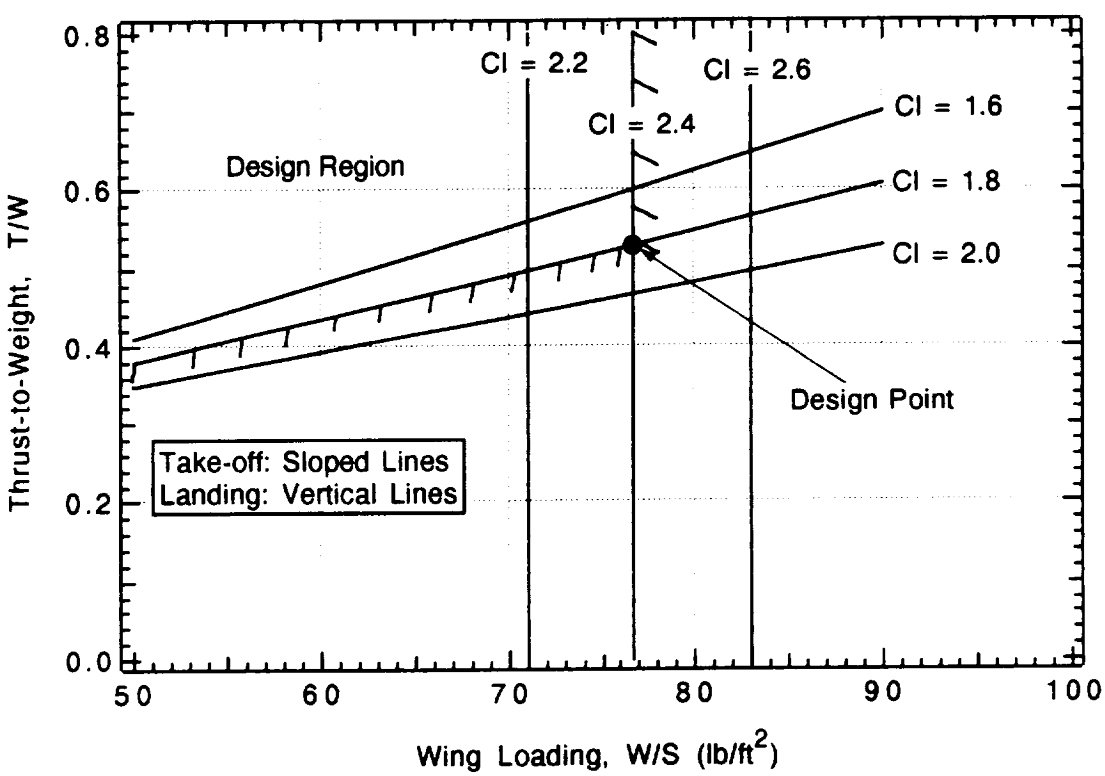


Figure 4.1 Preliminary Sizing Design Point.

4.1 WEIGHT ESTIMATION

The estimation of the gross take-off weight (W_{TO}) was computed using the mission fuel fraction method of Reference (2). The gross take-off weight was made up of three components: the operational empty weight (W_{oe}), fuel weight (W_f), and payload weight (W_{PL}).

The fuel fractions for the start-up, taxi, and take-off phases were determined by comparison to data from other fighter aircraft. A value of 0.8 for specific fuel consumption (C_j) was assumed, based on a range of C_j values obtained from similar aircraft. This selection was made at the high end of the given range of C_j's, because the aircraft will be flying at high power settings during the combat dash. A conservative value of 5 for lift to drag ratio was assumed from the range of given values.

The amount of time for the combat passes was estimated at approximately one minute, and was treated as a loiter for fuel fraction calculations. An extremely high value of 2.0 for C_j was chosen due to the high power settings required in combat situations. Originally a value for L/D of 5 was chosen for combat, but in order to take the load factor into account, a correction was made. Assuming an average value of 5 g's being pulled by the pilot during the combat run, a correction factor of 1/5 was multiplied into the original L/D equation. This was done assuming the combat lift would be 5 times the lift at 1 g, but the combat drag would be about 25 times the drag at 1 g. Consequently an L/D value of one was used in the final endurance equation.

For the bomb release portion of the mission it was assumed that no fuel is used during the instantaneous release of the weapons. However, there is a sudden weight decrease due to the bomb drop which affected the leg fuel fractions throughout the remaining portion of the mission. Therefore, the use of a bomb drop correction factor was necessary in the return dash phase of the mission.

The calculated value for the empty weight (W_E) using the regression formula was 25590 lbs. This value was only 0.37% different than the value determined using the mission fuel fraction method, and therefore, a gross take-off weight of 50000 lbs was deemed acceptable for the preliminary calculations. Consecutive iterations, however, changed this value to 51,642 lbs.

4.1.1 Sensitivity Studies and Growth Factors

The next step upon completion of the weight determinations was to conduct sensitivity studies of the change in take-off weight due to a variation of empty weight (W_E), L/D, and C_j. Other parameters which might affect take-off weight included payload weight (W_{PL}), range (R), and endurance (E).

The sensitivities of take-off weight due to specific fuel consumption, and lift-to-drag ratio computed with respect to both the range and endurance requirements are summarized in Table 4.1.

The importance of such studies can be correlated to the fact that the current fighter aircraft cost is approximately $500.0 per pound. It is evident that military need and affordability are balanced against each other throughout the design stages. Another important reason to conduct sensitivity studies is the fact that a large sensitivity may force changes in the design configuration altogether.

It was found that an increase in Cj increases the cost considerably. Therefore, Cj is a parameter which should be monitored carefully throughout the rest of the design process.

Table 4.1 Sensitivity Study Results

Sensitivity of Take-off Weight
with Empty Weight

$\partial Wto/\partial(We)$ (lbs) 1.85717438

Sensitivity of Take-off Weight with
L/D and Specific Fuel Consumption

	Dash 1 & 2	Loiter 1	Loiter 3
Cj	0.8	2	0.8
V (kts)	500	500	500
L/D	5	1	9
Range (nm)	250	N/A	N/A
Endurance (hrs)	N/A	0.01667	0.333333
$\partial Wto/\partial(Cj)$ (lbs)	Ø	2968.89629	6596.22147
$\partial Wto/\partial(L/D)$ (lbs)	-2849.5705	Ø	Ø

4.2 TAKE-OFF AND LANDING REQUIREMENTS

The SnoDog is designed for a take-off ground roll of less than 2,000 ft on a smooth runway, standard day. To fulfill this requirement, and to calculate the take-off thrust to weight ratio (T/W) it was assumed that the coefficient of rolling friction was 0.025, the engine bypass ratio = 1.5, and the Oswald efficiency factor (e) was 0.75. The wing loading (W/S) and the lift coefficient (C_L) were also varied to determine required thrust loadings.

For landing, the mission specifications of clearing a 50 ft obstacle and landing with a 2000 ft ground roll were applied. The thrust loadings required for given values of C_L were computed for the most restraining case, which was the heaviest landing weight. This landing weight was achieved with retained payload and 20 minute reserve fuel weight.

4.3 MANEUVERING REQUIREMENTS

The criteria for maneuvering required the SnoDog to carry standard stores with 50% of the internal fuel. The specifications also included requirements for an instantaneous turn at 6 g's (n = 6.0), and a sustained turn at 4.5 g's (n = 4.5), both at military speeds of 450 kts. It was assumed that e = 0.8 for this phase. Various ranges of W/S were assumed for constant C_L values in order to obtain T/W vs. W/S plots.

To clarify calculations for the sustained turn, the given value for n = 4.5 is misleading. The resultant load factor from a 4 g load due to the turn, and a 1 g load to keep the aircraft level, was actually 4.61 g's. Therefore, a load factor of 4.61 was used in the T/W calculations.

4.4 ENGINE-OUT CLIMB AND BALKED LANDING REQUIREMENTS

Climb requirements for military aircraft are usually given in mission specifications but no climb specifications were given for this aircraft. However, climb requirements for multi-engine aircraft with one engine inoperative are given in Military Specifications, MIL-C-005011B (USAF). These requirements are as follows:

1. Take-off climb requirements

    a) At take-off speed, V_{TO} = 1.1 V_{ST}, the climb gradient must be at least 0.005. The configuration for this requirement must be: gear down, flaps take-off, max power.

b) At the 50 foot obstacle and at 1.15 V_{ST}, the climb gradient must be at least 0.025. The configuration for this requirement must be: gear up, flaps take-off, max power.

2. Balked Landing Climb Requirement

At the 50 foot obstacle and at 1.2 V_{ST}, the climb gradient must be at least 0.025. The configuration for this requirement must be: gear up, flaps landing, max dry power.

4.5 FINAL CONCLUSIONS FOR PRELIMINARY SIZING

The results of the preliminary sizing determined the region from which a design point was selected. From Figure 4.1, it can be seen that the take-off distance curve for C_L = 1.6 and the landing distance curve for C_L = 2.2 provide the most constraints on the T/W vs W/S plot. The intersection point where W/S = 76.7 and a T/W = 0.53 was chosen to begin the iterative design process. The resulting preliminary total thrust and wing size requirements are shown in Table 4.2.

Several factors led to the selection of this design point. First, a point with a greater thrust-to-weight ratio could have been selected. However, the overall cost of the aircraft would rise due to resulting larger engine requirements. A point to the left of the chosen design point would also satisfy all design requirements. Yet, although a low wing loading shortens the landing distance, it also diminishes the ride quality of the aircraft. A higher wing loading therefore is conducive to the reduction of pilot fatigue during long missions, resulting in improved pilot combat effectiveness. For this reason, the highest possible wing loading was desired which still allowed for the landing distance requirement to be met.

T/W=0.53 and W/S=76.7 are the original sizing values that were used to begin phase two of the design procedure. These values have been adjusted, however, due to the more accurate calculations of this second phase. It is noted that other missions included in the analysis were the high-low-low-high and the ferry missions. The results in the preliminary design procedure found that the SnoDog also meets the requirements for these missions.

Table 4.2 Preliminary Sizing Results

Take-off Weight	50000 lbs
Empty Weight	25496 lbs
Fuel Weight	11433 lbs
Maximum Lift Coefficients	
Clean	$CL_{max} = 1.5$
Take-off	$CL_{max_{to}} = 1.8$
Landing	$CL_{max_L} = 2.4$
Aspect Ratio	6
Wing Area	652 Ft^2
Thrust at Take-off	26500 lbs

5.0 AERODYNAMICS

5.1 LIFT

5.1.1 Wing Parameters

The SnoDog employs a low mounted, aft swept, cantilever wing. The results of preliminary sizing of the wing planform design parameters are summarized in Table 5.1. These values were derived from the method outlined in References (3) and (4). The wing planform is shown in the SnoDog three-view in Figure 3.1 .

The wing area, S, aspect ratio, AR, and span, b, were determined from the preliminary design sizing . Parameters such as taper ratio, λ, dihedral, Γ, and twist, τ, were estimated using data from similar aircraft. The use of a supercritical airfoil and 20° of sweep, $\Lambda_{c/4}$, allowed a higher wing thickness ratio, t/c, without exceeding the drag divergence Mach number of approximately M = 0.8 . Advantages of using a supercritical airfoil also included a decrease in wing weight (since both bending and torsional stiffness increase with t/c), a higher maximum lift coefficient, and a greater wing fuel volume capacity. Storing fuel in the wing tends to simplify the fuel system and minimize center of gravity travel as fuel is spent (Reference 6). Curves constructed by varying thickness ratio and sweep indicated wing weight to be more dependent on the former than the latter. That is, the extra structural weight needed to sweep the wing was offset by the weight saved due to the thickness of the airfoil. In addition, a relatively low taper ratio value of 0.3 was employed

Table 5.1 Wing Parameters

b = 62.54 ft
S = 651.89 ft^2
$\Lambda_{c/4}$ = 20°
AR = 6.0
λ = 0.3
c = 10.43 ft
c_r = 16.04 ft
i_w = 0°
Γ = 1°
τ = -1°
t/c = 0.15
75-07-15 sc airfoil

to decreased wing weight. A washout of 1°, to alleviate undesired stall characteristics caused by the low taper ratio and moderate sweep, was estimated using data from similar aircraft. To simplify analysis, the SnoDog utilizes a straight taper wing with a constant spanwise thickness ratio . Further wing tailoring is expected if warranted by future analysis. The wing incident angle of 0° was determined by the cruise lift coefficient of approximately $C_{Lcruise}$ = 0.08 and the wing lift curve slope which was constructed. Dihedral, under the assumption that it would be necessary for lateral stability, was also estimated from similar aircraft to be 1°. It is likely that washout and dihedral will most likely be adjusted depending on results obtained from further stability and control analysis.

5.1.2 The Airfoil

The SnoDog's 75-07-15 supercritical airfoil shown in Figure 5.1 was taken from Reference (5). The series designation is as follows: 75 is the design Mach number times 100, 07 is the design lift coefficient in tenths, and 15 is the maximum thickness ratio in hundredths.

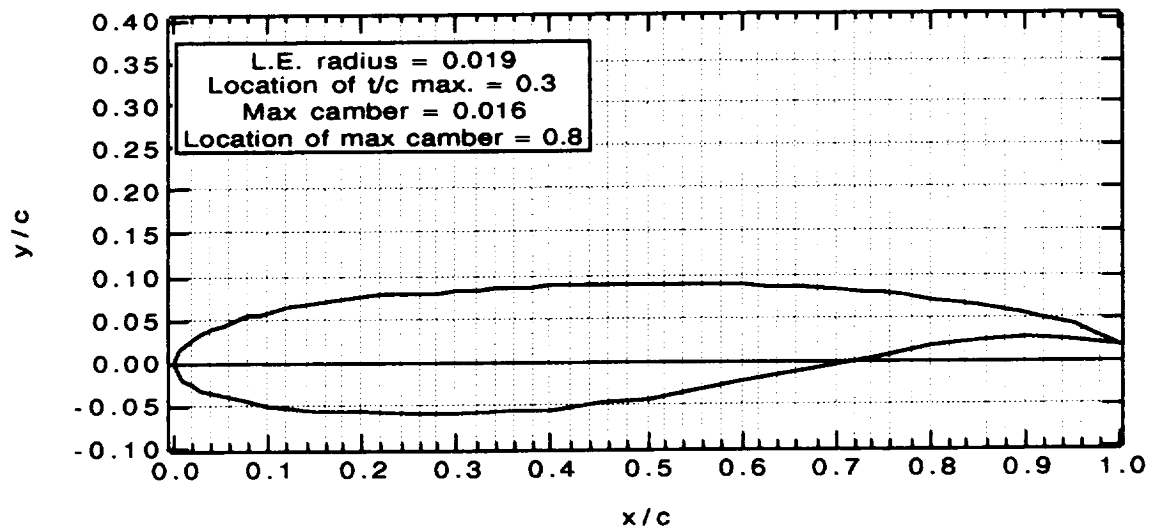


Figure 5.1 75-07-15 Supercritical Airfoil.

Available wind tunnel data was limited to those points depicted in Figure 5.2. The method presented in Reference (6) allowed the calculation of the maximum section lift coefficient along with its corresponding angle of attack . From the sectional data, the aircraft lift curve shown in Figure 5.3 was then calculated for the sea level cruise condition.

To determine the sectional lift parameters for approach (M = 0.196), Prandtl-Meyer compressibility corrections were implemented, since wind tunnel data was taken at compressible Mach numbers. The aircraft lift curve for

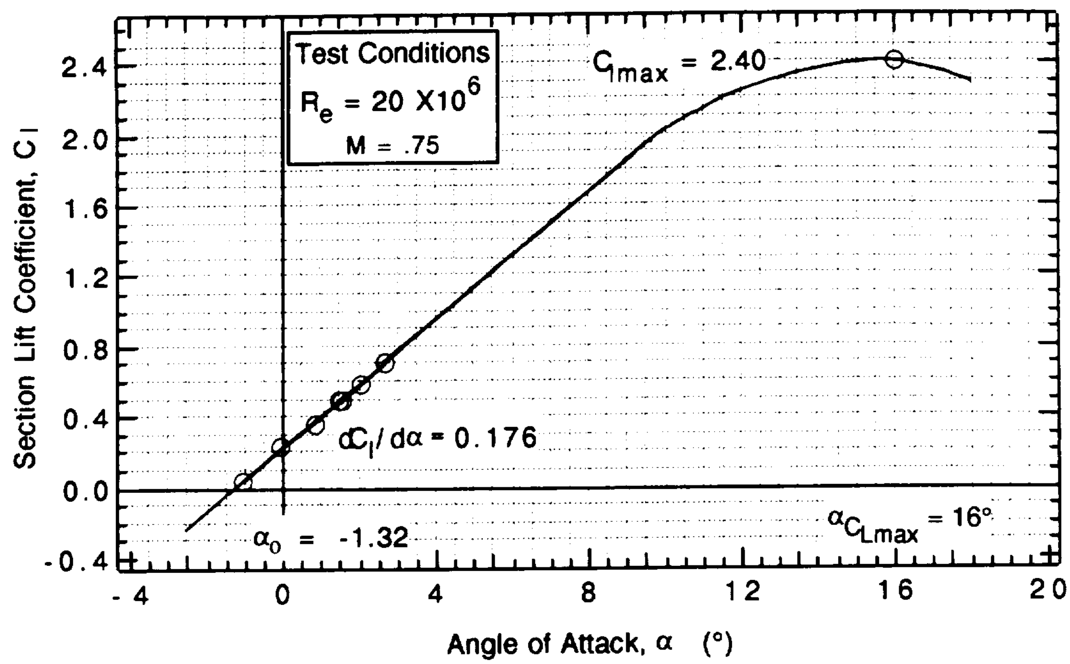


Figure 5.2 **The Variation of Section Lift Coefficient with Angle of Attack for 75-07-15 Airfoil.**

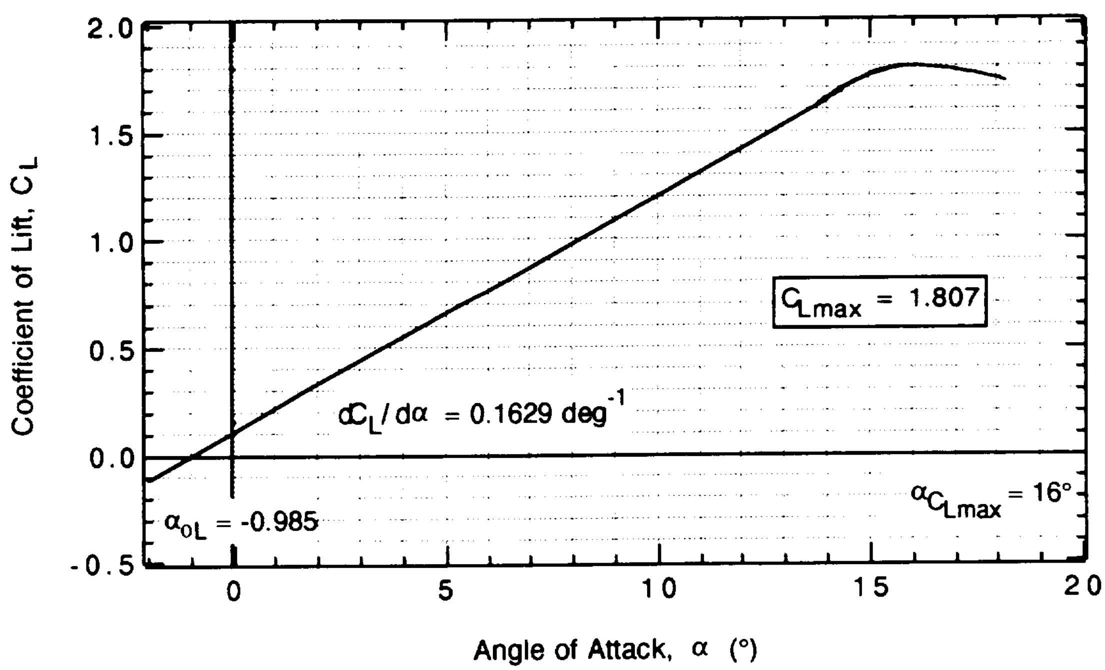


Figure 5.3 **The Variation of Aircraft Lift Coefficient with Angle of Attack at Cruise Conditions.**

clean (flaps up) configuration at approach is shown in Figure 5.4 along with the flaps down configuration.

