XVIII. RECENT NPS ENGINEERING DESIGNS APPLICABLE TO THE EXPEDITIONARY WARFARE PROJECT

A. INTRODUCTION

In recent years, NPS design classes have produced numerous conceptual designs for various sponsors, government agencies, and academic competitions. These ship and aircraft designs were reviewed for their relevance to expeditionary warfare as part of the ExWar design project selection process. Designs with the potential to fill capabilities gaps identified in the Top Down analysis were collected and evaluated for their potential to fill the gap. The following five designs, three aircraft and two surface ships, were judged to have high potential to fill capabilities gaps identified in the Top Down analysis.

The intent of this chapter is to present these recent NPS designs with the potential to fill some of the capability gaps identified in the Top Down analysis, with emphasis on the system's requirements, the analysis of alternatives leading to the final design configuration, and a brief description of that configuration. It should be noted, however, that the requirements driving these particular design solutions were not generated by the ExWar Integrated Project as part of a system of systems effort. As a result, in some cases the systems presented below were designed to meet mission requirements or scenarios that were not compatible with those derived in the Top Down analysis. This divergence in mission and scenario is noted where it potentially impacts the systems compatibility with the Integrated Project's requirements. In most cases, though, the differences in scenarios or operational concepts used to develop the conceptual designs did not significantly impact their potential to fill capability gaps.

This chapter contains material such as systems descriptions and analysis of alternatives information taken directly from each project's respective final report. Because of the large volume of imported material, individual paragraphs are not referenced back to the original document. For those interested in additional details on any of the platforms, the Final Reports of these design projects are collected as Volume V of the Integrated Project Final Report.

B. THE VIPER TILT ROTOR ESCORT AIRCRAFT

1. The Capability Gap

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 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.

2. The Viper Tilt Rotor Escort

The Viper is a tandem seat, twin engine, day/night, all weather, V/STOL advanced attack tilt rotor capable of armed escort, attack, reconnaissance, and ground support missions. It has a helicopter like vertical takeoff and a 400 kt dash speed while in airplane mode. The Viper makes use of the latest technology in lightweight structures, advanced propulsion systems, avionics, and armament. Major weapons systems are stowed inboard to reduce drag during high-speed flight, and then extended upon entering the area of operations. The wings are located aft with a forward sweep to provide a full field of view for threat identification and weapons employment. With additional weapons and fuel stores, the Viper is capable of conducting extended close air support and armed reconnaissance missions. A modern environmental control system allows the Viper to conduct limited operations in nuclear, biological, and chemical environments. The Viper is also capable of aerial refueling to allow for a self-deployment range in excess of 2450 NM. Designed for high altitude, high temperature conditions, it can support Marine and joint forces during combat in any theater of operations. The Viper's external configuration is presented in Figure XVIII-1 below.

Figure XVIII-1: The Viper Tilt Rotor Escort (Source: McEwan, et al., 1997)

3. Requirements Analysis

A team composed of members of the American Helicopter Society (AHS), helicopter industry, and the National Aeronautics and Space Administration (NASA) provided the requirements for the design competition. The Request for Proposal (RFP) described the following key requirements:

1) operate from the same ships as the MV-22;
2) have a two man crew;
3) have two or more engines and have a disk loading in a hover out of ground effect (HOGE) at primary mission gross weight (PMGW) of no more than 20 lbs/ft^2;
4) meet flight performance requirements under Navy Hot Day conditions;
5) have a vertical rate of climb (VROC) of at least 1000 fpm at PMGW with maximum rate power at sea level;
6) be capable of 400 kt dash speeds at 3000 ft;
7) maintain altitude and airspeed while maneuvering from –1.5 to +5.0 g at 250 kts, 3000 ft, and PMGW;
8) carry a primary mission payload of at least one turreted 20 mm cannon and 1500 rounds of ammunition, 4 AIM-9L Sidewinder air-to-air missiles, and 4 AGM-114 Hellfire air-to-ground missiles;
9) and be able to execute the mission profile contained in Figure XVIII-2 below.

The focus of the design competition requirements was the design of an aircraft capable of providing armed escort to MV-22 Osprey aircraft during ship to shore operations. The aircraft would also be capable of providing high speed, armed escort for the Long Range, Heavy Lift Aircraft currently under design as part of the ExWar Integrated Project. The design competition Request for Proposal specified that the aircraft must be capable of both engaging in air-to-air combat while escorting MV-22s to the landing zone and providing air-to-ground covering fire for the offload of troops and supplies within the landing zone. The design team's goals were to first satisfy the primary mission requirements and second, to design an aircraft capable of joint operations and combined arms scenarios.

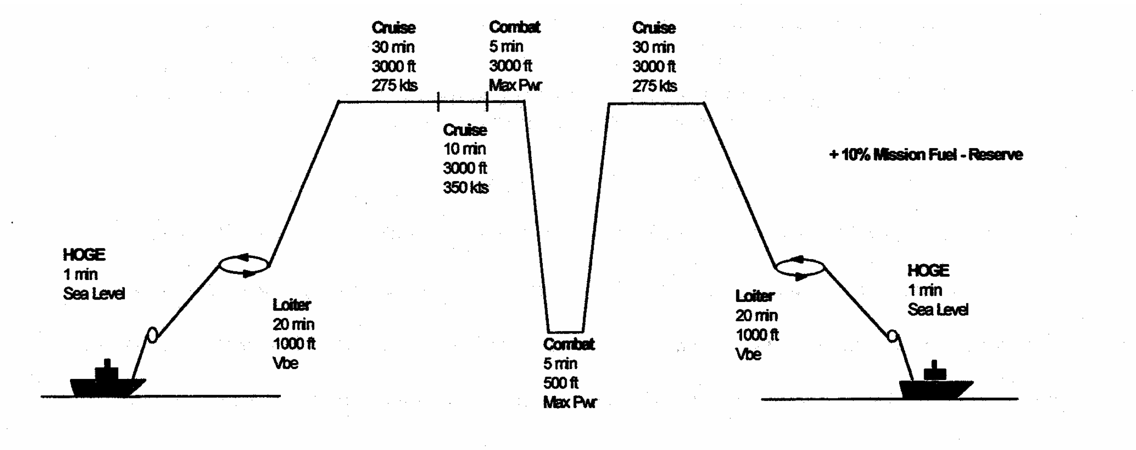

Figure XVIII-2: Tilt Rotor Escort Mission Profile (Source: McEwan, et al., 1997)

4. Analysis of Alternatives

In order to meet the requirements outlined in the RFP, several configurations were examined, including an Advancing Blade Concept (ABC) helicopter, a fan-in-wing aircraft, a tilt wing design, and a tilt rotor. The first step in the analysis was screening the concepts for the capability to perform the escort mission, and eliminating those designs that were unable to perform the mission. The results of this analysis are presented in the Screening Criteria Matrix presented in Table XVIII-1 below. The first six requirements come directly from the RFP. The seventh column, "Available Technology," was introduced by the design team to assess whether the technology needed to design, manufacture, and field a given configuration was available now or under development.

CONFIGURATION	RFP REQUIREMENT					
	DISC LOADING	*DASH SPD 400 KTS*	*1000 FPM VROC*	*MANEUVER ENVELOPE*	*MISSION PAYLOAD*	*AVAILABLE TECHNOLOGY*
ABC CONCEPT	YES	NO	YES	MAYBE	YES	YES
SLOWED/STOPPED ROTOR	YES	YES	YES	YES	YES	MAYBE
X-WING OR ROTOR-WING CONCEPT	YES	YES	YES	YES	YES	MAYBE
V/STOL JET	NO	YES	YES	YES	YES	YES
COMPOUND	YES	NO	YES	MAYBE	YES	YES
FAN-IN-WING	NO	YES	YES	YES	YES	YES
UNDUCTED FAN	NO	YES	YES	YES	YES	YES
TILT-WING	YES	YES	YES	MAYBE	YES	YES
TILT-ROTOR	YES	YES	YES	YES	YES	YES

** SHIP STOWAGE AND MISSION ENDURANCE WERE ACCEPTABLE FOR ALL CONFIGURATIONS.

Table XVIII-1: Tilt Rotor Escort Candidate Concepts Screening Criteria Matrix (Source: McEwan, et al., 1997)

The low disk-loading requirement (< 20 lbs/ft^2) eliminated any design concept, such as a V/STOL jet, with a high downwash velocity. The high dash speed criteria eliminated designs relying on conventional helicopter rotor designs because of the problems caused by retreating blade stall and advancing blade compressibility effects discussed in Chapter XV. Screening the nine initial concepts against these two requirements eliminated five potential designs, leaving the slow or stopped rotor, the rotor-wing, the tilt wing, and the tilt rotor design concepts for evaluation against the remaining criteria.

These remaining concepts were evaluated in a weighted Evaluation Criteria Matrix, Table XVIII-2, in order to determine the configuration best suited to perform the mission. RFP requirements were weighted with a one or two consistent with their relative importance in driving the overall design. Each of the remaining concepts then received a score from one to three based on the concepts ability to meet the requirement. The slowed/stopped rotor received low marks for dash speed and payload due in part to the requirement to fly and maneuver in the airplane mode, which renders the rotor and transmission system dead weight for significant portions of the mission profile. This configuration would also require either separate propulsion systems for the aircraft and helicopter flight modes or an engine that is convertible between modes, the former requiring a lot of excess weight and the latter representing an unproven technology.

The ability to fight and maneuver in airplane mode while taking off and landing in helicopter mode leads to an implied requirement for a rapid transition between airplane and helicopter flight configurations. The X-wing and rotor-wing concepts required extended transition times and high transition airspeeds to successfully execute the conversion and therefore received low marks in these areas. The X-wing configuration also presented a high risk for aeroelastic static divergence on the forward stopped blades.

The tilt wing concept's requirement to widely vary the wing angle during conversion and the need to fold the wing for shipboard storage resulted in a complex and heavy rigid wing tilt/fold system, making it doubtful the wing could successfully withstand sustained +5.0 g loadings.

CONFIGURATION	REQUIREMENTS/WEIGHTING						
	DISC LOADING/2	DASH SPEED/1	1000 FPM VROC/2	MANUEVER ELEMENT/1	MISSION PAYLOAD/1	AVAILABLE TECHNOLOGY DURABILITY/2	TRANSITION/2
SLOWED/STOPPED ROTOR	3	1	3	2	1	1	2
X-WING OR ROTOR WING CONCEPT	2	3	3	3	3	1	1
TILT-WING	2	2	3	1	2	3	2
TILT-ROTOR	2	2	3	2	2	3	3

SCALE: REQUIREMENT WEIGHTING: 1 OR 2 (2 BEING MOST IMPORTANT)
REQUIREMENT RANKING: 1-TO-3 (3 BEING BEST)

Table XVIII-2: Design Concept Evaluation Criteria Matrix (Source: McEwan, et al., 1997)

A key feature of the tilt rotor design was its ability to rotate nacelle angle to change its thrust vector. This adjustable thrust vector would dramatically enhance aircraft maneuverability, allowing the pilot to outmaneuver fixed and rotary wing aircraft in air-to-air combat. In a hover, nacelle angle adjustment produces expanded pitch pointing capability, further augmenting the weapon delivery envelope and potentially allowing the aircraft to engage hostile aircraft while remaining concealed at low altitude. The tilt rotor received moderate or high marks in all categories, and was thus deemed to be the most capable design to provide the mix of speed, maneuverability, payload, and technology required by the RFP.

The final Viper design, described in detail below, meets or exceeds all of the key requirements of the RFP as summarized in Table XVIII-3 below.

RFP Requirement	VIPER Design Capability
Operate from the same Navy ships as the V-22	Deck foot-print less than V-22; deployable from all LPD, LHA, and LPH vessels
Two-man crew	Tandem seating. Pilot occupies front seat, co-pilot/gunner in rear
Two engines minimum	Two T-406 turboshaft engines, identical to the V-22
Disc loading in HOGE at PMGW shall not exceed 20 lbs/ft^2	Two four-bladed rotors with a radius of 14.6 ft
Flight performance requirements are at Navy Hot Day conditions	Power available of 14,950 hp far exceeds power required of 7500 at 3000 ft on Navy hot day
VROC of at least 1000 fpm at PMGW at SL, at Maximum Rated Power	VROC power loading less than that for dash speed of 400 kts
400 knot dash speed at Maximum Rated Power, 3000 ft.	Max speed of 475 kts at 7000 ft
Maneuver capability of –1.5 to +5.0 g at PMGW, 250 kts, 3000 ft, while maintaining airspeed and altitude	With 10° flap deflection, sufficient power and lift for a 250 kts and 5-g turn
Primary Mission Payload: 1. Turreted 20 mm cannon 2. 1500 rounds ammunition 3. 4 AIM-9L air-to-air missiles 4. 4 AGM-114 air-to-ground missiles	Additional capability includes two AGM-114 Hellfire missiles
Primary Mission Endurance: 1. HOGE 1 min at SL 2. Loiter 20 min at V_{BE} at 1000 ft 3. Cruise at 275 kts, 3000 ft, 30 min 4. Cruise at 350 kts, 3000 ft, 10 min 5. Combat at MRP, 3000 ft, 5 min 6. Combat at MRP, 500 ft, 5 min 7. Cruise at 275 kts, 3000 ft, 30 min 8. Loiter 10 min at V_{BE} at 1000 ft 9. HOGE 1 min at SL 10. 10% of mission fuel for reserve	VIPER accomplishes primary mission and still has additional fuel and ammunition for subsequent tasks

Table XVIII-3: Requirements Compatibility Matrix (Source: McEwan, et al., 1997)

5. Detail Design

a. *General Configuration*

The Viper has a 25 deg forward swept, rear mounted wing with a front canard and a V-tail. Overall dimensions are shown in Figure XVIII-3. The fuselage includes a forward, center, and aft section primarily constructed of composite materials, supported by a primary load bearing composite keel beam. The forward section consists of the tandem crew station, electro-optical subsystem, and 20 mm cannon and 1500 rounds of ammunition. The gun is slewable to +15 deg and –45 deg in elevation and +-110 deg in azimuth. The center section comprises six internally mounted Hellfire missiles (two more than required), four externally mounted Sidewinder missiles, the canard, fuel cells, landing gear assembly, drive system, and wing assembly. Internal and external missile carriage configuration is presented in Figure XVIII-4 below.

Two Allison T-406 engines, identical to those used on the MV-22, with an integral infra-red suppression system and the V-tail complete the aft section. The engines are mounted internally and power transmitted through the wings to the nacelles and rotors. This concentration of mass near the aircraft centerline allows for enhanced roll performance relative to a design where the engines are mounted near the wingtips. The Viper has two four bladed prop-rotors, each with a 29.2 ft diameter, that supply sufficient power to meet the level 250 kt, +5.0 g turn requirement and attain a dash speed in excess of 400 kts. Detailed internal views of the Viper are provided in Figure XVIII-5. For additional configuration details and a complete design description of the Viper tilt rotor escort, see McEwan, et al., (1997).

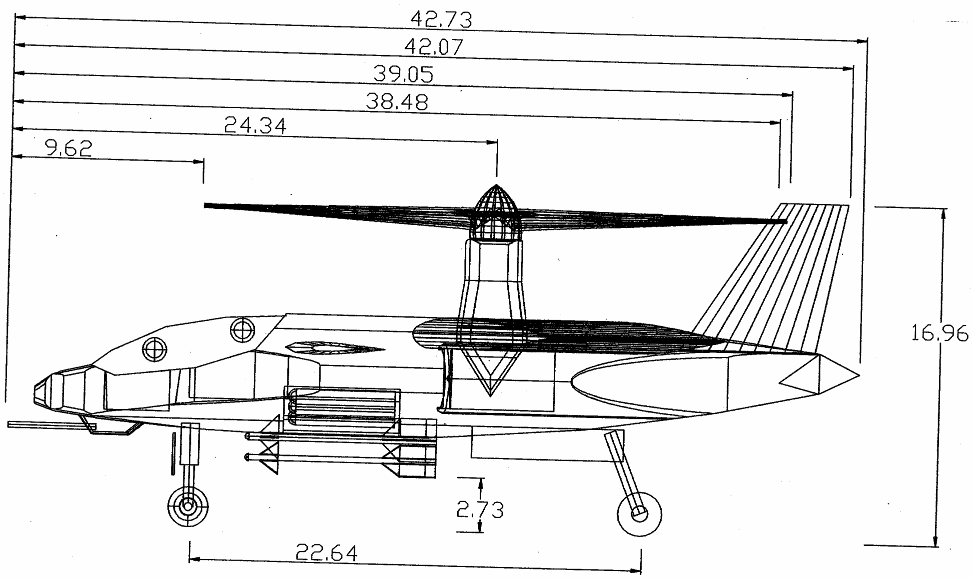

Figure XVIII-3: Viper External Configuration (Source: McEwan, et al., 1997)

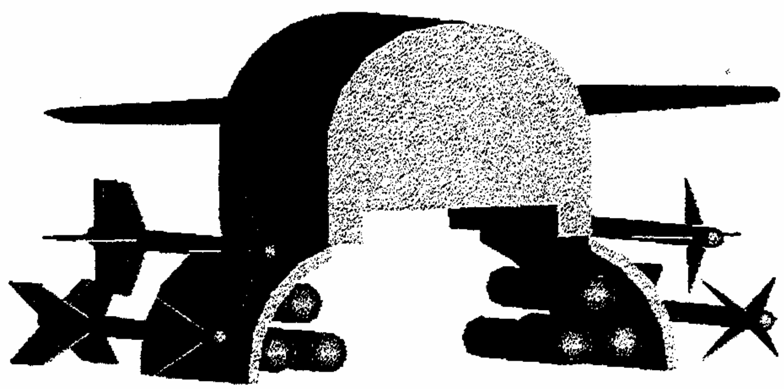

Figure XVIII-4: Viper Internal and External Missile Carriage Configuration (Source: McEwan, et al., 1997)

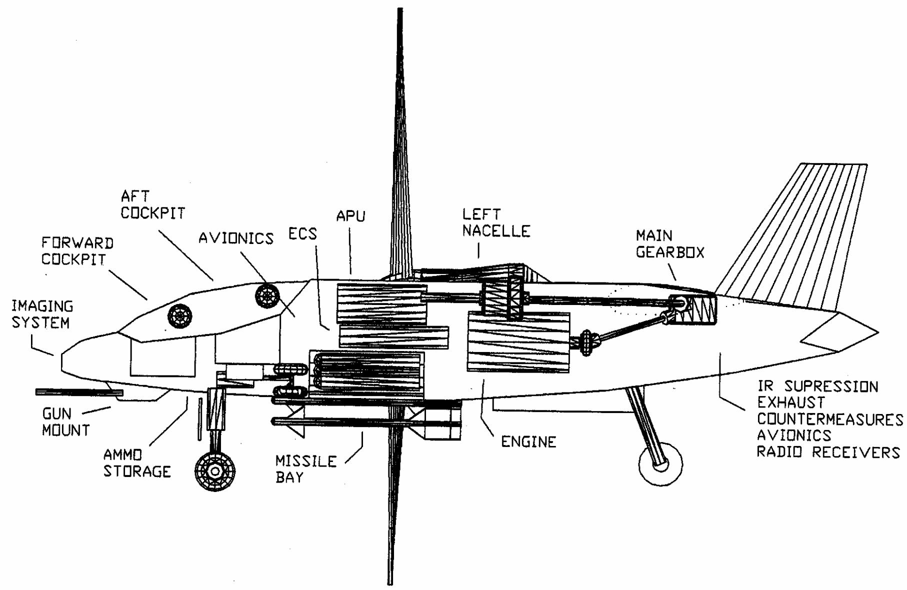

Figure XVIII-5: Viper Internal Configuration (Source: Mc Ewan, et al., 1997)

b. *Shipboard Compatibility*

Shipboard Compatibility is critical to deploying the Viper on LPD, LHD, LHA, and future expeditionary warfare ships. The Viper has a detailed blade and wingfold mechanism to achieve shipboard clearance for all spots, the hanger deck, and elevators. The folded configuration and its deck spotting are illustrated in Figures XVIII-6 and XVIII-7, respectively.

