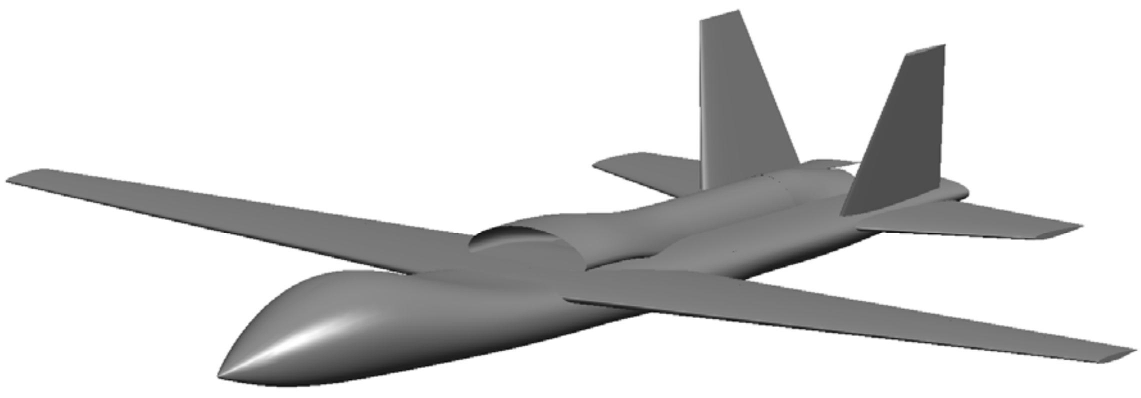
AIAA Design Competition

Advanced Gunship

Virginia Polytechnic Institute and State University

Spring 2005 Proposal



Team Archangel

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Executive Summary

Virginia Tech AIAA Team 3 presents the Archangel as the solution for the 2004-2005 AIAA Undergraduate Team Aircraft Design Competition Request for Proposal for an Advanced Gunship Design. Current world events demand a new gunship alternative to respond to rapidly changing situations. The aircraft must be highly survivable versus low-cost threats. In addition, the aircraft must provide precise, persistent firepower at an affordable cost. The aircraft must also have a low life cycle and acquisition cost to meet the defense budget plans.

When examining current gunships, the only real-life example is the AC-130. However, the practicality of this type of gunship is diminishing. Team Archangel decided not to re-invent the AC-130, but instead create a totally new gunship to meet the RFP requirements.

The Archangel is a single-engine aircraft, similar in size to larger fighters currently being used but significantly smaller than the AC-130. The design does not utilize guns; instead it carries state-of-the-art munitions that guarantee more kills at a lower overall cost with reduced collateral damage. The primary weapon is the Advanced Precision Kill Weapons System (APKWS). APKWS consists of 80 small laser-guided missiles that can easily engage small targets such as troops as well as light vehicles and buildings. Archangel also has the capability to carry laser and GPS-guided bombs for larger targets.

The other major feature that distinguishes Archangel from other aircraft is that the design will be unmanned. The technology is still under development, but it is believed that all these issues will be resolved by time of production. One major benefit of this design is that it will protect the lives of military personnel who normally would man this type of gunship. The Archangel design is capable of easily integrating this new technology because of the weaponry employed and the size of the aircraft.

The Archangel will be more agile then its AC-130 counterpart, allowing for improved survivability against future enemy capabilities. In addition, with the adaptation of the new Sniper

XR targeting system, the enemy can be targeted and fired upon from miles away, allowing the Archangel to remain outside the threat envelope. Overall, the innovative design of the Archangel is an effective, highly survivable aircraft, both physically and politically, that can attack a diverse array of targets.

Table E.1 Archangel General Characteristics

Length, ft	60
Height, ft	17.4
Wing span, ft	78.74
Wing area, ft^2	620
Wing sweep, deg	6
Aspect Ratio	10

Ceiling, ft	34400
Range, nm (ferry)	2600
Max Speed at altitude, kts	475
Approach Speed, kts	131
TOGW, lb	57750

Table of Contents

List of Figures

List of Tables

List of Symbols and Abbreviations

AAA:	Anti-Aircraft Artillery
A/C:	Aircraft
AIAA:	American Institute for Aeronautics and Astronautics
α:	Angle of Attack
APKWS:	Advanced Precision Kill Weapons System
APU:	Auxiliary Power Unit
AR:	Aspect Ratio
ATC:	Air Traffic Control
AVL:	Athena Vortex Lattice
$C_{y\beta}$:	Side-force Derivative due to Sideslip
$C_{n\beta}$:	Weathercock Stability Derivative
$C_{l\beta}$:	Dihedral Effect
C_{yr}:	Side-force Derivative due to Yaw
C_{nr}:	Damping-in-Yaw Effect
C_{lr}:	Rolling Moment due to Yawing
C_{lp}:	Damping-in-Roll Derivative
C_{np}:	Cross Derivative of the Yawing Moment due to Rolling Motion
CD:	Drag Coefficient
CEP:	Circular Error Probable
CF:	Skin Friction Coefficient
CFD:	Computational Fluid Dynamics
CG:	Center of Gravity
C_{Lmax}:	Maximum Lift Coefficient
C_p:	Coefficient of Pressure
D/q:	Drag per Dynamic Pressure
DLOS:	Digital Line of Sight
DOD:	Department of Defense
FAS:	Federation of American Scientists
FLIR:	Forward-looking Infrared Array
FLOPS:	Flight Optimization System
FOD:	Foreign Object Damage
GCS:	Ground Control Station
GEO:	Geo-stationary Earth Orbit
GPS:	Global Positioning System
HE:	High Explosive
HARM:	High Speed Anti-Radiation Missile
ICAO:	International Civil Aviation Organization
IR:	Infrared
JDAM:	Joint Direct Attack Munition
JOTBS:	Joint Operational Test Bed System
Λ:	Sweep
λ:	Taper ration
LEO:	Low Earth Orbit
LOS:	Line of Sight
M:	Mach Number
MAC:	Mean Aerodynamic Chord
MANPADS:	Man-Portable Air Defense System
MILSPEC:	Military Specification

MMW:	Millimeter Wave
NACA:	National Advisory Committee for Aeronautics
NASA:	National Aeronautics and Space Administration
OBIGGS:	On-board inert gas generation system
OTH:	Over the Horizon
P_H:	Susceptibility, inability of an aircraft to avoid threats
$P_{K/E}$:	Probability an aircraft will be killed per engagement
$P_{K/H}$:	Vulnerability, inability of an aircraft to withstand hits from threats
PTAN:	Precision Terrain-Aided Navigation
RCS:	Radar Cross Section
RFP:	Request for Proposal
RN:	Reynolds Number
SAM:	Surface to Air Missile
SDB:	Small Diameter Bomb
SFC:	Specific Fuel Consumption
SLST:	Sea Level Static Thrust
t/c:	Thickness to Chord Ratio
TSFC:	Thrust Specific Fuel Consumption
T/W:	Thrust to Weight
TOGW:	Take-off Gross Weight
UAV:	Unmanned Arial Vehicle
UCAV:	Uninhabited Combat Arial Vehicle
UHF:	Ultra High Frequency
USAF:	United States Air Force
UV:	Ultra Violet
W/S:	Wing Loading
VLM:	Vortex Lattice Method
VR:	Vulnerability Reduction
x/c:	Position over Chord

Chapter 1. Introduction and RFP Requirements

1.1 Introduction

Current events in the Middle East have generated a RFP for a highly survivable and adaptable aircraft for ground attack missions.

1.2 RFP Requirements

This proposal was generated by the AIAA to meet the significant need for a new advanced gunship to combat growing threats in changing situations around the world. A list of the design and mission requirements is given below with some added explanation.

<u>General Design</u>

1 Highly survivable versus growing MANPADS and AAA threats.

2 Mission radius of at least 500 nautical miles with an additional 4 hours minimum of loiter time, without refueling.

3 Capability of aerial refueling for extended missions if needed.

4 Counter/kill threats including personnel, trucks, light-armored vehicles, and buildings.

5 Design payload of 15,000 pounds or more of guns, missiles, bombs, and other weapons/projectiles. The goal is to make these weapons as cost-effective as possible. However, the weapons must be accurate to avoid civilian causalities. As a result, some non-traditional weapons were investigated.

6 Avionics and sensors will be needed to accommodate the mission given. They are not considered part of the payload.

7 Initial cruise ceiling is a 30,000 foot minimum at a cruise speed of no less than 400 knots.

8 The structural limit load factor is at least 3.5g's. This will allow for moderate evasive maneuvers if needed.

9 The maximum landing weight is equal to 80% of the maximum gross takeoff weight. This ensures if there is an emergency, the plane is still able to land without complication.

10 A factor of 1.05 should be multiplied to the ideal engine flow to account for engine wear and installation losses.

Additional Point Performance Requirements

1 Balanced field length at maximum TOGW should be less than or equal to 5,000 feet, at sea level for an ICAO standard day

2 Landing distance over 50 feet obstacle at operating weight empty plus 40% internal fuel and maximum payload must be less than or equal to 5,000 feet, at sea level, with one engine out, and an ICAO standard day, with wet runway.

1.3 Target Environments

A ground attack aircraft will face many target environments. Some of the main target environments that Archangel will face are described below along with insight into methods to effectively complete the objectives.

1) Isolated target
    a. Forward firing weapon with standoff range if the target has offensive capability (AAA, MANPAD, SAM).
    b. One shot-one kill to reduce vulnerability from unknown/hidden threats.
    c. Modern strike aircraft are very effective in this role (A-10, F-15E, F-16, F/A-18)
    d. The AC-130 is not very effective because of its side mounted weapons, slow speed, and limited firing range.
2) Compact group of targets or column of vehicles
    a. Multiple target tracking and attack.
    b. Short engagement time between shots.
    c. Coordinated attack capabilities to work in conjunction with other aircraft.
    d. Sufficient sensor systems to detect and appropriately prioritize targets (destroy lead vehicle to immobilize a convoy, destroy offensive capabilities, etc).

e. Combat maneuvers to provide persistent firepower.

    i. Circling the target area with “fixed” side mounted weapons leads to predictable flight paths and easier tracking for ground threats.

    ii. Multiple sequences of attack run, pass over target, and turn back to target with a short turn radius and quick turn rate. This requires extensive pilot attention, reduces situational awareness, and can be disorienting.

3) Target in close proximity to civilian facilities or friendly forces

    a. Collateral damage is unacceptable and must be prevented at all costs.

    b. Precision and balanced firepower.

        i. Targeting must be such that it minimizes the probability of collateral damage (Ref 1.1).

        ii. Targeting a spot in the dirt beside a building and not the building itself is very difficult and leads to miscommunication between pilot and mission planners (Ref 1.2).

        iii. Weapon used must be the smallest possible to destroy the target, but one shot-one kill reduces the likelihood that a weapon will miss and cause collateral damage.

    c. Constant communication with friendly forces position. Send precise targeting information to command headquarters for verification and clearance for engagement.

4) Complex and Developing Situation

    a. Combines multiple aspects of previously described situations

    b. Quickly switch between targets and attack modes

c. Precise timing and rapid target lock to attack targets of opportunity when available. Requires a constant loiter over target area within weapon range and maintaining survivability.

d. Ability to attack moving targets

e. Situational awareness of civilian/ friendly forces

f. Primary example is shown in an AC-130 combat footage video. The video shows an incident in Afghanistan where targets included personnel, vehicles, and a building in close proximity to a mosque (Ref 1.3).

The detailed target environment analysis shows how certain configurations might prove more effective than others. An aircraft with forward firing weapons, high maneuverability, and a sophisticated targeting system should provide the maximum mission flexibility. These ideas will be considered during further mission analysis and trade studies.

Chapter 2. Design Approach

2.1 Comparator Aircraft

One of the first steps in the design development was to research existing aircraft and conjecture as to how each of them would fit the design mission. The goal of looking at these aircraft was to find certain features from each aircraft that help fulfill the design mission, and then investigate how these features and characteristics can be integrated into the current design. The design mission focuses on delivering persistent and precise firepower to light ground targets while maximizing its survivability with economic firepower. Several different aircraft were investigated during the design process to see how each one would fit the design mission and what advantages and disadvantages they provide for fulfilling the mission. The existing models that had the most significant impact on the design are given.

AC-130

The AC-130 Hercules is the prototypical gunship in use today. The AC-130 has the ability to provide persistent firepower on multiple targets at a relatively low cost. With air refueling, the AC-130 also has the capability for extended range missions of over 1,300 nautical miles and extended loiter missions. It is heavily armored for missions including air interdiction of preplanned targets, base defense, and close air support. One drawback to using the AC-130 is that it is typically only used in night assaults because of its poor maneuverability and limited orientations relative to the target during attack. The AC-130 has been used effectively for over thirty years to take out ground defenses and targets (Ref 2.1).

A-10

The A-10 is effective against most ground targets and can provide close air support. It has several features that make it one of the most survivable aircraft in use, such as armor to protect key parts of the aircraft, including the cockpit. The A-10 utilizes a two engine design that incorporates internal and external foam to protect its self-sealing fuel cells. A redundant flight control system improves the aircraft's survivability by allowing the plane to be flown manually even when the flight control system is damaged. The A-10 is also able to carry out its mission in poor weather and low visibility conditions. Most of the A-10's parts are interchangeable, making it easy to service at areas with more limited facilities. The A-10 is an extremely survivable aircraft that can interdict ground targets with efficiency (Ref 2.1).

F-16 & F-35

The F-16 is a highly maneuverable aircraft that can deliver its weapons to ground targets with great accuracy. The F-16 is a single engine design and has been proven to be effective and survivable. A fly-by-wire system provides excellent control for the aircraft. The F-16 is even being considered for conversion to a UAV, but this design is experimental at this time (Ref 2.2). The F-16 provides a low cost aircraft that can complete a variety of missions efficiently. The F-35 is currently under development and set to replace the F-16. Like the F-16, it also features a single engine. The success of the F-16 and selection of the single engine F-35 as its replacement serve to validate a single engine design in combat situations (Ref 2.1).

B-2, F-22, & YF-23

The B-2 Spirit is an effective stealth bomber with an extremely long range. The B-2 has the engine inlet on the top of the fuselage to reduce the RCS/IR signature and improve its stealth. The B-2's exhaust is on top of the planform area to reduce its heat signature. The YF-23 is a dual engine design that features a mixed flow exhaust duct on top of its planform area to improve its survivability by reducing its heat signature. The B-2 and F-22 feature internal weapons for improved aerodynamics and RCS. Most of the features on the B-2 add to its stealth and allow it to enter heavily defended areas undetected to attack its target (Ref 2.1).

2.2 Configuration Concepts

There were four main configuration concepts considered for the design, shown in Figure 2.1. Each provided a unique approach to the requirements outlined in the RFP. Subsequently, each concept has its own benefits and deficits. The concept that best fits the mission requirements will be selected for further development.

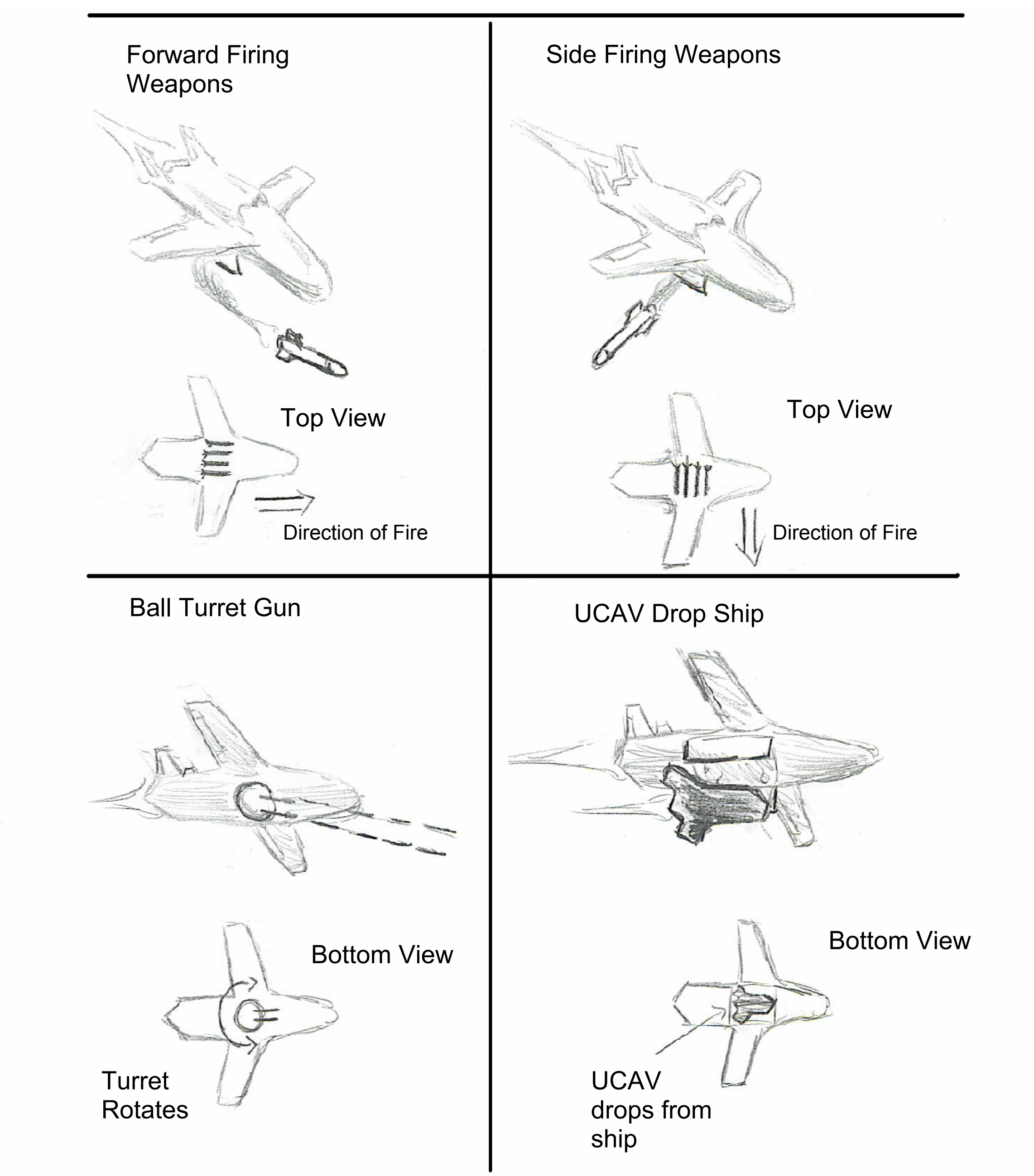


Figure 2.1 Configuration Concepts

Forward Firing Weapons Concept

The first concept features forward firing weapons similar to the A-10 attack aircraft. The attack approach would have the nose of the aircraft pointed toward the target and any set of modern weapons such as guns, rockets, missiles, or bombs could be used simultaneously. The forward velocity of the aircraft creates an initial velocity for the weapon that increases the impact energy for guns and the range of rockets, missiles, and bombs. Most of the weapons could be carried internally, reducing the drag and RCS. This concept could be unmanned or employ a crew of one or two. With forward firing weapons, the pilot must point the nose of the aircraft towards the target which is significantly easier than an independent targeting system. This concept is very traditional and there are many examples of current and previous strike aircraft that use this concept successfully.

Side Firing Weapons Concept

This concept features fixed side firing weapons similar to the AC-130 gunship. The side firing weapons allow the aircraft to provide continuous firepower to a specific spot as the aircraft circles the target. The side firing weapons would be limited to guns, rockets, and missiles but there may be adverse interactions with the forward velocity causing significant sideslip on a missile or rocket during launch. Also, the firepower of the aircraft would be limited to the side weapons are on, requiring significant maneuvering to target the other side of the aircraft, reducing the ability to attack targets of opportunity. Placing weapons on both sides of the aircraft would not be a good idea either, as it would significantly reduce the aircraft's firepower towards a single target. Forward firing weapons could be used in conjunction with the side firing weapons; however, they would not be able to be used simultaneously on the same target. The transition between side and forward firing weapon deployment would require maneuvers during which the aircraft would be unable to attack targets. Furthermore, if the weapons were unable to be fully retracted as on the AC-130, there would be a significant drag penalty resulting in reduced loiter and cruise efficiency along with an increase in RCS. The side firing weapons concept would require a crew of at least two because it would be very difficult for the pilot to correctly line up a target which is perpendicular to the flight path. Use of a gun-mounted camera would make aiming easier but would also require a significant decrease in situational awareness.

Turreted Gun Concept

This concept features a ventral mounted gun turret similar to the B-17 ball turret. The turret is used to counteract the firepower limitations of the side mounted weapons while still providing the benefits of persistent firepower while circling a target. The turret however is a complex mechanical system with its own drawbacks. The guns used in previous turrets tend to use a smaller caliber and shorter barrel, significantly reducing the firepower at long range. A turret that is capable of carrying a large caliber Gatling gun or a Howitzer would be very heavy and possibly not even feasible. The ammunition feeding system would need to be flexible, thus adding weight and complexity. Also, an externally turreted weapon would cause significant reduction in loiter and cruise efficiency as well as RCS. Attempting to design a retractable turret would add even more weight and complexity to the system. The gun turret concept would require a crew of at least two because the pilot would be unable to simultaneously aim the gun and fly the airplane while maintaining situational awareness. A gun turret camera with a heads-down view would significantly reduce situational awareness. A helmet mounted sight would improve the situational awareness reduction but would limit the targeting area to the pilot's field of view thus reducing the effective capability of the turret.

UCAV Drop Ship

This concept features a carrier aircraft which carries a UCAV into the target area and then releases the UCAV to attack the target while the carrier ship remains out of harm's way. This concept has the potential to combine the efficiency of a long range transport with the relative safety to the crew of a UCAV. This concept would require the design of two aircraft and would be very difficult from a systems design standpoint. The main drawback of this concept is that the UCAV must be retrieved in-flight which is very difficult and dangerous. Otherwise, it is essentially a cruise missile platform which is very expensive. Most of the expensive sensors can be placed on the carrier aircraft, but the UCAV would still require an engine as well as navigation, communication, and targeting systems. This concept requires a crew of at least two pilots, one for each aircraft with more pilots required for multiple UCAVs simultaneously deployed. Another significant complexity in the UCAV design is that it must be able to fit inside the carrier aircraft, possibly using some type of retractable wing.

Concept Selection

The final concept was selected to use forward firing weapons. This decision was based on its simplicity, effectiveness, and past performance. These qualities would lead to an optimum design with minimum weight, maximum efficiency and maximum firepower. The side firing weapons concept was rejected due to its limitations in attacking targets which are not clustered together. The turreted gun concept was rejected because the flexibility of firepower added by a single movable gun does not outweigh the significant development cost, complexity, and weight of a gun turret, especially when the long term factors of fuel burn and reduced RCS are considered. The UCAV drop ship concept was rejected because of its complexity and potential to become very expensive on a cost per kill basis. Until a good solution for mid-air retrieval of a UCAV is developed, this concept will be at a disadvantage. The forward firing weapons concept will provide impressive firepower on a platform that is optimized for minimum weight, fuel burn, and survivability.

2.3 Component Configuration Concepts

There are essentially two main weapon payload placement configurations, internal and external, each having a set of pros and cons. The specific considerations that apply to this mission are listed below.

Table 2.1 Payload Configurations

Internal Weapons • Reduced Drag • Reduced RCS • Bomb bay doors add weight and complexity • Complicated structural design • Reduced fuselage fuel capacity • Large volume requirements
External Weapons • Increased Drag • Increased RCS • Complicated aerodynamic design • Reduced structural weight • Span loading reduces wing structural weight, but requires more wiring which increases weight and complexity. • Reduced wing fuel capacity

The preferred weapons placement is within internal bays, primarily because of the reduced drag and RCS. This option will be explored as much as possible; however, structural considerations may dictate that some of the weapons be carried externally. If any of the weapons or fuel must be carried externally, the preferred method will be to use span loading to reduce the wing structural weight and avoid blocking the deployment of other internal payload.

Given available engines and the thrust requirements to complete the mission tasks, the aircraft will be in either a single or twin engine configuration. Regardless of the number of engines or the placement, the selection must satisfy a few basic criteria. There must be easy access to the engine for routine maintenance. The engine must also be easily removed for overhaul operations. There must be sufficient separation from the weapons bay and fuel tanks to reduce secondary damage from a blade out or fire. The thrust moments in any operating condition must be small enough that a reasonably sized tail can trim the aircraft. Listed below are the considerations involved for specific installation applications.

