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The KAPPA submersible craft concept, the result of a Carderock Division Naval Surface Warfare Center (CDNSWC) Innovation Center project, may be an effective, cost-efficient force multiplier that can perform covert missions in littoral regions and austere ports, assist in providing and maintaining access, and support other joint assets. The KAPPA craft concept is a stealthy, highly maneuverable craft, with a modular payload volume and flexible ocean interface that acts as part of a "cascading payloads" chain for improved littoral warfare operations.

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Submersible Combatant Concept For Improved Littoral Warfare

ABSTRACT

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INTRODUCTION

The KAPPA team was formed in May 2003 for a six-month project under the auspices of the CDNSWC Innovation Center. The project charter, developed by the team, is as follows:

> *Develop design concepts for a submersible craft functioning as part of a cascading payloads chain for improved littoral warfare operations.*

The team's name, KAPPA, comes from a derivative of the charter's theme: "CAscading PAyloads".

The "Littoral Gap"

The Project KAPPA team has coined the term "Littoral Gap" to refer to littoral operational capabilities not currently in inventory, as well as to the large cost differential between high-value, high-end U.S. Navy assets currently employed to deal with a growing number of relatively inexpensive means of access denial by enemy forces. This cost refers not only to acquisition, fabrication, and development costs of the platform, but is also measured in terms of the lives of U.S. sailors placed in harm's way and the opportunity costs associated with the high-end platform supporting unmanned systems in shallow waters in lieu of performing other missions.

"Cascading Payloads"

The future of joint warfare relies heavily on unmanned systems. Naval Power 21, the roadmap for the Navy in "Projecting Decisive Joint Capabilities" (Clark 2002), relies extensively on unmanned systems in its three fundamental concepts: Sea Strike, Sea Shield, and Sea Basing, as well as the ForceNet, the Naval Power 21 enabler. For example:

- Sea Shield: "Both dedicated and organic MCM forces will use new generations of sophisticated UUVs – eventually to be joined by unmanned air and surface vehicles- to detect, avoid, and neutralize mines at all depths." (Bucchi and Mullen 2002)
- Sea Strike: "Improvements to unmanned air, surface, and undersea vehicles will provide long surveillance dwell times and expanded warfare options while minimizing risks to the warfighter." (Dawson and Nathman 2002)
- SeaBasing: "Next-generation missiles, aircraft and unmanned vehicles will provide rich streams of information, to include optical, infrared, audio, seismic, radiological, magnetic, and thermal returns." (Moore and Hanford 2003)
- ForceNet: "Launched and maintained from forward-deployed ships and submarines, such sensors, including unmanned aerial vehicles, remote mine-hunting systems, and advanced deployable systems on the ocean's floor-will provide persistent and responsive networked sensor coverage to increase battlespace transparency, sharpen decision making, and guide operations." (Mayo and Nathman 2003)

In order to maintain their relatively small size the limiting factor in adjunct vehicles, especially undersea adjunct vehicles, is energy storage. In order to maximize the energy used in performance of mission execution, rather than transiting to the operations area, these vehicles must be deployed relatively close to the area of interest. Other systems, such as advanced deployable systems must be deployed in the littorals. Launch of air and surface systems could reveal the presence of an otherwise undetected SSN or SSGN. While it is possible to deploy, support, and retrieve many of these unmanned vehicles from a high-end platform (e.g., SSN, SSGN), there may be an efficient and cost effective means of managing these smaller vehicles and payloads. The solution is a modestly sized adjunct vehicle that can fill the intermediate role between the high-end platform and the smaller unmanned vehicles and other payloads.

The concept of "cascading payloads" is that of a tiered system of increasingly smaller units that deploy payloads. This concept, as it relates to the KAPPA craft, is graphically depicted in Figure 1. The KAPPA craft would be deployed from, and supported by, a mother ship. The mother ship role has not been exclusively assigned to any particular platform, and could be performed by a submarine or surface combatant, depending on the need for stealth. The KAPPA craft would then be used as a platform for deploying smaller payloads (e.g., UUVs, UAVs, ROVs). These smaller payloads could in turn deliver payloads of their own, such as sensors or weapons, or even smaller vehicles, and the "cascade" would continue.

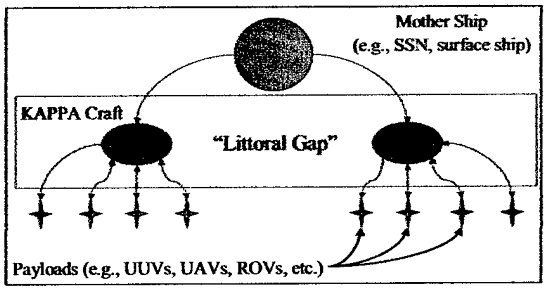

FIGURE 1. Cascading Payloads concept

Why KAPPA?

As mentioned previously, a high-end platform could perform many of the necessary missions in littoral regions. However, it is postulated that a moderately sized submersible craft acting as an intermediate platform is an efficient and cost effective means of performing these missions, particularly for the deployment of small unmanned vehicles. In that regard, the

KAPPA concept provides the following advantages:

1. Flexible payload volume with flexible ocean interface
2. Highly maneuverable
3. Stealthy
4. High risk tolerance
5. Increased stand-off for mother ship
6. Frees mother ship for other missions

One of the keys to improved littoral warfare is the ability to be flexible, both in terms of operations and payload delivery, as well as in the ability to quickly reconfigure for different missions. A submersible craft will encounter a broad range of different threats, and will operate in widely changing environments, when operating in littoral regions. Simultaneously, the defense and commercial industries have created a wide range of potential payloads, far outstripping the torpedo, mine, or missile options offered to a previous generation of submariners. In order to provide this much needed mission flexibility, the KAPPA craft concept will include a flexible payload volume, with a flexible ocean interface. The KAPPA craft design includes two payload interface modules (PIMs) that can support a wide array of different payload arrangements. The PIMs are external to the pressure hull; thus, the payloads can be easily reconfigured to provide an alternate set of capabilities in a short period of time. This provides a great deal of flexibility both to the payload designer, as well as to the force commander in determining the most appropriate strategy for a particular mission.

The successful navigation of littoral regions requires a high degree of maneuverability. Because of this need, the KAPPA vehicle design includes increased agility as a primary design decision. Much of the anticipated mission capabilities for the KAPPA vehicle also require it to be extremely stealthy. The smaller size relative to a current high-end platform (e.g., SSN, SSGN) provides a certain inherent improvement in stealth, but operating in littoral regions and shallow water also provides some additional disadvantages in terms of being detected. This means that stealth is a vital concern in providing sufficient survivability for the craft. To enhance stealth, the concept design includes an atmosphere independent propulsion system with an indiscretion ratio (ratio of time snorting/snorkeling to total operating time on mission) of zero.

The KAPPA craft is envisioned to be a much smaller platform than a traditional submarine. In addition, rigorous attention to manning decisions allow for a very small crew to effectively operate the KAPPA vehicle. Due to its relatively small size, it is anticipated that the cost of a KAPPA craft should be significantly less than a fully capable nuclear submarine. It is also highly maneuverable, with defensive "stay and fight" weapons. The attributes of small size, stealth, maneuverability, and small crew change the risk paradigm.

Finally, the use of the KAPPA craft as part of a cascading payload chain for performing littoral warfare missions provides additional stand-off to the mother ship. This is very attractive again in terms of the risk tolerance of a KAPPA craft versus a nuclear submarine. Furthermore, by transferring the duties of littoral warfare missions to the KAPPA crew, it frees the mother ship to perform other missions. This might, for example, allow for the high-end platforms (e.g., SSGN) to remain on-station performing strike missions for longer periods of time.

Another important part of the KAPPA concept design centers on changing the maintenance paradigm, improving crew habitability and safety, as well as quality of life and quality of work, and utilizing human factors engineering to reduce manning requirements and seamlessly integrate the sailor into the design.

The characteristics discussed above are essential to transforming the U.S. Navy's strategy towards littoral warfare. The KAPPA vehicle concept utilizes these characteristics to augment the current force structure and provide a cost efficient means of ensuring and maintaining access, performing intelligence gathering, and defeating enemy threats in littoral regions.

BACKGROUND

The Innovation Center located at the Carderock Division Naval Surface Warfare Center (CDNSWC) establishes multi-disciplinary teams to investigate high-risk, high-payoff problems of interest to the U.S. Navy. Project teams are generally composed of a small number of personnel who work on the project for a period of nominally six months. The Innovation Center provides an environment in which the teams are encouraged to develop creative solutions and explore new ideas while working towards securing funding for future development of their concepts after the completion of the project.

Because the problem presented was very broad in scope, the Project KAPPA team was comprised of a large number of individuals from a wide range of technical disciplines. Of note also was the representation on the team from the two submarine shipyards: Electric Boat (EB) and Northrup Grumman Newport News (NGNN).