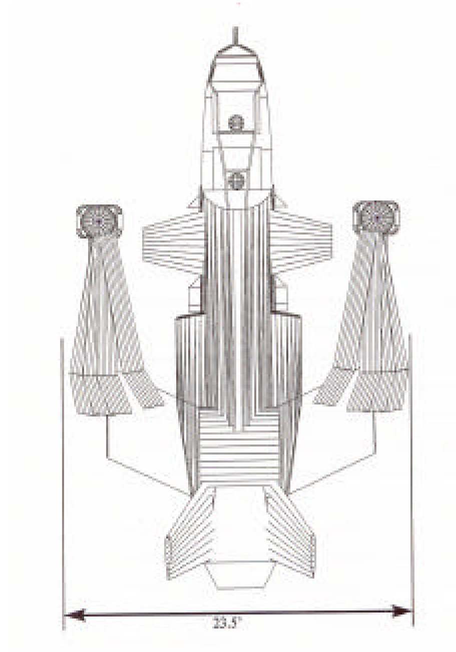

Figure XVIII-6: Viper Folded Configuration (Source: McEwan, et al., 1997)

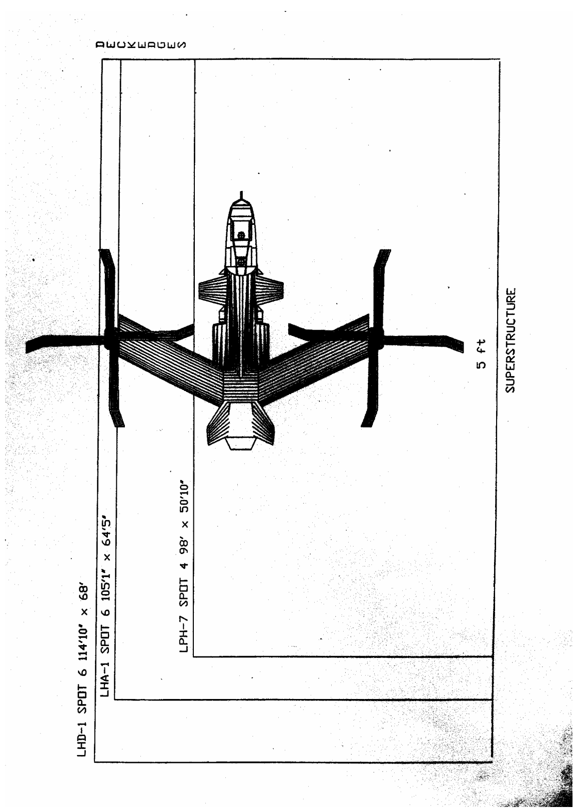

Figure XVIII-7: Viper Spot Factor (Source: McEwan, et al., 1997)

c. *Combat Survivability*

Aircraft combat survivability was an integral aspect of Viper's design. Survivability is defined as the ability to avoid or withstand a man made hostile environment. The Viper design attempted to reduce the likelihood of being detected or engaged by the enemy and, if this effort failed, to reduce the likelihood of a catastrophic attrition kill given a hit on the aircraft. The Viper's threat environment is similar to the Long Range, Heavy Lift aircraft it will be escorting with one important exception: the Viper has a requirement to engage in air-to-air combat against enemy fixed and rotary wing assets in order to protect the escorted aircraft; therefore, air-to-air missiles were considered in the survivability evaluation.

Susceptibility is a measure of the inability of an aircraft to avoid being detected and damaged by the hostile environment. In order to reduce the probability of detection, weapon launch, weapon tracking, and detonation of weapons against the Viper, numerous susceptibility reduction features were incorporated into the design. Radar and IR signatures were reduced through low observable fuselage construction techniques and use of a low infrared engine ejector fairing. The IR signature will be further masked with an ALQ-144 IR Jammer. Both radar and IR expendable countermeasures were designed into the aircraft. The aircraft was equipped with night vision goggle compatible cockpit and external lighting as well as a targeting forward looking IR radar. This will reduce the enemy's ability to detect the aircraft visually.

6. Conclusion

The Viper tilt-rotor escort represents a versatile and relatively low cost solution to the problem of strike and escort aircraft allocation in Expeditionary Strike Groups of the Future. The Viper's capability to perform additional missions of close air support, surface craft escort, and overall force protection increase the ExWar Task Force commander's flexibility in allocating aviation assets in an evolving combat environment.

C. THE SEA SPECTRUM SURVEILLANCE UNMANNED AERIAL VEHICLE

1. The Capability Gap

In order to provide a complete solution to the expeditionary force commander's ISR needs, the Systems Engineering and Analysis team devised a three tiered system of systems to provide the commander with the battle space surveillance they require to successfully complete the mission. The Sea Spectrum represents the middle tier of this system. The first tier consists of short range tactical UAV under the direct control of the ships of the Sea Base or the Marine forces ashore. The third tier consists of space-based assets like the Low Earth Orbit, Multi-Spectral Imaging "Persistent Peepers" satellite system designed by the Space System Operations curriculum. Persistent Peepers is discussed in detail in Chapter XVII.

The Chief of Naval Operations' Vision 21 calls for the deployment of Expeditionary Strike Groups (ESG) to global trouble spots with or without an escorting carrier battle group. While the organic Marine 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 air wing 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, for example, would simultaneously be able to provide early warning to the Marine forces ashore, helping detect inbound aircraft or inbound land attack cruise missiles.

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 battle group whenever the expeditionary strike group 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.

2. The Sea Spectrum Surveillance UAV

The Sea Spectrum UAV is a long range, high endurance, shipboard compatible, twin engine, joined wing unmanned aircraft capable of carrying a Global Hawk sized sensor package to an altitude of 60,000 ft and remaining on station up to 12 hrs at 300 NM from the task force with a 3000 lb combined sensor, avionics, and weapons payload.

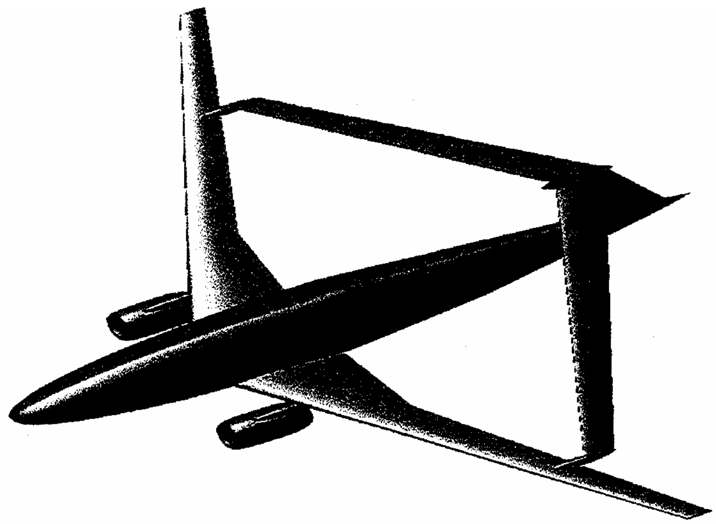

Figure XVIII-8: The Sea Spectrum UAV (Source: Russell, et al., 2001)

3. Requirements Analysis

PROJECT CROSSBOW was a joint venture of the SEI, TSSE, and Aeronautical Engineering programs at the NPS. The overall project goal was to design a total combat system, including ships and unmanned aerial vehicles, capable of quick response to instabilities in the world's littoral regions. One of these UAV designs was for a surveillance asset tasked to patrol ahead of the CROSSBOW force and also act as a command and control link to the other UAVs in the CROSSBOW air wing. The SEI team generated requirements for the Sea Spectrum UAV as part of the overall PROJECT CROSSBOW effort.

The requirements were passed to the AERO team in a Request for Proposal which was then iterated with the AERO design students as the concept evolved. The final iteration contained the following key requirements:

1) a mission radius of 300 NM;
2) a cruise airspeed of at least 400 kts at 60,000 ft;
3) a sustained turn rate of 10^{o} per second and an instantaneous turn rate of 12^{o} per second;

4) a climb rate of 4000 ft per minute at sea level standard day;

5) be capable of sustained accelerations from -1.0 to +3.0 g;

6) have a minimum of 12 hours on station endurance at 60,000 ft;

7) take off unassisted from an LHA using no more than 400 ft of takeoff roll with 25 kts of wind over deck (WOD);

8) carry a total payload of 3000 lbs, 500 lbs of which shall be weapons;

9) and be transportable 4 at a time in a C-5A Galaxy and also capable of self deployment from a forward operating base to the LHA.

4. Mission Profile

The primary mission of the Sea Spectrum UAV is high altitude surveillance of enemy activities via high performance listening and visual imaging devices. Sea Spectrum also has a limited capability to destroy enemy targets with precision guided bombs. Considered more dispensable than inhabited surveillance vehicles, the Sea Spectrum has a reduced need for engagement evacuation and safety features. The relatively high subsonic speed of the vehicle will help insure escape from enemy threats in great enough numbers to offset the cost of any losses, while at the same time saving the cost of incorporating costly afterburner and defensive systems. The Sea Spectrum mission profile is presented below.

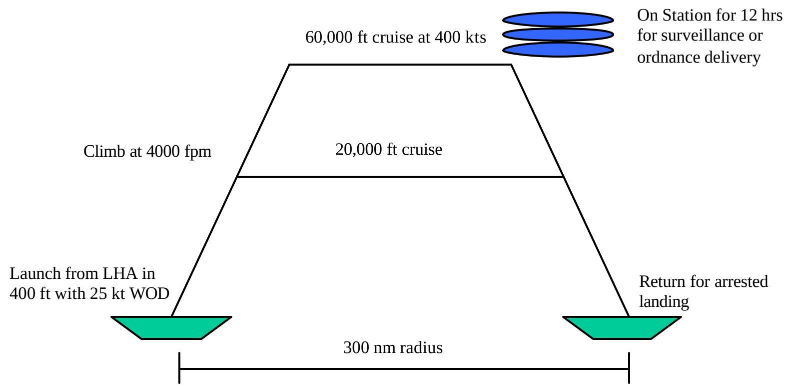

Figure XVIII-9: Sea Spectrum UAV Mission Profile (Source: Russell et al., 2002)

5. Conceptual Design Variants

a. *Quality Function Deployment*

The design team employed Quality Function Deployment (QFD) as a system integration tool during the initial design phase. A four level QFD model was used to identify important design variables and prioritize those that most significantly impacted the design team's ability to achieve the required performance. The technical correlations, or "roof," in each QFD level were used to provide a mechanism for comparing design parameters in order to determine possible conflicting design requirements, which could then be resolved through trade studies or further analysis.

In the first QFD matrix, the design requirements (customer attributes) were deployed into performance parameters. In the second matrix, the performance parameters were deployed into aircraft parts characteristics. In the third matrix, the parts characteristics were deployed into manufacturing processes. Finally, in the fourth matrix, the manufacturing processes were deployed into process controls.

b. *Conceptual Design Process*

Numerous configurations were considered; however, only four designs were closely examined for down select using NASA's Unix based Rapid Aircraft Modeling (RAM) software. RAM provided a relatively quick method for developing conceptual configurations that could be readily readjusted as the requirements changed or the need arose to examine the effects of design changes.

The driving factors behind the design were the competing abilities to launch unassisted and recover aboard the deck of an LHA/LHD class amphibious ship and flying with long endurance at high altitude. The shipboard compatibility requirements meant the aircraft would have a relatively large wing in order to produce sufficient lift at lower airspeeds and, hence, a lower stall speed. However, the same shipboard compatibility requirement limited the size of the wing that could be employed. The resulting large wing area/short wing span design space would have produced a low aspect ratio wing producing unacceptably high induced drag, which would adversely affect the requirement for an efficient high altitude, high endurance aircraft.

While numerous configurations were considered, four preliminary models were designed with the following common parameters: a high aspect ratio wing with minimum total area of 285.85 ft^2 and high lift devices employing coanda flow or externally blown flaps. This relatively large wing area was required to keep wing loading low. The incorporation of high lift devices was needed to meet the stringent shipboard landing and takeoff requirements. The engines used either ducting or leading edge placement to provide upper surface blowing (USB) to achieve the coanda effect over wing segments in the first four configurations.

A secondary effort was made to reduce radar cross-section and observability. Shielding the engines inside the fuselage and using ducting, or simply placing the engines over and forward of the wings was expected to reduce the aircraft's infrared signature.

The first configuration was a conventional design with a "V"-tail as shown in Figure XVIII-10 below. This design contained a single turbine engine in the nose of the aircraft with ducts to provide USB for generating the coanda effect over the wing's inner span. The bulbous fuselage resulted from engine and shielding placement requirements and the need to provide USB ducts. The large single engine in the nose of the aircraft required forward placement of the wing section with a mild sweep of 23^{o}. Even though this design had the simplest single engine configuration, the benefits were negated by the weight and complexity of the ducting required. Additionally, there were significant propulsion losses due to exhaust gas flow through the ducts.

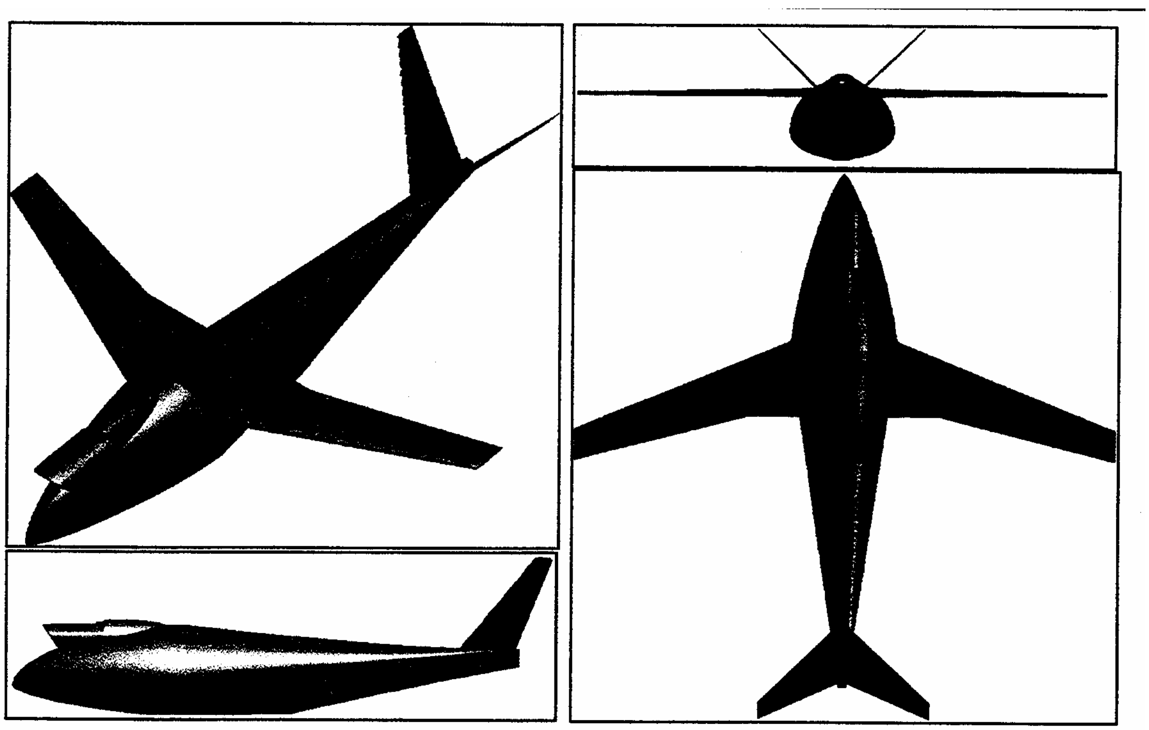

Figure XVIII-10: Sea Spectrum Candidate Configuration 1 (Source: Russell, et al., 2001)

The second configuration was also a conventional layout, but it eliminated the need for USB ducts by placing two smaller engines over the wing forward of the leading edge. The elimination of the need for ducting can be clearly seen in the disappearance of the hump at the wing/fuselage junction found in Fig. XVIII-10, Configuration 1. To compensate for the lower weight and aft placement of the two turbines relative to the single engine design of Configuration 1, the wing sweep was decreased to 21 deg. A benefit of a twin engine design was decreased weight of the power plants for an equivalent thrust rating. This decrease was somewhat offset by the additional engine controls, fuel systems, and structure needed for two engines. The disadvantages of this configuration included complexity of the control laws for one engine inoperative operation and the inability to use the coanda effect in asymmetric thrust conditions.

