POSTAL PENGUIN

An Unmanned Combat Air Vehicle for the Navy

Designed by:

Team Eight-Ball

Justin Hayes
Ben Smith
Chuhui Pak
Greg Little
Alex Rich
David Andrews
Nate Wright

Department of Aerospace and Ocean Engineering
Virginia Polytechnic Institute and State University

May 2, 2003

Executive Summary

This report is Team 8-ball's response to a US Navy Request for Proposals calling for designs for Unmanned Combat Air Vehicles (UCAV) capable of carrier operations and the performance of two missions, suppression of enemy air defenses (SEAD) and intelligence/surveillance/reconnaissance (ISR). The SEAD mission calls for a strike range of 500 nautical miles and a payload capacity of 4300 lbs, enough for either two JDAM or 2 HARMs. The ISR mission requires endurance operations of greater than 10 hours with no externally mounted fuel pods. The following table provides the complete RFP requirement list and some of the design implications of the requirements.

RFP Requirement	Specification	Effect of Specification
Mission 1, Strike Range	500 nm	High Fuel Requirements
Mission 2, Endurance	10 Hrs	Low TSFC, High Fuel
Payload	4,300 lbs	Internal Volume
Cruise Speed	> M 0.7	No Supersonic, Engine
Ceiling	> 45,000 ft	Engine, Aero Performance
Sensor Suite	GHISS	Volume, Integration
Stealth	Survivability	Oblique Angles
Carrier Ops		Structural Loads

Team Eight-Ball was formed to create a new UCAV to satisfy the USN RFP requirements and design a UCAV-N expressly tailored to integrate with two new small carrier designs developed by the Virginia Tech Ocean Engineering Senior Design Teams. The small carrier designs are half the size of current aircraft carriers, and will operate with advanced automated systems to reduce crew. The following table summarizes the requirements imposed due to the carrier operations requirement.

Carrier Operation Requirements	
Low Speed Handling	High Acceleration/Deceleration
Arrestor Hook	Removable Engine
Increased Structural Loading	Stowage Smaller than 30' square
Landing Gear Durability	Autonomous Carrier Landing

The aircraft ‘Postal Penguin’ is the result of this design process, which began with research on existing aircraft, alternative concept development, concept reduction and selection, and complete system design. Postal Penguin (shown below) draws from many features of modern fighter aircraft, including the Lockheed Martin JSF and the Boeing proposed JSF. A new experimental tail design is used to reduce the radar-cross section and drag characteristics of the Postal Penguin, and a proof of concept wind tunnel test was performed to verify the design originally created by Ralph Pelikan, a Boeing (and former McDonnell Douglas) engineer.

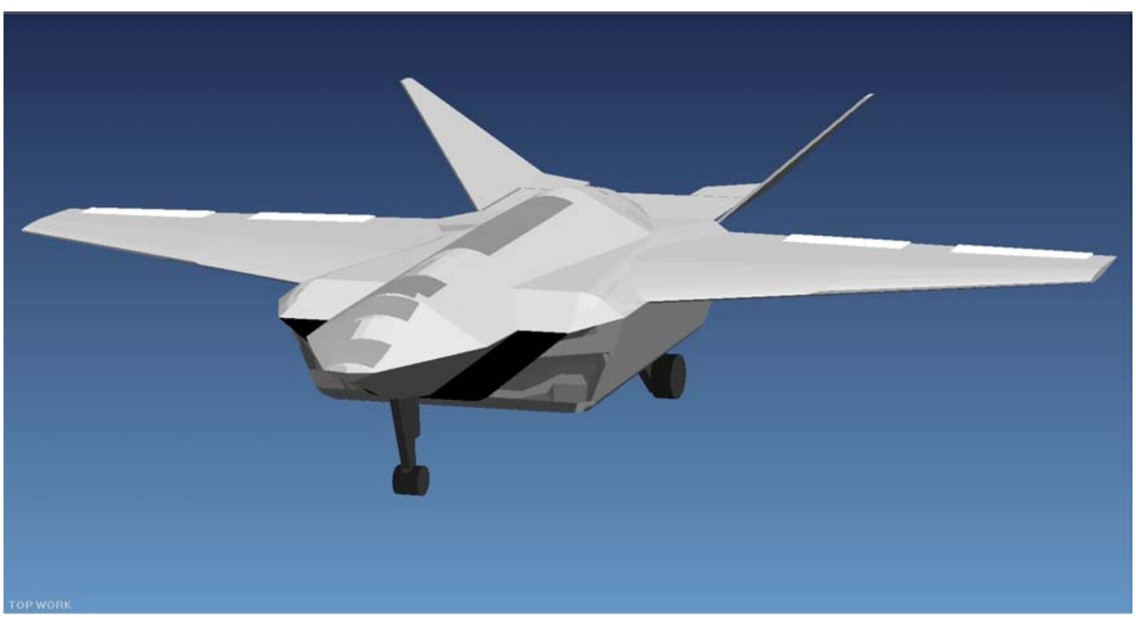


Figure ES-1 Postal Penguin Isometric Rendering

The Postal Penguin's geometric, aerodynamic, and performance characteristics (in its final configuration) are given in the table below. The Postal Penguin is capable of cruising at Mach 0.73 at an altitude of more than 40,000 feet, with an operation ceiling of 58,000 ft. The Postal Penguin successfully meets or exceeds all the requirements that are given in the RFP.

Postal Penguin General Characteristics

Characteristic		Characteristic	
Wingspan (ft)	45	Max Rate of Climb	10,250
Wingspan folded (ft)	30	Mach Divergence	0.78
Length (ft)	32	Cruise Mach	0.7
Wing Area (ft^2)	465	Cruise Altitude (ft)	40000
Aspect Ratio	4.35	Ceiling (ft)	62000
TOGW (lbs)	28500	Attack Range (nm)	500
Empty Weight (lbs)	10526	Max Range (nm)	1,250

Table of Contents

List of Symbols

α	Angle of Attack
β	Side Slip Angle
δ_a	Aileron Deflection Angle
δ_e	Elevator Deflection Angle
ε	Osswald's Efficiency Factor
ρ	Density
$C_{L\alpha}$	Lift Curve Slope
a	Lift Curve Slope
c	Chord
cbar	Mean Aerodynamic Chord
C_L	Coefficient of Lift
$C_{L,d}$	Coefficient of Lift, Desired
C_D	Coefficient of Drag
C_m	Moment Coefficient
$C_{m\alpha}$	Pitch Stability Parameter
K	Static Margin
h	Distance from MAC Tip to cg in Percent MAC
h_n	Distance from MAC Tip to Neutral Point in Percent MAC
h_{ht}	Distance from MAC Tip to Horizontal Tail Aerodynamic Center in Percent MAC

Index of Abbreviations

AGM	Air-to-Ground Missile
cg	Center of Gravity
CVN	Carrier Vehicle Nuclear
DOD	Department of Defense
EMALS	Electromagnetic Aircraft Launch System
EO	Electro-Optical
GHISS	Global Hawk Integrated Sensor Suite
HARM	High-speed Anti-Radiation Missile
ISS	Integrated Sensor Suite
JDAM	Joint-Direct Attack Munition
JSF	Joint Strike Fighter
MAC	Mean Aerodynamic Chord
MCS	Mission Control System
MTI	Moving Target Indicator
nm	Nautical Miles
ops	Operations
RATO	Rocket Assisted Take-Off
RCS	Radar Cross Section
RFP	Request for Proposal
SAM	Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SEAD	Suppression of Enemy Air Defenses
SFC	Specific Fuel Consumption
TSFC	Thrust Specific Fuel Consumption
UAV	Unmanned Air Vehicle
UCAV	Unmanned Combat Air Vehicle
UCAV-N	Unmanned Combat Air Vehicle – Navy
USN	United States Navy
WOD	Wind Over Deck
VSTOL	Vertical Short Take Off and Landing

Index of Tables

Index of Figures

Chapter 1 Mission Requirements, Comparative Aircraft Study

1.1 Introduction

This report describes the conceptual design of a Navy Unmanned Combat Air Vehicle (UCAV). This design was conducted in a two-semester aircraft design course at Virginia Polytechnic Institute and State University. The United States Navy (USN) recognizes the importance of developing UCAV systems due to the recent success of unmanned air vehicles (UAVs) in recent conflicts.

Removing the pilot eliminates the need for life support systems and allows for a lighter, simpler aircraft. No sorties are required for pilot training, and UCAVs can be placed in flight-ready storage for years, eliminating maintenance and personnel requirements.

The resulting need to develop autonomous weapons systems requires that studies be performed on the feasibility of carrier deployed autonomous combat aircraft. This design is a response to the need for UCAV technology to be employed for carrier based operations.

The mission of the UCAV-N is to provide a "new air warfare capability to the US Navy characterized by a weapons system that can act with the daring of a kamikaze" (RFP), but without the risk of allied loss of life. The absence of a human pilot relieves some design constraints and allows for cheaper, expendable, but powerful weapons systems.

To accomplish the design requirements set out by the RFP, research into similar UAV and combat aircraft was conducted to gain general insight into similar systems and approaches. Team Eight-Ball searched for aircraft that already fulfilled or could be modified to fulfill the RFP and that search is documented in the following section.

Concepts were then created and decision matrices used to analyze cost, feasibility, criterion, and risk. The concepts were reduced to the three best options, and then further analyzed to select the single best concept for further configuration and design.

The primary focus of this report is to document the configuration and design of the selected concept to conform to RFP requirements.

1.2 Request for Proposal Review and Analysis

In September 2002, Team Eight-Ball was given a request for proposal (RFP) to design a UCAV for naval carrier operations. The UCAV-N is to be carrier based on a newly designed carrier of deck length approximately 500 ft (designed by the ocean engineering design teams at Virginia Tech). The UCAV-N will carry 4,300 lbs of payload in the form of JDAM (Joint Direct Attack Munitions) or HARM (High-speed Anti-Radiation Missile) weaponry with an operational range of 500 nm. The UCAV-N must also have the capability to conduct 10 hour surveillance operations without refueling or the use of external fuel tanks.

The RFP also calls for the UCAV-N to employ stealth technology, with an emphasis on reducing the radar cross section (RCS) of the vehicle. Survivability of the UCAV-N will be dependent on its ability to remain undetected as it's top speed will not allow the outrunning of enemy interceptor aircraft or surface-to-air missiles (SAMs). The UCAV-N must have room to accommodate the Global Hawk Integrated Sensor Suite (GHISS) in addition to the internal fuel required for 500 nm range and 4,300 lbs of payload munitions required for the strike mission.

The requirements laid out in the RFP also imply significant design constraints not directly mentioned in the RFP. The need for internal weapons bays is inferred from the need for stealth. The stealth requirement is extremely important because the vehicle will not be supersonic and will not be able to outrun or outmaneuver enemy aircraft. The UCAV-N will not be an air-to-air capable dogfighter, so it is important that the enemy not be aware of the UCAV-N's presence during the mission.

The survivability requirement also requires stealth. The UCAV-N will primarily fly out of the range of small arms fire, but redundant systems for certain failure modes (loss of hydraulics, loss of a control surface, etc.) must be addressed.

Team Eight-Ball is working in conjunction with the OE senior design teams who are designing the carriers that the UCAV-N will operate from to create a complete weapons system that allows for the deployment of UCAV-Ns in hostile area while putting the fewest number of allied forces in harms way. The carrier is significantly smaller and more automated than its Nimitz class counterparts, with a useable deck length of about 500 ft, roughly half that of a full size Nimitz CVN. This carrier concept allows 35 UCAV aircraft on the carrier and 20 UAVs, which constrains the physical dimensions of the UCAV to less than 32 ft x 32 ft. Additionally, designing the aircraft with carrier storage and preparation in mind will benefit the overall system, and result in reducing personnel in hostile territory.

The structural burden on having to land on board a carrier (of length < 500 ft) introduces additional constraints in the form of robustness of systems including the landing gear, tail hook, wing box, and weapon deployment systems, which need to withstand aerodynamic loads of +4 and -1.5 gs, and takeoff and landing loads of 5 gs, and operate with relatively low maintenance. This required strength reduces internal payload area and fuel carrying capability. The UCAV-N structure must handle a dynamic pressure of 1,200 psi (M 0.9 at Sea Level). A safety factor of 1.5 is used in the analysis of ultimate design loads.

Maintenance also needs to be addressed because the number of people required on the carrier to service the UCAV-N fleet will be determined based on the time cycle of maintenance for the aircraft. Cost will also be impacted based on the required maintenance to keep a fleet operational. Keeping the cost of the system down is imperative if a UCAV-N weapons system is to be attractive to the Navy.

Table 1.2.1 outlines the RFP primary requirements and outlines the effect on design specifications that the RFP requirement imposes.

Table 1.2.1 RFP Main Requirements and Effects

RFP Requirement	Specification	Effect of Specification
Mission 1, Strike Range	500 nm	High Fuel Requirements
Mission 2, Endurance	10 Hrs	Low TSFC, High Fuel
Payload	4,300 lbs	Internal Volume
Cruise Speed	> M 0.7	No Supersonic, Engine
Ceiling	> 45,000 ft	Engine, Aero Performance
Sensor Suite	GHISS	Volume, Integration
Stealth	Survivability	Oblique Angles
Carrier Ops		Structural Loads

1.3 Global Hawk Sensor Suite

The RFP required that the navigation system utilize the Teledyne Global-Hawk Sensor Package. This sensor suite already exists and is used in the operational Global

Hawk aircraft, which has been used as a battlefield reconnaissance aircraft. This section will discuss the sensor package and its application to the UCAV-N.

Domination on the battlefield requires high quality intelligence. The Global Hawk Integrated Sensor Suite (ISS) manufactured by Raytheon Electronic Systems provides this intelligence without putting human life in danger to obtain it. The ISS provides unparalleled reconnaissance/surveillance and near real-time transmission of critical target information resulting in quicker and more informed combat decisions.

The ISS makes use of electro-optical (EO) and infrared (IR) sensors along with a synthetic aperture radar (SAR) and a moving target indicator (MTI). The use of multiple types of sensors allows for intelligence in most environmental conditions.

The following table shows the components that make up the ISS along with their dimensions and respective weights.

Table 1.3.1 GHISS Component List

Global Hawk Integrated Sensor Suite			
Component	**Dimensions (in)**	**Volume (ft^3)**	**Weight (lb)**
•Receiver/Exciter/Controller	19 x 16 x 19	3.34	101
•Integrated Sensor Processor	19 x 21 x 22.7	5.24	176
•Transmitter	19 x 12.2 x 24	3.22	90
•Sensor Electronics Unit	19 x 13.7 x 16.5	2.48	63.52
•Power Distribution Unit	14.4 x 5 x 19.5	0.81	40
•Antenna/Gimbal	14.4 x 49.5	N/A	95
•EO/IR Receiver Unit	24.5 x 26.2 x 42.3	15.7	271.3
•ISS Total	N/A	30.8	885

1.4 Carrier Operations and its Implications

The requirement for carrier operations drives some requirements and constraints on the vehicle. The capability to be launched from, and recovered by, an aircraft carrier is fundamental to the development of a usable concept, and places increased structural burdens on the design. The low speed handling characteristics of the aircraft must allow the aircraft to manage the difficult task of maneuvering to land on an aircraft carrier. This is particularly important because of the size of the carriers that the UCAV-N will integrate with.

The Northrop Grumman F-14 Tomcat is a good example of an aircraft that satisfied a wide variety of design constraints, including aircraft carrier operations. The best configuration for supersonic aircraft is a delta-style wing, but such wings do not provide the handling characteristics required for carrier landings. To overcome the problem, mechanical sweeping wings were added to make the wings conventional during landings. The wings however added weight and complexity, and therefore cost and maintenance.

1.4.1 Bolter

Another issue related to launch of the aircraft is the ability to bolter the plane should that maneuver be necessary. Bolter is a scenario where the landing aircraft fails to engage any of the arresting cables and is forced to perform a "touch and go" from the carrier deck in order to avoid the ditching of the plane. In order to have the option to bolter, every landing aircraft approaches the carrier at a higher speed than it would approach and land-based runway. Instead of attempting to flare the aircraft and slow to near the stall speed for landing, a plane landing on a carrier must fly hard into the deck and let the arresting system decelerate the aircraft. This is one reason that landing aboard a carrier is often called a "controlled crash". The ability to bolter is why carrier landings must be done at higher speeds. If the plane approaches the carrier near its stall speed and then fails to engage any of the arresting cables, there is not enough runway for the plane to re-accelerate itself and take off again. If the aircraft impacts the deck at the approach speed (1.2 times the stall speed) and fails to engage the arresting cables, it will have enough speed to launch again under its own power and avoid crashing into the ocean. Even if the plane contacts the deck at the approach speed, a large amount of power is required to successfully bolter the plane. This means that a power plant must be selected that is capable of producing the thrust needed to bolter from the carrier deck in an emergency situation.

1.4.2 Internal Carrier Operations

Once the airplane is safely aboard the ship it must be stored below deck, moved to a maintenance area for service, have unused weapons removed or be sent to the flight deck to be launched for another mission. No matter what is to happen to the aircraft, once aboard the carrier, it must be able to maneuver in tight spaces and take up as little space as possible when stored on the ship. In order to handle well on the carrier deck the plane must have a good turning radius with its nose gear. This will enable ground crews to maneuver the ship on the deck and easily move it onto and off of elevators in and around service bays and on the launch deck. When not in use, the plane must take up as little space as possible. The current design must not be too long or have too great a span. One way to save space in the span wise direction is to have folding wings that retract for more efficient storage of the airplane. The less space that a single plane takes up, the more aircraft the carrier will be able to carry. The ease of deck handling for the UCAV-N is of particular importance due to the fact that the ship for which the plane is being designed is going to cut down as much as possible on manned crew. The easier and quicker a plane can be moved around the deck, the fewer overall man hours will be dedicated to the planes. This will help keep the required crew to a minimum.

1.4.3 On-board Maintenance

The carrier design groups are interested in keeping the number of required crew to a minimum. Lower maintenance requirements for the UCAV-N will reduce the cost, lifecycle cost, and crew required to keep the fleet in operation. To make the aircraft easy to maintain on a ship with a limited crew, components that require regular service should be located in the airframe at a location that is easily accessible. The engine must drop directly out of the airplane for easy repair (from the bottom). Internal weapons bays are a good way to provide access to the interior of the airplane. With the bays empty and the doors open a significant portion of the interior of the aircraft will be exposed. This will enable crews to get access to internal components without disassembling the airframe.

1.4.4 NATO Takeoff and Landing

In addition to the carrier deck the UCAV-N must be able to land on a NATO standard runway. This is to comply with military regulations but should not be a problem for our design as the current NATO standard runway is 8000 feet long. This requirement is significantly less stringent than the other RFP requirements and satisfying those requirements will result in the satisfaction of this one.

1.5 Comparative Aircraft Study

The first step team Eight-Ball took was to research current aircraft that already satisfied, or could be modified to satisfy the RFP requirements. This section describes the aircraft that were found and what is useful about them in terms of the Navy RFP.

1.5.1 General Atomics, Predator

The General Atomics Predator weighs 2,250 lbs and is the first UCAV. Originally designed as a battlefield reconnaissance for field commanders, it was outfitted with a hellfire missile in Afghanistan and Yemen. This vehicle demonstrates the capability for UCAV technology, but cannot carry the required payload, nor meet speed and range requirements given in the RFP.

Figure 1.5.1 General Atomics Predator (General Atomics)

1.5.2 Teledyne, Global Hawk

The Teledyne Global Hawk is a sophisticated reconnaissance UAV with a range of 12,000 nm and an endurance of up to 35 hours. It also utilizes the sophisticated sensor suite that will be used on the UCAV-N and demonstrates the autonomous use of turbojet engines. The design however cannot be modified to make it a viable attack aircraft, and its wingspan precludes it from any sort of carrier operations.

Figure 1.5.2 Teledyne Global Hawk (Teledyne)

1.5.3 Tupolev, Tu-141

This Russian built UAV entered service in 1983 and utilized a rocket assisted take-off (RATO) to launch. The UAV weighed 13,702 lbs at launch, and had a service range of 540 nm. It carried thermal imaging cameras, TV cameras, and radiation detection equipment. The Tu-141 did not have any capability to carry weaponry and had no stealth characteristics, but it demonstrates that a fairly light weight UAV with the RFP range is possible.

Figure 1.5.3 Tupolev Tu-141

1.5.4 Boeing, Bird of Prey

The Boeing Bird of Prey was unveiled in October of 2002 and demonstrates a tailless design and a 'W' wing design, and large composite structural construction, which results in significant empty-weight reduction. The Bird of Prey at take-off weighs 7,400 lbs. The total development and prototype cost for the aircraft was $67 million.

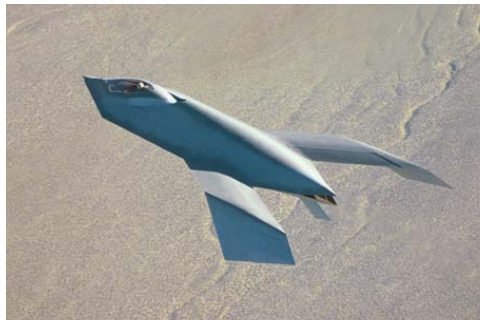


Figure 1.5.4 Boeing Bird of Prey (Boeing)

1.5.5 Boeing, X-45

The Boeing X-45A UCAV is a tailless 27-foot long, 8,000-pound (empty) vehicle and a take-off gross weight about double that with a 34-foot wing; a reconfigurable mission control system with robust satellite-relay and line-of-site communications links for distributed control in all air combat situations.

The Boeing X-45B (the larger of the two prototypes) will still carry a payload of only 2,000 lbs, but have similar range capabilities, about 500 nm. The empty weight is 14,000 lbs, and it will carry 5,400 lbs of fuel. It has a span of 47 ft. and a length of 32 ft.

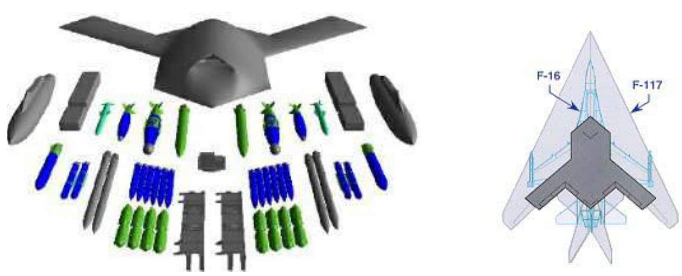


Figure 1.5.5 Boeing X-45 Payload and Size Drawings (Boeing)

1.5.6 Northrop Grumman, X-47 Pegasus

Pegasus has been designed and built to demonstrate aerodynamic flying qualities suitable for aircraft carrier operations. Specific demonstration objectives include:

- Low speed aerodynamic handling qualities
- Carrier landing systems compatibility
- Simulated arrested landings
- Air vehicle management system applicability to future unmanned air vehicles

Figure 1.5.6 Grumman X-47 Pegasus (Northrop)

1.5.7 Boeing, X-46 UCAV-N

This is the Boeing response to the USN RFP for UCAV technology operated from a carrier (Boeing). Some key features of the air vehicle include:

- Hoists in the vehicle's weapons bays allow for rapid rearmament
- Easy access to subsystems allows rapid maintenance and repair without altering the vehicle's radar signature
- Common support and built-in diagnostics/prognostics health management significantly reduces training and support costs.
- Combined hands-on and realistic simulation-based virtual training, along with technology enabled maintainers, reduces staffing requirements
- Its two-plus level maintenance concept is similar to that of the low cost Joint Strike Fighter approach

1.6 Comparative Analysis Conclusions

None of the aforementioned aircraft satisfy the requirements set forth by the RFP. They do however present design concepts that can and were utilized during the initial concept designs that will be discussed in the next section.

From the above research, a few key points were established as driving considerations in UCAV and UAV design, particularly with the range and payload constraints the RFP requires.

- Use of Composite Structures to Reduce Weight
- Weight Range, 15,000 – 30,000 lbs
- A New Design is Required

Chapter 2 Concept Creation and Reduction, Final Concept

2.1 Initial Concept Overview

Each member of Team Eight-Ball created an initial concept to satisfy the RFP. Some of the designs are actually combinations of concepts because of similarities. This section discusses briefly the concepts, and is summarized by pro-con charts following the descriptions.

2.1.1 Concept Delta

The Delta concept resembles current long range bomber reflecting the nature of the UCAV-N which is to perform SEAD strikes, and is not intended for any dog-fighting capabilities.

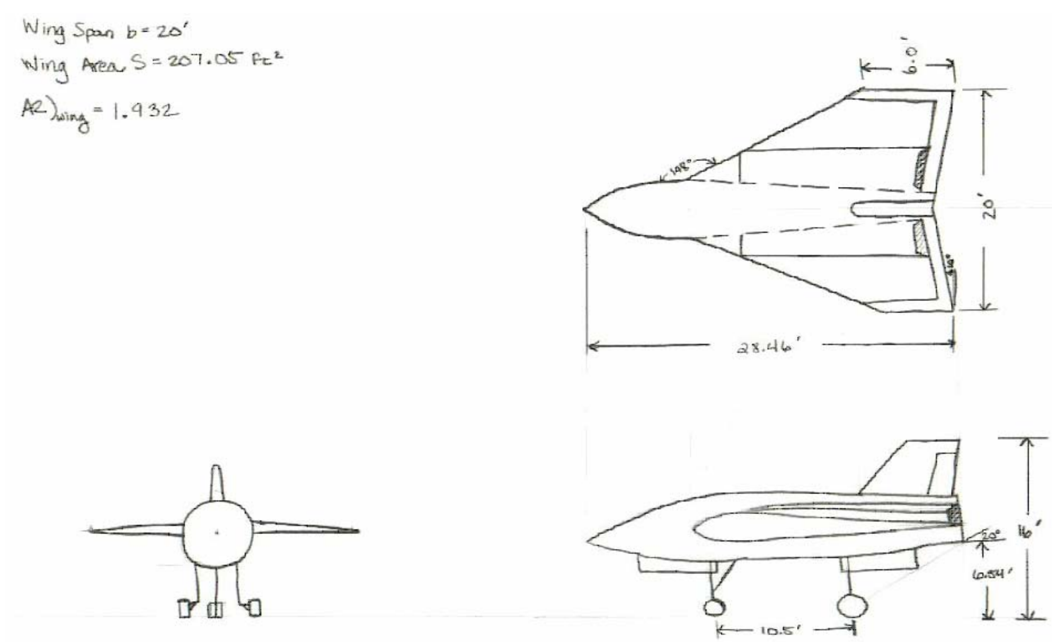


Figure 2.1.1 Concept Delta, Planform

2.1.2 Concept Bat

This concept has one engine, and the inlet is located on the upper side of the aircraft. The payload is to be stored in the lower part of the aircraft, and the sensor package is to be stored in the nose section of the aircraft.