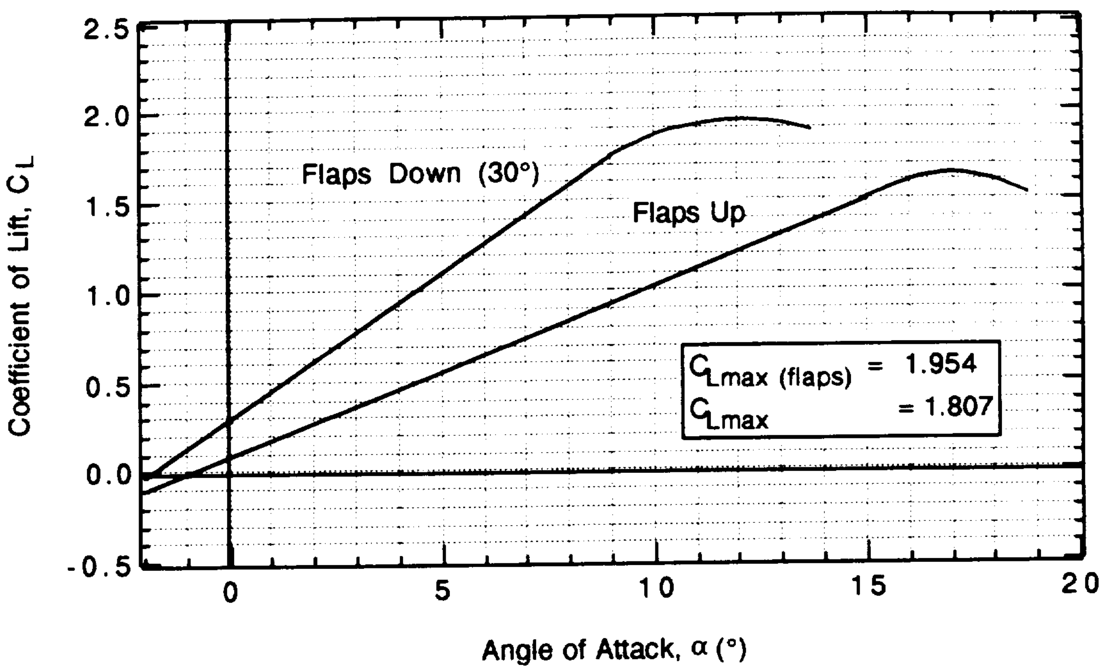


Figure 5.4 The Variation of Aircraft Lift Coefficient with Angle of Attack at Approach Conditions.

In general, supercritical airfoils tend to stall less abruptly, have higher maximum lift coefficients, and a higher lift curve slopes than NACA 4,5, and 6 digit airfoils with the same thickness ratio. The results presented indicate a supercritical airfoil would work well for SnoDog's design. However, at this point, it is recommended that further wind tunnel data be performed on the airfoil section to completely validate its use.

5.1.3 Empennage Parameters

The values, located in Table 5.2 , were determined for the horizontal tail using the sizing methods found in Reference (6).

Table 5.2 Empennage Sizing Parameters

Horizontal Tail	Vertical Tail
b = 17.7 ft	b = 8.07 ft
S_h = 103.7 ft^2	S_v = 54.24 ft^2 each
$\Lambda = 0°$	$\Lambda_{L.E.} = 9.4°$
AR = 3.86	AR = 1.2
$\lambda = 1.0$	$\lambda = 0.527$
c = 4.85 ft	c = 6.73 ft
c_r = 4.85 ft	c_r = 8.81 ft
$i_h = 0°$	$i_v = 0°$
$\Gamma = 0°$	cant angle = 12°
$\tau = 0°$	$\tau = 0°$
t/c = 0.10	t/c = 0.08
NACA 0010-43	NACA 0008

It was decided to employ a conventional, twin boom configuration with a horizontal tail attached atop the vertical tail to keep the horizontal tail out of the hot jet exhaust . This facilitated high angle of attack flight by projecting the horizontal surface up into free stream flow. The vertical tails have been canted inward 12°. The purpose for this was twofold. First, canting the vertical tails increases the chord of the horizontal tail for the given surface area of 103.7 square feet, which would increase the structural strength of the empennage. Second, canting the vertical tails would reduce the radar signature of the aircraft. In addition, although not a driving factor, the aircraft was considered more appealing to the eye, which could make it more marketable.

The two symmetric airfoils selected for horizontal and vertical surfaces were NACA 0010-43 and NACA 0008 respectively, and aerodynamic data can be found in Reference (7). The criteria for selection was based on the need for a higher critical Mach number over the empennage than that over the wing. Both airfoils satisfy this requirement, and therefore the SnoDog's control surfaces will remain effective at transonic speeds. The vertical tail was swept 9.4° to further increase the critical Mach number. The thickest airfoils allowable under the critical Mach number constraints were chosen to save structural weight.

5.1.4 High Lift and Control Devices

The size, location, and flap type for the SnoDog wing were estimated using the method outlined in Reference (3). The size and location of the elevator and rudder surface for the horizontal and vertical tail surfaces, respectively, were estimated from similar aircraft. A summary of the results is located in Table 5.3 below . Figure 3.1 shows their layout.

It was decided smaller, more efficient, Fowler flaps located on the inboard section of the wing would allow space for ailerons to be positioned on the outboard section of the wing. The use of ailerons would enhance lateral maneuverability which is desired for close air support missions. Although

Table 5.3 Control Surface Sizing	
Fowler Flap	Aileron
S_f = 23.44 ft^2 c_f/c= 0.3 Swf/S = 0.2212 δ= 30° n_i = 11.9 ft n_o = 18.83 ft	S_a = 17.44 c_f/c = 0.3 n_i = 19.97 ft n_o = 30.02 ft
Elevator	Rudder
S_e = 21.62 ft^2 b = 14.6 ft c = 1.51 ft c_t = 1.51 ft c_r = 1.51 ft	S_r= 16.12 ft^2 b = 7.26 ft c = 2.22 ft c_t = 1.67 ft c_r = 2.91 ft

Fowler flaps added complexity because of the slotted design, the trade off was considered worthwhile since this allowed smaller flap size. Plain flaps would have required a larger percent of the wing span. Double slotted flaps, although more effective than Fowler flaps, were deemed too mechanically complex. One of the SnoDog's main design drivers was simplicity. Fowler flaps offered a good compromise. Figure 5.4 depicts the lift curve slope at the approach flight condition for both flaps up and flaps fully extended (30°) . Figure 5.4 indicates that the landing lift coefficient of 2.4 desired in preliminary sizing was not obtained; however, it was determined in the performance analysis that the lift coefficient of 1.95 satisfied the critical landing distance requirements.

5.2 DRAG DETERMINATION

The drag polars for the SnoDog were computed for the take-off, landing, and cruise flight conditions using the methods of Reference (4). Values of drag for zero lift were calculated for each exposed surface of the aircraft, including stores, landing gear, and extended flaps. Trim drag was also calculated for each flight condition. Compressibility drag was neglected since the mission requirements do not require the SnoDog to fly at greater than Mach 0.8. This assumption, along with the assumption of parabolic drag polars, will give fairly accurate results (Reference 8). Transonic compressibility effects will be computed in the next design phase.

In order to compute the zero-lift drag coefficients, wetted areas were calculated for each surface exposed to the air flow. The wetted areas are shown in Table 5.4. The engine inlets and engine shrouds were considered part of the fuselage for drag calculation purposes.

Table 5.4 Wetted Areas

Wing	1097.8 ft^2	Booms	387.8 ft^2
Fuselage	922.1 ft^2	Empennage	384.0 ft^2

The engine placement for the SnoDog's twin-boom configuration allows base drag aft of the fuselage to be neglected. This is because the jet exhaust eliminates the usual wake region produced behind a blunt-ended body. The SnoDog fuselage was intentionally designed to produce the smallest amount of friction drag possible, since the drag from the fuselage generally accounts for up to half of the zero-lift drag of a subsonic aircraft (Reference 6). It has been found that fineness ratio greatly affects the skin friction drag of subsonic aircraft, with a fineness ratio of approximately six yielding the minimum amount of skin friction drag (Reference 6). The SnoDog has a fineness ratio of 5.26 (fuselage only), which is very close to the minimum drag region for subsonic aircraft.

Figures 5.5 and 5.6 show the trimmed drag polars for the SnoDog for the above mentioned flight conditions. The cruise drag polars were calculated for a weight of 45,021 pounds. The zero-lift drag coefficient for cruise in the clean configuration was 0.0174, and with stores was 0.0287. The drag polars for take-off and landing were both computed with stores, but the drag for landing configuration was significantly higher due to the need for full flap extension at touchdown. The zero-lift drag coefficients for take-off and landing were 0.0298 and 0.0478 respectively.

To complete the drag polars, it was necessary to determine the drag due to lift of the aircraft. A value for Oswald Efficiency Factor, e, was calculated to be 0.77 using the method of Reference (8). The drag polars were then constructed using the parabolic drag polar equation for subsonic flow:

$$C_D = C_{Do} + C_L^2/\pi eAR$$

Values for drag due to lift were then calculated for each flight condition with the methods of Reference (4). The resulting drag was then compared to the drag obtained by using the parabolic equation. The drag values differed by less than 5% for each flight condition, confirming the validity of the assumptions made.

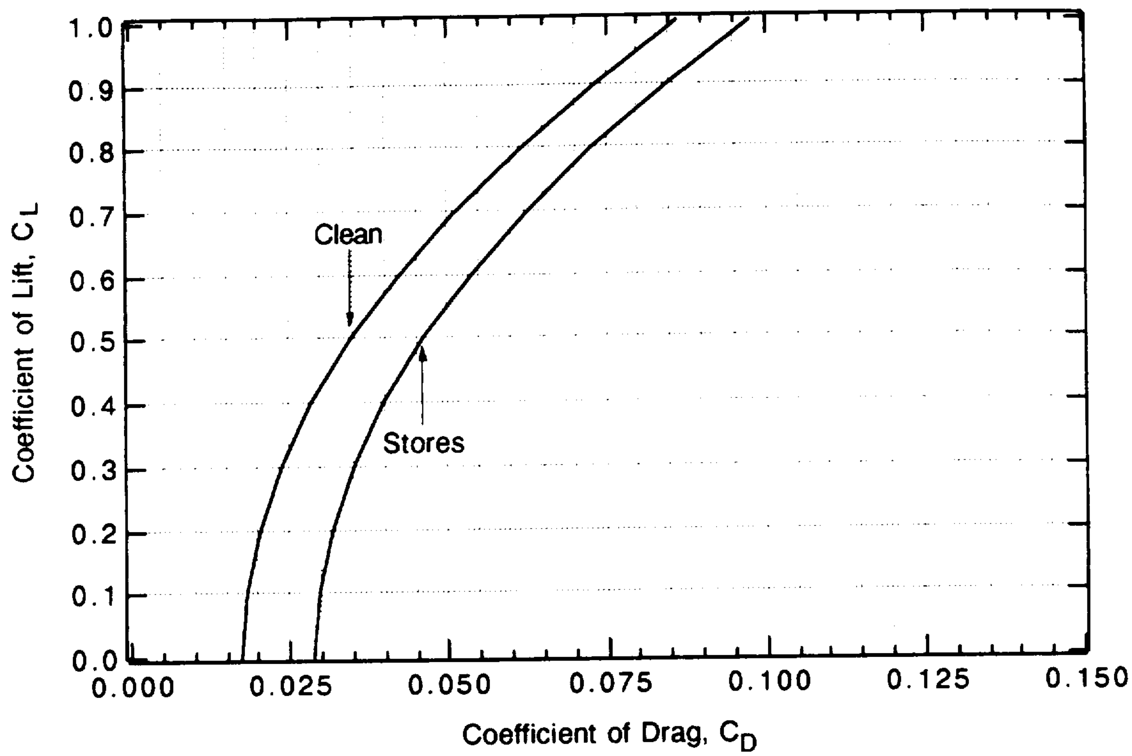


Figure 5.5 Drag Polars for Cruise Condition.

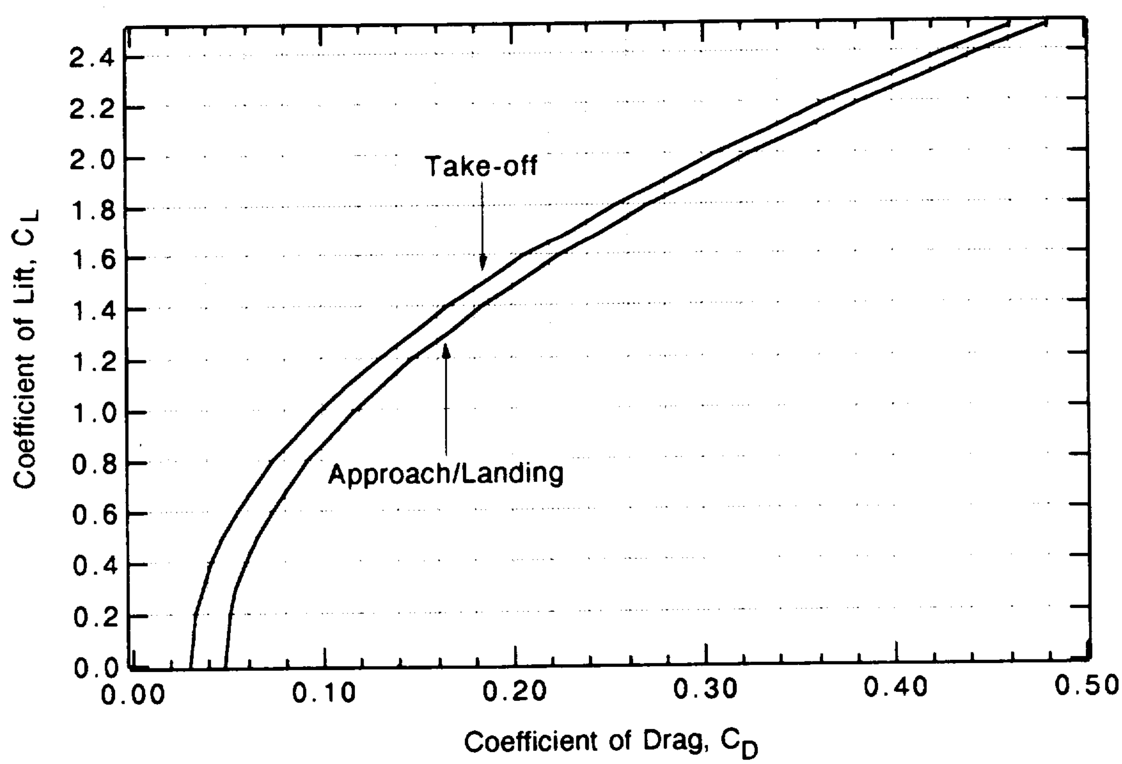


Figure 5.6 Drag Polars for Take-off and Landing.

6.0 PROPULSION

6.1 ENGINE SELECTION

The propulsion system selected for the SnoDog consists of two low bypass turbofans. The maximum installed take-off thrust was calculated to be 24,839 lbs using the methods of Reference (4). The maximum installed thrust at various altitudes is shown in Figure 6.1.

This paper engine, being developed for the year 2000, was chosen over existing engines. Because it will take advantage of the latest technologies, specific fuel consumption and performance will improve. Turboprops, turbojets and powered lift engines were also investigated. The turboprop could not operate at the Mach numbers the SnoDog was being designed for, while the turbojet had a higher specific fuel consumption and was noisier than the turbofan engine. Powered lift was not included in the design because of the SnoDog's role as a close air support aircraft. It increases the complexity of the propulsion system design, and therefore would increase the SnoDog's maintenance.

6.2 ENGINE SIZING AND DISPOSITION

For survivability considerations, the engines are separated by a Kevlar™ plate. If one engine explodes or catches fire, the plate will help insure that the second engine is not damaged. On the other hand, the engines are close enough together to prevent control problems if one engine does fail.

6.3 INLETS

Since the design mission requires dash speeds of up to Mach 0.76, the inlets were sized to this condition. The area of each inlet is 7.1 square feet, which provides both internal and external compression, and a Mach number at the compressor face of 0.4 . At take-off conditions, the inlets are a little undersized, but they are still able to deliver the required airflow. This resulted in extra drag at take-off. Instead of using intake doors, which would increase the complexity of the design, a rounded lip was used. This makes the lip less sensitive to flow angle, but increases loss due to separation of the exterior flow during cruise, Reference (9). A thick lip will help accommodate more air at take-off and reduce distortion, but a thin lip is ideal for cruise. A compromise was made and the lip thickness was chosen to be 5% of the inlet radius.

Pressure recovery for the twelve foot inlet was calculated to be greater than 98% at all flight conditions. This recovery does not , however, account for losses due to separation at the inlet lip. Testing would have to be conducted in order to determine this. Reference (9) states that a good inlet will produce a pressure recovery between 0.95 and 0.97. Therefore, after losses due to lip separation are accounted for the SnoDog's inlet should fall into this range. This recovery was accounted for when computing the installed thrust.

There is 21 feet of fuselage length before the inlet, therefore a boundary layer diverter is required to achieve maximum pressure recovery. A channel type diverter with a splitter plate was chosen because it provides the best performance and least weight (Reference 8). A cross sectional view of the engine inlet including the boundary layer diverter is shown in Figure 6.2.

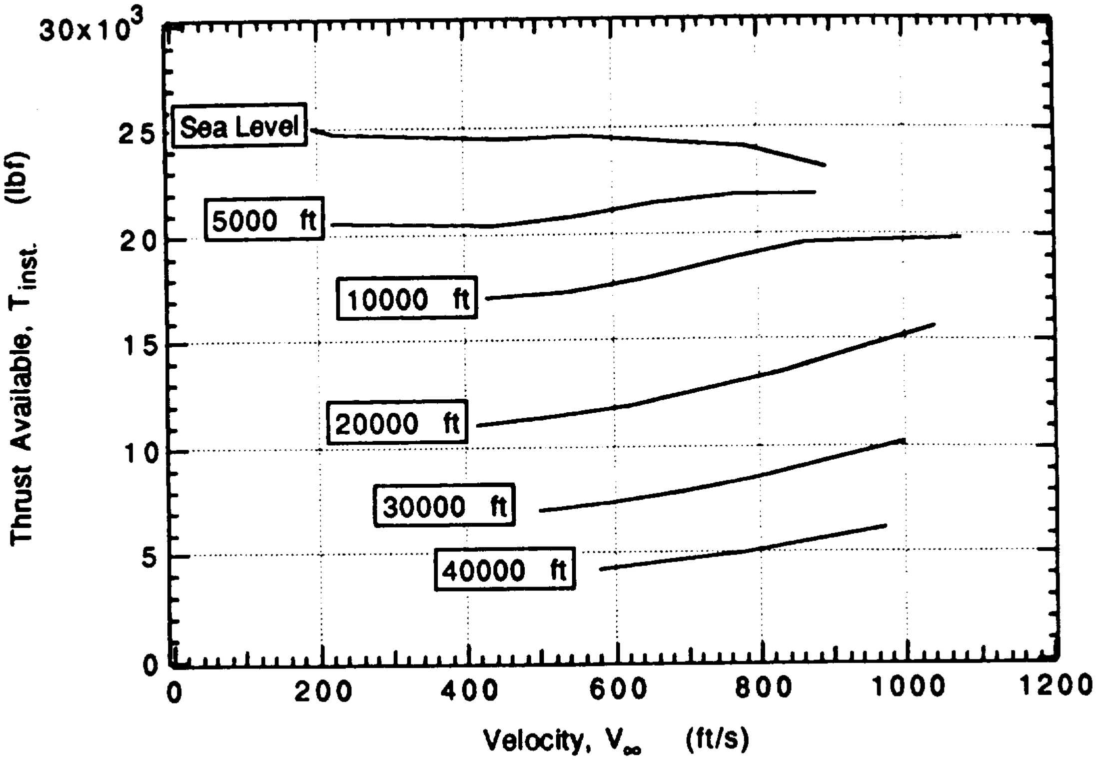


Figure 6.1 Installed Thrust Available.

