CHIMERA CSA

AEW ASW ES COD

Virginia Tech

VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

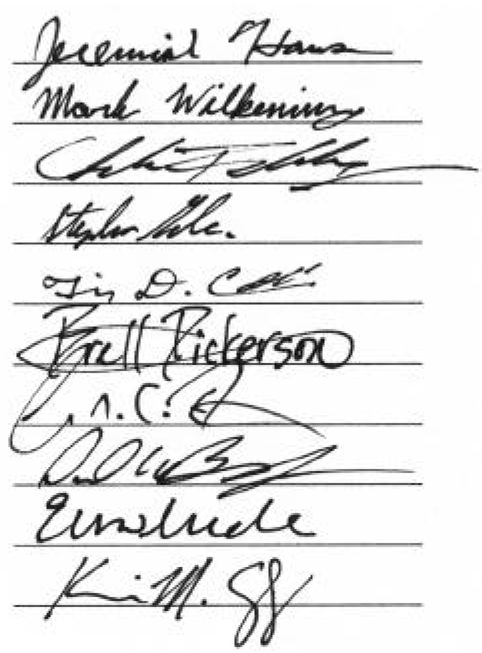
2000 / 2001 AIAA Undergraduate Team Aircraft Design

Background Courtesy of US Navy

June 4, 2001

Member Roster

Member:	**AIAA Member #:**	**Signature:**
Jeremiah Hansen	200109	
Mark Wilkening	199535	
Chuck Faulkenbury	200139	
Stephen Gabris	191301	
Timothy Collins	204318	
Brett Dickerson	204323	
Eric Kern	204317	
David Brown	204002	
Erin Crede	204005	
Kevin Cogley	204319	



Faculty Advisors

W. H. Mason

N. Kirschbaum

Executive Summary

The Chimera Group presents the Chimera as a solution to the 2000-2001 AIAA Undergraduate Team Aircraft Design Competition Request for Proposal (RFP) for a Naval Common Support Aircraft (CSA). The approach was for a capable, common, multi-role aircraft family suitable for Naval and land use.

The main drivers for this proposal were commonality for a multi-role aircraft family, capability rivaling modern aircraft, carrier deck requirements, and nominal life-cycle costs. Commonality for the aircraft family was achieved by keeping universal systems, engines, cockpit, wing structure, and empennage. Modern aircraft capabilities must be equaled or exceeded for the aircraft to be a viable replacement to current systems and to satisfy the RFP requirements, which are reiterated in Section 1.2. Carrier operational requirements and maintenance duties are cited in the RFP. Minimized production and life cycle costs are not RFP requirements, but a practical consideration for economical development of an aircraft for the military. The RFP drivers, combined with a realistic approach, were used to develop a practical and capable design.

The Chimera is a high-wing, twin-engine aircraft utilizing two fuselages. There is a Carrier On-board Delivery (COD) fuselage and a common fuselage for the Airborne Early Warning (AEW), Electronic Surveillance (ES) and Anti-Submarine/Anti-Surface Warfare (ASW/ASUW) roles. The fuselages of these variations consist of different electronics and role-specific components. All four variants share a common cockpit, landing gear, flight systems, engines, wing structure, and empennage. This allows for higher commonality for all the variants lowering manufacturing, maintenance, and life-cycle costs. The Chimera uses simple high-lift devices, electro-hydrostatic flight control systems, and currently used materials to simplify maintenance. Each variant has a compound taper wing with a moderately high aspect ratio for optimum performance based on RFP maneuverability requirements and drag reduction. Twin vertical tails allow for carrier hangar bay clearance without tail folding and address radome wake concerns. The Chimera is fitted with folding wings, an arrestor hook, and a catapult-capable nose gear for carrier operations. The aircraft family utilizes features based on RFP mission, carrier, and economic requirements.

Technology played a large factor in the development of the Chimera. The RFP requires the operational deployment of the Chimera by 2013. Allowing five years for testing and production, the Chimera will incorporate technology available by 2008. The aircraft structure is comprised of composite materials due to recent technological improvements in materials, and will assist in reducing maintenance and production costs. Advances in radar systems allow for a comparable range to current systems while reducing the weight. Aircraft engine advancements

allow for increased efficiency and lighter weight. With the latest engines, radar systems, and materials, the Chimera will be lighter, more efficient, and more capable than the current aircraft to be replaced. This reduces the operational costs of the aircraft while only marginally increasing the flyaway costs. Naval budgeting constraints provided the main reason for looking at economic requirements and costs.

The Chimera is a multi-role aircraft family with highly common components that do not sacrifice performance or requirements. Commonality provides a cost-savings to the Navy in acquiring aircraft, replacement part acquisition, and maintenance. The commonality, performance, and capability of this aircraft family make it the superior choice for a future common support aircraft. Table ES.1 shows how the Chimera meets or exceeds all requirements of the AIAA RFP. Figure ES.1 shows a basic common layout between the airframes. The Chimera aircraft family follows the popular principle of "In aircraft technology, simplicity is the ultimate sophistication" (Ref. ES.1).

Table ES.1 Mission Comparison Between Chimera and RFP Requirements

ASW/ASUW	**RFP**	**Chimera**	**AEW**	**RFP**	**Chimera**
Weapons Weight	5,200 lbs	5,622 lbs	**Avionics Weight**	12,000 lbs	12,000 lbs
Avionics Weight	5,000 lbs	5,000 lbs	**System Used**	AN/APS-145	IAI/ELTA
Endurance Time	4.5 hours	5 hours	**Endurance Time**	4.5 hours	4.5 hours
Loiter Altitude	25,000 feet	25,000 feet	**Loiter Altitude**	35,000 feet	35,000 feet
COD	**RFP**	**Chimera**	**ES**	**RFP**	**Chimera**
Avionics Weight	2,000 lbs	2,000 lbs	**Sensors Weight**	9,800 lbs.	9,800 lbs.
Payload Weight	10,000 lbs	10,000 lbs	**Endurance Time**	2.5 hours	4.0 hours
Passenger Capacity	26	27	**Loiter Altitude**	40,000 feet	40,000 feet
Range	1600 nm	2,000 nm			

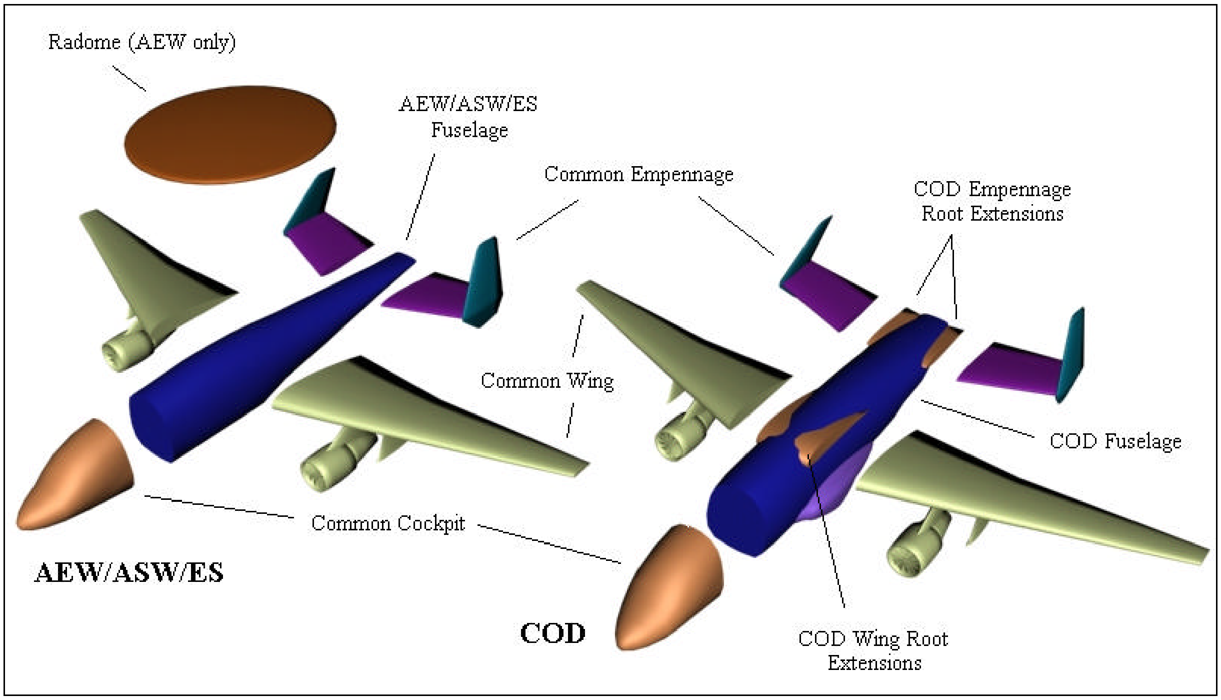


Figure ES.1 Two Main Fuselage Commonality Comparison for All Chimera Variants, 3-D

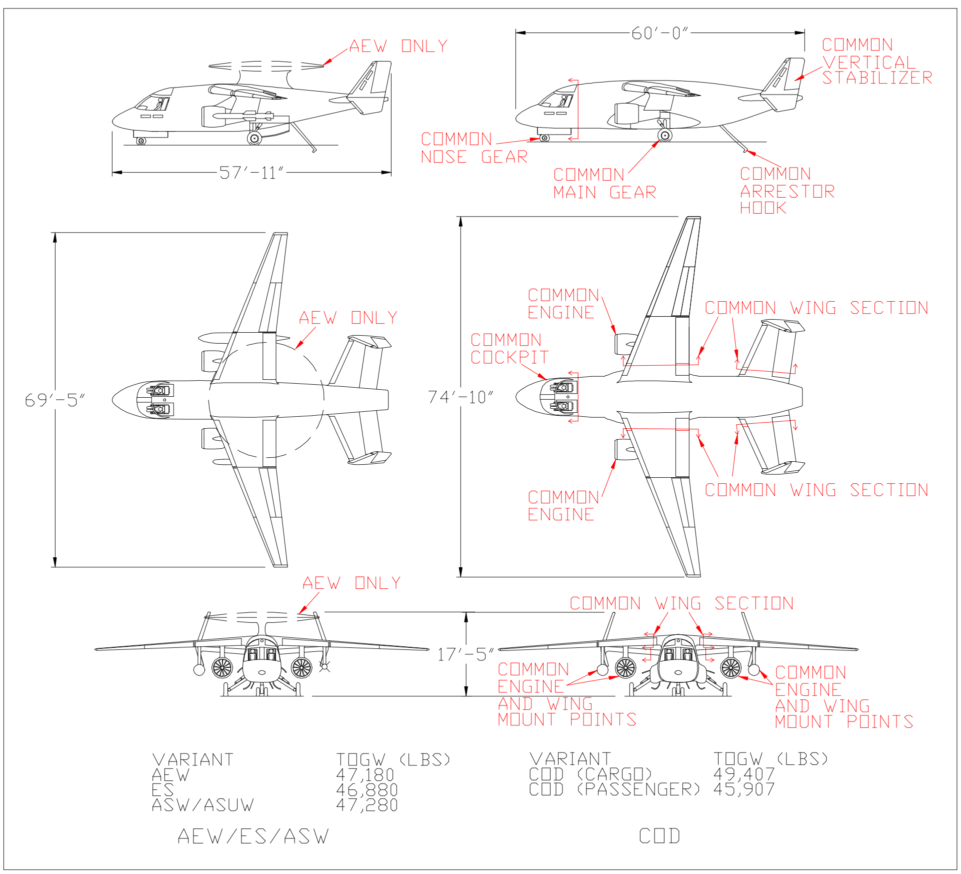


Figure ES.2 Two Main Fuselage Commonality Comparison for All Chimera Variants, 2-D

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AR**:** Aspect Ratio
C_{D0}**:** Skin Friction Coefficient or Parasite Drag
C_{DWAVE}**:** Coefficient of Drag due to Wave Drag
cg**:** Center of Gravity
C_L**:** Coefficient of Lift
C_{LMAX}**:** Maximum Lift Coefficient of the wing
e**:** Oswald Efficiency Factor
L/D_{MAX}**:** Maximum Lift to Drag Ratio
$M_{CRITICAL}$**:** Critical Mach Number
MDD**:** Drag Divergence Mach Number
S**:** Wing Area
S_{REF}**:** Reference Area of the Aircraft (The wing area extended to the centerline of the aircraft)
q **:** Twist of the Wing
V_{APPR}**:** Approach Velocity
V_{END}**:** End Velocity
V_{STALL}**:** Stall Velocity of the Aircraft
W/S**:** Weight to Area Ratio (Wing Loading)
W**:** Weight of the Aircraft
$W_{LANDING}$**:** Weight at Landing
ÄC_{D0}**:** Change in Skin Friction Coefficient or Parasite Drag
Äf**:** Flat Plate Equivalent Drag
r**:** Density of Air

List of Abbreviations

ACLS: Automatic Carrier Landing System
AEECS: All Electric Environmental Control System
AEW: Airborne Early Warning
AMLCD: Active Matrix Liquid Crystal Display
AOA: Angle of Attack
APU: Auxiliary Power Unit
ASW (ASUW): Anti-Submarine/Anti-Surface Warfare
C_{ACQ}: Acquisition Cost
C_{DISP}: Disposal Cost
C_{MAN}: Manufacturing Cost
C_{OPS}: Operating Cost
COD: Carrier On-Board Delivery
COTS: Commercial-Off-The-Shelf
C_{RDTE}: Research, Development, Test and Evaluation Cost
DFCS: Digital Flight Control Systems
EMI: Electromagnetic Interference
ES: Electronic Surveillance
FADEC: Full Authority Digital Electronic Control
FLIR: Forward Looking Infra-Red
HUD: Heads Up Display
KEAS: Knots Equivalent Airspeed
KTAS: Knots True Airspeed
LCC: Life Cycle Cost
MAC: Mean Aerodynamic Chord
MAD: Magnetic Anomaly Detector
RDTE: Research, Development, Test, and Evaluation
ROC: Rate Of Climb
SEROC: Single Engine Rate Of Climb
SFC: Specific Fuel Consumption
T/W: Thrust to Weight Ratio (Thrust Loading)
TBF: Time Between Failure
TCS: Tactical Control System
TOGW: Take Off Gross Weight
UAV: Unmanned Aerial Vehicle
WOD: Wind Over Deck

Chapter 1 Introduction and RFP

1.1 Introduction

The Chimera Group presents the Chimera aircraft as its concept for the common support aircraft competition. The Chimera has many missions to perform and was designed to meet the requirements of the American Institute of Aeronautics and Astronautics (AIAA) Undergraduate Team Aircraft Design Competition Request For Proposal (RFP). The Chimera meets all RFP requirements with a common aircraft family providing the greatest savings in costs and maintenance. The combination of uncompromised performance, competitive capacity in every role, and commonality sums up the philosophy used in the Chimera's development.

The most advanced technologies expected to be available by 2008, five years before the Initial Operation Capability date of 2013,will be used in the Chimera. Areas of technology expected to advance the most are radar systems, materials, and communication systems. Advanced technology use increases the production cost, but reduces life-cycle and maintenance costs. These technologies allow for faster retrofit, repair, and longer life of the aircraft. The extended life-cycle and lower associated costs offset the initial cost of the aircraft. This outlook on technology blends into the philosophy of completely meeting the RFP requirements to produce an advanced, affordable aircraft.

The Chimera Group's economical philosophy reflects the current needs of the Navy. Aircraft need to have versatility, high performance, low life-cycle costs, and minimal maintenance requirements. The Chimera satisfies these practical requirements and meets or exceeds current aircraft capabilities in each role. Aircraft versatility is satisfied by the integrated systems and two airframes. The airframes, although differing in volume and shape, share the same cockpit, systems, landing gear, engines, wing structure, and empennage. The common cockpit decreases repair and pilot instruction costs. Common systems and engines require a smaller pool of repair parts to service a fleet of aircraft. The smaller pool has two benefits: reduced storage area for common parts, and cheaper parts because of bulk purchases.

The Chimera's high performance addresses the RFP requirement for a structural limit load factor of 3.5 g's. In addition, there are loiter requirements: 4.5 hours at 25,000 and 35,000 feet (ASW/ASUW and AEW respectively), or loiter for 2.5 hours at 40,000 feet (ES role). The COD aircraft must have a range of 1,600 nautical miles. The aircraft family must have a dash speed of 425 knots at loiter altitude. Meeting these RFP requirements is important because they reflect role-specific requirements for delivering intelligence, early warning data, weapons, and cargo.

The maintenance needs of a naval aircraft are important on a space-limited carrier deck or hanger bay. Having many different spare parts for several aircraft takes up storage room and requires more maintenance training. Keeping the aircraft repairs inside the aircraft's 'shadow' makes it more serviceable on the carrier. Reducing part count in the simplicity of the systems makes servicing the aircraft simpler and more convenient. All these factors reduce the maintenance load for the mechanics and the carrier space requirements.

The life-cycle cost of the aircraft is a major concern in the modern Navy. The Chimera's commonality reduces the life-cycle cost of the aircraft due to the number of aircraft ordered, common parts, and interchangeability between aircraft. By reducing these costs, the Chimera is more economical than current Naval aircraft.

The Chimera Group used these requirements from the RFP and realistic considerations in the development of the Chimera aircraft. The result is an aircraft that meets or exceeds the requirements and current role-specific aircraft capabilities.

1.2 RFP Requirements

The common support aircraft is an aircraft concept that is attractive to the Navy for practical and economic reasons. Since it is a highly desirable project, the AIAA issued an RFP for the design competition to give realistic requirements for the project. The requirements from the RFP are stated and explained below.

1.) Aircraft structural limit load factor of 3.5 g's. This is to allow for basic maneuvers in combat with the ASW/ASUW version. This also allows an extra factor of safety in flight with turbulent conditions.

2.) The aircraft must be capable to give/receive aerial refueling. This requirement is for the aircraft to be able to refuel, and be refueled to extend an aircraft's range and endurance time.

3.) Launch Wind Over Deck (WOD) not greater than zero knots, approach WOD not greater than 5 knots. This is to ensure the aircraft can operate in the advent of unfavorable, low speeds from a carrier deck. WOD requirement allows proper stopping power for the aircraft, and appropriate go-around power for an aborted landing.

4.) Maximum Take-Off Gross Weight (TOGW) not greater than 90,000 lbs. This is to ensure the aircraft can land on a carrier properly.

5.) Dash speed not less than 425 knots.

6.) Aircraft fits within the following area: overall length of 60.0 feet, wingspan of 80.0 feet (folded span: 76.0 feet), and overall height no greater than 18.5 feet. The last two requirements are for aircraft carrier hanger openings.

7.) Launch Single-Engine Rate Of Climb (SEROC) not less than 200 ft/min, approach SEROC not less than 500 feet/min. This is to insure a minimum climb/approach angle for safety.

8.) Fuel for five minutes of full power operation and 5% fuel reserve. This is to allow for warm-up, taxi, and take-off fuel requirements and a reserve for emergency fuel requirements.

9.) AEW cruise at best altitude for 250 nautical miles to and from loiter station. AEW loiters for 4.5 hours at 35,000 feet on station at best endurance speed. Upon return to carrier, loiter at sea level for 20 minutes at best loiter speed. These requirements are for fuel requirements based on a specific mission profile and are illustrated in Figure 1.1.

10.) AEW allowance of 12,000 lbs for avionics/sensor weight.

11.) ES cruise at best altitude for 520 nautical miles to and from loiter station. ES loiters for 2.5 hours at 40,000 feet on station at best endurance speed. Upon return to carrier, loiter at sea level for 20 minutes at best loiter speed. These requirements are for fuel requirements based on a specific mission profile and are illustrated in Figure 1.2.

12.) ES allowance for 9,800 lbs avionics/sensor weight.

13.) ASW/ASUW cruise at best altitude for 245 nautical miles to and from loiter station. AEW loiters for 4.5 hours at 25,000 feet on station at best endurance speed and launches anti-ship missiles while on station. Upon return to carrier, loiter at sea level for 20 minutes at best loiter speed. These requirements are for fuel requirements based on a specific mission profile and are illustrated in Figure 1.3.

14.) ASW/ASUW to carry two advanced torpedoes, two advanced anti-ship missiles, and 68 type A sonobuoys. Avionics weight is 5000 lbs. This is to specify the ASW/ASUW weapons requirements for the ASW/ASUW mission.

15.) COD cruise at best altitude for 1600 nautical miles. Upon arrival, loiter at sea level for 20 minutes at best loiter speed. These requirements are for fuel requirements based on a specific mission profile and are illustrated in Figure 1.4.

16.) COD allowance for 2,000 lbs of avionics and 10,000 lbs of cargo or 26 passengers. As an additional requirement it was decided to be able to carry three 463L cargo containers as does the C-2 Greyhound.

Table 1.1 is a review of the important RFP requirements for each mission and the mission design drivers. The mission that defined the Chimera's performance limits is the COD. A secondary mission that drove aerodynamic development was the AEW. These set endurance and engine requirements because of the relatively higher drag and weight.

Table 1.1 Main RFP Requirements By Mission

ASW/ASUW	RFP	AEW	RFP
Weapons Weight	5,200 lbs	**Avionics Weight**	12,000 lbs
Avionics Weight	5,000 lbs	**System Used**	AN/APS-145
Endurance Time	4.5 hours	**Endurance Time**	4.5 hours
Loiter Altitude	25,000 feet	**Loiter Altitude**	35,000 feet
COD	**RFP**	**ES**	**RFP**
Avionics Weight	2,000 lbs	**Sensors Weight**	9,800 lbs.
Payload Weight	10,000 lbs	**Endurance Time**	2.5 hours
Passenger Capacity	26	**Loiter Altitude**	40,000 feet
Range	1600 nm		

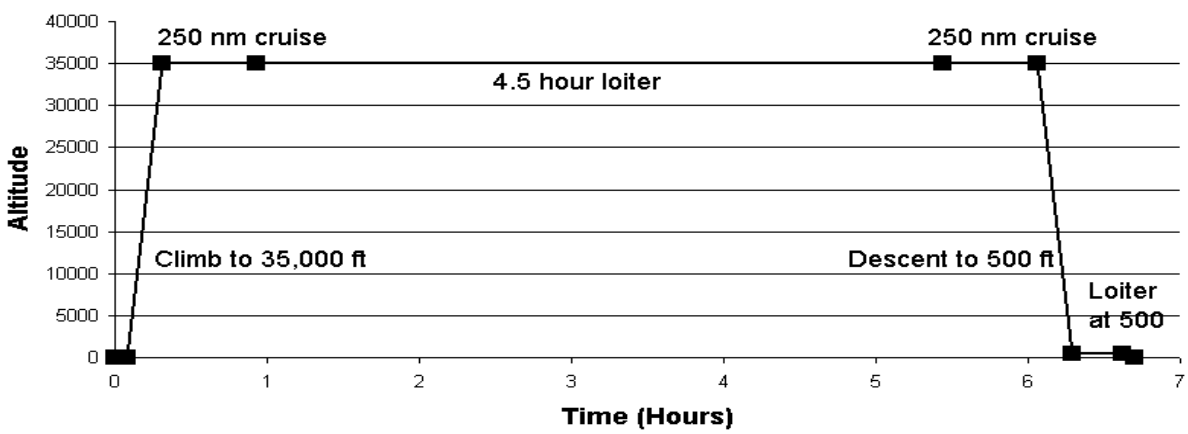


Figure 1.1 AEW RFP Mission Profile as a Function of Time

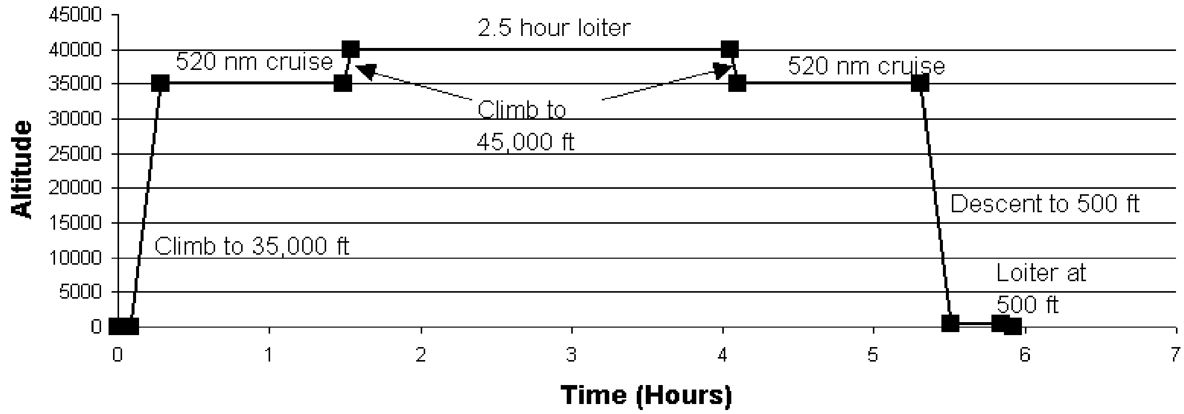


Figure 1.2 ES RFP Mission Profile as a Function of Time

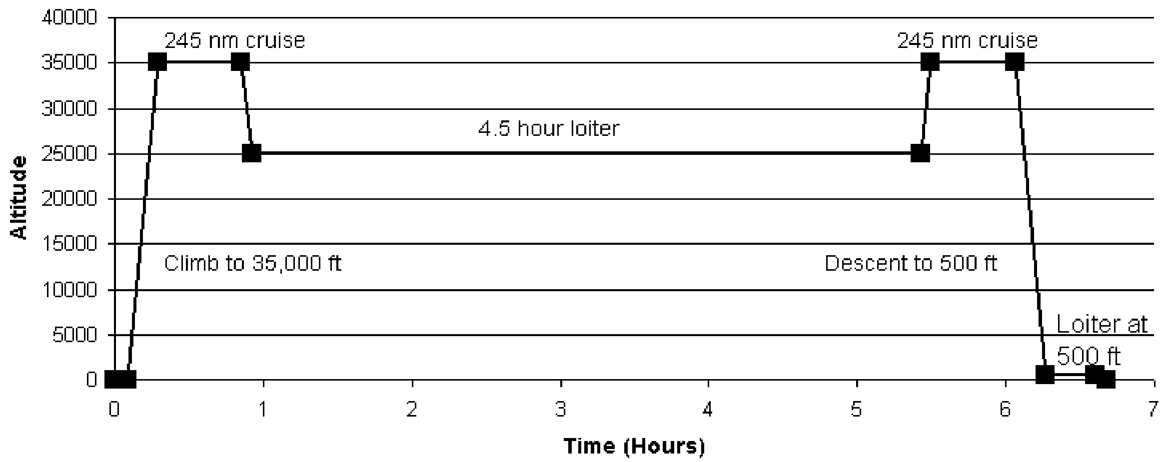


Figure 1.3 ASW RFP Mission Profile as a Function of Time

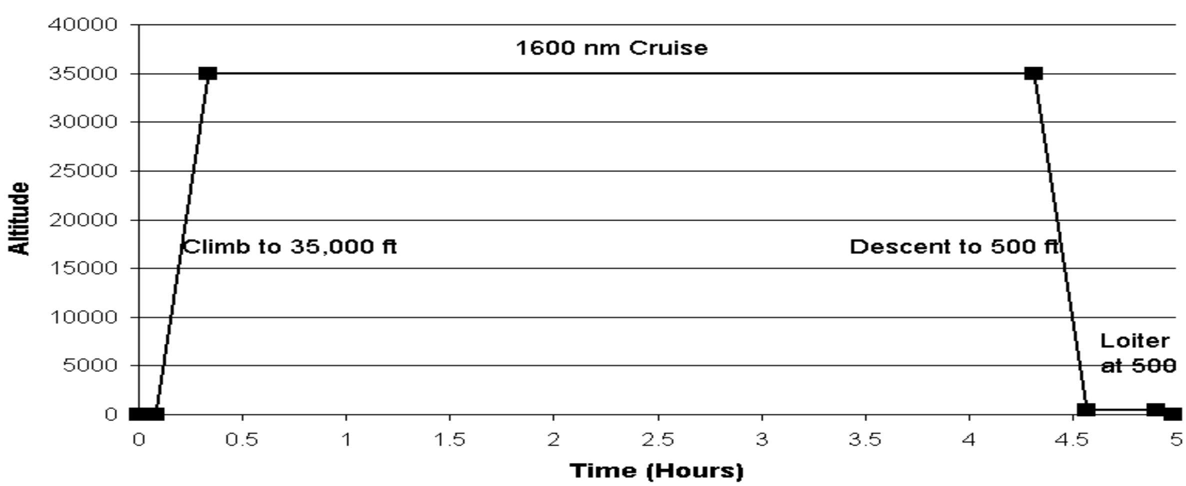


Figure 1.4 COD RFP Mission Profile as a Function of Time

Chapter 2 Comparison and Decision

The preferred concept emerged from eight original designs, each offered by members of the design team. Before creating these designs, a comparator study was performed between existing aircraft. These aircraft provided a set of systems and capability prerequisites, which were taken into account with the individual designs. The comparator studies focused on the C-2, E-2C+, S-3B, and ES-3A. Table 2.1 shows the current aircraft information.

Table 2.1 Comparator Study of Current Aircraft. Images Courtesy of F.A.S. (Ref. 2.1)




	Grumman C-2A	Grumman E-2C+	Lockheed S-3B	Lockheed ES-3A
Wingspan	80 ft 4 in.	80 ft 4 in.	68 ft 6 in.	68 ft 6 in.
Height Overall	15 ft 10.25 in.	18 ft 4 in.	22 ft 9 in.	22 ft 9 in.
Length	56 ft 10 in.	57 ft 6 in.	53 ft 4 in.	53 ft 4 in.
Wing Area	700.0 ft^2	700.0 ft^2	598.0 ft^2	598.0 ft^2
Empty Weight	35,000 lbs	38,063 lbs	26,650 lbs	27,000 lbs
TO Weight	57,000 lbs	53,000 lbs	52,539 lbs	52,539 lbs
Engine # and Type	(2) Turboprop	(2) Turboprop	(2) Turbofan	(2) Turbofan
Horsepower / thrust	4,600 shaft horsepower each	5,100 shaft horsepower each	9,275 lbs of thrust each	9,275 lbs of thrust each
Range	1,043 nm 10,000 lb cargo	1,395 nm	2,300+ nm	2,300+ nm
Cruise Speed	260 knots	268 knots	370 knots	370 knots
Max Speed	310 knots	338 knots	450 knots	450 knots
Climb	2,608 ft/min	2,513 ft/min	3,934 ft/min	3,934 ft/min
Ceiling	33,500 ft	37,000 ft	40,000 ft	40,000 ft
Armament	Carrier On-Board Delivery	24 ft diameter radome	3,958 lbs of munitions	Electronic Reconnaissance
Crew	4	5	4	4
Cost	$38.96 million	$51 million	$27 million	$33 million

Every specification was not given in the RFP, so current aircraft systems served as a basis for the CSA design decisions. One example of this is the AEW radar range; the current range of the E-2C+ served as a guide for the Chimera AEW variant. The weapon carrying capacity of the S-3B and the cargo capacity of the C-2 were very similar to the RFP requirements. As a result, the RFP requirements served as an appropriate guide for the initial designs of the CSA.

Figure 2.1 illustrates the design concept tree. The concept tree shows the progression of the aircraft revisions from the original eight on the bottom to the preferred concept at the top. The number below the aircraft is the number of different fuselages required to accomplish all the RFP roles. The original eight include several conventional designs, a joined wing design, a box wing design, and a twin boom design. These designs were produced by each team member and constituted different assumptions, technologies, and personal preferences.

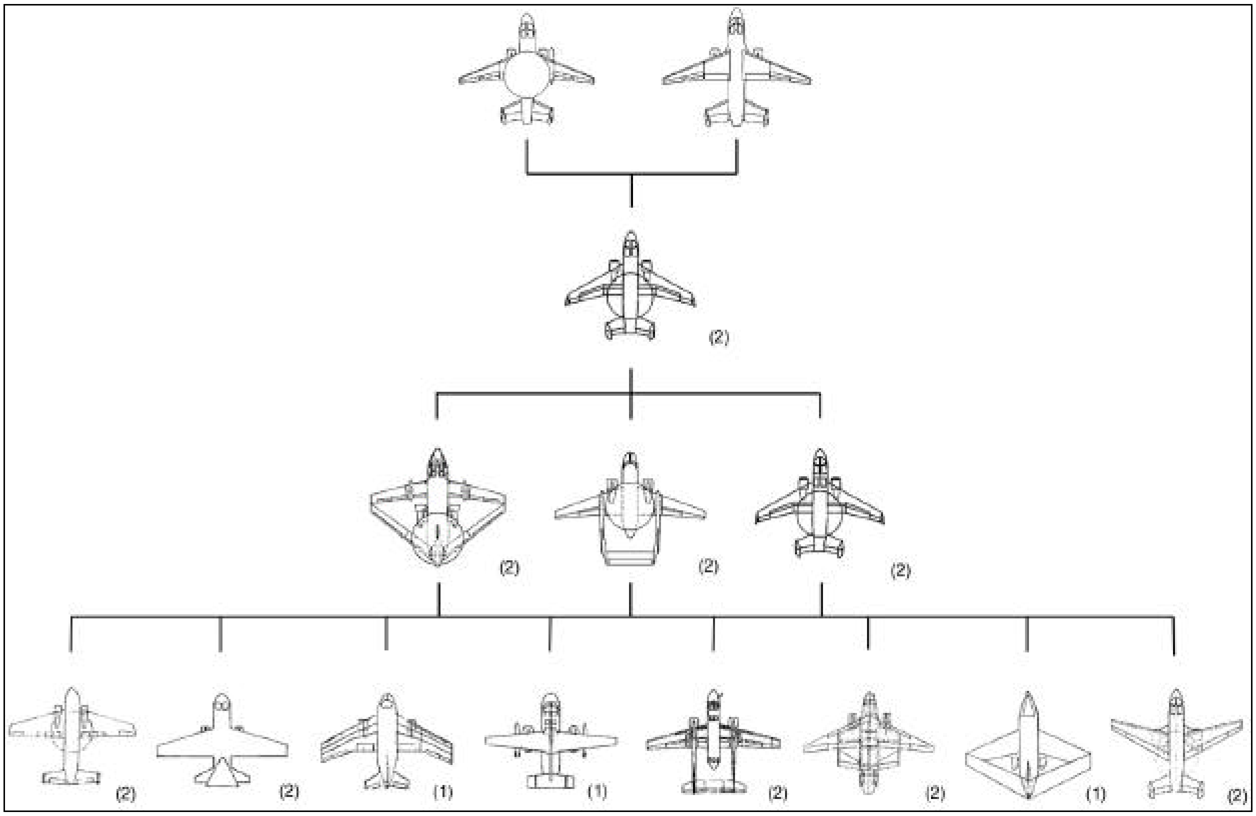
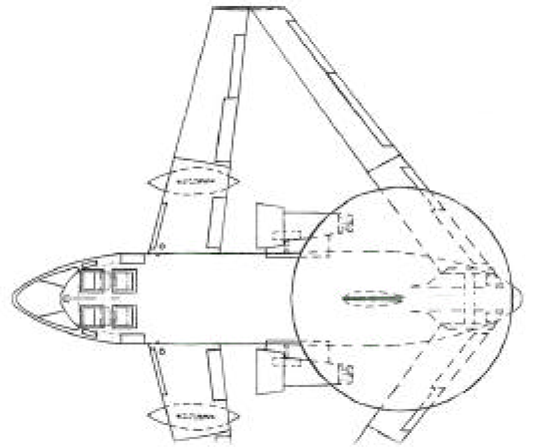


Figure 2.1 Concept Tree from the Individual Designs to the Preferred Concept

The first decisions and eliminations were mainly based on the practicality of each design, RFP requirements, economics, and maintenance considerations. The aircraft were also compared to existing aircraft in performance, capability, and carrier suitability. These comparisons allowed the group to view each design and determine which configuration incorporated the most creativity and practicality. The original eight aircraft designs were refined to three intermediate concepts.