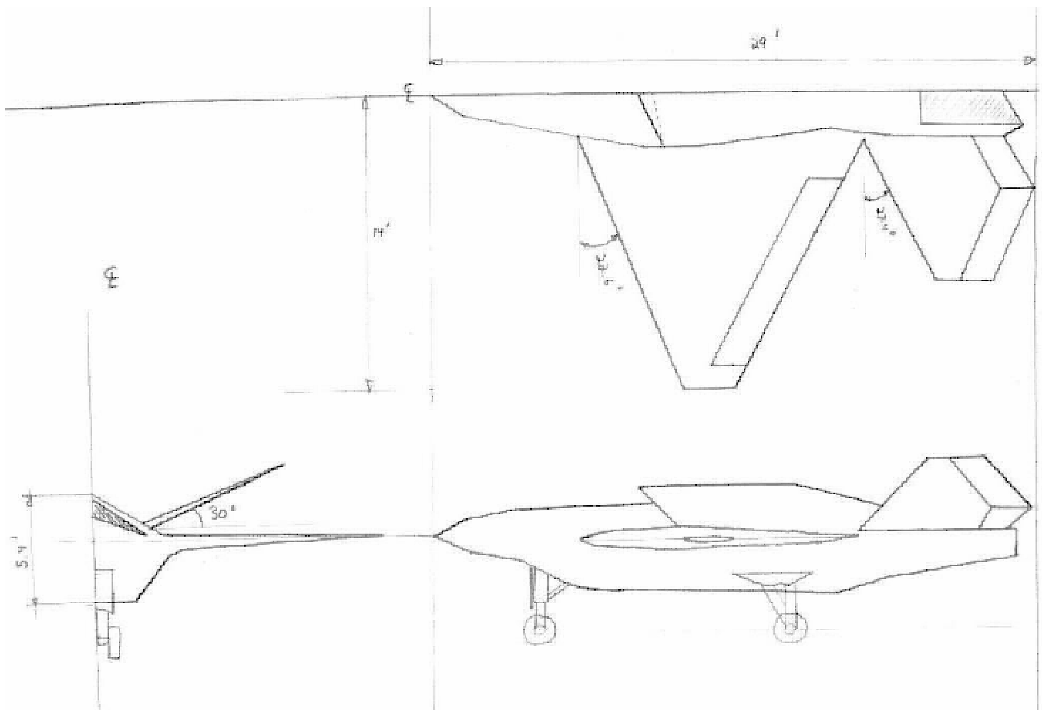


Figure 2.1.2 Concept Bat, Planform

2.1.3 Concept Flying Boat

The flying boat was designed to launch off a roller-coaster-style track that would carry it from storage, through weapons loading and fueling, and onto the magnetic catapult launching rail. The aircraft would then carry out its mission and return to land in the water along side the aircraft carrier. The lack of traditional landing gear allows for lower vehicle weight, less complexity, and lower cost. Retractable water skis replace the landing gear and allow the vehicle the ability to land in water.

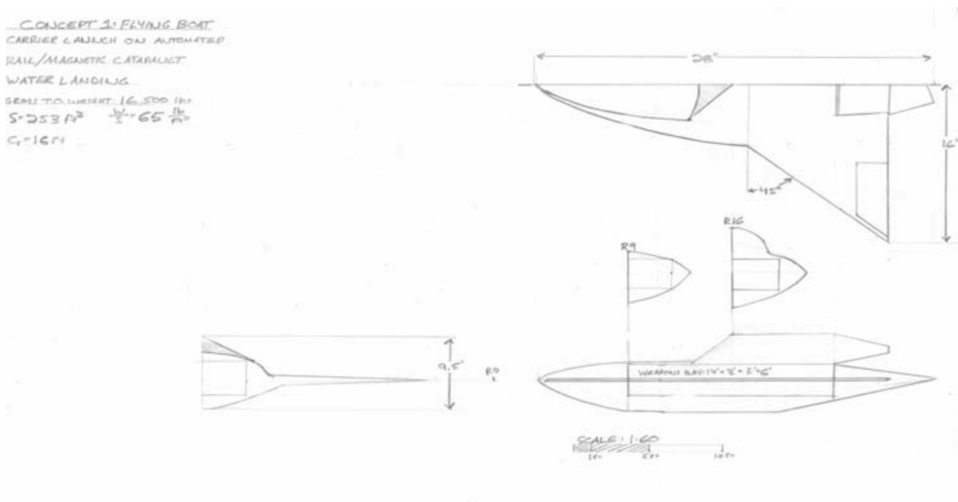


Figure 2.1.3   Concept Flying Boat, Planform

2.1.4   Concept Satan

This concept is based on modern jet-fighter designs with the intent to promote stealth. The bomb bay is internal to help keep the plane stealthy and to have clearance for the weapon systems specified in the RFP. The vertical tails are canted to reduce the radar signature of the plane, while maintaining control surfaces for pitch, roll, and yaw.

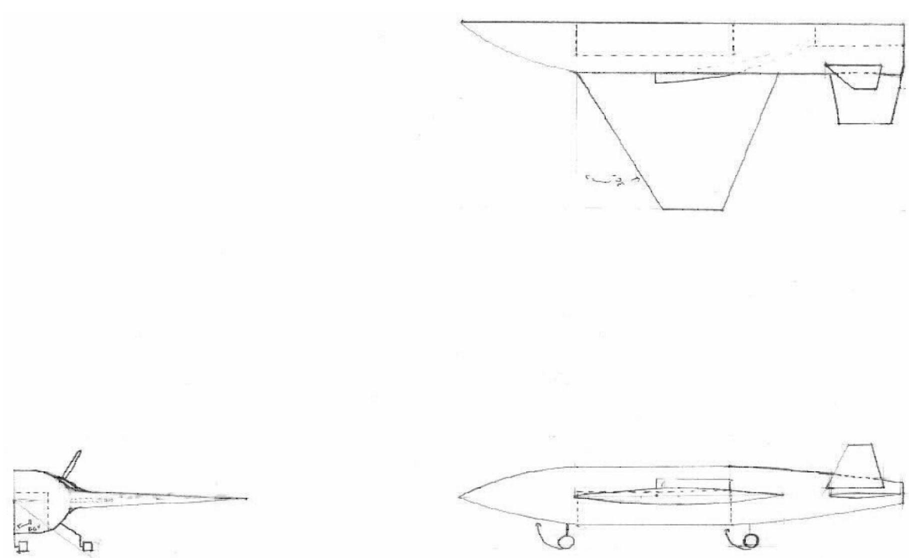


Figure 2.1.4   Concept Satan, Planform

2.1.5 Concept Stealth Wing

This concept was modeled after the F-117 Stealth Fighter. Similar characteristics include the highly canted vertical tails and the straight lines on the fuselage. These characteristics are all intended to decrease the radar cross section. The engine inlet is located on the top of the plane where the flow accelerates over the nose of the plane. The design features thrust vectoring to aid in longitudinal control. The fuselage tapers into the wing to provide more space for internal weapons bays, fuel storage and landing gear.

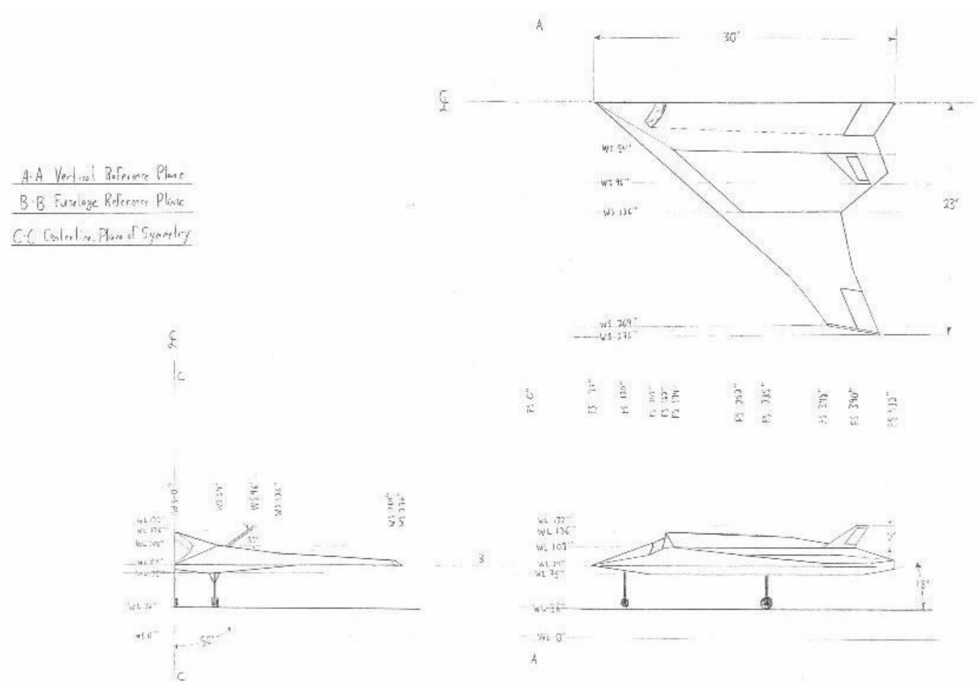


Figure 2.1.5 Concept Stealth Wing, Planform

2.1.6 Concept Beatle

Concept 6 was among the largest of the designs, with multiple control surfaces and large lifting areas for greater low-speed handling qualities, a crucial factor for carrier ops. A single engine was used, and the fuselage shape was modeled after the Boeing X-

45 UCAV concept, featuring the dorsally mounted engine inlet to allow greater room below for weapons bays.

Horizontal tails were included for greater handling, but vertical tails were left out to enhance stealth characteristics. With the lack of a yaw stabilization surface, weathercock stability was left to vectored thrust from the engine.

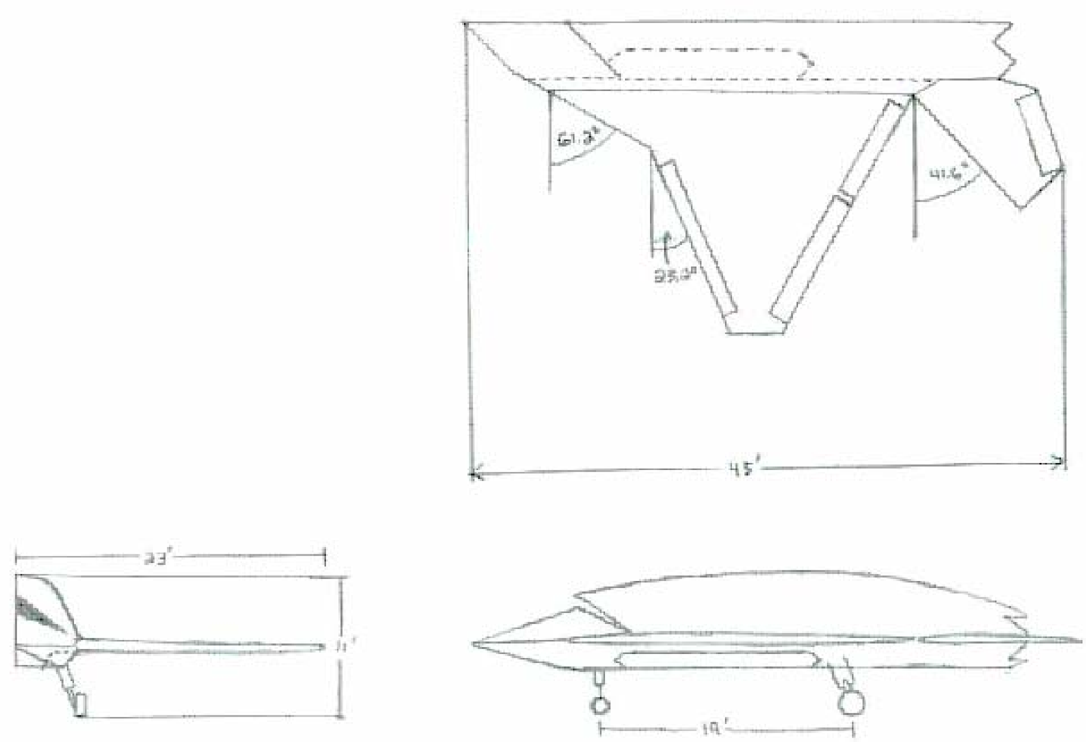
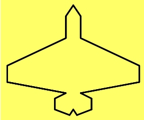
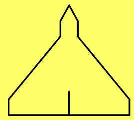
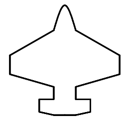
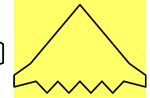
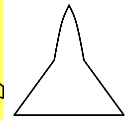
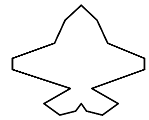


Figure 2.1.6 Concept Beetle, Planform

2.2 Initial Concept Analysis, Decision

The concepts were all analyzed relative to one another in an effort to reduce the concepts that would be considered in some depth. Table 2.2.1 outlines the decision matrix, and shows which of the initial concepts were chosen for additional analysis, and why.

Table 2.2.1 Initial Concept Decision Matrix

Criteria						
Take Off/Landing						
Stall Speed	**3**	**5**	4	**2**	7	1
Missed Cable	**4**	**3**	6	**2**	1	5
Weight!!	**2**	**5**	3	**6**	1	4
Performance						
Range	**500**	**500**	500	**500**	500	500
Payload Capacity	**4400**	**4400**	4400	**4400**	4400	4400
Stability/Control						
Manueverability	**2**	**1**	7	**5**	6	4
Controls	**1**	**2**	5	**3**	7	4
Operations						
Stealth	**1**	**5**	7	**2**	6	3
Totals	**13**	**21**	32	**20**	28	**21**

In order to rate the concepts, the important design criteria needed to be established. The important aspects considered in reducing the concepts were:

- Cost
- Weight
- Bolter Ability
- Dimensional Size
- Stealth, Survivability
- Ease of Carrier Integration

The outcome of this analysis was that the 6 initial concepts were reduced to 3 preferred concepts, which would be analyzed in greater detail ultimately resulting in picking a single final concept. The three that were selected are shown in Table 2.2.1 (Bat, Delta, and Stealth Wing).

2.3 Preferred Concepts Analysis

The next step was to further analyze the concepts to determine the best starting concept to satisfy the RFP. Analyzing the remaining concepts required the determination of design criteria to benchmark the concepts against RFP requirements, allowing the selection of a preferred concept.

Because the UCAV-N is carrier based, the size of the airplane determines the number that can be carried by the vessel. In coordinating with the ocean designers, the airplane was decided to be small enough to fit in a square 30-35 ft on each side, with a maximum height of 18 ft. The height restriction restricts the amount of wing that can be folded.

Concept Stealth Wing, which was based on the B-2 Spirit Bomber, requires a span that is too wide for carrier operations. Research indicated that flying wing concepts tend to require significant amounts of runway for take-off, and significant amounts of wing area to provide the required lift. Span would not be a problem on the other concepts due to the ability to fold wings at the ends, but this has not been done on flying wings, and the difficulties that are likely associated with that function would be a structural nightmare. Further, the aircraft has no control surfaces for dealing with yaw, which would create poor low speed handling characteristics, which is important for carrier based aircraft. It was decided that the remaining two concepts offered better feasibility for a carrier based vehicle.

Concept Delta has similar constraints. Delta wing aircraft have not to date been launched from a carrier system and very few current autonomous aircraft are designed with this configuration. Additionally, it is the heaviest of the aircraft because it uses multiple engines, which makes it more survivable, but less fuel efficient and significantly larger and heavier. The next chapter discusses the importance of weight and fuel efficiency on the aircraft selection, because of the serious mission constraints imposed by the RFP. The stealth characteristics are also poor because of the vertical tail and rounded features. However, the plane would have good low speed handling characteristics which is important in carrier landings.

Concept Bat is the most conventional concept. It has the smallest amount of interior volume, which may constrain its fuel carrying capability. It uses canted tails, which help provide some additional yaw control over the Stealth Wing, but less control than the Delta. It is the lightest of the vehicles, and allows for modification with relative ease.

The Stealth Wing concept was eliminated from discussion because of its limitations, which left the Bat and the Delta. Both aircraft had poor estimated static margins. The UCAV-N will not be required to fly supersonic, which delta-winged aircraft tend to be more efficient at, and delta wings also tend to have higher drag characteristics.

Table 2.3.1 summarizes the dimensional and some aerodynamic characteristics for the aircraft.

Table 2.3.1 Preferred Concept Data Sheet

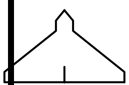
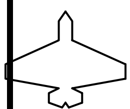
Concept	Wing Area (ft^2)	Span (ft)	Length (ft)	Static Margin	Volume (ft^3)	Weight (lbs)	$C_{l\alpha}$	$C_d/C_{l,d}$	$C_{m\alpha}$
	**208**	**20**	**29**	**-0.17**	**312**	**3**	**0.049**	**4**	**0.008**
	**252**	**28**	**29**	**-0.21**	**235**	**1**	**0.061**	**1**	**0.013**
	**562**	**46**	**30**	**n/a**	**420***	**2**	**0.202**	**1**	**n/a**

Table 2.3.1 shows that the concepts are fairly similar in most regards. The significant differences lie in the weight, wing area, and volume. The Stealth Wing was not studied in the same detail as the other concepts because it was determined that while it had more interior volume than its competitors, it could not hold an engine of the diameter needed for the aircraft. Because of the breadth of the missions demanded of the UCAV-N, only a high bypass high efficiency engine could be utilized to provide the range and power needed, all of which have fairly large diameters around four feet. That dimension ruled out the Stealth Wing because of its thin body design.

All of the aircraft are unstable, but the instability doesn't vary between the concepts. However, concept Bat is more reconfigurable, which will allow easier correction in the instability problem.

The $C_{l\alpha}$ shows what is expected conceptually. The flying wing has the best lift coefficient, and the conventional aircraft is second.

The approximate cg location of the flying wing was not calculated because the necessary propulsion system (discussed in the next chapter) would not fit in the aircraft. Fitting in a propulsions system with the needed characteristics to satisfy the RFP would require a gross redesign of the concept, and therefore the remaining concepts are better choices. This is why there was no static margin computed for this concept.

Solutions to this problem are to move aft the neutral point, or move forward the cg location. The engine placement for all of the concepts is in the rear of the plane, which is standard for most military strike aircraft. As a result of this, the wing (MAC) must be moved to move the neutral point, or the length of the front must be extended to increase the moment arm of the sensors package which is located in front. Since all other weight is fixed vehicle and fuel/payload, the only movable options are the GHISS and the engine.

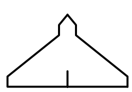
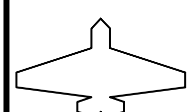
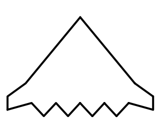
The engine is located in the rear, and at the center of the aircraft for several reasons. Firstly, most military aircraft locate the engines in this location, and it requires no ducting for outlet exhaust. This is important because ducting for exhaust is very high cost (due to the high temperature of the exhaust) because it requires titanium and ceramic ducting.

Additionally, for stealth purposes, it is beneficial to have the engine located in a nonlinear connection to the inlet, so that radar cannot bounce off the face of the engine through the inlet duct. This location for the engine and its inlets allow snaking the inlet and eliminating that detection possibility. Another possibility would be to use mesh over the inlet area, which would not allow the transmission of radar frequencies into the engine.

The endurance requirements also determine the engine requirements, while the strike mission determines the interior volume requirements. The minimum volume needed to house all of the fuel, payload, and sensors rules out the use of concept 4 (the flying wing concept).

A relative assessment of the important characteristics of the airplanes is presented in table 2.3.2. The table demonstrates that the flying wing is the poorest match with the RFP requirements. The delta wing concept has the least ability for easy configuration change, and since its static margin is as bad as the remaining concept, but significantly less adaptable, the best concept for further evaluation is the second preferred concept.

Table 2.3.2 Concept Selection Grid

Concept	Radar Section	Wing Area	Span	Static Margin	Usable Volume	Weight
	3	2	3	5	1	3
	2	1	1	5	2	1
	1	2	1	n/a	3	2

Another analysis tool that was used to study the aircraft was a carpet plot, presented in Figure 2.3.3. This plot shows the design constraints for Catapult Assisted Launch, and the selection of an engine that produces 19,000 lbs of thrust.

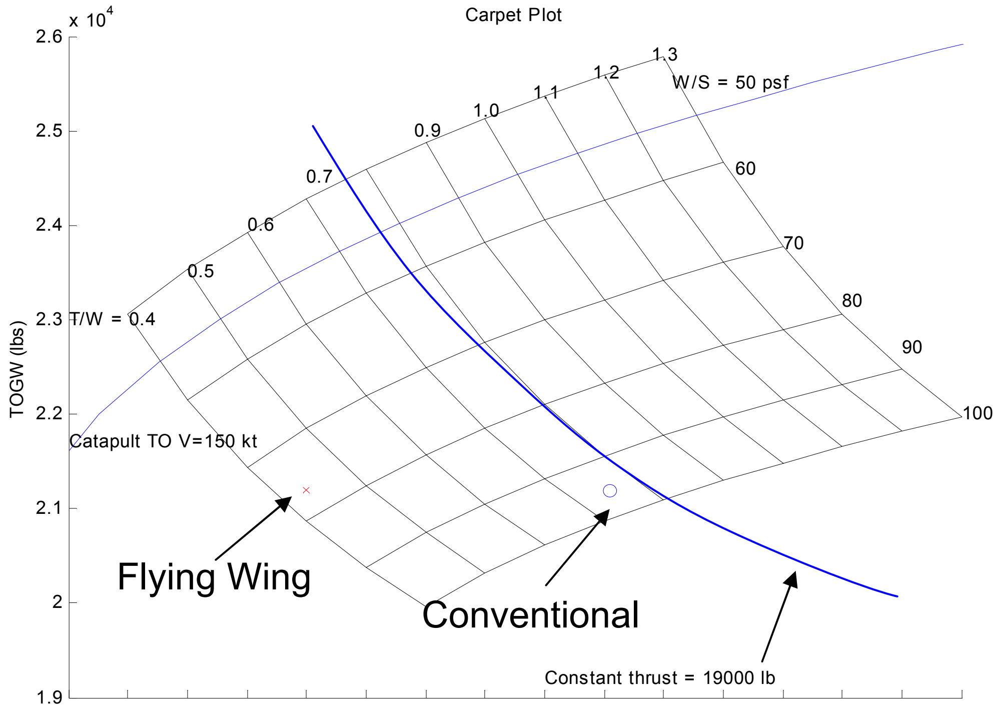


Figure 2.3.3 Carpet Plot for Preferred Concepts

The design point for the delta wing does not land on the carpet, which is why it is not represented on the plot. Thrust to Weight ratios between 0.4 and 1.3 and Wing Loadings of 50 and 100 psf.

2.4 Final Concept Decision

In determining what the final concept should be, the most important task was to decide on the over-riding design constraints. The key issues determined by the team were carrier suitability and stealth (survivability) and ease of modification for stability.

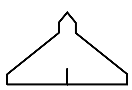
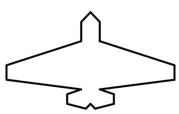
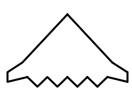
Through our investigation of the three concepts, key pros and cons were identified with all suggested concepts. The final decision matrix is shown in figure 2.4.1.

Table 2.4.1 Final Concept Decision Matrix

	AIRCRAFT WEIGHT	USABLE VOLUME	STATIC MARGIN	RADAR	LENGTH	WING SPAN	WING AREA	TOTAL
WEIGHTING	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
Delta	21	6	15	12	3	6	3	66
Bat	7	12	15	8	3	4	2	51
Stealth Wing	14	18	15	4	6	2	1	60

A 1:10 scale drawing of this concept was created, and the internal volume checked to verify that the dimensional size is approximately appropriate. The following table lists a summary of the three concepts.

Table 2.4.2 Final Concept Summary

	AIRCRAFT WEIGHT (lbs)	USABLE VOLUME (ft^3)	STATIC MARGIN	LENGTH (ft)	WING SPAN (ft)	FOLDED SPAN (ft)	WING AREA (ft^2)
	**33k**	**312**	**-0.17**	**29**	**20**	**20**	**208**
	**24k**	**235**	**-0.21**	**29**	**45**	**28**	**252**
	**40k**	**420***	**n/a**	**30**	**46**	**46**	**562**

The following table outlines the reduction of concepts from the initial 6 to the final one.

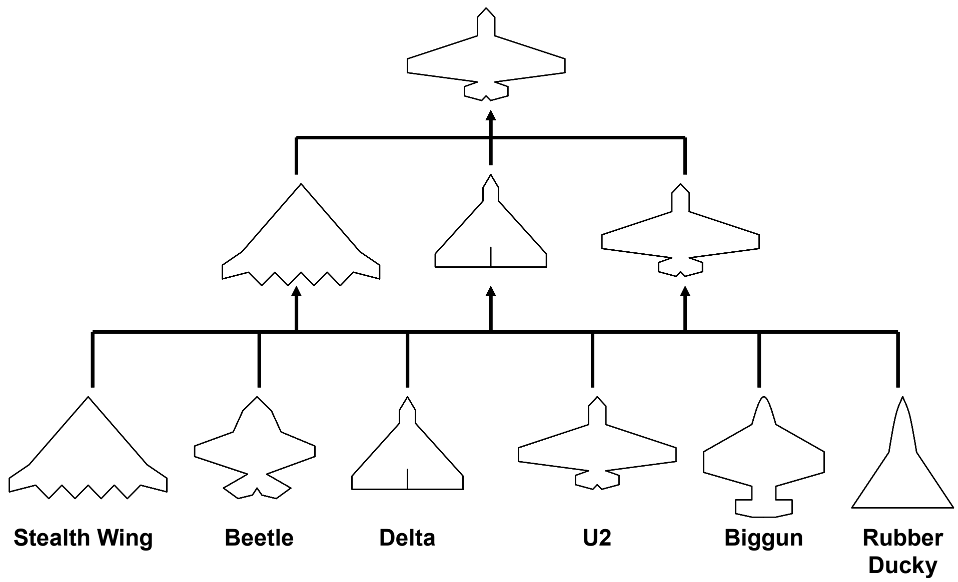


Figure 2.4.4 Decision Reduction Tree

Chapter 3 Final Configuration

3.1 Introduction

The selection of concept rat as a starting place for designing the next generation aircraft allowed the most flexibility and possibility for modification in completing the design. The design evolution from concept Bat to Postal Penguin (the final design) was significant due to identification of design and requirement problems that needed to be addressed, and the flexibility of Rat made it possible to complete.

3.2 Initial Problems

Cg travel

The first problem identified was an instability issue. The plane was determined to be particularly unstable in certain situations, particularly low fuel, empty weapons bay scenarios. If the stores were dropped and it ran out of gas, the plane would be incredibly unstable. The cg travel was of particular issue because it would move behind the main landing gear, which was a configuration killer. Figure 3.2.1 shows the cg travel with respect to the landing gear.

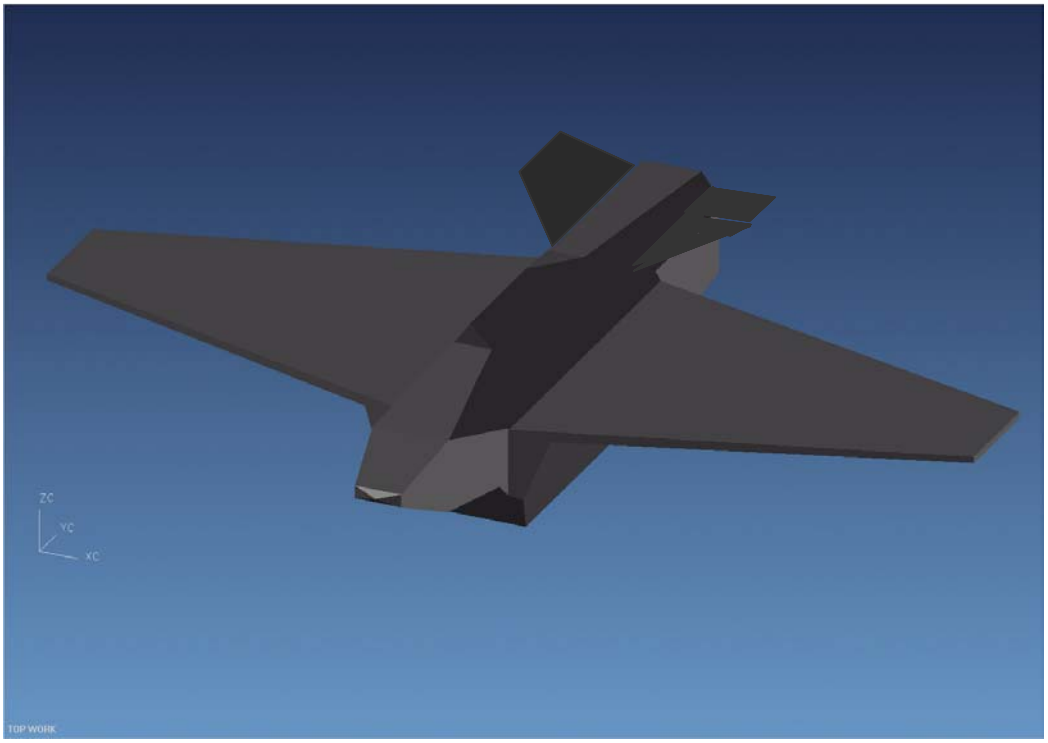


Figure 3.2.1 Initial Configuration (Rear Engine)

To resolve this problem, the engine was moved into the body of the aircraft, increasing the central diameter of the fuselage and moving the cg forward, resolving most of the instability issue, and removing the large moment created by hanging the engine out the aft of the airplane.

