XIV. LONG RANGE, HEAVY LIFT AIRCRAFT

A. INTRODUCTION

The Aeronautical Engineering Department, as part of the integrated ExWar project, agreed to design a conceptual aircraft to fill a capability gap identified through the Systems Engineering Top-Down analysis described in Chapter III. This chapter describes potential aviation solutions to the requirements – capabilities gaps identified from the Top-Down analysis, the aviation requirement – capabilities gap selected for a design solution, the design concepts generated to fulfill the requirement, the analysis of alternatives between these concepts, and some of the enabling technologies that make an aircraft system solution with a significant improvement over current capability possible.

B. REQUIREMENTS ANALYSIS

1. Candidate Aircraft Requirement-Capability Gaps Identified in the Top Down Analysis

This section discusses potential aircraft platform solutions to capability gaps identified during the Top – Down analysis and explains the rationale for selecting or rejecting them as the subject of the Aeronautical Engineering design project.

a. Escort Aircraft for Tilt Rotor and Other High Speed Transports

Proposed operational concepts like STOM call for insertions of men and materiel deep into hostile territory at ranges potentially exceeding 200 NM from the Sea Based task force. The primary troop transport to conduct these operations in the 2015 to 2020 timeframe is the MV-22 Osprey. The primary advantage of the MV-22 in this role is its 250 kt cruise speed, which enables it to move quickly through enemy air defenses to deposit Marines and limited quantities of sustainment directly to the objective area. This same high speed, however, combined with the MV-22's long combat radius, permits it to outstrip any potential escort aircraft with the exception of the AV-8B or Joint Strike Fighter (JSF). Even in the planned 4 bladed configuration, the AH-1Z will not have the speed or range to escort the MV-22 at its maximum cruise airspeed. Slowing the MV-22 to airspeeds compatible with the AH-1Z will not solve the range problem and will only increase the MV-22's threat exposure. Fixed wing assets will be in short supply in future Expeditionary Strike Groups (ESGs), and each aircraft diverted to escort MV-22s is one less aircraft available to provide close air support to Marines on the ground. This escort problem becomes even more acute with the potential introduction of high speed, heavy lift aircraft like the one discussed below.

A small number of dedicated high-speed escorts would increase the survivability of the MV-22 and other high speed transports while conserving fixed wing strike assets to provide close air support and fleet air defense. Equipping these aircraft for a secondary mission of providing limited close air support would further offload the fixed wing assets and provide planners with increased flexibility in parceling out strike packages.

The 1997 American Helicopter Society design competition centered around the need for such and aircraft and the NPS design, the Viper Tilt Rotor Escort (Wood, et al., 1997), took first place. As a result, this capability gap was not selected for the 2002-2003 design candidate and the Viper's potential as a candidate in the ExWar system of systems is examined in Chapter XVIII.

b. Organic Command and Control/Airborne Early Warning Platform

The Chief of Naval Operations' Vision 21 calls for the deployment of ESGs to global trouble spots with or without an escorting carrier battlegroup. While the organic Marine Air Combat Element (ACE) and the escort ships are capable of projecting a reasonable amount of firepower inland in support of operations ashore, one mission area where the ACE cannot match the carrier airwing capability is in airborne early warning and command and control. This role is performed by the E-2C Hawkeye for the ships of the CVBG.

The situational awareness and early warning provided by airborne assets are essential in a littoral environment rife with small surface combatant, cruise missile, and light aircraft or helicopter threats. While the AEGIS escorts have an outstanding capability against many of these threats, their systems do not have the OTH detection ranges attainable with airborne systems. These airborne systems would simultaneously be able to provide early warning to the Marine forces ashore, helping detect inbound aircraft or inbound land attack cruise missiles, for example.

These platforms also provide a valuable command, control, and communications relay capability. They can monitor and redirect surface craft during transit and provide similar services for assault and transport aircraft. Communications relay and downlink of radar and other data provides the Sea Based commander with enhanced situational awareness and the ability to "reach out and touch" the forces under his command under almost any circumstances.

There are several systems that provide partial solutions for these capabilities required – capabilities available gap. The first provides a carrier battlegroup whenever the ESG requires airborne early warning or command and control services. Further, the SH-60R helicopter carried aboard the escort ships has the ability to provide a similar, but more limited service than the E-2C. It is unclear, however, how many of these aircraft will be available to sail with every ESG to ensure a surveillance platform is available around the clock. The airborne early warning and command and control mission would also compete with the SH-60's force protection tasking. Finally, a UAV could provide the communications relay and some measure of the sensor capability provided by the E-2C or SH-60. These UAVs would not likely be large enough to provide the full spectrum of capability, but could provide a partial solution. Previous NPS designed UAVs with potential ExWar applications are described in Chapter XVIII.

Because of the range of partial solutions available and the CNO's stated desire to have carrier battle groups deploy with ESGs in most circumstances, this requirement – system gap was not selected for the 2002-2003 design project.

c. Organic Medium Endurance Unmanned Aerial Surveillance and Reconnaissance Vehicle

STOM concepts call for operations ashore across a wide operational area, with units driving directly to their objectives in swift, decisive maneuvers. This type of rapid movement through hostile territory requires detailed knowledge of terrain, weather, and enemy strength and disposition. This information must be rapidly available around the clock, with the ability to rapidly retask the gathering unit to keep pace with evolving operations.

Space systems, while having very high endurance, are not flexible enough to rapidly reconfigure their coverage areas and viewing window times. Unmanned assets provide a potential solution, but current organic UAVs, such as the Predator, are primarily tactical platforms, without the range and endurance to meet this need. While there are other systems, like Global Hawk, that can provide this capability, they are available in only limited numbers and are typically theater assets, and not necessarily under control of the ESG commander. An organic medium range and endurance "operational" level UAV is required to fill this mission capability gap.

As part of the 2001 Crossbow Project, an Aeronautical Engineering design team created the Sea Spectrum UAV (Newberry, et al., 2002), which was designed to provide the type of medium range and endurance command and control and surveillance needed to perform OTH ExWar missions. Because a potential design solution existed, a medium range and endurance UAV was not selected as the 2002-2003 Aero design project. The Sea Spectrum design and its applicability to the ExWar mission are discussed in Chapter XVIII.

d. Long Range, Heavy Lift Transport Aircraft

As previously discussed, STOM places a premium on being able to project combat power directly from the ships of the task force to the objective ashore. A large component of this combat power are large vehicles and heavy equipment, such as Light Armored Vehicles and the new lightweight 155 mm howitzer, that directly support combat operations. In order to implement STOM, a means must be found to move this equipment from the ships far inland to the objective.

The current Marine ship based platform for performing this mission is the CH-53E Sea Stallion. Detailed examination of the vehicles and equipment to be moved and the current and proposed upgraded configuration of the CH-53E showed the aircraft will not have the payload or range requirements to meet optimal STOM heavy lift requirements through 2025. No replacement aircraft capable of meeting these requirements is currently planned for acquisition. As a result, a long range, heavy lift aircraft was selected as the design project for the 2002-2003 Aeronautical Engineering design project. A detailed discussion of requirements and candidate design concepts follows below.

2. STOM and Air Transport Requirements

STOM emphasizes the advantages to be gained by directly striking objectives throughout the littoral battle space without "telegraphing" the blow with a prolonged logistics buildup in the vicinity of the operating area. As a result, functional analysis closely examined the matter of how troops, vehicles, and materials would be transported to the objective area in a STOM operation, as well as the allocation of the heavy lift transport task between surface and air transporters. STOM operations place a unique set of constraints on the types of transportation that must be available to provide the commander with a wide range of options across a range of scenarios. The potential distance of up to 200 NM between landing beaches and objective, combined with the capability of current and planned transporters, means that troops could be inserted directly to the objective while their heavier supporting equipment and vehicles, such as artillery and LAVs, could only be inserted at the beach or an intermediate point ashore. This requires a long transit across hostile terrain to join up with infantry asserted at the objective. The resulting delay in the arrival of these assets at the objective, their attrition along the way, and the need to escort the vehicles all decrease the rate of combat power projected into the objective area. In order to strike directly to the objective with a combined arms ground element, it is imperative that amphibious task forces have a means to insert larger vehicles and heavy equipment directly to the objective if it's required by the scenario.

This swift, surprise thrust towards multiple objectives requires elimination of a staple feature of Marine Corps amphibious operations to date, the "Iron Mountain." In the early stage of current operations, the Iron Mountain is built up over 7 to 10 days to provide supplies and materials to troops pushing forward to the objective. The Iron Mountain is usually collocated with a port facility or airport and is again supplied directly from CONUS or a forward supply base with the materials required to keep up the fight. Expeditionary Manuever Warfare (EMW) and STOM concepts require sustainment directly from the ships of the Sea Base, which would also be resupplied directly from CONUS or a forward supply base with the necessary materials. The mechanism for transferring the materials from the resupply ships to the ships of the Sea Base, and then from the Sea Base to the troops ashore, has not been defined, however, and is therefore considered as a secondary mission for the Long Range, Heavy Lift aircraft.

The Burma scenario, Appendix 5-1, was the primary scenario used for all requirements analysis below, except where noted otherwise.

3. Functional Allocation

The two types of transporters available to the task force commander are air and surface craft. While surface craft are capable of transporting much higher payloads than all but the largest fixed wing transport aircraft, they are limited by their transit speeds and the proximity of the beachhead to the objective. Surface craft can transit up to 200 NM inland along navigable rivers; however, reliance on these routes greatly restricts the number and location of potential operational areas. Aircraft, on the other hand, are payload limited relative to surface craft; however, they have significant speed and range advantages and are not limited by shorelines or objective locations.

	Speed	Cross Beach Range	Payload	Shipboard Compatibility
Surface Craft	--	--	+	+
Fixed Wing Aircraft	+	+	+	--
Helicopters	+	+	--	+

Table XIV-1: Relative Abilities of Transporter Platforms to Carry Materials Directly Ashore in Expeditionary Operations

The objective's distance inland and variety of terrain and elevation of the insertion points in the various scenarios described in Chapter V, and the wide range of potential objective locations clearly require this vehicle and heavy equipment transport task be allocated to an air platform.

