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Multiple–Purpose Subsonic Naval Aircraft (MPSNA) Multiple Application Propfan Study (MAPS)

D.M. Winkeljohn, C.H. Mayrand

LOCKHEED–GEORGIA COMPANY
A Division of Lockheed Corporation
Marietta, Georgia

Contract No. 3-24528
March 1986

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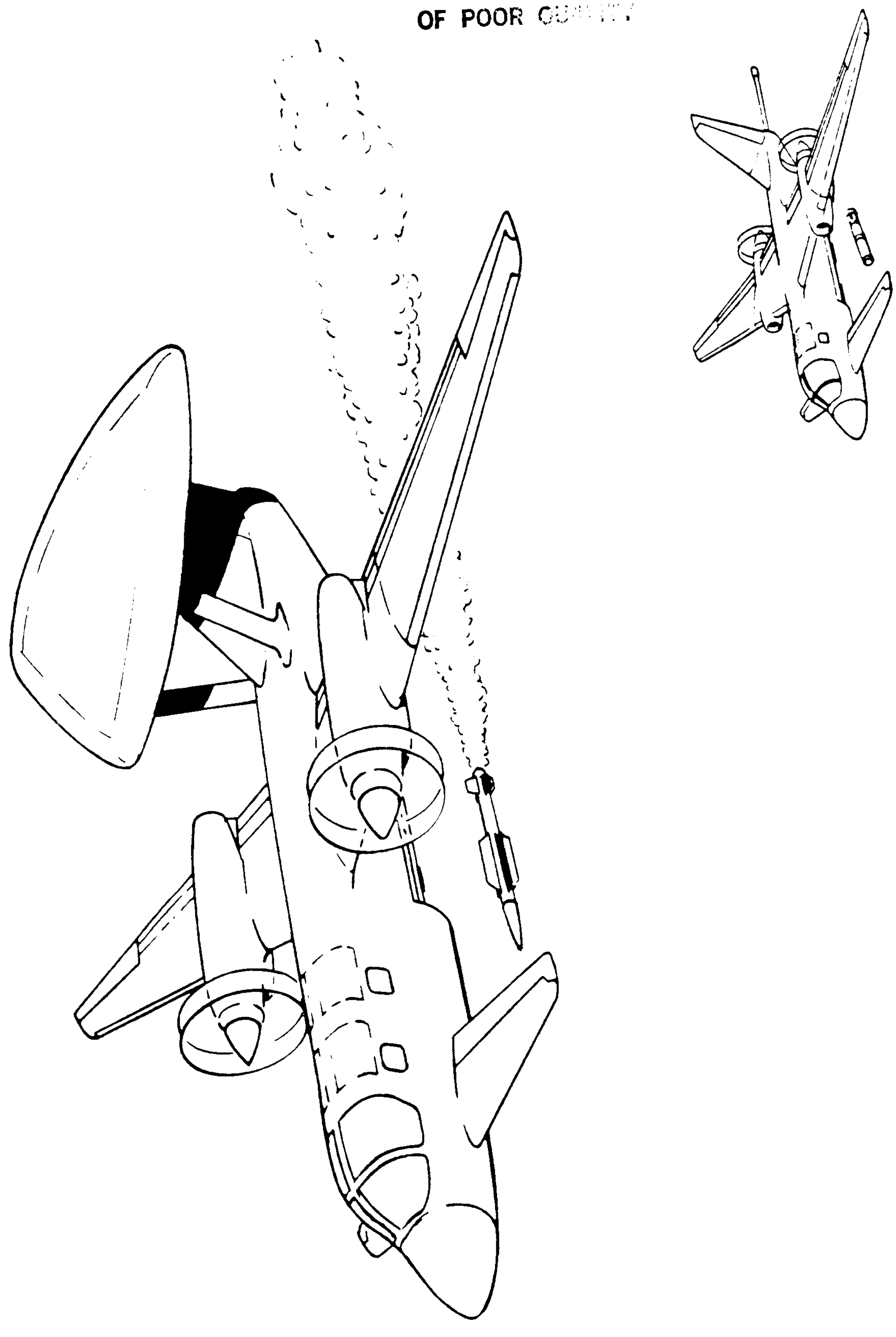

FOREWORD

The aircraft conceptual design study reported herein was performed by Lockheed-Georgia Company, under the technical direction of Susan Johnson, Advanced Turboprop Project Office, NASA Lewis Research Center, Cleveland, Ohio. Ms. Johnson was succeeded as technical manager near the conclusion of the study by Mr. Robert Dengler.

At the Lockheed-Georgia Company, the program manager was Douglas M. Winkeljohn. Responsible for concept development and configuration integration was C. H. Mayrand. Other contributors to the study from Lockheed-Georgia included M. B. Diamond, G. V. Gelly, M. K. Harris, and J. S. Phillips. In addition, mission, systems and payload data were provided by A. B. Bower, M. F. Leffler, and B. M. Quayle of Lockheed-California Company.

Program management for this study resides in the Advanced Design Division, R. O. Lowrey, Manager, of the Lockheed-Georgia Company, Marietta, Georgia.

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1.0 SUMMARY

This study compares the benefits of propfan propulsion systems relative to turbofans when applied to multipurpose carrier-based naval aircraft. The aircraft synthesized in this study incorporate technologies which will be available by 1991, and are based upon a mid-1990's Initial Operational Capability (IOC). The study was conducted in five tasks, which defined ten missions and performance requirements, established the levels of technology to be incorporated, generated aircraft concepts for conventional takeoff and landing (CTOL) and short takeoff/vertical landing (STOVL) and sized those concepts to perform the missions. A single turbofan type, a range of propfan configurations, and an unducted fan, were considered in this study.

The results of this study show that the propfan is a viable propulsion system for this class of aircraft and offers advantages in terms of fuel consumption while maintaining performance equal to the turbofan. The technologies necessary to implement this propulsion concept are currently being developed and several gas generator development programs now underway may yield engines in the proper size range for this class of aircraft.

2.0 INTRODUCTION AND BACKGROUND

2.1 INTRODUCTION

Propfan propulsion is an advanced technology that has been shown to have advantages in terms of fuel usage and operating cost for high-performance military and commercial transport aircraft, when compared with turbofan-powered aircraft of similar performance. This has been demonstrated by analytical studies and small-scale testing.

Transport aircraft require efficient cruise operation over a fairly narrow envelope of speed and altitude, and this efficiency is measured in operating and life cycle costs. NASA and the Navy have sponsored this study to assess the merits of propfan propulsion when applied to multipurpose carrier-based naval aircraft. The types of missions flown by these aircraft are much more demanding in terms of overall propulsion requirements than typical transport mission profiles, and may involve not only cruising flight, but also long periods of loiter at high and low altitude as well as high-speed dash performance at altitude and at sea level.

The purposes of the study are to identify the benefits of propfans relative to turbofans when applied to multipurpose carrier-based aircraft, to identify the technology requirements necessary to achieve the predicted benefits, and to define a plan to achieve the necessary level of technology in time for an introduction into fleet service in the late 1990s.

2.2 BACKGROUND

The United States Navy currently operates a number of aircraft types from the decks of aircraft carriers. These types range from aircraft essential to the fulfillment of the carrier's role of power projection (A-6, F/A-18, F-14), through those necessary for the defense of the carrier and accompanying ships of the battle group (F-14, S-3, E-2), as well as those aircraft which perform utility or supporting missions (C-2, KA-6, EA-6). The logistics pipeline necessary to support this large mix of aircraft types is substantial, and the broad range of specialized training for flight crew and maintenance personnel increases operating and support costs as well.

For some time, the Navy and contractors supporting the missions of the Navy have been examining aircraft suitable for carrier operations that could fulfill the requirements of several missions with a common airframe. The advantages of such an aircraft include greatly simplified spares supply and maintenance requirements, less specialized training, and reduced unit acquisition cost through the spreading of research, development, testing and evaluation costs (RDT&E), tooling costs, and other nonrecurring costs over greater quantity production of a common airframe and propulsion system.

Technologies and capabilities for naval warfare are rapidly evolving. This is true not only in the context of U.S. offensive naval operations, but also within the threat environment. The Soviet "blue water" navy is expanding dramatically. Soviet surface forces, which until recently were used primarily for coastal defense, now range far from home ports and now pose a significant threat to U.S. surface forces. As noted in "Aviation Week" and other unclassified sources, the Soviet navy has recently launched and is now fitting out that nation's first aircraft carrier equipped with catapults and arresting gear. Therefore, it is probable that the Soviet world-wide naval presence will include carrier-based aviation within the next decade.

The Soviet undersea threat continues to be formidable, with faster, deeper diving, and quieter submarines continually replacing or augmenting existing forces. In addition to torpedoes, many of these submarines will carry long range cruise missiles capable of being launched hundreds of miles from their targets.

In addition to the forces afloat, the Soviets maintain an expanding land-based maritime air force with global attack capability. These long range aircraft can also carry cruise missiles capable of launch from ranges far out of sight of their intended targets. These aircraft and missiles, when employed using tactics of mass attacks incorporating extensive electronic jamming and various means of deception, represent a serious challenge in the defense of large ship groups.

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Many of the aircraft now carried aboard U.S. carriers for defense and support missions will be deficient when matched against this expanding threat. Any new aircraft with true multi-purpose capability must be designed to incorporate advanced technologies and performance in such a way that the expanding threat can be successfully countered on, under, and above the surface of the world's oceans.

Within this study, missions are defined which significantly expand on current capability and which realistically address the long-range objectives of the U.S. Navy.

3.0 STUDY APPROACH

This study consisted of five technical tasks, and the total technical effort spanned nine months. A sixth task, encompassing various reporting requirements, paralleled the technical program and culminates in this final report. The task/time relationships of the study are shown in Figure 1.

The study drew on previously completed contracts and Independent Research and Development (IRAD) work in related areas, particularly during Task I, which requires the definition of missions, payloads, and various operational requirements.

A significant propfan technology data base is being assembled at Lockheed-Georgia as a result of various propfan-powered aircraft studies and the Propfan Technology Assessment (PTA) Program. Methodology appropriate to propfan performance was incorporated into this study as a result of this work. Through the use of this large body of data and the results of other completed studies, the technical effort in this study could be focused on those issues appropriate to the design comparison between propfan and turbofan aircraft concepts for multiple mission applications.

An outline, or roadmap, defining the study flow and major milestones, is shown in Figure 2. Tasks I through III were conducted nearly sequentially, with the assumptions and requirements developed in Task I used to generate concepts in Task II. A range of concepts was evaluated

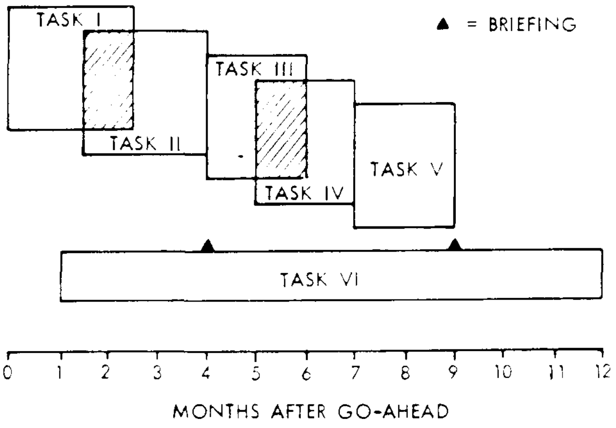

Figure 1. Task/Time Relationship

and reduced to four baseline (two turbofan, two propfan) configurations which would meet either of the two sets of composite mission requirements defined in Task I.

During Task III, these four concepts were refined and developed in detail, including detailed sizing and performance prediction. Various propulsion system and geometric sensitivity studies were also performed as part of this task.

Task IV, starting part way through Task III, produced STOVL derivatives of the CTOL propfan configurations developed in Task III.

Critical propulsion technologies associated with assumptions made in Task I and configurations developed in Tasks III and IV were identified in Task V and a development schedule was generated. A similar schedule for critical mission systems development was also produced.

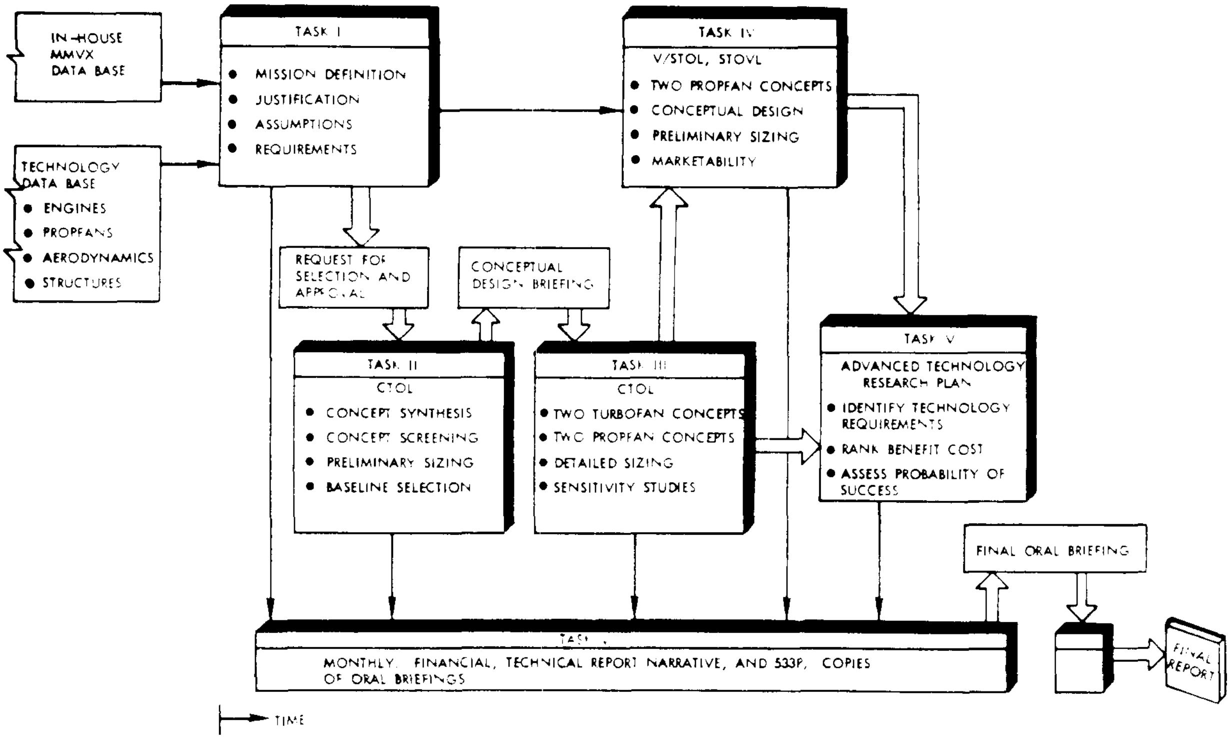

Figure 2. Study Overview Roadmap

4.0 STUDY BREAKDOWN

Each of the five technical tasks which comprise this study is discussed in the following sections. These tasks are:

Task I - Requirements, Assumptions and Guidelines
Task II - Conceptual Design (CTOL)
Task III - Detailed Calculations and Aircraft Optimization (CTOL)
Task IV - Alternative Designs - V/STOL and STOVL
Task V - Advanced Technology Research Plan

4.1 TASK I - REQUIREMENTS, ASSUMPTIONS AND GUIDELINES

This task establishes the groundrules and assumptions under which the remainder of the study is conducted. The study presumes an Initial Operational Capability (IOC) in 1995 for the conceptual designs developed herein. This implies technology readiness is required no later than 1991.

4.1.1 Operational Considerations

There is an increasing need to detect and classify potential targets and threats at much greater distances from our naval forces than is possible today. Particular targets of interest are high speed airborne platforms and missiles cruising at low altitude. The long range threat of cruise missiles, coupled with the ability of a single aircraft, ship or submarine to carry and launch several of these missiles, suggests an obvious advantage in being able to detect and destroy the launch platform prior to the release of its cruise missile payload.

The entire area of tactical command, control, and communication is in need of updating and standardization to include real time access to national sensor information.

There is a growing need to degrade the enemy's acquisition and targeting capability and thus reduce the range and delay the time at which both enemy aircraft and submarines can launch antiship cruise missiles.

Current capability is limited primarily by the range at which enemy airborne platforms and low altitude cruise missiles can be engaged.

In addition, the increased demands placed upon the basic Carrier Air Wing, or complement of aircraft on board the carrier, to provide for the basic defense of the Carrier Battle Group (CVBG) make it of primary importance that new support aircraft should be true multiple purpose systems, capable of supporting strike aircraft operations, capable of independent offensive action, and capable of providing for the defense of the Battle Group. In general, aircraft of this type would be used for:

- Providing early warning beyond the range of the carrier battle group's defensive fighters, with the ability to engage and destroy enemy airborne launch platforms as well as provide for its own defense. (Armed AEW)
- Providing early warning of impending attack by enemy aircraft, cruise missiles, surface ships, and surfaced submarines. (AEW)
- Providing surveillance and communication, command and control capabilities for the Navy's carrier battle group. (SC^3)
- Supporting naval aviation strike operations by suppressing a variety of early warning, acquisition, and fire control elements of enemy air defense systems. Further, the aircraft shall also contribute to fleet air defense by degrading the enemy's antiship missile capability. (EW)
- Serving as a weapons platform to launch air-to-air missiles against bombers and cruise missiles at both low and high altitudes. (AAW)
- Day/night all-weather surface and subsurface surveillance including both overt and covert track/trail operations; Projecting Anti-Submarine capability in remote ocean and coastal areas, both individually and in coordination with friendly force elements. Effective shallow water ASW operation is essential. (ASW)
- Projecting ASUW force (air-to-surface missiles HARPOON, HARM, MAVERICK, and TOMAHAWK) in remote ocean and coastal areas, both individually and in coordination with friendly force elements. Responding to developing surface threat situations by providing attack warning and/or over-the-horizon targeting parameters, and by independent standoff attack. (ASUW)
- Quick reaction mine warfare (MIW), both individually and in company with other offensive aircraft.

- Providing night/day, all-weather, scheduled and nonscheduled COD flights and associated receipt/distribution of material, mail, and passengers. Provisions must be made to accommodate large and odd size cargo, aircraft engines, palletized cargo, and litters. Other missions include medical evacuation and search and rescue. (COD)

- Providing night/day all-weather inflight refueling for all types of aircraft to maintain an aircraft on station, to top-off an aircraft returning to the carrier or waiting in queue to land. (IFR)

These considerations have led to the definition of ten missions, listed in Figure 3. These missions are here ranked according to their perceived importance to the U.S. Navy in the 1990s and within the context that they are to be performed by a multi-purpose support or utility aircraft.

The mission profiles are shown in Figures 4 through 13. In some cases, a particular performance parameter, indicated by an asterisk (*), is deemed so demanding that it may significantly compromise the size and cost of the aircraft. Parameters of this type are termed Category I design goals. When these parameters have been relaxed or eliminated they are referred to as Category 2 design goals. These categories are discussed in section 4.1.3.

1. AAEW - ARMED AIRBORNE EARLY WARNING
2. AEW - AIRBORNE EARLY WARNING
3. AAW - ANTI-AIR WARFARE
4. ASW - ANTI-SUBMARINE WARFARE
5. EW - ELECTRONIC WARFARE
6. SC^3 - SURVEILLANCE, COMMAND, CONTROL, AND COMMUNICATION
7. ASUW - ANTI-SURFACE WARFARE
8. MIW - OFFENSIVE MINE WARFARE
9. TANKER - INFLIGHT REFUELING
10. COD - CARRIER ONBOARD DELIVERY

Figure 3. Design Missions

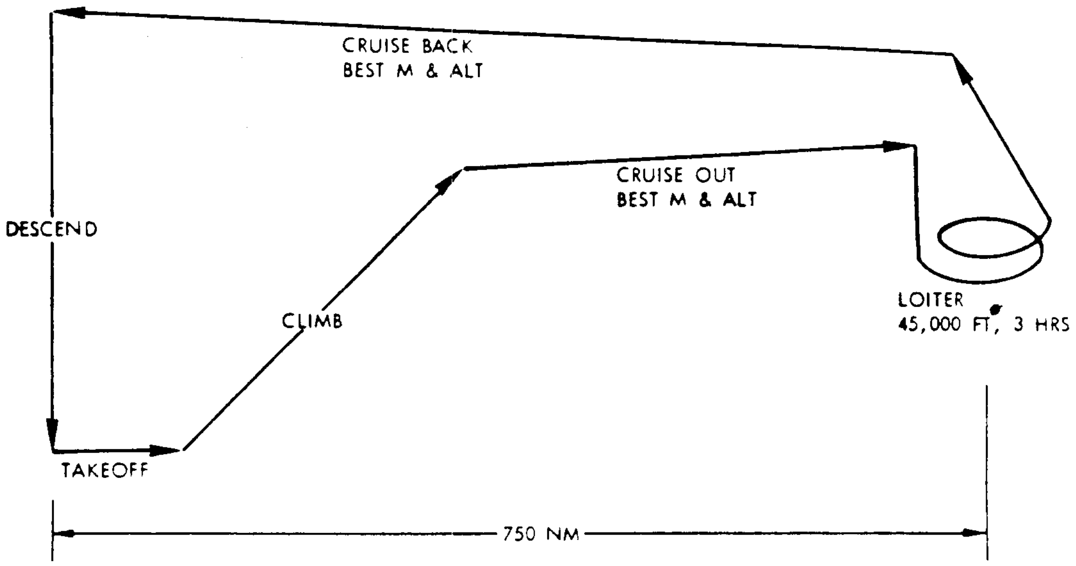

Figure 4. Armed Airborne Early Warning Mission Profile (AAEW)

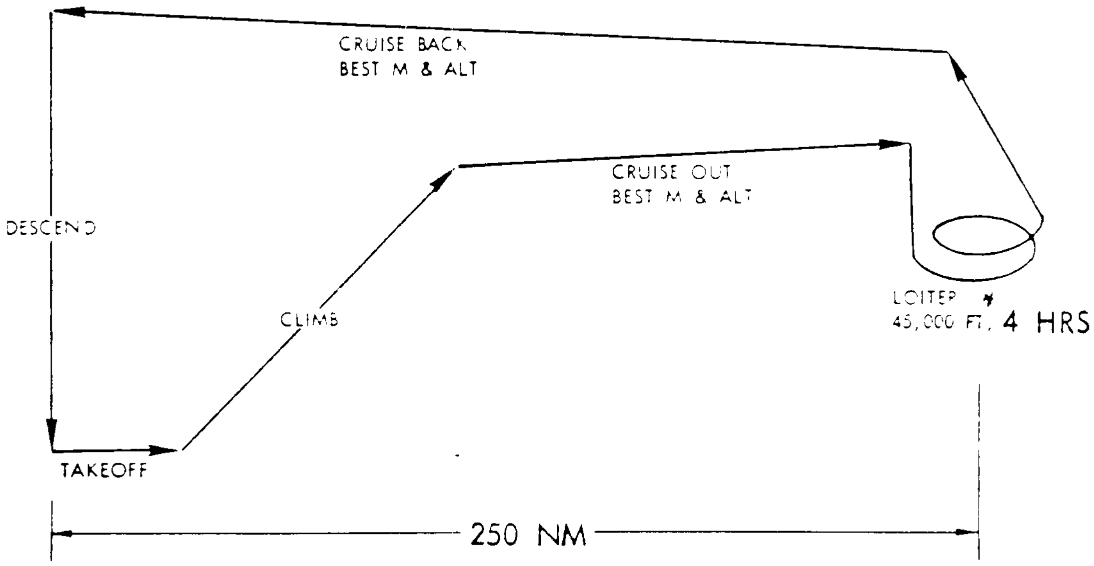

Figure 5. Airborne Early Warning Mission Profile (AEW)

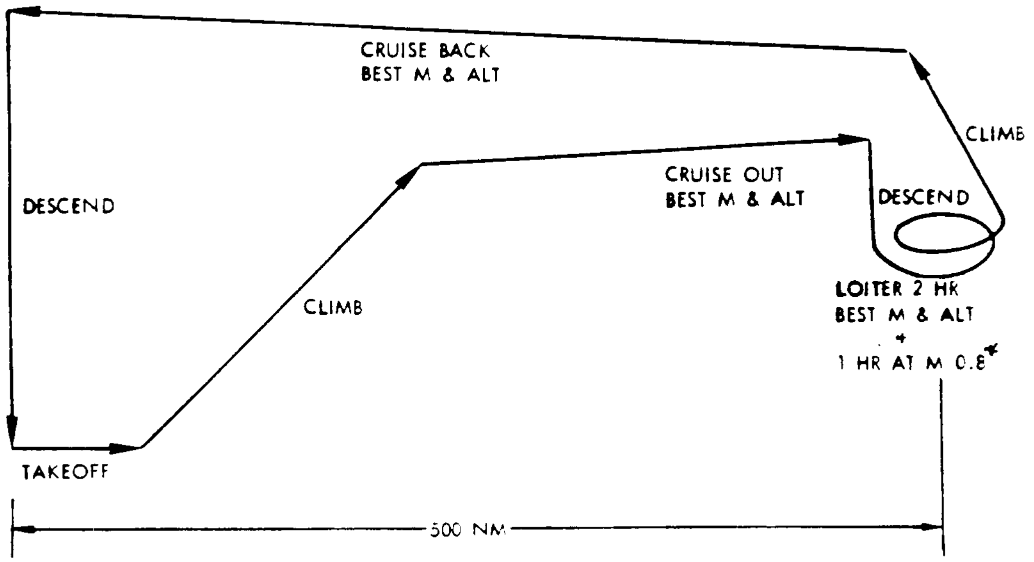

Figure 6. Anti-Air Warfare Mission Profile (AAW)

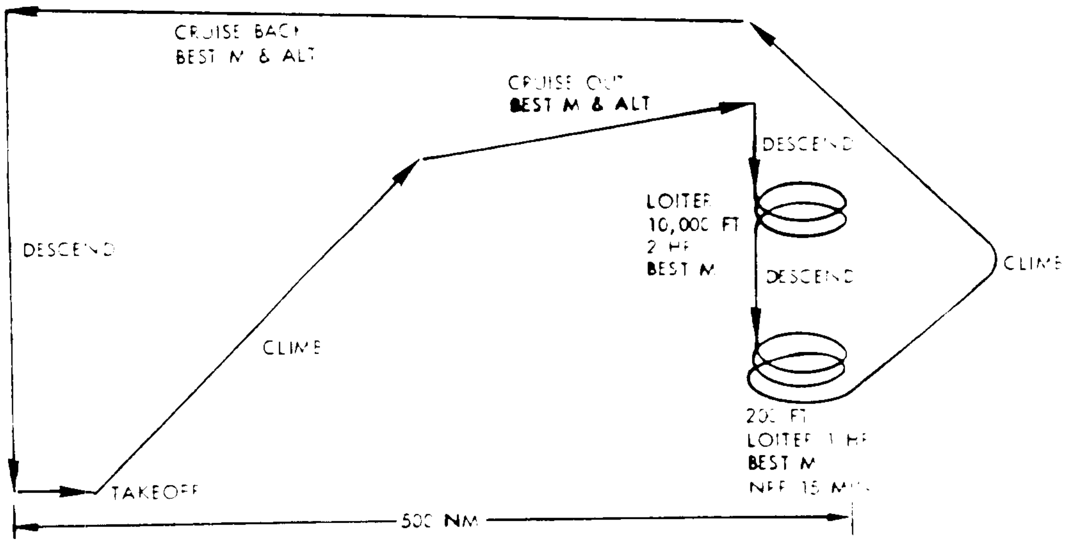

Figure 7. Anti-Submarine Warfare Mission Profile (ASW)

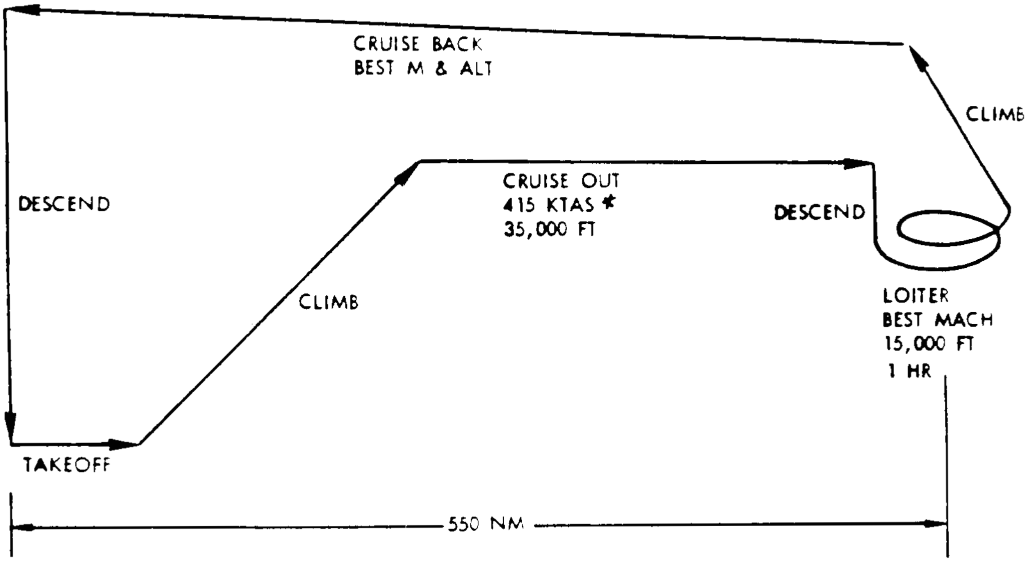

Figure 8. Electronic Warfare Mission Profile (EW)