Mach Divergence

Another issue was the drag divergence in cruise. The RFP requires the cruise to be greater than Mach 0.7, and the initial drag divergence for the selected airfoil (discussed later) was too close to Mach 0.7. One of the primary factors in the Korn equation for Mach Divergence is the half chord sweep. Initially, the planform had no sweep, but to solve the drag divergence issue, it was increased to 10 degrees, which results in a leading edge sweep of 23.7 degrees. This led to a drag divergence at Mach 0.76, which is satisfactory.

3.3 Pelikan Tail

A new tail design was adopted after reviewing a video tape (NOVA) on the JSF program. Ralph Pelikan designed a two post tail, as opposed to traditional four post tails. The experimental tail provides some stealth benefits (less total area, less radar cross section) and some drag benefits (less wetted area), but adds some complexity and has never been used on a fighter aircraft. To prove the concept, a model was built and tested in the Virginia Tech Stability Wind Tunnel. The tail and it's testing is discussed in further detail later.

3.4 Complete Configuration

Other minor changes occurred during the design process to make certain systems fit. Shoulders were added to accommodate the inlet systems, and the aft portion of the airplane was widened to utilize the Pelikan tail system. Figure 3.4.1 shows the Postal Penguin in its complete configuration.

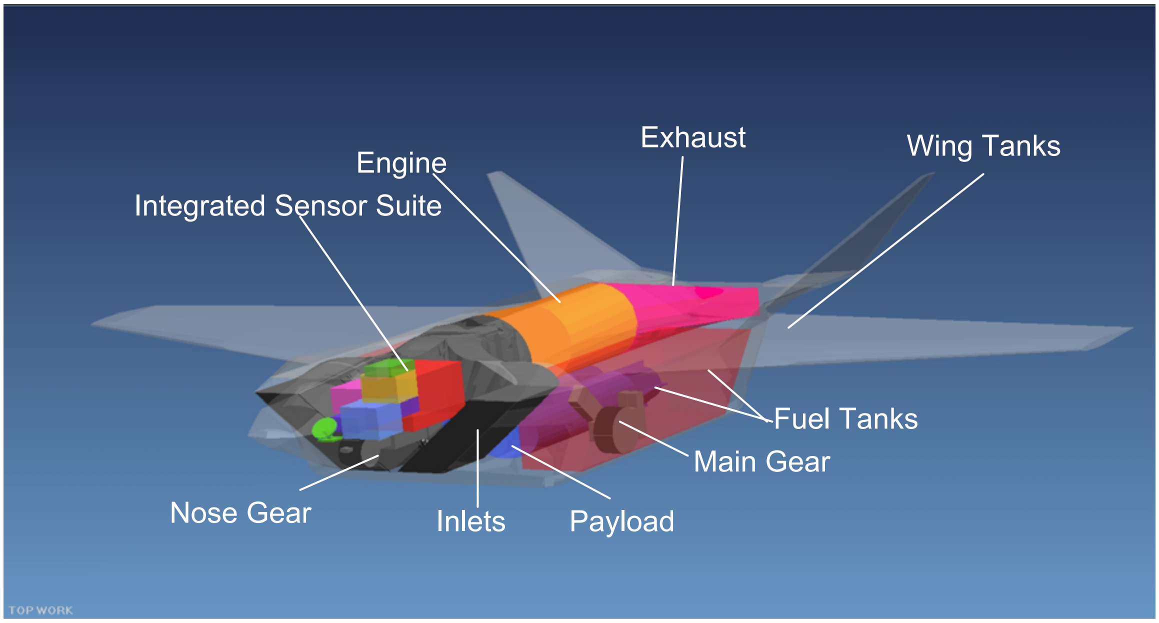


Figure 3.4.1 Complete Internal Configuration

The drawings of the configuration only show major components and systems incorporated into the design, and leave out smaller and minor aspects which would need to be considered in a design-to-build analysis. Such systems include backup batteries, wiring harnesses and support, fuel pumps and hosing, and hydraulic and pneumatic hosing.

The external configuration utilizes ailerons and flaperons, as well as a new tail design created by Ralph Pelikan (a Boeing engineer), which is discussed at length in later chapters. Figure 3.4.2 shows the external configuration and main features of the Penguin.

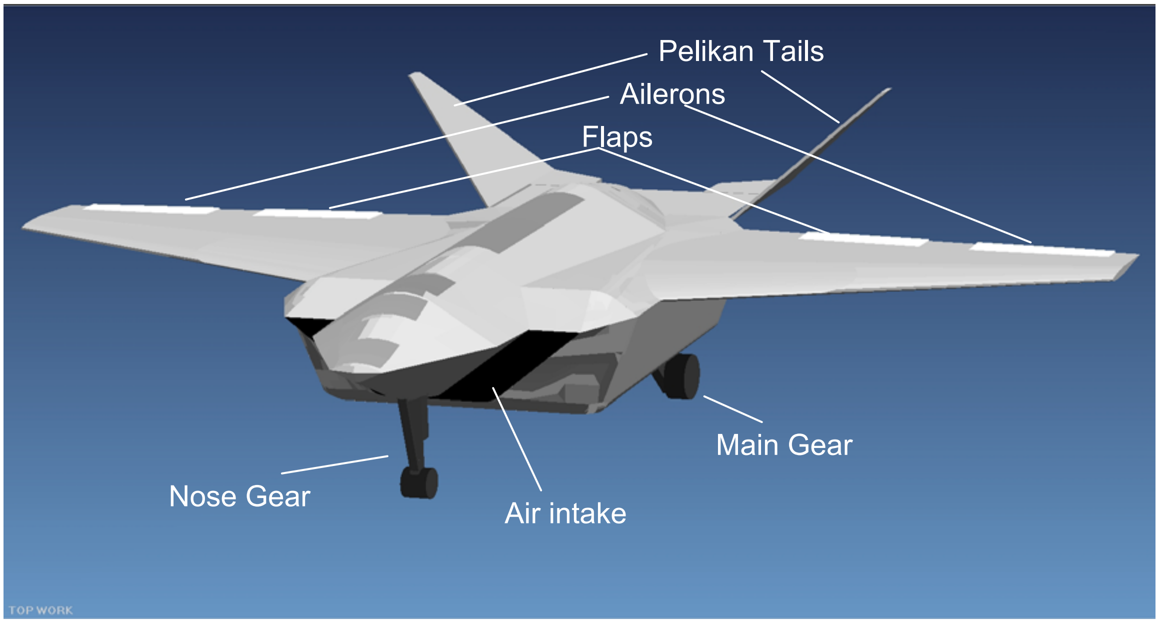


Figure 3.4.2 External Configuration

Figure 3.4.3 is a three view of the aircraft with dimensional properties, and figure 3.4.4 is an in-board profile of the aircraft.

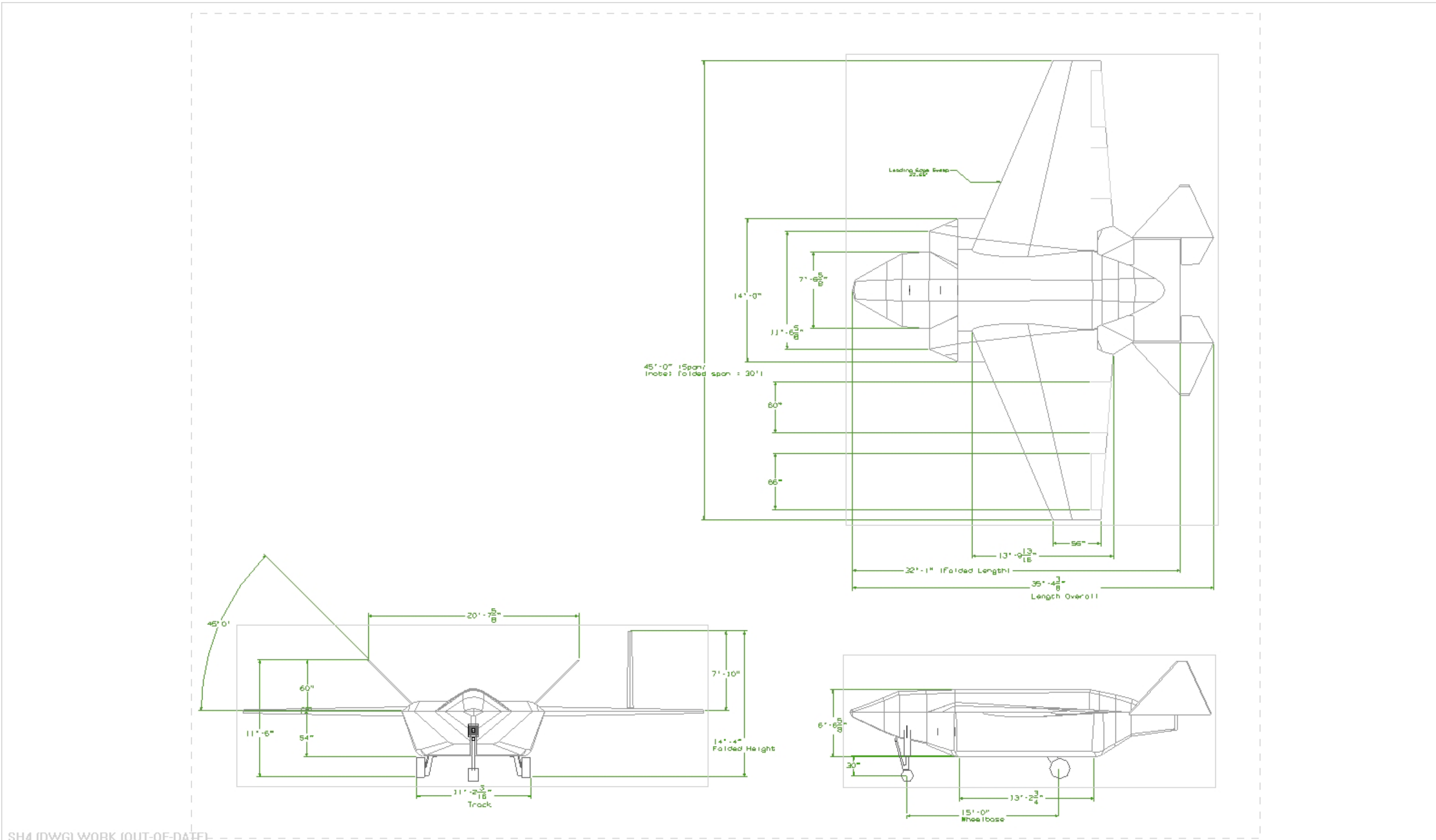


Figure 3.4.3 Three View Drawing

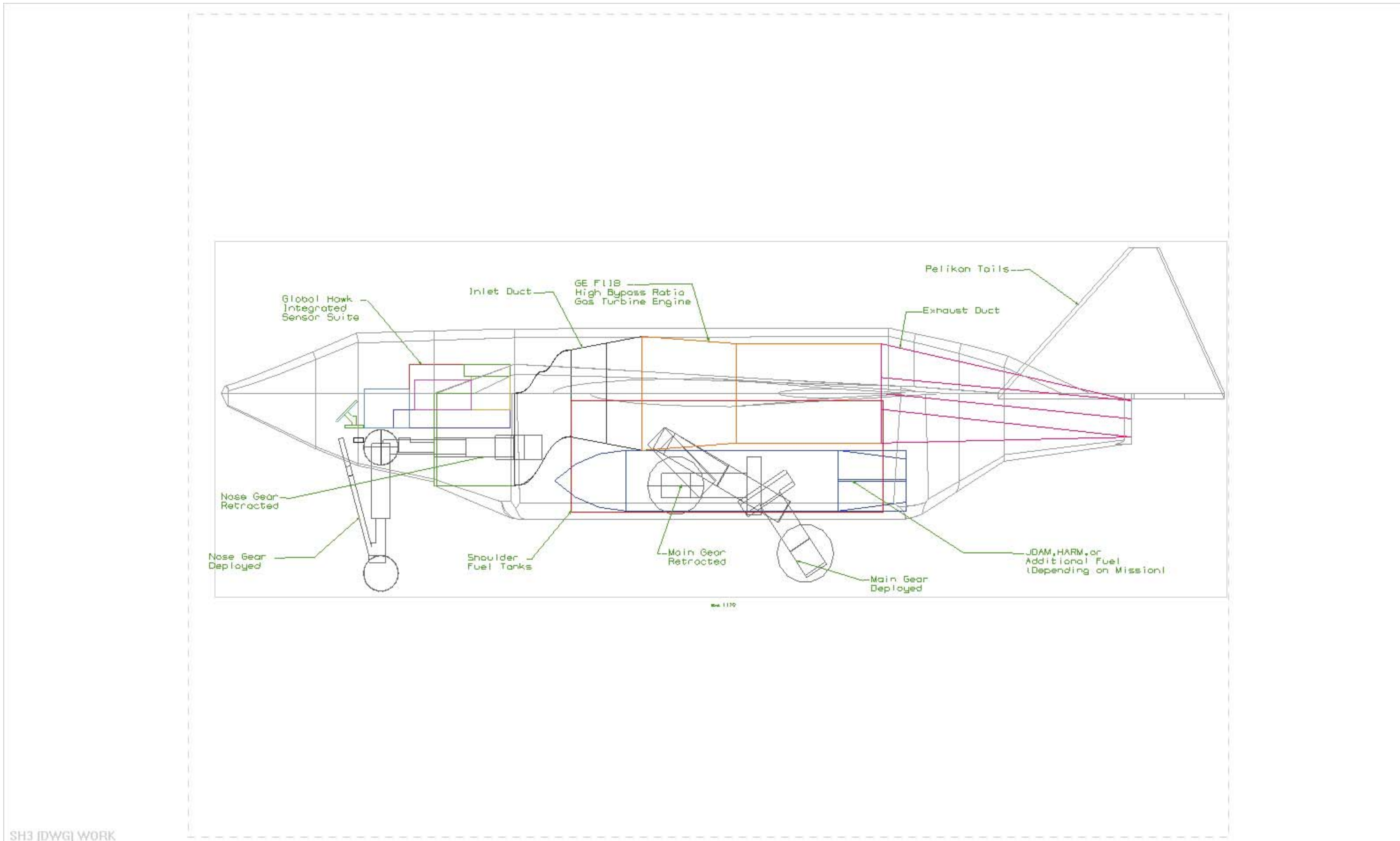


Figure 3.4.4 In-Board Profile

Chapter 4 Mission and Engine Analysis, Selection

4.1 Introduction

The UCAV-N has two major missions required in the RFP, a 10 hr surveillance/loiter mission and a 500 nm deep strike mission. Two basic equations (Equations 1 and 2) were used in order to determine the approximate volume and weight constraints as well as to examine desired engine characteristics. Both equations are applied only to the mission segment and does not include the fuel consumed in take off and landing. Equation 1 was used to analyze the weight and volume of fuel necessary for the loiter mission. The range equation (Equation 2) involves the assumption of constant velocity, constant α, and a drift up flight schedule. With these assumptions the range equation is merely the endurance equation multiplied by velocity and is subject to the same driving quantities.

The specific fuel consumption (SFC) is an engine characteristic and had values in a range of approximately 0.3 hr^{-1} - 0.9 hr^{-1} for engines in military aircraft. The lift to drag ratio of similarly sized aircraft was found to be from approximately 9-15 but is dependent on the aircraft. The final term that is in both equations is the weight fraction of the initial weight of the plane (w_1) to the final weight of the plane (w_2). The weight fraction corresponds to the fuel being consumed as well as weight being dropped from the aircraft like bombs or detachable fuel pods.

$$E = \frac{1}{SFC} * \frac{L}{D} * \ln(\frac{W_1}{W_2}) \quad (1)$$

$$R = \frac{1}{SFC} * \frac{L}{D} * V * \ln(\frac{W_1}{W_2}) \quad (2)$$

4.2 *Mission Program Results*

Following are some of the plots that helped lead to the determination of the engine specifications that are needed to satisfy the RFP.

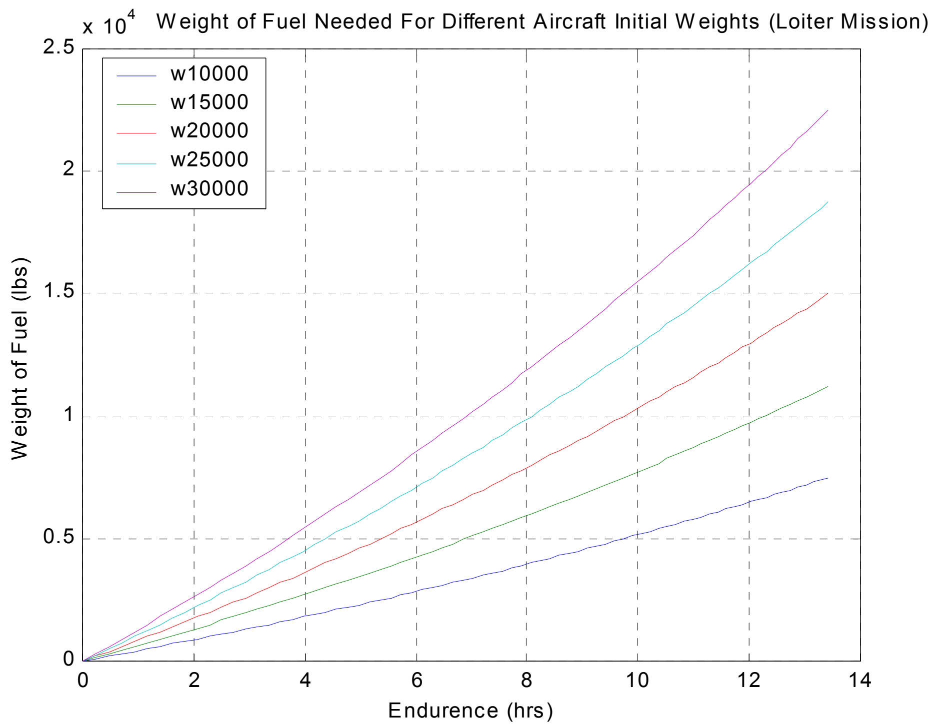


Figure 4.2.1 GE F-118 Fuel Weight v. Endurance

The major drivers in the range and endurance are L/D, SFC, and W_1/W_2. The L/D ratio is assumed constant for the aircraft as it depends on the shape of the aircraft. It is assumed 9 for all calculations involving range and endurance. The SFC has a large influence as low values (0.3 hr^{-1}) produce approximately three times the amount of range and endurance than the higher values (0.9 hr^{-1}). Figure 4.2.1 shows endurance plots for different structural weights (everything necessary to fly but fuel) of aircraft using the SFC of 0.324 from an F-118 engine.

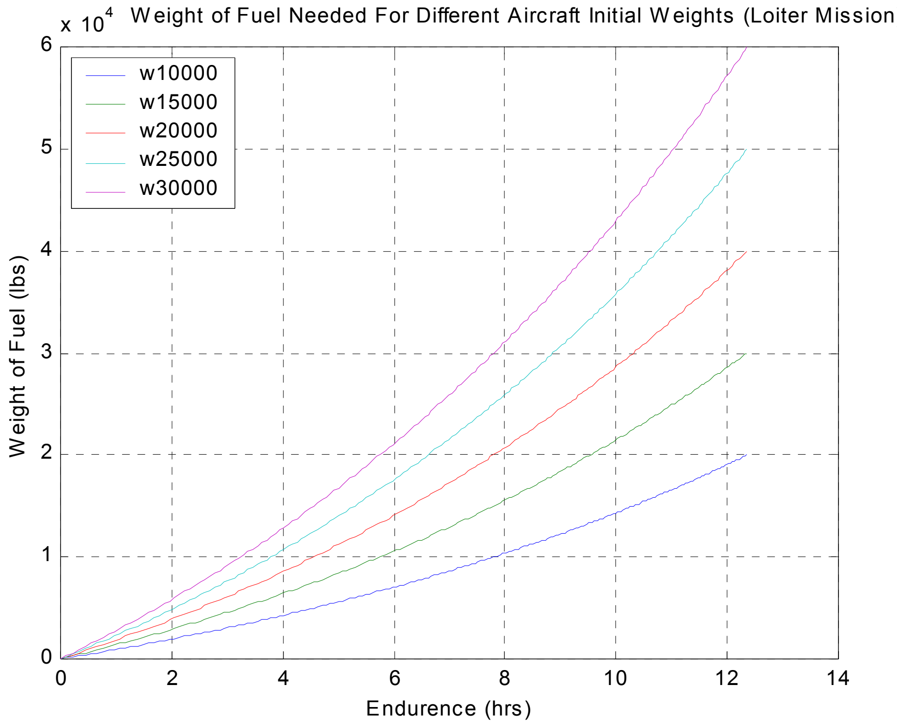


Figure 4.2.2 GE F-404 Fuel Weight v. Endurance

Figure 4.2.2 shows the same plot but instead of an F-118 engine, an F-404 engine with an SFC of 0.8. From these two graphs it is apparent that a low SFC is essential to meeting both the RFP requirements as well as the compatibility with the reduced size aircraft carrier system. An engine with a low SFC value helps to maximize range and endurance while minimizing the weight and volume of jet fuel. The volume of the fuel needed to fly corresponds directly to the amount of fuel necessary to fly the mission (Figure 4.2.2, Figure 4.2.3).

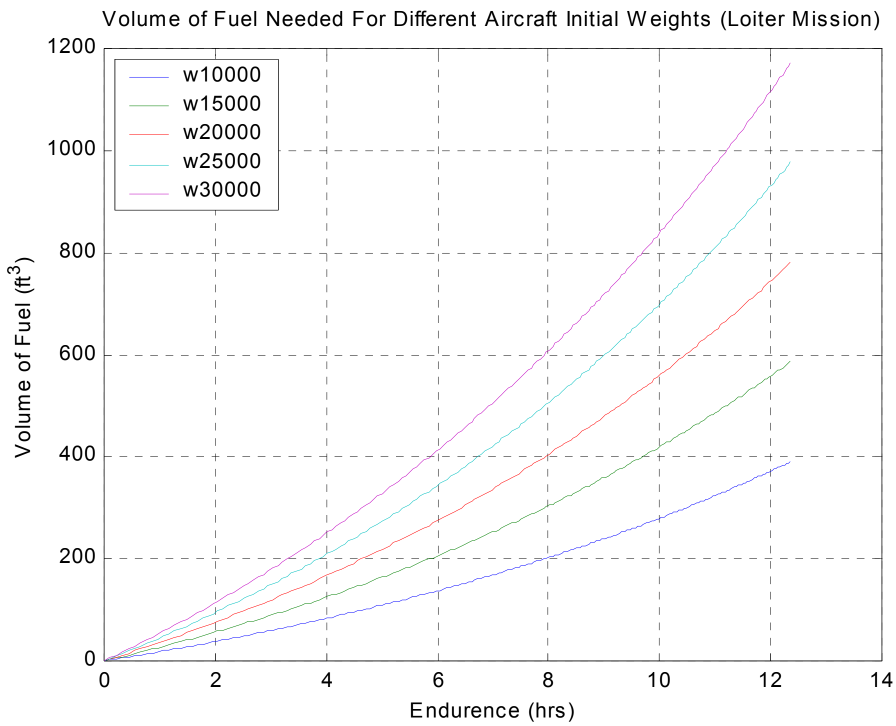


Figure 4.2.3 GE F-404 Fuel Volume v. Endurance

The weight fraction of the fuel drives up the values of range and endurance when the final weight is less than the initial weight but requires large values because it is located in a natural logarithm function. The major difference in this quantity in the deep strike mission and loiter mission is in the strike mission the plane will also lose weight from dropping its payload. For the calculation of the weight and volume of jet fuel for the strike mission a worse case scenario of no bombs being dropped was assumed. The other assumption in the calculation of range values was the plane has the same gross weight at the beginning of the mission for both the strike and loiter mission. The total gross weight used to calculate the range and endurance for comparisons was 25000 lbs.

Table 4.2.4 Engine Comparison Table

ENGINE	SFC [DRY] (hr^{-1})	THRUST [DRY] (lbs)	WEIGHT [DRY] (lbs)	LENGTH (in)	DIAMETER (in)
TF 34-GE-400A	0.363	9275	1478	100	52
F 118-GE-100	0.375	19000	3200	100.5	46.5
F 404-GE-1000	0.8	11000	1820	89	34.7
AE3007H	0.39	8290	1581	106.5	43.5
	LOITER FUEL WEIGHT (lbs)	LOITER FUEL VOLUME (ft^3)	STRIKE FUEL WEIGHT (lbs)	STRIKE FUEL VOLUME (ft^3)	
TF 34-GE-400A	8298	163	2503	49	
F 118-GE-100	8518	167	2581	51	
F 404-GE-1000	14722	288	5186	102	
AE3007H	8792	172	2679	53	

Note: All loiter and strike values calculated for the same initial weight at the beginning of the respective mission.

Table 4.2.5 Engine Selection Matrix

WEIGHTING	THRUST	SFC	$WEIGHT_{fuel}$	$WEIGHT_{eng}$	DIAMETER	LENGTH	TOT
	6	*5*	*4*	*3*	*2*	*1*	
TF 34-GE-400A	2	4	4	4	1	2	64
F 118-GE-100	4	4	4	1	2	2	69
F 404-GE-1000	3	1	1	3	4	4	48
AE3007H	1	3	3	2	3	1	46

Note: *The highest total corresponds to the engine selected for the design.

The final considerations in the engine selection were based on the weight of the engine, the thrust of the engine, the dimensions of the engine, the SFC of the engine, and the weight of fuel necessary for the endurance mission. The physical characteristics, thrust capabilities, and SFC for a lot of military aircraft engines were found at http://www.jet-engine.net/miltfspec.html. The values of these for a few engines can be seen in Table 4.2.3 along with the estimated values of weight and volume of fuel for each mission. The Engine characteristics were then weighted from 1 to 6 with 6 being the most important to our design requirements and each engine was rated for these characteristics from 1 to 4. Thrust (weight 6) was decided as the most important characteristic for carrier take off and landing and possibly if high enough adding bolter capability. The SFC with its powerful influence in fuel volume and weight was selected to be at a weight of 5. The weight of the fuel, weight of the engine, diameter or width of engine, and length of the engine were weighted at 4,3,2,1 respectively. The engine that scored the highest total is the F 118 GE 100, which was selected to power the UCAV-N (Table 4.2.4).

4.3 VSTOL

Vertical/Short Take Off and Landing (VSTOL) was considered but not utilized due to several factors including, weight, safety, cost, usefulness, and need. A VSTOL system would have added more weight, which adds cost and complexity to an otherwise simplistic system. The only Navy fighter to use VSTOL currently is the AV-8b Harrier JumpJet, which is used by the Marines, and rarely based on carriers. Instead the conventional FA-18 Super Hornet and F-14 Tomcat are used. The catapult capability of the aircraft carrier doesn't require a short take-off capability.

The purpose of the UCAV-N is to deploy an attack capability at minimal cost, both in terms of human cost and economic cost. The maintenance and equipment and weight costs associated with adding the VSTOL system don't make sense from a systems perspective, because the vehicle can perform the requirements without the additional system.

Safety is also a major concern. The Navy commissioned a study entitled the Harrier Review Panel Study (HaRP) to look into the increase in failure rates associated with the AV-8b Harrier. The Harrier is the least reliable airplane in the US arsenal, with failure rates more than double that of other aircraft. Figure 3.3.1 graphically compares the accident rates of the AV-8b with that of all other aircraft in the Navy combined.