CONCEPT DEVELOPMENT

During the first phase of the project, the KAPPA team defined an initial set of craft requirements to begin the concept development process. The focus of the Innovation Center is on developing high-risk, high payoff concepts; thus, it was decided to focus on exploring non-nuclear propulsion systems, because nuclear powered propulsion is a mature technology. Using the KAPPA charter as a starting point, the team then decided on a set of desired capabilities for the craft, which were synthesized from a variety of sources including team brainstorming, "Submarines...The Road Ahead" (NAVSEA 2000), Sea Power 21 (Clark 2002), the Littoral Combat Ship Concept of Operations (NWDC 2003), etc.

This initial set of desired capabilities covered a wide range of different mission areas and platform characteristics. These were organized into different war fighting mission areas. A separate foundational mission area, entitled "Enabling Naval Engineering", was also installed to represent those capabilities that were either inherent characteristics of the vehicle, or were abilities or processes that enabled the other primary war fighting missions to be performed. These would include attributes such as payload modularity, stealth, maneuverability, survivability, and connectivity with joint forces. The complete list of mission areas is provided in Table 1.

TABLE 1. KAPPA Mission Areas

ISRT	Primary Warfighting Mission Areas
Littoral ASW/ASuW	
Mine Warfare	
SOF Operations	
AAW	
Amphibious Warfare	
Enabling Naval Engineering	Foundational Mission Area

Using the mission areas in Table 1 to categorize the desired capabilities for the KAPPA craft, the team further proceeded to assign a ranking to all of the capabilities based on how important they felt that it was for the craft to possess. Based on this ranking process, the team decided that the most important mission areas to focus on for the KAPPA craft were the Intelligence, Surveillance, Reconnaissance and Targeting (ISRT), Littoral Anti-Submarine Warfare (ASW)/Anti-Surface Warfare (ASuW), and

Mine Interdiction Warfare (MIW) areas, along with those related capabilities listed in the Enabling Naval Engineering category. It was decided that these mission areas represented those most necessary and appropriate for a stealthy submersible platform that would operate in littoral regions. It was further postulated that much of the capabilities associated with these three primary mission areas would provide some level of capabilities in the other areas.

Mission Scenarios

In order to determine a set of craft requirements, it was necessary to first assess what the craft would be asked to do, and generally how it might operate. The next step in the project, then, was to develop a set of notional mission scenarios. The team decided to focus the mission scenarios on the three primary areas previously identified. The mission scenario development drew on the experiences of the team members, operator input, and discussions from the LCS CONOPS (NWDC 2003) and other documents. Several of these mission scenarios were then selected as an appropriate cross-section to set the initial craft requirements. These scenarios were not necessarily greatly detailed, but were used as a mechanism to establish the stressing design requirements of the craft (e.g., speed, endurance, etc.) and the required payloads, to begin sizing the craft and the power plant. These particular missions were selected because they addressed some of the driving concerns for the craft development, and are listed in Table 2.

For each of the notional mission scenarios, a speed profile was developed, along with a notional payload compliment that would be required to complete the mission objectives. All of this information was then used to develop an initial set of craft requirements to begin sizing the vehicle.

TABLE 2. KAPPA notional mission scenarios

Scenario Name	Comments
ISRT 1	Airborne littoral ISRT data collection
ISRT 2	Submerged littoral ISRT data collection
ISRT 3	Intelligence on vessel movements
Littoral ASW/ASuW 1	Forward destruction/ disruption of enemy submarines and small boats
MIW 1	Mine reconnaissance

The ISRT 2 mission scenario was the most demanding in terms of energy requirements, and the volume of the necessary mission payloads to complete the objectives. The mission profile for the ISRT 2 mission is shown in Figure 2.

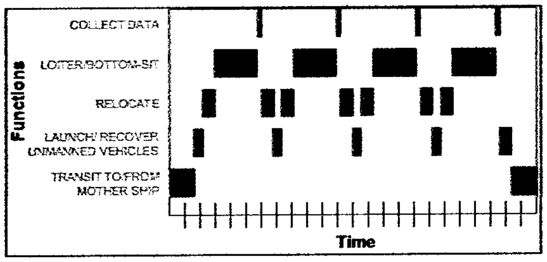

FIGURE 2. Notional ISRT 2 mission profile

The KAPPA craft initially transits from the mother ship to the area of interest. The KAPPA craft then performs a series of launching and/or recovering different unmanned vehicles, relocating, loitering during data collection by the unmanned vehicles, and then retrieving the data. This operational cycle of launch, relocate, loiter, and retrieve data is performed a total of 4 times during the mission. After the data collection has been completed, the KAPPA craft transits back to the mother ship.

The mission payload assumed for the ISRT 2 mission scenario includes 20 Remote Environmental Monitoring Units (REMUS) UUVs, 20 surf-zone crawler reconnaissance bots, and 5 Ariel autonomous legged vehicles (ALUVs). These unmanned vehicle (UV) mission payloads are shown in Figure 3.

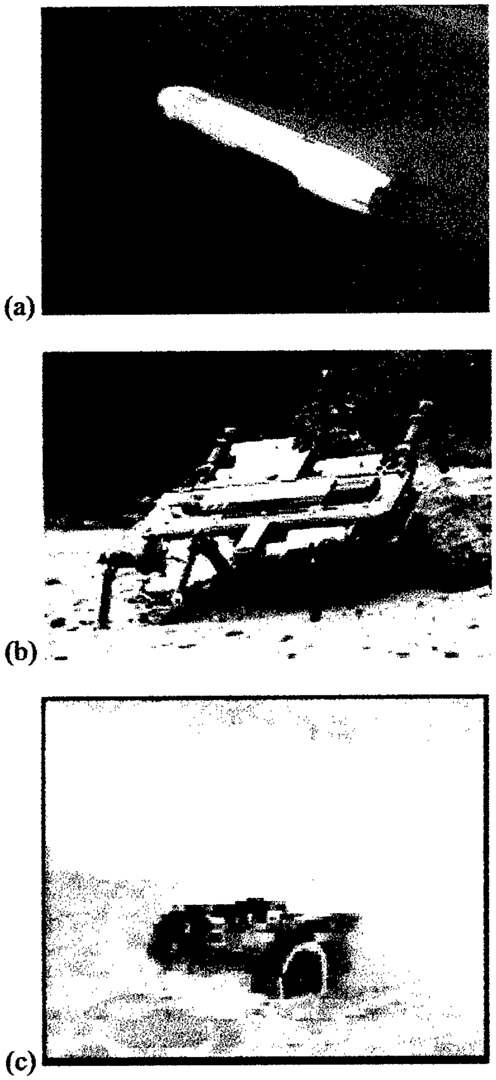

FIGURE 3. ISRT 2 mission payloads: (a) REMUS, (b) Ariel ALUV, (c) surf-zone crawler reconnaissance bot.

The surf zone crawler reconnaissance bots, developed as part of an Office of Naval Research (ONR) sponsored program, are small tracked vehicles that can search a predetermined region of the sea bottom, for the purpose of mapping a potential amphibious assault lane. The Ariel ALUV, which simulates the movement of a crab, is designed for the detection and removal of mines and other obstacles. The REMUS autonomous underwater vehicle is currently the U.S. Navy's tool of choice for shallow water mine countermeasure operations, and has a wide range of applications including harbor security operations, debris field mapping, environmental monitoring, and scientific sampling.

The total ISRT 2 mission duration is 190 hours, approximately 8 days, based on the advertised endurances of the unmanned vehicles (*Ariel Underwater* (n.d.), *Hydroid* (n.d.), *Foster-Miller* (n.d.)). The total on-station time is equal to 16 unmanned vehicle (UV) days. The on-station time is determined by the endurance of each of the unmanned vehicles multiplied by the number used.

Spiral Development

A spiral development approach was adopted for the craft design. Specifically, all of the concept development was assumed to be for a Flight 0 craft, such that the concept meets all of the threshold craft requirements. It was decided that the Initial Operating Capability (IOC) for Flight 0 would be 2012. In order to meet this IOC, it was further established that all components of the craft design must be at Technology Readiness Level (TRL) 7 or greater by 2008. TRL 7 is defined as having a system prototype demonstrated in an operational environment[1].

Craft Requirements

The ISRT 2 mission profile, in light of the projected IOC, was used to develop a set of craft requirements to populate the concept design. The final set of craft requirements is shown in Table 3. In developing the speed profiles for the mission scenarios, it was assumed that the burst speed could be sustained for a period of one hour before needing to recharge, and could be applied twice during a single mission. For the

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[1] ref DoD 5000.2-R

purposes of this concept design the cruise speed was defined as the maximum speed at which the vehicle could operate solely on the primary energy source, without the use of additional energy sources (e.g., batteries). The endurance was defined as the ability to sustain the crew (i.e., sufficient food stores and atmospheric control for that period of time), and is based on the notional eight day ISRT 2 mission with an additional 50% margin of safety.