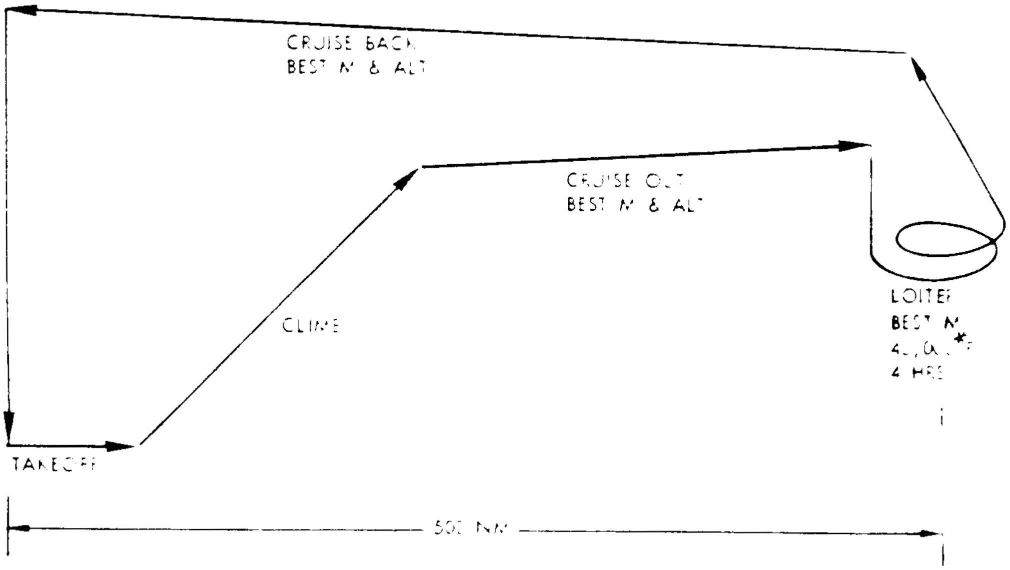

Figure 9. Surveillance, Command, Control and Communications Mission Profile (SC^3)

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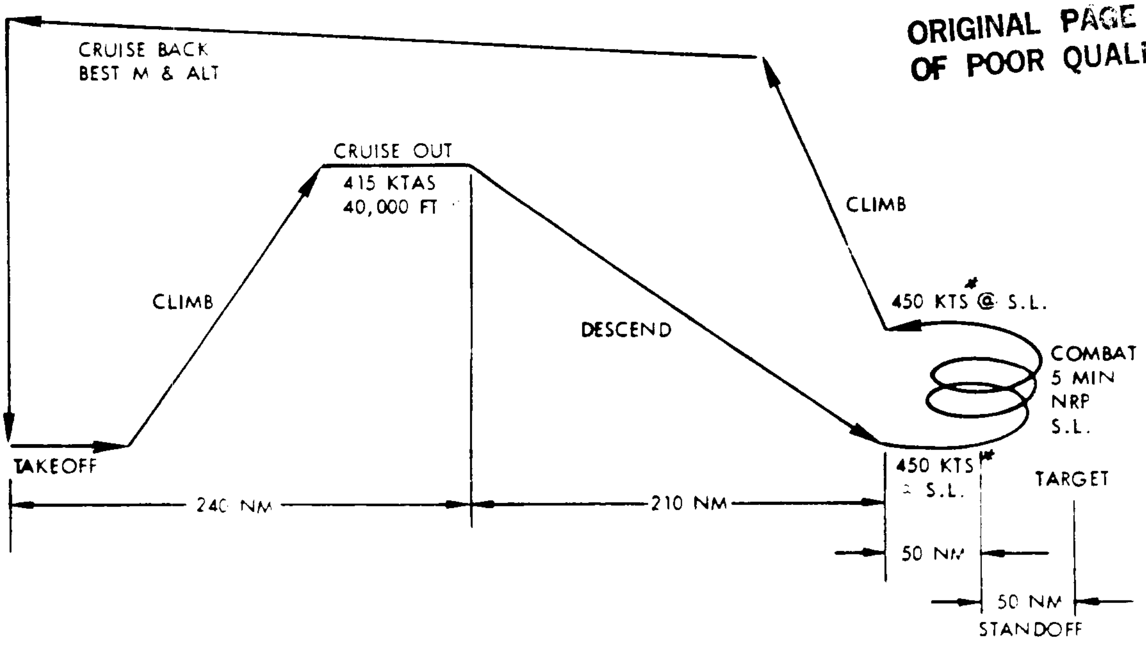


Figure 10. Anti-Surface Warfare Mission Profile (ASUW)

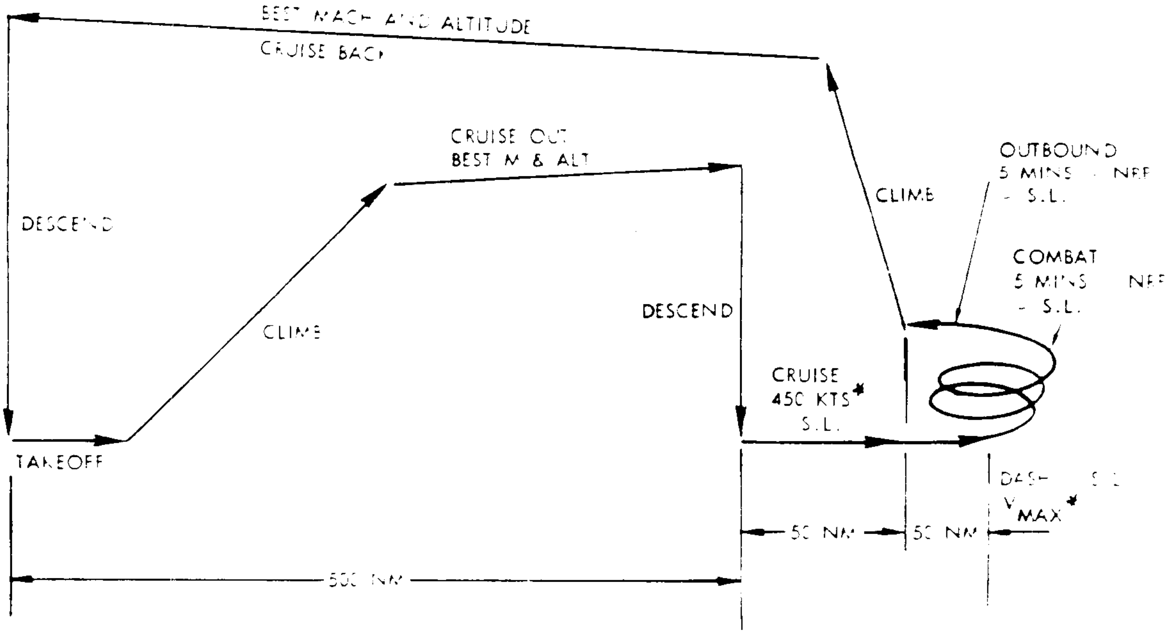


Figure 11. Mine Warfare Mission Profile (MIW)

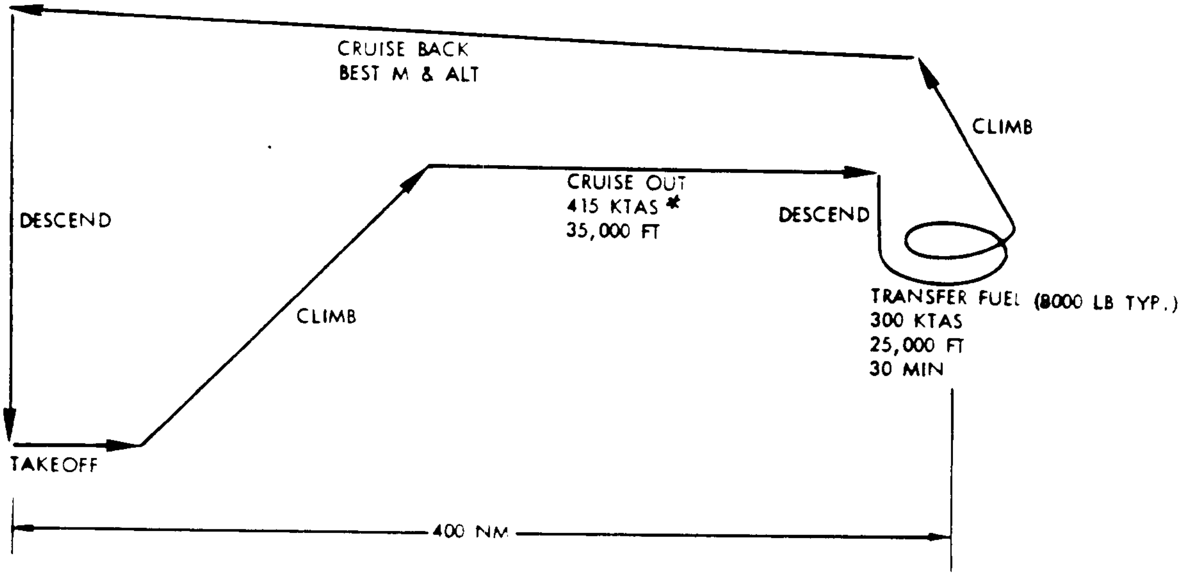


Figure 12. Tanker Mission Profile

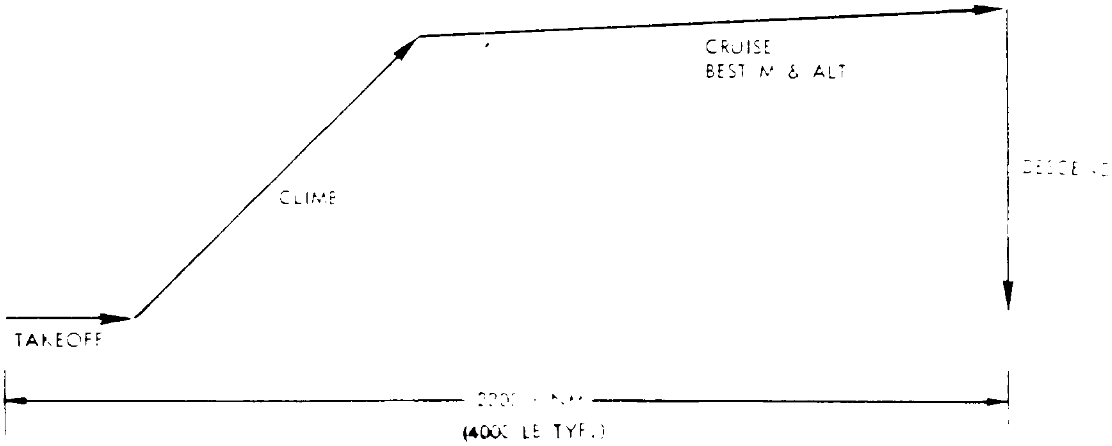


Figure 13. Carrier Onboard Delivery Mission Profile (COD)

4.1.2 Mission Descriptions

The emphasis in defining the following missions is to provide the ability to conduct both offensive and defensive air operations at long distances from the Carrier Battle Group. In the case of defensive operations this means extending the engagement envelope beyond the current Area Defense perimeter into the Outer Air Battle zone. The missions as described are contractor-derived, but are consistent with many Navy requirements.

4.1.2.1 Armed Airborne Early Warning (AAEW)

It is assumed for the purposes of this study that the F-14 aircraft will remain the primary weapons platform used to engage enemy aircraft. It is also assumed that it is most advantageous to attack the enemy bomber prior to the launch of its cruise missiles, and that in the late 1990's, the maximum launch range for these cruise missiles may be up to 300 nm from their intended targets. The F-14 could conceivably be used in four different ways to engage the enemy bombers:

1. Deck launch as a result of early warning and proceed toward the target at supersonic speeds.
2. Deck launch as a result of early warning and proceed toward the target at supersonic speeds and depend on air refueling to return.
3. Conduct a combat air patrol (CAP) operation at more than 300 nm from the battle group and proceed toward the target after early warning.
4. Deck launch as a result of early warning and proceed toward the target at subsonic speeds.

Option No. 1 must be rejected because the F-14 cannot reach a radius of 300 nm at supersonic speeds after deck launch and return without refueling.

Option No. 2, while technically feasible, is rejected on the basis that dependence on refueling after the engagement is too hazardous to the crew and the aircraft.

Option No. 3, although technically feasible, has operational limitations:

a) The F-14 can remain on station for less than one hour at 300 nm radius with sufficient fuel to engage one target.

b) The number of F-14s that could be maintained in a continuous CAP operation would be relatively small due to the large amount of resource required.

Option No. 4 has the following properties:

a) The AEW aircraft must operate at relatively long distances from the battle group.

b) A maximum number of F-14s could be made available at more than 300 n.m. from the battle group with sufficient fuel to make one intercept with almost one hour of loiter fuel remaining for additional intercepts as required.

c) The AEW aircraft must be armed for self-defense since it will operate outside the protection of the F-14s.

Option No. 4 is further examined to determine the radius from the battle group at which the AEW aircraft would have to operate.

The time required for the F-14 to proceed from combat ready deck launch to position for intercept 300 nm from the battle group is estimated to be less than 45 minutes.

For the purposes of this mission definition it is assumed that the enemy bombers can move at moderate supersonic speeds while carrying one external air-to-surface cruise missile and at low supersonic speeds with two external missiles. It is estimated that the bomber can travel less than 500 nm in a combination of subsonic and supersonic flight during the 45 minutes that it will take the interceptor to travel from the carrier to a position more than 300 nm from the battle group center.

It is assumed that the battle group will deploy at least two AEW aircraft and that the battle group is provided with sufficient intelligence to know the approximate direction from which the enemy bombers will approach.

Using the assumption that the enemy aircraft will approach at low altitude, an efficient location for the AEW aircraft is shown in Figure 14. The AEW coverage shown presumes a 45,000 ft. loiter altitude. If this altitude is reduced, the total sector coverage available would naturally be reduced. An AEW aircraft operating under these conditions is well beyond the range of defensive fighter protection. Therefore, it is necessary to arm the aircraft (using an advanced air-to-air missile system). The mission profile for this Armed AEW aircraft is shown in Figure 4. With a loiter time-on-station of three hours, this mission would require a total flight time of up to seven hours. Assuming a deck cycle time of 1.75 hours, this mission time is equivalent to four deck cycles.

The total flight time of seven hours imposes severe demands on the flight crew because of the typically very high work load imposed on AEW radar operators and controllers and because of the restricted environment within a relatively small aircraft. For these reasons, a total flight crew of two pilots and three operators is projected for this mission.

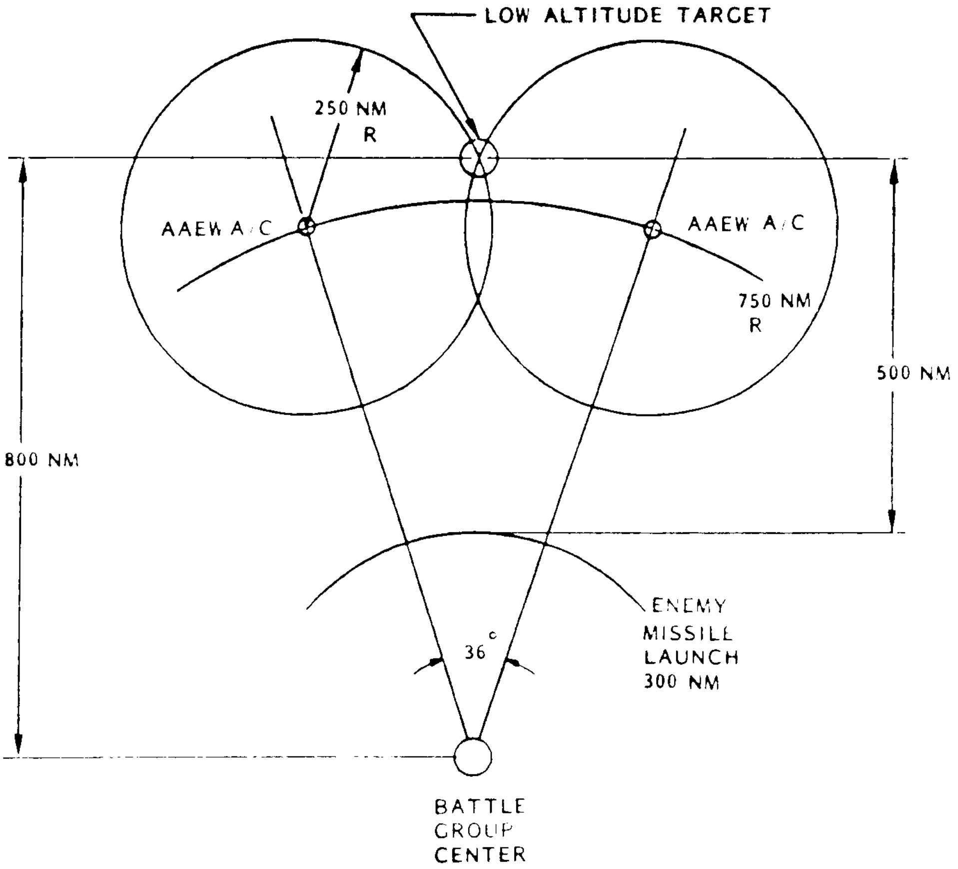


Figure 14. Outer Air Battle Mission Geometry

4.1.2.2 Airborne Early Warning (AEW)

An advanced long range surface-to-air missile system for ship defense may become a reality in the time frame that this study addresses. Such a missile system would depend on suitable aircraft for long range target detection and missile mid-course guidance. These missiles could supplant the F-14 as the primary defensive weapon against air launched cruise missiles.

It will then be possible for the AEW aircraft to operate much closer to the center of the battle group than was the case in the previous mission. This is because of the greatly reduced time of flight of the supersonic surface-to-air missile compared to a subsonic F-14. This consideration leads to the more conventional unarmed Airborne Early Warning mission as shown in Figure 5. Total mission time in this case would be 5 to 6 hours, or about three deck cycles.

4.1.2.3 Anti-Air Warfare (AAW)

To augment the defensive firepower of the F-14 and AAEW aircraft, it may be desirable to position aircraft on station, equipped with advanced air-to-air missiles, for the purpose of engaging enemy aircraft before they reach their cruise missile launch line. These defensive aircraft would operate under the control of the AAEW aircraft.

A study of the dynamics of engagement has shown that an on-station distance of 500 nm from the battle group is an efficient distance for aircraft in the AAW role. The flight profile for this mission is shown in Figure 6.

4.1.2.4 Anti-Submarine Warfare (ASW)

Submarine-launched cruise missiles will have a greater range than their air-launched counterparts. Launch distances of up to 500 nm are possible in the late 1990s. The ASW mission shown in Figure 7 provides for monitoring a sonobuoy field at 500 nm for two hours, plus one additional hour at low altitude for localization of a contact, and a final combat allowance for torpedo attack.

4.1.2.5 Electronic Warfare (EW)

The electronic warfare mission, shown in Figure 8, is consistent with the speed, altitude, and mission radius capability of a representative offensive strike force (A-6 and F/A-18). The function of the EW aircraft on this mission is primarily jamming. Electronic warfare missions which are defensive in nature, and in which the object is to degrade enemy targeting or guidance capability, can also be defined. However, these missions are typically less demanding on the airframe than the offensive EW mission shown.

4.1.2.6 Surveillance, Command, Control, and Communications (SC^3)

Because of the long distance (750 nm) between the Armed AEW aircraft and the battle group command center, it will be necessary to place one or more surveillance, command, control, and communication (SC^3) aircraft between the AEW aircraft and the battle group if line-of-sight communications are to be maintained. The flight profile for aircraft operating in this role is shown on Figure 9. Total mission time for this aircraft is consistent with that of the AAEW mission.

4.1.2.7 Anti-Surface Warfare (ASUW)

This mission is shown in Figure 10. Total mission radius of 500 nm is consistent with the potential range of surface ship-launched cruise missiles. The outbound leg of this mission is designed to keep the strike aircraft below the radar horizon of the surface ship threat. A 50 nm standoff launch of the strike weapon (Harpoon) is assumed.

4.1.2.8 Mine Warfare (MIW)

The flight profile for the mine warfare mission (MIW) is shown in Figure 11. The sea level dash speed of 450 knots, in conjunction with a maneuver load factor of 5, is intended to enhance survivability. Since the aircraft proposed in this study are likely to perform this mission in conjunction with fighter/attack aircraft (VF/VA), the performance goals of this mission (speed and altitude) are consistent with the capabilities of that class of aircraft, at least up to the final sea level dash to the target.

4.1.2.9 In-Flight Refueling (Tanker)

The tanker mission, shown in Figure 12, is compatible with the cruise performance capability of the A-6, F/A-18, and F-14 aircraft. A typical fuel transfer load is 8000 lb, but this load is varied parametrically in the study.

4.1.2.10 Carrier On-Board Delivery (COD)

A carrier on-board delivery range of 2200 nm was selected as representative of the distance from the west coast to Hawaii. A typical payload weight is 4000 lbs, but payload weight was actually varied parametrically during the study. The mission profile is shown in Figure 13.

4.1.3 Performance Category Requirements

A requirement of this study was to determine those mission and performance parameters which were most demanding and which would most significantly "drive" the resulting aircraft weight, size and cost. A relaxed set of parameters was then to be established which would retain some multimission capability but which would result in lighter, smaller aircraft. The former group of parameters is referred to in this study as "Category 1," while the latter is called "Category 2."

The particular parameters selected for both categories are listed in Figure 15. The primary emphasis for Category 1 has been to provide both high speed and high altitude capability. The speed requirements are to ensure compatibility with tactical aircraft that these study design concepts are intended to support and to enhance mission effectiveness and survivability, particularly for independent offensive operation.

The 45,000 foot loiter altitude requirement is intended to expand the Airborne Early Warning coverage, consistent with the increased range and lethality of the projected threat. The Category 2 altitude requirement of 40,000 feet, while still a significant improvement over current capability, represents a much more easily achievable goal than the Category 1 altitude. As will be shown later in this report, rapidly increasing vehicle and powerplant size begins to occur as the loiter altitude exceeds 40,000 feet.

In terms of aircraft size (fuel load, payload, etc.) the most demanding mission is the Armed AEW mission and it was used to size all conventional takeoff and landing (CTOL) concepts in the study. The ASW mission was used to size the Short Takeoff/Vertical Landing (STOVL) concepts. The reasons for this are explained in Section 4.4.1.

A summary of the capabilities of current aircraft is shown in Figure 16.

CATEGORY 1

- PERFORM ALL MISSIONS (TIME + DISTANCE)
- 45000 FT LOITER (AAEW, AEW, SC^3)
- .8 Mn AT 20000 FT (AAW)
- 450 KTS AT SEA LEVEL (ASUW, MIW)
- 415 KTS CRUISE AT 40000 FT (ASUW, TANKER)

CATEGORY 2

- PERFORM ALL MISSIONS (TIME + DISTANCE)
- 40000 FT LOITER (AAEW, AEW, SC^3)

(NO SPEED GOALS IN CATEGORY 2)

Figure 15. Performance Category Definitions

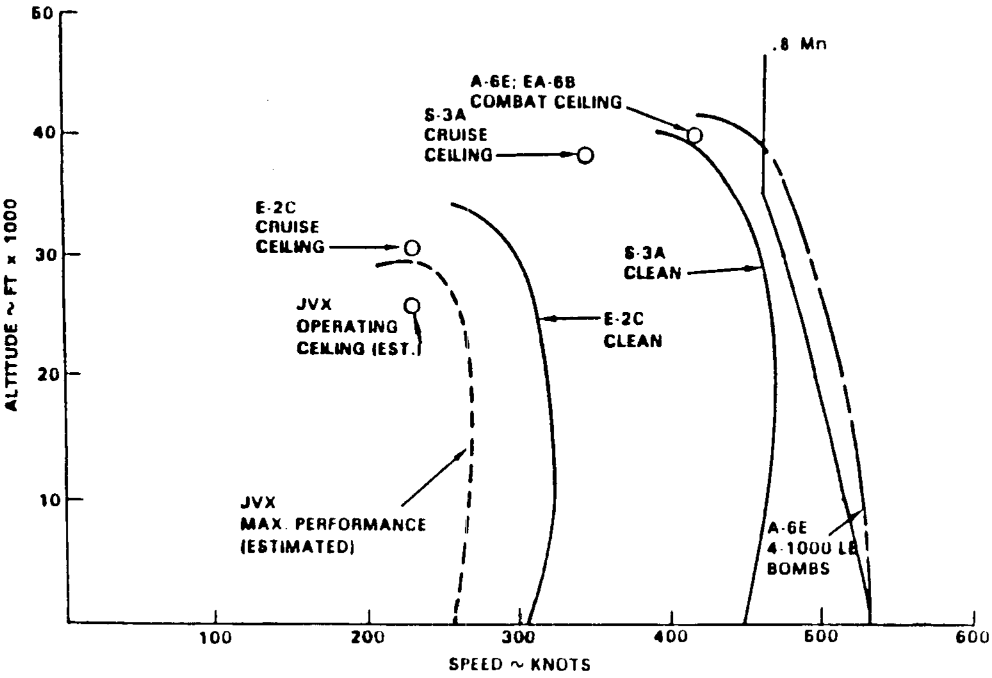


Figure 16. Performance of Existing Aircraft

4.1.4 Mission Equipment and Payloads

A summary of mission payloads and crew sizes is shown in Table I. Crew size for each mission has been selected based upon studies of task assignments and individual workload, considering the likely levels of automation in the 1995 timeframe. The inclusion of a so-called "pilot associate" and various "expert" systems will generally result in a reduction in crew complement required when compared to today's aircraft.

Actual payload items are shown in Figure 17, drawn to the same scale. It is assumed that all offensive stores are retained throughout each mission, except ASW sonobuoys, which are expended during the high altitude loiter segment of that mission. All tanker fuel is transferred at mid-mission.

TABLE I PAYLOADS AND CREW SIZE

	AAEW	AEW	AAW	SCCC	ASW	ASUW	MIW	EW	COD	Tanker
Crew and Equipment	(5) 1170	(5) 1170	(2) 468	(3) 702	(2) 702	(2) 468	(2) 468	(3) 702	(2) 468	(2) 468
Mission Avionics	5048	4548	4625	4025	1625	1625	1625	1250	-	-
Pylons and Racks	214	-	214	-	475	190	340	185	400	-
Stores:										
Missiles-AMS (6)	1800	-	1800	-	-	-	-	-	-	-
-HARPOON (2)	-	-	-	-	-	2500	-	-	-	-
-HARM (2)	-	-	-	-	-	-	-	1560	-	-
Torpedoes-ALWT (4)	-	-	-	-	3200	-	-	-	-	-
Sonobuoys-Mini (90)	-	-	-	-	1350	-	-	-	-	-
Mines (2)	-	-	-	-	-	-	4390	-	-	-
Chaff and Flares	54	54	54	54	54	54	54	54	54	54
Cargo	-	-	-	-	-	-	-	-	4000	-
Fuel	-	-	-	-	-	-	-	-	-	8000
TOTAL PAYLOAD	8286	5772	7161	4781	7406	4837	6877	3751	4922	8522

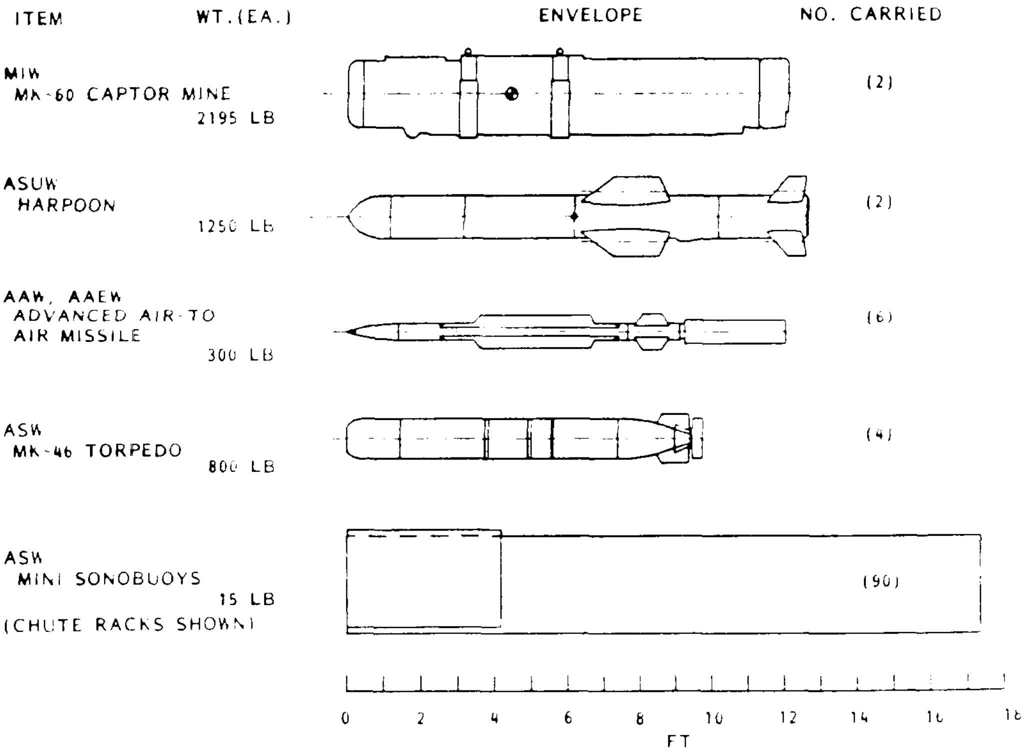


Figure 17. Payload Envelopes

This represents a conservative (and standard) approach to mission definition since in most cases the weapons are too valuable to jettison and it connot be assumed that a target will be engaged or an attack made on every sortie. On the other hand fuel can be jettisoned (or transferred) and sonobuoys, while representing a real cost, are not as expensive as missiles, mines, etc. Furthermore, because of the nature of ASW operations, sonobuoys are expended as a matter of course, even in peacetime, and as a routine part of training.