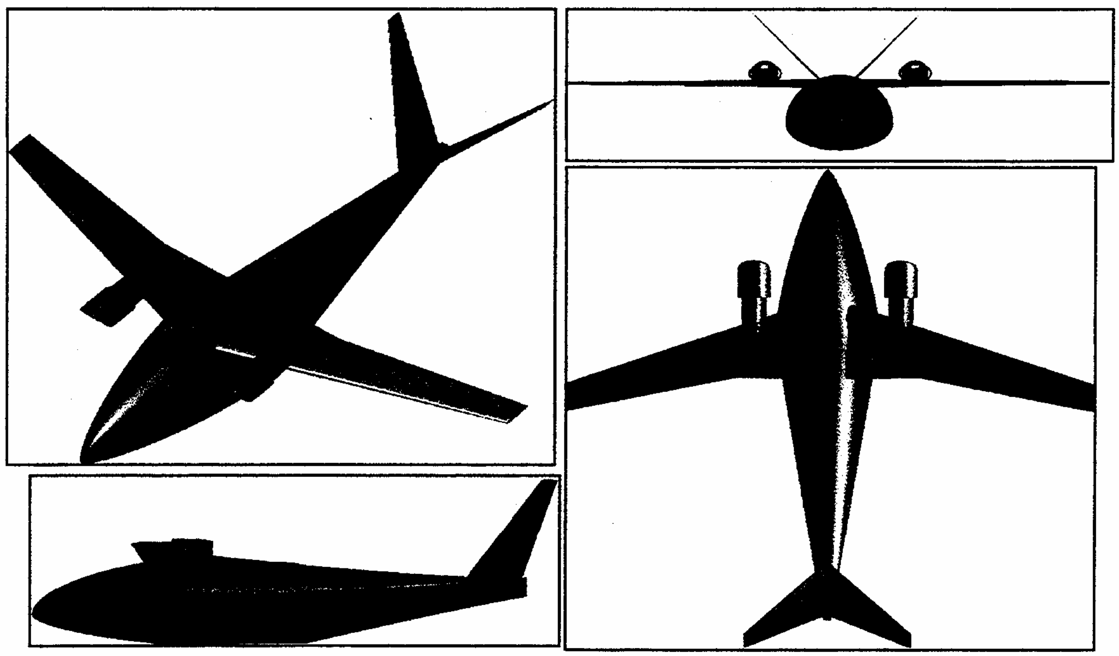

Figure XVIII-11: Sea Spectrum Candidate Configuration 2 (Source: Russell, et al., 2001)

The remaining two configurations were joined wing configurations. Joined wings were considered to afford the maximum wing area for a wingspan restricted aircraft. High aspect ratio wings are desirable for reducing induced drag; however, high aspect ratios are typically only possible at the expense of increased weight. By joining two wing sections, the structural requirements, and thus the additional weight, are reduced; therefore, two high aspect ratio wings can be made lighter than the corresponding individual wing structures. From a structural weight perspective, the optimal location for the connection between the forward and aft wings is at 60% span. The forward wing sweeps aft at 30 deg with 10 deg of dihedral while the aft wing sweeps forward at 31.1 deg with 30 deg of anhedral. Because the high aspect ratio wings have shorter cord lengths, root extensions were added to the forward wing in order to create sufficient area for USB generated lift. Since Configuration 3 is a single engine configuration, it required ducting to route USB air as in Configuration 1. While overall drag was reduced by the joined wing configuration, the USB air system increased weight and created cruise propulsion losses, as in Configuration 1.

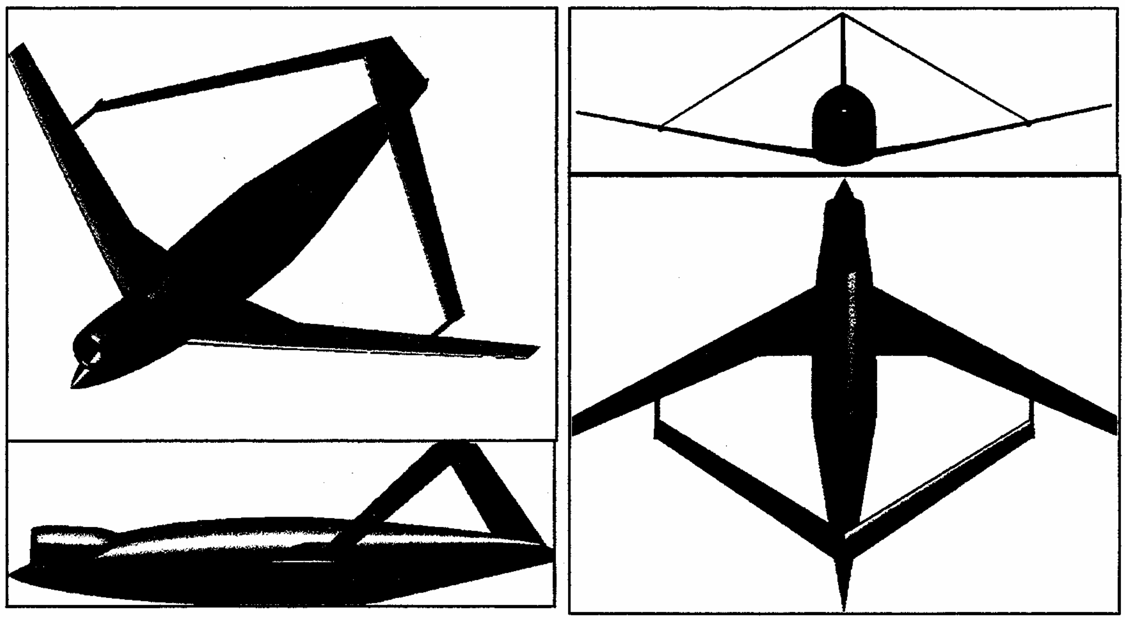

Figure XVIII-12: Sea Spectrum Candidate Configuration 1 (Source: Russell, et al., 2001)

Configuration 4 was geometrically similar to Configuration 3, with the exception of two small turbines mounted on the wing leading edge instead of a single, fuselage mounted engine. This engine mounting scheme eliminated the need for a complex USB air ducting system and the weight increases and cruise penalties encountered in the single engine design. The forward placement of the engines was required in order to take full advantage of the desired coanda effect. As before, the very high aspect ratio wings of this configuration required the use of inboard wing extensions for the forward wing in order to generate sufficient area on which the USB air could act. The design also incorporated large fowler flaps. Configuration 4 exhibited lower cruise drag throughout the mission profile relative to Configuration 2, the conventional wing, twin engine configuration.

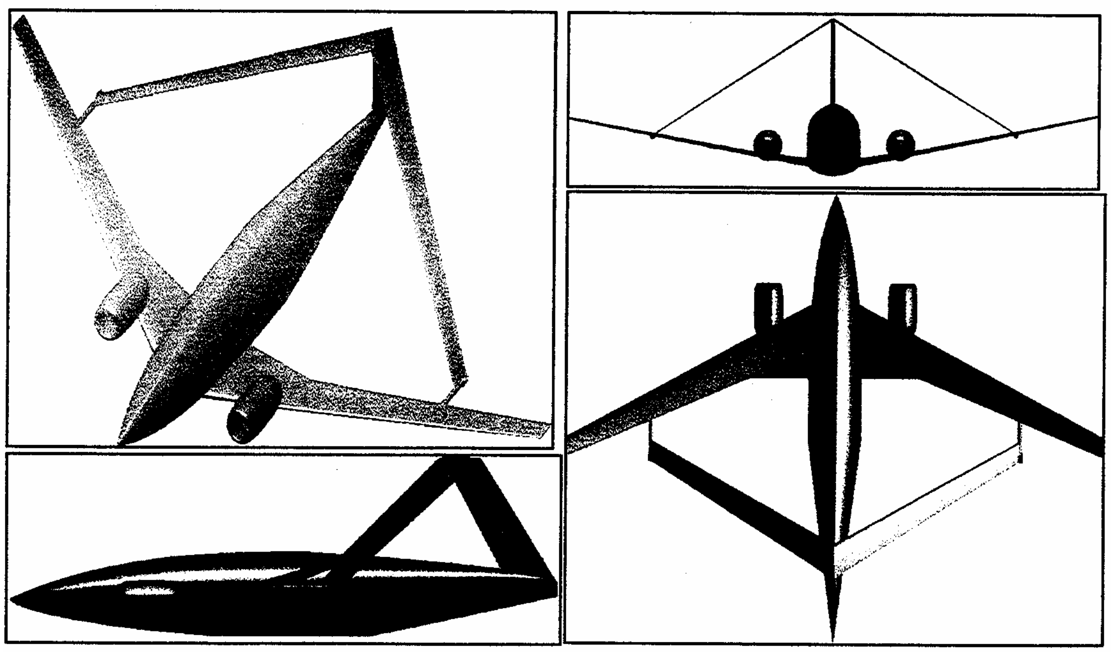

Figure XVIII-13: Sea Spectrum Candidate Configuration 4 (Source: Russell, et al., 2001)

The reduced structural weight of the wing, greater Guided Missile Cruiser range, increased fuel volume, greater directional stability relative to the conventional design, and lower induced drag, as weighted by the QFD process, combined to select Configuration 4 as the final design configuration. This configuration met or exceeded all the requirements set forth by the Systems Engineering and Integration Team as presented below.

Parameter	RFP Value	Sea Spectrum Value
Maximum Flyaway Cost	$ 12M (2001$)	$ 9.5M (2001$)
Operational Life	1000 Missions	1000 Missions
Weapons Payload	500 lbs	500 lbs
Range (1)	300 NM	300 NM
Endurance	12 hours on station	12 hours on station
Instantaneous Turn	12 degrees/sec @ Sea Level	19.5 deg/sec @ Sea Level
Sustained Turn	10 degrees/sec @ Sea Level	20 deg/sec @ Sea Level
Alternative Missions	IRSC @ 20,000 feet	Yes
Takeoff, Conventional	400 feet w/ 25kts wind over deck	400 feet w/ 25kts wind over deck
Signature	Low RCS/IR Signature	4.9 m^2/
Propulsion	COTS (Commercial Off-the-Shelf)	AE-3007 Variant
Deployment Envelope	4 shipped per C-17	Yes
Storage	20 years, (Near FMC)	Yes
Manning	Uninhabited Vehicle	Yes

Notes: (1) Cruise Mach @ 0.6973M at 60K feet

Table XVIII-4: Sea Spectrum UAV Requirements Compliance Matrix (Source: Russell, et al., 2001)

6. Conclusions

High Altitude, Medium Endurance UAVs such as the Sea Spectrum provide the expeditionary force commander with an organic ISR asset capable of operating directly from the ships of the Sea Base. As an integral part of the three tiered ISR system of systems, Sea Spectrum, along with tactical UAVs and space assets, will provide the commander with a complete ISR picture with which he can tailor his operations to take maximum advantage of the ever changing battle space.

D. THE SEA ARROW ARMED RECONNAISANCE UNMANNED AERIAL VEHICLE

1. The Capability Gap

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.

2. The Sea Arrow Unmanned Combat Aerial Vehicle (UCAV)

The Sea Arrow UCAV is a medium range, medium endurance, shipboard compatible, unmanned aircraft capable of conducting armed reconnaissance up to 200 NM from the host ship with a 6 hour on station time. The 200 NM combat radius specified for CROSSBOW Project is shorter than the 300 NM radius specified for the ExWar Integrated Project. The Sea Arrow would need to be reevaluated for range and payload in order to meet the requirements of future ExWar.

3. Requirements Analysis

A significant number of airborne missions must be launched from expeditionary aircraft carriers to support a battle group operating in a littoral environment. The inland target ranges described in these requirements are only half that required to support expeditionary operations as defined in the ExWar Integrated Project Top Down analysis. These missions fall into three main types as described below:

a. *Combat Air Support*

Of primary interest to the ExWar Integrated Project, combat air support provides spontaneous light fires in support of ground forces operating in the littoral environment up to 100 NM inland. Forward Air Controllers would be provided the ability to control the aircraft locally, while the shipboard pilot maintains safety of flight responsibilities. This mission requires the following:

Combat Radius:	200 NM
Loiter:	2 hrs (threshold), 4 hrs (objective)
Maximum Cruise Speed:	0.6 M (threshold), 0.8 M (objective)
Payload Capacity:	1500 lbs (threshold), 2500 lbs (objective)
Sensors:	Visual/EO
	Short Range Radar

b. *Combat Air Patrol*

The combat air patrol mission requires the Sea Arrow have the capability to carry state of the art (circa 2020) air-to-air missiles in order to engage enemy aircraft at standoff ranges from the ships of the task force. Intercept capability will reside in the missile vice the Sea Arrow. This mission requires the Sea Arrow be able to accept targeting information via data link from Network Centric Warfare nodes such as airborne ISR assets, ship sensors, and Expeditionary Warfare Grid sensors (described in section XVIII.6.B below) in addition to meeting the following requirements:

Combat Radius:	200 NM
Loiter:	2 hrs (threshold), 4 hrs (objective)
Maximum Cruise Speed:	0.6 M (threshold), 0.8 M (objective)

Weapons Loadout:	2 air-to-air missiles (threshold) 4 air-to-air missiles (objective)
Sensors:	Targeting Radar

c. ***Battlefield Interdiction***

This mission requires the Sea Arrow to deliver smart munitions on high value targets up to 100 NM inland in the littoral environment:

Combat Radius:	200 NM
Loiter:	2 hrs (threshold), 4 hrs (objective)
Maximum Cruise Speed:	0.6 M (threshold), 0.8 M (objective)
Payload Capacity:	1500 lbs (threshold), 2500 lbs (objective)
Weapons Loadout:	2 bunker busting and 2 airfield mining munitions
Sensors:	Visual/EO Targeting Radar

d. ***Suppression of Enemy Air Defenses***

Suppression of enemy air defenses requires the Sea Arrow have the capability to put enemy air defense radars out of action from more than 12 hours using high-speed anti-radiation missile like weapons scaled to the mission and employing 2020 technology. This mission requires the following:

Combat Radius:	200 NM
Loiter:	2 hrs (threshold), 4 hrs (objective)
Maximum Cruise Speed:	0.6 M (threshold), 0.8 M (objective)
Weapons Loadout:	3 High Speed Anti-Radiation Missile type weapons EW jamming capability

Sensors: Multi-band radar

e. *Armed Reconnaissance*

The armed reconnaissance mission required the aircraft to operate out in front, or on the flanks of, the task force in order to provide a means to detect, identify and, if necessary, destroy surface craft and other targets of opportunity. A secondary mission would be ISR or Electronic Attack (EA). These missions require the following:

Combat Radius:	250 NM
Loiter:	2 hrs (threshold), 4 hrs (objective)
Maximum Cruise Speed:	0.8 M
Payload:	TBD
Sensors:	Visual/EO
	Targeting radar

The design mission profile is presented below.

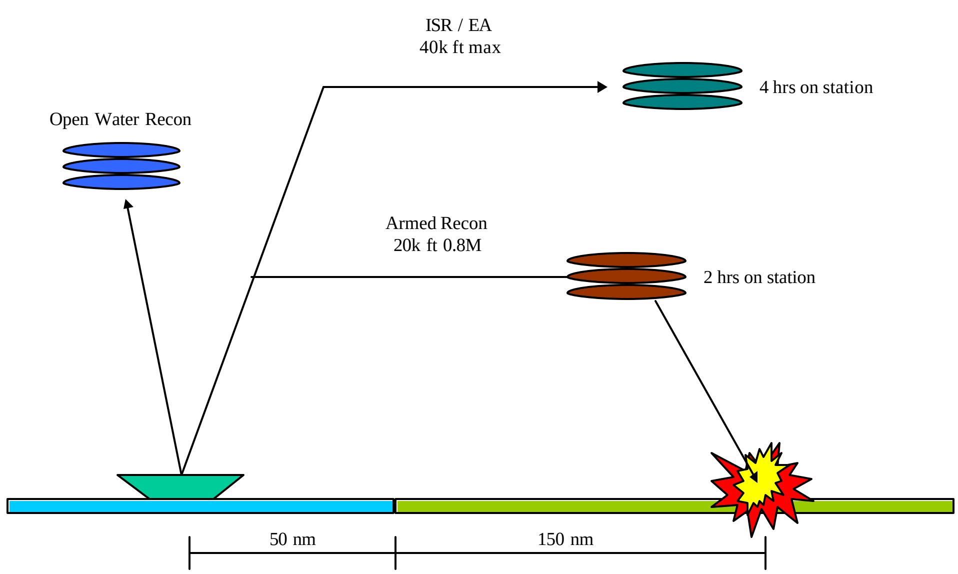

Figure XVIII-14: Sea Arrow Armed Reconnaissance Mission Profile (Junge, et al., 2001)

f. *Implied Requirements*

The following implied requirements were identified during the requirements analysis process:

Takeoff Distance: Conventional carrier takeoff distance

Sustained Maneuvering: 25 deg/sec at 200 kts and at sea level

Max Instantaneous Maneuvering: 28 deg/sec at 200 kts and at sea level

Landing Stall Speed: 86 kts

Maximum Airspeed: 0.8M at 10,000 ft

Accelerate from 0.4M to 0.8M in less than 4 sec at 5,000 ft

4. Conceptual Design Variants

a. *Quality Function Deployment*

The design team employed Quality Function Deployment (QFD) as a system integration tool during the initial design phase. A four level QFD model was used to identify important design variables and prioritize those that most significantly impacted the design teams ability to achieve the required performance. The technical correlations in each QFD level were used to provide a mechanism for comparing design parameters in order to determine possible conflicting design requirements, which could then be resolved through trade studies or further analysis.

In the first QFD matrix, the design requirements (customer attributes) were deployed into performance parameters. In the second matrix, the performance parameters were deployed into aircraft parts characteristics. In the third matrix, the parts characteristics were deployed into manufacturing processes. Finally, in the fourth matrix, the manufacturing processes were deployed into process controls.

b. *Conceptual Design Process*

Numerous configurations were considered; however, only four designs were closely examined for down select using NASA's Unix based Rapid Aircraft Modeling (RAM) software. RAM provided a relatively quick method for developing conceptual configurations that could be readily readjusted as the requirements changed or the need arose to examine the effects of design changes.

Wing area was the driving design constraint in all of the configurations. For initial competition, a wing area of 350 ft^2 was necessary to obtain the wing loading derived from constraint analysis. A high aspect ratio was also deemed desirable for high endurance and high turn rate sustainability. An effort was made to minimize the visual and radar cross-sections, as well. Though recent trends in UCAV design have tended toward topside engine intakes, presumably to reduce radar cross section, this was not considered in the current configuration analysis. The impetus behind avoiding this design consideration was the high angles of attack expected during the combat profiles and aircraft carrier suitability considerations.

Configuration 1, presented in Figure XVIII-15 below, was the only multi-engine concept put forward. Expense and complexity were the primary reasons for not placing a higher priority on the reliability and survivability attained by a multi-engine aircraft. There were also questions concerning controllability of a multi-engine UCAV in a single engine out configuration.

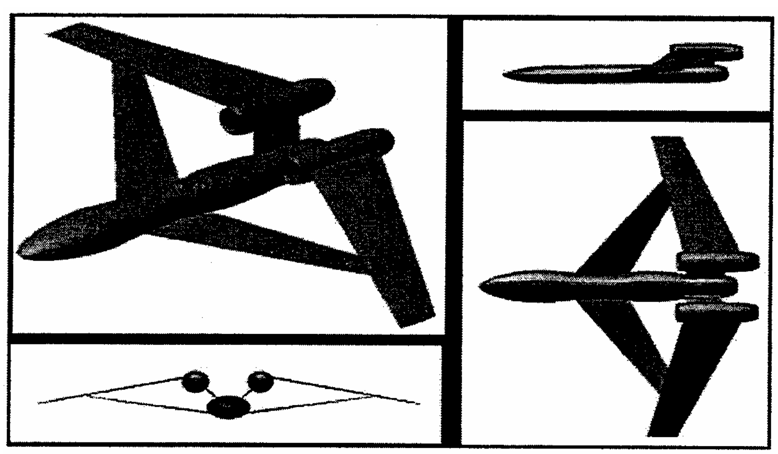

Figure XVIII-15: Sea Arrow Candidate Configuration 1 (Source: Junge, et al., 2001)

Configuration 1 incorporated the joined wing concept, with two wings combining to make as large a wing as possible. The lower wing also provides enhanced structural strength by acting as a strut brace. The reduction of tip losses from the lower wing is likely negated by interference drag at the upper/lower wing joint.

Configuration 2 incorporated a box wing concept in an attempt to reduce induced drag. Two large wings were incorporated into this design in an attempt to maximize total wing area.

