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Technical Report

Advanced Expeditionary Support Concept Vessel

by

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For decades the United States has used small landing craft in combination with heavy-tonnage offshore ships to land mobile units of soldiers and armor support on foreign soil. This proven strategy has led to a current logistics concept known as seabasing, in which equipment and personnel are transported from an offshore base to shore. The U.S. Navy and Marine Corps now seek to improve the transport of equipment and logistical support through the use of a flexible transport ship capable of moving equipment from the continental United States (CONUS) to the seabase, and then from seabase to shore. The goal of the Advanced Expeditionary Support Vessel (AESV) concept is to create a potential design for a multi-mission capable vessel that can travel from CONUS to seabase and to shoreline under a variety of load and mission conditions.

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Abstract

For decades the United States has used small landing craft in combination with heavy-tonnage offshore ships to land mobile units of soldiers and armor support on foreign soil. This proven strategy has led to a current logistics concept known as seabasing, in which equipment and personnel are transported from an offshore base to shore. The U.S. Navy and Marine Corps now seek to improve the transport of equipment and logistical support through the use of a flexible transport ship capable of moving equipment from the continental United States (CONUS) to the seabase, and then from seabase to shore. The goal of the Advanced Expeditionary Support Vessel (AESV) concept is to create a potential design for a multi-mission capable vessel that can travel from CONUS to seabase and to shoreline under a variety of load and mission conditions.

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1. Section I - INTRODUCTION

Background

1.1. Seabasing Concept

The U.S. Navy has begun to implement the early stages of a new concept known as seabasing as a way to provide strategic and logistical support to forward deployed marine forces. The inception of this concept in today's world is a logical military progression, as it has become more difficult for the U.S. to diplomatically secure port facilities around the world. The availability of foreign ports close to nations of conflict has decreased, and in the interest of becoming totally self-sufficient seabasing has been identified as a good solution. Therefore it is critical to the Navy's future to develop the sea basing concept and all the systems and ships that must interface with it. A seabase is essentially a floating base located in international waters that can be positioned offshore of any coastal nation as needed for military operations without host nation support.

1.2. Logistical Issues

The current model of sea basing is very advantageous to the Navy, but there are many logistical and technical issues that must be resolved for the sea base concept to perform as required.

Three issues that require development include: ship to ship transfer of cargo and personnel, sea base configurations, and sea base to shore connectors. Ship to ship transfer must be examined since the sea base is comprised of larger ships or marine structures that must be functional in the marine environment. Safety of transfer operations is the central focus of this development. The configuration of the sea base is important in ascertaining the most effective manner in which to conduct operations on the sea base. Finally, the ship-to-shore connector development involves the vessels that perform the last step of the logistical mission: disembarking equipment and troops ashore.

1.2.1. Prior Logistics Solutions

Previously, the USN has relied on the use of port facilities to organize, distribute, and disembark all of its supplies. With the introduction of the sea base, this will no longer be the case and the vessels used to transport supplies must change to accommodate this. Logistical support in the past has involved the use of small landing craft such as LCUs, LSTs, and LCACs in coordination with larger transport ships. This option is not desirable because it is time consuming and adds more vessels and complications to the logistics mission.

The AEV project seeks to reduce the need for multiple vessels and focuses on one vessel that will perform the sea base to shore mission.

1.3. Mission Statement

The task of the "Advanced Expeditionary Support Vessel" design team was to design a concept ship with the flexibility and capacity to alleviate some of the logistical issues faced by the U.S. Navy and marine forces both today and in the future. The standard practice of logistical missions has changed with the proposed use of sea bases, and the vessels that provide logistical support must change accordingly. The Advanced Expeditionary Support Vessel (AEV) is a ship designed to incorporate the change in re-supply methods and serve as a connector for both CONUS-to-seabase and seabase-to-shore missions, including the transportation and supply of personnel, vehicles, and cargo.

1.4. Mission Requirements

- Sail independently from CONUS to Seabase with Cargo Load (Excluding Passengers)
- Payload-2015 Marine Expeditionary Brigade (MEB) (Split into more than one load)
  - 6685 MT Total Load (Incl. Personnel)
  - 6800 Personnel
  - 431 Pieces of Equipment
  - 1690 MT of Petroleum Oils and Lubricants
  - 400 MT Fresh Water
  - Storage Capacity for 40 TEU containers
- 24 Knots Max Sustained Speed
- 15 Knots Cruising Speed
- 5000 nm range
- Military Sealift Command (MSC) operated
- Offload up to and including Sea State 4
- Aviation Support for Two CH53-E Helos
- Ship designed to tailored commercial ship design standards
- Stability standards to be DDS 079-1 compliant
- Desirable to have a multi-mission, multi-capable Flex deck
- Desirable that the ship be marketable and affordable to allied navies

A number of requirements were assumed by the design team to facilitate the design process of the ship. For the AEV requirement to support its beachhead operations, it was assumed that this is defined as supplying itself from its own stores with 500 tons of supplies a day for ten days. The assumed 500 tons is taken from "21st Century Options for Defense Logistics"[1]. Despite being designed to commercial ship standards the stability of the ship is to be DDS 079-1 compliant. The AEV will be operating only in or around secure beachheads, so this vessel needs no specific means of self-defense. The beaches this vessel will be operating near were assumed to have a gradient of 1:50.

The payload also needed to be assumed in order to properly design the ship; the MEB load was assumed to be the standard load that the ship would be designed to carry. The MEB is to contain 6800 personnel, 431 pieces of equipment, and 6685 metric tons of cargo. The flexibility of the ship would ensure that the other loads could be handled by the AEV with no problems.

1.5. Design Process

The design process of the AEV followed a four-step process of concept gathering, evaluation, chosen design focus, and development.

The design priorities for the AEV were determined from its primary mission of delivering troops and equipment to shore. There is some reluctance to use smaller vessels to ferry supplies from the vessel, so it was decided that unloading the payload from the ship itself was the main guideline. It was necessary to bring the ship as close to shore as possible, which meant a shallow draft. Other factors influencing the ship design were the amount of deck space available in the design, stability and seakeeping in rough seas, and ease of loading cargo on and off the ship.

The primary payload that this AEV is designed for is the MEB defined in appendix A of "Seabase to Treeline Connector Innovation Cell."[2] All other forms of payload are designed to fit around this requirement; they are seen as secondary to getting troops to shore.

1.6. Brainstorm

The first step in the design process for the AEV was writing down every idea that was thought of. Every idea for hull types, propulsion plants and ship-to-shore connectors was discussed with relation to the AEV's mission and the requirements of the project. The thoughts ranged from fairly traditional ideas such as an amphibious monohull, to more exotic thoughts such as detachable hulls to move cargo ashore.

1.7. Requirement Development

In the design of the AEV, several factors were deemed to be the primary areas of interest and were optimized to perform the mission tasks. The ideas from the brainstorming were put into context of how well they would work given the mission requirements. Trimming extraneous ideas from the pool was done using what were considered the most important mission objectives for the ship. The hull form of the ship was seen as the deciding factor in the AEV concept design, with the connectors to shore being secondary. The requirements to accomplish the AEV's mission from the hull's perspective became driving factors in the design. Primarily, in order to beach the ship, it would require a very shallow draft. The AEV must also have a very large cargo area to accommodate the amount of supplies and equipment called for by the missions. Some of the equipment, such as the M1A1 Abrams tank, is very heavy, and requires a ship that can handle the loading of such large pieces of equipment without problem. The AEV also needed to have space that could be used for a variety of purposes. The deck areas needed to be adaptable to a variety of mission situations that called for any number of loading schemes with a number of types of cargo.

1.8. Decision Process

Since the AEV was required to have a small draft and a large cargo area, existing monohulls did not fit into the project because large displacement ships have very large drafts. Faster, lighter ships would not be able to handle the large loads associated with the main missions of the AEV. A type of multi-hulled ship fit very well into the guidelines that were laid out for this project. The hull type was narrowed down to either a catamaran, or a trimaran. Work then began on designing a ship using one of the two forms, and a final decision was made based on mission criteria.

2. Amphibious Ship Research

List of Prior Ships Researched

An analysis of previous amphibious assault ships was a starting point for making a decision regarding the selection of an optimal hull form for the AEV.

2.1. Monohulls

The monohull form was the start for the AEV concept exploration process. According to Jane's Fighting Ships 2005-2006, all of the amphibious craft currently used by the U.S. Navy (USN) are monoholls or LCACs, with no current multi-hull ships being planned for the near future[3] .The design requirements for the ship were pushing the design team towards a high displacement, low draft ship, which fit none of the amphibious ships in USN at present. The following ships were investigated for possible modifications to fit our requirements.

2.1.1. U.S. Navy Amphibious Fleet Ships

LHD

The USN Wasp class Landing Helicopter Dock is a 41,650 LT ship that serves primarily as a landing and staging platform for amphibious assaults and LCAC excursions in littoral areas. The ship can carry 12 LCMs or 4 LCACs in a 13,350 square foot well deck, as well as a mix of 30 helicopters and six to eight AV-8B Harrier jets in addition to 2,000 troops[3]. While this ship is very robust, its draft is 8.1 m and would not have been able to fulfill the need to move soldiers and equipment directly from ship to shore without using the LCACs or LCMs. In addition to this drawback, the LHD is optimized for major aircraft support and logistics, while the AEV only needs the capability for light-helicopter operations.

LHA

The Tarawa class Amphibious Assault Ships were the precursors for the LHDs, and are very similar in both ship characteristics and mission payloads. The ship displaces 39,967 LT at 7.9 m draft, and features both a well deck and large landing platform area. It can carry a mix of helicopters and AV-8B aircraft, as well as one embarked LCAC or a variety of LCU/LCM arrangements[3]. This ship, like the LHD, falls short of meeting the design requirements of the AEV because of its deep draft and aircraft support role.

LPD

The Amphibious Transport Docks of the USN provide an interesting case for the basis of an AEV design, but again fall short of the requirements to land troops directly to shore. The San

Antonio class LPD ships displace 25,300 LT at full load draft of 7 m, and provide a similar platform as the LHD for the disembarkment of helicopters, VTOL aircraft, and troops. This class supports 25,000 sq. ft. of deck space for vehicles, 34,000 cu ft of cargo, and 720 Marines. The well deck can support two LCACs or one LCU for troop movement from ship to shore or seabase. The Austin class LPDs are an older class, with a full load displacement of 16,500-17,244 LT at 7 m draft. Over half of the Austin LPDs are fitted with an additional bridge to serve as flagships, and they contain both a flight deck and well deck with limited capability as compared to the San Antonio class ships. They can carry 930 troops, with the well deck supporting two LCACs or a variety of LCM arrangements[3]. Again, the primary problem with LPDs is that they require aviation and LCAC/LCU/LCM support for the movement of troops and equipment to shore. Scaling down one of these ships to get the draft requirements down to 4 m without compromising the stability or cargo capacity of the ship would have proven to be very challenging, if possible.

<u>LSD</u>

In a comparison of all of the ships currently commissioned in the U.S. Navy, the Whidbey Island and Harpers Ferry class Dock Landing Ships come the closest to providing a monohull answer to the AEV. These ships displaced between 15,939 and 16,740 LT at 6.3 m draft, and provide another mobile answer to landing troops and vehicles to shore via LCAC or helicopter. The Whidbey Island class is capable of carrying up to four LCACs, with an additional 5,000 cu ft for marine cargo. The Harpers Ferry class ships were built as cargo carrying LSDs, with 67,600 sq ft. for marine cargo. Both ships provided a platform for the landing of two CH53-E Sea Stallion helicopters, but no service facilities[3]. The main struggle in adapting this class of ship to the AEV's missions was the lack of any sort of Ro-Ro deck. The ship needed to have the flexibility for Ro-Ro cargo, helicopter operations and support, and container cargo, but not for LCAC transportation. Because the primary vehicle deck in the LSDs was an LCAC/LCU-carrying well deck, its design would have been poorly suited to our needs, in addition to having to make changes regarding the draft requirements for near-beach operations.

2.1.1.1. Other Monohull Designs

<u>LST</u>

The LST class ships were heavily relied on in World War II, particularly for their ability to beach heavy vehicles and equipment on the beachhead after the initial wave of troops had arrived via LCU or LCM. The U.S. Navy constructed a large number of these ships, though all ships under the LST classification have currently been decommissioned or sold to foreign navies. The last significant U.S. design of an LST was the Newport Class ship, which was commissioned in 1969. This ship class displaces 8,750 LT at a maximum draft of 5.3 m, and is notable for its bow ramp that was supported by twin-derrick arms. The vessel has a helicopter platform and the ability to carry 500 tons of vehicles in 19,000 square feet of vehicle stowage. This ship is beachable, with a full load forward-draft of 3.5 m, and an aft draft of 5.3 m [3]. The Newport class ships were a very close match to what the design team was looking for in the AEV: vehicle carrying capacity, low draft, and a mechanism to land heavy vehicles. However, not only were we looking to innovate from the designs of the past, but we needed a ship that was more robust than the Newport LST. Ultimately it did not have enough cargo or personnel carrying capacity, and we wanted the ability to get troops and vehicles to shore “feet-dry”. The Newport is limited in that at 5.3 m aft draft, the ramp can only reach to within about 90 m of dry beach, assuming a 1:50 beach gradient. This requires all vehicles offloading from the ship to either be amphibious themselves or to land on a dock or LCU. The design team did not want to be constricted by a need for docking facilities or ship-to-shore connectors, so the Newport class was taken out of consideration.

Danish Joint Support Ship (JSS)

While not technically an amphibious ship, this vessel serves as a good example of the innovation that can be made with flexibility towards cargo, systems, and personnel. The ship has a 6300 ton displacement at a draft of 6.3 m, and has the capability to carry and launch ground vehicles, helicopters, and small boats. The ship is built around a 2000 square meter “Flex-Deck” that can hold vehicles, containers, or helicopters, depending on the mission requirements. It has a 900 square meter multi-purpose deck that can embark two medium helicopters, and interchangeable modules for weapon, sensor, or systems packages. The AEV adopts a very similar configuration; the ship has a 1200 square meter flex-deck for containerized berthing, cargo, or hospital units, as well as a committed Ro-Ro deck for vehicles.

Ivan Rogov Class LPD

This Russian built LPD holds the distinction for achieving the highest displacement of any beachable amphibious ship commissioned in the world. The ship displaces 14,060 LT at full load, with a draft of 6.5 m. It has a bow ramp connect by a 200 by 45 foot vehicle deck, and has a helicopter deck and support hangar[3]. The main problem with the Rogov is its limitation on where it can beach; pictures that show vehicles leaving the ship either show a very low waterline (probably as a result of reduced loads) or a very steep beach gradient. The AEV design cannot make similar assumptions about beach accessibility. Therefore, a design like the Rogov would not have been feasible as a starting point for the AEV.

2.2. Catamaran Hull Forms

Several different types of catamaran designs were discussed at the concept stage. Catamarans were considered because of the benefits that they provide over traditional monohulls in terms of their large deck areas and cargo capacity at relatively small drafts. Several different types were investigated, and the catamaran was explored thoroughly as a concept; however, they were not as well suited for this project as a trimaran because of the deck space-to-displacement ratio, so the hullform was not chosen as the final design. The primary problem with catamarans is that they must be very long to meet the displacement requirements of a logistics ship, and the ratio of ship displacement to available cargo area is very low. Thus, catamarans have too much deck area, require considerable structural support, and would ultimately be too long to be feasible.

Partial Air Cushion Support Catamaran (PASCAT)

A PACSCAT design was researched and considered as a viable design option based on the promising draft and powering characteristics. These vessels rely on air cushions created by pumping air into recesses in the hull or by trapping air in between the hulls using skirts to reduce draft and hull resistance while increasing vessel speed. Current PACSCAT vessels have design drafts that are low enough to bring these vessels directly to a beach. This is advantageous for the AEV logistical mission since it allows for direct offload of equipment to the beach without the need for long causeways or landing craft. The reduction in draft requires pumping compressed air into recesses in the hull using an additional power source. Although this system uses power, the intention is that the savings in frictional resistance will outweigh the power needed to run the air compressors.

The type of PACSCAT that the design team analyzed the most was a traditional catamaran with recesses in the hull to allow air lubrication to reduce the frictional resistance. The issue with the PACSCAT design as a logistical support ship is that current vessels do not have large enough displacements for the AEV payload. Scaling up the structural and powering needs from current designs would be difficult and the performance of the ship would also be difficult to predict. The air compressors or lift fans add an additional 10-15% installed power but the required power at speed is only 60% compared to a similar catamaran without air lubrication. This prototype is promising yet is 1/5 of the scale that the team has conceptualized. Even with a maximum sustained speed of nearly half of this prototype's speed, the powering might be too large to be economical. Due to the issues involved in scaling up to our concept's size, this design was not progressed further.

Another PACSCAT variant considered consisted of a traditional catamaran with a 'skirt' between the side hulls at both ends of the ship. This skirt would be a semi-rigid material that would seal the area between the hulls to create a void of extra buoyancy while not increasing the wetted surface area of the ship. As with the other PACSCAT, air would need to be provided into the void to provide the benefit of the extra buoyancy. An issue that arises with this design is the sheer size and durability requirements of the skirt. The AEV must be capable of traveling at a minimum 5000 NM from CONUS to the Seabase and the skirt would have to sustain this operating range for at the very least one journey before undergoing maintenance. A possible solution to this issue is to incorporate a retractable or deploying skirt that is used between the sea base and the beachhead, but that remains retracted during ocean crossings. This would effectively reduce the wear and tear on the skirt, but the technology required to produce a reliable and fully functioning retractable skirt has not been developed extensively. Therefore, the power required in addition to the complexities of the skirt made this model of the PACSCAT unfavorable.

Wave-Piercing Catamaran

The wave-piercing catamaran is a design in which the bows of the side hulls are shaped in such a way that the ship parts the water as it travels through a wave, as opposed to riding on top of it. This provides a smoother ride and allows operations in higher sea states and is advantageous to this project given the sea state 4 requirement for the AEV. However, the design was not pursued due to potential structural concerns if the vessel were to be beached. The protruding bows are seen as a liability in beaching operations, since the structures can be modeled as extensions out from the main hull and might have a tendency to plow directly into the shore instead of sliding above it. The advantage that this hullform holds in being able to slice through waves is also the disadvantage of being susceptible to severe damage upon grounding.

Small Water-plane Area Twin Hull (SWATH)

The SWATH design was also considered as an AEV concept. The idea of the SWATH type hull is that most of the ships buoyancy is well below the surface of the water so that the water-plane area can remain small. This is desirable since the water-plane area determines how much heave a vessel has in periods of wave excitation. If there is little water-plane, then there is little heave. This results in a very smooth ride, and a very stable platform in which to conduct at sea operations. It also has the added virtue of creating almost no wave resistance since the hull submerged, though the submersion does create a penalty in skin friction.

This design also leads to various issues that lead to the SWATH being deemed unusable for the AEV project. Since the SWATH has very little water-plane area, it has very little ability to respond to variable loading. A small change in weighting of the vessel would result in a large change in draft. This also means there is no notable reserve of buoyancy in the ship until the cross structure becomes immersed. This problem could be solved by designing the submerged hulls larger than they need to be for operation and allowing the extra spaces as ballast tanks. This, however, creates much larger frictional drag that increases fuel consumption dramatically.

The other major problem with the SWATH is the large draft requirements. The same characteristics that make SWATH ships excellent oceangoing craft make them poor beaching craft and ultimately the large draft was unacceptable for the AEV. A ballasting type of SWATH was discussed to remedy this situation, with the hull having enough reserve buoyancy to allow it to ballast down to the typical SWATH condition for ocean going travel, then ballasting up until it was more of a catamaran riding on top of the water in order to beach. The amount of frictional drag that would have been introduced with the extra buoyancy and the problems with making the submerged hulls be weight bearing when on land made this inferior to other concepts, and was abandoned.

M-Hull

The M-Hull is a relatively new hull design that was developed by the M Ship Company originally to prevent wave erosion on the canals of Venice, Italy. The M-Hull consists of a planning monohull, tunnels on opposing sides, and rigid skirts completing the tunnels on the outside of the boat. The M-Hull captures air and diverts the bow wave through these hull tunnels, which creates a stable platform and goes a long way in reducing the wake and resistance of the boat. The company recently developed their hull into an 80 foot technology demonstrator called the Stiletto, which has a 40 foot beam and provides the deck area comparable to a 140 foot monohull. The ship's draft is only 3 feet and it is designed for speeds upwards of 60 knots, with uses including the high-speed insertion of Special Operations Forces[4]. The main drawback of this design is that it is too new and untested to be used as a proven concept. There is only a small amount of data for this hull available from the manufacturer. Independent information on this design is very limited.

This design has also never been tried for a larger vessel, especially one the size needed for the AEV. One can only speculate on how a partially damaged M-Hull would function. Modifying the hull so that it can be beached would also present a major challenge in that any modifications might compromise the benefits bestowed on it by its novel design. The lack of data and the scaling problems to a larger ship sized version are the main reasons that the M-Hull was not suitable for the AEV concept.

Hydroplane

A hydroplane design was never really considered a viable option for this project. The difficulties in creating a small strut structure on which to support the vessel while planing would be enormous and expensive, if possible at all. Vessels of the size of the AEV just are not capable at this time with being equipped as hydroplanes from a structural and mathematical standpoint. From a propulsion point of view, the amount of power that would be required to get the AEV planing would be prohibitive. Since the AEV needs a shallow draft, the hydrofoil would also need to retract to allow for beaching, which would add even more cost and complexity into an already difficult problem.

Wing in Ground (WIG) Effect Ship

Another design that was given brief consideration is the wing in ground effect ship, a low flying aircraft that uses aerodynamic ground effects to fly close to the water. Most WIG ships are small and cannot carry more than a few hundred pounds, though Boeing is trying to develop a very large WIG prototype and the Russian military built large-scale WIG ships in the late 1970's and early 1990's. While an effective way to move large amounts of troops, equipment, or cargo quickly, the high risk of losing such a loaded vessel would be unacceptable. Making the ship survivable would become a top priority and may affect its ability to be a useful tool.