Table 2.2 Engine Configurations

External engines • Easy access for maintenance. • Limited options for augmented exhaust to reduce IR signature. • Structural design is nearly independent of engine scaling. • Increased RCS, the fan face and nacelle produce very large radar returns.
Internal Engines • Reduced maintenance access, but still a possibility. Many other attack aircraft have internal engines. • Integration considerations with internal payload. The inlet duct must be routed around payload. • Reduced RCS, the fan face is typically in the aft section of the fuselage with a serpentine duct connecting the inlet to the engine.
Twin Engine Configurations
Overall considerations • Large separation required to prevent battle damage from affecting both engines. • Small separation to allow engine out yaw control
Aft Fuselage Internal (F/A-18) • Minimal wetted area increase. • Thrust line near CG.
Aft Fuselage External (A-10) • Possibility of jettisoning damaged engine. (Ref 2.3) • Forebody interference at high angles of attack.
Over-wing (B-2) • Interaction between control surfaces and exhaust. • Reduced maintenance access. Requires crane for engine removal. • Reduced effectiveness at high angles of attack.
Under-wing Pod (C-5) • Ground clearance issues, requires high wing. Greater threat of FOD such as gravel during takeoff and landing. • Span loading reduces wing weight.
Single Engine Configurations
Overall considerations • Engine failure means the aircraft is coming down. APU will provide power for control surfaces and electronics so the aircraft could perform a dead-stick landing. • Armor may be added to the engine to prevent damage from ground fire. • Engine must be mounted near horizontal centerline.
Aft fuselage internal (F-16, F-35) • Low placement makes routing inlet duct around payload more difficult. It also gives easier access for maintenance. • High placement gives more shielding from ground fire and makes a top mounted inlet easier. It also makes maintenance access more difficult. • F-16 and F-35 have the fuselage wrapped tightly around the engine which is mounted very near the vertical centerline. The engine on our aircraft has a high bypass ratio with a fairly large diameter so vertical shifting will be limited.
Tail mounted (Boeing 727) • Requires a very large single vertical tail. • Not feasible for an airplane of our scale.

The preferred engine configuration is a single engine mounted internally in the aft fuselage. This configuration provides the most cost effective balance of maintenance access, FOD protection, reduced RCS/IR signature capabilities, and structural integration. The performance evaluation made in parallel with the configuration layout is given in Section 2.4.

Engines which are mounted into wing pods have integrated nacelle and exhaust configurations. Internally mounted engines must have the inlet and exhaust integrated into the fuselage or wing. The inlet must be able to supply the engine with clean airflow during any flight path maneuver. The exhaust duct must be able to sustain high exhaust gas temperatures. Additionally the exhaust duct may be used to create mixing of the exhaust gas with cold air flow to reduce the IR signature. Considerations for specific inlet and exhaust configurations are listed on the next page.

Table 2.3 Inlet and Exhaust Configurations

Inlet Configurations
Chin mounted • Good for high angles of attack. • Greater threat of FOD during takeoff and landing • Very difficult integration with internal weapons
Side mounted • Standard for twin internal engine configurations • Split ducts have problems with pressure instabilities that can stall the engine.
Top mounted • Easier integration with internal payload • The inlet is shielded from ground radar which prevents the strong return from the fan face resulting in a reduced RCS. • Reduced effectiveness at high angles of attack, but it can be done at medium angles of attack. (B-2, Global Hawk, Tacit Blue)

Exhaust Configurations
Vectored Thrust • Increased maneuverability • Very expensive • Many moving parts, less reliable • Not necessary for this application
Circular Nozzle • Standard configuration, very easy to do. • Relatively high IR signature. • Easy engine removal for maintenance and overhaul.
Mixed flow duct on top of the fuselage/wing • Wide thin nozzle greatly increases mixing and reduces IR signature (F-117). • Requires more fuselage volume. • Fuselage parts must be designed to withstand high temperatures.

The preferred configuration is a top mounted inlet with a mixed flow exhaust duct on top of the fuselage. This configuration should have a low cost, integrate well with the internal payload, and provide a reduced RCS/IR signature.

Tail selection is a blanket term for the selection of control surfaces that provide pitch and yaw control to the aircraft. Certain tail designs add to the static stability of the aircraft. Some can even provide roll control when independently actuated, such as the all moving horizontal tail-planes on most supersonic fighters. The tail configurations that were explored for this design are pictured in Figure 2.2 and the detailed considerations for each are listed on the next page.

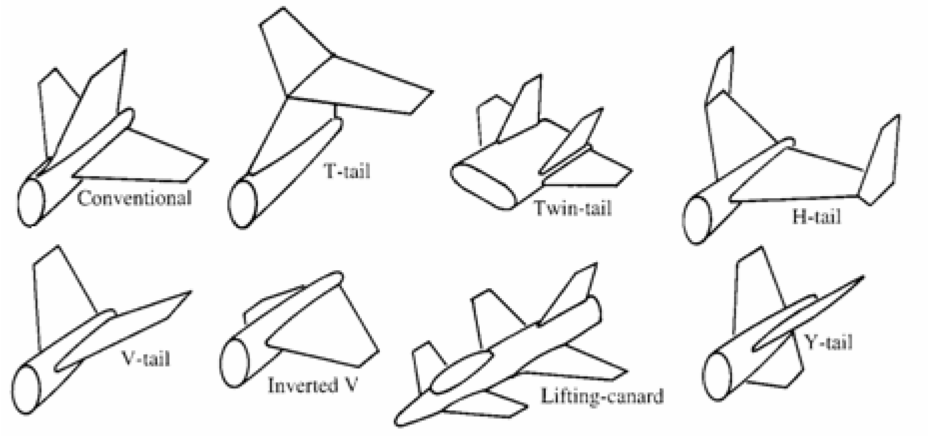


Figure 2.2 Tail Configurations (Modified from Raymer Ref 2.5)

Table 2.4 Tail Configurations

Overall considerations • Each surface will have approximately the same drag. A four surface tail will have approximately twice as much drag as a two surface tail, but the tail drag is only a fraction of the total aircraft drag. • Due to the high threat environment and survivability requirements, control surface redundancy is a major consideration. • Vertical surfaces tend to increase RCS
Tailless (Flying Wing) • Reduced drag • Reduced maneuverability, strict requirements on airfoil selection and CG location. • No redundant controls. Control surfaces must be coupled to produce desired effects.
2 Surface (V-tail, Inverted V-tail) • Good maneuverability when all surfaces are active. • Control surfaces must be coupled to produce desired effects. Single surface failure is likely to result in a loss of control.
3 Surface – (Conventional, Y-tail, Inverted Y-tail, H-Tail, T-tail) • Good maneuverability • Some control surface redundancy • Reduced rotation angle (tail scrape) must be considered for downward pointing surfaces.
4 Surface (Twin-tail) • Excellent maneuverability • Full redundancy of control surfaces • Increased drag
Canard • Improved cruise performance. • Very difficult to create an optimal design. Generally requires CFD. • Requires an aft vertical tail for yaw control and weathercock stability. • Inherently unstable design.

Tail selection has been narrowed to a 3 or 4 surface tail because of the control surface redundancy requirements. Final selection will be a trade study of control effectiveness, redundancy, drag, RCS/IR signature, and will be coupled with exhaust configuration selection. A canard configuration may provide slightly better performance but it adds complexity, design time, and design costs. Since this aircraft is pushing the envelope in many other areas, it was decided that the tail configuration should be as simple as possible to reduce costs and increase reliability. Aft tail configurations provide very good performance and are employed in most current designs. Therefore, the canard configuration will not be considered further.

This design mission has critical constraints on loiter time. High aspect ratios and specifically high wing span results in increased aerodynamic efficiency and improved loiter performance. While many distinctions in planform shape can be made, those distinctions become blurred at the high aspect ratio and span that this design demands. Other design factors such as tail arrangement, engine location, inlet and exhaust configuration, and weapons location have a greater driving effect on configuration layout. Once the other major pieces of the aircraft are selected, a planform must be chosen that integrates those pieces. The size and shape of the planform can then be adjusted to provide a best fit for the other design components. The major planform options that were considered are described on the next page.

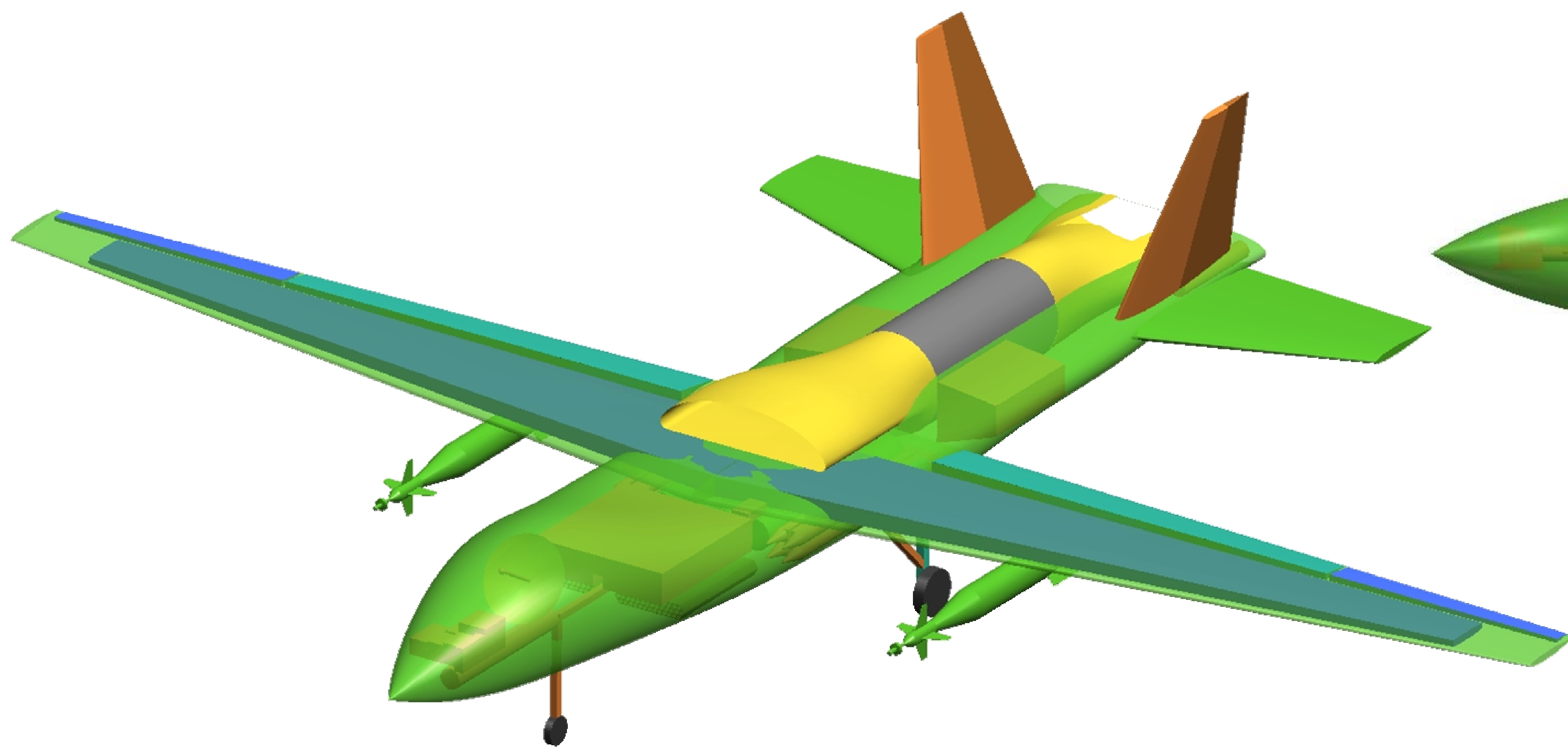
Table 2.5 Planform Configurations

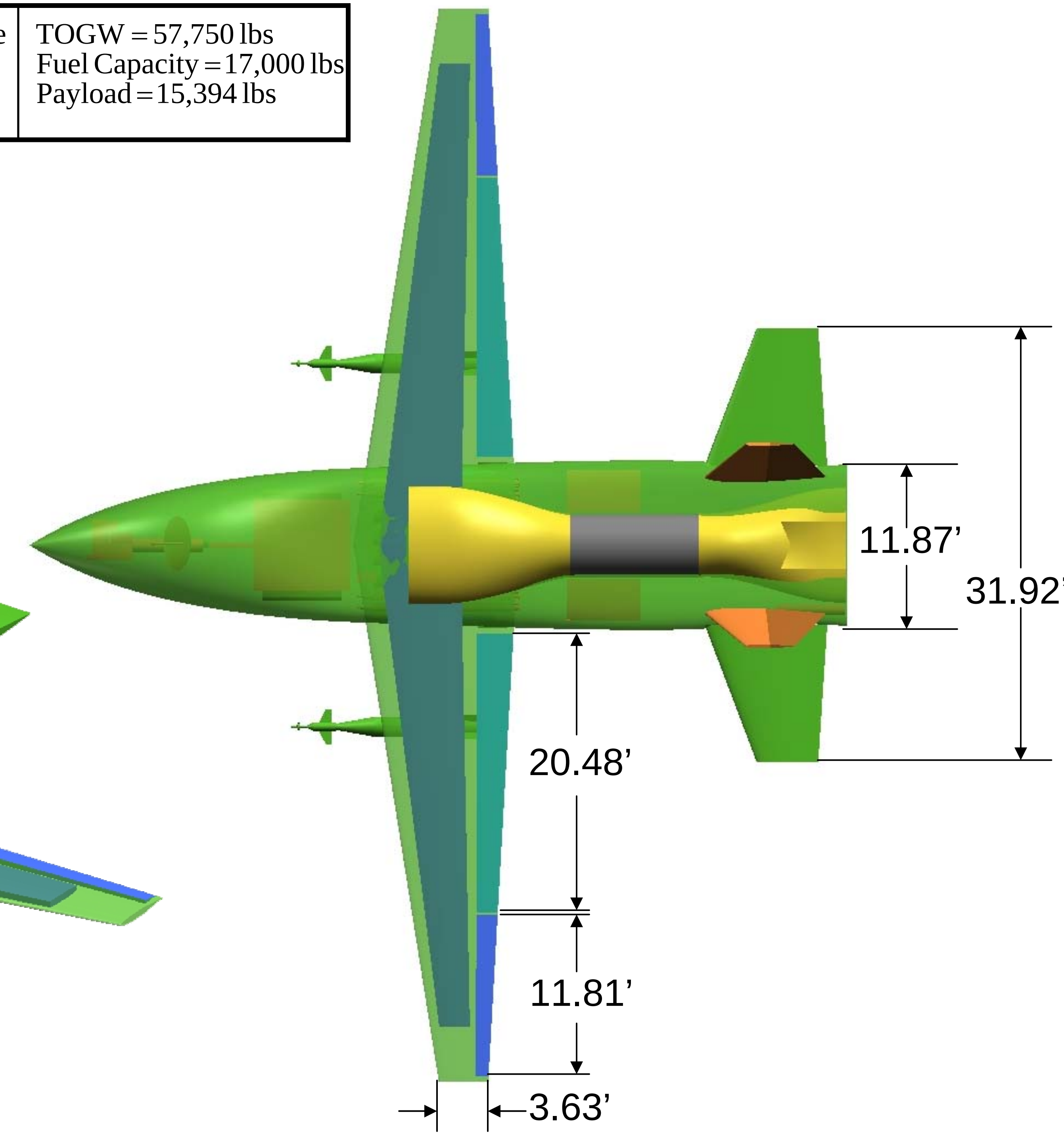
Conventional • Good subsonic performance. • Initial design can be performed without CFD.
Delta • High LE sweep improves high angle of attack performance. • At higher aspect ratios, delta wings begin to look like conventional wings.
Box Wing • Reduced wing structural weight. • Interactions between upper and lower wing surfaces. • Possibly reduced wing fuel capacity. • Optimal use is on very larger aircraft such as tankers and transports. • Weapons cannot be stored on wing because it would cause large pitching moment variations on release.
Forward Swept Wing • Very difficult and expensive to design. • Typically used in conjunction with a canard. • Good performance at high angles of attack. • Performance benefits are not experienced in this design's flight envelope.

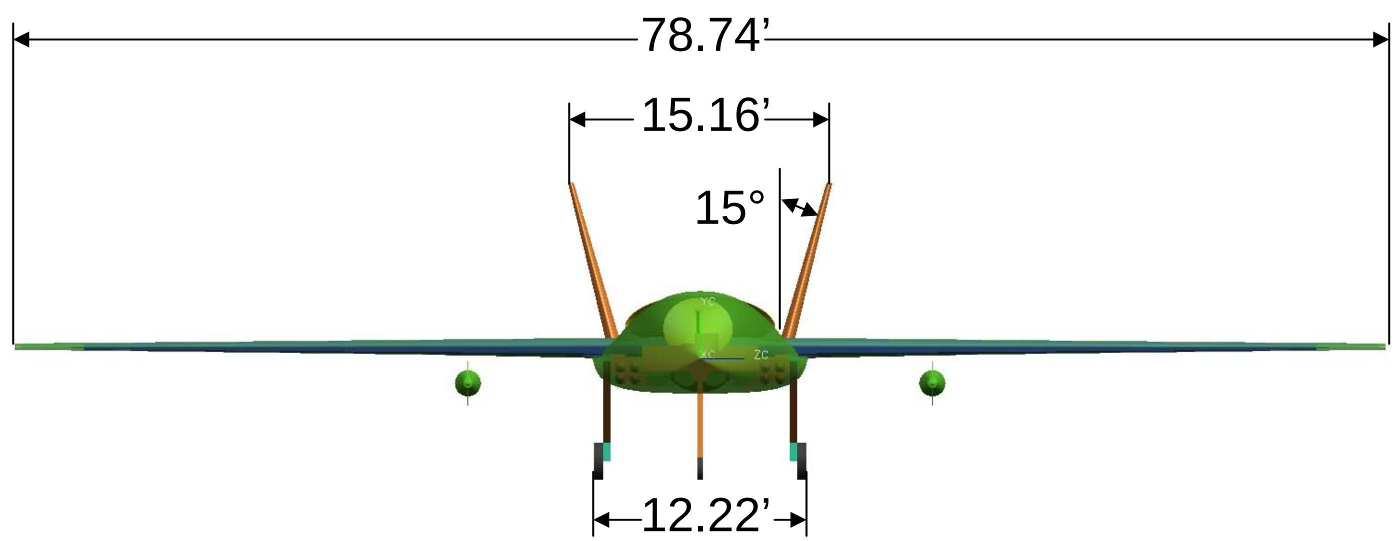
The box wing and forward swept wing can be very beneficial on specific applications. However, for this application they would require a huge cost and would return little if any benefits. The planform for this aircraft will look like a conventional wing. It will be blended into the fuselage to reduce drag and increase payload volume. The wing will be mounted on the middle or upper part of the fuselage to allow structural members to carry through the fuselage while allowing internal weapons. The parameters of root chord length and wing area will be driven by the payload configuration, while the span, aspect ratio, sweep, and airfoil thickness will be driven by cruise and loiter performance. Other significant factors include wing fuel capacity, takeoff and landing, control surface configuration, and roll performance.

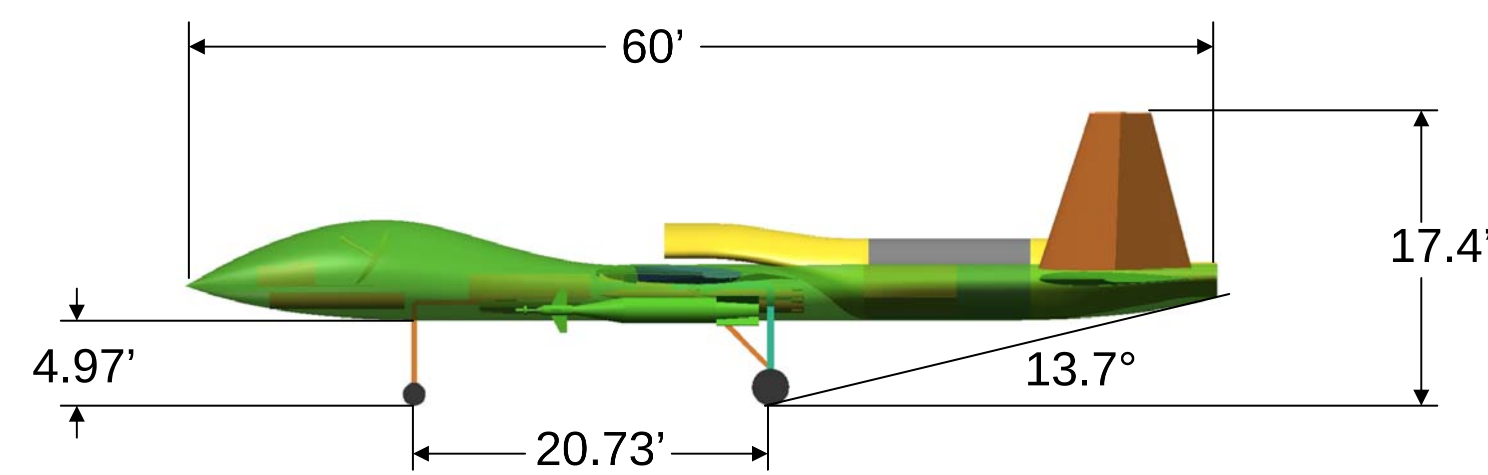
ARCHANGEL	3-View Drawing
	D. Jackson
	05/04/2005

$S_{ref} = 620\ ft^2$ $S_{HT} = 133\ ft^2$ $S_{VT} = 103\ ft^2$	$AR = 10$ $\lambda = 0.3$ $\Lambda_{c/4} = 6°$	57.1% AIAA Engine 56.5"D x 112.8"L $T_0 = 17{,}317$ lbs	TOGW = 57,750 lbs Fuel Capacity = 17,000 lbs Payload = 15,394 lbs

