Second Generation Design of Wave Adaptive Modular Vessels (WAM-V®): A Technical Discussion of Design Improvements

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ABSTRACT
In 2007, Marine Advanced Research introduced an entirely new class of vessel, the WAM-V® (Wave Adaptive Modular Vessels). A 100 ft technology demonstrator, named Proteus, was tested by Marine Advanced Research over 3000 nm in the Pacific, Atlantic and Mediterranean. It was also instrumented and tested by Carderock through a grant from the Office of Naval Research (ONR) in the fall of 2009. While much of the technology performed as expected or better, there were technical deficiencies that required revision. Most notable was the propensity for an oscillation to occur, in certain sea conditions, between the suspension system and inflatable hulls such that the central control and payload structure motion was amplified.

A second generation design required a redesign of the inflatable hulls and articulation system to address the oscillation. Additionally, a new suspension design was developed along with a folding method that allows the WAM-V vessel class to reduce its footprint by up to 70%.

The result is a scalable technology with great stability, low weight, high fuel efficiency, shallow draft, shock mitigation, helicopter-like deployment and retrieval of cargo/payload and, as previously mentioned, the ability to drastically reduce its footprint. The WAM-V can open up new possibilities at sea wherever these characteristics are desired.

KEY WORDS
Catamaran, lightweight, articulating, folding, inflatable hulls, suspension.

1.0 INTRODUCTION
A trip around the world aboard a 50’ ketch coupled with bouts of sea sickness would eventually challenge the conventional brute force approach to ship building. Marine Advanced Research, Inc. formed as a company in order to design, build and test an innovative idea that was born in the mind of one of its founders on that trip more than 30 years ago. This idea would eventually combine a catamaran configuration with an articulation system that uses hinges and ball joints; a suspension system; soft hulls and a geometry that allows the vessel to fold and reduce its overall footprint. Stresses on this vessel would be minimized by allowing the vessel to adapt to the waves instead of plowing or piercing through them. These reduced stresses would allow the vessel to be constructed with a minimum amount of material, further reducing the weight. At the same time, the vessel would provide greater stability due to the catamaran configuration, articulation and suspension systems.

Proteus (Figure 1) was the manifestation of the first generation design.

In 2009, two 12’ WAM-V USVs were designed and constructed based on the second generation design (Figure 2).

In 2010 and early 2011, a 33’ WAM-V (Figure 3), also for unmanned operations, was designed to be folded and stored in a standard 20’ ISO container. Construction of the 33’ WAM-V is scheduled to be completed by the summer of 2011.
2.0 FIRST GENERATION

The goal of the first generation WAM-V design/build iteration was a technology demonstrator to test the validity of the innovations developed under the program. The WAM-V technology was so new and non-conventional that computer modeling and simulations developed for ships were not applicable to this technology.

The following is a description of the individual components that comprise the WAM-V technology.

2.1 Hinged Engine Pods

The two engine pods are the aft most section of the hulls and account for roughly 25% of total length. They are connected to the inflatable portion of the hulls by a transverse hinge that allows the engine pods to rotate about the transversal axis. These hinged engine pods keep the propulsor in the water in sea conditions that would otherwise pull them out of the water.

2.2 Catamaran Configuration

The 2:1 length-to-beam ratio is a key component to vessel stability and also minimizes wave interference between the two hulls. This wide length-to-beam ratio is made possible by the transversely hinged engine pods at the end of each hull.

2.3 Long, inflatable, multi-chambered cylindrical hulls

The inflatable portion was designed to reduce high frequency wave vibrations, minimize digging and provide maximum safety. The air pressure inside the hulls can be adjusted based on the sea conditions to provide maximum reduction of high frequency vibrations. The cylindrical hulls have a tendency to slide down waves rather than dig into them (a common risk with conventional catamarans). The multiple air chambers ensure a high degree of survivability in case of a hull breach, as the vessel will be able to continue to operate even if 50% of the chambers are compromised. A secondary system, currently in development, would render the vessel nearly unsinkable.

The inflatable hull material provides excellent puncture and tear resistance at a fraction of the cost and weight of traditional hull materials. These hulls also provide a small wetted surface area (frictional resistance) and wave drag component that when combined with the low weight provides high fuel efficiency and long range. In addition, “smart materials” such as self-healing coatings could be used to protect the hulls from small arms fire. In case of accidental collision, the soft hulls absorb forces and minimize damage to the greatest extent possible. Conveniently, the soft hulls negate the need for fenders, which is extremely beneficial for an unmanned system. In the case of diesel fuel propulsion systems, the fuel can be stored in the inflatable hulls in fuel bladders as is the case for Proteus.

2.4 Articulation & Suspension Systems

In an effort to maximize the stability and minimize the shock loading and vibration to sensitive communication, occupants, sensor packages and weapons systems (especially in high sea states and severe weather conditions), the WAM-V technology is equipped with a specially designed suspension system to isolate the payload from wave impacts. In the first generation design, this suspension system is located between the forward arch and hulls and the aft arch and hulls. To further enhance the suspension system and minimize the stresses on the vessel components, four transverse hinges, one at each connection of arch to suspension, and one ball joint (at the center of the forward arch) allow the hulls to follow the sea surface semi-independently. This is due to the fact that the transverse hinges and ball joint allow the angle between the hulls to vary greatly without introducing stresses to the structure.