4.1.5 Avionics

The philosophy used in this study to define avionics weight and volume was to provide a common core of navigation, communications, and data processing equipment for each airframe and to increment this basic equipment with mission-specific modules for Airborne Early Warning, Anti-Submarine Warfare, and Electronic Warfare versions during airframe manufacture. All other missions would use one of these three versions of the basic airframe, except the Anti-Air Warfare mission.

For the AAW mission, it is presumed that the surface search radar of the ASW version would be removed as a quick change module, on the hangar deck of the carrier, and would be replaced by a fire control radar module compatible with the advanced missile used in the AAW mission.

A breakdown of representative avionic weights is shown in Table II.

4.1.6 Technology Data Base

The following technology levels and assumptions are used during this study:

4.1.6.1 Propulsion

An Initial Operational Capability (IOC) date of 1995 is assumed for this study. Consistent with that date, technology readiness is assumed to be no later than 1991. Single-rotation propfan readiness is assumed to be 1988, and counter-rotation propfan readiness is assumed to be 1990.

TABLE II AVIONICS WEIGHTS

	Core	AEW	AAW	CCC	ASW/ ASUW/ MIW	EW	COD/ Tanker
Communication:	(418)	(38)		(20)			
Intercom System	20	-	-	-	-	-	-
HF (Voice, Data)	100	-	-	-	-	-	-
UHF (Voice, Data, ADF, Relay, SATCOM)	40	20	-	20	-	-	-
VHF/UHF (Voice, ADF, Relay)	18	18	-	-	-	-	-
SATCOM - Modem/Data Terminal	20	-	-	-	-	-	-
Link-11 Data Terminal	20	-	-	-	-	-	-
Security - SATCOM	20	-	-	-	-	-	-
Security - Data	20	-	-	-	-	-	-
Security - UHF/VHF Voice, HF Voice	40	-	-	-	-	-	-
JTIDS	120	-	-	-	-	-	-
Navigation:	(410)				(50)		
INS (include Doppler Radome)	120	-	-	-	-	-	-
Data Terminal	15	-	-	-	-	-	-
Beacon	10	-	-	-	-	-	-
AHRS	35	-	-	-	-	-	-
ILS	10	-	-	-	-	-	-
GPS	40	-	-	-	-	-	-
Radar Altimeter	10	-	-	-	-	-	-
Air Data Computer	20	-	-	-	-	-	-
Cockpit Management System	20	-	-	-	-	-	-
SRS	-	-	-	-	50	-	-
ADF - UHF/VHF	15	-	-	-	-	-	-
ADF - HF	40	-	-	-	-	-	-
IFF	75	-	-	-	-	-	-
Sensors/Data Processing and Display:	(600)	(3600)	(3700)	(3200)	(1250)	(1000)	
ESM	150	-	-	-	-	-	-
ECM - Defensive	50	-	-	-	-	-	-
ECM - EW	-	-	-	-	-	1000	-
Search Radar	-	3000	3000	3000	-	-	-
Radar (include Fire Control)	-	500*	500	-	500	-	-
IRST (include FLIR)	-	200	200	200	200	-	-
MAD	-	-	-	-	50	-	-
Acoustic	-	-	-	-	500	-	-
Display/Processing	400	400	-	-	-	-	-
Installation:	(357)	(910)	(925)	(805)	(325)	(250)	
MISSION AVIONICS SUBTOTAL	0	4548 5048*	4625	4025	1625	1250	0
AVIONICS TOTAL	1785	6333 6833*	6410	5810	3410	3035	1785

* = Armed AEW

"Core" represents avionic equipment that is common to all the mission configurations. The equipment listed under the other columns is additional to the Core equipment and is used for the missions indicated in the column heading. The Mission Avionics subtotal is shown in the Payloads and Crew Size, Table I.

Advanced turbofan and turboshaft engine technologies as represented by parametric Pratt and Whitney STF 686 and STS 678 engines are incorporated in this study (References 1 and 2). Technology factors are used to adjust the SFC and engine weight to a 1991 availability date. These two engines are equivalent in terms of technology level, size, and general design characteristics, permitting direct comparison of turbofan performance with propfan systems derived from the turboshaft engine. Both of these parametric engines were originally derived for the Advanced Prop-fan Engine Technology (APET) studies conducted for NASA Lewis Research Center (Reference 3.)

The STS 678 is an advanced technology study turboshaft engine projected for commercial engine certification in the 1992 time period. The STS 678 is a twin spool engine. The high pressure spool incorporates an eleven-stage, axial flow high pressure compressor driven by a two-stage high pressure turbine. The low pressure spool incorporates a two-stage axial flow, variable geometry, low pressure compressor driven by a four stage low pressure turbine which also supplies the power for the output shaft to the gearbox and propfan.

The engine is in the 12,000 shaft horsepower class, with a design overall pressure ratio of 34.

Lack of available free turbine engine data, matched to a wide range of propfan configurations eliminated this particular engine type from the study. Nevertheless, the free turbine engine is a potential candidate and in fact, may be the preferred type of engine for this application. It is possible to more easily match the free turbine engine to the characteristics of the propfan propulsor. Furthermore, the demands of carrier operation require engines with rapid throttle response during landing approach and possible waveoff. These demands can be more easily met with a free turbine engine. Incorporating a propeller brake on a free turbine engine may make the issue of propeller hazard on the flight dock entirely moot.

The STF 686 engine is a twin spool, separate flow turbofan engine designed for commercial applications. The high pressure spool is a scaled version of the STS 678 high pressure spool, made up of an 11-stage high pressure compressor, a low emissions combustor and a two-stage high pressure turbine. The low pressure spool consists of a single-stage shroudless fan, a three stage low pressure compressor and a five-stage low pressure turbine.

It also includes an active clearance control system which controls the clearances of several components in order to minimize the fuel consumption at cruise. The system is activated for all operating conditions at altitudes above 15,000 feet.

The STF 686 engine has 19,350 pounds of takeoff thrust. Takeoff thrust is flat rated up to an ambient temperature 25°F above standard. In addition, it is flat rated up to an ambient temperature 18°F above standard for maximum climb, maximum cruise and maximum continuous ratings. The engine has a fan pressure ratio of 1.66, a bypass ratio of 6.97, and an overall compression system pressure ratio of 37.2 at the design point.

Propfans provide high propulsive efficiences over a wide range of speeds. Data for both single rotation (SRP) and counter-rotation (CRP) propfans in a variety of configurations have been provided by Hamilton-Standard (References 4 and 5).

In addition to the propfan concepts, which incorporate a gearbox between the engine and the propulsor (propfan), the General Electric Unducted Fan (UDF), or gearless propeller concept, is a potential candidate to propel the aircraft in this study. A brief comparison has been made based upon the projected GE36 UDF.

All propulsion systems used in this study are scaled over a fairly wide range of rated thrust. This scaling was accomplished using factors provided by the manufacturers to account for the non-linear effects of scaling on SFC and engine weight.

Although the parametric engines used in this study are optimized for commercial application, they are suitable for the types of military missions discussed in previous sections of this report. It is probable that any engine selected for this class of aircraft would be derived from a commercial version, if possible, to minimize RDT&E costs. If the engines were designed from the outset for military use, following common practices, they would likely be optimized to favor lighter engine weight and higher speed at some cost in cruise SFC and engine Time Between Overhauls (TBO). This would probably be achieved by using lower overall pressure ratios and higher turbine inlet temperatures.

The total range of propulsion concepts and propfan combinations that investigated in this study are shown in Figure 18.

4.1.6.2 Supercritical Aerodynamics

Aft-loaded airfoils (supercritical) are incorporated in this study. They have a significant drag reduction benefit at high subsonic speeds, at the expense of a slightly higher incompressible drag level and a relatively high negative pitching moment. Active controls and relaxed static stability are incorporated to shift the CG aft to counter the trim drag

GAS GENERATOR		PWA STS 678							GE 36	STF 686
PROP CONFIG.		4X4 COUNTER-ROTATING				6X6 CRP	10 BLD. SRP		UDF	TURBO-FAN
DISK LOADING (SHP/FT^2)		60	70	80	90	120	40	80		
VEHICLE CONCEPT	CTOL	√	√	●	○	√	√	√	√	√
	VSTOL	●	√	○	√		√	√		

√ = INVESTIGATED
○ = BASELINE, CATEGORY 1
● = BASELINE, CATEGORY 2

Figure 18. Propulsion Combinations

effect of the negative pitching moment. In addition, the basic supercritical section is modified slightly to minimize the negative pitching moment.

4.1.6.3 All-Electric Systems

The replacement of hydraulic systems with electrical ones will result in smaller actuator sizes and reduced weight. This is reflected in the study as an increase over statistically predicted electrical system weight and a corresponding (but greater) reduction in hydraulic system weight.

4.1.6.4 Relaxed Static Stability

Reduced positive static stability, artificially augmented electronically, will result in reduced tail size (or canard size) with a corresponding reduction in structure weight.

4.1.6.5 Active Controls

The high altitude requirements and long loiter times for the aircraft in the study drive the wing aspect ratio up for reduced induced drag. This has a detrimental effect on ride quality at high speed and low altitude.

Active controls effectively improve the ride quality by reducing the gust response of the aircraft. This technology is incorporated through an appropriate weight penalty in the control system.

4.1.6.6 Fly-By-Wire

Fly-by-wire control systems are consistent with the concept of an all-electric airplane and with the incorporation of relaxed static stability and active controls.

4.1.6.7 Avionics

Advanced avionics systems are assumed for all mission applications. They are represented by smaller "black boxes" and reduced weight. The surveillance radar used in the AEW and SC^3 missions is assumed to be a three-element electronically scanned and steered phased array, mounted in a radome. Conformal antenna arrays, integrated into the airframe, are technically feasible in the 1995 timeframe, but the radar performance requirements, which favor lower radar frequencies, tend to make the associated airframe compromises considerable. Because of the nature of the surveillance problem, full 360^{o} antenna coverage is required and this is difficult to achieve in a relatively small airframe with a conformal installation. Furthermore, the penalty associated with retaining the conformal radar on other versions of the aircraft or on missions which do not require radar are considered prohibitive.

An analysis of the possible range of radar frequencies which might be used for a high resolution surveillance radar resulted in the selection of the low end of the L-band (800 MHz) as the best compromise among a number of performance-related factors. A drawing of the proposed L-band phased array radome is shown in Figure 19.

Modular avionics, as discussed in Section 4.1.5 and listed in Table II, represent a substantial reduction in weight and volume compared to present systems.

4.1.6.8 Materials

Figure 20 shows the percentages of the various types of materials that are assumed to be used in the study aircraft. Aircraft in this study will be constructed primarily from advanced technology materials. The inclusion of the materials shown is accounted for by the application of "technology factors" to statistically predicted structure group weights.

The trend in aircraft structural design is to replace conventional aluminum alloys almost entirely with organic matrix composites (graphite/ epoxy, Kevlar/epoxy) and metal matrix composites (silicon carbide/aluminum, because of the significant strength and stiffness advantages and reduced weight.)

4.1.7 Carrier Compatibility

Aircraft conceptual designs generated during this study are compatible with operations from CV59 (Forrestal) class and larger carriers. Criteria

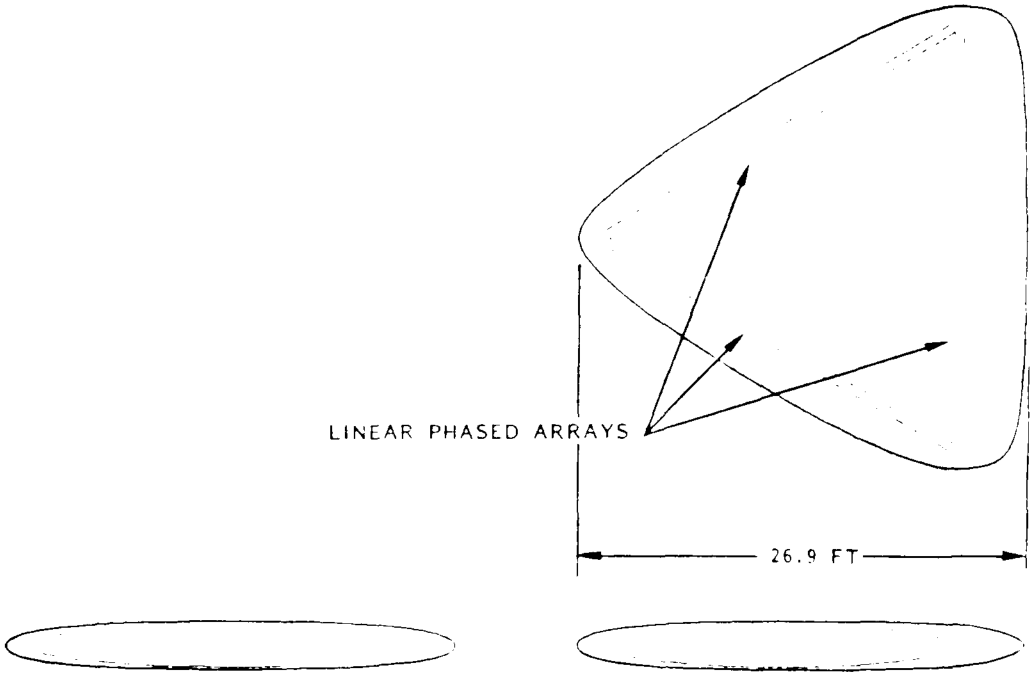


Figure 19. L-Band Radar Radome

MATERIAL	PERCENT OF AIRPLANE STRUCTURE	AREA OF APPLICATION							
		WING LEADING EDGE PRIMARY RIBS/FITTS	MAIN FUSELAGE AFT FUSELAGE	EMPENNAGE LEADING EDGES PRIMARY FITTINGS	NACELLES HOT AREAS ENGINE MOUNTS	L/G GEAR, WEAPONS BAY & ACCESS DOORS	LANDING GEARS ARRESTING GEAR	BOLTS, ETC.	ACTUATORS WINDSHIELD/CANOPY BRAKES & TIRES
ADVANCED ORGANIC MATRIX COMPOSITES	35 - 45	X X	X	X		X			
ADVANCED ALUMINUM	25 - 35	X	X	X X	X		X		
ADVANCED TITANIUM	5 - 7				X		X	X	
ADVANCED STEELS	5 - 8				X		X		
STANDARD STEELS	5 - 10						X	X	
MISCELLANEOUS	9 - 11								X

Figure 20. Projected Structural Material Mix

for catapult and arresting (waveoff) performance are shown in Figure 21. In general, because of the high thrust-to-weight ratios necessary to achieve high altitude and/or high speed, carrier suitability factors are not limiting in this study.

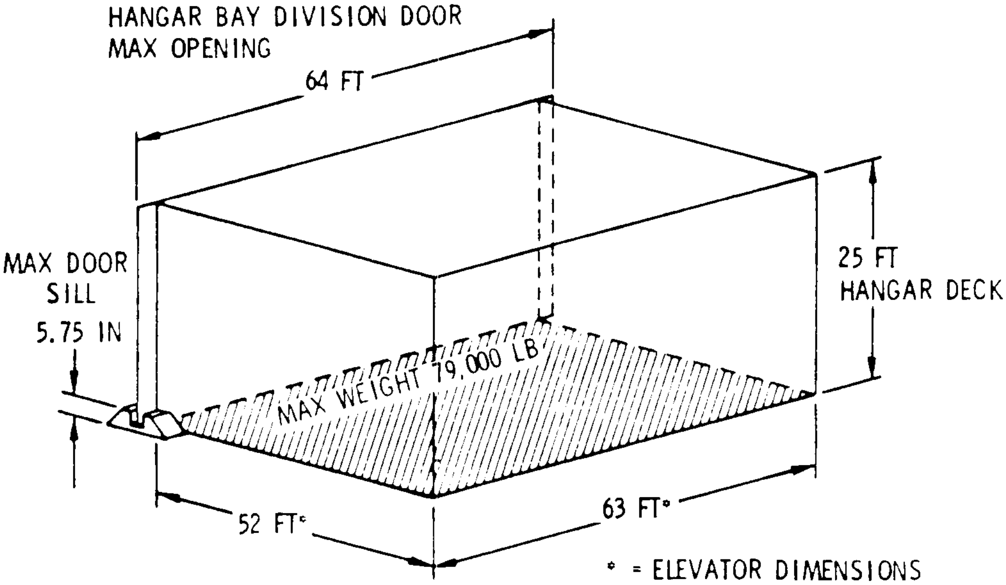
A composite diagram of applicable hangar deck and elevator restrictions is shown in Figure 22. Except for AEW radome clearance on the hangar deck, none of these restrictions is a factor in this study.

4.1.8 Projected Fleet Size

A number of aircraft types are currently deployed as part of a typical Carrier Air Wing. A representative air wing may total 86 aircraft, of which perhaps 22 are candidates for replacement by a single advanced multipurpose type as shown in Table III. Carrier-on-board delivery aircraft, as well as land-based (but carrier-suitable) Electronic Warfare (EW) aircraft and Marine Air Wing EW aircraft, which are not normally part of an embarked Carrier Air Wing, are also candidates for replacement. This is summarized in Table IV. Expanding these figures to account for the total authorized

- **CV 59 (FORRESTAL) AND LARGER CARRIERS**
- **C7 CATAPULT**
- **MK7-MOD3 ARRESTING GEAR**
- **TROPICAL (90^0) DAY**
- **.065 a/g - CATAPULT (BOTH ENGINES OPERATING)**
- **500 FPM - WAVEOFF (ONE ENGINE INOPERATIVE)**
- **ZERO WIND OVER DECK OR LESS**

Figure 21. Carrier Suitability Criteria



FORRESTAL (CV 59) CLASS

Figure 22. Carrier Geometric Limitations

TABLE III REPRESENTATIVE CARRIER AIR WING

AIRCRAFT TYPE	FUNCTION	SQUADRON	AIRCRAFT	CANDIDATE MPSNA
F-14, F/A-18	FIGHTER (RECONNAISSANCE)	2	24	
A-7, F/A-18	LIGHT ATTACK	2	24	
A-6, KA-6D	MEDIUM ATTACK, TANKER	1	14	4
S-3A	ANTI-SUBMARINE WARFARE (FIXED WING)	1	10	10
SH-3H	ANTI-SUBMARINE WARFARE (ROTARY WING)	1	6	
EA-6B	ELECTRONIC WARFARE	1	4	4
E-2B/C	AIRBORNE EARLY WARNING	1	4	4
			Σ86	Σ22

TABLE IV CURRENT SUPPORT AIRCRAFT FLEET SIZE

Type	Aircraft	Function	No. per CVW	No. per MAW	Total UE Aircraft*
VAW	E-2C	Airborne Early Warning	4	0	64
VS	S-3	Anti-Submarine Warfare	10	0	160**
VAQ	EA-6B	Electronic Warfare	4	5	84***
VQ	EA-3B	Electronic Warfare	(2 Sqn Total)	0	12
VAK	KA-6D	Tanker	4	0	64
VRC	C-2	Carrier Onboard Delivery	(60 A/C Total)	0	50

* Assumes 14 active, 2 reserve CVW's; 3 active, 1 reserve MAW

Currently 12 active, 2 reserve CVW

** Currently, VS reserve sqn's do not have aircraft; there are 11 sqn's for a Sqn UE of 110.

*** There are currently no reserve VAQ squadrons, and there are fewer VAQ detachments than CVW's. Continued EA-6 production may rectify this.

Unit Equipment (UE) strength, as well as various training, support, and replacement aircraft, projected for the late 1990s yields a potential production of over 700 airframes, as shown in Table V.

TABLE V PROJECTED SUPPORT AIRCRAFT FLEET SIZE

Possible Future CVW Composition with Armed AEW, Combined Jammer and SIGINT, No Tanker

Sqn Type	Total UE	Training Test & Support	Total Active	Pipeline	Attrition (est.)	Total
VAW	32	10	42	4	7	53
VFAW	96	29	125	13	31	169
VS	160	48	208	21	16	245
VAQ/VW	100	30	130	13	58	201
VRC	50	15	65	7	8	80
					Total	748

4.2 TASK II - CONCEPTUAL DESIGN

The objective of Task II is to obtain first order approximations for "optimized" turbofan and propfan aircraft concepts which will accomplish the performance goals (either Category 1 or Category 2) and the missions described in Task I. From the designer's point of view, this process consists of investigating configuration options which will accommodate the equipment, crew, payloads, and propulsion units defined in Task I, and, considering vehicle size, ship-board operations, structural and aerodynamic implications, accessibility, etc., selecting a "best" conceptual configurations. These configurations may be different for the turbofan and the propfan propulsion system.

From the analyst's point of view, the first-order optimization process consists of exercising notional turbofan and propfan configurations against the various mission requirements for a range of design parameters (wing loading and thrust/weight) to determine: (1) most critical mission(s), (2) most critical performance requirements, (3) relative "compatibility" of the various missions.

Detailed optimization of vehicle parameters is reserved for Task III.

The principal analytical tool used during conceptual design, and later during the more detailed analysis of Task III is a large Configuration Analysis Program (CAP) shown schematically in Figure 23. This program permits the rapid sizing of various configurations (for minimum Takeoff Gross Weight) against a particular selected mission (time and distance) while simultaneously computing additional performance parameters and alternative mission capability.

4.2.1 Design

The conceptual design process for this study has been broken down into five sequential steps:

1. Fuselage envelope definition.

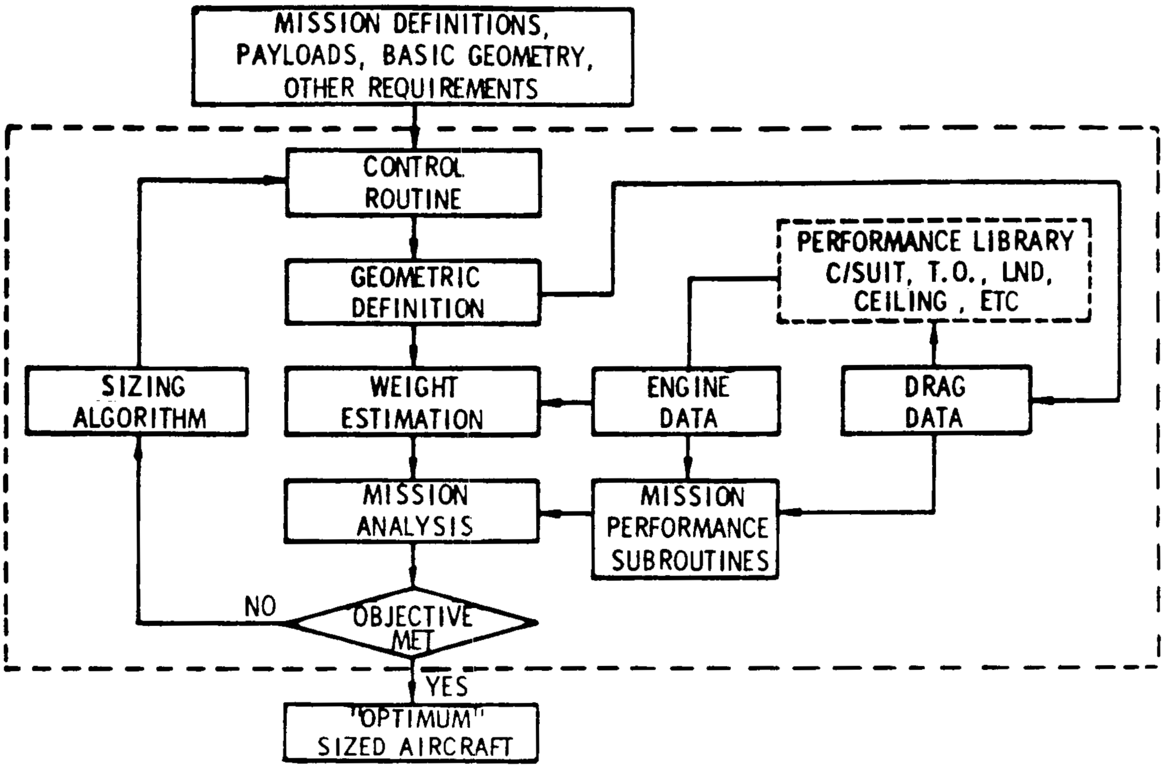


Figure 23. Configuration Analysis Program Schematic

2. Selection of nominal baseline geometric parameters.
3. Propulsion installation definition.
4. Exploration of configuration options.
5. Qualitative evaluation of configurations.

A brief description of each step follows:

4.2.1.1 Fuselage Definition

The central problem in designing the fuselage is one of packaging: weapons and payload, crew, fuel, and equipment. At the outset, it was decided that all weapons and disposable payload would be accommodated in a large unobstructed internal weapons bay, located on the aircraft center of gravity. A composite of all mission store envelopes plus clearance requirements yielded weapons bay dimensions of 3.1 ft x 6.5 ft x 17.7 ft. Around this weapons bay, crew, fuel, sensors, and equipment would be arranged. This led to the schematic layout shown in Figure 24. A philosophy was established early in this design task: a single minimum fuselage package (55 ft overall length), referred to as the Mk 1 would be developed for the ASW, AAW, ASUW, MIW, TANKER, EW, and possibly the COD missions (all missions which do not require surveillance radar). The Mk 1 fuselage configured for the ASW role is shown in Figure 25. Key features of the Mk 1 fuselage include accommodations for up to four crew members seated in forward facing zero-zero ejection seats, a central aisle with "stand-up" space to relieve crew fatigue on extended missions, a weapons bay located on the aircraft center-of-gravity (cg), fuselage fuel tanks, also centered at the aircraft cg, and a large nose radome compartment sized to house the ASW search radar scanner or alternatively the smaller AAW fire control radar scanner and transmitter module.

For the Armed AEW, AEW, and SC^3 missions, additional crew stations are required; hence, a three foot plug was added in the forward fuselage to accommodate a fifth and possibly sixth crew member. This addition would be balanced by the installation of the surveillance radar radome aft. This resulted in the Mk 2 fuselage, shown configured for the Armed AEW mission, in Figure 26.