2.1 Box Wing Concept Analysis

Length	55.8 ft		
Height	18.0 ft		
Folded Span	30.8 ft		
	Wing	Horizontal Stabilizer	Vertical Stabilizer
Dihedral (deg)	5.0°	-13.0°	
Area (ft²)	756.0	229.9	70.0
Span (ft)	64.0		4.5
Aspect Ratio	6.697		
Root Chord (ft)	8.0	6.0	10.0
Tip Chord (ft)	4.0	4.0	5.0
Taper Ratio	2.0	1.5	
MAC (ft)	8.0	6.0	
L.E. Sweep	15.0°	-35.0°	25°



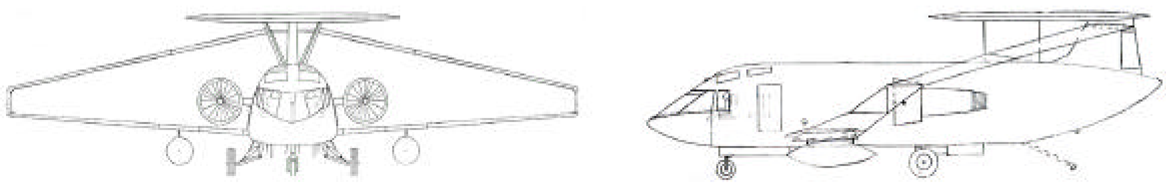


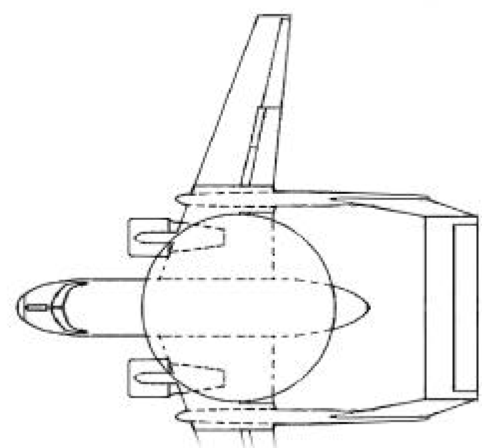
Figure 2.2 Box Wing Concept

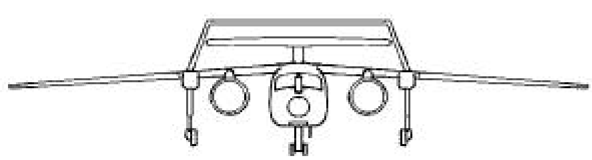
The box wing concept, shown in Figure 2.2, is an advanced aircraft in relation to the conventional cantilever wing layout of current aircraft. The joined wings are used to reduce the structural internal moments in the wings, thus decreasing the weight and material requirements with respect to a cantilever wing through less necessary structure. The main aspect of the concept is the wing structure, which has two oppositely swept wings joined at the tip and placed fore and aft of the center of gravity (*cg*). To enhance the structural benefits, the aft wings are joined near the tip of the two vertical tails. The wings on the intermediate design are joined at the tip, with the forward wing swept back 15º and with a dihedral angle of 5º. The aft wing is swept forward 35º and has an anhedral angle of 13º. The joining surface between the wings is a 3-foot vertical connection, which locks the wings together during flight, but separates at its mid-span for folding on the carrier deck. The forward wings are mounted near the bottom of the fuselage at its widest point, and the aft wings are mounted near the vertical tail tips. The twin vertical tails are attached two feet out from the centerline, with each tail inclined outboard from the vertical by 22º.

Based mainly on the Wolkovitch paper (Ref. 2.2) and the aircraft's unusual design, it was decided that further development of the box wing plane design was necessary because the aircraft had some potential structural and weight gains associated with the box wing concept. The potential advantages were investigated, but the results were not as promising as Wolkovitch claimed. Currently the only major advantage to using a box wing concept is for incorporating conformal radar. Due to complicated airflow and structural design, the computational time required to optimize this design would be much larger than that required for a conventional aircraft (Ref. 2.3). The benefits gained represent at best a 10% overall weight savings, yet this does not outweigh the penalties. Operational costs marginally improve by a few hundredths of a percent (Ref. 2.3), and the Wolkovitch savings fall into question in relation to the structural demands on carrier aircraft. The wings require a complex folding and support system, which drastically increases the weight of the wings. Another problem discovered was the loss of fuel tank area. With this wing design, the fuel tank volume reduces by a factor of at least 50% for the same total wing area. The increased structure and additional hardware negate any benefits of the box wing in weight savings and overall cost.

2.2 Twin Boom Concept Analysis

Length	57.5 ft		
Height	18.5 ft		
Folded Span	33.3 ft		
	Wing	Horizontal Stabilizer	Vertical Stabilizer
Dihedral (deg)	-5.0°	-0°	
Area (ft^2)	708.4	149.5	81.45
Span (ft)	76.0	23.0	9.05
Aspect Ratio	8.154	3.54	
Root Chord (ft)	15.5	6.5	11.5
Tip Chord (ft)	4.0	6.5	6.5
Taper Ratio	0.258	1.0	
MAC (ft)	10.45	6.5	10.25
L.E. Sweep	20.0°	0.0°	58°





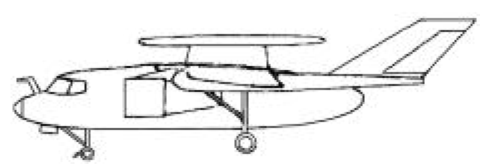


Figure 2.3 Twin Boom Concept

The twin-boom concept, shown in Figure 2.3, consisted of a central fuselage and twin booms connected by the wing and the horizontal stabilizer. This concept family would have two fuselages since the COD variant required a cargo volume large enough to accommodate three 463L size pallets or 26 passengers. The fuselage width for the AEW, ASW, and ES variants was 7 ft and the wingspan was 76 ft. An AN/APS-145 radar system would be mounted on the AEW aircraft. Likewise, a 12 ft long, 5.5 ft wide and 4 ft tall bomb bay would be installed on the ASW variant that would house two advanced torpedoes and two advanced anti-ship missiles. For ASW missions a MAD boom could be extended and retracted from the port boom. The wings on the AEW/ES/ASW variants were automatically actuated to fold backward on a skewed hinge similar to that on the E-2 and connect to the side of the booms, which gave the AEW/ES/ASW variant a folded span of 33 ft.

To fulfill the cargo requirements for the COD variant, a 2 ft spacer was installed down the centerline of the fuselage. This effectively increased the fuselage width to 9 ft and the wingspan to 78 ft. The dimensions of the cargo hold were 28 ft long, 7.5 ft wide, and 7.75 ft high. Passengers would be able to board through a side door while cargo could be loaded through a rear cargo door. The tail cone of the fuselage was actuated to fold vertically and allowed a 14 ft ramp to be extended. The COD variant would also act as a fuel tanker with a stored drogue and reel located in the port boom. As mentioned previously the wings folded backward on a skewed hinge, which gave the COD variant a folded span of 35 ft.

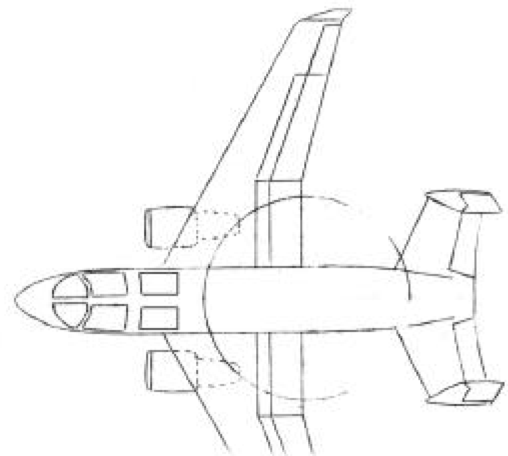
After analyzing this concept and comparing it to the other two concept families, several advantages and disadvantages were determined. Due to the placement of the booms, the main landing gear could be installed outboard of the engines, leaving the fuselage free of the volume penalty associated with the gears' retracted stowage. This would give the aircraft more stability during landing conditions, but would also increase the landing load moments on the wing structure, which would increase weight and maintenance cost. The twin boom concept would not need external fuel tanks because all reserve fuel could be stored in the booms. The horizontal stabilizer was connected to the booms, allowing an unobstructed loading path for the COD variant

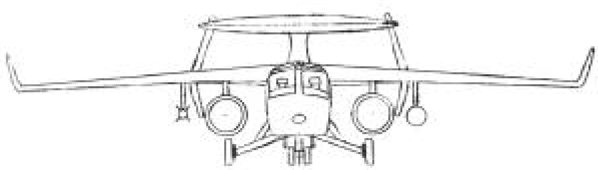
There were several detriments to the twin-boom concept, most importantly to the COD fuselage. To accommodate three 463-L size pallets, desired by the Chimera design, the fuselage would need to be extended further aft and beneath the horizontal stabilizer, inhibiting the vertical fold of the fuselage tail cone. This extension would also increase drag due to increased wetted area and would create venturi effects between the upper fuselage and the horizontal tail. Extending the fuselage would also negate the purpose of the booms. These negative results could be alleviated if only two 463-L pallets were carried, however the Chimera Team's design goal was to carry three pallets.

Cost was the final detriment to this design. In order to relieve problems associated with the COD variant, more research time would be needed. This would increase research and development (R&D) costs. Maintenance costs would increase because of the additional stresses to the twin booms and wing during arrested landings.

2.3 Conventional Concept Analysis

Length	58.6 ft		
Height	18.0 ft		
Folded Span	30.0 ft		
	Wing	Horizontal Stabilizer	Vertical Stabilizer
Dihedral (deg)	-3°	1°	
Area (ft^2)	595.38	178.15	70.0
Span (ft)	70.0	25.5	7
Aspect Ratio	8.23	3.79	
Root Chord (ft)	16.6	9.6	8.0
Tip Chord (ft)	4.9	7.0	4.0
Taper Ratio	0.295	0.729	
MAC (ft)	11.08	8.3	8.0
L.E. Sweep	28.7°	27.0°	44.5°





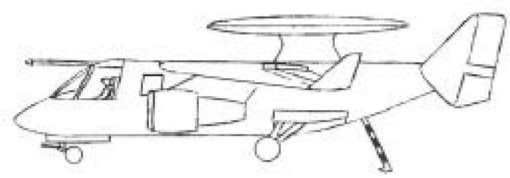


Figure 2.4 Conventional Concept

The third intermediate design, in Figure 2.4, was the conventional concept. The original eight concepts included a number of conventional type aircraft. The motivation toward this design was the cost effectiveness and the proven flight performance of current aircraft. The intermediate conventional concept combined ideas from each of the original concepts in an attempt to achieve the best mix of a high performance and cost effectiveness.

Figure 2.4 shows a three-view drawing of the intermediate conventional concept (ASW/AEW variant) and includes the main dimensions. The key dimensions are a 70.0 ft wingspan, 58.6 ft length, and 18.0 ft height. These dimensions met the carrier size box requirements and allowed some room for expansion if needed for later design changes, including the larger wingspan on a COD variant. The folded wingspan on the ASW version is 30.0 ft with the COD variant approximately three feet wider. The maximum folded span is 33.0 ft, giving the aircraft a smaller spotting factor than the other versions. The overall height of the aircraft is kept below the required 18.5 ft by using twin vertical stabilizers. This kept the height within carrier constraints without sacrificing vertical stabilizer area needed for control. With twin vertical tails a tail fold was not necessary. Non-folding vertical tails alleviate weight of actuators and braces and have higher structural integrity. The surface area of the twin tails was designed to be approximately equal to the surface area of a single vertical tail and does not increase the parasite drag. Additionally the use of twin vertical tails removes the vertical control surface from the turbulent wake of the radome and its pylon making the control surfaces more efficient.

This conventional design incorporates as much commonality in the aircraft family as possible. The wing outboard of the carry through wing box, engines, cockpit, and empennage are common for all four variants. The fuselage size is common for all but the COD variant, which had a three-foot spacer in the center of the fuselage providing the additional cargo space required in the RFP. The COD variant uses the same cockpit as the other three variants and the fuselage section is faired-in to connect with the cockpit width, but done so in a way that minimizes drag effects. The fuselage of the COD variant is designed around the ability to hold three 463L cargo containers or 26 passengers. The cargo containers will be loaded using an aft fuselage cargo ramp that opens similar to the current C-2 Greyhound. The AEW, ES, and ASW variants have a slightly different internal fuselage. The AEW and ES have additional seating and workstations for the radar/sensor operators and a weapons bay for the ASW.

Cost was among the most important issues behind this concept. This type of aircraft already exists, which should decrease its development costs. This concept will need little additional research and development costs as the conventional airframe is proven, and would be simpler and less expensive than the other designs. The aircraft should be able to use many Commercial-Off-The-Shelf (COTS) parts, decreasing manufacturing costs. Finally, this type of aircraft is proven in terms of structure and performance.

The disadvantages of this design are centered around the fact that the platform is not innovative. However, there are no questionable performance characteristics, which could decrease marketability. It is designed to use the latest advanced systems in each respective variant to accomplish each mission with increased efficiency and less operation cost compared to the numerous existing aircraft. Most importantly, it will use one base airframe and propulsion system.

2.4 Decision

Table 2.2 is a comparison between the three intermediate aircraft, which was used to select the preferred concept. The categories listed on the chart were given a scaling factor from one to eight (because there were eight categories) based on their importance; eight being used for the most important category. Each aircraft was then analyzed and given a score of -2 to 2 for each category, where a score of '2' was the best and '-2' the worst. If an aircraft was given a '0' for a category, this meant that it neither excelled nor was poor in that category. All of these individual category scores were multiplied by the scaling factor and an overall score was calculated for each initial aircraft. This chart allowed the team to use a numerical approach to select a preferred concept. The conventional intermediate aircraft had the highest score making it the preferred concept.

Table 2.2 Comparison Chart Between the Three Intermediate Designs

Category	Scaling Factor	Conventional	Twin Boom	Box Wing
Marketability	x1	+1	+1	-1
Overall Cost	x7	+2	+2	-1
Safety	x8	0	0	0
Drag	x5	0	-0.2	-0.5
Maintainability	x6	+1	+1	-1
Certifiability	x2	0	0	-1
TOGW	x5	0	0	+1.5
Performance	x5	-1	-1	+1
Totals		**16**	**10**	**1.5**

There were further reasons for choosing the conventional aircraft for the preferred concept. Comparing the different aircraft, the box wing concept was removed because of wing folding concerns and the fact that the weight advantages were minimal, if not altogether non-existent in the carrier environment. The twin boom aircraft was also removed because of concerns with aerodynamic interaction between the fuselage and tail in the COD variant and the probability of not being able to meet COD cargo requirements. Comparing the concerns, advantages, and disadvantages, it was decided that the conventional style was the best design.

2.5 Technology Decisions

Aside from deciding which concept to continue with for the final design, there were some technology decisions that needed to be made. These included: V/STOL systems, Unmanned Aerial Vehicles (UAV), radar systems used by the AEW variant, and whether all four variants would use a common fuselage design. These concerns were addressed early, allowing the appropriate research to begin.

Engine research needed to begin early on in the design so an approximate required thrust was calculated based on the preferred concept sizing. V/STOL was assessed before an engine was chosen for the aircraft. VTOL was quickly ruled out due to the large engines required for vertical take-off and landing and the fact that it was not required that the aircraft have this capability. Based on the fact that the added weight of engine configuration for STOL neutralized the benefits gained from the system, STOL was ruled out. The takeoff length would not be significantly reduced by a STOL system because of the added weight. Chapter 3 discusses the thrust vectoring concept used in STOL and the reasons why it was disregarded.

Incorporating Unmanned Aerial Vehicle (UAV) technology into the aircraft was debated. As of this date, there are no passenger-carrying UAVs. The reason for this is the lack of trust from the passengers. This posed a problem for our aircraft because one of the COD missions requires transporting 26 passengers. Because of commonality, the cockpit was designed to be the same for all the variants. Knowing this, a UAV aircraft was ruled out for the AEW, ASW, and ES missions as well. A second reason for not going with the UAV is the carrier landings. Some aircraft operating today, such as the F/A-18 Hornet, can land on an aircraft carrier without a pilot. Most pilots however do not fully trust this system and it still needs to be perfected because of the large number of variables involved when landing on an aircraft carrier. Reducing the number of people required on board the aircraft was desired to reduce weight. It was then decided that the normal crew of four aircraft operators could be reduced to two with technology. The AEW radar and electronic surveillance operators could be stationed on the aircraft carrier doing their jobs remotely. Having these two operators on the carrier has many advantages. Taking two people, two ejection seats, and other associated requirements of the two people off the aircraft will decrease the weight. If the aircraft was damaged or had a malfunction that caused it to crash, fewer lives would be at risk or lost. Finally, having the operators on the carrier would allow more operators taking shorter shifts, reducing fatigue and errors.

In order to proceed with stability, performance, weights, and other calculations, a decision for having a common fuselage needed to be made. It was desired that the aircraft family be as common as possible to cut down on costs. The fuselage needed to be larger for the COD variant than for the other three variants in order to fit the desired three 463L pallets. Keeping a common fuselage would cause the three non-COD variants to be larger than required. A drag analysis between the COD fuselage and the smaller fuselage of the other variants indicates that the COD fuselage has a 21% larger parasite drag. This difference influenced the decision to go with two fuselages, which would slightly increase production costs while lowering operating costs. Although two fuselages were decided upon, a common cockpit section was used on all the variants. The common cockpit is faired into the wider COD fuselage. This idea was based on increasing the commonality of the CSA family.

The radar technology used in the AEW was then investigated. Research into possible radar systems fell mainly between a conventional radome, phased array, and conformal radar. This research led to the choice of a phased array radome. The decision process is explained in-depth in the Systems chapter.

The design decision led to a discussion of the design options. Fundamental questions led the discussion between the three designs, and ultimately guided the overall design process of the preferred concept. The technologies utilized are some of the most modern as well as some of the older, more proven technologies. This combination allows for the utilization of higher efficiency systems in a more conventional, traditionally accepted design.

2.6 Final Sizing

The weight of the COD variant was determined to be the constraint on the final sizing of the Chimera aircraft family. This is mainly due to the weight constraints of take-off and landing. The carpet plot shown in Figure 2.5 was used to determine the final sizing of the COD variant. To generate this figure, the carrier take-off and landing, missed approach, and maneuver constraints were plotted against wing loading and thrust to weight. The Single Engine Rate of Climb (SEROC) constraints for take-off and approach were also calculated, but are not shown on this figure because they require a T/W below 0.3, assuming the use of two engines per variant. From initial weight estimates the TOGW of the COD was 52,000 lbs. From the carpet plot, a wing loading of 73 psf, a T/W ratio of 0.37, and a TOGW of 49,250 lbs were determined to be the design parameters of the COD. After reviewing the airframe material selection, a more accurate weight analysis showed that the use of composites reduced the structural weight by approximately 15%, reducing wing area and drag.

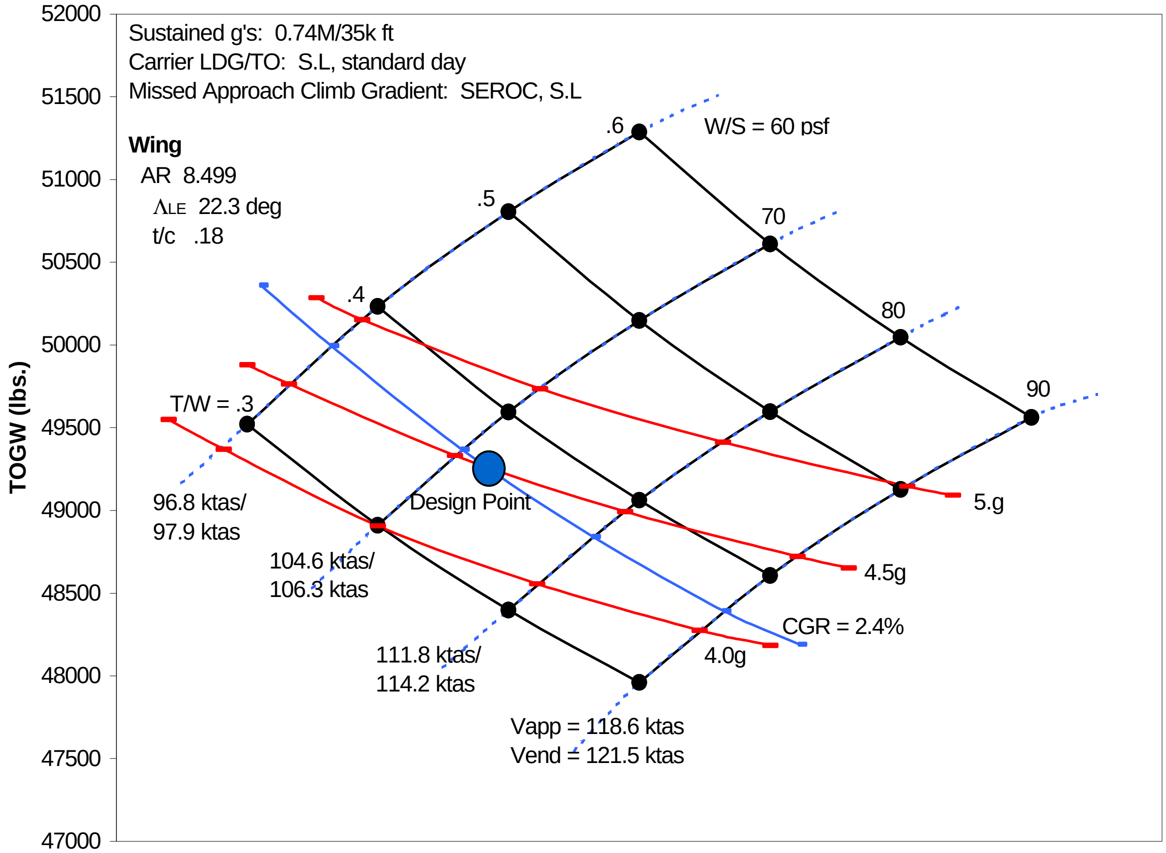
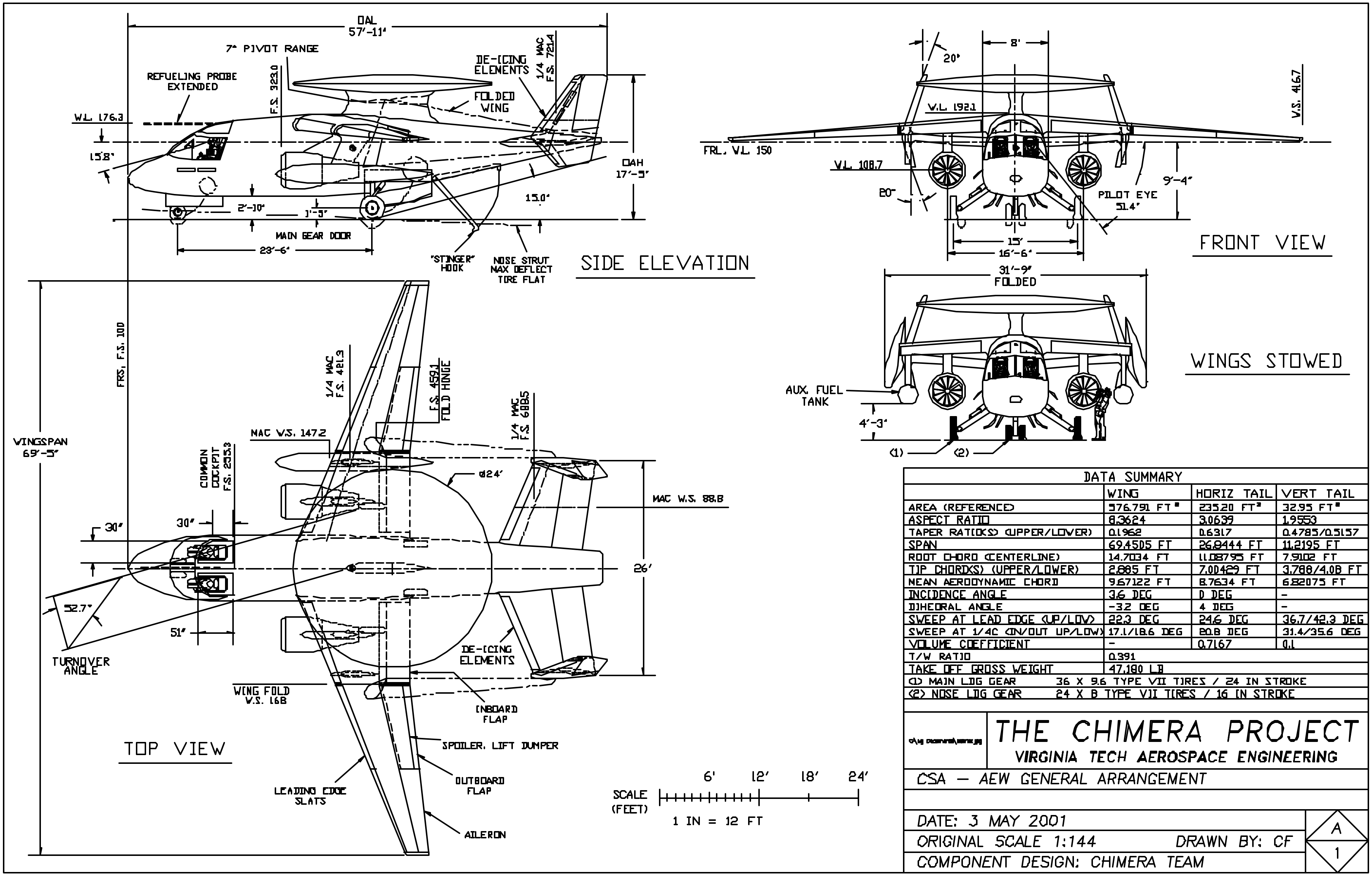


Figure 2.5 Carpet Plot for the Final Sizing Constraints for the COD Variant

2.7 Final Configuration

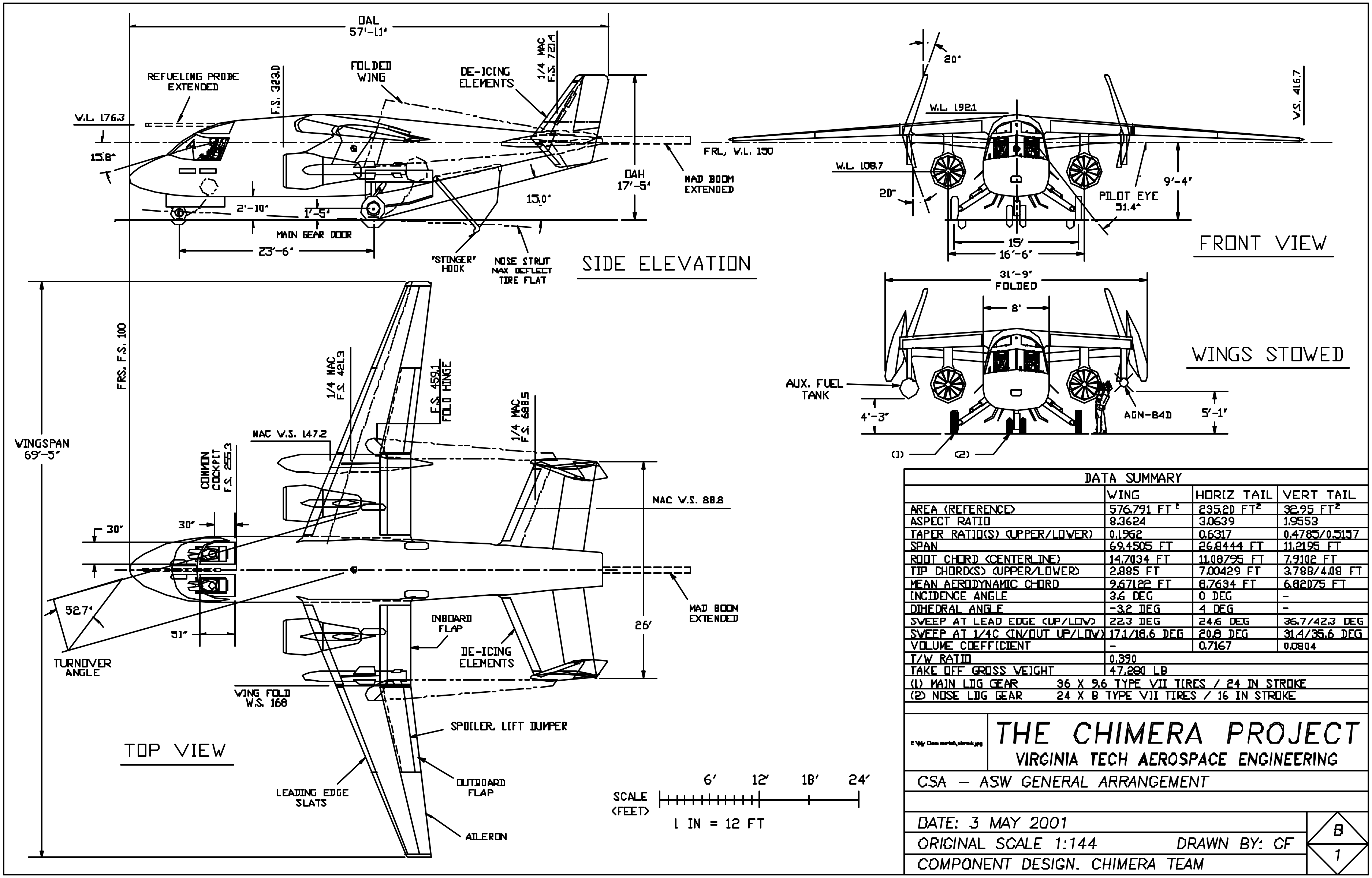
Figures 2.6 through 2.9 show the final general arrangements for the four Chimera variants. Figures 2.10 through 2.13 show the inboard profiles for each variant. The COD loading diagram in Figure 2.14 shows the 463L pallets and one half of the F119 JSF engine loaded through the rear cargo door/ramp. These configurations are the result of evaluations and design decisions, which are explained in detail throughout the following chapters.