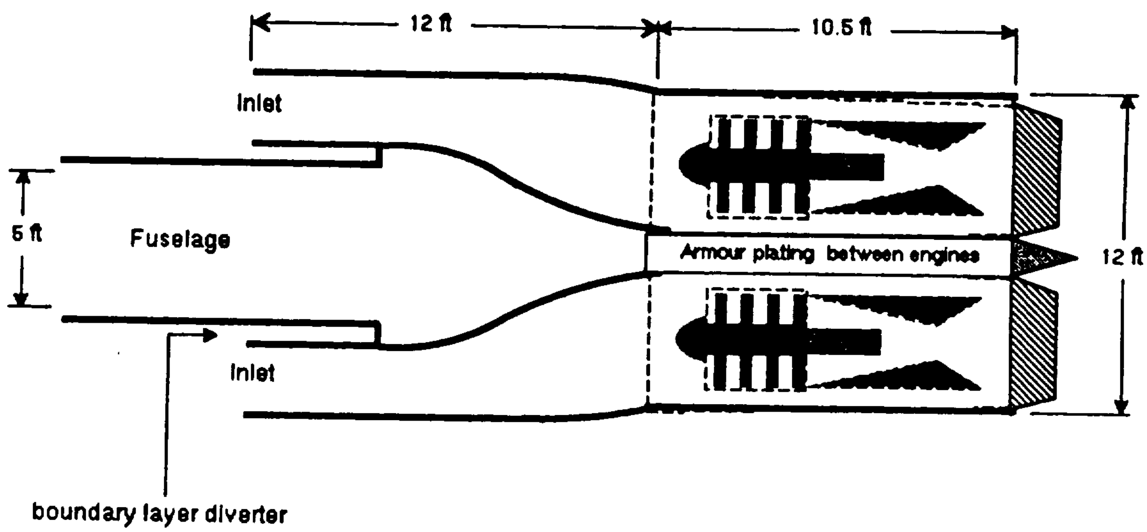


Figure 6.2 Inlet Cross Sectional Layout (1/4 in = ft).

7.0 STRUCTURES

7.1. V-n DIAGRAM

The operating flight strength limitations of the SnoDog are presented in Figure 7.1. The velocity versus load factor diagram was constructed using mission specifications and military requirements. The positive and negative limit load factors are +7.5 and -3.0 respectively (Reference 10). The various speeds shown in Figure 7.1 are defined as follows:

a) V_{s1}, the minimum steady flight speed (+1g stall speed), is found at 109.0 knots using the equation:

$$V_{s1} = [\, 2\, (W/S) / \rho\, C_{Nmax} \,]^{1/2}$$

Where W is the design maximum take-off weight of 51,642 lbs and C_{Nmax} is the maximum normal force coefficient using an approximation of $1.1 C_{Lmax} = 1.98$ (Reference 10).

b) V_L, the design maximum level speed, is at 543.0 knots based on mission specification requirements and Reference (10) .

c) V_a, the design maneuvering speed, is found at 299.0 knots using the equation:

$$V_a = (V_{s1})\, (n_{lim})^{1/2}$$

Where n_{lim} is the limit maneuvering load factor at V_L, the design maximum level speed.

d) V_d, the maximum diving speed, is found at 678.0 knots using the approximation: $V_d = 1.25\, V_L$ (Reference 10)

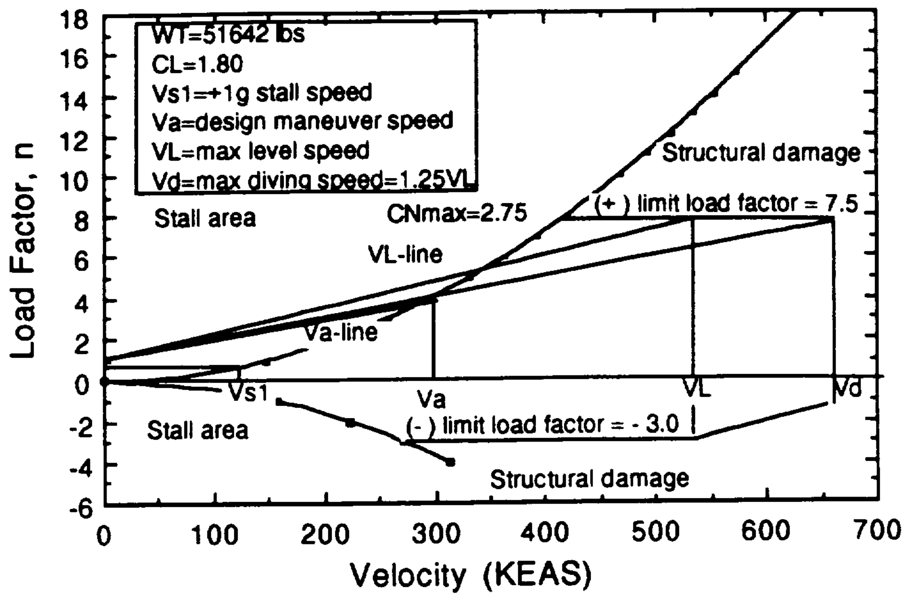


Figure 7.1 V-n Diagram.

7.2 WING STRUCTURE

7.2.1 Wing Design

When designing the structure of the wing, several factors were considered. Reference (1) required load factors in the range of -3.0 to +7.5 g's. Using a safety factor of 1.5, a load range of -4.5 to +11.25 g's was obtained. Load factors of this magnitude required heavier components, such as the bombs, to be distributed along the span to approximately match the lift distribution generated by the wing. The two load distributions counteract each other generating a smaller bending moment. The locations of these components required hardpoints, which drove the placement of the spars and ribs. Flaps and ailerons were the next components to be integrated into the wing structure. In doing so, the relocation of the spars and ribs were anticipated and accommodated. The placement of landing gear was also considered. The structure supporting the gear must be able to support the aircraft during the impact of landing as well as on the ground with full stores. The structural layout of the planform is shown in Figure 7.2.

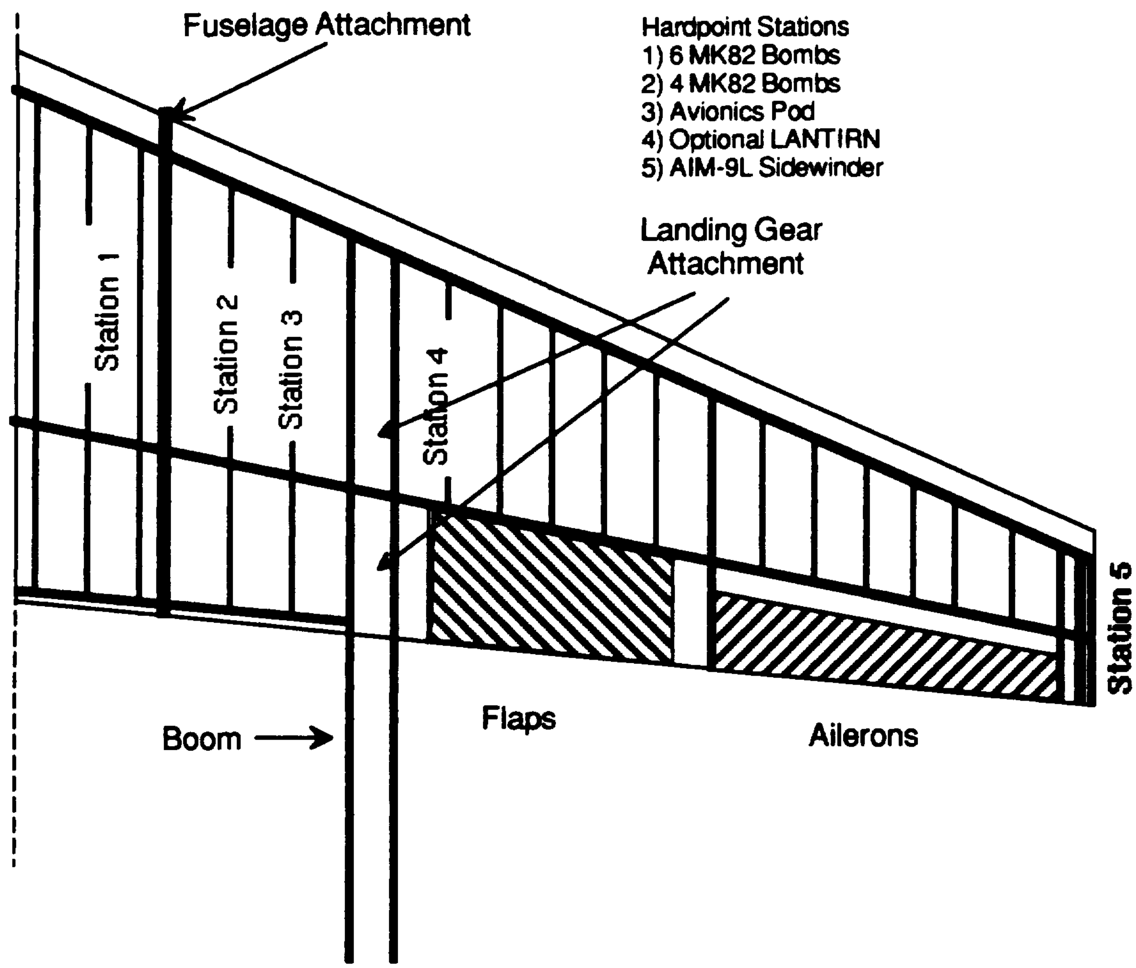


Figure 7.2 Wing Structural Layout.

7.2.2 Load Analysis

A single spar was used for the load analysis. To determine the shear and bending moments, the wing was modelled as a cantilever beam (References 11,12,13). In Figure 7.3, the model span is shown with loads due to lift, armament, landing gear, fuel, and the weight of the wing itself. Notice that the landing gear attachment point has the highest loading of 75,000 lbs, which was due to impact during landing. The taper ratio of this particular planform was such that the lift distribution was close to elliptical. Therefore an elliptical load distribution was placed on the beam to model the aerodynamic loads. Though the magnitude of the

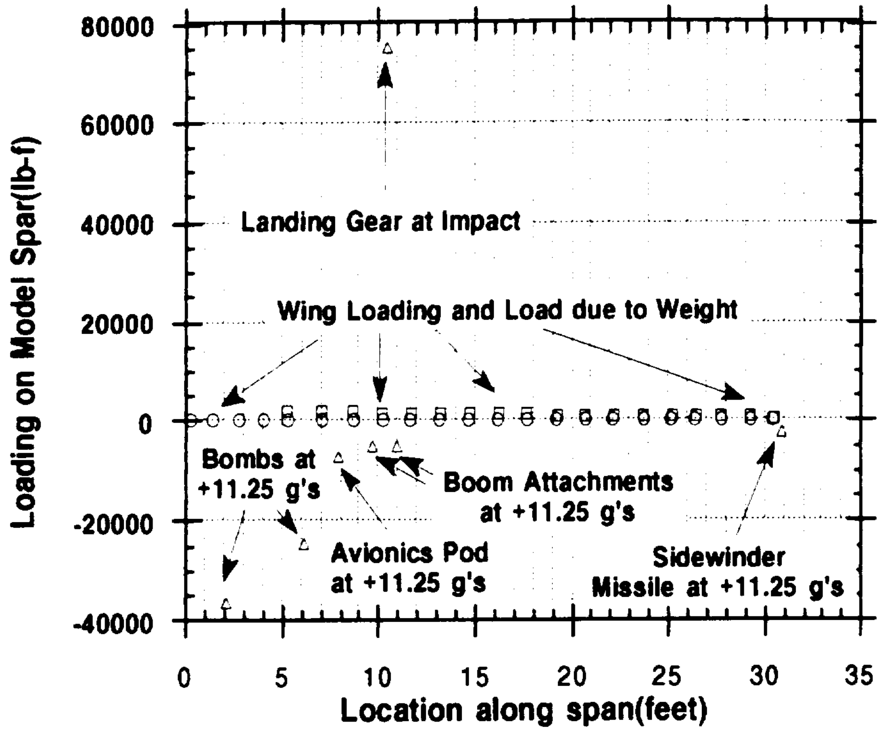
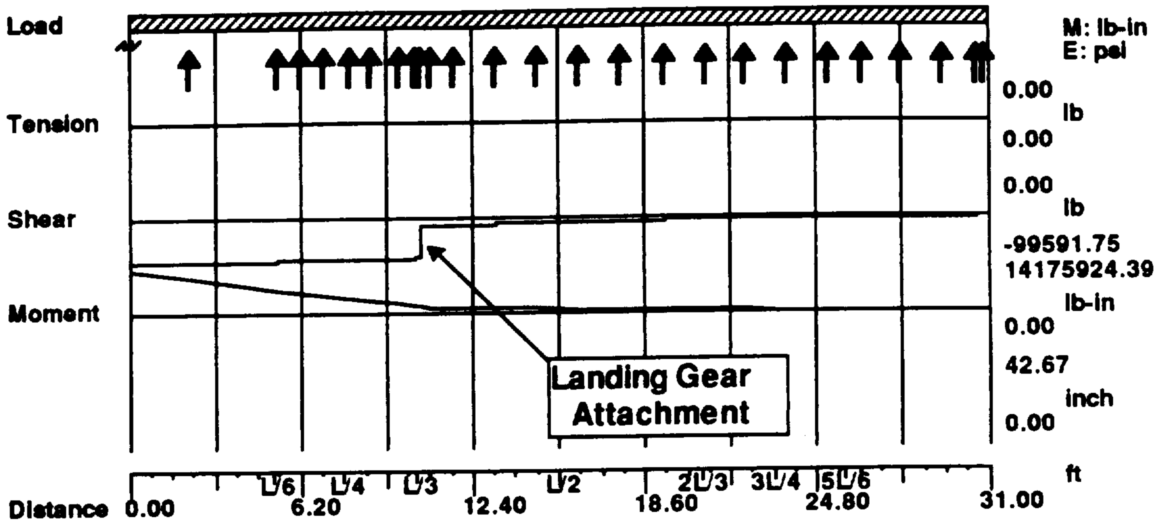


Figure 7.3 Wing Loading of Model Spar.

lift distribution was small compared to the landing gear load, its consideration was necessary when analyzing the outboard portion of the wing structure. Other loads encountered for this wing were due to the boom attachment points, bombs, Sidewinder missiles, and avionics pods. The actual weight of these items depend greatly on the load factor during

40 any particular maneuver. Once all the maximum load values were obtained, FRAMEMAC™ (Reference 10) was used to obtain shear loads and bending moments along the span (Figure 7.4). FRAMEMAC™ models beams as well as frame type structures under distributed loads, concentrated loads, and applied moments. Values obtained along the span are listed in Table 7.1.

Loading due to Wing Loading and Armament
(20 Panels with Point Loads)



7.4 Analysis of Spar by Beam Theory.

Table 7.1 FRAMEMAC™ Analysis - Wing Spar

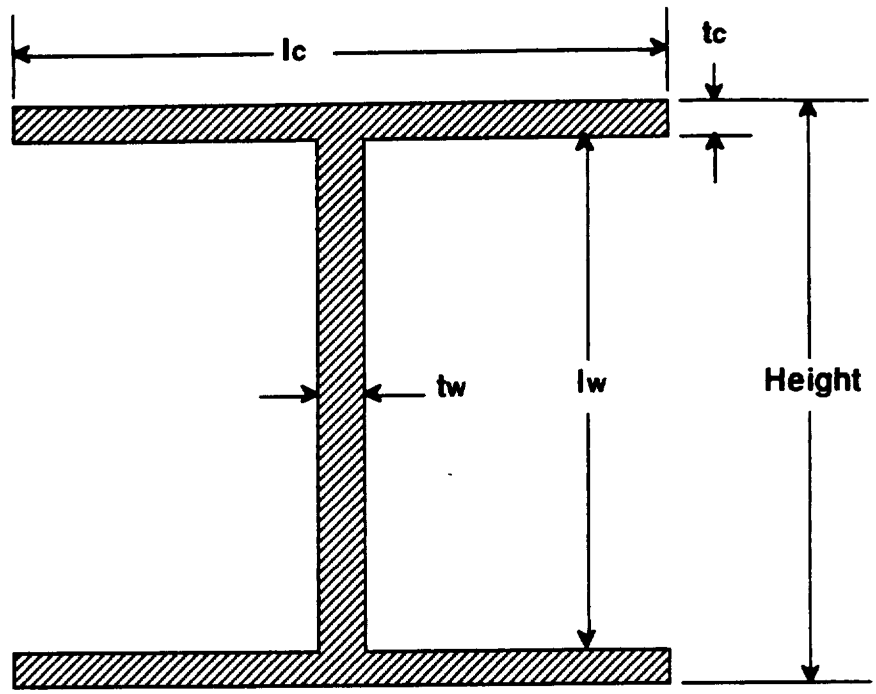
	Data from FRAMEMAC™		Calculated Design Values	
Distance from Root (feet)	Shear in Y-Direction (lbs-f)	Bending Moment in X-Direction (in-lbs)	Shear in Y-Direction (lbs-f)	Bending Moment in X-Direction (in-lbs)
0	99591	14.0×10^6	125156	$14.1 \text{ X } 10^6$
3.0	98456	10.5×10^6	113596	10.9×10^6
6.2	95935	6.5×10^6	102468	6.5×10^6
9.4	91962	3.3×10^6	94420	3.4×10^6
10.1	91796	2.4×10^6	91793	2.8×10^6
12.3	14090	1.7×10^6	85446	2.3×10^6
20.5	8290	661966	55899	971140
26.5	4319	184400	37307	486980
30.7	2644	2506	25042	251776

7.2.3 Wing Spar Sizing

Aluminum 2014-T6 was the chosen material for the wing spars, ribs, and skin (References 14,15). With a yield stress of 60 ksi and yield shear stress of 32 ksi, this alloy was stronger than steel at one third the weight and is very machinable, thus reducing tooling costs. An I-beam was used for the wing spar. Assuming total height, flange width, and web thickness, parameters such as moments of inertia, maximum shear, and maximum bending moment were calculated and compared to corresponding values from the FRAMEMAC™ analysis (Table 7.1). Through successive iterations, the final dimensions presented in Figure 7.5 were achieved.

Though the spar is very large, the wing of the SnoDog is 15% thick providing ample room. With two main spars of this magnitude and a third half-spar for redundancy, the wing would experience less deflection, and thus less cyclic stress during high g maneuvers. Ribs combined with the spars created a structure capable of handling shear from all horizontal directions, while also maintaining control over bending moments due to aerodynamic forces. The torsional moments induced by lift and drag would be counteracted with the use of skin attached to the ribs by means of stringers. The stringers act as stiffeners to keep the skins from buckling under extreme loads.

More thorough analysis in the future would further optimize the spar sizing. A spar with a varying cross-sectional area would greatly reduce the amount of material being used as well as weight. A finite element structural analysis program, such as CAEDS™, will be implemented in future studies of the SnoDog.



Wing Spar Cross Sectional Dimensions

	Height (in)	Width (in)	tc (in)	tw (in)
At Root	24.0	14.0	1.0	0.4
At Tip	6.0	5.0	.16	0.31

Figure 7.5 Spar Cross Section.