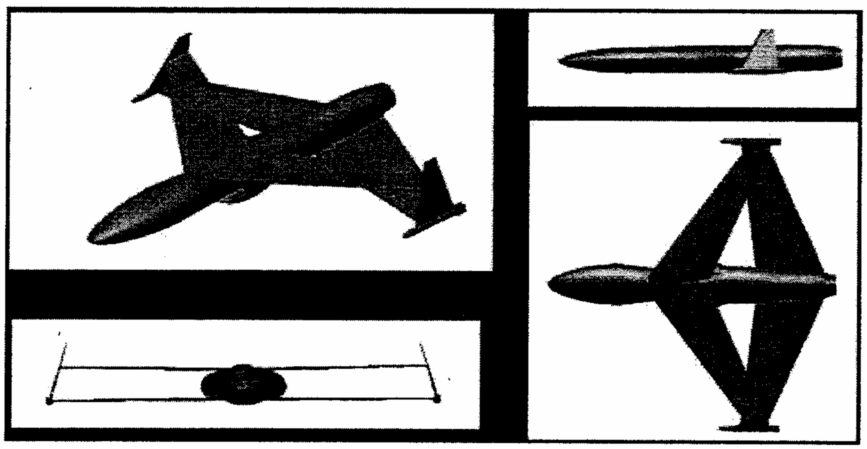

Figure XVIII-16: Sea Arrow Candidate Configuration 2 (Source: Junge, et al., 2001)

Configuration 3 incorporated a canard to provide enhanced maneuverability at the cost of more robust control requirements. A canard provides additional lifting area as opposed to the down force generally found on a conventional tail surface. A leading edge extension was also incorporated on the main wing in an effort to energize the flow over the main wing aft of the canard due to the effect of canard downwash on the main wing.

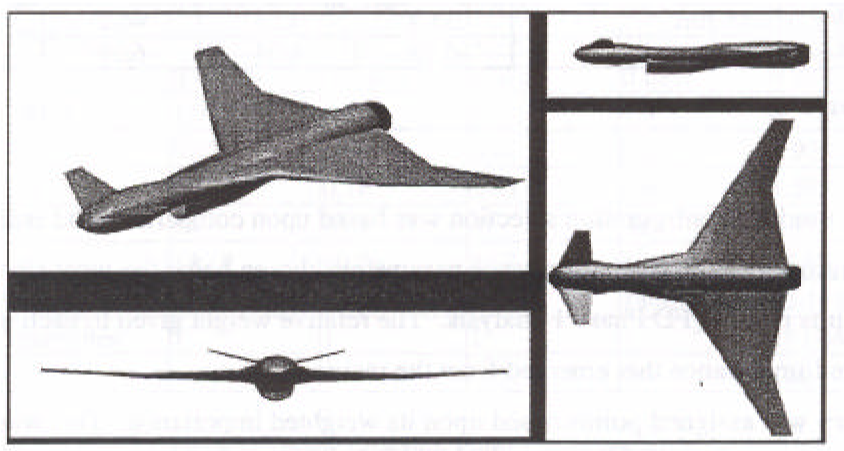

Figure XVIII-17: Sea Arrow Candidate Configuration 3 (Source: Junge, et a.,l 2001)

Configuration 4 incorporated outboard empennage surfaces which were termed variable incidence stabilators. Arguably the least proven, and therefore the highest risk design, it provides the benefit of increased control effectiveness or reduced control area owing to the fact the control surfaces are placed outside the downwash of the main wing. In a high lift configuration, an increased dynamic pressure originating from the wing tip vortex further enhances control effectiveness.

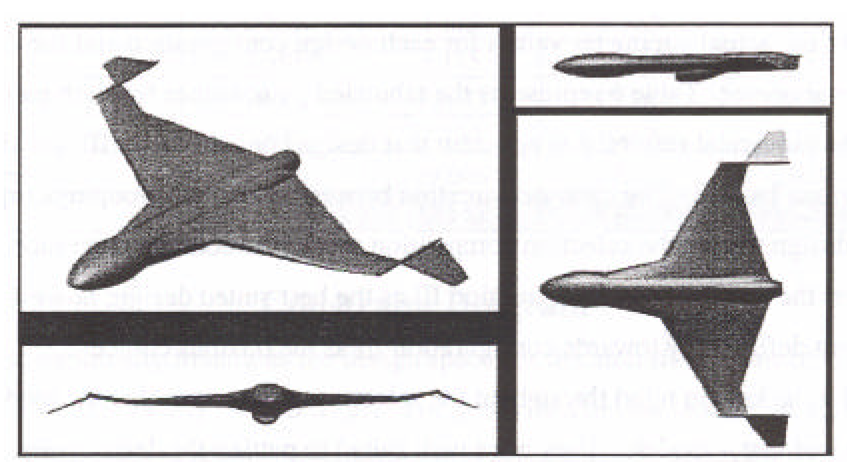

Figure XVIII-18: Sea Arrow Candidate Configuration 4 (Source: Junge, et al., 2001)

5. Final Configuration

A weighted comparison and ranking of significant performance parameters, based on the QFD analysis, was used to select the final configuration. Based on these results, it was readily apparent Configurations 3 and 4 provided a much better potential to meet the requirements than Configurations 1 or 2.

Choosing between Configurations 3 and 4 proved more difficult. On a purely numerical basis, Configuration 3 appeared to have a slight edge; however, it also had some obvious drawbacks. First, its wingspan was approximately 6.0 ft (15%) wider than Configuration 4, a difference which could have a major impact on shipboard operations. A second concern was potential directional stability problems at low Mach due to the lack of a vertical tail. Both of these problems could be overcome, but at an increase in cost and complexity. When these additional considerations were taken into account, Configuration 4 was chosen as the design configuration.

6. Conclusion

The final design, using Configuration 4, met or exceeded all the system requirements levied by the Systems Engineering and Analysis team. Sea Arrow presents an interesting departure point for requirements generation and design of an organic UCAV for the ships of the future Sea Base.

E. MARITIME PREPOSITIONING FORCE SHIP 2010

1. Background

Current Maritime Prepositioning Ship (MPS) squadrons are used to preposition supplies, vehicles, and equipment throughout the world for use in times of crisis by a MAGTF of MEB size. Current doctrine requires a secure airfield and port (or beachhead) be available near the objective so the MPS assets can be offloaded and married ashore with arriving MAGTF personnel. To employ the full capability of the MEB, a friendly airfield capable of supporting the MAGTF ACE must be available within flying range of the objective.

Throughout this subsection, the term MAGTF will be understood to mean a MEB sized force, and it is assumed the capabilities discussed would also apply to smaller units. Maritime Prepositioning Force (MPF) 2010 and Beyond is a concept under which a next-generation MPF will contribute to forward presence and power projection: capabilities which will remain central to U.S. deterrence and conflict resolution strategies well into this next century through doctrine such as STOM, which enables MAGTF forces to assault inland objectives directly, without the need to secure and defend a port or beachhead for MPS offload. STOM strives to deliver combat capable units with sufficient strength to accomplish the mission and resupply them without the use of an MPS generated "Iron Mountain," or supply depot, which delays the arrival of combat forces at the real objective and is in turn vulnerable to enemy attack.

As mentioned above, the current MPS squadrons are not capable of supporting STOM doctrine, since they require a secure airfield and port (or beachhead) to offload their cargo and marry up MAGTF cargo and personnel. Additionally, MPS squadrons do not provide the capability to support additional MAGTF aircraft, such as the F/A-18 and EA-6B at sea. The objective of the MPF 2010 design project was to produce a conceptual ship design, which in sufficient numbers will thoroughly implement the MPF 2010 and Beyond concept. The conceptual design, hereafter referred to as MPF 2010, will operate in squadrons of five and be capable of fully supporting an ACE consisting of JSFs, MV-22s, and other Marine rotary-wing aircraft. An MPF 2010 squadron will carry all the equipment currently found on a MPS squadron, as well as the vehicles and equipment current part of the Fly in Echelon. MPF 2010 will provide for the at sea arrival of MAGTF personnel and the at sea marrying of MAGTF personnel with their equipment prior to reaching the Amphibious Objective Area (AOA). Upon arrival at the AOA, the MPF 2010 will provide a Sea Base from which MAGTF air, ground, and amphibious assets can project power deep into enemy territory.

2. Requirements Analysis

The first step in the ship design process is to determine the requirements for the new ship design. These requirements can be broken down into two categories: requirements that are being met by current ship designs and requirements that are not. Requirements that are being met by a current ship design may be satisfied in the new ship design by either implementing design features that are being utilized in current ships or developing innovative new solutions to these requirements. In either case, the requirement has already been identified and a solution to the requirement exists. The second requirement category, requirements which are not currently being met, is often more difficult to define than the first. This, in part, is due to the fact that when a new strategy or operational concept is defined, it is frequently difficult to translate that strategy or concept into tangible requirements for a ship design. This was the case with the translation of the STOM and MPF 2010 and Beyond concepts into design requirements for the MPF 2010 ship. Implementing these concepts using MPS is a radical departure from current practice. As a result, a significant period of time, the first six weeks of the project, was taken up in analyzing and defining the requirements for MPF 2010.

The Center for Naval Analysis (CNA) conducted a Mission Area Analysis of the Sea Basing concept for MPF 2010 and Beyond, which resulted in a set of requirements for **several ship designs** intended in various combinations to meet the stated needs. The NPS TSSE design team used the Center for Naval Analysis derived requirements as a starting point to derive requirements for the MPF 2010 ship. Some requirements were modified and some were added to the requirements delineated by Center for Naval Aanalysis in order to produce the requirements for a **single ship design** that would meet the needs of the MPF 2010 and Beyond.

3. Design Decisions

In order to translate ship requirements into a ship design, decisions had to be made regarding how to meet those requirements. These decisions were constrained by the requirements themselves, currently available technologies, future technologies, and the design team's collective experience. These constraints notwithstanding, a considerable degree of latitude remained with respect to the direction the design process could take.

a. *Design Philosophy*

Early in the design phase of MPF 2010 several design premises were identified in order to guide the design process. These premises were the primary driving forces determining the evolution of the overall design. These premises were:

- The desire to maintain Marine unit cohesion.
- The maximization of mission flexibility.
- The desire to achieve commonality of design between MPF 2010 ships to the maximum degree possible.
- The desire for MPF 2010 ships to have capabilities more commensurate with military rather than civilian applications.
- The intent to use innovation to the maximum degree possible.

Maintaining unit cohesion was considered extremely important. In order to employ STOM, MAGTF units must be able to operate efficiently and expeditiously. When a combat unit is subdivided into its smaller components, a finite period of time is required to reconstitute that unit into its original form. Each additional subdivision of a component adds another finite time increment to the time required for reconstitution. Additionally, if a unit is required to marry up with its equipment, additional time is required if equipment is not co-located with the unit's personnel. As a result, the further a unit and its equipment is subdivided and spread out over many ships, the more coordination is required to reconstitute that unit prior to engaging an objective. It was therefore determined, in order to minimize the delays associated with the transfer of personnel and equipment between ships prior to conducting a STOM operation, the MPF 2010 ships needed to have a size and configuration sufficient to allow entire units (personnel plus their equipment) to be co-located in a single ship. Maintaining unit cohesion was applied in the design at the infantry battalion level, the tank company level and the artillery battery level. This became a major design driver in determining both the size and number of MPF 2010 ships required to support a MEB.

Mission flexibility and design commonality are two sides of the same coin. Common designs provide the MAGTF Commander with more mission flexibility; for example, if MPF 2010 ships are essentially interchangeable, the MAGTF Commander would have the freedom to tailor ship loadouts to the anticipated mission needs. Further, if one ship is rendered incapable of performing its mission, a specific mission capability is not completely lost, since the remaining ships of the squadron have at least part of the same capability. Commonality of design also allows the MAGTF Commander the flexibility to engage multiple objectives with similarly capable platforms over a large littoral region. Finally, design commonality provides for streamlined ship production, simplified maintenance concepts, and less complex operation between ships.

The design team aggressively sought out and investigated new and innovative concepts. Transitioning from current maritime prepositioning ship designs to the design resulting from the MPF 2010 and Beyond concept required significant departures from conventional thought.

Although not specifically included as a design constraint, overall cost significantly influenced squadron size. A squadron of many ships of a smaller size would, theoretically, increase the force survivability (i.e. losing one out of ten small ships reduces force capability by a smaller magnitude than losing one out of five larger ships); however, as the number of ships to perform a given mission is increased, the overall cost of that squadron of ships increases. Additionally, a force of many small ships would not necessarily be capable of maintaining unit cohesion to the degree desired.

b. *Design Objectives*

The MPF 2010 and Beyond concept is based upon four principles: force closure, amphibious task force integration, indefinite sustainment, and in-theater reconstruction and redeployment of the MAGTF. Further, it will be necessary for MPF 2010 ships to be pre-deployed for extended periods of time in anticipation of the requirement to conduct STOM operations. The project's design objectives were intended to efficiently and effectively incorporate the requirements derived from these four pillars, along with the pre-positioning requirement, into the design of the MPF 2010 ship. These objectives were divided into three parts, in descending order of priority: primary, secondary, and tertiary objectives. Numerical order within the objective groups below, however, does not imply precedence.

Primary Objectives:

a) The combined capacity of 5 ships shall provide the required support for an entire MAGTF (excluding heavy lift and electronic countermeasure aircraft), its Naval Support Element, and its associated equipment, vehicles, and aircraft. All ships will be interchangeable, subject to loadout.
b) Load out flexibility.
c) Operational flexibility.
d) Flexibility of USMC support operations.
e) Ability to navigate to and dock at MPF loading facility at Blount Island, FL.
f) Seaworthiness.
g) Rapid deployment and recovery of MAGTF.
h) Capability to sustain MAGTF forces from sea.
i) Capabilities to receive re-supply at sea.
j) Cargo handling capabilities which include:
    1) Selective retrieval.
    2) Automation to the maximum degree feasible.
    3) The ability to perform maintenance on embarked equipment "in place" or with minimal movement of surrounding cargo.
    4) Ease of cargo access and movement.
    5) Minimization of movement of cargo

Secondary Objectives:

a) Anti-ship missile self-defense capability.
b) Capability to embark MAGTF personnel en route to the objective.
c) Interoperability with other U.S. military assets (including C4I).
d) Minimization of the number of support personnel, during both prepositioning and MAGTF employment.
e) Minimization of ship maintenance during both pre-positioning and MAGTF employment.
f) Compatibility and flexibility for navigation in restricted waters and ports.
g) Habitability.

Tertiary Objectives:

a) Combat Survivability.
b) Commonality between systems.
c) Ability of multiple U.S. shipyards to construct.
d) Use of commercial off-the-shelf technology (COTS) where feasible.
e) The employment of modularity of construction where possible.
f) To design in modularity of upgrade where possible.
g) Safety of personnel.
h) Cost minimization.

An illustration of the MPF 2010 design concept which resulted from these requirements is presented in Figure XVIII-19 below.

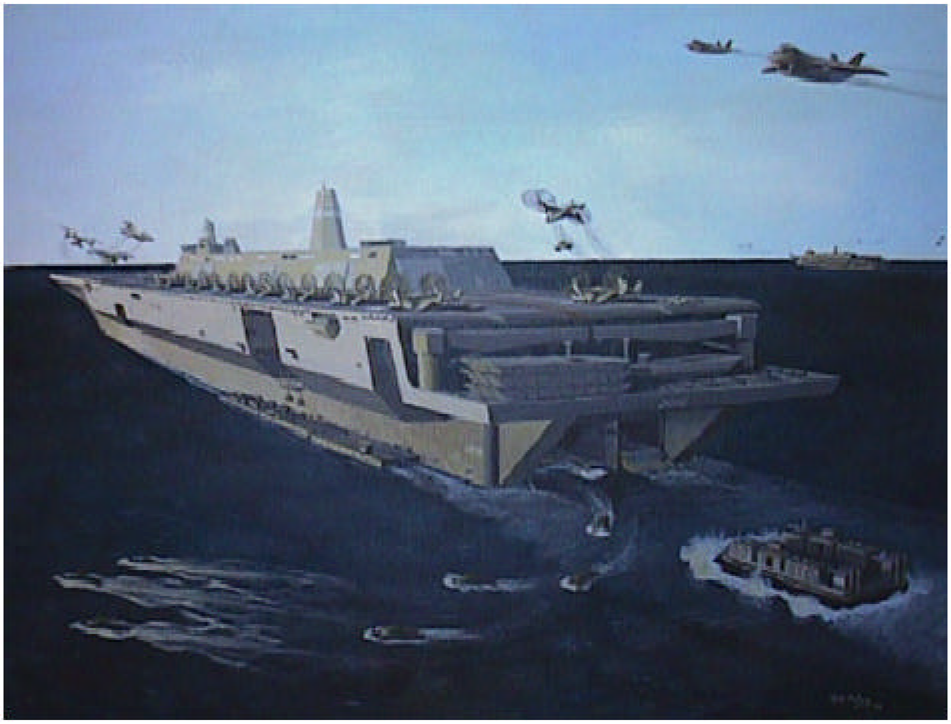

Figure XVIII-19: The Maritime Prepositioning Force Ship 2010 (Source: Anderson, et al., 1999)

4. Operational Concept

a. *MPF 2010 Prepositioning*

There are currently three Maritime Prepositioning Force (MPF) squadrons: MPRSON One, which operates in European waters; MPSRON Two, which operates out of Diego Garcia; and MPSRON Three which operates out of Guam and Saipan. None of the MPF squadrons have "permanent" homeports; rather, they are continuously forward deployed, rarely travel together, and routinely visit various allied ports within their respective areas of responsibility. On 24-hours notice, each MPF ship can leave port and reach any region in its area of responsibility within approximately seven to ten days. It was anticipated that the MPF 2010 squadrons would be prepositioned and operate in a manner similar to that of the present-day MPF squadrons.

b. *Notional Operational Timeline*

The operational timeline sets out the sequence of events occurring from the time the tasking order is received until the time at which the MPF 2010 squadron arrives in the AOA. This timeline is notional in that the actual times involved would depend on several factors, such as the location of each ship when the crisis occurs, where the crisis occurs, and the classified operational plan for the squadron affected. The timeline was based on the fact that the MPF 2010 squadron will be used to augment an on station ARG. It was further assumed that a CVBG was in the vicinity of the AOA providing air superiority. Finally, the timeline took into account the ability of the ARG to conduct self-sustained combat operations for fifteen days prior to MPF 2010 squadron arrival.