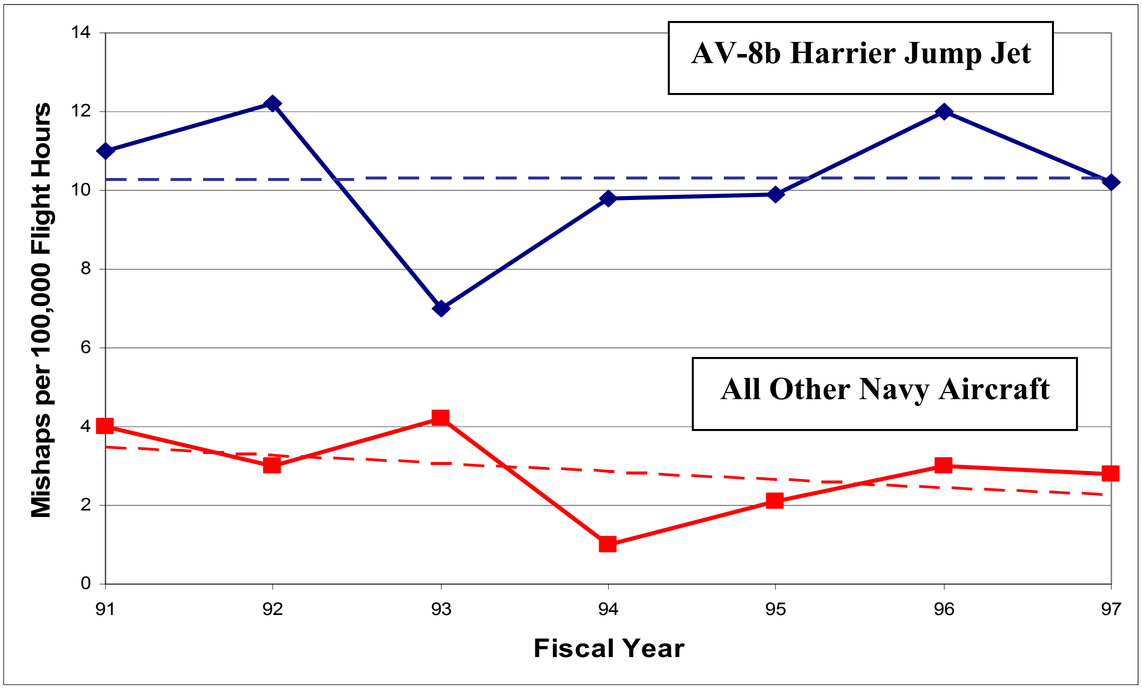


Figure 4.3.1 Mishaps Comparison in USMC VSTOL Aircraft

The Navy VSTOL aircraft have experienced 55 Peacetime Vehicle Losses (17 lives lost) just due to accidents, and have mishap rates of between 14 and 20 per 100,000 hours of flight time. VSTOL would also require additional engines or more powerful (les efficient) engines that would impede on the aircraft's ability to meet range and endurance requirements.

Chapter 5 Vehicle Systems

5.1 Introduction

Autonomous vehicles are much more systems oriented than conventional fighter aircraft since there is no pilot around which to design the vehicle. The system itself must be capable of fulfilling all its missions in as small a package as is feasible, as cheaply as possible, and with superior effectiveness to current conventional manned aircraft. Because of that purpose, the vehicle was designed around its requirements, with volumetric analysis being used to determine the minimum size of the aircraft, instead of conventional aerodynamic regression.

This method allowed for the development of the smallest, lightest, and therefore cheapest, possible aircraft. This section will detail all of the independent systems that the UCAV-N utilizes, their placement, function, and reasons for selection.

5.2 Avionics, Global Hawk Integrated Sensor Suite

The avionics the UCAV-N utilizes is an off the shelf product produced by Raytheon, and its use was determined by the RFP. The benefits of using a pre-existing product are the cost and lead time savings. It has already been developed, and requires no further serious research and development, reducing the cost of the vehicle overall. Additionally, the system is neither large nor heavy, reducing the weight, cost, and volume of the aircraft. Less volume of internals means more volume for fuel, always an added bonus.

5.3 Engine System

The engine system and selection was detailed in chapter 3. The selection of the GE-F118 jet engine provided a high bypass engine that consumed vastly less fuel than other attack aircraft, which was necessary to satisfy the stringent endurance and mission strike requirements. The engine is depicted to the right.

GE-F118
(courtesy GE Aircraft Engines)

5.4 Weapons Systems

The weapons that the UCAV-N will carry were defined by the RFP. It must be capable of carrying either 2 High-speed Anti-Radiation Missiles (HARM) or 2 Joint Direct Attack Munitions (JDAM) bombs. Both weapons systems are used in SEAD strike operations, and are highly guided, allowing the aircraft to fire and forget.

AG-88 HARM
(courtesy Global Security)

Both weapons systems are 10 feet long (roughly 1/3 the size of the aircraft), which makes placing them in the aircraft difficult. The bomb bay is over a third of the aircraft length, so accessing the bomb bay is difficult due to landing gear placement and a relatively low belly height (distance from the ground to the plane). Most modern aircraft that carry these munitions are larger aircraft, or aircraft that mount them on wings, instead of internally.

GBU-32 JDAM
(courtesy Global Security)

The requirement for internal storage of munitions and fuel significantly impacts the UCAV-N shape and design, resulting in a boxier and shorter aircraft.

The UCAV-N is also designed for a very small crew ship, requiring as much of the operations to be performed autonomously. The UCAV-N will have the ability to arm its weapons before take-off (or in-flight) by using pin puller mechanisms instead of traditional pins pulled by a crewman. The loading and unloading of the aircraft weapons will also be performed autonomously, discussed in greater detail in chapter 4.

5.5 Weapons Bay

The weapons bay is designed to hold all the weapons stores described in the previous section and fuel pods for the endurance mission. The additional fuel pods will allow for carrying more fuel, corresponding to an increase in range. Additionally, the weapons bay could be used to convert the aircraft into and electronic version allowing jamming support to the fighters. This requires the bay to have doors 13 feet long and over 2 feet wide. The bay must house over 4 feet in weaponry abreast, and 13 feet in length, without obstruction. To carry JDAM bombs, already existing launching mechanisms are being used to reduce cost, and reduce analysis requirements. The existing launch mechanism is shown in Figure 5.5.1 below, and pneumatically ejects the store. Integrating the ejector system is simple, tying directly into holder in the weapons bay.

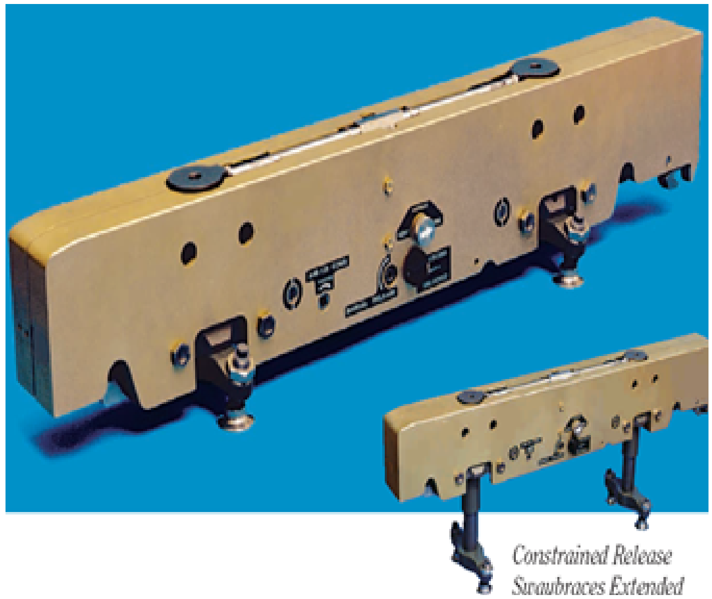


Figure 5.5.1 JDAM Ejecting Mount

The HARM stores must be rail launched, which requires the weapons to be in the free stream during launch. Since all weapons must be stored internally, this provides an additional design problem, which was satisfied by mounting the rails onto the weapon bay doors. This configuration requires significant additional strength in the hinges of the weapons bay, and increased power to the hydraulics responsible for lowering and raising the bay doors, but is the simplest method to place the HARM into the free stream. Other methods were considered, including retractable rail mounts on a hydraulic system to raise and lower the store itself, but similar systems would require extending the height of the bomb bay, which would fundamentally alter the shape of the vehicle, as well as add additional cost and complexity.

5.6 Landing Gear and Arresting Hook

The UCAV-N's main landing gear are modified F/A-18 gear, scaled to support lighter loads since the UCAV-N is significantly lighter than the F/A-18. The nose gear was designed to fit in the nose between the avionics and the engine intake. The tight space required a new innovative design, described in Figure 5.6.1. The gear utilizes a pinned strut that folds between the wheels, and an actuator that forces the strut to rotate, extending the gear downward.

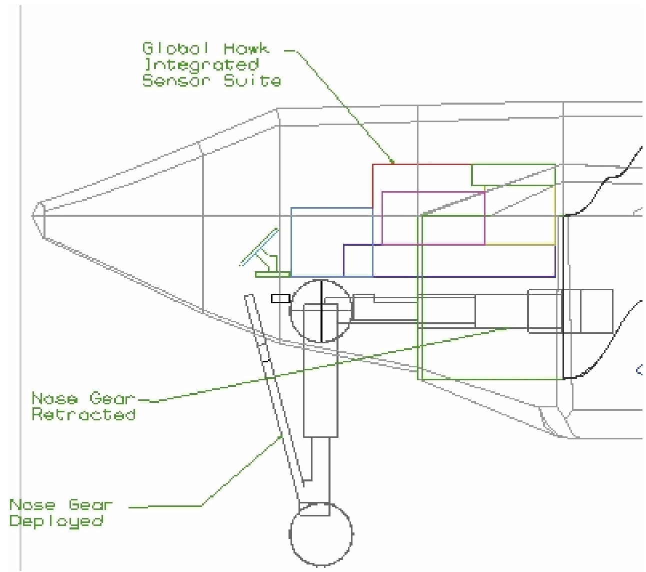


Figure 5.6.1 Nose Landing Gear Configuration

The tires selected are type VII, in part due to their light weight, and commonality on current aircraft carriers, and proven track record in carrier use. The controlled crash of a carrier landing stresses the tires and gear cyclically

Backup pneumatic systems are included in case of hydraulic failure to ensure that the landing gear and arresting hook can be deployed in emergency situations.

The arresting hook weight was estimated for cg calculations (Raymer), but the system itself was not designed for this report. Conventional systems are assumed to work for our purposes, and placement will link with the rear bulkhead.

5.7 Pelikan Tail

The Pelikan Tail system is an experimental tail configuration that allows for a two post tail in place of modern fighter four post tail systems. This reduced drag and radar cross section (theoretically). Wind tunnel tests were performed as a proof of concept for this report, and the system is discussed in greater detail in chapter 12.

5.8 Inlet/Exhaust

The engine inlet was designed after the Lockheed Martin F-22 and JSF design, with front angled inlets just aft of the nose. Figure 5.8.1 shows the front inlet configuration. The shoulders were added to the fuselage to fit the inlets as they lead to the power plant. Radar precautions are taken in the inlet by bending the inlet to reduce the likelihood radar will hit the engine, and are lined with radar absorbing material for further stealth protection.

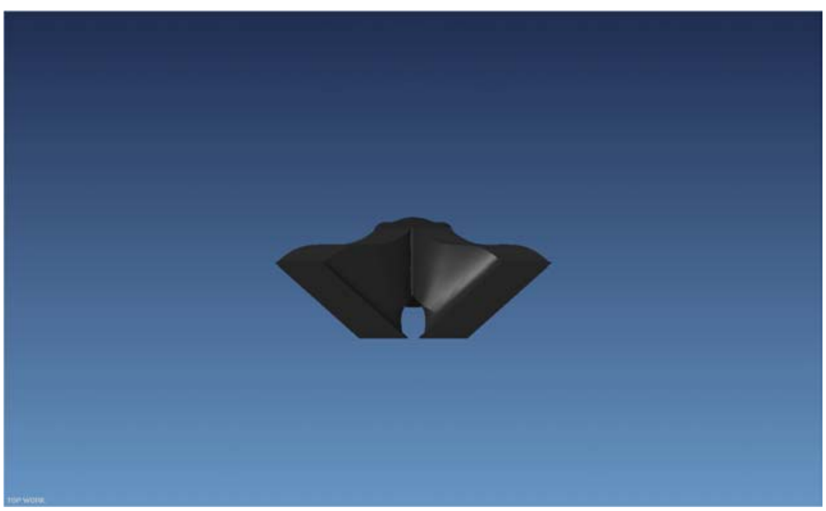


Figure 5.8.1 Front Inlet Configuration

The exhaust system is modeled after the B-2 Spirit bomber, with a square exhaust shielded by the tail system. The exhaust system will be cooled to reduce heat signatures. The inlet/engine/exhaust configuration is shown in Figure 5.8.2.

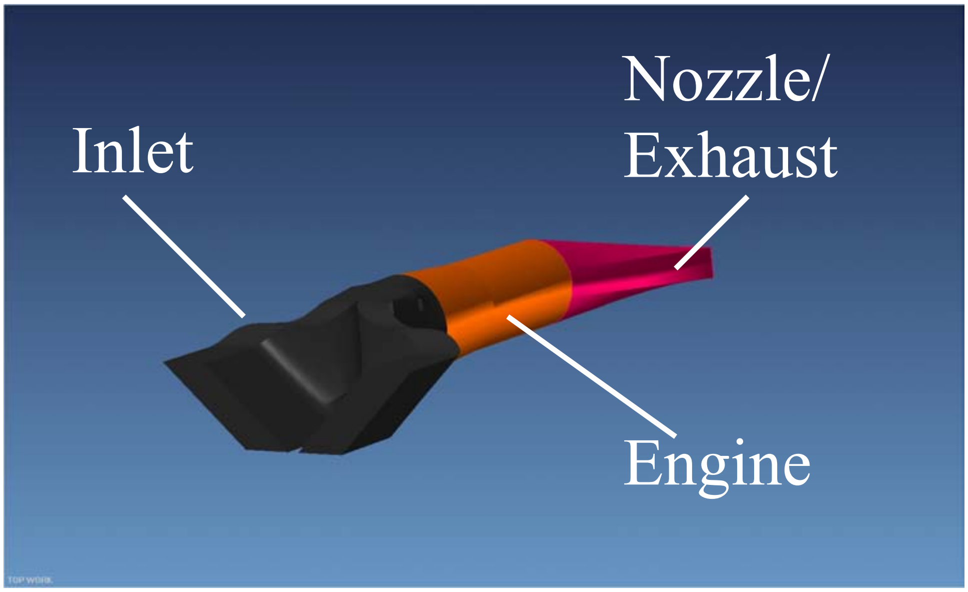


Figure 5.8.2 Inlet/Engine/Exhaust System

5.9 Electrical Systems

Backup electrical systems were selected to augment the power supplied by the engine in emergency and power up situations. Power to start the engines, and run the aircraft while on the carrier but without power plant operation. Sealed batteries are used to supply DC power for avionics and flight control run-up. The primary source of power is provided from generators run by the turbine engine. The generators provide A/C power, which can be converted to DC for systems that require it.

The layout of electrical wiring is redundant throughout the aircraft for survivability (see chapter 13) in case the aircraft is partially damaged. The power systems are all tied into the general electric system, providing triple redundancy in the power distribution, increasing the survivability of the aircraft. Because the aircraft is unmanned, loss of power to the flight control systems or sensor systems is catastrophic.

5.10 Electromagnetic Aircraft Launch System (EMALS)

The aircraft carrier that will be the floating home for the UCAV-N has yet to be designed in full but it is known that it will be roughly half the size of the current Nimitz class aircraft carrier. This means that our launch and recovery scenarios will have significant geometric constraints. The carrier deck that the UCAV-N's will have to take-off from and land on will likely be shorter than current carrier decks. This will be a key in the design of the plane as well as in the design of the catapult and arresting gear system. The current Nimitz class carriers employ steam driven catapult and arresting systems that are run off the main nuclear reactor. The alternative to steam for the new carriers is an Electromagnetic Aircraft Launch System (EMALS) that will exceed the performance of the steam systems. Figure 5.10.1 shows the energy output of several different catapulting systems, including steam and electromagnetic systems.

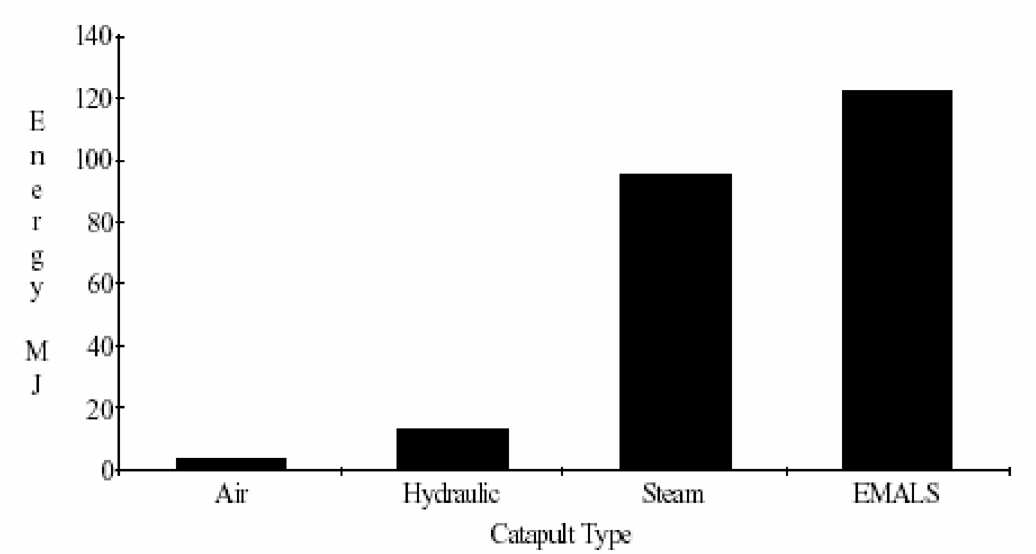


Figure 5.10.1 Energy Output for Various Catapult Systems (Doyle)

In addition to increased energy output for the system, EMALS has other significant characteristics that make it superior to steam catapult launching. The control associated with the method is significantly enhanced, which reduces the Peak/Average Acceleration ratio. This should increase the fatigue life of parts like tail hooks, arresting gear, and front landing gear. The range for end speed of launch is also greater, and end speeds can be predetermined for each aircraft. The ability to select end speed is varies to +/- 3 knots.

Chapter 6 Aerodynamics

6.1 Introduction

Aircraft aerodynamics for the UCAV-N were not specifically stated within the official RFP. That being said, they were inherent in virtually every other set of requirements and presented many buried limiting factors within other systems. UCAV-N presented an interesting design challenge in that it did not lend itself to a classic sleek and streamlined military aircraft. For one thing, an emphasis was stated in the RFP to reduced radar detectability, which often required straight, common angles to be present rather than lift-friendly curves. The other limitation present was one of size. The carrier the aircraft was designed to populate is half the length of the current *Nimitz* class vessels, necessitating a length and width requirement. These factors, combined with the aircraft's ability to perform in everyway a normal strike aircraft could perform and more, led to a squat, blocky design which is not particularly suited to aerodynamic qualities.

6.2 Airfoil Selection and Wing Geometry

The geometry of the wings was influenced by four primary factors: the location of the neutral point, the transonic regime the vehicle would likely see in cruise and dash modes, the endurance mission, and the necessity of the wings for fuel storage.

In the initial search, a supercritical (SC) airfoil was examined. Supercritical features on an airfoil were necessary due to the speeds at which the Postal Penguin would be traveling, just below Mach Drag Divergence. The SC(2)-0712, with 12 percent thickness, was thought to provide a nice balance of low drag with good volume for fuel storage. The airfoil is shown in Fig. 6.2.1.

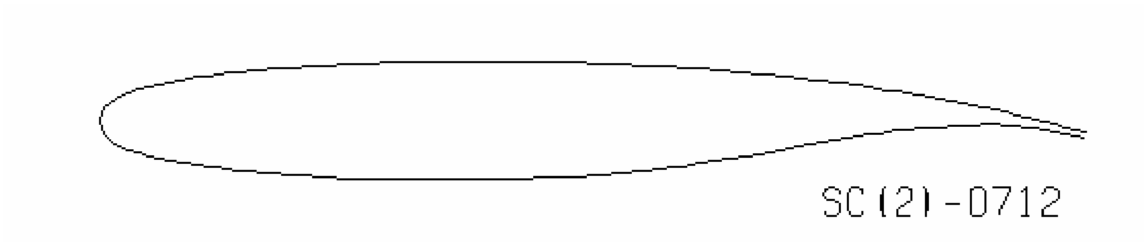


Figure 6.2.1 SC(2) – 0712 Airfoil

It was eventually determined that this airfoil did not have the necessary performance abilities. Hence, a search was launched into a database of medium-speed supercritical (MS) airfoils in an attempt to find one that would provide both the transonic capabilities and the necessary range of lifts for a carrier-borne aircraft as versatile as UCAV-N. This led to the investigation of the MS(1)-0317 airfoil, which featured better lift coefficient and angle of attack characteristics as well as a markedly higher thickness for fuel volume . In addition, the airfoil had less camber and so was optimized for use at a lower design lift coefficient. Figure 6.2.2 shows the outline of this airfoil.

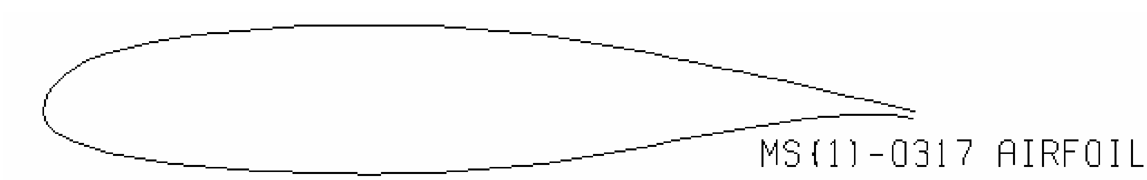


Figure 6.2.2 MS(1) – 0317 Airfoil

The values for C_L max and max alpha for the airfoil were determined to be too low for the high performance needed for carrier takeoff and landing. Further examination led to the selection of a medium speed supercritical airfoil, the MS(1)-0313. This provided a reasonably thick airfoil section (13 %), resulting in a great deal of room for fuel storage as well as improving the CL max by 0.15 and provided a greater alpha range of movement. The airfoil is displayed in Fig. 6.2.3.

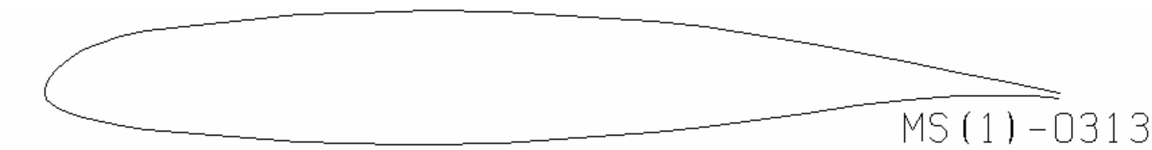


Figure 6.2.3 MS(1) – 0313 Airfoil

Some comparison factors between the three airfoil shapes are displayed in Table 6.1 below. While the thicker MS variant displayed a greater maximum angle of attack at altitude, it was felt that the additional lift afforded by the thinner airfoil would offset that sacrifice.

Table 6.2 Airfoil Comparison

40kft	C_{Lmax}	α_{max}	t/c
SC(2)-0712	1.3	3.1	0.12
MS(1)-0317	1.38	6.8	0.17
MS(1)-0313	1.42	5.2	0.13

The geometry of the wing itself is displayed in the chart below and planform below, Figure 6.2.4. The large wing area gives a large L/D ratio for the size of the aircraft, which is crucial for the endurance mission, while the sweep assists in delaying M_{DD} and transonic effects on the wing.

AR	λ	b	S	MAC	Λ 1/2	L/D Max
4.36	0.29	45 ft.	465 ft	11.4 ft	10 deg	13.8
W/S	**c_r**	**c_t**	**SL $C_{L\ max}$**	**A/C C_{D0}**		
73.1 lbs/ ft^2	16 ft	4.67 ft	1.73 (w/o flaps)	0.01804		

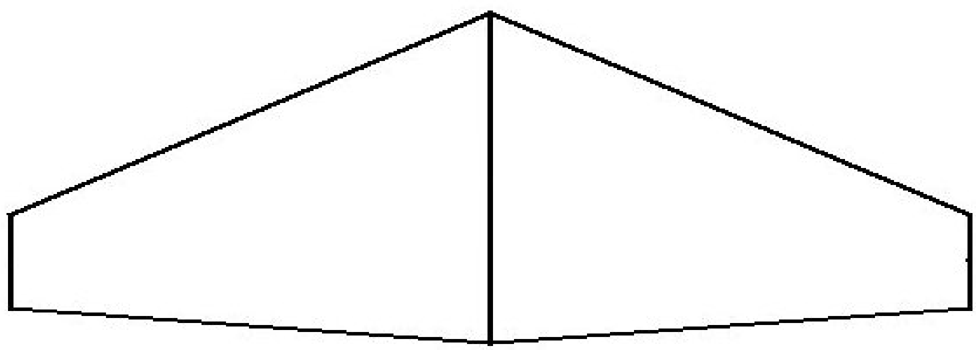


Figure 6.2.4 Wing Planform and Data

6.3 Drag

The small size of the UCAV-N gives it a large advantage in its drag profile. With a wetted area of just over half of many larger military craft, the skin friction drag is greatly reduced. The vehicle has no appendages (beyond aerodynamic surfaces) that stick out from the main form of the body, which simplifies matters from an analysis perspective.

Numerous calculations for Mach drag divergence (M_{DD}) were performed as the design evolved, wing sweep increased and the desired C_L was refined. Using a Korn analysis, various values of the lift coefficient were compared with wing sweep values and a number of lines for M_{DD} were produced. Figure 6.3.1 is an example of one of these analyses.

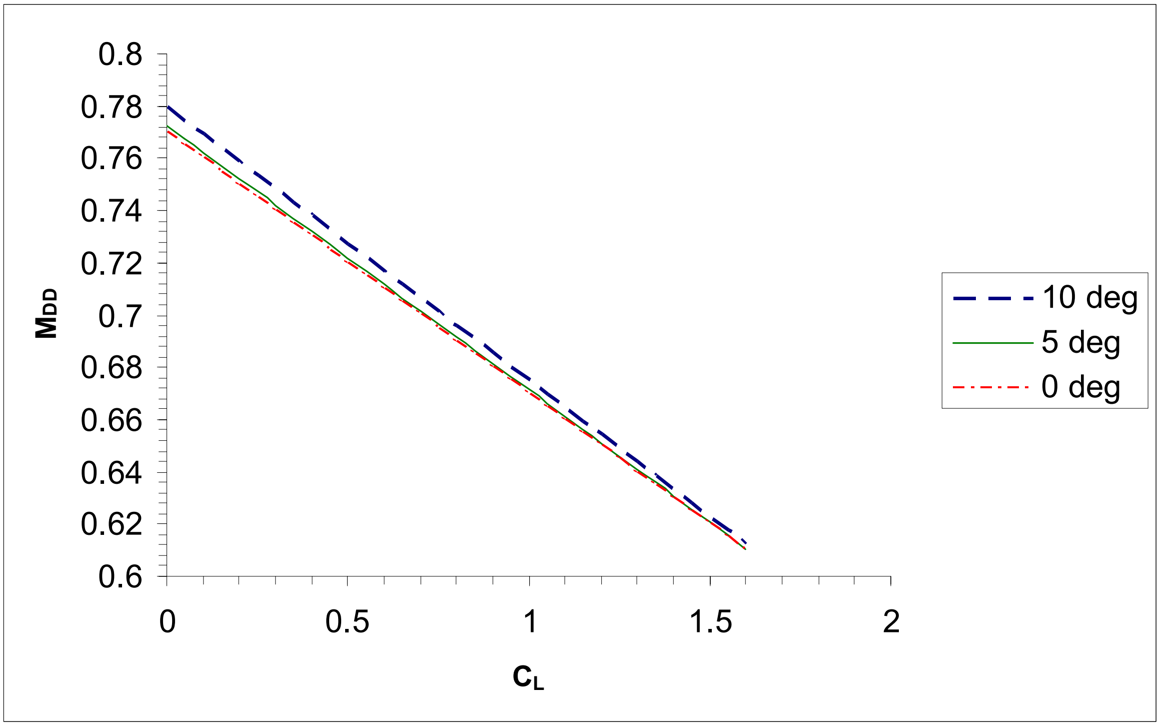


Figure 6.3.1   Mach Drag Divergence versus Lift Coefficient

Further analysis with Korn was done to verify the wing thickness selection. Wing thickness proved to have a deciding effect on the Mach Drag Divergence number, and the change in thickness between the two airfoils pushed the number to the higher value needed for the RFP-required cruise velocity. The plot illustrating this is shown in Figure 6.3.2.