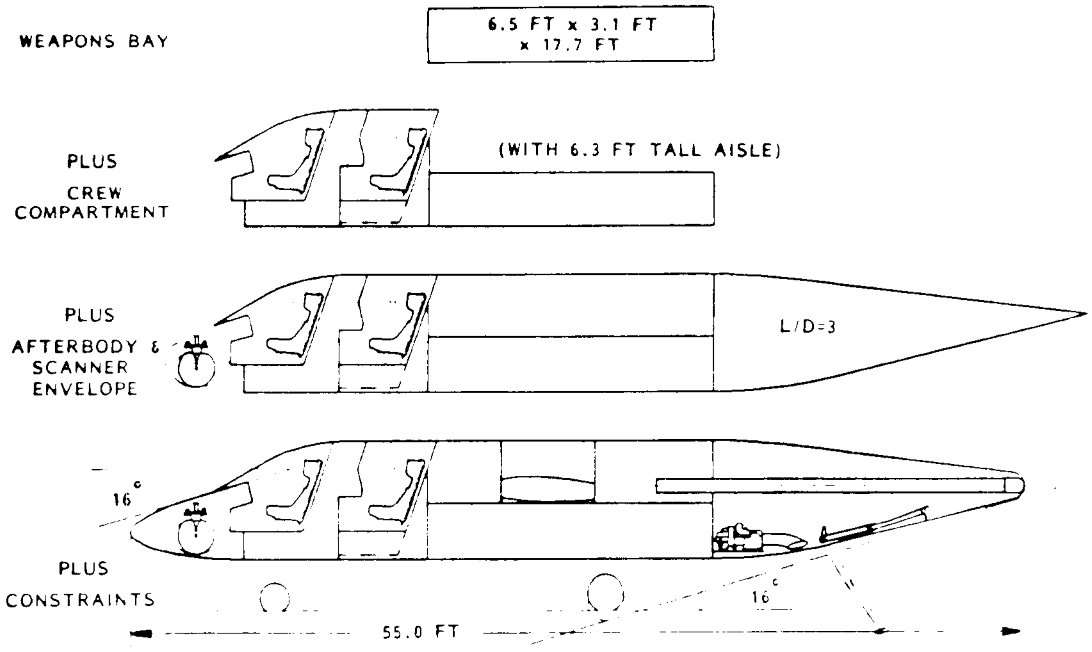


Figure 24. Fuselage Layout

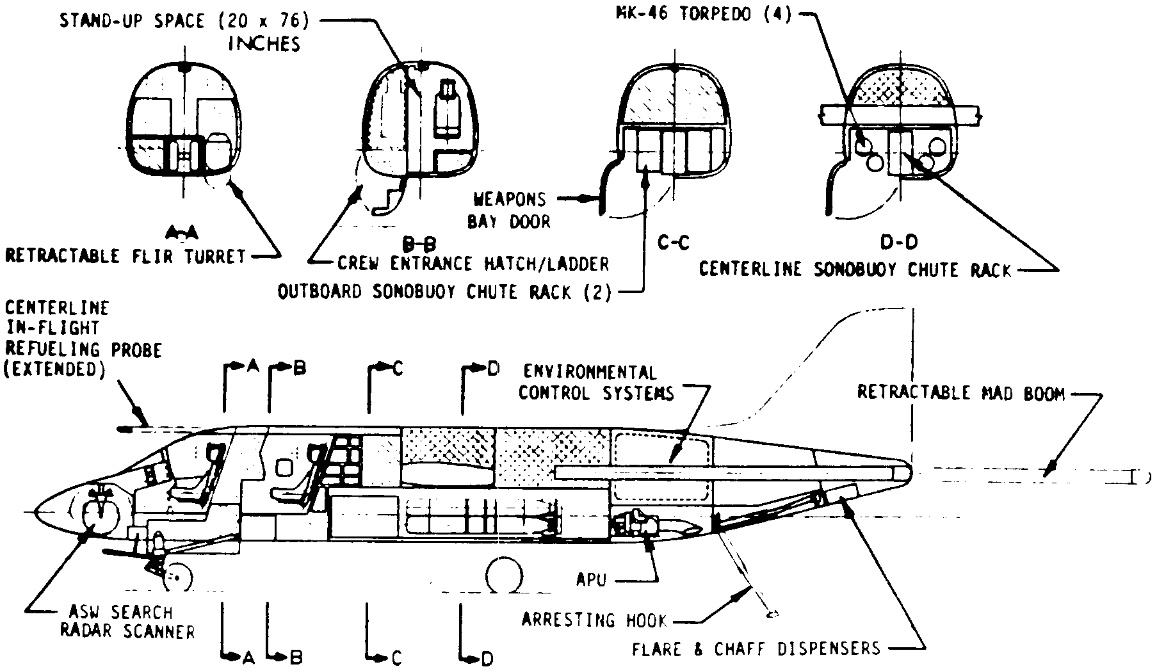


Figure 25. MK1 Fuselage Inboard Profile (ASW)

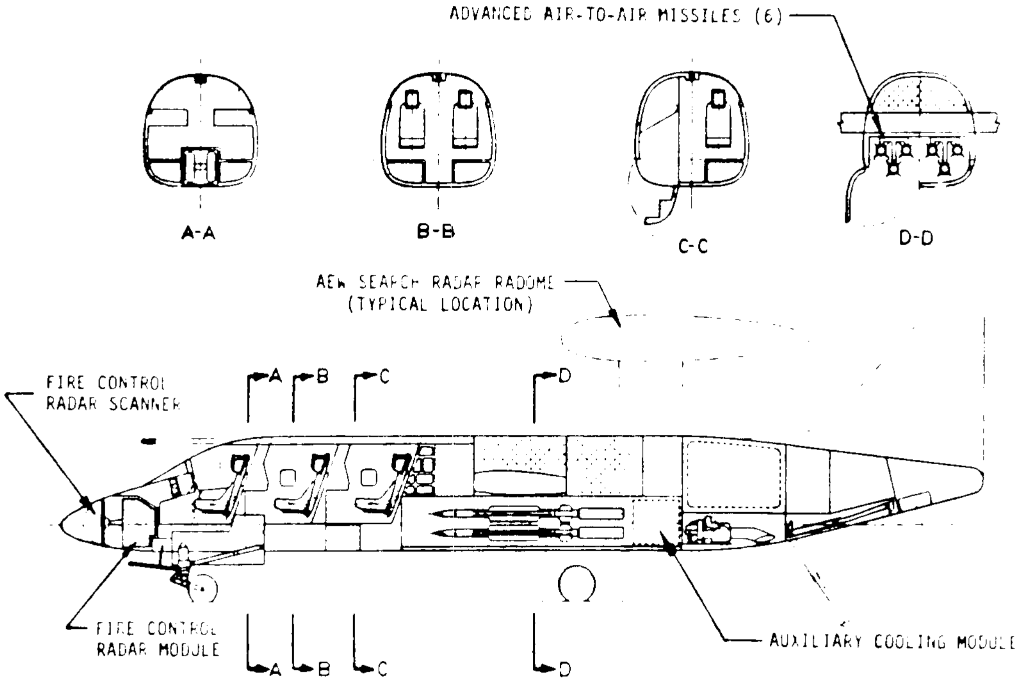


Figure 26. MK2 Fuselage Inboard Profile (AAEW)

4.2.1.2 Baseline Geometric Parameters

To establish a point of departure for the study of configuration options, a set of baseline geometric and general aircraft parameters was selected based on previous Navy multipurpose configuration studies, experience with the Lockheed S-3A Navy ASW and COD aircraft, and preliminary analysis conducted for this study. The initial parameters are listed in Table VI.

4.2.1.3 Baseline Propulsion Installations

Preliminary propulsion installation drawings, such as the arrangements shown in Figures 27, 28, and 29 were prepared for turbofan and propfan concepts. The turbofan nacelle arrangement was developed around the Pratt and Whitney STF 686 turbofan.

TABLE VI GEOMETRIC ASSUMPTIONS

Surface Geometry

	Wing	Horizontal Tail	Vertical Tail
TAPER RATIO	0.3	0.35	0.33
ASPECT RATIO	7	4	1.1
SWEEP	25° L.E.	0° T.E.*	0° T.E.*

* L.E. Sweep is a function of taper and aspect ratio

Tail Volume

Horizontal Tail Volume = 0.60

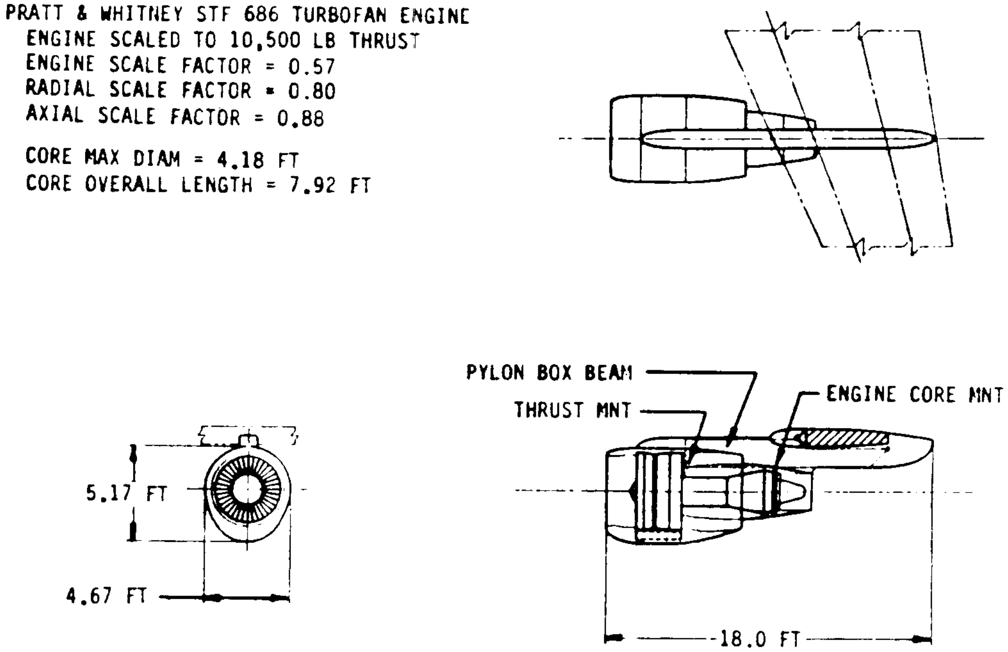
Vertical Tail Volume = 0.066

Initial Baseline Aircraft Sizing

Thrust-to-Weight Ratio = 0.5

Wing Loading = 100 PSF

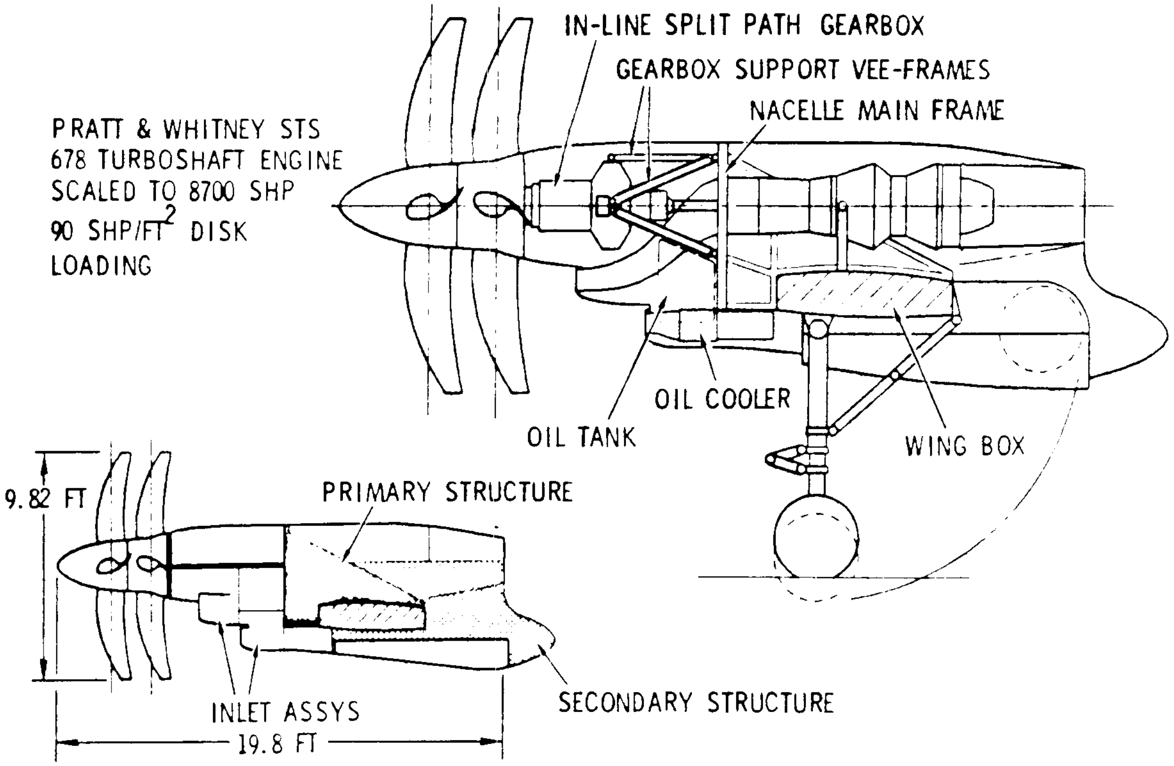
Takeoff Gross Weight = 42,000 LB



PRATT & WHITNEY STF 686 TURBOFAN ENGINE
ENGINE SCALED TO 10,500 LB THRUST
ENGINE SCALE FACTOR = 0.57
RADIAL SCALE FACTOR = 0.80
AXIAL SCALE FACTOR = 0.88

CORE MAX DIAM = 4.18 FT
CORE OVERALL LENGTH = 7.92 FT

Figure 27. Turbofan Installation (Typical)



PRATT & WHITNEY STS 678 TURBOSHAFT ENGINE SCALED TO 8700 SHP
90 SHP/FT^2 DISK LOADING

Figure 28. Tractor Propfan Installation Concept (Typical)

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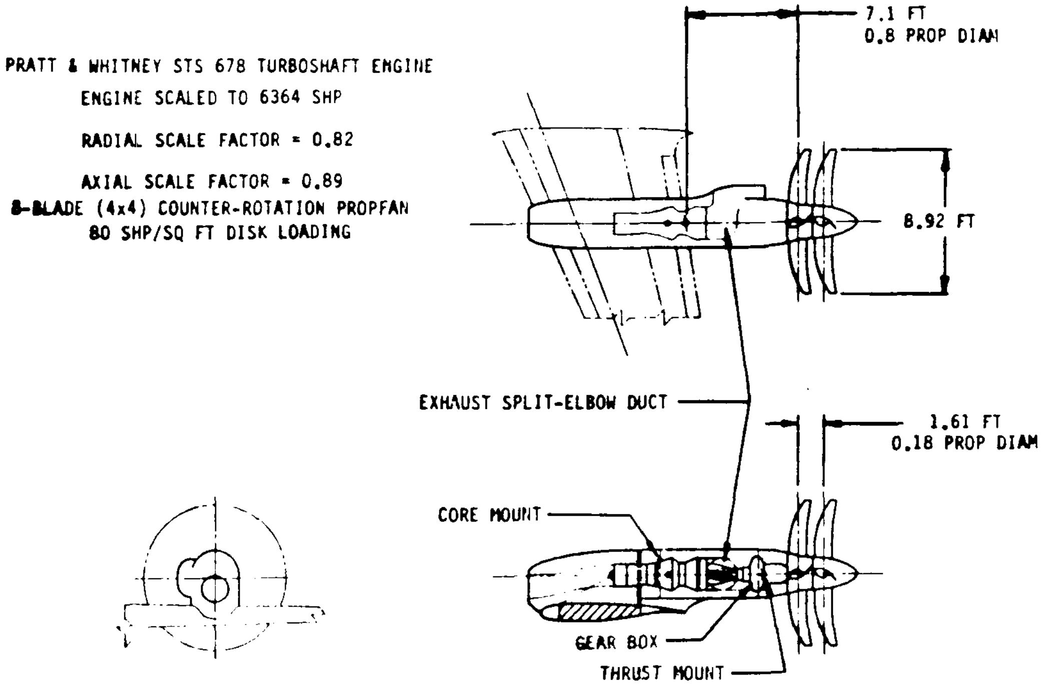


Figure 29. Pusher Propfan Installation (Typical)

Early propfan nacelle arrangements, including tractor and pusher types in both overwing and underwing configurations, were developed around the Pratt and Whitney STS 678 turboshaft core engine driving an 8-blade (4x4) counter-rotation propfan (CRP).

4.2.1.4 Layout of Configurations and Options

Configuration general arrangements for a wide variety of concepts were developed. Configuration combinations were considered for the following:

- o FUSELAGE baseline Mk 1
- o PROPULSION

  Turbofan

  - wing pylon mounted
  - fuselage mounted (aft)

Propfan

- wing mounted
  - underwing
  - overwing
- tail mounted
- tractor
- pusher

o WING LOCATION

Midwing, above weapons bay, landing gear in the wing root

Highwing, landing gear podded or in nacelle

o EMPENNAGE

Mid-fuselage horizontal, conventional

"T-tail"

Twin fins

High-fuselage conventional

Mid-fin

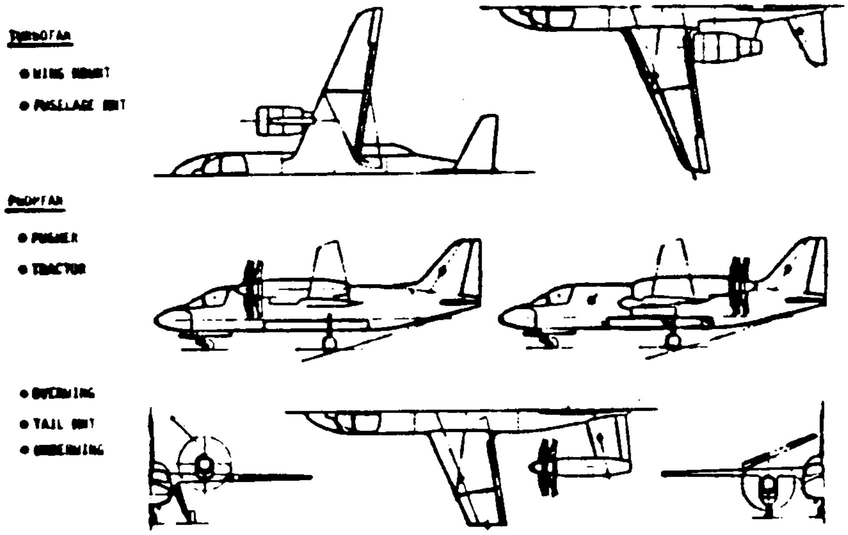
Canard

Several of the configuration options are shown in Figure 30.

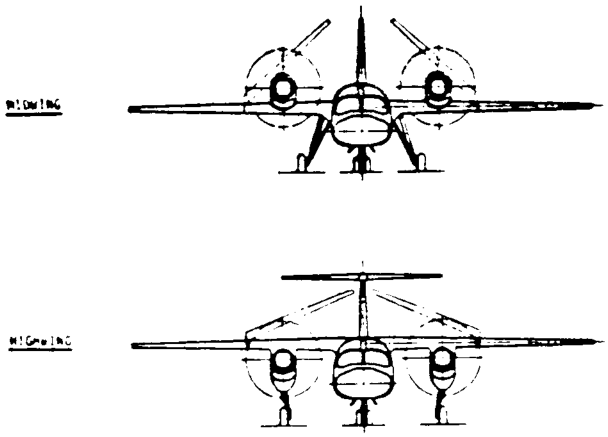
4.2.1.5 Configuration Evaluation

The evaluation of the various configurations was conducted subjectively, through the application of a series of simple criteria, relating to basic aircraft design practices, special problems of carrier suitability, store and sensor integration, propulsion integration, and acoustic factors. The various criteria were weighted according to relative importance, and each configuration was rated against each criterion. A total of 22 configurations were evaluated against 14 separate criteria. Configurations and criteria are listed in Table VII. The configurations which were selected as a result of that evaluation are shown in Figures 31 and 32.

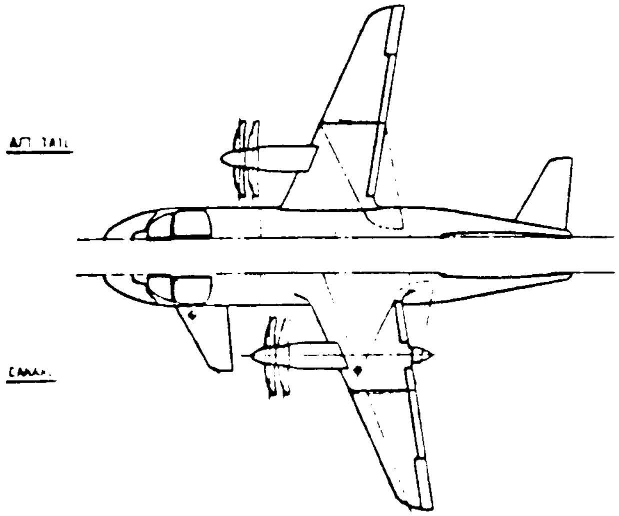
The turbofan concept is a conventional arrangement with wing pylon-mounted engines. Fuselage mounted engines offered some advantages



PROPULSION LOCATION



WING POSITION



EMPENNAGE LOCATION

Figure 30. Configuration Options

TABLE VII CONCEPTS AND SELECTION CRITERIA

- CONFIGURATIONS

TURBOFAN

AFT TAIL, MIDWING, CONVENTIONAL PYLON
AFT TAIL, MIDWING, FUSELAGE MOUNTED
AFT TAIL, HIGHWING, CONVENTIONAL PYLON
AFT TAIL, HIGHWING, FUSELAGE MOUNTED

PROPFAN-TRACTOR

AFT TAIL, MIDWING, UNDERWING NACELLE
AFT TAIL, MIDWING, OVERWING NACELLE
AFT TAIL, MIDWING, TAIL MOUNTED
AFT TAIL, HIGHWING, UNDERWING NACELLE
AFT TAIL, HIGHWING, OVERWING NACELLE
AFT TAIL, HIGHWING, TAIL MOUNTED
CANARD, MIDWING, UNDERWING NACELLE
CANARD, MIDWING, OVERWING NACELLE
CANARD, HIGHWING, UNDERWING NACELLE
CANARD, HIGHWING, OVERWING NACELLE

PROPFAN-PUSHER

AFT TAIL, MIDWING, UNDERWING NACELLE
AFT TAIL, MIDWING, OVERWING NACELLE
AFT TAIL, HIGHWING, UNDERWING NACELLE
AFT TAIL, HIGHWING, OVERWING NACELLE
CANARD, MIDWING, UNDERWING NACELLE
CANARD, MIDWING, OVERWING NACELLE
CANARD, HIGHWING, UNDERWING NACELLE
CANARD, HIGHWING, OVERWING NACELLE

- SELECTION CRITERIA

GENERAL AIRCRAFT DESIGN

- AERODYNAMIC EFFICIENCY
- STRUCTURAL EFFICIENCY
- BALANCE
- VISIBILITY
- MECHANICAL SIMPLICITY

CARRIER-BASED AIRCRAFT DESIGN

- CATAPULT/ARREST COMPATIBILITY
- SPOTTING
- WING STORES COMPATIBILITY
- BARRIER SUITABILITY

PROPULSION INTEGRATION

- INSTALLATION AERODYNAMIC EFFICIENCY
- INSTALLATION MECHANICAL EFFICIENCY
- ACOUSTICS
- ENGINE OUT CAPABILITY
- ENGINE ACCESSABILITY

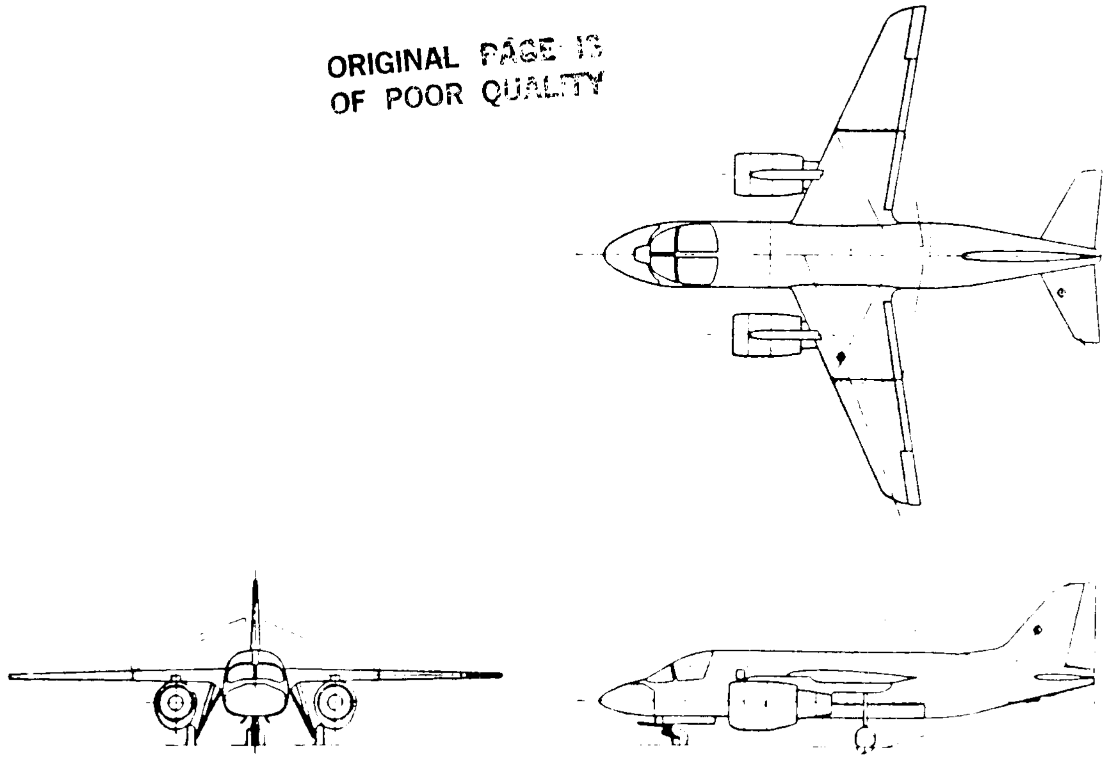


Figure 31. Selected Turbofan Concept

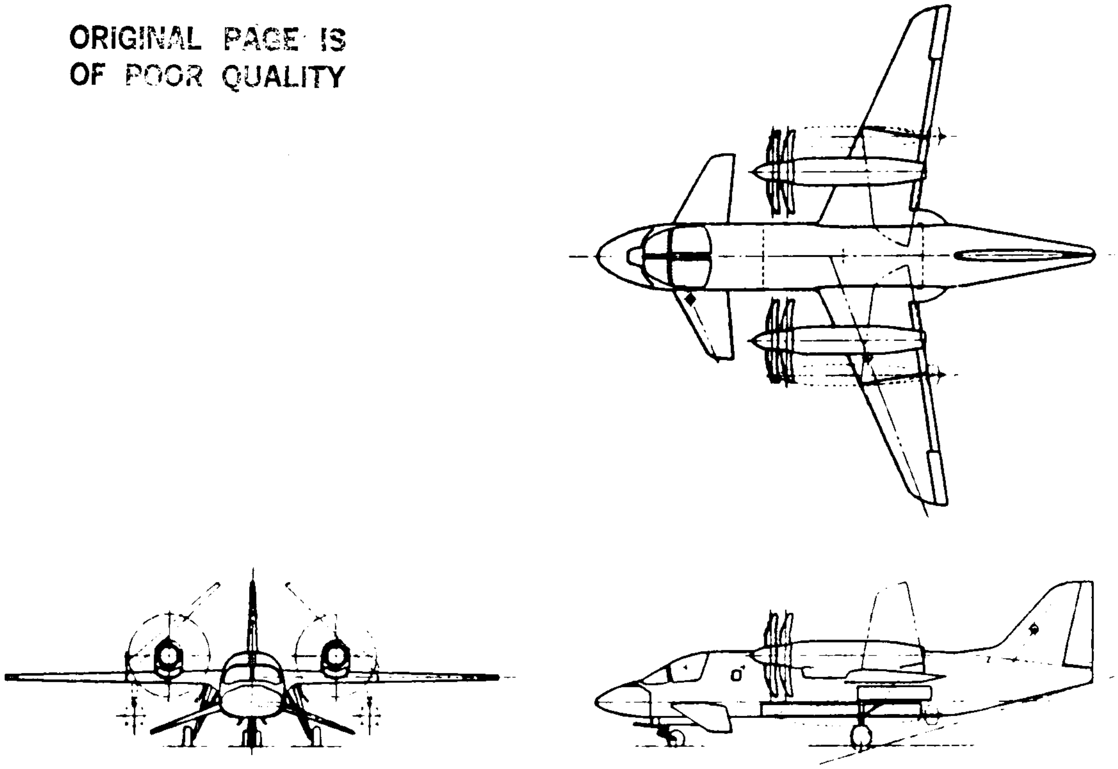


Figure 32. Selected Propfan Concept

from the standpoint of wing mounted store attachment and release. Fuselage mounting, however, presents aircraft balancing problems by offsetting the engine weight well aft of the aircraft center of gravity (cg). Normally the weight of aft mounted engines would be balanced by moving the fuselage forward with respect to the wing. This option is not available in this study because of the relationships between the fuselage contours, internal weapons bay located on the cg, and wing location with respect to the cg as dictated by stability and control requirements.

The selected propfan baseline, although unconventional in appearance, embodies many features which are highly desirable in a multipurpose, carrier based aircraft. Important features include spacing between the crew and propfans, which reduces acoustic treatment requirements and affords passive protection from blade failure. The folded layout is compact, requiring minimal use of carrier deck space (reduced "spotting" factor), stemming primarily from the placement of the propfan between the canard and wing (which yields secondary benefits of reduced deck handling hazard and propeller protection in the event of a barrier engagement). The tractor layout keeps the props well clear of the deck and arresting cables during recovery and permits the location of jettisonable free fall stores on pylons attached inboard of the wing fold. The large, unobstructed weapons bay is cleanly integrated directly below the wing box structure. A conventional arrangement with tractor engines would locate the plane(s) of the propfan well within the crew compartment area. A pusher installation would not accept wing store stations inboard of the wing fold - a desirable feature on this class of aircraft. Pusher engines mounted above the wing would result in a high thrust line which would introduce large trim changes with power change - an unacceptable feature for carrier suitable aircraft - or the wing would have to be mounted low on the fuselage and the carry through structure would interfere with the large weapons bay. Finally, the canard layout additionally permits the possible installation of swing tail for cargo (COD) variants. These features are summarized in Figure 33.