Once the tasking order was received and the MPF 2010 ships were underway, the Operational Preparation Party would be the first to come onboard as the ships steamed towards the Intermediate Staging Point. The Operational Preparation Party was separate from the Advance Party onboard each MPF 2010 to support the embarkation of the MAGTF. The OPP would prepare the prepositioned equipment, vehicles, and craft for use by the Marines upon the arrival of the MAGTF. Once the MPF 2010 ships arrived at the Intermediate Staging Point, the MAGTF would be embarked. It was estimated it would take three days to bring an entire MEB of 18,000 personnel on board the five ships in the squadron.

c. *MAGTF Embarkation*

In time of crisis, the appropriate MPF 2010 squadron would be dispatched to the region of concern. Shortly after the MPF 2010 squadron was dispatched, a Marine MAGTF would leave CONUS enroute to the ships of the MPF 2010 squadron. In order for the MAGTF to execute its mission immediately upon arrival in the region of concern, it was necessary to provide an Intermediate Staging Point. The Intermediate Staging Point was a port or other area where the MAGTF can embark the MPF 2010 squadron in an expeditious manner. The design did not allow for the delivery of troops directly to the ships.

d. *Intermediate Staging Point (ISP)*

It would be necessary to have the Intermediate Staging Point at or near an airport capable of supporting strategic lift aircraft. The strategic lift aircraft would ferry MAGTF personnel and their carry-on gear and equipment to the vicinity of the Intermediate Staging Point. The ACE will have the option of either flying directly to the MPF 2010 squadron or via the Intermediate Staging Point. Once at the Intermediate Staging Point, the MAGTF would transit to the MPF 2010 squadrons via air, sea, a combination thereof, or embark in port. Although it would not be necessary for the Intermediate Staging Point to be located adjacent to a port facility, an in-port embarkation would typically represent the fastest and most economical way to embark the MAGTF. If a port facility was unavailable, it would still be possible to embark the MAGTF via organic lighterage, amphibious craft, and rotary-wing aircraft; however it would be necessary for the MPF 2010 squadron to remain relatively close to the Intermediate Staging Point for the duration of the embarkation. This method would risk damage or degradation of craft necessary for the expeditionary assault mission, however, so an in-port embarkation would be preferred. A final option would be to use a HSV or high speed amphibious craft similar to the Russian Pomornik class air cushion vehicle. The Pomornik is capable of carrying 310 troops at a speed of 55 knots to a range of 300 NM.

e. *Advance Party*

Only a minimum number of personnel would be maintained on board an MPF 2010 ship, so it is expected that an advance party of support personnel would arrive on board the MPF 2010 ships prior to MAGTF embarkation. The advance party personnel would have to be of sufficient quantity and skill to be able to support the embarkation of the MAGTF from either air or sea. In the event that MAGTF personnel are embarked in port, it would still be necessary for a sufficient number of flight support personnel to arrive on board the MPF 2010 ships prior to embarking of the ACE. It was assumed that the personnel normally embarked on MPF 2010 ships would be able to adequately support limited flight operations, such as the arrival of a small number of aircraft containing the advance party; however, these arriving aircraft would need to contain adequate personnel to support subsequent flight operations.

5. Amphibious Operations

a. *Introduction*

The primary objective of MPF 2010 is to support STOM operations with both amphibious and air assets. MPF 2010 was designed to meet these requirements for two basic operating scenarios that were different than the Burma scenario used in the other ExWar project conceptual designs and discussed in Chapter VI. In these scenarios, which can be found in the MPF 2010 report contained in Volume V of the ExWar Integrated Project Report, the MPF 2010 ships were assigned the following roles:

- MAGTF support as currently provided by the MPS squadrons.
- Support and Reinforcement of the MAGTF from the sea. This was accomplished either by employing the MPF 2010 squadron as a Sea Base or as a force of ships operating semi-independently in geographically diverse regions.

Both types of sustainment and support operations embrace the STOM concept and are equally valid for the MPF 2010 and the Family of ExWar Ships concepts. The first scenario assumed that MPF 2010 would off-load the MAGTF in a permissive environment either in stream using organic lighterage or via a pier, similar to how MPS squadrons currently operate. This corresponds to the Current Architecture in the ExWar Integrated Project.

The second scenario anticipates that the MPF 2010 squadron would conduct STOM in or near a hostile environment, initially from OTH ranges to as close as 4 NM, using organic air assets, lighterage, LCACs, LCUs, and AAAVs for force delivery and sustainment. The deployment of the MAGTF from MPF 2010 would commence once the ship is within 25 NM of the beach-landing site. This differs from the ExWar Integrated Project CONOPS contained in Chapter VII, which assumes the assault would be launched from as far as 75 – 100 NM offshore.

Finally, it was also assumed the operational objective was located 60 NM inland, or a total of 85 NM from the Sea Base. This also differs significantly from the 200 NM inland or 275 NM from the Sea Base envisioned in the ExWar Integrated Project CONOPS.

b. Combat Operations

MPF 2010 supported rapid amphibious deployment (and recovery) of MAGTF forces through its ability to conduct LCU, LCAC, AAAV and over-the-side operations simultaneously. Due to its split well deck design, MPF 2010 could support LCU operations while simultaneously launching and recovering LCACs and/or AAAVs. Once MPF 2010 had deployed its organic lighterage, it would be capable of offloading (and onloading) equipment via either its over-the-side cranes or its side ramps as well via the well deck.

Combat loaded personnel could proceed directly from their berthing areas in the sponsons to the vehicle decks, flight deck, or the well deck staging area in order to embark on the appropriate craft or vehicle for a near immediate departure. This arrangement of berthing, vehicle decks, flight deck, well deck, and side ramps provided for the rapid amphibious deployment or recovery of surface craft and personnel.

The ships of the MPF 2010 squadron, acting either semi-independently or as a sea base, would commence amphibious and air operations from 25 NM offshore. One infantry battalion would be offloaded via MV-22 while a second was nearly simultaneously offloaded by AAAV. A third battalion would be inserted later via air. Within the same time frame, the Landing Support Battalion, one Tank Company, and the Light Armored Recon Company would be moved by LCACs organic to the MPF 2010 ships. Each ship would contain two LCACs and one LCU. Although these numbers were not consistent with CNA assumptions, it was judged that the number of LCACs available from a MEU sized ARG, and sufficient to handle the requirements of a battalion, would be insufficient to handle the requirements of a brigade. These craft must be available on the MPF 2010, since removing the LCAC assets from the ARG would reduce the ARG's ability to conduct independent operations. This LCAC distribution would likely require the procurement of additional LCACs (only a limited number have been procured to date), or the development and procurement of a follow-on design. Once ashore, this force, in combination with elements from the MEU ARG (if already present), would secure the immediate coastal area permitting the ships of the MPF seabase to move to within four miles of the beach. The remainder of the Ground Combat Element (GCE) scheduled to move ashore is offloaded using a combination of organic lighterage, LCAC's and LCUs. After the Ground Combat Element and associated support units are ashore, the MPF 2010 squadron then moves back to a point 25 nm offshore. From this position the MPF 2010 squadron will be able to commence resupply and combat service support to the troops ashore by air. This last part of the operation also varies considerably from the ExWar Project CONOPS, where the Sea Base remains well offshore throughout the offload and subsequent sustainment phase.

6. Flight Deck Operations

The ACE of the MAGTF would operate from MPF 2010 ships at sea, in contrast to the current MPS employment method in which the ACE is operated from secure shore based airfields near the objective. By basing the ACE onboard MPF 2010, the MAGTF's flexibility and responsiveness in conducting STOM operations would be enhanced. Additionally, the requirement to obtain secure, shorebased airfields within range of the objective area would be removed.

It was assumed that a 48 aircraft ACE consisting of JSF, MV-22, SH-60, AH-1, UH-1, and CH-53 aircraft would operate from all five ships of the MPF 2010 squadron. The JSF and AH-1 aircraft would primarily be utilized for strike and close air support of Marines on shore. Although use of the JSF in a force protection and air combat role is possible, it was assumed this mission would be delegated to aircraft from the supporting aircraft carrier. The UH-1 aircraft would be primarily used for command and control and medical evacuation, rather than troop transport. MV-22 and CH-53 aircraft will be used for transporting cargo and personnel from the MPF 2010 to and from shore. Finally, the SH-60 would be utilized for search and rescue (to include plane guard), force protection anti-submarine warfare, and to provide a minimal mine spotting capability.

The aviation combat element of the MPF 2010 was modeled after information provided by the Center for Naval Analysis study. The aircraft complement assumed by Center for Naval Analysis is as follows:

60 JSF	5 EA-6B
12 KC-130	36 MV-22
9 CH-53E	18 AH-1W
6 UH-1N	20 SH-60

The aircraft, with the exception of the KC-130s and EA-6Bs, were distributed between the ships as follows:

Ship 1 30 JSFs 4 SH-60
Ship 2 30 JSFs 4 SH-60
Ship 3 12 MV22 4 SH-60 3 CH53 6 AH-1W 2 UH1
Ship 4 12 MV22 4 SH-60 3 CH53 6 AH-1W 2 UH1
Ship 5 12 MV22 4 SH-60 3 CH53 6 AH-1W 2 UH1

Although specific aircraft load-outs were assumed for the design of MPF 2010, nothing in the design would prevent a MAGTF commander from reconfiguring the aircraft load-out to suit the needs of his particular mission. Due to the commonality in ship design, any MPF 2010 ship could accommodate any aircraft supported by the MPF 2010 squadron. This would provide the MAGTF commander with a wide array of aircraft load-out options, to include the mixing of both JSF and rotary wing aircraft on one MPF 2010 ship.

a. *Aircraft Flow*

The first two ships would carry the JSF Load-Out described above. JSFs would land on three dedicated landing areas with jet blast collectors at the aft end of the flight deck as shown in Figure XVIII-20 below. The JSF would shut down its engine upon landing, and subsequent movement of JSF thereafter from parking until re-launch would be accomplished by towbots that attach to the front wheel of the JSF. This will enhance the safety of, reduce noise level on, and minimize jet blast damage to the flight deck. Towbots will move the JSF about the flight deck and hangar to parking, maintenance, rearm/refuel and launch areas as necessary. The forward starboard flight deck will be available for launch and recovery of miscellaneous rotary wing aircraft. Aircraft and/or cargo can be pre-staged in this 140 feet by 120 feet location during JSF operations. Once a pause in JSF launch operations occurs, a rotary wing aircraft could be launched, recovered, or allowed to transfer cargo. Access to and from the hangar for these operations will be via the forward hangar door. A minimal capability to send and return cargo and personnel to and from the beach may be conducted through this location. Additionally, the SH-60 functioning as plane guard would operate from this area. Two of the ships of the five ship MPF 2010 squadron would carry the JSF loadout.

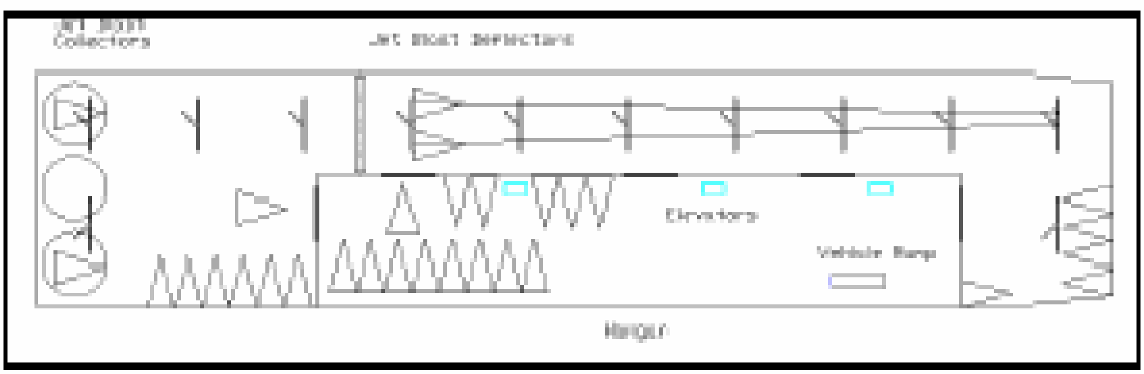

Figure XVIII-20: MPF 2010 JSF Loadout Flight Deck Layout (Source: Anderson, et al., 1999)

The final three ships would carry the Rotary Wing Aircraft Load Out described above. Rotary wing aircraft will set down at the various helicopter landing spots on the flight deck as shown in Figure XVIII-21 below. If an aircraft is to be immediately flown again it will remain on its spot until ready to launch. It will be rearmed and refueled, loaded, or unloaded as necessary while in place on the flight deck. Aircraft that will not be immediately turned around will shut down their engines, fold their rotors and/or wings as appropriate, and be towed to the hangar or elsewhere on the flight deck as necessary by a towbot. Three of the five ships in the MPF 2010 squadron would carry the rotary wing loadout.

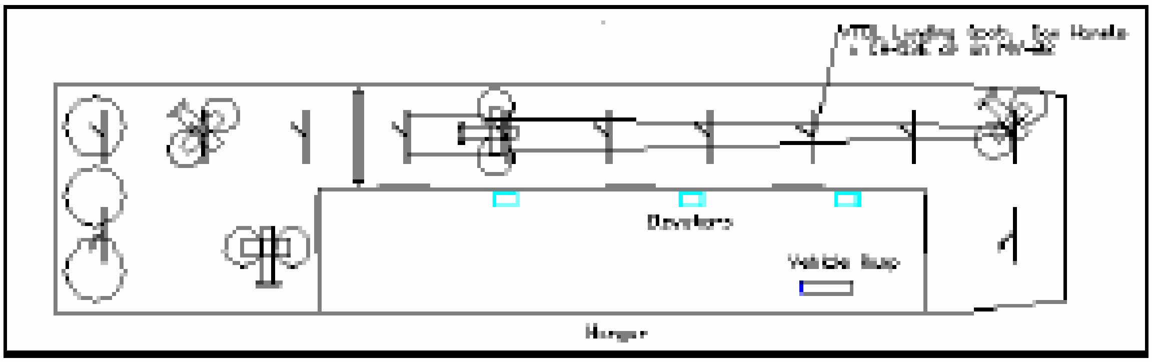

Figure XVIII-21: MPF 2010 Rotary Wing Loadout Flight Deck Layout (Source: Anderson, et al., 1999)

7. Force Deployment

Under normal conditions, the MPF 2010 squadron would be forward deployed without the MAGTF or ACE onboard. MAGTF personnel and aircraft would be brought to the forward-deployed ships as the need arises. Force deployment would be accomplished with the ships tied up next to the pier in an intermediate port or while the ships were underway to the objective. In the later case, all personnel, their carry on equipment, and all the aircraft of the ACE must be brought onboard directly. An air traffic control team would be initially flown onboard as part of the AP. These first aircraft would land with minimal assistance from onboard personnel. Once the ships were ready to receive the remainder of the MAGTF and its equipment, the remaining aircraft would be flown onboard.

8. Replenishment

There are a number of methods for replenishing the MPF 2010 at sea while simultaneously providing support for MAGTF operations. Since the MPF 2010 squadron would only have a sufficient quantity of supplies to support 30 days of MAGTF operations, it would be necessary to resupply the MPF 2010 while they remain forward deployed. This included the ability to be replenished from outside sources as well as conducting the transfer personnel and equipment between ships of the squadron. Two scenarios were used to examine these issues.

The first scenario was an assault operation of limited duration. In this case the MPF 2010 would expend a portion of its cargo, as determined by the length and intensity of the operation. Upon completion of the operation, the MAGTF personnel and equipment could be recovered, and the ships could then proceed to a port facility where the expended cargo would be replaced, the wounded transferred to a shore hospital facility, and own ship's supplies can be replenished. MPF 2010's 25-knot maximum speed supports the ability to rapidly transit from the AOA to a port and back. In the situation where the port facilities are not available or the MPF 2010 must remain in the AOA, replenishment ships would provide re-supply. While the use of replenishment ships would allow the MPF 2010 to remain in the AOA, the time, effort, and number of assets required to accomplish re-supply would be greater.

The second scenario consisted of sustained combat operations ashore. This scenario was the most demanding in terms of the ability to re-supply MPF 2010. In this scenario the MPF 2010 exhausted all of its cargo in the AOA in support of operations ashore. As each ship was emptied it would either retire from the AOA and rendezvous with Combat Logistics Force (CLF) replenishment ships or proceed to a nearby friendly port for re-supply. Operations ashore supported by MPF 2010 required dedicated support. The amount of supplies and support required would quickly overwhelm the CLF replenishment ships were they tasked to support the entire operation of the Amphibious Task Force. In order for MPF 2010 to remain near the AOA, it would be necessary for either dedicated shuttle ships to augment the capacity of the CLF replenishment ships or for the MPF 2010 to repeatedly transit to and from a re-supply port. The MPF 2010 organic hospital would care for the MAGTF wounded for the first 30 days of combat operations, and then be augmented by a dedicated hospital ship thereafter. Any MPF

2010 ship transiting to a re-supply port would also have the option of off-loading its wounded there, assuming that appropriate medical facilities were available.

Regardless of the scenario, MPF 2010 would provide greater flexibility for resupply than the current MPF architecture. With port facilities available, MPF 2010 could transit at 25 kts to a port where it could load supplies with organic cargo handling equipment. In cases where the port is relatively close to the AOA (i.e. about a day's transit), MPF 2010 could reload faster by returning to the port than it would be able to by replenishing at sea. During this time period, the remaining MPF 2010 ships would "take in the (operational) slack" created by the ship being re-supplied. This would allow the MPF 2010 ships to re-supply at a port on a rotating basis. Indeed, if operations required no more than 4 MPF 2010 ships are required to be on station, one MPF 2010 ship could be continuously involved in transiting and resupply.

In the event that the CLF replenishment ships are used for re-supply, there are three methods available. The first method is underway replenishment using the Standard Tensioning Replenishment Along Method system. This is the most common method of underway replenishment for U. S. Navy ships. The Standard Tensioning Replenishment Along Method requires that the receiving and the supply ship be fitted with special equipment. MPF 2010 will be fitted with this equipment and will be able to conduct replenishment along side. The second method is the Vertical Replenishment. Vertical Replenishment uses helicopters or MV-22's to lift supplies from the replenishment ship to MPF 2010. (It should be noted Vertical Replenishment can be used for re-supplying from shore to ship also.) The last method is the in-stream method. This method uses either CLF replenishment ships or shuttle ships that are married to MPF 2010 so that supplies can be quickly transferred from one ship to the other. This method is the second fastest way to re-supply MPF 2010, but it requires a low sea state and requires compatibility between ships for transferring cargo. This method allows MPF 2010 to remain in the AOA and to be re-supplied quickly. An alternative in-stream method can be accomplished while MPF 2010 and either the shuttle ships or the CLF replenishment ships are at anchor. In this case re-supply would occur via lighterage, which is slower and would also require a low sea state.

9. Sustainment Of Forces Ashore

MPF 2010 will be fully capable of independently sustaining a MAGTF for the 30 days of combat. After these 30 days of combat, MPF 2010 will be fully capable of sustaining a MAGTF with regular support from re-supply assets. MAGTF sustainment will consist of resupply, medical evacuation, force movement, and delivery of maintenance contact teams.

Depending on the distance of the landing force from the MPF 2010, resupply may be accomplished via lighterage, LCAC, LCU, or rotary wing assets. As the landing force becomes further removed from the MPF 2010, resupply will depend primarily upon rotary wing assets, primarily the CH-53E and MV-22. Medical evacuation will be primarily conducted via MV-22 and UH-1N (4B) aircraft.