DATA SUMMARY

	WING	HORIZ TAIL	VERT TAIL
AREA (REFERENCE)	576.791 FT²	235.20 FT²	32.95 FT²
ASPECT RATIO	8.3624	3.0639	1.9553
TAPER RATIO(S) (UPPER/LOWER)	0.1962	0.6317	0.4785/0.5157
SPAN	69.4505 FT	26.8444 FT	11.2195 FT
ROOT CHORD (CENTERLINE)	14.7034 FT	11.08795 FT	7.9102 FT
TIP CHORD(S) (UPPER/LOWER)	2.885 FT	7.00429 FT	3.788/4.08 FT
MEAN AERODYNAMIC CHORD	9.67122 FT	8.7634 FT	6.82075 FT
INCIDENCE ANGLE	3.6 DEG	0 DEG	–
DIHEDRAL ANGLE	-3.2 DEG	4 DEG	–
SWEEP AT LEAD EDGE (UP/LOW)	22.3 DEG	24.6 DEG	36.7/42.3 DEG
SWEEP AT 1/4C (IN/OUT UP/LOW)	17.1/18.6 DEG	20.8 DEG	31.4/35.6 DEG
VOLUME COEFFICIENT	–	0.7167	0.1
T/W RATIO	0.391		
TAKE OFF GROSS WEIGHT	47,180 LB		
(1) MAIN LDG GEAR	36 X 9.6 TYPE VII TIRES / 24 IN STROKE		
(2) NOSE LDG GEAR	24 X 8 TYPE VII TIRES / 16 IN STROKE		

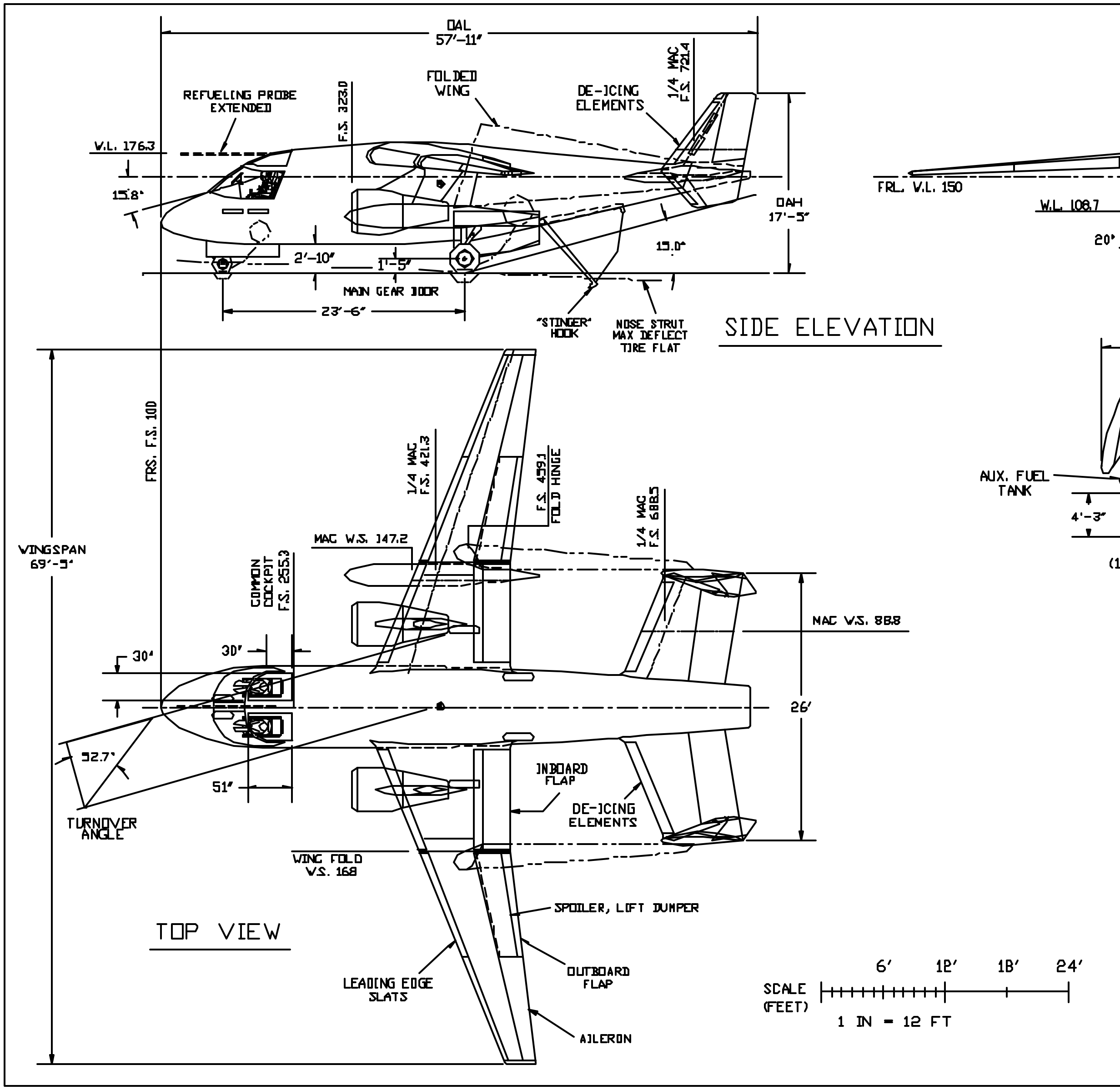
Figure 2.6 AEW Variant General Arrangement



DATA SUMMARY

	WING	HORIZ TAIL	VERT TAIL
AREA (REFERENCE)	576.791 FT²	235.20 FT²	32.95 FT²
ASPECT RATIO	8.3624	3.0639	1.9553
TAPER RATIO(S) (UPPER/LOWER)	0.1962	0.6317	0.4785/0.5157
SPAN	69.4505 FT	26.8444 FT	11.2195 FT
ROOT CHORD (CENTERLINE)	14.7034 FT	11.08795 FT	7.9102 FT
TIP CHORD(S) (UPPER/LOWER)	2.885 FT	7.00429 FT	3.788/4.08 FT
MEAN AERODYNAMIC CHORD	9.67122 FT	8.7634 FT	6.82075 FT
INCIDENCE ANGLE	3.6 DEG	0 DEG	-
DIHEDRAL ANGLE	-3.2 DEG	4 DEG	-
SWEEP AT LEAD EDGE (UP/LOW)	22.3 DEG	24.6 DEG	36.7/42.3 DEG
SWEEP AT 1/4C (IN/OUT UP/LOW)	17.1/18.6 DEG	20.8 DEG	31.4/35.6 DEG
VOLUME COEFFICIENT	-	0.7167	0.0804
T/W RATIO	0.390		
TAKE OFF GROSS WEIGHT	47,280 LB		
(1) MAIN LDG GEAR	36 X 9.6 TYPE VII TIRES / 24 IN STROKE		
(2) NOSE LDG GEAR	24 X 8 TYPE VII TIRES / 16 IN STROKE		

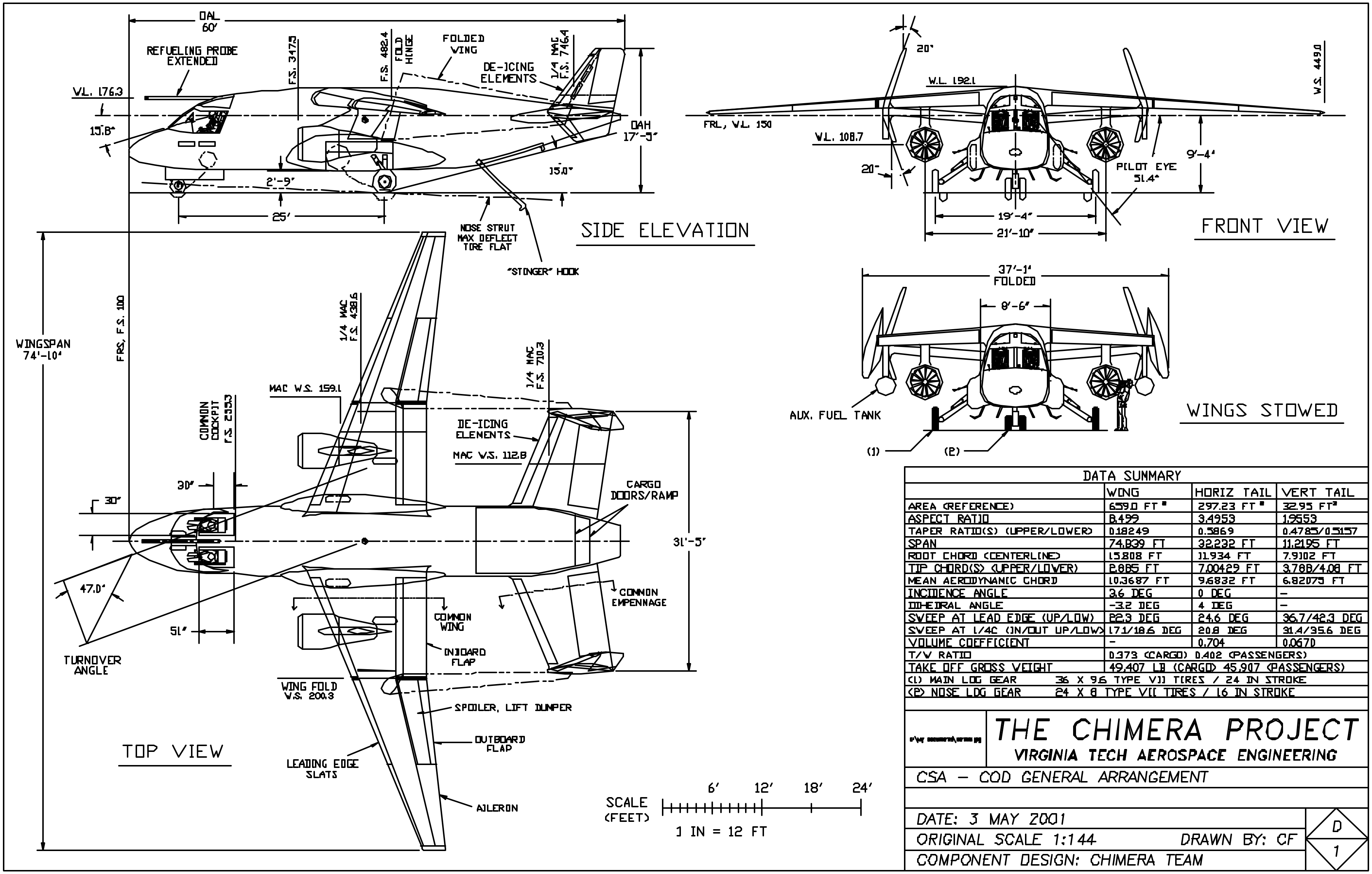
Figure 2.7 ASW Variant General Arrangement



DATA SUMMARY	WING	HORIZ TAIL	VERT TAIL
AREA (REFERENCE)	576.791 FT²	235.20 FT²	32.95 FT²
ASPECT RATIO	8.3624	3.0639	1.9553
TAPER RATIO(S) (UPPER/LOWER)	0.1962	0.6317	0.4785/0.5157
SPAN	69.4505 FT	26.8444 FT	11.2195 FT
ROOT CHORD (CENTERLINE)	14.7034 FT	11.08795 FT	7.9102 FT
TIP CHORD(S) (UPPER/LOWER)	2.885 FT	7.00429 FT	3.788/4.08 FT
MEAN AERODYNAMIC CHORD	9.67122 FT	8.7634 FT	6.82075 FT
INCIDENCE ANGLE	3.6 DEG	0 DEG	-
DIHEDRAL ANGLE	-3.2 DEG	4 DEG	-
SWEEP AT LEAD EDGE (UP/LOW)	22.3 DEG	24.6 DEG	36.7/42.3 DEG
SWEEP AT 1/4C (IN/OUT UP/LOW)	17.1/18.6 DEG	20.8 DEG	31.4/35.6 DEG
VOLUME COEFFICIENT	-	0.7167	0.0804
T/W RATIO	0.393		
TAKE OFF GROSS WEIGHT	46,880 LB		
(1) MAIN LDG GEAR	36 X 9.6 TYPE VII TIRES / 24 IN STROKE		
(2) NOSE LDG GEAR	24 X 8 TYPE VII TIRES / 16 IN STROKE		

THE CHIMERA PROJECT
VIRGINIA TECH AEROSPACE ENGINEERING
CSA – ES GENERAL ARRANGEMENT
DATE: 3 MAY 2001
ORIGINAL SCALE 1:144   DRAWN BY: CF
COMPONENT DESIGN: CHIMERA TEAM
C 1

Figure 2.8 ES Variant General Arrangement



DATA SUMMARY

	WING	HORIZ TAIL	VERT TAIL
AREA (REFERENCE)	659.0 FT^2	297.23 FT^2	32.95 FT^2
ASPECT RATIO	8.499	3.4953	1.9553
TAPER RATIO(S) (UPPER/LOWER)	0.18249	0.5869	0.4785/0.5157
SPAN	74.839 FT	32.232 FT	11.2195 FT
ROOT CHORD (CENTERLINE)	15.808 FT	11.934 FT	7.9102 FT
TIP CHORD(S) (UPPER/LOWER)	2.885 FT	7.00429 FT	3.788/4.08 FT
MEAN AERODYNAMIC CHORD	10.3687 FT	9.6832 FT	6.82075 FT
INCIDENCE ANGLE	3.6 DEG	0 DEG	–
DIHEDRAL ANGLE	-3.2 DEG	4 DEG	–
SWEEP AT LEAD EDGE (UP/LOW)	22.3 DEG	24.6 DEG	36.7/42.3 DEG
SWEEP AT 1/4C (IN/OUT UP/LOW)	17.1/18.6 DEG	20.8 DEG	31.4/35.6 DEG
VOLUME COEFFICIENT	–	0.704	0.0670
T/W RATIO	0.373 (CARGO) 0.402 (PASSENGERS)		
TAKE OFF GROSS WEIGHT	49,407 LB (CARGO) 45,907 (PASSENGERS)		
(1) MAIN LDG GEAR	36 X 9.6 TYPE VII TIRES / 24 IN STROKE		
(2) NOSE LDG GEAR	24 X 8 TYPE VII TIRES / 16 IN STROKE		

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THE CHIMERA PROJECT

VIRGINIA TECH AEROSPACE ENGINEERING

CSA – COD GENERAL ARRANGEMENT

DATE: 3 MAY 2001

ORIGINAL SCALE 1:144 DRAWN BY: CF

COMPONENT DESIGN: CHIMERA TEAM

D 1

Figure 2.9 COD Variant General Arrangement

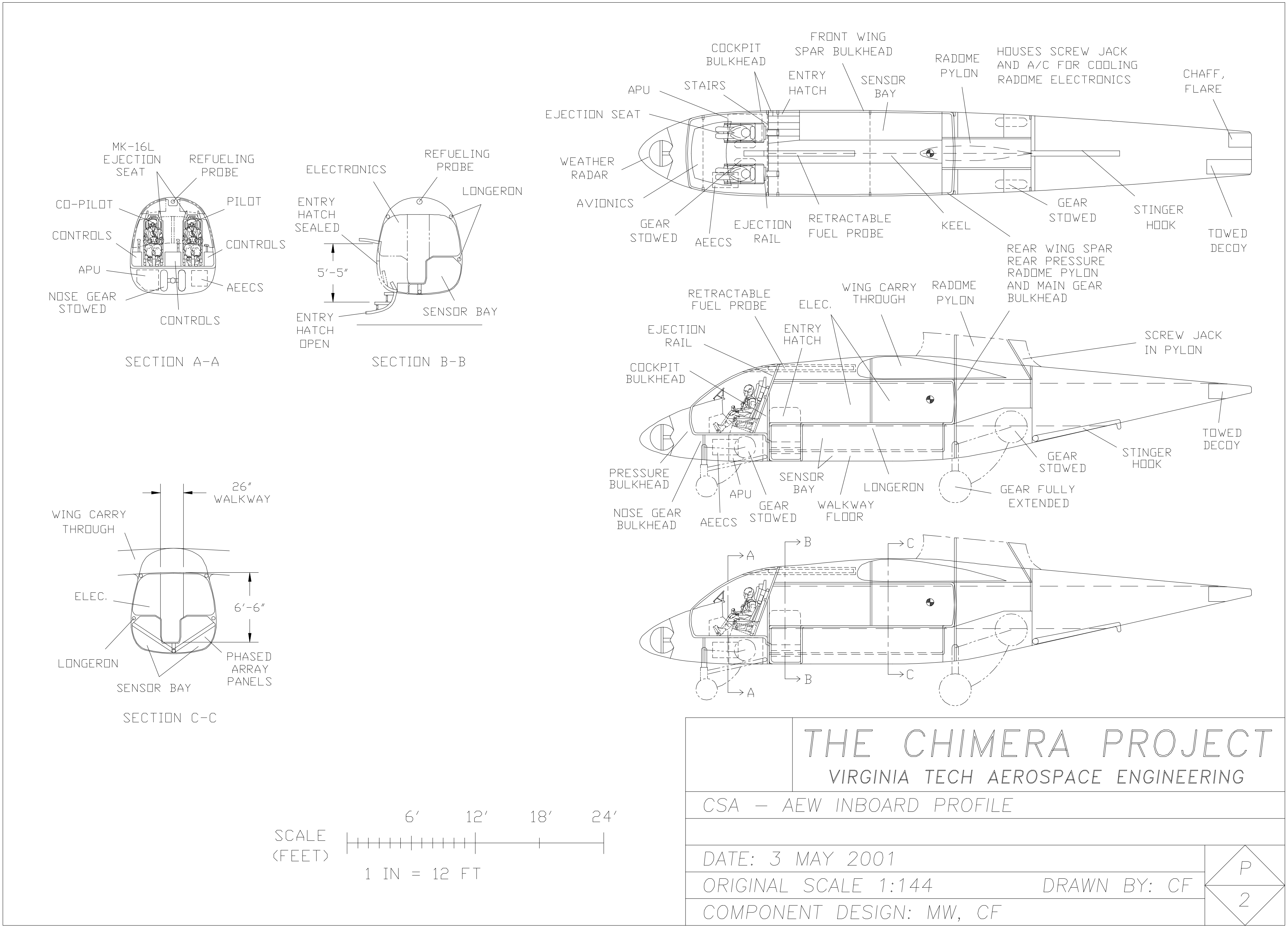

Figure 2.10 AEW Inboard Profile

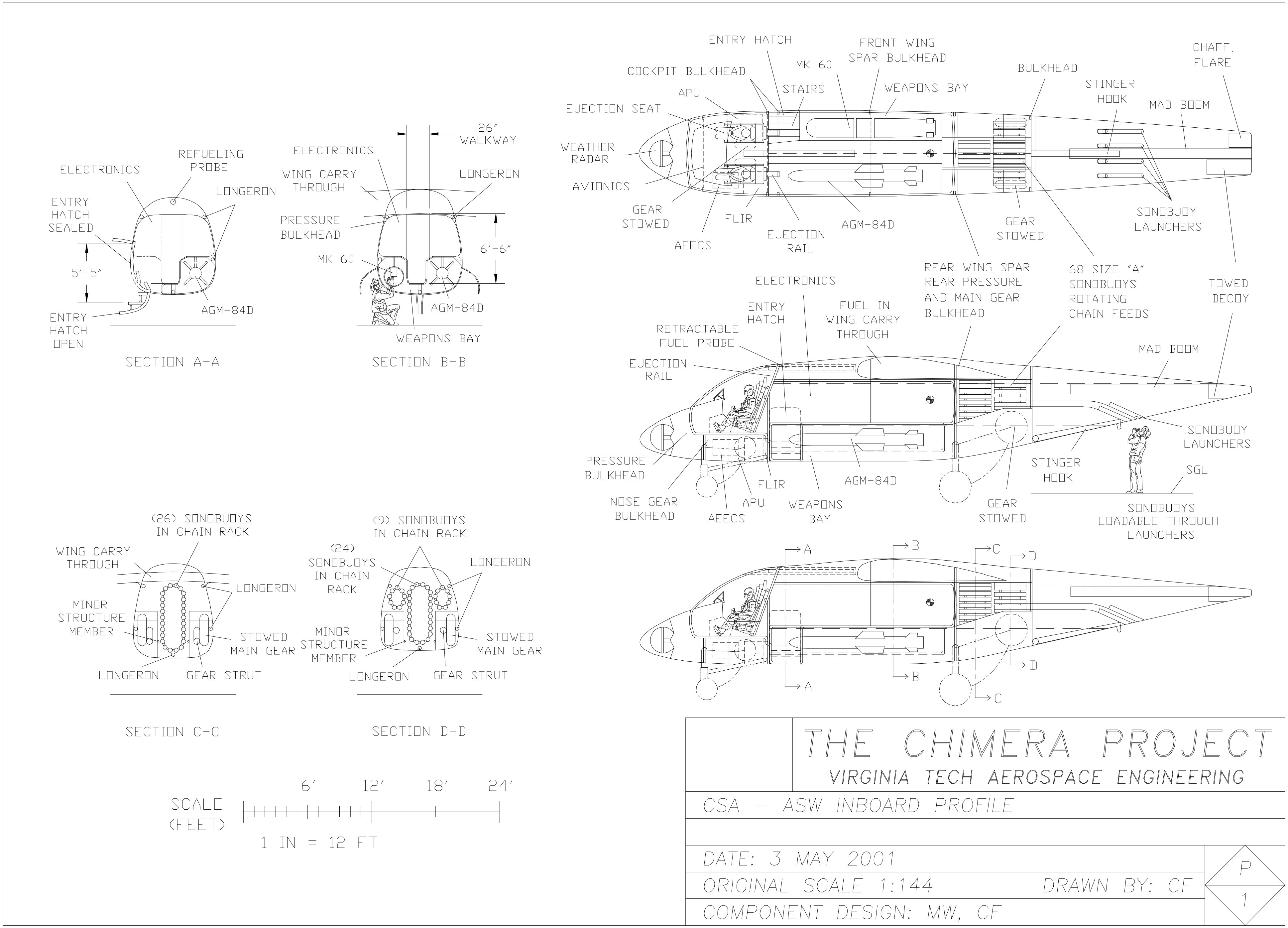

Figure 2.11 ASW Inboard Profile

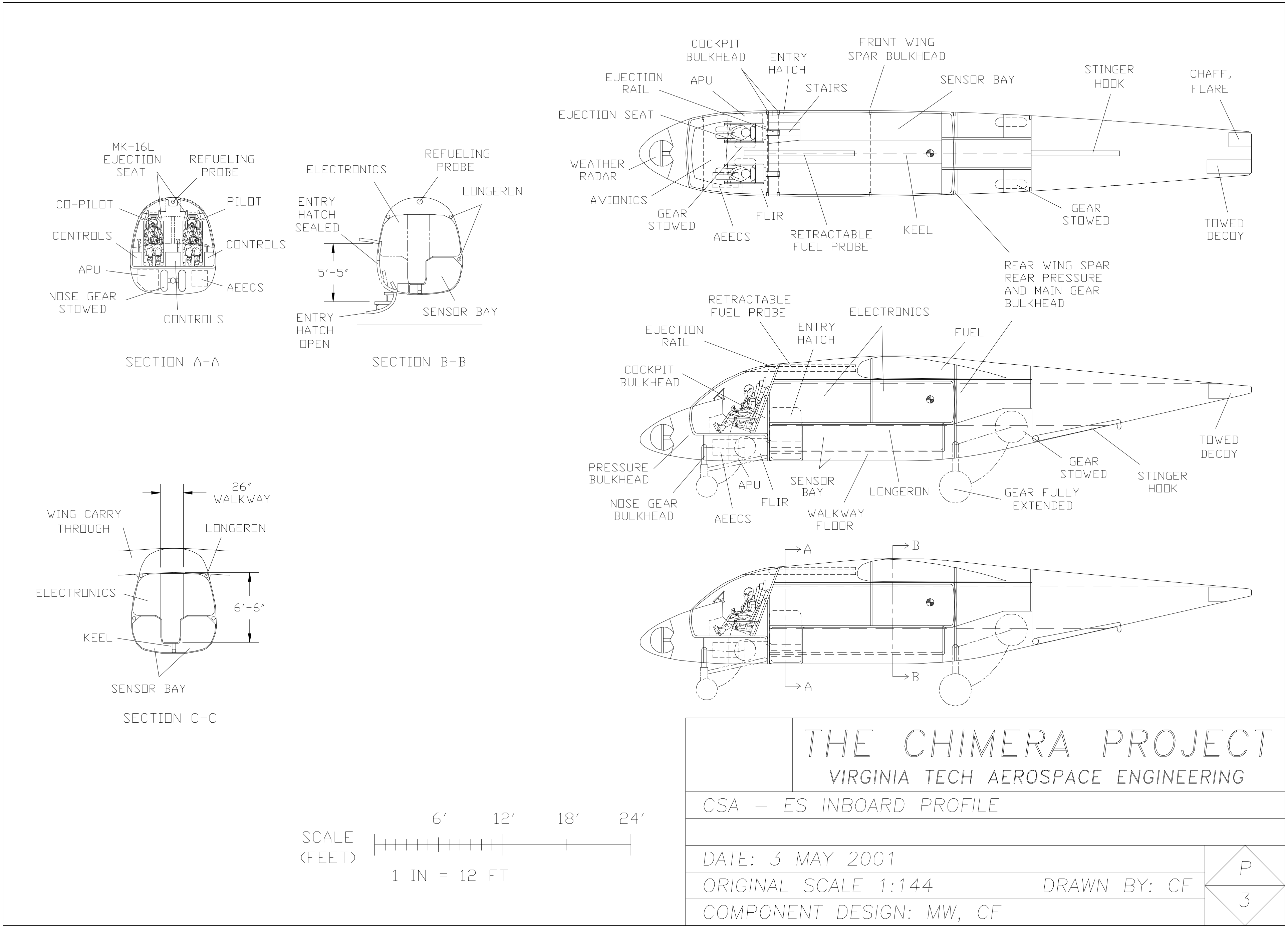

Figure 2.12 ES Inboard Profile

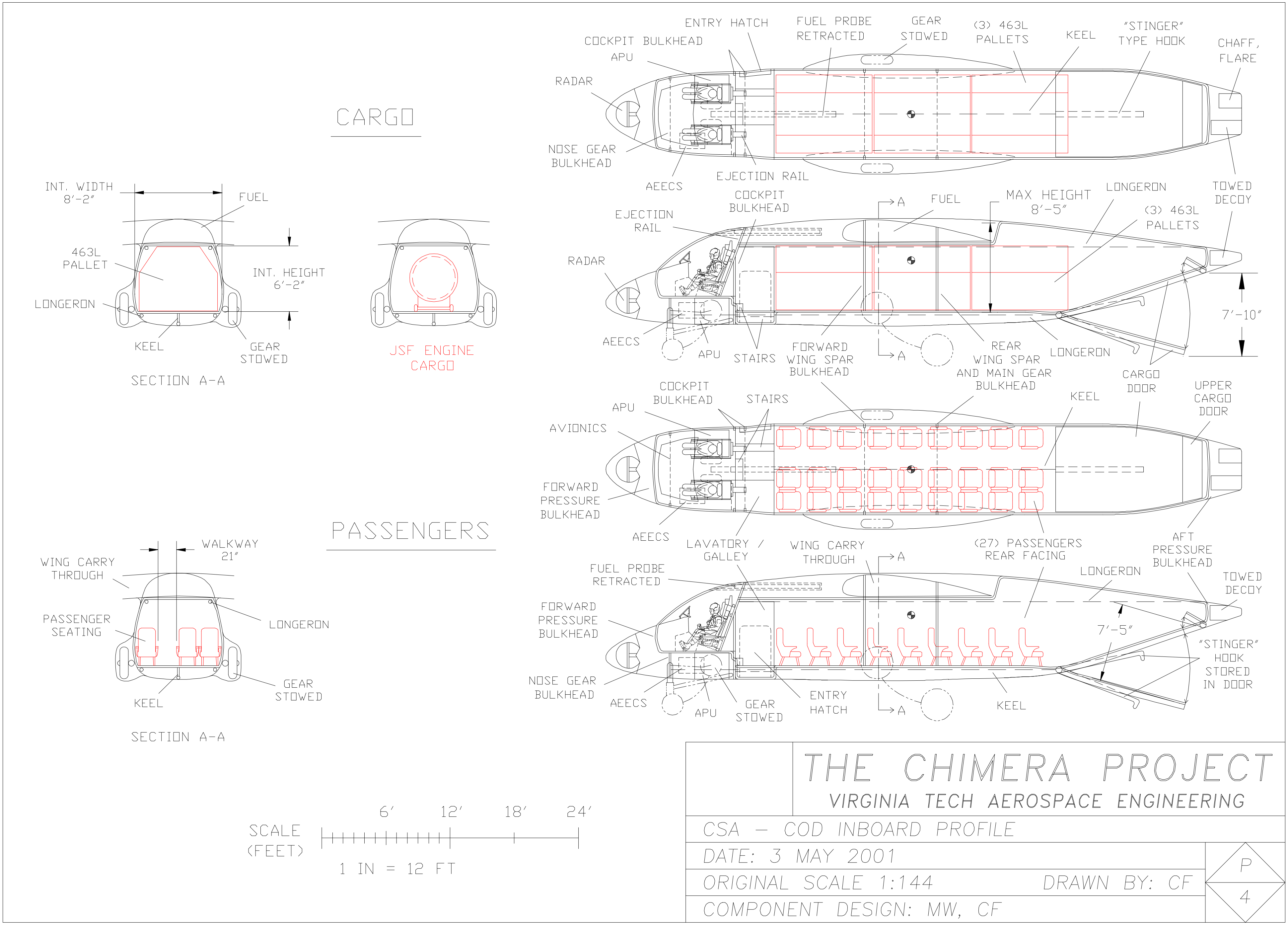

Figure 2.13 COD Inboard Profile

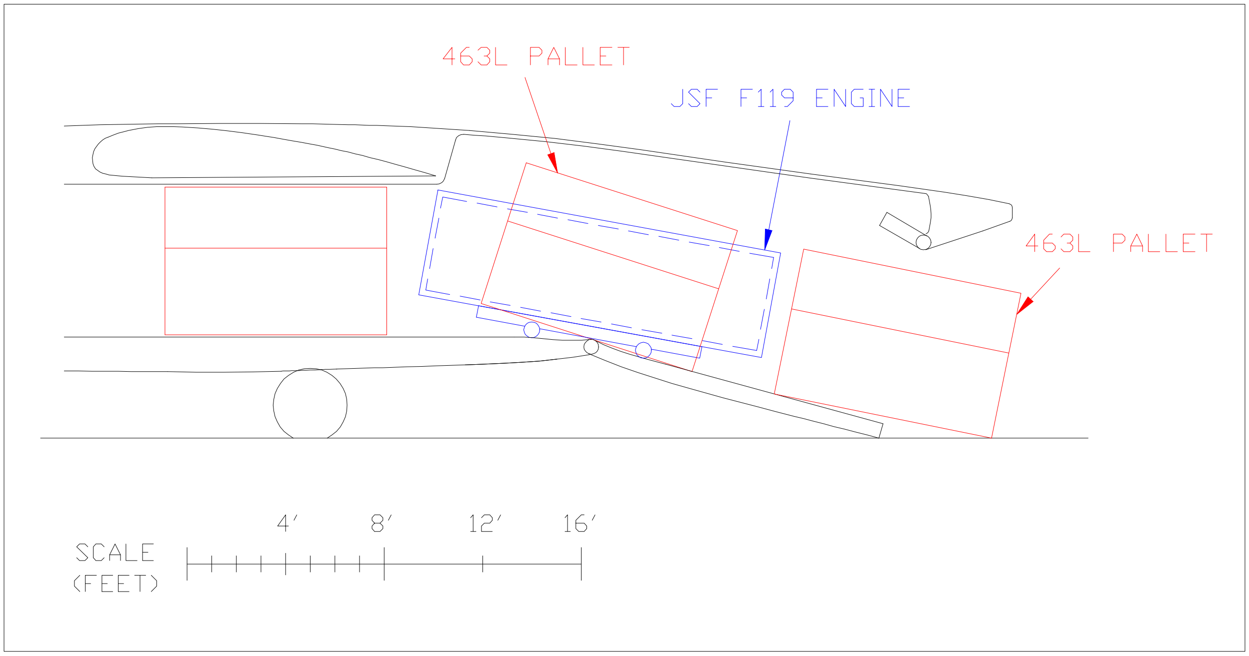

Figure 2.14 COD Variant Loading Diagram with 463L Pallet and F119 JSF Engine

Chapter 3 Propulsion Systems

This chapter describes the thrust requirements, propulsion system selection process, the selected powerplant and its performance characteristics, engine removal, and other propulsion technologies considered for the Chimera Project. The engine selection criteria are based on the following constraints:

1) Take-Off Gross Weight (TOGW) of the COD
2) The drag of the AEW variant
3) Single Engine Rate Of Climb (SEROC) at take off of no less than 200 ft/min
4) SEROC at approach of no less than 500 ft/min
5) Dash speed of 425 KTAS (0.74M/35,000 ft)

3.1 Thrust Requirements

The weight of the COD variant is the most important engine selection criteria. Since it is the heaviest of all the variants, its weight is the most important constraint on the thrust to weight ratio (T/W). From initial weight estimates, the COD had a weight of 58,000 lbs. Using a T/W ratio of 0.4 a propulsion system in the 11,000 to 14,000 lbs thrust class was required, assuming the use of two engines for each variant. From the carpet plot discussed in Chapter 2, Fig 2.5, the design parameters for the COD were shown to be a wing loading of 73 psf and a T/W ratio of 0.37 with a TOGW of 49,250 lbs. As previously discussed, the structural weight was decreased 15 % by using composites lowering the TOGW of the COD variant to 49,400 lbs. To stay within the constraints of the carpet plot a T/W ratio of 0.37 is needed requiring a minimum static thrust of 9,050 lbs per engine at S.L.

The drag of the AEW variant is the second most important engine selection criteria. The AEW variant, as shown in Figure 3.1, requires more thrust than the other variants, due to the added drag of the 24 ft diameter radome above the fuselage. This data is taken from the drag analysis in Chapter 4, and assumes that thrust equals drag during cruise.

The remaining constraints are required by the RFP. First the aircraft must maintain a SEROC of no less than 200 ft/min. Assuming that the take-off velocity is the end speed produced by the catapult, a thrust of 5,320 lbs (0.17M/S.L.) is required for the COD variant to achieve this rate of climb. An approach SEROC of no less than 500 ft/min is also required. Assuming a fuel/armament dump of 6,000 lbs and an approach speed at 1.2 V_{STALL} (0.148M/S.L.), a thrust of 6,518 lbs is required for the COD variant to meet this requirement. Finally, a dash speed of 425 KTAS is required. From the thrust required curves, shown in Figure 3.1, the thrust needed for the AEW variant to reach this velocity is 4,800 lbs at 0.74 M and 35,000 ft.