TABLE 3. KAPPA Craft Requirements

Requirement	Threshold
Burst Speed	25 kts
Cruise Speed	10 kts
Depth	300 ft
Endurance	12 days
Crew	11
Payload Specialists	Up to 4
Payload Volume	4500 ft^3

VEHICLE DESCRIPTION

The craft requirements were used as a basis for developing the KAPPA vehicle concept. The final concept design is shown in Figure 4. A solid modeling software package, SolidWorks®, was used to generate solid models of the vehicle concepts developed as part of this effort. This was an extremely valuable tool for estimating weights and volumes, system arrangements, clearances, hull-form shaping, and general visual inspection of system interactions, potential problems, and possible vehicle operations. The vehicle is somewhat elliptical in shaping, with x-stern control surfaces. The non-pressure hull skin is composed entirely of composite materials, specifically Carbon Fiber Reinforced Plastic (CFRP). The KAPPA vehicle is approximately one-quarter the displacement of a *Virginia* class submarine.

The primary propulsion consists of two 5000 Hp rim-driven podded propulsors mounted on wing struts. The hybrid power plant combines an 810-kW Proton Exchange Membrane (PEM) fuel cell with a 12.7 MWhr lithium-ion battery compliment. This hybrid propulsion and power scheme was developed such that the vehicle was able to meet all of the threshold craft requirements (Table 3).

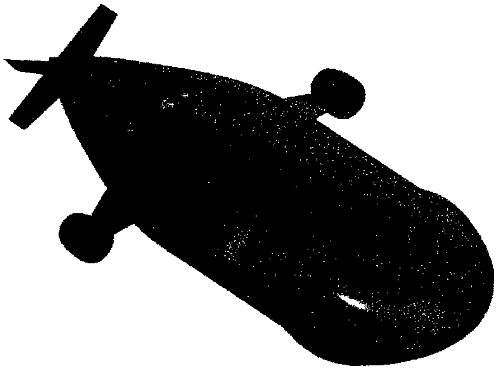


FIGURE 4. KAPPA vehicle concept model

The overall vehicle characteristics are given in Table 4. The breadth is measured from the outer edge of each podded propulsor. Of particular note is the payload fraction based on the submerged displacement, which is higher than current submarine designs.

TABLE 4. KAPPA Vehicle Characteristics

Sub. Displacement	1850 LT
Length on Axis	136 ft
Beam	46 ft
Breadth	81 ft
Depth	23 ft
Draft	17.5 ft forward 19.7 ft aft
Payload Volume	Ext. Modular: 8960 ft^3 Ext. Organic: 1000 ft^3
Payload Fraction	15.6% Δ

An isometric view showing the system arrangements inside the non-pressure hull is given in Figure 5, and a top view is given in Figure 6. Details regarding the craft systems and arrangements will be provided in the sections that follow.

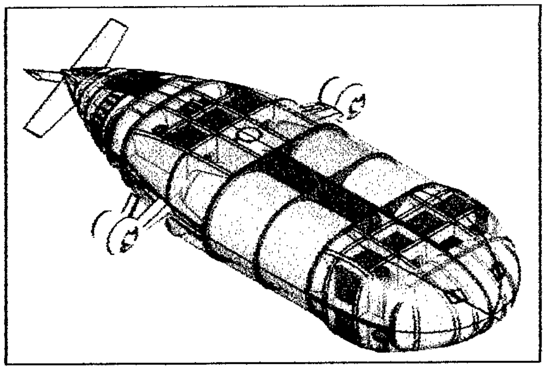


FIGURE 5. KAPPA arrangements

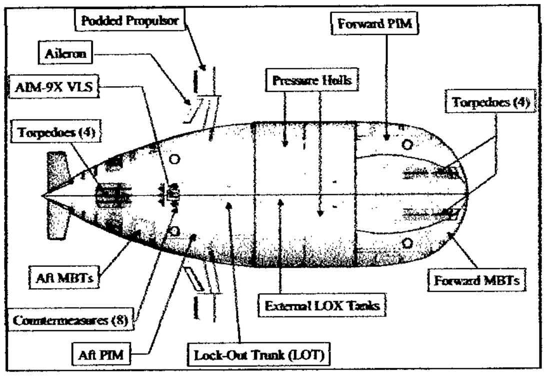


FIGURE 6. KAPPA arrangements (top view)

Composite Non-Pressure Hull

Composite structures are being selected for an increasingly wider variety of Navy assets. Navy sponsored RDT&E efforts at CDNSWC and other Navy labs, private industry, and universities have made composite structures a feasible and affordable option for designers. In fact, some structures, such as the Advanced Enclosed Mast on the LPD 17 would not be possible without composites. In the case of the KAPPA vehicle there are compelling reasons to use composite materials for the non-pressure hull structure, including ease of fabrication of curved surfaces and reduced maintenance.

Composite materials are known for their ability to be cost-effectively molded to doubly curved shapes. The recreational marine industry has taken advantage of this for pleasure boat hulls. ONR is currently investigating the potential cost savings of fabricating the complicated geometry of the bow and stern of surface ships from composites. A standard submarine shape could be approximated from singly curved cylindrical and conical panels, but the KAPPA vehicle shape has only limited areas that are singly curved. This complexity lends to the use of composite materials for fabrication of the hull. The advantage of using composite materials for maintenance reduction is that they do not corrode.

The non-pressure hull (NPH) for the KAPPA vehicle (Figure 7) is composed entirely of Carbon Fiber Reinforced Plastic (CFRP), both for the outer hull skin and the support structure. The support structure is also integrated completely with the structures for the PIMs, organic weapons, and the main ballast tanks (MBTs). The MBTS are also composed entirely of CFRP. This total design provides an advantage in allowing for modular construction, as the MBTs can be fabricated separately from the rest of the non-pressure hull and separately certified. Then the forward and aft NPH sections can be constructed individually, and then attached to the pressure hull support collar frames. The outer hull skin can then be attached to the NPH support structure. This scenario provides a number of advantages and potential cost savings by *constructing smaller pieces and then* assembling the whole structure. This modular construction scenario for the non-pressure hull is shown in Figure 7.

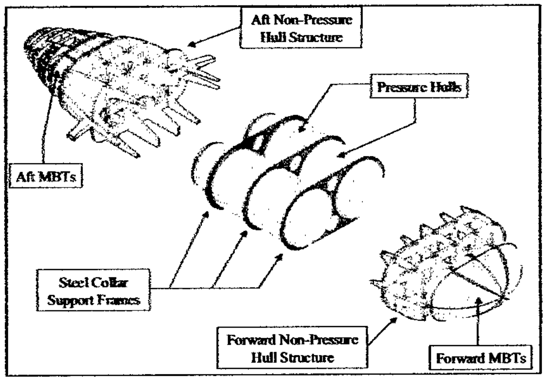


FIGURE 7. NPH modular assembly

NPH Design Process

The hull skin is composed of solid CFRP panels (i.e., not cored sandwich panels) with hat section stiffeners. Solid skins were chosen because there would be no core crushing issues due to the relatively low requirement for the maximum operating depth, and a solid skin is easier to fabricate on doubly curved surfaces, particularly compared with sandwich panels using high density, high crush strength cores. The hat section stiffeners are cored with 32 lb/ft^3 syntactic foam, as demonstrated on *Seawolf* and *Virginia* class submarines.

The loads used for the initial design are wave slap, structural weight, and internal pressure of the MBTs. The wave slap, which is assumed to be 1000 lb$_f$/in^2, controlled the basic external panel design. The average panel bay is set at 48" x 24". *Table 5 summarizes the panel properties,* stresses and deflections.

TABLE 5. KAPPA NPH panel details

Length	48 in
Width	24 in
Thickness	0.5 in
Allowable stress	30 ksi (plane tension/compression)
Load	1000 lb$_f$/in^2
Max. deflection	0.06 in (fully fixed edges)
Defl/span	0.13%
Max Bending Stress	
Panel center	14 ksi (FS 2.1)*
Panel edge	8 ksi (FS 3.8)

*FS = Factor of Safety

The layout of the KAPPA vehicle can be divided into three basic structural areas. The pressure hulls themselves form the structure for the middle body, and the forward and aft NPH structures cantilever off the pressure hulls. This is shown in Figure 8.

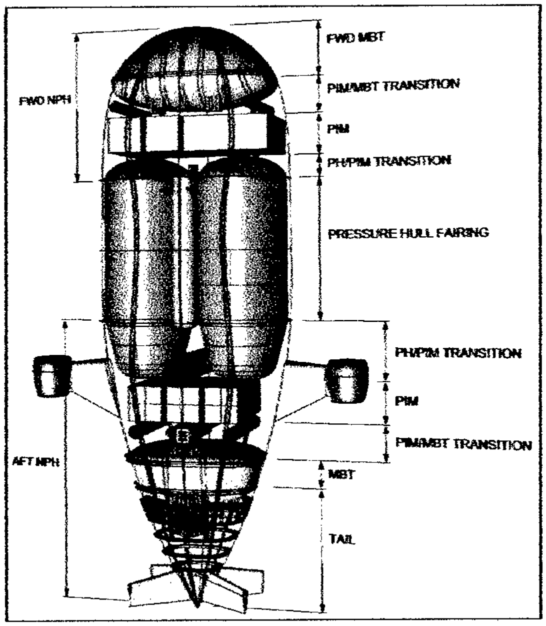


FIGURE 8. KAPPA NPH structural divisions

Main Ballast Tanks

The transient internal pressure of the MBTs can reach 45 psi when the tanks are blown. The tanks are curved, taking advantage of the hulls hydrodynamic shape, to allow them to be a more efficient structure for internal pressure, more akin to a cylindrical pressure vessel than a pressurized flat sided box. Major ring frame stiffeners are added roughly every 4 ft in the athwartships direction. These are augmented by smaller frames running normal to the ring frames every 2 ft, forming nominally 2' x 4' compartments. The forward and aft halves of the forward MBT (Figure 9) have a similar structural design to the Composite Advanced Sail. Using the 0.5 inch thick skin and a cylindrical pressure vessel approximation, the maximum in-plane skin stress is 10 ksi (FS 3.0 on allowable stresses). The actual geometry and penetrations will increase the stress concentrations and will require local reinforcing.