3. Concept Generation (Ship)

Introduction of Concepts

3.1. Catamaran Hull Form

Significant design work and research was put into developing a catamaran concept that would be evaluated next to a trimaran design to be pursued as the final concept design of the AEV. The conceptualization process for the catamaran can be found in Appendix C, where it details the cat-hull revisions that led to the final catamaran concept. Figure 1 shows the final revision of the catamaran hull. For reasons explained at the end of this section it was not chosen to be pursued as a final design.

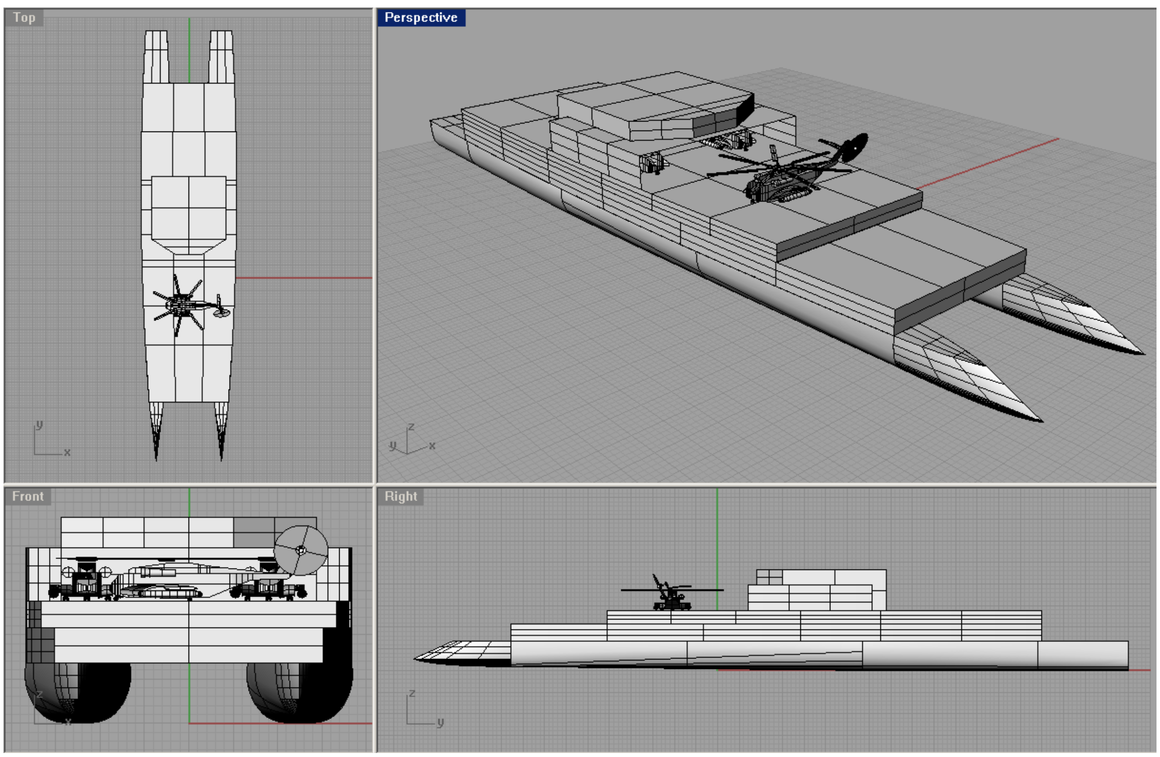

Figure 1: Final Catamaran Concept Design

Table 1: Final Catamaran Concept Design

	Cat-Concept
LOA	165 m
Draft	4m
Max beam	37 m
Displacement	8,834 MT
PAX area	2028 m2
Ro-Ro area	4312 m2

3.2. Trimaran Hull Form

3.2.1. Center Hull

After exploring the many catamaran hull forms, a trimaran hullform was investigated for its application to the AEV. In standard trimaran design, the center hull is the main displacement portion of hull and the side hulls provide extra stability and the capability for added deck area. For the AEV, a long slender center hull with a relatively high beam was selected. The first design had deep V aft portion of the hull, a square stern, and the bow section came to a semi point with a wave piercing bow. Additionally, there was a 1 m keel rise which extended 81 m aft from the bow. Given a 1:50 beach gradient, this gave the ship the ability to get 50 m closer to the beach. Several issues were determined with this design. In order to obtain sufficient displacement the draft had to be in the five to six meter range, which was deemed too high for near shore operations. Also, a new stern was added which increased the length by approximately 20 m; the original stern can be seen in Figure 2, with the new extended stern visualized in Figure 3.

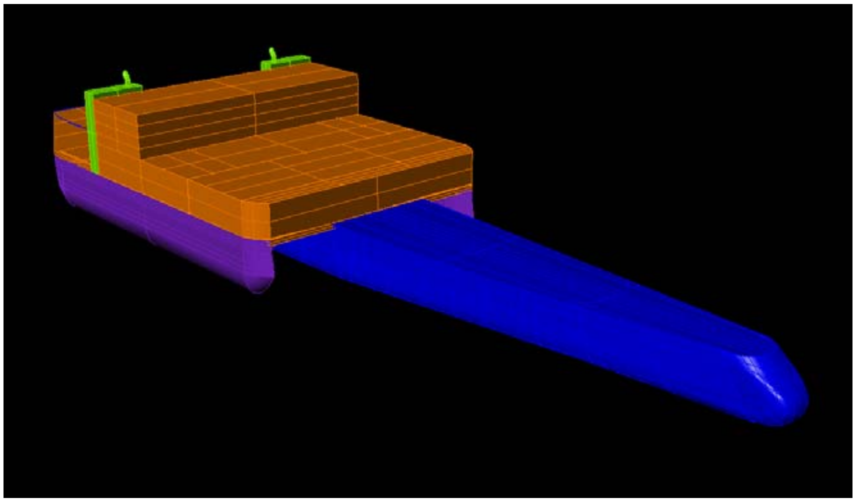

Figure 2: Trimaran Concept with original sidehulls and stern

The next revision to the trimaran hull form was to decrease the V-form in the midsection of the hull. This redesign had two favorable characteristics: more displacement and a lower draft. The draft of the vessel was now brought to approximately 4 m, which was the original goal for the design team.

3.2.2. Side Hulls

The first concept side hulls provided approximately 10% of the total ship displacement. This type of side hull had the advantage of adding to the total cargo carrying capabilities of the ship. This type of sidehull, was quite far outside of the historical range of displacements for trimarans. Additionally, it had a high beam and the form was dissimilar to any other trimaran designs, as seen above in Figure 2.

For this reason the side hulls were redesigned to better represent the side hulls found on the USNA trimaran study, which was to be used as a model for predicting the resistance of our hull. The inboard surfaces of the hulls form a vertical surface, while the outboard profile was designed to have a more typical hull form, as seen in Figure 3.

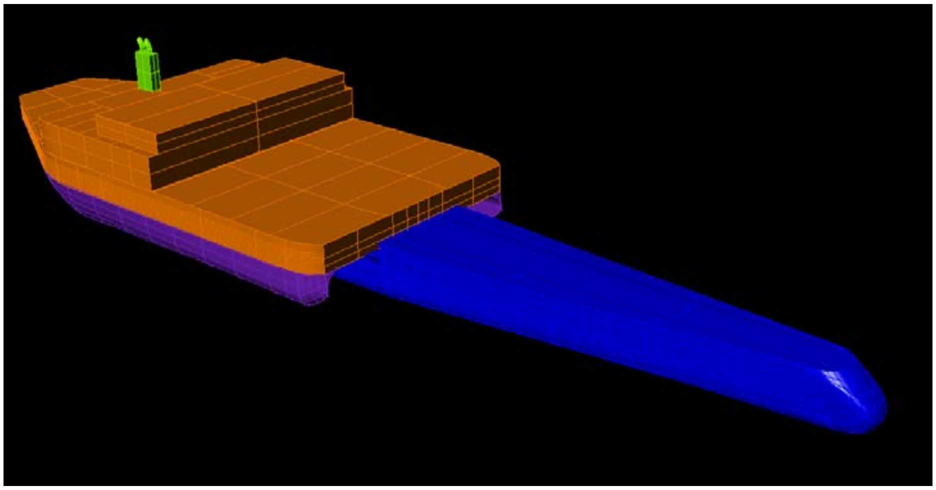

Figure 3: Trimaran Concept with revised sidehulls and stern

3.2.3. Crossdeck & Superstructure

The crossdeck connecting the three hulls was designed in a very simple manner. The initial design seen in Figure 2 provided space for the helo hangers and limited passenger space. The enclosed deck spanned from about midships to approximately 30 m from the stern with an open weather deck extending to the stern for structural integrity. The MSC crew accommodations were located on two decks placed on top of the crossdeck and the bridge located above there. Upon initial analysis of this arrangement, it was determined that several issues could be solved by redesigning the superstructure. The enclosed crossdeck was extended to the stern and was also extended forward approximately 10 m. In doing this, the structural integrity of the ship was increased while providing added space for cargo and passengers. The helo hangars were relocated to be placed in the center of the deck house with the crew accommodations located around the perimeter of the bay, as seen in Figure 3.

Two further revisions of the crossdeck and superstructure were also considered, both with significant changes to the location of the passenger and helicopter space; these revisions were an experiment with optimizing deck space, but fell short of the original layouts. Concepts 3 and 3a move the helicopter bay forward of the crew, passenger, and cargo locations, rather than the traditional stern location. This allowed for the reorganization of the passenger and cargo space, but still could not provide the same amount of deck area as the Concept 2 design, even with the 3a revision. Both Concept 3 revisions can be seen in Figure 4.

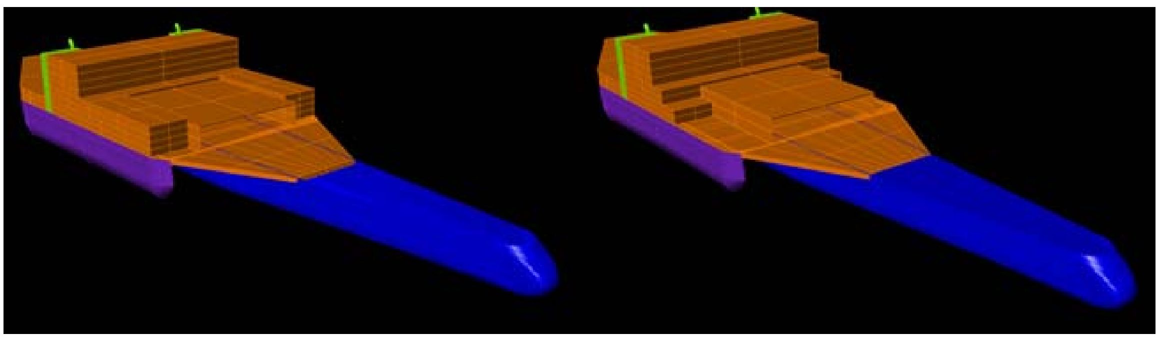

Figure 4: Trimaran Concepts 3, to the left, and 3a, to the right

The final decision for the trimaran concept was made based on the data in Table 2.

Table 2: Trimaran Concept Data

	Concept 1	Concept 2	Concept 3	Concept 3a
LOA	161 m	181 m	181 m	181 m
Draft	4m	4m	4m	4m
Max beam	48.8 m	48.8 m	48.8 m	48.8 m
Displacement	10,000 mt	10,700 mt	10,700 mt	10,700 mt
PAX area	1312 m2	4306 m2	3259 m2	3853 m2
Ro-Ro area	4006 m2	4006 m2	4006 m2	4006 m2

While all four concepts demonstrate the same amount of Ro-Ro area, the second variation has the highest value for passenger and cargo area, which was critical for the design needs of this ship. The decision was made to go with Concept 2 as the trimaran variant of the AEV concept, and was the design chosen over the catamaran as the final AEV design.

Concept Selection Process

With the two primary concepts created, a choice had to be made regarding which one to develop further in terms of subdivision, powering, propulsion, deck arrangements, and causeway utilization. While both concepts showed promising criteria for the AEV design, the trimaran was ultimately better suited for the final concept design.

Both concepts have significant deck areas, as well as space for crew considerations and helicopter operations. However, the trimaran offers deck space comparable to the catamaran but with a higher displacement. This is desirable from a weights standpoint, since the lightship weight would be high for both ships given the large deck areas required. The trimaran concept shows about 2,000 tons more displacement than the catamaran at the same draft, yet demonstrates comparable deck area for Ro-Ro cargo and much higher passenger and cargo areas. The design team decided that this balance between cargo area and displacement made the trimaran a better choice to develop, and the trimaran concept 2 design was chosen as the final concept design of the AEV.

3.3. Evolution of Concept (Trimaran Concept 2)

3.3.1. Subdivision

The subdivision for the concept was driven primarily by two major factors: damaged stability and vehicle stowage. Ultimately the smallest compartments permissible would have been the best solution from a stability standpoint, while no watertight bulkheads at all would have presented the best environment for the arrangement of vehicles on deck. A collision bulkhead was first fitted, as per commercial shipping requirements, under the American Bureau of Shipping (ABS) standard of 0.05*Longitudinal Center of Buoyancy (LBP), or about 9.6 m from the Forward Perpendicular (FP). Aft of the collision bulkhead, DDS 079-1 stability criteria still applied to the ship, which dictates that the compartments should have a spacing of 10 feet plus 0.03 LBP, or 8.48 m for our concept. The longest vehicle in the MEB at 12.4 m is the Assault Breacher Vehicle (ABV) so the starting point for the bulkhead spacing was 13 m in order to provide a minimum of clearance for that vehicle. The next driver for the bulkheads was the need for a bulkhead to run continuously from the keel to the strength deck on top of the vehicle/container deck. This last requirement drove the final bulkhead spacing, which allowed for a 9.6 m forward collision bulkhead, then 9 bulkheads with 18 m spacing, and finally a 9.3 m bulkhead in the stern; this spacing placed the fifth bulkhead directly under the front bulkhead of the passenger deck. The last short compartment was necessary to ensure that the flooding was contained in the event of an aft collision or shell opening.

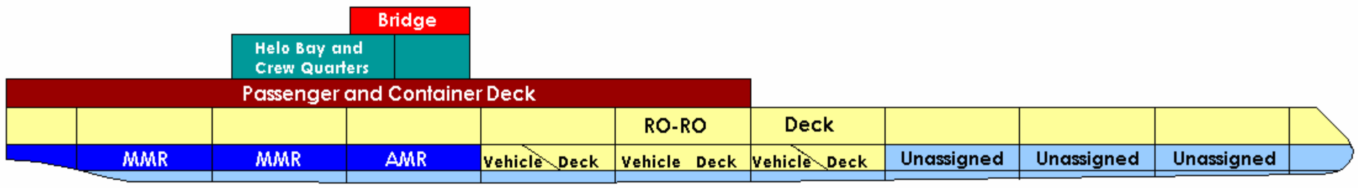

Figure 5: Trimaran Concept Subdivision

Figure 5 shows the general subdivision as well as the compartment arrangement for the ship. The lower deck houses the three unassigned compartments, the MMR and AMR, and the lower vehicle decks. The unassigned compartments on the first deck and in the double bottom allow for the tankage space required for fuel, freshwater, and other liquid cargoes. The second deck is solely a Ro-Ro deck. Above that lies the passenger and container deck, helo-bay and crew quarters, and bridge, all of which are discussed in their respective sections. As can be seen in the figure, the final ship concept contains 11 watertight zones, with watertight bulkheads between each compartment on the Ro-Ro deck and one watertight bulkhead between the sixth and seventh compartment lower vehicle decks.

3.3.2. Ro-Ro Arrangements

The Ro-Ro deck was one of the driving factors of the ship design. The deck spans the length of the ship and is separated into sections by means of bulkheads sealed with sliding watertight doors. During the transport of the MEB to or from the seabase, the Ro-Ro deck will be used to transport the vehicles of the MEB. Since the MEB must be broken into five loads in order to transport it, the five different loads must have a unique layout depending on what equipment is being transported in that particular load. A preliminary breakdown of the loads is given in table 3.

Secondary vehicle spaces are located in three compartments below the Ro-Ro deck. These spaces were designed to allow a M1097 (humvee) unobstructed access. For this reason these spaces are primarily reserved for humvees in the preliminary layouts of the three vehicle decks. The humvees are also evenly dispersed through the loads to provide maximum utility from the vehicle spaces during the mission.

Table 3: Ro-Ro loading breakdown

	Load 1	Load 2	Load 3	Load 4	Load 5
M1A1	5	9			
AAAV	12	9	12	9	6
M88A1		1			
M1097	20	20	20	19	20
M198		0	18		
LVS Mk48		2			
M101A2	20				
M390		21			
LAV					25
Mk1 GI Joe	1360	1360	1360	1360	1360
FRKLFT			2		5
AVLB					1
MEWSS					3
MTVR	21	5	32	50	25
MRC	33				
M9293/Q46		2		2	
ABV		1		1	

The layout shown in figure 6 indicates one feasible arrangement of vehicles on the Ro-Ro deck for “Load 1” from table 3.

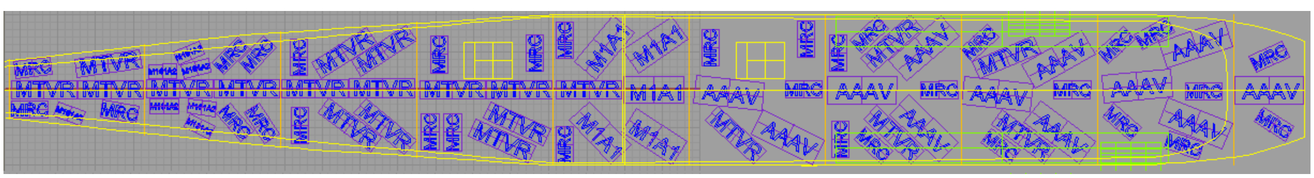

Figure 6: Ro-Ro Deck Layout

The vehicles are oriented towards the center of the ship to try and ease the loading and unloading of them without maneuvering the vehicles in confined spaces. There is sufficient space left for manipulation of the vehicles after they have been placed in the Ro-Ro deck.

The layout takes into account the turning radii of the vehicles within the holds. Vehicles and equipment with larger radii are placed in a manner that should facilitate easier loading and unloading, while the smaller pieces are placed in areas that require a more nimble vehicle.

Figure 7 is a layout of the three vehicle spaces located beneath the Ro-Ro deck. The arrangement on this level is much more in the style of a parking lot since the humvees are more maneuverable than most of the other equipment and are more suited to being placed in such a manner.

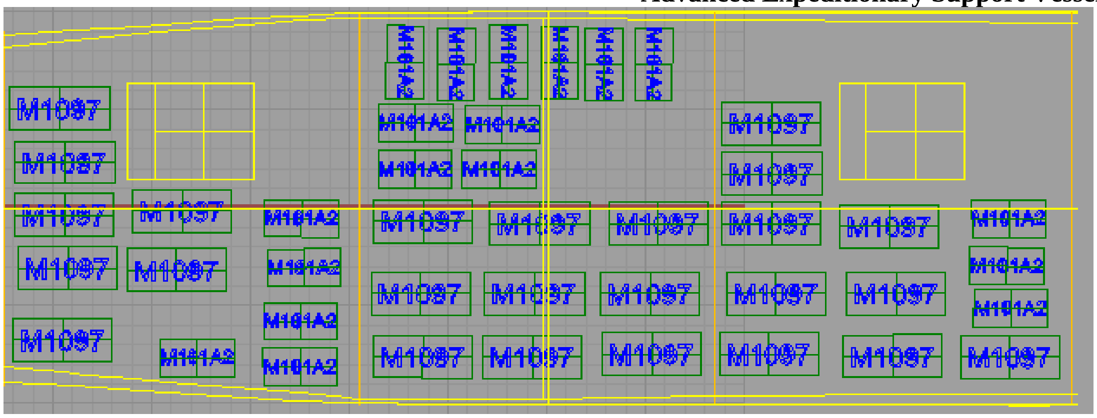

Figure 7: Vehicle Deck Layout

When the AEV is not carrying the MEB loads (during humanitarian aid missions or after offloading the payload onto shore) the Ro-Ro deck is ideal for holding other objects. It can hold other vehicles, or be used as temporary housing for any number of cargo or equipment. Since the decks are to be designed to hold the largest and heaviest ground equipment the MEB has, it should have no trouble housing any other vehicle. The rest of the conceptualized Ro-Ro deck layouts can be found in Appendix A.

3.3.3. General Arrangements

The general arrangements on board the AEV have been designed to incorporate the needs of the crew as well as the marines that will be transported aboard. The crew and officer decks are separate from the main passenger and cargo decks, and have been designed to accommodate the personnel listed in Table 4. The arrangements for these two decks is discussed in section 8.2.3.1, *Crew Arrangements*. The arrangement of the main deck that houses the marines and containerized cargo is discussed in section 3.3.5, *Main Deck Arrangements*.

Table 4: Crew and Officer Breakdown

Personnel	Military Sealift Command (MSC)	Aviation Detachment
Officers	12	4
Crew	18	14

The number of MSC crew listed above is based on MSC crew sizes for ships of similar displacement to the AEV. The number of crew listed in the aviation detachment is based on the required flight and maintenance crews for two Sikorsky CH-53E helicopters.

3.3.4. Crew Arrangements

The mission requirements of the AEV ship describe several mission situations that depend on extended operation for transport, beachhead support, and ship relocation. These missions require facilities for the crew and officers to live aboard the AEV for up to 30 days. Accordingly, ship habitability for officers and crew aboard the AEV has been considered with respect to the arrangement of living spaces on two decks aboard ship. These decks include all facilities and spaces that are standard for MSC personnel and comply with the MSC, COMSCINST 9330.6D (6 June 1991), habitability codes.