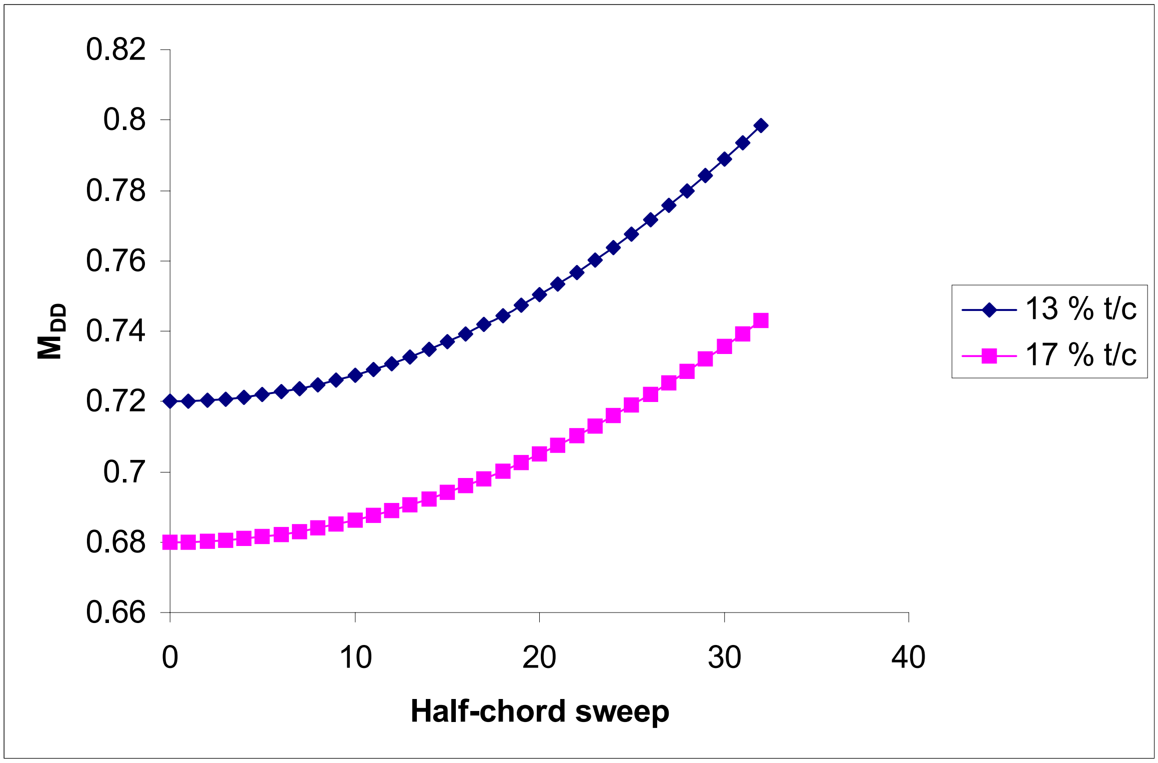


Figure 6.3.2 Mach Drag Divergence vs. Half-Chord Sweep

Drag buildup was determined using a combination of Raymer and the friction.f code. Wave drag began to occur shortly after 0.7 Mach at 40,000 feet, and the building up CD0 in the flight regime leading up to that point is visible on Figure 6.3.3 below. The Penguin paid penalties in drag due to its angular surfaces (designed for stealth purposes), but as stated earlier its small size relative to other military strike vehicles allowed it to compensate for those penalties and maintain an acceptable amount of drag over its flight envelope.

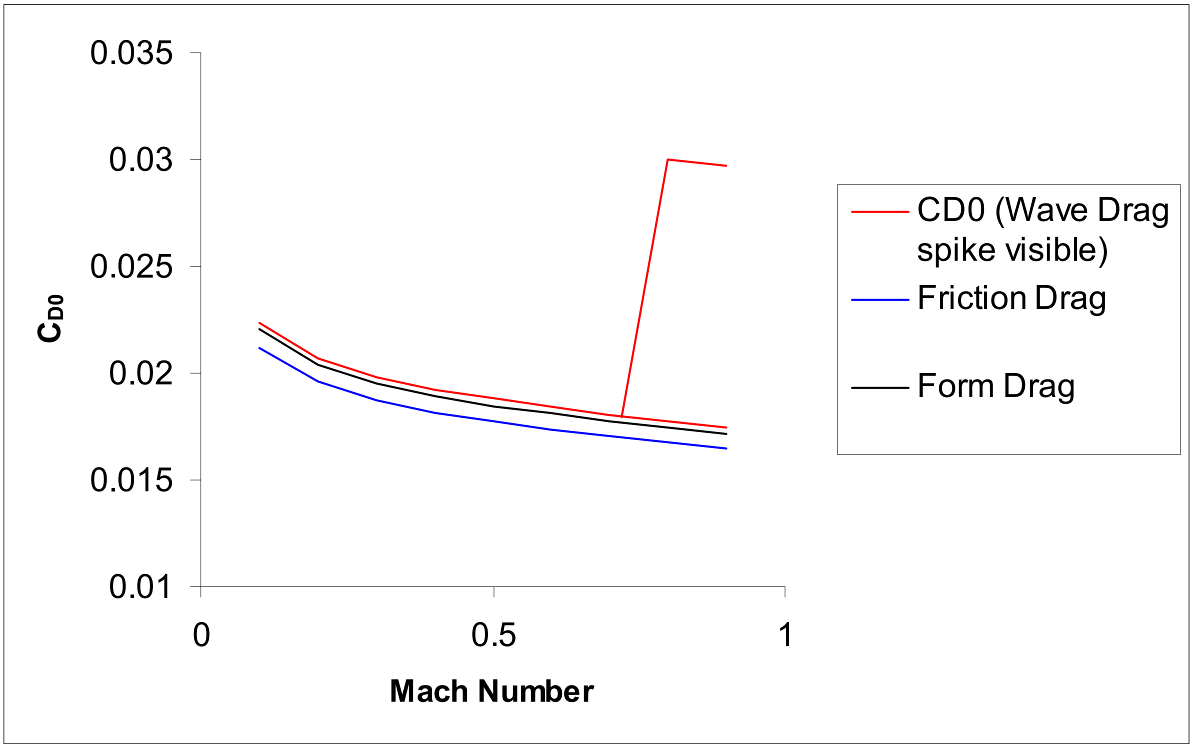


Figure 6.3.3** C_{D0} **vs. Mach Number

From the data provided by XFOIL and the friction.f code used for finding friction and form drag, the drag polar for the cruise altitude of 40,000 ft was developed (Fig 6.3.4). The point of maximum L/D is marked out in red.

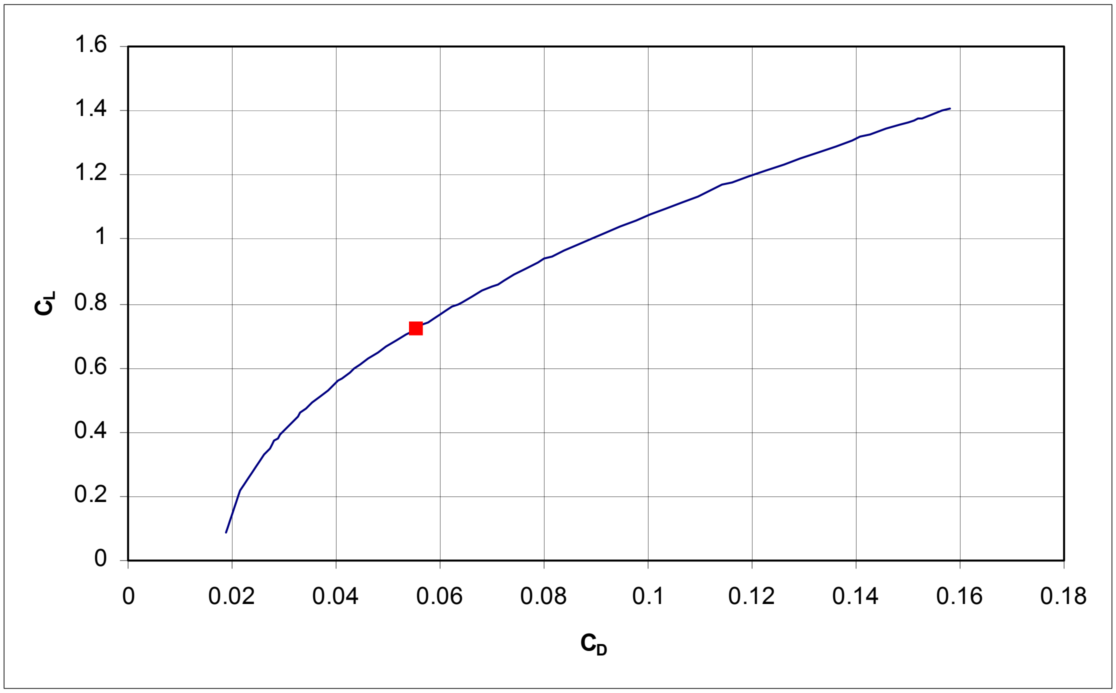


Figure 6.3.4   Drag Polar at 40,000 ft, L/D max marked at 13.8.

6.4   High Lift Devices

To enable the Penguin to achieve the best possible performance in takeoff and landing modes (i.e., as slow an approach speed as possible), a set of plain flaps were designed on the inboard section of the wing to improve maximum lift coefficient. The area of the flaps is 13.49 ft^2 each. Using calculations found in Raymer, the addition to the lift coefficient per angle of deflection in radians was found to be 0.75 per radian. The flaps have a maximum deflection of 30 degrees, which translates into an increase of 0.40 in the lift coefficient. This brings the maximum lift coefficient to a value of 2.13. The system of flaps, combined with the low TOGW and high S for the Penguin, means that the vehicle could conceivably take off, turn right back around, and land at essentially maximum weight with no fuel dumping necessary (barring a mechanical problem with a related system). While this is an unlikely scenario, it could be a savings in fuel money should the need arise

Chapter 7 Vehicle Performance

7.1 Introduction

Performance requirements for the UCAV-N were as follows: The UCAV-N must be able to cruise at a speed of 0.7 Mach at 40,000 (or greater) feet with a sea level maximum speed of no less that 0.85. Its required missions involve a deep strike/interdiction of 500 nm radius carrying either 2 JDAM's or 2 HARM's, and a 10 hour loiter/reconnaissance mission. Both missions state that mid-air refueling is not permitted. Initial rate of climb for any mission cannot be less than 8,400 ft/min.

7.2 Rate of Climb Requirements

Rate of climb (ROC) calculations were performed using Raymer's methods. First a velocity for best ROC (at sea level) was calculated.

$$V = \sqrt{(\frac{W/S[T/W + \sqrt{(T/W)^2 + 12C_{D0}K}]}{3\rho C_{D0}}}$$

Equation 7.2.1 Velocity for Best Rate of Climb

Using sea level values for density and the low end of thrust the engine is capable of producing (assuming that it will not perform optimally at sea level), the best ROC velocity was calculated using equation X.1 from Raymer, *Aircraft Design, A Conceptual Approach*.

Using this velocity a vertical velocity was calculated in feet/sec, using equation 7.2 also from Raymer.

$$Vv = \frac{TV}{W} - \frac{2KW}{SVr} - \frac{CD0\,S\,V^3 r}{2W}$$

Equation 7.2.2 Vertical Velocity for best ROC

The calculated ROC was 10,260 fpm, above the lower limit as stated by the RFP.

7.3 Maximum Speed Requirements

The weight of the aircraft grew to as much as 34,000 lbs gross takeoff. With these limitations, a worst case thrust-drag bookkeeping plot put the maximum sea level speed at Mach 0.83. This is slightly below the RFP requirement but minor enough that it is believed to be insignificant.

7.4 Range Requirements

In designing the Postal Penguin, the fuel required for the endurance loiter was the limiting factor. Since the tanks were designed with that mission in mind, they were over-engineered in the case of the range mission, giving the aircraft a potential to achieve ranges greater than specified by the RFP. This would translate into a greater ability to linger over target areas, effectively transforming the purely strike mission into a strike/loiter mission, allowing the craft to receive changes of orders from the operators on the carrier or to pick and choose itself from among numerous targets.

7.5 Endurance Requirements

Greater fuel will be utilized in the endurance mission, though the removal of the bombs relaxes the weight restrictions somewhat. Endurance was calculated by determining the L/D max using the drag polar data and plot. The resulting value of 13.8 was used in the endurance equation found in *Introduction to Aeronautics: A Design Perspective.*

$$\text{Endurance} := \left(\frac{1}{ct}\right)\cdot\left(\frac{L}{D}\right)\cdot\ln\left(\frac{W1}{W2}\right)$$

Equation 7.5.1 Endurance Equation

The maximum value of endurance was determined to be 14.5 hours, 45% beyond the 10 hour requirement. This was achieved at 40,000 feet at a speed of Mach 0.54.

Below is a table of the relevant data for the Postal Penguin's performance characteristics.

Table 7.5.1 Performance Characteristics

RFP	**Endurance**	**Range (40,000 ft)**	**Max Speed (SL)**	**Initial ROC (SL)**
	14.5 h	550 nm	0.83 M	10260 ft/min
Carrier	**T/O Accel.**	**Stall Speed**	**Approach Speed**	**T/O speed**
	5g	109 kts	131 kts	150 kts
Other	**Ceiling**	**L/D Max**	**Loiter Velocity**	**Range Velocity**
	57,700 ft	13.8	0.54 M	0.71 M

Chapter 8 Control and Stability

8.1 General Information and Control Derivatives

The stability and control analysis of the Postal Penguin was performed using JkayVLM (Kay), estimation techniques out of *Dynamics of Flight* (Etkins), and a Nasa control power assessment spreadsheet VTnascpc (Waszak). The program JkayVLM was used to determine estimates of the longitudinal and lateral-directional stability derivatives for the Postal Penguin. The JkayVLM uses a vortex lattice method with three degrees of freedom to produce the control derivatives. The code calculates both longitudinal and lateral directional derivatives with the following degrees of accuracy: α derivatives good, q derivatives poor, Cy_β and C_{l_β} poor, C_{n_β} good, $C_{Y\text{-}r}$ and C_{l_r} poor, C_{n_r} good, and p derivatives good.

Table 8.1.1 Control Derivatives for the JDAM MISSION

	Take Off	Cruise	Landing
C_{l_q} (/rad)	4.45539	7.86041	4.50488
C_{m_q} (/rad)	-7.60242	-12.34949	-7.67143
C_{l_r} (/rad)	0.02938	0.03318	0.02993
C_{n_p} (/rad)	4.805	6.7797	4.76629
C_{l_p} (/rad)	-0.07127	-0.00718	-0.07263
C_{n_r} (/rad)	-0.04358	-0.04745	-0.0449
C_{l_β} (/rad)	0.04441	0.04893	0.04431
C_{n_β} (/rad)	0.04473	0.05186	0.04626
C_{Y_β} (/rad)	-0.22226	-0.23979	-0.22192
$C_{l\_\delta a}$ (/rad)	0.24009	0.27608	0.23932
$C_{n\_\delta a}$ (/rad)	-0.30377	-0.36426	-0.30976
$C_{l\_\delta r}$ (/rad)	0.94212	1.08387	0.93912
$C_{n\_\delta r}$ (/rad)	0.23988	0.27613	0.2391
$C_{Y\_\delta r}$ (/rad)	0.08656	0.30253	0.08713

The Postal Penguin's control surface sizing and takeoff rotation speed are as follows. The Postal Penguin has two control surfaces; an aileron and a flap, on each wing, which provide it with both, roll control and high lift capabilities respectively. The aileron size is 7.28 ft^2 and the flap size is 13.49 ft^2. There are two potential options for the rear control surfaces for the Postal Penguin: canted tails with the rudder and elevator coupled in the same control surface, and a Pelikan tail developed by Ralph Pelikan (discussed later in the report). The coupling of the rudder and the elevator in the same control surface couples both the lateral directional and the longitudinal parameters for the aircraft. The area for the control surface on one of the tails is 8.42 ft^2. The Penguin has a take off rotation speed of 206 ft/sec, 199 ft/sec, and 206 ft/sec for its loiter, Jdam, and Harm mission respectively.

8.2 Steady Level Flight Assessment (1g)

The Postal Penguin is controllable over its complete flight envelope at steady level flight (1g) (Table 8.2.1). The aircraft requires low angle of attack and small control surface deflections at Cruise speeds to maintain trim, which is desirable for both low drag and small radar signatures. The aircraft has its most demanding in the case of take off for the JDAM mission and in all three missions for landing for these cases the angle of attack and lift coefficient goes up to about 12.54 degrees and 1.16 respectively. The maximum lift coefficient of the plane is 1.73 without flaps and 2.13 with flaps so the Postal Penguin can easily handle the lift requirements throughout its design envelope. The angle of attack also falls with the acceptable range for operation though it is approaching the stall angle at landing speed. The maximum elevator deflection required for steady level flight is approximately –5.85 degrees, which is under the max elevator control surface deflection (±30 degrees).

Table 8.2.1 Control Power for Steady, Level Flight (1g)

	Stall	Take Off	Cruise	Landing
Altitude	Sea Level	Sea Level	40 000 ft	Sea Level
Mach #	0.165	0.227	0.7	0.197
JDAM MISSION				
δ_e (degrees)	-5.57	0.85	0.28	-3.9
C_L	1.6	0.85	0.48	1.12
α (degrees)	17.99	9.26	-0.84	12.54
HARM MISSION				
δ_e (degrees)	-5.85	0	0.4	-3.49
C_L	1.6	0.85	0.48	1.12
α (degrees)	13.56	0	-0.85	8.06
LOITER MISSION				
δ_e (degrees)	-5.66	-0.13	0.06	-3.51
C_L	1.66	0.88	0.49	1.16
α (degrees)	14.16	0.32	-0.68	8.46

8.3 Sideslip/Crosswind Landing Assessment

The sideslip, β, control power assessment was done for multiple values of sideslip ranging from 0 to 20 degrees. The Postal Penguin could handle the entire range of sideslip over the entire flight envelope. Shown below in Table 8.3.1 is the special case for a crosswind landing where the speed is 20 percent of the airspeed of the jet. In each of the three cases the Postal Penguin could handle the crosswind landing with its control surfaces and small changes in bank angle.

Table 8.3.1 Control Power Assessment Of Sideslip (β=11.5 degrees)

	Take Off	Cruise	Landing
Mach Number	0.227	0.7	0.197
JDAM MISSION			
δ_a (degrees)	1.79	1.82	1.81
δ_r (degrees)	0.34	0.22	0.32
Bank Angle (degrees)	2.84	6.9	2.75
HARM MISSION			
δ_a (degrees)	1.81	1.83	1.82
δ_r (degrees)	0.32	0.21	0.31
Bank Angle (Degrees)	2.67	6.92	2.64
LOITER MISSION			
δ_a (degrees)	1.79	1.82	1.82
δ_r (degrees)	0.34	0.22	0.31
Bank Angle (degrees)	2.57	5.13	1.96

8.4 Roll Assessment

The Postal Penguin with a maximum aileron deflection of ±30 degrees and a maximum rate of deployment of 3.1 rad/sec meets and exceeds the military regulation for roll performance. The military requirement is approximately 45 degrees in 1.4 seconds (Raymer) and is met throughout the entire flight envelope as shown in Table 8.4.1.

Table 8.4.1 Control Power Assessment Of Roll Performance

	Take Off	Cruise	Landing
Mach Number	0.227	0.7	0.197
JDAM (degrees/sec)	201	638	262
HARM (degrees/sec)	202	456	262
LOITER (degrees/sec)	201	562	262
*Military Requirement: 45 degrees in 1.4 seconds			
***Roll Rate Attained Using Maximum Rate Of Aileron Deflection (3.1 rad/sec)**			

8.5 Dynamic Stability

The Postal Penguin meets the dynamic stability requirements for longitudinal and lateral movements as specified in military regulations (Roskam).

Table 8.5.1 Dynamic Stability Assessment

	Postal Penguin		**Military Requirements**	
	ξ	**ω_n (rad/sec)**	**ξ**	**ω_n (rad/sec)**
Short Period	0.875	6.38	$0.35 < \xi < 1.3$	$2.15 < \omega_n < 7.72$
Phugoid	0.051	N/A	$\xi > 0.04$	N/A
Dutch Roll	0.45	0.33	$\xi > 0.4$	$\omega_n < 0.4$

Chapter 9 Structures and Materials

9.1 Structures

The requirements set by the RFP for the structural aspects of the design includes design limit load factors of +4.0 and –1.5 vertical g's with 100 percent internal fuel and 100 percent internal payload. Also the aircraft must withstand dynamic pressure of at least +1200 psi . The factor of safety of 1.5 was also given. Lastly, the aircraft must be able to endure the harsh corrosive environment of carrier operations.

The major sections of the aircraft can be broken down into the fuselage, the wing box and the tail. The 4 longerons in the fuselage begin behind the sensor suite and run the length of the fuselage to the end of the weapons bay. The longerons form a box shape in the fuselage with 2 on the floor of the fuselage in the corners of the fuselage and 2 longerons where the wing meets the fuselage. The extruded J shaped stiffeners were chosen for the aircraft spaced at 6 inches apart to help prevent buckling of the skin.

Six bulkheads were placed in the aircraft as shown in figure 9.1.1. The bulkheads were placed in the aircraft to bear significant loads in the different parts of the aircraft. The bulkheads include:

1. nose gear / sensor suite bulkhead
2. beginning of the inlets / weapons bay bulkhead
3. main landing gear / aft wing spar / weapons bay bulkhead
4. rear of weapons bay bulkhead
5. tailhook / engine outlet bulkhead
6. tail bulkhead

Bulkheads 2 through 5 are connected to the longerons to distribute the loads on the aircraft more evenly.

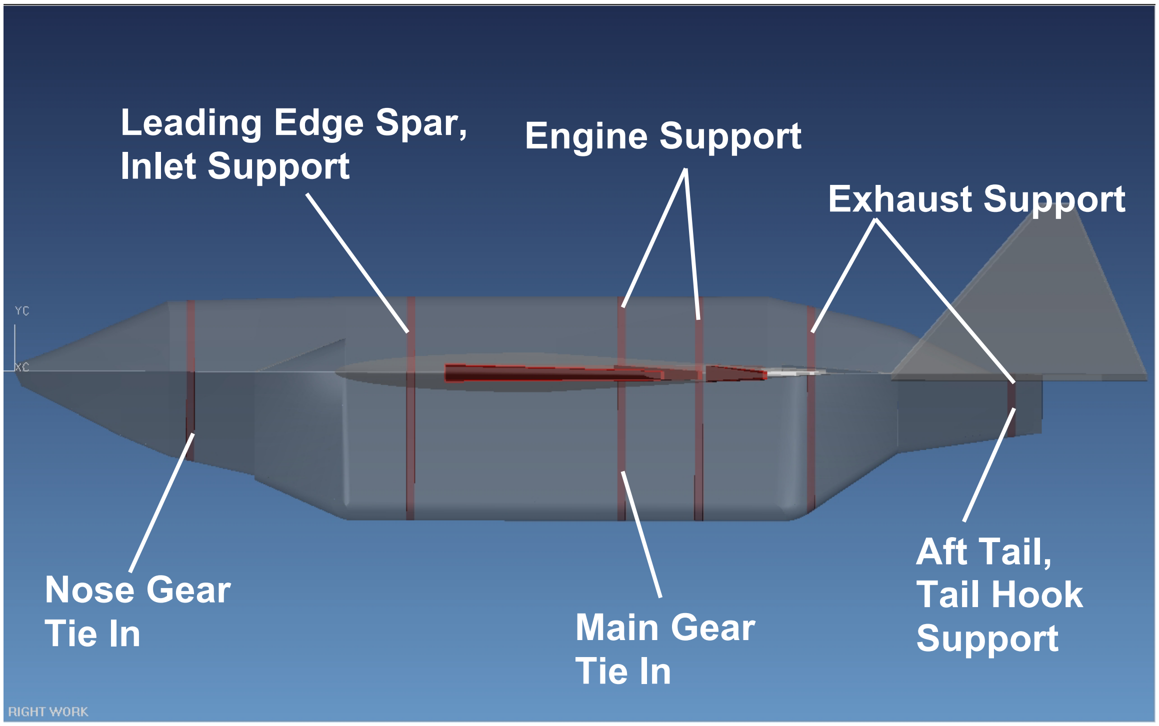


Figure 9.1.1 Postal Penguin Structural Layout

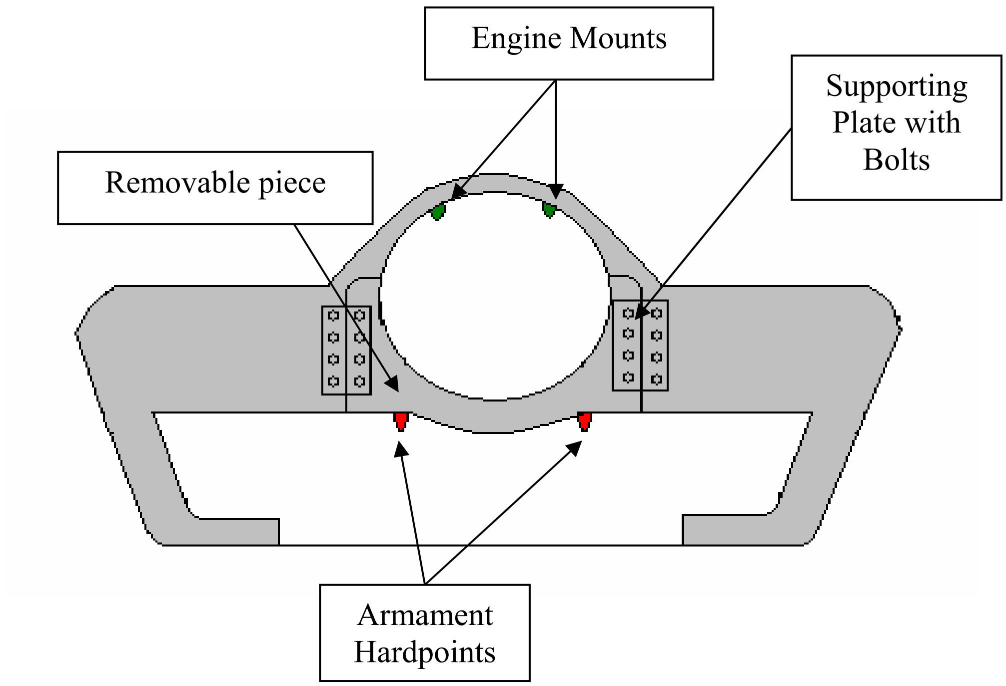


Figure 9.1.2 Bulkhead #3 and #4 Design

Figure 9.1.2 shows the cross sectional view of bulkhead #3 and #4. Bulkheads 3 and 4 had to have a removable section beneath the engine because the Navy requires the engines on the aircraft be removable through the bottom of the aircraft. Therefore the center bulkheads had to be created with a detachable piece in the center. Rather than cutting the bottom piece of the engine encasing bulkhead straight beneath the engine, the cut was widened on the sides to distribute the armament loads better throughout the removable piece. The removable section is bolted to the main part of the bulkhead with a supporting plate on both sides of the bulkhead. The bottom part of the removable section was created rounder to better distribute the pressure and loads throughout the section to alleviate the problem of having a large point load on the center of the bottom of the removable section.