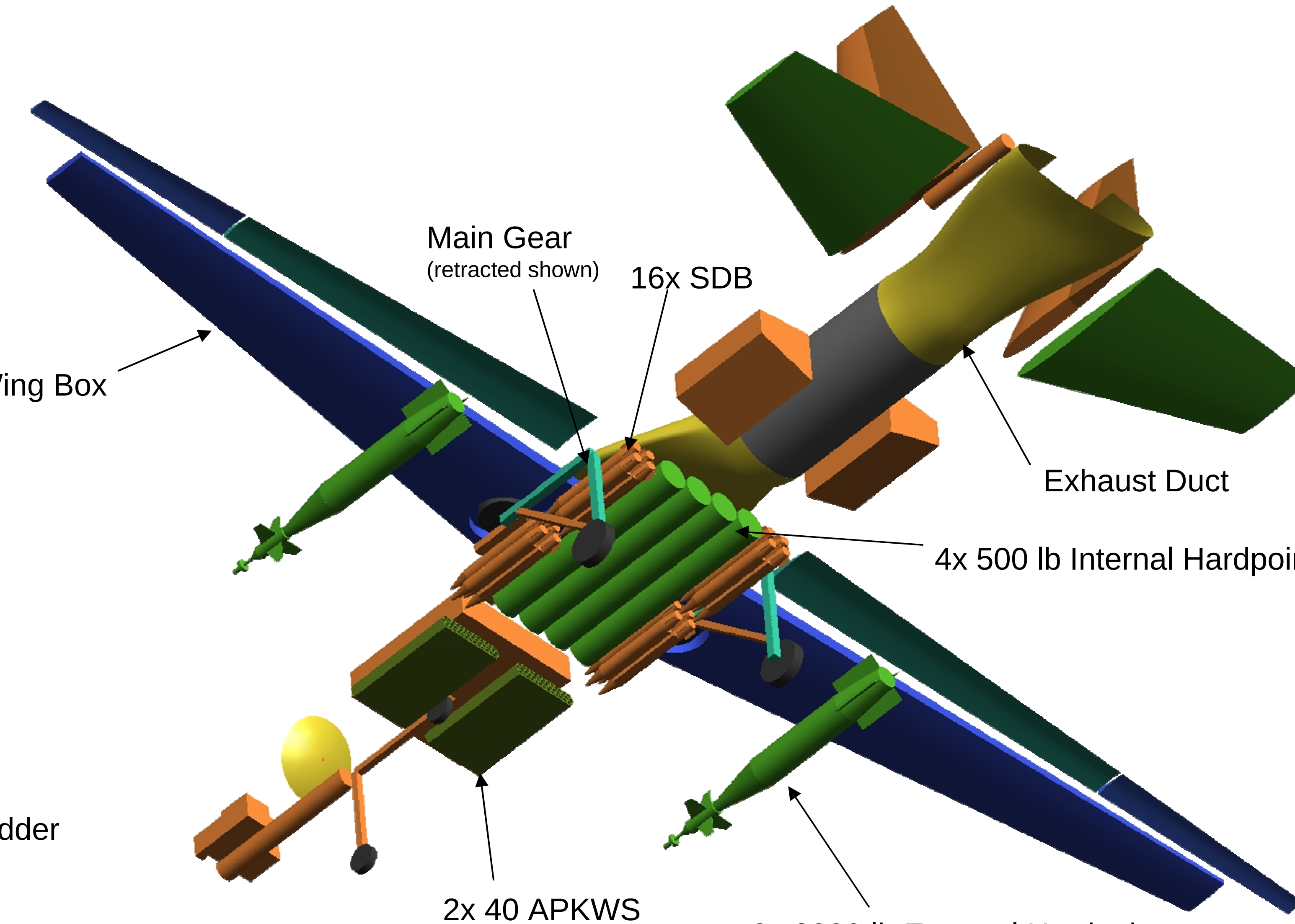


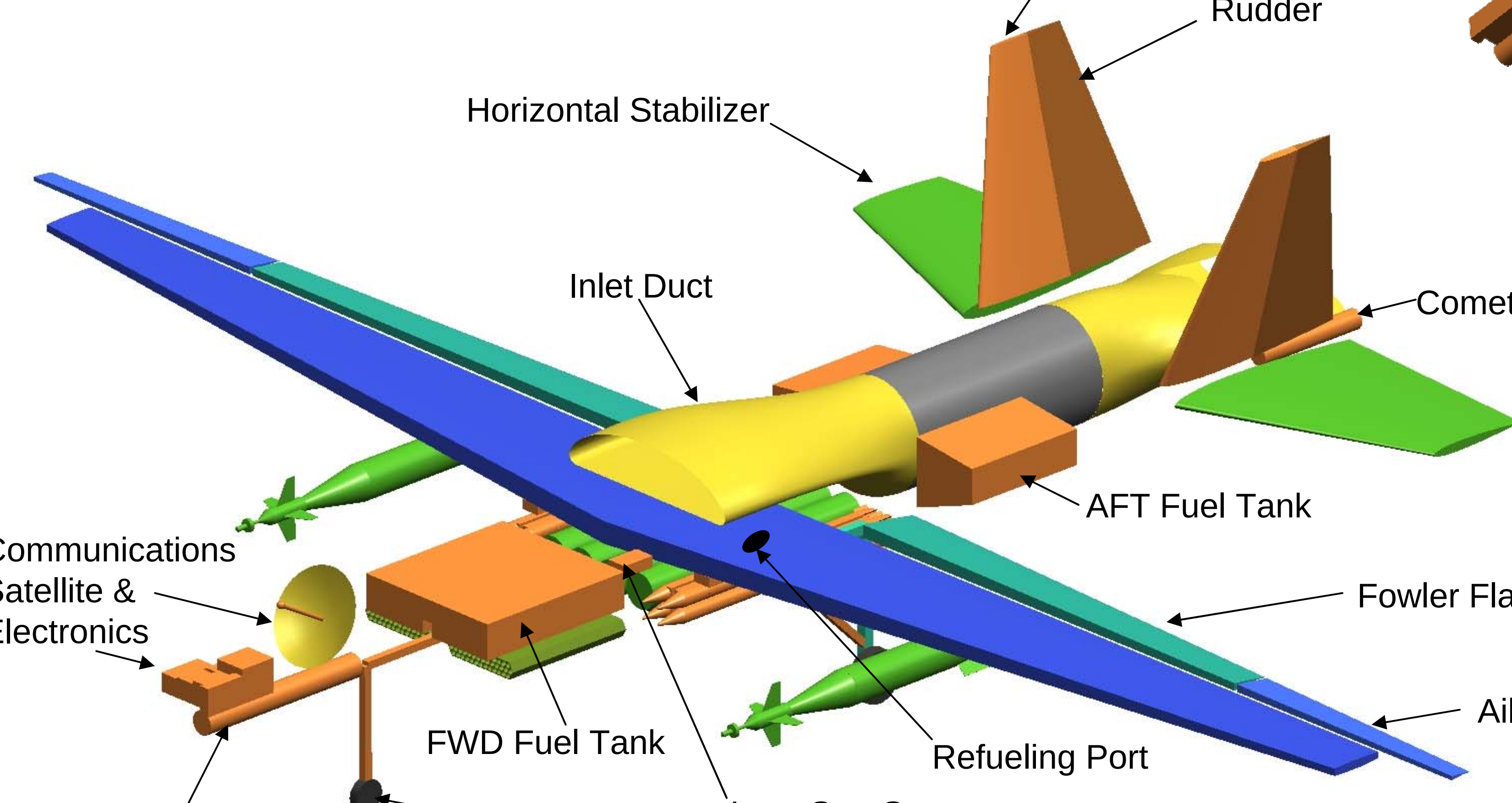




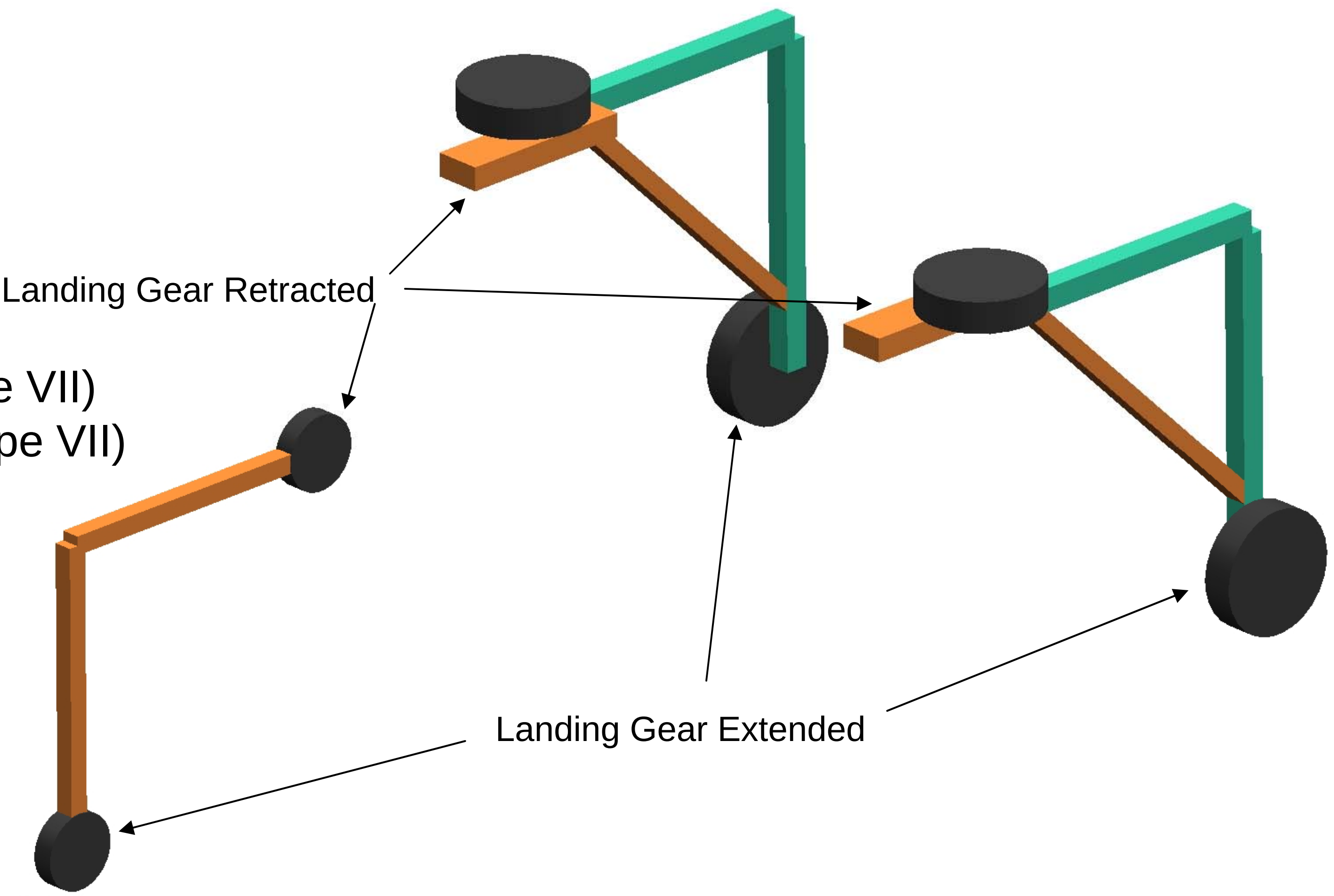


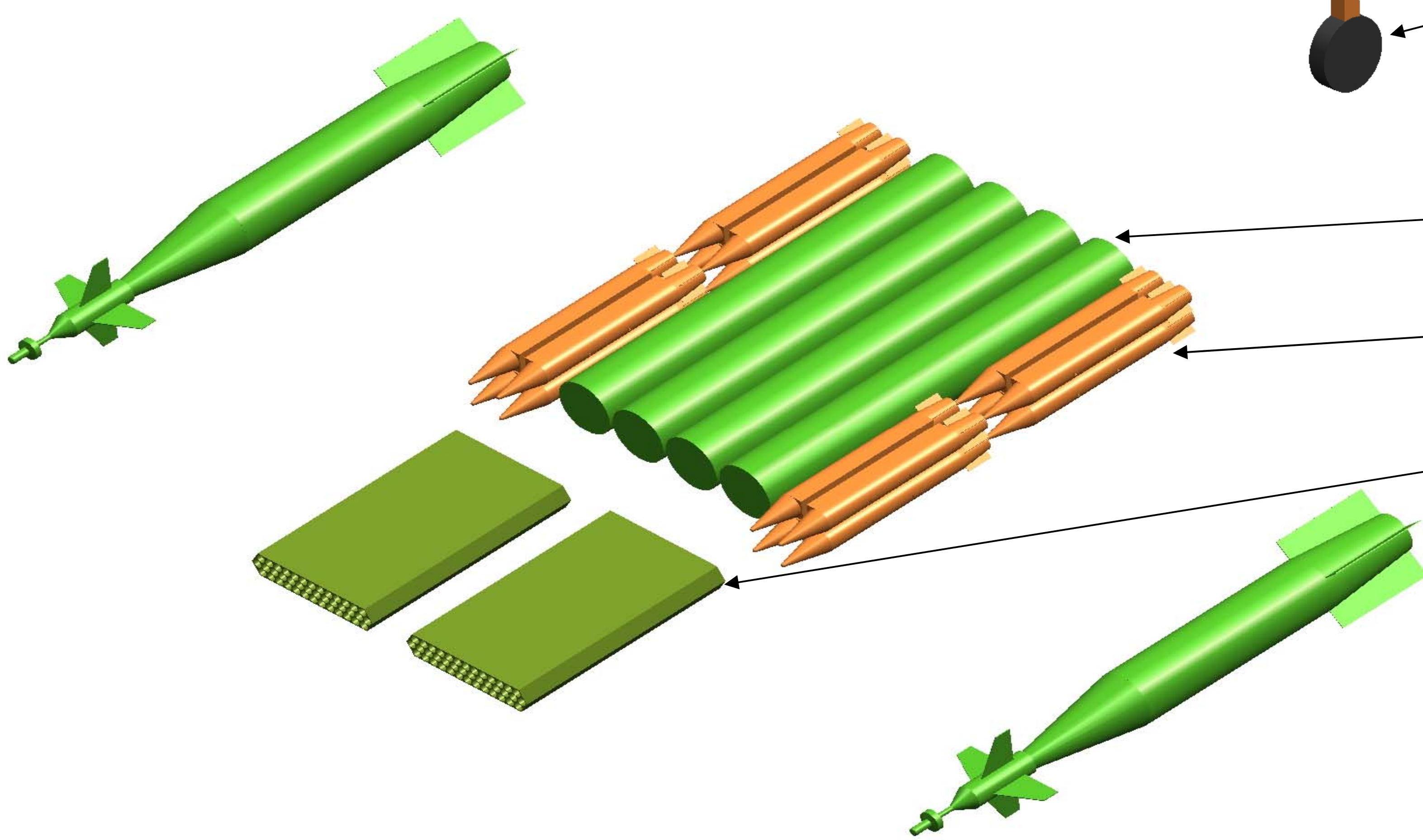
ARCHANGEL	Layout Drawing
	D. Jackson
	05/04/2005





ARCHANGEL	Payload & Landing Gear Configuration
	D. Jackson
	05/04/2005





2.4 Mission Analysis

The mission analysis was performed using FLOPS version 6.11. FLOPS is a program that takes basic aircraft configuration data to create a mathematical model of the aircraft performance. FLOPS uses general aircraft dimensions to estimate the aircraft weight using statistical curve fits to previous aircraft. It also incorporates basic wing geometry to develop drag polars and a component skin friction drag buildup. The engine performance was input from the given engine deck after the appropriate scaling factors and installation losses were computed using an external MATLAB script. FLOPS then uses this data to analyze the cruise and climb performance at various Mach numbers and altitudes. A mission profile is input with appropriate mission segments, each with Mach number and altitude constraints. FLOPS then performs a time step integration of the mission to find the fuel burn and optimizes according to a weighted objective function and constraints. Detailed takeoff and landing analysis are also computed.

The optimum design approach for Archangel was based on two main factors. The gross weight must be minimized to provide the least possible manufacturing cost and thus the lowest purchase price. The fuel burn must be minimized to reduce the direct operating cost. Of course, the gross weight and fuel burn are coupled such that a lower gross weight will typically require a lower fuel burn. An extensive study was performed to find the minimum possible gross weight and fuel burn for Archangel. Parametric variations were used on all available variables in a fashion similar to Powell's pattern search, which uses a steepest descent method on each variable. The most significant of these parametric variations was the thumbprint plot of T/W versus W/S shown in Figure 2.6. This figure shows the constant contours of gross weight, fuel weight, landing field length, and takeoff field length, as well as the T/W required for a 30,000 ft cruise climb ceiling, combat climb ceiling, and best range cruise. The cruise climb ceiling and combat climb ceiling are defined to be the altitude at which the climb rate is 300 and 500 ft/min respectively (Ref 2.4). The requirement stated in the RFP is that the cruise climb ceiling be at least 30,000 ft at the initial cruise weight. Other constraints requirements given in the RFP are that the takeoff and landing field length be less than 5000 ft with additional stipulations which were accounted for in the calculations. The goal of the thumbprint plot is to graphically show the optimum design and corresponding constraints. The steepest descent vectors for the fuel weight and gross weight are nearly perpendicular to the takeoff field length constraint. This means that a significant decrease in fuel and gross weight is controlled by the takeoff field length and correspondingly the takeoff C_{Lmax}. A fuel weight valley is shown near T/W=0.293, W/S = 98 lb/ft^2. It was determined that a Fowler flap high lift configuration with a C_{Lmax} of 2.0 would be the best high lift system to reduce fuel burn without adding significant control surface weight. Thus, the design point of T/W = 0.3, W/S = 93 lb/ft^2 was chosen on the steepest descent vector of fuel burn while leaving a small margin on takeoff distance. This design point leaves margin on the landing field length and cruise climb ceiling requirements.

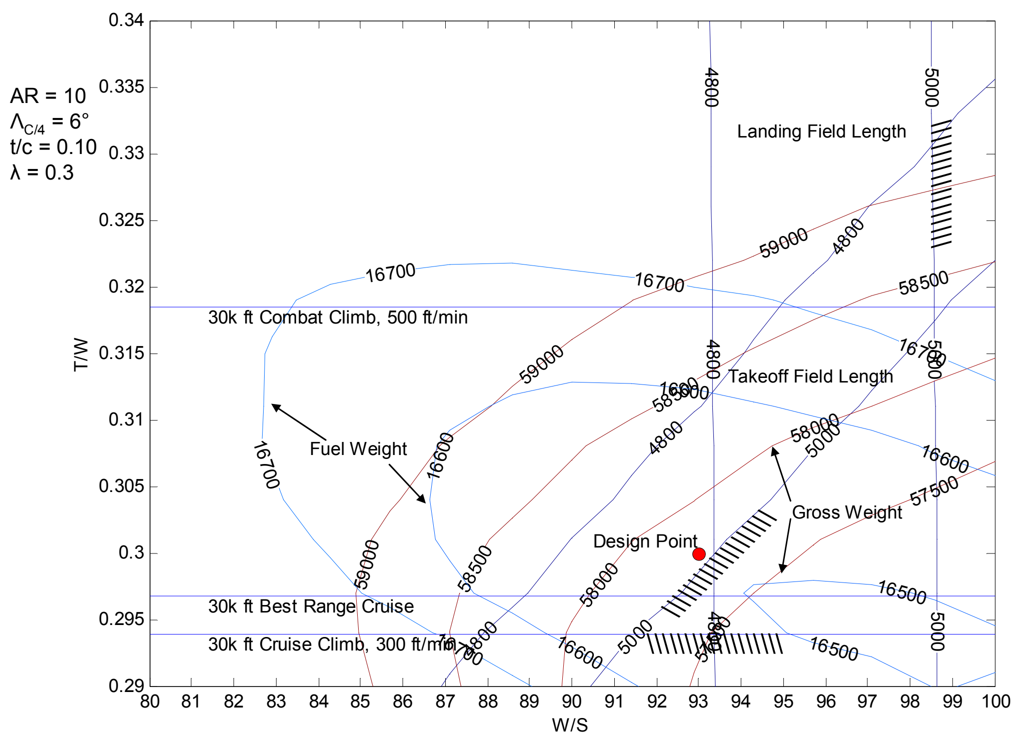


Figure 2.6 Thumbprint Plot

Other significant parametric optimizations involved the wing sweep angle and airfoil thickness ratio. Figure 2.7 shows the variation of fuel and gross weight with wing sweep. It can be seen that the weights are nearly independent of sweep up until 10° where they begin to increase rapidly. A wing sweep of 6° was chosen for initial design considerations, but it was noted that the wing sweep could easily change within the 0-10° range to fine tune the CG placement. A similar study showed that a minimum fuel burn was achieved for an airfoil t/c of 0.08. However, since internal weapons were desired for Archangel, the wings needed to hold most of the fuel forcing a t/c of 0.10 to achieve this fuel capacity.

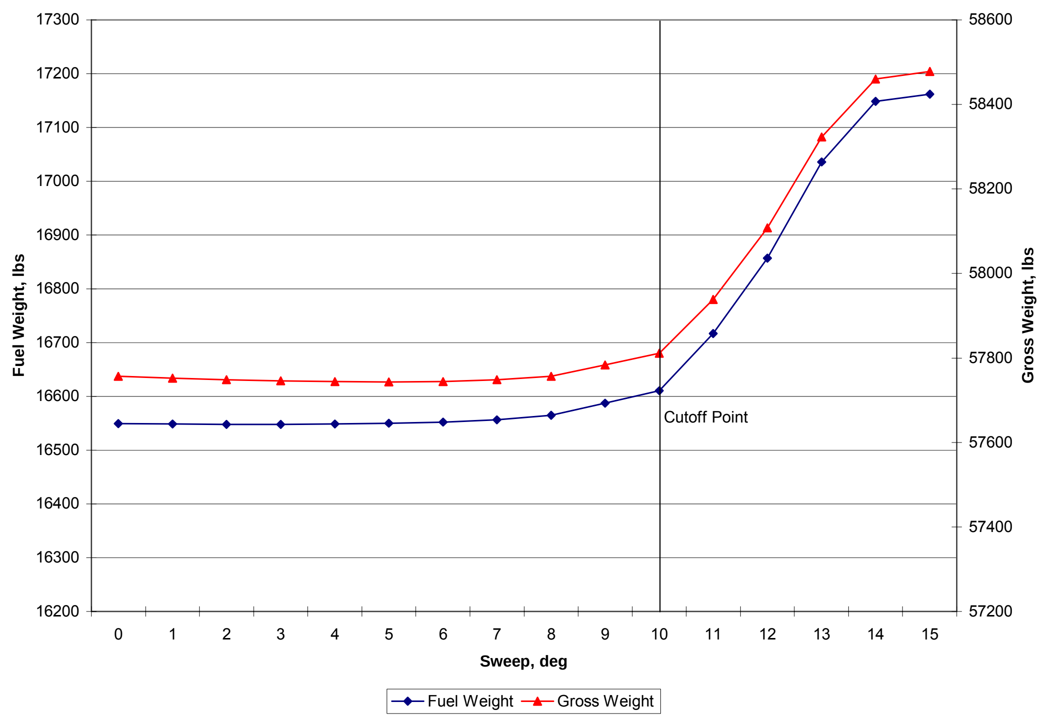


Figure 2.7 Fuel Weight and Gross Weight vs. Wing Sweep

The component drag buildup for Archangel is shown in Table 2.6. It shows the skin friction drag contribution of each wetted component. The main contributors to the skin friction drag are obviously the wing and fuselage. The drag penalties (using D/q values given in Raymer Ref 2.5) for the two main external payload configurations are also shown. The external fuel tanks contribute a major drag penalty of 16 drag counts thereby reducing their effectiveness to increase aircraft range.

Table 2.6 Component Drag Buildup

COMPONENT	SWET	LENGTH	RN	CF	CDF
	SQ FT	FT	MILLIONS		
WING	1020.5	7.87	15.6	0.00268	0.00631
HORIZONTAL TAIL	279.5	6.66	13.2	0.00276	0.00177
VERTICAL TAIL	239	5.87	11.6	0.00281	0.00155
FUSELAGE	1517.2	60	118.6	0.00199	0.00581
VERTICAL TAIL	239	5.87	11.6	0.00281	0.00155
MISCELLANEOUS					0.00102
TOTAL	3295.2			**Cdo**	**0.01801**
External Weapon Configuration				D/q	ΔCd
2000 LB BOMB				0.18	0.00029
2000 LB BOMB				0.18	0.00029
				Cdo	**0.018591**
External Fuel Tank Configuration				D/q	ΔCd
300 GALLON				0.5	0.000806
300 GALLON				0.5	0.000806
				Cdo	**0.020204**

The design mission weight breakdown is shown in Figure 2.8. This figure shows the contribution of each component to the aircraft weight in the design mission configuration. The payload weight fraction is over 25% and much higher than most other strike aircraft, making Archangel one of the most efficient weapons delivery platforms. The mission fuel fraction is also greater than 25% even though Archangel is a very aerodynamically efficient platform, showing the extent of the mission range and loiter requirements. The mission profiles for the design mission and ferry mission are shown in Figures 2.9 and 2.10 respectively. These figures also show the fuel burn during each segment of the mission. The design mission profile shows that the 4-hour loiter is the most significant mission segment for fuel burn. Any possible improvements in fuel burn for this segment should be seriously considered. The combat missions segment was conservatively estimated to contain 10 minutes of combat coupled with the release of 1500 lbs, or 10%, of the required payload. The ferry mission profile shows that the ferry mission was not a limiting constraint for Archangel. The fuel burn for the ferry mission is 7.5% less than the fuel burn for the design mission.