4. Proposed and Current Platform Capabilities

This Aeronautical Engineering design project is a long range, heavy lift aircraft to support Marine Corps, joint, and coalition force operations ashore up to 200 nm inland in a forcible entry environment. In the assault phase of operations, the aircraft will transport vehicles and equipment up to the size and weight of a combat loaded Light Armored Vehicle (LAV), Medium Tactical Vehicle Replacement (MTVR), truck or the Heavy-Expanded Mobility Ammunition Trailer (HEMAT) from the Sea Base 100 NM offshore to the objective up to 200 NM inland. In the sustainment phase of operations, the aircraft will transport bulk resupply materials and equipment weighing up to 37,500 lbs over the same distance. Detailed derivation of these requirements is presented below.

Currently, the primary asset for air piece of heavy equipment transport is the CH-53E. The long range, heavy lift aircraft, however, is not intended to be, and should not be construed as, a simple one-for-one platform replacement for the CH-53E, although many of the mission requirements overlap.

The Marine Corps currently employs three types of aircraft for long-range transport and sustainment: the CH-46E, the CH-53E, and the C-130. A medium lift rotory wing aircraft primarily used for troop transport and sustainment, the CH-46 is not capable of meeting the heavy lift payload or range requirements. The ExWar study timeframe concerns the period 2015-2020, by which time the CH-46E will have been replaced by the MV-22A. While it meets the transport range requirement, the MV-22A does not have sufficient internal or external payload capacity to transport heavy equipment or large quantities of bulk logistics.

The CH-53E does not have sufficient external load capacity to lift heavy equipment such as the MTVR and HEMAT needed to support USMC field artillery ashore. It does not have sufficient range with large and heavy external loads like the LAV to support the STOM operations up to 200 NM inland envisioned in the future. Additionally, current force plans call for the phase out of the CH-53E by 2025. Even the current proposed upgrade to the CH-53E, referred to as the CH-53X, is only capable of carrying 28,000 lb external payloads to 200 NM, which will not allow the carriage of heavy equipment to the distances envisioned in the STOM operational concept (Bonholtzer and Bonholtzer, 2002).

The C-130, while capable of transporting large payloads, cannot easily carry larger vehicles such as the MTVR, HEMAT, or LAV internally and, further, is not shipboard compatible.

5. Requirements Drivers

a. *Payload (Weight)*

Payload and range are the requirements drivers for the aircraft design. Payload is expressed in terms of both weight and volume, or cube. The initial mission payload for the long range, heavy lift aircraft is primarily vehicles and equipment; however, after the initial assault, the ability to move large quantities of sustainment materials from the ships of the Sea Base to the troops ashore becomes critical as well. The reduction or elimination of the "Iron Mountain" in EMW means that all materiel (fuel, ammunition, food, water, spares, as well as replacement troops and gear) required to support the brigade size force must flow directly from the Sea Base to the objective area. In general, though, these loads are smaller in size and weight than the heavier vehicles the aircraft needs to transport (LAVs, MTVRs, HEMAT, etc). The aircraft payload weight requirement, then, was based on the vehicles it needed to transport vice the sustainment materials. A summary of these various vehicle weights is presented in Figure XIV-1.

Examination of the figure shows a gradual increase in weight up to about 15 short tons (stons), followed by a sharp increase to almost 70 stons for an M1A1 tank. Lifting 70 ston currently requires a C-5 or C-17 class lift capability and was thus deemed too challenging a design point for a shipboard compatible transport. The AAAV was also considerably heavier than the other vehicles; however, since they would likely swim ashore and proceed overland to the objective or remain onboard the ships of the task force, they were also not considered a candidate for air transport. All remaining vehicles and equipment are under 16 stons, or 32,000 lbs. The cut-off point for vehicle payloads is then in the LAV, MTVR, HEMAT range. In order to account for combat loading of the platforms (fuel, ammo, and crew) as well as future growth, the target payload requirement was set at 18.75 stons, or 37,500 lbs.

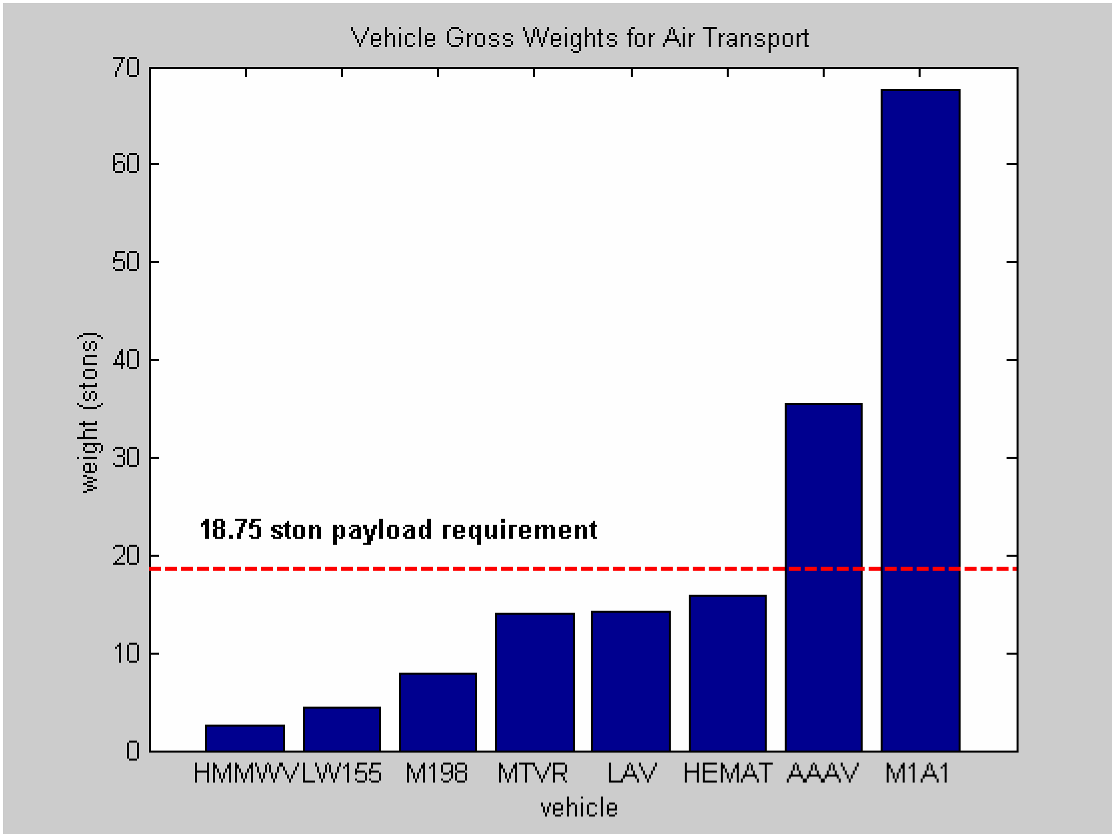

Figure XIV-1: Vehicle Gross Weights (Source: MAGTF II / LOG AIS, 2002)

A potential secondary mission of the aircraft is to transfer supplies and equipment ashore from ships sent from a forward supply base or CONUS to replenish the Sea Base. In many future operational concepts, these materials would arrive in standard shipping containers. The largest of these containers, the 8’ x 8’ x 40’ container, is capable of storing weights of up to 80,000 lbs, which is considerably beyond the proposed payload weight requirement. The smaller 8’ x 8’ x 20’containers carry a maximum load of 40,000 lbs and are, therefore, closer to the payload value proposed for the aircraft design. Any intended use of these aircraft to transport loaded containers between ships of the Sea Base presumes center of gravity and other weight and balance information is available for every container to ensure safe and effective transfer. Current operational concepts call for this transfer to be performed between the ships themselves via crane or other onboard transfer mechanism. Use of aircraft to transport these loads is a secondary mission and is not considered sufficient cause to increase the design payload weight from 37,500 lbs to 40,000 lbs.

b. Payload (cube)

Payload is also stated in terms of cargo volume. This is a difficult quantity to specify without reference to a particular airframe. Helicopters can enjoy a payload cube advantage over fixed wing aircraft, since large volume and oversized loads can be carried externally, where conventional aircraft must carry the loads within the fuselage.

Overall, the aircraft must be capable of transporting equipment as large as an LAV or MTVR and HEMAT variant used to support the new lightweight 155 mm howitzer. The sustainment payload volume is a minimum of 2 wide, 3 deep, and 1 high 48” x 40” standard wooden pallets, each with a 66.25” high load. Personnel requirements are not specified, the aircraft must be capable of carrying the maximum number of troops or personnel that can be accommodated as a result of the payload cube and weight requirements stated above.

The system should also be capable of handling 8’ x 8’ x 20’ and 8’ x 8’ x 40’ standard shipping containers (weighing no more than 37,500 lbs) as well as up to 4 8’ x 8’ x 5’ “quadcons” (weighing no more than 37,500 lbs total). These containers may be transferred either from logistics support or pre-position ships to the assault ships of the Sea Base or taken directly to the troops ashore.

c. ***Range***

Reviews of various STOM documents and CONOPS provided distance capability between Sea Base and shoreline and shoreline and objective. These documents pointed to a desired ship to shore distance of 100 NM, and then up to an additional 200 NM from shoreline to the objective. As a result, the un-refueled radius of action requirement was set at 300 NM.