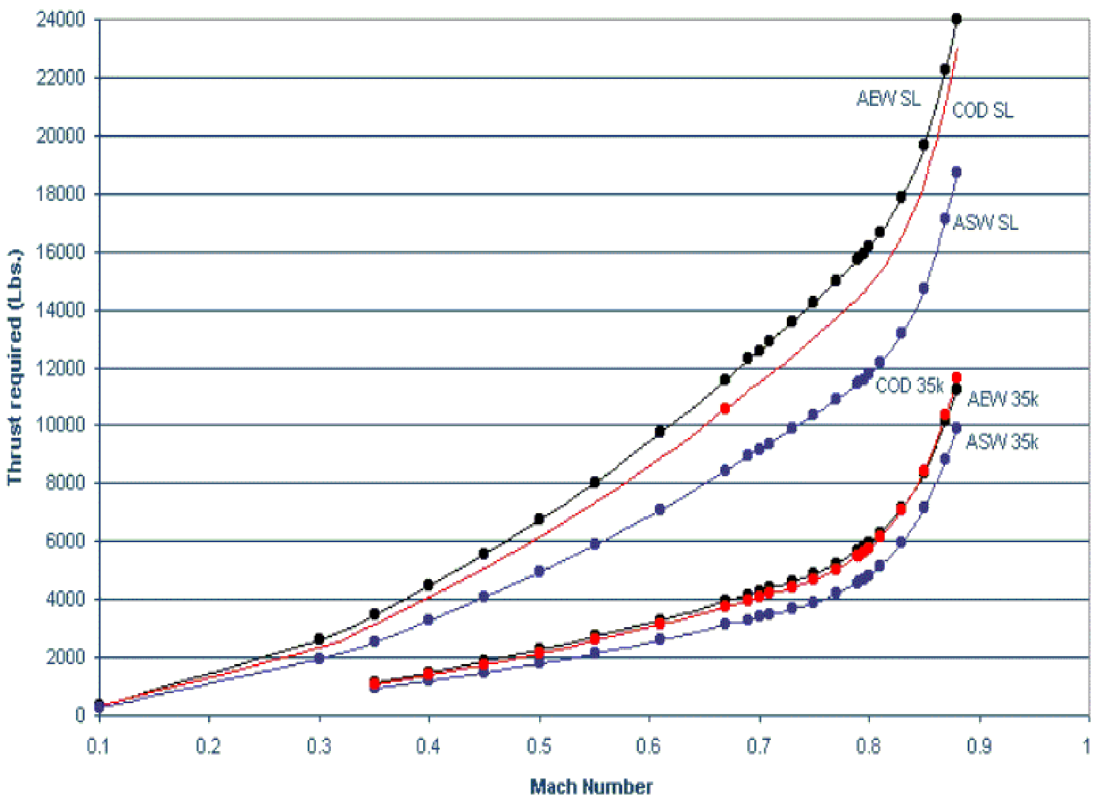

Figure 3.1 Thrust Required for the COD, AEW, and ASW Variants at S.L. and 35,000 ft

3.2 Engine Selection

To lower overall research and development costs a Commercial-Off-The-Shelf (COTS) engine will be used to power the Chimera aircraft family. Based on the thrust constraints defined above, several initial engine candidates were investigated using data from several sources, but primarily the *Aviation Week Source Book* (Ref. 3.1). These engines are high and low bypass turbofan engines with thrust classes ranging from 9,000 to 14,000 lbs. The specifications of these initial candidates are shown in Table 3.1. Although each of these candidates meet the thrust constraints, the CF34-3b1 and TF34-400A engines were selected for further study because of their low weight and Specific Fuel Consumption (SFC) and their close fit to the carpet plot requirements discussed in chapter 2. Due to the CF34-3b1 having 30% fewer parts, which should decrease maintenance cost (Ref 3.2), and its improved high altitude performance, it was chosen to power the Chimera aircraft family. The CF34-3b1 engine is shown in Figure 3.2. A Full-Authority-Digital-Electronic-Control (FADEC) System will control the engine.

Table 3.1 Initial Engine Candidates

Maker	Model	Type	Max Power at S.L. (lb thrust)	SFC (lb/hr/lb)	Max Dia. (in.)	Max Length (in.)	Dry Weight w/o tailpipe (lb.)	Bypass Ratio
GE	TF34-400	AFF	9275	0.363	52	100	1478	6.2
GE	CF34-3b1	AFF	9220	0.346	49	103	1670	6.2
GE	CF34-8c1	AFF	13780	0.37	52	128	2350	4.8
RR/BMW	BR710	AFF	14000	0.39	52.9	87	3520	4.0
RR	Tay611	AFF	13850	0.694	44	95	2951	3.07
RR	Spey511	AFF	11400	0.84	33	110	2483	.78

Thrust vectoring was initially considered for the Chimera project to augment our high lift systems by adding direct lift. This would allow for a lower speed at approach and landing. Two techniques were considered which would allow for two-dimensional thrust vectoring. One technique was combining the exhaust produced by the engine's core and fan and sending it through a vectoring nozzle similar to that found on the F-22. The second technique involves using hydraulics to pitch the entire engine. Due to carrier constraints on blast deflection and stability and control issues at low velocities, the static thrust could only be vectored at angles less than 10º. This would only produce 1,600 lbs of added lift per engine at sea level. Since the added weight of the nozzles and hydraulics needed to vector the thrust is estimated at a total of 3,000 lbs, the thrust vectoring concept was disregarded based on cost effectiveness.

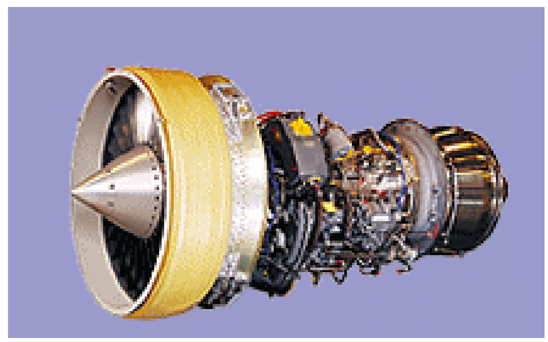

Figure 3.2 CF34-3b1 Propulsion System
Courtesy http://www.ge.com/aircraftengines

3.3 Engine Performance Characteristics

The performance characteristics for the CF34-3b1 were estimated using the "onx/offx" programs written by Dr. Jack Mattingly (Ref 3.3). The thrust available curve as a function of Mach number is shown in Figure 3.3 for varying altitudes. The thrust constraints are plotted on this figure as the amount of thrust required per engine. These requirements are lower than the available thrust, which shows that the CF34-3b1 engine produces sufficient thrust. Figure 3.4 is a plot of the engine's SFC as a function of Mach number. The cruise SFC and loiter SFC for each variant is also plotted on this figure.

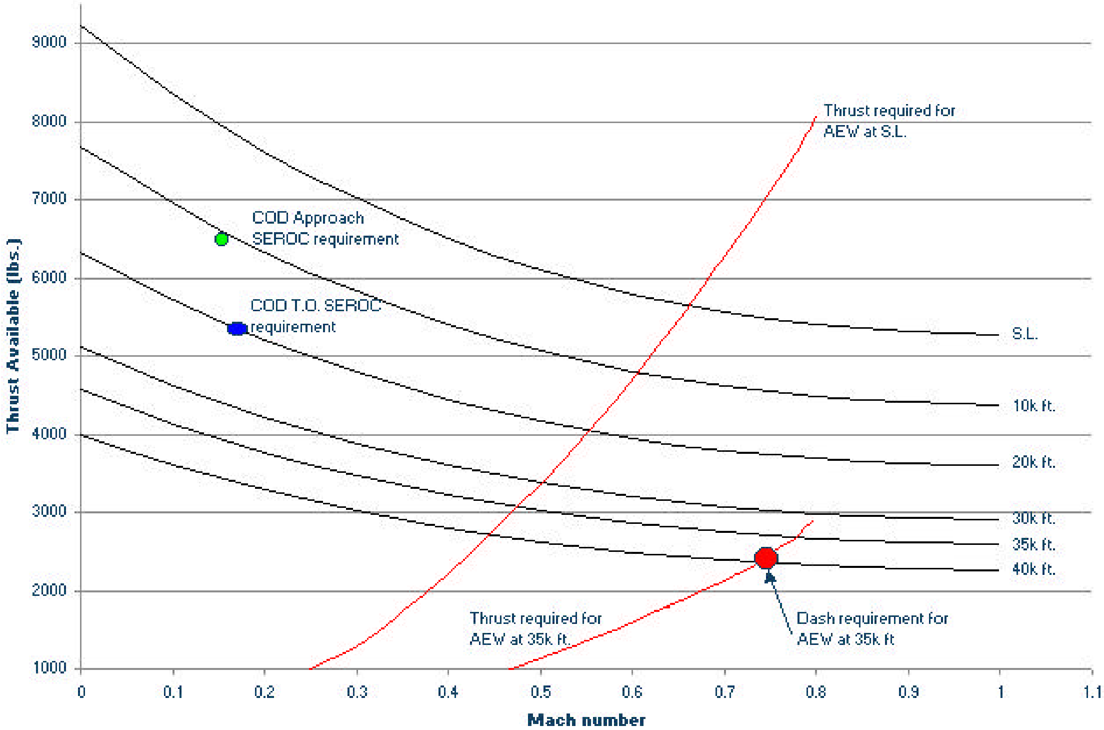

Figure 3.3 Thrust Available for the CF34-3b1 with Thrust Constraints

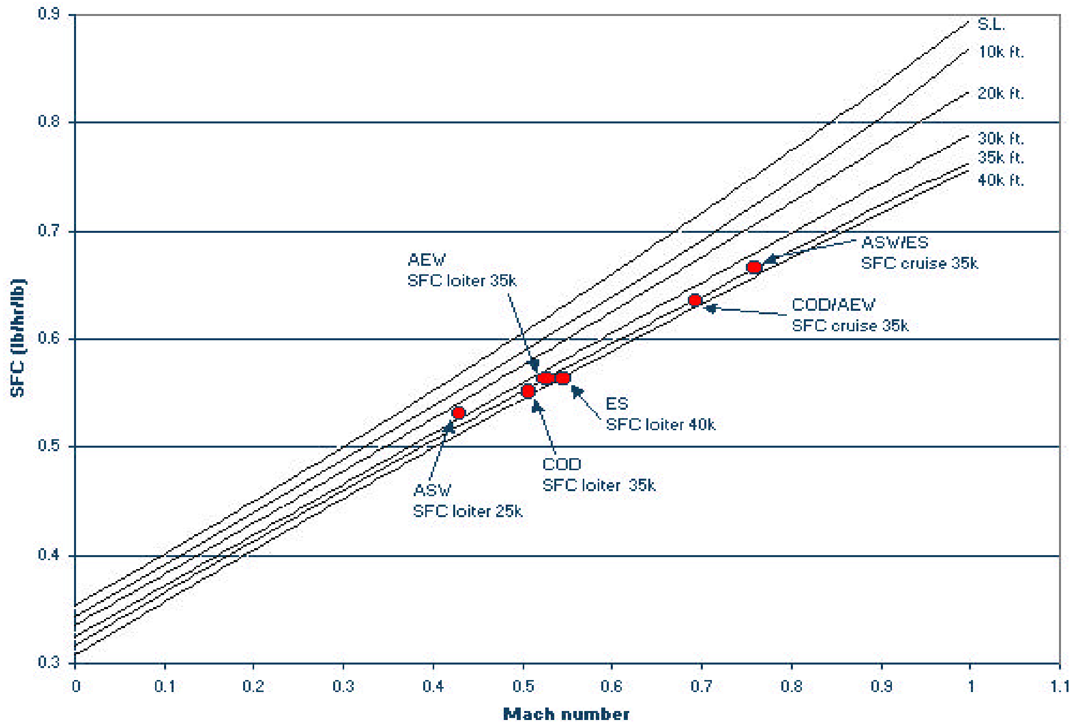

Figure 3.4 SFC as a Function of Mach Number for the CF34-3b1

3.4 Engine Removal and Maintenance

The engines are wing-mounted on the Chimera to decrease the complexity of engine removal during maintenance. The engines will be lowered onto engine dollies for maintenance via split, outward opening engine cowlings. For the COD variant, the engines are mounted 10 ft, 11 in. from the centerline of the fuselage and 5 ft, 10 in. from the ground. This provides an opened cowling to fuselage clearance of 1 ft, 9 in. and a clearance of 3 in. from the auxiliary fuel tank, when carried. For the AEW, ASW, and ES variants the engines are mounted 8 ft, 3 in from the centerline and 5 ft, 11 in. from the ground. This gives a cowling to fuselage clearance of 11 in. and a clearance of 3 in. for the auxiliary fuel tanks. For the ASW variant the auxiliary fuel tanks are replaced with AGM-84D missiles. When in this configuration there is an open cowling to fin clearance of 5 in. to the tip of the missile fin. Figure 3.5 illustrates these clearances.

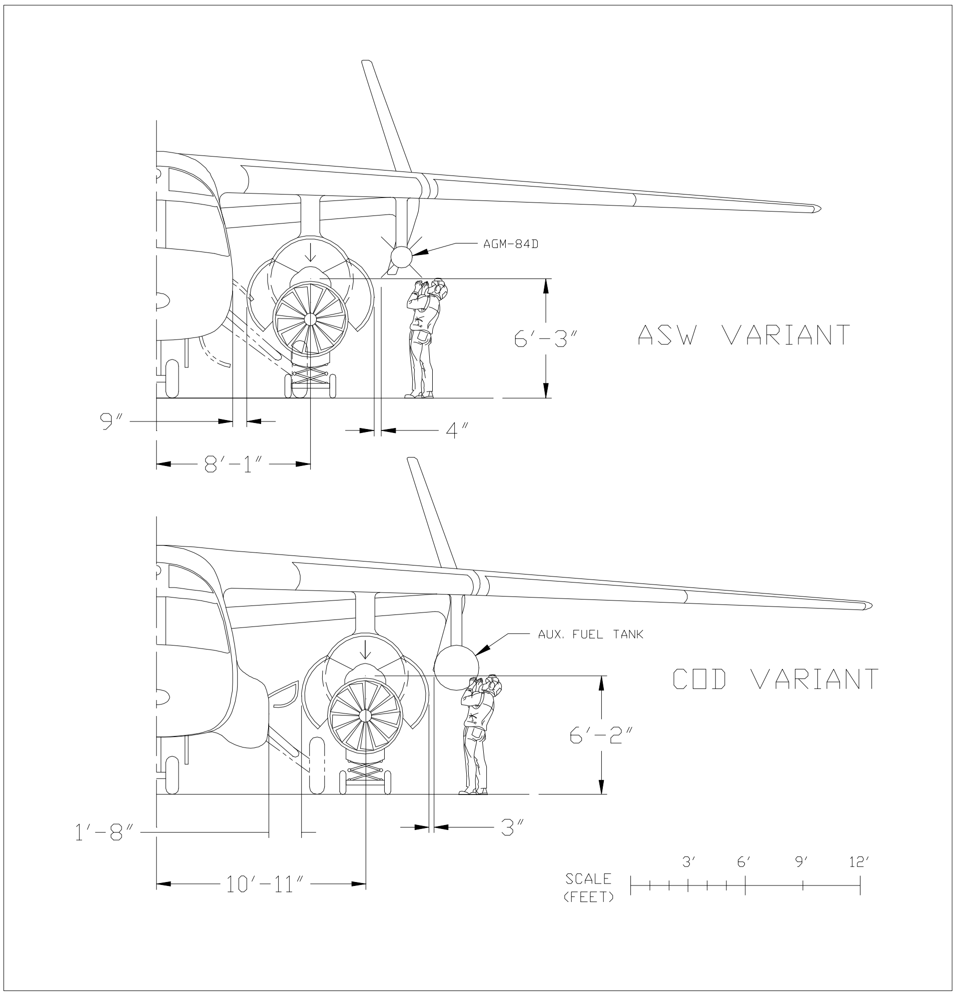

Figure 3.5 Engine Clearances for the COD and ASW with Engine Removal

Chapter 4 Aerodynamics

4.1 Preliminary Analysis

The CSA poses some interesting problems from an aerodynamic design prospective. In the early stages, the design was narrowed from three concepts down to the one detailed design by analyzing the parasite drag, C_{D0}, for each of the concepts. This was done by using the program Friction.f, (Ref. 4.1). This drag analysis was performed for each of the concepts, keeping in mind the different reference areas, S_{REF}, of each and comparing them according to actual drag value. This produced results that showed quantitatively which design to analyze in detail. The results of the drag analysis of these three concepts showed that the conventional design was the most efficient, followed by the twin boom concept, and then the joined wing concept.

Once the narrowing was completed, the optimum wing sweep and airfoil section were found. Modified "Korn" equations (Ref. 4.2) were used to find the sweep and percent thickness of the wing, at Mach 0.67 (652 KTAS) and 35,000 ft, which was initially estimated to be the region of the flight envelope in which the aircraft would cruise. These calculations indicated that a leading edge sweep of 22 ^{o} and a thickness to chord ratio of about 0.15 would be optimum. From this data it was decided that the supercritical Korn airfoil 75-07-15 would be the best since it has a thickness ratio of 0.151 with a design Mach number of 0.75, see Figure 4.1 for profile. This will allow our aircraft to have a high drag divergence Mach number and allow it to dash at well above the required Mach 0.74, without excessive wing weight. The family of aircraft will have the following cruise Mach numbers: the COD and AEW will cruise at Mach 0.7, and the ES and ASW will cruise at Mach 0.75. These different cruise velocities can be attributed to the specific range of each aircraft and it's associated drag.

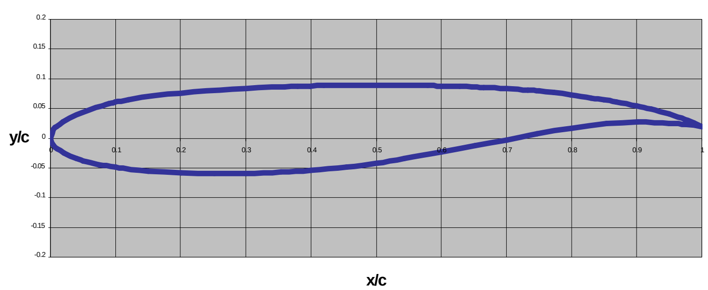

Figure 4.1 Korn 75-07-15 Airfoil

Another drag analysis was done to determine whether one or two fuselages would satisfy the COD requirement and would best accomplish the mission requirements for our family of aircraft. It was determined that a non-rotating radome best fulfilled the AEW mission for the Chimera concept. A drag analysis was performed to determine the parasite drag on a large COD type fuselage with a radome attached and compared to that of as smaller fuselage that would accomplish the AEW/ASW/ES - type missions with a radome attached. This analysis determined that one large fuselage encompassing all mission requirements would not be efficient enough to properly fulfill the RFP requirements. The details of the preliminary analysis are as follows: the equivalent flat plate drag at Mach 0.67 for the COD type fuselage with radome was 22.6 ft^2, while the equivalent flat plate drag at Mach 0.67 for the AEW/ASW/ES fuselage with radome was 18.7 ft^2. This analysis shows a flat plate drag, *Äf*, of 3.9 ft^2, or a 20.8% increase in parasite drag due to the larger fuselage.

An analysis similar to the one above revealed that one single vertical pylon for the radome on the AEW variant was aerodynamically superior to three radar strut pylons. The parasite drag, C_D on the aircraft with one support was 0.02441, while the drag on the aircraft with three was 0.02568. This analysis shows a 5% increase in parasite drag by using three supports vs. using a larger, single one. This single support for the radome also has room to incorporate cooling systems as stated in the systems section of the paper.

It was thus decided that the Chimera would use two differently sized fuselages and a single radar pylon, allowing the aircraft characteristics to be determined. The wing characteristics are as follows in Table 4.1.

Table 4.1 Wing Data on Chimera Variants

Aircraft	**ASW/AEW/ES**	**COD**
Aspect Ratio	8.36	8.50
Wing Sweep (°)	22.5	22.5
Reference Wing Area (ft^2) *	577	659

4.2 Drag Buildup

The parasite drag on the Chimera aircraft family is due to several factors. These factors are: the basic skin friction, the form drag, the upswept tail cone of the fuselage, the pitot tube, the arresting hook, and the basic configuration of the fuselage and appendages. The appendages include landing gear blisters for the COD, the pylon-radome on the AEW variant, antennas on the ES variant, and the wing-mounted auxiliary fuel tanks for overload conditions. The drag on the pitot tube and arresting hook are computed from a flat plate equivalence on other military aircraft, and the upswept tail cone drag is computed from Torenbeek (Ref. 4.3). This upswept tail drag is substantial, so it was necessary to modify the original designs to minimize this, yet retain the benefits of the upswept tail from a systems and loading standpoint. The drag on the antennas for the ES has been estimated from comparator aircraft and from other appendages with known equivalent flat plate drags. The C_{D0}'s for the aircraft

* The Reference area for the COD variant is larger due to the increase in wingspan from the spacer inserted down the fuselage centerline.

components were calculated by dividing the flat plate and form drag of each component by the reference area of the aircraft. An example of the drag buildup can be seen in Table 4.2. The *Äf* column is the equivalent flat plate drag of the parts of the aircraft and was used to get a quantitative idea for how much drag each variant has in relation to one another. A direct comparison of C_{D0} values could not be used however as they have different reference areas.

Table 4.2 Drag Buildup

S_{REF} AEW/ASW/ES	**577 ft^2**	**S_{REF} COD**	**659 ft^2**
S_{REF} Fuselage	**69.26 ft^2**	**S_{REF} Fuselage**	**89.15 ft^2**

	AEW	**AEW**	**ES**	**ES**	**ASW**	**ASW**	**COD**	**COD**
Appendage	***DC$_{D0}$***	***Df***	***DC$_{D0}$***	***Df***	***DC$_{D0}$***	***Df***	***DC$_{D0}$***	***Df***
Upswept Tail	0.00253	1.46	0.00253	1.46	0.00253	1.46	0.00609	4.01
Arrest Hook	0.00026	0.150	0.000260	0.150	0.000260	0.150	0.000228	0.150
ES Antennae	0	0	0.000381	0.220	0	0	0	0
Pitot	1.73 ‰ 10^{-5}	0.010	1.73 ‰ 10^{-5}	0.010	1.73 ‰ 10^{-5}	0.010	1.52 ‰ 10^{-5}	0.010
D **Append.**	0.00281	1.62	0.00319	1.84	0.00281	1.62	0.00633	4.17
Large Parts								
Fuselage	0.00405	2.34	0.00405	2.34	0.00405	2.34	0.0042	2.77
Nacelles	0.00656	3.79	0.00656	3.79	0.00656	3.79	0.00574	3.78
Engine Pylons	0.00075	0.433	0.00075	0.433	0.00075	0.433	0.00075	0.433
Wings	0.00609	3.51	0.00609	3.51	0.00609	3.51	0.00587	3.87
Horizontal Stab.	0.00201	1.16	0.00201	1.16	0.00201	1.16	0.00176	1.16
Vertical Stab.	0.00255	1.47	0.00255	1.47	0.00255	1.47	0.00223	1.47
Radome & Pylon	0.00483	2.79	0	0	0	0	0	0
C_{D0}	**0.0297**	**17.1**	**0.0252**	**1.84**	**0.0248**	**14.3**	**0.0268**	**17.7**

From these drag buildups along with the “friction.f” program, charts of the coefficient of drag vs. Mach number were constructed, as seen in Figure 4.2. This figure shows the coefficient of drag as the Mach number increases. The C_D given in this chart takes into account the effects of wave drag and drag due to lift as well as parasite drag for the four variant types. The line labeled “$M_{CRITICAL}$” is at the critical Mach number, and the “*MDD* Line” is a line at the estimated drag divergence Mach number as taken from Ref. 4.4.

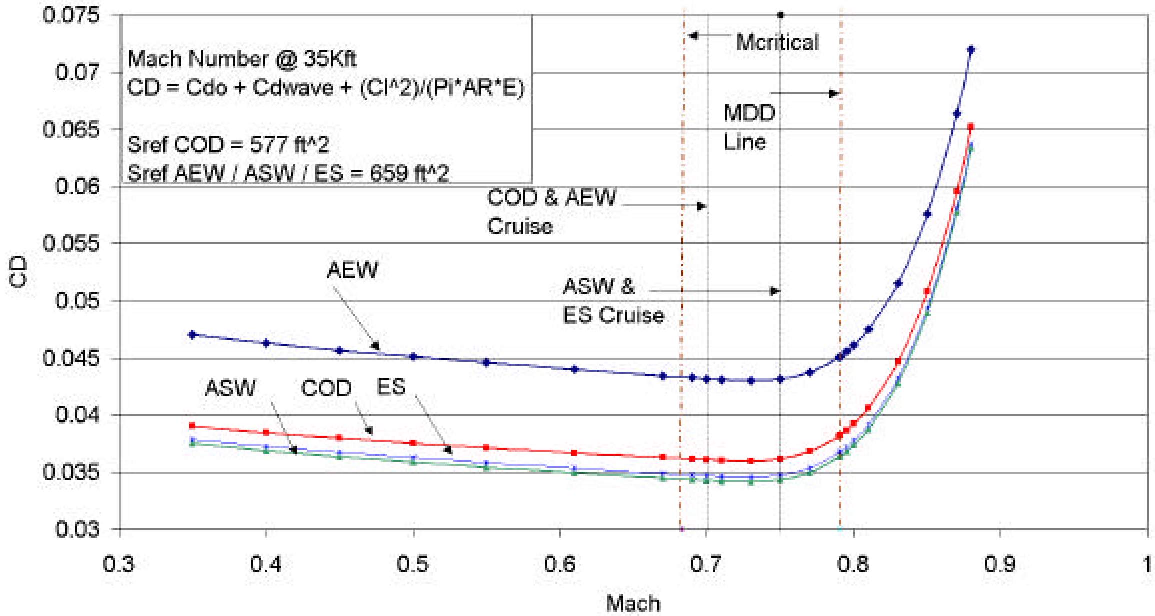

Figure 4.2 Drag Divergence for Chimera Variants

The data from the above chart can be converted to show the actual drag forces vs. Mach number as seen in Figure 4.3. The drag polar for the cruise configuration is given in Figure 4.4 and is useful in determining the thrust required for the aircraft, as seen in the propulsion section of this report.

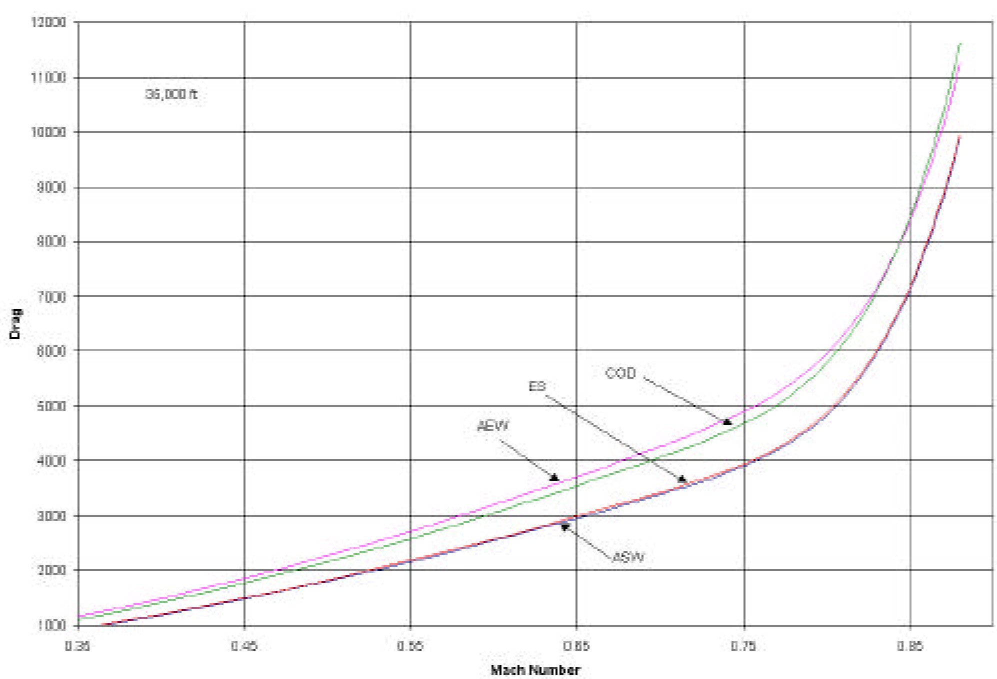

Figure 4.3 Drag Increase Due to Mach Number for Chimera Variants

Figures 4.2 and 4.3 show that the drag on the COD aircraft is slightly less than that of the AEW aircraft in the required flight region. The ASW/ES aircraft, however, has a much lower drag than that of the other two variants.

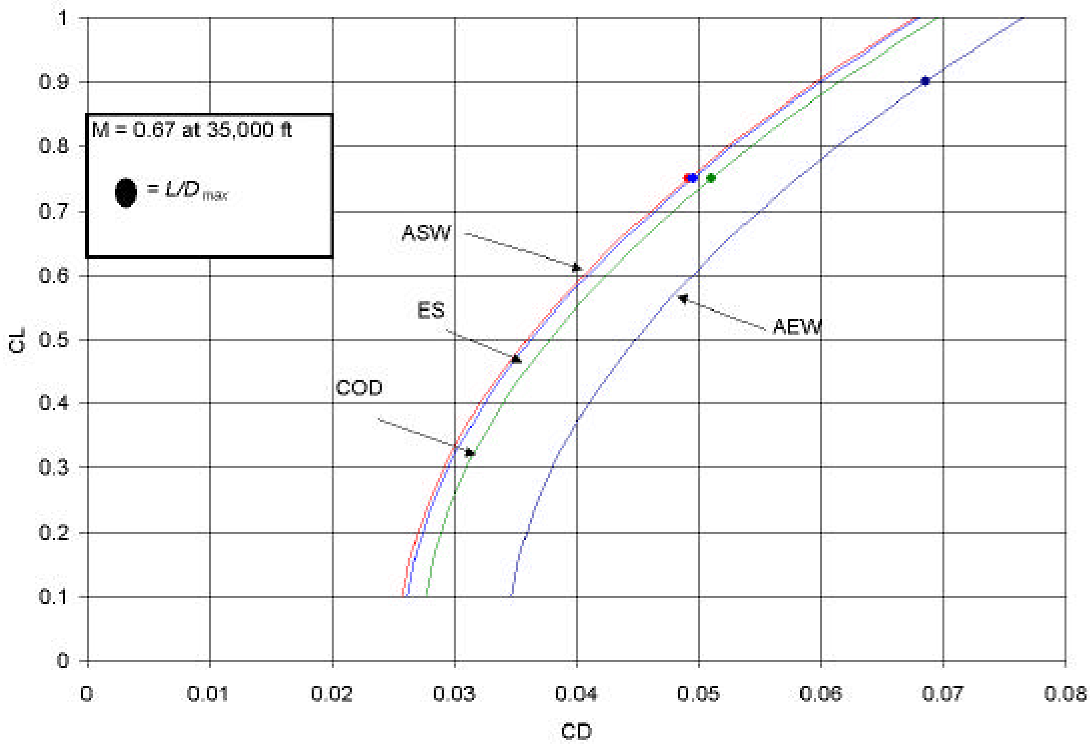

Figure 4.4 Drag Polars for the Chimera Variants

Using this drag data and with the aircraft design frozen, the specific range was estimated. The specific range of the aircraft was found by using the "fsr.f" program (Ref. 4.5). This program finds the optimum flight speed and altitude for aircraft operation. It assumes C_{D0} and SFC independent of altitude, and is locally centered about the optimum range altitude as discussed in the Performance chapter. The optimum specific range was found to be approximately 148 nm/1000 lb fuel at 35,000 ft and Mach 0.7 which is the approximate speed and altitude at which the COD will operate. This specific range means that we will be required to carry about 12,000 lbs of internal fuel to complete the missions and have the required fuel reserves.

4.3 Wing Design

The wings on the Chimera aircraft, using the Korn 75-07-15 series airfoil, will have a thickness to chord ratio of 0.151 from the centerline of the aircraft out to the fold of the wing, at which point it decreases linearly from 0.151 to 0.12 at the tip of the wing. This may have to be modified slightly to allow for a straight line wrap method of manufacturing. This thickness ratio variation was chosen from a study of comparator aircraft and will allow for ease of manufacture, increased fuel volume, and cost savings over a more complex distribution. This will also allow for a thick leading edge to facilitate the proper placement and actuation of the leading edge slats that will be discussed in section 4.4. This distribution of the wing thickness can be seen in Figure 4.5, below.

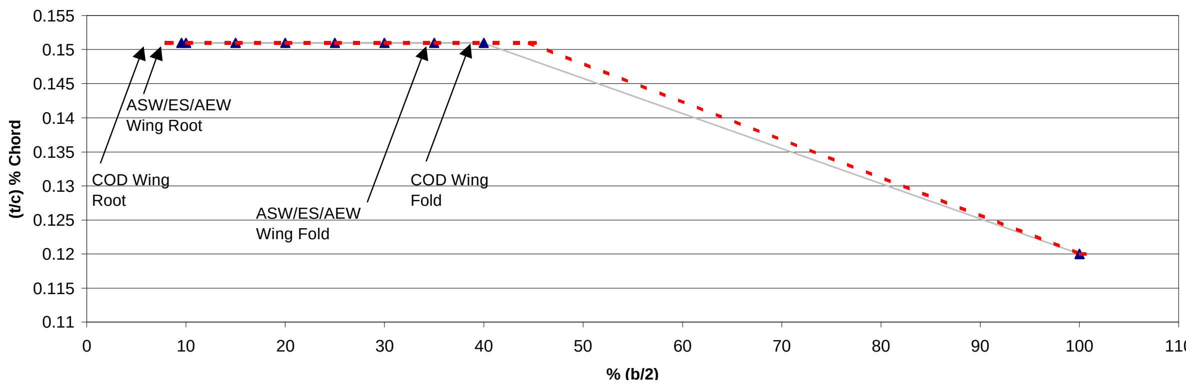

Figure 4.5 Wing Thickness Distribution for the Chimera Aircraft

The twist distribution of the wing was also estimated from comparator aircraft and was defined with cost and ease of manufacture in mind as well as basic aerodynamic principles. The wing incidence will be 3° constant to the fold, then will change from 3° to –2° at the tip. See Figure 4.6 for the details of this design. The constant inboard incidence will decrease venturi-like effects in the region between the fuselage and the nacelle under each wing and the lower wing surface, which will cause interference and drag.

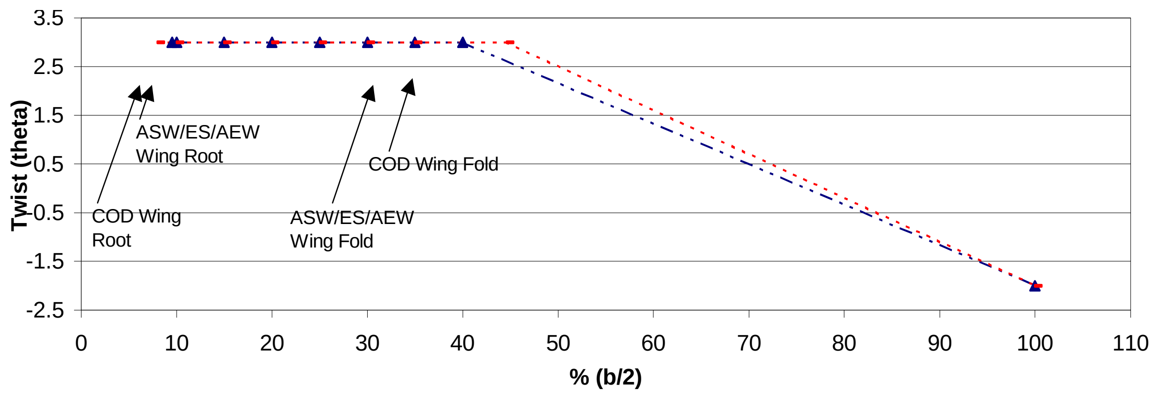

Figure 4.6 Wing Twist Distribution for the Chimera Aircraft

4.4 High Lift System

The S-3 comparator aircraft has a C_{LMAX} of 2.63 using Fowler flaps and leading edge flaps, while the ES-3A has a C_{LMAX} of 2.72 using similar high lift systems. These values were reasonable estimates and were used as a starting point for the high lift system. From Torenbeek, (Ref. 4.3) single-slotted Fowler flaps at landing are capable of giving a value of 2.7 for C_{LMAX} for our wing sweep and flap configuration. Using a stall speed of 92.5 KTAS it was determined that the COD would require a C_{LMAX} of at least 2.67 at landing. This is within the limits of a single-slotted Fowler flap wing with leading edge slats. Table 4.3 shows the data used for the comparison of the Chimera COD (which needs the highest C_{LMAX} at landing of our variants) and the S-3 and ES-3A. Figure 4.7 shows a cross section of the Chimera's wing just outboard of the wing fold. The high lift devices are clearly shown.