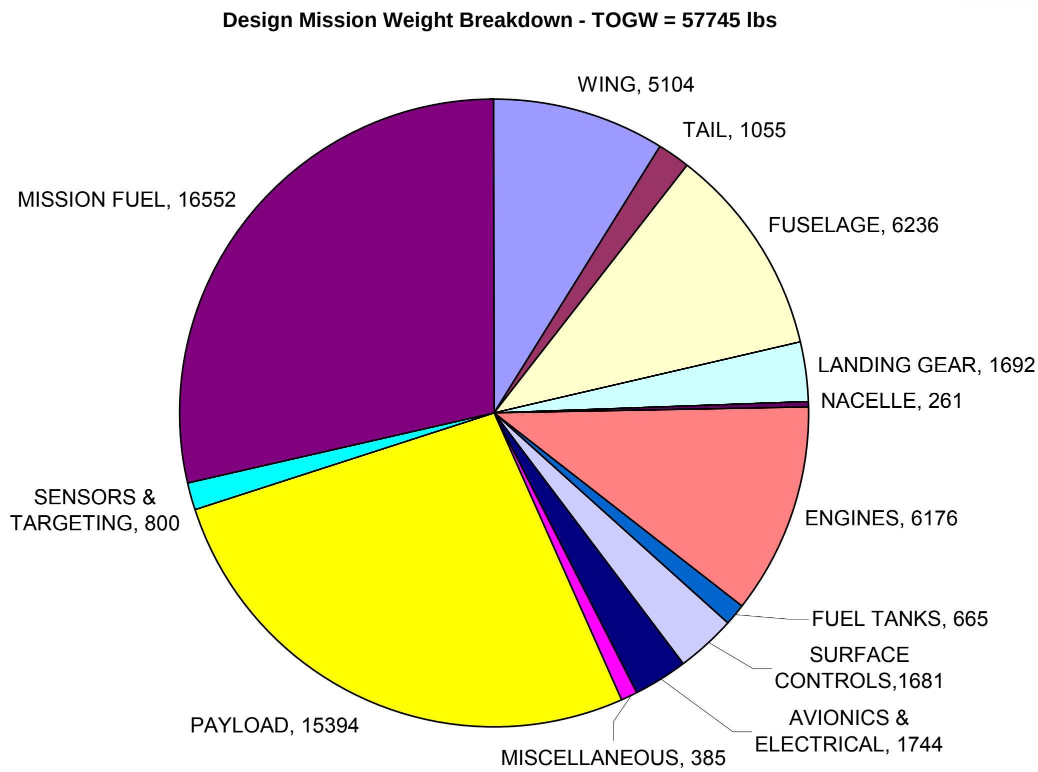


Figure 2.8 Design Mission Weight Breakdown

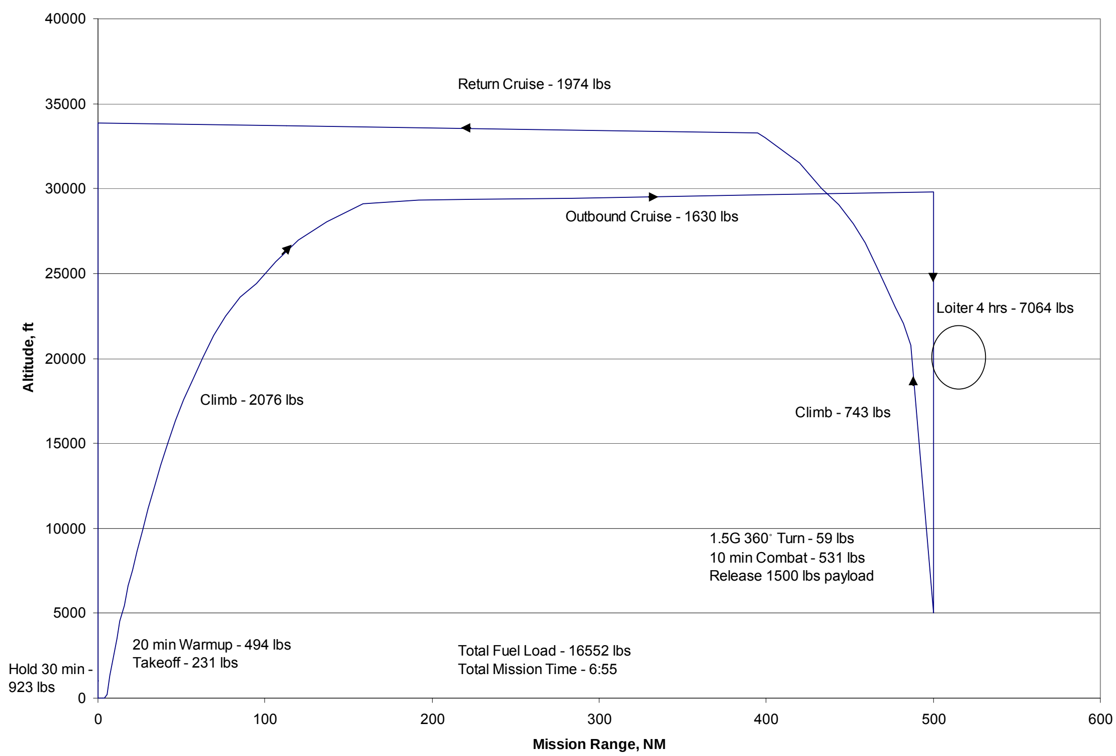


Figure 2.9 Design Mission Profile with Segmented Fuel Burn

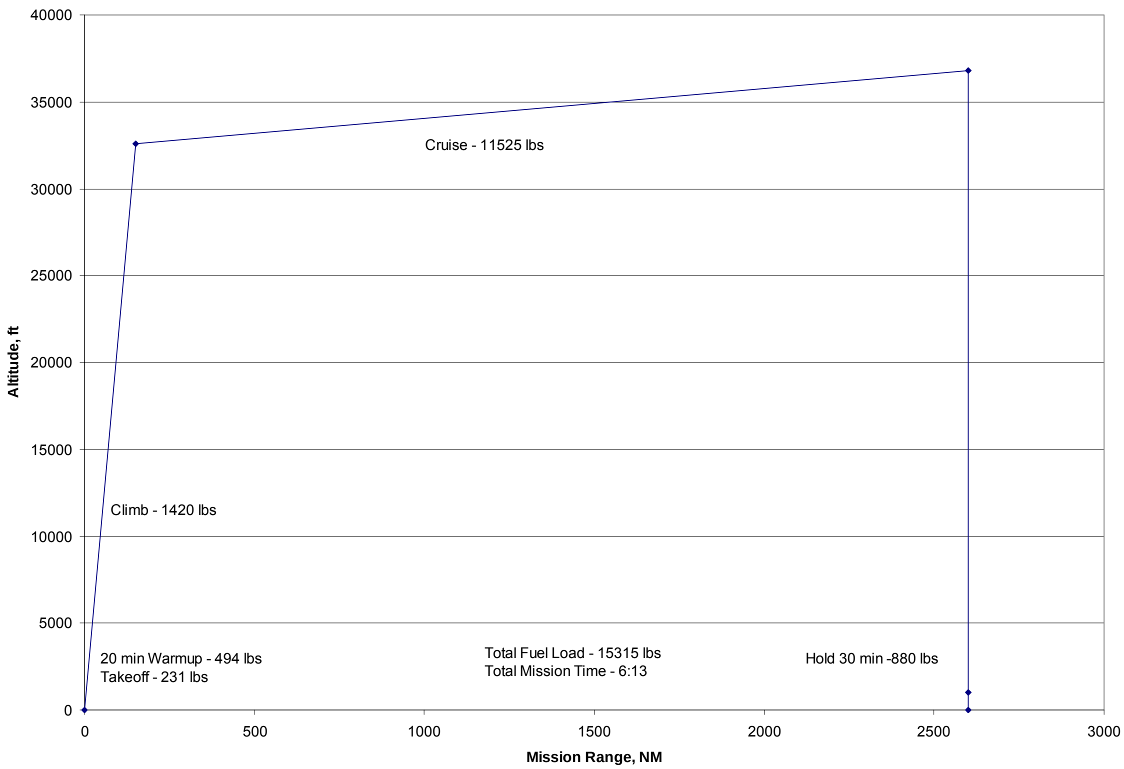


Figure 2.10 Ferry Mission Profile with Segmented Fuel Burn

An optimization study on the wing aspect ratio showed a significant decrease in fuel burn and gross weight for higher aspect ratio wings. This is a direct result of the induced drag being inversely proportional to the wing span squared. Since the loiter requirement is one of the limiting factors where most of the fuel burn occurs, the wing span should be maximized to produce the least possible induced drag and minimize the fuel burn. Since the structural limit load factor is a relatively low at 3.5 g's, the wing weight does not significantly increase with span and the fuel burn weight saved dominates. The limiting factor on the maximum span is the roll rate requirement as the wing span dominates the roll rate damping. A trade study showed that a maximum aspect ratio of 10 could be used in conjunction with 30% span, 25% chord ailerons to meet the MILSPEC 8785C Level 1 Ground Attack roll performance requirement. Additional roll performance can also be achieved using differential horizontal stabilizers, a technique common on modern fighter aircraft. To meet the low speed roll rate requirements, spoilers can be used for roll control. The spoilers are also very effective at reducing the landing distance. In the FLOPS analysis, a conservative spoiler effect of $\Delta C_{Lspoiler}$=-0.5 and $\Delta C_{Dspoiler}$=0.05 was used for the landing analysis. Since Archangel is a single engine aircraft, and the landing distance requirement specifies that one engine must be inoperative, a thrust reverser was not an option. Instead, a combination of spoilers and speed brakes were used to achieve a landing distance of 4660 ft from the approach speed of 131 kts over a 50 ft obstacle. The design takeoff field length is 4986 ft with a rotation velocity of 123 kts, liftoff at 136 kts and 150 kts velocity over the 50 ft obstacle. Figure 2.11 shows the detailed takeoff and landing time histories.

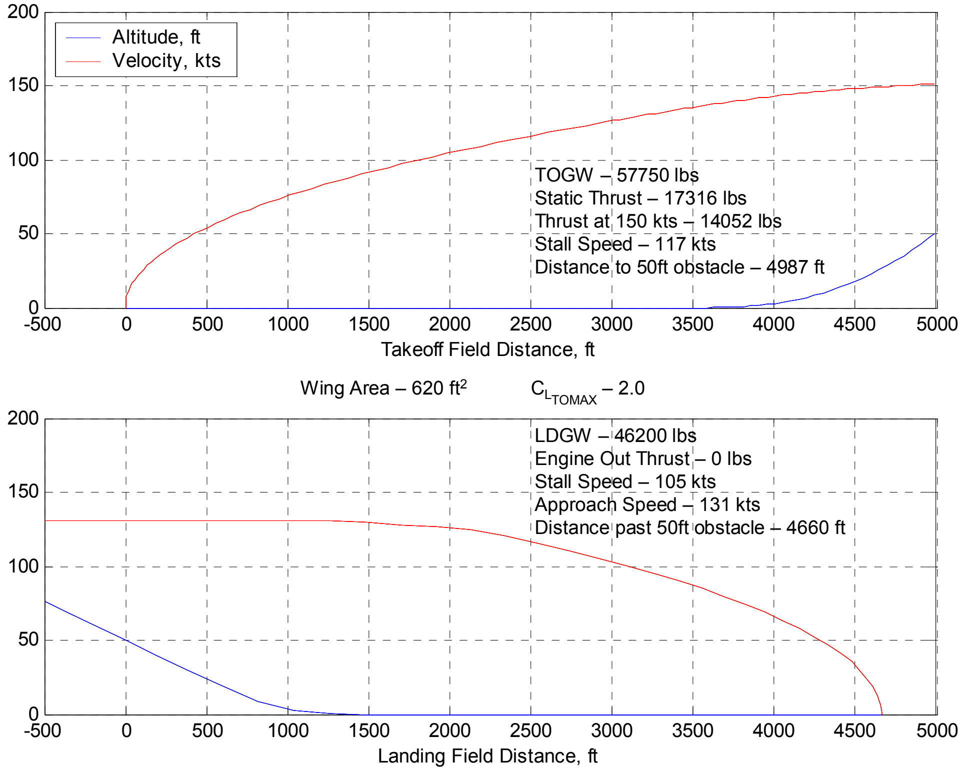


Figure 2.11 Takeoff and Landing Profiles

Chapter 3. UAV Design

3.1 Manned vs. Unmanned

A current question facing military aircraft design is whether to design a manned or unmanned aircraft. Historical precedent calls for a manned aircraft, while the idea of an unmanned aerial vehicle (UAV) is the wave of the future. During preliminary analysis, the mission of an advanced gunship seemed to require having a crew onboard; however, military branches and politicians are continually placing more and more emphasis on applying UAV technology to military applications, so it was decided to make the design unmanned. (Ref 3.1)

3.2 Situational Awareness

The mission of a gunship lends itself to an onboard crew primarily due to the benefits of situational awareness. Conversely, a UAV would limit the first-hand knowledge available to the controller with regard to threats, other aircraft, and location of battle damage. Part of the decrease in situation awareness in UAVs stems from the current military practice of having more than one aircraft per controller. This problem is not inherent in the UAV design, but rather lies in current military operational procedure. This practice may be acceptable for reconnaissance missions, but would be grossly inefficient in a combat situation.

As different attack methods were explored, it was found that in order to maintain the gained situational awareness of a manned design; several people would have to operate various systems independently of one another to prevent an overwhelming workload on one person. The recent conflict in Afghanistan required persistent firepower on a certain area, such as attacking a group of buildings. These sorts of targeting situations would distract the pilot from potential threats. The solution to this disadvantage lies in adding another person to the cockpit to control the weapons. Protection for the crew, however, comes at the high cost of weight, a precious commodity in aircraft design. The titanium bathtub of the A-10 is a prime example of this. Additionally, adding people to the crew’s complement also decreases its political survivability.

In a world where each American casualty is reported on the evening news, the Department of Defense wants to be able to carry out an attack without putting pilots' lives at risk.

Stand Off Distance

By using AWPKS, an aircraft could attack from 10,000 ft. at a radius of 5 miles while still providing persistent firepower. This kind of weapons configuration, in addition to the use of guided bombs, allows an aircraft to attack a target outside of AAA threat envelopes and at the edge of most MANPAD threat envelopes. Combining this with the Sniper pod creates a stand off distance suitable for a UAV.

3.3 The Future of UAV Design

A proposal has been made for converting the F-16 into a UAV, allowing for immediate realization of how UAVs can fit into the modern battlefield (Ref 3.2). Modifying the F-16 in this manner would be a step towards air occupation. Though a majority of the mission would be handled autonomously by the aircraft's computer, a human would be kept in the loop to control targeting and weapons release, as well as flight during takeoff and landing. Switching between full operator control and limited operator control will help keep bandwidth use to a minimum.

Despite current problems with UAVs, including bandwidth saturation, jamming, and reduced situational awareness, the Department of Defense has asked for several reports regarding the timeline of full integration (Ref 3.3) The general consensus indicates that the USAF will utilize UAVs exclusively by 2025 (Ref 3.4). Archangel follows this plan. The concern with limited bandwidth is addressed by choosing how the operator interfaces with the aircraft. The plan laid out for the F-16 significantly untangles communication lines.

It was decided that the design would be an UAV to utilize the advantage that the design offers. The UAV design has more of a future with the military, and its advantages outweigh the features of a manned design.

Chapter 4. Weights

The only weight restriction given by the RFP is that the aircraft must carry a payload of 15,000 lbs. The design meets this criterion. The initial sizing and weight of the design came from the FLOPS mission program. Initially, the design TOGW was determined to be 68,000 lbs. After refining the configuration, scaling down the engine, and improving the wing, the design TOGW ended up being 57,700 lbs. The fuel required was reduced to get the lower TOGW. As shown from the configuration breakdown (Fig. 2.8), the fuel required to complete the design mission is the largest component of the aircraft's weight at 30%. The payload is 25% of the total TOGW.

4.1 Component Weight Breakdown

Table 4.1 Component Weight Breakdown of the Archangel

Component	Unit Weight(lb)	Total Weight (lb)	Location relative to nose (ft)
Fuselage	6236	6236	30
Wing	2552	5104	30.5
Horizontal Tail	584	584	54.75
Vertical Tail	471	471	54.75
Engine	6176	6176	44.4
Rocket Launchers	1255	2510	21.64
Small bombs (70 in long)	285	2280	26.55
	285	2280	32.459
Large bombs (120 in long)	800	1600	30.49
	800	1600	30.49
Landing Gear nose	583	583	14
main gear	583	1166	38
Avionics and systems	800	800	2
Controls, power plant, etc	900	900	5
Sniper pod	100	100	2
Fuel tanks in wings	5000	10000	30
Tank weight	282	564	30
Fuel tanks in fuselage	3000	3000	15
	4000	4000	40
Tank weight	95	95	15
Tank weight	95	95	40
2000 lb hardpoint	2400	4800	30
Survivability	300	300	59
Total		55244	

Table 4.1 gives the component weight breakdown for the Archangel. Most systems were estimated as a single weight. All payload and fuel tanks are given. This breakdown is important for the determination of the longitudinal center of gravity.

4.2 Longitudinal Center of Gravity

The longitudinal center of gravity was determined by balancing the moment associated with each of the components of the aircraft. This analysis was performed for several flight conditions to find the extreme forward and aft locations of the center of gravity. The results can be viewed in Figure 4.1 below.

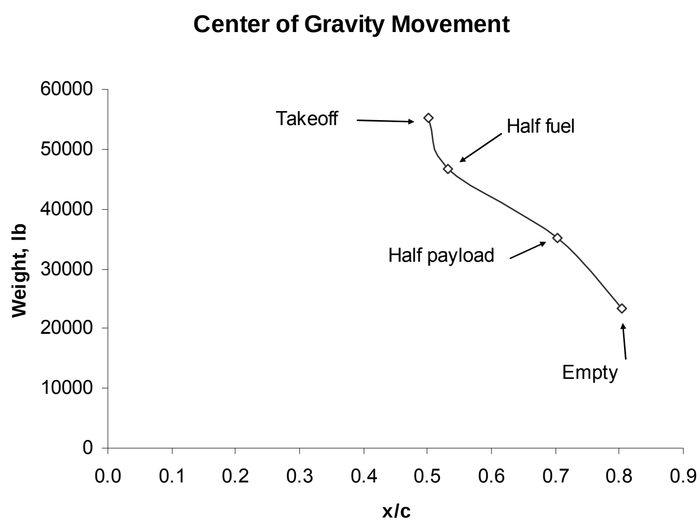


Figure 4.1 Longitudinal Center of Gravity Travel for the Archangel

The extreme operating conditions for the longitudinal center of gravity occur at takeoff (TOGW) and at the empty weight, where the entire payload has been expended and the fuel used. The center of gravity moves aft during the mission through a range of 30% MAC, or about 2.4 ft. This movement is a critical factor in determining the size of the horizontal tail in order to maintain static stability at all flight conditions. The fuel tanks in the fuselage are capable of pumping fuel between each other to help maintain an optimal CG location.

4.3 Vertical Center of Gravity

The vertical center of gravity of the Archangel was found from a datum plane 5 ft below the aircraft. At takeoff, the vertical center of gravity is 7.37 ft from the datum plane, and at empty weight it is 7.54 ft. These values are important considerations in designing the landing gear.

Chapter 5. Stability and Control

The Archangel is capable of performing within all stability requirements set forth in the RFP. The decision was made during the design process to make the aircraft statically stable at all flight conditions to negate the need for an artificial stability system. An 8-10% minimum static margin was desired to ensure this. The aircraft also had to be able to produce enough moment during takeoff to rotate the nose up, and it needs to be able to trim at its center of gravity extremes.

5.1 Control Surfaces

The Archangel utilizes a conventional horizontal tail and twin vertical tail system. The horizontal tail is an all-moving tail that has an effective deflection range of -10° to 10°. The all-moving tail was chosen for simplicity and for its ability to generate the moments required to trim the aircraft. It was sized using a longitudinal control constraint plot, explained later within this report.

The twin vertical tail system was chosen because it helps reduce the tail size, and assists in shielding the single engine. The vertical tails were sized using tail volume coefficients, typical of most military aircraft (Ref 5.1).

Ailerons, acting as the primary method of controlling the rolling moment of the aircraft, utilize 30% of the wing span. The control system of the Archangel was kept as simple as possible so that bandwidth could be kept available for other key systems.

5.2 Horizontal Tail Sizing

The size of the horizontal tail was found using a longitudinal control constraint plot, also known as an X-plot. This analysis determines the tail area needed to have consistent static stability, a trimmed aircraft at the extreme CG locations, and enough moment to rotate nose up at takeoff. Since static stability is desired at all flight conditions, the neutral point location is the aft constraint on the center of gravity. The forward constraints for trim and takeoff are the forward limits on the center of gravity.

The neutral point of the configuration for various tail areas was found using J-Kay VLM (Ref 5.2). Figure 5.1 shows the planform input into the program that matches the chosen configuration. The tail area was varied to get the desired relation. The output C_M/C_L was used to find the neutral point.

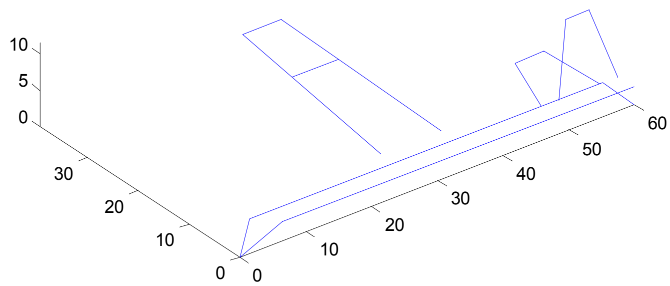


Figure 5.1 Archangel Input Planform for J-Kay VLM.

The forward limit for takeoff was found using a static analysis of the aircraft at takeoff speed to determine the tail moment required to rotate the nose upward. The corresponding tail area was found for different CG locations to obtain the desired relation. The forward limit on center of gravity to trim was found using moment coefficients output from J-Kay VLM and lift coefficients from JavaFoil. The following equation was used to find the forward limit:

$$h_{\min} = h_n - \frac{C_{M0} + C_{M\delta f}\delta_f - C_{M\delta t}\delta_t}{C_{L\max} - C_{L\delta t}\delta t} \qquad \text{(Ref 5.3)}$$

The aircraft center of gravity travel determined earlier is represented on the plot by two vertical lines, since it was found that the tail area had a negligible effect on center of gravity travel.

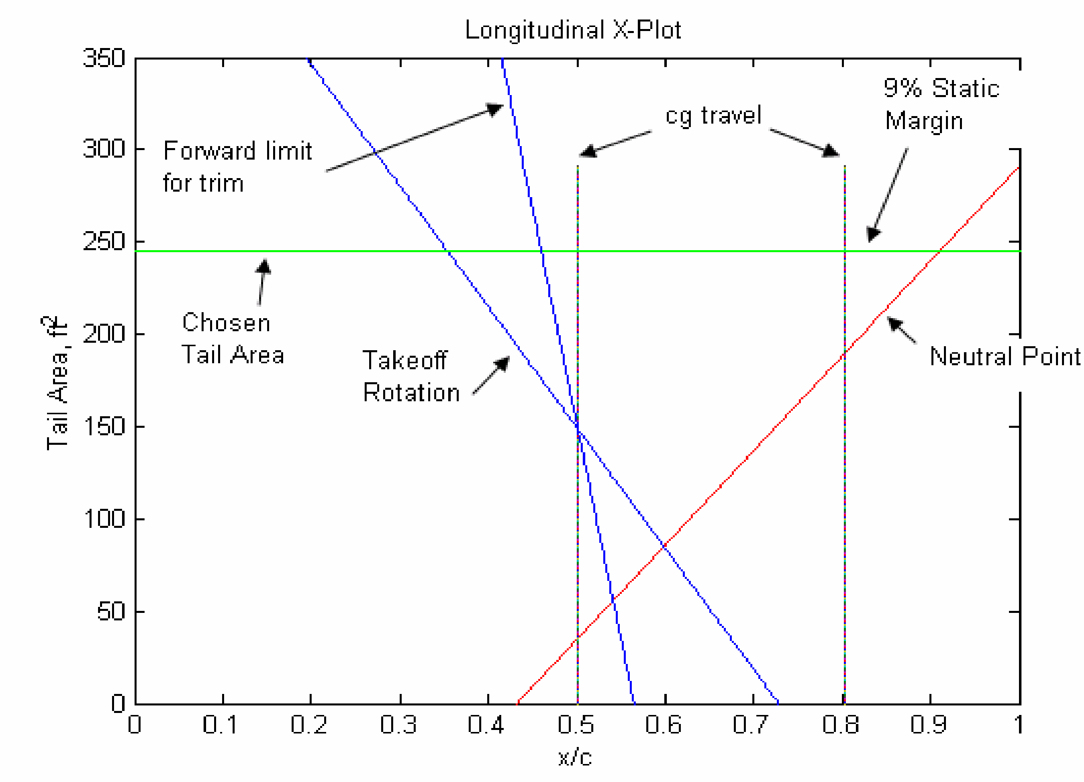


Figure 5.2 Longitudinal Control Constraint Plot

The optimal horizontal tail area was found to be 245 ft^2. This represents the total area of the wing, and corresponds to an exposed tail area of 140 ft^2. At the chosen tail area, the aircraft is statically stable at all flight conditions with a 9% static margin at the aft-most center of gravity.

5.3 Stability Derivatives and Flight Dynamics

Using the input planform given in Figure 5.1, J-Kay VLM produced the stability derivatives for the configuration.

Table 5.1 Major Stability Derivatives for the Archangel

$C_{y\beta}$	-0.40039
$C_{n\beta}$	0.09067
$C_{l\beta}$	-0.03478
C_{yr}	0.24520
C_{nr}	-0.06507
C_{lr}	0.02094
C_{lp}	-0.62200
C_{np}	-0.32982

Originally, AVL was going to be used to investigate the dynamic responses of the Archangel. However, the data that AVL produced was deemed to be inaccurate and unreliable. The derivatives presented here from J-Kay VLM are to give a quick idea of the basic characteristics of the design. Of note, the $C_{n\beta}$ of the design is positive, indicating directional stability. However, an extensive analysis of the flight dynamics could not be performed due to time constraints and unreliable data, so another method was needed.

To investigate the flight dynamics, a more qualitative approach was used. The flight dynamics of the Archangel were investigated in the flight simulation program X-Plane (Ref 5.4). This program allowed the user to get a hands-on feel of how the design would perform in flight. After modeling the Archangel design into the program and investigating its properties, it was determined that a simple yaw and pitch damper was needed in the flight control system. With the addition of these dampers, it was concluded that the design performed well in all flight conditions and no major problems in flight control were present.

Overall, the control system employed in the Archangel design is able to handle the aircraft in all flight conditions with no major stability problems. The system also meets the chosen design requirements of static stability and trim.