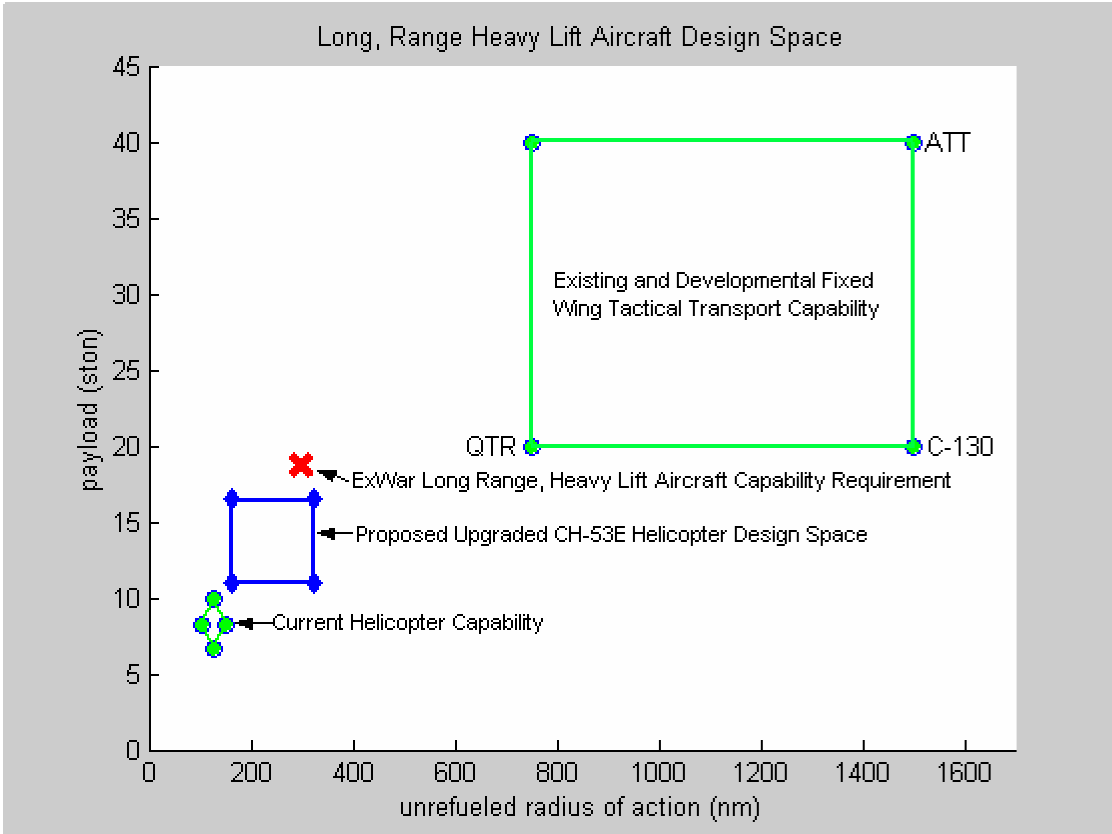

Figure XIV-2: Design Space for Expeditionary Warfare Transport Aircraft (Source: Van Buiten, 2002)

This radius of action was combined with the payload weight requirement and compared to current lift capability and current heavy lift helicopter design space as presented in Figure XIV-2. While the design was not limited to a helicopter, current helicopter design space was readily available and serves as a reasonable means to analyze the validity of the requirement in terms of technical feasibility. From the data presented in the figure, the requirement appears reasonable, in that it lies along a roughly linear growth path from current capability through new helicopter capabilities. While the ExWar aircraft design point lies above the new helicopter design space, the concept designs were not limited to conventional helicopters. Additionally, this aircraft design is being asked to lift a greater payload than the aircraft used to generate the new helicopter design space shown in the figure.

d. *Speed*

Platform speed was not specified, since the aircraft type was not fixed in the requirements. For a range of aerodynamic reasons, conventional fixed wing aircraft are capable of significantly higher maximum and cruise speeds for a given payload than helicopters. Specifying a specific high or low end cruise airspeed would have unfairly penalized the aircraft or helicopter ends of the design spectrum, and the requirement specifically strove for a range of potential solutions.

Despite the need to prevent introducing a platform specific bias, transport aircraft productivity is partly a function of platform speed, and so speed was addressed indirectly in the requirements. It was strongly desired, for example, that platform airspeed speed be as close to that of the MV-22A as reasonably possible, in order to maximize flow ashore and minimize the complications of scheduling and escorting a number of platforms with widely divergent capabilities. In order to keep the number and size of future Sea Base ships small, it is desirable to minimize the number of platforms required to support the brigade ashore during sustainment operations. Since the number of loads delivered ashore per hour is at least partly a function of aircraft transit speeds, plots of the number of aircraft (carrying the maximum 37,500 lb payload) required for sustainment operations over a range of airspeeds were used to determine a feasibility band for design speeds (Figure XIV-3). This plot is a top-level approximation, assuming each aircraft carries the maximum payload (37,500 lbs) of sustainment materials on each trip and that the loading and unloading times for each payload are the same. It does not take into account how the materials are packaged or whether they are carried internally or externally. Material requirements for surge and sustained operations were taken from Kennedy (2002). As can be seen from the chart, the incremental increase in airspeed required to decrease by one the number of aircraft required increases markedly above 200 - 225 kts. This speed band approaches the 250 kt cruise airspeed of the MV-22A, which was previously described as highly desirable. As a result, 200 – 225 kts became the benchmark airspeed for evaluating the initial set of design alternatives.

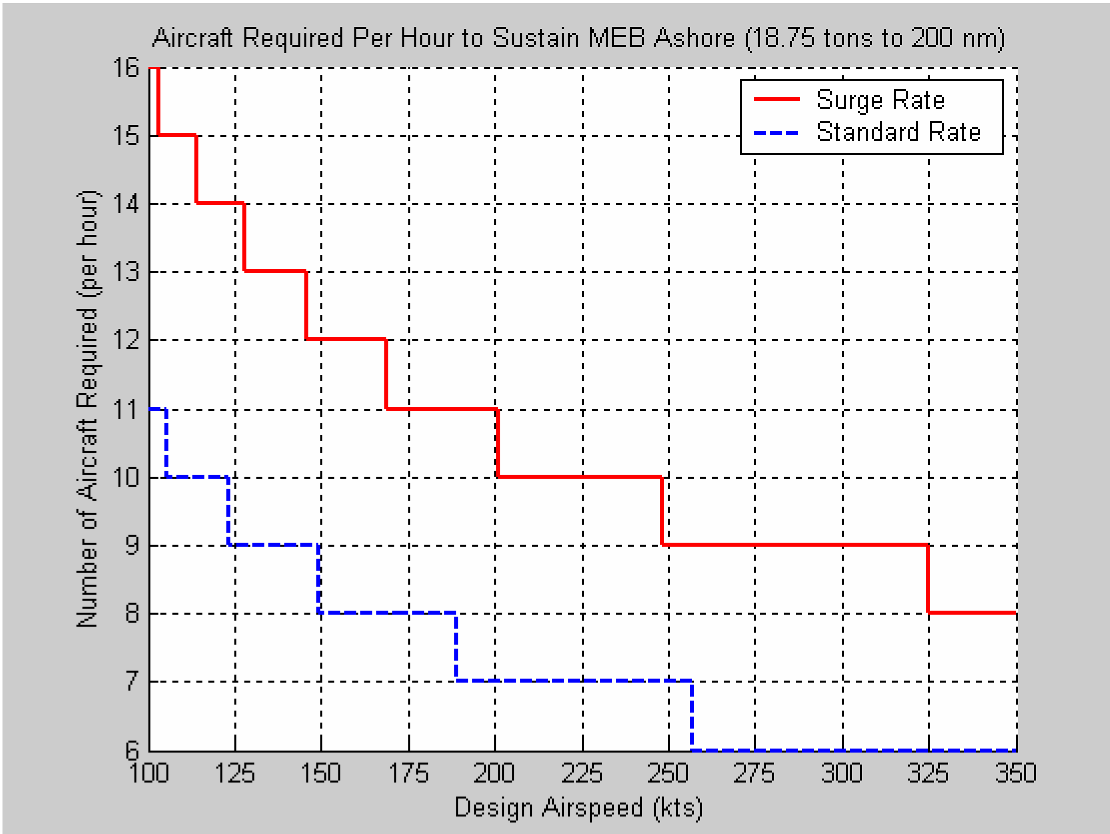

Figure XIV-3: Number of Aircraft Required vs. Speed (Source: Kennedy, 2002)

6. Survivability Requirements

Long range, heavy lift aircraft Combat Survivability was addressed in the term project for the AA4251 Aircraft Combat Survivability course in the 2002 Summer Quarter (Appendix 14-2). Because the Burma scenario had not been fully fleshed out at the beginning of the survivability study, the Indonesian scenario, presented in Chapter V, was used to perform the analysis. Comparison with the completed Burma scenario shows the results for a survivability analysis based on the Burma scenario should not vary significantly from the results obtained with the Indonesia scenario.

The primary threat to the troop and material transport aircraft in either scenario are shoulder fired, infrared (IR) guided SAM with contact warheads and small caliber (7.62 and 12.7 mm) anti-aircraft artillery gun penetrator rounds. The aircraft design must be capable, therefore, of sustained operations in a threat environment consisting of man portable SAMs, small caliber anti-aircraft artillery, and small arms fire with minimum impact on mission capability.

The Combat Survivability study evaluated the quad tilt rotor and compound helicopter design configurations described below for their single shot probability of kill ($P_{K|SS}$) against these weapons in the stated threat environment. All of the design concepts evaluated had only minor differences in survivability features and required the inclusion of the same vulnerability and susceptibility reduction techniques. Signature reduction is required for IR and visible signatures. IR jamming is also required. Expendables, such as chaff and flares, are necessary to defeat modern IR SAM threats. Modification of tactics provided some return, although each design concept had unique advantages in this area. The quad tilt rotor had the ability to transit above most threat envelopes, while the compound helicopter had an advantage in using terrain masking and low level flight to minimize exposure to threat systems. Threat suppression was required in all scenarios to eliminate higher order SAM and anti-aircraft artillery systems. Basic survivability design features are required in both design concepts. In addition to incorporating survivability requirements, the aircraft design must minimize the time required to repair any likely battle damage. For a detailed aircraft combat survivability analysis of the various design concepts, see the Aircraft Combat Survivability Term Project Final Report enclosed as Appendix 15-2.

7. Additional Requirements

The aircraft must be capable of day/night and all weather operations to the maximum extent permitted by the payload. The aircraft must be capable of operating in a temperature range from $-45^{o}C$ to $+60^{o}C$ and up to 12,000 ft MSL (minimum) in mountainous terrain.

In order to maximize operational flexibility and make provisions for self-deployment, the aircraft must be capable of in-flight refueling with current and projected in flight refueling platforms.

In order to minimize turn around time in the objective area, the aircraft must be capable of offloading all palletized payload without any additional manpower using only onboard equipment in 15 minutes or less. Similarly, squadron personnel must be able to load the aircraft on board ship to maximum payload in 15 minutes or less. Squadron personnel must be able to reconfigure the aircraft on board ship from the passenger to the cargo configurations or vice versa in 15 minutes or less. This is comparable to the turn around time achievable with legacy platforms using additional personnel. The intent of these requirements is to maintain the current capability without using additional personnel at the objective or on the flight deck.