2.5 Modularity

The WAM-V technology is modular. The entire vessel can be broken down to individual components that can be quickly replaced. Specifically, each engine pod can be switched out (<15 minutes) for maintenance, mission specific propulsion or horsepower requirements, etc. The inflatable hulls can be detached from the rest of the structure and replaced if damaged. Also, the payload sensor packages can be quickly swapped in cases of alternate mission requirements, maintenance, or malfunction. This allows the vessel to be operational at all times (an additional engine pod can be rotated in during service intervals), serve multiple roles (mission specific payloads and propulsion), provide efficient inter-deployment turnaround, and achieve low maintenance costs. The modularity also shortens the construction cycle allowing for parallel component construction. The individual pieces can be shipped to the appropriate location for final assembly. Additionally, replacement parts can be manufactured, stored and utilized on an as needed basis.

2.6 Elevated, Central Superstructure

The elevated superstructure design provides an excellent vantage point for the above water sensor suite while the unobstructed access to the water under the central structure (helicopter-like operation) allows direct vertical deployment/recovery of payload packages (e.g. sonobuoys, sonar, UUVs, USVs) with simple remote controlled winch systems (Figure 4). This central, vertical deployment eliminates the stability problems associated with side deployment.

![Fig. 4. Deployment/Recovery of Payload Package](image)
2.7 First Generation Results

Extensive sea trials were conducted with *Proteus* in order to evaluate all of the design innovations of the WAM-V vessel class. The results are discussed below.

2.7.1 Hinged engine pods

The hinged engine pods performed as expected. *Proteus* was tested up to a sea state 4 with no noted loss of propulsion. The engine pods independently follow the surface of the water as they are free to rotate about the transverse hinge.

2.7.2 Catamaran configuration

As one might expect, the 2:1 length-to-beam ratio was critical in vessel stability especially with respect to roll.

2.7.3 Long, inflatable, multi-chambered cylindrical hulls

The nylon reinforced polyurethane inflatable hulls were an advantage over other materials in a number of ways. These hulls were extremely effective in storing and transferring fuel. A total of 1800 gallons of fuel was stored in the hulls (900 each) and the fuel was transferred to the day tanks in the engine pods simply by the air pressure of the hulls. The hulls were also beneficial during intentional and accidental groundings on both rock and sand with zero notable damage. However, the inflatable hulls did have one unintended deficiency. The flexibility of the hulls coupled with the movements of the suspension system produced unwanted oscillations that amplified the motion of the suspension system. The effect is similar to a car going over closely spaced speed bumps to the point that the oscillation creates a “bucking” effect.

2.7.4 Articulation & suspension systems

The suspension system was effective at reducing motions in the medium to low frequency range, i.e. medium to high amplitude waves except when the oscillations due to the flexibility of the inflatable hulls coupled with the motion of the suspension system to amplify the vertical displacement. In order to further evaluate the system, rigid aluminium tubes were added along the inflatable hulls and the aft suspension system was blocked to assess the effects. This reduced the flexing of the inflatable hulls but not enough to fully evaluate the suspension system. Nevertheless, the initial stiffness of the suspension system transmitted too much of the impact to the structure without providing progressive spring characteristics.

The transverse hinges and ball joint were sufficient to allow the movements of the two hulls with respect to each other without creating additional stresses except in one notable location. Namely, a torque around the vertical axis at the connection of the aft arch to the aft suspension. The angle of rotation was less than 5 degrees and easily dissipated by the flexibility of the inflatable hulls. However, this was a major consideration in the second generation design.

2.7.5 Modularity

The modularity of the technology had many practical benefits. The engine pods were easily disconnected (less than 15 minutes) and brought ashore for routine maintenance that could not be performed in the water, e.g. bottom painting. The center payload for *Proteus* was a secondary vessel that was used to get supplies in small boat harbors that could not accommodate a 100’ long vessel.

2.7.6 Elevated, central superstructure

Visibility from the elevated, central superstructure was excellent. We were able to assist a harbor patrol boat in locating and retrieving a swimmer that was crossing a high traffic ship lane. This was only possible because of the high vantage point.

Deployment and retrieval of the secondary vessel was very easy due to the straight vertical deployment. Inexpensive electric winches were sufficient for *Proteus*.

2.8 Summary

Overall, the first generation design proved that a lightweight, low cost, modular, long endurance, stable, low draft, ocean capable vessel based on the WAM-V technology was feasible. Interest from industry and the Government further proved that a market existed for a commercial version of the WAM-V vessel class. However, a second generation design was necessary.

3.0 SECOND GENERATION

Due to the promising results of the first generation design, the second generation design focused on addressing the deficiencies discovered during sea trials as well as providing additional capabilities.