The crew quarters are located on the first deck above the main cross-deck, and are situated around the helicopter bay. As shown in Figure 8, there are 8 staterooms for the MSC crew and another 7 staterooms for the flight crew of the aviation detachment. This deck also houses the galley, officer and crew mess rooms, and a crew lounge. The largest portion of this deck is used by the helicopter bays which house two CH-53E helicopters. Additional room for helicopter maintenance gear, workshops, and spare part lockers are located in these designated aviation bays.

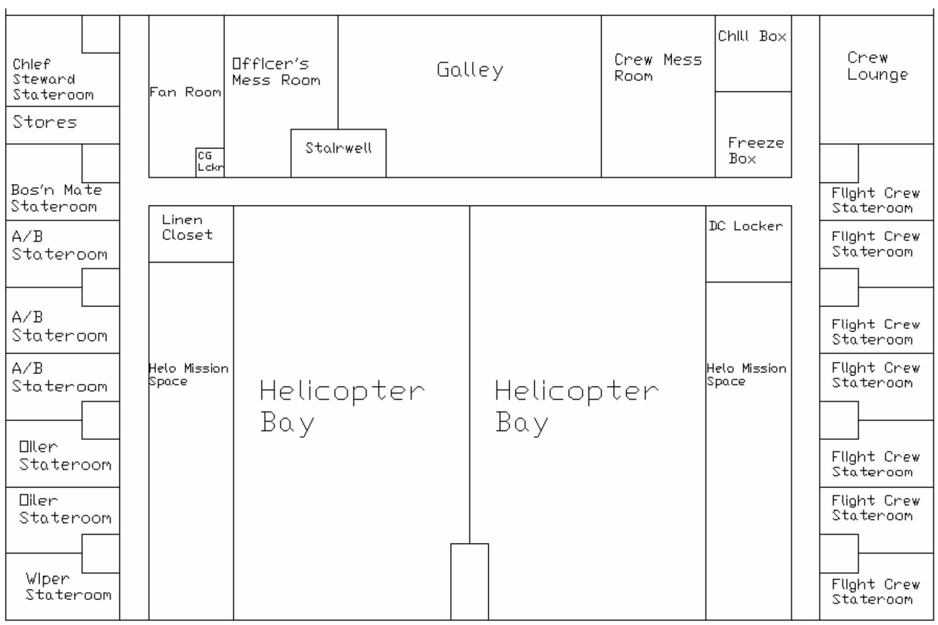

Figure 8: MSC and Aviation Crew Deck

The officer's deck is located one deck above the crew, and has a similar layout with staterooms situated on the perimeter of the helicopter bays. These aviation bays extend into the second deck due to the height requirements of the CH-53E helicopters and the required room for aviation equipment. On this deck there are four pilot staterooms and the captain's stateroom with attached office. Additional rooms have been placed on this deck as specified in the MSC, COMSCINST 9330.6D (6 June 1991), habitability codes. The officer's lounge and laundry as well as a technical library have been included in this deck. Figure 9 also shows that excess room exists on this deck in case adding other compartments or equipment is desired.

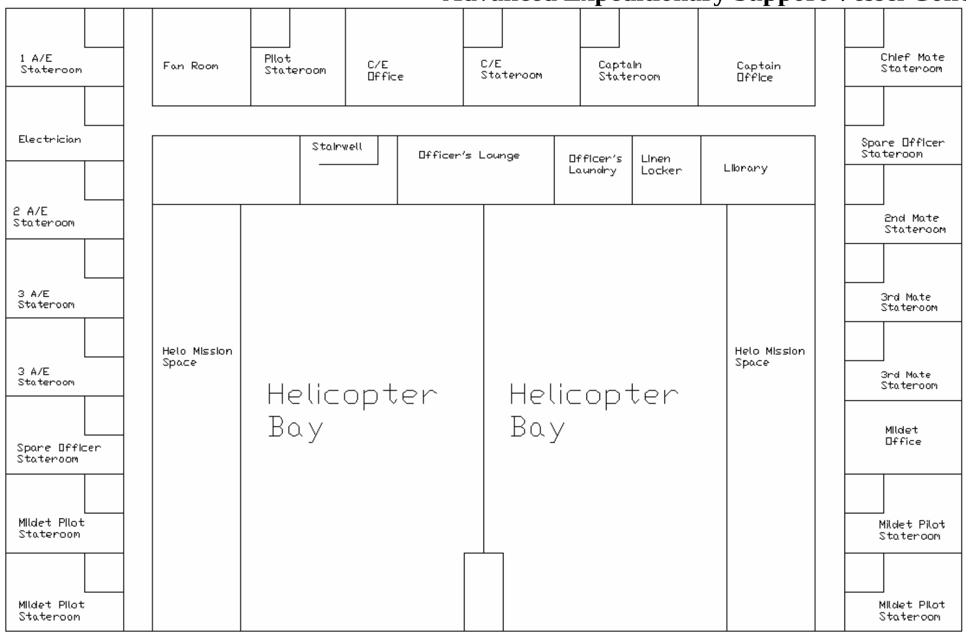

Figure 9: MSC and Aviation Officer Deck

As a measure of the habitability of the AEV, a comparison between the MSC required stateroom areas and the AEV designated stateroom area is shown in Table 5.
The area allotted to living spaces exceeds the requirements for the officers by 12.5% to 26.5% and for the crew by 5.8%. The requirements with respect to areas and distribution of heads, berthing, and showers have also been accounted for in accordance with this habitability requirement.

Table 5: AEV Personnel Requirements

	Req. Area m2/pers	Allotted Area m2/pers	Percentage of Req. Area %
MSC			
Officers	17	21.5	126.5
Crew	13	13.75	105.8
Mil-Det.			
Officers	16	18	112.5
Crew	13	13.75	105.8

3.3.5. Main Deck Arrangements

The main deck of the AEV is a multipurpose deck comprised of an adaptable cargo area that doubles as a container or Flex deck, and a separate passenger compartment. During any logistics mission, this deck contains all the containerized and palletized supplies in the mission payload as well as a portion of the marines traveling to shore. To fulfill this requirement, the main deck is separated at the cargo hold from the seating compartment with a bulkhead that also provides structural support to the superstructure. Another bulkhead provides similar support at the rear of the superstructure and splits the seating area in half.

An evaluation of the AEV payload and the MEB equipment that must be transported to shore was performed to come up with potential loading cases. Based on cargo and personnel loading conditions shown in Appendix B, the AEV has been designed to carry a fifth of the MEB equipment and personnel. This means that a total of 1400 tons of personnel and gear (1360 marines) must be accommodated for the trip from sea base to shore. Additionally, one of the mission requirements of the AEV requires storage for 40 TEU containers. Figure 10 shows the general layout of the entire deck and from this diagram the separated compartments and seating can be seen.

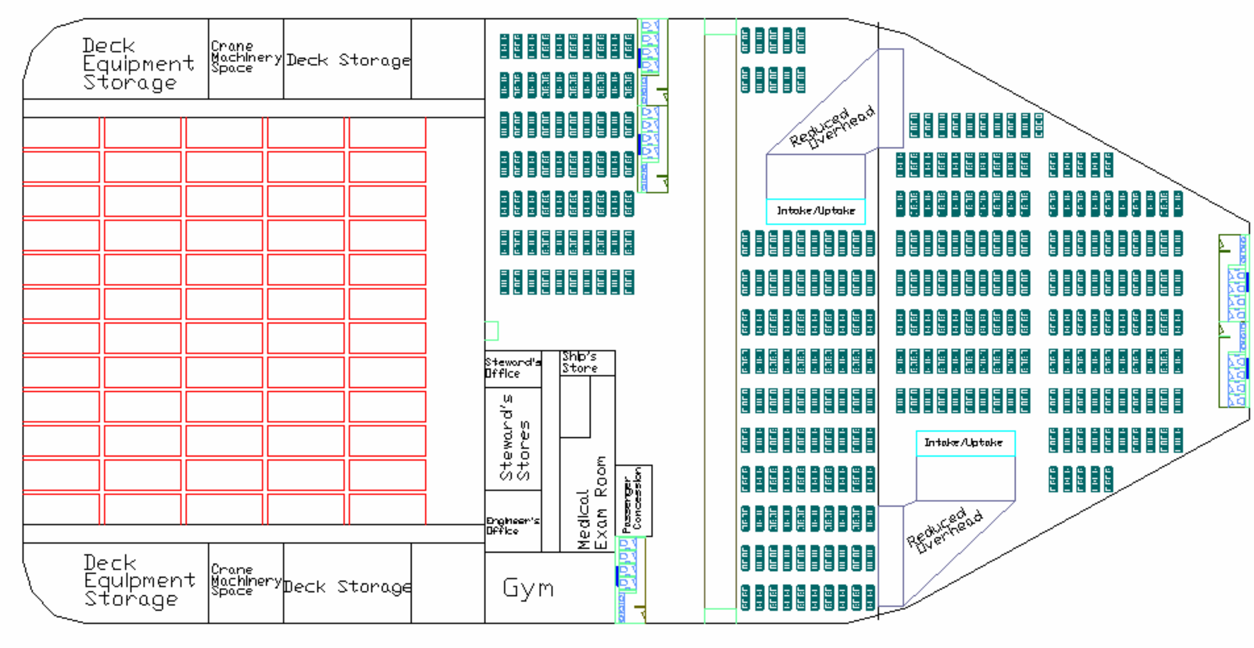

Figure 10: Main Deck Arrangements

The cargo area located on the fore section of the deck can hold 60 TEU containers, which is 1.5 times the required amount. These containers are loaded onto the AEV through a hatch on the deck above and then they are positioned using an X-Y crane enclosed within the cargo compartment. This entire space is 1200 m^2 and can be used as an adaptable space when supply containers are removed. Also located in the forward section of the deck are deck equipment storage spaces as well as the machinery spaces for the 60-ton cranes on the deck above.

The passenger compartment located from amidships to the aft of the main deck is capable of accommodating 1360 marines with their combat equipment. Figure 10 shows the location of the seating as well as the 5 heads that are distributed within the compartment. Also present on this deck is the medical examination room, engineer's office, gym, ship stores, and passenger concession. The accommodation is large enough for the marines, yet additional room is available within the compartment in case the seating needs to be resized or relocated. The remaining space in the compartment after the accommodation sizing is determined will then be used for tables and lounging spaces. The figure above also shows the location of the intakes/uptakes and the reduced overhead where the intake/uptakes are vented towards the sides of the ship.

3.3.6. FLEX Deck

The adaptability of the cargo compartment on the main deck allows the cargo area to be used for many purposes. The multi-purpose deck is used primarily for cargo, but the potential secondary capabilities include space for medical centers, humanitarian aid shelters, additional seating and berthing for troops, and dining facilities. Since the deck is completely empty, these alternate missions are achieved by utilizing containerized hospitals, troop transport and berthing, and modular dining facilities. An example of a containerized hospital from the "UniTeam: Medical and Hospital." [9] webpage is shown in Figure 11.

Figure 11: Modular and Containerized Hospital

The use of containerized modules to modify the capability of the Flex deck allows the AEV to become a multi-mission ship without requiring the AEV to have mission specific variants. The simplification of medical facilities, berthing, and even munitions storage through the use of containers is central to the feasibility of the FLEX deck. Several more figures in Appendix A show some other common containerized items.

3.3.7. Weight Breakdown

The weight of the structure of the ship, SWBS 100, was found by using the structures data of a similar ship and scaling the numbers to match those of the AEV. The ship used as a reference in the estimation was a trimaran variant of the Joint Logistics Support Ship (JLSST). The JLSST was chosen since diagrams of its hull structure were available, and the fact that it is a trimaran creates a more reasonable estimation for the AEV. The number of transverse and longitudinal supports was counted for a section of the ship, and the weights of the individual supports were added along with the weight of the plating for the hull section. This was done for a section of the main hull, and a section of one of the side hulls. The section weights were then extrapolated along the length of the hulls to give a representation of the total structural weight of the AEV concept design. The analysis estimated the weight to be approximately 80% of the total lightship weight. However, after comparing this number to historical data from other amphibious ships in the same size range, the design team concluded that the 80% value was too high. To compensate for this discrepancy, the structures weight estimate was reduced to approximately 62%, which is slightly higher than the trend line for other amphibious cargo ships. For the SWBS 200 weights, a spreadsheet utilizing historical data points to create trend lines was used to estimate each parameter of the machinery spaces. Each weight that was known (engine weights and waterjets) was fed directly into the spreadsheet and the remaining weights were left to historical interpolation. The remainder of the SWBS weights, 300-600 (SWBS 700 was not included in our ship design), were estimated by manually extracting the algorithms utilized by the ASSET program and calculated by hand to obtain estimates, which allowed a quick simple method for acquiring the necessary weights for the other systems. Corrections were added to compensate for the added weights of the deck cranes, stern ramps, and other additional equipment. The following table displays the results of these estimates.

Table 6: Weight Breakdown

SWBS	WT (MT)
100 Hull Structure	4,460
200 Propulsion Plant	705
300 Electrical Plant, General	345
400 Command and Surveillance	105
500 Auxiliary Systems, General	1,025
600 Outfitting and furnishings	710
Lightship (with 5% margin)	7,920
Cargo Weight	1,730
Fuel	1,240
Total Weight	10,700

Included in the cargo weight is the highest load of the five loads to carry an MEB as well as the weight of 4 150’ sections of the inflatable causeways. The fuel weights were estimated by using the power requirements to propel the ship at 24 kts for a range of 5,000 nm at the fuel efficiency of the selected engines. Added to this fuel weight is sufficient fuel to run two of the ship service generators at full capacity for a duration of 30 days.

4. Powering and Propulsors

4.1. Resistance and Powering

Given the very few historical data points for comparison, the United States Naval Academy (USNA) trimaran model test was used as a basis for resistance and powering requirements. Table 7shows a comparison of the two hulls. This comparison shows that there are some substantial differences in the geometry of the hull, the ratios traditionally used in resistance calculations are close enough to warrant comparison, though a margin of error is needed to rectify many of the main differences that cannot be scaled.

Table 7: Geometry Comparison

	USNA Hull[5]	AEV Hull	
LOA	128	181	m
LWL	128	181	m
Breadth (main)	9.76	20	m
Draft	4.57	4	m
Displacement	3126	10,700	tons
Wetted Surface	580	4254	m2
L/B	13.15	9.05	
B/T	2.14	5.00	
L/(disp)^1/3	8.75	8.32	
Fn	0.25	0.29	@ 24 kts
Re	1.50E+09	2.12E+09	
Cb	0.53	0.71	

Until more testing is done on trimaran hulls of various shapes, a completely accurate scaling will not be available for the AEV hull design chosen, simply because it is unlike any other trimaran that has been tested for resistance and powering characteristics.

The USNA results were established using scale model testing of their hull and applying a weighted average of the ITTC-57 friction line values of the three hulls to scale the test data to a full-scale vessel. The USNA model had a resistance of 9.755 N, which was assumed to be the same as an AEV concept model[5]. The same weighted averaging scheme was used with the data of the AEV to determine the residual resistance coefficient of the model, and the results were then used to find the total resistance of the AEV at full scale sustained speed. Table 8 below shows the resistance data for the ship at 24 kts.

Table 8: Resistance Data AEV

Speed (knots)	24
speed (ft/s)	41
Fn (model)	0.2956
Cr (model)	0.0019
Re (main)	1.90E+09
Re (sec)	5.67E+08
Cf (total)	0.0015
Caa	0.0001
Ct	0.0035
EHP(no drag)	20,000
Appendage Drag (hp)	3,635
Air Drag (hp)	606
EHP(final) (hp)	24,440
Shaft Power (hp (MW))	36,000 (27)

The final powering numbers seen above assume a series of efficiencies and margins to come to a final SHP number for engine selection. The final EHP of 24,440 HP, including air and appendage drag, is derived strictly from the USNA data with no powering margin included. The SHP value that was calculated assumes a 68% powering efficiency, which brings the SHP required to approximately 36,000 horsepower, or 27 Megawatts (MW).

Using the value of 27 MW, a suitable engine had to be found to provide enough power to operate at 80% MCR, or 33.6 MW of power. The decision came down to a diesel engine or gas turbine, the advantages and disadvantages of which are listed below.

- Diesel Engine
  - Fuel Efficient
  - Lower Overall Cost
  - Reliable
  - Heavy
  - Used More in Commercial Practice
- Gas Turbine
  - Expensive
  - High Power Density
  - High Fuel Consumption

– Large Intakes/Uptakes

The decision was made to go with a diesel engine based on its higher fuel efficiencies, lower overall cost, and reliability verses the gas turbine.

The diesel engine that the design team selected is the Wartsila 12V38, a 600 RPM medium speed diesel that provides 8.7 MW of power, has an SFOC of 0.174 kg/kW-hr, and weighs 88 tons[6]. This specific engine was chosen primarily because it fit the height requirements of the AEV engine spaces, yet still provides ample power. Four of these engines are used in the AEV to provide 34.8 Megawatts of power, which gives the ship another 3.9% margin above the required 33.8 Megawatts to operate at 80% MCR. The engines are paired, with two to each shaft connected through a double-reduction, locked train reduction gear, the sizing of which was estimated based on ASSET algorithms.

4.2. Propulsors

Modern ships have a variety of choices when it comes to propulsion units, ranging from canvas sails to water-jets. Even with the traditional screw propeller prevalent on ships today, there are many variations that allow for a greater degree of control and efficiency. To accurately determine which system would be best suited for the AEV, the design priorities were used to guide the decision making process. The design requirements that guided the propulsor selection were as follows:

- Shallow draft needed to reach near-beach littoral areas
- High thrust and maneuverability at low speeds necessary for de-beaching
- Unit must be robust enough to power ship at sustained speed

4.2.1. Screw Propellers

Screw propellers are the dominant method of propulsion in the water. As a result, they were the starting point for analysis of the most effective means of propulsion for the AEV. The design team established that the mission requirements of the AEV demand multiple different operating points, which would require different propeller arrangements for maximized efficiency through the mission ranges.

A controllable pitch propeller (CPP) would solve some of these problems in that it would allow for maximum efficiency not only at sustained and endurance speed, but also at the low speeds that would be associated with de-beaching the vessel. This would add a great deal of extra mechanical complexity into the design, particularly the propeller hub itself, but the advantages over the traditional propeller would make a CPP a necessity to suit the mission requirements.

Other options that were briefly discussed along with the CPP were surface-piercing and super-cavitating propellers. A surface-piercing propeller can bestow advantages to ships in certain operating envelopes, but the speeds at which the AEV would be running does not benefit from this type of propeller. A super-cavitating propeller also has its advantages in high-speed applications, but not at the speeds at which this vessel would be operating.

In addition to the propeller itself, there are also considerations to be made regarding its attachment to the ship. Podded propellers would give the ship finer control in close quarters maneuvering, which would be a tremendous advantage when navigating close to beachheads. However, a pod would have a larger draft than the typical shaft-propeller arrangement seen in most ships today, which is a great restriction for the AEV to travel close to shore.

Shrouded propellers, such as kort nozzles, are another option that can add more thrust at low speeds as compared to a shroud-less propeller. These advantages are again outweighed by the need for a low draft solution, and it is also unclear whether the shroud would amount to an increase in the ship's total drag at higher speeds, including the AEV's cruising speed.

In any arrangement, screw propellers are very susceptible to the risk of grounding that is always present during beaching operations. Even with precautions to ensure that the stern of the ship does not get too close the sea floor, an errant rock or a slight increase in beach gradient could easily cause propeller damage that would be potentially crippling for the ship. This, combined with the higher draft requirements associated with propellers, makes the screw propeller a poor choice for the design of the AEV.

4.2.2. Voith-Schneider

Voith-Schneider vertical axis propellers give an incredible amount of control to a ship operator. However, this fine control scheme comes with its own challenges, such as a very complex mode of power delivery, a very large draft requirement, and a relatively untried system compared to more conventional means of propulsion. The system has not yet been tested in vessels as large at the AEV, and there is no information on how fast vessels equipped with this propulsor can travel. At this point in their development, Voith-Schneider drives are too exotic and untested in large ships for a recommendation of using them in the AEV.

4.2.3. Water-Jets

Water-jets have traditionally been confined to high-speed craft, particularly alternative hullforms such as hydrofoils and catamarans. New water-jets are demonstrating higher efficiencies at lower velocities, which would be advantageous to a ship that has a large range of operating speeds.

Water-jets have a unique advantage in that there is no draft restriction, given that the entire propulsion unit is housed within the hull of the ship. They can also be supplied with directional nozzles that allow the jet stream to be directed in various ways to increase control of the vessel. The degrees of freedom provided by these nozzles are not as large as the best podded propellers, but the range of motion is still great enough to suit the missions of the AEV, and the draft advantages far outweigh the small loss in maneuverability.

While the water-jet provides many solutions for the AEV's propulsion requirements, it does face one major drawback: the intake. Most conventional water-jet designs used on ships today use intakes on the bottom hull, below the water line and at the ship's stern. At the shallow depths the AEV is going to be operating in, this could easily cause the intake of silt, rocks, and other debris in the vicinity of the beach. Silt would merely cause losses in efficiency and rapid erosion of the impeller, while rocks and debris could cause severe damage that would leave the ship grounded. A method would have to be in place to ensure that no sizable rocks were sucked in through the intake, and that the silt proposed no serious threat to the jet impeller.

Water-jets, though not perfect, provide the best solution to the challenge of powering a ship in both blue water and littoral beach environments. Their flexibility and power make them the best choice of propulsor for the needs of the AEV.

4.3. Chosen Propulsor

The propulsor that the design team chose to fit on the AEV is the Lips LJ150E water-jet[7]. Two of these water-jets were found to provide adequate power to propel the AEV, and are located in the space directly behind the MMR, with the inlets located approximately 3.6 m behind the transom. The water-jets have the ability to be steered using directional buckets, which provides the AEV with additional maneuverability.