In order to accommodate the rapid ebb and flow of future STOM operations, the aircraft must be capable of communicating and exchanging information with the amphibious battle group and ground troops through line of sight (LOS) and OTH systems.

The aircraft must not be less capable in nuclear, biological, and chemical environments than current platforms. The aircraft should be designed to permit easy decontamination aboard ship.

If the final design is a fixed wing aircraft or tilt rotor, the aircraft must be able to take-off and land from the TSSE designed family of ships with the maximum payload and winds over deck of no more than 10 knots and at a temperature of 95^{o} F. If the final design is a helicopter, it must be able to hover out of ground effect (OGE) at 5000 ft MSL and 95^{o}F.

The complete Final Requirements Document for the long range, heavy lift aircraft design is enclosed as Appendix 15-1.

8. Mission Profile

The mission profile presented in Figure XIV-4 below was a non-airframe specific profile to allow initial design concept evaluation. It needed further specification for the aircraft design characteristics unique to the final design concept. Choosing a vertical takeoff and landing aircraft, for example, would require specification of hover out of ground effect conditions and times required for takeoff and recovery.

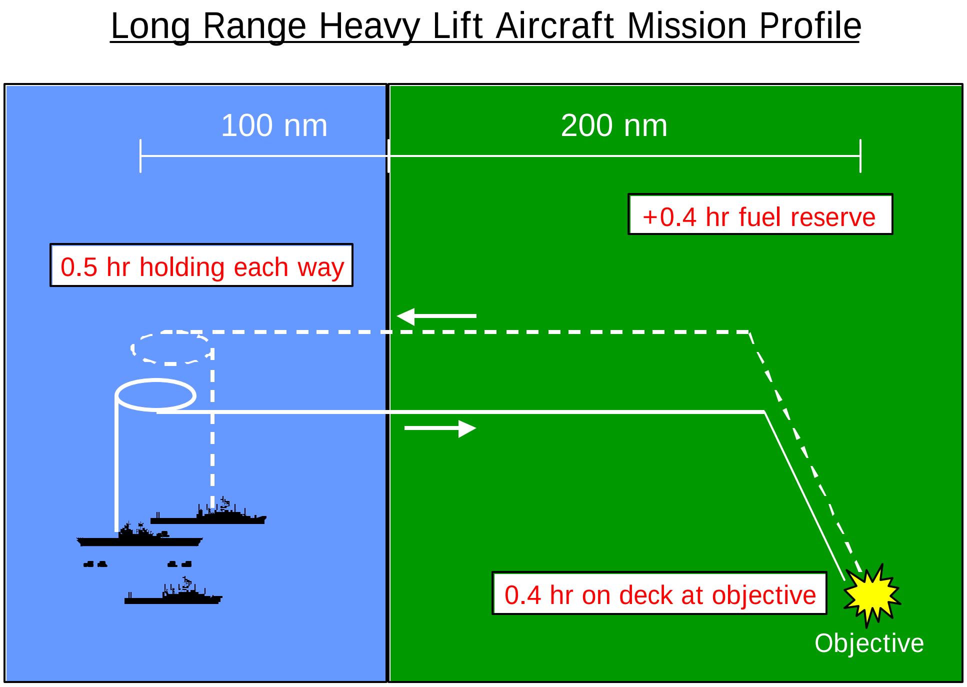

Figure XIV-4: Long Range, Heavy Lift Aircraft Mission Profile

The half hour delays on departure and recovery account for rendezvous with other transport and escort craft and marshalling delays, respectively. The 0.4 hour delay at the objective reflects the takeoff and landing operations plus the 15 minute self offload capability described above. The fuel reserve is roughly 10% of the in-flight mission duration at 200 kts.

9. Shipboard Compatibility

The long range, heavy lift aircraft will operate from ships of the amphibious task force, specifically the Amphibious Assault and Logistics Support variants of the family of ExWar platforms currently under design by the TSSE curriculum and discussed in Chapter XV of this report. To maximize operational flexibility in the interim, the aircraft should also be compatible with legacy and planned force ships, i.e. LHD, LHA(R), and MPF(F), to the maximum extent possible. Compatibility is defined as the ability to launch; recover; load and offload troops, vehicles, and supplies; and the availability of fuel, hanger, and maintenance facilities.

The design aircraft shall have, as a maximum, a spot factor no larger than twice the CH-53E (threshold), but preferably a spot factor no more than 1.5 times that of the CH-53E (objective). The spot factor requirement shall apply to both spread and folded configurations.

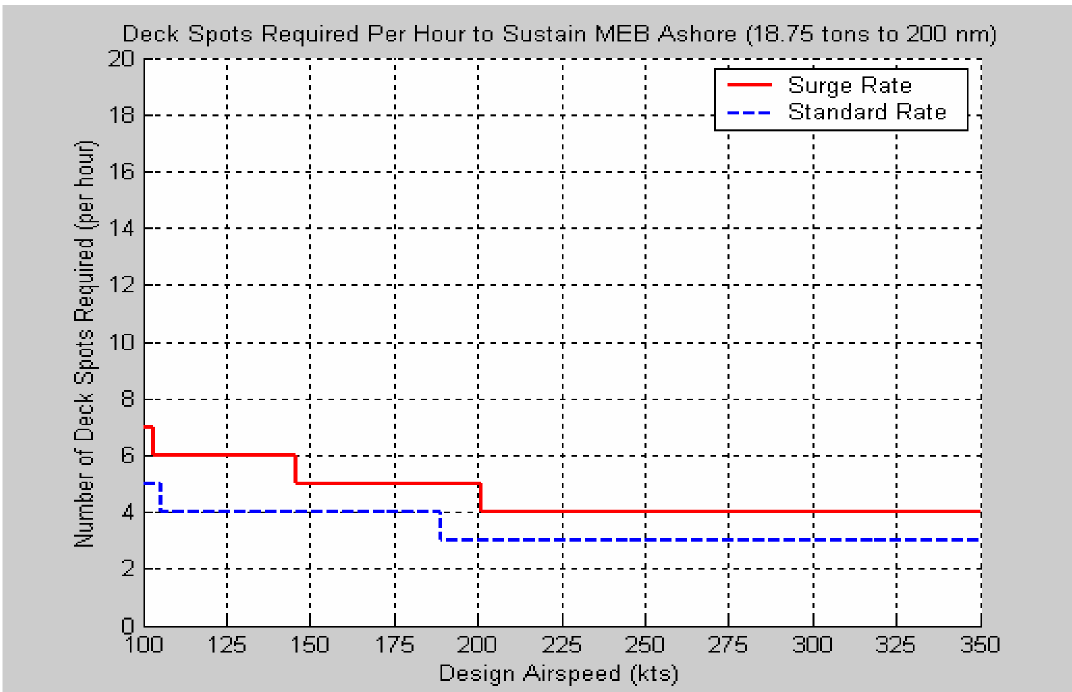

Figure XIV-5: Number of Deck Spots Required for Sustainment vs. Airspeed (Source: Kennedy 2002)

A critical design point for the Family of ExWar Ships under concurrent design by the TSSE curriculum is the number of deck spots required to provide full sustainment of the brigade ashore. The number of aircraft required to provide this support, and thus the number of flight deck spots required, is partly a function of the aircraft's cruise speed. A plot of this relationship is presented in Figure XIV-5.

The lower the number of deck spots required for sustainment, the greater the flexibility of scheduling other operations and spotting resupply materials across the ships of the sea base. Examination of the figure shows that the minimum number of deck spots required occurs when aircraft transit speeds are at or above 200 kts, which is consistent with the target airspeed requirements discussed above. As in Figure XIV-3 above, the plot assumes each aircraft carries the maximum payload (37,500 lbs) of sustainment materials on each trip and that the loading and unloading times for each payload are the same. It does not take into account how the materials are packaged or whether they are carried internally or externally. The sizing of deck spots and associated additional space for spotting and preparing loads for pick up was performed by the TSSE design group based data on the Aero conceptual design and payload characteristics.

Additional shipboard compatibility requirements and their impact on the TSSE design are discussed in Chapter XVI.

C. ANALYSIS OF ALTERNATIVES

Preliminary examination of current aircraft technologies produced five basic design concepts with potential to meet the initial set of requirements: a conventional fixed wing aircraft, a STOVL fixed wing aircraft, a quad tilt rotor aircraft, a compound helicopter, and a conventional helicopter. The Aero engineering design team was broken into groups to evaluate each of these potential solutions against the requirements. Each of these groups gathered data on their assigned design concept from academic and industry sources and verified the potential performance through computerized calculation of the platforms' aerodynamic characterisitics.

The requirement to carry heavy lift payloads at relatively high speeds from a ship to troops ashore led to several obvious design constraints. The aircraft would need to have low disk loading for efficient load carrying. It would need to be fairly fast to attain adequate productivity. It would need a low spotting factor for ship compatibility. The design must be simple to attain low cost and high reliability. To allow takeoff and landing from the ship and unprepared sites ashore required a vertical takeoff and landing (VTOL) or short takeoff and landing (STOL) aircraft.

The basic results from the Analysis of Alternatives for each design concept are discussed below and summarized in Table XIV-1. In depth aerodynamic analysis results and methodology are described in the Aeronautical Engineering Design Group First

Quarter Design Report (Selvy and Goebel, 2002) contained in Volume II of the ExWar study report.

1. Conventional Fixed Wing Aircraft

A conventional aircraft, such as a C-130, C-5, or C-17, can move large amounts of personnel and materials over long distances and at great speeds; however, they are only marginally ship compatible. While C-130s have been landed on nuclear-powered fixed wing aircraft carrier (CVN) class ships as demonstrations in the past, they have not been loaded to operationally representative gross weights. Additionally, these landings were performed to a deck cleared of other aircraft, which is not an operationally viable flight deck configuration. A CVN flight deck is not constructed to withstand repeated touchdowns at large aircraft maximum landing weights. Landings and takeoffs required high winds over deck, which limited the maneuverability and operations areas of the ships. The CVN trials landed and launched a single aircraft at a time. Finally, current and planned assault ships are smaller than today's CVNs. Simultaneous aircraft launch and recovery, in addition to offload and breakdown of transported loads, would require an immense flight deck, considerably larger than today's large aircraft carriers.