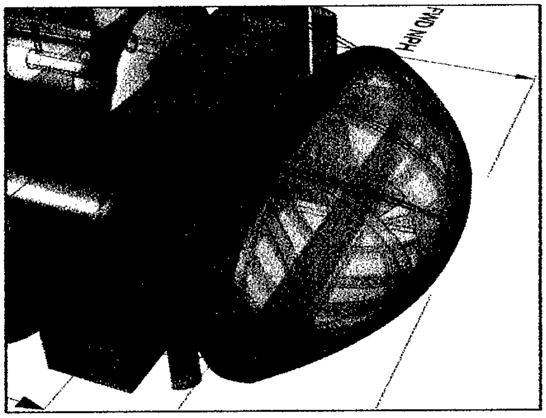


FIGURE 9. Forward NPH arrangement

Payload Interface Module

The aft PIM region requires three 8' square openings in the top and bottom of the hull for a total of six, and the forward PIM requires four on top, two at each side and four on the bottom. These holes in the skin prevent using the stressed stiffened skin design of the MBTs. Instead the main structure for the forward PIM region is 5 main longitudinal bulkheads that connect to the pressure hull frame at the forward end of the pressure hull cylindrical section. These bulkheads also connect to the main ring frames of the forward MBT (see Figure 10). The longitudinal bulkheads are augmented by discontinuous athwartships bulkheads.

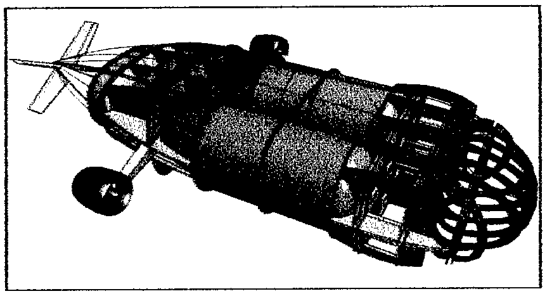


FIGURE 10. NPH structure for PIMs

The aft PIM structure has a similar arrangement, but the design is easier due to the location of the PIMs (more contact area with the pressure hull frame) and only vertical access for the PIMs.

Struts for the podded propulsors are aligned with the gap between the aft end of the pressure hulls and the forward face of the PIM section. This is buttressed by framing linked into the PIM bulkheads. There may be a structural advantage to have the strut run the full width of the hull, but this would require increasing the PIM/pressure hull gap. The Tail structure keeps the stressed skin structure of the aft MBT. Ring frames are placed every 4 ft, between which run smaller stiffeners every 2 feet, forming nominally 2' x 4' panels (partially shown in Figure 11).

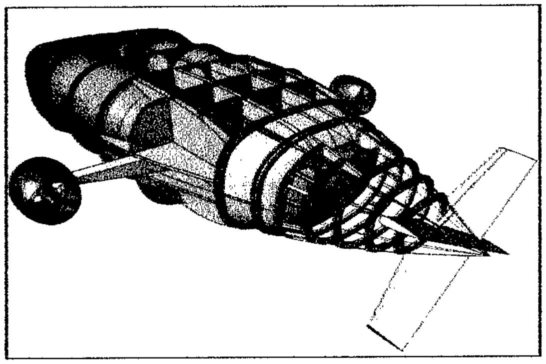


FIGURE 11. NPH tail structure

External Modular Payloads

The KAPPA vehicle has two payload interface modules (PIMs), one forward and one aft. The forward PIM measures 8ft x 40ft x 20ft, and is designed to accommodate 8ft x 8ft x 20ft long International Standard Organization (ISO) containers. These containers can be placed in the forward PIM in a variety of different arrangements with minimal modifications to the support structure. Figure 12 shows the forward PIM with 2 ISO containers with the long axis oriented athwartship on the starboard side, and two oriented vertically on the port side, but many configurations are possible. The aft PIM is designed to hold 3 8ft x 8ft x 20ft long ISO containers arranged with the long axis oriented vertically (Figure 13).

The use of external payload modules allows the vehicle to be quickly reconfigured for different missions. In addition, it provides a mechanism for easily integrating new technologies that are developed to meet emerging enemy threats without unnecessary and costly modifications.

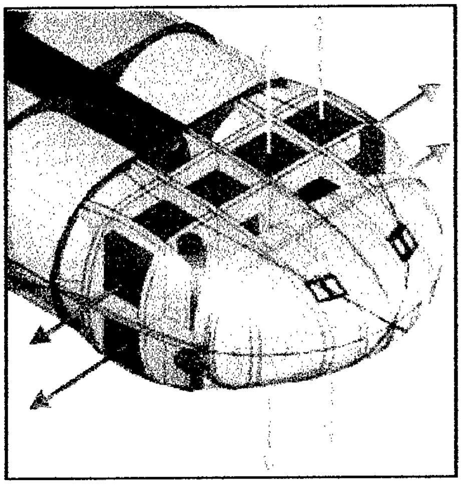


FIGURE 12. Forward PIM

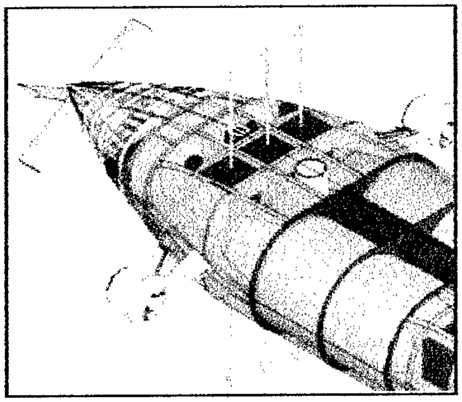


FIGURE 13. Aft PIM

Flexible Ocean Interface

The KAPPA vehicle has a very flexible ocean interface. As shown in Figure 12, the forward PIM has the ability to launch and/or recover various payloads (e.g., UUVs) from the top and bottom of the craft, as well as athwartships. This flexibility removes certain limitations that may prevent certain types of payloads from being launched from this kind of platform. This flexibility also extends to the payload designer, who now has a greater freedom to incorporate new technologies that may more effectively deal with new enemy threats. The payload designer can incorporate the launch (and recovery) interface (hatch) and device that is optimal for their payload. Future naval platforms should not have weapon specific interfaces with the water (e.g., torpedo tubes, VLS tubes, etc.), and should not constrain the size or shape of the payloads or vehicles used (DSB 1998). It is envisioned that payload designers of the future will have a defined interface control document, not unlike the system used by the National Aeronautics and Space Administration (NASA) for the space shuttle.

Organic Weapons and Sensors

In addition to the external payload modules, the KAPPA vehicle design includes organic weapons and sensors that are designed for self-defense and data collection and monitoring. The organic weapons and sensors included in the KAPPA vehicle concept are shown in Figures 14 and 15.

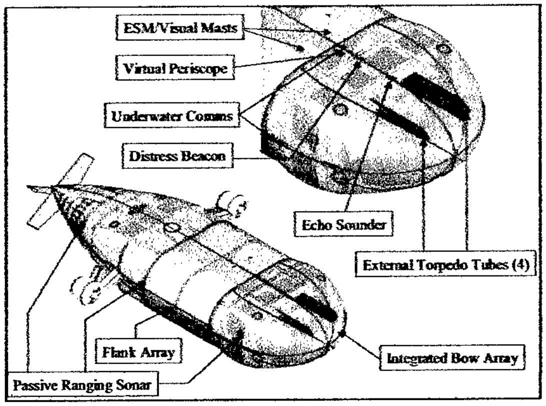


FIGURE 14. Organic weapons and sensors

For self-defense, the vehicle includes two 6.75-inch countermeasures tubes holding 4 countermeasures each, an AIM-9X sidewinder missile launcher for anti-air defense, and a total of eight encapsulated lightweight torpedoes. The torpedoes are arranged with four firing forward and four firing aft. The organic weapon suite is designed to give KAPPA the ability to stay and fight when necessary.