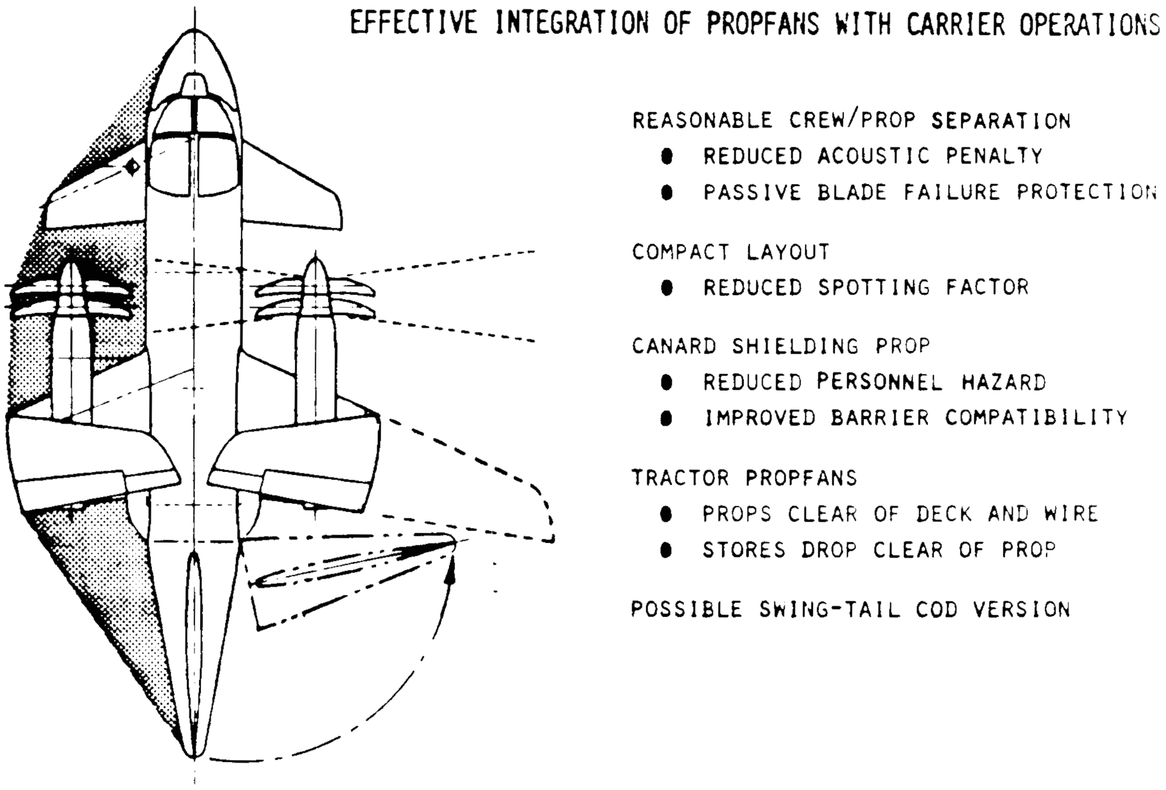


Figure 33. Advantages of Selected Propfan Configuration

4.2.2 Analysis

In order to obtain a quick estimate of required aircraft size, a representative configuration, similar to the baseline turbofan concept eventually selected, was sized for each of the ten missions defined in Task I. The parametric turbofan engines (STF 686) and corresponding turboshaft engines (STS 678) with 4x4 counter-rotating propfans (disk loading of 80 SHP/ft^2) were used during this analysis. This step revealed the following characteristics:

1. Representative propfan-powered aircraft were consistently lighter than turbofan-powered aircraft for any mission at corresponding wing loading and thrust-to-weight ratio.
2. The Armed AEW mission was critical (maximum TOGW).
3. 45,000 ft. loiter for the Armed AEW, AEW, and SC^3 missions could be achieved with propfan-powered aircraft at lighter gross weights than turbofan powered aircraft, even though the required sea level static thrust/weight ratio was greater for the propfan.
4. Carrier suitability constraints were not a factor when the powerplants were sized to achieve high altitude loiter.
5. Substantial high speed dash capability was a fallout of the high thrust-to-weight ratio necessary to maintain a 45,000 foot loiter altitude.

The conceptual design baseline selections and preliminary sizing established the following groundrules for Task III:

1. The Armed AEW mission would be used to establish optimum wing geometry and fuel volume. With a crew of five required for this and the AEW missions, the odd crew station would be achieved by installing a plug in the ASW fuselage.
2. The ASW mission equipment and crew would be used to establish basic fuselage configuration and volume.
3. All other tanker, COD, SC^3, AEW, and EW mission capability would be a fallout of sizing for the AAEW mission.
4. The single configuration optimization figure of merit would be minimum gross weight.

The choice of minimum gross weight as an optimization parameter, rather than minimum Life Cycle Cost (LCC), minimum block fuel, or some other figure of merit is borne out by the following considerations:

1. Minimum TOGW corresponds roughly to minimum physical size - an important consideration for carrier-based aircraft.
2. Although minimum fuel consumption is important, fuel cost for this class of military aircraft is a small percentage of operating cost.
3. Many factors which radically affect Life Cycle Cost - personnel costs, for example - must be assessed with more detailed analysis than would be possible in this conceptual design study.
4. Minimum TOGW would be roughly proportional to Life Cycle Cost, at least in a first-order analysis.

4.3 TASK III DETAILED CALCULATIONS AND OPTIMIZATION

During this task the baseline CTOL configurations, roughly sized in Task II, were optimized against mission and performance requirements. In addition, the sensitivities of TOGW, structural weight and fuel weight to several key propulsion and performance-related parameters were developed.

4.3.1 Wing Geometry

Wing geometry was optimized for minimum TOGW for the Armed AEW mission. Analysis showed that when sized for loiter altitudes of either 45,000 or 40,000 feet, minimum aircraft TOGW was achieved at design wing loadings (W/S) within a range between 80 and 100 lbs/ft^2, both for the turbofan and the propfan-powered baseline aircraft. Therefore, a design wing loading of 100 lbs/ft^2 was selected. The higher wing loading favors the high speed requirements of some of the other missions. Figure 34 shows the sensitivity of TOGW to wing aspect ratio. Boundaries for 40,000 foot and 45,000 foot loiter altitude are shown on these plots. As each of the points necessary to develop these plots was computed, using the Configuration Analysis Program, performance for each of the alternative nine missions (Section 4.1.2) was also computed using the appropriate equipment and payload, and the airframe which was sized for the AAEW mission. Performance boundaries related to those alternate missions are superimposed on Figure 34. The only alternate mission performance which influences wing geometry selection beyond that required for the AAEW mission is the high speed dash requirement of the Anti-Air Warfare (AAW) mission (.8 Mn at 20,000 feet) and, in the case of the propfan, AAW mission fuel. The latter boundary is not critical for the turbofan configuration. In other words, for certain combinations of aspect ratio and design T/W, the AAW mission is more critical for the propfan than the AAEW mission.

This is because for a given aspect ratio and design T/W, AAEW mission fuel required is significantly less for the propfan than for the turbofan. At the same time, the high speed dash of the AAW mission (1 hour at .8 Mn) requires a relatively higher propfan power setting (because of the propfan's greater thrust lapse with speed) and a relatively higher fuel burn than the turbofan.

Although the statistical structural weight prediction method used in the analysis shows that increasing aspect ratio continued to lower the required TOGW throughout the range investigated (up to AR = 11), concerns with the validity of the prediction at the highest values led to the decision to limit maximum value of aspect ratio to 9.0. Since the

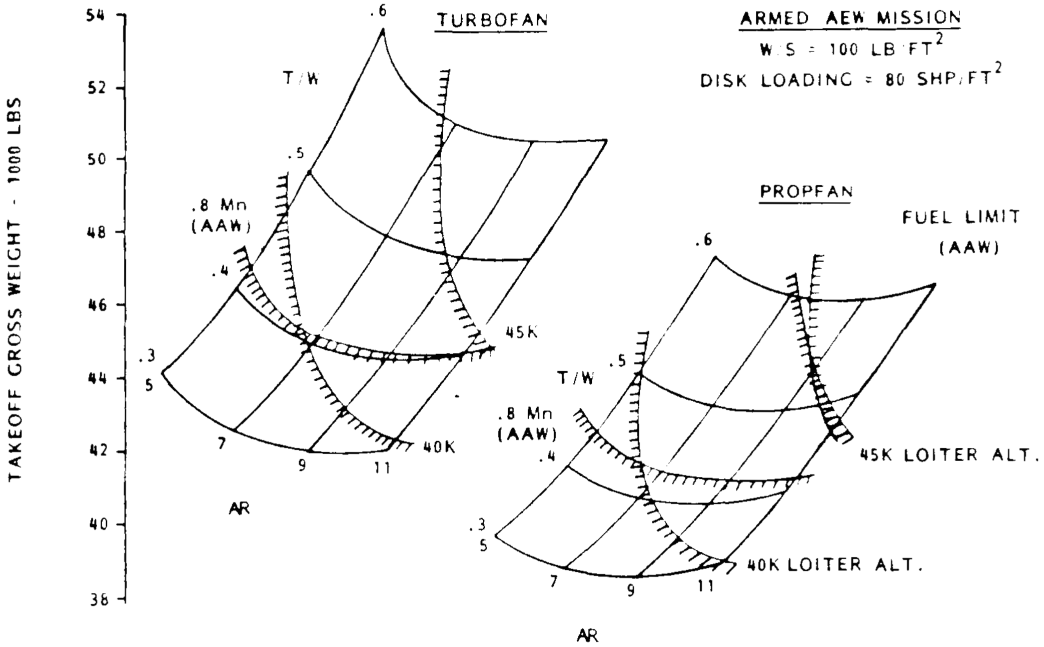
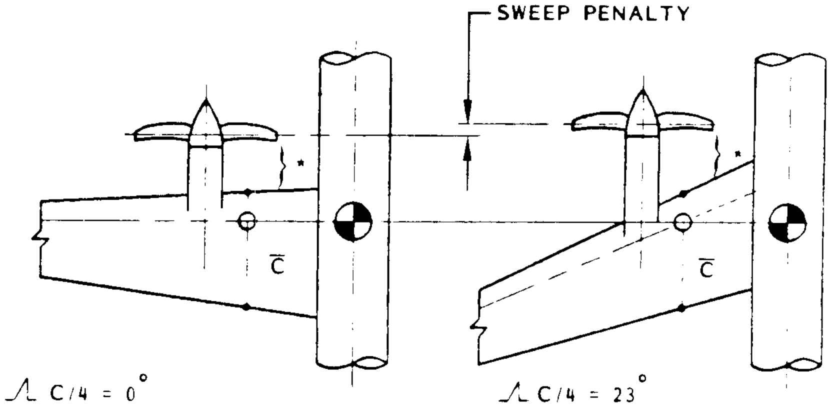


Figure 34. Variation of TOGW with Aspect Ratio and T/W

variation of TOGW with aspect ratio along the altitude boundaries is similar for both turbofan and propfan propulsion systems, this decision does not adversely influence the comparison of the two propulsion systems. The AAW fuel limit forced the Category 1 (45,000 ft loiter) propfan to an aspect ratio less than 9.0. An examination of Figure 34 indicates that the minimum TOGW for the Category 1 propfan configuration occurs at an aspect ratio of 8.5. An aspect ratio of 7.5 was selected to provide a "cushion" between the boundaries imposed by the 45,000 foot loiter altitude and the AAW fuel limit. Wing thickness ratio and taper ratio were not optimized but were selected based upon the results of previous studies.

Wing leading edge sweep of 25 degree was selected as the best compromise between subsonic high speed drag rise and propfan propeller/wing leading edge spacing. As illustrated by Figure 35, for a given wing mean aerodynamic chord (MAC) location relative to the aircraft cg, increased wing leading edge sweep will force the propfan forward to maintain leading edge clearance as specified by Hamilton Standard installation guidelines (Reference 8.) This increases the weight of the nacelle structure, and moves the propfan into the region of the crew compartment. Examination of higher sweep angle than 25 degrees for the turbofan configuration showed no significant advantage.



* = REQUIRED PROP TIP CLEARANCE

Figure 35. Propfan/Wing Leading Edge Relationship

4.3.2 Disk Loading

Figure 36 shows the sensitivity of TOGW to propfan sea level static disk loading, using the Category 1 wing geometry (AR = 7.5) and the 4x4 counter-rotating propfan configurations. The shape of the boundary curves is very similar for the Category 2 wing geometry (AR = 9.0). The high altitude loiter (45,000 ft) favors high disk loadings and in fact, TOGW continues to go down (albeit very slowly) at disk loadings above the maximum value examined of 90 SHP/ft^2. A slight bucket appears, near 80 SHP/ft^2 for the 40,000 ft loiter altitude.

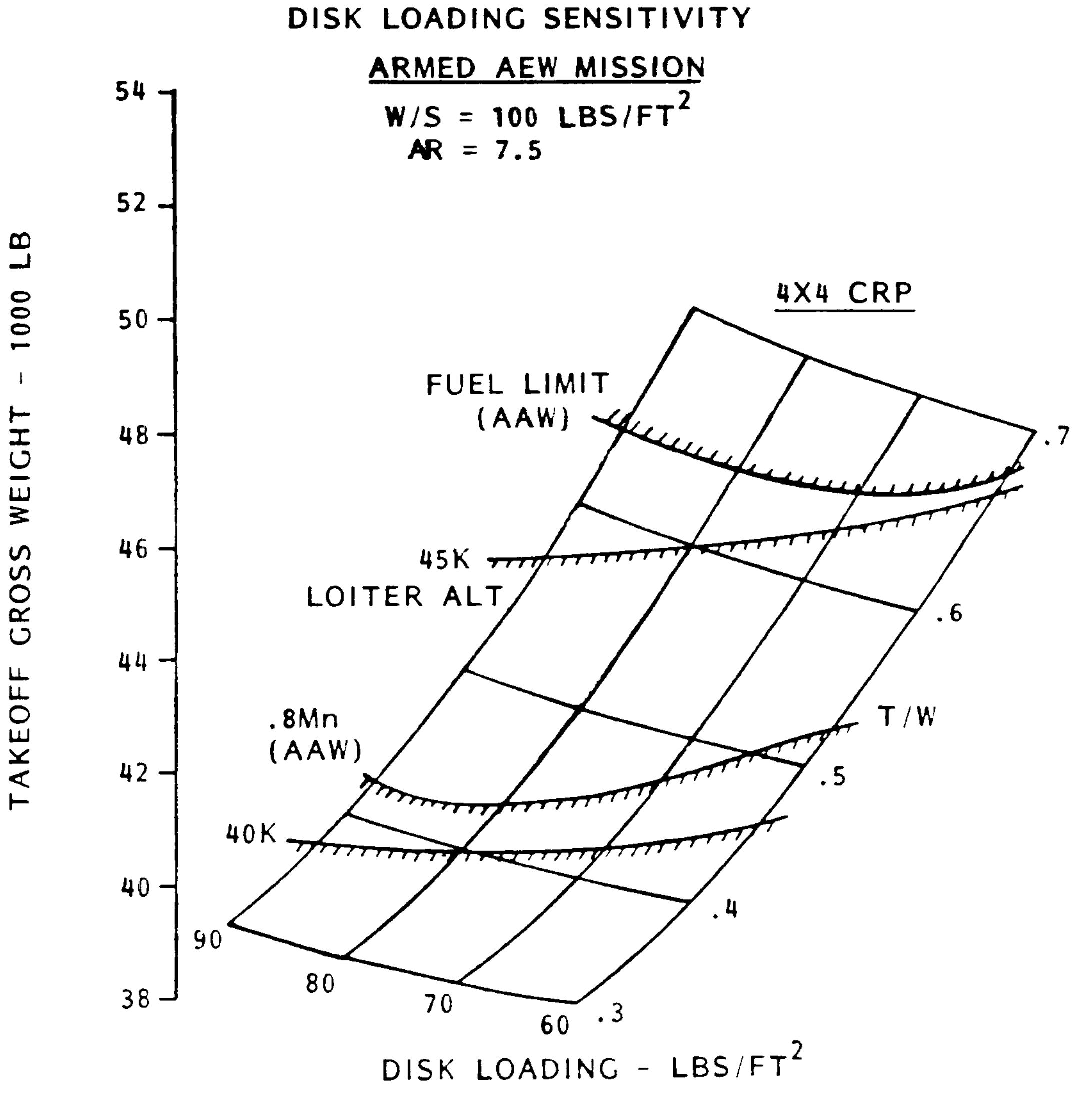


Figure 36. Variation of TOGW with Propfan Disk Loading and T/W

4.3.3 Baseline Design

On the basis of optimization procedures such as discussed in the preceding sections, baseline configurations were selected which would meet all of the performance goals established at minimum AAEW Takeoff Gross Weight. A summary of the selected parameters and relevant performance is shown in Figure 37.

The "optimized" baseline aircraft, in the ASW/EW configuration, are shown in Figures 38 through 41. The Category 1 propfan AAEW configuration (AEW radome and 3 foot fuselage plug) is shown in Figure 42. A breakdown of principal weight items is shown in Figure 43, and is presented in terms of percentages of TOGW in Figure 44.

The structure was designed by the AAEW mission, which has the highest TOGW, landing weight, and flight design gross weight, with a design load factor of 4.0. The ASW/EW version (Mk1) uses the identical airframe with a three foot fuselage plug removed (and the associated crew space) along with the radome and attaching structure. The incremental weight change due to radome, antenna, fuselage plug, and fin modification is 2000 lbs. The MK 1 aircraft have a higher load factor capability for the alternative missions because the required TOGWs and empty weights are significantly less than for the AAEW mission.

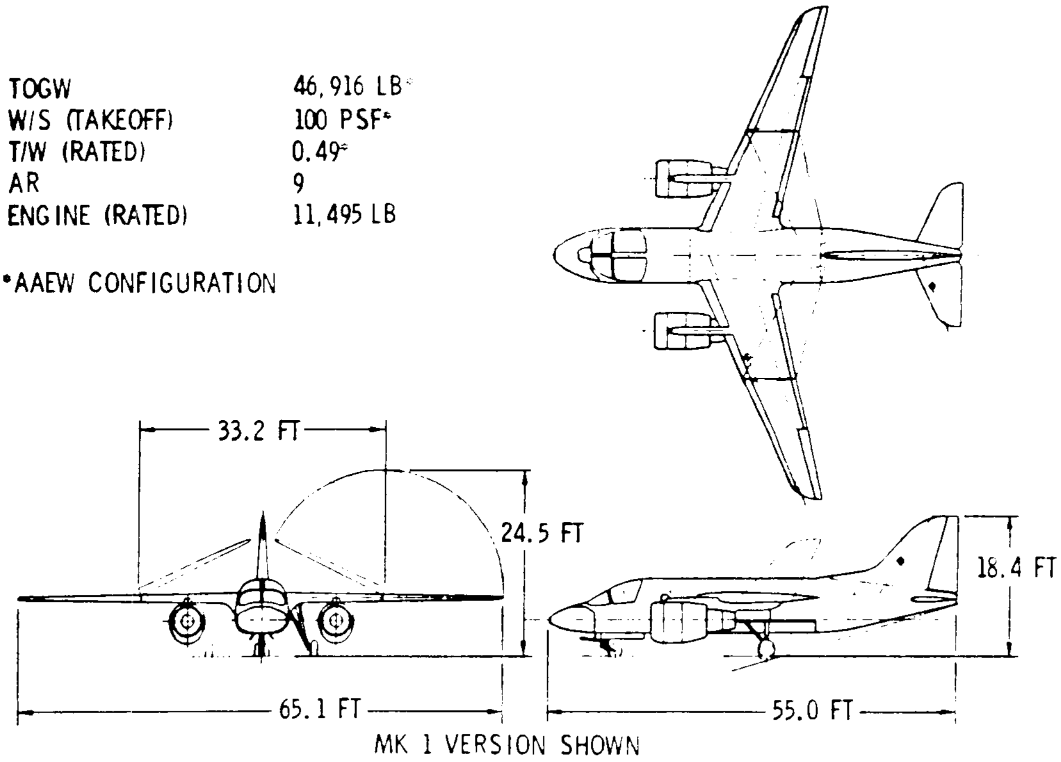
A first order analysis of operating and support (O&S) costs for each of the baseline aircraft revealed that fuel cost - the principal difference between turbofan and propfan O&S costs - was less than 5 percent of total operating cost, as shown in Figure 45. The other elements of the cost data - principally personnel and maintenance - were projected based upon current Navy program factors for similar classes of aircraft. Only with a more in-depth analysis of maintenance requirements, spares and other support can a true assessment of difference in O&S costs be made. This sort of analysis was beyond the scope of this study.

Figure 46 shows the range of TOGW and empty weights for the baseline turbofan and propfan Category 1 and 2 aircraft equipped for the other nine selected missions.

For the AEW and SC^3 mission, this includes the Mk 2 fuselage and AEW radome of the AAEW mission. For all other missions the Mk 1 fuselage is

	PERFORMANCE CATEGORY			
	1		2	
	TURBOFAN	PROPFAN	TURBOFAN	PROPFAN
TOGW (AAEW) - LBS.	46916	45994	44315	40827
T/W (UNINST.)	.49	.57	.41	.42
ENGINE SCALE	.60	.77	.47	.47
DISK LOADING - SHP/FT^2	-	90	-	80
WING LOADING - LBS/FT^2	100	100	100	100
ASPECT RATIO	9.0	7.5	9.0	9.0
LOITER ALTITUDE (AAEW) - FT.	45000	45000	40000	40000
LOITER SPEED (AAEW) - KTS.	351	357	309	308
DASH MACH (AAW)	.80	.80	.79	.75
CRUISE SPEED (ASW) - KTS.	430	422	428	367
RUN-IN SPEED (ASUW) - KTS.	450	450	438	431
COMBAT SPEED (MIW) - KTS.	466	489	437	430

Figure 37. Baseline CTOL Performance Parameters



TOGW	46,916 LB*
W/S (TAKEOFF)	100 PSF*
T/W (RATED)	0.49*
AR	9
ENGINE (RATED)	11,495 LB

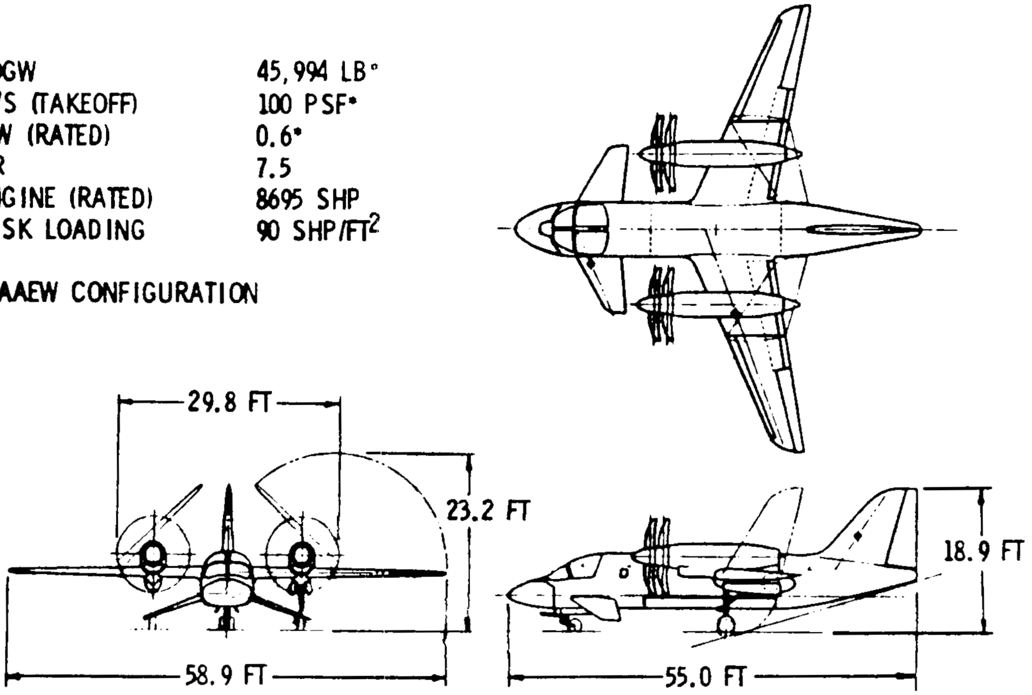
*AAEW CONFIGURATION

MK 1 VERSION SHOWN

Figure 38. Category 1 Turbofan Baseline

TOGW	45,994 LB*
W/S (TAKEOFF)	100 PSF*
T/W (RATED)	0.6*
AR	7.5
ENGINE (RATED)	8695 SHP
DISK LOADING	90 SHP/FT^2

* AAEW CONFIGURATION

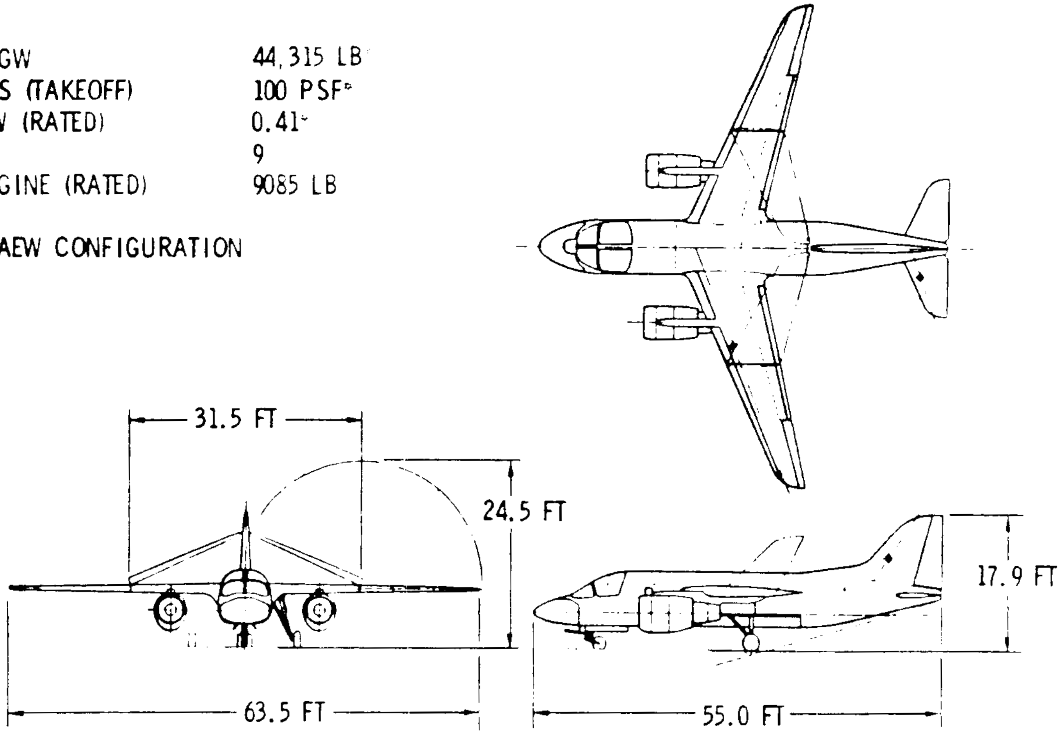


MK 1 VERSION SHOWN

Figure 39. Category 1 Propfan Baseline

TOGW	44,315 LB*
W/S (TAKEOFF)	100 PSF*
T/W (RATED)	0.41*
AR	9
ENGINE (RATED)	9085 LB

*AAEW CONFIGURATION



MK 1 VERSION SHOWN

Figure 40. Category 2 Turbofan Baseline

TOGW	40,827 LB*
W/S (TAKEOFF)	100 PSF*
T/W (RATED)	0.42*
AR	9
ENGINE (RATED)	5040 SHP
DISK LOADING	80 SHP/FT^2

*AAEW CONFIGURATION

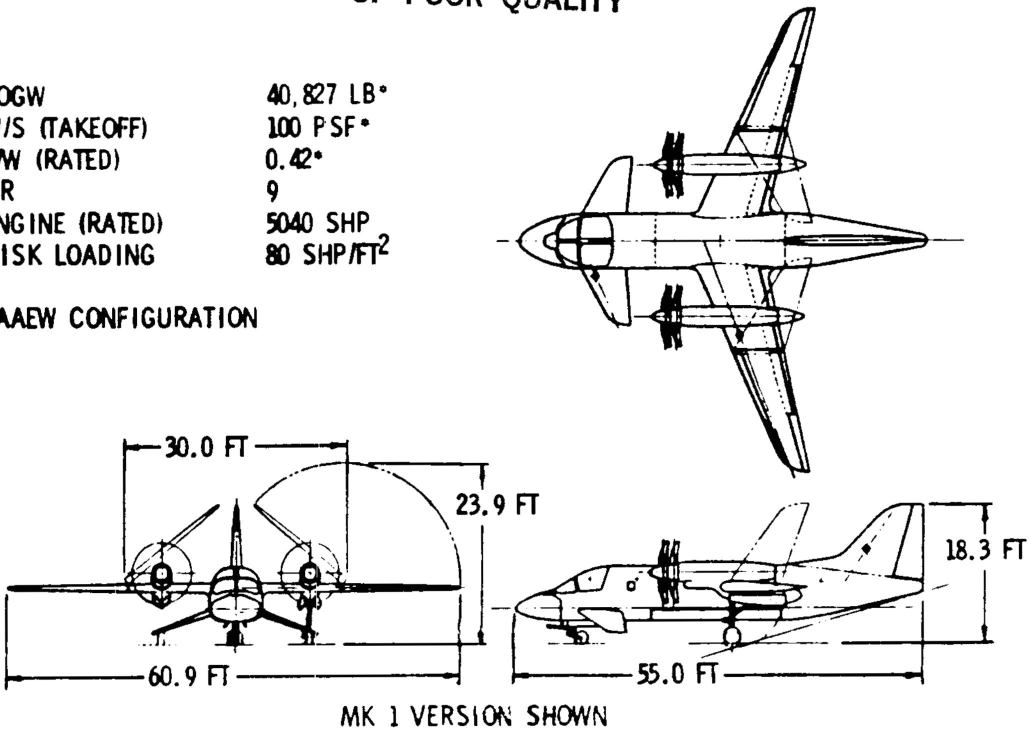


Figure 41. Category 2 Propfan Baseline

CATEGORY 1 PROPFAN SHOWN

- USES MARK 2 FUSELAGE
- RADOME TRIMMABLE

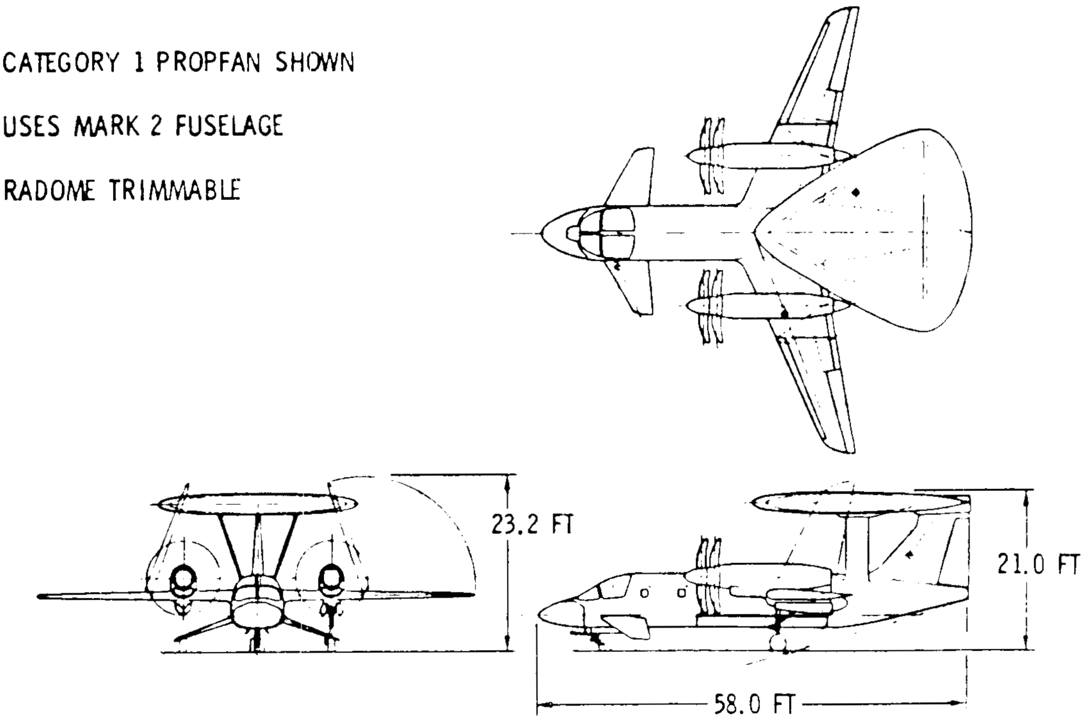


Figure 42. Baseline Propfan AAEW Configuration

	TURBOFAN 1	PROPFAN 1	TURBOFAN 2	PROPFAN 2
● STRUCTURE GROUP	15255	15521	14559	14497
● PROPULSION GROUP	5948	6836	4956	4738
ENGINES	4841	3107	3976	2338
GEARBOXES	0	954	0	512
PROPELLERS	0	1412	0	856
● FIXED EQUIPMENT	10432	10434	10422	10415
AVIONICS - CORE	1785	1785	1785	1785
AVIONICS - MISSION	5048	5048	5048	5048
● EMPTY WEIGHT	31635	32791	29937	29650
CREW AND EQUIPMENT	1170	1170	1170	1170
TRAPPED FUEL	127	105	118	84
PYLONS AND RACKS	214	214	214	214
● OPERATING WEIGHT	33146	34280	31439	31118
CHAFF AND FLARES	54	54	54	54
MISSILES (6)	1800	1800	1800	1800
USEABLE FUEL	11916	9860	11022	7855
● TAKEOFF GROSS WEIGHT	46916	45994	44315	40827

ALL WEIGHTS IN LBS.