Conventional fixed wing aircraft require a relatively large, level, semi-prepared landing strip ashore, as well. Their payloads are large, approximately 80,000 lbs, and would often be too large to handle for the company or smaller sized forces they would be called on to support. Flying these aircraft with half or quarter payloads to better meet the sustainment needs and transport capabilities of small units would result in large excess capacity and waste valuable flight deck real estate to host additional aircraft. Conventional aircraft also do not have the maneuverability to perform "hostile ingressions," and their size and maneuverability severely limit their survivability in a close-quarters ExWar environment.

For this particular mission, a typical fixed-wing heavy lift transport would be an over-design: more range, payload, and speed than required, in addition to the limitations of size and the need to fly at altitude to operate efficiently. Even a scaled-down fixed-wing transport aircraft would likely not be small enough to launch off of an aircraft carrier, whose catapults are currently limited to aircraft on the order of an E-2C Hawkeye or C-2 Greyhound, whose maximum takeoff gross weights are approximately 57,000 lbs. Therefore, based on these considerations of size and STOVL incompatibility, the conventional fixed-wing aircraft was discarded as a possible solution for the ExWar long range, heavy lift aircraft design.

2. Vertical and Short Take-Off and Landing (V/STOL) Aircraft

Vertical and Short Take-Off and Landing (V/STOL) aircraft have the conceptual advantage of merging fixed wing aircraft high speeds with helicopter-like small takeoff and landing area requirements. The ability to lift large amounts of materials from a Sea Base ship without a takeoff roll and transport it at high speeds to the troops ashore has obvious appeal for the ExWar design.

V/STOL aircraft come in many sizes and configurations and are discussed here in general. There are two V/STOL heavy lift aircraft currently in the initial stages of development for military use. The Bell helicopter quad tilt rotor displays a unique potential with regard to the mission requirements and is discussed separately below. The Boeing Advanced Theater Transport tilt wing concept developed by their Phantom Works is roughly the size and weight of a C-130 and is not capable of vertical takeoff or landing. It is expected to have many of the same shipboard compatibility issues as the conventional fixed wing aircraft and was not considered in this study.

While a notional V/STOL design should have no difficulty meeting the speed and radius of action requirements, lifting a 37,500 lb payload could prove difficult. Past V/STOL designs have not had payload capabilities much in excess of approximately 20,000 lbs. The power required to lift this payload in a vertical or nearly vertical takeoff is quite high, leading to high fuel consumption and subsequent adverse range impacts. A large engine scaled to meet this high takeoff power requirement would then have to be carried throughout the remainder of the mission, further decreasing fuel efficiency.

	37,500 lb Payload	300 nm Radius of Action (unrefueled)	200 –225 kt transit speed	Shipboard Compatibility	Survivability	Summary
Helicopter						UNDERDESIGN
Compound Helicopter						CANDIDATE
Quad Tilt Rotor						CANDIDATE
VSTOL Airplane						OVERDESIGN
Conventional Airplane						OVERDESIGN

-- Likely to meet requirement

-- May have difficulty meeting requirement

-- Unlikely to meet requirement

Table XIV-2: Requirements Compatibility Matrix for the Long Range, Heavy Lift Aircraft

The shipboard compatibility aspect is difficult to address, since there are no examples of V/STOL aircraft in this size class. V/STOL aircraft are essentially fixed wing aircraft, so in order to lift the design payload, they must be roughly the size of a conventional aircraft with a similar payload. Their gross weight is typically larger, since V/STOL aircraft need additional engine power and thrust vector altering mechanisms to accomplish a short takeoff. A V/STOL design concept, then, would encounter many of the same shipboard compatibility issues as the conventional aircraft discussed above.

A V/STOL aircraft has roughly the same size and maneuverability as a conventional fixed wing aircraft and thus roughly the same survivability issues. Further, the more complex engine mechanisms required for V/STOL capability increases the aircraft's vulnerable area, increasing the vulnerability relative to a comparably sized conventional airplane.

A final consideration is the historical engineering difficulty encountered in bringing V/STOL designs to fruition. Over the past 40 years, numerous and varied V/STOL design concepts have been prototyped, from tilt props and tilt wings to vectored thrust and designs incorporating separate lift and cruise engines. Of the 45 major designs documented by ANSER Corp.(undated), only two, the AV-8 and the YAK-38, have led to operational aircraft, and only the Harrier remains in operational service today. Two others, the X-35 and the MV-22, are in the Engineering Manufacturing and Development stage of procurement. The remaining historical V/STOL configurations were complex and expensive, and most proved notoriously difficult to produce and field.

As a result of its potential shortcomings in meeting the payload, shipboard compatibility, and survivability requirements, a generic V/STOL aircraft was not considered further as an ExWar heavy lift aircraft design concept.

3. Quad Tilt Rotor

One design concept among the V/STOL aircraft displayed a much greater potential to solve the problem of designing an ExWar heavy lift aircraft, and was therefore broken out separately for consideration. The quad tilt rotor concept, similar to the Advanced Transport Rotorcraft concept currently being advanced by Bell helicopter, is based on MV-22 tilt rotor technology. A pair of additional nacelles mounted on a second wing, are attached to a C-130 sized fuselage, giving a total of four prop rotors to provide thrust for hover and forward flight. A model of the Bell quad tilt rotor and its relative size to the MV-22, are presented in Figure XIV-7 below.

Quad tilt rotor technology offers several distinct advantages over other V/STOL platforms. First, the design has the size and power to carry a reasonable percentage of the 37,500 lb payload requirement outlined in requirements document while remaining ship-compatible. Secondly, a quad tilt rotor would have a large speed advantage over a conventional or even compound helicopter. Because of its ability to fly as a pure prop-driven airplane in forward flight, and will easily exceed the 200-225 kt target airspeed.

Figure XIV-7: A Quad Tilt Rotor Design and the MV-22 (Source: Bell Helicopter)

Initial analysis showed that it may, in fact, be faster than the MV-22, even when carrying a maximum payload. Thirdly, the quad tilt rotor is more maneuverable than conventional fixed wing aircraft and the tilt rotors provide the flexibility to use either very low level or high level ingress, as appropriate, to reduce exposure to anti-aircraft threats. Its vertical landing capability eliminates the need for long approaches to a prepared site, which also increases threat exposure times. Last, and most significantly, the Quad Tilt Rotor takes advantage of existing technologies and components, in particular the tilt rotor nacelles of the V-22 Osprey and tentatively (for the purpose of the Analysis of Alternatives) the fuselage of the C-130 Hercules. The 2015-2020 timeframe of the ExWar project does not provide a sufficient period to depend on the research, development, and production of a significant technology breakthrough to provide radically different alternative propulsion and structural solutions.

The quad tilt rotor is an option that very nearly satisfies the system requirements and could be designed almost immediately; however, there are still several unresolved issues with the basic design as evaluated for the Analysis of Alternatives. The first concerns the props on the MV-22 nacelles: at the time of the analysis, Bell was developing a four-bladed version of the props to use on the quad tilt rotor in place of the three-bladed props used on the MV-22. The performance increase, and thus the speed and payload increase, which would be gained from this four-bladed prop is unknown. A C-130 fuselage was chosen to evaluate the quad tilt rotor design concept due to the readily available data on its characteristics; however, is there a fuselage that would increase the performance of the quad tilt rotor sufficiently to justify not using a common, pre-existing fuselage? Also, will the cargo bay of the quad tilt rotor, regardless of the fuselage used, be able to satisfy the mission requirement of loading and unloading using only the aircrew in fifteen minutes, or will an external load system be necessary, reducing internal cargo capacity? Finally, what will be the aerodynamic effects of sticking four tilt rotors and two large wings onto one fuselage? Will the trailing vortices off the upwind tilt rotors interfere with the downwind tilt rotors? Could the tilt rotors be situated such that the trailing vortices from the upwind tilt rotors flow over the rear wings like a coupled-canard, and generate additional lift (thus improving range or decreasing required onboard fuel)? While these questions remain, the Quad Tilt Rotor, based on the mature tilt rotor technology developed for the MV-22, is a lower risk option than a new design concept V/STOL aircraft such as those discussed above.

While there are numerous design considerations needing further analysis, the quad tilt rotor design concept has excellent potential to fulfill the ExWar long range, heavy lift aircraft design requirements because of its payload, range, speed, shipboard compatibility, and survivability characteristics, as well as the maturity of the underlying tilt rotor technology, and was, therefore, selected as a candidate for further analysis and potential design.

4. Conventional Helicopter

Conventional helicopters like the CH-53E have been the mainstay of Marine Corps airborne expeditionary logistics for many years. Helicopters have well known speed, payload, and range characteristics. They are inherently shipboard compatible and a wide range of systems is available to help them meet survivability requirements. The relatively slow speed of most helicopters (120-140 kts) means increased threat exposure times and, therefore, additional systems (suppression, decoys, jammers, etc.) are required to counter the modern anti-air threat. The weight of these systems decreases the amount of payload the aircraft is capable of carrying, so the faster and more maneuverable the helicopter, the better.

Helicopters have a limited ability to carry large payloads. As the payload weight grows, the size and or number of engines required increase, as does the size of the transmission required to drive the rotor head. For helicopters with higher disk loadings, such as helicopters designed around shipboard space constraints, the growth of transmission weight can grow incrementally faster than the payload increase until the transmission becomes unbuildable. The 37,500 lb payload required for the ExWar assault and sustainment missions would create these problems in any potential conventional helicopter design solution. By way of comparison, Sikorsky aircraft is looking at upgrading the CH-53E transmission and engines to carry 20,000-25,000 lbs to 300 nm (Van Buiten, 2002) as previously illustrated in Figure XIV-2.

Helicopters are also range limited by their internal fuel capacity and relatively low airspeeds. As payloads increase, fuel consumption increases and range decreases. Additional fuel can be designed in, but usually at the expense of payload capacity. Current helicopters are bumping up against the limit of current engine and transmission technology and there is some risk in attaining the desired 300 nm radius of action with the 37,500 lb payload in an aircraft sized to remain shipboard compatible.