5. Stability

The stability for the concept trimaran was calculated using the Rhino Marine plug-in for the Rhinoceros 3D CAD program. It allowed the team to calculate intact stability, as well as a form of damaged stability using a lost buoyancy method. The damaged stability criterion was determined using DDS 079-1, "Stability and Buoyancy of U.S. Naval Surface Ships".

5.1. Intact Stability

The intact stability measurements were all taken at the design draft and displacement for the ship: 4.25 m and 10,700 MT, respectively. Because of the manner in which the weights are calculated, using ASSET algorithms and other smear weights, the exact VCG for the ship was not able to be determined; the multiple loading conditions that the AEV faces also contributes to the problem of finding an accurate vertical center of gravity. This led to the estimation of a range of Keel to the Center of Gravity (KG) values, with 8 m being the lowest possible estimated KG for the ship and 15 m being the max, and a 12 m curve being our closest estimate to the true KG value of the concept at most loading conditions. The range of KG values is a very conservative one, with the maximum and minimum estimates assuming extreme loading conditions that would probably only occur in special missions where the ship was either empty or loaded with extremely heavy cargo on the upper decks. Table 9 shows data obtained for the ship at design conditions:

Table 9: Hydrostatics Measurements for Concept Hull

Freeboard: Center Hull	5.5 m	**VCB**	2.63 m
Freeboard: Aft Section	9.5 m	**LCF**	-101.2 m
LCB	-101.4 m	**Waterplane Area**	3198 m^2
Wetted Surface	4343 m^2	**KM**	20.3 m

Given the very large Keel to Metacentric Center (KM) of the ship, the Center of Gravity to the Metacenter (GM) would never be less than 5.3 m, even at the maximum KG value that was assumed. For most conditions the ship would have a GM estimate around 8 m, which makes the ship extremely stable in an intact condition. In addition to the high GM, the ship has very high freeboard values, especially in the aft section of the ship where the cargo/troop deck provides additional buoyancy. It should be recognized that such a large GM value creates complications with seakeeping, and that the trimaran concept would probably have a very short roll period. This would need to be addressed in future iterations of the ship design process, and could be solved by artificially lowering the GM with different loading conditions. Figure 12 presents the GZ curve for the concept:

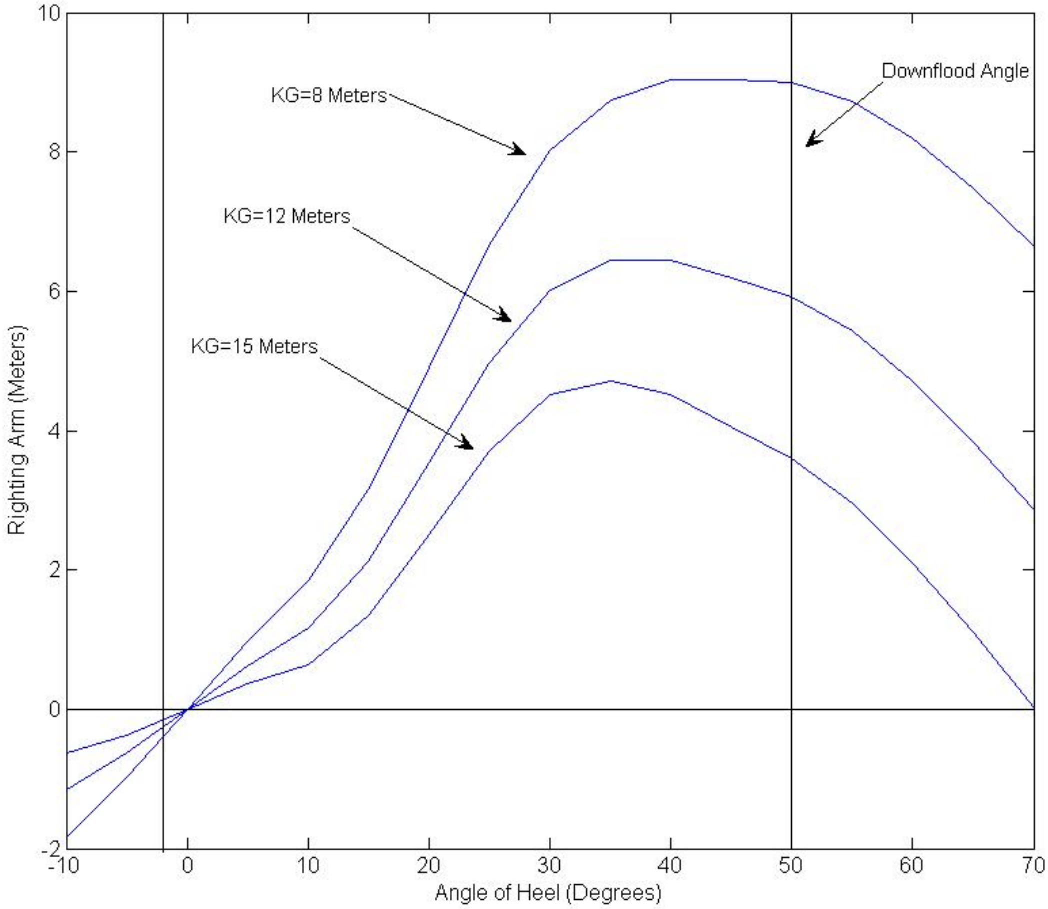

Figure 12: GZ Curve for Trimaran Concept

The Righting Arm (GZ) curve seen above reinforces the excellent intact stability of the ship, even with a high KG value. The lowest maximum righting arm value for the range is about 4.6 m at 35 degrees, with the highest occurring at around 9 m for a 42 degree roll. The angle of vanishing stability does not occur until 70 degrees in any of the cases with the assumption of no downflooding, and in the case of the highly stable 8 m KG the angle is extrapolated well past the point where the ship would capsize in a realistic heeling situation. It should be noted that the waterline would reach the intakes at a downflooding angle of 50 degrees, and the GZ curve past this point is inaccurate for any realistic heeling situation. However, a 50 degree angle is an acceptable one for the purposes of this concept, and is not seen as a detriment to the overall stability characteristics of the trimaran.

All of the stability numbers provided by the hydrostatics analysis point to the trimaran concept having excellent intact stability in almost all loading conditions. While a complete and detailed analysis of the KG was not completed for this level of the concept design, the design team was satisfied that this concept has excellent stability through a large range of KG values.

5.2. Damaged Stability

Originally the design team had hoped to complete a damaged stability analysis using Hydromax, a commercial software tool designed for damaged stability calculations. However, because of technical difficulties, the team decided to approach the problem using Rhino Marine to perform a basic floodable length calculation using a lost buoyancy method, rather than a full computer analysis.

The trimaran concept was broken into three separate damaged conditions: a forward damaged condition, a midships damaged condition, and an aft damaged condition. As per DDS 079-1 section 2.5.3.3.4.1.1 part c, the ship falls under Category 1-Combatant Types and Personnel Carriers such as Hospital Ships and Troop Transports. This criterion dictates that the ship should be able to withstand an opening in the hull up to 0.15 of the LBP at any given point along the ships length, 27.15 m for the trimaran concept. The bulkhead spacing for the ship is 18 m, with a 9.6 m collision bulkhead in front and a 9.4 m collision bulkhead in the stern. Therefore, the damaged conditions were assumed to be the following: flooding of the forward two compartments, three midships compartments, and the two aft compartments. These conditions were based on a collision forward or aft that would compromise 27.15 m of length and two compartments, or a shell opening midships of 27.15 m that would span a single compartment and two bulkheads, and therefore flood three watertight compartments.

A model of the ship was created for each of these conditions, with the flooded compartments removed completely from the ship (Figures 13, 14, and 15).

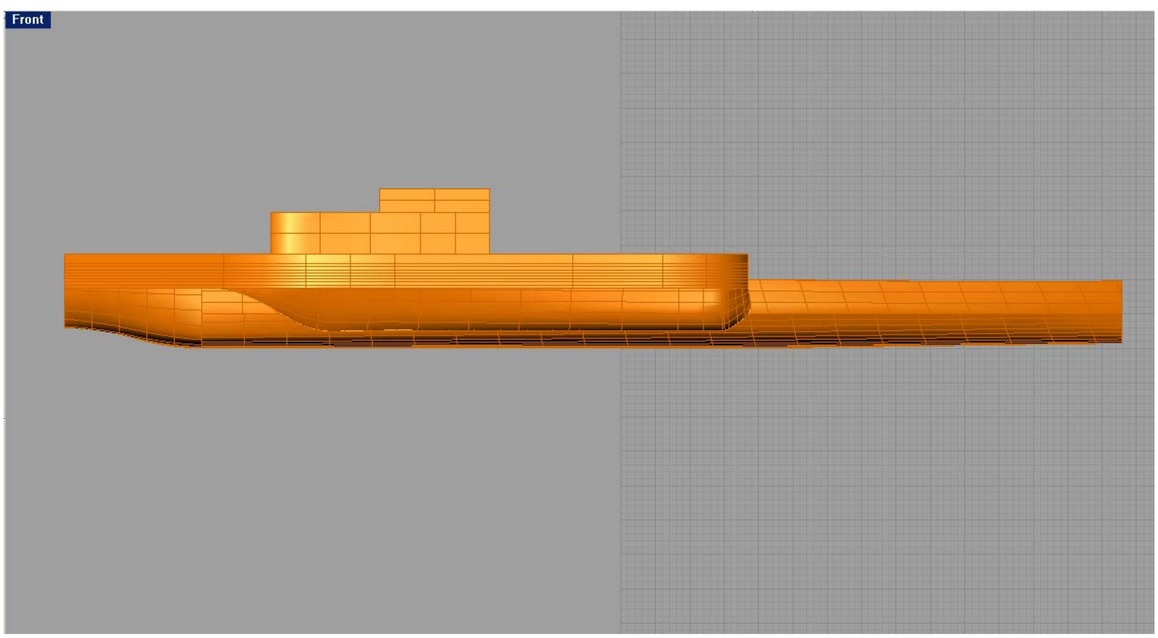

Figure 13: Trimaran Damaged Stability Forward Condition

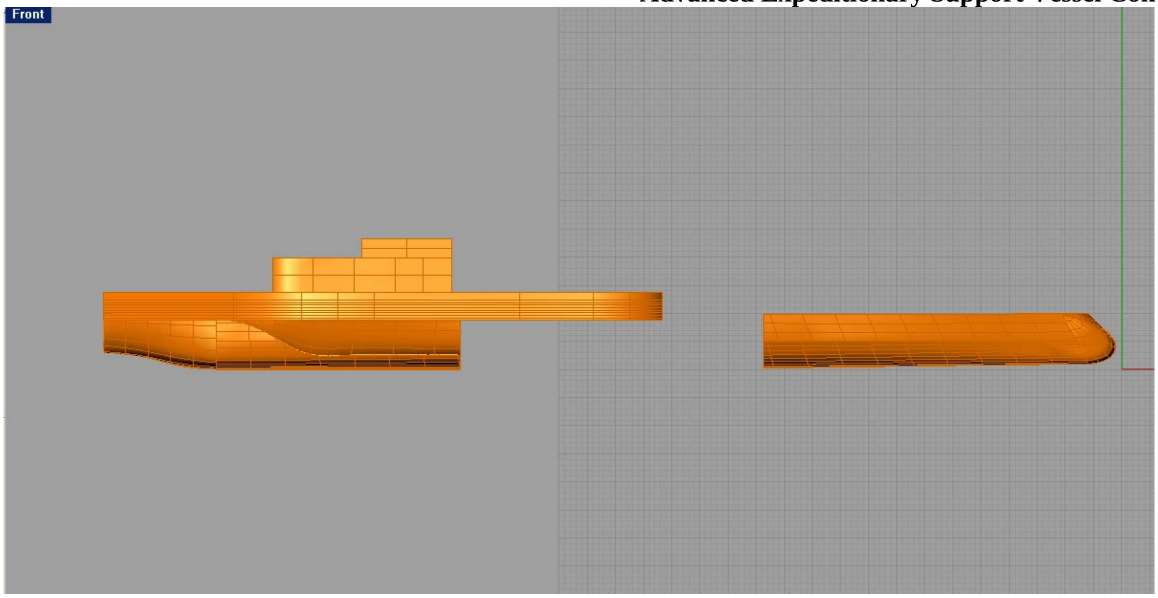

Figure 14: Trimaran Damaged Stability Midships Condition

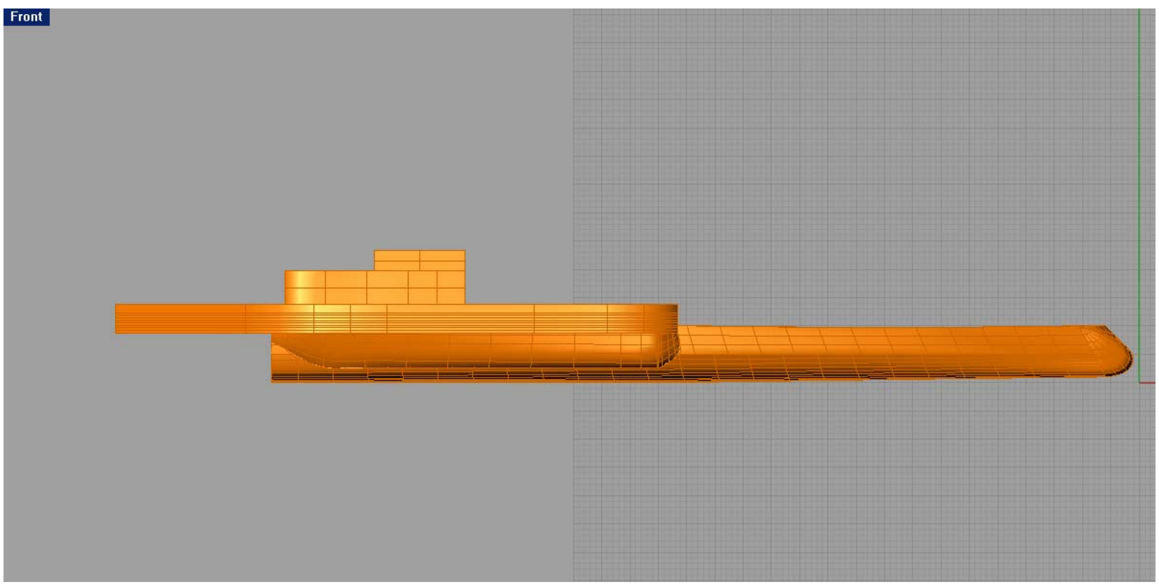

Figure 15: Trimaran Damaged Stability Aft Condition

A hydrostatics analysis was completed for each of these conditions, with the waterplane trimmed to match the LCB and displacement of the intact ship. This process allowed for the assumption that the LCB will not change for very small angles of trim, as compared to a computer damaged stability analysis where ship would be trimmed until the LCB and LCG were at the same horizontal location. Table 10 shows the data compiled for each of the damaged conditions of the ship.

Table 10: Damaged Stability Data for Three Damage Conditions

Condition	Displacement	Trim Angle	Forward Draft(m)	Aft Draft(m)	LCB(m)
Intact	10,700	0	4.5	4.5	-101.4
15% LBP Forward	10,700	0.65	5.9	3.9	-101.9
15% LBP Midships	10,700	0.5	7.3	5.7	-101.6
15% LBP Aft	10,700	-1.5	2.7	7.4	-101.3

As can be seen, the trim angles never exceed 1.5 degrees. The most important pieces of information to note in the table are the values for the forward and aft drafts. The goal was to keep the damaged waterline below the Ro-Ro deck, given that the deck is sealed with sliding watertight doors that run the risk of failing. However, this ideal was extremely difficult to achieve with a 4.5 m draft, and ultimately the waterline for the worst damage cases is above the 5 m height of the Ro-Ro deck. The midships condition is the most drastic of the three, with high drafts both forward and aft, though it should be well noted that the ship has a 10 m depth and therefore still possesses 2.7 m of additional freeboard. The aft condition shows a very high aft draft, as would be expected, but again still demonstrates adequate freeboard in a flooded condition. None of the flooding cases show a situation where the ship would face the risk of downflooding because of green seas on deck or a dramatic loss in displacement that would cause the ship to sink.

For this stage of the concept, all of the damaged cases for the trimaran concept showed that the ship has adequate damaged stability The design team also recognized that in a midships or aft damage case, the upper troop/container deck provides a huge amount of additional buoyancy in the event of a opening in the main hull structure. The team was ultimately satisfied that both the intact and damaged stability of this concept were acceptable, and that the design was feasible from a stability standpoint. A full DDS 079-1 analysis should be completed before a second design iteration is started.

6. Research Ship to shore Connectors

Though the trimaran is a robust ship by itself, it requires some sort of ship-to-shore connector to complete its directive to land troops, cargo, and vehicles to the beachhead from the seabase. The next section of the paper covers the research and concept studies that were undertaken to find a connector that would fulfill the mission and shipboard requirements.

6.1. Current types

LCAC

The Navy currently uses the Landing Craft Air-Cushion (LCAC) as one of the most effective amphibious vehicles. The ability of this vehicle to move across deep and shallow water, traverse the surf, and travel up and over the beach make it a good option for an AEV offload vehicle. The greatest advantage of this craft is that it can carry heavy payloads at speeds exceeding 40 knots. This vehicle, through the use of bow and stern ramps, is capable of carrying 60 tons of Ro-Ro cargo. Therefore, all MEB equipment is capable of being carried aboard the LCAC, however only a single M1A1 Abrams Tank can be carried at one time. Since the MEB has a total of 14 M1A1 tanks as well as some other large and heavy items to bring ashore, the feasibility of using the LCAC to offload a logistics ship is less promising.

The LCAC is certainly capable of offloading all of the MEB equipment but the time frame that is necessary to perform it in is simply not available. The offload is best performed if done under the cover of darkness, allowing approximately an eight hour window to offload. Assuming travel times, loading and unloading times, and a clear path to the debarkation area, a few LCACs alone cannot get the job done. An alternative to reduce time is to have as many LCACs as possible. This requires significant space for the craft including a well deck on the AEV or at the seabase for loading or when not in use. Also a large number of LCACs significantly increases the maintenance, manpower, fuel, and cost necessary to offload the AEV.

LCU

The Landing Craft Utility (LCU) is another option for vessel offload that carries a large payload at slower speeds. The LCU is capable of carrying 180 tons of personnel and equipment at speeds of 11 knots and given enough water can deliver its cargo directly to the beach. The LCU relies on a bow loaded open deck that can accommodate up to three M1A1 tanks and as many as 400 marines with their combat gear. The cargo size and payload limitation is an improvement over current high speed craft like the LCAC, but the slower LCU spends a long time traveling from seabase to shore. Additionally the vessel must either be sailed from CONUS to the seabase or carried in a well deck. The AEV is not intended to have a well deck and therefore the LCU will not have a berth inside the AEV. Thus, the LCU represents a higher capacity but space intensive craft.

Helicopters

Helicopters are a versatile aircraft that can and have been used for the transport of equipment and personnel from ship-to-ship and from ship-to-shore. These aircraft are especially useful since they can be configured to transport personnel and equipment, and travel much faster than any of the current landing craft. One of the mission requirements for the AEV already requires the use of two medium size helicopters, so the availability of helicopters is ensured. The two helicopters for the AEV have been chosen to be CH-53Es, which have high volume and payload capabilities. The 16-ton payload allows for the lighter MEB vehicles and equipment to be carried as well as containerized supplies. The seating capacity can accommodate around 40 people, but can be increased with adaptable seating arrangements.

Helicopters provide high flexibility in the movement of equipment, yet their operational requirements, maintenance, and complexity are a disadvantage for the MEB force. The amount of ship movement due to seas is a concern in high sea states since landing the helicopters becomes more difficult. Overall, the rate of transfer of personnel and material is not very effective with helicopters since landing is necessary for both the loading and the unloading of personnel and equipment and transfer time is slowed down.

Hover Barges

One method of equipment transportation over land and sea is the hover barge concept, which acts as a non self-propelled air cushion. These barges are similar to the LCAC in that lift fans create an air cushion on which the vehicle rides. The barges can take loads up to a few hundred tons and do not carry their own propulsion plants. These barges are towed around by other vehicles and require external sources to position them. They are relatively simple since the propulsion system is from an external vehicle, but they are large and will require a large space aboard ship if used. If used, these barges will require a large space aboard ship to store them and the relevant equipment and workshops to maintain them.

100% Amphibious equipment

Another method to ensure that all MEB equipment is delivered to shore is the inception of a completely amphibious MEB force. This task requires that all MEB vehicles travel across water from the ship to the shore, go up the beach, and then continue with their objectives. While some of the MEB vehicles, such as the AAAV and the LAV, are amphibious and can achieve this task, there are many more vehicles that are not capable of making it from ship to shore under their own power. By requiring a 100 percent amphibious MEB vehicle force, significant redesign has to be realized and implemented, which is outside the scope of this study. A primary concern is maintaining the current capabilities of the MEB while at the same time ensuring that vehicles can travel to shore in sea state 4. This option is certain to be expensive and poses its own set of problems.

In addition to redesigning the vehicles to make it ashore under their own power, the personnel and supplies must be offloaded from the ship as well. This requires that new vehicles be added to the MEB that can transport people and supplies directly to shore. Containers, fuel and water tanks, and generators are among some of the materials that must make it to the beach and currently no amphibious MEB vehicles can do this. As a result, this method of performing beach offload is not yet the most practical or safest option.

Structures

In addition to the ship-to-shore vehicles that are in place currently, there are several structures that aid in the offloading of equipment to shore. These structures perform one task that is vital in logistical offload; they bridge the gap between ships, that are either grounded or at their minimum operational depth, and the shoreline. Depending on the ship's distance from the shoreline, a ship may employ only a ramp or it could rely on a causeway system. Either method of depositing equipment and personnel ashore is acceptable, since everything can be unloaded from the same location all in one go. These types of offloads have the advantage of being considerably less time consuming, provided the initial deployment of the structure is quick.