Chapter 6. Aerodynamics

6.1 Airfoil Selection

Given the flight performance and airspeed requirements from the RFP, it was immediately realized that either a NACA 6-series or NASA Supercritical airfoil would provide the greatest benefit to the design. Integrating a 6-series with a drag bucket around the cruise envelope would be a tremendous advantage to fuel consumption rate; however, the required cruise speed of 400 knots borders on the transonic region, which, without the assistance of a specially designed airfoil, is accompanied by a tremendous drag build up and dramatic loss in performance due to the formation of shock waves over the surface of the wing. A comparison of pressure coefficient plots, as seen below in Figure 6.1, can be used to demonstrate this difference.

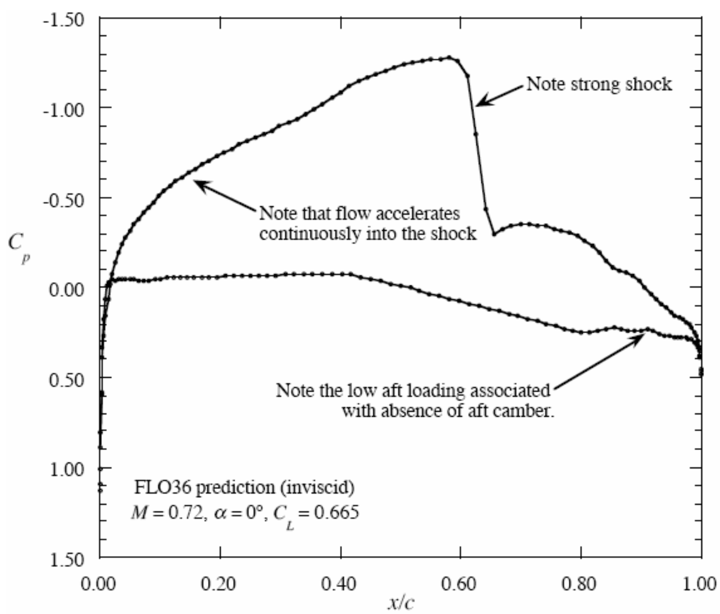


Figure 6.1 C_p Plot of a NACA 64A410 at M=0.72, α = 0, C_L=0.665 (Ref 6.4)

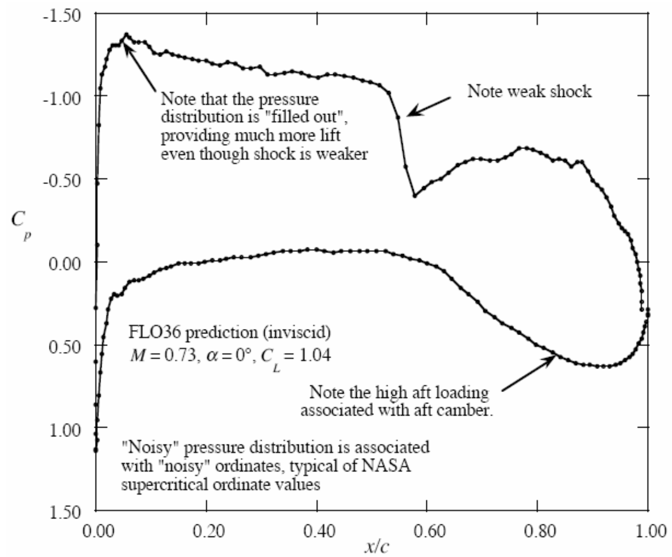


Figure 6.2 C_p Plot of a NASA Foil31 at M=0.73, α = 0, C_L=1.04 (Ref 6.4)

Additionally, changes in pitching moment due to Mach number, known as “Mach tuck,” and loss of control surface effectiveness can create unrecoverable situations. Therefore, to differentiate between the two, the drag divergence Mach number was investigated. This was accomplished using the Korn equation, shown below.

$$M_{dd} = \frac{\kappa_A}{\cos\Lambda} - \frac{(t/c)}{\cos^2\Lambda} - \frac{c_l}{10\cos^3\Lambda}$$

Here, κ_A is an airfoil technology factor (0.87 for NACA 6A-series, and 0.95 for supercriticals), *t/c* is the thickness of the airfoil as a percentage of the chord, C_l is the airfoil lift coefficient, and Λ is the wing sweep angle at the leading edge. Factoring in the 10 percent thickness determined by the necessity for internal structure and fuel capacity, a cruise C_l of 0.4, and a minimized sweep angle of 15 degrees, a visual comparison can be made through the following graph shown in Figure 6.3.

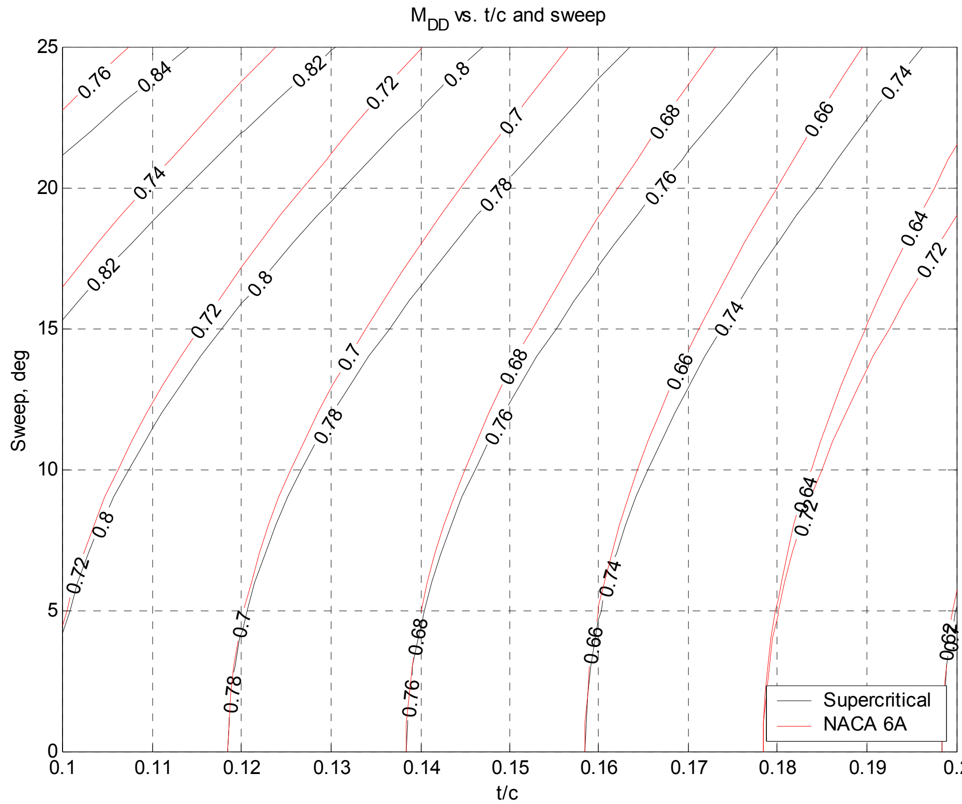


Figure 6.3 Plot Showing the Variance of Drag Divergence Mach Number with Thickness and Leading Edge Sweep.

This shows that the higher drag divergence Mach number of the supercritical airfoils will be necessary for this application. Carrying on calculations for the supercritical through the use of Lock's drag rise equation,

$$C_D = 20\,(M - M_{crit})^4,$$

and the definition of the drag divergence Mach number, $\partial C_d/\partial C_M = 0.1$, this yields a critical Mach number of 0.71 by the relation

$$M_{crit} = M_{dd} - \left(\frac{0.1}{80}\right)^{1/3}$$

After assessing the performance of several NASA supercritical airfoils, including the 20410, 20412, 20610, and 20612, it was ultimately decided that the NASA SC(2)-0610 was best-suited for this task.

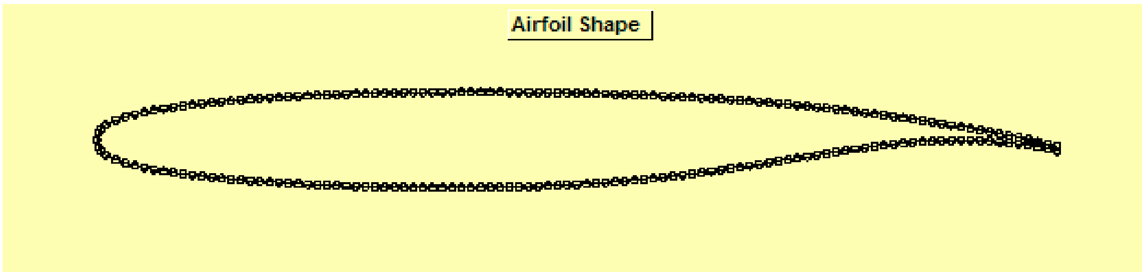


Figure 6.4 Shape of a NASA SC(2)-0610 Airfoil as Generated by JavaFoil

The following lift curve was generated using the Eppler stall model found in JavaFoil.

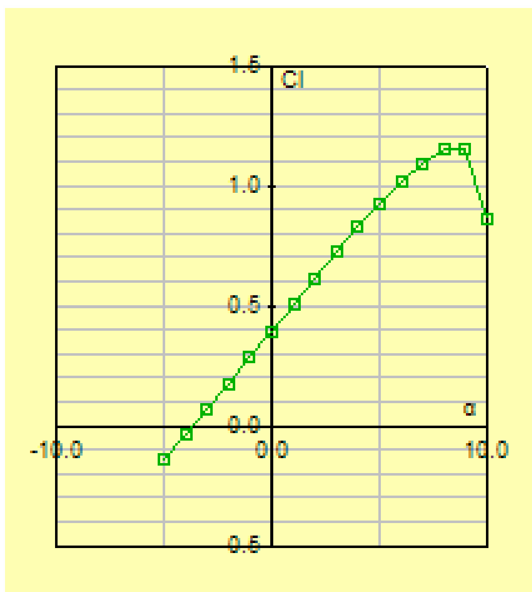


Figure 6.5 C_L Curve for the NASA SC(2)-0610 Airfoil at M=0.3, as Generated by JavaFoil

This shows that the SC(2)-0610 is capable of generating a maximum lift coefficient of approximately 1.15 at just under 10 degrees angle of attack using a free stream Mach number of 0.3. The zero lift angle of attack is nearly negative four degrees.

Additionally, JavaFoil was able to generate a pressure coefficient plot at the same conditions.

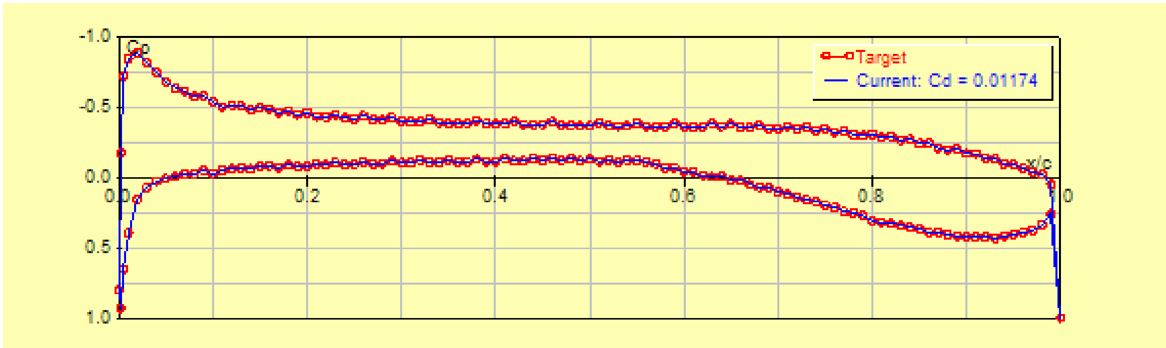


Figure 6.6 Cp Plot of a NASA SC(2)-0610 Airfoil Flying at M=0.3, α=0, as Generated by JavaFoil.

When compared to the previous supercritical Cp plot, one can see that this airfoil offers excellent performance. The relatively consistent thickness accounts for the symmetrical region through the middle, and the spike at the aft-most edge is a glitch in JavaFoil's programming caused by the requirement of a rear stagnation point.

6.2 3-D Wing Performance

Though JavaFoil has proven itself time and time again to be an invaluable potential flow tool in airfoil analysis, its 3-D considerations are quite limited. It was therefore necessary to include some additional calculations which might more accurately describe the actual conditions experienced by the aircraft.

Initially, Mark Drela's AVL vortex lattice code was going to be used as the primary 3-D analysis tool for aerodynamics as well as dynamic stability. The aircraft was modeled accordingly, as shown below, and run cases were generated to test the different modes of flight.

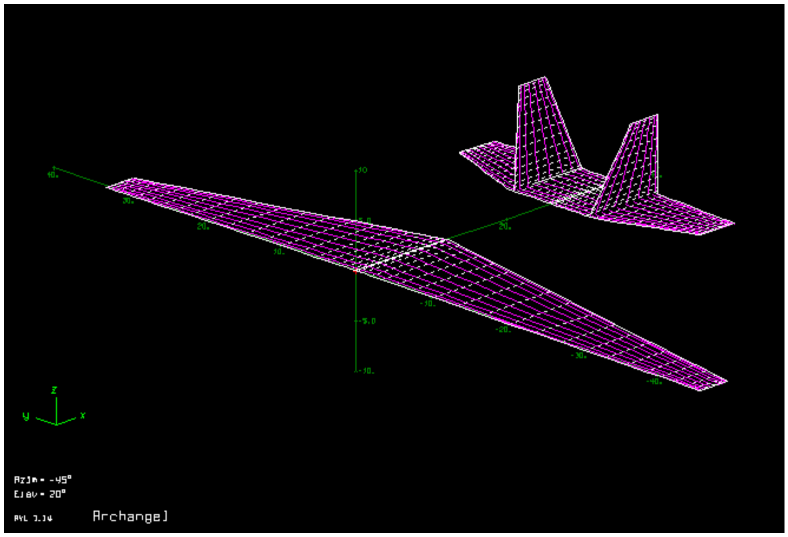


Figure 6.7 Computer Generated Model of the Archangel used in AVL.

However, with the exception of reasonable values of $C_{L\alpha}$, C_{do}, and one or two other variables, none of the stability derivatives or dynamic damping ratios being yielded was remotely close to being considered a reasonable value. After verifying through the use of other programs such as J-Kay VLM that the aircraft was in fact a sound concept, it was realized that a hidden discrepancy in one of the input files was preventing the program from running correctly. Due to time constraints, this analysis was therefore scrapped.

Basic theoretical equations were therefore used to obtain the lift curves, and drag polars required. These equations were acquired through the use of Raymer's "Aircraft Design: A Conceptual Approach." $C_{L\alpha}$, for instance, was attained through the following equation.

$$C_{L\alpha} = [2\pi A(S_{exp}/S_{ref})F] / \{2+[4+(A\beta/\eta)^2(1+(\tan^2\Lambda_{maxt}/\beta^2)]^{1/2}\},$$

Where

$$\beta = (1-M^2)^{1/2}$$

$$F = 1.07(1+d/b)^2$$

Here, *d* represents the diameter of a circular approximation of the fuselage, and η is commonly assumed to be 0.95. This equation was used to determine $C_{L\alpha}$ for both the wing and the NACA

0009 tail. The values were 5.55 and 6.089, respectively, ignoring compressibility effects. $C_{L\alpha}$ for the wing was used to generate an approximate lift curve.

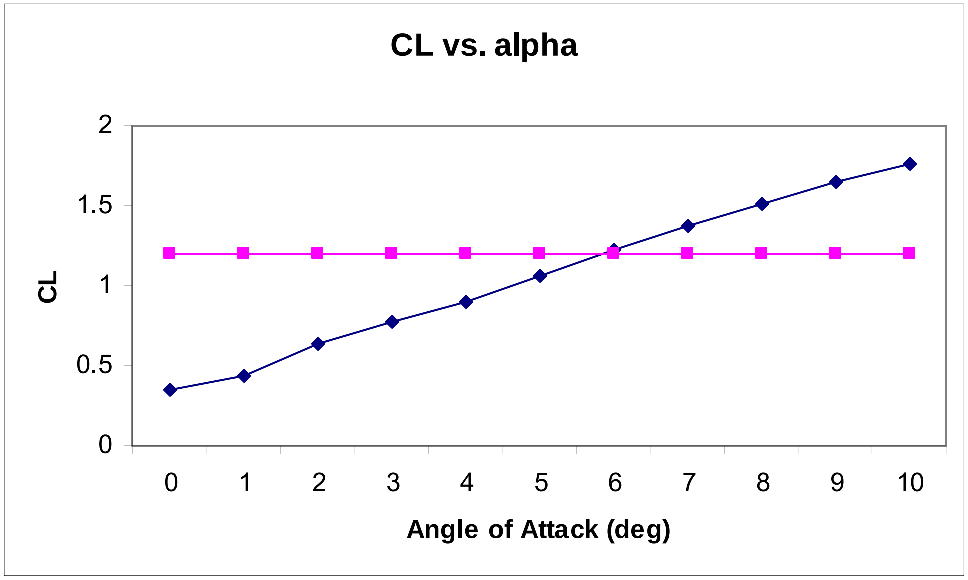


Figure 6.8 Lift Curve for the Entire Wing.

The pink horizontal line at approximately 1.2 represents the limitation of the equation's accuracy. Beyond this point, the assumptions within the equation begin to lose their effectiveness and error becomes large. Technically speaking, this graph suggests that the Archangel should have approximately 0.12 degrees of incidence angle on the wing, but because of the inherent uncertainty, incidence was neglected.

A trimmed drag polar was created in a fashion similar to that of the lift curve slope by using a C_{Do} value of 0.021 obtained from the FLOPS program, and the following equation.

$$C_D = C_{Do} + K[C_{L\alpha}(\alpha+i_w)]2 + (S_h/S_w)K_hC_{Lh}^2,$$

where

$$C_{Lh} = C_{L\alpha h}[(\alpha+i_w)(1-C_{L\alpha}/C_{L\alpha M=0})+(i_h-i_w)-\alpha_{0Lh}].$$

In the above equations, i_w, and α_{0Lh} both go to zero since there is no initial incidence on the wing and the zero lift angle of attack of a symmetrical airfoil is zero degrees. The incidence of the tail was determined by dividing the change in moment with respect to changes in angle of attack,

$C_{M\alpha}$, by the change in moment with respect to elevator deflection, $C_{M\delta e}$. This ended up being approximately 1.28 degrees. Merging this data with the lift curve shown above produced the following chart.

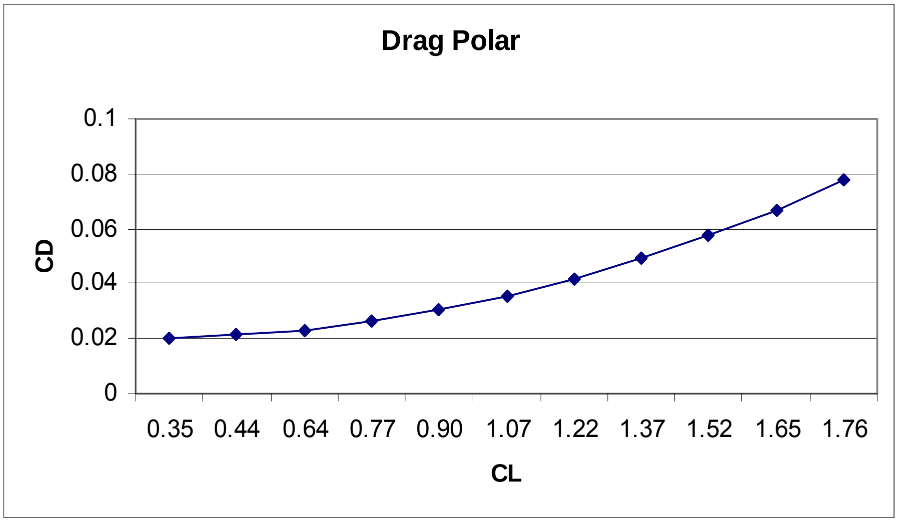


Figure 6.9 Trimmed Drag Polar for the Archangel.

Drawing a straight line from the origin such that it intersects the curve at only one point reveals an L/D max of about 20.89.

6.3 High Lift System

The first thing that comes to mind when designing a high lift system for an aircraft is whither to choose a system that would produce the best performance or a system that is of the most simplicity mechanically. Designing for performance would involve a complicated flap system, such as a triple-slotted trailing edge flap with a leading edge flap. A system such as this would enable the aircraft to have a heavier TOGW and increase the overall range of the aircraft. However, it will also lead to a more complicated structural and mechanical system on the wing and therefore an increase in overall weight and cost, and also maintenance cost. After examining the tradeoffs, the simplicity direction was taken. Thus, the high lift system on the aircraft will be designed to meet the required C_{Lmax} for takeoff and landing, no more, no less.

To achieve this required C_{Lmax}, some limiting conditions had to be taken into consideration: aileron usage, spar locations, and the undercarriage storage. With the aileron set at 30% span and the fuselage taking 17.2%, the most span-wise usage allowed for the flap would be at 52.8%. The spar location is set at 25% chord at the trailing edge, therefore, only 25% chord can be used for trailing edge flap. At the undercarriage of the wing, one hard-point was set at each side of the wing. With that in mind, the max flap-deflection was determined to be at 40 degrees.

With the target C_{Lmax} being 2.0, and C_{Lmax} of the SC20610 airfoil determined from JavaFoil to be 1.185 at an angle of attack of 10°, a ΔC_{Lmax} of 0.815 is desired for the wing. To determine the ΔC_{Lmax} needed, equations from Raymer's Aircraft Design book (Ref 6.1) was used.

Figure 6.10 shows a plot of the span-wise percentage vs. ΔC_{Lmax} of the different high lift devices. The horizontal line indicates the ΔC_{Lmax} needed, at 0.815. Since the simplest system is desired, the most logical solution would be the Fowler flap of 50% span. This system is chosen so no leading edge flaps would be necessary.

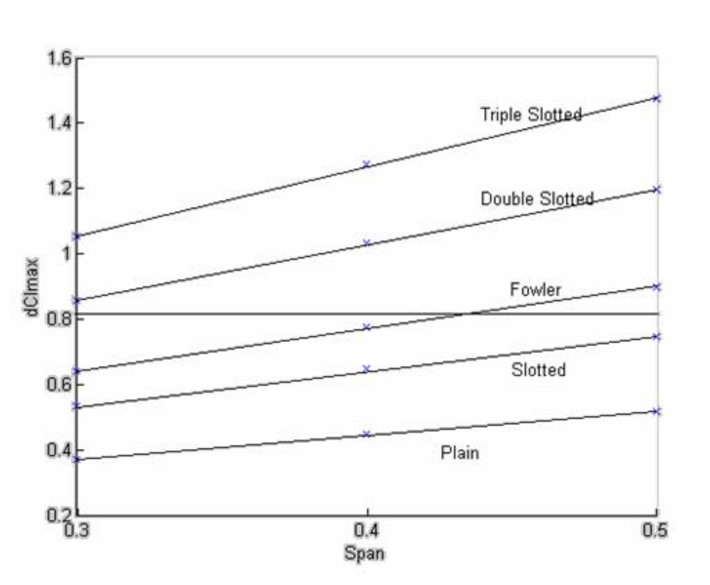


Figure 6.10 ΔC_{Lmax} of Various High Lift Devices at Different Span Percentages

Figure 6.11 shows a plot of angle of attack versus CL for the airfoil, Fowler flap at landing, and Fowler flap at takeoff. The C_{Lmax} with Fowler flap is 2.08 at 3.4° for landing and at 5.6° for takeoff. Figure 6.12 is a plot of the drag polar with flaps down.

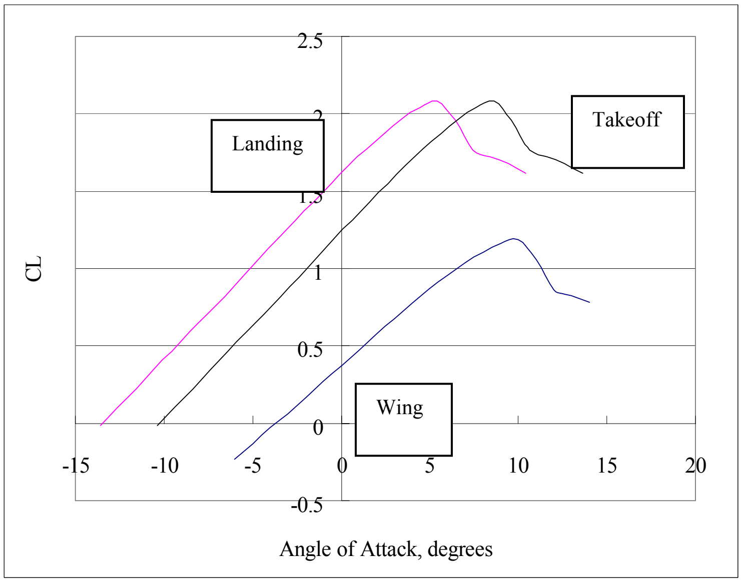


Figure 6.11 C_L Curve of the Wing with Fowler Flap at Takeoff and Landing

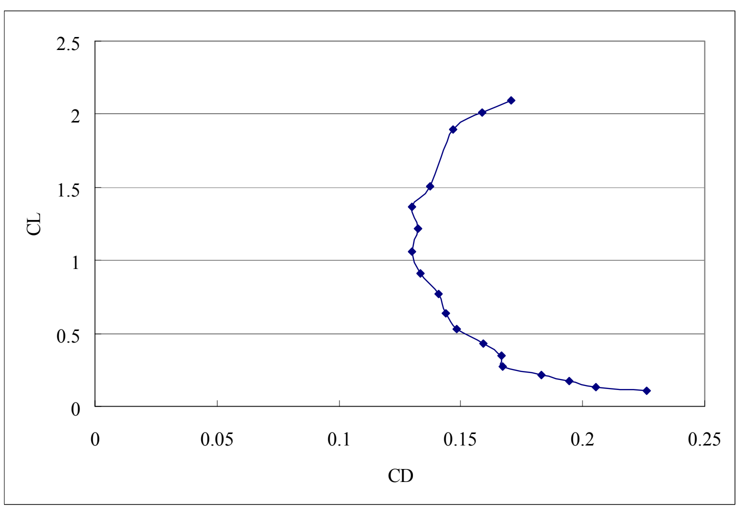


Figure 6.12 Drag Polar for Flaps Down Configuration

In conclusion, with simplicity in mind to achieve the desired C_{Lmax} of 2.0, a Fowler flap that consist 50% span and 63.9% wing area was chosen. The resulting C_{Lmax} came out to be 2.08.