Force movement will be conducted via LCAC, LCU, AAAV, and MV-22. As the landing force becomes more removed from the MPF 2010, or if rapid force movement is required, the MV-22 will be the primary vehicle for this task. Due to the similar construction of all MPF 2010 ships, greater flexibility is provided for force sustainment. Since any aircraft or watercraft within the MPF 2010 squadron is fully interoperable with any MPF 2010 ship, and each MPF 2010 ship has similar support capabilities (such as medical facilities, for example), it is possible to conduct force sustainment from any MPF 2010 ship via any asset available. The only limitation is the supply load out of the individual MPF 2010 ship. This greatly enhances the MPF 2010 squadron's ability to expeditiously and efficiently sustain the MAGTF, whether collectively or individually.

10. Conclusions

MPF 2010 provides an excellent example of the kinds of tasks needed to support STOM operations from a Sea Base. In the three years since the MPF 2010 was designed, however, the number and nature of tasks to be performed by the Sea Base have grown considerably. MPF 2010 also does not address the concern about the proliferation of hull forms required to support the ExWar mission. While MPF 2010 provides an excellent design for a one for one replacement for MPF ships as part of the MPF(F) program, the scope of the design is somewhat limited in addressing some of the larger system of system issues for future expeditionary warfare. The NPS TSSE design project supporting the ExWar Integrated Project, the ExWar Family of Ships, builds upon the work that went into the MPF 2010 design and expands the scope of the requirements to address additional issues. A more detailed discussion of the MPF 2010 can be found in Volume V of the ExWar Integrated Project Final Report. Additional details concerning the ExWar Family of Ships can be found in Chapter XVI of this report.

E. THE SEA LANCE LITTORAL WARFARE SMALL COMBATANT SYSTEM

1. Capabilities Gap

ExWar forces are forced to operate in littoral regions, within several hundred miles of an enemy's coastline, in order to conduct their mission. The littoral environment offers many unique hazards including mines; diesel submarines; small, heavily armed missile and gun boats; shore launched anti-ship cruise missiles; and asymmetric attacks from civilian craft. These threats are frequently found at greater densities in littoral regions and, as these threats continue to proliferate, current force protection packages may be increasingly unable to successfully counter them. A new type of escort is therefore required to support future expeditionary operations. These combatants would be able to fight their way into contested littoral waters against small, heavily armed ships to seek out and destroy enemy access denial capability and pave the way for the safe establishment of the Sea Base. Many current concepts for these forces consist of small, networked combatants and their accompanying sensor package. The SEA LANCE Littoral Warfare Small Combatant System was the embodiment of one of these small, distributed combatant concepts.

Force protection modeling, as part of the Sea Base analysis, highlighted the difficulties faced by current ESG escort packages in defeating a littoral threat from a large number of missile patrol craft. In the simulation effort described in Chapter XXI, an escort force consisting of small, highly networked combatants proved more successful in preserving the Sea Base assets than today's ESG escorts.

It should be noted that this Sea Lance design is different from the Sea Lance II design developed as part of the CROSSBOW Project littoral combatant system.

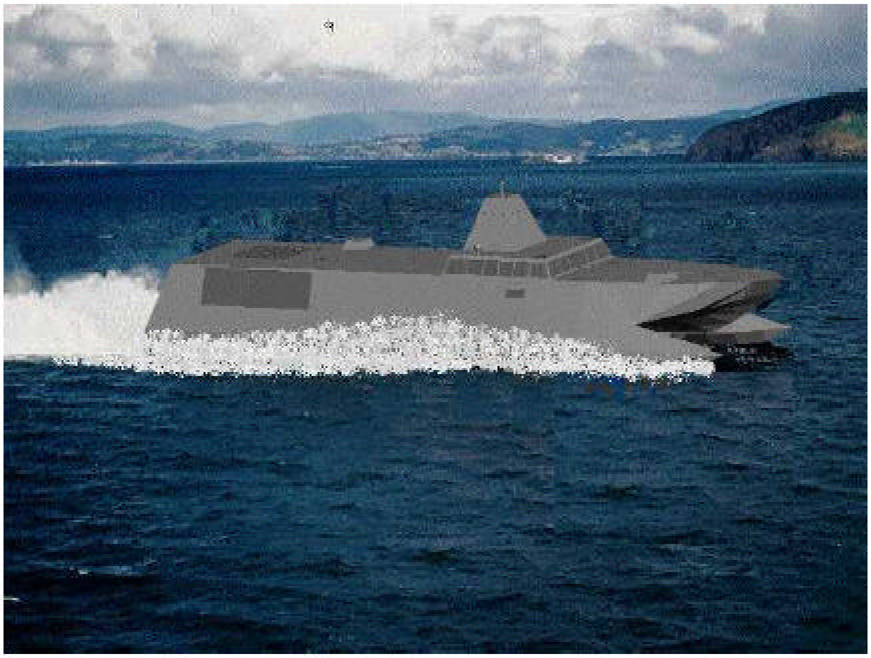

Figure XVIII-22: The SEA LANCE Littoral Combatant (Source: Markle, et al., 2001)

SEA LANCE was designed as the deployment mechanism for the Expeditionary Warfare Grid proposed in the Capabilities of the Navy after Next (CNAN) study being conducted by the Naval Warfare Development Command, in Newport, Rhode Island. The overall system, composed of the SEA LANCE and Expeditionary Grid, was designed to be capable of providing the deployability, flexibility, versatility, lethality, and survivability necessary within contested littoral waters and provide to the operational commander with the awareness and access assurance capability which was found to be lacking in the current and planned fleet.

2. The Expeditionary Sensor Grid

SEA LANCE craft will be forward-based throughout the world to allow a rapid response to the area of interest. Forward bases will provide the necessary force logistic support. The forward base will be located approximately 1000 NM or less from the coast of the adversary nation. The SEA LANCE squadron will be outfitted at the forward base with the desired Expeditionary Warfare Grid components and will transit with no logistic support beyond that carried by its fellow SEA LANCE craft.

The Expeditionary Warfare Grid will be deployed in a "cul-de-sac" region as shown in Figure XVIII-23. This region can be a gulf, group of islands or any region that has restricted maneuverability in a littoral environment. Most coastal countries have such regions. They are typically vital in terms of enemy operations and strategy. Since "cul-de-sacs" are the most likely place to establish an expeditionary warfare Sea Base, they are thus likely focal points of any access denial strategy. The "cul-de-sac" will have a radius of 400 NM or less and the adversary nation will encompass the entire area of the cul-de-sac. The land littoral region will extend approximately 200 NM inland from the coast of the adversary nation. The sea littoral will be defined as extending 500 NM from the coastline of the adversary nation and 1000 feet below the surface of the water. The air littoral region will extend to 90,000 ft above the land and sea littoral.

The adversary nation will have significant access denial capability within the sea littoral region. This access denial capability could seriously impair operations of current and planned fleet assets by creating an unacceptable risk to the units and personnel. SEA LANCE craft will transit from the forward base into the access denial region, deploy the Expeditionary Warfare Grid and transit out to refuel/rearm (if necessary) with CLF or other logistic units. This refueling/rearming will be conducted outside the access denial region at a point approximately 600 NM from the coast of the adversary nation. Prior to this refuel/rearm SEA LANCE craft will not have logistic support. The exception to this may be to provide logistic support from one of the other SEA LANCEs (i.e. a "tanker" variant).

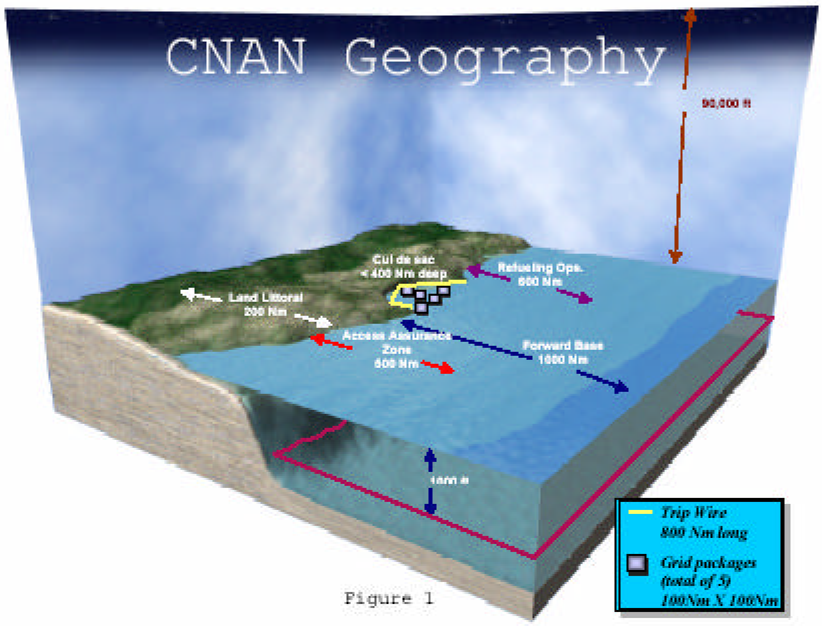

Figure XVIII-23: The "Cul-De-Sac" Region and Expeditionary Sensor Grid (Source: Markle, et al., 2001)

SEA LANCE will transit at 15 knots, deploy the Expeditionary Warfare Grid at 15 knots, and conduct engagements at 40 knots. The Expeditionary Warfare Grid will consist of a tripwire and 5 grid boxes. The tripwire will be approximately 800 NM long and be placed in close proximity to the adversary nation's coast. The tripwire will consist of sensors only as depicted in Figure XVIII-23. The Expeditionary Warfare Grid elements will have limited mobility and three lines of elements could be deployed by each SEA LANCE on a single pass through the area. The grid boxes cover an area of 100 NM by 100 NM. They will consist of both sensor and weapon packages. The grid boxes will be deployed within the cul-de-sac. Three of the grid boxes will be deployed along the entrance spaced 100 NM apart. The remaining two grid boxes will be placed in a line perpendicular to the grid line at the entrance, centered in the cul-de-sac and spaced 100 NM apart. The grid's sensor and weapons elements represent a total weight is 6,000 LT with a total volume of 170,000 ft^3.

3. Mission Need Statement

With the end of the Cold War, the diplomatic and military worldview has shifted from a global-war scenario to one of regional crisis situations. This implies a very important shift in operational orientation for the Navy, because the battlefield has moved from "blue waters" into the "contested littoral environment." Emerging powers are developing massive access denial capabilities to prevent power projection into their territory. The size of the "contested littoral" environment of threat nations continues to grow. The Navy needs to develop a system that can provide assured access in these closely contested littoral environments. The "Navy After Next" must marry new capabilities with the best capabilities of the current and planned fleet to gain, sustain and exploit that access. It must be an integral part of Network Centric Warfare and be capable of joint and combined operations. An essential key to success in the littoral environment is increased numbers of sensors, weapons, combatants and unmanned vehicles to produce a force structure capable of tipping the scales in our favor. Numbers will matter and the Navy After Next must be affordable and yet be robust enough to provide the support required of our current forces as well as produce the numbers necessary to upset the future littoral force imbalance. The combatant and its payload must be expendable to the extent that it is not viewed as a high value unit, but have a level of survivability capable of allowing the crew time to "eject" when the combatant is no longer capable of sustaining them (much like modern-day aircraft). The current and planned fleets are not ideally suited to directly operate in the highly complex and hostile littoral environment. Concealment together with the surprise factor, inherent to the enemy operating in its own littorals, will pose undue risk to our conventional power projection assets. This weakness creates the need to develop a capability that will allow gaining, maintaining, sustaining and exploiting access to the littorals, in order to project power into enemy territory.

4. Operational Requirements

a. *Description of Operational Capability*

In support of the mission needs statement, the Naval Warfare Development Center is conducting a Navy research program, which will explore new CNAN that will take advantage of the leading edge technology and information superiority. The NPS TSSE Program is supporting the Platform Team of the Naval Warfare Development Center CNAN study. The NPS TSSE team will develop a design of a combatant(s) which will distribute the Expeditionary Warfare Grid discussed in the mission needs statement, tend (and be part of) the Expeditionary Warfare Grid once in place, and become an integral part of the warfighting capability of the Expeditionary Warfare Grid system in support of the Expeditionary Warfare Grid's access mission.

The Expeditionary Warfare Grid system will consist of four parts: a global satellite-based network, logistic support ships (which may or may not be the existing logistics force), a distributed sensor and weapons system, and small combatants that deploy/tend the sensors and weapons. The Expeditionary Warfare Grid is assumed to be robust, secure, and readily accessible for two-way exchange of information. Antenna requirements will not exceed 40 cm in diameter and need not be aimed at specific satellite coordinates.

The logistics force will be capable of providing any asset needed by the combatants. This will include food, replacement parts, fuel, replacement-distributed components, Fly-Away Teams for extensive preventive/corrective maintenance, and all administrative support. The logistic force will provide crew replacements for the combatants during extended operations. The logistic force will not provide berthing or long-term mooring for the combatants or their personnel. The logistic force will not be capable of transporting the combatants. Logistics replenishment will be performed in relatively safe waters and in modest sea states.

The sensors will be connected to the Expeditionary Warfare Grid via some form of modems and will have some limited mobility. The sensors are acoustic arrays, radar array elements, magnetic detectors; electronic support measures sensors, IR detection arrays, and optical elements. The weapons are also connected to the network and receive their firing authorization via the network. The weapons will include torpedoes, torpedo-based mines, surface-burst fragmentation mines, canister surface-to-air missiles, canister surface-to-surface missiles, and strike missiles. The sensors and weapons will be deployed wherever they are tactically needed. This may include blue water, in littoral waters, near the shore or inland. The combatants will carry the sensors and weapons. Some of the sensor and weapon capability of the Expeditionary Warfare Grid will be organic to the combatants. The combatants will have the capability of exercising local command and control of the sensor and weapons within the Expeditionary Warfare Grid.

It is expected that the combatants will be capable of a trans-oceanic crossing when time is not a concern. It is envisioned that the ocean transit will be limited to 1000 Nm or less by use of appropriate forward basing of some kind (i.e. Guam, Naples, Hawaii, Diego Garcia, etc). Forward bases may be subject to attack by the enemy, so the combatants must be capable of rapid sortie. The access denial area is extends approximately 500 NN from the enemy's coastline. The Expeditionary Warfare Grid will be distributed within a "cul-de-sac" that has a radius of approximately 400 NM. The combatants will be required to transit 100 NM outside the access denial area to obtain logistic support.

The Expeditionary Warfare Grid/Combatant System must perform the following:

a. Perform early warning: detect, classify and track contacts
b. Destroy or drive off enemy coastal waterborne commerce
c. The combatant must deploy, monitor, protect and control sensor/weapon Expeditionary Warfare Grid

Some possible Expeditionary Warfare Grid/Combatant System missions include:

a. Protection of anchorages and operating areas
b. Harbor and restricted waters blockade
c. Theater Ballistic Missile Defense
d. Area Mine mapping operations
e. Escort for amphibious and logistic forces
f. Strike warfare
g. Shallow water ASW

Some possible Combatant missions include:

a. Maritime Interdiction Operations

b. Non-combatant Evacuation Operations

c. Special Operations Force insertion/extraction

d. Independent operations (showing the flag)

e. Strategic deception operations

b. *Shortcomings of Existing Systems*

The current fleet and the programmed Navy are capable of performing the assured access and intelligence gathering mission in the contested littoral environment. However, they have some significant shortcomings:

a. To overcome the access denial capability within the littorals, the present and planned Navy must come dangerously close to the coast of the aggressor nation. This presents a problem in the following areas:

i. **Cost.** Current and planned fleet assets are far too expensive to risk damage while operating in the littoral environment. This expense is both in the cost to procure and operate one of the ships as well as the large loss of life onboard one of our personnel-intensive ships.

ii. **Stealth.** Even with stealth measures, these ships are too large to enter and operate within these waters undetected. A smaller combatant may be able to operate within the littorals for extended periods of time without being detected, localized and identified.

iii. **Mind Set.** Other nations and our country view these ships as "high value" units. This is ideal for the purposes of power projection and deterrence, but these ships become prime targets during a conflict. A smaller ship may be viewed by an adversary as annoyance rather than a threat worth expending valuable ammunition on.

b. In the current environment, data collection sensors are forced to standoff at ranges that are so great that they can no longer provide the required information rapidly, timely and with sufficient coverage and volume to provide a commander with information required to support accurate tactical choices. There must be an increased number of sensors available and these sensors must be viewed as expendable enough to be placed in a high-risk environment.

c. The Expeditionary Warfare Grid and combatant system must be capable of providing the deployability, flexibility, versatility, lethality, and survivability necessary within the contested littorals to provide the operational commander with the awareness and access assurance capability lacking in today's fleet and fleet of the future.

c. Range of Capabilities Required

The proposed Expeditionary Warfare Grid/Combatant System shall provide the following capabilities (note: the System includes the combatant):

a. The system shall be capable of sufficiently weakening the area denial capability of the aggressor to allow an acceptable level of risk to the planned fleet in the littorals.
b. The system will have an anti-ship missile defense capability.
c. The system will have an area air defense capability.
d. The system will have an area Undersea Warfare capability.
e. The system will have an area Surface Warfare capability.
f. The system will be capable of supporting choke point and harbor blockade operations.

g. The system will be capable of sending and receiving data throughout the Network Centric Warfare Environment.

h. The system will be interoperable with any Joint/Combined Task Force.

i. The system will be capable of operating in mined waters.

j. The system shall be designed to produce a low signature (underwater acoustic, airborne, acoustic, IR, and electromagnetic).

k. The system shall perform precision strike missions against land-based targets.

The Combatant shall provide the following capabilities:

a. The combatant will have a minimum sustained speed (80% of full power) of 30 knots with a goal of 34 knots.

b. The combatant will have a maximum speed of 38 knots with a goal of 40 knots. The combatant displacement will not exceed 1000 LT.

c. The combatant will not exceed 100 million dollars in “first ship” cost (FY 01 dollars).

d. The combatant shall conduct transits in sea state 6, deployment operations as well as fight in sea state 4 and small boat operations in sea state 3.

e. The combatant will be capable of conducting a trans-oceanic crossing with dedicated logistic support.

f. The combatant will have a range of 3000 NM with a goal of 4000 at a minimum endurance speed of 13 knots with a goal of 15 knots.

g. The total combatant force shall be capable of carrying 6000 LT of Expeditionary Warfare Grid components with a volume of 170,000 ft3.

h. The combatant will have a point air defense capability.

i. The combatant will have a maximum crew size of 20 officers and enlisted combined with a goal of 13.

j. The combatant will be capable of operating within a Chemical, Biological, and Radiological environment.

k. The combatants shall be capable of performing Maritime Interdiction Operations and support Non-combatant Extraction Operations.

l. The combatant shall be capable of refueling and replenishing at sea.

m. The combatant shall be capable of receiving stores via vertical replenishment.

n. The combatant shall be capable of providing limited accommodations for special operations teams, maintenance support Fly-Away Teams and combatant squadron staff.

o. The combatant will have standard couplings and connections to receive hotel services from the pier.

p. The combatant's combat systems suite must be capable of operating in the open ocean as well as the littoral environment.

q. The combatant shall be capable of towing a combatant of approximately its size.

r. The combatant will be designed with a 10-year with a goal of a 15-year frontline service life.

s. The combatants control for all systems will be located in a single location and be networked as much as possible to support minimum manning.

t. The combatant will utilize advanced technologies in its systems and design materials to minimize the size and weight of the craft while maximizing the payload fraction.

u. The combatant crew accommodations (berthing and messing) will be austere to maximize the utility of the combatant.

v. The combatant will be configured to accept payload modules to perform additional mission capabilities after they have deployed the distributed Expeditionary Warfare Grid components.