Table 4.3 Comparison landing data* from current aircraft

	V_{APPR} (ft/s)	V_{STALL} (ft/s)	Ñ	$W_{LANDING}$ (lbs)	S (ft^2)	W/S (lb/ft^2)	System	C_{LMAX}
S-3	170.136	141.78	0.002378	37700	600	62.83333	Flaps, Slats	2.63
ES-3A	170.136	141.78	0.002378	39000	600	65	Flaps, Slats	2.72
Chimera ASW	178.23	148.53	0.002378	38500	577	66.72	Flaps, Slats	2.54
Chimera COD	171.98	143.3167	0.002378	43000	659	65.75114	Flaps, Slats	2.67

* The landing data for Table 4.3 was determined from estimates of the max landing weight of the aircraft, and using the equation: $CL_{\max} = \dfrac{W/S}{0.5\times r \times V_{stall}^{2}}$. Where W = weight at landing, S = Wing reference area, $\tilde{n}$ = density of air, and V_{STALL} = Stall Velocity of the aircraft.

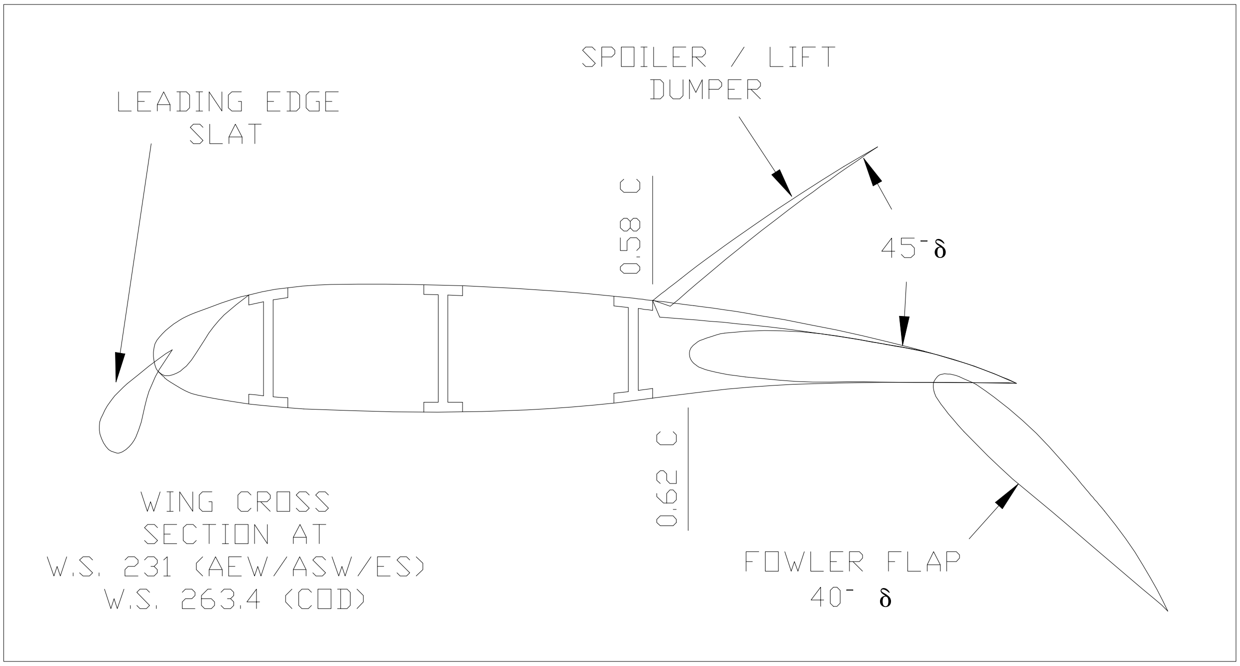

Figure 4.7 Airfoil Cross-Section Just Outboard of the Wing Fold, Including High Lift Devices

As noted in section 4.5, the horizontal tail has an inverted airfoil, which will help relieve the pitching moment caused by extending the flaps. This inverted camber airfoil will also efficiently counter the negative pitching moment induced by the wing's supercritical airfoil.

4.5 Empennage Design

The horizontal tail airfoil has an inverted 64A412 section at the root and 64A410 at the tip. These inverted airfoil sections were selected to counter the negative pitching moments induced by the wing's supercritical section. The horizontal tail will be lightly loaded at cruise so as to minimize the trim drag associated with the configuration. The vertical tail employs a constant thickness ratio symmetrical NACA 63A010 section. The thinner airfoil sections at the junction of the horizontal and vertical tails are employed to avoid Mach divergence drag and flow breakaway with attendant buffeting. The differing location of their chord-wise maximum thicknesses should also help alleviate this problem.

Chapter 5 Performance

Several performance constraints, based on factors discussed in chapter 4, were required by the RFP. These include: take-off SEROC of no less than 200 ft/min, an approach SEROC of no less than 500 ft/min, and a dash speed of 425 KTAS (0.74M/35,000 ft). Maximum range, loiter time, and ceiling were also determined to show that the Chimera aircraft family could complete all four missions as required. For the purposes of this performance analysis the use of a C-13-2 catapult launch system and a Mark 7 Mod 3 arresting gear system were utilized.

5.1 Rate of Climb Requirements

Based on weight analysis the COD variant was chosen as the constraint for the SEROC requirements due to having the largest TOGW. Using Equation 5.1 for carrier take-off, taken from *Aircraft Design: A Conceptual Approach* (Ref. 5.1), the end speed was calculated for the COD variant assuming zero wind-over-deck (WOD). The thrust available for the COD variant at an end speed of 109.4 KTAS was determined from the performance

$$V_{END} = \sqrt{\frac{2.42\left(\frac{W}{S}\right)_{TAKEOFF}}{\rho\, C_{LmaxTO}}} - V_{WOD} - \Delta V_{THRUST} \qquad \text{(Eq. 5.1)}$$

charts in chapter 5. From this data the SEROC at take-off was calculated to be 683 ft/min using Equation 5.2, taken from Anderson's *Aircraft Performance and Design* (Ref 5.2).

$$ROC = \sqrt{\frac{\frac{W}{S} * Z}{3\rho C_{D0}}}\left(\frac{T}{W}\right)^{\frac{3}{2}}\left[1 - \frac{Z}{6} - \frac{3}{2\left(\frac{T}{W}\right)^2\left(\frac{L}{D}\right)^2 * Z}\right] \qquad \text{(Eq. 5.2)}$$

$$Z = \frac{3V^2 \rho C_{D0}}{\frac{T}{W}\frac{W}{S}}$$

At approach, a fuel/armament dump of 6,000 lbs was assumed decreasing the gross weight of the COD to 43,400 lbs. The approach velocity was determined assuming $V_{APPR} = 1.2\ V_{STALL}$, and the thrust available at this velocity was calculated as previously discussed. An approach SEROC of 861 ft/min was determined from the previous equations. These rates of climb exceed the requirements and are shown in Table 5.1.

5.2 Dash Speed Requirements

The larger drag produced by the AEW variant (Fig. 3.1) determined the constraint on dash speed because it requires the largest amount of thrust during cruise at 35,000 ft. Figure 5.1 shows the thrust available vs. the thrust required per engine at 35,000 ft. The thrust required curve was determined from the drag analysis in chapter 4. The intersection of these curves corresponds to the maximum velocity obtainable by the AEW variant at 35,000 ft, which is 447.3 KTAS (Mach 0.78). This shows that the AEW variant can dash at a speed higher than the required dash speed of 425 KTAS (Mach 0.74).

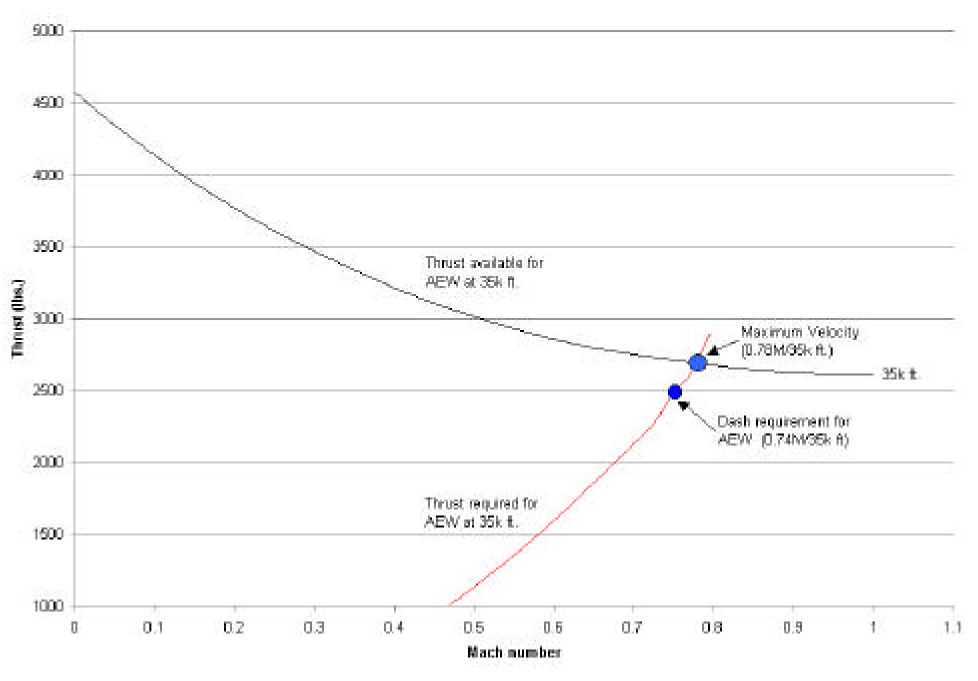

Figure 5.1 Thrust Required vs. Thrust Available (per engine at 35,000 ft) for the AEW variant

5.3 Mission Performance Requirements

Each variant uses the same fuel tanks to increase the commonality and to lower the overall production cost. Because each variant will carry an equal volume of fuel, the weight of the COD variant was chosen as the constraint on the required fuel volume. Using a known cruise SFC from comparative aircraft and the “Fsr.f” program (Ref 4.4), specific range calculations were made to determine an optimum cruise altitude and speed for the COD variant. Figure 5.2 is a contour plot of the calculated specific range as a function of altitude and Mach number, and shows that the optimum specific range for the COD is 148 nautical miles (nm) per 1,000 lbs of fuel at (0.70M/35,000 ft.). Table 5.1 shows the optimum cruise altitude and speed for each variant. From the mission requirements shown in Table 1.1, the COD variant must travel 1,600 nm and loiter for 20 minutes at sea level. Using the optimum specific range determined previously the fuel required to travel 1,600 nm is 10,811 lbs. Using maximum loiter equations from Reference 5.2 a fuel volume of 423 lbs is required to fulfill the loiter requirement. The RFP also states the each variant must carry a fuel volume of 5 % of the total mission fuel for reserve. Therefore, to fulfill the mission requirements the COD variant must carry approximately 12,000 lbs of fuel.

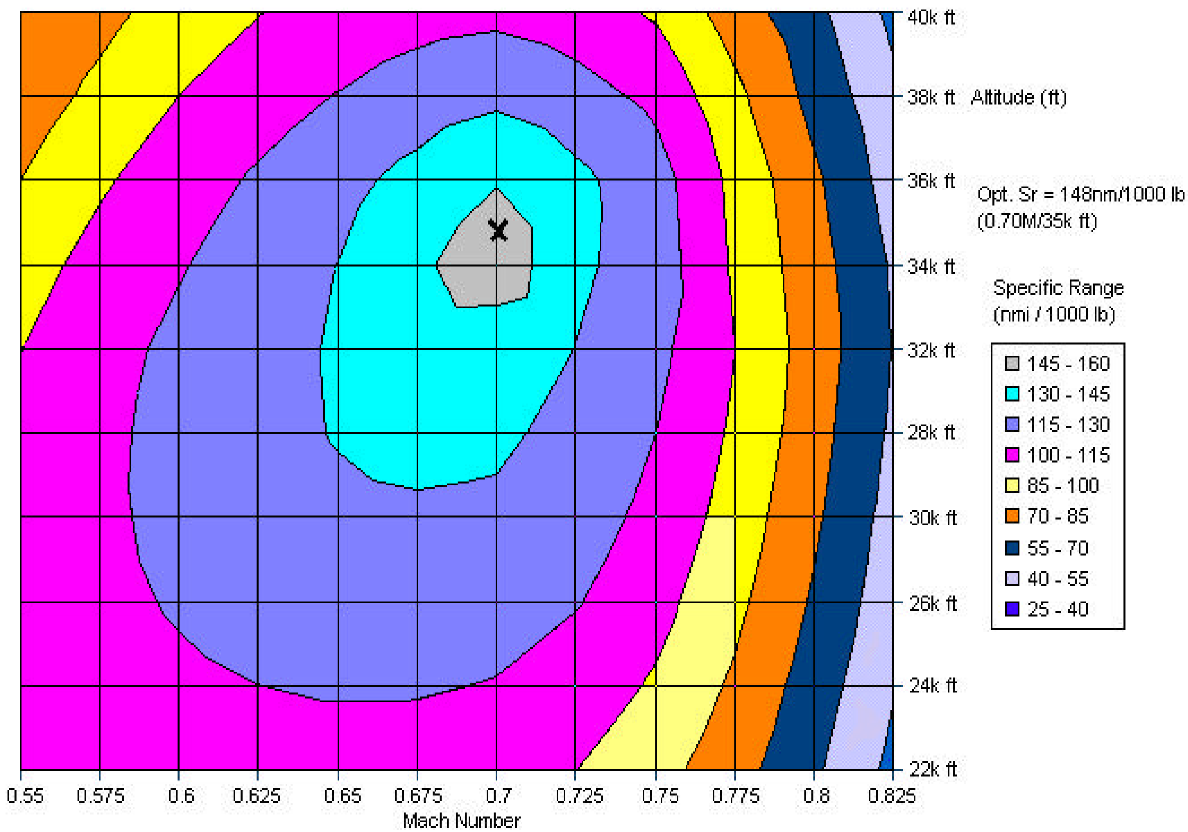

Figure 5.2 Contour Plot of Optimum Specific Range, Cruise Altitude, and Cruise Speed for COD variant

To compare the Chimera aircraft family against comparative aircraft, the ceiling, minimum take-off ground roll, and approach speeds were calculated for each variant. These values are shown in Table 5.1 along with those of the S-3B Viking. Due to the larger gross weight and similar thrust of the S-3B, the values differ slightly but provide a reference for comparison.

Table 5.1 Maximum Performance Characteristics

	COD	AEW	ASW	ES	S-3B
SEROC T.O. (ft/min)	683	792	870	894	
SEROC Approach (ft/min)	860	1070	1170	1085	
Approach Speed (KTAS)	101.9	105.6	105.8	105.2	100.8
End Speed (KTAS)	109.4	114.1	114.6	114.0	
Ceiling (ft)	47,500	50,200	53,100	53,220	40,000
Min Time to Climb to 35,000 ft (min)	15.2	12.4	13.7	12.1	
Min T.O. Ground Run (ft)	2,744	2,740	2,735	2,725	2,648
Optimum Cruise speed and altitude	0.7M/35,000 ft	0.7M/35,000 ft	0.75M/35,000 ft	0.75M/35,000 ft	

Chapter 6 Stability and Control

The control surfaces for the Chimera are common with the exception of an elevator span extension on the COD variant for increased pitch control power. The vertical stabilizers are canted inward, giving the rudders a 21º deflection from vertical. This causes rudder deflections to slightly affect pitch. The size of each vertical stabilizer is 61.9 ft^2. Rudders provide primary yaw control and secondary pitch moment in maneuvers, and they are 19.8 ft^2 each. The horizontal stabilizer has an area of 239.5 ft^2, which provides the primary pitch damping, while its elevators of 31.3 ft^2 each provide the primary pitch control. Inboard and outboard Fowler flaps are located at the trailing edges of each wing, and they are separated by the wing fold. The flaps have a total movable surface area of 131.4 ft^2. The spoilers are located forward of the flaps, immediately outboard of the wing fold. Each aileron is 20.3 ft^2. Full span leading edge slats are used to improve the lift coefficient during take-off, landing, and high AOA conditions.

6.1 Method of Analysis

The stability and control analysis of the Chimera Aircraft was carried out by a variety of methods programmed in FORTRAN. The longitudinal derivatives were found using the methods by Kay (Ref. 6.1). This code uses the planform of the aircraft to calculate stability derivatives and important control criteria. The code was verified against a modeled Boeing 747 to ensure reliability. Lateral stability was calculated using a separate code (Ref. 6.2). The output of this code was also compared against a modeled 747 to maintain a common reference between the two codes. The lateral stability code could not model twin vertical tails with its input structure. This required modifying methods from Digital DATCOM (Ref. 6.3) to consolidate the tails into an equivalent, single vertical tail. The area ratio of the vertical stabilizer surface to the rudder surface for the 747 and the Chimera aircraft were examined for consistency of DATCOM's estimation. Between these two codes all the stability derivatives could be estimated.

The Chimera was evaluated at four flight conditions, which include: take-off, landing, high altitude cruise, and low altitude dash. The addition of external weapons further defined the dash and cruise capabilities. The stability values for the COD variant are shown in Table 6.1 as compared to the AEW/ES/ASW variants. The takeoff and cruise conditions are compared since the COD variant did not differ greatly from the other three variants. Table 6.2 shows the control derivatives for the COD variant with takeoff and cruise comparisons. The COD variant was chosen for both evaluations because of its larger size, weight, and control requirements.

Table 6.1 Stability Derivative Comparison Between Chimera Variants

Mission Station	COD Takeoff	AEW/ES/ASW Takeoff	COD Cruise Loaded	AEW/ES/ASW Cruise Loaded	COD Landing	COD Dash Loaded
Altitude	0 ft	0 ft	35,000 ft	35,000 ft	0 ft	0 ft
Mach	0.2	0.2	0.68	0.68	0.2	0.75
***cg* X(h)**	26.63	27.32	26.63	27.32	26.63	26.63
Y	5.60	5.55	5.60	5.55	5.60	5.60
C_{La}	5.609	5.15	5.604	6.12	5.609	5.712
C_{Ma}	-0.045	0.0106	-0.117	0.120	-0.045	-0.087
C_{Lq}	12.98	9.55	11.68	10.67	12.98	10.72
h_p	27.03	27.63	27.03	27.63	27.03	27.03

Table 6.2 Control Derivative Comparison Between Chimera Variants

Mission Station	COD Takeoff	AEW/ES/ASW Takeoff	COD Cruise Loaded	AEW/ES/ASW Cruise Loaded	COD Landing	COD Dash Loaded
C_{Lda}	0.0461	0.461	0.0449	0.046	0.0461	0.0447
C_{yb}	-1.43	-1.55	-1.24	-1.58	-1.431	-1.16
C_{nb}	0.189	0.147	0.187	0.136	0.189	0.187
C_{lb}	0.053	0.054	0.048	0.053	0.053	0.047
C_{yr}	0.279	0.283	0.298	0.295	0.279	0.280
C_{nr}	-0.104	-0.110	-0.112	-0.119	-0.104	-0.110
C_{lr}	0.040	0.042	0.043	0.044	0.040	0.043
C_{lP}	-0.251	-0.232	-0.266	-0.234	-0.251	-0.268
C_{nP}	-0.064	-0.067	-0.054	-0.068	-0.0636	-0.052
C_{ndr}	0.069	0.063	0.062	0.065	0.069	0.063
C_{mq}	-21.5	-13.4	-19.4	-14.7	-21.5	-16.0
C_{ydr}	-0.170	-0.175	-0.163	-0.183	-0.170	-0.161
C_{ldr}	-0.001	-0.002	-0.011	-0.002	-0.001	-0.020

6.2 Static Stability

The longitudinal FORTRAN stability code was used to calculate the neutral point of the aircraft. The neutral point was found to be 27% of the Mean Aerodynamic Chord (MAC) for normal flight and takeoff. This configuration gives the Chimera a stability value of 8%. With a low stability factor, flight is more efficient with less trim loads. Acceptable *cg* variations in the aircraft extend from 15% MAC to 27% MAC. This yields a *cg* difference of 1.1 ft and a maximum instability factor of –2.22%. This degree of instability is still controllable by human pilots in case of a digital flight control system failure, and it is the maximum degree of instability for which the aircraft is designed. During large AOA the neutral point shifts aft, which increases the stability of the Chimera.

6.3 Engine Out

With large outboard engines, the Chimera must be able to maintain flight in the event of an engine failure. The lateral stability code was used to estimate the reactions in the event of an engine out. The takeoff condition was evaluated because it is the worst-case scenario (fully loaded COD at 49,407 lbs with one engine out). The constraints on this scenario are a 5° bank angle with full rudder deflection. The code calculates the other control deflections and sideslip angle necessary to maintain straight and level flight. A small aileron deflection is required to achieve the most efficient sideslip angle of less than 2°. The AEW variant was found to have a smaller sideslip and less aileron deflection than the COD variant because of its different engine location and overall fuselage length. The deflections for the COD are shown in Table 6.3.

Table 6.3 Engine Out for Chimera Aircraft

Variable	AEW	COD
b	1.312 °	1.497 °
f	5.00 °	5.00 °
d_a	-0.801 °	-1.37°
d_r	20.0 °	20.0 °
$C_{n\ avail}$	0.025	0.029

6.4 Dynamics and Flight Qualities

As previously mentioned, the Chimera will utilize a Digital Flight Control System (DFCS) which is discussed in detail in the Systems chapter. While the aircraft is still controllable without it, the DFCS significantly reduces pilot workload which is preferable for carrier operations. The twin vertical tails outboard of the fuselage centerline and the large horizontal tail contribute to outstanding damping ability, displayed in the derivative chart (Table 6.4). Methods from Etkin and Reid (Ref. 6.4) were used with the derivatives obtained in Kay's stability code to derive these roots. Since these methods are approximate, they were double checked with the data of the Boeing 747. These methods yield a 6.1% error when compared to the 747 data, which shows that the methods are reasonably accurate. Table 6.4 compares the Chimera airframe's stability derivatives to that required by MIL-SPEC F-8785C handling qualities (Ref. 6.5).

Table 6.4 Stability Parameters for the Chimera COD and AEW Variants

		MIL-STD Class II Cat. A Level 1 Requirements	COD	AEW
Short Period	Damping	$0.35 < \xi_{SP} < 1.3$	0.561	0.573
	Natural Frequency	2.15 rad/s < ω_{SP} < 7.72 rad/s	3.23 rad/s	3.16 rad/s
Phugoid	Damping	$\xi_{PH} > 0.04$	0.354	0.471
Dutch Roll	Damping	$\xi_{PH} > 0.19$	0.380	0.342
	Natural Frequency	$\omega_{ND} < 0.4$	0.951	1.10

Chapter 7 Materials and Structure

7.1 Materials

Aircraft materials used on the Chimera must be able to survive the harsh sea environment and the stresses of carrier deployment. Environmental concerns and RFP maneuverability requirements dictate the materials to be used. The criteria used for choosing materials are an abbreviated list from Reference 7.1 (Page 95). The following criteria are based on importance from most important to least important:

1) Specific Modulus/Static Strength efficiency
2) Fatigue
3) Environmental Stability
4) Manufacturing - ease of fabrication and availability
5) Costs

The specific modulus is the modulus divided by the density of a material, a strength per unit mass value for comparing different materials. Composites traditionally excel in the specific Young's modulus, but lack in specific shear modulus when compared to traditional metals. Thermoplastics fall below metal specific moduli but are light weight and impact resistant. Table 7.1 lists common metals and composites and their associated moduli (Ref. 7.2).

Table 7.1 Comparison of Select Materials

Material	E (10^6 psi)	G (10^6 psi)	Fiber Orientation	Density (lb/in^3)	E/r	G/r
Aircraft Steel (5Cr-Mo-V)	30	11	---------	0.2810	106.7616	39.14591
Chrom Moly Steel (AISI 4130)-sheet	29	11	---------	0.2830	102.4735	38.86926
Aluminum 2017	10.4	3.95	---------	0.1010	102.9703	39.10891
Aluminum Clad 2024 (24 st)	10.7	4	---------	0.1000	107	40
Aluminum Clad 7075-T6 sheet	10.3	3.9	---------	0.1010	101.9802	38.61386
Magnesium HK 31A	6.5	2.4	---------	0.0674	96.43917	35.60831
Titanium Ti-6A1-4V	16	6.2	---------	0.1600	100	38.75
Nickel Alloy: Rene 41	31.6	12.1	---------	0.3000	105.3333	40.33333
3501-6/AS4 Epoxy/Carbon Fiber*	20.5	---------	0°	0.0572	358.1412	---------
F655/IM7 BMI Resin/Carbon Tape*	23.3	------ (0.75)	0^o (+/- 45^o)	0.0516	451.9884	(14.54898)
FM652/T300 BMI Resin/ Carbon fiber*	11.05	------ (0.79)	0^o (+/- 45^o)	0.0511	216.4121	(15.4719)

Fatigue over the life of the aircraft is an important aspect for carrier duty. Because of repeated high-load and low-load cycles, the material must be resistant to the fatigue associated with these cycles. Some metals and most composites are resistant to fatigue and were considered because of this capability. Thermoplastics are resistant to fatigue. The resistance to fatigue is an important aspect in avoiding high maintenance requirements for a carrier-borne aircraft.

Environmental stability is essential for materials operating in a wide range of temperatures, humidity, and corrosive conditions. The operating temperatures for a naval aircraft vary greatly from below zero Fahrenheit to well over 100^{o} Fahrenheit. Corrosion from sea water and sea air are important considerations when operating aboard naval vessels. The materials must be able to withstand this chemical and abrasive corrosion. Corrosion reduces the strength, fatigue life and high-cycle stress resistance of metals. While chemical corrosion is a problem for metal, humidity affects composites to a greater extent. Composites absorb humidity from the atmosphere reducing their strength as well as adding approximately 2-5% to their weight (Ref. 7.2). Thermoplastics can resist humidity, fatigue and corrosion.

Conventional materials include stainless steel, aluminum, and titanium. These metals are corrosion resistant, have high relative strengths, relatively inexpensive cost, and good fatigue resistance. Composite materials fall into several categories depending on the fiber used, fiber orientation, and substrate used. All composites are more prone to impact damage than metals. The most common composite used in current naval aircraft is carbon fiber/epoxy. Carbon fiber/epoxy, like most composites, is corrosion resistant, fatigue resistant, and has a comparable tensile strength to metals. Carbon fiber/epoxy is used on such current aircraft as the AV-8B Harrier, F/A-18 E/F SuperHornet, and in the JSF program. Composites are generally more expensive than metals to manufacture, but carbon fiber/epoxy is the most inexpensive composite on the current market.

Thermoplastics are impact resistant and bond easily to composites, making them ideal for high-impact areas to shield composites. Thermoplastics can be reformed through heating and reshaping, easing repair requirements. The relatively low strength of thermoplastics limits their use to low-load areas. Thermoplastics also have a slightly higher cost than conventional materials, and they are commonly used in a variety of high impact, low stress areas.

Composite usage has been increasing in aircraft, from the AV-8B, F/A-18 E/F, F-22, and the JSF program. The benefits of composites outweighed the drawbacks. The higher specific modulus of composites and their resistance to corrosion and fatigue, we decided to go with a composite airframe. Extensive use of advanced composites with their reduced part count reduces aircraft weight and saves fuel, yet the drawback is cost. This initial cost disparity will prove to be worthwhile over the life cycle costs of the aircraft with respect to required fuel usage and maintenance.

Composites will comprise the majority of the aircraft structure. Carbon-fiber composites will be used for the internal airframe and skins. Thermoplastics will be used in low-stress, high impact areas such as the trailing edges, access panels, wing fold covers and bomb bay doors. Stronger or more impact-resistant composites will be used where needed. Bismaleimide (BMI) resin is an example of such a matrix that would be coupled with carbon fiber to create a more rigid and durable aircraft. Metals will be used only when necessary, such as aluminum leading edge slats for durability. Figure 7.1 shows the materials location breakdown for the Chimera. The illustrated airframe is for the ASW/ES/AEW, and the COD material data is also included.

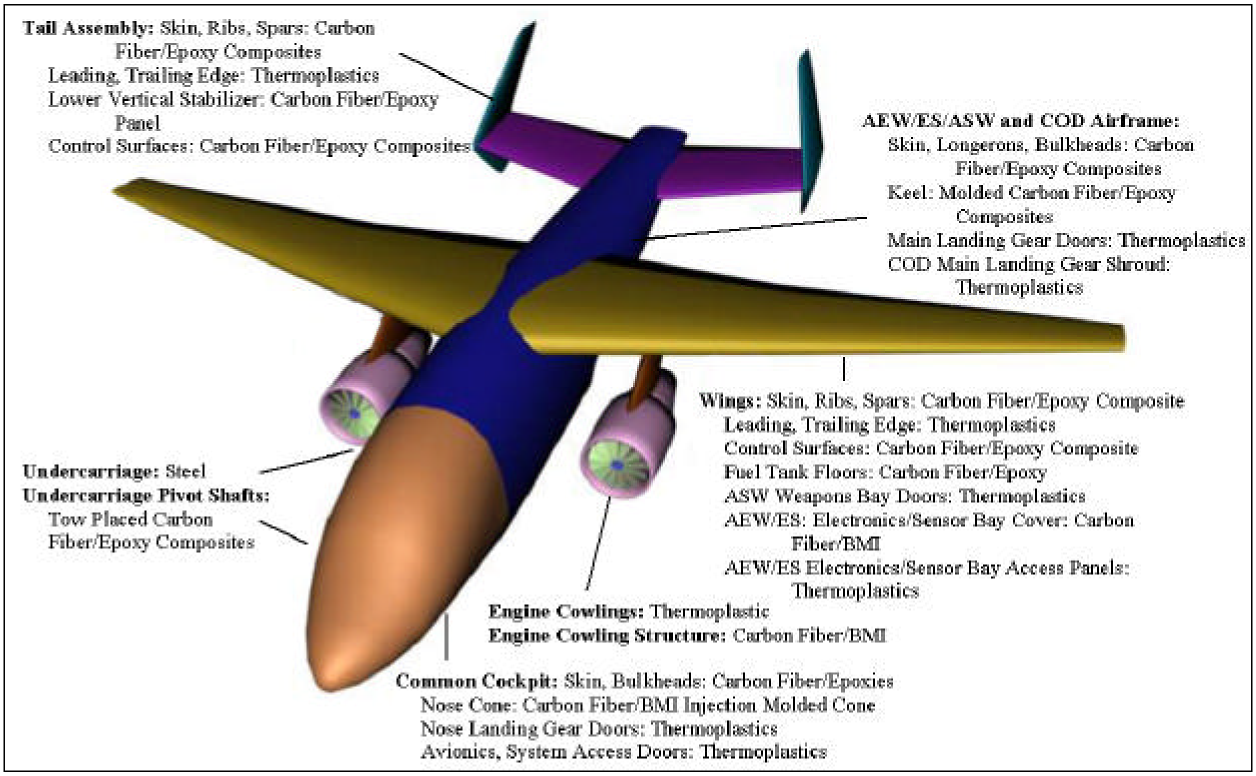

Figure 7.1 Material Distribution of the Chimera ASW Variant

Carbon fiber/epoxy composites are vulnerable to impact fracture and delamination. High-impact prone areas such as the bomb bay doors and leading edges are not composites but thermoplastics. The leading edge slats are aluminum with the leading edge underneath as thermoplastics. The nose cone is made of more impact-resistant, injection molded BMI resin composites. The repair of composites will be easier based on the introduction of the F/A-18 E/F and the JSF into the Navy.

7.2 Structures

The structural layout of bulkheads and longerons is common between all the variants (Figures 7.3 and 7.4). The main structural skeleton includes five longerons. Four longerons are located in a box shape in the fuselage and run from the farthest aft bulkhead on the common cockpit section to the main landing gear bulkhead. The fifth longeron is the keel and runs along the bottom centerline of the aircraft. This longeron is longer than the other four. The keel is designed to attach to the nose landing gear well, creating a much stronger joint to absorb the nose tow catapult loads at that location. The arrestor hook is attached to the keel to distribute the stresses of arrested landing. Each landing gear well includes smaller longerons to stiffen and tie the well to bulkheads and the keel.

The bulkheads are located at the high load areas along the length of the fuselage. Those bulkheads include pressure bulkheads, nose gear and main gear bulkheads, ejection seat bulkheads, wing spar bulkheads, horizontal tail spar bulkheads, and other assorted load distributing bulkheads. Each bulkhead connects to each of the five longerons, allowing for the loads to be distributed throughout the aircraft.

The wings contain three main spars. The forward spar is at 12% chord outboard of the engine rib structure. The mid spar is located in the middle of the fore and aft spars and does not carry through the fuselage. This mid spar terminates at approximately 75% of the span. It provides a mid-chord locking structure for the skewed hinge wing fold. The aft spar is at approximately 56% chord outboard of the wing fold with the inboard aft spar perpendicular to the inboard wing fold. Ribs were placed every 36 in. along the wingspan and as necessary in areas of high load such as the engine pylons and the external load pylons. Additionally the wings have closure ribs directly inside and outside of the wing folds. The composite skin will be stiffened with integral stringers to resist buckling and assist in load carrying capacity. The tail sections were modeled after the wings with the same rib spacing, yet the horizontal and vertical tails contain two spars each.