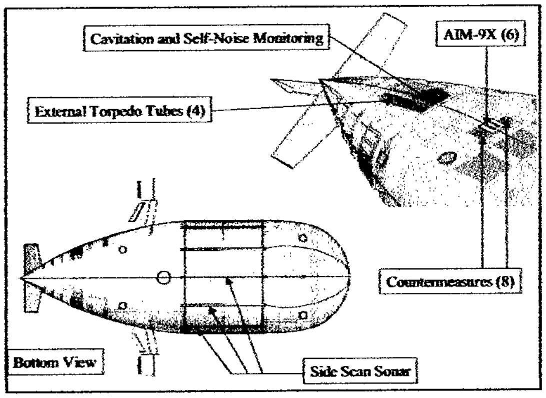


FIGURE 15. KAPPA self-defense weapons

The organic sensor suite includes an integrated bow conformal (IBC) array, which includes medium frequency (MF) passive, high frequency (HF) active, and HF passive sonar capabilities. The vehicle concept also includes passive ranging sonar to port and starboard, and side scan sonar arranged along the underside of the vehicle to provide sufficient area coverage underneath the craft. Electronic warfare support measures (ESM) and visual imaging is accomplished through small retractable masts that are used during transient "porpoising" maneuvers for burst data transmission. Additional visual imaging is accomplished by means of a virtual periscope, which allows for imaging above the surface of the water while the vehicle remains submerged.

Propulsion and Maneuvering

The propulsion and maneuvering scheme for the KAPPA vehicle is shown in Figure 16. The main propulsion is provided by two 5000-Hp rim-driven podded propulsors that are mounted on wing struts. The wing control surfaces are necessary to provide roll control. The pods were mounted at the end of the wings to take advantage of the added maneuverability in a turn. The pods are also able to rotate 360 degrees to aid in vertical translation, and possibly for de-bottoming.

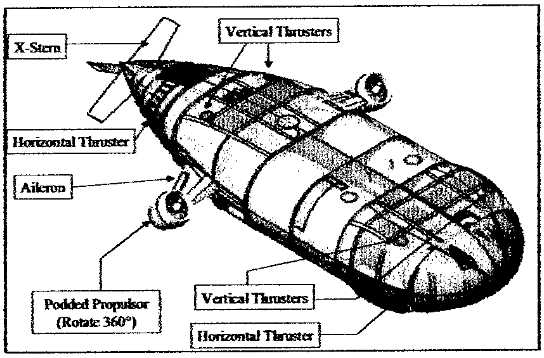


FIGURE 16. KAPPA propulsion and maneuvering systems

The KAPPA craft concept also takes advantage of ailerons on the trailing edge of the wing struts for additional maneuverability and control. The large lever arm provided by the wings also allows for the pods to be used to generate differential thrust for maneuvering. The craft has stern appendages oriented in an x-configuration. Low speed maneuvering is accomplished through the use of vertical and horizontal tunnel thrusters distributed at the bow and the stern.

Resistance Estimates

The hybrid power plant that was selected for the KAPPA vehicle concept consists of an 810-kW Proton Exchange Membrane (PEM) fuel cell with a 12.7 MWhr lithium-ion battery compliment. This power scheme is sufficient to meet the burst speed and cruise speed craft requirements (Table 3).

To arrive at the estimated power and energy requirements, an empirical formula was used to estimate the effective horsepower required to propel the fully submerged craft (Gilmer and Johnson 1982):

$$EHP = \frac{\frac{1}{2}\rho V^3}{550}\left[(C_{VBH} + C_A)S_{BH} + \sum C_{VAP}S_{AP}\right] \quad (1)$$

where ρ is the fluid density, V is the ship velocity, and S_{BH} and S_{AP} are the wetted surface areas of the bare hull and appendages, respectively. C_{VBH} is the viscous resistance coefficient of the bare hull, C_A is a roughness allowance for full-scale resistance estimates, and C_{VAP} is the viscous resistance coefficient of the appendages. The bare hull viscous resistance coefficient was estimated according to:

$$\frac{C_V}{C_F} = 1 + 0.5\left(\frac{B}{L}\right) + 3\left(\frac{B}{L}\right)^3 \qquad (2)$$

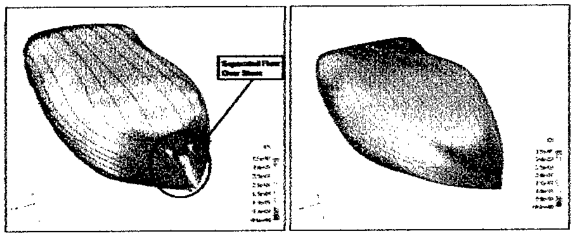
where B is the craft's beam, L is the length, and C_F is the skin friction coefficient:

$$C_F = \frac{0.075}{(\log_{10} \mathrm{Re}_L - 2)^2} \qquad (3)$$

Re_L is the Reynolds number based on the craft length.

It should be noted that it was initially unclear whether these empirical methods for estimating the resistance would be accurate for a non-traditional hull shape; previous studies were applied to bodies of revolution. In order to verify the resistance estimates, computational fluid dynamics (CFD) techniques were used to obtain predictions of the viscous flow field that develops as the craft moves through the water. These numerical techniques yield predictions of the hydrodynamic forces on the craft as well as details of the boundary layer that develops along the body. Numerical flow field predictions were obtained using the unstructured, incompressible Reynolds Averaged Navier-Stokes (RANS) flow solver U^2NCLE, which has been developed at Mississippi State University (Hyams 2000). The Spalart-Allmaras model (Spalart and Allmaras 1992) was used to account for the effects of turbulence on the mean flow.

The results of the CFD analyses showed that the empirical prediction methods were sufficiently accurate for predicting the resistance of this non-traditional hull shape at this early design stage. An additional benefit of the CFD analyses was that it provided useful information regarding the flow field along the hull form. The numerical analysis showed flow separation that was occurring at the stern of the craft. This was then corrected by lengthening the vehicle and providing a smoother transition along the aft body. These results are shown in Figure 17.



(a) Bare Hull (b) Modified Bare Hull

FIGURE 17. CFD predictions of stern flow

Power Plant Sizing

A survey of potential Air Independent Propulsion (AIP) mechanical and electro-chemical power sources was conducted, and the power densities and energy densities of the various systems were compared. The team did not pursue nuclear propulsion, because the Innovation Center charter calls for high risk technologies, while nuclear propulsion was judged to be a mature technology. A spreadsheet was developed to determine relative power and energy requirements for each of the notional mission scenarios. The ISRT 2 mission profile was the most stressing in terms of energy requirements and was selected as the baseline for power plant evaluation and sizing. None of the mechanical or electro-chemical systems evaluated, when sized as standalone systems, were attractive based on required volume and weight. The spreadsheet was then modified to provide optimization of a hybrid system that combined the most attractive mechanical and electro-chemical options. This initial optimization resulted in the smallest and lightest hybrid plant consisting of a reformed diesel Proton Exchange Membrane (PEM) Fuel Cell coupled with Lithium-ion battery cells.

The craft requirements called for the capability to perform two 25-knot bursts, of one-hour duration each. The initial energy calculations were conducted with these bursts occurring in the last two hours of the mission. Since this was not realistic from a mission perspective, a second plant optimization was performed. Back to back bursts (essentially a two hour burst) would drive the batteries to an unacceptable size, so the two bursts were separated by one hour at loiter speed, which assumes the equivalent of 3 knots propulsion power for station keeping. At the end of the first burst, the only energy remaining is a 20% battery reserve limit. A moderate interim speed, up to 12 knots, could be used between bursts but would drain the battery below the operating reserve limit, or limit the second burst duration by approximately 7 minutes.

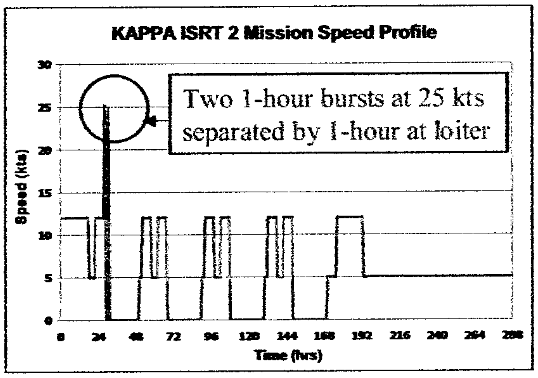


FIGURE 18. Notional ISRT 2 speed profile

Several locations of the burst sequence were explored in an attempt to determine the most demanding location. The most limiting occurrence, shown in Figure 18, was near the beginning of the ISRT 2 mission in hours 28-30 following the first "Relocate" *phase (see Figure 2). The final hybrid fuel* cell plant and battery sizes were determined based on this burst location.

Pressure Hulls

The KAPPA vehicle concept contains two identical pressure hulls, constructed of HY100 steel, that are compartmentalized into four sections. These have been organized into a command and control space, and three engineering spaces, as shown in Figure 19. The port and starboard pressure hulls are connected via a lock-out trunk (LOT), which also provides ingress/egress and a mating surface for docking with other vehicles. The LOT is shown in greater detail in Figure 20. Additional access is available to machinery spaces via logistics plug trunks (LPTs).