Ramps

For ships that have shallow drafts and are able to nearly reach the shoreline, ramps are a viable option for unloading any Ro-Ro equipment, whether self-propelled or via some equipment moving vehicle. Current ramps used on large Ro-Ro ships like the LMSR are folding and articulate left and right. These ramps are heavy duty and allow even the heaviest tanks to roll into or out of the ship. A similar style of ramp would be advantageous in the AEV concept. By combining a folding or telescoping ramp with bow doors, the Ro-Ro cargo in the AEV could be unloaded rapidly. The usefulness of an unloading ramp is characterized by the depth at which it can be deployed and the depth of water that the MEB vehicles can ford on their way to shore. If the AEV can move to a shallow enough area and the vehicles can drive off a ramp onto the bottom, then the ramp is very useful.

A concern with any ship ramp is the weight and strength of the structure. The loads that the ramp must deal with for an AEV loading condition include the 60-ton M1A1 Abrams tank; however, the ramp should stay as light and simple as possible. The heavier the ramps become, the more reinforcement necessary in the hinging and the retraction mechanisms. Current ramps on the LMSRs weigh on the order of 100 tons and to incorporate such a ramp into the bow of the AEV would require losing valuable space at the front of a Ro-Ro deck. An improvement could include the use of a composite in the structure or the deck of the ramp. This reduction in weight could ease the size of supporting machinery that would fold or deploy the ramp.

Causeways

Where bow ramps begin to lose their effectiveness based on water depth and the vehicle's inability to ford the remaining water to shore, causeways begin to come into their own. These floating sections are modular and can be securely connected to one another to create bridges from the ship to the shoreline. A key characteristic of these causeways is that no matter how far the distance is to shore, as long as a sufficient number of modular sections are available the bridge can be connected from ship to shoreline.

These causeways allow quick unloading of vehicles in calm seas. When the weather is worse, the causeways continue to work but become much more limited in the number of vehicles that they can safely support. Above Sea State 3 the causeways are no longer effective and the offload must stop. Current designs are steel barges that weigh nearly 90 tons and are connected from end to end as well as from the sides. The causeways also require a warping tug to position and help hold the modular sections inline during assembly of the causeway and when strong currents are present. The greatest issue is that the causeways must be stowed and their size and weight do not make this an easy task. Aside from the ability to stow the modules and their difficulty in maintaining a high sea state operation, these causeways provide a rapid and effective way for vehicles and personnel to offload.

Beaching

Getting equipment ashore from a large ship is a task that usually requires established port facilities with deep water to accommodate the ship's draft. However, this sort of facility is not readily available on a beachhead and ships may have to rely on smaller watercraft or bridging structures to get equipment past their minimum operational depth. An alternative to this is to beach the logistics ship. Beaching the vessel provides a fairly stable and stationary point from which to disembark equipment. The smaller the draft of the vessel the closer to shore the disembarkation point will be and presumably the easier the offload. Using the assumed fifty to one beach gradient, a beaching vessel with a draft of three meters or less at the bow (and has a rake shallower than the beach gradient) can place the bow 150 m or closer to the beach. Then ramps and causeways can be used at shorter distances than normal.

If the vessel beaches then a dynamic positioning system of thrusters or vectored thrust should be in place to maintain a steady position. The vessel must be robust enough in the bow to withstand the abrasion of sand and rocks, and the entire hull must be able to withstand the other incurred loads. Bow doors opening to the Ro-Ro deck will be standard for driving vehicles out of the end closest to shore. To make beaching feasible, the ship will have to be able to release itself from the shoreline. Large suction forces will be encountered and depending on the reversing capabilities of the AEV, new technology may be necessary to provide some sort of lubrication to the portion of the hull that is in contact with the sand or mud of the shore. This system could include a releasing agent, water pumped through openings in the hull, or using compressed air.

Dredging

When approaching shallow waters, the AEV will be forced to maintain a safe water depth unless it has been designed to beach and environmental factors allow it to do so. However, if the AEV requires a deeper draft, an option for reaching the shoreline is using a high capacity dredger to carve out a dock for the vessel to pull into. This will allow the vessel to unload from three sides and maintain its position with minimal power usage. The loading/unloading capabilities of the ship will be maximized in this configuration, but the use of another vessel, the dredger, will be required.

The highest capacity commercial dredgers can remove approximately 30,000 m^3 of bottom per hour. Given enough time, an area to offload directly from the ship could be created in the beach. Although this is a large time investment at first, the time made up by having a direct offload to the beach could be advantageous. A large assumption is that such a vessel would be available to the U.S. Navy in the deployment time of the MEB and the AEV. Also the dredger would have no other purpose than to wait at the seabase and dredge when needed, and would not be useful on a very rocky beach. The manpower needed, time wasted, and fuel usage would most likely remove this option as effective for the AEV mission requirements.

6.2. Evaluation of Current Connectors

The current connectors, while fully operational, have left room for improvement. Helicopters, for example, can operate in a variety of conditions from almost anywhere, but they can only carry small payloads, and are very maintenance intensive. The current causeways are bulky and require a lot of effort to set up and dismantle, but provide a stable and reliable position to load and offload cargo and equipment form ships. In general, the current methods cannot move enough material (helicopters and LCACs), or are very slow (causeways and LCUs). A method is needed that combines the ability to land large amounts of cargo quickly and efficiently.

7. Concept Generation of Ship to Shore Connectors

7.1. List of Concepts

7.1.1. Causeway Concepts

Several potential causeway systems have been considered for the task of delivering the MEB equipment to shore. These offload designs have been favored since they allow the AEV to beach in relatively shallow water yet do not require it to travel all the way to the shoreline. The primary consideration that has been made for these designs is that the AEV is able to beach and has reached a depth of 3.5-4 m. Using the 1:50 beach gradient this places the bow and the front of the Ro/Ro deck 125-150 m away from the shoreline.

7.1.1.1. Inflatable Causeway: 1

The first inflatable causeway concept was based on the idea that the sea floor would present the most stable platform for a heavy vehicle transfer. The concept begins with two large inflatable parallel tubes that rest on the ocean surface. These tubes would be on the order of 4-6 m in diameter, and would be connected with inflatable air-beam arches. Between the tubes there would be a strip of composite decking strips that would roll out into a ramp, which would be connected to the tubes via a tough material membrane such as Kevlar.

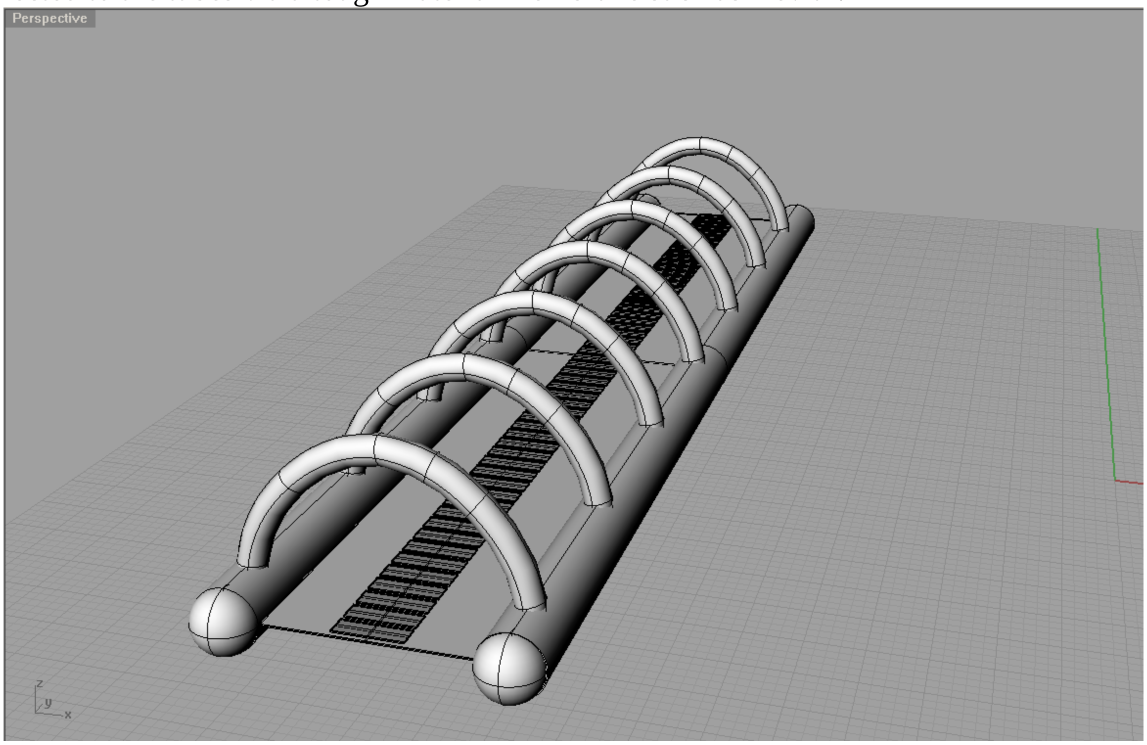

Figure 16: The Inflatable Causeway Concept 1 deployed on sea surface with no vehicles

When the entire structure rolled out from the ship, the side and arch connector tubes would be inflated, leaving the decking floating in the middle until a vehicle rolled onto the composite decking. At this point, the vehicle would sink to the bottom and drive along the decking strips that are now resting on the sea floor. This action would pull the tubes together, and the hydrostatic pressure would keep the sidewalls taut.

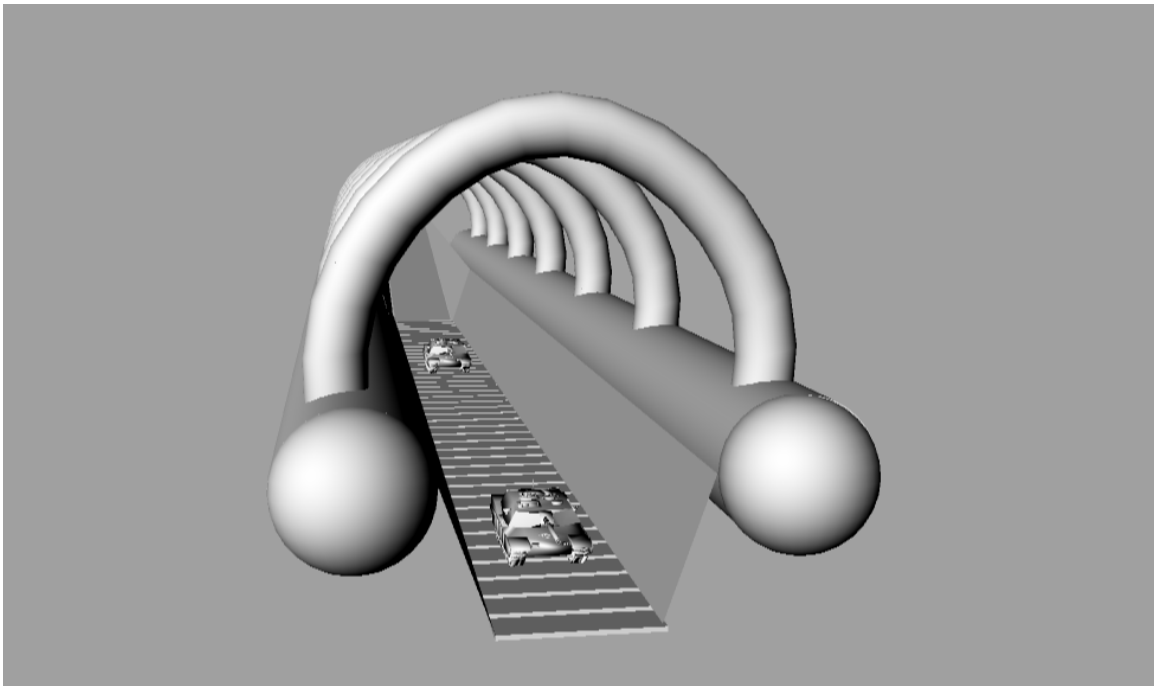

Figure 17: The Inflatable Causeway Concept 1 deployed on the sea floor

The major advantage for this type of causeway is the use of natural seabed to provide support for the vehicle weight, rather than the inflatable tubes themselves having to provide all of the support and stability. However, the challenges associated with this concept are numerous. Air-beam technology is advancing quickly enough to make this sort of structure a reality, but some engineering would have to go into creating tubes this large as well as a material fabric tough enough to support the deck structure. The decking structure itself would resemble composite grating available commercially today, but would again have to be a redesign from the products currently on the market. One of the main liabilities of this design is convincing the average Marine Corps tank driver to travel over 100 m to shore while 4 m below the water's surface, with the ever looming risk of puncturing the material "walls" of the ramp; proper material selection could eliminate much of this risk, but there is always the threat of a major accident introducing a tear that could quickly compromise the safety of the ramp. These issues, while challenging, do not depend on any new or expensive technology to fix, which makes this concept a distinct possibility for the future.

7.1.1.2. Inflatable Causeway: 2

This concept branched from the original bottom-resting inflatable causeway, with the intention for vehicles to move along the surface of the water rather than the sea floor. It utilizes the same horizontal inflatable beams, as well as the air beam arches, but includes a series of inflatable support columns to support the membrane and decking material on the surface.

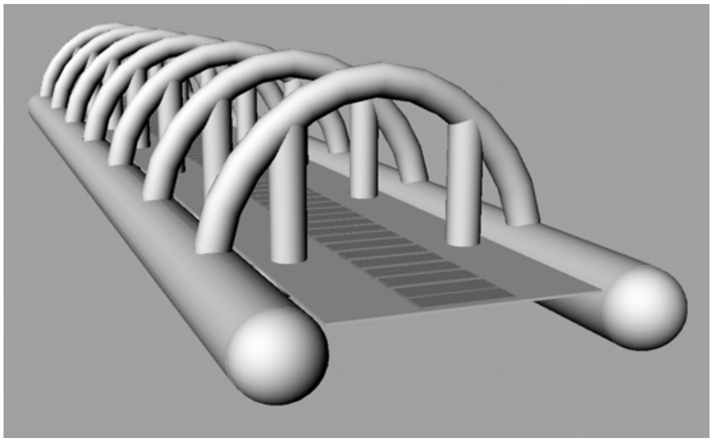

Figure 18: Inflatable Concept 2

This concept was only briefly explored and considered, as the challenges associated with supporting a flexible membrane with up to 70 tons moving across it are numerous. The first inflatable concept had the benefit of a solid surface, the sea floor, for the decking and vehicles to drive across; this concept relies of the support of the airbeam columns and hydrostatic pressure of the water to hold the vehicles. Ultimately this concept would have required a large commitment of research and development to determine whether or not it was even feasible for the airbeam structures and membranes to support such large loads on a variable surface like the ocean.

7.1.1.3. Elevated Causeway Concept

The second inflatable causeway concept is combination of a set of inflated pontoons that support a folding composite deck structure (Figure 19). This concept involves a causeway deck that folds about a longitudinal axis and can be locked in the folded or unfolded position. When unfolded, the two main pontoons are to be filled by an air compressor and support the deck above with tubes that are positioned vertically on top of the pontoons. The main tubes are prevented from moving inwards or outwards by three inflated arches that arc up to the bottom of the deck. The main pontoons displace more then one hundred tons at two meters of draft and are 17 m long by 8.5 m wide. This displacement is nearly twice the weight of the heaviest vehicle in the MEB payload.

The causeway is designed to be modular so that as many modules as necessary can be connected in series to reach the shoreline. The last module will contain a ramp to allow vehicles to roll onto the sand. To prevent motion created in the long chain of modules these decks can be secured side by side to counter the bending from cross currents or beam waves. The primary concerns to make sure that this design is feasible include the strength of the deck structure to support the weight and its connection to other modules. The stability also needs to be addressed, as the modules may react poorly to waves in sea state 4 and vehicles or personnel may be unable to use the causeway.

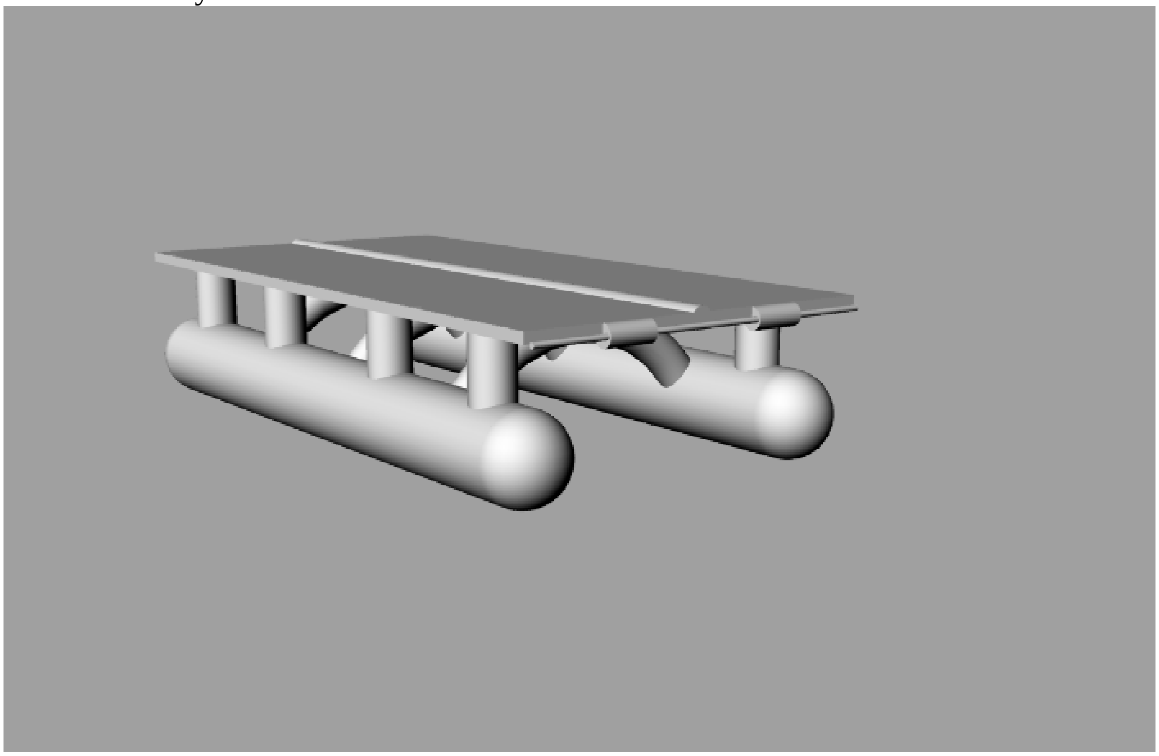

Figure 19: Elevated Causeway Concept

7.1.1.4. Lightweight Modular Causeway System (LMCS)

Another inflatable causeway concept is the Lightweight Modular Causeway System currently under research and development by the U.S. Army and the Coastal Hydraulics Laboratory. This causeway system, shown in Figure 20, is a series of hinging deck structures connected to one another by pins and supported by inflatable tubes. Each deck section is 25 feet wide by 10 feet long with two inflatable pontoons attached to grooves beneath the deck. These grooves allow the inflatable tubes to store flush when deflated. A total of 15 deck structures are connected in series to create 150 foot causeway modules. The LMCS modules are designed to support the weight of the heaviest MEB payload item: the M1A1 Abrams tank. When the module is inflated, the causeway's rigidity is maintained with tension straps running lengthwise below the tubes. These straps pretension the structure and counter the bowing effect produced by the inflated tubes.

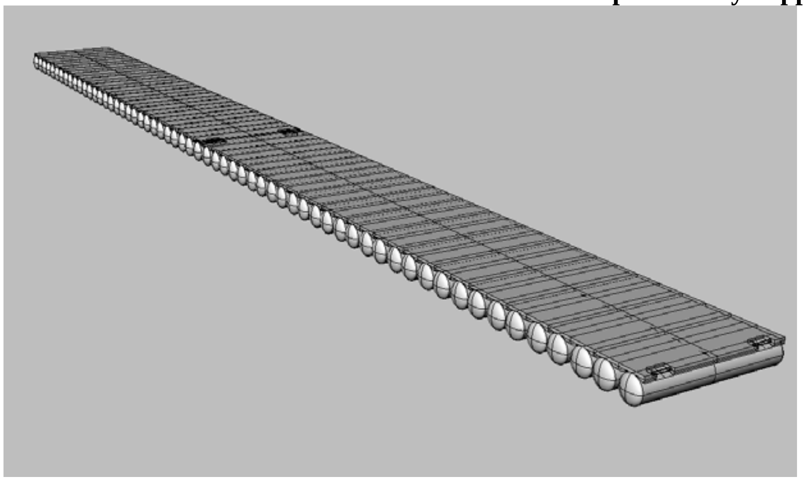

Figure 20: Lightweight Modular Causeway System

The characteristic design feature of this concept is its compact storage and reduced weight. The individual decks are hinged at each end so the modules can be folded along a transverse axis. Figure 21 shows the LMCS in both the deployed and partially folded stages as described in the "ETA: Rapid Port Enhancement." presentation[10]. The 150-foot modules can be split in two, and the remaining decks are folded up into a volume that is 23% of the storage volume of current causeways.

Figure 21: Lightweight Modular Causeway System

7.1.2. Other Connectors

7.1.2.1. Composite Ramps

The most central piece of equipment used to move Ro-Ro cargo aboard is clearly the Ro-Ro ramps. These large steel structures are designed to support large loads and be deployed and retracted many times in their operational lifetime. Due to the extreme loads and complex mechanisms used to fulfill their operating ranges, these ramps are very heavy. By incorporating composite materials and manufacturing, it would be possible to create lighter and potentially more durable ramps. The ability for these ramps to have longer design lengths would be useful to get equipment ashore especially in very shallow beach gradients. A potential concept is to use longer lighter ramps that can be folded and stowed aboard without taking up as much space as current designs.