The V-n diagram in Figure 7.2 shows the limitations for loading based on velocity. This is important in showing the maneuvering envelope to which the structure will be subjected. The structure was designed for a positive 3.5-g and a negative 1-g turn, with a 1.5 factor of safety. This maximizes safety and minimizes weight.

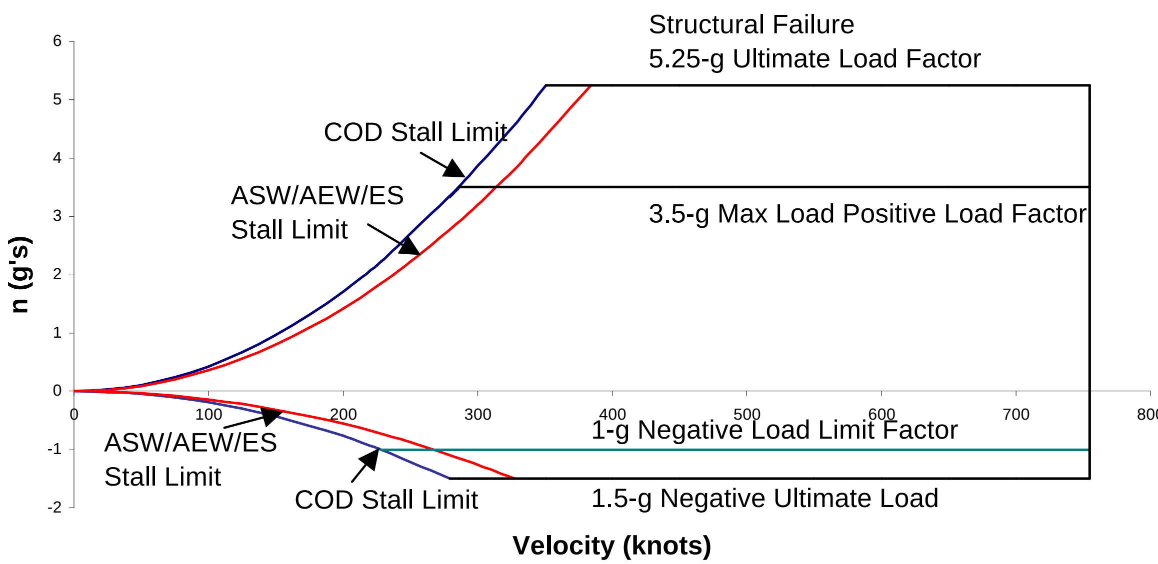

Figure 7.2 V-n Diagram of the AEW/ES/AEW and the COD Loading Factors

The structure diagrams for the AEW/ES/ASW and the COD are Figures 7.3 and 7.4, respectively. The longerons have a common connection to the cockpit. The wings and empennage between the two variants are common with an extension on the COD variant elevator and leading edge slat span.

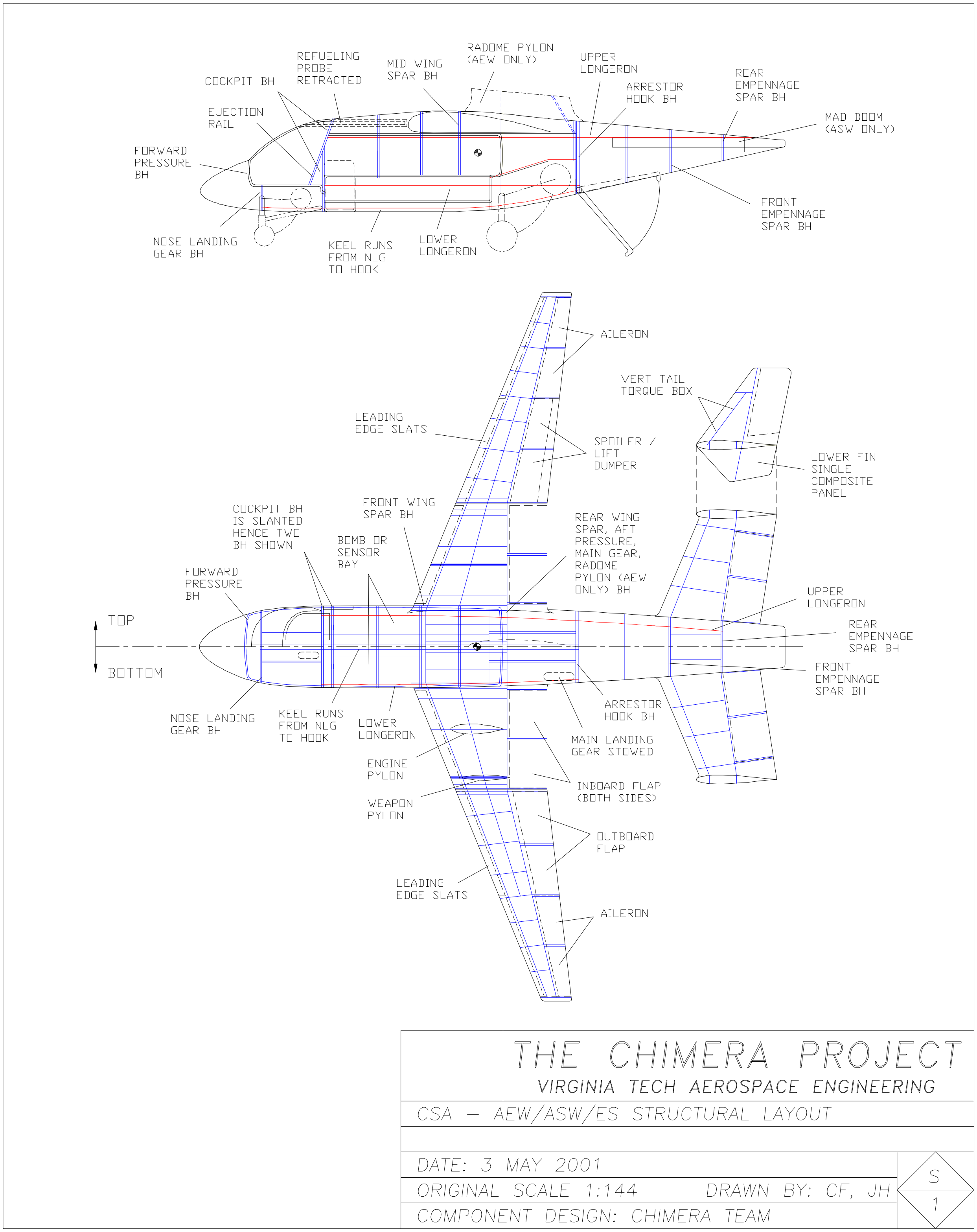

Figure 7.3 AEW/ES/ASW Structural Layout

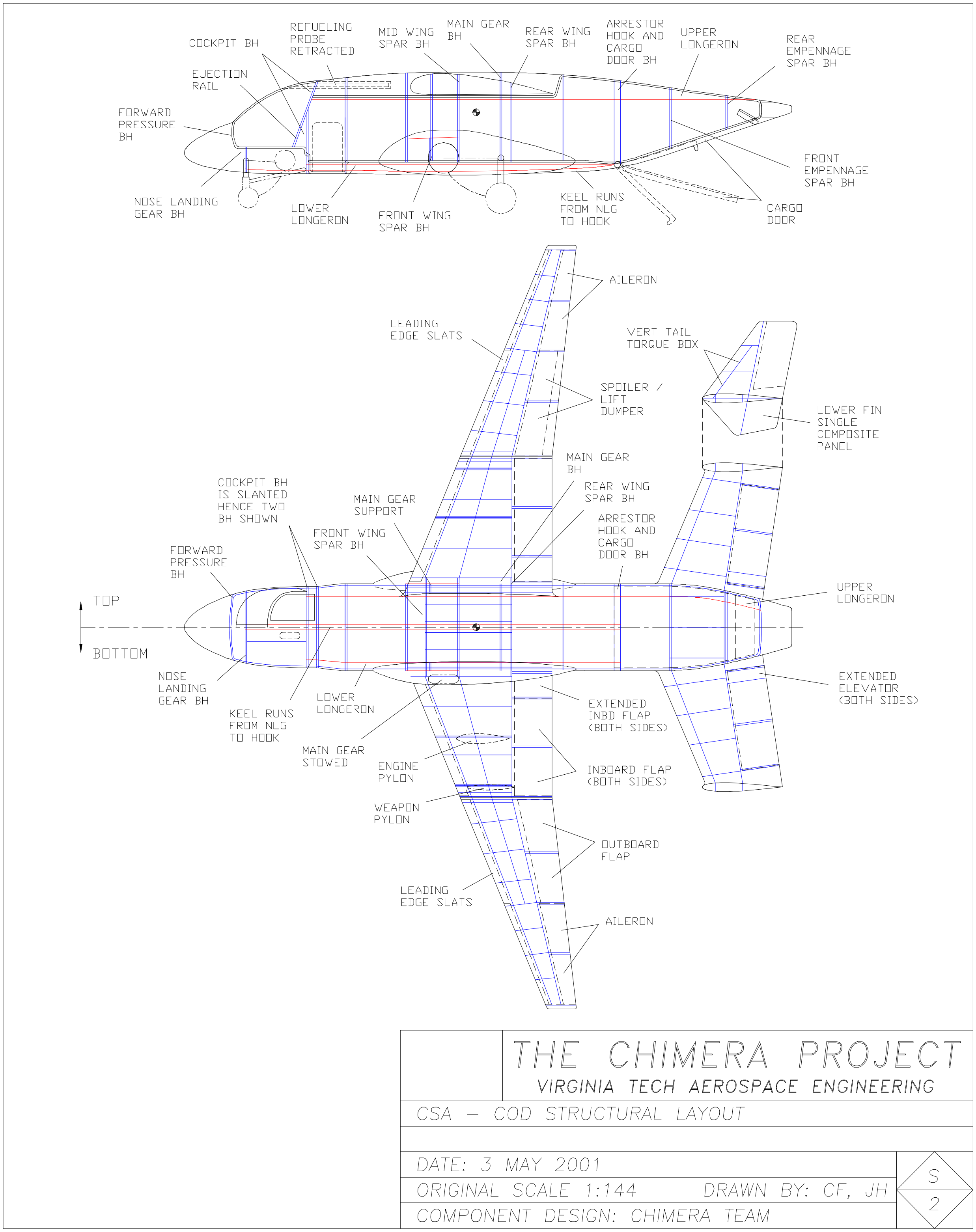

Figure 7.4 COD Structural Layout

Chapter 8 Systems

8.1 Basic layout

The interior for each variant is specifically suited to fit each mission requirement. The basic fuselage layouts for the ASW, ES, and AEW variants are similar to that of the Lockheed S-3B Viking. The layout of the COD variant is similar to that of the Grumman C-2A Greyhound. As previously mentioned, the basic cockpit layouts for all four variants are identical, with the only differences being mission specific displays and controls for the starboard seat operator. The pilot will sit in the port seat, which will have the primary flight controls. The COD variant will have full dual flight controls for both crew members. Aft of the cockpit on the starboard side will be the entry hatch followed by the weapons bay on the ASW variant and the sensors bay on the ES and AEW variants. The common internal bay was incorporated on all variants to keep the ASW, AEW, and ES fuselages common. This common bay is filled with mission specific equipment for each variant. All of these bays are sized around the weapons bay on the ASW variant which is staggered to accommodate the AGM-84 Harpoon internally on the port side. Additionally the ASW variant will incorporate a retractable FLIR (forward looking infra-red) pod beneath the floor under the pilot's ejection seat. All variants incorporate a large pressurized section for internal electronics. This allows the crew onboard to access various system components while in flight. All systems will be integrated via a fiber-optic backbone, which not only eliminates hundreds of pounds of expensive wiring, but also aids in aircraft-wide communication between all individual systems. Other advantages of fiber-optics are its ease of maintenance and superior upgradeability compared to conventional wiring systems. This system will be based on the U.S. Navy's "Hairy Buffalo" system, which is currently undergoing flight testing (Ref 8.1). Growth space is incorporated into all variants allowing for future upgrades when newer technologies become available.

8.2 Radar Systems

Considerable research was done to find the best possible radar system to use on the AEW variant. The current radar system used on the Grumman E-2C+ Hawkeye is the Lockheed Martin AN/APS-145. This radar is housed in an external rotating 24 ft dome on top of the aircraft fuselage. Current ranges of this system are in excess of 350 nautical miles (Ref. 8.2). While executing an AEW, mission it is imperative to be able to detect and track as many targets as possible. To use a less powerful radar in our AEW variant than the AN/APS-145 would be to decrease the current capabilities, which is considered unacceptable.

The advantages of using conformal array radar are obvious when the aerodynamic drag of conventional systems are considered. Conformal radar is comprised of a series of antennae around the aircraft that work together to form a 360º radar image. Unfortunately the technology needed for conformal array radar to compete with the range of conventional systems will not be available by our 2008 technology timeframe. If we were to incorporate conformal radar, additional costs for research and development would need to be appropriated up front. Current projections of technology timeframes for conformal radar based on currently allocated NAVY funds are as follows: operational design by 2012 and comparable range to the AN/APS-145 by 2025 (Ref. 8.3). Again, these are rough projections from Naval Air Systems Command (NAVAIR) but should be close estimates based on the fact that a lack of Navy funding for further research and development has placed research of these systems on the back burner.

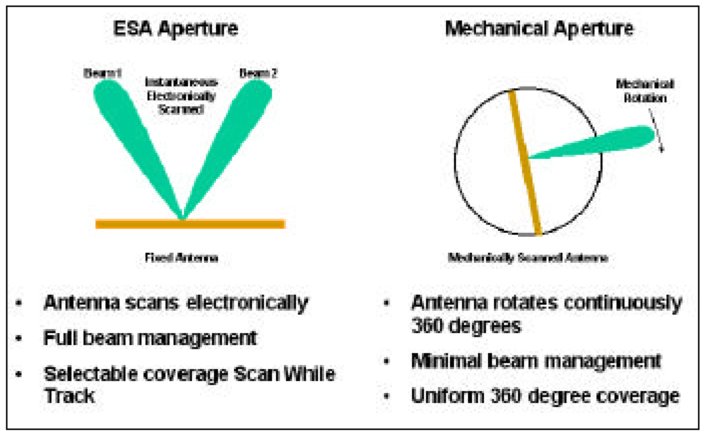

Figure 8.1 Comparison of Electronic vs. Mechanical Beam Steering (Courtesy of Northrop Grumman Electronic Sensors and Systems Sector)

Phased array radar works through a series of panels that operate through frequency modulation. Each individual array electronically steers the radar beam to scan a specific area (Figure 8.1). This allows for a flat panel array or a stationary radome that may be aerodynamically designed to minimize drag. Additional advantages of phased array radar lie in its ability to operate in different surveillance modes (Figure 8.2).

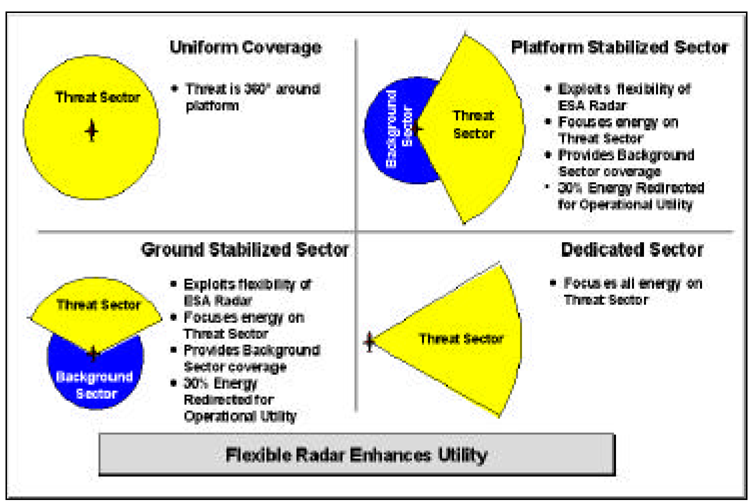

Figure 8.2 Typical Surveillance Modes (Courtesy of Northrop Grumman Electronic Sensors and Systems Sector)

Currently there are three main AEW radar systems currently incorporating phased array radar.

The Northrop Grumman MESA (Wedgetail) radar was developed for AEW&C and is mounted on top of a Boeing 737 (Figure 8.3). Advantages of this radar system are its long range (200+ nm) and its 360º coverage with a scan time of less than 10 s. This system also incorporates a combined radar and IFF suite. Disadvantages of this system are its size and weight. The MESA radar itself is about 25 ft long and 10 ft high. Placing this on top of a carrier aircraft while keeping below the 18 ft vertical limit would not be possible without folding the array. Additionally, extra space inside the fuselage would need to be allocated for the extra cooling systems needed for radar electronics.

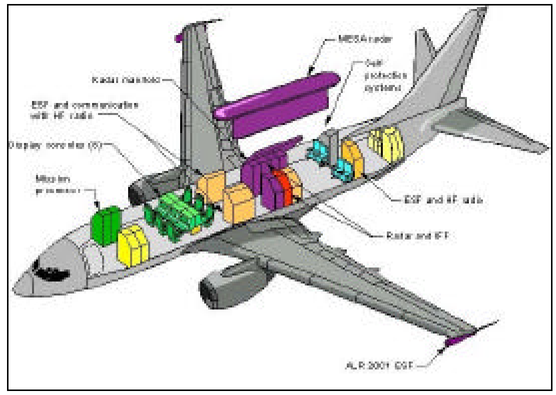

Figure 8.3 Northrop Grumman MESA Radar (Courtesy of Northrop Grumman Electronic Sensors and Systems Sector)

In a cooperative effort, Raytheon and the Israel Aircraft Industries (IAI) developed an electronically scanned array radar that can either mounted in flat panels (*Elta Phalcon*) or can be housed in a 30 ft fixed radome (*Elt*a). Currently the *Elta Phalcon* is mounted on Boeing 707's operated by the Chilean Air Force. Future plans call for the radome configuration to be mounted on an Airbus A310 as shown in Figure 8.4. This radar has the same advantages as the MESA radar with a little longer range however, it is housed in a 30 ft radome which is still too large for a carrier aircraft to accommodate. The current 24 ft rotodome on the E-2C+ Hawkeye is about the maximum sized radome that can be carried on our aircraft (Ref. 8.4).

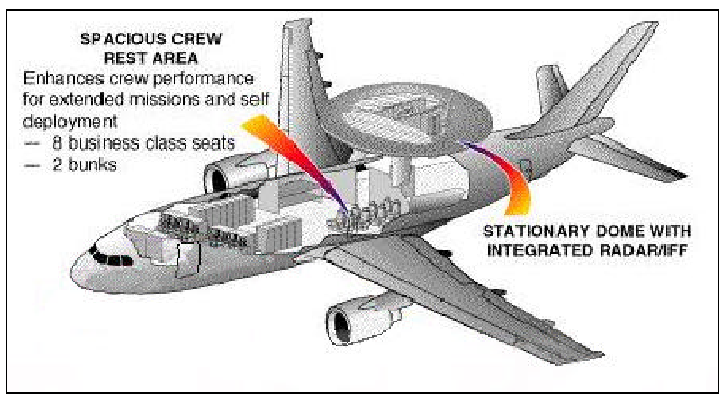

Figure 8.4 Raytheon/IAI *Elta* Radar (Courtesy of the Airborne Early Warning Association, www.aewa.org.)

The last phased array radar system considered was the Ericsson PS-890 *Erieye* radar. Currently this system is operated on Saab 340’s in Sweden and on Embraer EMB-145’s in Greece and Brazil (Figure 8.5). The only main advantage for this radar system is its cost. Detriments are that it can only scan 150° to either side and its range is not comparable to the current AN/APS-145 system. Other radar systems reviewed but not considered were a scaled down version of the phased array rotodome as used on the USAF E-3B and the USAF JSTARS flat panel radar system as used on the USAF E-8. Both of these were ruled out because of their excessive size and weight.

Figure 8.5 Ericsson PS-890 *Erieye* Radar (Courtesy of the Airborne Early Warning Association. www.aewa.org.)

Conformal radar was scrutinized for incorporation into the design but because of its lack of sufficient range it was not chosen. The Northrop Grumman MESA radar did not decrease the overall drag significantly enough to warrant changing the AEW variant around internally to accommodate the additional cooling systems. In the end, a hybrid version of the Raytheon / IAI *Elta* radar was picked because of its range and overall performance parameters and the fact that the additional cooling systems could be installed into the pylon structure. The hybrid would be functionally the same as the current *Elta* radar, however near future advances in technology will allow the radar system to be installed in a 24 ft dome vice a 30 ft dome. Though this approach increases the drag of the aircraft in the AEW configuration, the advantages in range, target acquisition, and fuselage commonality make this the preferred choice. Table 8.1 details a comparison of all radar systems considered.

Table 8.1 Radar Comparison

	Pros	**Cons**
Conformal Array	Minimal Drag	Cost, Technology not Feasible Until 2025 at the Earliest
Northrop Grumman MESA (Wedgetail)	Range, Coverage, Beam Steering, Lower Drag	Size (Needs a 10-ft Vertical Array)
Lockheed Martin AN/APS-145	Range, Coverage	Conventional Rotodome
Raytheon / IAI Elta Radar	Range, Coverage, Beam Steering	Size, Conventional Radome
Ericsson Erieye PS-890	COST	Range, Coverage (150° to either side)

The radome and centerline support pylon will be designed as a self-contained structure, which will be attached to the fuselage as a complete unit. In addition to having less parasite drag as seen from the previous drag calculations, the single pylon structure is large enough to accommodate internally the additional air conditioning systems needed for the increased cooling demands of the phased array radar electronics. Two NACA style air intakes bring in air from either side of the pylon and the air is exhausted from a single port at the rear of the pylon. This exhaust port has a closure flap used to reduce drag when the system is not operating.

To achieve the best radar picture possible, the Grumman E-2C+ Hawkeye flies with 10° flaps in order to keep the radar level with the horizon. This restricts the operational envelope when flying AEW missions. To alleviate this problem, a jackscrew will be mounted in the radome pylon and will replace the rear radar support. A pivot on the front radome support allows the jackscrew to raise and lower the radome as needed. This will enable the crew to keep the radar horizontal despite changes in the aircrafts AOA. This system will be limited however to 5° up and 2° down AOA because of complications in the pivot support mechanism if the angle gets too large. An inner gap seal assures smooth airflow around the pylon and radome at all pivot angles. Figure 8.6 details the AEW radome pylon.

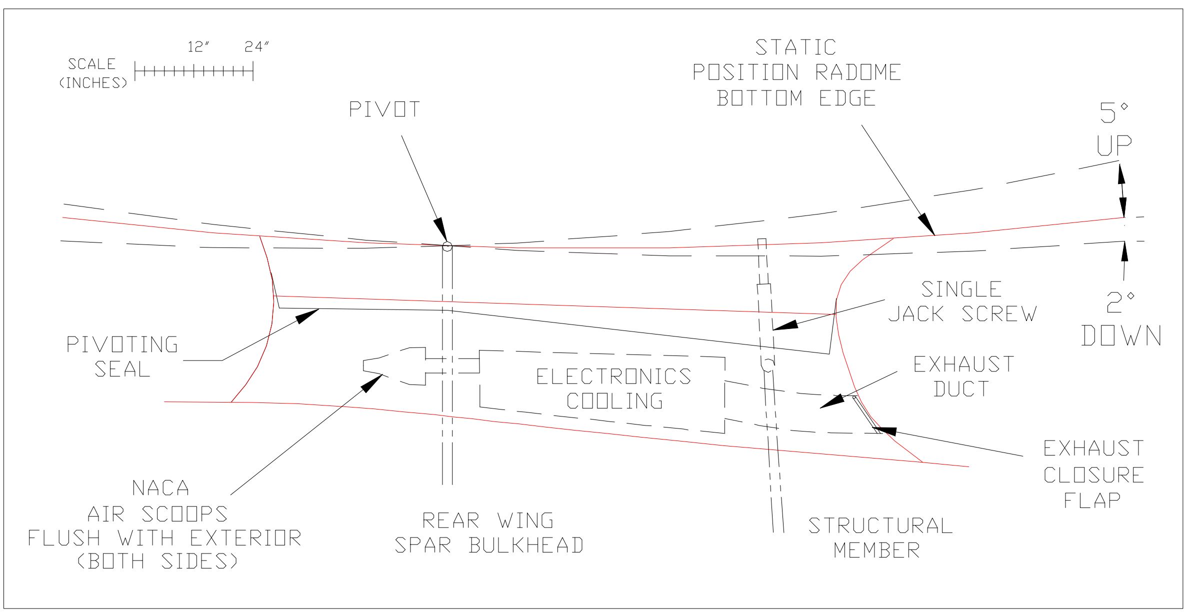

Figure 8.6 Radome Pylon Detailed Assembly

Because of our decision to go with a conventional radome, the ejection seat flight path will interfere with the radome structure at high speeds. To resolve this problem, explosive detonating cord will be mounted on the radome attach points. During a high speed ejection sequence, the radome explosive cords detonate, severing the radome from the aircraft. Following a slight time delay, the copilot's seat fires first and is then followed by the pilot's. Both ejection seats ride up extended rails that telescope 4 ft above the fuselage. These extended rails ensure that the ejection seats and the ejected radome will properly clear one another. During a low speed ejection, below 180 KTAS as found during takeoff and approach, the radome does not need to be jettisoned because the ejection path will assume a more vertical trajectory. Thus, the extended ejection rails alone will provide all of the necessary clearance. This also allows for a faster ejection sequence, which is paramount when close to the ground or water.

Provisions in the fuselage structure allow for the use of the current AN/APS-145 radome along with structural accommodations for two rear crew stations for export variants. The extra crew provisions are necessary for export to countries without the advanced data link systems of the US. The same centerline radome support will be used in this configuration as with the domestic *Elta* radar configuration. Ejection sequences will be the same in the case of a four seat ejection however the two rear seats will deploy first and will follow 7 ft telescoping ejection rail extensions instead of the 4 ft extensions as on the front.

The payload bay in the AEW variant will feature two angle mounted phased array panels which will be used to supplement the main radar in identifying low flying objects such as cruise missiles, surface targets, and stealthy airborne targets. These phased array radar panels will operate on a higher frequency X band than the main radar. X band frequencies are used for shorter ranged tracking and airborne intercept and are more effective at identifying stealthy targets than conventional VHF, UHF, L, S, and C bands (Ref 8.5).

The ASW variant will feature a Raytheon AN/APS-137 B(V)5 maritime surveillance radar. Versions of this radar were first installed on NAVY P-3 Orion's in 1998. Capabilities of this system include long range surface search and target tracking, periscope detection in high sea states, ship imaging and classification using Inverse Synthetic Aperture Radar (ISAR), and Synthetic Aperture Radar (SAR) for overland surveillance, ground mapping, and targeting (Ref. 8.6). As with all radar systems in all variants, extra growth space is incorporated into the design for the installation of newer radar systems when they appear. A conventional Magnetic Anomaly Detector (MAD) boom is installed in the aft section of the fuselage and is extended for use.

The ES variant will feature extensive incorporation of communication and intelligence gathering equipment. The Lockheed ES-3A Sea Shadow added over 60 various antennas to the basic S-3B airframe. Similar antennas will be added to the Chimera airframe for this mission but with the advance in technology over the next seven years, many of these antennas will be able to be mounted flush with the surface. This will minimize the increase in parasite drag due to antennae.

8.3 Tactical Control System (TCS)

Because all variants only incorporate two onboard crew stations, additional systems were needed to lessen the pilot and co-pilot workload during AEW, ASW, and ES missions. The ability to exclude aft crew stations is a direct result of the advanced technologies developed from the U.S. military's Unmanned Aerial Vehicle (UAV) programs. The PMA 263 office within NAVAIR heads up the Navy's involvement with UAVs, and one of their current programs is developing the Tactical Control System (TCS). The TCS is designed to control all UAV functions from a common data link system. This system will be joint service compatible and will be installed on all Navy aircraft carriers, cruisers, and destroyers. Figure 8.7 details the different levels of control. For the purpose of this design, Level III control will be utilized because the pilot onboard will handle flight control (Ref. 8.7).

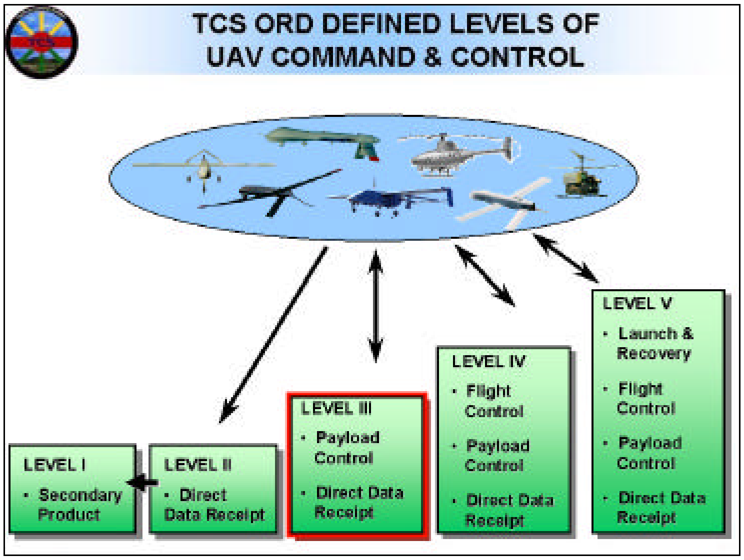

Figure 8.7 TCS Levels of Command and Control (Courtesy of Lt Cmdr Dave Seagle, PMA 263, NAVAIR.)

The heart of the TCS system is a Q-70 workstation (Figure 8.8). These workstations are current equipment on US Navy aircraft carriers, cruisers, and destroyers, as well as US Air Force aircraft and US Army ground stations. The power with using this system lies in its ability to allow the AEW aircraft to fully communicate with any ship, aircraft, ground unit or UAV by using Link 16 datalink technology. A Raytheon AN/ARC-187 Satellite Communications System will not only relay all data and voice communications to the battle group and surrounding aircraft, but via satellite the system will allow communication to virtually anywhere in the world.

Figure 8.8 Q-70 Work-Station, (Courtesy of Lt Cmdr Dave Seagle, PMA 263, NAVAIR)

8.4 Cockpit

The instrument panel on all variants is dominated by Active Matrix Liquid Crystal Displays (AMLCD) along with programmable touch-screen controls. Figure 8.9 details the instrument panel layout. The pilot's section incorporates two 8 in. × 6 in. displays for primary systems and three 4 in. × 4 in. multifunction displays for secondary systems. Honeywell was chosen as the supplier for these displays because their systems are current off-the-shelf products and are compatible with other current Navy aircraft (Ref. 8.8). A Heads Up Display (HUD) is provided to the pilot (and copilot on COD variants) for maximum situational awareness. Touch-screen displays, as found in the Boeing F/A-18 E/F, are used throughout the cockpit for various system controls. These were chosen for their ability to be programmed for different functions during different flight and mission profiles. Backup attitude, airspeed, altitude, and directional indicators are located on the bottom portion of the pilot's instrument panel in the event of a full display system failure.

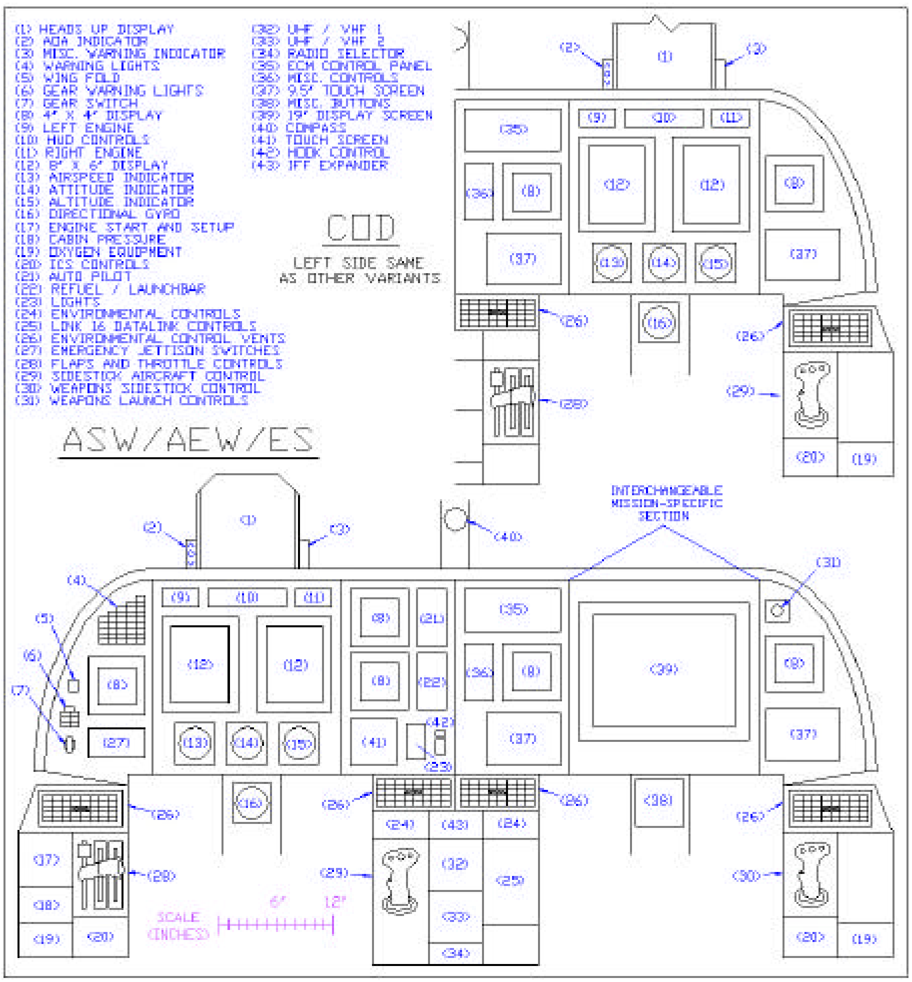

Figure 8.9 Instrument Panel for All Variants

Primary flight control is accomplished through the use of a side-stick controller on the pilot's right side and a throttle quadrant on the left. Conventional rudder pedals are used for yaw control during flight and steering control on the ground.