Helicopters are also limited in their forward flight maximum airspeeds by retreating blade stall and advancing blade compressibility. Retreating blade stall is a result of the increased angle of attack resulting from the decreased relative airspeed produced by summing the blades rotational velocity and the aircraft's forward flight airspeed (Figure XIV-9). As the blade rotates through the region, the rapid onset and end of stall conditions on each blade as it passes through the retreating side can put tremendous cyclical loads on the rotor head and flight control support structure, leading to fatigue and premature replacement. In extreme cases, retreating blade stall can lead to a loss of lift on the retreating side of the rotor disk, causing the aircraft to depart controlled flight until blade loads are reduced. The onset of retreating blade stall for a given airframe comes at lower airspeeds for heavier payloads, since the blades have a higher angle of attack for a given airspeed. Advancing blade compressibility effects, or "Mach Tuck," results from the aft movement of the aerodynamic center along the blade chord as the advancing blade speed approaches supersonic velocities. The effects of compressibility are similar to the fatigue and reliability effects of retreating blade stall. For a complete discussion of these phenomena, see Strepniewski and Keys (1984). While there are rotor blade design techniques to limit the onset and effects of blade stall and compressibility, they are unlikely to allow level flight cruise speeds in excess of 200 kts for aircraft of the size and payload under consideration here. As a result, conventional helicopters are only marginally capable of airspeeds approaching the 200 - 225 kt target speed range proposed for the long range, heavy lift ExWar aircraft.

Because of the difficulty conventional helicopters face in attaining the speed, payload, and range required of the ExWar aircraft, they were not considered a viable candidate design concept.

5. Compound Helicopter

A compound helicopter employs an auxiliary propulsion system to provide thrust greater than that which the rotor or rotors alone could produce, allowing dramatically increased forward speeds. Wings may or may not be provided to further reduce the lift required from the rotor system. A compound helicopter has potential advantages over a conventional helicopter design in speed, payload, and range.

The speed advantage is a result of adding auxiliary propulsion to the conventional helicopter. The auxiliary propulsion, whether in terms of a pusher prop, tilt rotor, or ducted tail fan, off loads the main rotor, since it does not have to produce as large a forward thrust vector component for a given airspeed as a conventional helicopter. The addition of a wing further offloads the rotor head, since it now needs to produce less lift for a given payload and airspeed combination. The reduction in blade angle of attack increases the margin for retreating blade stall, allowing increased speeds. Further, since the main rotor isn’t carrying the full load, its revolutions per minute (RPM) can be reduced, increasing the margin for advancing blade compressibility. As a result, compound helicopters are easily able to attain forward airspeeds in excess of 200 kts and perhaps as high as 240 kts, well above the target airspeed zone for the ExWar aircraft.

Because the main rotor head does not need to bear the entire load, a compound helicopter is capable of carrying greater payloads than a conventional aircraft. The decrease in main rotor blade angle of attack and RPM, combined with the wing generated lift, allow heavier payloads without the adverse effects of stall or compressibility. While the wings create some additional drag in forward flight, it can be countered by properly designing the increased thrust provided by auxiliary propulsion systems.

Finally, compound helicopters have greater range than conventional helicopters because of decreased fuel consumption from the offloaded main rotor and the ability to store additional fuel in the wings without automatically reducing payload volume or weight.

Because they overcome the potential risk areas of conventional helicopters while retaining the benefits of survivability and shipboard compatibility, compound helicopter concepts were retained, along with the quad tilt rotor, as candidates for further development. A detailed discussion of the advantages and disadvantages of compound helicopters is found in paragraph XIV.D.1 below.

D. ENABLING TECHNOLOGIES

1. Compound Helicopters

A compound helicopter is a modified conventional helicopter that has an auxiliary propulsion system to provide additional thrust beyond that already produced by the rotors. This extra thrust helps unload the rotor in forward flight and increase forward speeds by delaying the onset of retreating blade stall and advancing blade compressibility effects. Wings may also be incorporated into compound helicopter designs in order to further offload the main rotor during higher speed forward flight.

Figure XIV-8: Model of AH-1Z with vectored thrust ducted propeller and lifting wings (Source: Piasecki Aircraft, 1996)

The helicopter has proven itself as an efficient vertical take-off and landing aircraft. There is, however, a continuing desire to expand the performance capabilities of the helicopter, particularly its speed. A helicopter's maximum forward airspeed is fundamentally limited by the restrictions of retreating blade stall and advancing blade compressibility on the rotor. These effects are the result of combining the rotor's rotational velocity and the forward motion of the aircraft. Because of these aerodynamic limitations, the 249 mph world speed record, achieved by the Westland Lynx (Westland, 2002), is unlikely to be significantly exceeded by a conventional helicopter.

Alterations to the helicopter's configuration are required to achieve higher forward velocities, which requires alleviating the problems of retreating blade stall and compressibility effects on the advancing blade at high speed. One method used to achieve higher speeds is to rotate the rotor(s) forward and use them as propellers, and generating forward flight lift by a fixed wing. This is the basis of the tilt rotor concept. A more conservative solution is to modify the existing helicopter configuration, augmenting the rotor as a form of lift and thrust with the addition of a wing and an auxiliary propulsion source. This is the basis of the compound helicopter concept.

A wing increases in lifting effectiveness with increasing velocity, which complements the decreasing effectiveness of the rotor on a Compound Helicopter, offloading its thrust requirements. The auxiliary propulsion of a Compound Helicopter also off-loads the rotor of its thrust requirements, but more importantly eliminates the need for the rotor disk tip path plane to tilt forward in flight in order to generate a forward component of the rotor lift vector. The reduction in rotor thrust therefore reduces the required rotor collective pitch and delays the associated blade stall and compressibility effects until higher aircraft forward flight velocities. Since the wing of a compound helicopter unloads the main rotor, retreating blade stall, which limits most conventional helicopters to forward flight speeds of about 150 kt., does not become an issue in compound helicopters until about 240 kt.

Unlike the tilt rotor concept, the compound helicopter retains the large main rotor, which also retains the helicopter's good hover and low speed maneuverability characteristics. The combination of the rotor and wing also give the compound helicopter two sources of lift to call upon at high speed, so the aircraft has improved forward flight maneuverability over a similar conventional helicopter. Additionally, off-loading the rotor reduces the main source of aircraft vibration, allowing much lower design vibration levels, resulting in significant improvements in reliability and reducing crew fatigue. The compound helicopter has a developmental advantage over the tilt rotor aircraft in that it is a less complex evolution of conventional helicopter designs which should encounter fewer developmental technical difficulties.

The compound helicopter does present some aerodynamic and design difficulties. Adding the wing increases the aircraft's weight and blocks a portion of the rotor downwash during hover flight. These factors can adversely impact the payload that can be lifted, which is crucial to the aircraft's productivity. There is also the added complexity of the wing structure and the transmission or power supply for the auxiliary propulsion source. The aerodynamic interactions between the rotor, wing, and stabilizer can be complex, and can severely affect the performance of the wing in particular, if the interactions are not properly taken into account in the design.

Compound helicopter design seeks to minimize hover and payload penalties and reduce the increased mechanical complexity relative the conventional helicopter, while simultaneously maximizing the forward flight speed, maneuverability, and range that give the compound helicopter a distinct advantage over conventional helicopter designs.

The challenging speed, payload, and range requirements resulting from the STOM operational concept demands new technologies like the compound helicopter be studied for applicability in any new designs.

2. Tip Driven Rotor Systems

In tip driven rotors, air is pumped out through piping in the rotor blades and then ejected either directly aft or at a downward angle through small trailing-edge orifices or jets at or near the blade tips. The exit of these high pressure gases provides the propulsive force necessary to keep the rotor turning and can simultaneously produce substantially increased lift over transmission driven rotor blades with conventional airfoil sections. There are several different concepts used to generate the high pressure gases required. Some designs use engine exhaust or compressor bleed air and pump these gases through plumbing running the length of each rotor blade. Others use the transmission to pressurize air, which is then pumped to the tips and combined with atomize fuel to generate jet propulsion directly at the blade tips. This last design concept, incidentally, would not require engines in the conventional sense, since combustion occurs at the blade tips.

The greatest advantage to tip propulsion is elimination of the transmission and the resulting anti-torque requirement in single-rotor helicopters. Without the torque generated by the transmission driving the main rotor head, a tail rotor or other anti-torque device is no longer required. A tip driven system's increased lift potential could be used to prevent retreating blade stall or to reduce the tip speed to avoid compressibility problems to augment or in lieu of the similar effects gained from employing a compound helicopter concept. Additionally, by varying the effect both collectively and cyclically, the system could replace the feathering bearings used in conventional helicopters, simplifying main rotor head design and reducing maintenance requirements.

Tip drive systems are not without drawbacks, however. All pressure jet schemes for driving the rotor have a low efficiency: around 40%, as opposed to approximately 80% for a conventional transmission driven system (Prouty, 2000). Efficiency is reduced because a large amount of energy is required to accelerate the drive air's momentum up to the rotational speed of the blade tip nozzle. The system for moving high temperature and pressure air from the engines or transmission to the rotor head and out through highly flexible rotor blades is complex and has historically proved difficult to manufacture. The pressurized air system is highly susceptible to fatigue and other failure modes. Finally, a potential safety problem exists in that rotor control can be lost following engine failure, since, while autorotative flow through the disk would maintain rotor RPM, aircraft control is entirely dependent on the engine pumping air out the blades. If this particular tip drive scheme is used, a back up source of pressurized air is required to guarantee aircraft control.

Tip drive technology has been revisited periodically since the late days of World War II. With the increased emphasis on high speed transport required by the new STOM operational concept, tip drive technology should be reexamined for applicability to new aircraft designs.

3. Reverse Velocity Rotor Systems

Reverse velocity rotor systems are a very recent development, designed to address the aerodynamic issues contributing to the retreating blade stall and advancing blade compressibility phenomena that currently limit maximum helicopter forward flight speeds. Reverse velocity rotor systems represent a revolutionary high speed VTOL configuration. By taking a new approach to address high-speed aerodynamic issues, these systems are capable of attaining speeds significantly greater than conventional, or even compound helicopters. Initial analysis shows cruise speeds in excess of 300 kts are possible with these systems.