7.1.2.2. Balloon Assisted Cable Designs

A potential design that has not been fully explored is the combination of cable line systems and balloons. The transport of equipment is based on a zip-line system in which an elevation change in the ends of the support cables allows equipment to slide towards the lower end. This system uses balloons to provide an elevation change and to lift the equipment being transported. This concept would require quite a bit of planning since wind velocities must be accounted for and rough weather could potentially be difficult to deal with. At the very least the equipment is deployable in high sea states as long as the AEV is relatively stationary. Returning equipment aboard would require the system to be set up in reverse and is thus not very effective, since whatever mechanism launches the balloons would have to be brought to shore and then be retrieved.

7.1.2.3. Cable Bridge

Another system that transports equipment and personnel above the surf is the cable bridge concept. This system allows troops and equipment to be transported across a suspension bridge that is deployed from the ship. Large diameter cables would be sent to shore and tensioned using a cannon. The tension would be provided on the ship end by winches or a similar device. The bridge structure would then need to be deployed and would hang from the cables. This design would be difficult to deploy in the dark without creating unsafe conditions. The storage of the cable aboard when not in use would not be a large concern; however, the bridge material storage would require more space.

7.1.3. Vehicles

To get supplies to the shore from the ship, there needs to be in place a system that can perform this task in sea state 4. One such system considered was a type of vehicle that could be loaded with the necessary materials and be moved from the ship to the shore. There are many types of transportation that could be used for such an endeavor.

7.1.3.1. Expeditionary Fighting Vehicle

One vehicle design considered was based on the United States Marine Corps's (USMC) new expeditionary fighting vehicle (EFV). The EFV is a troop carrier that can travel across stretches of ocean and across beaches and land under its own power. Using an EFV based vehicle as a cargo carrier would eliminate any need for the ship to beach. However, the effort of turning the EFV from a small time troop transport/offensive vehicle into a major cargo carrier would be outside the scope of this project and a study for a future design team to explore.

7.1.3.2. Amphibious Forklift

More synergetic with the idea of a beaching vessel is the concept of an amphibious forklift. The forklift would have to be large to withstand the pressures of the surf beating it as it operates and to handle the loads that it would be required to carry. In the assumptions that the beach gradient is fifty to one, and the ship will have a three meter draft at the bow, the forklift would be required to operate in waters up to three meters deep one-hundred fifty meters from shore in sea state 4. The forklift would need to be very large and very robust, and the speed at which the forklift could operate would most likely be heavily restricted by its operating environment. Creating a method in which the forklift could transport large objects such as an M1A1 Abrams tank would also be an incredibly difficult for such a vehicle. An amphibious forklift would be a useful tool in the field, though trying to use one as the only option for loading and unloading a ship is not considered practical.

7.1.3.3. Detachable Hull

An innovative but complicated concept is one in which a portion of the vessel actually detaches from the main vessel and sails to shore under its own power. The ship as a whole can than have a large draft needed for carrying large cargos from CONUS to the seabase, and still have a portion of the ship that can have a very shallow draft to beach and unload the cargo at the shoreline. All problems of designing an ocean capable craft that can also beach are solved. Unfortunately, having a ship that can detach a portion of the hull, yet still have both of its sections remain seaworthy, and reform again in sea states presents additional concerns that would have to be addressed. Both parts of the ship would need its own crew, powering systems, and fuel supply. A mechanism that can hold the two hulls together during travel and release near the shore and reattach would have to be designed before the ship could be considered as an option.

7.1.3.4. Glider

Using a rocket-powered glider to lift the cargo into the air close to shore and let it glide as far as it needs to in shore would be a fast, convenient option for transportation. The wind would be a much greater factor in this design than in any other, since after the lift of the rocket the glider would not be powered and would at most have movable vanes to help guide it to the right place. Securing a safe and relatively soft landing for any piece of equipment, or personnel would be of utmost consideration in any rocket glider designs of the future. Creating a cheap rocket to lift the payload into the air would also be desirable, and one would also need to take into account any damage the gliders would take from enemy fire. Even though this vessel is not required to work in a contested beachhead, the occasional burst of enemy weaponry would have to be assumed in any war zone. The subsequent loss of any men or material after the glider was too damaged to land safely would need to be considered before employing such means as the main conveyance of materials to the shoreline.

7.2. Discussion of Advantages and Disadvantages

The causeway was selected as the ship-to-shore connector for numerous reasons. The trimaran concept does not fully beach, so designing a ramp for a span 150+ m would have been both impractical and space prohibitive. All of the vehicle connectors currently in use require a well-deck to transport them across blue-water areas; a well-deck would require a complete redesign and would also inhibit the Ro-Ro capability of the trimaran design. All of the other ideas, including cables bridges, fully amphibious vehicles, gliders, and detachable hulls, require technology that is currently in development and outside the scope of this project.

For the trimaran concept, the causeway was seen as the most effective manner to move passengers, cargo, and vehicles from a position 225 m offshore without the use of auxiliary vehicles, excessive ramps, or undeveloped technology.

7.3. Calculations and Evaluation of Concept

With the focus on ship-to-shore connectors narrowed down to causeways, a weighted decision matrix was used to evaluate which causeway had the most promising characteristics. The weighted matrix was split up into ten criteria to evaluate performance. These criteria are listed in Figure 22 which also shows the weight factors of each criteria and the capability of each causeway to match that criteria. The weight factor was calculated by comparing the criteria to one another, and is shown in Appendix B. The capability for a causeway to perform the required task is ranked using the numbers 1, 3, and 5. The matrix is set up such that larger number shows more capability with respect to criteria.

Weighted Decision Matrix

Criteria	Weight Factor	Solid Existing Causeway	Elevated Inflatable	Surface Inflatable	Bottom Inflatable	Army Surface Inflatable
Durable	0.183	5	3	1	1	3
Storage Factor	0.144	1	3	3	3	5
Stability	0.183	5	1	5	5	3
Dep. Time	0.038	1	3	5	5	3
Tug Assist	0.125	1	3	5	5	3
R&D	0.058	5	1	1	1	3
Ovhd Restrict.	0.048	5	5	1	1	5
Weight	0.106	1	5	3	3	5
Pot. Hazzard (flood, mov't)	0.077	3	3	5	1	5
Extra Equip. (air, crane)	0.038	3	1	3	3	1
	Total	3.118	2.75	3.268	2.96	3.674
	Normalized	0.62	0.55	0.65	0.59	0.73

Figure 22: Weighted Decision Matrix for Inflatable Causeways

7.3.1. Lateral Loading Analysis

A lateral loading analysis of two inflatable causeway concepts was performed to assess the concepts' margin of safety at the highest operational sea state requirement. This analysis was also performed to further validate the inflatable causeways as sufficiently developed designs for the AEV project. The analysis was meant to describe the loads and stresses from cross-currents and beam waves, and was represented using a high cross current velocity of 4 knots. The two evaluated designs were the elevated causeway and the LMCS. Basic assumptions were made to simplify the loading analysis and to provide equal evaluation criteria. The assumptions are listed below.

<u>Assumptions</u>:
1. Laterally loaded causeway modeled as a simply supported beam
2. Uniformly distributed load due to drag force on inflated tubes
3. Tubes fully submerged in 4 knot uniform flow
4. Solid deck structures (calculation of moment of inertia)
5. Tubes in cross flow (Elevate Causeway)
6. Tubes parallel to flow (LMCS)
7. Loading based on drag force of cylinders in flow

The calculation of the loading is based on the drag force acting on cylinders in flow. The assumption of fully submerged tubes is necessary in this calculation to validate the coefficients of drag used as well as simplifying the drag force to a pressure force only, and neglecting any residual drag.

The results of the analysis indicate the LMCS has lower drag forces associated with it since the frontal area is smaller than that of the elevated causeway of an identical length. Since the overall load is smaller for the LMCS, the distributed load and the maximum bending moment are also smaller than the values of the other causeway. Table 11 summarizes the lateral loading analysis.

Table 11: Summary table for lateral loading analysis.

	Bending Moment (kN-m)	**Elevated Causeway**
LMCS	2166.3	1468.9
Elevated Causeway	3791.4	1259.4
LMCS/Elev. Causeway %	57.1	116.6

The bending moment of the LMCS is 57.1% of the other causeway while its deck stress is 116.6% of the elevated causeway. The reason for the larger deck stress in the LMCS is that its deck thickness is 15.24 cm compared to the thicker deck of the other causeway which is 25 cm. A more comprehensive summary of calculated values is located in Appendix B. This appendix also contains the causeway specifications required in the calculation of the lateral loading.

8. Chosen Causeway

8.1. Evolution of Concept

The causeway concept chosen for the AEV is the Lightweight Modular Causeway System. This design has been found to be the most appropriate ship-to-shore connector based on its throughput capabilities as well as its storage and deployment characteristics. With a design weight of less than 60 tons and a payload large enough for the Abrams tank, the LMCS has undergone two stages of scale testing. Deployment of the causeway has also been analyzed and is discussed in a later section of this report.

The first stage of scale testing in the research and development is the 1:12 scale concept demonstration. This concept is shown in Figure 23 from the "ETA: Rapid Port Enhancement" presentation[10]. It models the actual parameters of the proposed design. The hinged joints in between deck structures a well as the inflatable tubes are to scale and fully functional. The scale model also has undergone a scaled payload test of the Abrams tank as shown on the right of the figure below. The proof of concept of the LMCS was performed using a 1:3 scale model of the causeway at the Coastal Hydraulics Laboratory. Both wave and payload testing were performed. The wave testing is shown in Figure 44, of Appendix A and the payload test was performed using a bulldozer to represent the scaled weight of the M1A1 tank.

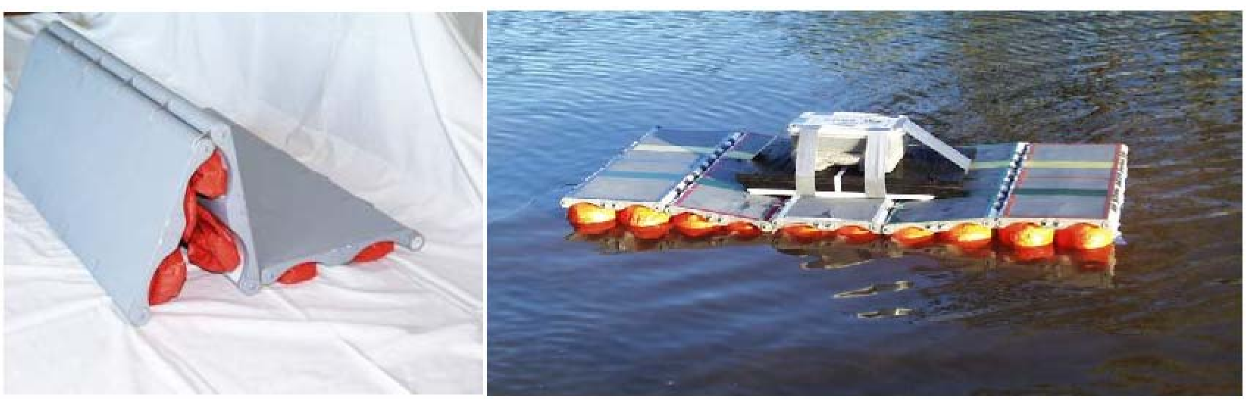

Figure 23: Concept Demonstration of LMCS 1:12 Scale

8.2. Detailed Description

The Lightweight Modular Causeway System represents a new approach to minimizing the issues that affect the functionality of current causeways. Working in conjunction with the AEV trimaran, the LMCS has been incorporated into the ship concept due to its low weight, reduced storage volume, and higher sea state operations. The current iteration of the LMCS is a 150-foot long, partially inflatable module split up into 15 individual deck structures with inflatable tubes attached underneath. In the deflated mode, these deck structures can fold in such a way that the causeway folds like an accordion. When the causeway is inflated, tension straps located around the inflation tubes provide rigidity to the causeway by pre-tensioning the deck and causing it to arch upwards as shown in Figure 23. Some of the principal characteristics for the 150-foot section are listed below:

- Weighs less that 60 tons
- 25 feet wide
- Length split into fifteen 10 foot hinging sections
- Two inflatable tube per 10 foot section
- Capable of being split into two 75 foot sections for storage
- Folded causeway is a 25 x 17 x 10 foot box

8.3. Deployment Concept

8.3.1. Deployment method

With the AEV ship and the causeway concepts determined, the next course of action is to conceptualize the interface between the two concepts. Analysis of the storage and deployment configurations of the LMCS aboard the AEV is critical to ensure the completion of the AEV missions. Considerations in this analysis include: deployed causeway configuration, storage locations, inflation time, unloading/loading in the required sea state range, and additional equipment.

The first consideration in incorporating the LMCS into the AEV missions is to determine the location of the causeway. Since the majority of the MEB cargo is Ro-Ro equipment, it is a good idea to place the LMCS in a location where the vehicles can quickly drive onto the causeway and then to shore. With the causeway at the bow and open bow doors, the equipment can be offloaded to the beach in a direct and efficient manner. Beached in 4 m of water and assuming the 1:50 beach gradient, the AEV requires a causeway length of 200 m. This means that four LMCS modules must be linked in series to reach the shore. The proposed deployed causeway location is displayed in Figure 24.

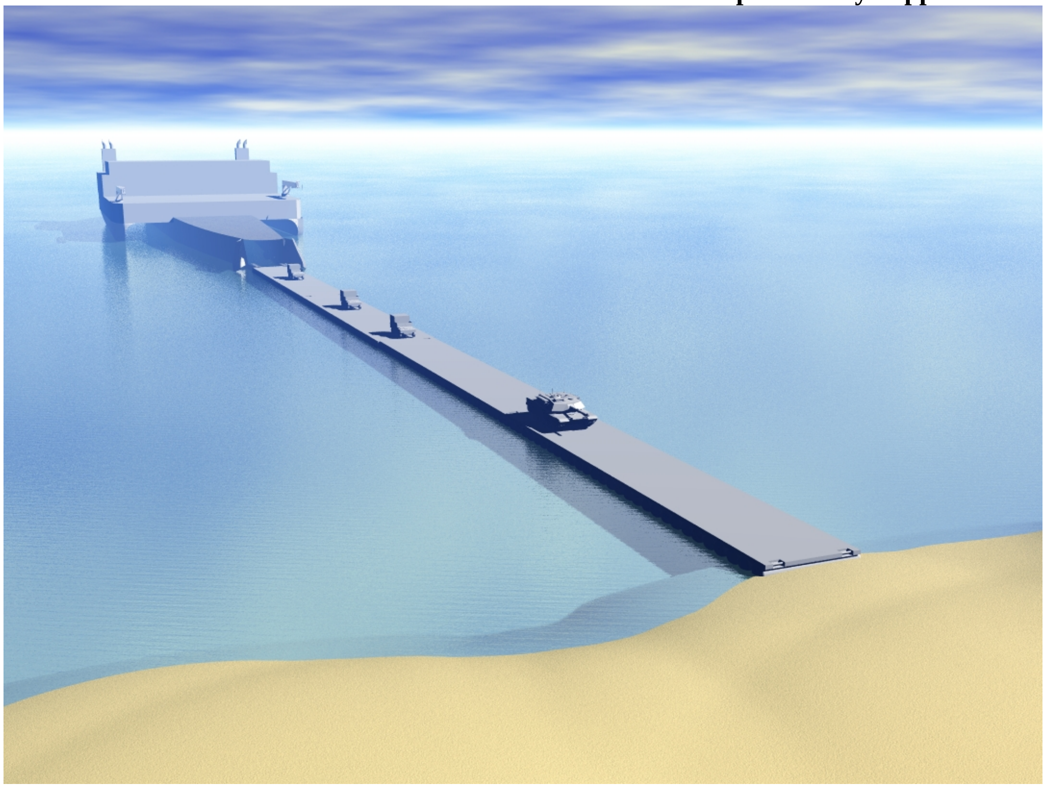

Figure 24: Deployed LMCS Location

As a logistics ship that is not part of the initial assault wave, the AEV is not constrained by the "cover of darkness" time frame. However, time is still a driving factor for the causeway-ship interface, and storage location can affect deployment time significantly. To reduce the amount of time needed to prepare and deploy the LMCS, the causeways will be stored on the deck above the container space. This deck has space for the causeway sections to be stored separately and inflated simultaneously. With an estimated fill time of 3 hours per LMCS section, the inflation process will begin at the sea base or while underway. Once the AEV is beached, the causeways are put over the side with cranes and positioned using RHIBs or other small watercraft. Figure 25 shows the unloading of the LMCS.

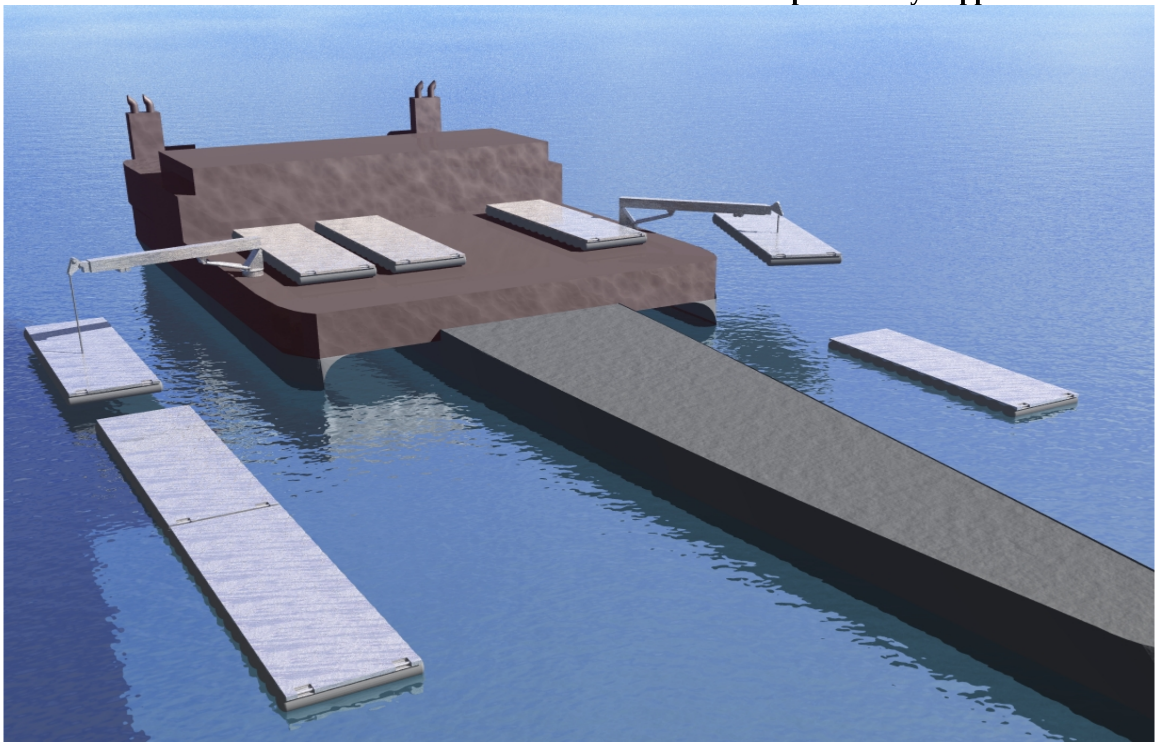

Figure 25: Causeway Unloading

8.3.2. Additional Necessary Equipment

The causeway system is unloaded from the ship using telescoping cranes located on the causeway deck. The offload of the LMCS requires two Techcrane T200 telescoping cranes. Each crane takes care of four 75-foot sections of the LMCS and positions them in the water next to the ship. The cranes are also used to lift containers out of the cargo area and onto the deck. A table describing the loading capabilities of the Techcrane T200 is listed in Appendix B. Once the causeway modules are in the water, watercraft are required to move the sections into place. This task is taken care of by several RHIBs. The additional equipment required for causeway is as follows:

- Two cranes (Techcrane T200)
- Rigid Hull Inflatable Crafts (RHIB) or other similar watercraft
- Personnel (Positioning and securing causeways)

9. Conclusion

9.1. Design Summary

The final AEV design is a trimaran hullform that has the following characteristics and capabilities:

- Overall length and width: 181 m x 48.8 m
- 10,700 MT displacement
- 5,000 nm Range at 24 kts
- 1360 Passenger Seats
- Carries 1/5 of MEB
- 1200 sq m of Cargo/Flex Space
- Operates in SS 4
- Unloads using an inflatable causeway
- Multi-mission capable

Though it cannot move an entire MEB in one trip, the design team feels that the design is a significant improvement over the current ship-to-shore connectors used today. The ship is both robust and flexible in its cargo carrying and beaching capabilities, and fulfills the requirements laid out for it at the beginning of the design process. Figure 26 shows a view of the final trimaran design with causeways stored on deck.

Figure 26: AEV Trimaran Design with causeways on deck

9.2. Future Work Required

There is still much work that needs to be done to turn the AEV from a concept design into a working vessel design.

The causeway technology for the air structures needs to be further developed and tested at the full-scale prototype level, especially to determine whether or not it functions well in a high sea-state marine environment. The interface between the causeway and the AEV needs to be developed and tested to provide a secure crossing point from the vessel to the causeway, and the connectors for the inflatable sections also need to undergo more development for setup and breakdown procedure.

More testing on trimaran designs needs to be completed in order for the AEV hull concept to be properly optimized for hydrodynamics, particularly the sidehull placement and shape and their effect on residual resistance. Currently there are no trimarans similar to the AEV concept being publicly developed, and as such there is no resistance and powering data for a large displacement, low speed trimaran design.

The current vehicle space layouts, while demonstrating that all of the vehicles fit in the space allotted, are not optimized for vehicle loading and unloading. Further work should be done to determine the most favorable vehicle placements for rapid loading and unloading using the causeway system.