7.3 FUSELAGE STRUCTURAL LAYOUT

The fuselage structure was laid out using the procedure of Reference (6). Detailed structural layout of the fuselage is shown in Figure 7.6. The spacings chosen for the major frames and and longerons were:

- **Frames:** 16.0 inches
- **Longerons:** 8 .0 inches
- **Structural depth:** 2.0 inches

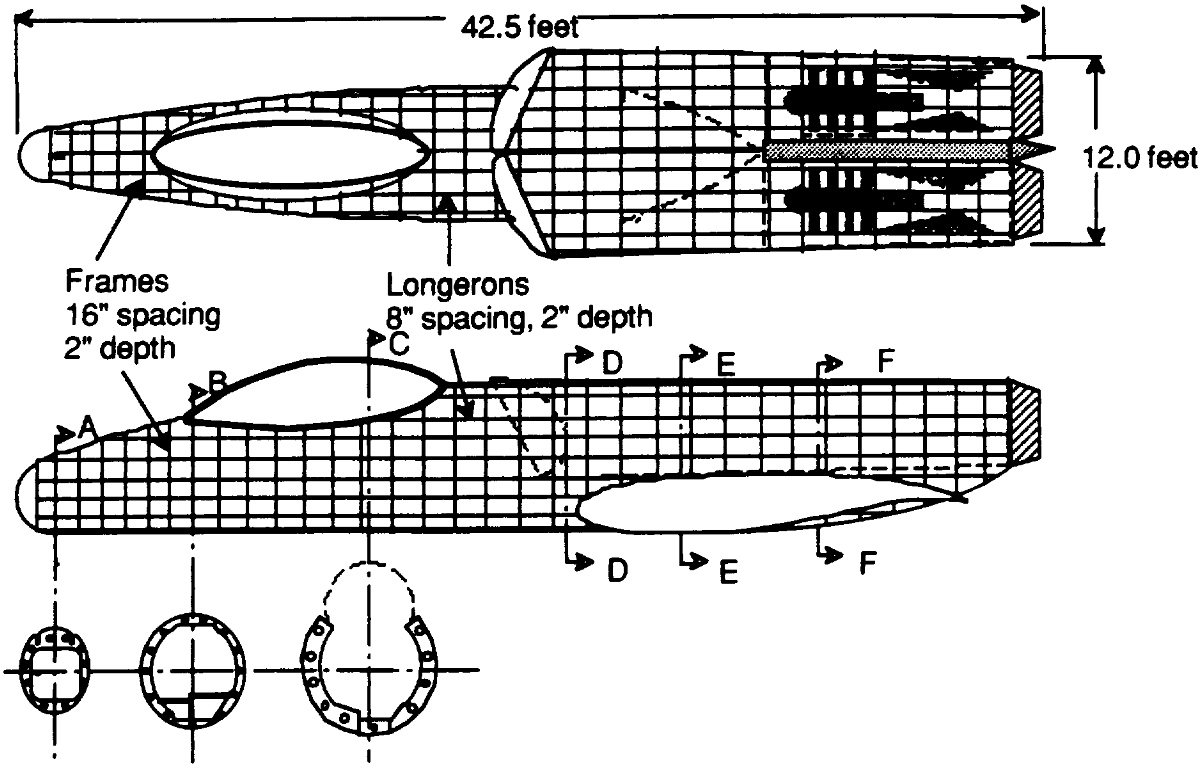


Figure 7.6 Fuselage Structural Layout.

The nose section contains the cockpit, cannon, radar, and nose gear. The radar is mounted to the bulkhead forward of the cockpit. The landing gear is installed off center on the fuselage to allow the cannon to be mounted on the side. The cannon is off-set in such way that the firing barrel would line up with the center line of the aircraft, which avoids a yawing problem when the cannon is fired.

The nose gear is mounted to the bottom of the cockpit and to stiffened fuselage frames. The cannon is attached to the ammunition drum mount, as well as to frames of it own. The ammunition drum is mounted to thickened bulkheads and the cannon is suspended from the barrel support ring and the firing block.

The major cutouts in the fuselage are the nose wheel well opening and the cockpit opening. These are strengthened by using stiffened stringers and frames around the wheel well and thickened skin around the canopy.

The typical frame structures of the aft fuselage are shown in Figure 7.7. The main loads for this section are carried by longerons in the center of each side of the aft fuselage, and these longerons bolt to the wing at several wing spar locations.

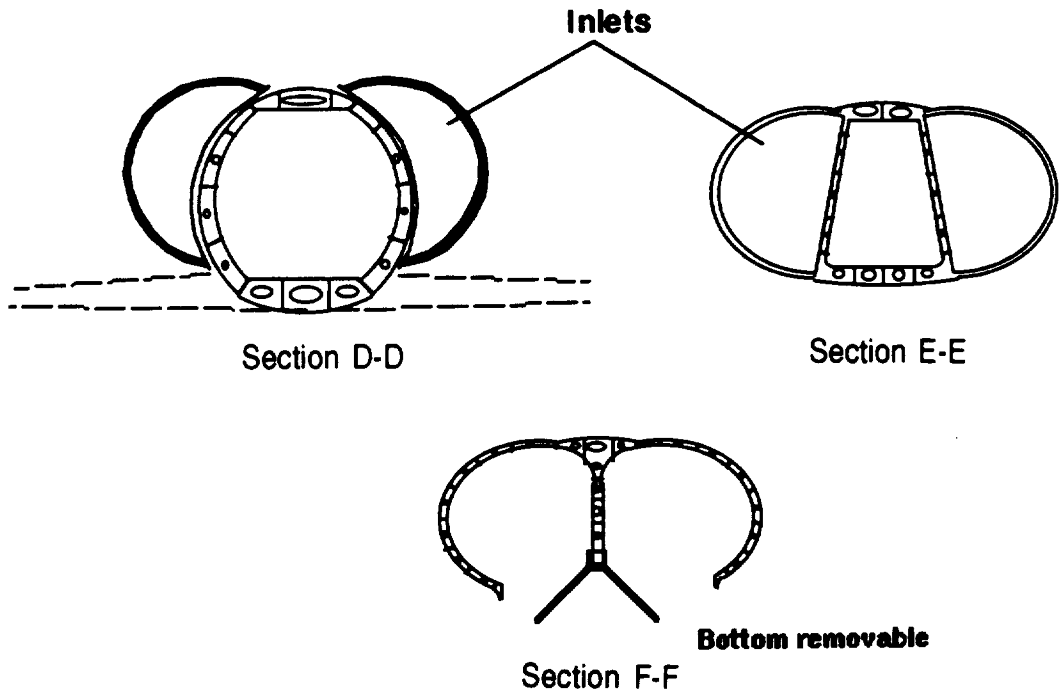


Figure 7.7 Aft Fuselage Cross Sections.

The engines are mounted to the thickened frames of aft fuselage. The Kevlar™ plating is located between engines for maximum survivability if one engine was hit. The exhaust nozzles are surrounded by titanium heat shields. The lower aft fuselage skins are removable for engine access.

7.4 FUSELAGE MATERIALS SELECTION

The fuselage of the SnoDog is built for maximum survival with light-weight structures. Following, is the materials distribution in the fuselage:

• **2024 ALUMINUM** : Fuselage structures, skins

2024 Aluminum has high-strength characteristics and is inexpensive. 2024 Aluminum is used in lightly loaded internal frames and longerons, and external skins. Using this type of material has the advantage of being easier and less expensive to repair than composite materials.

• **ARALL** : Fuselage skins

Arall (Armid - Aluminum laminate) is an advanced metal material that can be formed into sheets. Its laminate structure prevents its use in milled or extruded structure, but work wells in high stress areas. Therefore, Arall is used for fuselage skins .

• **TITANIUM** : Engine nozzles, platting between engines

• **GRAPHITE EPOXY** : Fuselage nose.

This structure allows for the radar transmission.

• **PLEXIGLAS™** : Canopy.

This material is selected for the canopy as it is lighter than glass, easily formed and readily available.

A detailed layout of the fuselage skin is shown in Figure 7.8, and the selected types of materials and thicknesses are shown in Table 7.2:

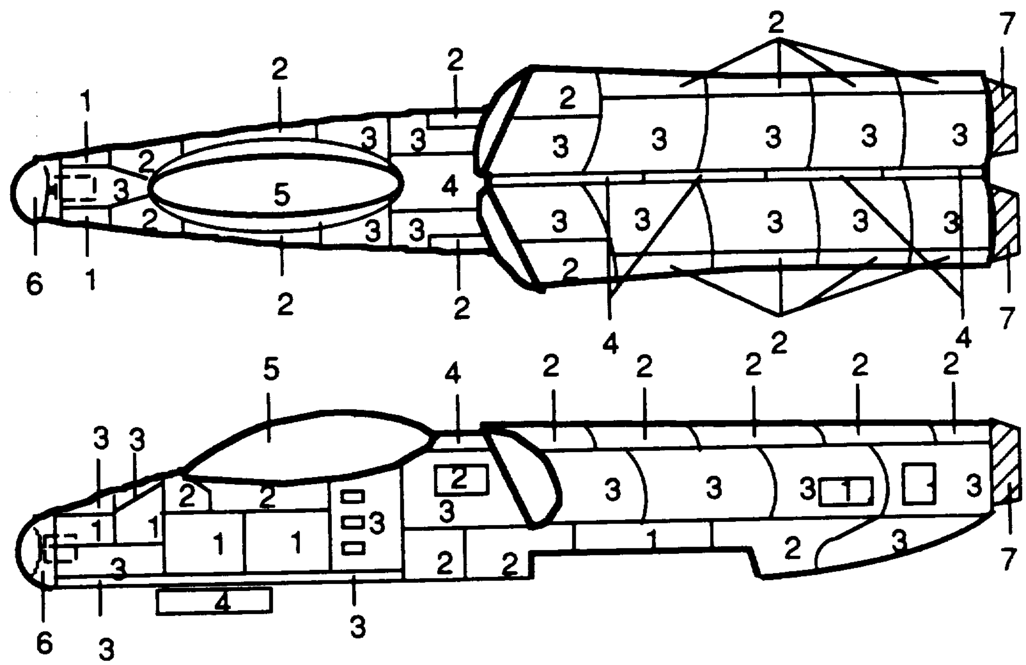


Figure 7.8 Fuselage Materials Layout.

Table 7.2 Fuselage Skin Materials

Item	Material	Thickness (inches)
1	2024 Aluminum	0.040
2	2024 Aluminum	0.045
3	Arall - (Amid-Aluminum Laminate)	0.045
4	Arall (Amid-Aluminum Laminate)	0.055
5	Plexiglas™	0.050
6	Graphite Epoxy	0.045
7	Titanium	----

7.5 BOOM STRUCTURE

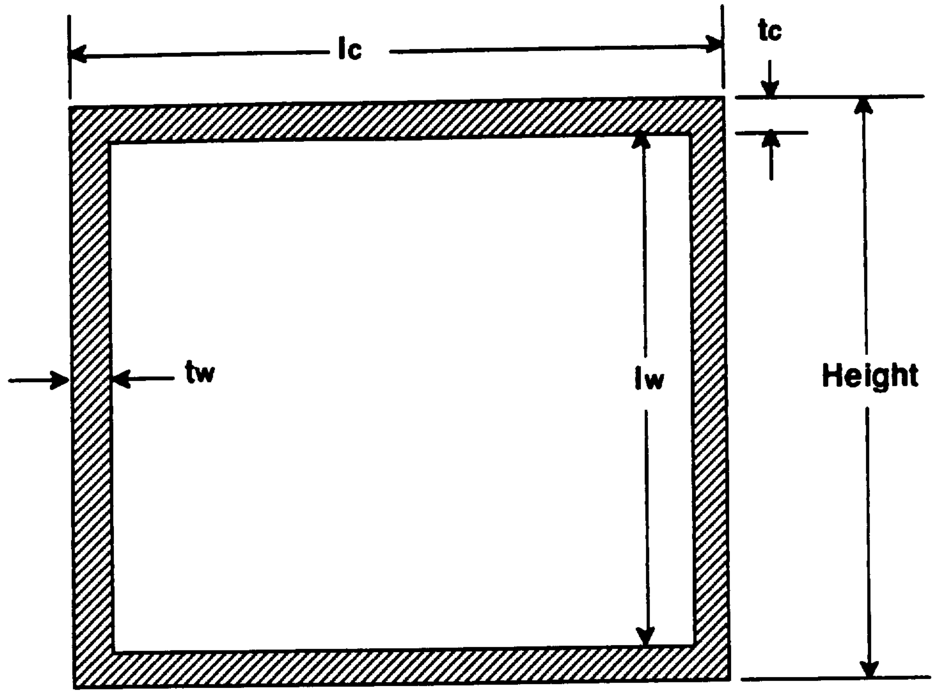
7.5.1 Boom Design

The major factor of boom design was their desired rigidity to support the weight of and the aerodynamic loads induced by the empennage. This is especially important during turning maneuvers as well as climb and dive situations. Another consideration was the survivability of the aircraft, because the booms are the only members supporting the major directional control surfaces.

With the concept of survivability and strength in mind, the booms were designed using a box type cross-section (Figure 7.9). The box configuration provides stiffness in the horizontal and vertical directions, and the hollow center allows for routing of control systems to the empennage. By analysis, or even conceptually, one can see that the bending moments generated by the empennage decrease at locations closer to the directional control surfaces so the booms are tapered as they extend toward the empennage, saving material and weight.

7.5.2 Boom Structural Analysis

The booms were sized in the same manner as the wing spars. Analysis was done using FRAMEMAC™ to obtain values of shear in the vertical direction and the bending moments about the X-axis. Analysis was done at 11.25 g's as with the wing spar analysis, and the results are depicted in Figure 7.10 and Table 7.3. Moments of inertia, shear, and bending moments were calculated for various



Boom Cross Sectional Dimensions

	Height (in)	Width (in)	tc (in)	tw (in)
At Point of Attachment	18.0	18.0	0.25	0.25
At Empennage	7.6	4.5	0.25	0.25

Figure 7.9 Boom Cross Section.

heights, widths, and thicknesses, and then compared with values calculated by FRAMEMAC™ until the values matched. A boom that is 18" X 18" at the wing attachment and 7.6" X 4.5" at the end of the tail was found to be more than adequate. A wall thickness of 0.25" was chosen with survivability in mind, and helps to protect the control lines inside each boom from small arms fire. In a worst case scenario, with one boom detached, a torque of 153,000 in-lbs is generated at the other boom.

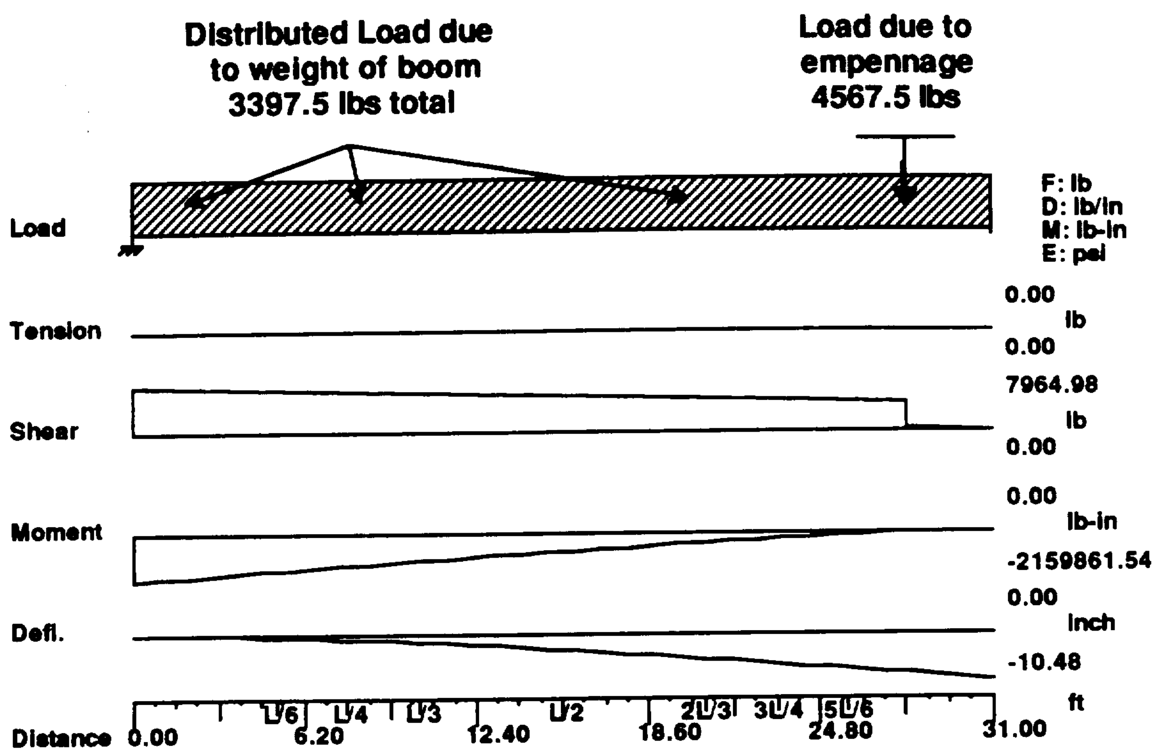


Figure 7.10 Analysis of Boom by Beam Theory.

Table 7.3 FRAMEMAC™ Analysis - Booms				
	Data from FRAMEMAC™ (Values are in lbs and in-lbs)		Calculated Design Values (Values are in lbs and in-lbs)	
Distance from POA* (ft)	Shear in Y-Direction (lbs)	Bending Moment in X-Direction (in-lbs)	Shear in Y-Direction (lbs)	Bending Moment in X-Direction (in-lbs)
0.0	7955.0 lbs	2.15×10^6	128,000	4.4×10^6
10.0	6867.0 lbs	1.27×10^6	92,444	2.5×10^6
20.0	5779.0 lbs	0.51×10^6	60,444	1.2×10^6
25.0	5214.0 lbs	0.18×10^6	46,222	0.79×10^6
27.5	4950.0 lbs	0.03×10^6	32,000	0.61×10^6

* - Point of Attachment

Using the smallest cross-section (7.6" X 4.5"), the maximum allowable torque was calculated to be 500,000 in-lbs. Using a factor of safety of 1.5, the plane can still achieve ±2.0 g's without imparting damage to the surviving boom.

7.6 EMPENNAGE STRUCTURE

The empennage was sized using similar aircraft such as the Grumman F-14 and the McDonnell Douglas F-15 and F/A -18 (Reference 17). Since the empennage did not carry any loads except those due aerodynamic loads, its structure was not as complex as that of the main wing. The horizontal tail was prone to the exhaust gases of the engines, thus it needed some form of chemical protection. Further researched resolved that an aluminum skin would provide sufficient resistance to chemical corrosion. The spars and ribs would be made from 2014-T6 aluminum alloy. This type of aluminum alloy has a very low coefficient of thermal expansion which was deemed necessary for the horizontal stabilizer. The vertical tails also employ an aluminum skin. The spars and ribs use the same 2014-T6 aluminum alloy as the horizontal tail. Aluminum was chosen for its excellent yield stress and shear stress as well as low weight (References 14,15).

8.0 STABILITY AND CONTROL

8.1 WEIGHT AND BALANCE

Component weights were estimated for the SnoDog by using average values calculated from weight equations of Reference (8) and Reference (10), and Table 8.1 lists the weights of each component and its corresponding center of gravity location. Figure 8.1 shows these center of gravity locations on the airplane.

The aerodynamic center for the SnoDog was located at 29.8% of the mean aerodynamic chord. This value was calculated using the methods of Reference (4). This aerodynamic center is farther back than most other subsonic aircraft due to the SnoDog's supercritical airfoil.

The take-off weight for the SnoDog was 51,642 pounds, which includes 12,596 pounds of payload. At this weight, the static margin was -4.37%. As the mission of the SnoDog progressed, the airplane became more unstable. This is a desirable characteristic, because the airplane will become more maneuverable as it approaches its target. The static margin at an empty weight of 26,726 was -10.19%.

Because of the SnoDog's inherent static instability, a stability augmentation system is required. Four flight control computers were incorporated into the SnoDog's design to provide redundant flight controls and a feedback system.