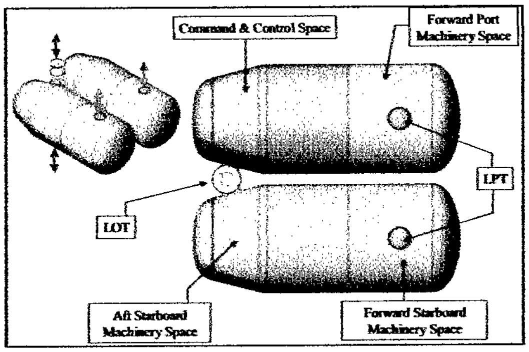


FIGURE 19. Pressure hull arrangement

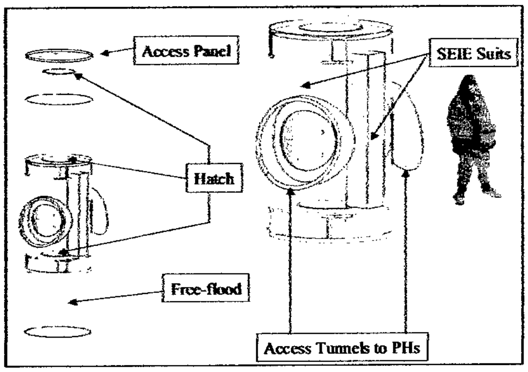


FIGURE 20. KAPPA lock-out trunk (LOT)

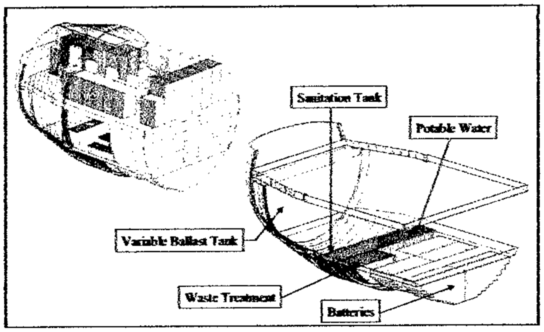
One of the driving ideas behind the KAPPA vehicle concept centers on taking an aggressive stand to change the current maintenance paradigm. One element of this design perspective is that the engineering spaces are normally unmanned. This provides several benefits, including the ability to operate the engineering spaces with reduced oxygen content for fire suppression. Normal access to these spaces from the command and control space is then only possible after adjusting the atmospheric support systems. Emergency access to the engineering spaces can be accomplished through the LOT with the aid of emergency breathing equipment. The LOT provides a bottom mating surface for mating with SSNs and SSGNs and a top mating surface for mating to the Advanced SEAL Delivery System (ASDS). The LOT also provides for emergency egress of the crew in the event of casualty. For this purpose, the LOT contains a number of submarine escape and immersion equipment (SEIE) suits, which provide oxygen support as well as thermal protection. Additionally, the top hatch of the LOT can act as a mating surface for a Submarine Rescue and Diving Recompression System (SRDRS).

Internal Arrangements

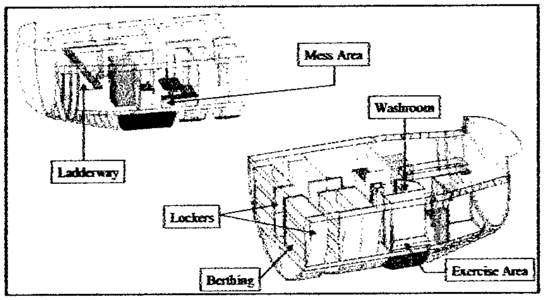
For this concept design, some attention was also paid to the system arrangements internal to the pressure hulls. As mentioned previously, the pressure hulls were divided into four separate compartments. Several views of the command and control space are shown in Figure 21.

The bilge area below the lower deck contains sanitation and potable water storage tanks, a waste treatment system, and the portion of the batteries necessary to power the systems in the command and control space in the event of primary power loss. This battery section is sufficient to provide life support and environmental controls in the event of a casualty.

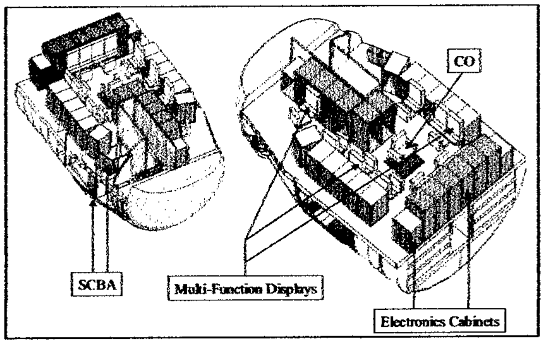
The lower deck contains the crew living spaces, including a wash room and a mess area. A small exercise area has also been included to maintain crew fitness while stationed aboard the KAPPA craft. The berthing contains a sufficient number of billets for the entire crew and maximum payload specialist compliment. The bunk size and locker storage are equivalent to those of a chief petty officer on a *Seawolf* class submarine[2].



(a) Bilge Level



(b) Lower deck



(c) Upper deck

FIGURE 21. Command and Control space

The lower deck also provides access to the lock-out trunk (not shown) and to the forward port machinery space through a hatch (not shown). A ladderway leads from the crew living areas to the control room on the upper deck. From here, all operations of the vehicle can be performed and monitored. There are sufficient multi-function displays

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[2] OPNAVINST 9640.1A

to allow use by all watch-standers and the maximum number of payload specialists simultaneously.

The internal arrangements were also defined for the engineering spaces in a similar manner. Here the primary concern was arranging sufficient storage space for the liquid oxygen storage tanks and batteries. An example of these arrangements, for the forward port machinery space, is shown in Figure 22.

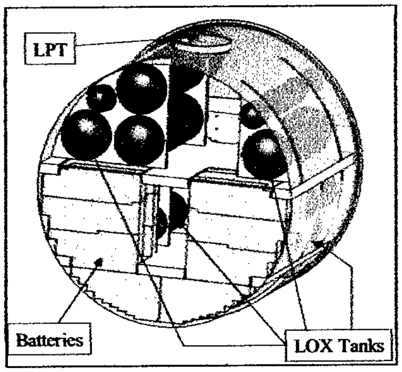


FIGURE 22. Forward port machinery space

Human Systems Integration

Due to the small crew size envisioned for the KAPPA vehicle, it was important to address the way that the sailors would interact with the craft to effectively perform their missions. The normally unmanned engineering spaces require sufficient automation and monitoring technologies to eliminate the need for underway maintenance by the crew. Distributed sensor networks provide the crew with increased situational and system condition awareness. This philosophy eliminates a large number of mundane tasks and routine maintenance that would require a larger crew to perform.

Because the crew is confined to a relatively small space while embarked, additional attention was paid to improve the habitability of the KAPPA craft. This was done by providing sufficient berthing spaces to accommodate the entire crew and payload specialist compliment to minimize the need for hot-racking. Each crew member and passenger is also allotted an increased amount of storage space, partially based on the need to accommodate the possibility of mission specific equipment used by the payload specialists. The wash room has been designed to provide personal privacy, while also maximizing the usable space. Leisure and fitness improvements have also been accounted for in the design, including a small work out area. Organic Light Emitting Diode (OLED) displays reduce heat management and space requirements, and careful attention was paid to the arrangement of the control stations for increased efficiency.

Given the higher risk tolerance afforded by the small crew, additional attention was also paid to improvements in crew safety. The unmanned engineering spaces allow for reduced oxygen content for fire suppression, and additional compartmentalization of the pressure hulls has been included to help isolate the crew spaces. The automation technologies included in the concept design further call for automated damage control systems to reduce the risks to the crew. In the event of casualty, the lock-out trunk (Figure 20) allows for the entire crew to be able to exit the vehicle in only three sorties.

CONCEPT OF OPERATIONS

The core of the KAPPA concept of operations (CONOPS) is to serve as an adjunct vehicle between a high-end platform delivering smaller adjunct vehicles in the littorals. The overall CONOPS to achieve this is divided into several stages: Operations, Logistics & Maintenance, and Training & Readiness & Manning.

Operations

A number of factors play significant roles in each of KAPPA's operational stages. The

KAPPA Team focused on providing flexibility to the warfighter in developing the CONOPS. The result in the operational section is a series of valid options that the warfighter can select from depending on the situation at hand.

Another important factor is its endurance energy source, the PEM fuel cell. The fuel cell requires diesel fuel and an oxidizer, liquid oxygen (LOX). In a forward deployed situation LOX is difficult to provide in the volumes required by KAPPA. One focus of the CONOPS is to maximize the use of LOX for missions and minimize the use of LOX in transits.

The first stage in the operational cycle is getting the vehicle from the Continental United States (CONUS) to the theater of operations. The KAPPA Team examined a wide range of options. In that examination the KAPPA Team assumed that the means selected would have to achieve its IOC in 2012 when KAPPA becomes operational and that stealth is not the highest priority during this stage of operations. The goal was to identify technically feasible, operationally acceptable options that minimize cost and completely avoided research, design, testing, and evaluation costs and KAPPA unique acquisition costs (e.g., the acquisition of KAPPA transport platforms). The options identified include both the physical means of getting the KAPPA to theater and the *timing of when KAPPA goes to theater*.