Currently the AEV has space for a folding stern ramp to load and unload Ro-Ro cargo, but no ramp has been specifically designed for the ship. Future iterations of the concept would need to include an analysis of the space and weight requirements of the stern ramp for the vessel.

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Appendix A: Detailed Diagrams

Vehicle Layouts

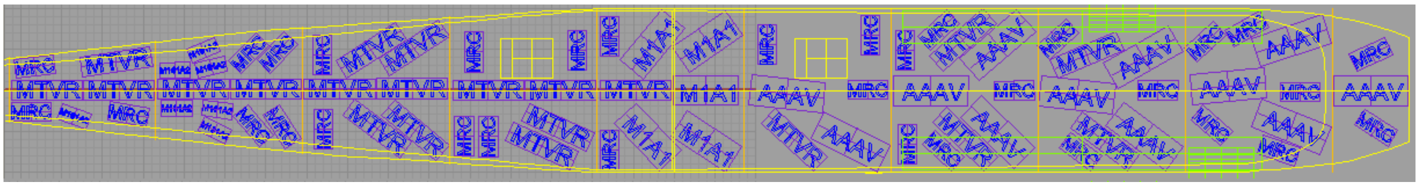


Figure 27: RO-RO Layout #1

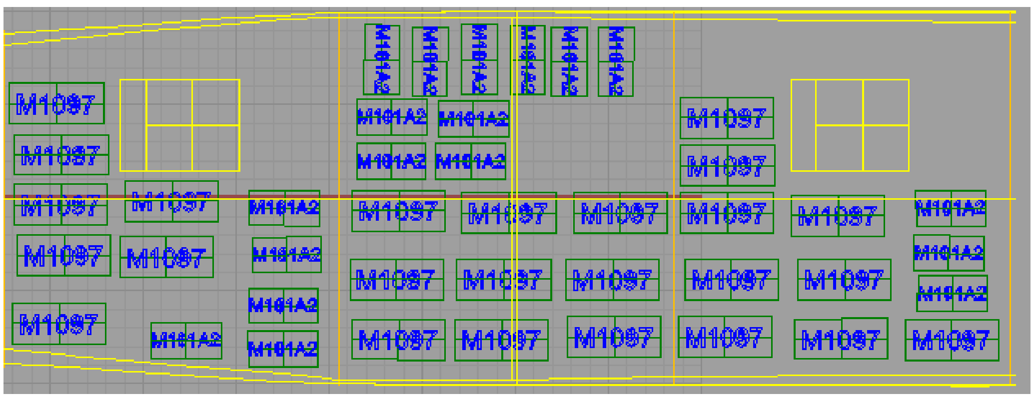


Figure 28: Vehicle Deck Layout #1

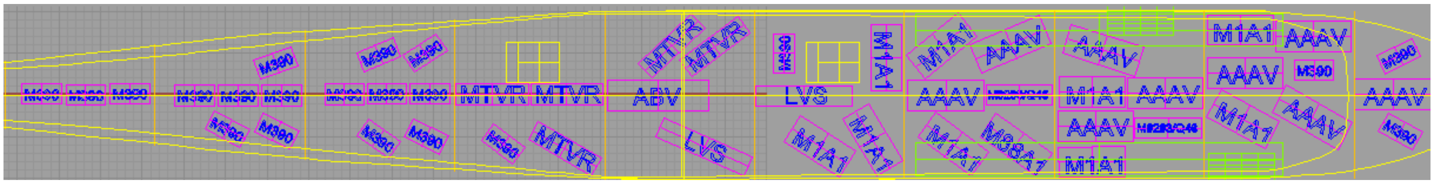


Figure 29: RO-RO Layout #2

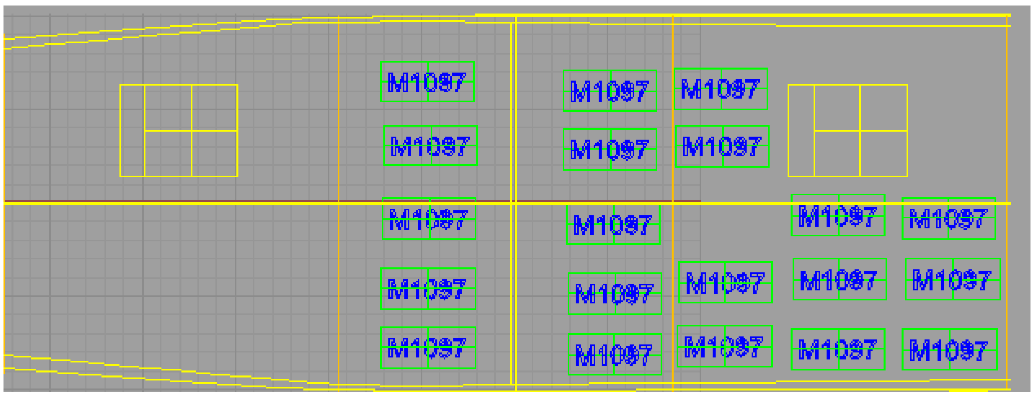


Figure 30: Vehicle Deck Layout #2

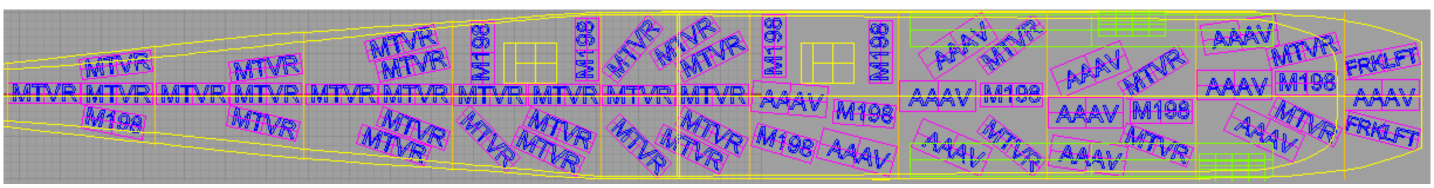


Figure 31: RO-RO Layout #3

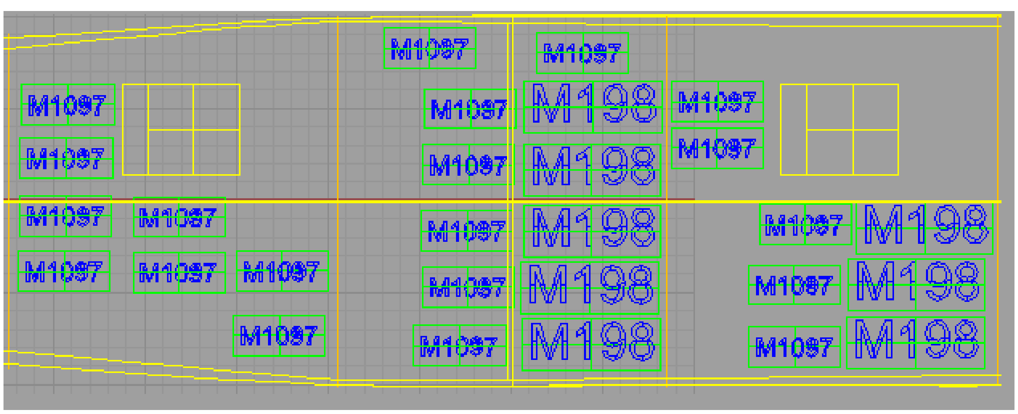


Figure 32: Vehicle Deck Layout #3

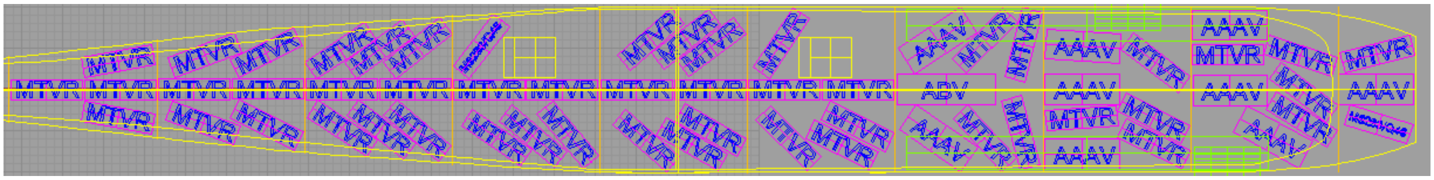


Figure 33: RO-RO Layout #4

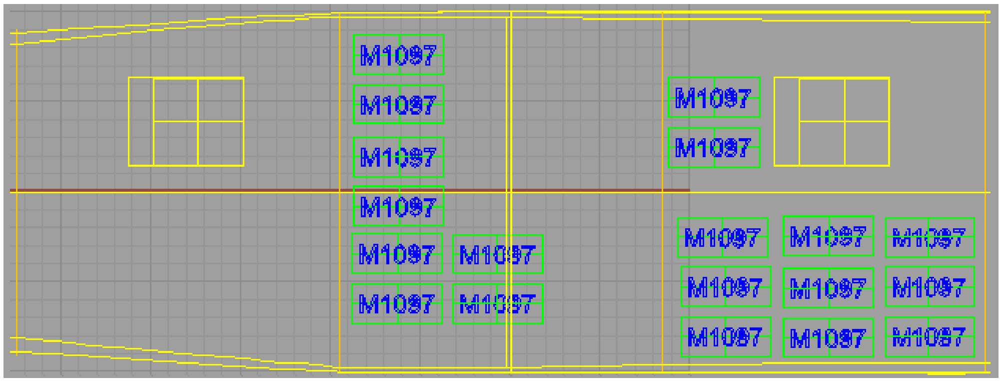


Figure 34: Vehicle Deck Layout #4

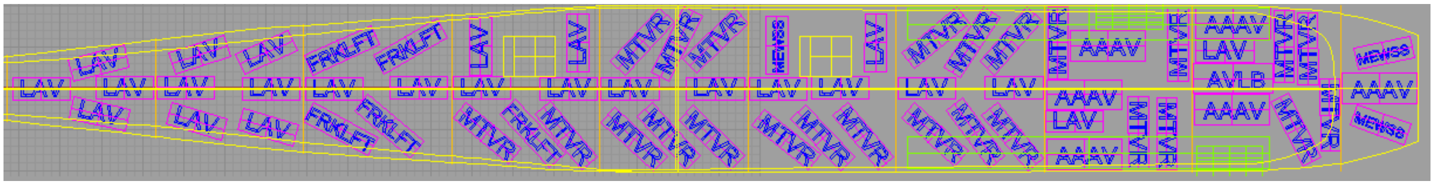


Figure 35: RO-RO Layout #5

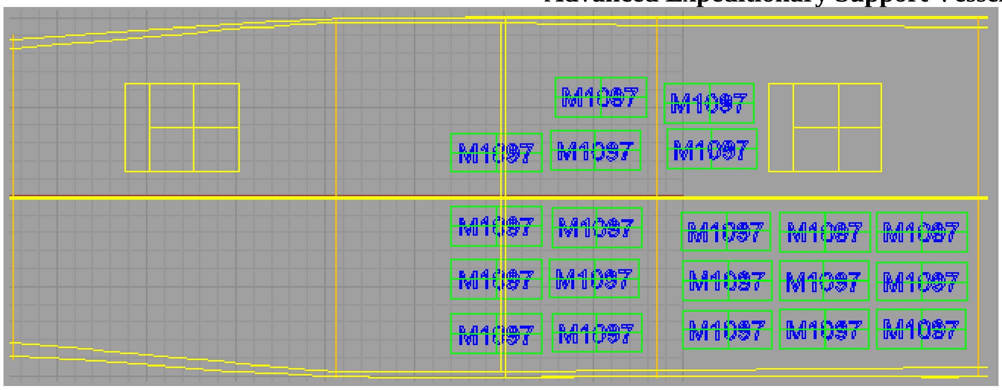


Figure 36: Vehicle Deck Layout #5

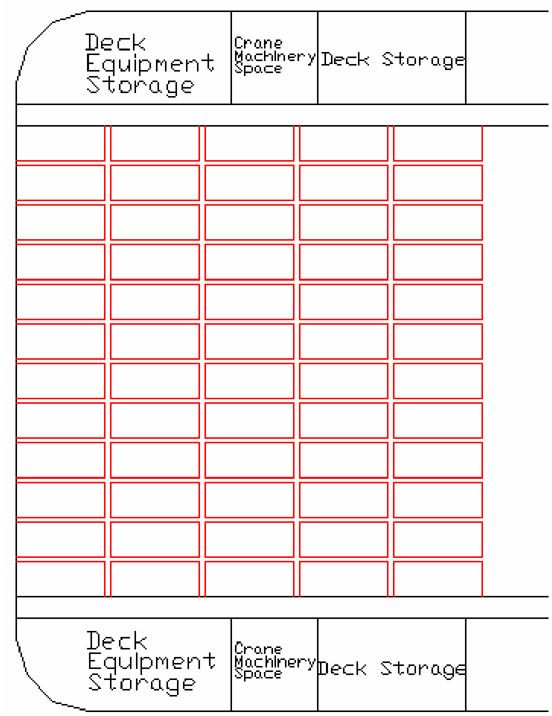


Figure 37: Container Cargo Area

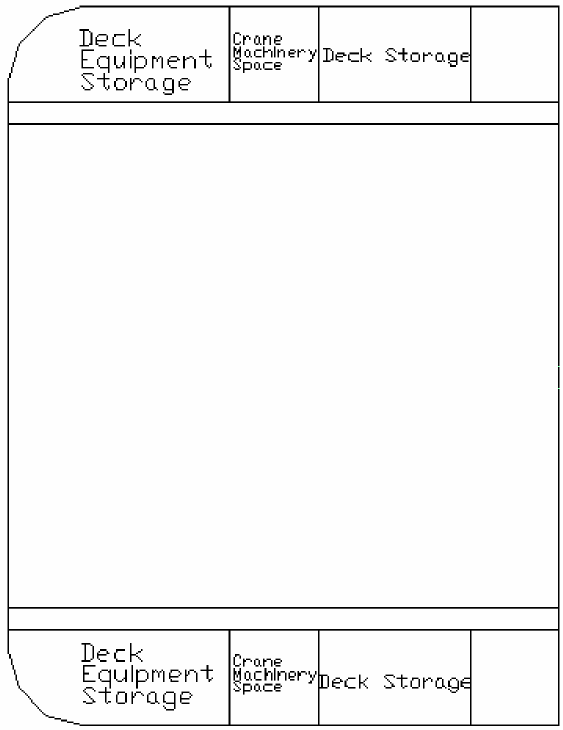


Figure 38: FLEX deck

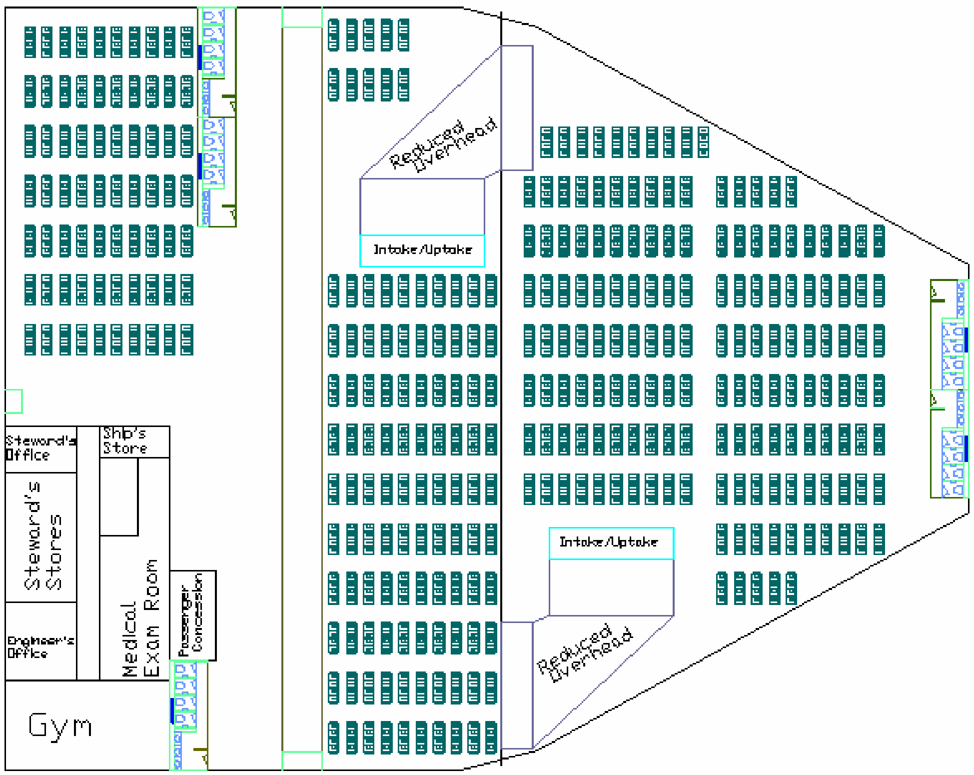


Figure 39: Passenger Compartment

Figure 40: EADS Transport and Berthing Container[8]

Figure 41: Uniteam Modular Dining Facilities[11]

Figure 42: Uniteam Munitions Storage[12]

	Durable	Storage Factor	Stability	Dep. Time	Tug Assist	R&D	Ovhd Restrict	Weight	Rigid Surface	Pot. Hazzard (flood, mov't)	Extra Equip (air, crane)	Total	%
Durable		1	0	1	1	1	1	1	1	1	1	19	18.27
Storage Factor	-1		-1	1	1	1	1	0	1	1	1	15	14.42
Stability	0	1		1	1	1	1	1	1	1	1	19	18.27
Dep. Time	-1	-1	-1		-1	0	-1	-1	1	-1	0	4	3.85
Tug Assist	-1	-1	-1	1		1	1	0	1	1	1	13	12.50
R&D	-1	-1	-1	0	-1		1	0	1	-1	-1	6	5.77
Ovhd Restrict.	-1	-1	-1	1	-1	-1		-1	1	-1	0	5	4.81
Weight	-1	0	-1	1	0	0	1		1	-1	1	11	10.58
Rigid Surface	-1	-1	-1	-1	-1	-1	-1	-1		-1	-1	0	0.00
Pot. Hazzard (flood, mov't)	-1	-1	-1	1	-1	1	1	1	-1		-1	8	7.69
Extra Equip. (air, crane)	-1	-1	-1	0	-1	1	0	-1	-1	-1		4	3.85
												104	100

Figure 43: Weighted Decision Matrix Factors for Inflatable Causeways

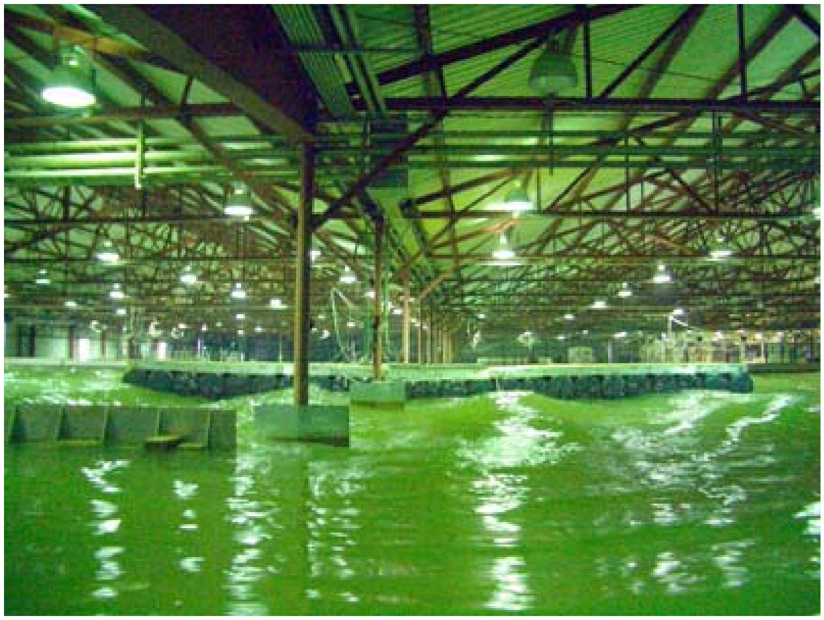


Figure 44: Wave Testing of the LMCS 1:3 Scale Model[13]

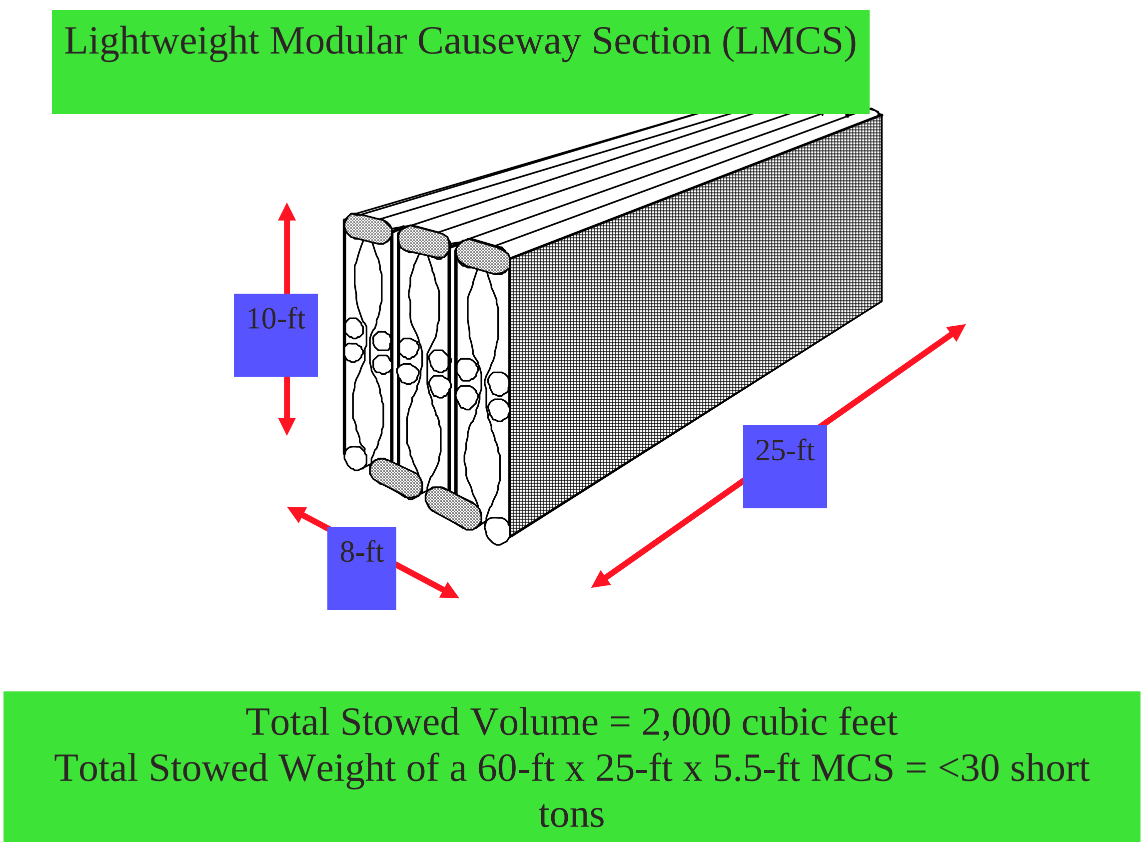


Figure 45: LMCS Folded Volume Calculation[10]