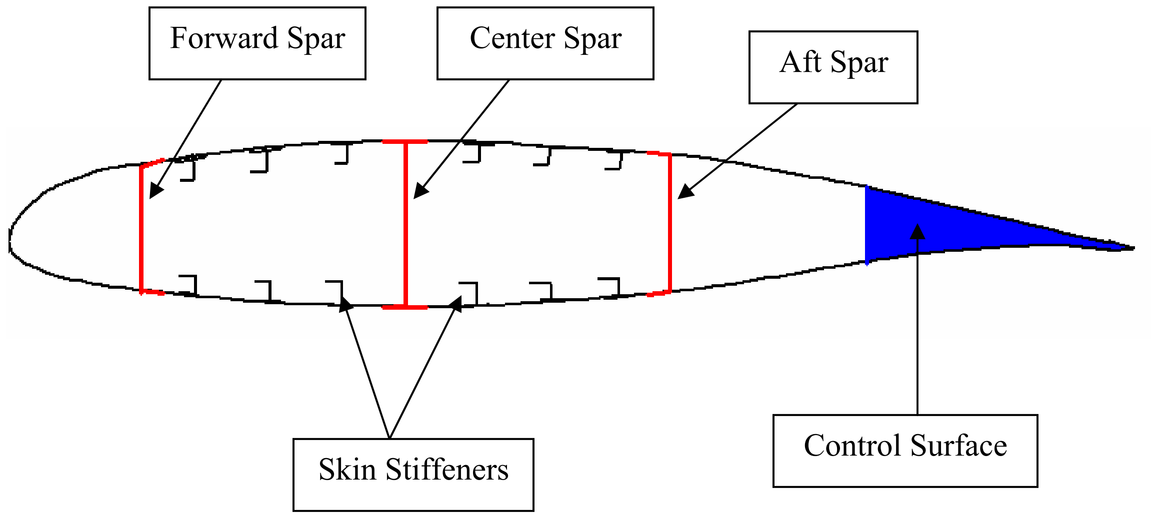


Figure 9.1.3 Wingbox Layout

The wing box consists of 3 main spars as shown in Figure 9.1.3. The forward and the aft spars are C beam spars while the center spar is an I-beam spar. The center spar was incorporated into the design to help resist shear lag in the aircraft's wings. The forward spar is placed 12 percent of the chord, the center spar is at 36 percent of the chord and the rear spar was placed 60 percent of the chord. The rear spar was placed here to allow room for the control surfaces on the wings. To store the aircraft on the carrier, the wings have to fold up 7.5 feet from the edge of the wings. Since this portion of the wing cannot carry much load, the center spar was placed only to the fold to reduce the structural weight of the wings. The ribs are placed 2 feet apart and perpendicular to the spars before the fold in the wing and 2.5 feet apart after the fold. Two holes are drilled into the ribs to reduce the structural weight and it will allow pipes and wires throughout the wing since fuel will be stored between the first 5 ribs in the wing box.

The tail structure created challenges due to the selection of the pelikan tail. The horizontal surface of the tail is very small in relation to the canted part of the tail, therefore the bulk of the structural material in the tail was designed in the canted tails.

The horizontal portion of the tail only has a spar that tie to the tail bulkhead and attaches to the vertical canted spar. It also has only one rib. The vertical canted tail has one spar running the length of the tail and ribs perpendicular to the spar spaced 16 inches apart.

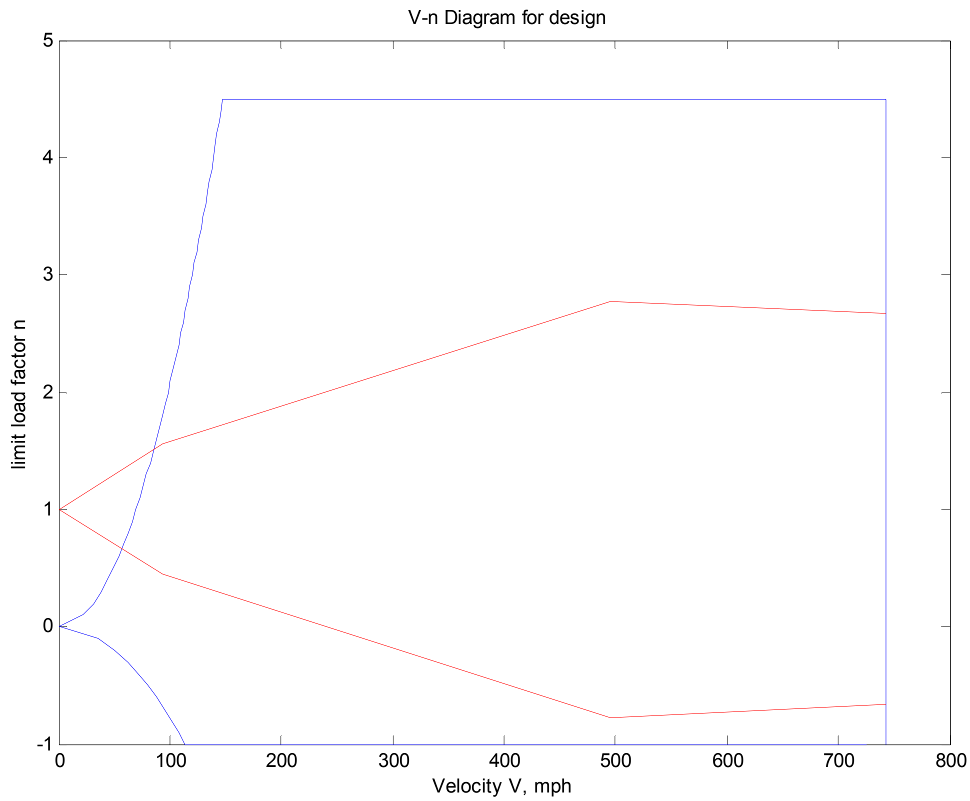


Figure 9.1.4 V-n Diagram

The V-n diagram shown in Figure 9.1.4 was constructed for design loads given in the RFP. From this diagram, it shows that the maneuver flight envelope is the limiting boundary for our design and not the wind gust loads.

9.2 Materials

The materials chosen for the design were based mostly on resistance to corrosion, the weight of the material, strength, fatigue properties and how readily available the material was. The cost was not as significant of an issue since it was assumed that most of the composites used on this aircraft should be more accessible and cheaper 10 years from now.

Aluminum 7075-T6 was chosen for the stiffeners, ribs and spars. This type of aluminum was chosen because it has low fracture toughness and good stress corrosion resistance (Niu). Aluminum 2024 – T3 was chosen for the bulkheads because it has the best fracture toughness, slow crack growth rate and good fatigue life.

Our biggest structural concern in the design of this aircraft was keeping the weight down on the aircraft since it has to be small yet carry 4400 pounds of armaments and 14000 pounds of fuel. Aluminum is readily accessible, cheap and weighs considerably less than steel or titanium which made it a desirable material for the internal structure of the aircraft. Maintenance and upkeep of these materials are cheaper and easier than with any other material available.

Most of the outer surface of our aircraft will be constructed of composites. Although composites are a lot more expensive than metals such as aluminum the weight reduction of composites helps to keep the weight of the aircraft down which was very important in our design. Composites like Kevlar/ Epoxy or Graphite/ Epoxy weighs half as much as 2404 – T3 aluminum (Niu).

We decided to use a carbon composite with epoxy resin for the skin of the aircraft. Table 1 showed the material properties of different composites that were used to decide which materials to use for the skin. The carbon composite provides high resistance to corrosion, creep and fatigue and high specific strength (SP Systems website). The epoxy resin will help to combat the corrosive environment the aircraft will have to endure. It also has high water resistance (SP Systems website).

The control surfaces of the airplane including the flaps and ailerons are constructed of aramid composites. Aramid composites were chosen for the material properties of high specific stiffness and high impact resistance (SP Systems website).

Table 9.2.1 Material Properties of Several Composites

Material Prop	Carbon HS	Carbon HM	Aramid LM	Aramid HM	E - glass
Tensile Str (MPa)	3500	3500	3600	3100	2400
Tensile Modulus (GPa)	160-270	325-440	60	120	69
Typical Density (g/cc)	1.8	1.8	1.45	1.45	2.5
Specific Modulus	90-150	180-240	40	80	27
Laminate Impact Strength (ft lb/in^2)	~ 50	NA	~295	~ 295	~260
Cost (dollar / kg)	24 - 64	24 - 64	24 - 40	24 - 40	1.6 - 3.2

Bismaleimides (BMI) will be used to make the inlets and outlets since BMI can operate at high temperatures around 250 degree Celsius. The weapons bay doors will be constructed of silicon composites because it has good resistance to high temperatures and fire resistant properties (SP Systems website). Since the HARMs will be rail launched from the weapons bay doors, fire resistance is needed for the doors.

The landing gear and supports are constructed of titanium. Since the aircraft must withstand significantly large loads when landing and the catapult assisted takeoff, the landing gears needed to be made of strong and durable material. Although steel is cheaper than titanium, titanium weighs about 77 percent less than steel (Niu). Figure 9.2.1 shows the material usage on the Postal Penguin.

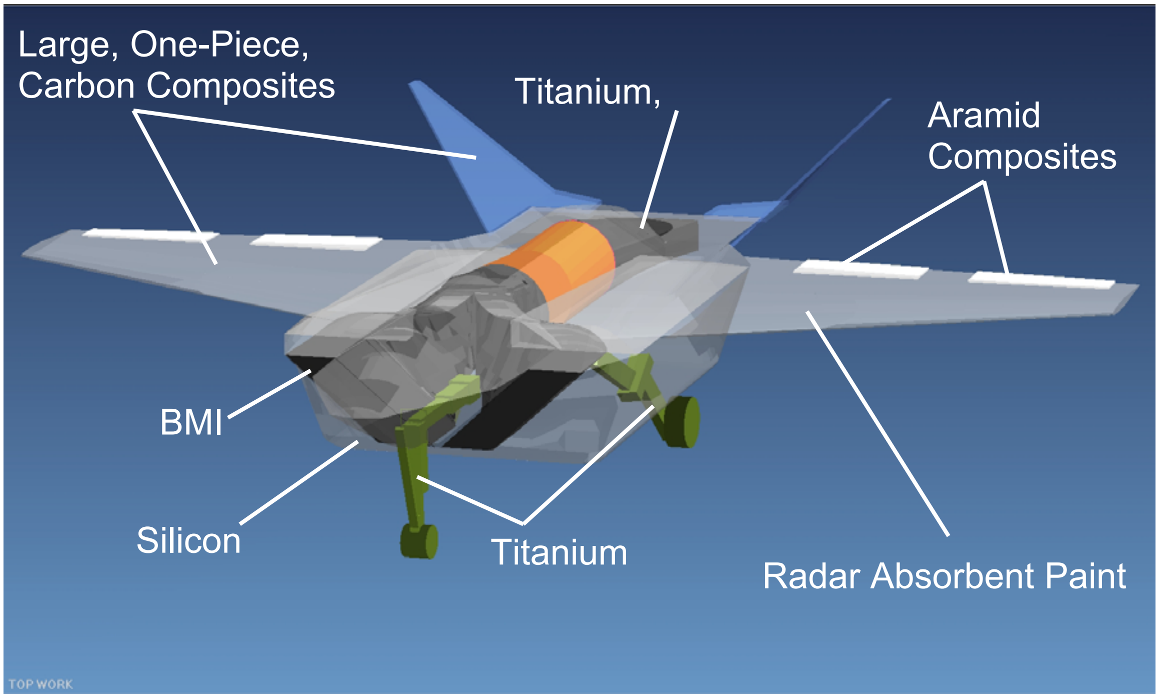


Figure 9.2.1 Material Usage

Chapter 10 Weights Analysis

This chapter will outline the placement of weights within the aircraft and explain the cg travel involved in each of the mission executions. It will also outline the process by which the aircraft was modified to allow stable flight. Weight estimations were made using equations found in the Raymer text. Tables 10.1-3 show the spreadsheets used in calculating weights and centers of gravity for the JDAM, HARM, and loiter missions.

Table 10.1 JDAM Mission Calculations

	Weight (lbs)	#/% of item	Station (in)	X Mom (lb * in)
Wing	825.43671	1	191.27316	157883.8879
Tail	322.477579	1	384.96	124140.9688
Fuselage	5752.3	1	182	1046918.6
Nozzle	200	1	360	72000
Landing Gear				0
nose gear	800	1	100	80000
main gear	1025	2	204.25	418712.5
arrester hook	400	1	342	136800
Propulsion System				
engine	3200	1	234.18	749376
fuel pumps, lines, etc.	164.8	1	191.27	31521.296
unusable fuel	287	1	191.27	54894.49
engine oil	38	1	134.18	5098.84
ISS				
reciever	101	1	69.88827	7058.71527
controller	176	1	93.18436	16400.44736
sensor processor	90	1	93.18436	8386.5924
transmitter	63.52	1	69.88827	4439.30291
sensor electronics	40	1	102.99324	4119.7296
power distribution	95	1	69.88827	6639.38565
antenna/gimbal	271.3	1	56.40106	15301.60758
EO/IR reciever	885	1	101.76713	90063.91005
De-Icing Tail Ldg Edges	200	1	177.5	35500
De-Icing Tail Wing	150	1	328.3	49245
usable fuel				
right fuse tank	5300	1	213.6	1132080
left fuse tank	5300	1	213.6	1132080
right wing tank	1775	1	191.27	339504.25
left wing tank	1775	1	191.27	339504.25
Stores				
JDAMS	2300	2	220.6998	1015219.08
Useful Load	19575			
zero fuel & stores weight	15711.83			
TOGW	34461.83			
CARRIER LDG GW	23141.83			
Combat Weight	27386.83			

Table 10.2 HARM Mission Calculations

	Weight (lbs)	#/% of item	Station (in)	X Mom (lb * in)
Wing	825.43671	1	191.27316	157883.8879
Tail	322.477579	1	384.96	124140.9688
Fuselage	5752.3	1	182	1046918.6
Nozzle	200	1	360	72000
Landing Gear				0
nose gear	800	1	100	80000
main gear	1025	2	204.25	418712.5
arrester hook	400	1	342	136800
Propulsion System				
engine	3200	1	234.18	749376
fuel pumps, lines, etc.	164.8	1	191.27	31521.296
unusable fuel	287	1	191.27	54894.49
engine oil	38	1	134.18	5098.84
ISS				
reciever	101	1	69.88827	7058.71527
controller	176	1	93.18436	16400.44736
sensor processor	90	1	93.18436	8386.5924
transmitter	63.52	1	69.88827	4439.30291
sensor electronics	40	1	102.99324	4119.7296
power distribution	95	1	69.88827	6639.38565
antenna/gimbal	271.3	1	56.40106	15301.60758
EO/IR reciever	885	1	101.76713	90063.91005
De-Icing Tail Ldg Edges	200	1	177.5	35500
De-Icing Tail Wing	150	1	328.3	49245
usable fuel				0
right fuse tank	5300	1	213.6	1132080
left fuse tank	5300	1	213.6	1132080
right wing tank	1775	1	191.27	339504.25
left wing tank	1775	1	191.27	339504.25
Stores				0
HARMS	800	2	220.6998	353119.68
Useful Load	19575			
zero fuel & stores weight	15711.83			
TOGW	34461.83			
CARRIER LDG GW	23141.83			
Combat Weight	27386.83			

Table 10.3 Loiter Mission Calculations

	Weight (lbs)	#/% of item	Station (in)	X Mom (lb * in)
Wing	825.43671	1	191.27316	157883.8879
Tail	322.477579	1	384.96	124140.9688
Fuselage	5752.3	1	182	1046918.6
Nozzle	200	1	360	72000
Landing Gear				0
nose gear	800	1	100	80000
main gear	1025	2	204.25	418712.5
arrester hook	400	1	342	136800
engine	3200	1	234.18	749376
fuel pumps, lines, etc.	164.8	1	191.27	31521.296
unusable fuel	287	1	191.27	54894.49
engine oil	38	1	134.18	5098.84
ISS				
reciever	101	1	69.88827	7058.71527
controller	176	1	93.18436	16400.44736
sensor processor	90	1	93.18436	8386.5924
transmitter	63.52	1	69.88827	4439.30291
sensor electronics	40	1	102.99324	4119.7296
power distribution	95	1	69.88827	6639.38565
antenna/gimbal	271.3	1	56.40106	15301.60758
EO/IR reciever	885	1	101.76713	90063.91005
De-Icing Tail Ldg Edges	200	1	177.5	35500
De-Icing Tail Wing	150	1	328.3	49245
usable fuel				0
right fuse tank	5300	1	213.6	1132080
left fuse tank	5300	1	213.6	1132080
right wing tank	1775	1	191.27	339504.25
left wing tank	1775	1	191.27	339504.25
Useful Load	19575			
zero fuel & stores weight	15711.83			
TOGW	34461.83			
CARRIER LDG GW	23141.83			
Combat Weight	27386.83			

Early in the development of the design, it was found that there were significant issues with both CG travel and instability due to the placement of certain systems. The lack of the pilot, life support systems, and traditional avionics meant that a traditional engine-in-back design would not work for the UCAV-N. The 21% MAC unstable static margin necessitated a change in structure of the aircraft. To improve the stability situation, the engine was moved to toward the front. Weapons were placed directly below the engine and the fuselage was widened to allow the addition of two fuel tanks with centers of gravity near those of the engines and weapons. With the addition of wing sweep to move the neutral point back, these changes greatly reduced. Figures 10.4-6 show the final aircraft's static margin as a percentage of mean aerodynamic chord for each mission with a given initial fuel load.

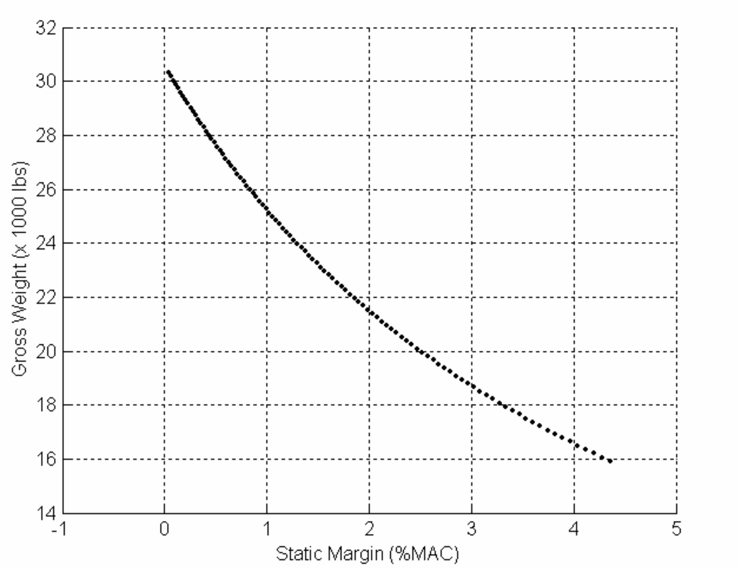


Figure 10.4 Loiter Mission Stability Changes

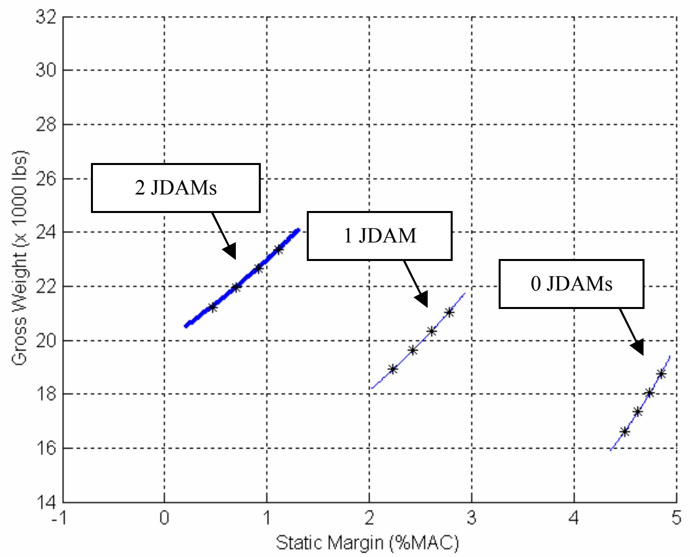


Figure 10.5 JDAM Mission Stability Changes (* indicates 20% of fuel load)

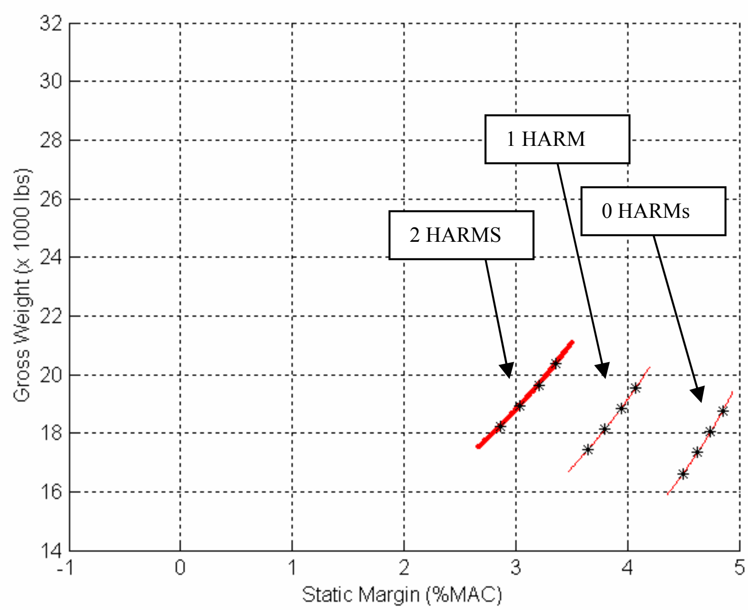


Figure 10.6 HARM Mission Stability Changes (* indicates 20% of fuel load)

Chapter 11 Carrier Integration and Suitability

11.1 Introduction

It has become increasingly evident that the need for UCAVs will increase dramatically in the coming years. It has been determined that using an Aircraft carrier as a launching platform for these unmanned aircraft provides an opportunity and a great deal of flexibility for UCAVs. Two versions of a new class of aircraft carrier are currently being designed by students in Virginia Tech's Ocean Engineering department, and these carrier designs will be the launching platform for the current UCAV-N design. The two versions of the aircraft carrier being designed are smaller than a more traditional Nimitz Class aircraft carrier measuring 660 ft in length as apposed to the 1100 + ft of the Nimitz class carrier. The new carrier designs are also narrower than the current Nimitz Class carriers. The smaller size of the carrier designs in progress poses several obstacles that must be overcome so that the current UCAV-N design can be integrated with the carrier. These obstacles include storage and refueling, takeoff length, and landing length. Communication with the carrier design teams has been necessary to overcome these challenges. In the paragraphs that follow a brief description of the challenges faced and the corresponding solutions related to carrier operations will be presented.

11.2 Autonomy On-Board

Both of the new carrier designs were conceived with a substantially smaller crew than that of a Nimitz class carrier in mind. In order to achieve a smaller crew automation was a necessary consideration in the carrier design. For the UCAV-N design the need for automation was also considered. For example, the ocean engineers wished to load the payload of the UCAV-N in a completely automated fashion. Therefore, the aircraft was designed so that the weapons payload could be loaded from the bottom by a dolly designed by the ocean engineers. The ocean engineers also wanted to move the aircraft throughout the carrier autonomously using an automated dolly design affectionately named SPOT.

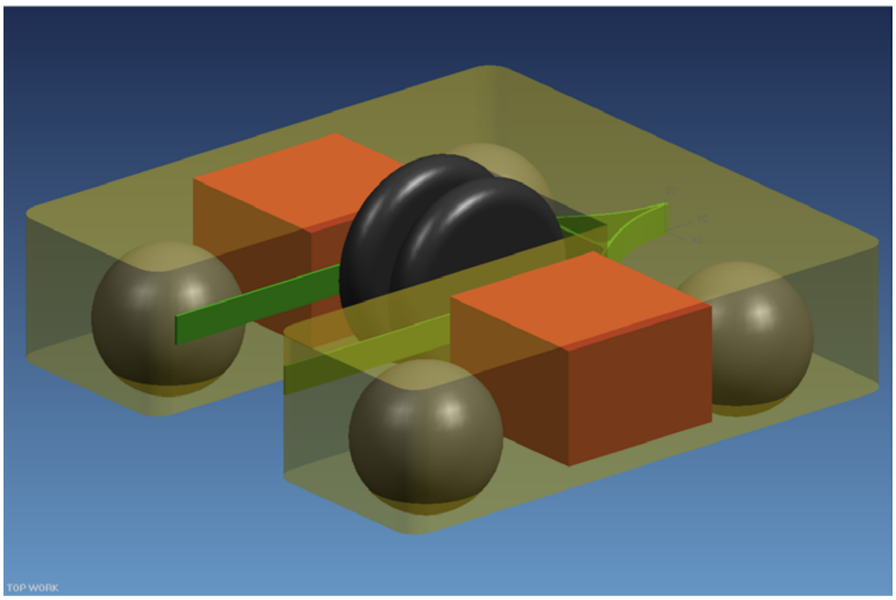


Figure 11.1 "SPOT"

The UCAV-N design is designed to be launched, fly its mission, and land automatically. In addition to the UCAV-N's automated capability, it is designed to be friendly to automated ship systems such as storage, refueling, movement throughout the ship, and armament.

11.3 Stowage, Internal Operations

Both of the new carrier designs will launch the current UCAV-N design from beneath the landing deck. This configuration is shown in the figure below.

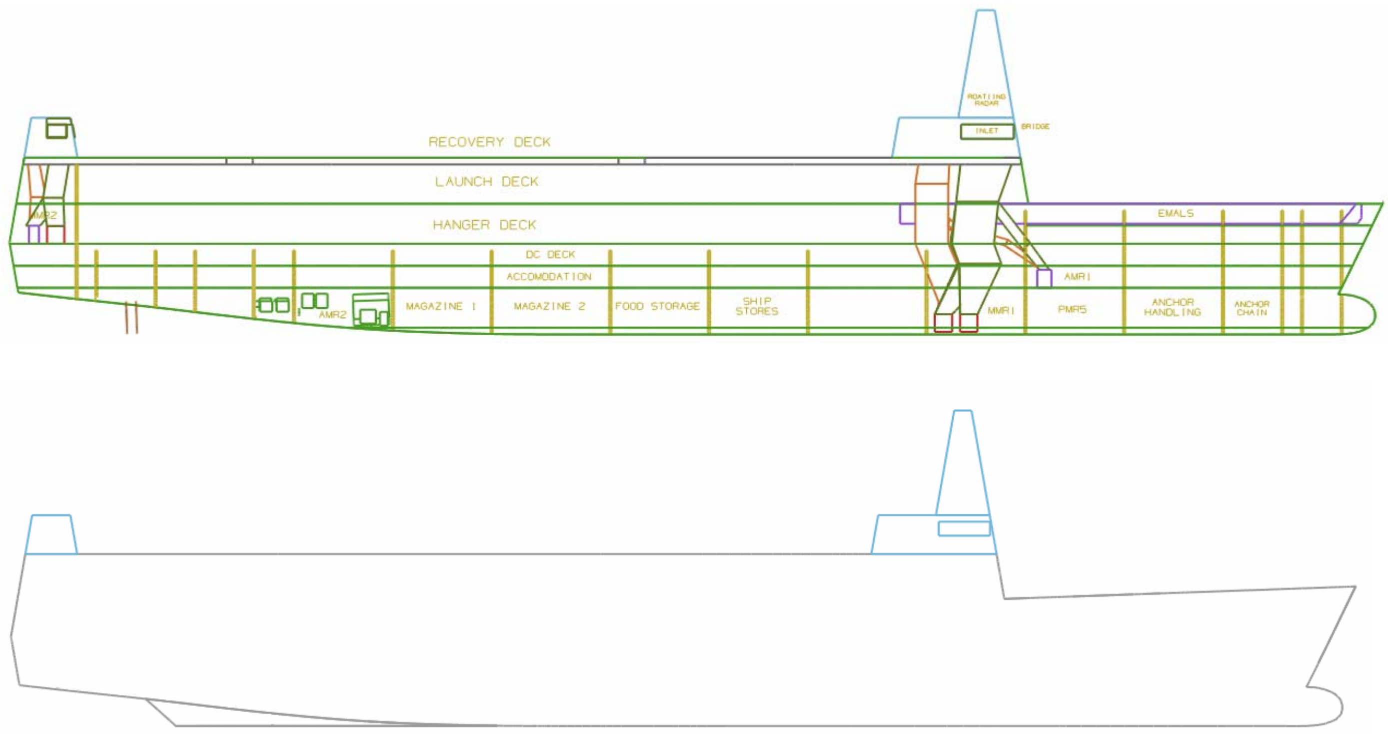


Figure 11.3.1 Side-Views of Carrier 1

Therefore the UCAV-N design had to be robust enough to be launched in a very short distance (i.e. withstand a 5g acceleration). This short takeoff length will be made possible by state of the art EMAL catapult systems. In addition to the short takeoff distance requirements the aircraft had to be able to land in short distances (about 300 ft as apposed to the current 800 ft). The shortened runway made a slower approach speed and precise control priorities. The UCAV-N was designed to have a stall speed of about 105 knots. This stall speed allowed the approach speed to be in the neighborhood of about 125 knots. This relatively slow approach speed lends itself to aid in the recovery phase of the mission. The recovery will be accomplished by a hook and cable system similar to the ones currently used on the Nimitz class carriers and will not stress the aircraft much more than an existing cable and hook design would. This is true because the cable run out on the new carrier design is the same as that for a Nimitz. The big difference in the Nimitz class recovery systems and those designed by the ocean engineers here at Virginia Tech is that on a Nimitz carrier the incoming aircraft has a larger target zone on the runway in which to catch a cable whereas on the new carrier design there is very little room for error in the actual landing phase.