For all variants except the COD, the copilot's section is dominated by a 19 in diagonal flat panel display. To either side of the central display are a 4 in. × 4 in. multifunction display and a 9.2 in. diagonal touch-screen. The 19 in. center display and the 9.2 in. touch-screen are taken directly from the Q-70 workstation. This setup essentially duplicates the Q-70 workstation which the flight systems operators will be using onboard the carrier. Modifications will have to be made to the COTS components to allow them to withstand the vibrations and environmental concerns associated with carrier aviation.

The copilot's right console is dominated by a weapons control side-stick and on the left are the Link 16 and radio controls. The copilot's side-stick is used primarily for target selection and acquisition. Because of the complete integration of all aircraft systems via its fiber-optic backbone, the copilot's side-stick can also be used for aircraft flight control with the throttle and other necessary systems controlled by touch-screen functions. The instrument panel layout was designed to provide maximum ergonomic comfort for the pilot and copilot. Environmental controls and vents are also included for crew comfort. The instrument panel is sectioned with side panels angled for straight on viewing from the crew station.

Figure 8.10 Martin Baker Mk 16 L (Courtesy of Martin Baker Aircraft Company Ltd)

On the COD variant the 19 in. center display is replaced by the same 8 in. × 6 in. displays as found on the pilot's panel. The Link 16 controls are replaced with duplicate throttle controls and a HUD is also included.

The ejections seat of choice are the Martin Baker Mk 16 L (Figure 8.10). This seat is currently flying in the T-6 Texan II, Eurofighter 2000, French Rafale, and updated versions of the T-38. The seat has full zero speed / zero altitude escape capability and protects in ranges up to 450 KEAS and altitudes exceeding 35,000 ft. The main advantage with using this seat is that it contains the same high value consumables as the Navy Aircrew Common Ejection Seat (NACES). This allows for most of the line-serviceable parts to be interchanged with ejection seats from other aircraft on the carrier, thus reducing the number of spare parts needed (Ref. 8.9). Figure 8.11 shows the ejection seat and cockpit layout.

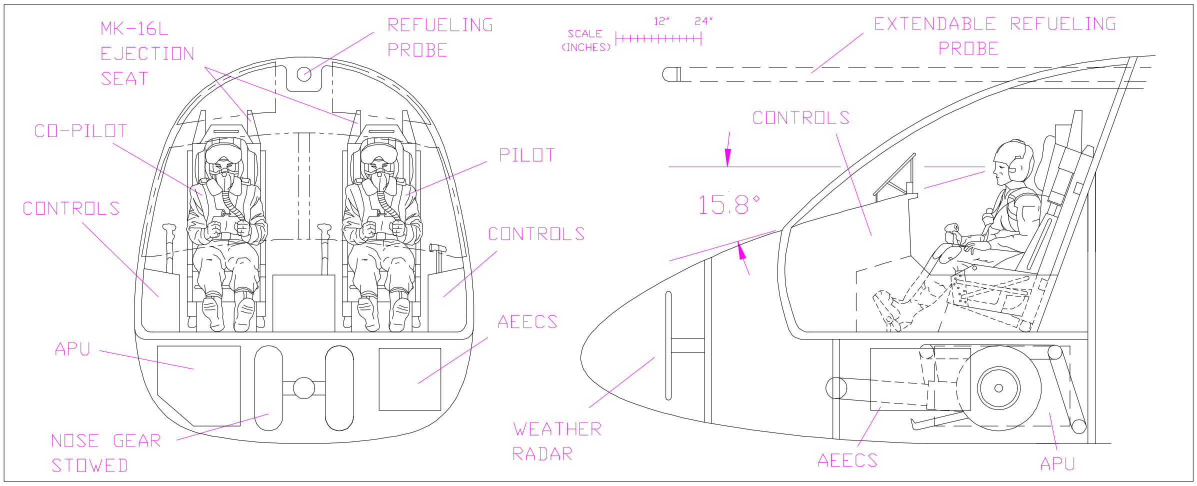

Figure 8.11 Ejection Seat Installation and Cockpit Layout

8.5 Electrical System

An Allied Signal 36-200 Series APU will provide the auxiliary power needed to start the engines without the use of ground equipment. This particular model was chosen because of its lightweight and small size and is also the same as used on all variants of the Boeing F/A-18 Hornet (Ref. 8.10). This offers greater parts commonality between carrier aircraft. A sealed lead acid battery provides utility DC power for APU starting and avionics run-up without APU power. The battery also provides in-flight emergency power for the flight controls and avionics until the APU or main engines can be restarted.

Because this aircraft's flight control system is completely dependent on electrical power, multiple backup generators will be incorporated. For primary electrical power, turbine run generators from each engine will be used. These 65 kVA generators provide AC power, which is then converted to DC for the various aircraft systems. Electrical power is routed through power lines from each engine on either side of the aircraft. This ensures that if one side of the aircraft is damaged, the power line on the opposite side will be able to distribute the electrical power needed to run the various aircraft systems. For triple redundancy, a generator on the APU will be utilized for emergency power.

8.6 Flight Controls

The flight control system will be comprised entirely of electrically powered hydrostatic actuators with fly-by-light control. This setup allows for ease of integration into the DFCS. All variants will have dual independent electro-hydrostatic systems, one being the primary and the other for backup. This fly-by-light approach is currently under development by Parker Aerospace and Hamilton Sundstrand for use on Lockheed Martin's JSF aircraft (Ref.

8.11). The advantage of this type of flight control system over previous hydraulic systems is that most hydraulic lines running though the aircraft are eliminated – thus drastically reducing the weight and maintenance requirements. In their place are fiber-optic cables, which can be decoupled for maintenance or replacement. These fiber-optic cables are also run on each side of the aircraft with the electrical power lines for increased survivability, in case of fuselage damage.

There are two different types of electro-hydrostatic actuators: linear and rotary. The linear actuators use a piston type arrangement for control deflections of the ailerons, elevators, rudders, and spoilers. The rotary types use a geared approach and are used for flap and slat extension and retraction. With either actuator, hydraulic reservoirs are located inside each system so the only external connections are the fiber-optic control input and electrical power cables.

The main difference between an electro-hydrostatic system and current fly-by-wire systems is that the response time for control deflection is almost instantaneous with electro-hydrostatic systems whereas there is a slight lag on the current system. In current fly-by-wire systems, electric motor power control actuators are geared for operation. As a result for full control deflection, the electric motor has to fully wind through the gears, thus causing the time delay. An additional advantage of fiber-optic cabling is that it is less susceptible to electromagnetic interference (EMI) than conventional fly-by-wire systems. Figure 8.12 details the flight control system of our aircraft. Shown in this figure are the electrical paths connected to the control actuators. Drawing technology from the computer gaming industry, force feedback control sticks will give the positive control feedback associated with conventional hydraulic systems. This approach eliminates the complex mechanical pulleys and wires used in the Boeing 777 for tactile control feedback.

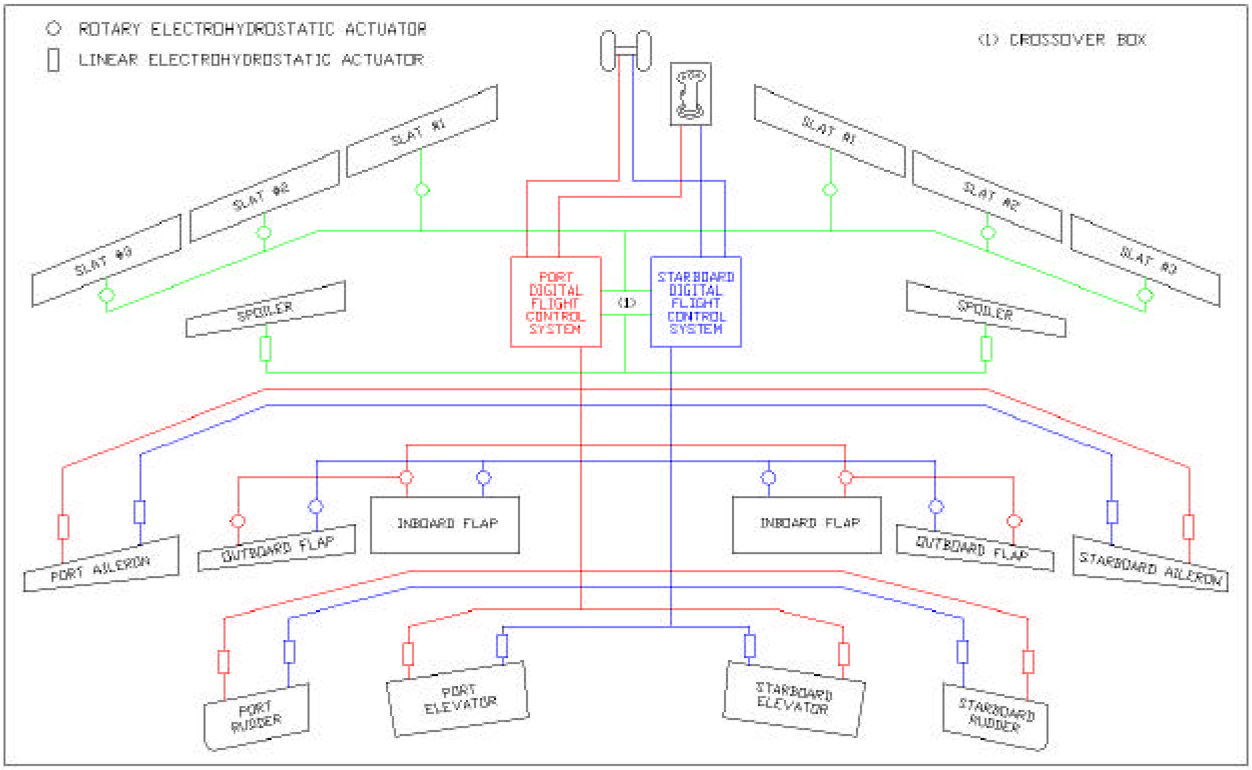

Figure 8.12 Flight Control System Diagram

8.7 Digital Flight and Engine Control System

Dual-redundant Digital Flight Control Systems (DFCS) are used to monitor all control surface deflections in relation to aircraft attitude and speed. When particular control stick and rudder pedal movements are sensed, the DFCS system automatically determines what combination of rudder, aileron, elevator, and spoiler deflections are necessary to achieve the maximum maneuvering performance. During autopilot operation, the DFCS assumes complete control of the aircraft, constantly optimizing the flight controls for the most efficient deflections. The DFCS also coordinates aircraft trim based on pilot input, thus eliminating the need for conventional trim tabs.

Engine control is accomplished by means of a Full Authority Digital Electronic Control (FADEC) system, which continuously monitors the engines and adjusts for optimum performance. This FADEC system combined with the DFCS fully integrates into the aircraft's auto-pilot system allowing for full autonomous control of the aircraft in flight and automatic carrier landings. These automatic carrier landings are accomplished through the coupling of the aircraft's Automatic Carrier Landing System (ACLS) with the aircraft carrier's ACLS SPN-42, which compensates for deck motion while guiding the aircraft onboard. During manual carrier landings, the FADEC system provides for auto-throttle, which reduces the pilot's workload during carrier landings.

8.8 Fuel System

The fuel system is common on all aircraft variants with the AEW variant being the design driver in requiring the most fuel for its mission. The maximum fuel required is 12,100 lbs of JP-5 including reserves. This fuel is held internally in three integral wing tanks and one bladder tank aft on the spar carry through. Fuel is drained first from the wing tanks, then from the bladder tank, and finally from the main center tank. This minimizes the inertia change due to fuel use. The main center spar box tank is located between the wing roots and the fuel bladder is located just aft of the spar carry through. The wing tanks are located on each wing between the wing roots and the wing folds (Figure 8.13). Each outer wing tank holds 2,543 lbs (385.3 gal U.S. or 51.5 ft^3) of fuel and the center integral and bladder tanks hold 7,086 lbs (1,073.6 gal U.S. or 143.5 ft^3) combined. This gives a total internal fuel capacity of 12,173 lbs (1,843.8 gal U.S.). Additional fuel can be carried in two standard 300 gal U.S. external fuel tanks for a total of about 4,000 lbs. of additional fuel.

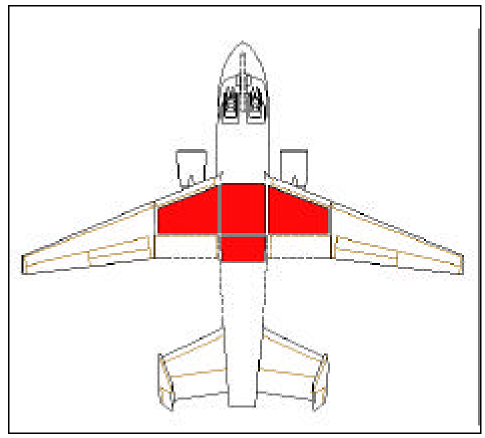

Figure 8.13 Locations of Internal Fuel Tanks

For extended missions or emergency holding, a retractable air-to-air refueling probe is incorporated which is located directly above the cockpit. The configuration is the same as that on the Lockheed S-3 Viking. Through the use of an ARS 31-301 buddy store refueling pod mounted on either wing weapons pylon, all variants can provide refueling capabilities to other aircraft using a drogue style refueling probe. These pods have been accounted for in the aerodynamic analysis. A fuel dump is also located at the rear of the fuselage between the horizontal stabilizers.

8.9 Environmental Control System

In order to minimize internal ducting, bleed air is replaced by an All Electric Environmental Control System (AEECS) for cabin pressurization. This type of system eliminates the heavy ducting needed to run pressurized air from the engines to the pressurization unit. The AEECS is located under the cabin floor of the cockpit on the port side of the nose gear on all variants. It is directly in front of the retractable FLIR pod on the ASW variant. Recognizing the importance that crew comfort plays during long duration missions, temperature controlled air vents are located on either side of the pilot and copilot seats.

8.10 Anti-Icing and Lightning Equipment

Traditional rubber inflatable de-icing boots as used on the E-2 Hawkeye and the C-2 Greyhound were not chosen for this aircraft because of the high maintenance and power consumption associated with these systems. Additionally, conventional bleed air anti-icing systems were ruled out because of the increased complexity of routing bleed air lines through movable slats on the leading edges of the wing. Instead a low power Electro-Expulsive Deice System (EEDS) will be used on all leading edges of the wings, horizontal, and vertical stabilizers. This system was originally developed by NASA and uses one-thousandth the power of existing electro-thermal deicers and weighs one-tenth as much. It consists of an elastic, rubber-like boot, which is embedded with flexible, conducting copper ribbons separated by slits. Capacitors discharge strong electric pulses into the ribbons, creating an electromagnetic field that forces adjacent conductors violently apart and the boot surface to jump and break up any ice buildup. (Ref. 8.12) Traditional hot air ducts are used to de-ice the windshield.

Aluminum strips are imbedded in the outer skin surfaces of the composite vertical tails and along the tops of the wings, fuselage, and horizontal stabilizers to protect against lightning strikes. Because the Chimera's structure is comprised mostly of composite materials, electrical conducting strips are needed to dissipate the electrical energy from a lightning strike.

8.11 Aircraft Lighting

Exterior aircraft lighting is accomplished through the use of conventional lighting systems (Figure 8.14). Red and green position lights located on the wing tips and tops of the vertical stabilizers with additional anti-collision strobe lights incorporated into the wingtips. Conventional flourescent formation lights are located on the sides of the fuselage just below the cockpit windows, on the wing tips, and on the upper portion of the vertical stabilizers. Landing and taxi lights are located on the strut of the nose-gear.

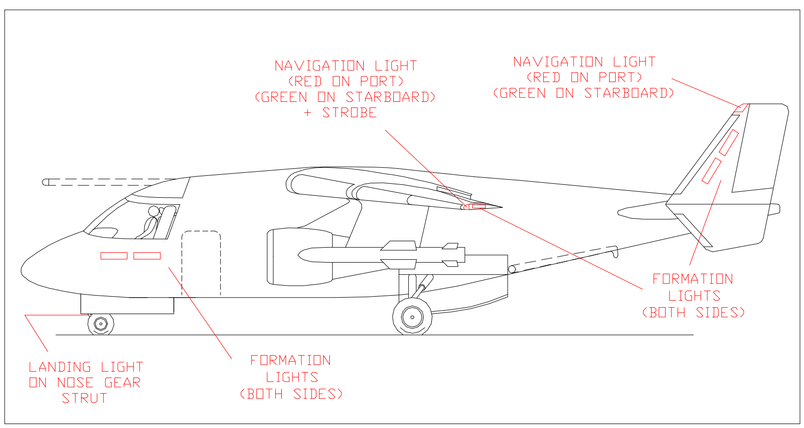

Figure 8.14 Locations of Exterior Aircraft Lighting

8.12 Landing Gear and Arrestor Hook

The Chimera's main landing gears were modeled after a gear system proposed by Grumman in 1969 for their VSX proposal for an ASW aircraft. The nose gear is a conventional strut-braced, dual wheel design. Both are shown in Figure 8.15. The design of the nose gear and main gears are the same in all variants with the exception that the main gears on the COD variant are rotated left to right, allowing them to fold forward instead of aft. This commonality allows for more efficient manufacturing and maintenance as well as a reduced overall cost. This main gear rotation approach has been previously implemented and proven successful between the S-3B Viking and the Vought A-7 Corsair II. To incorporate the same main gear on all variants, the axles were changed so that the gear is canted correctly to avoid wheel divergence during takeoff and landing.

Each main gear has a stroke of 24 in. with a single tire. It retracts aft, flush into the fuselage of the AEW, ASW, and ES, and retracts forward into the fairings on the sides of the COD. The folding link nose gear has a stroke of 16 in and consists of two tires. The nose gear assembly retracts aft into the fuselage and utilizes a folding link drag brace to accommodate launch bar catapult loads. Both the main and nose gears are designed to be able to absorb a descent of over 1,400 feet per minute during landing.

A conventional 4,000 psi hydraulic system operates both the landing gear and arrestor hook retraction systems as well as the weapons bay door opening system. A pneumatic backup system is included for emergency gear blow-down in case of a hydraulic failure.

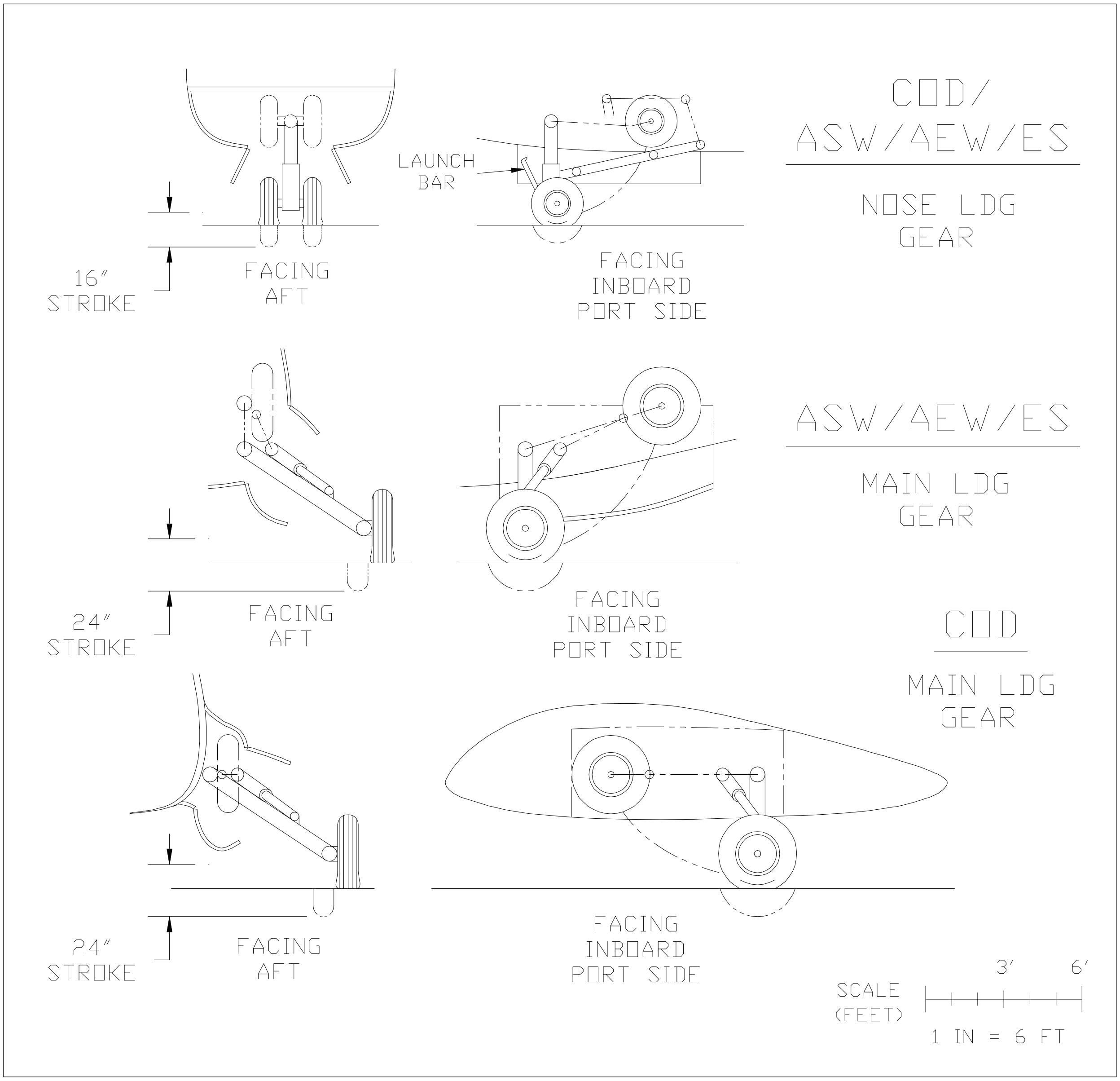

Figure 8.15 Nose and Main Landing Gears for All Variants with Retracting Geometry and Stowage

Type VII tires are employed on the main gear and have an outer diameter of 36 in. and a width of 9.6 in. The nose gear tires, also Type VII, measure 24 in. × 8 in., respectively. These tires provide good ground flotation and have sufficient steel belts to protect against tire damage or blowouts during carrier landings. The brakes on the main gear feature a carbon brake weighing 23 lbs resulting in a weight savings of about 55 lbs per wheel over a steel counterpart. The carbon brakes also dissipate heat more efficiently than steel brakes, which is important in maintaining brake efficiency during heavy brake usage. An adaptive antiskid system is incorporated to prevent the wheels from locking during operation on ice or on wet pavement.

The arresting hook is a conventional stinger type hook that is semi-recessed into the fuselage tail cone to reduce drag (Figure 8.16). The hook is attached directly to the keel longeron, which runs the length of the aircraft forward to the nose gear drag link brace attachment. This configuration distributes the loads from carrier landings throughout the airframe. For lateral compensation the hook is capable of swiveling 20º to either side during off center arrestment wire engagement. This is also shown in Figure 8.16. On the COD variant the hook is recessed into the cargo door and is structurally attached to the airframe on the same pivot as the cargo door.

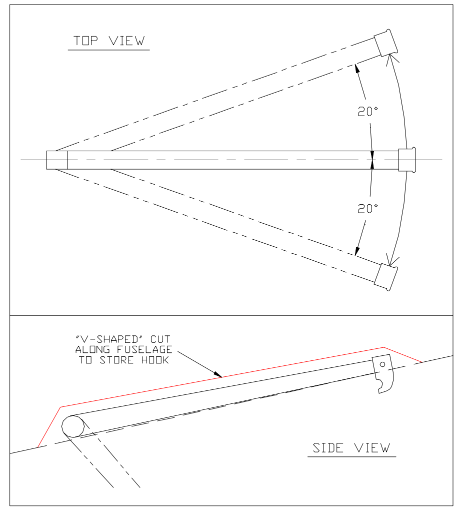

Figure 8.16 Arrestor Hook Configuration and Lateral Motion

8.13 Weapons and Defense System

The RFP set the basis as to which weapons were considered for possible use by the Chimera ASW variant. It required the ability to carry two advanced torpedoes and two anti-ship missiles. This and many other weapon loading configurations can be fulfilled. Weapons were selected based on mission requirements and current weapon loadouts of existing aircraft. Standard internal ejector racks located in the weapons bays are incorporated so most US/NATO weapons can be carried on the Chimera aircraft.

The Chimera is designed to primarily employ the Mk-54 advanced torpedo as well as the AGM-84D Harpoon anti-ship missile. The Mk-54 is an updated derivative of the current Mk-50 torpedo and will be operational by 2002. The Harpoon is currently used on many Navy aircraft today and is the NATO standard for anti-ship missiles. Sixty-eight A-sized sonobuoys will be used to track enemy ships and submarines. These weapons were selected because of their adherence to the RFP requirements and their commonality with existing Navy aircraft.

Table 8.2 Weapons Statistics
(All Mk-54 Statistics are based upon the Mk-50 Torpedo)

	Advanced Torpedo Mk-54 (Mk-50 information basis)	**Anti-Ship Missile AGM-84D**	**Sonobuoys (A-size)**
Dimensions	112” length, 12.5” dia.	151” length, 13.5” dia.	36” length, 4.75” dia.
Weight	750 lbs	1,145 lbs	34 lbs
Preferred Weapon Location	Internal Weapons Bay	External Wing Pylons	Internal Sonobuoy Stowage Compartment

The weapons bay of the ASW variant is designed to accommodate the mission specific weapons as well as most weapons currently in US/NATO inventory. The weapons bay is divided into two sections as shown in Figure 8.17. Each bay is 43.5 in. wide with the center divider enclosing the keel longeron, which runs from the nose gear drag link attachment to the tailhook attachment. The starboard bay has a length of 159.6 in., and the port bay is 180 in long which gives the following volumes: 124.7 ft^3 for the starboard bay and 151.1 ft^3 for the port bay. The starboard bay was shortened to accommodate the boarding ladder and the port bay was widened to accommodate an AGM-84D Harpoon internally. A 20° weapons clearance is provided for weapon ejection on both internal bays.

The top of the bay is a 1 in. thick pressurized deck, above which lies the electronics suite for the aircraft. There are four weapons bay doors (2 for each sub-bay) that hinge on the sides of the fuselage and at the keel. The side doors open wide enough to allow for ease of weapons loading on the ground but still provide sufficient structural rigidity when open in flight. Weapons bay doors are operated on the same hydraulic system as the landing gear and arresting hook retraction mechanism.

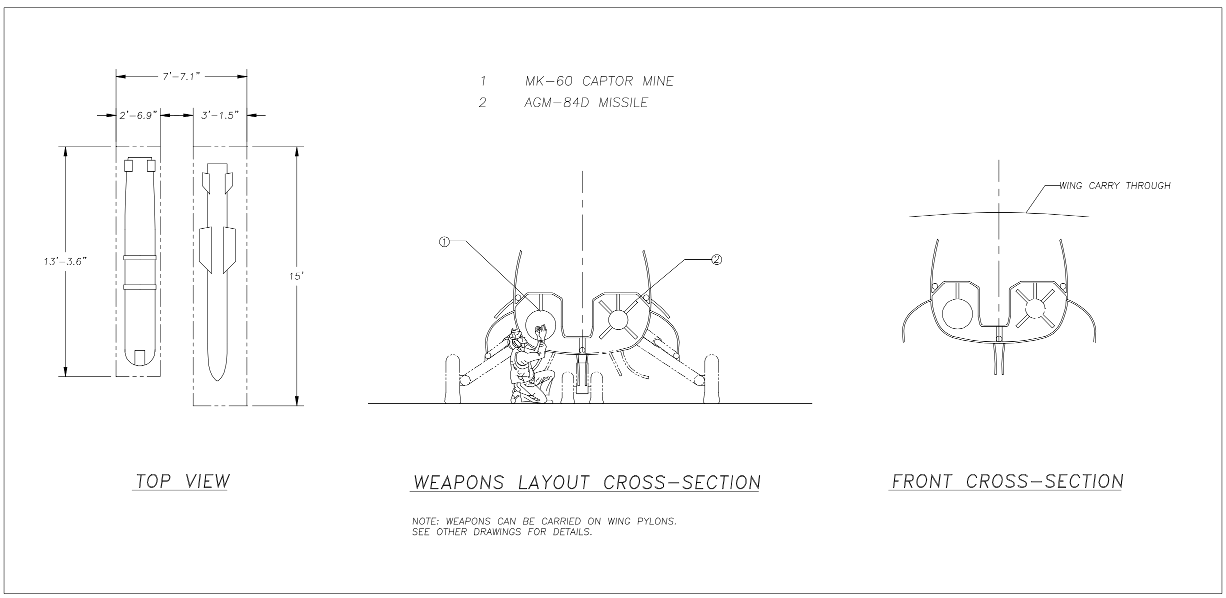

Figure 8.17 Weapons Bay Detailed Configuration

The maximum weapons load-out for a typical ASW mission consists of two Mk 54, 56, 57, or 60 torpedoes in the internal weapons bay and two AGM-84D Harpoon anti-ship missiles on the external pylons. Sixty-eight A-sized sonobuoys are stored in rotating rack installations aft of the rear pressure bulkhead as detailed later in this section. Even though this aircraft is able to return to the carrier with a full weapons load-out, most missions will only carry one torpedo and one Harpoon. In this situation all of the weapons will be able to be carried internally and the external wing pylons can be removed to decrease drag and minimize the radar signature. Mk 81, 82, 83, and 84 dumb bombs, as well as laser-guided bombs, can be mounted internally or externally on single or multiple bomb racks. Figure 8.17 also shows weapon diagrams and loading clearances.

The 68 A-sized sonobuoys are stored internally on rotating chain-linked belts powered by an electric motor. The sonobuoys are fed and launched through four launch tubes located underneath the magnetic anomaly detector (MAD) boom installation. Each launch tube corresponds to one of the four sonobuoy storage belts. Sonobuoy loading is accomplished in a reversed process by loading each through the corresponding launch tube and then the internal powered mechanism loads the sonobuoys back onto the corresponding storage belt. Figure 8.18 details the sonobuoy setup. Though this setup is more complicated than the gravity launch tubes as on the S-3B, it was chosen in order to keep the empennage structure common with the AEW and ES variants.

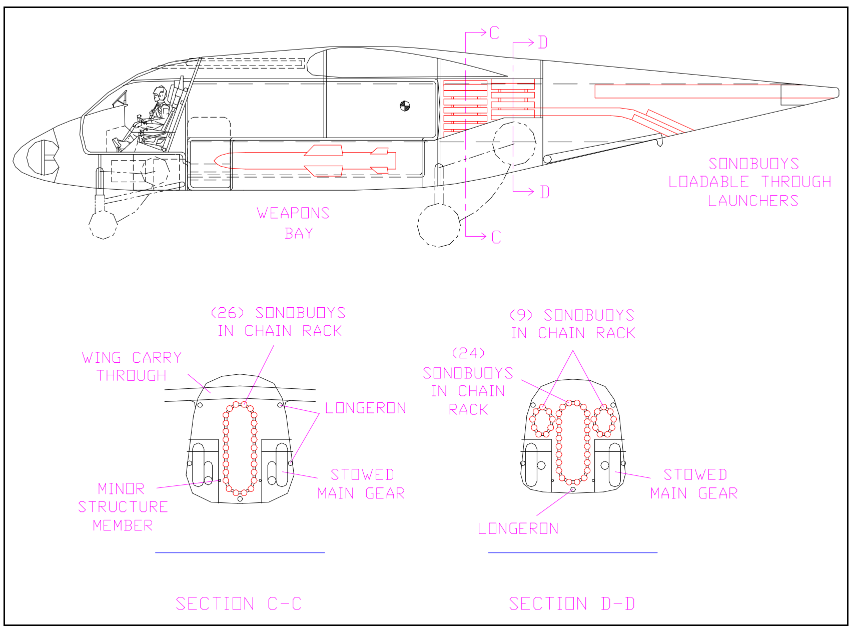

Figure 8.18 Sonobuoy Detailed Configuration

The radar warning receiver used on all aircraft variants will be the Raytheon AN/ALR-67(V)4 countermeasures receiving set. This system was picked because it is the current U.S. Navy standard and is used on all versions of the F/A-18 Hornet. The AN/ALQ-187 will be used as the primary electronic jamming countermeasure. This system includes conventional chaff and flare dispensers and will be augmented by the AN/ALE-50 towed decoy system that will be used as the final defense against incoming missiles. These are both installed in the tail cone of the Chimera and can be seen on the inboard profiles, Figures 2.10 through 2.13.

Chapter 9 Weights, Moments, and Cg's

9.1 Weights Breakdown

The weights summary is listed for all the variants in Tables 9.1 through 9.5, showing the ASW, AEW, ES, COD-Passengers, and COD-Cargo variants. Each component weight was either calculated using *Roskam's Airplane design: Part 5* (Ref. 9.1), estimated from data collected on existing systems, or assigned as determined by the RFP. Each component was placed in the aircraft and after a summation of their moments a center of gravity was calculated for all three axis on each variant. The TOGW and empty weights for the five variants (including two COD variants) are compared in Figure 9.1.