Figure 43. Baseline CTOL Group Weights - AAEW Mission

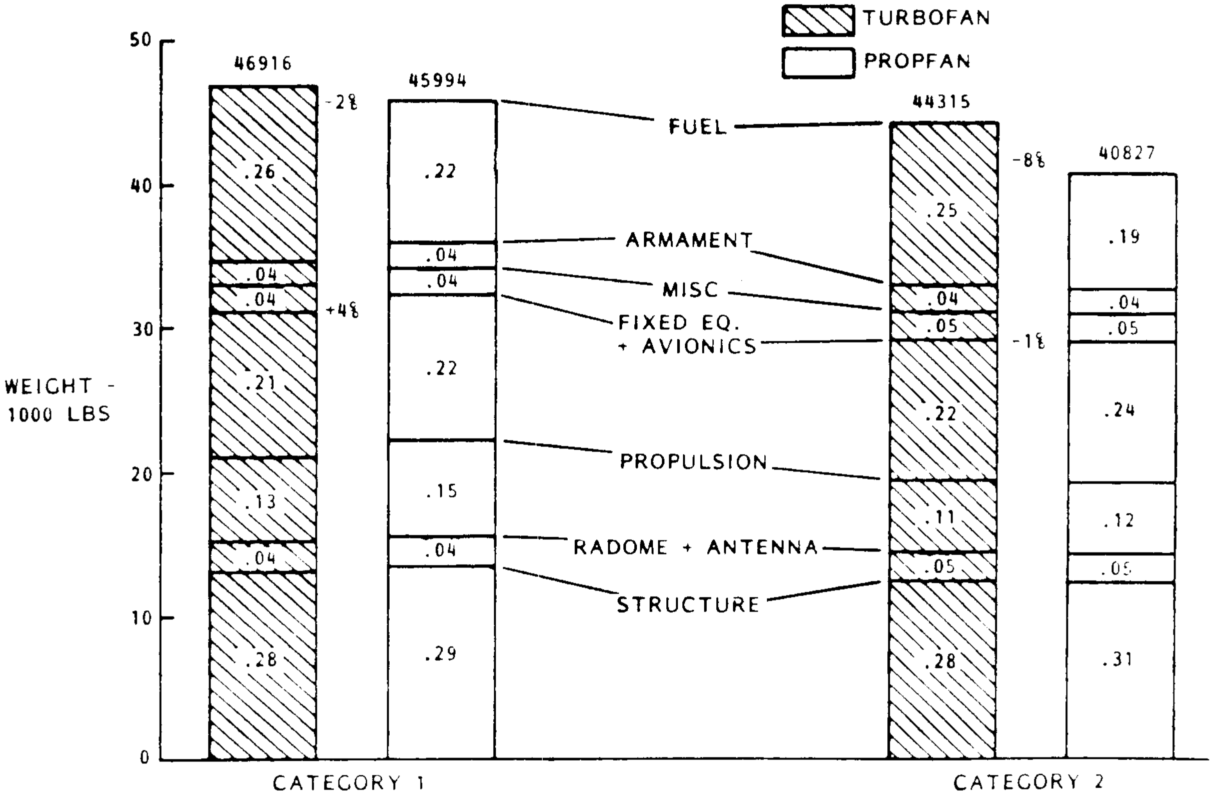


Figure 44. Baseline Weight Comparison - CTOL

- CATEGORY 1 SIZING
- PROPFAN
- ASW VERSION
- 250 AIRCRAFT
- 600 FH/YEAR
- 1985 DOLLARS

COST ELEMENT	COST/FORCE - $M	$M/AC/YR	$/AC/FH
AVIATION FUEL	27.36	.109	182.48
OTHER DIRECT O&M	233.39	.934	1555.94
DIRECT MANPOWER	194.77	.779	1298.48
INDIRECT O&S	91.31	.365	608.23
INDIRECT MANPOWER	48.84	.195	325.57
TOTAL OPERATING COST	595.67	2.383	3971.14

FUEL IS LESS THAN 5% OF OPERATING COST

Figure 45. Typical ROM Operating and Support Costs

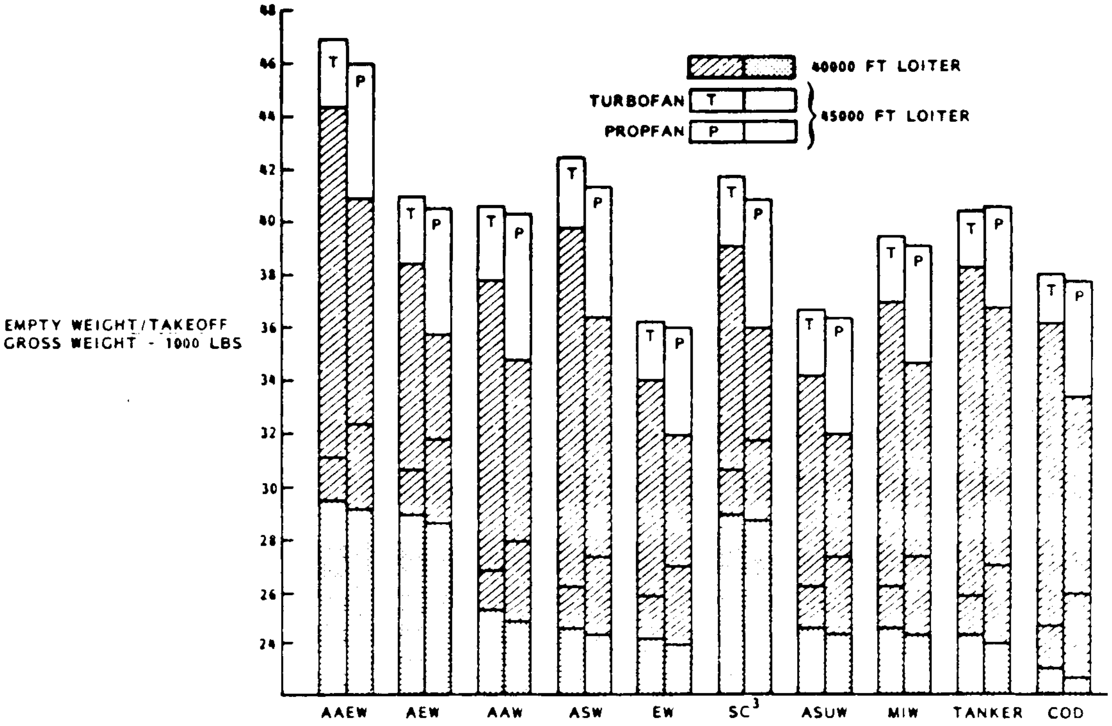


Figure 46. TOGW and Empty Weight for Alternate Missions

used. In each case, appropriate mission avionics and payload is added to the baseline airframe.

It is apparent from examination of this figure and the preceeding weight breakdowns that the relative advantages of the propfan over the turbofan in terms of TOGW, fuel fraction, and empty weight increases significantly as the performance constraints are reduced from Category 1 to Category 2 levels.

4.3.4 Sensitivity of Sizing Mission

To determine the severity of the Armed AEW mission requirements and whether the emphasis in this mission on high altitude and long mission time might adversely affect the choice between propfan and turbofan propulsion, the baseline aircraft were resized for the Anti-Submarine Warfare mission. This mission places a premium on efficient cruise and mid-to-low altitude loiter. Wing geometry was not reoptimized (constant AR, wing loading), but thrust-to-weight ratio was established by carrier suitability, specifically the landing waveoff requirement.

The resizing results in aircraft which are about 22 percent lighter than those sized for Category 2 Armed AEW, but the ratio of propfan TOGW to turbofan TOGW remains nearly constant at 0.92, as shown in Figure 47.

The higher structural weight fraction of the AAEW aircraft shown in this figure is because the weight of the fuselage extension, radome, and radar antenna are included as part of the structure.

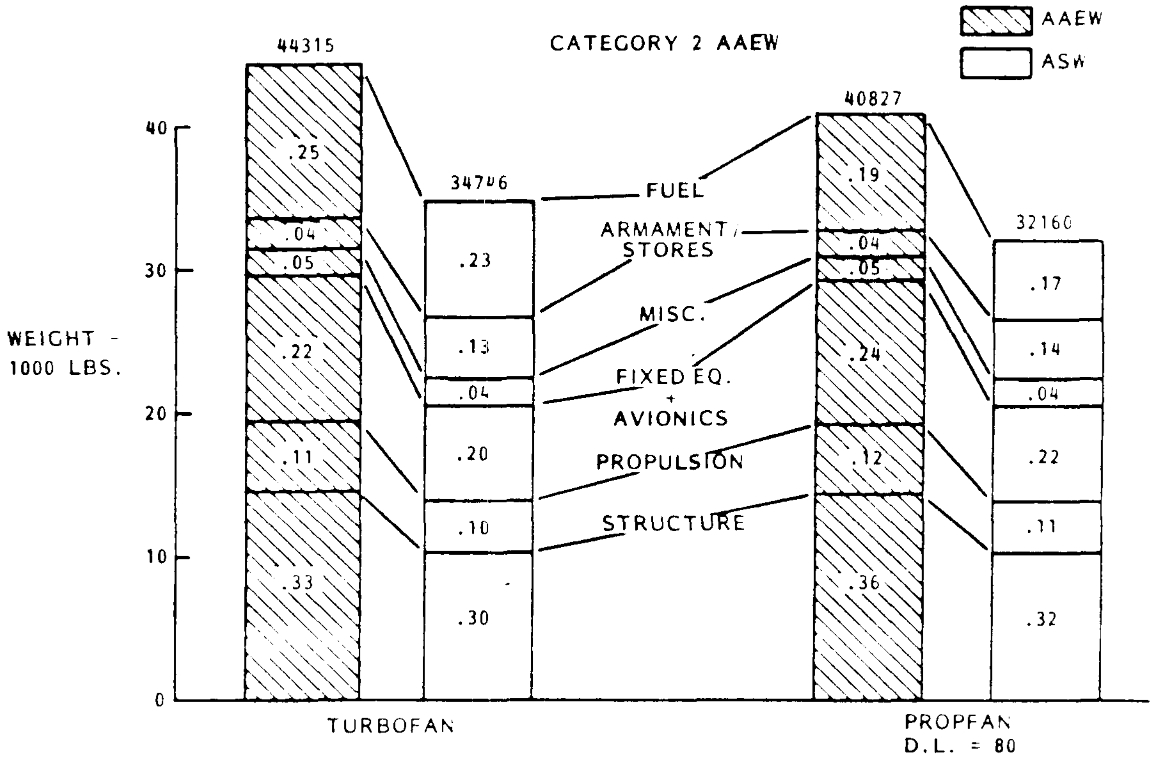


Figure 47. Comparison of AAEW Weight vs ASW Weight

By comparing the TOGWs of this figure with those of the Category 2 mission of Figure 46 (airframe sized for AAEW) it can be seen that a TOGW "penalty" of about 13 percent is associated with using an airframe sized for the AAEW mission to perform the ASW mission.

4.3.5 Choice of Tractor vs Pusher Propfan

The results of the conceptual design process, and in particular the selection of a tractor propfan configuration over a pusher arrangement, may seem contrary to current propfan design trends. However, this choice is borne out by consideration of all Navy mission requirements, in conjunction with some specific design restrictions. The upper illustration of Figure 48 depicts the selected propfan arrangement, configured for the armed AEW mission with the Mk 2 fuselage, radome and optional external fuel tanks attached to pylons located just inboard of the wing fold. The most significant potential problem with this arrangement is the relatively close proximity of the propfans to the crew compartment, which aggravates noise and vibration problems. If a pusher arrangement is attempted in order to separate the propfan from the crew, other more severe problems are created. A major problem, illustrated in the lower view, is aircraft balance. In the tractor arrangement, the propulsion-group weight (propfan, nacelle, gearbox, core engine, etc.) is evenly distributed about the aircraft center of gravity (cg). In the pusher arrangement, however, propulsion weight is aft of the cg. A standard design practice to correct for the aft location of the propulsion weight is to shift the fuselage group forward to balance. As noted during the discussion on the development of the fuselage envelope, shifting the fuselage also moves the weapons bay away from its central position on the aircraft cg. Unacceptable trim changes would occur when heavy payloads, such as tanker fuel or large weapons, are deployed. Other problems with the pusher configuration include wing stores separation clearance, sonic fatigue on the light-weight radome structure (which cannot move forward without interfering with crew ejection), propfan blade clearance relative to carrier deck and arresting wire, increased spotting factor, and greater exposure of the flight deck crew to the propellers.

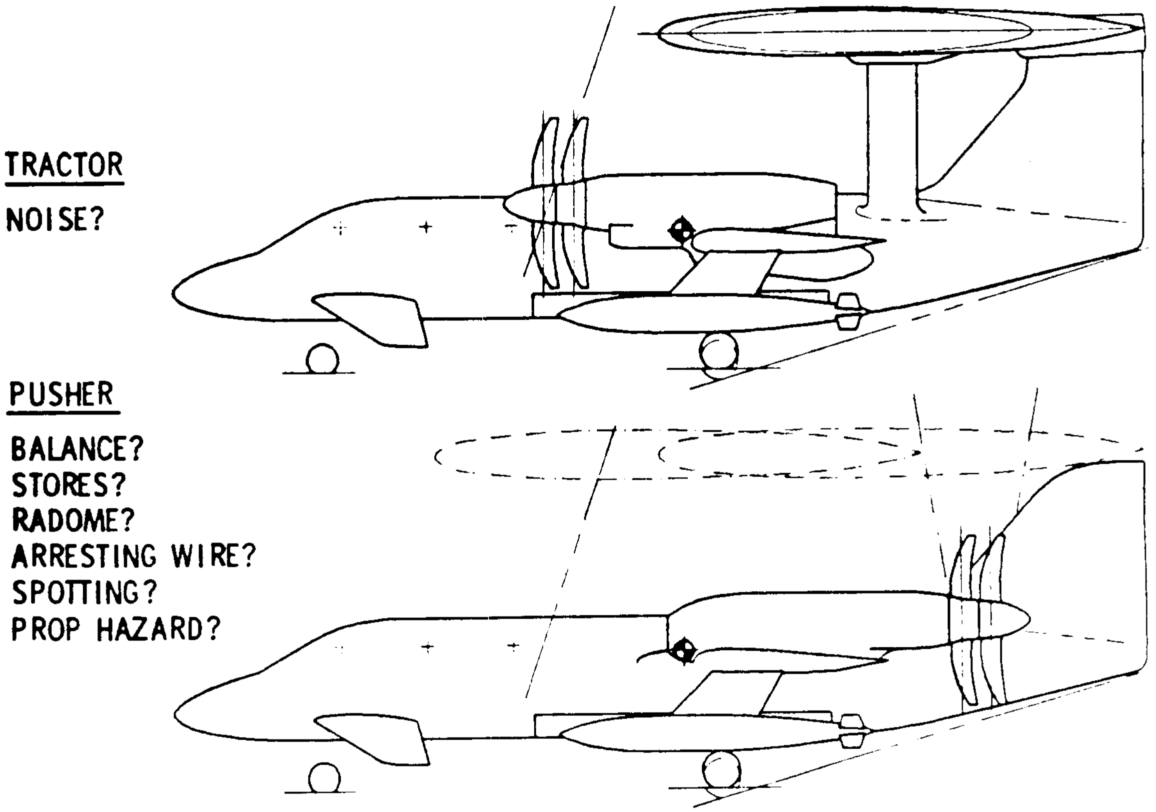
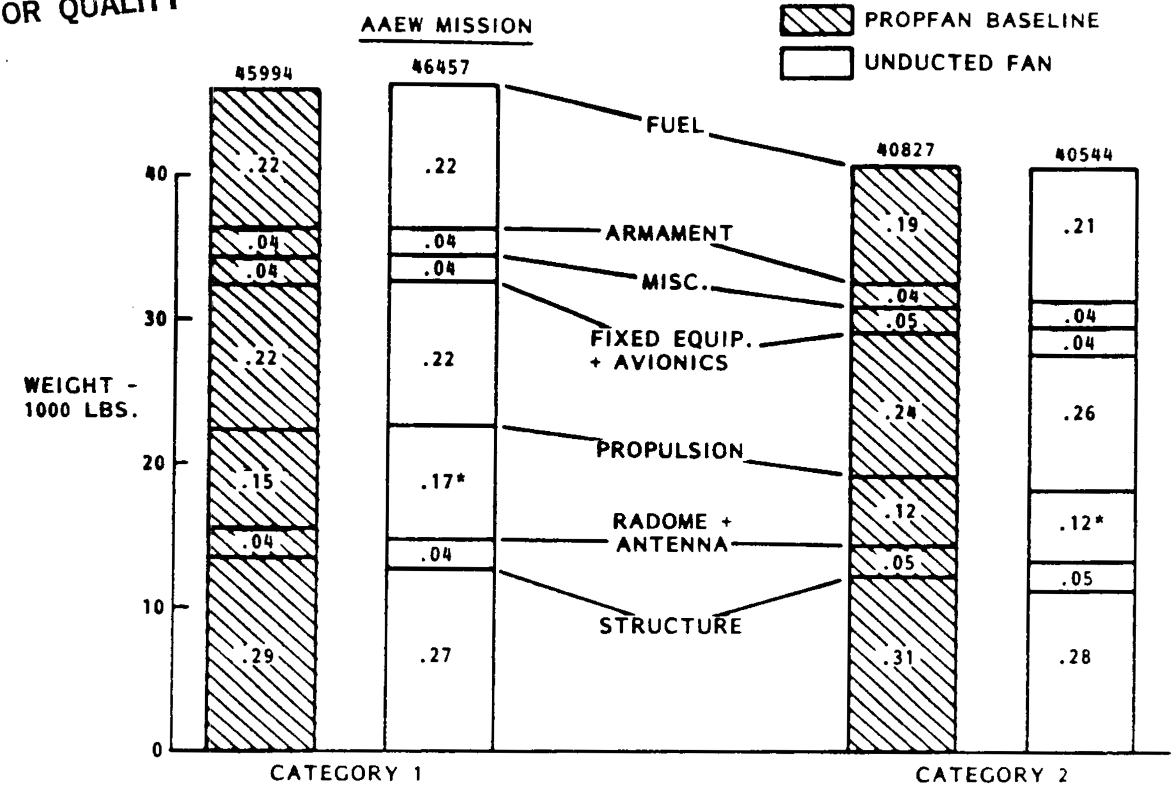


Figure 48. Comparison of Tractor To Pusher Propfan Arrangements

4.3.6 Alternative Propulsion Concepts

A preliminary comparison was made between the propfan baseline concepts and a similar configuration, adapted to a scaled version of the GE36 Unducted Fan (UDF). Although no layout was developed, it was assumed that the UDF engines would be wing mounted in a pusher configuration. The results of that sizing exercise are shown in Figure 49. The figure shows that the UDF-powered aircraft are virtually identical in size to the propfan versions, and a choice between the two propulsion concepts would have to be made on the basis of other factors (see preceding section). The UDF data are scaled far below the size of the GE36 engine and the sized powerplants are much closer to the GE38 UDF. Data for the GE38 powerplant were unavailable in the proper format for this study, but a spot check of the scaled GE36 data at selected points in the Armed AEW mission flight profile shows the GE38 SFCs to be about 5 percent higher than scaled GE36 values at corresponding flight conditions.



* INCLUDES PORTION OF NACELLE WEIGHT

Figure 49. Comparison of Propfan To Unducted Fan

4.3.7 Sensitivities

A number of sensitivity excursions were conducted for performance and technology parameters to determine their impact on mission weights.

4.3.7.1 Effect of Loiter Altitude

Figure 50 depicts the effect of design AAEW loiter altitude on aircraft size. Wing loading and aspect ratio are not reoptimized. Along the upper portion of the curves, the loiter altitude requirement establishes engine size, while along the lower (nearly vertical) portion, landing single-engine waveoff rate of climb (500 fpm) is critical and sizes the engines. As shown on the left-hand figure, propfan aircraft empty weight exceeds turbofan aircraft empty weight above 41,500 ft loiter altitude, while the middle chart shows that propfan TOGW exceeds the turbofan weight above 45,500 feet. The greater lapse rate of thrust with altitude of the propfan compared to the turbofan is reflected in the right-hand figure by the increasing divergence of the required static thrust-to-weight curves.

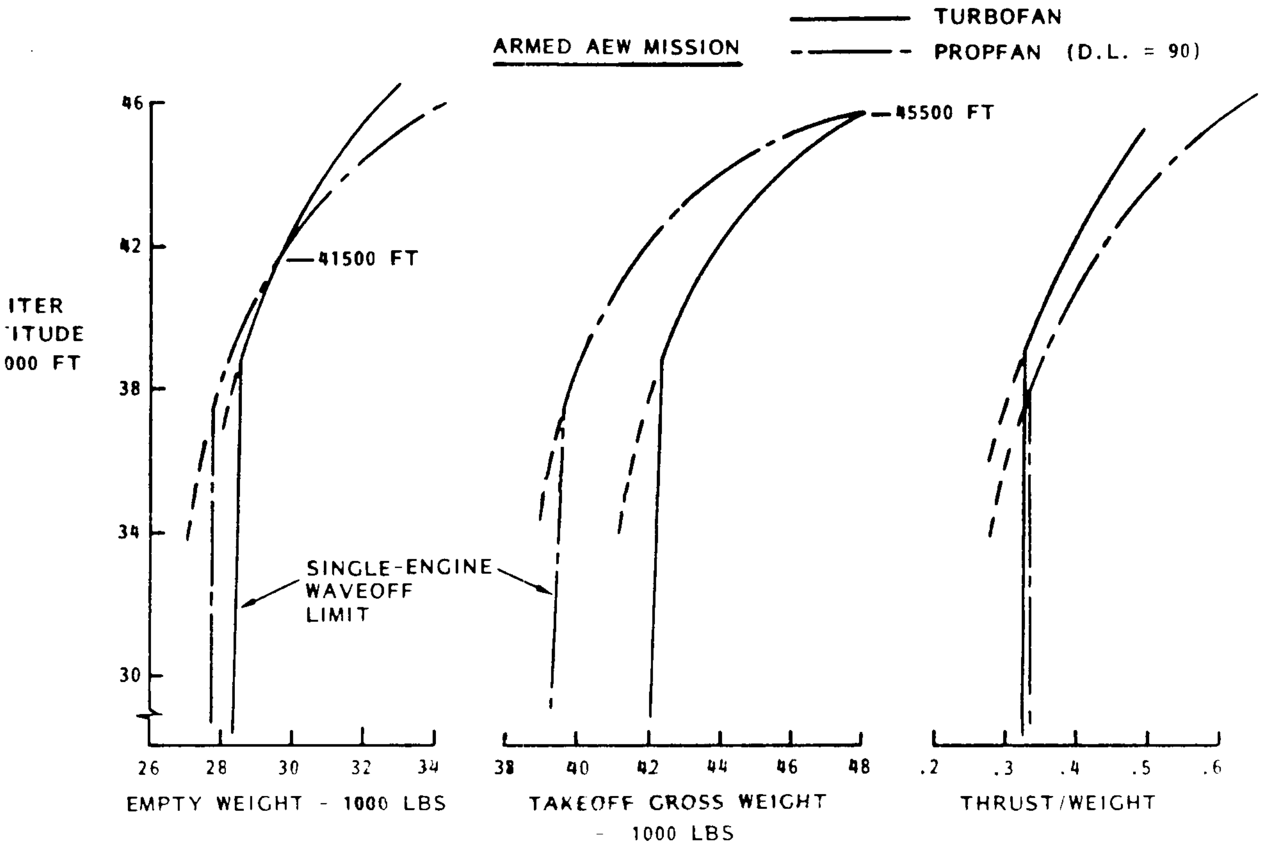


Figure 50. Effect of Loiter Altitude on TOGW and Empty Weight

4.3.7.2 Effect of Soundproofing

Both the turbofan and the propfan baseline aircraft assume a nominal level of cabin soundproofing in the weight estimation procedure. This weight is implicit in the statistical base that defines fuselage structure and furnishings weights. The effects of additional propfan soundproofing material, in terms of pounds of soundproofing treatment per square foot of cabin surface area, are shown in Figure 51. These curves assume that the soundproofing "treatment" is applied uniformly over the entire cabin surface area, exclusive of transparencies (302 ft^2). The horizontal boundary lines shown on the figure are the associated values for the baseline turbofan aircraft. While the propfan aircraft would always maintain an advantage in fuel weight for any reasonable amount of additional soundproofing treatment, Category 2 propfan aircraft empty weight will quickly exceed turbofan empty weight, as will Category 1 propfan Takeoff Gross Weight. Thus, many of the advantages of propfans in terms of weight savings could be lost if soundproofing is shown to be a major problem.

Prediction of cabin sound pressure level and design of soundproofing treatment were beyond the scope of this study.

A variety of isolation and soundproofing techniques are currently being developed by several airframe manufacturers, in parallel with the development of advanced propeller technology, and may make the penalties associated with propeller noise and vibration elimination relatively small.