Figure 8.2 shows the center of gravity excursion. The static margin changes from -1.79 % to -11.65%. This corresponds to a center of gravity travel of only 13 inches or 9% of the mean aerodynamic chord. The most forward center of gravity occurs when the airplane is carrying only ammunition. This

Table 8.1 Weight and Balance

	WEIGHT	X CG LOCATION	Z CG LOCATION
Wing	4307	463.4	186.9
Fuselage	3576	320	199.7
Horizontal Tail	435	794.9	286.7
Vertical Tail	377	793.6	247
Nose Gear	304	160	175.4
Main Gear	1235	530	176.6
Nacelles	126	524.8	217
Booms	604	662.4	181.76
Engine	6388	538	216.32
Air Induction system	592	427.5	216.32
Fuel System	550	473	236.8
Engine Controls	24	205	211.2
Engine Starting System	214	450	211.2
Flight Control System	814	640	217.6
Hydraulics and Pneumatics	346	556.8	180
Electrical System	587	403	204.8
Instruments	134	204.8	211.2
FLIR	429	480	165.12
LANTIRN	429	480	165.32
Radar	160	121.6	192
Chaff-flare dispenser	389	563.2	185.5
Antennas	40	794	255
Avionics	300	323.2	224
Air cond, anti-ice, pressure	386	397	187
Oxygen System	17	243	295
APU	225	448	236.8
Furnishings	272	256	211.2
Armament	445	352	211
Launchers and racks	956	460.8	166.4
Gun	1840	262.4	179.2
Paint	225	428	217.6
Trapped fuel and oil	250	473.6	186.9
Crew	225	243	294.4
Wing fuel tanks	11845	448	182.4
Ammunition	2106	320	189.44
Bombs - inboard	5050	448	157.44
Bombs - outboard	5050	475	160
Sidewinders	390	535	198.5
		CG X	CG Z
EMPTY WEIGHT	26726	458.9745753	200.7578276
OPERATING EMPTY WEIGHT	27201	457.3225065	201.4050476
TAKEOFF WEIGHT	51642	450.9877522	188.1877995

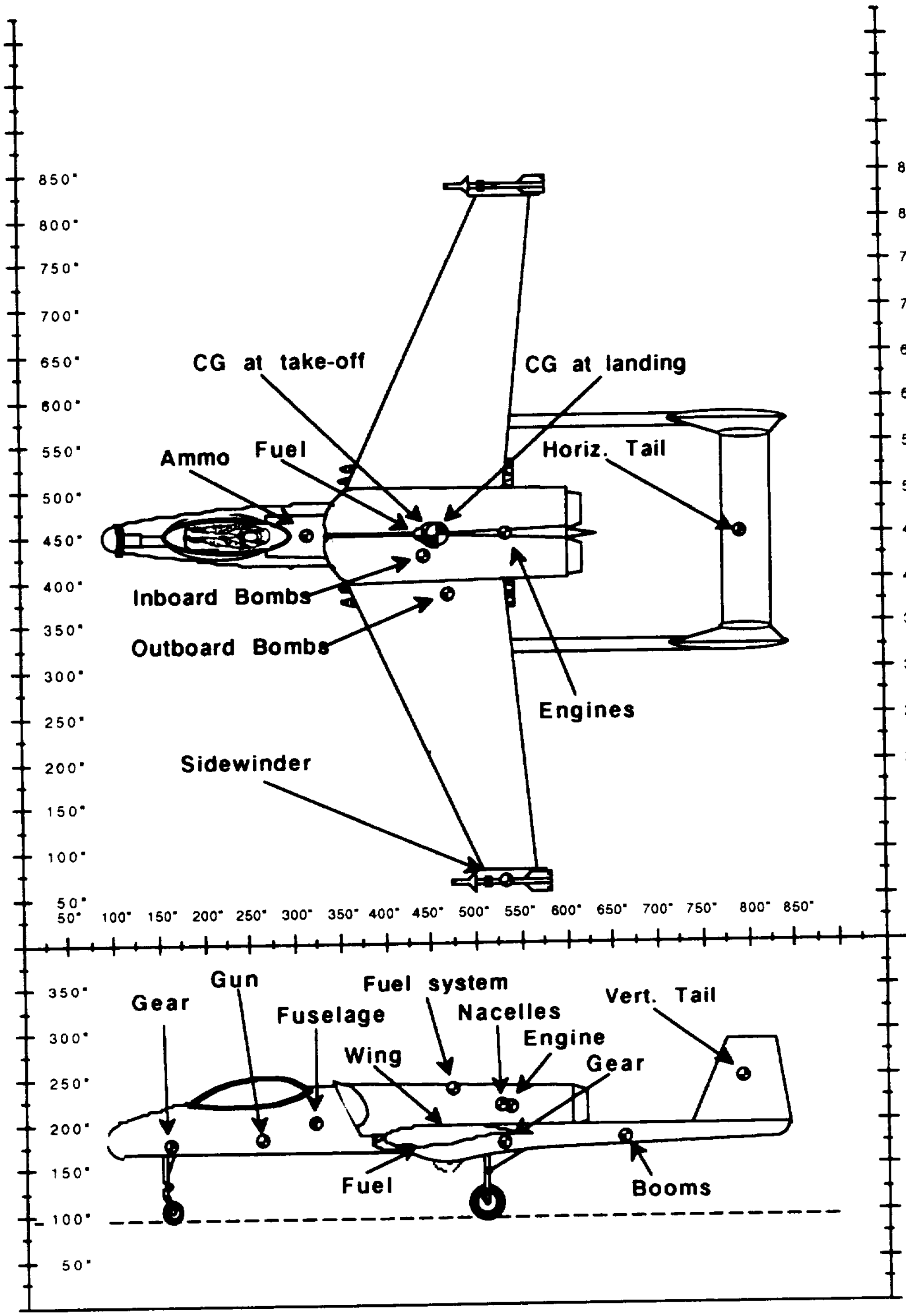


Figure 8.1 - CG Locations.

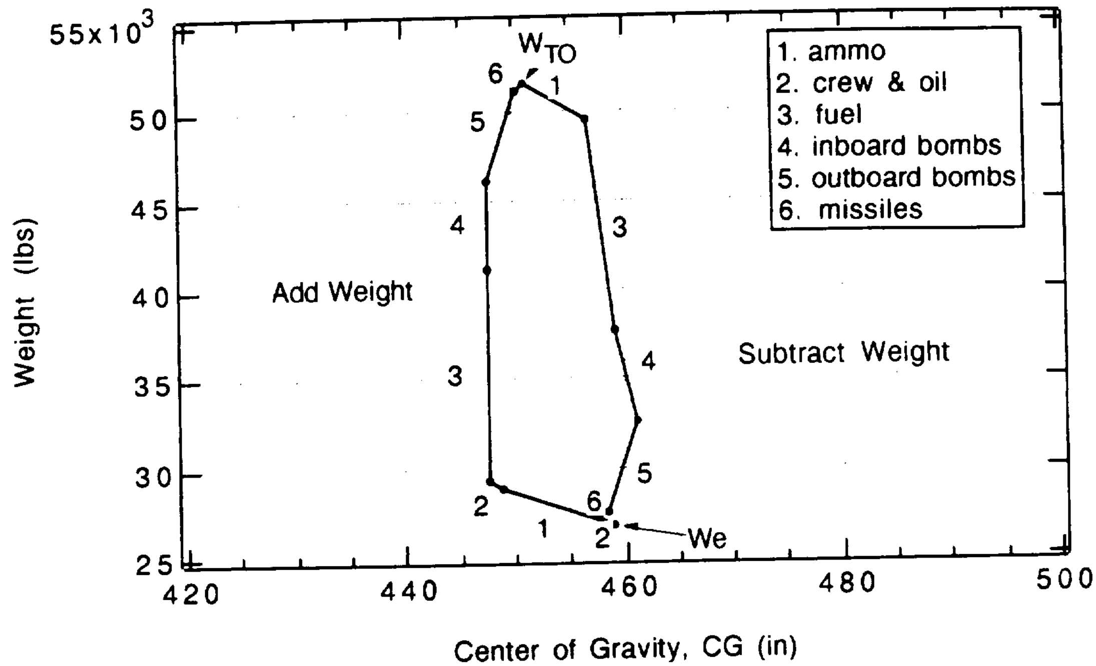


Figure 8.2 Center of Gravity Excursion.

would be the condition when the airplane is the most stable. This condition will not occur during a typical mission except when landing. This is a desirable quality since a stable aircraft is better for landing conditions.

8.2 STABILITY DERIVATIVES

Stability derivatives for the SnoDog were calculated using the methods of References (4) and (18). Two flight conditions from the design mission profile were chosen for derivative calculations, and these flight conditions are presented in Table 8.2.

Table 8.3 lists the calculated longitudinal and lateral stability derivatives of the SnoDog for each flight condition, along with estimated accuracies of

Table 8.2 Flight Conditions		
	A	B
Phase	Cruise	Approach
Configuration	Full Stores	Missiles, Gear, and Flaps
Altitude	Sea Level Std	Sea Level Std
Mach number	0.756	0.196
Fuel (%)	44.10	17.16
Aircraft Wt (lbs)	45021	31730
Static Margin (%MAC)	-4.62	-2.77
Ixx (slug-ft2)	6459	3739
Izz (slug-ft2)	109598	106196
Iyy (slug-ft2)	103140	102457
Ixz (slug-ft2)	4843	5651

each derivative (Reference 19). The SnoDog was designed to be longitudinally unstable for increased maneuverability over that of existing subsonic attack aircraft, which can be seen by the positive values of $C_{m\alpha}$ for both flight conditions. This longitudinal instability will require a digital fly-by-wire control system for the aircraft. The control system will add cost to the development, production, and maintenance of the SnoDog, but the added advantages of reduced pilot workload along with the capability of increased maneuverability, greatly outweigh the cost.

The sizing of the horizontal stabilizer was critical to the stability performance of the aircraft due to the desired longitudinal instability. The actual size of the stabilizer was constrained due to the twin boom design, and the desired inward-canted vertical stabilizers. This fixed the span due to the location of the tips of the vertical stabilizers. The chord was sized using the volume-coefficient method of Reference (3), and the resulting area was found to be adequate for the amount of instability desired.

The vertical stabilizers were also initially sized using the volume-coefficient method of Reference (3). It was concluded however, that the initial

Table 8.3 Static Stability Derivatives

Steady State Coefficients			
C_{L1}	0.0816	0.8554	
C_{D1}	0.0240	0.0982	
C_{m1}	-0.1509	-0.1667	
Longitudinal Derivatives			**Estimated Accuracy**
C_{Lu}	0.0000	0.0000	± 20 %
C_{mu}	0.0831	0.0300	± 20 %
C_{Du}	0.0000	0.0000	± 20 %
$C_{L\alpha}$	9.4137	5.3397	± 5 %
$C_{m\alpha}$	0.4345	0.1479	± 10 %
$C_{D\alpha}$	0.1018	0.6294	± 10 %
$C_{L\alpha}$	0.1743	0.1751	± 40 %
$C_{m\alpha}$	-0.2075	-0.2085	± 40 %
$C_{D\alpha}$	0.0000	0.0000	± 50 %
C_{Lq}	0.0000	0.0000	± 20 %
C_{mq}	-2.9831	-1.1446	± 20 %
C_{Dq}	0.0000	0.0000	± 30 %
Lateral/Directional Derivatives			**Estimated Accuracy**
$C_{l\beta}$	-0.04315	-0.17401	± 20 %
$C_{n\beta}$	0.11730	0.11150	± 20 %
$C_{y\beta}$	-0.84211	-0.84211	± 20 %
$C_{l\beta}$	-0.00015	-0.00016	± 5 %
$C_{n\beta}$	-0.00099	-0.00105	± 10 %
$C_{y\beta}$	-0.00228	-0.00242	± 10 %
C_{lr}	0.05870	0.20756	± 40 %
C_{nr}	-0.00933	-0.02383	± 40 %
C_{yr}	0.61299	0.75397	± 50 %
C_{lp}	-0.22910	-0.34321	± 20 %
C_{np}	-0.01938	0.00376	± 20 %
C_{yp}	-0.05601	-0.05601	± 30 %

sizing produced too much lateral/directional stability, and the fin sizes were reduced to increase maneuverability. This decrease in size also helped reduce the small amount of compressibility drag present at cruise condition.

The control derivatives of the SnoDog fall within acceptable ranges given in References (4) and (19), and are presented in Table 8.4. The elevator size was initially too small, but was increased due to the need for greater elevator power for take-off rotation and to counter the aircraft's longitudinal pitching moments.

Table 8.4 Control Derivatives

Cd_{ih}	0.0000	0.0000
Cl_{ih}	0.9308	0.9222
Cm_{ih}	0.0558	0.0565
$Cd_{\delta e}$	0.0000	0.0000
$Cl_{\delta e}$	0.6491	0.6431
$Cm_{\delta e}$	0.0249	0.0252
$Cy_{\delta a}$	0.0000	0.0000
$Cl_{\delta a}$	0.0466	0.0585
$Cn_{\delta a}$	-0.0008	-0.0132
$Cy_{\delta r}$	0.4825	0.4825
$Cl_{\delta r}$	0.0160	0.0160
$Cn_{\delta r}$	-0.2028	-0.2028

It should be noted that the analytical methods for determining stability derivatives listed in Table 8.3 are fairly inaccurate. To increase accuracy and develop a meaningful discussion of static stability, it would be necessary to at least perform scale model wind tunnel tests; but, ideally, flight test results would be used.

Elevator trim angles were computed for the cruise and approach flight conditions, and were found to be 3.24° and 6.90° respectively. The corresponding trim angles of attack were -0.07° and 6.61°.

Stability performance of the SnoDog was analyzed for flight with one engine out. Due to the engine locations being close to the centerline of the aircraft, the asymmetric thrust produced negligible yaw; and only 1.58° of rudder input is necessary to trim for this condition.

8.3 DYNAMIC STABILITY

Modal frequencies and damping ratios for the SnoDog are shown below in Table 8.5, and are calculated using the approximations found in Reference (20). Exact analytical solutions are not used because of the general inaccuracy in the known methods for determining the stability derivatives. The calculated values were compared to empirically determined values given in Reference (20) to predict handling qualities which range from level 1 to level 3, level 1 being the desired goal and level 3 being unacceptable. The handling qualities calculated for the SnoDog were unacceptable for several stability modes, and this confirmed the need for a stability augmentation system. Feedback gain settings using optimal control theory have not yet been determined.

Table 8.5 Modal Frequency and Damping Ratios

Mode	Cruise		Approach	
Short Period	omega = 5.14 zeta = .137	unacceptable	omega = 1.11 zeta = .08	level 1
Phugoid	omega = .066 zeta = .169	level 1	omega = .210 zeta = .012	level 2
Dutch Roll	omega = 6.05 zeta = .042	level 2	omega = 1.55 zeta = .071	level 2
Spiral	t(1/2)=.395	unacceptable	t(1/2)=2.031	unacceptable
Roll	tau = .022	level 1	tau = .033	level 1

9.0 PERFORMANCE

9.1 TAKE-OFF AND LANDING

The mission specifications for the SnoDog require that it be able to operate from a 2000 foot airstrip. It was therefore necessary to calculate the ground-roll needed for the SnoDog on take-off and landing to ensure compliance with the specifications. Both ground-rolls were calculated using the method of Reference (21). Using propulsion and weight data, and assuming a concrete runway, a take-off ground-roll of 1748 feet was calculated. This exceeded the mission specification by 252 feet, 1.2 seconds from the end of the runway using a lift-off velocity of 212 ft/sec.

The landing ground-roll was calculated to be 1181 feet for the completed design mission, far exceeding the mission specification. However, it was necessary to calculate the ground-roll for an emergency landing immediately following take-off. For the fully loaded SnoDog, a landing ground-roll was calculated to be 1995 feet.

9.2 SPECIFIC EXCESS POWER

Power available curves were calculated for the SnoDog using engine data for altitudes of sea level, 10000 feet, 20000 feet, 30000 feet, and 40000 feet. Power required curves were calculated using results from the calculated drag polars and lift coefficients. Specific excess power curves were then produced, and these curves were used to calculated climb performance of the

SnoDog. The specific excess power is depicted in Figure 9.1. It should be noted that compressibility effects were not taken into account when computing specific excess power. Therefore the excess power at the higher Mach numbers would actually be lower.

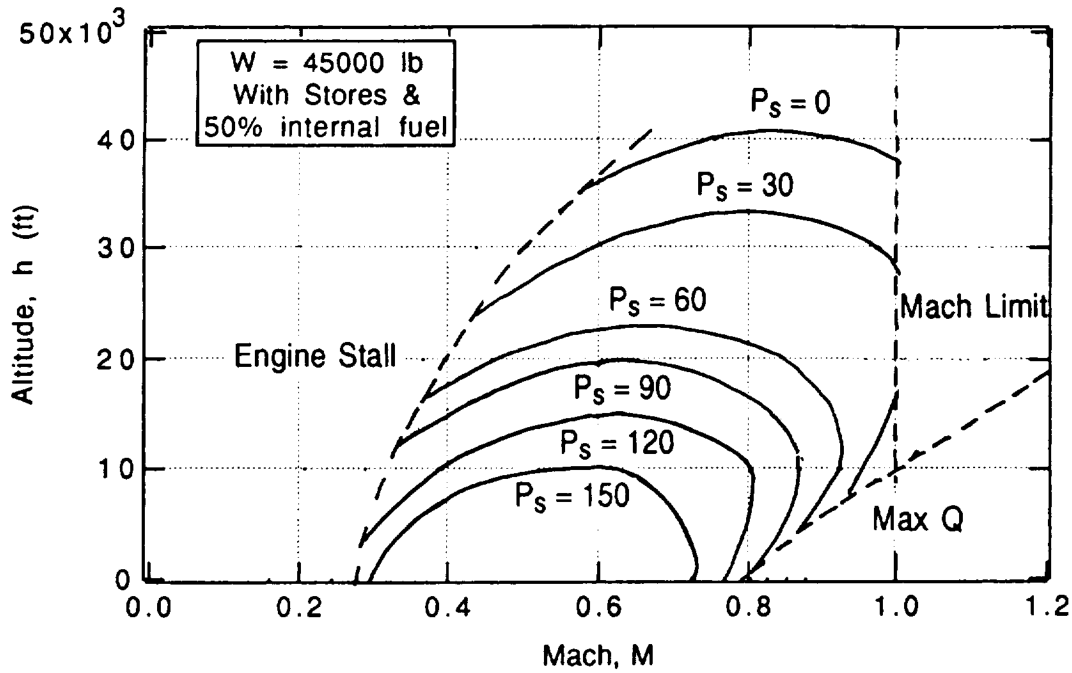


Figure 9.1 Specific Excess Power (ft/s).

9.3 CLIMB

There were no mission requirements specified for climb gradient or rate of climb. However, the SnoDog must meet the take-off and approach climb gradients required by military specifications. At take-off, the climb gradient must be 0.005 with one engine inoperable. A climb gradient of 0.0247 was attained, which easily meets the requirement. For landing approach, a climb gradient of 0.025 was required and a climb gradient of 0.110 was attained.

Figure 9.2 shows the rate of climb versus altitude for the SnoDog at combat weight. At sea level, the aircraft can climb at a rate of 12,794 feet per minute. When the aircraft is not carrying external stores the climb rate goes up to 17,768 feet per minute.

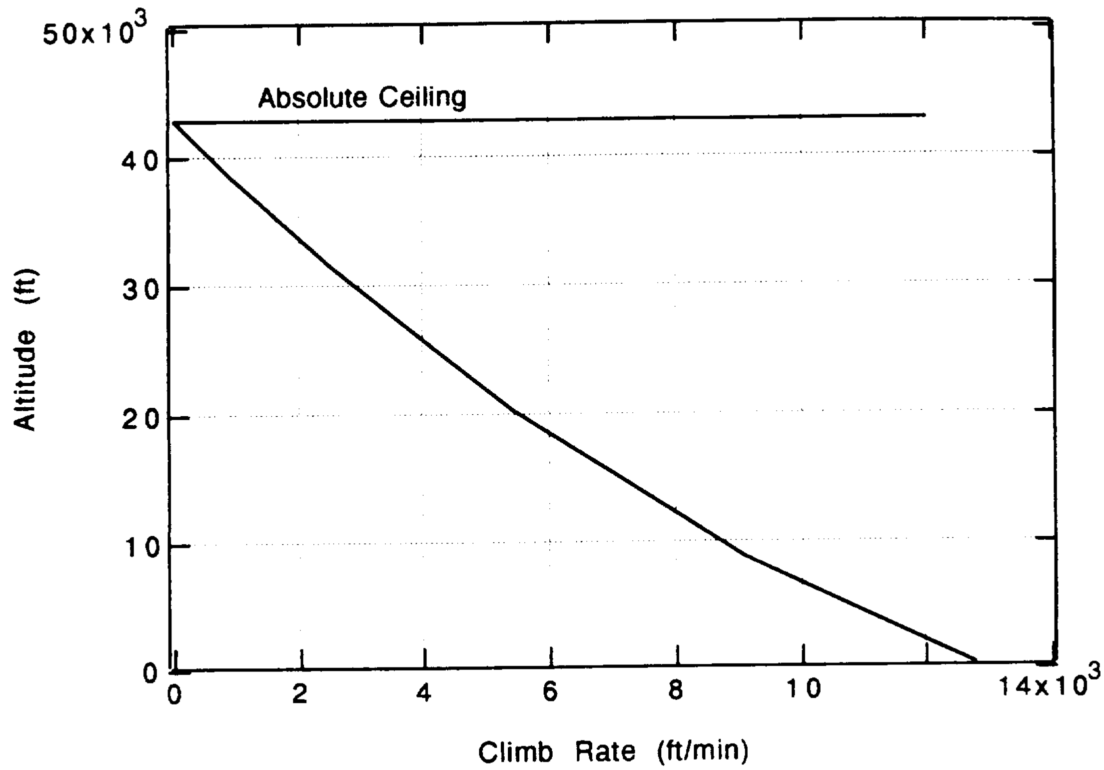


Figure 9.2 The Variation of Rate of Climb with Altitude.