5. Analysis of Alternatives

a. Alternative Architectures

There are three main architectures that the NPS TSSE design team considered. The first of these is a medium size combatant with a tow, or trailer, carrying additional weapons, sensors, logistics support, etc (Option I). The second consists entirely of medium size combatants (Option II). The final architecture is a mixture of small and medium sized combatants (Option III). A representative combatant already in production was used to illustrate the range of capabilities and limitations of the architecture. The representative combatant may or may not look like or have the same capabilities as the TSSE design, but were provided as a starting point to estimate size, range, naval architecture parameters, etc.

1. *Option I: Medium Size Combatant (450 LT) with Tow (450 LT)*

In this option the combatant is designed as just that, an extremely capable fighting craft that is designed to be a warship. However, this combatant must be capable of connecting to and towing a "barge" of approximately the same displacement at the desired transit and deployment speeds of 15 knots. The combatant will contain largely self-defense weapons and be capable of defending itself and the Expeditionary Warfare Grid. The vast majority of the Expeditionary Warfare Grid components will be contained on the tow to provide maximum flexibility of the combatant. The tow may also provide some of the fuel required during the transit and deployment phases of the operation. The tow system will be of a semi-fixed design, similar to that depicted in Figure XVIII-24. This figure depicts a SLICE/KAIMALINO configuration currently studied by the Office of Naval Research Advanced Hullforms Program and Lockheed/Martin Corporation.

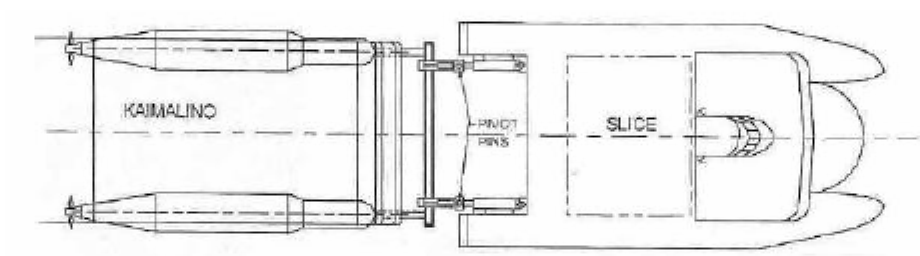

Figure XVIII-24: Notional Surface Craft with Tow System Configuration
(Source: Markle, et al., 2001)

In higher sea states the tow may be extended to a conventional tow or may be rapidly disengaged to allow the combatant greater maneuverability during an engagement. The Swedish “GOTEBORG” class is representative of modern combatants in the 450 LT displacement range.

Figure XVIII-25. Swedish Goteborg Class Surface Combatant (Source: Markle, et al., 2001)

Nation:	Sweden
Class:	GOTEBORG
Number in Class:	4
Built by:	Karlskrona Shipyard
Displacement:	420 tons (full load)
Dimensions (ft):	187 x 26 x 6.6
Speed:	30 knots
Range:	1900 NM at 12 knots
Propulsion:	3 MTU 16V 396 TB4 diesels (8700 hp)
	KaMeWa 80-S62-6 water jets
Electrical:	3 285-kVA diesel generators

Weapons:	1 Bofors 57mm
	1 Bofors 40mm
	4 torpedoes
	8 RBS-15 SSM
	A/S Mortars 4 Saab 9-tube launchers
Sensors:	Sea Giraffe (G/H Band) air and surf
	2 Bofors Sea Viking optical directors
	Thomson Sintra VDS
	Simrad hull mounted active sonar
Manning:	7 Officers, 36 enlisted
Construction:	Steel Hull
	Aluminum Superstructure
	Fin stabilizers
Improvements:	Upgrade Sonar (CDS Hydra)
	IRST director
	Passive Towed Array

2. *Option II: All Medium Size Combatants (600 LT)*

This variant was looked at to assess the cost/benefit of building the entire combatant system using a single hull design versus the alternative of a system with more than one design, such as that in Option I. This combatant would need to carry all the Expeditionary Warfare Grid components. It would either need to have a reduced number of organic weapons or greater numbers of hulls to maintain a higher payload fraction of organic weapons. The combatant would have the flexibility, upon completing deployment of the Expeditionary Warfare Grid, to transit out of the access denial zone and have weapons modules placed in its now empty grid deployment modules. The Swedish VISBY class as an example of the displacement range of the medium size combatant.

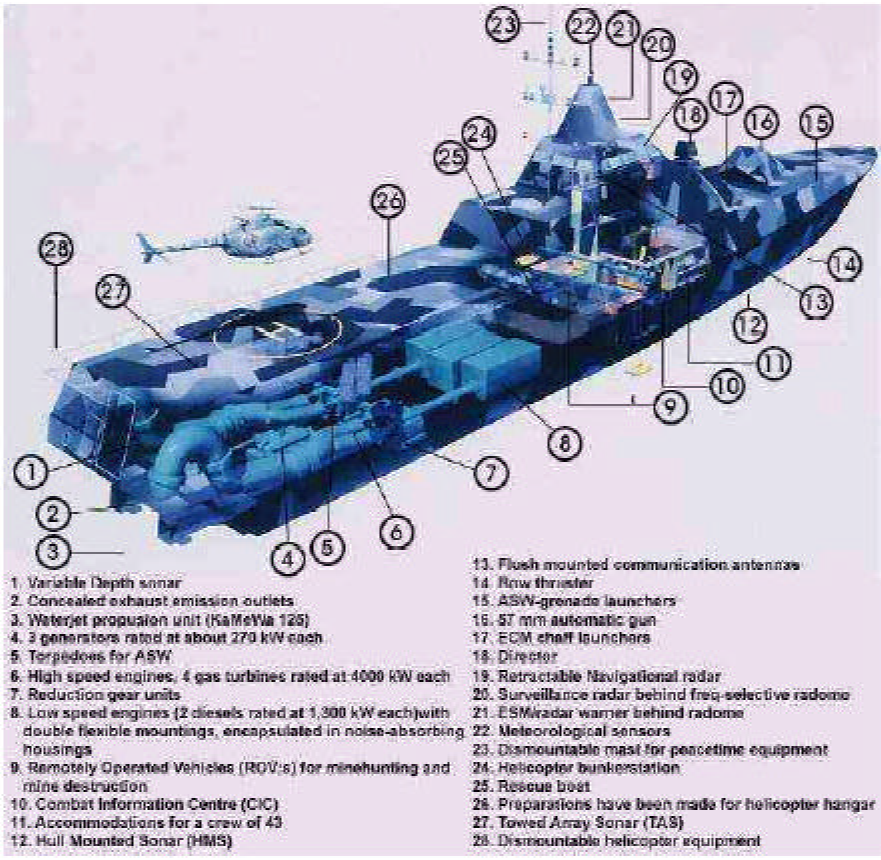

Figure XVIII-26: Swedish Visby Class Combatant (Source: Markle, et al., 2001)

Nation:	Sweden
Class:	VISBY
Number in Class:	6 planned
Built by:	Karlskrona Shipyard
Displacement:	600 tons (full load)
Dimensions (ft):	236 x 34 x 7.9
Speed:	38 knots (max) 35 (sustained)
Range:	2300 NM at 15 knots
Propulsion:	4 Allied Signal TF50A gas turb (5370hp)
	2 MTU 16V 2000 N90 diesels (1760 hp)
	KaMeWa 125 SII water jets (21480 shp)
Electrical:	3 270-kVA diesel generators

Weapons:	1 Bofors 57mm
	1 Bofors 40mm
	4 torpedoes (400mm tubes)
SSM:	8 RBS 15 MKII inertial guidance, active homing
	A/S mortars Saab Alectro 601 127mm
Sensors:	Bow mounted high frequency sonar
	Computing Device Canada hydra
	Passive towed array and Variable Depth Sonar active
	Ericsson Sea Giraffe 3D(C band)Air/Surf
	Celcius Tech Pilot (I band) Surface
	CEROS 200 MK3 Fire Control (I/J band)
Manning:	6 Officers, 37 enlisted
Construction:	GRP/FRP Hull and superstructure
	Fin stabilizers
Aviation:	Helo capable
	Hangar

3. *Option III: Mixture of Small (250 LT) and Medium (800 LT) Size Combatants*

This design was thought of as the “fighter” and “freighter” architecture. The small combatant would be designed primarily as a combatant, while the medium combatant would be designed to carry the majority of the grid components. As in the case of the 600-ton combatant of Option II, the larger (800 ton) combatant in this option would have the flexibility upon completing deployment of the Expeditionary Warfare Grid to transit out of the access denial zone to have weapons modules placed in its now empty grid deployment modules. The UM AL MARADIM Class is considered representative of the 250 LT “fighter” and the Laksamana LAKSAMANA Class representative of the 800 LT “freighter”.

Figure XVIII-27: Kuwaiti Um Al Maradim (Combattante I) Class Combatant
(Source: Markle, et al., 2001)

NATION:	Kuwait
Class:	Um Al Maradim (Combattante I)
Number in Class:	8 planned
Built by:	CMN, Cherbourg
Displacement:	245 tons (full load)
Dimensions (ft):	138 x 27 x 6.2
Speed:	30 knots
Range:	1300 NM at 15 knots
Propulsion:	2 MTU 16V 538 TB93 diesels (4000 hp)
	2 KaMeWa water jets
Weapons:	1 Giat type M621 20mm
	1 Orobreda 40mm
SSM:	4 BAe Sea Skua (semiactive)8.1 NM
SAM:	may be fitted with Simbad twin for Mistral missiles
Sensors:	Thomson-CSF MRR, 3D, C-band, air and surf
	BAe Seaspray Mk3(I/J band) fire control
Manning:	5 Officers, 24 enlisted

Construction:	Steel Hull

Figure XVIII-28: Malaysian Laksamana (Assad) Class Combatant (Source: Markle, et al., 2001)

NATION:	Malaysia
Class:	Laksamana (Assad)
Number in Class:	4
Built by:	Fincantieri, Breda, Mestre, Marghera
Displacement:	705 tons (full load)
Dimensions (ft):	204 x 30 x 8
Speed:	36 knots (max), 34 knots (sustained)
Range:	1900 NM at 18 knots
Propulsion:	4 MTU 20V 956 TB92 diesels (5030 hp)
	4 propellers
Electrical:	3 diesel generators
Weapons:	1 OTO Melera 76mm/62 Super Rapid
	2 Breda 40mm/70 (twin)
	6 torpedoes (324 mm)
SSM:	6 OTO Melera/Matra Otomat Tesea Mk2
SAM:	1 Selenia/Elsag Albatros launcher (4 cell/2 reload),
Sensors:	Selenia RAN 12L/X (D/I band) air and surf
	2 Selenia RTN 10X (I/J Band) fire control

	1 Selenia RTN 20X (I/J Band) fire control
	STN Atlas Elektronik, 94-41, hull mount
Manning:	52 (combined officer/enlisted)
Construction:	Steel Hull

b. Measures of Effectiveness(MOE)/Measures of Performance(MOP)

The following Measures of Effectiveness (MOE) and Measures of Performance (MOP) were utilized for the Analysis of Alternatives:

1. Flexibility: How well the mission is performed
2. Versatility: How many missions can be performed
3. Lethality: How much weapon capability
4. Survivability: How well can craft survive in high
Threat environment
5. Deployability: How easy to arrive in theatre

Table 1: Measures Of Effectiveness/Performance	Flexibility	Versatility	Lethality	Survivability	Deployability
1. Range	X				X
2. Speed	X		X	X	X
3. Grid Deployment Order	X				
4. Payload Capacity	X	X			
5. Sea Keeping	X		X		X
6. Organic Sensor Capacity	X	X	X		
7. Cost a. Total Fuel Consumed b. Number of personnel at risk c. Procurement d. Maintenance/Upkeep	X	X	X	X	X
8. Multiple Mission Capability		X			
9. Modularity		X			
10. Craft Organic Weapons		X	X		
11. Weapons Load Out			X		
12. Stealth			X	X	
13. Suceptability a. Speed b. Stealth c. Point Defense	X		X	X	
14. Vulnerability a. Armor b. Redundancy c. Egress Capability d. Arrangement of Equipment/Spaces				X	
15. Endurance					X
16. Habitability					X
17. Logistic Support					X

Table XVIII-5: Analysis of Alternatives Matrix (Source: Anderson, et al., 1999)

c. Operations Analysis

In order to estimate and compare the effectiveness of the proposed SEA LANCE designs, it was necessary to formulate a salvo equation that could be used on all platforms of interest. This equation was used to develop a spreadsheet that calculates the engagement results of our design options one salvo at a time. The designs are evaluated using various sets of initial conditions in order to compare their relative performance. To account for the dual role of most defensive weapons as missile defense and anti-air weapons, both planes and incoming missiles are considered targets. If there are no targets detected, with respect to weapon type, then no weapons are fired during that salvo. If there are ANY targets detected, a full salvo is fired.

Threat-specific defensive weapons, active, and passive defense characteristics are estimated for each platform type.

A "Weapon Kill Factor" is calculated by estimating the average number of defensive weapons expended (i.e."Shoot, Shoot, Look, Shoot") to destroy one offensive weapon before it hits the platform. It is assumed that if there were two defensive weapons fired at an incoming surface-to-surface, or air-to-surface missile, it would be destroyed. All other offensive weapons are immune to this form of defense. The "Weapon Kill Factor" is that fraction of incoming offensive weapons destroyed by defensive weapons.

Some platforms also have active and/or passive defenses. To take this into account, the fraction of incoming offensive weapons deceived by any combination of these (i.e. Electronic Countermeasures, chaff, decoys,…, etc.) was calculated as the "Platform Deception Factor." This calculation assumes that the number of shots expected to miss, out of 100 shots fired at the target. This was estimated as 30 for our opposition and manipulated as required to meet our mission objectives (typically 50-75) for the SEA LANCE combatant. A value of 50 for torpedo decoys was used across the board. Aircraft were assumed to avoid 90 "air mines" out of 100 and this was included in this factor, even though it doesn't exactly fit the definition. This factor applied to only surface-to-surface missiles, air-to-surface missiles, air mines, and torpedoes. All other weapons were assumed to be immune to this form of defense.

To estimate the damage inflected by these hits, the number of hits (weapon specific) required to kill each platform is determined. For the all of the variations of the SEA LANCE combatant, it was assumed that one hit would result in a mission kill. In this case if the salvo calculations resulted in fractional units remaining, the number was rounded down prior to calculating the next salvo. For larger platforms, requiring multiple hits to kill, fractional units were carried over and considered damaged. Due to the nature of the calculations, the damage had no effect on the delectability of the craft, but did reduce its weapon delivery capability and its sensor contribution.

Up to this point it is assumed that the opposing force detects all platforms. This assumption has been used in the past to evaluate blue water engagements of large ships. This was not considered "safe" in this application due to the size, possible stealth, and geographic location of the platforms being evaluated. A platform's detectability was based on size and stealth. This, however, did not account for the ability of the opposition to locate the target platforms. In an attempt to correct for this, estimations of expected sensor characteristics were coupled with the number of platforms and the possibility of non-organic sensors (referred to generically as intelligence), to quantify the sensor ability of each side of the engagement. Assumptions made to estimate how easily a platform can be detected are based on comparisons of its physical size, relative stealth, and the accuracy of expected intelligence that would be available on platforms of that type. For the purposes of these calculations, "intelligence" refers to all non-organic sensor systems, but is used for stationary targets only (i.e. bases, ballistic missile sites,…, etc.). The range a platform of its size would be detected was compared to a "Standard Platform" (i.e. Boeing 747 for an airplane, PERRY (FFG-7) Class for a ship, or LOS ANGELES (SSN 688) Class for a submarine).

Based on a curve fit using existing ship designs, the change in radar cross section is approximately equal to the fractional change in displacement raised to the 3/2 power. Unfortunately, the detection range scales with the 4th power of cross section. Estimates were made of the opposition characteristics based on the same standard platforms, chosen due to the Team's familiarity with those units. Because both sensor and detection characteristics were normalized to these platforms, changing the "standard" platform would not change the relative performance of any sensor or the detectability of any platform. In an access assurance situation, the goal is to clear an area for the blue water fleet to "safely" operate. This scenario lends itself to the notion that the SEA LANCE combatant would sweep the area for possible threats and engage the enemy as it encounters them. Likewise, the opposition forces are principally land based and/or littoral; therefore their pattern of operation would be unidirectional as well. In both cases, it is assumed that there would be a "front line" of some shape that would form the principal search area. Sensor characteristics were used assuming that there was this line of engagement. For our scenarios, this distance was assumed to be about 200 NM.

It is assumed that if a platform is detected that both sides are coordinated enough to target it, regardless of the source or quality of the initial detection. When the larger platforms were destroyed, all the assets allocated to that platform were destroyed as well. For example, if an air base was destroyed, all the aircraft at that base are destroyed too. The calculations were integrated into a spreadsheet capable of predicting several possible scenarios for each of the three options.

1. *Opposed Grid Insertion*

It is assumed that the SEA LANCE combatants meet with naval resistance at 500 NM and engage them while attempting to transit and deploy the trip wire and grids. The first salvo involves all opposition naval forces, the full land based ASM threat, and 10% of its "merchant" fleet. A three salvo per day model was used and 25% of available aircraft attack each salvo (when applicable). By the time of the next engagement, another 10% of the merchant fleet is in range and the opposition aircraft support the attack along with all surviving forces. The third and fourth salvos both add another 30% of the merchant fleet to all remaining forces. By the fifth salvo, the SEA LANCE combatant would be about 480 nm into the area and the remaining 20% of the merchant fleet are now in range. Assuming the worst-case scenario, the SEA LANCE combatant would have to transit another 400 nm into the area before laying the trip wire. This takes them until salvo number nine. Once the trip wire is deployed, it adds sensor capability but no weapons to the SEA LANCE combatant/system. After the grid is deployed, both the sensor and weapon capabilities are increased. The first salvo that makes use of this increased capability is salvo number eleven. It should be noted that both the trip wire and the grid are assumed to be cargo until deployed. As each SEA LANCE combatant/GDM is destroyed, the capability of the trip wire and grid is degraded. After the trip wire and grid are deployed, they are immune to attack and are only degraded by logistics.

2. *Semi-Opposed Grid Insertion*

In this scenario, the first salvo doesn't take place until after the trip wire is deployed, while the grids are being deployed. The SEA LANCE combatant engages with the added benefit of the trip wire's sensors, but not the weapon capability of the grids. The first salvo involves all opposition naval forces, the full land based ASM threat, and 100% of its "merchant" fleet. The next engagement includes 25% of available aircraft along with all surviving forces. After the second salvo, all grid weapons and sensors are available.