4.3.7.3 Single-Rotation vs Counter-Rotation Propfans

Single-rotation propfans were compared to counter-rotation propfans for the design Armed AEW mission as shown in Figure 52. The increased weight of the SRP gearbox and propeller, plus the slightly reduced cruise efficiency due to swirl losses, compared to the counter-rotating propfan are reflected in the 6 to 10 percent increase in mission gross weight. SRP

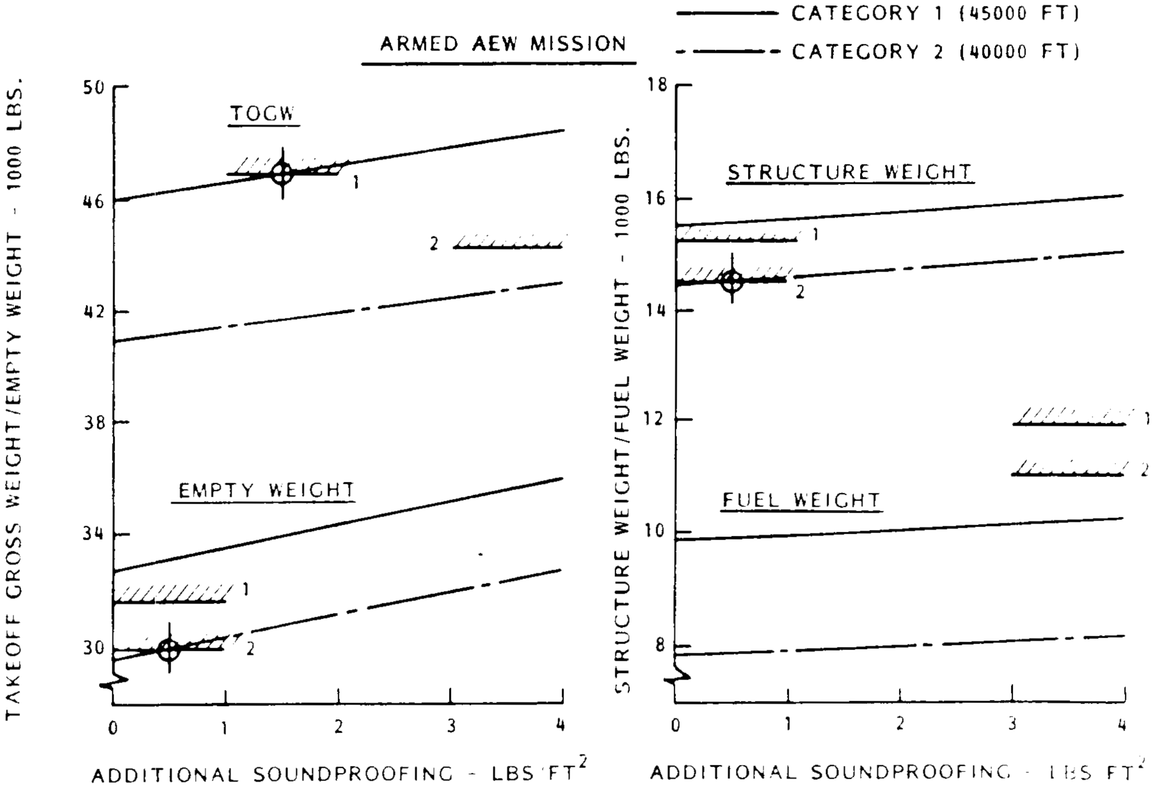


Figure 51. Effect of Additional Soundproofing on Propfan Weights

data were unavailable for disk loadings (SLS) above 80 SHP/ft^2 and so the Category 1 weights for SRP are slightly pessimistic (the Category 1 CRP disk loading is 90 SHP/ft^2). Category 2 disk loadings are directly comparable (both 80 SHP/ft^2).

4.3.7.4 Effects of Propfan Blade Technology

Improvements in the design of propfans by the early 1990s may lead to reduced blade weight due to advanced airfoil shapes which will allow equivalent propeller performance with reduced blade area and due to improved materials and designs for blade spars. The effect of the estimated propfan weight savings on aircraft weight parameters is shown in Figure 53. The weights are based upon equations supplied by Hamilton Standard Company.

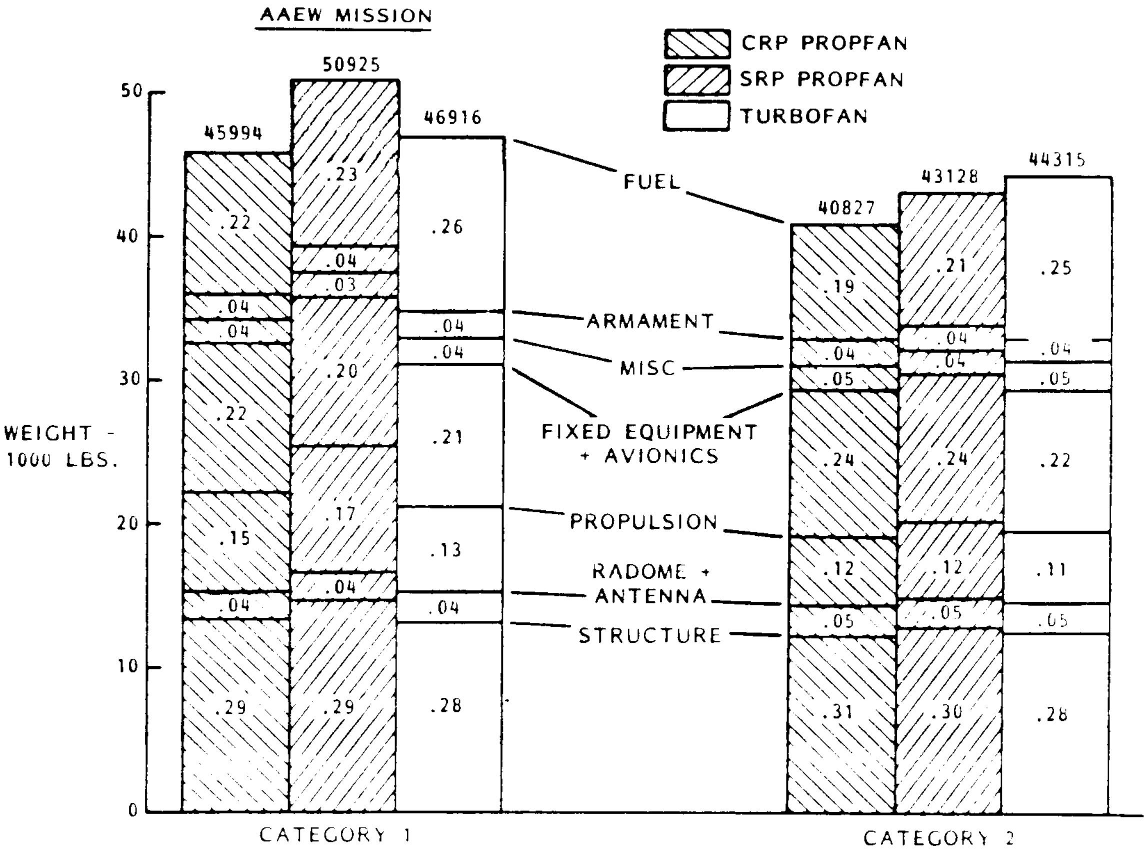


Figure 52. Comparison of CRP To SRP Propfans

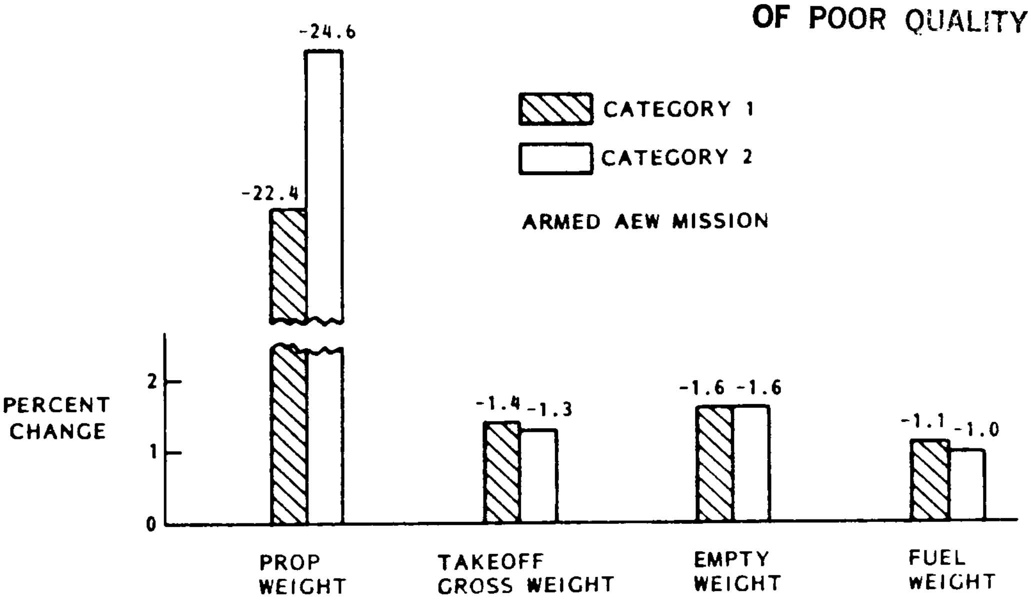


Figure 53. Effect of Propfan Far Term Blade Technology on Weight

4.3.7.5 Effect of Propulsion SFC Change

Specific fuel consumption (SFC) levels used in this study are based upon Pratt and Whitney projections for "most likely" values, or those values which are achievable with slight technical risk. The effect of changes in these basic values on various weight items is shown in Figure 54.

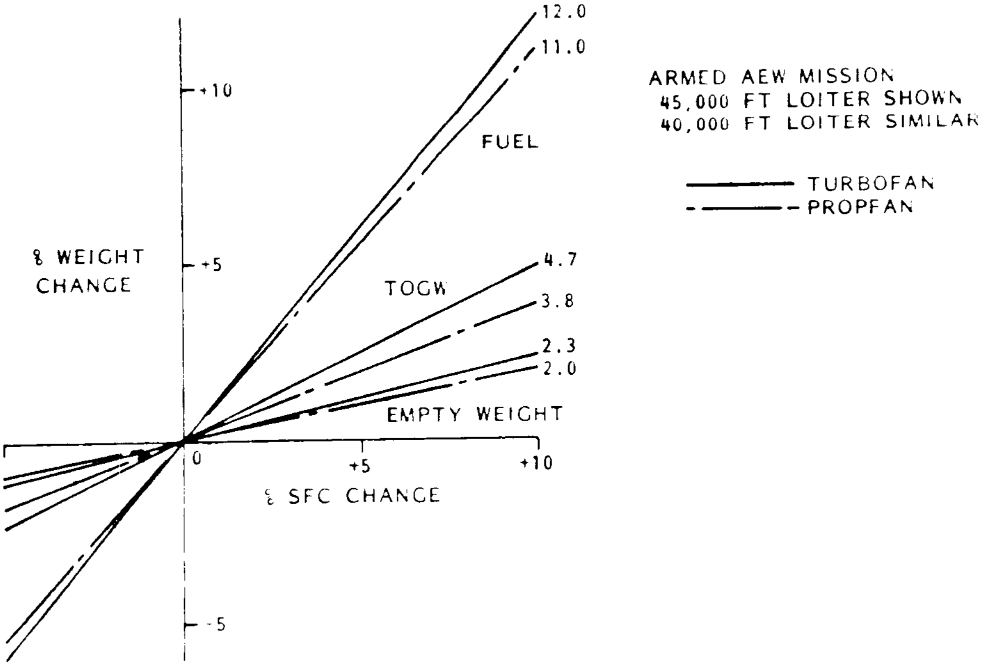


Figure 54. Effect of SFC Change on Weight

4.3.8 Tanker Derivative

Both the tanker and the Carrier Onboard Delivery (COD) missions require changes to the aircraft beyond the simple replacement of payload items. In the case of the tanker version, the approach used in this study was to make a minor modification to the Mk 1 fuselage, consisting of the removal of the weapons bay doors and the installation of a tanker module (tanks, reel, hose, and drogue) installed in the weapons bay and attached to door hinge points, weapons hardpoints, and appropriate plumbing and electrical connectors. The resulting concept, shown in Figure 55, accommodates over 13,000 lbs of additional fuel and would not require a dedicated tanker on board the carrier. This module could be installed on the carrier hangar deck or on the flight deck after the weapons bay doors are removed.

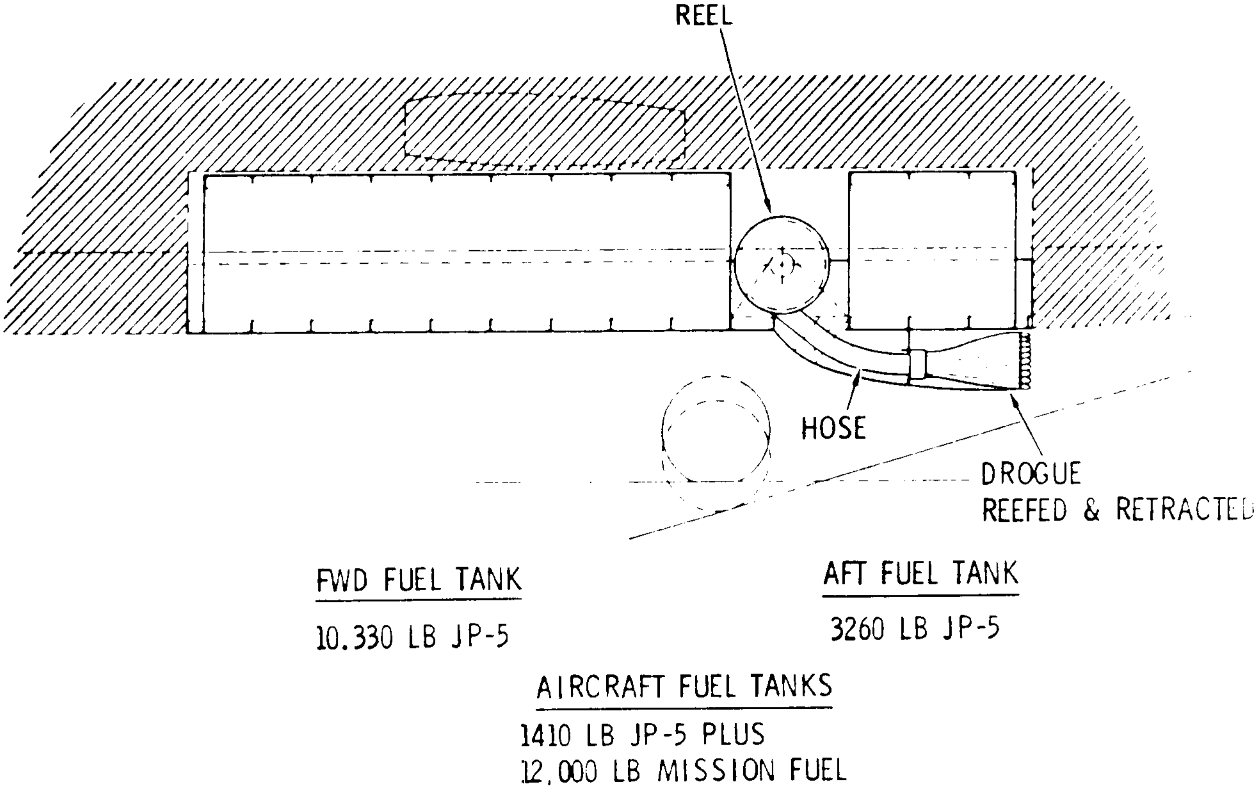


Figure 55. Tanker Module (Weapons Bay Installation)

4.3.9 COD Derivative

A number of options are available to perform some form of Carrier Onboard Delivery (COD) mission at varying levels of cost or complexity. Approximately 353 cubic feet of cargo volume is available in the existing weapons bay. This capability is essentially available at no cost other than the cost of cargo containers or harnesses to exploit the weapon suspension hardpoints. The next lowest cost alternative to increase COD capability is to remove and replace the weapons bay doors with a cargo fairing shell. The fairing could add an additional 2.1 feet of depth to the weapons bay. This alternative is illustrated in Figure 56. More cargo volume can be obtained by designing a new fuselage. Two approaches to new fuselage design can be distinguished. The lowest cost approach is to maintain the original fuselage outer contours. This method maximizes the amount of structure common to the standard fuselage. This allows retention of the forward fuselage, including the flight station, radome, canard, and canard carry through structure, as well as the empennage and afterbody, which would be reconfigured as a swing tail. To fully use the available fuselage volume, the wing would be moved to atop the fuselage. However, most of the wing and primary nacelle structure would be unchanged. A higher cost alternative would be to abandon the original fuselage contours in favor of new lines designed to a specific set of operational requirements such as the accommodation of standard cargo pallets.

The variation of COD payload with range (using the unmodified Mk 1 fuselage) is shown in Figure 57. Curves for the Category 1 propfan and the Category 2 turbofan fall between the two curves shown.

4.3.10 Spotting Factors

A measure of the carrier "real estate" occupied by a particular aircraft is the spotting factor, which is the ratio of the area of a polygon bounding the extremities of the folded aircraft to the area bounding a reference aircraft, typically the A-7. The spotting factors of the four baseline CTOL aircraft are shown in Figure 58, with the spotting

CATEGORY 1 PROPFAN SHOWN
TURBOFAN SIMILAR

- WEAPONS BAY DOORS REMOVED
- COD FAIRING SHELL ATTACHED (INTERNAL DIMENSIONS 5.2 FT (H) X 6.3 FT (W) X 17.7 FT (L))
- 3.2 FT X 14.8 FT SIDE CARGO DOOR

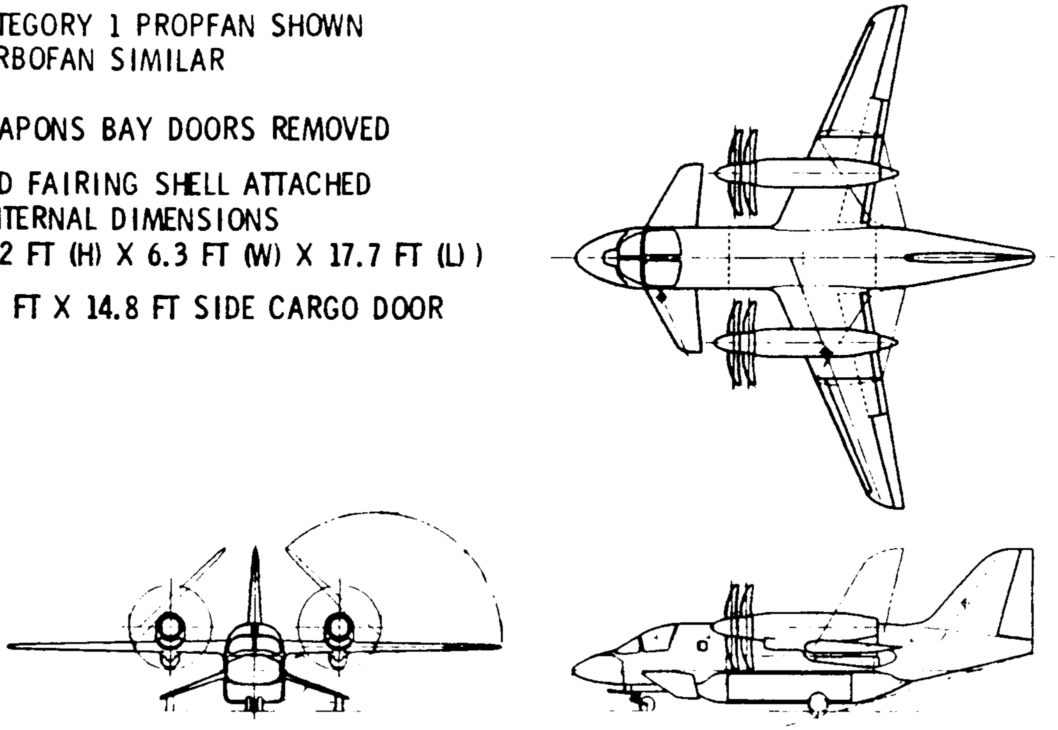


Figure 56. COD Derivative Modification

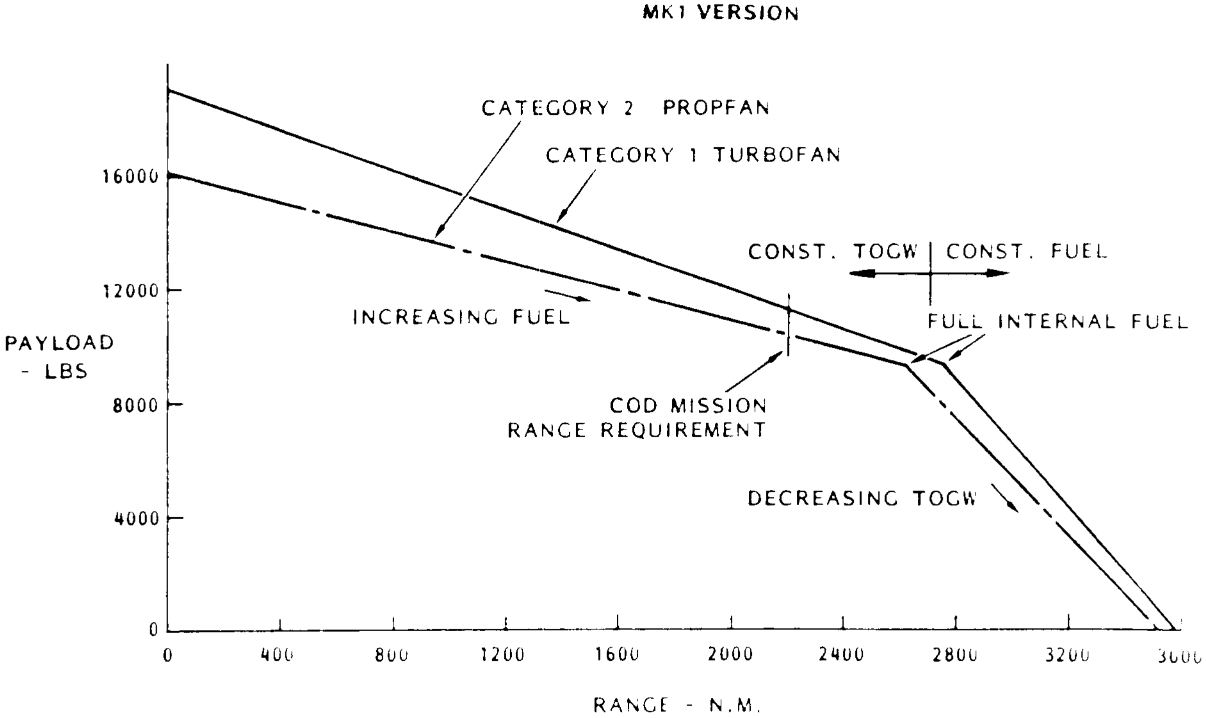


Figure 57. COD Payload vs Range

factors of the S-3A and E-2C for comparison. This figure illustrates the particularly compact arrangement of the propfan baseline concepts.

4.4 ALTERNATIVE DESIGNS - V/STOL AND STOVL

In this task, vertical takeoff and/or vertical landing concepts which use propfans for both lift and cruise thrust are explored.

4.4.1 Ground Rules and Assumptions

Several groundrules were established for the execution of Task IV. V/STOL concepts should be relatively similar in size to the conventional takeoff and landing (CTOL) concepts, in order to utilize at least the basic fuselage developed in Task III. In addition, previous design studies of V/STOL aircraft which had very long mission times and, consequently, very different takeoff and landing weights, established that very severe penalties were associated with requiring the aircraft to takeoff vertically (Reference 5). A rough analysis of aircraft TOGW required to perform the ASW mission when the initial thrust/weight ratio was greater than 1.0 showed that the aircraft would weigh over 60,000 lbs. Therefore, the

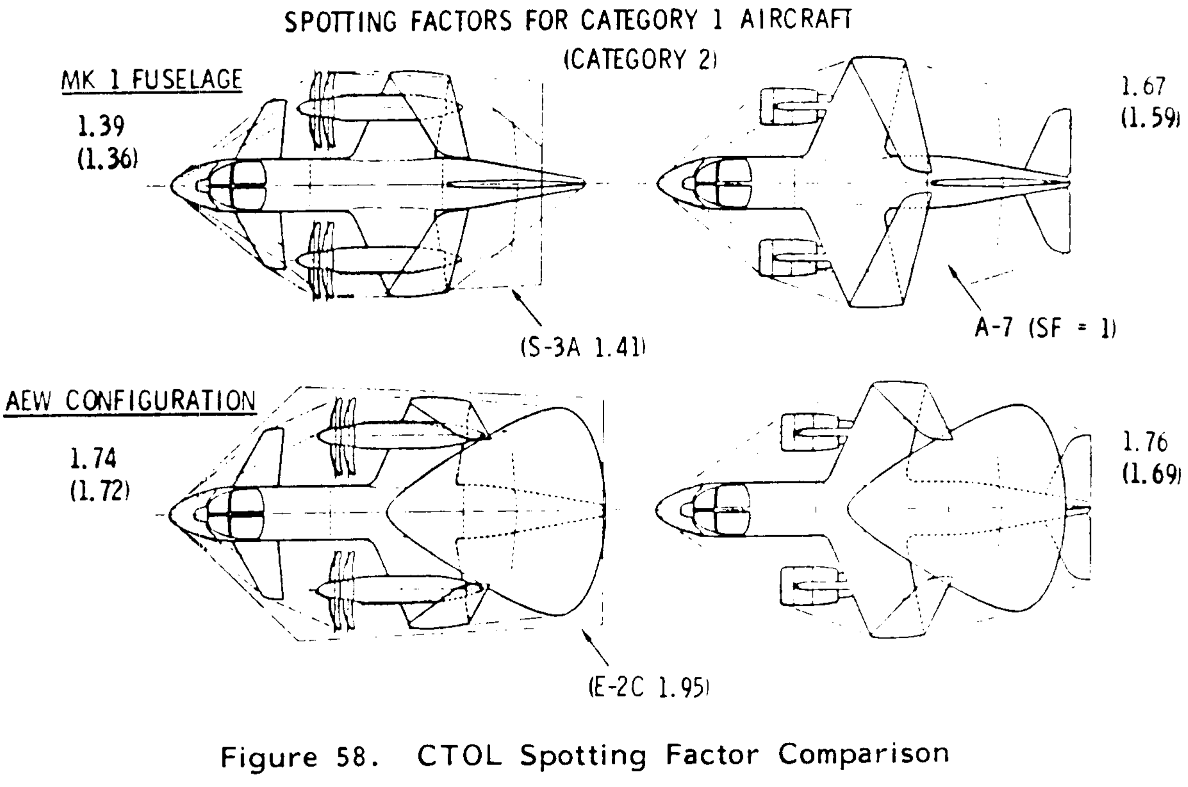


Figure 58. CTOL Spotting Factor Comparison

decision was made to design for vertical landing and very short, conventional free deck takeoff (approximately 300 ft) (STOVL). The propulsion systems were subsequently sized for landing vertically at the heaviest mission landing weight (AEW Mission). While actual takeoff performance was not computed for this very abbreviated design task, previous studies have shown that 300 to 400 foot takeoffs are achievable at the design thrust/weight ratios by optimally tilting the thrust vector (propfan) and with only modest or no additional wind over deck required.

Another decision was made to abandon the Armed AEW mission and the Anti-Air Warfare mission and to size the aircraft for the Anti-Submarine Warfare mission. The rationale for this decision was that designing for either the AAEW or AAW mission, both of which have long mission radii and loiter times, would generate very large STOVL aircraft inconsistent with the goal of near CTOL-sized aircraft. On the other hand, the loss of the AAEW and AAW mission capability could be partially offset by operating the STOVL aircraft from non-CV ships at the outer edge of the battle group. Such ships might be of the helicopter amphibious assault (LPH, LHA) type in order to permit a short free deck takeoff.

Retention of the basic AEW mission (Section 4.1.2.2) maintains the choice of 45,000 or 40,000 ft loiter altitude, as well as the other mission speed requirements which establish Category 1 and Category 2 baselines.

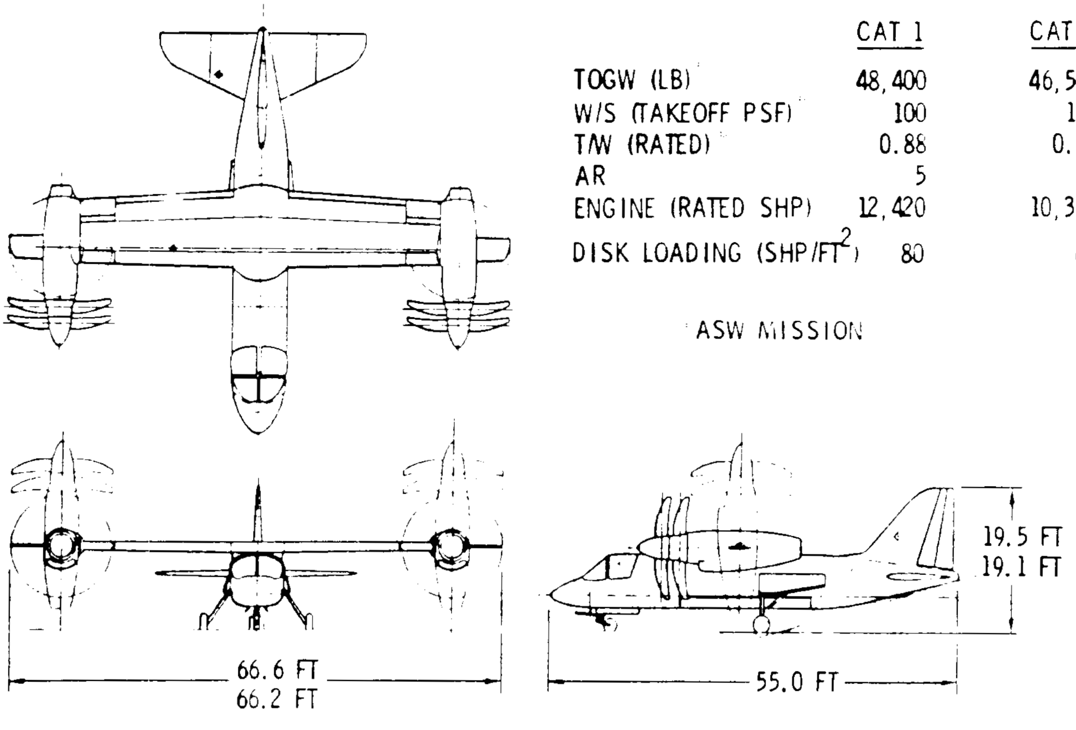
4.4.2 STOVL Baseline Concept

The STOVL aircraft developed during this study have wing tip mounted tilt nacelles. The engines are connected by a high-speed drive shaft to distribute power in the event of engine failure. Sections of the wing outer panels forward and aft of the wing box tilt down to reduce wing blockage during hover. When in vertical flight, yaw control is provided by vanes outboard of the nacelles in the propfan slipstream, and roll is controlled by differential thrust created by propfan blade pitch change. Pitch control is achieved by utilizing a special Auxiliary Power Unit (APU), which has a high residual exhaust thrust, as a reaction control. The APU is a dual unit (for redundancy). The fuselage for the STOVL aircraft is the same as for the CTOL aircraft, except for changes to the wind screen, canopy, and nose contours to increase over-the-nose and over-the-side visibility during transition and hover.