Two viable options were identified for the timing of KAPPA's movement to theater: pre-positioning and surging KAPPAs in response to crisis. The most favored, or normal, mode would be to pre-position KAPPAs in-theater. Prepositioning is defined as forward basing KAPPAs in each of the oceans, similar to the Maritime Prepositioning Force (MPF) used by the Navy to position Marine Corps equipment within close proximity to operating areas in the Mediterranean, Persian Gulf, and the Indian and Pacific Oceans.. Prepositioning is routinely used by the U.S. Navy; in addition to the MPF, the Seventh Fleet is based in Japan and minesweeping assets are prepositioned in Bahrain. KAPPAs might be positioned in Diego Garcia; Sasebo, Japan; and La Maddelena, Italy allowing for KAPPAs to be on-station faster in the majority of the world's littorals than they could be if transiting from CONUS. For example, a KAPPA transiting from Norfolk to the U.S. Fifth Fleet headquarters in Manama, Bahrain at KAPPA's 10 knot transit speed would take over a month, while a KAPPA making the journey from Diego Garcia to Manama, Bahrain would be on-station in only 10 days.

The KAPPAs would arrive at the prepositioned site by means of commercial heavy lift craft. The United States and foreign powers routinely use heavy lift craft for moving naval combatants. Figure 23 is a photograph of US minesweepers embarked on a heavy lift ship and Figure 24 shows the Dutch submarine *Saelen* returning from Operation Iraqi Freedom. Prepositioning by means of heavy lift ship is attractive because the KAPPAs are close to trouble areas, without dedicating another asset to perform the escort duties required for a KAPPA during a transoceanic voyage.

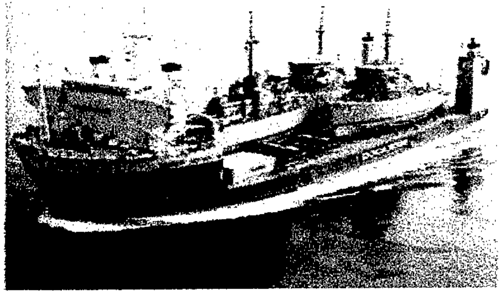


FIGURE 23. US Minesweepers on a heavy lift ship

The second option for timing KAPPA's movement into theater is surging them into theater. This would not be done routinely, but as needed when the real-world situation required more KAPPAs in-theater than the Navy's resources could support on a continuing basis or when the real-world situation required more KAPPAs in-theater than the force planners predicted. The team envisioned that there would not be sufficient time to procure commercial heavy lift assets and that operational concerns (e.g. stealth) might preclude the use of commercial heavy lift assets so the KAPPA would deploy submerged, with a mother ship in the escorting role.

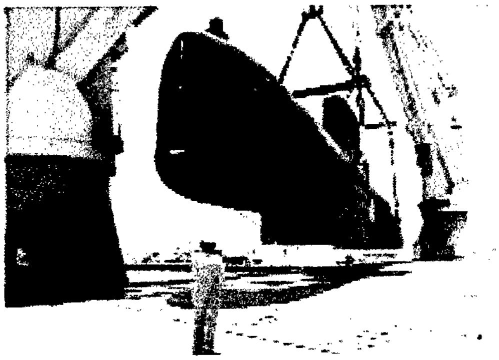


FIGURE 24. Danish *Saelen* embarking on heavy lift ship

Once in theater the KAPPA vehicle, when required, must transit to the operating area (OPAREA). In examining the options for getting to the OPAREA the KAPPA Team used a slightly different set of assumptions and goals. While still assuming that the means selected would have to achieve its IOC in 2012, the assumption for getting to the OPAREA was that stealth is a high priority during this stage of operations. The goal was to identify technically feasible, operationally acceptable options that minimize cost. The only option that met these criteria was for the KAPPA to self-deploy. For short transits from prepositioned sites the KAPPA could self-deploy without support and still arrive with adequate stores for most missions; for example, the transit from Sasebo, Japan to Gunsan, South Korea would be less than 500 nm. However, KAPPA would require support for the majority of transits from prepositioning sites to OPAREAs.

Support during the transit could take a number of forms, depending on the operational context and the resources available to the warfighter. The most attractive option is for the KAPPA vehicle to be self-propelled by its own propulsion system while receiving energy via an umbilical from a nuclear powered submarine mother ship (SSN or SSGN). This option is inherently stealthy, preserves the KAPPA's entire load-out of diesel fuel and LOX for the actual mission, and extends the KAPPA's reach infinitely. While more investigation is required, the KAPPA team's study concluded that this was feasible with the *Virginia* Class SSN. The impact for the mother ship would include incorporation of a new power transformer, a new frequency converter, and a cable management system. The Submarine Advanced Sail, scheduled to achieve IOC within the 2012 timeframe would be a natural home for such equipment. There would also be an impact on the submarine's energy supply and probably a reduction in the submarine's stealth during the transit. A future class of submarine that incorporates an "all-electric" architecture would offer the opportunity to increase the transit speed of the submarine/KAPPA pair, potentially up to the KAPPA's maximum speed of 25 knots.

Another option is for a surface ship to tow the KAPPA. While less stealthy than a submerged mother ship, this option preserves KAPPA's fuel/LOX and allows for faster transit speeds than the KAPPA vehicle would normally be capable of individually. A future class of surface ship that incorporates an "all-electric" architecture would offer the opportunity for the KAPPA vehicle to be self-propelled by its own propulsion system while receiving energy via an umbilical.

Another option is for the KAPPA vehicle to be fitted with an external energy source or fuel/LOX tanks (e.g. towed fuel bladder or battery saddle bags). This option maintains the KAPPA's internal stows, but requires acquisition of these external features and would not dramatically extend KAPPA's transit range.

Finally the KAPPA could be towed by a submerged mother ship. This option is inherently stealthy, preserves the KAPPA's entire load-out of diesel fuel and LOX for the actual mission, extends the KAPPA's reach infinitely, and allows for a transit speed of up to 25 knots; however, the ship integration issues and operational issues for the mother ship are substantially more difficult than using a power tether.

Once in the OPAREA the KAPPA vehicle would conduct its missions. While the actual missions would vary, the KAPPA team assumed that KAPPA would begin its unescorted transit 200 nm from the objective, providing 200 nm of standoff for the mother ship, with a nominal mission duration of eight days. KAPPA's expendable resources include fuel, LOX, payload, and food. The KAPPA Team determined that the most difficult to replenish are LOX and payload. With that in mind, the KAPPA was designed with sufficient LOX for two 8-day missions and an additional 40% in reserve, and enough payload for two nominal missions. Fuel and food capacity for a single 8-day mission with 40% reserve of fuel and 50% reserve of food was also accounted for.

When replenishment is required there are a number of options:

(1) SSGN

Fuel: The KAPPA could perform connected replenishment from an SSGN. Building on the automated astern refueling concept (Anderson et al. 1998), the KAPPA team performed a high level arrangement study of the system required to refuel from the SSGN. The SSGN system used about 1/3 of a D5 tube for a refueling receptacle, collapsible hose, hose reel, pump, and an Open Frame Vehicle (MR-2) ROV. This is shown in Figure 25. The ROV is used to swim the receptacle into a position where the KAPPA could insert its refueling probe. The ROV utilized is already in the Navy's inventory and the pump is government off the shelf. The remainder of that D5 tube and others as required would be filled with marine diesel fuel. The refueling rig and fuel bladders would be designed for pier side removal/insertion from the SSGN.

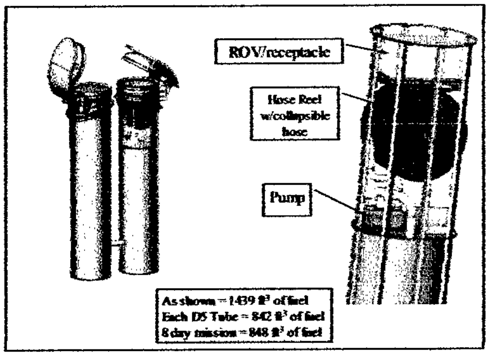


FIGURE 25. Notional SSGN astern refueling rig

Food: Transfer of food from the SSGN to the KAPPA vehicle requires the KAPPA to temporarily mate to the Lock-Out Chamber on the SSGN and the food be passed through the trunk.

Payload: The normal 8'x8' ISO boxes used for payload would be too large for SSGN to carry and the volume of LOX required too large for SSGN to carry as well.

LOX: LOX is too difficult for SSGN to provide in the foreseeable future.

SSGN is the stealthiest mother ship in the inventory and with the KAPPA's onboard LOX and payload capacity an SSGN mother ship could provide the fuel and food necessary for several KAPPAs to perform consecutive 8-day missions.

(2) Surface ship

Fuel: The surface ship would use the automated astern refueling concept that has been proposed for surface ship refueling and the KAPPA would use the same probe as for SSGN refueling.

Food: Food could be passed via small craft or recovered by KAPPA during the refueling evolution.

Payload: Depending on the type of surface ship, payload modules could be carried as well. Payload tugs have been conceptualized to provide underwater maneuvering to the payload modules to enable payload reload. Payload modules would be attached to the PIM tugs (Figure 26). The entire assembly would then be craned over the side of the ship and set in the water. At that point the KAPPA crew would take control of the PIM tugs, orient the payload module, position the payload module for insertion into the PIM and then insert the payload module into the PIM (Figure 27). The PIM tugs would then be detached and exit the KAPPA. The surface ship would regain control of the PIM tugs as required.