Table 9.1 ASW Weights Summary

ASW					
Component	Weight	Xcg	Zcg	X-Moment	Z-Moment
	lbs.	FS (in.)	(in.)	in.-lb.	in.-lb.
Structures					
Fuselage	3313	412	60	1364956	198780
Wings	4146	450	102	1865700	422892
H. Tail	1750	716	94	1253000	164500
V. Tail	287	754	110	216398	31570
Main gear	1600	452	24	723200	38400
Nose Gear	400	184	20	73600	8000
Arrestor system	250	580	24	145000	6000
Composite Struc. Savings	-1780				
Propulsion					
Engines (2)	3340	376	36	1255840	120240
Cowling/Pylon (2)	1770	370	48	654900	84960
Systems					
Radome	0	484	140	0	0
Fuel Sys.	893	436	100	389348	89300
Oil	50	340	90	17000	4500
In-flight refuel sys.	45	292	108	13140	4860
Ejection seats (2)	320	229	48	73280	15360
Electrical Sys.	1293	380	60	491340	77580
APU	420	220	30	92400	12600
a/c, press, de-ice	2044	288	48	588672	98112
Flight Controls	2314	390	60	902460	138840
Avionics	500	172	28	86000	14000
Oxygen Sys	45	240	36	10800	1620
Lube System	100	320	60	32000	6000
Intruments	4500	330	54	1485000	243000
Furnishings	0	430	40	0	0
Weapons/Expendables					
Armament	5200	430	12	2236000	62400
Decoys	50	790	50	39500	2500
Flares/Chaef	30	790	50	23700	1500
Miscellaneous					
Pilots (2)	400	229	50	91600	20000
Passengers/Cargo	0	430	48	0	0
Contingency W (5%)	1600	300	60	480000	96000
Fuel (Usable)	12100	408	100	4936800	1210000
Fuel (Unusable)	300	408	100	122400	30000
TOGW	47280			19664034	3203514
Zero fuel, with Payload	34880			14604834	1963514
Empty Wt.	29200			12214034	1877114

	X - CG (FS)	Z - CG
TOGW	415.91	67.76
Zero Fuel, with Payload	418.72	56.29
Empty Wt.	418.29	64.28

Table 9.2 AEW Weights Summary

AEW					
Component	Weight	Xcg	Zcg	X-Moment	Z-Moment
	lbs.	FS (in.)	(in.)	in.-lb.	in.-lb.
Structures					
Fuselage	3313	412	60	1364956	198780
Wings	4146	450	102	1865700	422892
H. Tail	1750	716	94	1253000	164500
V. Tail	287	754	110	216398	31570
Main gear	1600	452	24	723200	38400
Nose Gear	400	184	20	73600	8000
Arrestor system	250	580	24	145000	6000
Composite Struc. Savings	-1780				
Propulsion					
Engines (2)	3340	376	36	1255840	120240
Cowling/Pylon (2)	1770	370	48	654900	84960
Systems					
Radome	2100	484	140	1016400	294000
Fuel Sys.	893	436	100	389348	89300
Oil	50	340	90	17000	4500
In-flight refuel sys.	45	292	108	13140	4860
Ejection seats (2)	320	229	48	73280	15360
Electrical Sys.	1293	380	60	491340	77580
APU	420	220	30	92400	12600
a/c, press, de-ice	2044	288	48	588672	98112
Flight Controls	2314	390	60	902460	138840
Avionics	500	172	28	86000	14000
Oxygen Sys	45	240	36	10800	1620
Lube System	100	320	60	32000	6000
Intruments	7500	330	54	2475000	405000
Furnishings	0	430	40	0	0
Weapons/Expendables					
Armament	0	430	12	0	0
Decoys	50	790	50	39500	2500
Flares/Chaef	30	790	50	23700	1500
Miscellaneous					
Pilots (2)	400	229	50	91600	20000
Passengers/Cargo	0	430	48	0	0
Contingency W (5%)	1600	300	60	480000	96000
Fuel (Usable)	12100	408	100	4936800	1210000
Fuel (Unusable)	300	408	100	122400	30000
TOGW	47180			19434434	3597114
Zero fuel, with Payload	34780			14375234	2357114
Empty Wt.	34300			14220434	2333114

	X - CG (FS)	Z - CG
TOGW	411.92	76.24
Zero Fuel, with Payload	413.32	67.77
Empty Wt.	414.59	68.02

Table 9.3 ES Weights Summary

ES					
Component	Weight	Xcg	Zcg	X-Moment	Z-Moment
	lbs.	FS (in.)	(in.)	in.-lb.	in.-lb.
Structures					
Fuselage	3313	412	60	1364956	198780
Wings	4146	450	102	1865700	422892
H. Tail	1750	716	94	1253000	164500
V. Tail	287	754	110	216398	31570
Main gear	1600	452	24	723200	38400
Nose Gear	400	184	20	73600	8000
Arrestor system	250	580	24	145000	6000
Composite Struc. Savings	-1780				
Propulsion					
Engines (2)	3340	376	36	1255840	120240
Cowling/Pylon (2)	1770	370	48	654900	84960
Systems					
Radome	0	484	140	0	0
Fuel Sys.	893	436	100	389348	89300
Oil	50	340	90	17000	4500
In-flight refuel sys.	45	292	108	13140	4860
Ejection seats (2)	320	229	48	73280	15360
Electrical Sys.	1293	380	60	491340	77580
APU	420	220	30	92400	12600
a/c, press, de-ice	2044	288	48	588672	98112
Flight Controls	2314	390	60	902460	138840
Avionics	500	172	28	86000	14000
Oxygen Sys	45	240	36	10800	1620
Lube System	100	320	60	32000	6000
Intruments	9300	330	54	3069000	502200
Furnishings	0	430	40	0	0
Weapons/Expendables					
Armament	0	430	12	0	0
Decoys	50	790	50	39500	2500
Flares/Chaef	30	790	50	23700	1500
Miscellaneous					
Pilots (2)	400	229	50	91600	20000
Passengers/Cargo	0	430	48	0	0
Contingency W (5%)	1600	300	60	480000	96000
Fuel (Usable)	12100	408	100	4936800	1210000
Fuel (Unusable)	300	408	100	122400	30000
TOGW	46880			19012034	3400314
Zero fuel, with Payload	34480			13952834	2160314
Empty Wt.	34000			13798034	2136314

	X - CG (FS)	Z - CG
TOGW	405.55	72.53
Zero Fuel, with Payload	404.66	62.65
Empty Wt.	405.82	62.83

Table 9.4 Passenger COD Weights Summary

COD-Passengers					
Component	Weight	Xcg	Zcg	X-Moment	Z-Moment
	lbs.	FS (in.)	(in.)	in.-lb.	in.-lb.
Structures					
Fuselage	3700	412	60	1524400	222000
Wings	4146	450	102	1865700	422892
H. Tail	1750	716	94	1253000	164500
V. Tail	287	754	110	216398	31570
Main gear	1600	452	24	723200	38400
Nose Gear	400	184	20	73600	8000
Arrestor system	250	580	24	145000	6000
Composite Struc. Savings	-1840				
Propulsion					
Engines (2)	3340	376	36	1255840	120240
Cowling/Pylon (2)	1770	370	48	654900	84960
Systems					
Radome	0	484	140	0	0
Fuel Sys.	893	436	100	389348	89300
Oil	50	340	90	17000	4500
In-flight refuel sys.	45	292	108	13140	4860
Ejection seats (2)	320	229	48	73280	15360
Electrical Sys.	1293	380	60	491340	77580
APU	420	220	30	92400	12600
a/c, press, de-ice	2044	288	48	588672	98112
Flight Controls	2314	390	60	902460	138840
Avionics	500	172	28	86000	14000
Oxygen Sys	45	240	36	10800	1620
Lube System	100	320	60	32000	6000
Intruments	1500	330	54	495000	81000
Furnishings	1300	430	40	559000	52000
Weapons/Expendables					
Armament	0	430	12	0	0
Decoys	50	790	50	39500	2500
Flares/Chaef	30	790	50	23700	1500
Miscellaneous					
Pilots (2)	400	229	50	91600	20000
Passengers/Cargo	5200	430	48	2236000	249600
Contingency W (5%)	1600	300	60	480000	96000
Fuel (Usable)	12100	408	100	4936800	1210000
Fuel (Unusable)	300	408	100	122400	30000
TOGW	45907			19392478	3303934
Zero fuel, with Payload	33507			14333278	2063934
Empty Wt.	27827			11942478	2039934

	X - CG (FS)	Z - CG
TOGW	422.43	71.97
Zero Fuel, with Payload	427.77	61.60
Empty Wt.	429.17	73.31

Table 9.5 Cargo COD Weights Summary

COD-Cargo					
Component	Weight	Xcg	Zcg	X-Moment	Z-Moment
	lbs.	FS (in.)	(in.)	in.-lb.	in.-lb.
Structures					
Fuselage	3700	412	60	1524400	222000
Wings	4146	450	102	1865700	422892
H. Tail	1750	716	94	1253000	164500
V. Tail	287	754	110	216398	31570
Main gear	1600	452	24	723200	38400
Nose Gear	400	184	20	73600	8000
Arrestor system	250	580	24	145000	6000
Composite Struc. Savings	-1840				
Propulsion					
Engines (2)	3340	376	36	1255840	120240
Cowling/Pylon (2)	1770	370	48	654900	84960
Systems					
Radome	0	484	140	0	0
Fuel Sys.	893	436	100	389348	89300
Oil	50	340	90	17000	4500
In-flight refuel sys.	45	292	108	13140	4860
Ejection seats (2)	320	229	48	73280	15360
Electrical Sys.	1293	380	60	491340	77580
APU	420	220	30	92400	12600
a/c, press, de-ice	2044	288	48	588672	98112
Flight Controls	2314	390	60	902460	138840
Avionics	500	172	28	86000	14000
Oxygen Sys	45	240	36	10800	1620
Lube System	100	320	60	32000	6000
Intruments	1500	330	54	495000	81000
Furnishings	0	430	40	0	0
Weapons/Expendables					
Armament	0	430	12	0	0
Decoys	50	790	50	39500	2500
Flares/Chaef	30	790	50	23700	1500
Miscellaneous					
Pilots (2)	400	229	50	91600	20000
Passengers/Cargo	10000	430	48	4300000	480000
Contingency W (5%)	1600	300	60	480000	96000
Fuel (Usable)	12100	408	100	4936800	1210000
Fuel (Unusable)	300	408	100	122400	30000
TOGW	49407			20897478	3482334
Zero fuel, with Payload	37007			15838278	2242334
Empty Wt.	26527			11383478	2218334

	X - CG (FS)	Z - CG
TOGW	422.97	70.48
Zero Fuel, with Payload	427.98	60.59
Empty Wt.	429.13	83.63

Variation between the take off and empty weights in Figure 9.1 is the result of the different mission requirements for the variants. The empty weight of the AEW carrying the 2,100 lb radome will always be greater than the empty weight of any other variant. Each variant is carrying different amounts of electronics (except the two COD variants), which leads to further differences in empty weight between them. Figure 9.1 shows that the ASW has the largest difference in take off and empty weights (payload expended). The reason for this large difference is that the ASW carries the largest expendable load of fuel, sonobouys, and weapons. The two COD variants differ in weight because 27 passengers and required furnishings do not weigh as much as a fully loaded cargo COD, with 10,000 lbs payload.

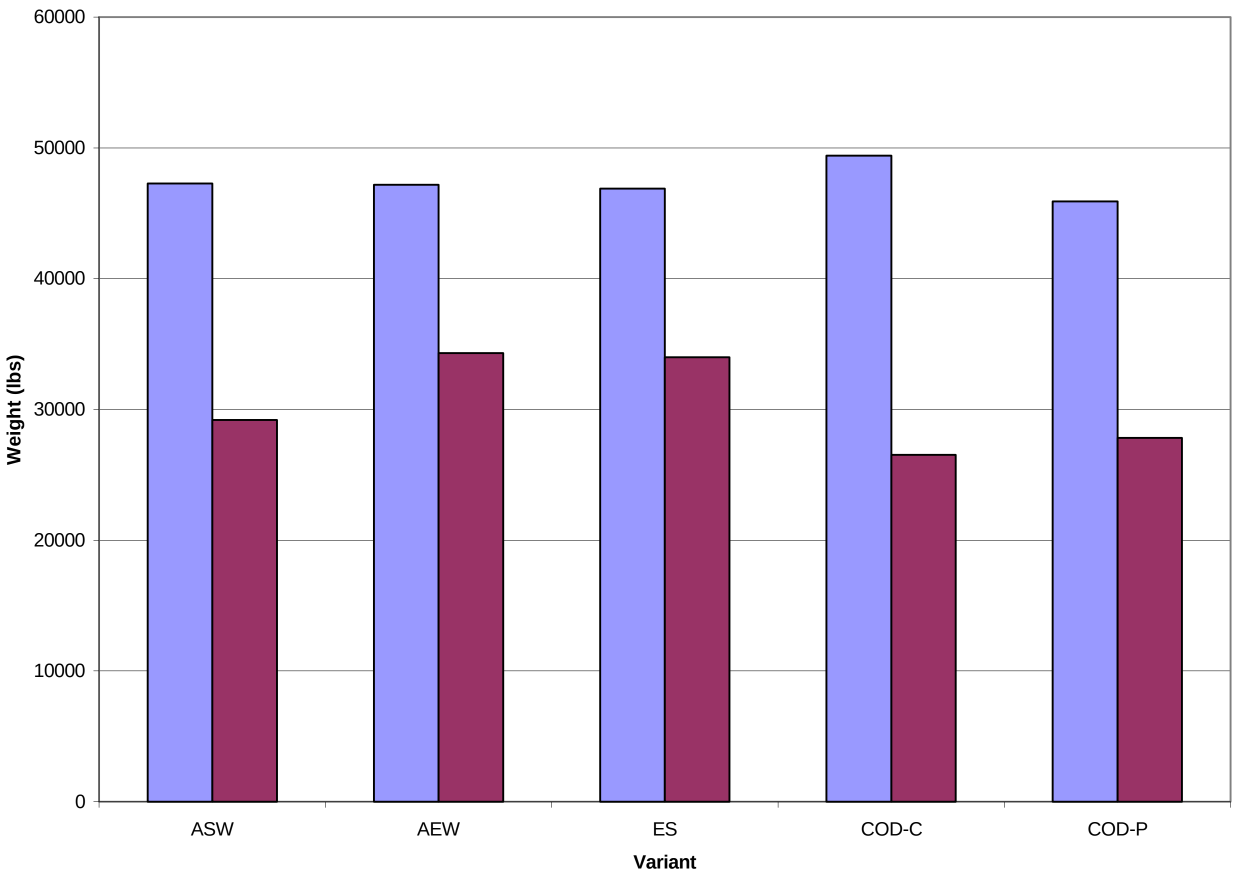

Figure 9.1 TOGW and Empty Weight Comparison

9.2 Center of Gravity Travel

The *cg* location will change during the specific missions. Figure 9.2 shows the *cg* location change for the ASW variant during a typical RFP mission. The ASW variant has the largest expendable load of all the aircraft and therefore the in-flight *cg* change will be the largest for this variant. The forward and aft limits are based on desired stability described in Chapter 6. Figure 9.2 shows that the *cg* changes only a few inches even when large loads are expended. This was accomplished by locating the fuel tanks and weapons bays close to the total aircraft *cg*.

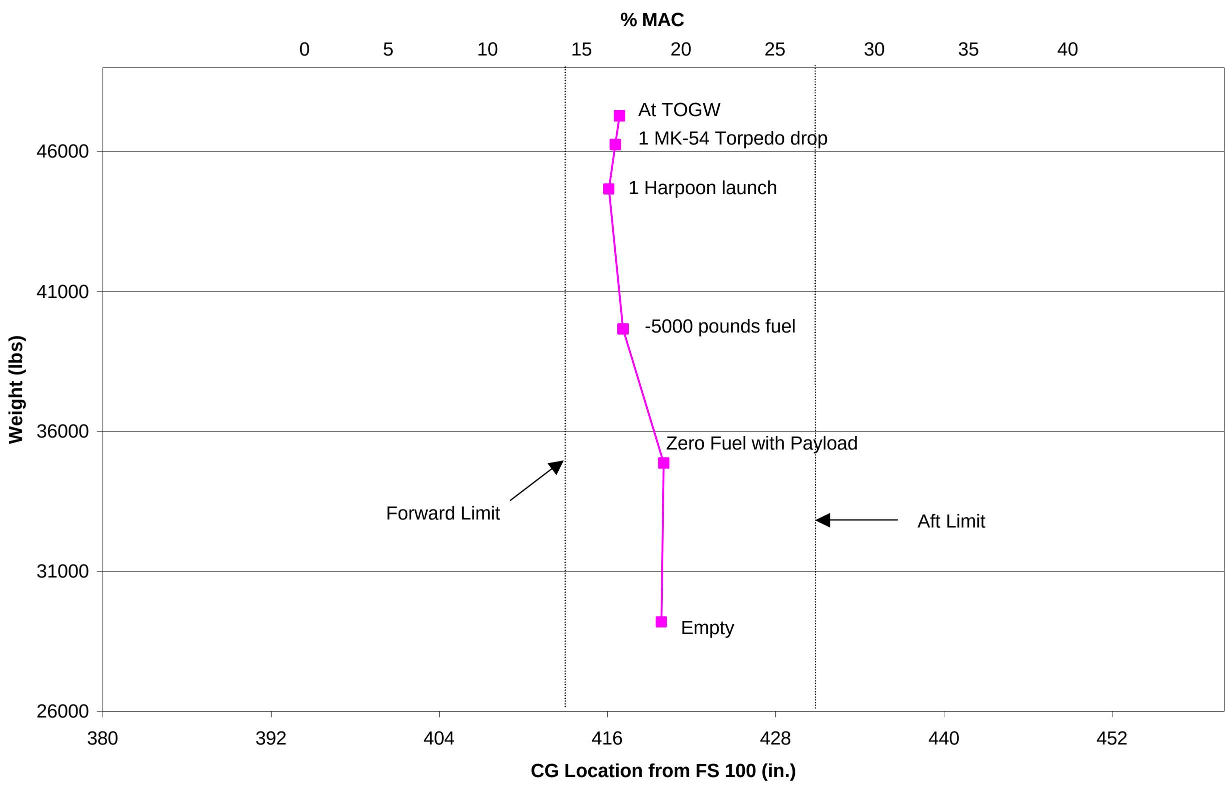

Figure 9.2 *Cg* Travel During the ASW Mission

Chapter 10 Cost Analysis

In today's competitive world, winning a contract not only necessitates satisfying the proposal's required parameters, it entails doing so at the lowest, most affordable price. Most often the lowest bidder wins the contract, especially when all the proposed designs meet the stated requirements. Estimating the cost of an aircraft, military or commercial, is no easy task. However, the weight and the cost of the aircraft are distinctly related. The Chimera family aircraft are lightweight, versatile planes, with near-complete airframe commonality, which translates into a very affordable price. Typical airplane evolution consists of 6 phases:

<u>6 Phases to Airplane Evolution</u>

Phase 1: Planning and Conceptual Design
Phase 2: Preliminary Design and System Integration
Phase 3: Detail Design and Development
Phase 4: Manufacturing and Acquisition Cost
Phase 5: Operation and Support
Phase 6: Disposal

Roskam's *Airplane Design: Part VIII* (Ref. 10.1) and *Raymer's Aircraft Design: A Conceptual Approach* (Ref. 10.3) was used to estimate the cost of the Chimera. The Chimera Project costs include: Research Development Test and Evaluation Cost, Manufacturing Cost, Acquisition Cost, Operating Cost, Disposal Cost and Life Cycle Cost. The Chimera production run of 350 aircraft includes 10 for Research, Development, Test, and Evaluation (RDTE) purposes, 250 for service by the US Navy, and 90 available for sale to foreign countries. The foreign export aircraft production reduces domestic U.S. aircraft unit cost. Table 10.1 shows the production breakdown.

Table 10.1 Total Number of RDTE and Service Aircraft for Chimera Production Run of 350 Aircraft

	RDTE A/C	**US Navy Service A/C**	**Foreign Purchase**
COD	3	44	6
ASW	2	102	38
AEW	3	60	40
ES	2	44	6
Total	10	250	90

The following sections provide a walkthrough of total price determination for the ASW variant. Table 10.8 summarizes all of the finalized cost value for all four variants.

10.1 Research Development Test and Evaluation Cost (C_{RDTE}) – Phases 1, 2, 3

C_{RDTE} = Airframe Engineering and Design Cost + Development Support and Testing Cost + Flight Test Airplanes Cost + Flight Test Operations Cost + Test and Simulation Facilities Cost + RDTE Profit + Cost to finance the RDTE phase

The RDTE cost involves taking a conceptual design on paper and making it into a certified aircraft with the intent of full production. The TOGW, empty weight, engine, and avionics costs were utilized to determine the RDTE cost. The CF-34 engines were estimated to be $2.5 million each. The costs required for phases 1-3 and their breakdown are shown in Table 10.2:

Table 10.2 Breakdown of RDTE Costs for the ASW Variant

Category	**Cost***
Airframe Engineering and Design Cost	$106.0
Development Support and Test Cost	$27.1
Quality control cost for the flight test airplanes	$336.0
Flight Test Operations Cost	$2.0
Test and Simulation Facilities Cost	$31.4
Profit Over Flight Test Airplanes	$62.8
Cost to Finance The Flight Test Airplane	$62.8
Total	**$628.0**

*All Costs in millions of year 2001 dollars

Table 10.2 shows the final cost estimation of C_{RDTE} is roughly $628,000,000 for Phases 1, 2 and 3 of the design process. This value is ideal when the amount of new technology and materials are factored into the Chimera. Figure 10.1 shows the RDTE breakdown of costs.

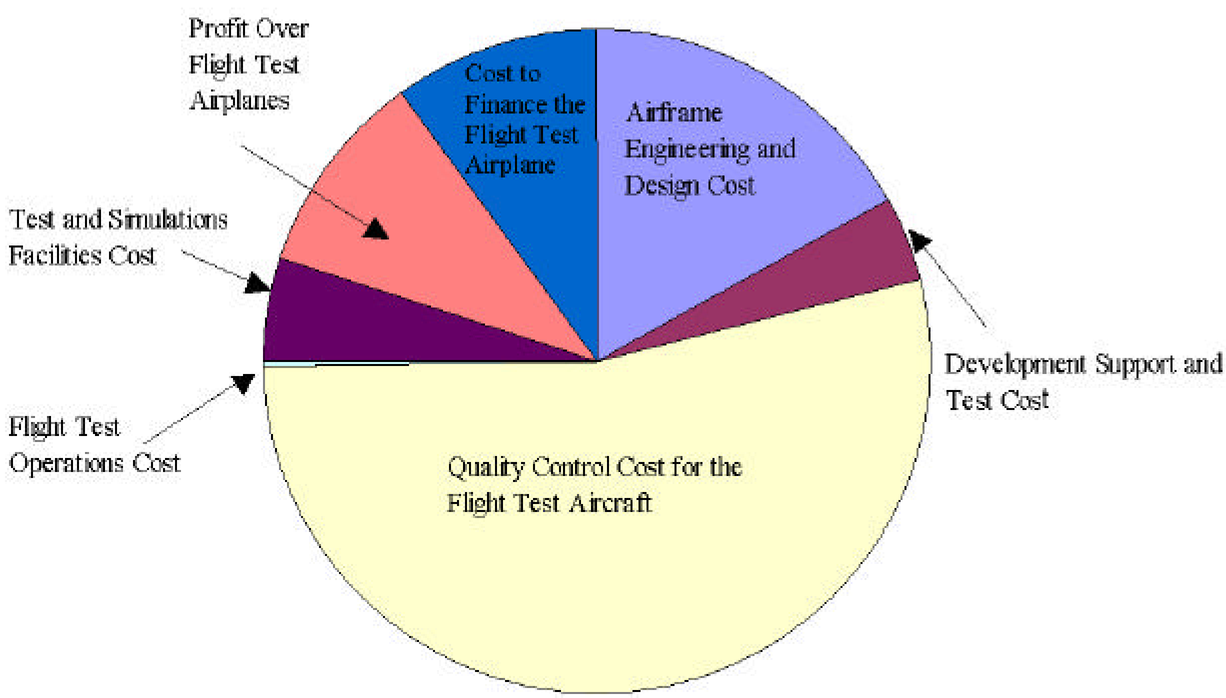

Figure 10.1 Percentage of RDTE Cost

10.2 Manufacturing Cost (C_{MAN})

C_{MAN} = Airframe Engineering and Design Cost + Airplane Production Cost + Production Flight Test Operations Cost + Cost of Financing the Manufacturing Program

The manufacturing cost is a function of the airframe weight, the maximum velocity of the aircraft, the quantity of aircraft produced, and technology factors assumed. Throughout five years of manufacturing, 140 ASW aircraft will be produced, assuming 38 aircraft for foreign sale, as seen in Table 10.1. In addition, the active service life was assumed to be 25 years, and a materials technology factor of 3.0 was assumed for the Chimera due to the large percentage of composite materials (see Figure 7.1 in the Materials chapter). Table 10.3 lists the costs required to determine the total manufacturing cost.

Table 10.3 Breakdown of the Manufacturing Cost for the ASW Variant

Category	**Cost***
Airframe Engineering and Design Cost	$123.8
Quality Control Cost	$3,433.0
Cost of Flight Test Operations	$74.5
Total	**$3,630.0**

*All costs in Millions of year 2001 dollars

After factoring government interest rates into the equation, the final cost estimation of C_{MAN} is $4,035,000,000 for the manufacturing phase of the design process.

10.3 Acquisition Cost (C_{ACQ}) – Phase 4

C_{ACQ} = Manufacturing Cost + Profit Made by Manufacturer

The acquisition cost is the amount of capital required to purchase the entire fleet of aircraft. Table 10.4 gives the acquisition cost breakdown.

Table 10.4 Breakdown of Acquisition Costs for the ASW Variant

Category	**Costs***
Program Manufacturing Cost	$4,034.0
Profit Over the Manufacturing Phase	$403.0
Total	**$4,438.0**

*All costs in millions of 2001 dollars

The profit over the manufacturing phase is estimated to be ten percent of the total manufacturing cost. Taking the profit into consideration, the final cost estimation of C_{ACQ} is roughly $4,438,000,000 for Phase 4 of the design process. This would be a baseline value as to what “price” the U.S. government would purchase the Chimera fleet.

10.4 Operating Cost (C_{OPS}) – Phase 5

C_{OPS} = Program Fuel, Oil and Lubricants Cost + Direct Personnel Cost + Indirect Personnel Cost + Consumable Materials used in Conjunction with Maintenance Cost + Program Spares Cost + Program Depots Cost + Program Miscellaneous Cost

The operating costs are based on fuel, aircrew and maintenance personnel, consumable materials, spares, and miscellaneous costs. The costs associated with the Operating Cost breakdown as follows in Table 10.5:

Table 10.5 Breakdown of Operating Cost for the ASW Variant

Category	Costs*
Program Fuel, Oil, and Lubricants Cost	$664
Program Cost of Direct Personnel	$2,347
Program Cost of Indirect Personnel	$908
Program Cost of Consumable Materials	$180
Program Cost of Spares	$1,118
Program Cost of Depot	$1,048
Program Cost of Miscellaneous Costs	$721
Total	**$6,306**

*All costs in millions of 2001 dollars

After factoring in additional program costs, the final cost estimation of C_{OPS} is $6,986,000,000 for Phase 5 of the design process. The operating cost per hour was calculated to determine the cost to actually operate the aircraft. The operating cost per hour is a good indication of how efficient an aircraft is to operate. The operating cost, for the ASW, was found to be roughly $ 6,700 per hour. Table 10.6 shows the operating costs for the Chimera family. Comparing these values to the $13,000 per hour of the E-2C and $9,000 per hour for the S-3B (Ref. 10.2), the Chimera proves to be extremely cost efficient, with a savings of over $2,000 per hour.

Table 10.6 Operating Cost per Hour for the Chimera Variants

Variant	Operating Cost per hour*
ES	$6,756
COD	$7,044
ASW	$6,653
AEW	$7044

*All costs in 2001 dollars

10.5 Disposal Cost (C_{DISP}) – Phase 6

$C_{DISP} = 0.01*LCC$

The disposal cost was estimated to be 1 percent of the total life cycle cost. Simple algebra was used to determine the Disposal and Life Cycle Costs. The final cost estimation of C_{DISP} is roughly $122,000,000 for Phase 6 of the design process.

10.6 Life Cycle Cost (LCC)

Life Cycle Cost - The total cost of an airplane program incurred during the airplanes life cycle. (Ref. 10.1 Pg. 9)

LCC = $C_{RDTE} + C_{ACQ} + C_{OPS} + C_{DISP}$
LCC = $.6 + $4.4 + $7 + .1 Billion
LCC = $12.1 Billion safely

To determine the unit cost of the ASW variant, production of 140 total aircraft was assumed. Three of the 140 are used for the RDTE phase, leaving 137 aircraft used to determine unit costs. Table 10.6 shows the unit cycle costs for the manufacturing, acquisition, program and life cycle phases. From Table 10.7, the manufacturing unit cost for each ASW aircraft is about $27 million; the acquisition unit cost is roughly $29 million and the program unit cost $34 million.

Table 10.7 ASW Variant Unit Costs

Category	Cost*
Manufacturing Unit Cost	$26.7
Acquisition Unit Cost	$28.7
Program Unit Cost	$33.9
Life Cycle Unit Cost	$85.8

*All costs in millions of 2001 dollars

Table 10.8 gives a summary of the different costs for all of the five variants. The prices in Table 10.8 are for the total number of aircraft produced. Table 10.8 shows that the ASW variant LCC is approximately $4 billion more than the AEW, which carries the radome and associated radar and avionics. The ASW variant is approximately $6 billion more than the ES, which contains roughly $7 million worth of high tech electronics. The reasoning behind this far greater LCC is 140 ASW aircraft are to be produced, equivalent to the total number of AEW and ES aircraft combined. However, the greater the number of aircraft produced lessens the cost of an individual unit for the manufacturer to produce. This translates into greater savings, as shown in the affordable life cycle cost for all the Chimera variants.

Table 10.8 Costs for a 340-Aircraft Fleet

Variant	Number Produced	RDTE	Manufacturing	Acquisition	Operating	Life Cycle
COD	*50*	$0.523	$1.96	$2.15	$3.08	$5.82
AEW	*100*	$0.634	$2.99	$3.29	$4.00	$8.01
ASW	*140*	$0.628	$4.03	$4.44	$6.99	$12.17
ES	*50*	$0.530	$2.29	$2.52	$2.96	$6.07
Total	*340*	$2.315	$11.27	$12.4	$17.03	$32.07

*All costs in billions of US dollars, 2001

10.7 Fly Away Costs

Fly away cost is found by dividing the production cost by the number of aircraft being produced. The production costs consists of seven aspects of production:

1) Engineering Cost for Production
2) Tooling Cost for Production
3) Manufacturing Labor Cost for Production
4) Quality Control Labor Cost for Production
5) Cost of Manufacturing Materials for Production
6) Engine Cost
7) Avionics Cost

The production costs differ for each variant due to difference in avionics and airframe production costs. To determine the total fly away cost for 250 aircraft, the individual fly away costs was calculated. Table 10.9 shows the total production and fly away costs for each variant.

Table 10.9 Total and Unit Fly Away Costs for 250 Aircraft

Variant	Total Production Cost*	Number of A/C produced	Fly Away Cost*
AEW	$1,063.0	60	$17.7
ASW	$1,570.0	102	$15.4
ES	$970.0	44	$22.0
COD	$953.0	44	$21.7
Total	$4,556	250	$18.2

*All costs in millions of year 2001 dollars

The fly away costs calculated for the Chimera are very affordable values. The large number of aircraft produced for the ASW and AEW variants dramatically lowers the fly away costs. This is the “learning curve” effect. The more aircraft produced, the more the manufacturer learns and the cheaper the next aircraft produced. (Ref. 10.3, p. 580)

10.8 Comparison of the Chimera family to Existing Aircraft

To determine how economically beneficial the Chimera is it was compared to the existing aircraft. Figure 10.10 shows the cost of the S-3B, C-2A, E-2C, and the ES-3A and compares them to the Chimera equivalent aircraft. A positive difference (column 5 of Table 10.10) indicates a savings in cost.

Table 10.10 Cost Comparison of the Chimera Family to Existing Aircraft

Existing Aircraft	Acquisition Cost (Ref 10.2)	Chimera Equivalent	Acquisition Cost	Difference*	% Savings
Lockheed S-3B	$27 million	Chimera ASW	$28.7 million	**$ -1.7**	**0.0%**
Grumman C-2A	$38.96 million	Chimera COD	$31.8 million	**$7.16**	**18.4%**
Grumman E-2C	$51 million	Chimera AEW	$37.7 million	**$13.3**	**26.1%**
Lockheed ES-3A	$33 million	Chimera ES	$37.9 million	**$-4.9**	**0.0%**

*Difference in millions of dollars

Clearly each Chimera aircraft is economical if not far superior to its existing counterpart, proving the worthiness of the family. Although slightly more expensive than its predecessor, the ASW variant price is small compared to the technological benefits over the Lockheed S-3B. The real economic advantages of the Chimera are shown in the AEW and COD variants. The advanced technology along with the unique systems of the aircraft saves over $20 million for the both variants. The AEW variant alone is 26% less expensive than the Grumman E-2C, with a savings of over $13 million. Achieving increases in performance and capability, with substantial decrease in cost, the Chimera is in a league of its own.

10.9 Costs Summary

Designed to have a more affordable “sticker price” and operating cost than its predecessors, the Chimera accomplished its goals. Superior in performance and technology, the Chimera proves to be affordable and a step ahead of the competition. With an inexpensive fly away cost the Chimera proves it is a clear contender for the CSA.

Chapter 11 Conclusion

The Chimera is a balance of the newest technology and proven methodology to produce a viable and practical solution to the CSA competition. The beginning design phases covered the critical issues and requirements of the aircraft and the RFP. The core RFP requirements and the desire to find an innovative solution to the problem led the design process. These requirements determined how the initial designs were drawn, scrutinized, and evaluated. After the initial evaluations, the designs were redrawn to address various concerns which led to a more competitive solution. A further evaluation of the available technologies and capabilities led to new issues in the design process. This iterative process eventually led to the current Chimera configuration.

Significant effort was made in the analysis of conformal radar and the possibility of incorporating it into the final design. Based on NAVAIR projections as well as the limited amount of unclassified material available, conformal radar was determined not to have sufficient range for the AEW mission. Because of this and the self-imposed requirement to at least match current AEW systems, the external stationary radome was determined to be the best choice for the Chimera aircraft despite its aerodynamic drawback and non-innovative design.

The Chimera incorporates the highest possible commonality in airframe systems and structure between the variants. This reduces manufacturing, logistic, and repair costs, and it minimizes the amount of necessary spare parts stored on the carrier. The use of systems with longer life cycles, higher TBF's, higher efficiencies, and advanced technologies reduces the Chimera maintenance requirements, increases the mission readiness, and extends the aircraft lifespan. This extended lifespan reduces Chimera life-cycle costs, making it a more viable option for the Navy than the current aircraft fleet.

This is the Chimera Group's proposal for a Common Support Aircraft for the AIAA Undergraduate Aircraft Design Competition. The aircraft is cost efficient, meets or exceeds the requirements placed on it, and utilizes the newest technologies. The Chimera is the most feasible design with the highest possible level of commonality and practicality, abiding by the principle of "In aircraft technology, simplicity is the ultimate sophistication" (Ref. 11.1).

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