The SnoDog's altitude ceilings were estimated using the specific excess power calculated for cruise, and are as follows:

Combat ceiling = 40443 feet
Cruise ceiling = 41389 feet
Service ceiling = 42345 feet
Absolute ceiling = 42826 feet

Since the SnoDog is a low level aircraft, these ceilings are more than adequate. For ferry missions the aircraft will cruise at 30,000 feet, which is still well below the cruise ceiling.

9.4 FUEL CONSUMPTION

The SnoDog uses two low bypass turbofan engines so the fuel consumption is lower than that for turbojets. At sea level dash speeds of 500 knots, the thrust specific fuel consumption is about 0.8. When cruising at 30,000 feet the specific fuel consumption goes down to about 0.74.

Reference (1) required that the SnoDog complete three mission profiles. These were a low level mission, a high-low-low-high mission, and a ferry mission. The fuel used for each mission is shown in Table 9.1. The maximum internal fuel capacity of the SnoDog was 11,900 pounds.

Table 9.1 Mission Fuel Loads

Mission	Takeoff Weight	Fuel Weight	Range Nm	Loiter Time
Design	51642	11845	500	20 min (reserve)
H-L-L-H	51642	11845	500	16 min (pre-combat)
Ferry	38382	11190	1500	20 min (reserve)

To complete the design mission and still have 20 minutes of reserve fuel, the SnoDog must carry 11,845 pounds of fuel. At a dash speed of 500 knots the lift-to-drag ratio is about 2.7. This low value is caused by the drag due to weapon stores and the high speed.

Using the same amount of fuel for the high-low-low-high mission, the SnoDog was able to loiter for 16 minutes before combat and still have 20 minutes of reserve fuel. When cruising at 30,000 feet with stores, the SnoDog can attain lift-to-drag ratios of up to 9.7. This greatly increases fuel economy.

The ferry mission required a range of at least 1,500 nautical miles. This was accomplished by cruising at 30,000 feet with 11,190 pounds of fuel. As an option, the aircraft can carry up to four 300 gallon external fuel tanks for a total of 19,700 pounds of fuel. With this fuel, the aircraft could travel a total distance of 2,350 nautical miles.

The equations used to calculate best cruise speed and lift-to-drag ratios were from Reference (8) and are as follows:

$$V_{best\ range} = sqrt(2W/\rho S * Sqrt(3/ \pi\ e\ A\ C_{Do}))$$

$$C_{L\ best\ range} = sqrt(C_{Do}\ \pi\ e\ A/\ 3)$$

$$C_D = C_{Do} + C_L^2/ \pi\ e\ A$$

$$C_{L\ min\ drag} = sqrt(C_{Do}\ \pi\ e\ A) \qquad \text{for loiter}$$

The ferry mission range calculation was broken up into three 500 nautical mile segments. This accounted for the weight decrease as fuel was burned.

In conclusion, the SnoDog can complete all three missions with internal fuel.

9.5 MANEUVERING FLIGHT

Mission specifications require the aircraft with 50% internal stores, traveling at a combat speed of 450 kts at sea level, to be able to sustain a 4.5 g level turn, and an instantaneous 6.0 g level turn. In addition, the aircraft must also be capable of re-attacking (time between first and second weapons release) in less than 25 secs. The criteria for these requirements to be met are that the maneuvering lift coefficient ,C_{Lman}, be less than the aircraft's maximum lift coefficient , C_{Lmax} , and that thrust available,T_{avail} be less than thrust required, T_{req}. The SnoDog met the requirements and is capable of a maintaining a sustained 7.48 g level turn at a bank angle of 82.32°, a turning rate of 18.02°/sec, and a turning radius of 2415.36 ft. Re-attack time under these conditions was calculated to be 19.98 secs.

9.6 LEVEL ACCELERATION

An additional performance requirement to be met by the SnoDog carrying standard stores with 50% fuel was the capability to accelerate from Mach 0.3 to 0.5 at sea level in less than 20 sec. This required an acceleration of approximately 11.2 ft/s^2. The SnoDog, under the above constraints, met the acceleration requirement, and can accelerate at a rate of 13.8 ft/s^2 which corresponds to a time of acceleration of 16.17 sec.

9.7 PERFORMANCE SUMMARY

Table 9.2 presents a summary of the performance parameters calculated for the SnoDog. These parameters were compared with the performance of the close air support aircraft used today by the U.S. Military, the Fairchild A-10. These data were obtained from References (17,22,27). Some performance paramaters for the A-10 were not available, but the SnoDog's performance clearly exceeds that of the A-10 based on the data available. The SnoDog also clearly meets all the performance specifications of Reference (1).

Table 9.2 Performance Summary & Comparison

Parameter	Required	SnoDog	A-10
Take-off ground roll	2000 feet	1748 feet	4000 feet
Landing ground roll	2000 feet	1995 feet (max)	2000 feet
Take-off climb gradient	0.005 *	0.0247	NA
Approach climb gradient	0.025 *	0.110	NA
Sea level climb rate (stores)	NR	12800 ft/min	6000 ft/min
Sea level climb rate (clean)	NR	17800 ft/min	NA
Service ceiling	NR	42300 feet	45000 feet
Absolute ceiling	NR	42800 feet	NA
Maximum speed	NR	500 kts	380 kts
Combat speed	NR	450 kts	380 kts
Re-attack time	< 25 sec	20 sec	18 sec
Turn Radius (combat speed)	NR	2420 feet	1200 feet
Turn Rate	NR	18 °/sec	25 °/sec
Time to Accelerate (from M=0.3 to M=0.5)	< 20 sec	16.2 sec	NA
Max Range (internal fuel)	1500 nm	1556 nm	2300 nm
Sustained loadfactor	4.5 g	7.48	NA
Instantaneous loadfactor	6.0 g	7.50	NA

* Military Specifications with one engine inoperable
NR - Not required
NA - Not available

10.0 SYSTEMS

10.1 COCKPIT LAYOUT

The SnoDog cockpit was designed for a single pilot and accentuates visibility, minimal pilot workload, and minimal pilot distraction. Figure 10.1 shows the SnoDog cockpit layout and visibility vectors. Table 10.1 compares the visibility from the cockpit of the SnoDog with the required visibility dimensions from Reference (6).

Table 10.1 Cockpit Dimensions and Visibility

Dimensions	Required	Achieved
Over the Nose	11°	15°
Head Clearance	3 inches	3.2 inches
Canopy Width	32 inches	44.8 inches
Frame Width	30 inches	36 inches
Over the Side	N/A	45°
Seat Tip Back	N/A	30°

The HOTAS (Hands On Throttle And Stick) concept has been utilized in the SnoDog to minimize pilot workload and reduce in-cockpit visual tasks. All instruments are function grouped and placed within easy sight of the pilot.

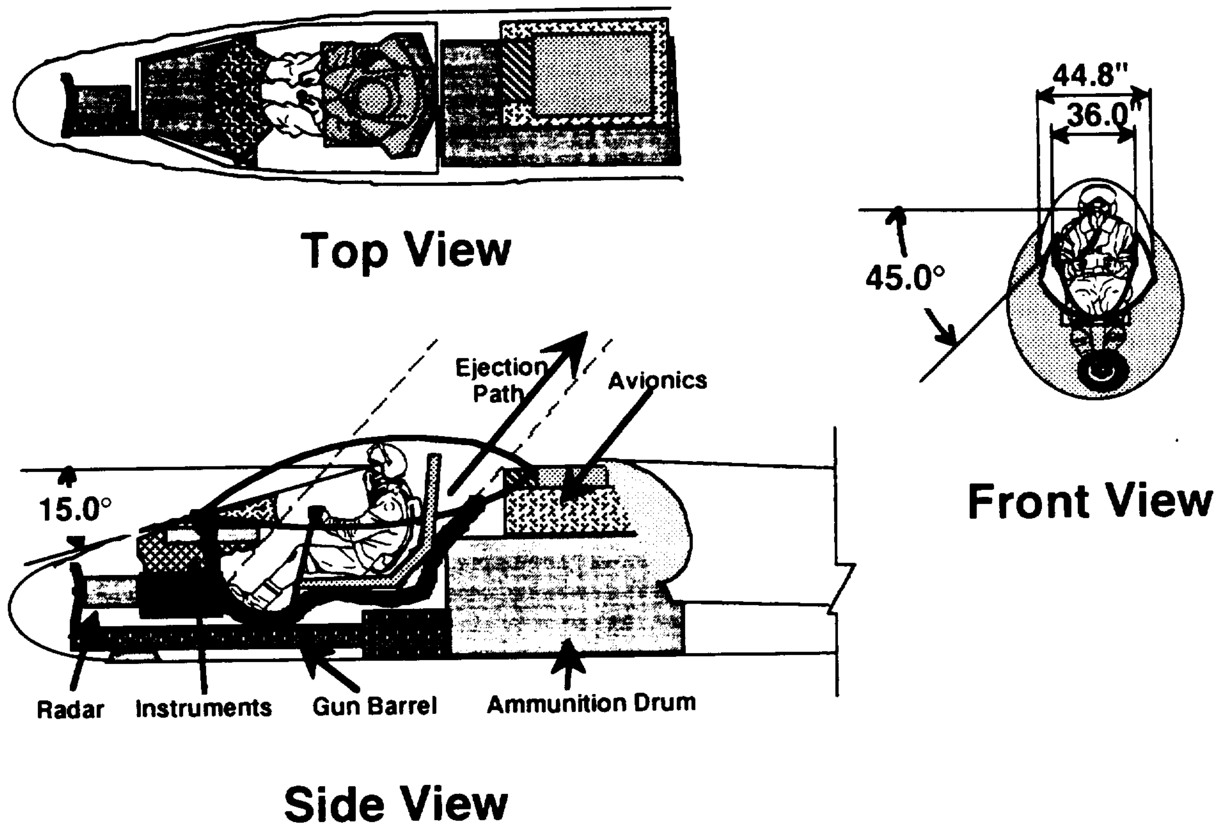


Figure 10.1 Cockpit Layout and Visibility

The SnoDog is equipped with a zero-zero ejection seat. The ejection seat clearances are shown in Figure 10.1. A centrally mounted control stick has been incorporated to facilitate pilot comfort and ease of operation.

10.2 AVIONICS

The avionics chosen for the SnoDog reflect the requirement for low cost while satisfying all mission objectives. The avionics and equipment can be categorized into six systems. These are:

1. Communications System
2. Navigation System
3. Targeting and Weapons System
4. Data Display System
5. Data Processing System
6. Electronic Counter Measures (ECM)

The projected production date for the SnoDog is the year 2000. In light of rapidly changing technology in the area of electronics and avionics, it would seem imprudent to select specific components and specify their model numbers, cost, etc. Instead, it is assumed that the specific avionics for the SnoDog will be selected by balancing cost and state-of-the-art equipment at the time of development. Similar systems will be presented here to provide a basis of comparison. The layout of the avionics system is shown in Figure 10.2.

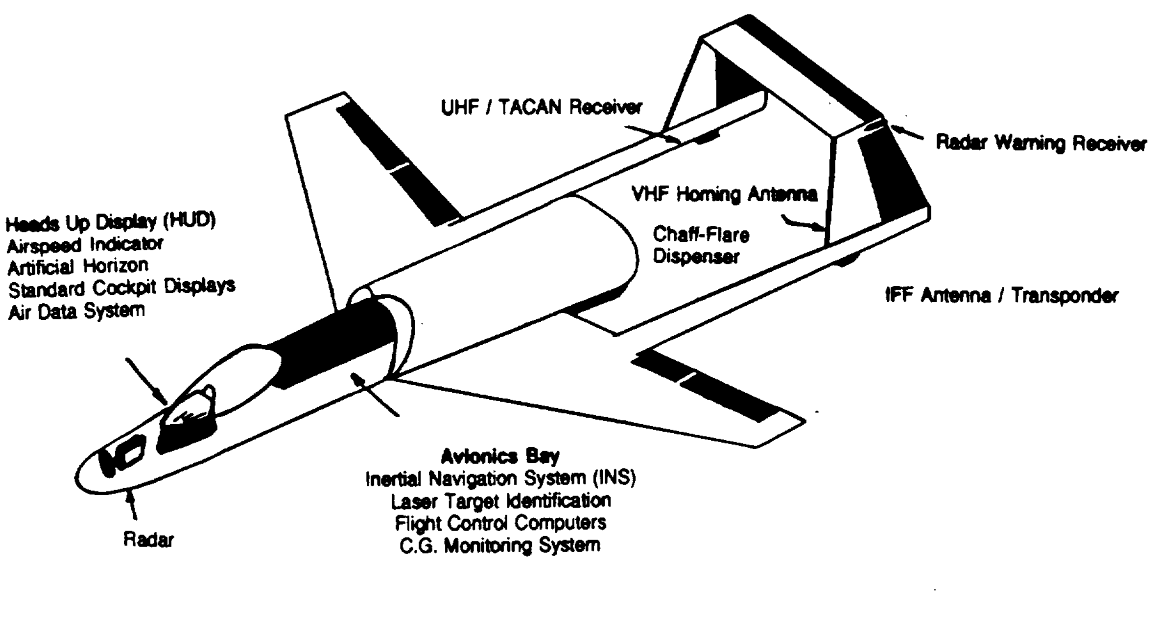


Figure 10.2 SnoDog Avionics Layout.

10.2.1 Communication System

Table 10.2 lists the components of the communication system.

Table 10.2 Communication System Components
IFF Antenna/Transponder UHF/TACAN Receiver VHF/AM Homing Antenna

The SnoDog incorporates standard communication devices typical of aircraft of its type. (Reference 22)

10.2.2 Navigation System

Table 10.3 lists the components of the navigation system.

Table 10.3 Navigation System Components
Inertial Navigation System (INS) TACAN Receiver Radar Altimeter Instrument Landing System LANTIRN

Although Tactical Air Navigation (TACAN) systems are generally less expensive than inertial navigation systems (INS) (Reference 23), the low level flight requirements and the design mission justify the expense of an INS. However, for longer flights and as a backup navigation system, a TACAN receiver will be installed. As the SnoDog will be flying quite low and often in adverse conditions, a radar altimeter with a built-in ground proximity warning system will be used, as will a standard instrument landing system. Finally, the SnoDog will be fitted with LANTIRN (Low Altitude Navigation and Targeting by Infrared at Night). This system consists of two self-contained pods carried beneath the wing, one for navigation and one for targeting, and houses both a Terrain Following Radar (TFR) and Forward-Looking Infra-Red system (FLIR) (Reference 22). The navigation and targeting information are displayed on the HUD. This highly effective package is currently used on the Fairchild A-10, the McDonnell Douglas F-15, and the General Dynamics F-16 (Reference 22).

10.2.3 Targeting and Weapons System

Table 10.4 lists the components of the Targeting and Weapons System.

Table 10.4 Targeting and Weapons System
Radar Laser Target Identification System LANTIRN

The radar chosen for the SnoDog will be a simple, small, look-ahead radar, similar to the radar chosen for the Northrop F-5 (Reference 23). A laser target identification system will be installed, much like the one used on the Fairchild A-10 (Reference 22). This system will allow the SnoDog to acquire targets designated by forward air controllers, and display the targeting information on the HUD. The dual navigating and targeting system LANTIRN, discussed above, is included here.

10.2.4 Data Display System

Table 10.5 lists the components of the SnoDog Data Display System.

Table 10.5 Data Display System Components
Heads Up Display (HUD) Airspeed Indicator Artificial Horizon Standard Cockpit Displays

The SnoDog data display system emphasizes low cost and simplicity. Standard cockpit displays are used, including an airspeed indicator and artificial horizon. A heads up display will show navigation and targeting information. This display will need to be slightly more sophisticated than the one used in the Fairchild A-10 to recognize advances in technology (References 22,23).

10.2.5 Data Processing System

Table 10.6 lists the components of the Data Processing System.

Table 10.6 Data Processing System
Flight Control System Air Data System CG Monitoring System

The data processing system for the SnoDog will be slightly more complex than the Fairchild A-10 due to the Fly-By-Wire system the SnoDog employs. It includes a flight control system, an air data system, and a center of gravity monitoring system.

10.2.6 Electronic Counter Measures

The components of the electronic countermeasures used by the SnoDog are shown in Table 10.7. The SnoDog uses little in the way of electronic countermeasures. A standard chaff-flare dispenser, similar to the rather large one used by the Fairchild A-10 will be included (Reference 23). A hardpoint will be provided for an ECM (electronic counter measures) pod as a customer option.

Table 10.7 ECM Components
Chaff-flare Dispenser Optional ECM Pod

The avionics chosen for the SnoDog reflect the current technology and perceived needs in order for the mission of close air support to be successful. There should remain, however, an attitude of flexibility towards these choices. As technology improves, one should not hesitate to update these selections.

10.3 FLIGHT CONTROL SYSTEM

The flight control system for the SnoDog is shown in Figure 10.3. The SnoDog's inherent instability necessitates the use of a digital fly-by-wire system. Rather than employing a conventional hydraulic system, the control surfaces are moved using electrohydrostatic (EHS) actuators. These electrically signalled devices have self-contained hydraulic pumps and motors and are sized to be interchangeable along any control surface (Reference 24).

The selection of the EHS system over a traditional hydraulic system was based on a tradeoff. Although it is easier in hydraulic systems to locate and fix problem spots (Reference 25), they are inherently heavier and bulkier than electrical systems (Reference 26). These features are magnified when considering a separate hydraulic system should be added for redundancy and

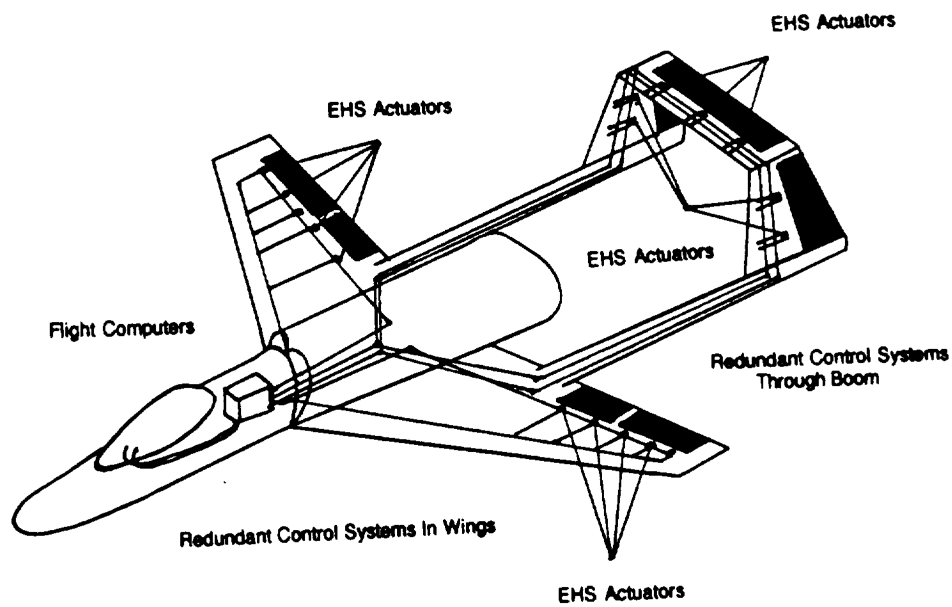


Figure 10.3 SnoDog Flight Control System.

increased survivability. In addition, one hit could conceivably cripple the entire hydraulic system, whereas if a part of the EHS system were hit, only one actuator on one control surface would be affected.