Chapter 7. Propulsion

7.1 Type of Propulsion System

The design mission requires a cruise speed no less than 400 knots at an altitude of 30,000 ft, yielding a cruise Mach number of 0.678. The mission also calls for a four hour loiter time which will require a large amount of fuel. Fuel weight constitutes a large percentage of the total weight of the aircraft, so a low SFC will be needed to optimize the design. A turbofan engine generally provides a low SFC and low exhaust gas temperature. In order to take advantage of these properties, a low SFC, high bypass ratio turbofan engine will be used. The high bypass ratio helps reduce the exhaust gas temperature and therefore reduces the aircraft's heat signature.

A turbofan engine deck was provided by the AIAA with the desired qualities, but before committing to this engine, other engines were researched. The General Electric F118-GE-100 was compared to the AIAA engine. The F118 has a SFC of 0.67 at sea level and maximum power, while the AIAA engine has a SFC of 0.35 at the same conditions. Other engines were also researched, but none were found to give the SFC performance that the AIAA engine has. Another problem with using other engines is obtaining the full engine deck. Since the AIAA engine deck was accessible and it offered very good performance, it was chosen to be used on this aircraft.

7.2 Number of Engines

Throughout the design process of Archangel, the goal was to keep the overall weight as low as possible in order to have an efficient weapon platform. The target T/W for this design was to be around 0.3. After optimizing the aircraft, the TOGW is 57,700 lbs, yielding a maximum thrust of 17,310 lbs. Since the given AIAA engine is being used, it had to be scaled to fit this design. When deciding between single or twin engine configurations, several factors were taken into consideration. Keeping the weight down is especially important to this design considering the required loiter time, but, at the same time, the propulsion system must be reliable in flight. To meet our design T/W target, one AIAA engine would have to be scaled down almost to the minimum limit of 15,000 lbs of thrust (15k < SLST < 50k from AIAA). If two AIAA engines were used, they would have to be scaled down beyond this limit. As a result, only one engine will be used for Archangel's propulsion system.

Since Archangel is operating in a high-risk environment, a single engine appears to be especially vulnerable; therefore, in-flight shutdowns were researched. There are five main reasons for in-flight shutdowns: mechanical failure, bird strike, hail ingestion, icing, and battle damage. Modern engines are so reliable that mechanical failure is rarely a problem. The F-16 and the F-35 are single engine aircraft and are designed to spend much of their time within the threat envelope. A serpentine inlet duct reduces the effect of bird strike or hail ingestion by absorbing the initial impact. Icing around the inlet can be prevented by a heating system that prevents ice to form around the inlet.

The last main possibility of an in-flight shutdown is battle damage. The weapons selected allow Archangel to remain at the outer range of AAA and MANPADS threats, which significantly reduces the possibility of battle damage. The engine will be installed internally and armored in order to protect it. The inlet and exhaust will be located above the planform area to reduce RCS/IR signature and also prevent damage from impact. All of these factors will contribute to the reduction of $P_{K/E}$. Since Archangel is unmanned, no life will be lost if the engine fails and the aircraft goes down in hostile territory.

7.3 Inlet/Exhaust Configuration

The engine will be located inside the aft fuselage along the centerline. The inlet will be placed above the fuselage, with a serpentine duct leading to the engine face. The RCS and FOD will be reduced with the inlet positioned above the fuselage. Since the inlet is above the fuselage, it creates more room for weapons or fuel. The inlet is shown below in Figures 7.1 and 7.2.

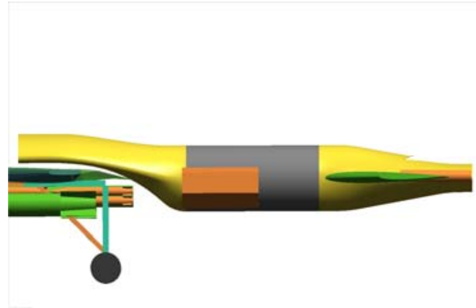


Figure 7.1 Isometric View of Inlet. **Figure 7.2** Side View of Inlet.

The inlet area was designed for cruise speed of Mach 0.7. Most turbofan engines require the flow to be around Mach 0.4 when it enters the engine. The job of the inlet is to capture the air and slow it down to the suitable speed. Upon further research, it was found that subsonic flow tends to expand and slow down half the required amount outside the inlet and half inside the inlet (Ref 7.1). This means that the inlet only has to perform half of this work (Mach 0.55 to Mach 0.4). The following isentropic compressible flow relationship was used to calculate the ratio of inlet area to engine face area:

$$A/A^* = 1/M * [2/(\gamma + 1) * (1+(\gamma - 1)/2 * M^2)]^{(\gamma + 1)/2(\gamma - 1)} \qquad \text{(Ref 7.1)}$$

This equation was used to calculate A/A* at the inlet face (Mach = 0.55) and again at the engine face (Mach = 0.40). The ratio A_{inlet}/A_{engine} was calculated by dividing these values and eliminating A*. The area of the inlet was calculated to be 78.92% of the engine face area. The cross-sectional area of the inlet varies from a half ellipse with rounded corners at the inlet face to a circular cross-section in order to meet the engine face.

Calculations were completed to analyze the boundary layer over the fuselage. Flat-plate boundary layer theory was used to calculate a boundary layer of about 3.5 inches 30 feet back from the nose of the aircraft (Ref 7.2). Other aircraft have boundary layer diverters from 3 to 4 inches tall. So from this calculation and research, the bottom of the inlet on Archangel will be installed 3.5 inches above the fuselage.

The exhaust nozzle is designed to release the hot gas over the planform area in order to help increase mixing and reduce the IR signature, ultimately reducing $P_{K/E}$. The exhaust comes out of the rear of the engine in a circular cross-section. The exhaust nozzle is designed to flatten out the flow as wide as possible across the aft fuselage with open area on top in order to allow maximum mixing with the free stream flow. This design concept was noticed on other aircraft, notably the F-117. Since no pressure values were available, an approximation was used to match the exhaust area to the inlet area. All analysis of the landing distance shows that no thrust reverser is needed to meet the requirement.

Figure 7.3 Exhaust configuration.

7.4 Installation Losses/Engine Wear

Once an engine is installed, a thrust loss must be accounted for due to pressure recovery in the inlet and some other factors. A perfect pressure recovery (P_1/P_0) is 1.0, but since Archangel has a serpentine duct, the pressure recovery is estimated to be 0.94 (Ref 7.1). Thrust loss is calculated using the following equation:

$$\% \text{ thrust loss} = C_{ram} [(P_1/P_0)_{ref} - (P_1/P_0)_{actual}] \times 100\% \quad \text{(Ref 7.1)}$$

where C_{ram} is a "ram recovery correction factor" and is 1.35 for subsonic flight. Using Archangel's pressure recovery, a thrust loss of 8.1% will occur when the engine is installed. The AIAA engine also has 200 hp extracted for accessories. This has a very small effect upon installed thrust, so it was ignored for initial design. Due to installation losses and engine wear, the RFP calls for a factor of 1.05 to be multiplied to the ideal engine fuel flow. This was taken into account for all mission analysis.

7.5 Final Design of Propulsion System

A single scaled version of the given AIAA engine will be used in this design. After mission analysis was completed, final weight of the aircraft was set, and installation losses were taken into account, it was determined that the engine will be scaled to 57.1%. This gives the following engine thrust and dimensions:

Table 7.1 Engine Thrust, SFC, and Dimensions

SLST	18,843 lbs
Installed Thrust	17,317 lbs
SFC	0.35
Diameter	4.71 ft
Weight	6176 lbs
Length	9.40 ft
Area of engine face	17.39 ft^2

- scaling equations from AIAA

Since the inlet area needs to be 78.92% of the engine area, the inlet area will be 13.73 ft^2. It is 2.06 ft tall in the center, and 8.5 ft wide. It is also 11.88 ft forward of the engine face. This installed thrust gives the target T/W of 0.3, and sufficient thrust to perform the mission.

The AIAA engine provides a low SFC engine that will give very efficient performance over the entire flight envelope. Having a low TOGW and high engine efficiency are very important factors for cost. Due to these factors, the engine's purchase cost, depreciation, and maintenance cost will all be reduced. The following plots show the engine's performance at different Mach numbers.

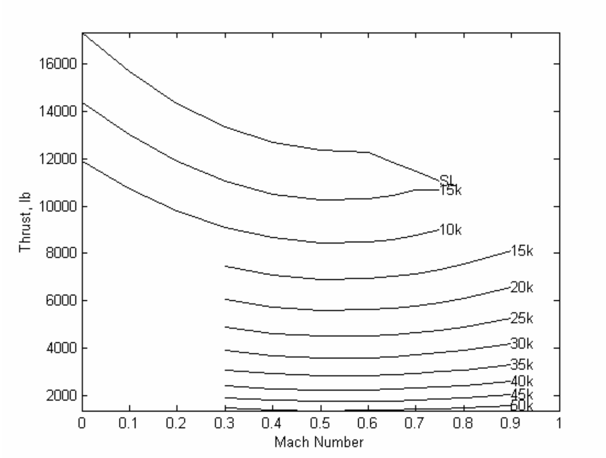


Figure 7.4 Thrust versus Mach Number.

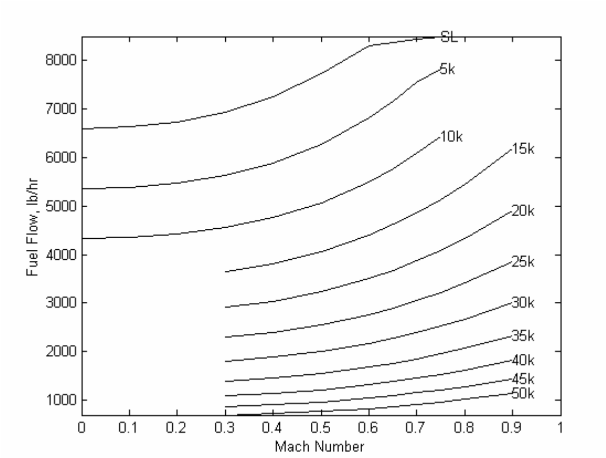


Figure 7.5 Fuel Flow versus Mach Number.

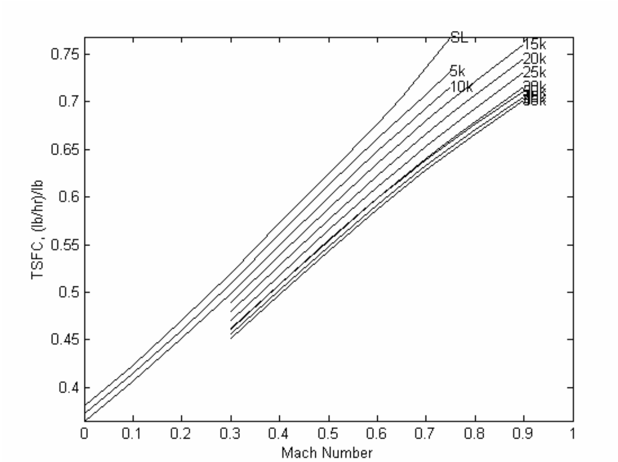


Figure 7.6 TSFC versus Mach Number.

Chapter 8. Survivability

The mission-threat analysis for the AIAA Gunship describes the threats in the target area that are estimated to have a maximum altitude of at least 10,000 ft. These threats include a light or medium caliber AAA and MANPADS (infrared guided missile). Both the gun projectile and the MANPADS missile are assumed to have a high-explosive (HE) warhead with a contact fuse.

8.1 Vulnerability Reduction Features

The probability of an A/C kill given an encounter with the AAA threat without any survivability enhancements is assumed to be 0.18 (Ref 8.1). This can be reduced to the design requirement of $P_K < 0.10$ by utilizing the following vulnerability reduction features.

1. Component redundancy (with separation)

Redundant electric controls and actuators will be used for control surfaces in order to increase survivability. The actuators and wires/optical cables will be separated by at least 2 ft. in any direction once they leave the command center. Also, several means of communicating with the UAV will be used.

<u>Weight:</u> doubles the weight of single flight control or motor

<u>Cost:</u> approx. $1000 per lb (fabrication and installation) (Ref 8.1)

<u>Survivability Levels:</u> Potential reduction in $P_{K/H}$ of 5%. (Ref 8.1)

2. Component location

The exhaust of the propulsion system will be located on top of the fuselage to reduce IR signature to MANPADS threats which originate from the bottom of the A/C. This placement also reduces RCS since any AAA radar will come from underneath the A/C. The critical components for communication and directing the flight of the UAV will be placed on the top of the fuselage to shield it from ground fire. Critical components will be oriented so as to minimize their presented area in the anticipated threat direction. Most fuel tanks are located in the wing, away from the hot engine and top-mounted intake to prevent ingestion of fuel from damaged tanks. One fuel tank is located beside the cold section (fan and compressor) of the engine.

3. Active damage suppression

Engine bay fire detection and protection will be provided by detectors and extinguishers mounted inside the engine cowling and around the engine core. Fire extinguishers are also a system safety benefit in peace time.

Weight: 20 kg per engine (includes the fire warning system)

Cost: $100,000 for development plus $2000 per kg for fabrication and installation

Survivability Levels: Potential 20% reduction in $P_{K/H}$ if added to all engines (Ref 8.1)

Damage to a flight control surface is detected and identified, and the flight control laws are modified to maintain safe flight. Similar VR features exist for engine control subsystems. Weight, cost, and survivability levels are unknown.

4. Passive damage suppression

- Damage tolerance: High fracture toughness materials such as composites will be used to prevent crack propagation. Large diameter, thin-wall control rods will be used that can function with perforations caused by projectiles and secondary fragments.
- Ballistic resistance: High-strength materials will be used to protect gearboxes and actuator systems, preventing the total penetration of an impacting penetrator or fragment.
- Delayed failure: High temperature tolerant materials will be used to serve as a barrier in areas where critical components might be exposed to a fire.
- Leakage suppression: Self-sealing lines or vacuum-fed fuel lines.
- Fail-safe response: Throttle control device designed to revert to predetermined setting if throttle control is lost. Control surfaces become locked in a flyable position in the event of a total loss of control of the surface actuator.

- Fire and explosion suppression: Fire suppressant foam will be inserted in dry bay areas of the wing and fuselage adjacent to fuel tanks. This does not permit the ratio of fluid vapor and air to rise to levels that will support combustion.

Weight: 4.4 lbs per 350 cubic ft of dry space (includes a fire warning system) (Ref 8.1)

Cost: $100,000 for development plus $2000 per kg for fabrication or installation, no annual or maintenance costs (Ref 8.1)

Survivability Levels: Potential 25% reduction in $P_{K/H}$ if applied to up to 50% of the dry bay volumes (assume no advantage for applying foam to more than 50% of the dry bays). If not applied to all dry bay volumes, the 20% reduction must be decreased by the fraction of dry bay volume that is protected (Ref 8.1).

One of the ways investigated to render ullage of the fuel tanks inert with nitrogen gas was using an OBIGGS system manufactured by Air Liquide. This system replaces the combustible mixture of air and gas above the fuel with inert gas and helps reduce fire and explosion when the fuel tanks are punctured. Fuel tank ullage protection is also a system safety benefit in peace time.

An alternative to the expensive OBIGGS system is the FuelShield foam system being developed by BlazeTech. FuelShield is not only a cheaper alternative for inerting the fuel ullage, but also includes hydrodynamic ram protection. Hydrodynamic ram occurs when a projectile enters the liquid portion of the fuel tank and forms a shock wave and resulting cavitations, which greatly damages the tank structure. FuelShield's bubble system aerates the fuel and breaks up the formation of shock waves. The foam used in this system takes up less than 1% of the fuel volume in the tank. Also, FuelShield can be left inoperable until the A/C enters a threat environment. The advantages of FuelShield compared to the three commercially available technologies for protection against ignition in the fuel tank ullage can be found in Table 8.1 (Ref 8.2).

Table 8.1 Comparison of Fuel Ullage Inerting Technologies

Item	OBIGGS	Open-Cell Foam	In-Tank Fire Suppression	FuelShield
key limitation	Complex	Maintenance problems	No acceptable Agents as yet	None
Expendables	None	None	Small	Small
On-demand use	Yes	No	Yes	Yes
Space/ weight	Large	Medium	Medium	Small
Reliability	Medium	Medium	Unknown	High
Power	High	None	None	Low
O&M	Medium	Major	Medium	Medium
Hazard	Oxygen leakage	None	Accidental release	None
Cost	High	Low	Medium	Medium

Considering the cost and weight saved by using FuelShield instead of OBIGGS and assuming the same survivability levels to be the same, if not greater than OBIGGS since the BlazeTech technology also includes hydrodynamic ram protection, Archangel will utilize FuelShield as its fuel ullage fire and explosion protection.

Weight: approx. 6.02 kg

Cost: $200,000 (Ref 8.2)

Survivability Levels: Potential 30% reduction in $P_{K/H}$ if applied to all fuel tanks. If applied to a tank, it must be applied to the entire tank. If not applied to all tanks, the 30% reduction must be decreased by the fraction of the tank top surface fuel area (half full) that is unprotected versus the entire tank top surface fuel area (half full). (Ref 8.1)

5. Component shielding

Armor is used to protect vulnerable components in direct line to threat from projectiles and fragments. The weight and cost depends upon the material used as well as the amount. Armor increases the survivability of A/C from small caliber ballistic threats.

6. Component elimination or replacement

Fuel-feed suction devices will be used instead of a fuel-feed boost pump. This reduces the possibility of pumping fuel through holes incurred during combat into areas where a fire can start. Optical fibers will be used to replace electrical flight control linkages to reduce weight and vulnerability to electromagnetic effects (Ref 8.1). Being a UCAV, Archangel will reduce the consequences of a downed aircraft. In the unmanned aircraft, the onboard pilot has been replaced with a less vulnerable electro-optic sensor/electronic controller.

The above VR features lower the $P_{K/E}$ of the designed gunship below the required 0.1 for the AAA threat. For the AAA threat and the baseline design with no VR features:

P_K (baseline) = [P_H (baseline)]•[$P_{K|H}$ (baseline)] = 0.18.

In order to get a more survivable A/C with one or more SR or VR features:

P_K (more survivable) = [P_H (more survivable)]•[$P_{K|H}$ (more survivable)]

Dividing the more survivable equation by the baseline and solving for the P_K (more survivable) results in: P_K (more survivable) = 0.18•SR•VR,

where SR = the relative change in susceptibility = [P_H (more survivable)]/[P_H (baseline)] and VR = the relative change in vulnerability = [$P_{K|H}$ (more survivable)]/[$P_{K|H}$ (baseline)]. Using this equation and the reduction percentages for all the VR features the survivability level is:

P_K = 0.18•[SR=1]•[VR=0.95•0.75•0.7•0.8] = 0.072.

8.2 Susceptibility Reduction Features

In the case of the MANPADS threat, the overall P_K without any survivability enhancements is assumed to be 0.45 (Ref 8.1**)**. This can be reduced to the $P_K < 0.10$ requirement through use of the vulnerability reduction features listed above and the susceptibility reduction features listed below.

1. Threat warning: The following systems will be integrated into the A/C for MANPADS and AAA radar warning. They will be integrated into the airframe, rather than in pods to reduce RCS.

AN/AAR-57 Common Missile Warning System will be used for IR missile/MANPADS detection.
<u>Weight:</u> 51.9 lbs
<u>Cost:</u> $191,000 (Ref 8.3)

AN/ALR-69 Radar Warning Receiver will be used to detect radar guided threats.

Weight: 50 lbs
Cost: $12,500 (Ref 8.4)

2. Noise jammers and deceivers

Radar and IR noise jammers and deceiver pods will be able to be mounted upon the external hard points in the form of ECM pods if the A/C is known to operate in a very high threat area.

3. Signature reduction

The A/C will have a reduced RCS by storing munitions in weapon bays and keeping smooth contours exposed to the ground, where the primary radar threat signals will emanate. Also, RAM will be used on exposed surfaces to reduce radar returns.

The heat signature of the A/C will be reduced by having the engine inlet and exhaust on the top of the fuselage. The twin vertical stabilizers provide shielding of the exhaust flow from the sides until mixing has reduced the exhaust temperature. There will be no cockpit to produce a heat source or radar return from cockpit displays and controls. An appropriate paint will be applied to keep visible detection to a minimum.

4. Expendables

Several methods of defeating IR missiles using expendables and/or targeted lasers were explored. A system was needed that was designed specifically to defeat MANPADS. One option was the DIRCM –AN/AAQ-24 Directional Infrared Countermeasures or “Nemesis”. However, this system would cost over $1.5 million to install in Archangel. The AN/ALE-50 Towed Decoy System was considered as another alternative for IR missile suppression. This system has been proven with high-altitude supersonic fighters and is not suitable for the Archangel attack/gunship design.

The Comet pod is selected to defeat the MANPADS IR missile threat. Comet is a concept development program at the Air Force's Air Expeditionary Force Battlelab, at Mountain Home AFB, Idaho. It is designed to defeat MANPADS systems and is based on technology developed for a Raytheon towed IR decoy system. The pod works much like the towed IR decoy, slowly dispensing pyrophoric material behind the aircraft to create a realistic engine-plume signature that can defeat IR guided missiles. Additionally, it contains enough material to provide over 30 minutes of coverage. Comet is entirely preemptive, with no cueing required. Using technology derived from advanced special-material flares, the Comet is fully covert in the visible spectrum, creating a continuous false target that lures infrared threats away from the intended target. The pod can be loaded and ready for use in less than one minute. All components in the multi-platform dispenser controller can be serviced while the pod is on the aircraft (comet ref??).

Weight: 200 lbs

Cost: $300,000 approx.

Survivability Levels: Potential reduction of P_H of 60% or more

The AN/ALE-47 Countermeasures Dispensing System will be used in order to dispense chaff to defeat any radar threats or tracking devices. Flares can also be dispensed by this system if need be for a backup to the Comet system. The AN/ALE-47 can be integrated into the airplane for reduced RCS.

5. Threat suppression

Threat suppression is performed by attacking hostile air defense threats. This includes the use of anti-radiation missiles to damage enemy radar antenna or the supporting mechanical and electronic equipment.

6. Weapons, tactics, flight performance, crew training, and proficiency

The current gunship design utilizes stand-off attack weapons in order to remain outside the maximum lethal range of enemy air defense systems. There will be no onboard crew, which minimizes fatigue and maximizes the amount of time the A/C can loiter at the target area. This permits more threats to be engaged with one flight.

Using the above SR features and also the VR features successfully lowers the $P_{K/E}$ of the designed gunship below the required 0.1 for the MANPADS threat. For the MANPADS threat and the baseline design with no VR features:

P_K (baseline) = [P_H (baseline)]•[$P_{K|H}$ (baseline)] = 0.45

Using the reduction equation, the survivability levels achieved are calculated as follows:

P_K = 0.45•[SR=0.4]•[VR=0.95•0.75•0.7•0.8] = 0.072.

Since the P_K of Archangel is 0.072 for both the AAA and MANPADS threats, 7.2% of the time the A/C encounters a threat, it gets killed.

The approximate cost of all these survivability enhancements is $900,000. However, the cost of losing an airplane by not including these enhancements is $27 million. By including the enhancements, per 1000 encounters with threats, only 72 A/C may be lost. On the other hand, with no enhancements, 180 A/C would be lost to AAA threats and 450 lost to MANPADS threats per 1000 threat encounters.