3.1 Rigid Member Between Inflatable Hulls and Arches

A rigid member, termed “ski” (Figure 5), was added to the top of the inflatable hull, in order to address the oscillations between the suspension system and flexible hulls. This member eliminates the coupling of the inflatable hull motion (due to twisting and bending) and the suspension system which produced the unwanted oscillations. By eliminating that coupling, the pressure in the inflatable portion can be adjusted as necessary in order to reduce high frequency wave vibrations much like a vehicle tire (a great benefit to onboard equipment and occupants).

Fig. 5. Rigid member or "ski"
3.2 Articulation & Suspension Systems
Eliminating the torque about the vertical axis at the ends of the arches was even more important with the addition of the ski, as that force would be transferred to those connections if not addressed. The rear arch connection points were redesigned as double axis hinges to accommodate the small rotation about that vertical axis. The connections at the end of the forward arches were redesigned as ball joints. This allows the hulls to follow the sea surface semi-independently, and provides the highest degrees of freedom (resulting in lower stresses) while maintaining vessel integrity.

The suspension system was redesigned to incorporate progressive air springs in the design instead of the much stiffer leaf springs used in the first generation design.

3.3 Foldability
The unique geometry of the WAM-V technology allows the vessel to fold and reduce its footprint by up to 70% (Figure 6).

![Fig. 6. Example of a WAM-V folded.](image)

The engine pods are rotated inboard and the bow sections of the inflatable hulls are deflated and drawn in to reduce the overall length of the vessel. The six jointed sections of each arch are hydraulically folded (similar to knuckle crane folding) reducing the width. For example, the WAM-V USV 33 is able to reduce its width from 16’ to less than 8’ and its length from 33’ to under 19’. This allows the WAM-V USV 33 to fit inside a 20’ ISO container which can be transported by military or commercial assets. Conversely, multiple WAM-V USV 33s can be folded and stored inside a LCS. The WAM-V USV 33 can also be air transported in the folded configuration.

3.4 Scalability
While scalability was part of the original concept for WAM-Vs, the idea was further defined in the second generation design with the introduction of WAM-V USV 12 and WAM-V USV 33. As previously mentioned, WAM-V USV 12 is 12’ long and was designed and built for unmanned operation. WAM-V USV 33, also for unmanned operation, is 33’ long and currently in production with a completion date of summer 2011.

WAM-Vs can be produced in sizes anywhere from 12’ to 150’. Small WAM-V USVs could be launched and recovered by larger WAM-Vs. This would provide additional capabilities and a common platform for simplification.

3.5 Second Generation Results
The WAM-V USV 12 was the first built based on the second generation design. Preliminary testing in the San Francisco Bay showed that the vessel could run at maximum speed (15 knots) into head seas of up to 2 feet. When scaled and compared to what was possible with Proteus, the second generation design sea keeping potential is much greater than that of the first generation.

3.5.1 Rigid member between inflatable hulls and arches
This rigid member or “ski” completely eliminated the oscillation noted in the first generation. That oscillation was a limiting factor in the maximum sea state for Proteus. The WAM-V USV 12 was able to reach maximum speed in a head sea without negative impact to the vessel or on board equipment. Video captured from the elevated, central superstructure showed the stability at that location.

3.5.2 Articulation & suspension systems
The addition of the double axis hinges at the aft arch and the ball joints at the forward arch kept the stresses at those locations to a minimum. The progressive air springs provided a small number of bottoming out events even in the extreme condition of maximum speed in a head sea. Further refinement of the suspension design could produce even better results.

3.5.3 Foldability
The WAM-V USV 12 was easily folded for transport by two people or could be taken apart or put together by one trained person in under 10 minutes. This made transport of the vessel extremely easy.

3.5.4 Scalability
The scalability of the WAM-V technology allows for quick design turnaround times for new sizes within the vessel class. This has been especially evident in the second generation design of the WAM-V USV 12 and WAM-V USV 33.

3.6 Summary
The second generation design has succeeded in addressing the major deficiencies defined during testing of the first generation. Additionally, the foldability of the design has opened up an exciting aspect of the WAM-V vessel class. Further refinement of the suspension system and the hydrodynamics of the hulls themselves should further enhance the technology. Also, further reductions in weight will be realized by using the results from the testing to predict stresses and reduce material in areas that are overdesigned.
4.0 Conclusion
The WAM-V was not designed to replace existing technology. Rather, the technology was developed to push the boundaries of what is possible, and in doing so provide additional capabilities/advancements. Specifically, the WAM-V technology provides a stable, low weight, shallow draft multihull vessel with high fuel efficiency and shock mitigation. It accomplishes this with a catamaran configuration, lightweight materials and an articulation and suspension system that reduces the stresses on the structure. The unique geometry allows the vessel to deploy and retrieve payloads from the elevated superstructure with minimal effect on vessel stability as well as reduce the footprint of the vessel up to 70% for both operation and storage. The WAM-V vessel class can be designed and built in multiple sizes for use in brown, green and blue water.