Reverse velocity rotor systems are built around double-ended airfoils. This airfoil design minimizes the impact of retreating blade apparent velocity reduction caused by summing the blades rotational velocity and the aircraft's forward flight velocity as illustrated in Figure XIV-9 below. At high forward airspeeds, the retreating blade can, theoretically, be in a reverse flow condition, which, with conventional rotor blades, would completely eliminate the potential to generate lift. Use of a symmetrical, double ended airfoil allows the generation of lift with both forward and reverse flows across the blades, which would allow the generation of lift on the retreating side at a dramatically wider range of airspeeds than conventional blades.

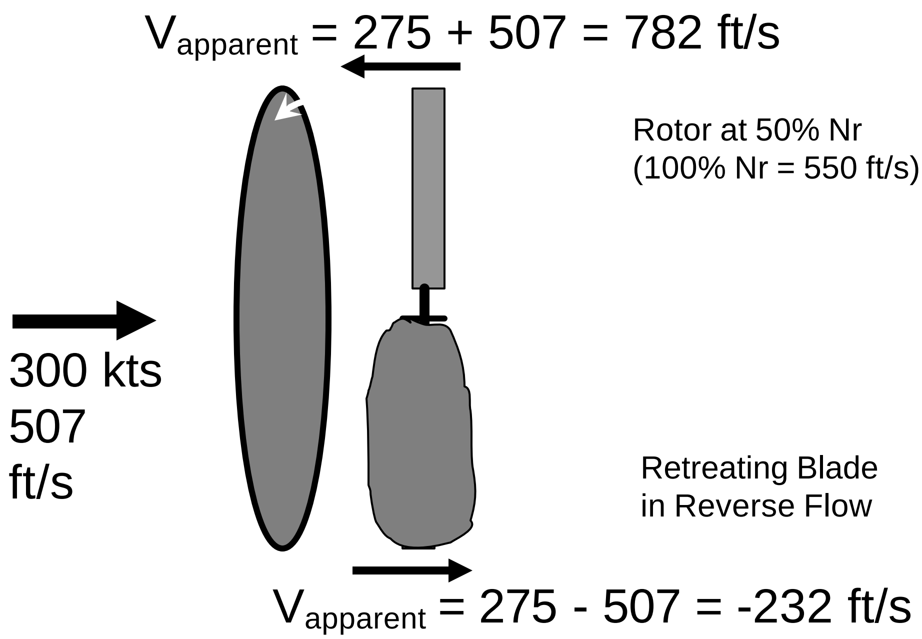

Figure XIV-9: Airflow Across a Helicopter Rotor System at High Forward Airspeed (Source: Ashby and Eadie, 2002)

A variable-speed transmission added into the system can provide additional benefit. As forward airspeed increases, rotor RPM can be decreased to maintain the advancing rotor blade tip Mach number below 0.9. This stabilizes the flow environment across the rotor disk with increasing airspeed and provides for predictable lift generation.

While baseline reverse velocity rotor systems utilize the main rotor as the primary lift source across the entire speed regime, they could be combined with other design concepts to further improve performance. Reverse velocity rotor blade systems, for example, could be extremely useful in design concepts like compound helicopters that utilize auxiliary propulsion. The higher portion of forward speed range possible with auxiliary thrust produces problems simple offloading of the rotor head cannot easily resolve. Aerodynamic problems in this high- speed regime can be addressed, however, with reverse flow concepts. Reverse velocity rotor systems have been demonstrated in wind tunnel tests, and the results are promising.

Unlike the compound helicopter design concepts, reverse flow rotor systems maintain the excellent vertical takeoff and landing characteristics of the pure helicopter. As described above, the hover performance of compound designs can be degraded due to rotor downwash impingement on the wing and the additional weight required by auxiliary propulsion systems. Reverse flow rotors also have the advantage of not requiring reconfiguration during the transition to high-speed flight found in other high speed helicopter schemes such as the stop rotor. Finally, reverse flow rotor systems have a design advantage in that they significantly leverage existing helicopter aerodynamic and design expertise, as opposed to aircraft requiring a revolutionary design approach.

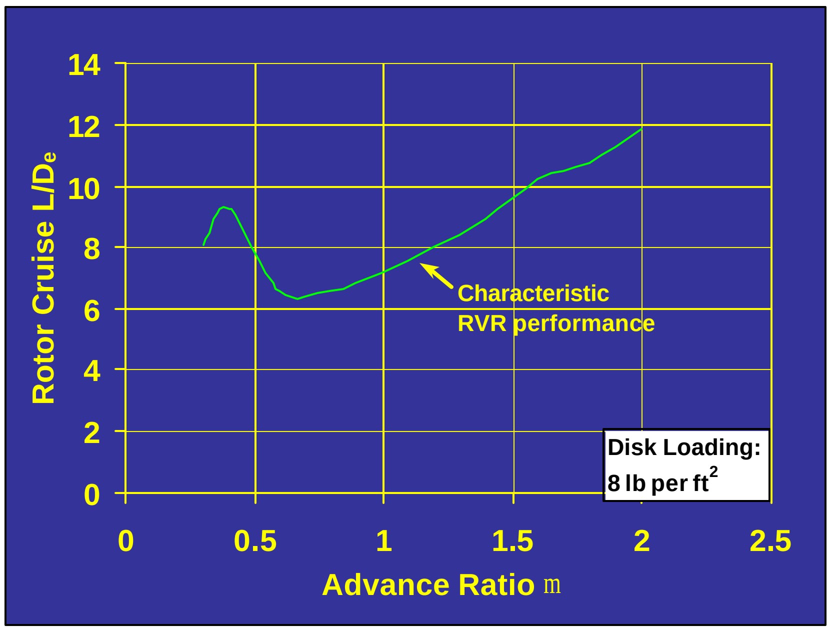

Figure XIV-10: Reverse Velocity Rotor Performance (Source: Ashby and Eadie, 2002)

While reverse velocity rotor systems offer numerous potential advantages in high -speed helicopter design, there are a number of technical issues needing resolution before they can be implemented in an operational design. Airfoil optimization for the rotor blades themselves and aerodynamic optimization of the entire rotor system are open areas of enquiry. The accompanying rotor dynamic analysis required for flight control development must be completed. Flight control laws utilizing Individual Blade Control schemes are needed to implement reverse flow technology. Advanced variable speed transmissions must be developed and the variable speed technology integrated with the flight control laws. Finally, the integration of various auxiliary propulsion schemes and compound wing configurations must be evaluated and incorporated into a working design.

While the technology is still new and developing, reverse velocity rotor systems have the potential to revolutionize the design of V/STOL transports and their contribution to the ExWar mission.

E. DETAIL DESIGN

1. Introduction

Based on the configurations selected in the analysis of alternatives, the aeronautical engineering design team developed five different conceptual designs for evaluation of mission suitability. The designs centered on two different configurations: a single quad tilt rotor design and a four separate compound helicopter configurations.

2. Quad Tilt Rotor Configuration

The quad tilt rotor configuration shown in Figure XIV-11 below has a takeoff gross weight of up to 130,000 lbs and carries up to 20,000 lbs of fuel for the 37,500 lb design payload. Additional details and aerodynamic analysis of the quad tilt rotor configuration can be found in the Aero design team’s First Quarter Report, enclosed as Appendix XX.

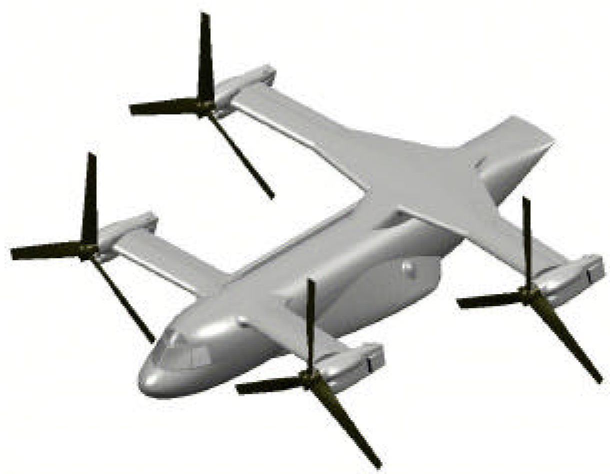

Figure XIV-11 Quad Tilt Rotor Concept Configuration (Source: Aero Design Team)

3. Compound Helicopter Configurations

The compound helicopter concepts varied widely, as shown in Figures XIV-12 through XIV-15 below; however, because of the common requirement and the use of the existing C-130 fuselage in initial designs, in general, the following characteristics can be expected of the compound solution:

Length = 100-135 feet
Width = 78-90 feet
Height = 22 feet
Main Rotor Diameter = 78-90 feet, 6-7 blades
Wing Area = 500-650 square feet
Weight = 110,000-120,000 lb MGW (full fuel and 40,000 lb payload).
Fuel Weight for mission = 19000 lb.
Payload=40,000 lb
Range=600 NM
Speed 220 knots

Rotor drive can be either reaction (tip-drive) or conventional, with reaction drive potentially providing additional benefit as discussed in paragraph D.2 above. The reaction drive contemplated for the conceptual design uses only high-pressure air from the engines' gas generator output at the rotor tips instead of tip jets, so fuel will not be passed through the rotor blades. Additional details and aerodynamic analysis of the compound helicopter configurations can be found in the Aero design team's First Quarter Report, enclosed as Appendix XIV-XX.

a. *The Compound Tilt Rotor Concept*

The first concept envisions equipping a compound helicopter with tilt rotor nacelles on a wing forward of the main rotor disk as shown in Figure XIV-12. In hover the forward nacelles are oriented vertically to increase disc area providing hover thrust. In forward flight the nacelles rotate forward to provide auxiliary thrust and the lift loading is borne by the main rotor and the forward wing. The tilt rotor wing is placed forward, rather than aft, of the main rotor to prevent adverse vibrations caused by main rotor wake impingement on the tilt rotors' attached wing.