Also enhancing the survivability of Archangel is the method of attack being used. The A/C uses stand-off, guided weapons which can be deployed several miles from the intended target. The maximum range for MANPADS in use today is a slant range of 5.3 miles and for AAA is 6 miles vertical. Archangel will descend to a height of 10,000 ft as required by the RFP; however, it will be several miles away to deploy its guided weapons. The Sniper pod enables the Archangel to identify targets up to 40 nautical miles away. If Archangel enters the threat envelope, it is designed with a reduced RCS and heat signature, which limits the capability of heat-seeking MANPADS missiles and radar tracking from AAA. Also, using the advance Missile Warning System and other jammers Archangel will be able to successfully defeat all enemy air defenses. It is assumed that all air-to-air threats will be neutralized by other aircraft such as the F-15 or F-22.

Chapter 9. Weapons

The specified targets of the design gunship are buildings, personnel, AAA, and lightly armored vehicles. The goal for weapon selection is to maximize lethality, precision, persistence, flexibility, and affordability.

The existing weapons that will be able to satisfy the requirements can be divided into the following categories: bombs, missiles/rockets, cluster bombs, and guns/cannons. Bombs can be further divided into guided and unguided bombs. Due to the destructive power of these bombs, they are the best suited against fixed targets such as buildings or AAA. Since the RFP does not specify hardened or bunkered buildings, all bunker-buster bombs are left out of the consideration.

Listed in Table 9.1 are the bombs under consideration, their acquisition costs, range, and circular error probability (CEP).

Table 9.1 Bombs Considered

Bombs	Range (miles)	CEP (ft)	Acquisition Cost
General Purpose			
Mk-81 (250 lbs)	Unavailable	Unavailable	$268.50
Mk-82 (500 lbs)	Unavailable	Unavailable	$1,707
Mk-83 (1000 lbs)	Unavailable	Unavailable	~$2,000
Mk-84 (2000 lbs)	Unavailable	Unavailable	$2,380-$5,756
Paveway II			
GAU-12 (500 lbs)	9	26	$21,896
GAU-16 (1000 lbs)	9	26	~$23,000
GAU-10 (2000 lbs)	9	26	$24,722
Paveway III			
GAU-24 (2000 lbs)	12	26	$54,246
JDAM			
GBU-29 (250 lbs)	17	43	~$20,000
GBU-30 (500 lbs)	17	43	~$20,000
GBU-31 (2000 lbs)	17	43	$22,339
GBU-32 (1000 lbs)	17	43	~$20,000
Small Diameter Bomb			
GBU-39/B (250lbs)	69	43	~$64,000

Unguided bombs are the most destructive weapons available at the least cost, but, with no guidance, success rate is far from optimal. Guided bombs are general purpose bombs equipped with a guidance package. JDAM and SDB are INS/GPS guided, while Paveway II and III are laser guided. With theses guidance packages, the guided bombs are able to respond to sophisticated enemy air defenses, operate in poor visibility and adverse weather conditions, and are able to deliver the bombs at low altitudes. Shown in Figure 9.1 is an altitude vs. range graph of the Paveway II and Paveway III guided bombs compared to that of the general purpose bomb.

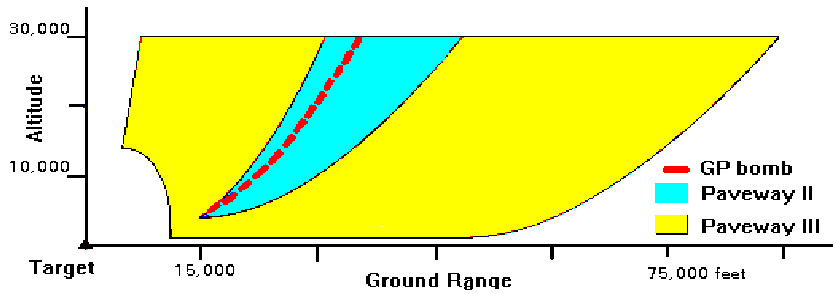


Figure 9.1 Range and Altitude Graph for General Purpose Bombs, Paveway II, and Paveway III (Ref 9.4)

Missiles are primarily used for moving targets such as tanks, vehicles, and air defense systems. Missiles that fit the target requirements are listed in Table 9.2, along with their respective range and price.

Table 9.2 Missiles Considered (Ref 9.4)

Missiles	Range (miles)	Acquisition Cost
AGM-65 Maverick	17	$130,000
AGM-88 HARM	30	$310,000
APKWS	3+	$10,000
Hydra-70	3+	$490

The Mavericks have a wide variety of usage. They can be used against armored targets, air defense systems, ships, and buildings. The High speed Anti-Radiation Missile, also known as HARM, was developed as a supersonic air-to-surface missile used to target radar-equipped air defense systems. The disadvantage of these missiles, though, is their high acquisition cost. The APKWS is derived from the war proven Hydra-70 (70mm or 2.75 inch) unguided rockets, used both in helicopters and fixed-winged aircrafts. Installed in APKWS is a laser sensor and guidance package, but everything else is the same as the Hydra-70: the M66 rocket motor, M151 10 lbs HE warhead, and the M423 point detonating fuse.

Cluster bombs are most useful for wide area destruction of soft targets. Table 9.3 lists the selection of cluster bombs that fit the target requirements. Cluster bombs can either have guidance on the bomb and/or the sub-munitions. Guidance on the bombs increases the cost, as one can see comparing the CBU-87 and the CBU-87WCMD, $14,000 and $55,746, respectively.

Table 9.3 Cluster Bombs Considered

Cluster Bombs	**Acquisition Cost**	**Bomblets (targets)**
CBU-52	$1542-$2280	220 personnel, material
CBU-58	$2,893	650 flammable targets
CBU-59	N/A	717 personnel, material
CBU-71	$4,692	650 incendiary
CBU-78	NA	45/15 tank/personnel
CBU-87	$13,941	300 light armor, personnel
CBU-87 (WCMD)	$55,746	300 light armor, personnel
CBU-97	$330,000	10/40 armor, support vehicle
CBU-97 (WCMD)	$349,524	10/40 armor, support vehicle
Mk-20	$3,711	247 tank armor vehicles

The last weapon group that will be introduced is guns/cannons. Listed in Table 9.4 are the cannons that were considered for this design. Since the cannon needs to be fired from an altitude of 10,000 feet, it would eliminate most of the cannons in use today. The various versions of the AC-130 gunship use different combinations of guns such as 7.62mm miniguns, 20mm cannons, 40mm Bofors cannons, and 105mm Howitzers.

Table 9.4 Cannons Considered

Guns/Cannons	Weight(lb)	Range(miles)	Cartridge cost	Rate of Fire (round/min)
GAU-4 20mm Vulcan	248	0.35	$4.87-$16.91	6000
GAU-8 30mm Avenger	620	0.8	$24.75	3900
L60 40mm Bofors	966	5.2	$16.14	140
M102 105mm Howitzer	3200	7.1	$160.00	1

The first question that needed answering when making the final selection on the weapons is whether guided or unguided weapons fit the requirements better, or a combination of the two. Unguided general purpose bombs, unguided cluster bombs, Hydra-70 rockets, and all the guns/cannons listed in Table 9.3 have the same advantage of low cost, but they also possess the same disadvantages of low accuracy, standoff range, and altitude.

Guided weapons provide accurate and precise strikes from a much further distance, increasing the survivability of the aircraft. The accuracy of the guided weapons introduces another desired characteristic in that it requires less weight per kill. The accuracy of the guided weapons also significantly reduces the need for multiple attack runs or circling the target continuously. The final decision is that the primary weapons will be guided, but the aircraft will be capable of using unguided weapons in situations where they are acceptable.

In order to provide persistent firepower, guns and cannons were investigated first. Guns such as the Vulcan or the Avenger have a range lower than the required deployment height of 10,000 feet (Table 9.4); thus, they are both ruled out from the start. The two cannons that fit the RFP range requirement are the L60 40mm Bofors and the M102 105mm Howitzer. These guns have great lethality, but since they are unguided, the kill is far from guaranteed. Guided weapons have a much better success rate than unguided weapons. In order to use the Bofors or the Howitzer cannons, the aircraft would have to use an attack pattern such as the AC-130. The AC-130 attacks by circling above the target and firing their cannons at the target. Attacking in this manner provides persistent and economic firepower, if one gets close enough and the weather is favorable. However, this puts the aircraft at high risk of MANPADS and AAA threats.

A better alternative to provide persistent firepower exists in the APKWS. Instead of using cannons, these guided rockets would raise precision and eliminate the need to circle the target. Although the Bofors and the Howitzer have a greater range than APKWS, the ranges listed in Table 9.4 are the maximum ranges with which the fired projectile can travel. The further the cannon shell flies, the worse the accuracy becomes. Against moving targets, the accuracy would decrease greatly as well. The APKWS, on the other hand, does not have this problem. With its laser guidance system, the APKWS can be fired from an estimated 5 miles away from a fixed-wing A/C. Using the APKWS would reduce the MANPADS threat while providing precision with a 3 ft CEP, a 30 ft blast radius, and a 160 ft fragmentation radius.

The APKWS will be able to provide persistent, precision firepower at all non-building targets required by the RFP. Table 9.5 contains the cost analysis done between the cannons and the APKWS. The calculations were done assuming 0.005 radian dispersion on all of the cannons and an 80% hit rate within the dispersion area. These are optimistic assumptions, as those numbers come from the Avenger specifications. The following equations were used for the calculations in Table 9.5:

Dispersion radius = (distance away)*tan(0.005 radians)

Hit Probability = $(\pi*(\text{Blast radius})^2)/(\pi*(\text{Dispersion radius})^2)*0.8$

Cost per kill = 1/(Hit Probability)*(Cost per shot)

Table 9.5 Cost per Kill Analysis

	Dispersion Radius (ft)			Blast Radius (ft)	Hit Probability			Cost per Kill		
Weapon/Range	**10kft**	**3mi**	**5 mi**		**10k ft**	**3 mi**	**5 mi**	**10k ft**	**3 mi**	**5 mi**
L60 40mm Bofors	50	79	132	10	0.032	0.012	0.004	$504	$1259	$3515
M102 105mm Howitzer	50	79	132	170	9.248	3.704	1.326	$160	$160	$160
APKWS	3	3	3	30	80	80	80	$10k	$10k	$10k

Table 9.5 shows the cost per kill for the three weapons at distances of 10,000 ft, 3 miles, and 5 miles. 10,000 ft is the deployment altitude specified by the RFP, thus the minimum distance required. 3 miles is the estimated range of the APKWS used on rotary A/C, and 5 miles is the estimated extended range of the APKWS being used on a fixed-wing A/C. The hit probability of the two cannons decreased significantly with increasing distance, notably the 40mm Bofors. The

decrease in accuracy of the Bofors is significant, making the cost per kill jump from $504.4 at 10,000 ft to $3,515 at 5 miles. The cost per kill for the APKWS stayed constant because of its laser guidance package and the wide blast radius compared to its dispersion radius (CEP radius). It also remained the same for the Howitzer because of its very wide blast radius. Collateral damage cannot be ignored with this very wide blast radius.

Presented in Table 9.6 is the kill/weight analysis made on the Bofors, Howitzer, and the APKWS. It was made with a reference weight of 2510 lbs, which is the weight of 80 APKWS and 2 launchers. The calculation was done by using the following equation:

Kill/Weight rating = (2510-cannon weight)/(cartridge weight)/(shots per kill)

The Howitzer has a negative rating because the cannon weight is more than the reference weight. A heavier reference weight was not used because versatility of weapons was desired. Increasing the reference weight would cut in to weight to be used for other weapons such as cluster bombs.

Table 9.6 Kill/Weight Analysis

Weapon	Cannon Weight (lbs)	Weight per cartridge (lb)	Shots per kill			Kill/Weight rating		
			10k ft	3 mi	5 mi	10k ft	3 mi	5 mi
L60 40mm Bofors	966	4.74	31.25	78.01	217.8	10.423	4.175	1.495
M102 105mm Howitzer	3200	33	1	1	1	-20.9	-20.9	-20.9
APKWS	110	30	1	1	1	80	80	80

The kill/weight rating for the APKWS is significantly higher than the Bofors and Howitzer. For the same 2510 lbs of load, APKWS can kill 80 targets at all distances, while Bofors can at most do 10 and decreases to 1 at 5 miles away.

The final analysis is done by dividing the cost per kill by the kill/weight rating, which will show the cost efficiency of the 'kill weight' of the weapon. It will be referred to as the weight cost in this report. Since the howitzer gives a negative number in the kill/weight ratio because of its weight, it is excluded from this part of the calculation. The weight cost of the 40mm Bofors and the APKWS are shown in Table 9.7.

Table 9.7 Weight Cost Analysis

	Weight Cost		
Weapon	10,000 ft	3 miles	5 miles
L60 40mm Bofors	$48.39	$301.56	$2,350.63
APKWS	$125.00	$125.00	$125.00

Figure 9.2 is a plot of the weight cost analysis. The weight cost of the 40mm Bofors is lower than those of APKWS at the minimum distance of 10,000 ft, but became higher at 3 miles and much higher at 5 miles. It was calculated that, at 2.4 miles away, the weight cost of the 40mm Bofors will be equal to the weight cost of the APKWS. Thus, at distance higher than 2.4 miles, APKWS would be the more efficient choice.

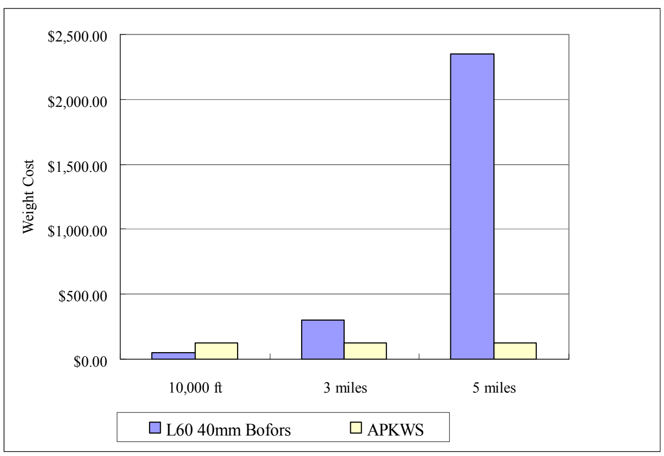


Figure 9.2 Weapons Weight Cost plot

Further analysis was done by taken into account the cost of the aircraft, using the survivability probability of 0.10 and assuming there will be one encounter for every kill. There will be an additional cost of $2,800,000 per kill ($28,000,000 per aircraft) for the distance of 10,000 ft. At 3 miles, it is assumed that the chance of encounter will be lessened by 25% because of the limited range of the threats. This will give us an addition of $2,100,000 per kill. At 5 miles distance, the aircraft will be out of or at the edge of most threats, reducing chance of encounter to 25%, adding $1,400,000 per kill. The cost/kill plot with the addition of the aircraft cost is shown in Figure 9.3. It clearly shows the insignificance of the cost of the weapons when taking into account the cost of the aircraft.

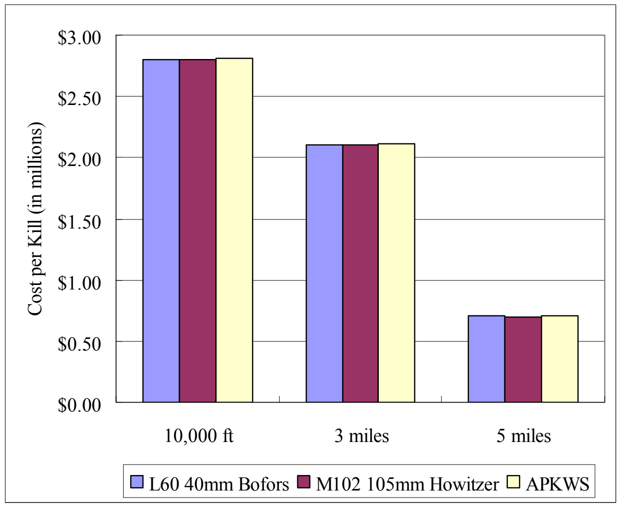


Figure 9.3 Cost per Kill with Aircraft Cost

Figure 9.4 shows the weight cost of the 40mm Bofors and the APKWS with addition of aircraft cost. The plot shows the 40mm Bofors weight cost to be much higher than that of the APKWS. It also shows that the Bofors weight cost rises while the APKWS weight cost decreases as the distance from the target increases. With the addition of the aircraft cost, APKWS becomes the more optimal solution at any distance.

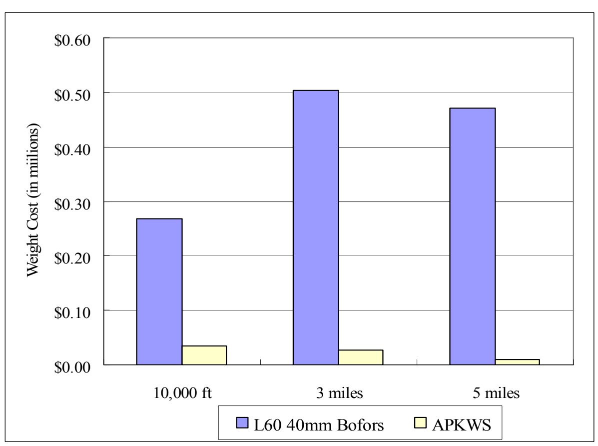


Figure 9.4 Weight Cost with aircraft cost

The APKWS is a better alternative to the cannons. It provides persistent firepower by providing 80 kills with just 2510 lbs of weapons. It provides precision firepower by using laser guidance system on the rockets. Lastly, it has been proven by the analysis done in this report that it is the more economically efficient solution.

In conclusion, for the four target requirements given by the RFP, the following weapons were selected:

Personnel – Cluster bombs, APWKS

AAA – APWKS, cluster bombs, Guided bombs

Light armored vehicles – APWKS, cluster bombs

Non-bunker buildings – Guided bombs, cluster bombs (small buildings)

The selected weapon layout would provide versatility with the ability to eliminate each target in at least two different ways and provide persistent, precision firepower economically at those targets.

Chapter 10. Materials and Structure

10.1 Materials

Aircraft materials used on the Archangel must be able to minimize weight enough to accomplish the missions set out in the RFP, but also have the strength to withstand fatigue and possible enemy encounters. As a result, this aircraft will use a combination of metals and composites. The most important properties needed have just been mentioned; however, environmental effects as well as manufacturing and acquisition costs are also important.

Table 10.1 shows a list of material choices for this aircraft with the most important properties listed. Specific strength is the strength divided by the density and is used to show relative performance of materials in high strength applications. Similarly, specific stiffness is stiffness divided by density which is used to show relative performance of materials used in areas where vibration and aeroelastic effects are significant. The estimated cost will tend to be a little high because they do not reflect buying the material in bulk. Purchasing information for the metals is based on cost per pound of sheet, while the composite pricing is the cost per pound of tape.

Table 10.1 Chosen Materials (Ref 10.2)

Material	Density (lb/sq.in.)	Specific Strength (K in.)	Specific Stiffness (M in.)	Estimated Cost (US $/lb)
Aluminum (7050-T7451)	0.102	685	100	3
Titanium (6Al-4V)	0.160	840	100	28
Steel (PH13-8Mo)	0.279	720	100	4
Carbon/Epoxy (IM7/977-3)	0.057	5825	390	90
Carbon/BMI (IM7/5250-4)	0.056	6230	395	100
Carbon/Thermoplastic (IM7/PEEK)	0.058	5570	390	190

Fatigue over the life of an aircraft is an important characteristic to consider in material selection. The structure is subject to varying loads and must be able to withstand this stress over a lifetime of many years. Some metals and most composites are fatigue resistant, a highly desirable quality. Although initial cost is high, these materials have a reduced long term maintenance cost offsetting the initial cost.

Environmental stability is the material's ability to operate in situations of highly changing temperature, pressure, humidity, and possibly corrosive conditions. Cured composites can withstand pressure, humidity, and corrosion much better than metals. Many metals can corrode over time if they are subjected to humid situations, unless they are coated or corrosive-resistant. One concern for composite structures is the use of UV resistant resin additives to reduce structural degradation.

Conventional aircraft metals in use today are aluminum, titanium, and steel. Their benefits include high strengths, resistance to corrosion and fatigue, and a relatively low cost of acquisition and production. They have been tested and proven in industry and they can be designed to handle most situations.

Composites provide benefits that can not be matched by metals, including phenomenal strength and very low density. Each part can be custom tailored to the needs of the situation. For example, if the structural loading is already known, the fibers can be oriented to produce a fully stressed, minimum weight design. Composites also have a high crack resistance increasing usable life. They can take advantage of unitization, making one part instead of several parts, to reduce assembly costs. The downsides to using such materials are the high production costs and relative lack experience within industry. However, the continual increase in composite usage has reversed this trend.

Thermoplastics and thermosets are the most widely used matrix materials in airframe structures. Thermoplastics are very impact resistant and can be reformed with application of heat and pressure, allowing for damage repair. A few disadvantages are that the cost is higher than that of most other materials, and they are not as strong as thermoset epoxies. So they are usually used in lower stress applications. Thermosets are cheaper and can be used in very high stress applications. However, they cannot be repaired like thermoplastics.

The following is a planned material usage for the Archangel attempts to balance the importance of material properties with cost. Aluminum will be used for the ribs as wells as the fuselage stringers. Titanium will be used mainly around the engine compartment to protect the aircraft body from the heat generated by the engine because of its excellent thermal properties. Also, titanium will be used to form the two main wing spars to aid in strengthening the wing and help prevent failure from battle damage. Steel, due to its bulk, will only be used for the landing gear and fasteners on the aircraft. Composites will be used on the rest of the aircraft, including the main fuel tank/wing box, skin, tail assembly, wing control surfaces, longerons, and main bay door.

10.2 Structures

The V-n Diagram shows the loading as a function of velocity (Figure 10.1) over the flight envelope for Archangel. The cruise speed is labeled at a value of about 455 knots. The structure was designed for a positive 3.5g load and a negative 1.5g load, with a factor of safety of 1.5 applied to both of these numbers (which gives the ultimate load factor). This ultimate load factor is the point of structural failure for the aircraft. Gust factors were applied, but the effects were small enough that it did not expand the load envelope.

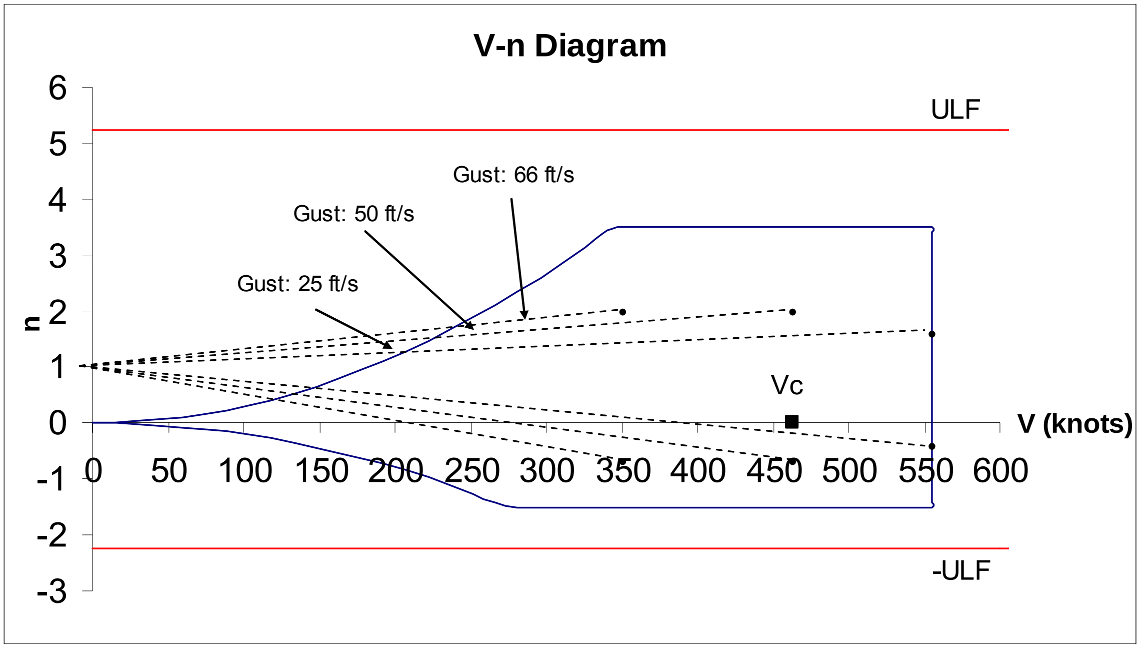


Figure 10.1 V-n Diagram for Archangel

The structural layout for this aircraft has not been drawn in CAD, due to the large amount of time that the rest of the design took to research and implement. However, the framework has been conceptualized and will go as follows. Since Archangel is an unmanned aircraft, the typical pressure bulkheads found in most aircraft are not needed. The wing will have a two-spar construction, with the leading spar at 12% of the chord, and the rear spar at 67% of the chord. The ribs will be laid out perpendicular to the rear spar, which is in the line of flight. The ends of the wing fuel tanks will include a closing rib to ensure strength in the tip. The rib spacing will be no greater than two feet. The horizontal and vertical tails will be a composite honeycomb structure, giving these stabilizers sufficient strength with a very low weight penalty.