The SnoDog's flight control system has four interactive flight control computers, generating a single output. Each of the four computers is capable of guiding the control system independently, in the event of failure (Reference 23).

10.4 HYDRAULIC CONTROLS

The hydraulic system for the SnoDog is independent of the flight control system. The approximately 3,000 psi hydraulic system controls the landing gear, wheel brakes, and nose-wheel steering. The pumps are engine-driven, with an auxiliary system run from the APU.

10.5 FUEL SYSTEM

The fuel system for the SnoDog is shown in Figure 10.4. The system consists of four internal fuel tanks, pumps, fuel lines, a venting system, and a fuel management system.

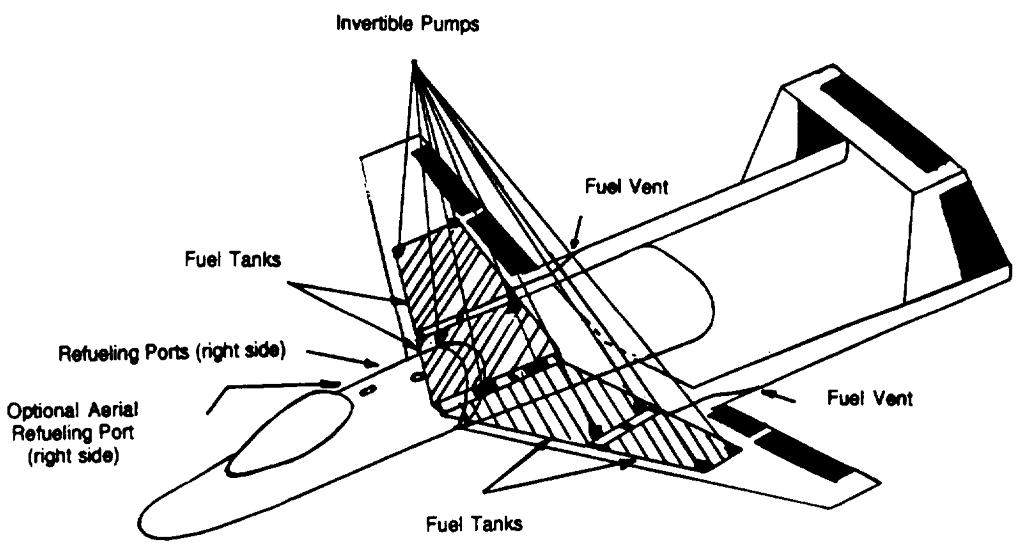


Figure 10.4 SnoDog Fuel System.

The fuel is contained in four self-sealing, bladder tanks located in the wings. Each tank has several compartments utilizing one-way valves for fuel management. In addition, each compartment has an individual, invertible fuel pumps. Excess fuel is vented from the underside of the wing, near the boom junction. The refueling port is located on the right side of the fuselage. The SnoDog has the capability of carrying four external fuel tanks, each carrying a fuel volume of 300 gallons.

A fuel management system will be utilized to minimize c.g. travel, optimize fuel flow, and relocate fuel in the event one of the tanks is damaged.

10.6 ELECTRICAL SYSTEM

The SnoDog relies on a standard electrical system. The primary power system is engine-driven, with the APU (auxiliary power unit) and batteries providing power for the backup system. The electrical system provides power for the following:

- internal and external lighting
- flight instruments and avionics
- engine starting system
- flight control system

The layout for the electrical system was designed with the following guidelines in mind: accessibility, shielding from lightning strikes, and accessibility to ground power hookups (Reference 24).

In case of failure of the primary electrical system, the APU will provide power for the control surfaces and flight computers.

10.7 AUXILIARY POWER UNIT

An APU was included in the SnoDog design to provide ground power for engine starting and systems, to provide backup power to selected systems, and to provide emergency power if necessary. As a close air support aircraft, the SnoDog will possibly be operating from unimproved airfields. The APU is therefore necessary in order to avoid the need for ground power carts. Although the APU does require some degree of maintenance itself, the need for minimal ground support outweighs this factor.

The auxiliary power unit is located inside the fuselage, between the inlets. This location insures that no APU exhaust gases will be ingested into the engine inlet and vice-versa.

10.8 WEAPONS INTEGRATION

In addition to the mandatory ordnance outlined in the RFP, the SnoDog will be capable of carrying a variety of weapons system combinations to allow it greater diversity and mission capability. Several of the possible missions that the SnoDog could be adapted for, and the probable stores these missions would require, are outlined in Figure 10.5. Reference (27) was used to come up with generalized attack mission weapon requirements. Subsequently, Reference (24) was used to establish the weights for the weapons and stores selected, and these are outlined in Table 10.8 below.

The amount of ordnance, avionics, and fuel stores selected for specific missions would, of course, be restricted by the maximum take-off weight of the aircraft of 51,642 lbs. which includes the design payload weight of 12,596 lbs.

Thus, using the weights in Table 10.8, the exact amount of fuel and stores that could be carried to perform the suggested missions can be determined.

In summary, the SnoDog is an aircraft that can be employed in a variety of attack roles. With its large payload capability, it can carry a wide variety, and large numbers, of ordnance to increase the effectiveness of its combat sorties.

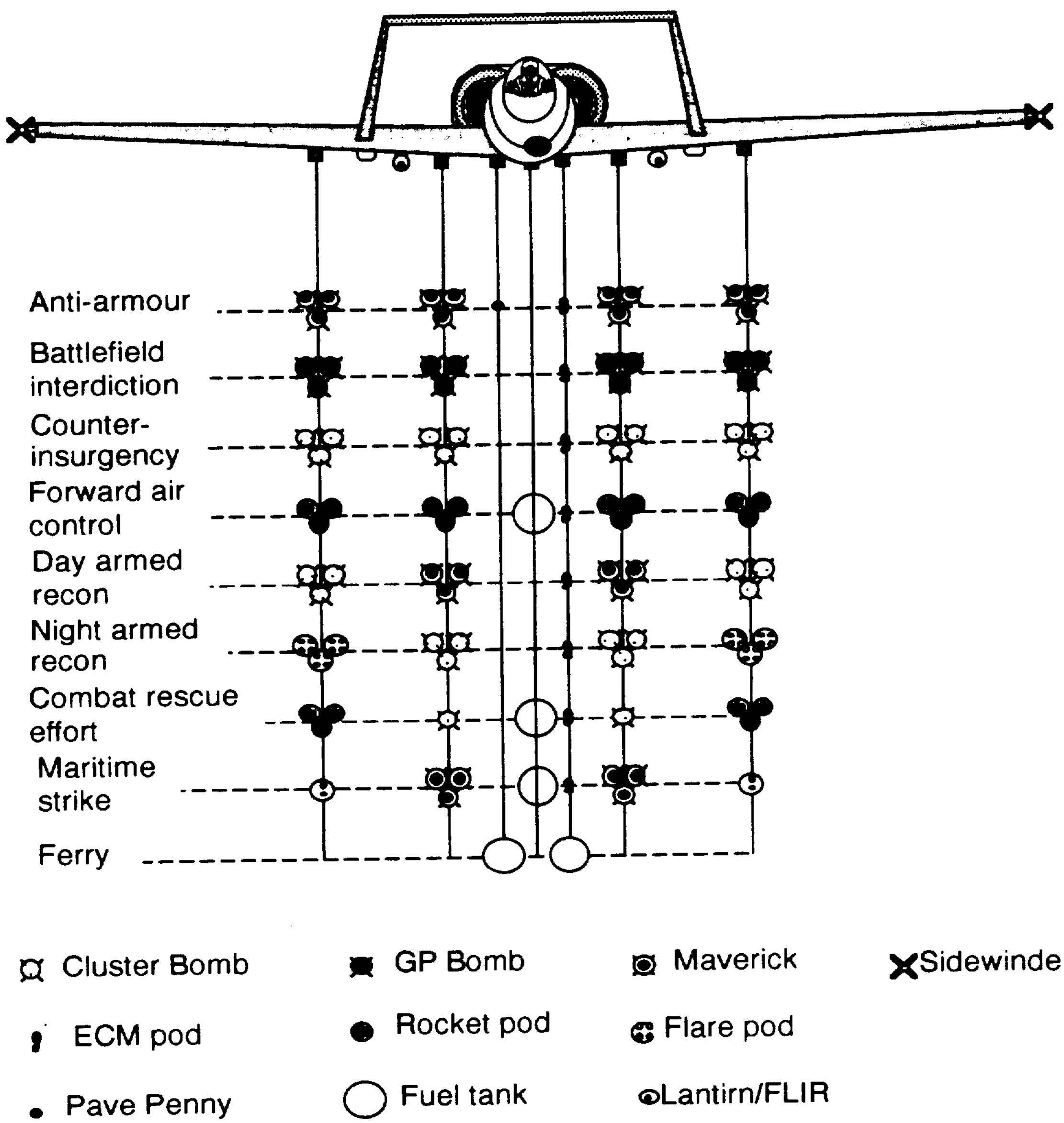


Figure 10.5 Weapons System Integration

Table 10.8 Weapons Systems Weights

Store	Weight (lbs)
GP bomb (Mk 82)	500
Cluster bomb (SUU-30)	500
Maverick ASM	463
Rocket pod (LAU-3)	415
Flare pod	30
ECM pod (AN/ALQ-101)	540
Pave Penny	32
Fuel tank (370 gall.)	289
LANTIRN/FLIR	544/431

11.0 LANDING GEAR

Tricycle landing gear was selected for the SnoDog for various reasons. The steering capability of tricycle gear during taxiing and after landing is better than both the tail dragger and tandem landing gear configurations. Operation of tricycle landing gear tends to be less involved than other gear types, because tricycle gear has stable taxi performance, thus preventing ground loop. Furthermore, with tricycle gear, the takeoff rotation procedure is more straightforward than with the tail dragger configuration. Finally, pilot visibility with tricycle gear is good, while the forward view of taildraggers tends to be limited. Retractable landing gear was used for the SnoDog for aerodynamic drag considerations.

The disposition of the landing gear was dictated by ground clearance and tip-over criteria, (Reference 2) as well as space and structural considerations. The nose wheel was offset from the aircraft centerline in order to accommodate the 30mm GAU-8 cannon that will be placed in the nose of the aircraft. Rotation clearance criteria dictated that the main gear be placed near the trailing edge of the wing, and lateral tip over criteria required that the distance between the main gear tires be at least 195". Figures 11.1 and 11.2 show the tip-over and clearance angles of the SnoDog landing gear. The originally proposed main gear folded underneath the fuselage, but due to the increased distance between main gear tires, this became unfeasible as the retraction space would be moved from underneath the fuselage to the thin part of the wing. It was then decided to locate the main gear in the booms to provide adequate structural support and volume to house the retracted gear.

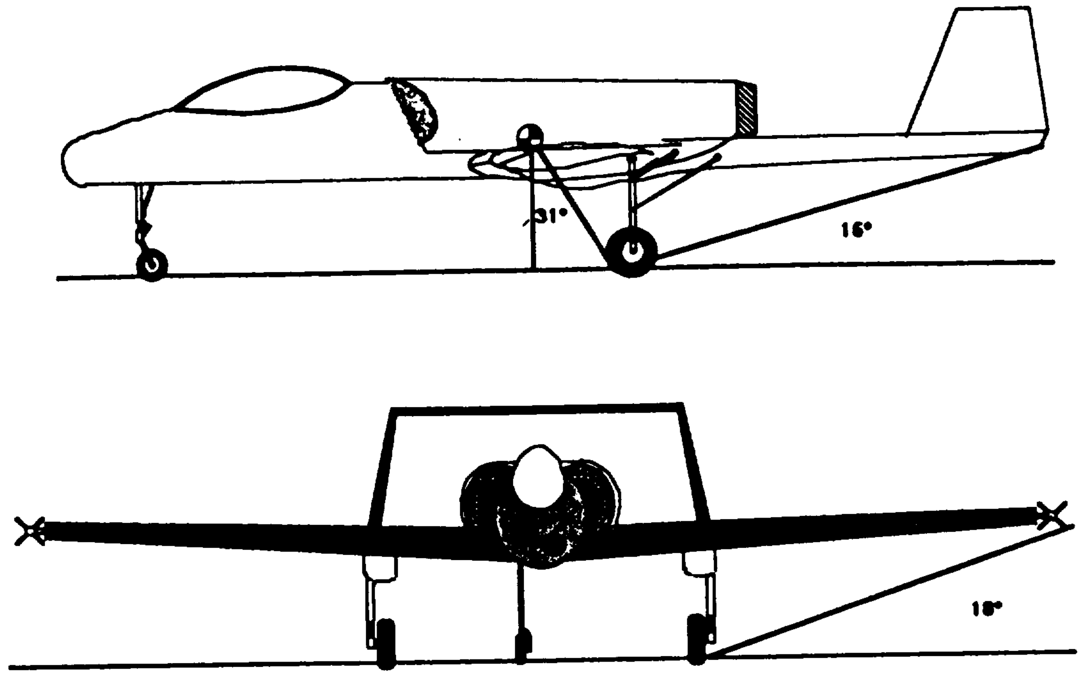


Figure 11.1 Tip-over and Clearance Angles.

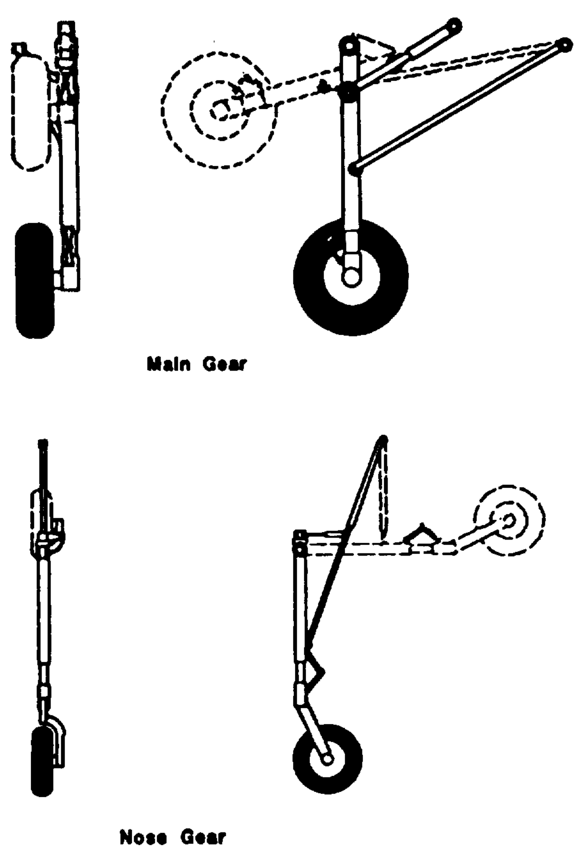


Figure 11.2 Landing Gear Detail.

The main gear retract forward into the thick part of the wing using the floating link retraction mechanism shown in Figure 11.3. The tires remain vertical when retracted to reduce the complexity of the landing gear, thereby increasing their reliability. The drag of the booms was increased slightly due to the necessity of wheel fairings. Rotating the wheels so they lie flat would affect a larger portion of the wing and require structural modifications around the retraction volume, thus increasing the weight. The bottom of the tires are also slightly exposed, providing contact points that the aircraft can land on with minimal damage in the event of landing gear failure.

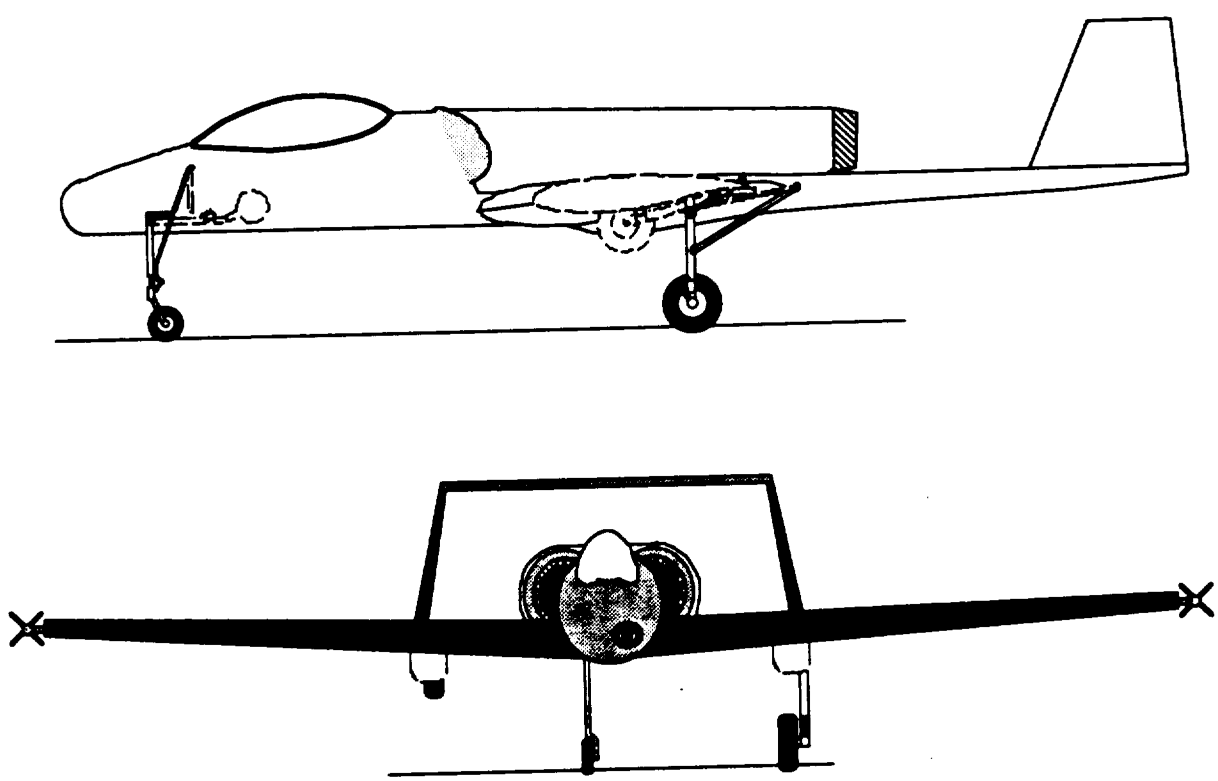


Figure 11.3 Landing Gear Retraction.

Tires were sized using the method of Reference (24). A summary of tire dimensions is given in Table 11.1. The minimum tire size that would safely carry the static and dynamic loads are used to minimize the required retraction volume. This results in higher tire pressures than are recommended for operation from unimproved runways such as dirt or grass. Considering the availability of runways worldwide and the successful operation of attack aircraft from already existing Air Force Bases in the recent Gulf War, this should not limit SnoDog operation significantly. Larger tires can be fitted on the SnoDog with minimal enlarging of the wheel fairings around the main gear if needed.

Table 11.1 Tire Specifications

	Tires per strut	Max Diameter in.	Max Width in.
Main Gear	1	37	11.5
Nose Gear	1	22	6.8

	Max Loading Lbs	Pressure PSI	Max Speed Ft/sec
Main Gear	31200	245	264
Nose Gear	7900	190	293

12.0 GROUND SUPPORT AND AIRCRAFT MAINTENANCE

A low maintenance aircraft requiring minimal ground support was among the primary design goals for the SnoDog. In fact, the configuration and on-board systems were largely selected to maximize these aspects.