The ground rules for required thrust in hover used in this study assume all engines operating at rated power with an allowance for trim and control on a tropical day. It is assumed that the aircraft would be recovered conventionally in the event of an engine failure. That is, there is no allowance for vertical landing capability with one engine out. It is possible to provide an overspeed, overtemperature, or emergency engine rating to partially offset an engine failure, but this option was not explored. The aircraft is equipped with ejection seats at every crew position.

Figure 59 depicts the STOVL general arrangement. A breakdown of principal weights with the baseline sized for the ASW mission is shown in Figure 60. Significant performance parameters are shown in Figure 61.

Propulsion thrust-to-weight ratio and disk loading were simultaneously varied to achieve the appropriate AEW loiter altitude (40,000 or 45,000



	CAT 1	CAT 2
TOGW (LB)	48,400	46,500
W/S (TAKEOFF PSF)	100	100
T/W (RATED)	0.88	0.89
AR	5	5
ENGINE (RATED SHP)	12,420	10,350
DISK LOADING (SHP/FT^2)	80	60

ASW MISSION

Figure 59. STOVL Baseline General Arrangement

	CATEGORY	
	1	2
● STRUCTURE GROUP	13643	13256
● PROPULSION GROUP	10430	9777
ENGINES	4102	3613
GEARBOXES	1887	1764
PROPELLERS	2606	2725
● FIXED EQUIPMENT	7018	7011
AVIONICS - CORE	1785	1785
AVIONICS - MISSION	1625	1625
● EMPTY WEIGHT	31090	30043
CREW & EQUIPMENT (3)	702	702
TRAPPED FUEL	121	113
RACKS AND CHUTES	475	475
● OPERATING WEIGHT	32388	31333
CHAFF AND FLARES	54	54
SONOBUOYS	1350	1350
TORPEDOES	3200	3200
USEABLE FUEL	11375	10595
● TAKEOFF GROSS WEIGHT	48368	46533

ALL WEIGHTS IN LBS.

Figure 60. STOVL Baseline Group Weights

	PERFORMANCE CATEGORY	
	1	2
TOGW* -LBS	48368	46533
T/W*(UNINST.)	.88	.89
ENGINE SCALE	1.160	.968
DISK LOADING -SHP/FT^2	80	60
WING LOADING* - LBS/FT^2	100	100
ASPECT RATIO	5.0	5.0
LOITER ALTITUDE (AEW) -FT	45000	40000
LOITER SPEED (AEW) -KTS.	359	311
CRUISE SPEED (ASW) -KTS.	425	420
RUN-IN SPEED (ASUW) -KTS.	450	450
COMBAT SPEED (MIW) -KTS.	512	504

*ASW MISSION

Figure 61. STOVL Baseline Performance Parameters

feet) for the two performance categories and vertical landing capability at maximum landing weight (AEW mission) while simultaneously sizing the aircraft to perform the ASW mission. A breakdown of TOGW and empty weights for all eight remaining missions is shown in Figure 62. It should be noted that the aircraft have some reduced capability for the Armed AEW on AAW missions but they cannot complete the full time and distance requirements for those missions.

To permit folding of the aircraft without breaking the high-speed drive shaft between nacelles, the wing of the STOVL aircraft pivots atop the fuselage as shown in Figure 63. The nacelles are rotated to vertical and the slab tail planes are folded.

The STOVL concepts illustrated in this task are consistent in size with the CTOL baseline designs and, pending a more detailed analysis, they appear to be viable alternatives to the CTOL designs. In particular, because of the inherent high static thrust/weight ratio inherent in the concept, they have very good high speed capability.

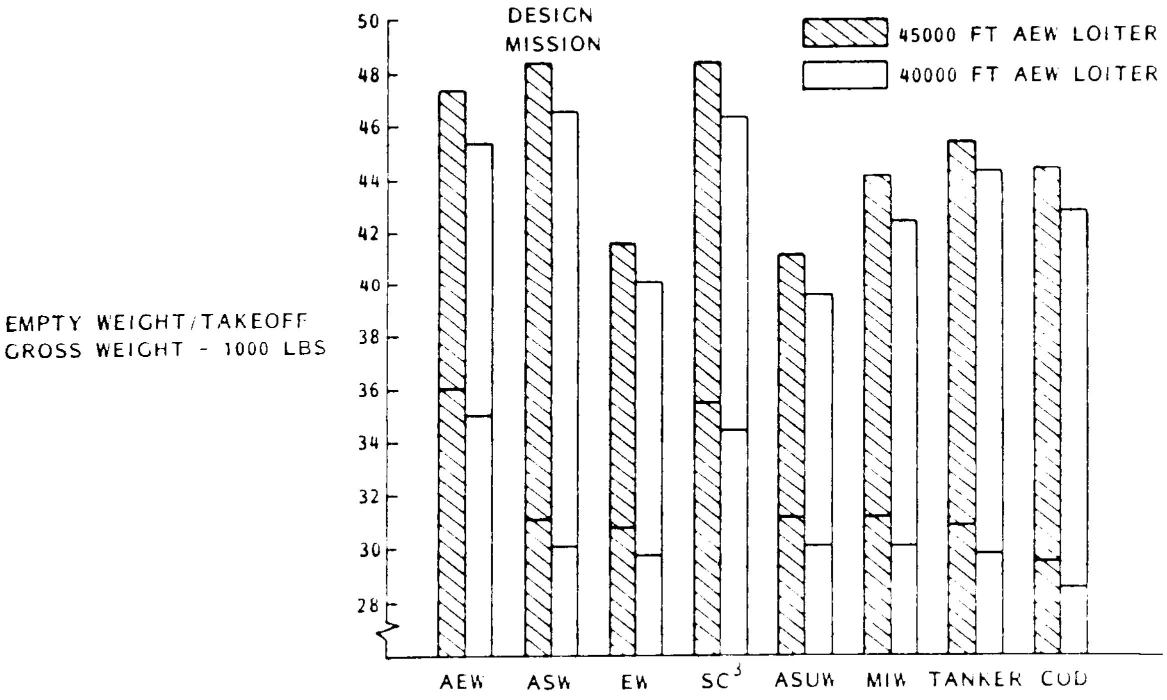


Figure 62. STOVL Alternate Mission Weights

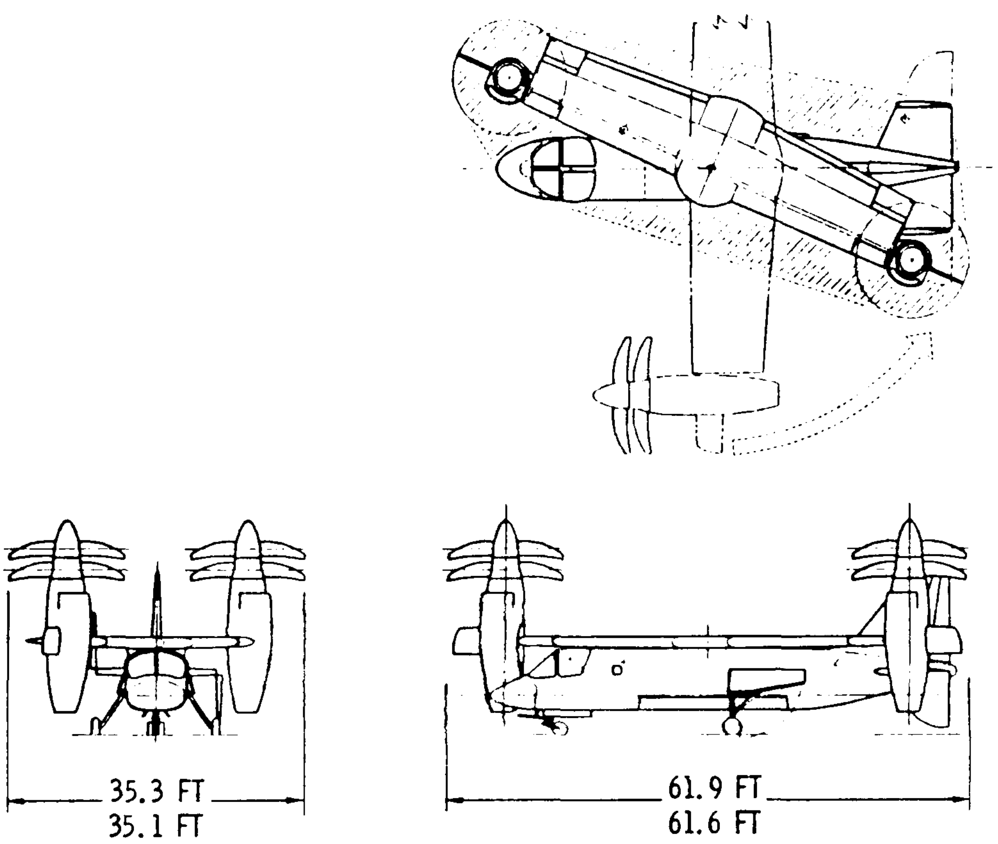


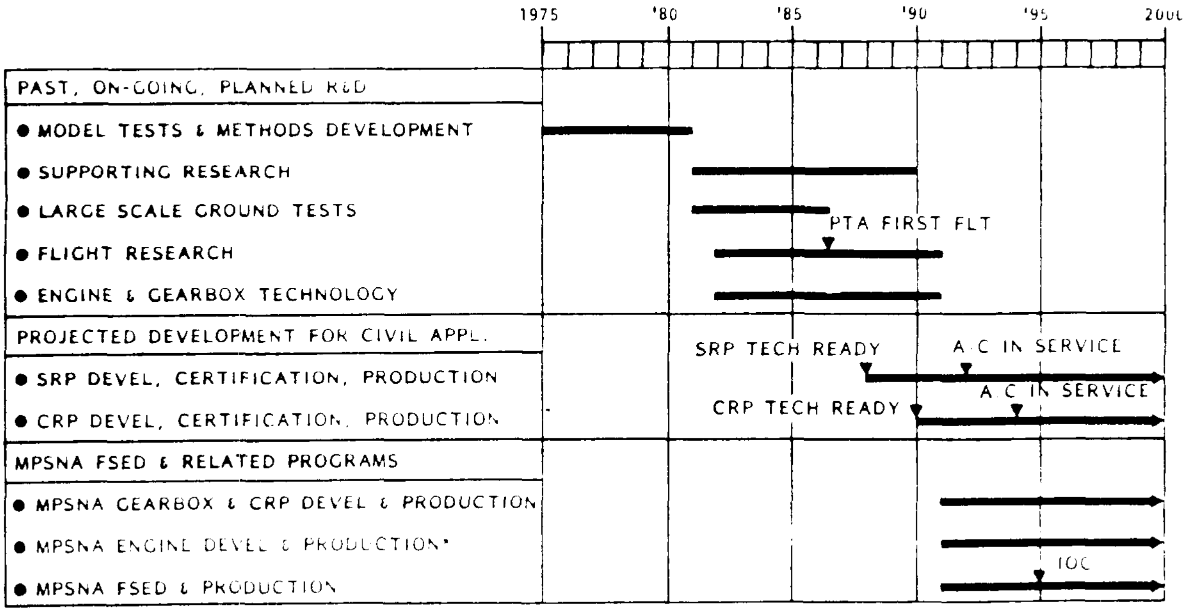
Figure 63. STOVL Folding Concept

4.5 TASK V - ADVANCED TECHNOLOGY RESEARCH PLAN

During this task, research and technology requirements necessary to develop propfan powerplants for this class of aircraft (both CTOL and STOVL) were reviewed. No requirement for additional propfan-related basic research beyond current and planned activity was discovered. Applied research on details of specific configurations will be required, as in any new aircraft development program. Specifically, acoustic and aerodynamic interactions between the propulsion system and the airframe for the specific propulsion installation must be investigated and optimized. Furthermore, accelerated life testing of representative propfans and related hardware would be useful.

Figure 64 outlines previous, current, and projected propfan research programs resulting in technology readiness for the single-rotation propfan in 1988, and technology readiness in 1990 for the counter-rotation propfan. A fully certified commercial, propfan-powered transport is expected by the early 1990s. Although technology development is currently focused on commercial programs, it also is applicable to aircraft of the type presented in this study. The first commercial propfan application is envisioned on a 120-to 150-passenger twin engine aircraft. Such an aircraft will require turboshaft engines developing between 12,000 and 13,000 SHP. Engines of this size will be appropriate for the short takeoff-vertical landing (STOVL) concepts defined in Task IV.

The conventional takeoff and landing (CTOL) concepts use engines between 5000 SHP and 8700 SHP, which will benefit from commercial engine, gearbox, and propfan development and experience. These smaller engines are expected to be development and growth versions of existing or planned engine programs, which are noted on Table VIII. By adapting one of these engines, the normal new engine development cycle of approximately eight years can be trimmed to about four years, or about the same development time as the propfan and gearbox.



* ASSUMES GROWTH DERIVATIVE OF T501, T701, OR GE27 MTDE

Figure 64. Propfan Technology Development Schedule

TABLE VIII CANDIDATE ENGINE PROGRAMS

GE27 MTDE*	(JVX)	6000 SHP CLASS
PW3005 MTDE*	(JVX)	
T501**	(JVX)	
T56 SERIES IV	(DEVELOPMENT FOR E-2C)	5914 SHP
T56 SERIES V		7165 SHP
T701	(HEAVY LIFT HELICOPTER)	8079 SHP

* ORIGINALLY 5000 SHP CLASS
** SELECTED FOR JVX (V-22)

Several engine programs currently underway, or planned for the near future, are applicable to the CTOL concepts defined in this study. For the Category 2 propfan concept, which as sized requires about 5040 SHP, engines developed for the JVX (now the V-22 Osprey) are well suited. Engines designed under the Modern Technology Development Engine (MTDE) program, although originally in the 5000 SHP class, have calculated growth potential of ten to twenty percent and may serve as the basis for engines for even the Category 1 aircraft, which require about 8700 SHP.

Cross-shafting, necessary for the STOVL concepts, is now being developed for the V-22 program. Scale-up of the shafting design to accommodate the higher torques of the STOVL concepts will require further development, but the risk associated with that development is considered modest.

Avionics systems are the heart of many missions projected for this class of aircraft. The U.S. Navy has a number of product improvement and advanced development programs underway which will bring the required capability on line for a 1995 Initial Operational Capability. Many of those programs are identified on Figure 65. AMSS, or Advanced Multipurpose Sensor System radar, while not yet an active development program, is projected as a possible development of the Navy's High Altitude Remotely Piloted Sensor System (HARPSS). This radar technology is an important element for the success of the AEW class of aircraft depicted in this study.

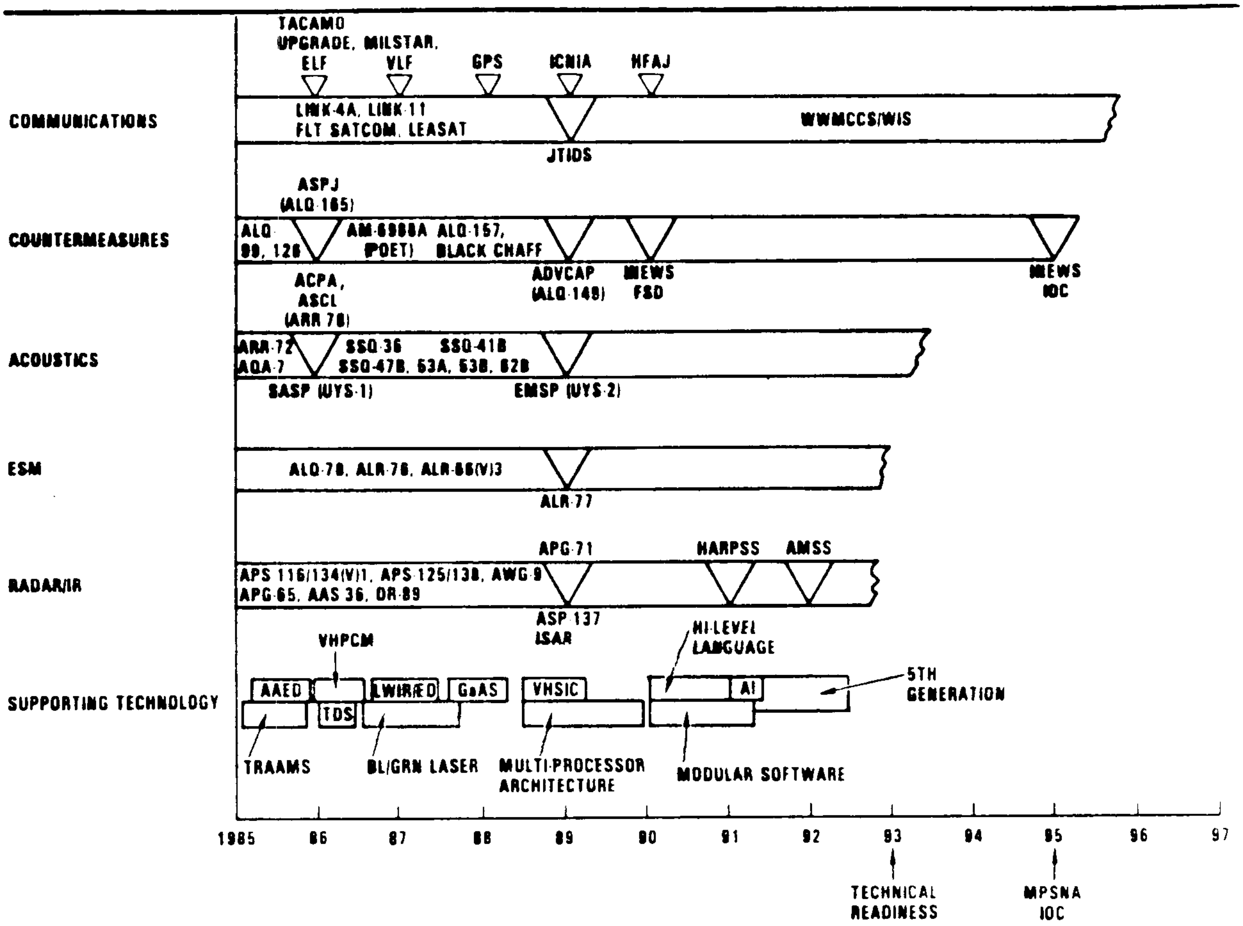


Figure 65. Avionics System Development Schedule

ROM acquisition cost estimates, which account for the estimated additional propfan technology development, are shown in Figure 66. In this figure, the mission avionics cost is separated from the basic aircraft (with core avionics included) cost and spread over a total procurement based on fleet size projections of Task I.

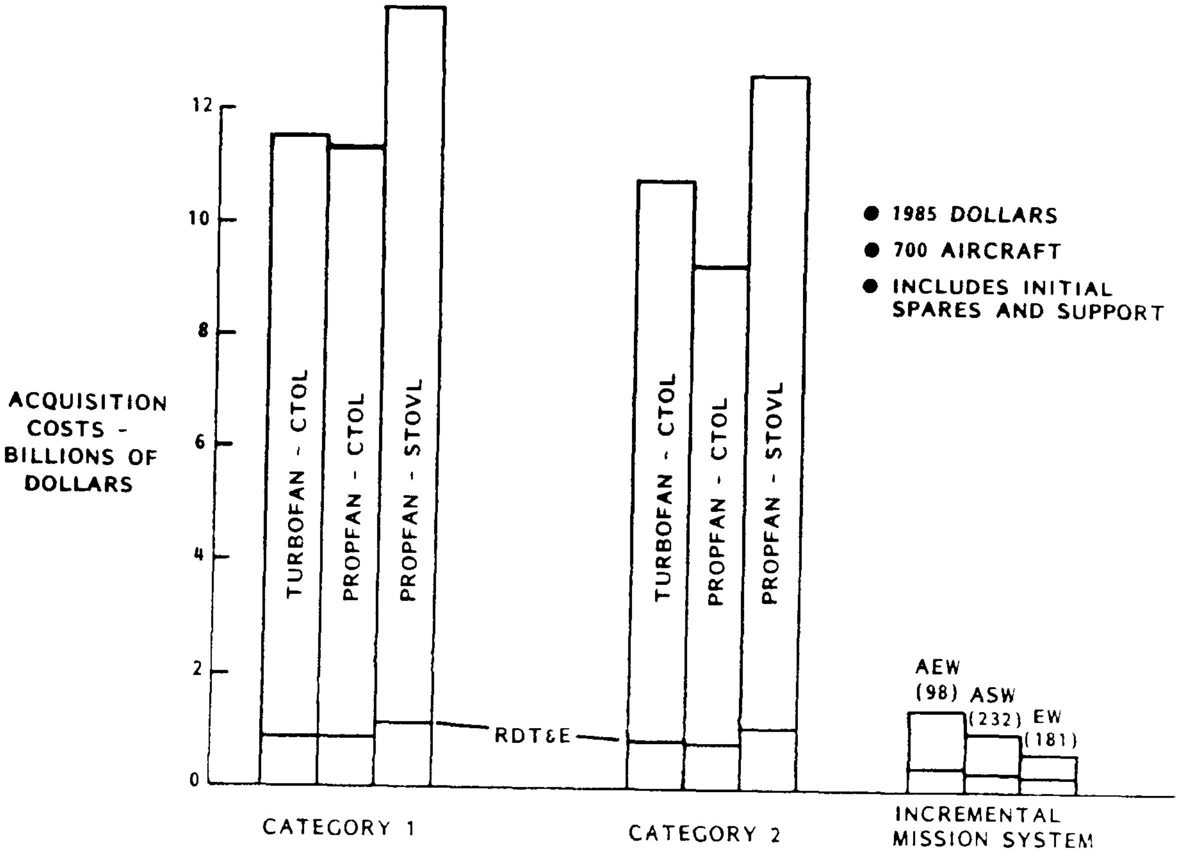


Figure 66. ROM Acquistion Cost Estimate

5.0 CONCLUSIONS

Although this study was conducted at the conceptual level and sought to take a broad "cut" through many missions, aircraft configurations, and propulsion combinations, certain fundamental conclusions can be drawn.

1. Propfan propulsion systems (and advanced propellers in general) are fully capable of providing aircraft performance consistent with the speed, altitude and mission goals established at the outset of this study.

2. Propfan systems enjoy a significant advantage in fuel burn for the missions defined, compared to a representative turbofan, although low peacetime utilization of this type of aircraft diminishes the associated cost benefits of that savings.

3. The inherent high static thrust-to-weight ratio of either the turbofan or propfan, necessary to achieve high altitude loiter, provides ample thrust for high acceleration at low speed. This is reflected in the fact that catapult and waveoff accelerations are not critical for any of the concepts.

4. The propfan-powered STOVL concept has significant mission capability, including high speed, at design gross weights which are consistent with the CTOL concepts.

5. Propfans can be satisfactorily integrated into the Carrier Air Wing - issues of deck handling and safety can be resolved (e.g., free turbine engine/propeller brake).

6. The real issue for the propfan concept is cabin noise and vibration. The goal of compact size for carrier spotting is contrary to the techniques currently advocated for cabin isolation - displacing the engines far from the cabin. If this

issue can be resolved through the continued application of technology, at reasonable weight penalty, propfans may be the propulsion system of choice for multipurpose naval utility and support aircraft.

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7.0 GLOSSARY

ACRONYMS AND ABBREVIATIONS (Cont'd)

IOC	Initial Operational Capability
IRAD	Independent Research and Development
JTIDS	Joint Tactical Information Distribution System
JVX	V-22 "Osprey" V/STOL Aircraft
LCC	Life Cycle Cost
L.E.	Leading Edge
LHA	Amphibious Assault Ship (Helicopter - "Tarawa" Class)
LPH	Amphibious Assault Ship (Helicopter - "Iwo Jima" Class)
MAC	Mean Aerodynamic Chord
MAD	Magnetic Anomoly Detector
MAW	Marine Air Wing
MHz	MegaHertz
MIW	Mine Warfare
Mn	Mach Number
MPSNA	Multi-Purpose Subsonic Naval Aircraft
MTDE	Modern Technology Development Engine
NASA	National Aeronautics and Space Administration
O&S	Operating and Support (Costs)
PTA	Propfan Technology Assessment (Program)
RDT&E	Research, Development, Test and Evaluation
ROM	Rough Order of Magnitude
SATCOM	Satellite-Communications
SC^3	Surveillance, Command, Control, and Communication
SFC	Specific Fuel Consumption
SHP	Shaft Horsepower
SIGINT	Signal Intelligence
SLS	Sea Level Static
SRP	Single-Rotation Propeller
STOAL	Short Takeoff-Arrested Landing
STOVL	Short Takeoff-Vertical Landing
TBO	Time Before Overhaul
T.E.	Trailing Edge
TOGW	Takeoff Gross Weight
T/W	Thrust/Weight
UDF	Unducted Fan
UHF	Ultrahigh Frequency

7.0 GLOSSARY

ACRONYMS AND ABBREVIATIONS

AAEW	Armed Airborne Early Warning
AAW	Anti-Air Warfare
A/C	Aircraft
ADF	Automatic Direction Finder
AEW	Airborne Early Warning
AHRS	Attitude Heading Reference System
ALWT	Advanced Light Weight Torpedo
AMS	Advanced Missile System
AMSS	Advanced Multi-purpose Sensor System
APET	Advanced Propfan Engine Technology
APU	Auxiliary Power Unit
AR	Aspect Ratio
ASUW	Anti-Surface Warfare
ASW	Anti-Submarine Warfare
CAP	Combat Air Patrol
CAP	Configuration Analysis Program
C.G.	Center of Gravity
COD	Carrier Onboard Delivery
CRP	Counter (Contra) Rotating Propeller
CTOL	Conventional Take Off and Landing
CV	Aircraft Carrier
CVBG	Carrier Battle Group
CVW	Carrier Air Wing
ECM	Electronic Counter Measures
ESM	Electronic Surveillance Measures
EW	Electronic Warfare
HARPSS	High Altitude Remotely Piloted Sensor System
IFR	In-Flight Refueling
HF	High Frequency
IFF	Identification - Friend or Foe
ILS	Instrument Landing System
INS	Intertial Navigation System
IRST	Infra Red Search and Track (set)

7.0 GLOSSARY

ACRONYMS AND ABBREVIATIONS (Cont'd)

UE	Unit Equipment
VA	Attack Aircraft (Navy)
VAK	Tanker Aircraft (Attack Aircraft Derivative)
VAQ	Tactical Electronic Warfare Aircraft (Navy)
VAW	Early Warning Aircraft (Navy)
VHF	Very High Frequency
VF	Fighter Aircraft (Navy)
VQ	Electronic Warfare Aircraft (Navy)
VRC	Resupply/Utility Aircraft (COD)
VS	Anti-Submarine Warfare Aircraft
V/STOL	Vertical/Short Takeoff and Landing
VTOL	Vertical Takeoff and Landing
W/S	Wing Loading (Weight/Area)

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	10. Work Unit No.
9. Performing Organization Name and Address Lockheed-Georgia Company 86 South Cobb Drive Marietta, Georgia 30063	11. Contract or Grant No. NAS3-24528
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	14. Sponsoring Agency Code 535-03-01

15. Supplementary Notes

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(Previously S. Johnson, NASA Lewis Research Center)

16. Abstract

A Conceptual design study compared a selected propfan-powered aircraft to a turbofan-powered aircraft for multiple Navy carrier-based support missions in the 1995 timeframe. Conventional takeoff and landing (CTOL) propfan and turbofan-powered designs and short takeoff/vertical landing (STOVL) propfan-powered designs are presented. Ten support mission profiles were defined and the aircraft were sized to be able to perform all ten missions. Emphasis was placed on efficient high altitude loiter for Airborne Early Warning (AEW) and low altitude high speed capability for various offensive and tactical support missions. The results of the study show that the propfan-powered designs have lighter gross weights, lower fuel fractions, and equal or greater performance capability than the turbofan-powered designs. Various sensitivities were developed in the study, including the effect of using single-rotation versus counter-rotation propfans and the effect of AEW loiter altitude on vehicle gross weight and empty weight. A propfan technology development plan was presented which illustrates that the development of key components can be achieved without accelerated schedules through the extension of current and planned government and civil propfan programs.

17. Key Words (Suggested by Author(s)) Propfan, Multi-Mission, Advanced Turboprops, AEW, ASW, Carrier-Based Aircraft, Multi-Mission Navy Aircraft.	18. Distribution Statement [redacted] This document will remain under distribution limitation until March 1989.

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