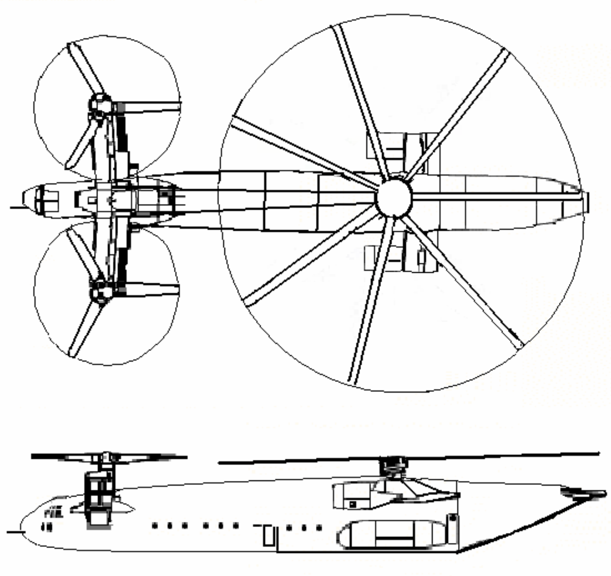

Figure XIV-12: Compound Tilt Rotor Concept (Source: Aero Design Team)

The compound tilt rotor is envisioned as a four-engine machine. Two engines are located in the tilt rotor nacelles to drive the prop rotors. The remaining two engines are located aft, astride the transmission and drive the main rotor. Counter-torque can become an issue in this concept, since there it is not possible to balance out the large main rotor torque by conventional means such as counter-rotating the forward prop rotors. It is therefore expected that the two aft engines will independently drive the main rotor through a reaction (tip-drive) mechanism and the forward prop rotors will counter rotate to eliminate torque.

b. *The Cheyenne Pusher Concept*

The AH-56 Cheyenne was the last compound helicopter developed for the U.S. military in the late 1960s and early 1970s. It featured a large wing carrying ordnance and a pusher prop in the tail for increased forward flight speeds. Although developmental flight test results proved the soundness of the compound-pusher configuration, the Cheyenne lost out to the AH-1 Cobra as the Army's new attack helicopter design.

The Cheyenne Pusher concept is a compound helicopter with a mid-body wing, conventional rotor, tail rotor, and pusher propeller as shown in Figure XIV-13.

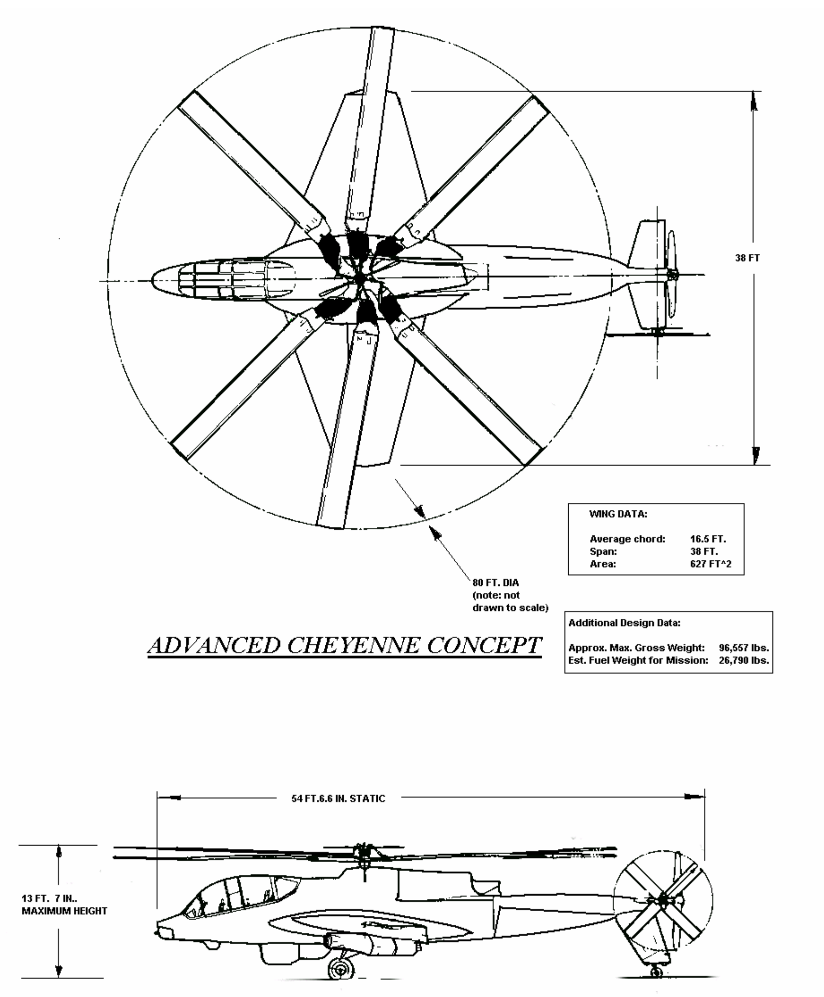

Figure XIV-13: The Cheyenne Pusher Concept (Source: Aero Design Team)

Although not explicitly shown, it is envisioned as a four-engine machine. Note that the dimensions and fuselage configurations shown below are not representative; however, an accurate set of the aircraft's initial dimensions are provided in the figure. The fuselage is expected to be much more substantial to handle anticipated cargo dimensions. A variation of this concept that uses a ducted fan for both directional control and forward propulsion is also contemplated.

c. *The Reaction Pusher Concept*

The third design concept is a compound helicopter with two wings, reaction driven rotor, and two pusher propellers as shown in Figure XIV-14 below. Although not explicitly shown, it is envisioned as a four-engine machine. Anti Torque is not required due to the reaction main rotor drive.

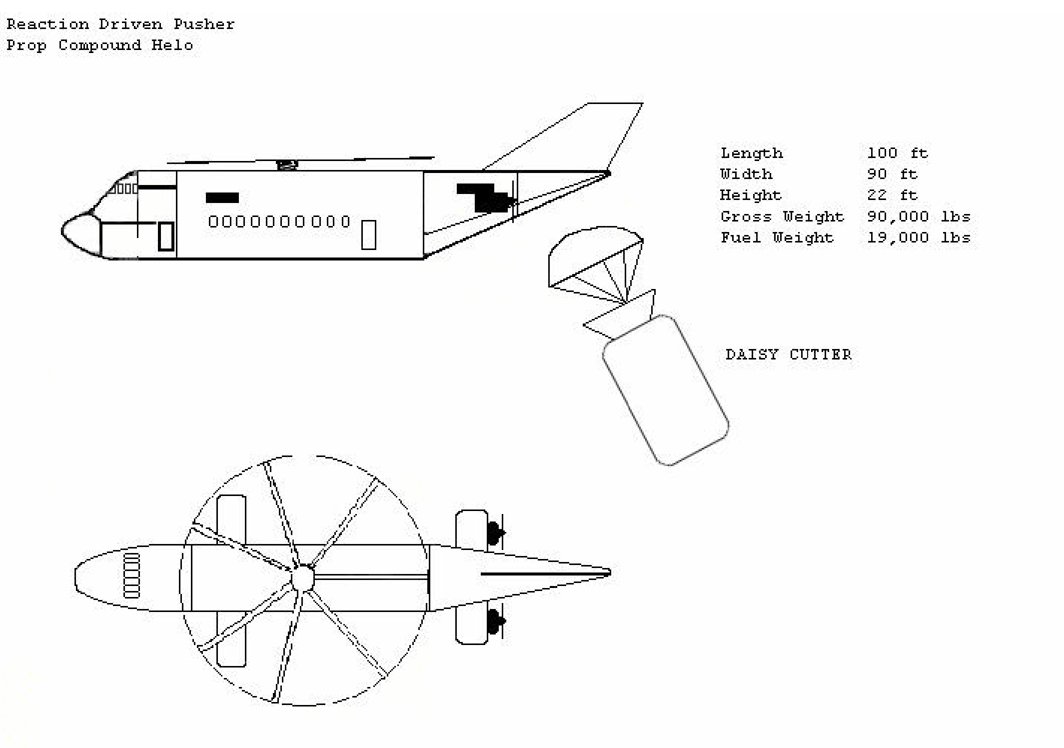

Figure XIV-14: The Reaction Pusher Concept (Source: Aero Design Team)

d. The Tandem Compound Concept

The fourth concept is a tandem main rotor compound helicopter with a mid-body wing and two main rotors. The rotors are conventionally driven and counter rotate for anti-torque. Although not explicitly shown, it is envisioned as a four-engine machine. Two engines provide thrust to both main rotors in a conventional manner such as found in the CH-46 and CH-47. The other two engines provide auxiliary propulsion. It has not been determined whether these engines will be turbo props or jet engines.

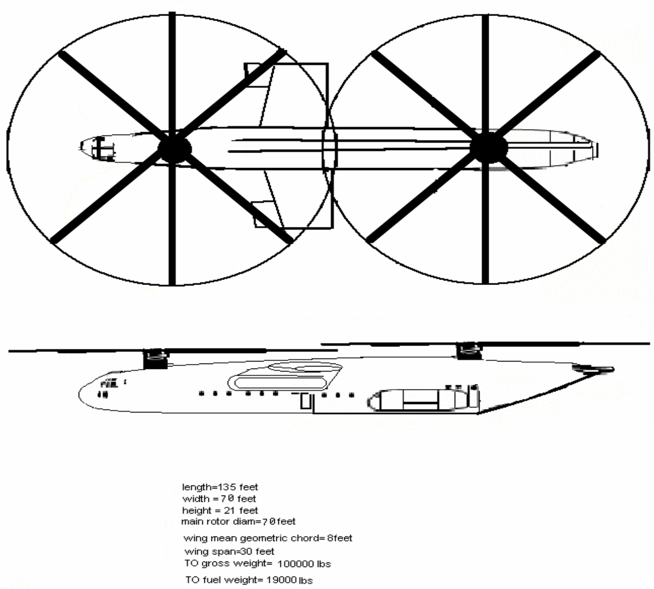

Figure XIV-15: The Tandem Compound Concept (Source: Aero Design Team)

4. Final Design Concept Selection and Detailed Design

Final design concept selection and detailed design will occur in the Winter Quarter and will be complete at the end of March, 2003. The final design report will be incorporated as Volume II of the ExWar Integrated Project report at that time.