The configuration selection of the SnoDog lends many favorable characteristics to its degree of maintainability. First of all, the twin booms and vertical stabilizers will be manufactured to be used on either side of the aircraft. This makes repairs and parts acquisition easier and faster. Also, the twin boom configuration allows access to the whole circumference of the two turbofan engines, thus allowing many repairs to be easily and quickly done while the engines are still in the aircraft. In the event that the engines do have to be removed, they can be removed more quickly than with a conventional configured aircraft. This is due to the easy accessibility of the engine control lines. The aircraft configuration also helps prevent engine damage and excessive wear, in that its high mounted engine inlets will be very resistant to foreign object damage from any debris on the runway.

In conjunction with the aircraft's ease of ground servicing, is the placement of its access panels and ground service ports, shown in Figure 12.1. Access panels are placed strategically on the aircraft to allow easy service and removal of aircraft components. Furthermore, ground servicing ports, such as those for fuel loading, oxygen recharging, and ammunition reloading, are all placed low enough on the fuselage to allow ground crews to access them without having to use special equipment or stepladders. In addition, the low wing configuration of the aircraft results in hard point locations that are low enough for ground crews to access while standing on the ground.

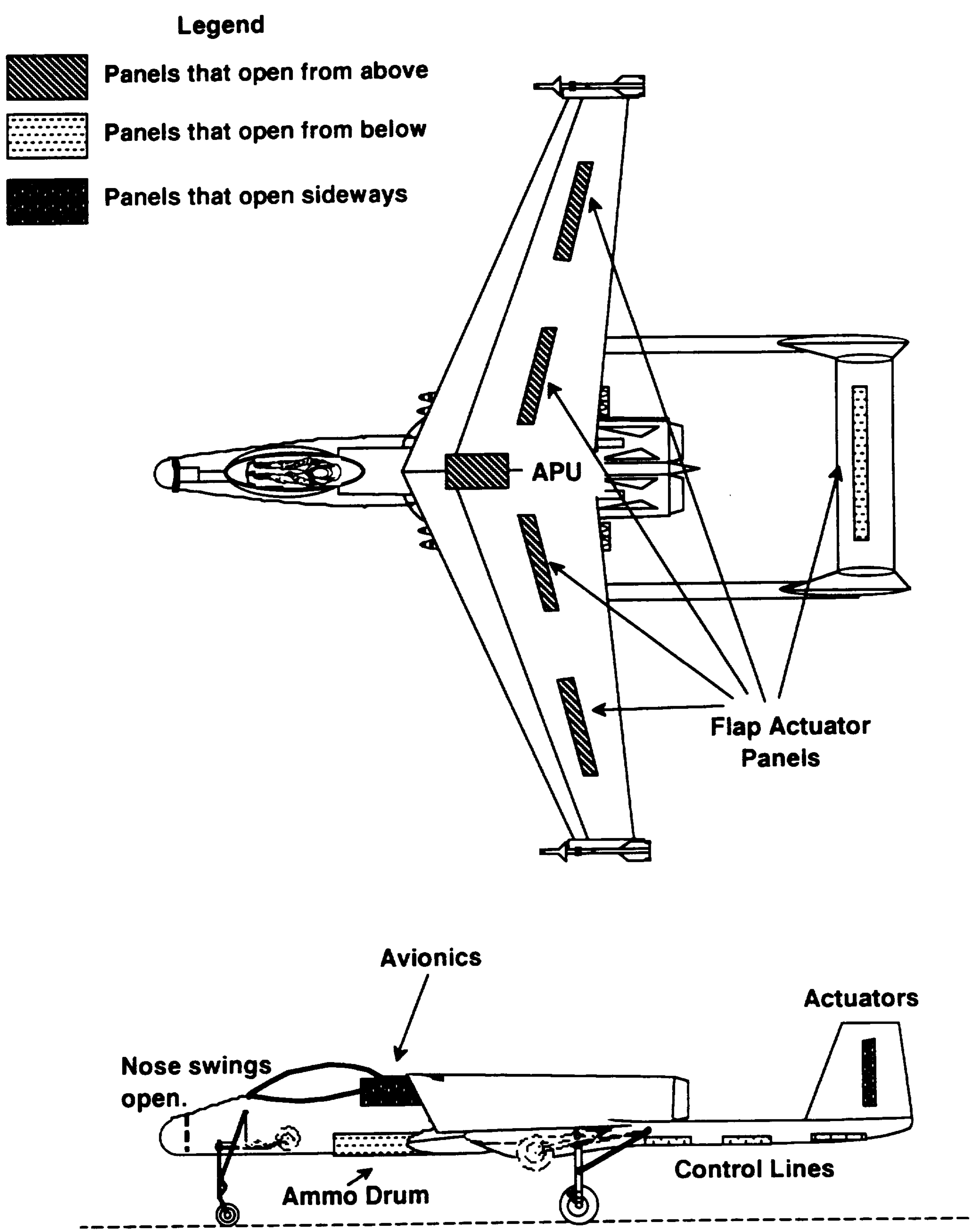


Figure 12.1 Access Panels

The above factors will significantly ease servicing and drastically decrease aircraft turn-around time.

The SnoDog's on-board systems were selected to decrease its ground equipment requirements and improve its ability to operate from remote areas. The specific equipment needed to service this aircraft will be very similar to the equipment requirements for the A-10. This is due to the fact that both aircraft employ many of the same weapons systems. Also it was the choice of the design team to utilize proven equipment already existing in the military inventory.

13.0 COST ANALYSIS

The RAND DAPCA IV cost estimating relationship (CER) of Reference (8) was used to calculate the projected life cycle cost (LCC) of the SnoDog in 1986 dollars, which was then projected to estimated 1995 dollars using a cost escalation factor (CEF) from Reference (28). This LCC reflects the total costs required for the aircraft from its initial conceptual design, to its retirement from service. LCC, as defined by Reference (8), includes the following:

- Research, development, test, and evaluation (RDT&E) cost.
- Flyaway, or production, cost.
- Support equipment and spares cost.
- Special construction cost.
- Operations and maintenance cost.
- Disposal cost.

The LCC breakdown for the SnoDog is shown in Table 13.1.

The RDT&E+Flyaway cost includes program costs for the aircraft from the initial design through production, including tooling and materials. This cost was calculated using equations 18.1 through 18.9 in Reference (8). The resulting unit cost of $14.8 million per aircraft was obtained based on a production run of 500 aircraft. The cost of $1.6 million per engine was estimated by using information from Reference (28), and then projected to1995 dollars. While the avionics cost was estimated by Figure C1 of Appendix C, Reference (29), where it is suggested to roughly estimate avionics to be 15-25% of unit cost. Here a judgement was made to use 20% of the unit cost because, although the aircraft will have low-cost attack avionics, it will be flown by a digital fly-by-wire system. It is important to note that the LANTIRN avionics price was not included, as these avionics are not absolutely necessary to mission execution. These are usually billed as an after market add-on.

Table 13.1 LCC Breakdown (in millions of 1995 dollars)

RDT&E+Flyaway:		
	Engineering costs=	617.68
	Tooling costs=	425.26
	Manufacturing costs=	1877.83
	Quality control costs=	276.17
	Devel support costs=	98.89
	Flight test costs=	43.49
	Manufacturing materials costs=	979.22
	Engine production costs=	1612.00
	Avionics costs=	1480.00
	Total RDT&E+Flyaway cost=	7411.53
	<per aircraft>=	14.82
Operations & Maintenance:		
	Crew costs/yr=	74.51
	Maintenance labor cost/yr=	165.65
	Materials cost/yr=	165.65
	Fuel cost/yr=	376.03
	Total Ops & Maintenance/yr=	781.84
	<per aircraft>/yr=	1.56
Life Cycle Cost:	(based on 20 year service life)	
	LCC=	46.10

The operations and maintenance cost, the largest contributor to LCC, includes fuel, oil, crew personnel, ground personnel, maintenance, and other indirect costs. This is a particularly difficult cost to estimate, as it is based on degree of use and length of service. To estimate this cost a service life of 20 years was used, with an average of 400 flight hours per aircraft per year, and a projected 1995 market price of $1.50 per gallon for jet fuel. Furthermore, Reference (8) suggests using a value of between 15 and 20 maintenance hours per flight hour, and the calculations were made using a value of 15 due to the design goal to produce a low maintenance aircraft.

The other aspects of LCC, including ground support, special construction, and disposal, were neglected for various reasons. Ground support equipment costs were viewed to be a very minor part of the LCC, as the aircraft was designed for minimal ground support, and most of its ground support needs can be met by existing equipment. Special construction costs were assumed to be zero because this aircraft will not require the special construction of any hangars, runways, or special facilities. Lastly, disposal costs were considered negligible due to the recommendation of Reference (8).

As a low cost attack aircraft was one of the design goals, several decisions were made to attain that goal. Due to the inability of the CER's to show the affect of these decisions, the are outlined here qualitatively:

- interchangeable empennage components.
- use of conventional materials.
- low-cost avionics systems.
- conventional flight controls and high-lift devices.

Using interchangeable empennage components, consisting of the boom and vertical tail, will reduce the unit cost by requiring less tooling to form these components. Furthermore, this will simplify manufacturing and reduce production time as empennage components can be produced without regard to what side is needed.

In addition, the SnoDog's use of conventional aircraft materials will lower its unit cost significantly. This is due to the lack of special tooling or manufacturing processes that are necessary for many of the new composite, steel, or titanium materials. This particular aspect was, however, reflected in the RDT&E+Flyaway cost by using a material "fudge factor" of 1.0 rather than the 1.5-2.2 suggested by Reference (8) for these other materials.

Due to the large expense of modern avionics, only the basic attack, navigation, communication, and flight control avionics were selected. Although a fly-by-wire system is required due to the aircraft's instability, this has been accounted for by assuming avionics costs to be 20% of the unit cost. Futhermore, additional specialized avionics pods can be affixed to the aircraft's hardpoints according to specific customer needs, so the costs of these avionics were not included.

Finally, the SnoDog will have only conventional flight controls and high-lift devices. This will keep the aircraft's production costs lower when compared to aircraft using sophisticated vectoring or air blowing devices.

In comparing the unit cost of the SnoDog to many modern attack and fighter aircraft, it can be seen that the SnoDog's price tag of 14.8 million is quite reasonable. Futhermore, although the aircraft will be fitted with basic attack avionics, it will be expandable on a per mission basis through the use of various sensors and ECM pods. The overall operations and maintenance costs will be lower than comparable aircraft due to the SnoDog's ruggedness and ease of maintainability.

14.0 MANUFACTURING PLAN

14.1 MANUFACTURING BREAKDOWN AND ORDER OF ASSEMBLY

From the cost analysis section of this report, the manufacturing cost is estimated at $14.8 million per aircraft. This cost consists of labor and material cost to manufacture the SnoDog including airframes, two turbofan engines, avionics, and production tooling costs.

Figure 14.1 shows the various parts which comprises the SnoDog. The first phase of production includes the assembly of the fuselage. All the control surfaces and the booms will be built by subcontractors and when received, will be assembled at the manufacturing plant. Once the empennage parts are attached, the next stage includes the assembly and attachment of the wings. The final assembly includes the installation of the engines and the missile launchers. Final connections of all the power, control, and environmental system can then be checked and the SnoDog is ready for shipping.

The manufacturing process will be kept simple to keep production costs down. Typical manufacturing methods and processes will be used. The SnoDog contains interchangeable parts between the left and right sides for components such as the rudders and main landing gear. There are two main reasons to include interchangeable parts. First, because this would require fewer manufacturing methods during production. Second, if a part is damaged in combat, it will be easier to get replacement parts. Therefore, only a selected stock would have to be kept on hand.

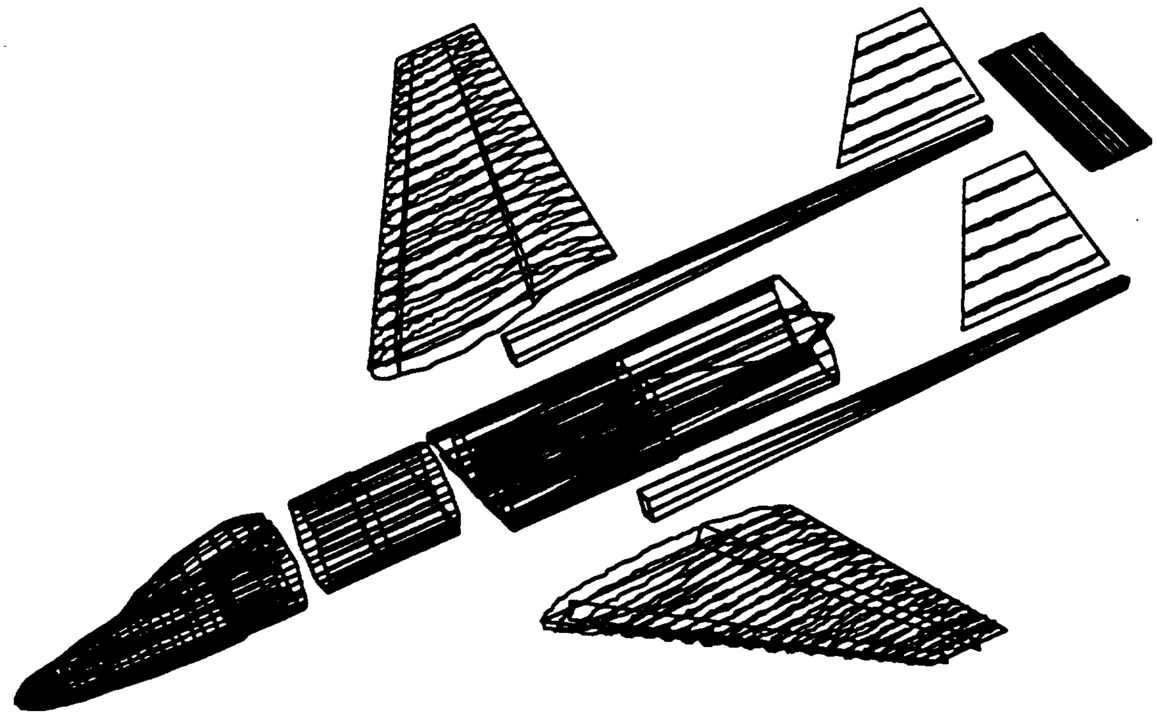


Figure 14.1 Manufacturing Breakdown.

14.2 PRODUCTION SCHEDULE

For the production of 500 aircraft, a 5-year time frame has been selected as the most beneficial time schedule. Table 14.1 shows the production schedule of the SnoDog within the given time frame. Production within the first year produces the fewest number of aircraft because production methods and

Table 14.1 Production Schedule		
Month	Year	Total aircraft/month
1	1	2
2		3
3-4		4
5-7		9
8-50	2-4	9
50-56		7
57-60	5	6

unexpected problems have been taken into account. By the second year the production of the SnoDog increases to a maximum rate of nine per month.

14.3 CORPORATE STRUCTURE

Figure 14.2 shows the proposed corporate structure for the manufacture of the SnoDog. In order for the assembly of the SnoDog to run smoothly, management is important. The requirements to become a manager include:

- Program Manager: 15-20 years of experience in engineering and management.
- Section Chief: 10 years of engineering experience
- Project Engineer: 3-5 years of engineering experience

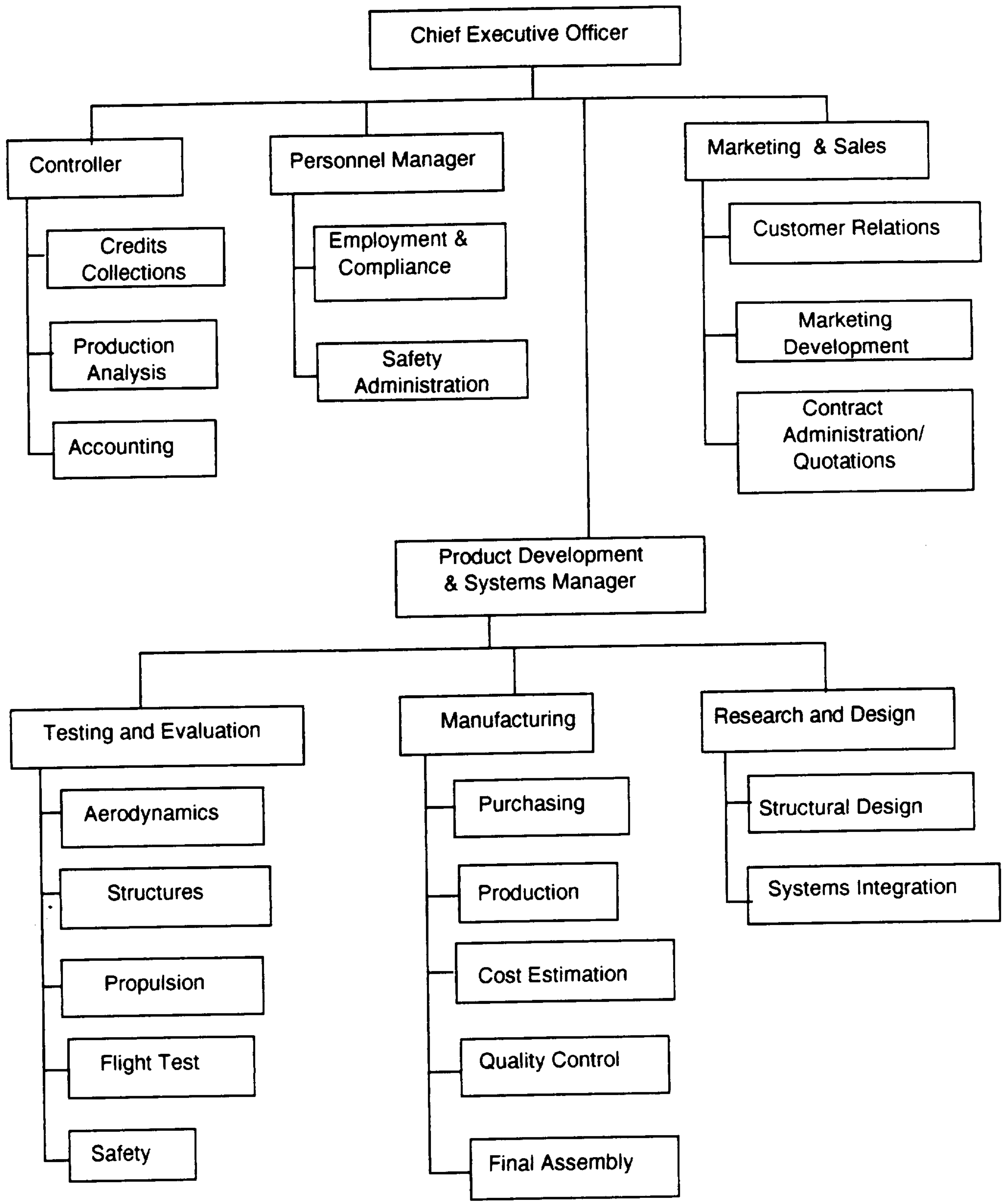


Figure 14.2 Corporate Structure.

15.0 CONCLUSIONS

The preliminary analysis shows that the SnoDog meets or exceeds all mission requirements outlined in Section 2.0 and Reference (1). As a close air support aircraft, the SnoDog combines simplicity of design with effective mission execution. It can deliver its ordnance at higher speeds, with better accuracy and a greater frequency than the current close air support aircraft.

Three primary design drivers for the SnoDog were: maneuverability, survivability, and maintainability. The SnoDog's inherent instability makes it highly maneuverable. Survivability features include: twin engines for redundancy, high-mounted engines for protection, ability to fly with one vertical stabilizer severely damaged and redundant control systems. The use of conventional materials makes the SnoDog easy to repair. Interchangeable parts, such as stabilizers, actuators, and body panels aid in maintenance of the SnoDog. Numerous access panels and full-circumference access to the engines also decrease maintenance time and dollars.

The SnoDog can easily be adapted to perform other missions. Additional hard points are provided for external fuel tanks and weapons stores. Also, an aerial refueling port is provided.

Future design phases planned for the SnoDog include, but are not limited to, the following:

- Transonic compressibility calculations
- Computational fluid dynamics analysis
- Finite element analysis of the aircraft structure
- Full control theory analysis,including feedback gain calculations

These analyses will complete the final iterations for the SnoDog, the close air support aircraft of the future.

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