3. *Unopposed Grid Insertion*

In this scenario, the first salvo doesn't take place until after the trip wire and grids are deployed. The SEA LANCE combatants engage all opposition naval forces, the full land based ASM threat, and 100% of its "merchant" fleet with full capability trip wire and grids. The second salvo includes 25% of available aircraft along with all surviving forces.

4. *Conclusions*

The results of the Operations Analysis were presented in a series of figures such as Figure XVIII-29 below. This plot shows the amount of Opposition Capability Remaining for an Opposed Grid Insertion against a Sea Lance force. The 400 LT with Tow, Option 1, clearly leaves fewer enemy units able to resist further grid insertion. The results were similar for the other two scenarios, with Option 1 performing as well or better than the other two options.

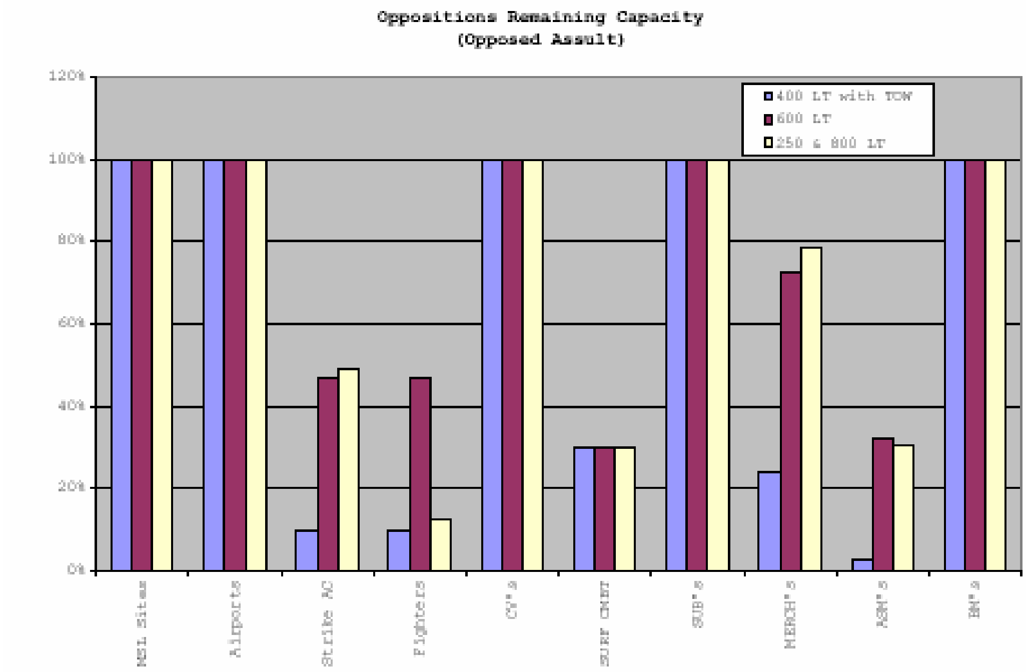

Figure XVIII-29: OPFOR Capability Remaining For Opposed Grid Insertion (Source: Markle, et al., 2001)

d. Flexibility

The team defined flexibility as a measure of how well the option performed the mission. Option I, the 450-ton combatant with equal-sized tow, was at the top of this category. The tow is immensely flexible and modular by the nature of its design. The range lost due to the increased powering requirements when towing the "trailer" can be recouped by providing additional fuel capacity on the tow. Payload capacity is the best for the dollar spent because of the high payload fraction associated with the tow. Analysis of Option 1 resulted in the fewest number of manned combatants to complete the mission. This would put the fewest number of personnel at risk. The maintenance and upkeep costs should be less than the other options because of the lower complexity of the tow, which is essentially an unpowered (except for emergencies), uninhabited barge. The other options pay the price of increased complexity (propulsion, electrical, habitability, etc.) by having the combatants carry the network components.

Assuming that modularity means that the combatants can be outfitted with weapons and/or sensor modules following deployment of the network, Option II and III could carry a greater number of organic sensors and weapons than Option I following deployment of the network. This would limit their flexibility during deployment of the network, but increase it following deployment. This would greatly increase the complexity of the Option II and III designs and would provide a number of difficult challenges to overcome. The modular change-out would need to be performed at sea and would require the combatant to return outside the access denial zone to rendezvous with the POM logistic force, change-out and then return to the access denial zone, a round trip of up to 1200 NM. Although the conversion of the "freighter" to "fighter" capability is attractive, the time and logistics support force required to do so is felt to be an excessively high penalty. The tow can shift to a "fighter" role quicker, simply by releasing the tow, and without the need for logistic support. Option I does have its challenges as well. The tow must be capable of operating in the sea states outlined in the requirements document. The design will need to account for the vessel interaction issues of the combatant with a fixed tow, solve the material and controls requirements of the fixed tow, produce a platform with the stability to deploy the network and conduct the secondary missions outlined in the requirements document.

e. Versatility

The team defined versatility as a measure of how many different missions could be performed by an option. The team chose Option I as the overall choice in this measure. Option I has the advantage that the towing craft becomes a very capable combatant when it is no longer towing the "trailer". It is capable of performing secondary missions such as Maritime Interdiction Operations or Special Operations Forces insertion. The tow could be placed on a sea anchor following the deployment phase. It could then be used as a "lily pad" for helicopter or UAV operations. It would also provide another target of relatively the same size and shape of the combatant for the adversary to consider. It could also be utilized as a platform to house the retrograde and unexpended network components once the overall mission is completed. The other options could produce variants that would be capable combatants, but would do so at the expense of network carrying capability. All the platforms would be designed with modularity in mind. This could lead to the argument that the larger platform could house more modules of a more diverse nature and therefore be more versatile. This could lead to the choice of the “fighter/freighter” concept of Option II. The towed vessel of Option I would provide as much versatility of payload as the freighter of Option II without the burden of protecting the larger, less capable freighter. Therefore, Option I was the choice for this versatility.

f. Lethality

The team defined lethality as a measure of the ability to inflict damage to the enemy and the extent to which the enemy’s mission capabilities) are degraded or eliminated by the damage inflicted. This MOE/MOP evaluates the combatants, not the entire system. This is the only MOE/MOP that Option I did not come out the winner. Option II faired the best under this definition because of its size and ability to carry a large amount of lethal payload. Assuming modularity is designed into the craft and/or some of the medium-size combatants (800 LT) may be designed as fighters vice freighters, this option would provide a large, mobile organic weapons capability. The 250 LT small combatants would provide a fast, extremely maneuverable platform to transport this option’s lethality rapidly around the area of operations. Option I performed well in this option too. The combatant (450 LT) would provide a large amount of organic weapons capability and could rapidly transit the area of operations when the tow was detached. Conceivably the tow could have weapons modules placed in it, but that would add complexity to both the tow and the modules themselves. Overall, Option II was the best because of its large freighter with the ability to carry a large amount of organic weapons and its small fighter with its stealth and high degree of maneuverability.

g. Survivability

The team defined survivability as a measure of how susceptible an option is to attack, how vulnerable it is to that attack, and how well it recovers from the attack. All of these factors will determine the level of survivability of the individual option. The operations analysis based on cost in the Appendix (page A-53) shows that the Option I beat the other options in all the scenarios when placed on a level playing field. It also shows that the 450 LT combatants with its tow beat all the other combatants in all the scenarios with the exception of the opposed assault. The increased stealth of the 250 LT combatants provides it with less susceptibility and therefore greater survivability in this scenario.

The vulnerability of the combatants should be about equal. They will all be designed with relatively the same degree of redundancy (minimal), armor (none), and egress capability (maximum for crew survival) and with relatively the same equipment and space arrangements. The larger combatants may have a slight advantage in number of minor weapons hits it can absorb, but it is assumed that none of these craft, due to their relatively small size, are capable of surviving a cruise missile or similar sized weapon hit. The tow may provide some deception when it is "anchored" following deployment of the network. It is relatively the same size and shape as the combatant and will provide the adversary another to track to identify. The recoverability of the craft should be relatively the same as well, which is minimal. They will all have the same basic automated damage control and firefighting systems capable of dealing with minor operational casualty or weapons effects but, in the aftermath of any significant weapon hit or fire, they are assumed to be non-recoverable. Accordingly, most survivability design features are dedicated to maximizing the ability of the crew to safely abandon ship. Option I was evaluated as the best overall in this measure.

h. Deployability

The Team defined deployability as a measure of how long the crew can be sustained on board (habitability), how much outside support it requires and how often it requires outside support. If habitability were based on size, the 800 LT craft component of Option III would be best but, since Option III also includes the smallest (250 LT) craft as well, which would be the worst, overall Option III does not do well. The 450 LT craft of Option I and the 600 LT craft of Option II would probably be of comparable design, with the exception that Option II would need space and volume for network components and habitability may be sacrificed to meet mission requirements. Option I has the greatest potential for storing sufficient fuel on the combatant and tow without sacrificing network carrying capacity. The logistic support required to provide the 800 LT craft of Option III with the rearming necessary to transform from a freighter to a fighter would add significantly to the total ownership cost of the option. All of the combatants would probably have relatively the same requirements in terms of parts, maintenance, underway replenishment, etc. Overall, Option I was found to be the best of all the options.

i. Architecture Conclusion

Option I was the winner in 4 of the 5 MOE/MOP. The Team assigned equal weight to each of the 5 MOE/MOP and therefore Option I was the choice of the 3 architectures reviewed. Option III was the next best alternative, possessing some of the same attractive features as Option I, but paying some substantial penalties for this level of performance. Option II performed the worst in all but one of the categories. It followed the adage that a ship designed to be a jack of all missions, will be a master of none.

6. Architecture Definition

The team analyzed the following options to choose the architecture's hull form, hull material, propulsion plant and mechanism to convert the propulsion plant's mechanical work into thrust.

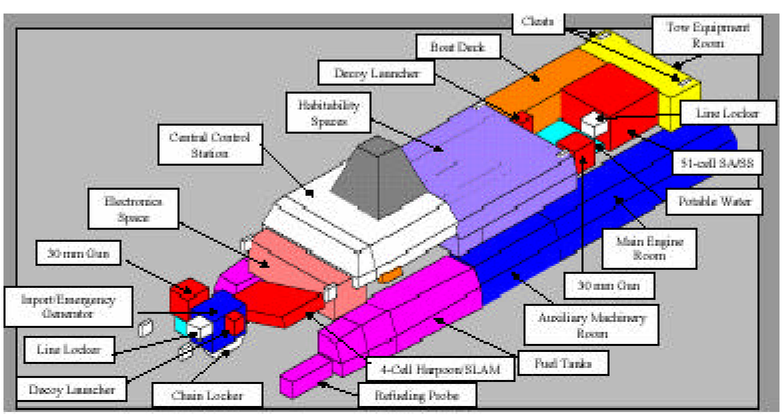

Figure XVIII-30: SEA LANCE Internal Configuration (Source: Markle, et al., 2001)

a. Monohull versus Wave-Piercing Catamaran

Flexibility, versatility, lethality, survivability, and deployability attributes of the combatant hull form are crucial to the achievement of the mission of the vessel. Analysis of hull stability and sea keeping, hull resistance and powering requirements, payload capacity and other characteristics and capabilities against the above attributes revealed that a Wave-Piercing Catamaran hull form would provide the required characteristics necessary for the combatant to meet all mission requirements.

Sea keeping, maneuverability and operability characteristics are essential for successful mission completion. The combatant is required to perform open ocean transits in Sea State 6, network deployment operations as well as fight in Sea State 4 and small boat operations in Sea State 3. The combatant is also required to perform refueling and replenishing operations at sea. Additionally, the combatant will conduct vertical replenishment operations.

After reviewing sea keeping information for several hull forms and the measures of performance, the Wave-Piercing Catamaran was judged the best to meet all fundamental requirements. In general, a Wave-Piercing Catamaran is a catamaran with long, slender outboard hulls designed to slice through waves. A flared center hull incorporated into the cross-structure provides wave deflection. The above-water potions of the outboard hulls slope sharply forward toward the waterline, allowing the bows to pierce through waves.

b. Wave Piercing Catamaran

The following are generalized sea keeping, maneuverability and operability characteristics for the wave-piercing catamarans.

1. *Sea Keeping*

1. Maintain a relatively high percentage of calm water speed in high sea state conditions.
2. Ride control systems are able to control relatively high deck-edge accelerations.
3. A Shock mounted bridge could further reduce accelerations.

2. *Maneuverability*

1. Ship's turn radius is relatively larger at high speeds.
2. Relatively good turning ability at slow to medium speeds.

3. *Operability*

1. Capable of a relatively the same endurance as monohulls
2. Requires large amounts of fuel during high speed long-range transits

c. Monohull

The following are general sea keeping, maneuverability and operability characteristics for a conventional monohull.

1. *Sea Keeping*

1. Experience substantial speed reduction in heavy seas.
2. Speed reduction required to diminish undesirable ship motion, slamming and deck wetness as wave height increases.
3. Larger monohulls are less sensitive to rough seas than smaller monohulls.
4. Active stabilization systems provide improved sea keeping.
5. Wave-piecing monohulls improve sea-keeping performance in rough seas, requiring less speed reduction.

2. *Maneuverability*

1. Good maneuvering performance at higher speeds.
2. Directional stability improves with increasing ship speed.
3. Overall maneuverability is significantly affected by size, type and location of steering/propulsions system.
4. Poor position-keeping, station-keeping, and low speed maneuvering performance.

3. *Operability*

1. Rugged, simple and survivable.
2. Forty knots appears to be the maximum practical speed.
3. High speeds are achieved with a cost.

d. Other Comparisons of Monohull versus Catamaran

The catamaran has a greater payload capacity (weight) than the monohull of the same general characteristics. A catamaran has greater flexibility as far as hull option to improve stealth. The catamaran has a greater combat efficiency (high speed >15 knots) than the monohull. However, the monohull has greater transit efficiency (low speed <15 knots) than the catamaran. Since the majority of the operations will be performed at high speed, the catamaran is the choice based on powering requirements. The catamaran provides a large deck area to provide space for combat systems, cargo handling and stowage or aviation operations.

e. Hull Form Conclusion

The characteristics listed above meet or exceed the measures of performance required of the combatant. For a small ship, the wave-piercing catamaran provides superior seakeeping characteristics, improved stealth, greater combat efficiency, greater deck area and greater payload than a monohull. The tow option was further analyzed to determine if the hull forms should both be catamarans or a combination of catamaran and monohull. There was a slight benefit powering advantage to the catamaran combatant and monohull trailer. The analysis of towability, directional stability and equivalent motions favored the catamaran combatant and catamaran tow variant with relatively the same displacements. This is not to say that the other combinations of tow and trailer could not be produced, but that they would require increased complexity and more than likely greater cost. The commonality between the hull form of the combatant and trailer will likely decrease design, fabrication and production costs. The small advantage in powering that the combination of monohull and catamaran provides does not outweigh the large number of benefits from producing a catamaran/catamaran combination.

f. Hull Material

There were three general classes of materials analyzed for use during the design effort. They were steel, aluminum, some composite (i.e. glass/fiber reinforced plastic) structure, or a combination of them. The team did not want to rule out either aluminum or composites, but made a determination that steel would be used on a limited basis for structural strengthening only. Steel has the advantage of being stronger and less susceptible to damage of fire or weapons. However, it is more costly and produces a lower payload fraction than aluminum or composites. Steels exceed the survivability requirements of the craft and produce undesirable payload fractions and excessive cost. Aluminum and/or composites can be designed to meet the requirements and will be primary construction materials utilized during the design project.

g. Propulsion Plant

The choices for propulsion plant were gas turbine, diesels, or a combination of the two. Gas turbines have a small machinery box size relative to a diesel plant of the same horsepower. The large intake and exhaust ducts required for the gas turbine are a significant draw back. The diesel consumes less fuel than the gas turbine for the range of speeds from 5 through 40 knots. This is a critical point given the distances that the combatant must travel. Fuel consumes a large amount of the payload and any extra payload lost to fuel is network payload that cannot be carried. The large intake and exhaust ducts that are required for the gas turbine also take up volume that could be utilized for network components as well. The gas turbine will require a reduction gear for both propellers and water jets. The weight of the gas turbine and its associated reduction gear will exceed the weight of a medium speed diesel that could be directly connected to both the water jet and the propeller. For these reasons the gas turbine was eliminated as a choice for propulsion throughout the range of speeds required. It should be noted that the team recognizes the ongoing advances in gas turbine technology and would reconsider this decision if the weight and specific fuel consumption figures approached those of diesels. Option I will be powered by a plant consisting of entirely diesel engines.

h. Conversion of Mechanical Work into Thrust

The process of converting the work of the diesel engines into thrust becomes even more difficult with the fact that we are towing a vessel for a good portion of the mission. Designing a combatant that can attain a maximum speed of 40 knots without the tow and a speed of at least 15 knots with the tow while maintaining the maximum efficiency throughout the range to conserve fuel is a difficult problem. The optimum propeller to produce the maximum thrust while towing is obviously not the propeller that you would want to push the ship through the water at 40 knots. Even a controllable pitch propeller would have problems achieving the maximum efficiency throughout the range. Another problem of a propeller is that it will normally increase the navigational draft of the combatant. A good alternative that may improve on the above problems is the use of water jets. The water jets could be sized and arranged to provide the maximum thrust at their most efficient speeds. They also are not as draft limiting as propellers.

i. Overall Conclusions of the Analysis of Alternatives

The architecture chosen was Option I, which is a 450 LT combatant with a 450 LT vessel with a semifixed close proximity tow. The hull form will be a wave-piercing catamaran combatant and wave-piercing catamaran tow. The hull will be made of aluminum, composites or a combination of the two with steel utilized for structural support where necessary. The propulsion plant and electrical generation will be composed of diesel engines an d their work will be converted to thrust by water jets.

7. Conclusions

The Expeditionary Warfare Grid and SEA LANCE systems provide a new and innovative solution to the problem of access denial in littoral regions. As confirmed by Force Protection analysis as part of the Sea Basing excursion study effort, littoral combatant ships such as SEA LANCE can play a major role in keeping the Sea Base safe from enemy attack. When the SEA LANCE capabilities are paired with the situational awareness provided by the Expeditionary Sensor Grid, the force commander has all the tools at the ready to ensure the unhindered conduct of Sea Base operations.

G. CONCLUSIONS

When analyzing the capabilities required to conduct ExWar against the capabilities available in the current and planned fleet, several apparent capabilities gaps emerged. Many of these capabilities were allocated out to platforms for consideration as candidates for the design classes associated with the ExWar Integrated Project. Prior to selecting candidates, recent NPS designs were examined in order to avoid redesigning a platform that had been the subject of a design effort in the past few years. If there was a design that appeared to fill, wholly or partially, one of the gaps, it was set aside for further examination of its applicability to the overall ExWar system of systems.

The designs discussed above were considered whole or partial solutions to some of these capability gaps. Each of these systems performs a function that will be essential to conducting the STOM operations of tomorrow and have no current or planned system to fulfill their role. These systems and their configurations should be carefully examined in further analysis in order to determine their precise role in future expeditionary operations and become the subjects of research and development efforts to bring these or similar capabilities to the fleet.