The fuselage will have four main longerons running along the length of the aircraft along with secondary stringers. Ring frame bulkheads will reinforce key locations, such as around the engine and landing gear. The wing box will carry most of the load applied from the wings and run continuous through the fuselage to connect the fuselage loads. The wing box will also be used as the main fuel tank with a capacity of 10,000 lbs of JP-8. This structural layout is very traditional compared to modern transport aircraft.

10.3 Landing Gear

The goal in designing the landing gear was to keep the system as simple as possible. Mimicking the landing gear of a similar, pre-existing aircraft was the best way to accomplish this task. After researching several other aircraft, it was decided that the F-35 was the best complement to Archangel based on takeoff weight, fuselage shape, and payload placement.

The placement of the landing gear is based on the forward and aft extremes of the center of gravity, gross weight, minimum and maximum nose weight limits, and tip back angle. The minimum and maximum static nose loads are respectively 8% and 15% of the gross weight (Ref 10.4). The tip back angle has to be 14% because the nose gear can not interfere with the nose sensors. This is also why the nose gear retracts aft. The tires were sized off a Goodyear chart of many A/C of similar size and loads (Ref 10.5). The sizes of the tires were kept as small as possible in order to accommodate the design. There was not enough fuselage space for larger tires. The only other notable feature of the landing gear is that as the main gear retracts forward, it rests above the payload. The landing gear is illustrated in Figure 10.2; and the final specifications are given in Table 10.2.

Figure 10.2 Landing Gear

Table 10.2 Landing Gear Dimensions

Distance from nose to nose gear	13.30 feet
Distance from nose to main gear	34.97 feet
Tip back angle	14 degrees
Tip over angle	52 degrees
Main tire	26.6 x 6.6 inches (Type VII)
Nose tire	16 x 4.4 inches (Type VII)
Max braking nose gear load	14,919 pounds (26% of GW)
Max static nose gear load	8655 pounds (15% of GW)
Min static nose gear load	4616 pounds (8% of GW)
Main gear load (per strut)	26,542 pounds (46% of GW)

Chapter 11. Sensors and Avionics

Any successful high-production aircraft is designed not only for aerodynamic performance and fuel efficiency, but also for longevity. In order for an aircraft to maintain its usefulness throughout its many years of service, it must employ cutting edge technologies at the time of conception. This is especially true of military aircraft such as the Archangel. While initially expensive, these advanced technologies end up being cost-effective over several years.

This particular design concept utilizes equipment not currently fully employed by any branch of the military. Instead it was designed with the knowledge that the A/C would not be put into production for several years. For this reason, many of the systems described in this section are in the development or testing phase at the manufacturer's facilities. This will ensure a long, healthy, useful lifespan for Archangel.

11.1 Tactical System

When initially considering targeting systems, the first step taken was investigating the pods used by current aircraft with similar mission objectives. The A-10 Warthog, for instance, utilizes the Pave Penny, a passive laser tracker which computes the target's precise location based on the reflected energy. This system can be integrated with several of the weapons currently being considered for use on the Archangel, including AGM-65 Maverick missiles, cluster bombs, and various laser guided bombs. Unfortunately, the range of the weapons themselves now greatly exceeds the range of the targeting capabilities of the Pave Penny. Ultimately, this proves to be ineffective cost-wise, and reduces the overall survivability of the aircraft by forcing it to move closer to hostile forces. It was therefore dismissed as a possible option.

This issue was resolved shortly thereafter when research yielded information on Lockheed-Martin's new Sniper XR (eXtended Range). Currently undergoing its final stages of testing with the U.S. government, Lockheed-Martin has managed to well-surpass the current industry standard in targeting technology. Among its numerous features are a forward looking infrared sensor, laser spot tracker, and laser marker.

Figure 11.1 Sniper XR Targeting Pod (Ref 11.6)

The heart of this system lies in its third generation forward looking infrared array (FLIR), capable of producing remarkably clear images at significantly farther ranges than previously achieved. This is accomplished through a 3-5 micron mid-wave infrared staring focal array. The staring array, as opposed to a sweeping array, allows for higher resolution images because the image is generated in full rather than being pieced together by line-scanning. This arrangement also helps prevent “blooming,” or saturation of the image due to detonation of a weapon, which is a common problem with sweeping arrays.

The most notably impressive feature on this pod is its range. The recognition range for the Sniper XR is between 40 and 50 nautical miles, a distance two to three times longer than any of its predecessors. At this point, the range of the weapons becomes the limiting factor in determining the standoff distance between the aircraft and its target. Employing mid-range smart weapons such as the Paveway II at an altitude of 20,000 ft. gives a slant range of approximately 9.5 nautical miles, which is well out of reach for AAAs and MANPADs, yet still well within the targeting pod’s capabilities.

Complimenting the Sniper’s range is its wide field of regard. With constant roll support, -155° to 35° pitching support, and -90° to 90° yawing support, high maneuverability is maintained while sustaining weapons tracking. For instance, a pilot could release a guided weapon, and then turn 90° to the left while climbing in order to evade an incoming threat, all while continually tracking his weapon the entire way to the target. This is made possible by a gimbal inside the sensor that will pitch and yaw to keep the target lock. The window in the pod's nose rotates to accommodate rolling maneuvers. Should the pilot ever perform a maneuver that masks the sensor's view of the target however, a flashing 'M' will appear on the main display along with a small white rectangle, showing where to turn in order to reacquire the signal.

In displaying the infrared return, pilots are given the option of white-hot FLIR polarity or black-hot. This assists in distinction between objects through a wide variety of conditions. Cloud shadows, for example, may obscure darker vehicles in white-hot mode; however, in black-hot, the same vehicle would appear as an easily traceable, bright white object against a dark surface. For improved resolution in the visible spectrum, the Sniper offers a CCD-TV camera with digital zoom capabilities. Switching between these modes can occasionally lock up the system, but a two to three second recalibration quickly brings the system back up in the desired mode. The next software updates, expected well before the production of Archangel, promises to fully resolve the issue.

As with any advanced technology, there is the matter of the price tag. A recent mass order sale of the pod to the U.S. Air Force set the government back $28.3 million for 21 units, a cost of approximately $1.3 million per pod. While initially expensive, the price will work itself out over the years, as the pod proves its reliability time and time again. Also, consideration must be given to the fact that this technology allows the plane to fight outside the range of the enemy's anti-aircraft weapons, greatly improving survivability, and reducing the cost of aircraft replacement.

11.2 Navigation

Primary navigation for Archangel will rest in the hands of Raytheon's Anti-jam Protection Technology Receiver (RAPToR). This device, based on the Lightning Strike SAASM, is a 24-channel, dual frequency, all-in-view GPS module. It provides the highest possible nonaugmented position-velocity-time (PVT) performance within a minimal volume (2.45 in. width × 3.40 in. length × 0.59 in. height) and weight (<100 g). However, one of the primary concerns with GPS is its susceptibility to jamming. The RAPToR contains within its circuitry Raytheon's Direct Measurement Processing technology to reduce the chance of such an incursion. This provides the key to the receiver's advanced anti-jamming claim.

There are other problems with GPS technology however, that might prove detrimental in a tactical situation, including transmission interference and blackout. This can occur when solar flares or sunspot activity disrupt the regularity of the ionosphere through which satellite communications must pass. These disruptions appear in the form of both diffraction and refraction effects, which can cause short term signal fading and severely reduce the tracking capabilities of the GPS receiver. In extreme cases, it can completely disrupt signal acquisition. With this in mind, a backup system is being considered for installation which will operate independently of the GPS network.

The Precision Terrain Aided Navigation system (PTAN), developed by Honeywell and slated to be fully integrated into various systems by 2006 , is a 100% autonomous alternative to the current GPS employed by U.S. military aircraft. The concept behind this technology is that a terrain-radar return can be matched against a hyper-accurate map stored in the plane's computer, pinpointing the A/C location. PTAN does this by splitting the signal from an interferometric synthetic aperture radar sensor, which is essentially a radar altimeter with a significant aperture reduction. The two beams measure small differences in terrain height to either side of the center and are returned to two separate antennas. By calculating the difference in path lengths, the system can determine not only that there is a high point, but whether the high point is to the right or left of the beam's footprint. The processed data is then compared to a map of the local terrain in the craft's computer, and telemetry information is supplied to the pilot. As an added benefit, an additional sensor points forward to assist in collision avoidance.

The primary concern with any radar-centric system is detection and jamming by the enemy. Although information regarding this topic is being withheld by Honeywell, sources say that they have integrated a “stealthing technology” into the system to make it impervious to detection.

Efficiency on the battlefield is, unfortunately, too often determined by the current weather conditions. BAE Systems, under contract by NASA and the U.S. Air Force, is working on a project which would eliminate this factor in a “go/no go” situation. This technology, known as Synthetic Vision, would allow for flight through 0/0 conditions (0 ft. ceiling, 0 ft. runway visual range) induced by cloud coverage, rain, snow, and sand.

While infrared technology has come a long way in expanding the operating conditions under which flight is allowed, it is only truly effective at night, in clear conditions, when thermal signatures are not obscured. This presents a problem when attack timing is critical under adverse weather conditions. Synthetic Vision resolves this issue by fusing the data from current infrared weather sensors with data obtained from millimeter wave (MMW) technology. The wire-frame return is then draped by aerial photography to create a more easily interpretable image of the local terrain for the pilot.

These sensors are by no means limited to forward views either. By placing antennas on the sides and rear of the A/C, the pilot is given the option of seeing through the plane’s skin at any location. This greatly increases situational awareness and provides a tactical advantage when under fire.

11.3 Flight and Tactical Control

Several methods of flight control were investigated since the Archangel was designed as a UAV. Initial research revealed an initiative to create a networked system whereby any branch of the U.S. armed forces could control any of the other branch’s UAVs from a remote location. This network, known as the Joint Operational Test Bed System (JOTBS), was supposed to be the future of UAV control. Unfortunately, the development rate is such that this structure will not be in place by the time it is needed. Therefore, other methods had to be researched.

The Global Hawk has been selected as the model system for flight and tactical due to its reliability. L-3 Communications has combined Line of Sight (LOS) communication with a secondary satellite link for Over the Horizon (OTH) communication whenever autonomous control is insufficient or ineffective.

When LOS is available, information is transmitted directly from the Mission Control Element (MCE) to and from the A/C via an X-band datalink. Utilizing the X-band allows for an impressive bandwidth stream in both uploading and downloading data. The upload rate, as viewed in Figure 11.2, is approximately 200Kbps, and the download rate is variable, operating at 10.71, 137, or 234Mbps. This is a significant improvement over the other system on the market, utilized by the Altair, which transmits at 19.2/19.2 Kbps over the C-band.

LOS communication is limited to times when the aircraft can be seen directly by the MCE without interference from mountainous terrain or the horizon. It also has a distance limitation of 120 nautical miles at 60,000 ft. For this reason, a secondary transmitter is operated on the Ku-band to maintain connectivity via satellite (SATCOM). In this scenario, one uplink and one downlink are operated simultaneously on the same frequency to send commands, video, and telemetry data back and forth between the craft and the control station. The uplink data stream is operated at 200 Kbps, while the downlink is capable of being maintained anywhere from 1.544 to 50 Mbps. Again, significant improvement is marked over the Altair's 200/500 Kbps.

Additional bandwidth is obtained in both LOS and SATCOM modes though a continuous UHF signal. The bandwidth gain, however, is hardly significant enough to justify the additional weight, providing only an additional 1.2 Kbps up and 9.6 Kbps down at 38 pounds.

CDL LOS LINK

Features
- X-band
- Selectable downlink data rates
- Fully CDL Class 1 compatible
- COMSEC compatible
- Spread spectrum waveform on uplink
- Two axis steerable antenna
- Modular design (SEM E)

Performance Specifications

Forward link
- 200 Kb/s composite rate
- Viterbi coded (R=1/2, K=7)
- Interleaved
- BPSK modulated
- Direct sequence spread
- RF tunable in 5 MHz steps
- BER < 1 X 10^{-8} w/o encryption

Return link
- 10.71/137/274 Mb/s data rates
- Viterbi coded (R=1/2, K=7) (10.71 Mb/s rates)
- Interleaved (10.71 Mb/s rates)
- Offset QPSK modulated
- RF tunable in 5 MHz steps
- 70 Watt TWTA
- BER < 1 X 10^{-8} w/o encryption

Antenna
- Two axis 9" parabolic
- Automatic pointing

Ku-BAND SATCOM LINK

Features

Ku-band
- 1.544-47.85 Mb/s return link data rates (selectable)
- Compatible with INTELSAT & PANAMSAT COMSEC compatible
- Modular design (SEM E)
- Three axis steerable antenna

Performance Specifications

Forward link
- 200 Kb/s composite data rate
- FEC - R=1/2; K=7 concatenated with Reed Solomon R=192/208
- Interleaved
- QPSK/BPSK modulation
- RF tuneability in 20 kHz steps across all three ITV bands
- BER < 1 X 10^{-8} w/o encryption

Return link
- 1.544 to 50 Mb/s data rate
- FEC - R=1/2 or 3/4 K=7 concatenated with Reed Solomon - R=192/208
- Interleaved
- QPSK/BPSK modulation
- RF tuneability in 20 Khz steps
- 400 Watt TWTA
- BER < 1 X 10^{-8} w/o encryption

Antenna
- 48", three axis parabolic
- Automatic acquisition
- Open loop pointing or open loop assisted self scan

Figure 11.2 Global Hawk ICS Transmission Performance in LOS and SATCOM modes (Ref 11.5)

All in all, the communications system involves the use of 14 pieces of equipment, seen below in Figure 11.3. Weighing in at 375 lbs, the package requires 3.822 kW of power, and an environment maintained between -54°C and 60°C. Dimensions can be found in Figure 11.4.

One major concern with satellite communication is the delay resulting from the large distances through which the signal must travel. For standard geo-synchronous satellites, this delay is approximately 1/8 of a second. Obviously this poses a problem when operating a tactical vehicle that requires precision timing. To reduce this effect, low-earth orbit (LEO) satellites with a delay of approximately only 0.0033 seconds are utilized.

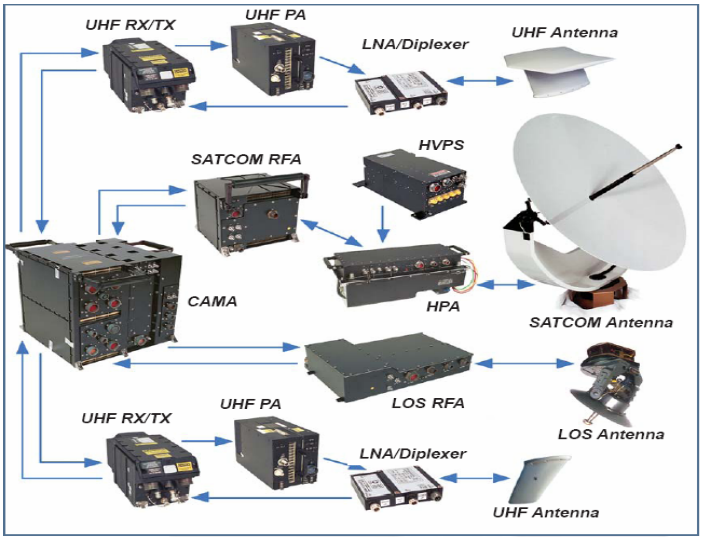


Figure 11.3 Global Hawk Integrated Communication System package (Ref 11.5)

ICS CHARACTERISTICS

	L"	W"	H"	Weight (lbs)	Power (Watts)
CAMA	17.2	16.8	19.2	85	310
SATCOM RFA	16.2	10.4	11.9	26	78
HVPS	18.7	10.2	7.7	40	1800
HPA	22.5	10.4	9.3	56	33
SATCOM ANT	54.6	48.8	48.8	46	35
LOS RFA	21.2	14.0	5.2	35	495
LOS ANT	14.6	10.2	10.2	9	7
UHF RX/TX (ea)	9.8	5.0	5.6	13	150
UHF PA (ea)	10.0	5.0	7.0	14	700
UHF LNA/Diplexer (ea)	6.0	5.4	1.2	3	7
UHF SATCOM Antenna	15.9	13.0	8.4	8	-

Figure 11.4 Itemized Global Hawk ICS package weight, volume, and power breakdown. (Ref 11.5)

Another issue requiring resolution is the bandwidth limitation on satellite communications. Operating the synthetic vision, GPS and targeting systems simultaneously has the potential to overload the transmission. Currently, the U.S. military is working to improve its LEO satellite network by launching numerous, capable satellites into orbit. It is impossible to determine at this point exactly how much bandwidth the Archangel's systems will require. However, given the vast improvement in technologies between the Altair and the Global Hawk, this setback should be minimized.

Chapter 12. Cost

The cost of the Archangel is driven by the desire to create a reusable, unmanned, weapons platform that can be used for ground attack while not risking the lives of pilots. During Operation Iraqi Freedom, 802 Tomahawk cruise missiles were used for missions where the risk to a pilot was too great. Each missile cost $0.5 million a piece, yielding a total cost of $401 million. To reduce this price while still being able to attack 800 targets, eight Archangel aircraft are needed. The cost projection for the production of 100 and 400 aircraft can be seen in Table 12.1**.** If a program of 400 Archangels is generated, a unit cost of $27.4 million, including weapons cost, results. Eight Archangel aircraft, produced at $220 million, provide the same number of kills as 800 Tomahawks for just over half the cost. While the cost of the communication system and control trailer is unknown, the Archangel system is still presumed to be less expensive than current methods of attacking ground targets without pilot risk.

Table 12.1 Cost Projection for 100 and 400 Production Aircraft

100 Aircraft	Run Cost	Unit Cost
Reasearch Test Development and Engineering	$2,180,000,000.00	$5,450,000.00
Operation	$5,680,000,000.00	$61,575,000.00
Disposal	$54,100,000.00	$935,250.00
Acuisition	$3,280,000,000.00	$27,400,000.00
Life Cycle	$5,410,000,000.00	$93,525,000.00
400 Aircraft	Run Cost	Unit Cost
Reasearch Test Development and Engineering	$2,180,000,000.00	$21,800,000.00
Operation	$24,630,000,000.00	$56,800,000.00
Disposal	$374,100,000.00	$541,000.00
Acuisition	$10,960,000,000.00	$32,800,000.00
Life Cycle	$37,410,000,000.00	$54,100,000.00

The Archangel's cost was found using Roskam's cost estimation method from part VIII of his airplane design book series (Ref 12.1). This method requires the takeoff gross weight, maximum velocity, empty weight, and the number of airplanes for production. Roskam's method to calculate life cycle cost breaks the calculation up into four parts: first, the research, development, test and evaluation cost; second, the acquisition cost; third, the operating cost; and fourth, the disposal cost. This cost estimate does not include the cost of our communications system nor all of our threat countermeasures. To test this method, the acquisition cost was computed for the AC-130, A-10, and F-15 and then compared to their given acquisition cost, as seen in Table 12.2. This table demonstrates Roskam's cost method as a good approximation for estimating the cost of Archangel.

The projected life cycle cost of the Archangel, spanning a total of 25 years, breaks down into Research Test Development and Engineering, Operation, Acquisition, and Disposal costs. Research Test Development and Engineering cost is the development cost for the first 10 aircraft. Two of these aircraft are built without engines or avionics for dry testing and balance. This expenditure is driven by the man hours spent on the design, and preparation and testing of these aircraft. The operation cost is the cost of using the aircraft, including maintenance, fuel, personnel, and spare units. The acquisition cost, as discussed earlier in this section, is what the Department of Defense would spend to purchase the aircraft, $27.4 Million in the case of the Archangel. The disposal cost is the final piece of the Life Cycle cost. It describes the cost to get rid of the aircraft, and is usually 1% of the total.

Table 12.2 Cost Method Comparison to Known Costs for the A-10, F-15, and AC-130

	Archangel	A-10	AC-130	F-15
Takeoff Weight lbs	57,567	51,000	155,000	68,000
Empty Weight lbs	41,383	unknown	unknown	41,383
Max Velocity kts	465	365	261	1,629
Number of program Aircraft	400	700	21	400
Calculated Acquisition Cost	$24 million	$22 million	$31 million	$42 million
Known Acquisition Cost		$13 million	$22.9 million	$43 million

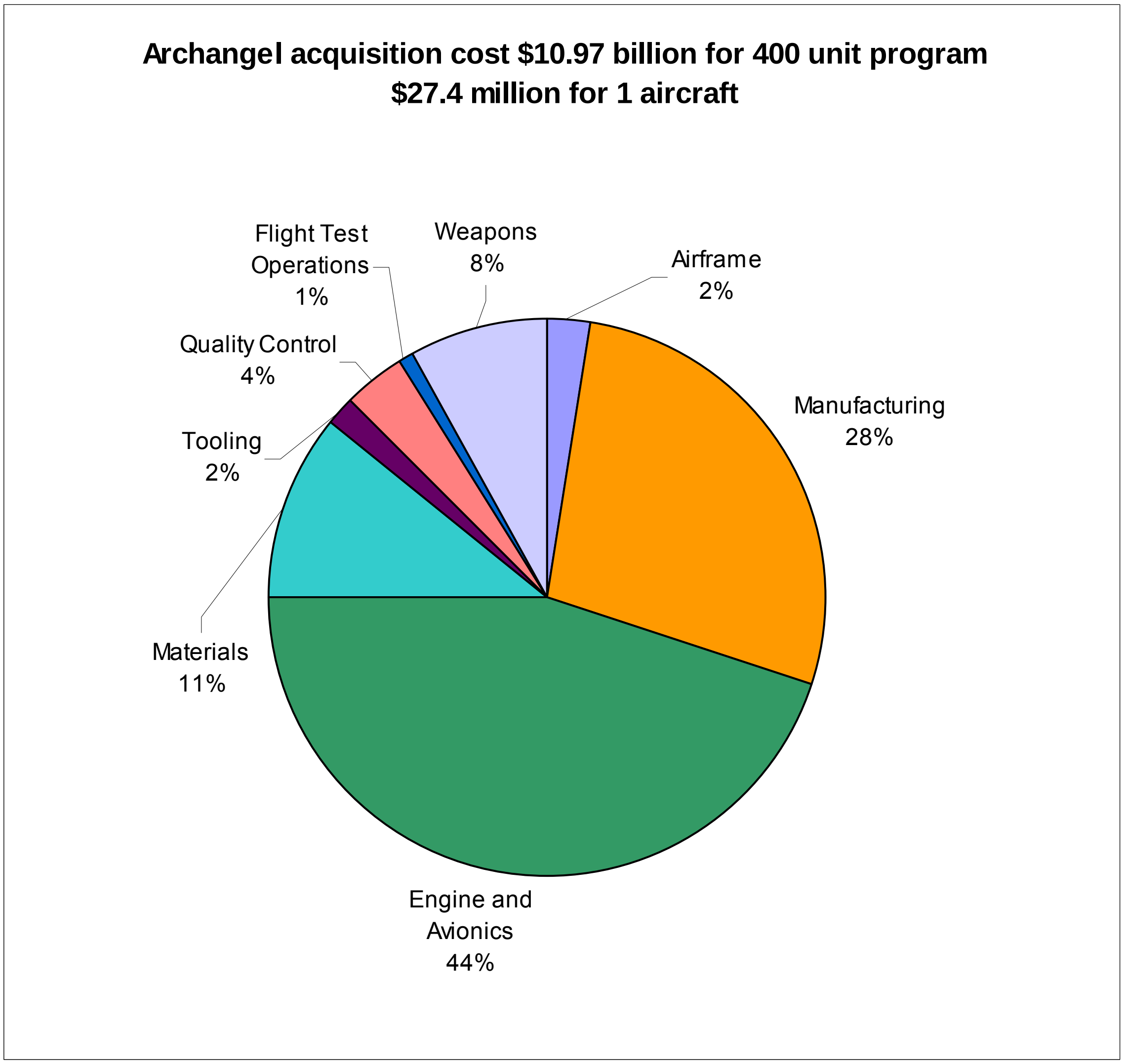


Figure 12.1 Archangel Acquisition Cost Breakdown

Chapter 13. Conclusion

The Archangel provides a unique solution to a growing threat. Although it does not have the lowest initial cost, in the long run, it is the most attractive option. The Archangel is a highly survivable, unmanned aircraft that incorporates some of the most sophisticated technology in the world. It meets the requirements set forth by the RFP in a distinctly innovative manner, with a usefulness that will extend far into the future.

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