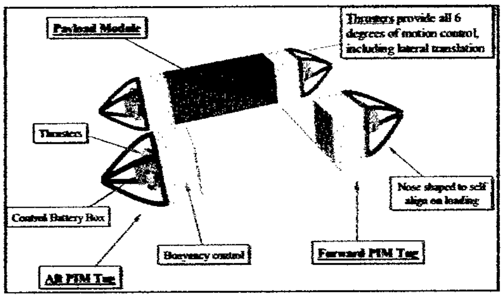


FIGURE 26. PIM reloading tug concept

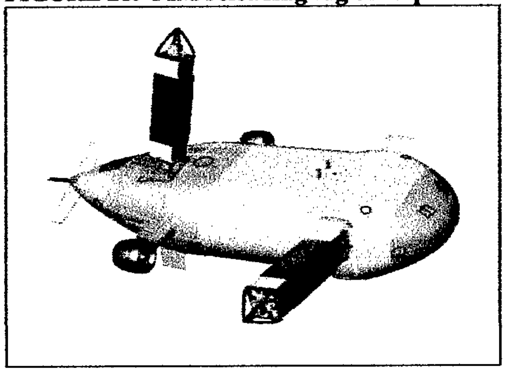


FIGURE 27. PIM tugs loading KAPPA

LOX: There is no feasible means with today's technology for a surface ship to replenish LOX on the KAPPA vehicle.

(3) Aircraft

Aircraft could be used for replenishment of KAPPA's food and for time-critical payload modules. Aircraft would fly to a pre-selected location and drop both food and payload modules by parachute. The payload modules would have PIM tugs connected before being dropped from the aircraft. KAPPA would surface to recover food supplies, but could remain submerged for mission payload replenishment.

(4) Sea Base

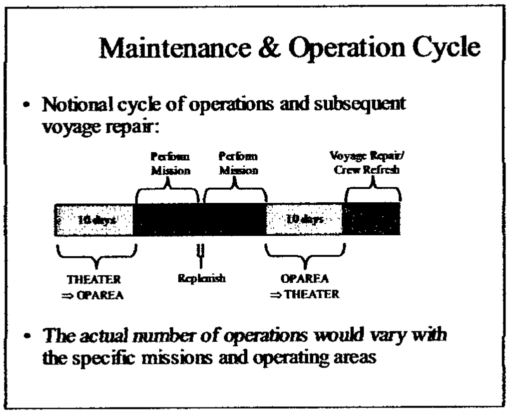
The Sea Base proposed by the Chief of Naval Operations as part of Naval Power 21 offers the possibility of full service KAPPA replenishment, including LOX. Additionally, KAPPA could provide a force protection role for the Sea Base.

Maintenance, Training, Readiness & Manning

The KAPPA requires a small crew in order to meet the objectives of having a craft suited for operating in the littorals with a higher risk tolerance. The KAPPA team took a balanced approach towards the small crew size, addressing all three functions that personnel perform – maintenance, damage control, and watchstanding.

To reduce the maintenance demands on personnel, KAPPA adopted a Condition Based Maintenance philosophy in order to reduce unneeded maintenance actions, conducting no maintenance while underway except for mission critical items. Instead maintenance would be performed in port by a mixture of the KAPPA crews from those KAPPAs currently stationed in port at the prepositioned site, augmented by fly-away teams from CONUS as required. Figure 28 shows a notional schedule of at sea operations and in-port maintenance.

To reduce the damage control requirements a number of approaches were taken. One involves extensive use of monitoring technologies so that issues can be identified and dealt with before they become significant problems. Additionally the craft, as previously discussed, is compartmentalized into 4 compartments. The engineering compartments are normally unmanned, so the partial pressure of oxygen in the space is reduced below the level required to support a fire. Should a fire break out, the fact that the spaces are unmanned facilitates use of an automated fire suppression system (e.g. halon).


Maintenance & Operation Cycle

- Notional cycle of operations and subsequent voyage repair:

- *The actual number of operations would vary with* the specific missions and operating areas

FIGURE 28. KAPPA maintenance & operations schedule

To minimize watchstanding requirements the KAPPA team assumed that a high degree of automation would be used. The KAPPA team then performed a zero-based manning review and developed a notional manning concept (Figure 29).

Watchstation	#
CO	1
Pilot	3
Organic Payload Operator	3
Mechanical Engineer	2
Electrical Engineer	2
	11

- Condition Based Maintenance
- No underway maintenance

FIGURE 29. KAPPA manning concept

Watch durations would be 8 hours for all watchstanders. A description of the watchstanding duties is given in Table 6, and the qualifications required to be assigned to a KAPPA crew are given in Table 7.

TABLE 6. KAPPA watchstanding duties

Watchstation	# Watch Sections	Remarks
Commanding Officer	N/A	
Pilot	3	Demanding watchstation in congested littorals
Organic Payload Operator	3	• Organic weapons • Organic sensors • Communications
Mechanical Engineer	2	• Monitor plant status • Assist Organic Payload Operator
Electrical Engineer	2	• Monitor plant status • Assist Organic Payload Operator

TABLE 7. KAPPA crew qualifications

Watchstation	Qualification	Paygrade:
Commanding Officer	Post-Department Head Submariner	Lieutenant Commander
Pilot	Qualified VIRGINIA Pilot or Copilot	Senior enlisted
Organic Payload Operator	STS, ET or FT	Mid-grade enlisted
Mechanical Engineer	Machinist's Mate	Mid-grade enlisted
Electrical Engineer	Electrician's Mate	Mid-grade enlisted

KAPPAs will get underway for actual missions. KAPPAs will also virtually participate in fleet battle experiments and joint task force exercises in a simulation/"hardware in-the-loop" stimulation manner. Refresher training will be conducted at the prepositioned sites using simulators. This avoids the costs associated with unnecessary underway (fuel, wear and tear, etc.) ship operations.

The crew will be assigned to KAPPA as a unit to improve cohesion. Crews will complete initial KAPPA training together, with the entire crew attending propulsion plant school and organic payload operator school. Crew members will all be cross-trained/qualified in the engineering and organic payload operator watch stations. The Commanding Officer and the Pilots will also attend pilot school. The crew's tour of duty will be 36 months to ensure that they have an opportunity to return to nuclear duty in a timely manner in order to maintain their proficiency as nuclear trained personnel.

KAPPA schools will emphasize simulator based training, the same simulators the crews will use to maintain their proficiency once they complete initial qualification and are forward deployed at the preposition sites. Simulators will be used in order to minimize costs while maximizing repetitions in a realistic environment. Scenarios used in the simulators at the schools will start with basic challenges and gradually increase the difficulty. Schools will conclude with scenarios based on the area of the world where the KAPPA crew will be based (e.g. CENTCOM). Simulations will include local geography, bathymetric conditions, and littoral traffic. Once they complete initial qualification the KAPPA crew will be forward deployed to marry up with the KAPPA craft at their preposition site.

Payload: Specialists, Maintenance, Training

KAPPA has sufficient accommodations, food and work-stations for four payload specialists. The payload specialists are not part of KAPPA crew. The payload specialists might be uniformed Navy, Department of Defense civilian employees, or even contractors depending on the mission payload. The payload specialists embark for specific missions then debark. Some payload modules will be pre-positioned in-theater while others will be surged into theater for specific tasking. The payload modules are "All-up rounds". Once embarked on the KAPPA the payload modules are external to the pressure hull and no maintenance can be performed on them. Payload modules will either be shipped to CONUS for overhaul or overhauled at the preposition site when they require maintenance.

Each payload module includes an embedded onboard training device. The embedded training devises will allow for the payload specialists and the KAPPA crew to train on use of the payload module while transiting to a mission area. These onboard training devices will also be available for use with the simulators/stimulators in the preposition sites so that the KAPPA crew can prepare for prospective missions.

CONCLUSIONS

The KAPPA submersible craft concept, the result of a Carderock Division Naval Surface Warfare Center (CDNSWC) Innovation Center project, is proposed as an effective, cost-efficient force multiplier that can perform covert missions in littoral regions and austere ports, assist in providing and maintaining access, and support other joint assets. The KAPPA craft concept is a stealthy, highly maneuverable vehicle, with a modular payload volume and flexible ocean interface that acts as part of a "cascading payloads" chain for improved littoral warfare operations.

The KAPPA submersible concept is not without challenges. The KAPPA Team identified several technology gaps between performance demonstrated today and performance projected during the concept design. Foremost among these technology gaps are: external weapons and payload development, enclosed atmosphere fuel cell fluids management, including reformer energy consumption and stealthy venting of reformer waste products to the sea, liquid oxygen integration, integration of composite structures, and signature management of the external propulsion pods. With sound engineering, diligence, and appropriate investment of resources, however, the aggressive vision of the KAPPA vehicle concept for improved littoral warfare can be realized.

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