The carrier designs are both relatively small in size so storage was a serious constraint. The UCAV-N design had to be limited to less than 32 ft in length, and the folded wingspan had to be no greater than 31 ft. Size constraints were the most restrictive constraints experienced by the UCAV-N design team. With the size constraints came challenges associated with fitting in all of the required payload and components. The JDAM's and HARM missiles that the UCAV-N is required to carry are more than a third of the length of the aircraft. These weapons had to be stored internally along with a sensor suite package, power plant, structure, landing gear, and sufficient fuel to accomplish any one of three missions. Fitting all of the necessary components into the UCAV-N design was no small task and drastically affected the layout design of the plane. The resulting design has folded wings so that a necessary span could be obtained. The weapons bay that was designed is very wide and deep to accommodate large weapons like the JDAM. Thus, the UCAV-N design has a short and squatty appearance from the side.

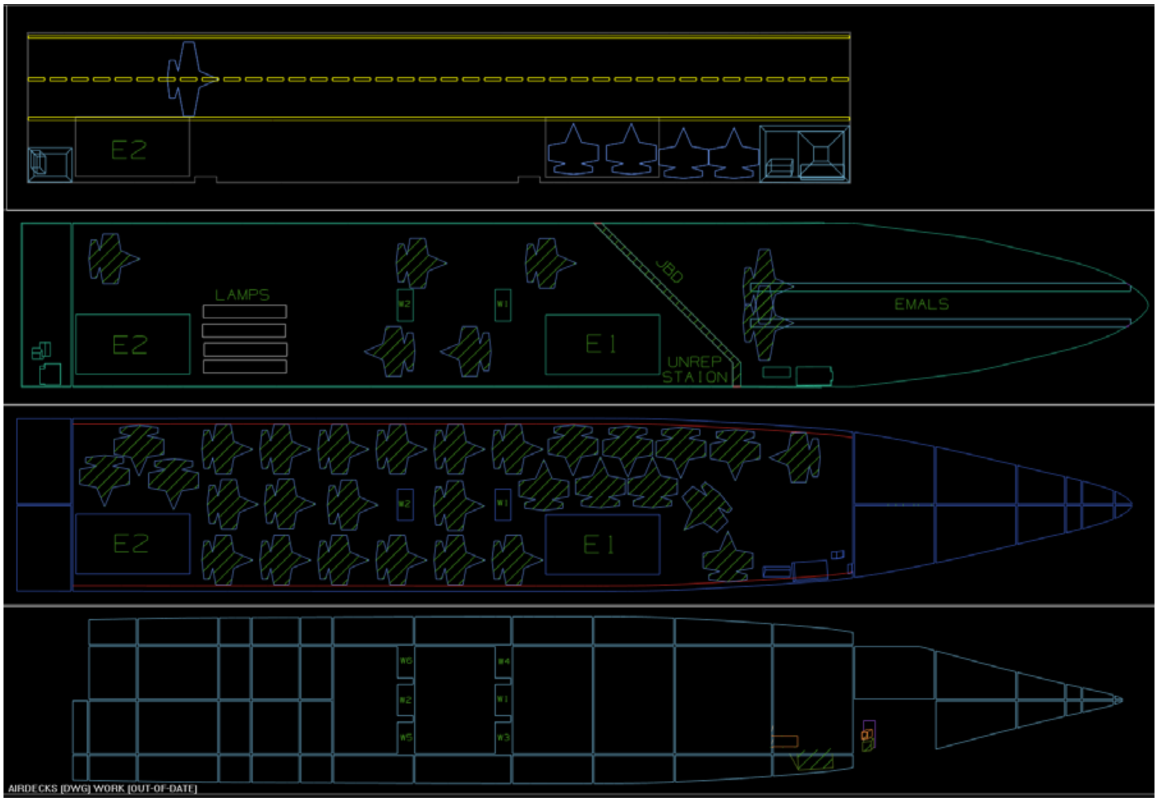


Figure 11.3.2 Carrier Airplane Layout

Even with the large weapons bay, fitting in all of the necessary components was a difficult task and required innovative thinking and design of nose gear systems and fuel tanks.

11.4 Additional Requirements

Another challenge that was encountered was the NAVY requirement for vertical removal of the power plant. In order to remove the engine out the bottom of the aircraft it was necessary to design bulkheads that allowed for this. Two bulkheads support the engine. The engine sits inside of the quasi-ring structure of each bulkhead. In order for the engine to be removed a removable piece was designed as part of the bulkhead. When this piece is removed, the engine is free to translate vertically downward and out through the bottom of the plane. When the piece is inserted it provides necessary structural integrity to the bulkhead.

To summarize, the UCAV-N design must be able to takeoff and land in much shorter distances than conventional aircraft because the carriers that are being designed to transport and deploy the current UCAV-N design are significantly smaller than traditional aircraft carriers. Also, the smaller size of the new carrier designs places size constraints on the UCAV-N design as it relates to structural integrity, stability and control, and aerodynamics considerations. The desired automation capabilities of the new carrier designs as well as NAVY regulations were considered during the design of the UCAV-N and affected the final design. These constraints along with the requirements from the UCAV-N RFP dictated the physical characteristics of the UCAV-N design and resulted in a unique physical appearance. The current UCAV-N design is adequate to fulfill all requirements and perform well in a carrier based operations role.

Chapter 12 Pelikan Tail, Aerodynamic Testing

12.1 Introduction

In exploring different options for reducing our RCS we came across a revolutionary tail configuration called the Pelikan tail. This Pelikan tail was a design that Boeing considered for their X-32 Joint Strike Fighter concept. The idea was proposed by Ralph Pelikan, a former McDonnell Douglas engineer who was inherited by Boeing when they acquired McDonnell Douglas. Boeing initially settled on the Pelikan tail because it gave them a perceived stealth advantage over Lockheed's X-35 concept. This was one of the factors that made the Pelikan tail configuration attractive to the UCAV-N design. It was recognized early that stealth would be the largest and most important factor in the survivability of the UCAV-N. With much of the early configuration emphasis on stealth, the Pelikan tail provided a powerful design option to help reduce the RCS of the UCAV-N.

The Pelikan tail is a configuration that obtains all necessary pitch and yaw forces from only two full-flying, rear control surfaces. A picture of a Pelikan tail concept is shown below, in figure 12.1.

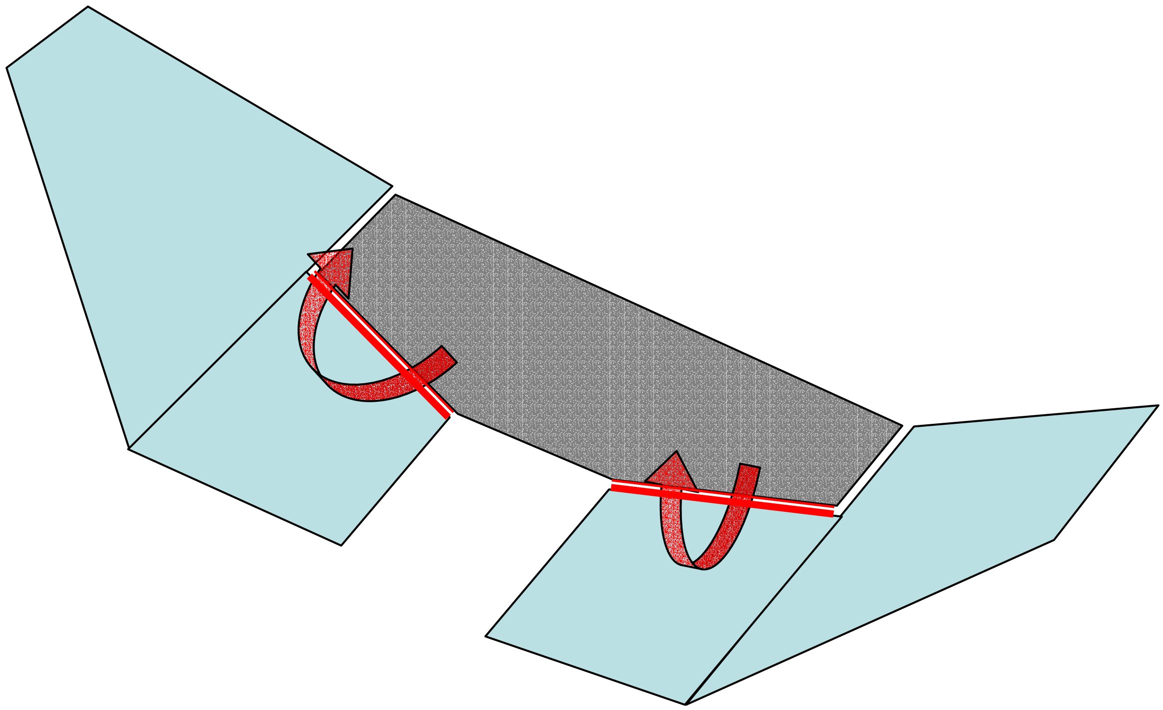


Figure 12.1 Pelikan Tail Model

The above model shows the two Pelikan tail surfaces attached to a single mounting plate as would be done in a wind tunnel testing. It is shown this way to more clearly demonstrate the concept. Of major importance in Figure 11.1 are the angled hinge lines, shown in red. It's the angle of the hinge line that helps to provide the side force when the surfaces are deflected.

12.2 Why Implement the Pelikan Tail

The key reason for choosing the Pelikan tail is stealth. As was mentioned previously, stealth will provide the UCAV-N with the majority of its survivability. With so much riding on the stealth of the airplane, every opportunity to reduce the UCAV-N's RCS was taken. The Pelikan tail has only the two tail surfaces as compared to a conventional tail that has either three of four tail surfaces. This means that the Pelikan tail has less surface area with which to reflect radar energy to a threat. In addition to the reduction of surface area, the Pelikan tail's surfaces are canted to a significant degree which reduces the RCS of the aircraft even further. Another advantage to the Pelikan tail configuration is the reduction in skin friction drag. With less wing area in the tail of the airplane there will inherently be less skin friction drag. It was not calculated how many drag points will be saved by the Pelikan configuration but it will certainly be an improvement. The use of only two rear control surfaces as compared to the usual three or four also means that there only need to be two hydraulic actuators in the aft section of the airplane. This will be a significant weight savings and it will mean fewer hydraulic lines and control system components running to the rear of the plane. The Pelikan tail is a revolutionary tail design that will become more common as the need for stealth increases as it is sure to do in the coming years. On top of reducing the Postal Penguin's RCS, it will reduce the drag along with the weight and the complexity of the plane.

12.3 Obtaining Pitch Force

To generate the pitch forces needed to control the airplane, the Pelikan tail utilizes the two horizontal surface sections of each tail piece. Additional pitch forces will be obtained from the canted vertical surfaces when they are deflected. There will be side forces produced when the tails are both deflected for pitch but they will be equal and opposite and will therefore cancel each other out. In relation to the yaw forces, obtaining the pitch forces is far less complicated for the Pelikan tail configuration.

12.4 Obtaining Yaw Force

Obtaining the side force to produce yaw to control the airplane was the main obstacle facing the implementation of the Pelikan tail. As the vertical surfaces are canted further and further the effective area used to produce side forces is reduced. This is an unfortunate inverse direct relationship between the stealth of the Pelikan tail and the effectiveness of the tail for stability and control purposes. Higher cant angle means a lower RCS but it also results in less control effectiveness, whereas a higher cant angle will provide sufficient side force but would drive the RCS of the plane higher and higher. This is an issue that will be addressed in more detail later. To illustrate how the Pelikan tail generates side force the following schematic shows the Pelikan tail set up to produce a side force to the right.

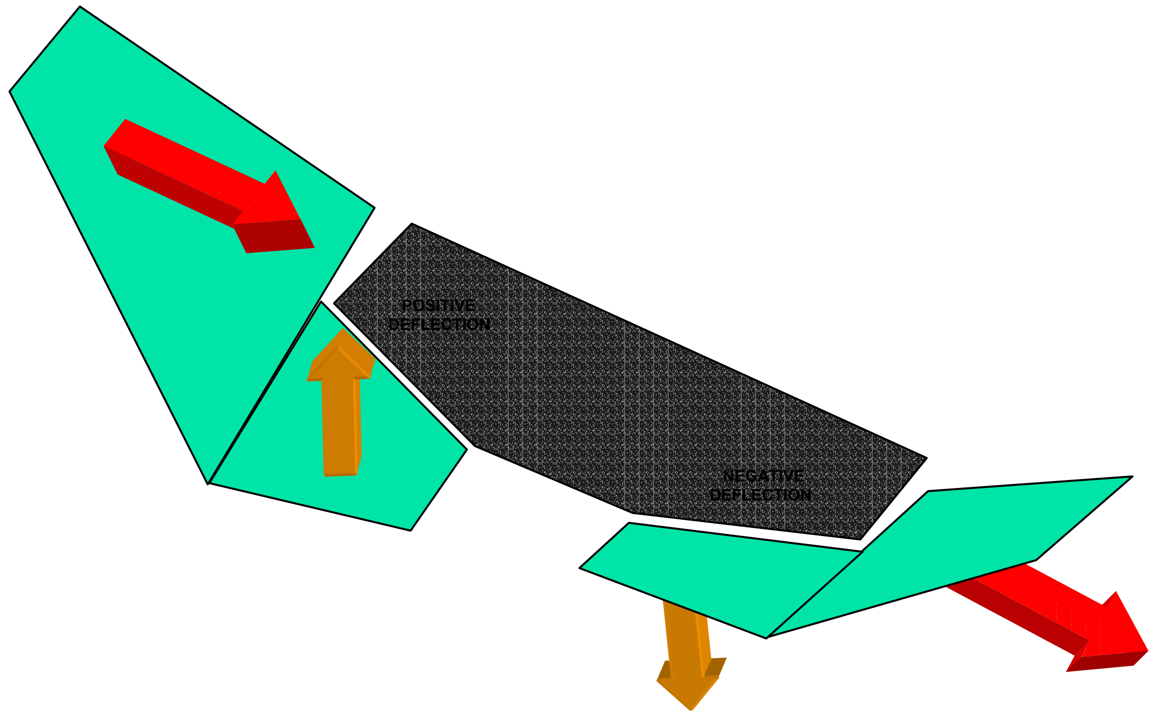


Figure 12.2 Obtaining Yaw Force

Figure 12.2 shows the left Pelikan tail surface with a positive deflection and the right surface with an equal negative deflection. As is illustrated with red arrows, these deflections result in side forces in the same direction. The orange arrows reveal one of the challenges faced by the Pelikan tail, the addition of a rolling moment to a yaw force input to the control surfaces. This rolling moment has a very small moment arm with respect to the centerline of the aircraft and will be easily compensated for by the autonomous flight control system using the ailerons. While correcting the rolling moment was easy, the question remained can enough side force be obtained to control the airplane? Due to the fact that the Pelikan tail had never been implemented before it was decided that if it was to be incorporated into the UCAV-N wind tunnel data would be needed in order to justify its use on the UCAV-N.

12.5 *Wind Tunnel Testing*

The opportunity was presented to the UCAV-N team to test a Pelikan tail concept in the stability wind tunnel. The conditions under which the tests were conducted were that the UCAV-N team provided the testing model and the experimental goals. The actual testing was conducted by a third party with all the experimental data available to the UCAV-N team.

The wind tunnel model was designed with two canted vertical tail surfaces attached to a base plate that mounted to the sting in the stability wind tunnel. The symmetric tail surfaces were drafted in Unigraphics with NACA 0012 airfoil sections used for the canted vertical surfaces of the tail. After the sections were drafted in Unigraphics, the files were reformatted and transferred to the Z Corporation 3-Dimensional printer. The 3D printer fabricated the tail sections and then they were run through a thermal waxing process to make the pieces more rigid. After this, the sections were coated with fiberglass and epoxy to be sure they would stand up to the abuse of wind tunnel testing. The mounting base plate was constructed out of ½-inch thick poplar board. Poplar was chosen due to its high toughness and relatively low weight compared to standard pine board. A diagram showing the dimensions of the mounting plate is shown in Figure 12.3.

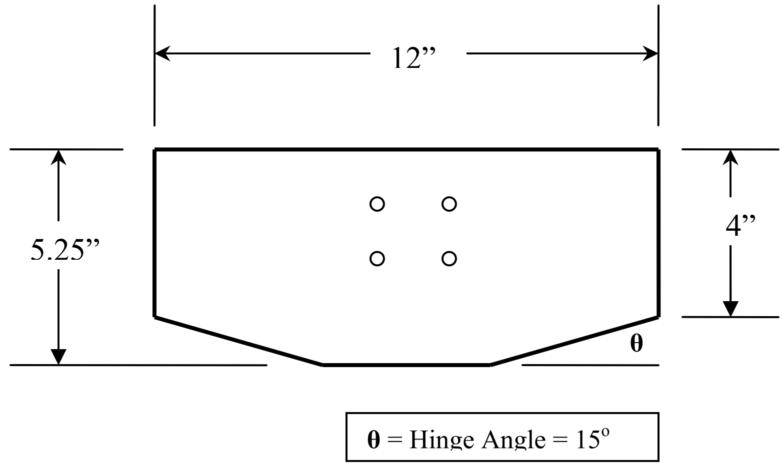


Figure 12.3 Dimensioned Base Board

Mounting holes were drilled in the base plate as shown above so the model could be easily attached to the wind tunnel sting and then the leading edge of the model was rounded to improve flow around the base plate. After the base plate was complete, brass hinges were attached to the finished tail sections with epoxy and fiberglass. Once the epoxy set, the hinges were screwed to the base plate completing the Pelikan tail model. In order to fix the tail sections in different deflected positions for testing, a set of metal braces were crafted that held the free-floating hinged tail sections in any one of 3 different positions. Braces were created to set each tail section at +/-20° as well at zero. This enabled the tail model to be set up in nine different configurations for testing.

A dimensioned drawing of the entire wind tunnel testing model is shown below in figure 12.4.

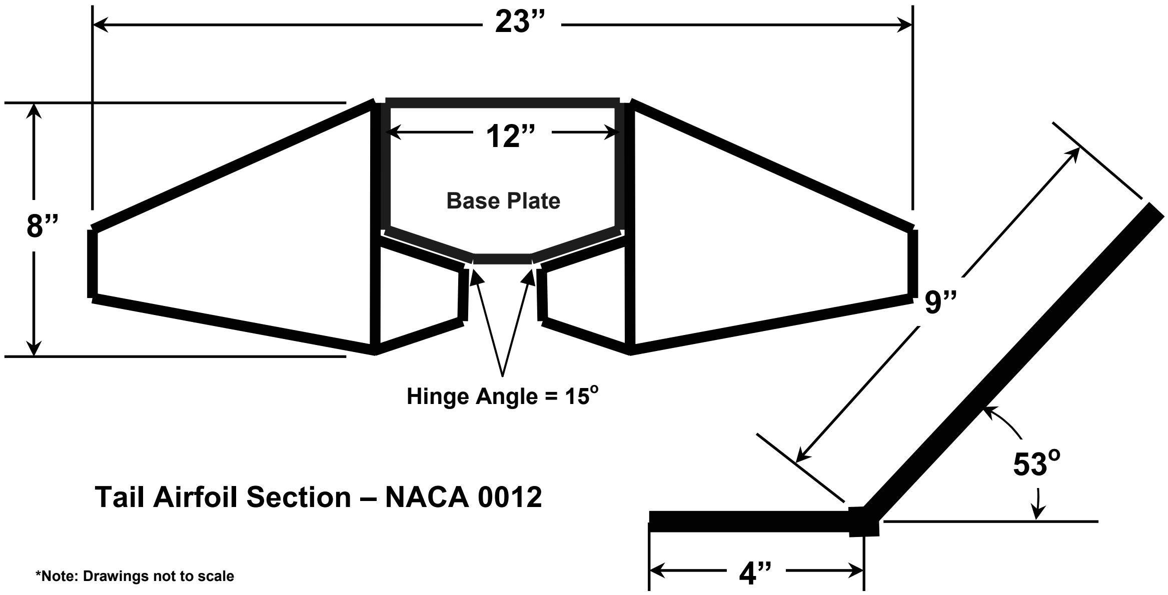


Figure 12.4 Dimensioned Model Drawing

12.6 Wind Tunnel Testing Data

The wind tunnel testing was conducted by the members of Rafael Perez’s AOE 3054 lab group which consisted of Andrew Parker, Brian Cavanaugh, James Pembridge, Eric Harris, Rich Stark and Andrew Thorne. Perez’s lab group conducted the tests on Wednesday April 16th, 2003 in the stability wind tunnel facility at Virginia Tech. The tests were all run with the dynamic pressure at 3 inches of water which corresponded to a flow speed of approximately 80mph. The Reynolds number for the tests under these conditions was 540,000. The model was mounted on a variable pitch sting mount in the wind tunnel and at every tail configuration the model was run from -5 to +5 degrees angle of attack in single degree increments. Automated laboratory computer systems captured the data from the sting and generated data tables of C_L, C_D, C_Y, C_l, C_n, and C_m all versus angle of attack for each tail configuration. All plots are shown in Appendix I.

Overall the results from the wind tunnel tests were very encouraging to the validity of the Pelikan tail. While most all the data represented solid flight control characteristics from the Pelikan tail, it is clear that more research and testing needs to be done prior to flight integration. The plot of C_Y indicates that when the yaw force is normalized with respect to the wing area, it might be too small to produce the power needed to control the airplane. This is not discouraging however because the testing was very limited and even the limited data showed that the Pelikan tail behaved similarly to a conventional tail. More testing would yield the opportunity to increase the size of the tail sections, change the cant angle or use different airfoil sections to improve the quality of the data. There was a limited amount of data and due to the fact that the UCAV-N team was not in direct control of the testing, some issues that needed to be addressed were not. All told however, the wind tunnel data was strong enough to support the implementation of the Pelikan tail into the Postal Penguin design.

12.7 Pelikan Tail Conclusions

The Pelikan tail is a revolutionary design configuration that is sure to get more attention and see more use as the need for stealth increases. The challenges of implementing a completely new tail into the UCAV-N were many but the rewards were just as numerous. The Pelikan tail configuration will provide the UCAV-N with excellent stealth characteristics and will reduce the weight and complexity of the tail. The wind tunnel testing provided strong support for the use of the Pelikan tail and showed that it is a viable flight control surface.

Chapter 13 Survivability, Redundancy, and Vulnerability

The survivability of a combat aircraft depends on many different factors. Some of these factors can be addressed by the aircraft designer, some are left to the operators of the aircraft and other factors are totally independent of the actual aircraft and its mission. Survivability of an aircraft is said to be the probability that the aircraft will be within range of enemy radar, the radar will identify the aircraft, a threat will be launched, and the threat will disable or destroy the aircraft. Whether or not the aircraft is within range of enemy radar is left almost entirely up to the tactics employed by the operator of the aircraft. Intelligence information regarding the location of hostile radar sites is used to determine where it is safe for aircraft to fly and where it is unsafe; this factor of survivability is beyond the scope of the aircraft designer. Once within enemy radar range the survivability of the aircraft can be increased if its Radar Cross Section (RCS) is reduced. This is where the aircraft designer can begin to directly influence the survivability of the vehicle. RCS reduction, also referred to as stealth, is an emerging field in aircraft design. The F-117 Nighthawk and B-2 Spirit are two aircraft that were designed with stealth as the top priority. Both have been highly successful, in fact many consider the B-2 to be the best airplane ever designed, but in these two examples many other design characteristics were sacrificed to enable such a high level of stealth. Both planes are subsonic, not very maneuverable, and have no defensive weapons of their own. That is to say that they were designed with only stealth in mind. The F-22 Raptor is an example of an airplane that was made highly stealthy and yet is capable of super-cruise, is highly maneuverable and carries both offensive and defensive weapons. One of the Raptors key characteristics was sacrificed to yield such a good design, and that was cost, the expected price per unit for the Raptor is close to 100 million dollars. Despite its immense price tag, the F-22 issued in a new age of military aircraft design in which all defense oriented vehicle systems will have to take stealth into serious consideration. The F-117, B-2, and F-22 are all good examples of how good stealth characteristics can greatly improve survivability. If the enemy can't see you, he can't shoot at you.

While stealth can be an extremely powerful defensive characteristic, it is inherently a passive safety feature. That is to say that, if the enemy somehow manages to identify the airplane and shoots at it, the stealthiness of the aircraft doesn't help the survivability much at all. Once a threat has been fired at the aircraft, the agility and maneuverability of the plane become the driving factor in its survivability. This is what separates the F-22 from the F-117 and the B-2, the F-22 is a very stealthy airplane by any modern standards but it has the added advantage of being highly maneuverable as well. This is another area where aircraft designers can improve the survivability of the airplane. By increasing its max rate of climb, speed, acceleration and many other flight characteristics the designer can increase the chances that the plane will be able to evade the threat propagator.

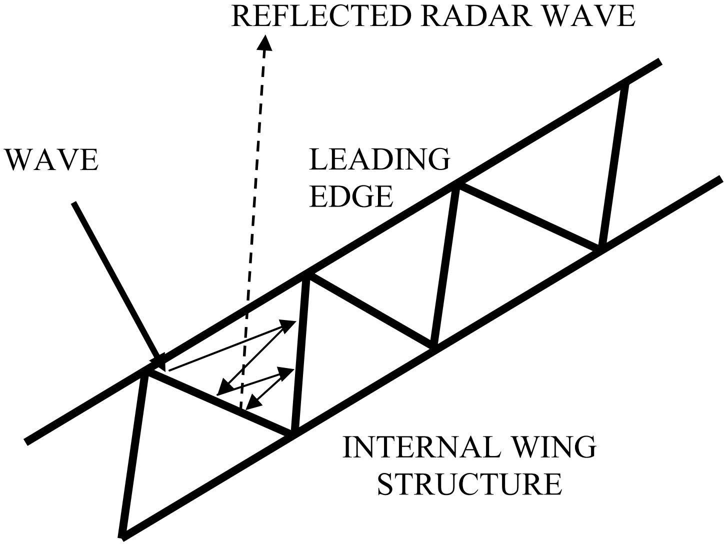
Stealth can decrease the chances that the enemy can see an aircraft, agility and maneuverability can decrease the chances that the enemy can hit an aircraft, but there is always present the chance that the threat will target and impact the aircraft. The ability of an aircraft to withstand physical damage inflicted by an enemy threat is called the vulnerability of the aircraft. An example of an airplane with extremely low vulnerability is the A-10 Thunderbolt. A slow and heavy airplane, with comparatively poor agility, the A-10 remains one of the safest warplanes to take into hostile territory due to its ability to survive direct attack. The A-10 utilizes triple redundant control systems with two hydraulic systems augmented by a direct cable connection that may be used to fly the aircraft in an emergency with no hydraulic fluid remaining. Furthermore, the aircraft's engines are shielded from heat seeking missiles by the horizontal and vertical tail assemblies. They're also separated from each other by the fuselage, which acts as a shrapnel barrier when one of them is struck. The pilot is protected by a 2-inch-thick titanium "bath tub", making him nearly as well armored as the tanks he is trained to destroy. All of this makes for an extremely durable aircraft. The cost of all of this durability is in the weight of the aircraft and the lack of sophistication in its systems. To operate A-10s safely, the Air Force must ensure air dominance before allowing them in theater. Due to its complete lack of stealth and relatively low speed, it is both highly visible to enemy surface to air missiles and fighters *and* a very easy target to hit. All this redundancy and added safety is another direct way that the aircraft designer can improve the survivability of the aircraft, by making it tough enough to take a beating and keep on flying.

Through the use of stealth, agility, and durability the aircraft designer can decrease the chances that the aircraft will be destroyed by the enemy while performing its mission. The B-2 uses only stealth technologies to keep itself safe and it has been highly successful, the F-22 while stealthy in its own right, utilizes high maneuverability, agility and speed to evade an attack. The A-10 is not stealthy and does not possess superb maneuverability but it can withstand a huge amount of abuse and still remain in tact and in control. It was decided that stealth technology would have to provide the majority of our planes survivability. The weight penalty was far too high for our design to make the

UCAV-N as rugged as the A-10 in terms of surviving a direct attack, and while our design has solid maneuverability its slow top speed means that it will not be able to evade a direct attack. It is simply not designed for speed. Once it was determined that stealth would be our main focus for survivability, examination of stealth measures began. Several characteristics of the design were employed to improve the stealth of the aircraft. One of the most noticeable contributions of stealth to the design is the tail. The choice to employ a revolutionary and still experimental Pelikan tail for the aircraft was made specifically to reduce the RCS of our configuration. A standard 4 post tail is one of the main contributing factors to an identifiable RCS. One of the biggest reasons for the B-2 being so invisible to enemy radar is the fact that it has no vertical surfaces whatsoever. The Pelikan tail utilizes only two rear control surfaces and they are canted at 53^o so as to reduce their RCS contribution from side looking radar systems.

Another design configuration characteristic that was added in part to help the stealth of the plane was the leading edge sweep. With around 20^o of leading edge sweep the aircraft will be less vulnerable to threat radars as it approaches them. An unswept leading edge would reflect a great portion of the radar waves directed at it, whereas a swept leading edge reflects more of the radar energy away from the source. Another stealth consideration that will most certainly be incorporated into the UCAV-N design is the use of radar absorbent material. RAM, as it is called, is a material that covers most of the entire airplane and can absorb a significant amount of radar energy and thereby not returning that energy to an enemy radar station. Magnetic RAM is a material that incorporates iron oxides, or iron ferrites into the wing skin and the paint on the outside of the aircraft. These iron based materials transform radar energy into heat energy and thereby return a small percentage of the radar energy back to the threat radar.

Stealth was also incorporated into the structures design of the UCAV-N. While sweeping the leading edge of the wing effectively reduces the RCS, further attention can be paid to the design of the structures of the wing to reduce its RCS even further. The wing of any aircraft design must contain a good deal of structural components in order to support the loads needed to give the aircraft lift and support any fuel or stores that are placed in or on the wing. The reason that the internal structure of the wing can be important to stealth is that some frequencies of radar waves can actually penetrate the wing skin. Wing internals, while structurally efficient, are not designed at all to be stealthy and would reflect radar waves directly back to the source. Restructuring the wing is not a feasible solution to this problem so the internal structure of the wing must be shielded by something to prevent the radar waves from reflecting back to the source. Figure 1 shows a jagged triangular formation that will be added into the leading edge of the wing to reflect and absorb any radar waves that penetrate the wing skin.



Entire structure coated with RAM

With the entire structure coated with RAM and the surfaces angled as shown, the incoming radar waves will become significantly weaker and then be deflected so what little radar energy does reflect does not return to the source radar.

To further enhance the stealth characteristics of the UCAV-N, the entire aircraft will be coated with magnetic RAM in the form of specially formulated iron-based paint. The engine inlet will be constructed out of a single piece of material so that it is seamless and will therefore reflect very little radar energy. The exhaust system of the plane will be coated with special ceramic tiles that absorb a portion of the heat released from the engine thereby reducing the heat signature of the plane. These extra factors, coupled with the new tail configuration and the swept wings will provide the Postal Penguin with excellent stealth characteristics and should be sufficient, along with proper tactics, to keep it safe when conducting its mission.

Beyond the stealth aspect of the design there will be other redundant systems employed to further increase the survivability of the UCAV-N. A redundant flight control system for the aircraft will be easier to utilize because of the autonomous nature of the UCAV-N. Because a computer is all that is required to fly and land the plane, a backup computer would be easily installed and could switch over instantly in the event of an emergency. In other words, the plane could be completely controlled from anywhere either on board the aircraft or from a remote location whereas a piloted aircraft must be controlled from the cockpit. Another advantage to not having a piloted aircraft is that there is no obvious target on the aircraft to shoot at. In a piloted aircraft, the cockpit is the command center for the plane, but in a UCAV the central nervous system for the plane can be located anywhere, and it can be well shielded.

Chapter 14 Cost Analysis

This chapter is miss-titled. When one considers the price of a modern military system, the paramount concern must be the value of the system in a strategic context rather than its cost in dollars. In the current political environment, the value of a soldier's life is beyond the sentimental. Casualties have become a driving factor in American military strategy and must be considered in every set of plans created. Time and time again, public opinion has been so swayed by casualties that the President has been forced to draw down or even remove American military forces from sensitive regions. Guerrilla tactics are now a widely accepted standard for the enemies of the US, who believe that they can achieve success by out-lasting our county's desire to fight. They seek to knock pilots from sky and either kill them or take them prisoner, while disseminating information to the media and fighting a war of public relations. While one may ask what the cost of the aircraft is, our team asks: what is the price of not fielding this aircraft as soon as possible?

The UCAV-N is our answer to guerrilla-style tactics of attrition. This aircraft is designed to suppress the systems that pose the greatest risk to American jets, to strike the facilities where the enemy plans his attacks, and to observe the battlefield where American soldiers are put in harm's way. It does this without risk to human crew. For less than the price of the F-18 program, the Penguin offers the ability to accomplish all of these missions with a re-usable vehicle that will never place a pilot in the sights of the enemy. The UCAV-N is a revolutionary aircraft that gives more strategic-value per dollar expended than almost any other weapon's system in the inventory because it is absolutely unique in its capabilities.

Tables 14.1 and 14.2 show the projected costs for production runs of 100 aircraft and 500 aircraft respectively. It should be noted that the life cycle costs, based on a 20-year projected service life, are considerably lower than they would be for a conventional manned aircraft. This is due to the fact that the UCAV-N will not be used to maintain aircrew certification and training. The aircraft will only need to fly during wartime, which reduces the expenditures for consumables such as fuel and oil, as well as maintenance hours and replacement parts.

Table 14.1 Cost for a Production Run of 100

Run Costs	
RDT&E	$2,363,246,486
Flyaway and CC	$3,803,394,489
Support and Spares	$1,121,207,450
Operations&Maintenance	$1,178,521,382
Civil Purchase Price	$5,606,037,250
Military Procurement Cost	$4,924,601,939
Program Cost	$7,287,848,425
Life Cycle Cost	$8,466,369,807

Unit Costs	
RDT&E	$23,632,465
Flyaway and CC	$38,033,945
Support and Spares	$11,212,075
Operations&Maintenance	$11,785,214
Civil Purchase Price	$56,060,373
Military Procurement Cost	$49,246,019
Program Cost	$72,878,484
Life Cycle Cost	$84,663,698

Table 14.2 Cost for a production run of 500

Run Costs	
RDT&E	$3,438,197,303
Flyaway and CC	$9,308,675,561
Support and Spares	$2,317,613,248
Operations&Maintenance	$5,892,606,908
Civil Purchase Price	$11,588,066,240
Military Procurement Cost	$11,626,288,809
Program Cost	$15,064,486,112
Life Cycle Cost	$20,957,093,020

Unit Costs	
RDT&E	$6,876,395
Flyaway and CC	$18,617,351
Support and Spares	$4,635,226
Operations&Maintenance	$11,785,214
Civil Purchase Price	$23,176,132
Military Procurement Cost	$23,252,578
Program Cost	$30,128,972
Life Cycle Cost	$41,914,186

References

1.1 United States Navy. *Request for Proposals, UCAV-N*. 2002
1.2 United States Navy. *Request for Proposals, UCAV-N*. 2002
1.3 Raytheon Corporation Product Website, avail http://www.raytheon.com
1.4 Carrier Suitability Testing Manual, NAVAIR, Pax River MD, 1998
1.4 Northrop Grumman Corporation Website, avail http://www.ng.com
1.5.1 General Atomics Corporation Website, avail http://www.generalatomics.com
1.5.2 Teledyne Corporation Website, avail http://www.teledyne.com
1.5.3 Tupolev? Ask alex.
1.5.4 Boeing Corporation Website, avail http://www.boeing.com
1.5.5 Boeing Corporation Website, avail http://www.boeing.com
1.5.6 Northrop Grumman Corporation Website, avail http://www.ng.com
1 Other sources include, Federation of American Scientists, avail http://www.fas.org, and Global Security, avail http://www.globalsecurity.org
2.5.4 Raymer, Daniel P. *Aircraft Design: A Conceptual Approach*, AIAA Education Series, 1999
3.2 Korn Equations
3.3 NOVA. *Battle of the X-Planes*. PBS Special
4.1 Raymer, Daniel P. *Aircraft Design: A Conceptual Approach*, AIAA Education Series, 1999
4.2 General Electric Corporation Website, avail http://www.ge.com
4.2 Pratt & Whitney Corporation Website, avail http://www.pratt-whitney.com
4.3 VSTOL SHIT!!!!!
5.2 Raytheon Corporation Product Website, avail http://www.raytheon.com
5.3 General Electric Corporation Website, avail http://www.ge.com
5.4 Global Security Organization, http://www.globalsecurity.org (22 Jan 2003)
5.5 JDAM Mounting Stuff
5.7
5.8
6.2 Mason, William H. *Configuration Aerodynamics Notes*. available: http://www.aoe.vt.edu/~mason/
6.2.1 XFOIL http://raphael.mit.edu/xfoil/
6.2.2 XFOIL http://raphael.mit.edu/xfoil/
6.2.3 XFOIL http://raphael.mit.edu/xfoil/
6.2 XFOIL http://raphael.mit.edu/xfoil/
6.3 Daniel P. Raymer, *Aircraft Design: A Conceptual Approach*, AIAA Education Series, 1999
6.3.1 Korn Equations
6.3.2 Korn Equations
6.3.3 Korn Equations
6.3.4 Raymer, *Aircraft Design,* friction.f excecutable code on Mason's website, http://www.aoe.vt.edu/~mason/
6.4 Raymer, *Aircraft Design*, Brandt, Stiles, Bertin, Whitford, *Introduction to Aeronautics, A Design Perspective,* AIAA Education Series, 1997.

7.1 United States Navy. *Request for Proposals, UCAV-N*. 2002
7.2 Raymer, Daniel P., *Aircraft Design: A Conceptual Approach*. AIAA Educational Series
7.3 Raymer, Daniel P., *Aircraft Design: A Conceptual Approach*. AIAA Educational Series
7.4 Raymer, Daniel P., *Aircraft Design: A Conceptual Approach*. AIAA Educational Series
7.5 Bertin, Whitford, *Introduction to Aeronautics*
8.1 J Kay (computer code and users manual), available: http://www.aoe.vt.edu/~mason/Mason_f/MRsoft.html
8.1 Waszak (computer code available), available: http://www.aoe.vt.edu/~mason/Mason_f/MRsoft.html
8.1 Etkin, Bernard. *Dynamics of Flight*. New York: John Wiley & Sons, 1996
8.3 Roskam, Jan. *Airplane Design Part VII: Determination of Stability, Control and Performance Characteristics*. Lawrence, KA: DARcorporation 2002
8.4 Raymer, Daniel P., *Aircraft Design: A Conceptual Approach*. AIAA Educational Series
9.1 Niu, Michael. *Airframe Structural Design*. New York: Conmilit Press, 1988
9.1 SP Systems, avail http://www.spsystems.com
9.2 Raymer, Daniel P., *Aircraft Design: A Conceptual Approach*. AIAA Educational Series
13 Ball, Robert E. *The Fundamentals of Aircraft Combat Survivability Analysis and Design*. New York: AIAA Educational Series, 1985

Partial Alphabetic Listing of References:

Boeing Corporation, http://www.boeing.com (22 Jan. 2003)

Carrier Suitability Testing Manual, NAVAIR, Pax River MD, 1998

DARPA, http://www.darpa.gov (22 Jan. 2003)

Doyle Michael R., Electromagnetic *Aircraft Launch System – EMALS*. Naval Air Warfare Center, Aircraft Division, Lakehurst, NJ

Global Security Organization, http://www.globalsecurity.org (22 Jan 2003)

Invisible Defenders Organization, http://www.invisible-defenders.org (22 Jan 2003)

Lamar, J.E., and Gloss, B. B., *Subsonic Aerodynamic Characteristics of Interacting Lifting Surfaces with Separated Flow around Sharp Edges Predicted by a Vortex-Lattice Method*. NASA TN D-7921, Sept., 1975.

Lamar, J.E., and Frink, N.T., *Experimental and Analytic Study of the Longitudinal Aerodynamic Characteristics of Analytically and Empirically Designed Strake-Wing Configurations at Subcritical Speeds*. NASA TP-1803, June 1981.

Lamar, J.E., and Herbert, H.E., *Production Version of the Extended NASA-Langley Vortex Lattice FORTRAN Computer Code*, - Vol. I - User's Guide, NASA TM 83303, April 1982.

Margason, R.J., and Lamar, J.E., *Vortex-Lattice FORTRAN Program for Estimating SubsonicAerodynamic Characteristics of Complex Planforms*. NASA TN D-6142, Feb., 1971.

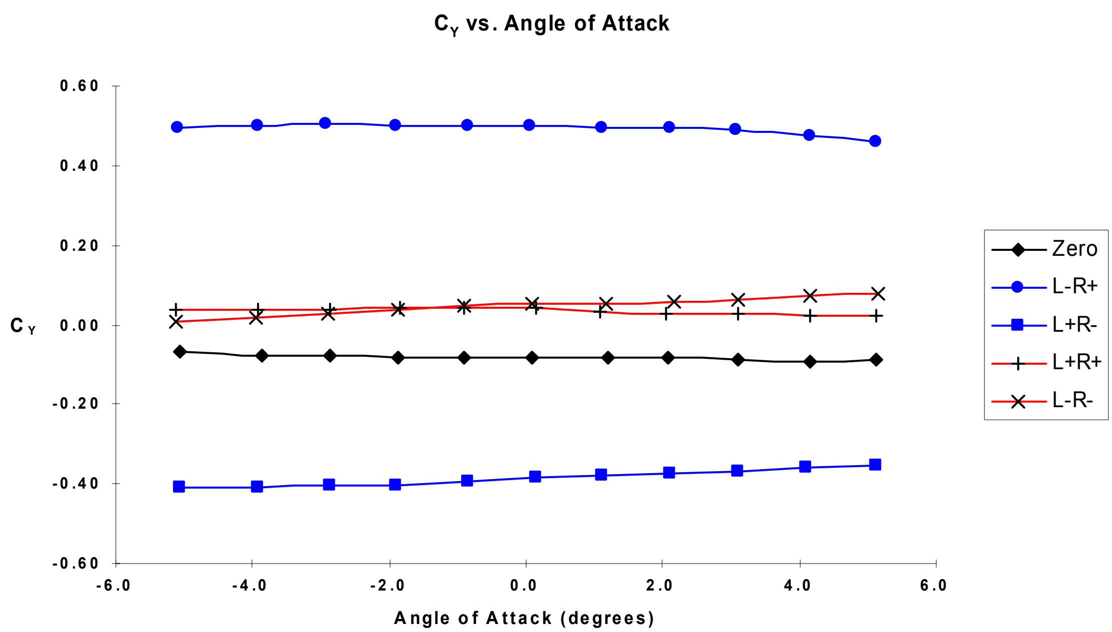
Northrop Grumman Corporation, http://www.ng.com (22 Jan. 2003)

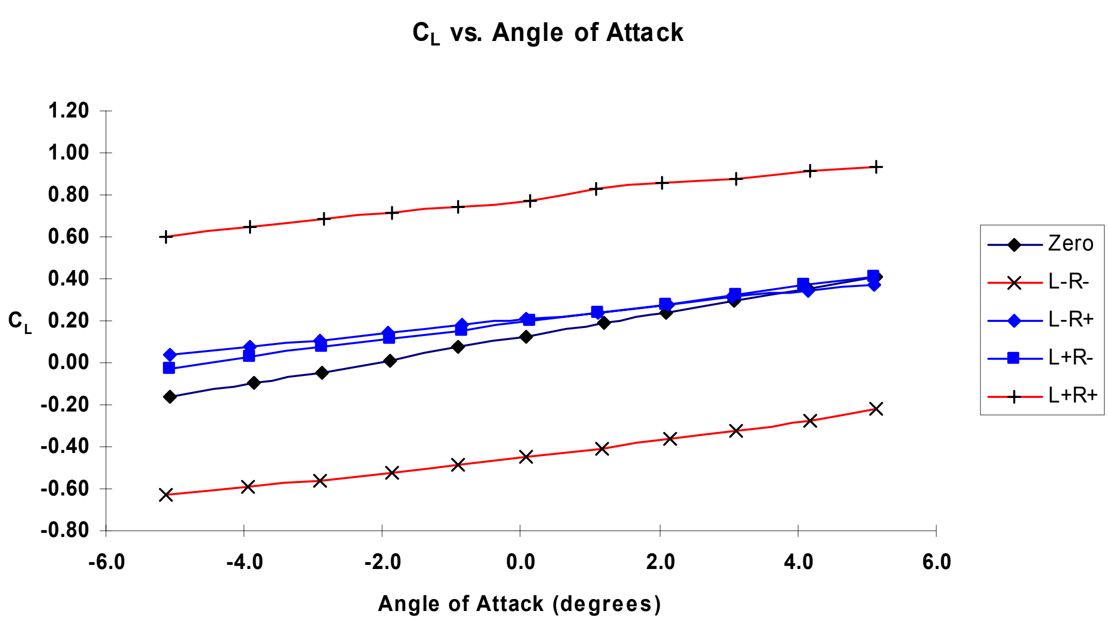
Raymer, Daniel P., *Aircraft Design: A Conceptual Approach*. AIAA Educational Series

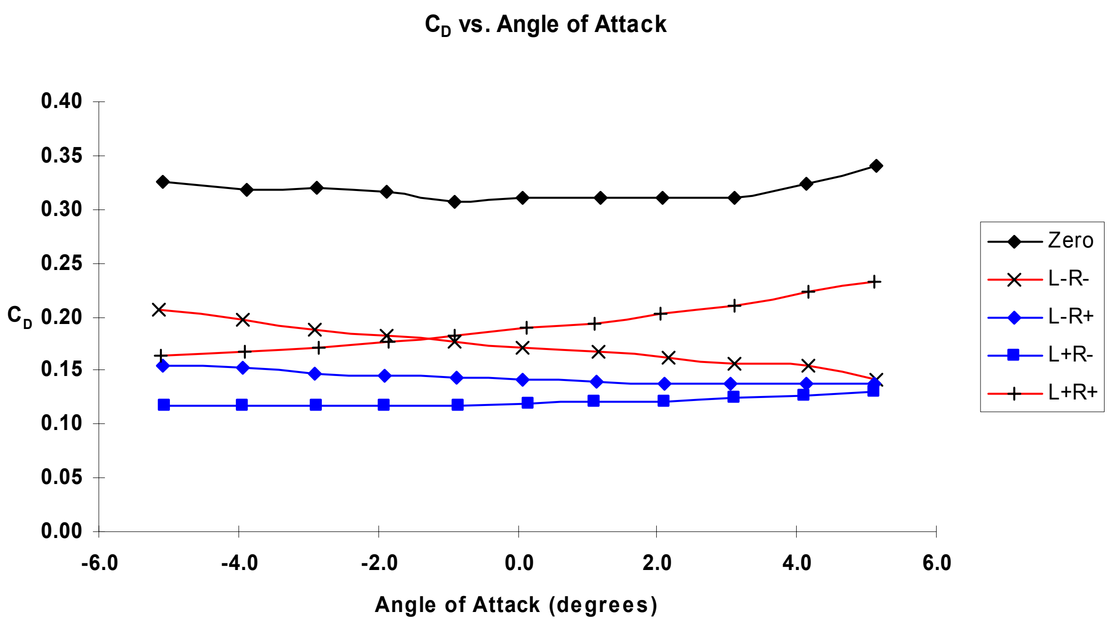
United States Navy. *Request for Proposals, UCAV-N*. 2002

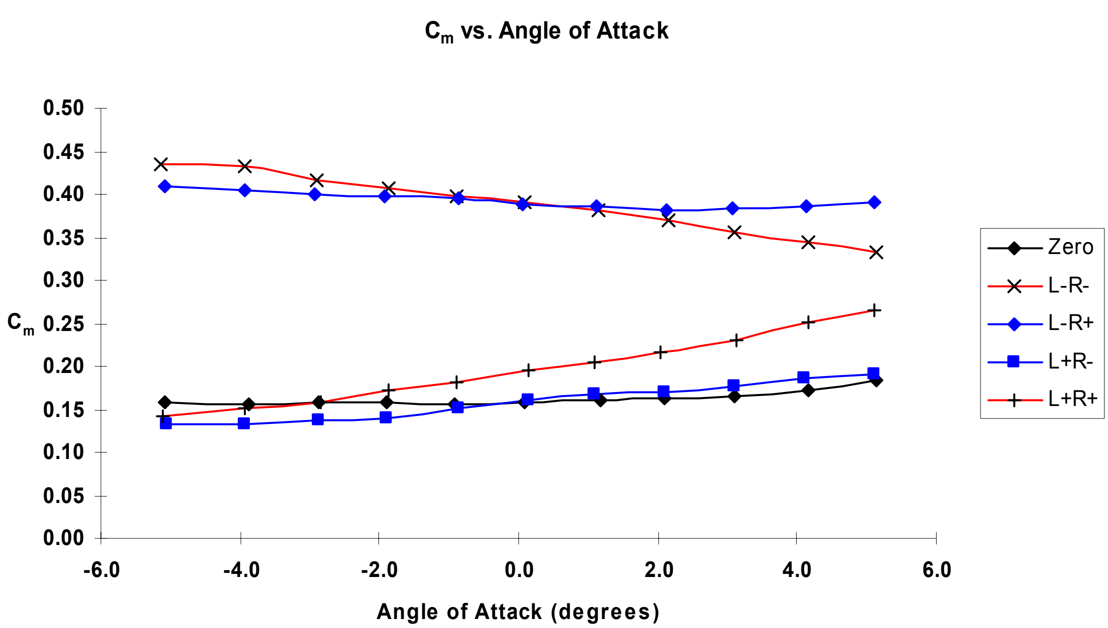
Appendix I Pelikan Tail Data

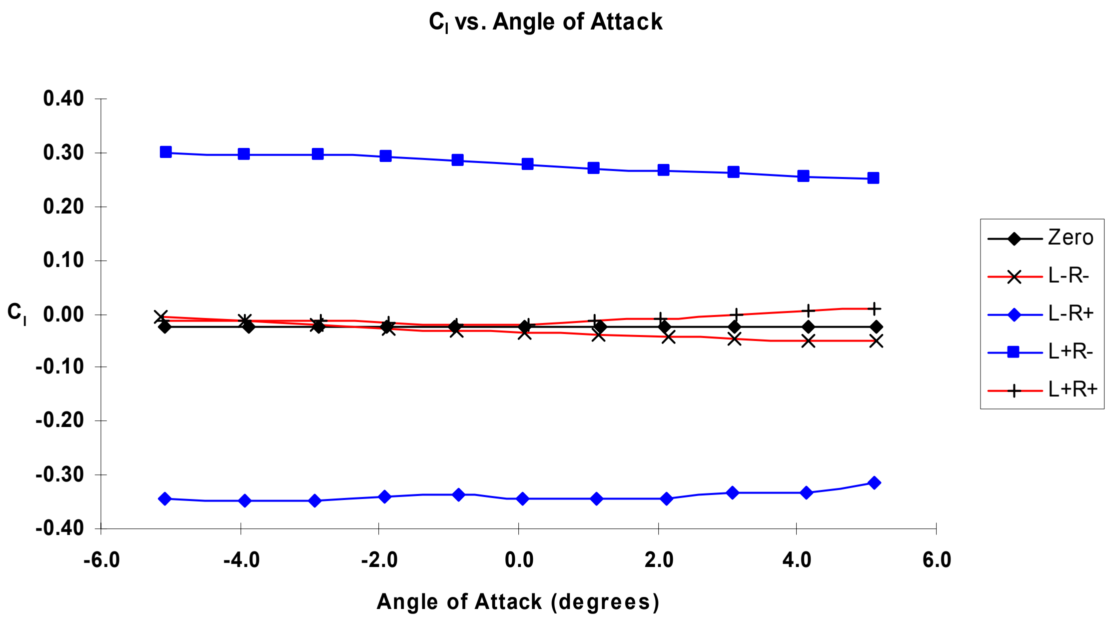
Blue lines represent full yaw deflections, left and right.
Red lines represent full pitch deflections, up and down.
Black line is the undeflected case.

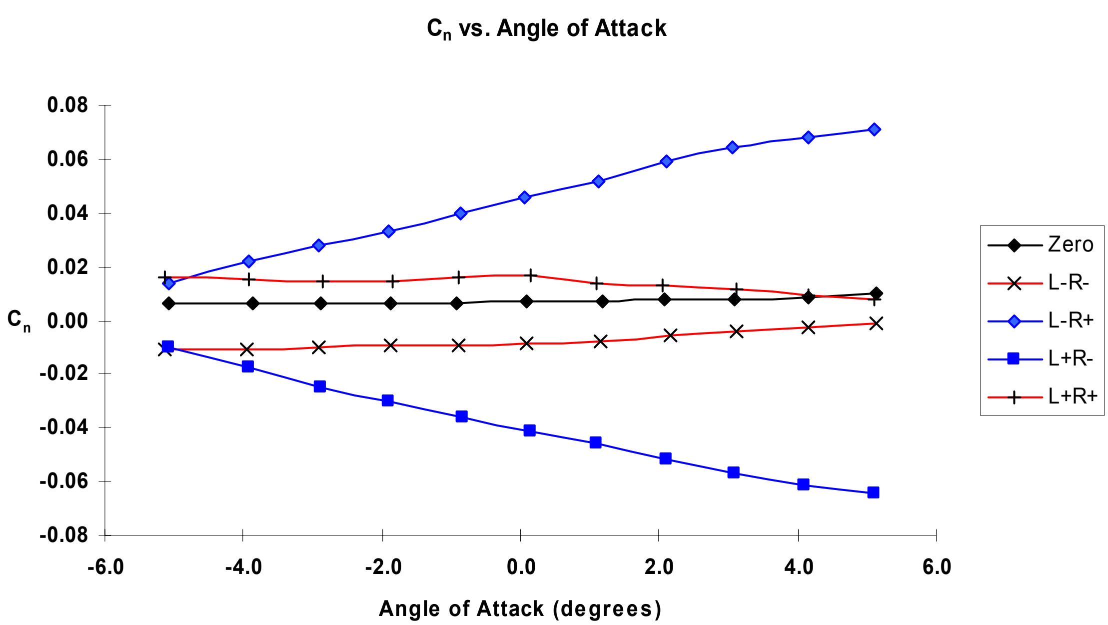





C_D vs. Angle of Attack
0.40
0.35
0.30
0.25
C_D 0.20
0.15
0.10
0.05
0.00
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
Angle of Attack (degrees)
Zero
L-R-
L-R+
L+R-
L+R+


C_m vs. Angle of Attack
0.50
0.45
0.40
0.35
0.30
C_m 0.25
0.20
0.15
0.10
0.05
0.00
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
Angle of Attack (degrees)
Zero
L-R-
L-R+
L+R-
L+R+


C$_l$ vs. Angle of Attack
0.40
0.30
0.20
0.10
C$_l$ 0.00
-0.10
-0.20
-0.30
-0.40
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
Angle of Attack (degrees)
Zero
L-R-
L-R+
L+R-
L+R+


C$_n$ vs. Angle of Attack
0.08
0.06
0.04
0.02
C$_n$ 0.00
-0.02
-0.04
-0.06
-0.08
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
Angle of Attack (degrees)
Zero
L-R-
L-R+
L+R-
L+R+