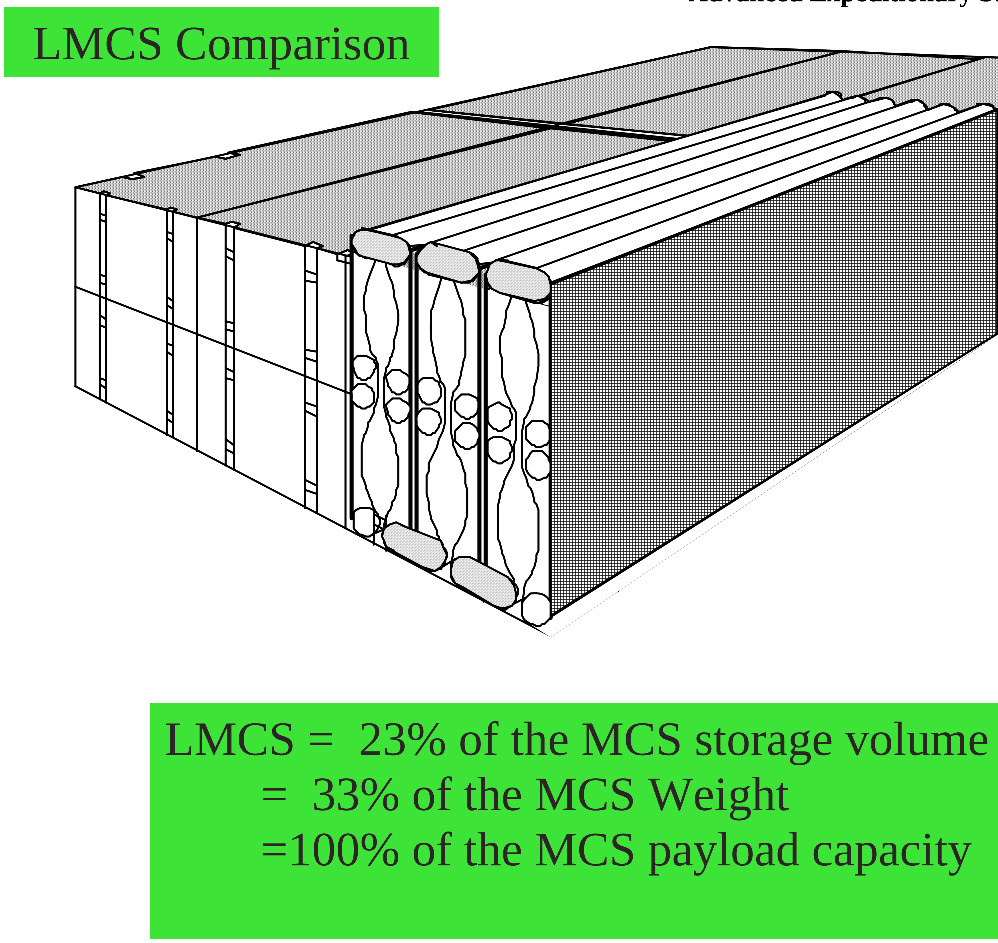


Figure 46: LMCS Comparison Diagram[10]

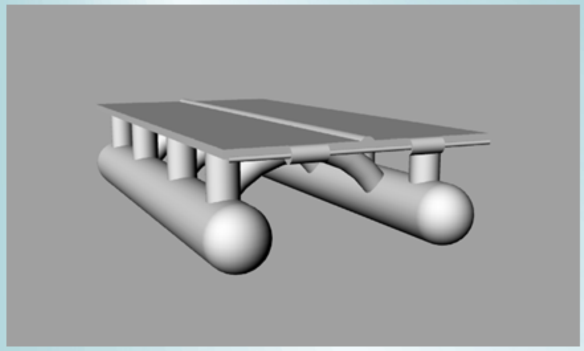
Appendix B : Payload and Lateral Loading Charts

Table 12: MEB Load Breakdown/Weight and Area totals

	Load 1			Load 2			Load 3			Load 4			Load 5				Total	REQ'd
		Area	Weight		Area	Weight		Area	Weight		Area	Weight		Area	Weight			
M1A1 (Tank)	5	145.119	286.1	9	261.2142	514.98		0	0		0	0		0	0		14	14
AAAV (Tank)	12	399.672	342.36	9	299.754	256.77	12	399.672	342.36	9	299.754	256.77	6	199.836	171.18		48	48
M88A1 (Tank)		0	0	1	27.7498	48.93		0	0		0	0		0	0		1	1
M1097 (hummvee)	20	218.436	77.2	20	218.436	77.2	20	218.436	77.2	19	207.5142	73.34	20	218.436	77.2		99	99
M198 (twd. How.)		0	0	0	0	0	18	381.7152	144		0	0		0	0		18	18
LVS Mk48 (art. Trk)		0	0	2	56.5104	50.8		0	0		0	0		0	0		2	2
M101A2	20	142.486	12.6		0	0		0	0		0	0		0	0		20	20
M390 (trailer)		0	0	21	241.8528	48.72		0	0		0	0		0	0		21	21
LAV (lt. arm. Veh)		0	0		0	0		0	0		0	0	25	466.5825	393.25		25	25
Mk1 GI Joe	1360	2448	272	1360	2448	272	1360	2448	272	1360	2448	272	1360	2448	272		6800	6800
FRKLFT		0	0		0	0	2	45.5404	30.04		0	0	5	113.851	75.1		7	7
AVLB (bridge)		0	0		0	0		0	0		0	0	1	34.812	54.7		1	1
MEWSS (sm Tk)		0	0		0	0		0	0		0	0	3	55.9899	47.19		3	3
MTVR (truck)	21	449.442	247.59	5	107.01	58.95	32	684.864	377.28	50	1070.1	589.5	25	535.05	294.75		133	133
MRC (truck)	33	369.7155	154.11		0	0		0	0		0	0		0	0		33	33
M9293/Q46		0	0	2	39.2616	21.74		0	0	2	39.2616	21.74		0	0		4	4
ABV (tank)		0	0	1	44.0664	49.9		0	0	1	44.0664	49.9		0	0		2	2
		4172.871	1391.96		3743.855	1399.99		4178.228	1242.88		4108.696	1263.25		4072.557	1385.37			

Lateral Loading Analysis

Properties of Sea Water at 15 C		
Density:	1020	kg/m^3
Dynamic Viscosity	1.14E-03	Ns/m^2



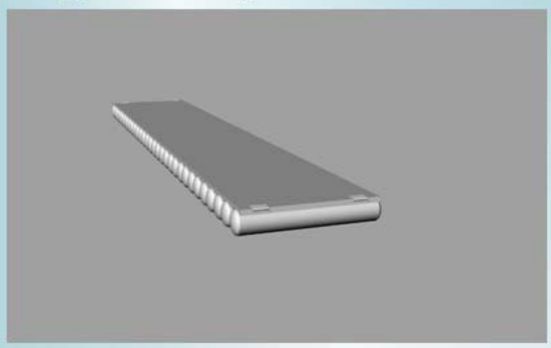
	Assumptions:
1	Fully Submerged Tubes in the Largest Loading Case
2	Tubes are in Cross-Flow
3	The Highest Cross-Current is a 4 knot, Uniform Flow That Extends at Least 2m Deep.
4	Deck Structure is Solid Material (Moment of Inertia Based on This Assumption)
5	Distributed Load Due to Pressure on Tubes
6	Drag Force Based on Frontal Area

Tube		Deck	
Length	Diameter	Width	Thickness
17 m	2 m	8.5 m	0.25 m
# of Modules	Total Causeway Length		
9	153 m		

Figure 47: Specifications of the Elevated Causeway

Lateral Loading Analysis

Properties of Sea Water at 15 C`		
Density:	1020	kg/m^3
Dynamic Viscosity	1.14E-03	Ns/m^2



	Assumptions:
1	Fully Submerged Tubes in the Largest Loading Case
2	Tubes are Parallel to Flow
3	The Highest Cross-Current is a 4 knot, Uniform Flow That Extends at Least 2m Deep.
4	Deck Structure is Solid Material (Moment of Inertia Based on This Assumption)
5	Distributed Load Due to Pressure on Tubes
6	Drag Force Based on Frontal Area

Tube		Deck	
Length	Diameter	Width	Thickness
7.62 m	2 m	7.62 m	0.1524 m
# of Modules	Total Causeway Length		
4	182.9 m		

Figure 48: Specifications of the Lightweight Modular Causeway System

Table 13: Loading values of the Elevated Causeway

Cross Current Velocity		Reynolds #	Drag Coefficient	Frontal Area	Total Load	Distributed Force	Max Bending Moment	Max Plane Deck Stress
(Knots)	(m/s)		Cd	m^2	N	N/m	Nm	kPa
0	0.000	0.0000E+00	0	306	0.00	0.00	0.00	0.00
0.2	0.103	1.8411E+05	1	306	1652.01	10.80	31594.65	10.50
0.4	0.206	3.6823E+05	0.8	306	5286.42	34.55	101102.87	33.58
0.6	0.309	5.5234E+05	0.3	306	4460.42	29.15	85305.54	28.34
0.8	0.412	7.3645E+05	0.3	306	7929.64	51.83	151654.30	50.38
1	0.514	9.2057E+05	0.3	306	12390.06	80.98	236959.84	78.71
1.2	0.617	1.1047E+06	0.3	306	17841.68	116.61	341222.18	113.35
1.4	0.720	1.2888E+06	0.3	306	24284.51	158.72	464441.29	154.28
1.6	0.823	1.4729E+06	0.3	306	31718.55	207.31	606617.20	201.51
1.8	0.926	1.6570E+06	0.3	306	40143.79	262.38	767749.89	255.03
2	1.029	1.8411E+06	0.3	306	49560.23	323.92	947839.38	314.85
2.2	1.132	2.0252E+06	0.3	306	59967.88	391.95	1146885.65	380.97
2.4	1.235	2.2094E+06	0.3	306	71366.73	466.45	1364888.70	453.39
2.6	1.338	2.3935E+06	0.3	306	83756.79	547.43	1601848.55	532.10
2.8	1.440	2.5776E+06	0.3	306	97138.05	634.89	1857765.18	617.11
3	1.543	2.7617E+06	0.3	306	111510.51	728.83	2132638.60	708.42
3.2	1.646	2.9458E+06	0.3	306	126874.19	829.24	2426468.80	806.02
3.4	1.749	3.1299E+06	0.3	306	143229.06	936.14	2739255.80	909.93
3.6	1.852	3.3140E+06	0.3	306	160575.14	1049.51	3070999.58	1020.12
3.8	1.955	3.4982E+06	0.3	306	178912.43	1169.36	3421700.15	1136.62
4	2.058	3.6823E+06	0.3	306	198240.92	1295.69	3791357.50	1259.41

Table 14: Loading values of the Lightweight Modular Causeway System

Cross Current Velocity		Reynolds #	Drag Coefficient	Frontal Area	Total Load	Distributed Force	Max Bending Moment	Max Plane Deck Stress
(Knots)	(m/s)		Cd	m^2	N	N/m	Nm	kPa
0	0.000	0.0000E+00	0.99	44.33	0.00	0.00	0.00	0.00
0.2	0.103	6.3133E+04	0.99	44.33	236.91	1.30	5415.87	3.67
0.4	0.206	1.2627E+05	0.99	44.33	947.66	5.18	21663.48	14.69
0.6	0.309	1.8940E+05	0.99	44.33	2132.23	11.66	48742.82	33.05
0.8	0.412	2.5253E+05	0.99	44.33	3790.63	20.73	86653.90	58.75
1	0.514	3.1566E+05	0.99	44.33	5922.87	32.39	135396.72	91.80
1.2	0.617	3.7880E+05	0.99	44.33	8528.93	46.64	194971.28	132.20
1.4	0.720	4.4193E+05	0.99	44.33	11608.82	63.48	265377.57	179.94
1.6	0.823	5.0506E+05	0.99	44.33	15162.54	82.91	346615.60	235.02
1.8	0.926	5.6819E+05	0.99	44.33	19190.09	104.93	438685.37	297.45
2	1.029	6.3133E+05	0.99	44.33	23691.46	129.55	541586.88	367.22
2.2	1.132	6.9446E+05	0.99	44.33	28666.67	156.75	655320.12	444.33
2.4	1.235	7.5759E+05	0.99	44.33	34115.71	186.55	779885.10	528.79
2.6	1.338	8.2072E+05	0.99	44.33	40038.57	218.93	915281.82	620.60
2.8	1.440	8.8386E+05	0.99	44.33	46435.27	253.91	1061510.28	719.75
3	1.543	9.4699E+05	0.99	44.33	53305.79	291.48	1218570.47	826.24
3.2	1.646	1.0101E+06	0.99	44.33	60650.15	331.64	1386462.40	940.08
3.4	1.749	1.0733E+06	0.99	44.33	68468.33	374.39	1565186.07	1061.26
3.6	1.852	1.1364E+06	0.99	44.33	76760.34	419.73	1754741.48	1189.79
3.8	1.955	1.1995E+06	0.99	44.33	85526.19	467.66	1955128.62	1325.66
4	2.058	1.2627E+06	0.99	44.33	94765.86	518.19	2166347.50	1468.87

Appendix C : Catamaran Concept Design

Low-Draft Catamaran Design Concepts

The designs that follow were created using tools available through the Rhinoceros program. The software's 3-D modeling capability combined with the Rhino Marine package allowed for the rapid modeling of basic hullforms and deck arrangements, as well as the ability to measure the characteristics for both, including hydrostatic and deck area values.

Concept I: The Low-Draft Beaching Hull

This hullform is the basis for all of the catamaran concepts, though the hullform itself changed numerous times in the concept exploration process. The hull began as a simple shape, with no bilge and a straight keel, as well as a parallel mid-body throughout:

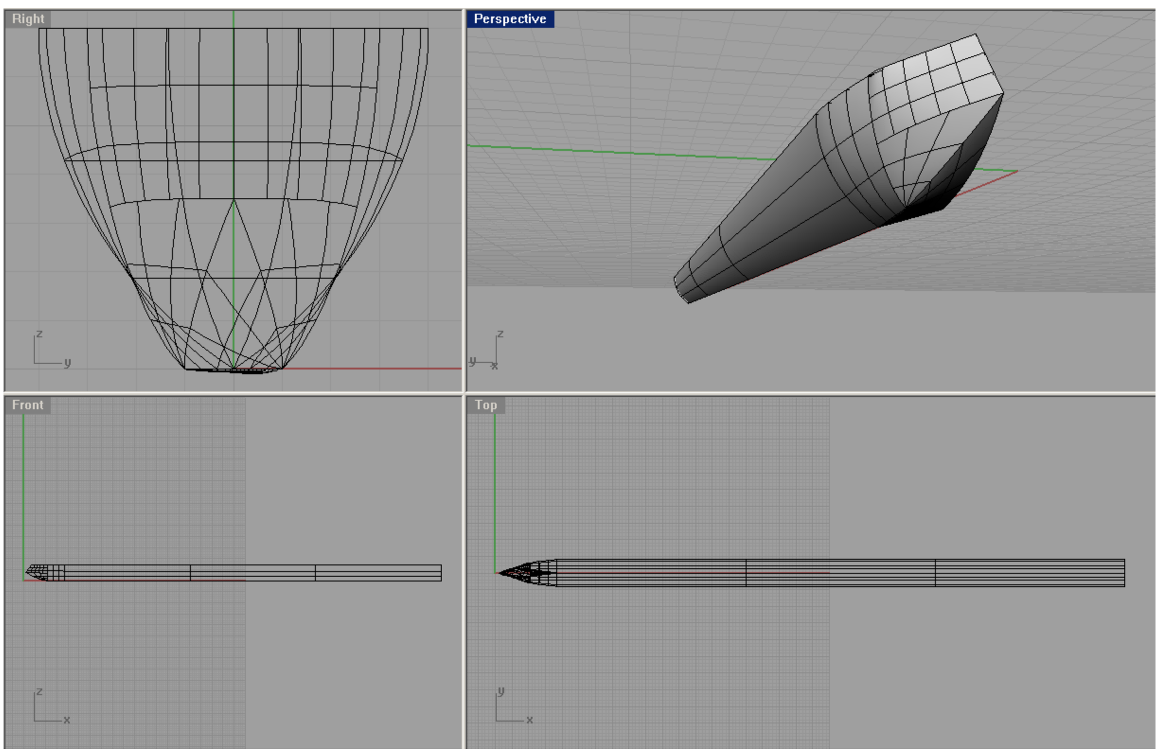


Figure 49: Catamaran Concept Hull Generation I

As can be seen in Figure 49, the hull employs a wave-piercing bow as well as a sloped prow to accommodate the beaching process, as well as a flat-transom stern. This bow was used for all subsequent generations of the hull design, though it did face certain modifications in the third generation of hullform.

The second-generation hull was further modified by adding shape to the mid-body, as well as transforming the keel on the bottom to a flat-bottomed shape. These were the only two significant changes, and mainly served as a learning tool for using Rhino to create the mid-body shape:

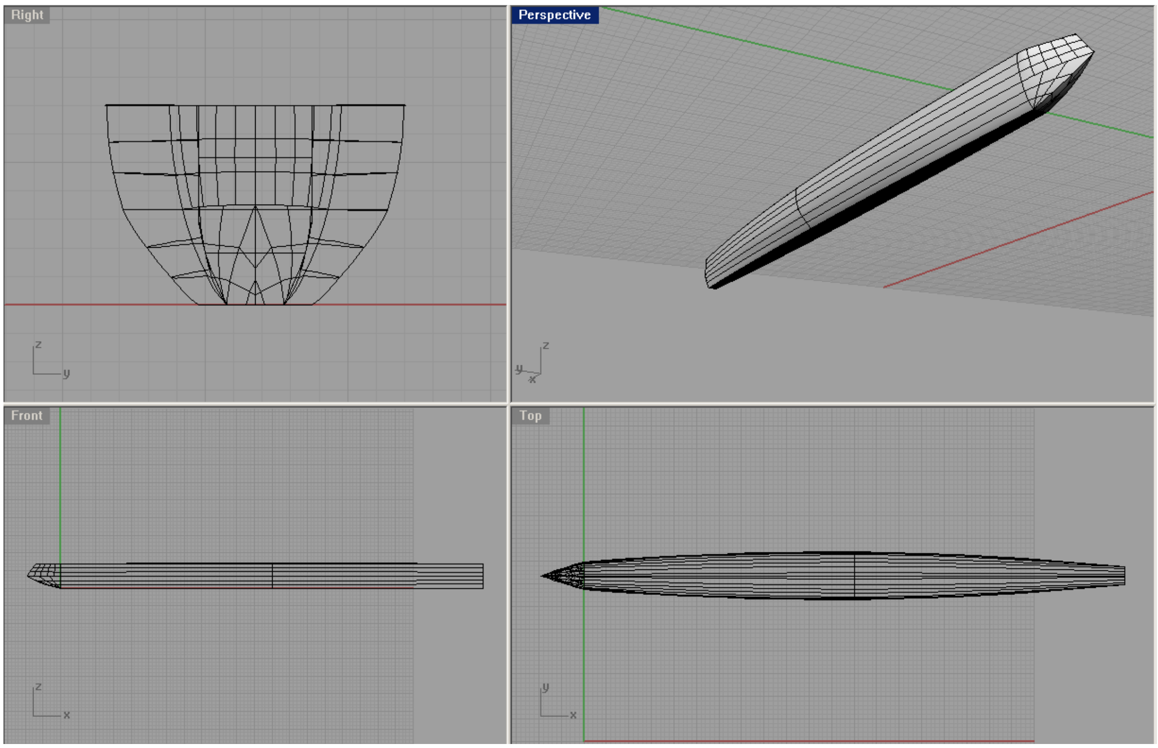


Figure 50: Catamaran Concept Hull Generation II

Adding shape to the mid-body increases the displacement of the hull, which is desirable from the standpoint of our design objective to find a high-displacement, low draft hull. However, the lines of the hull were still lacking in both aesthetics and practicality, and needed to be improved upon in the next generation of concept.

The last generation of the hull form pushed to fix these problems, and was mainly driven by two factors: the need for a very low draft, and the need for a hydrodynamically feasible hullform. The rounded bilge that was adopted provides better hydrodynamic characteristics than the hard lines of the two previous hull iterations. The bow, while remaining very similar to the preceding hulls, was modified slightly; the prow was lengthened, and the slope that enhances its beaching ability was smoothed and extended to accommodate as gentle a beach-gradient as possible. The flat transom remained, and is not indicative of the stern shape required for a propulsion unit to be added; it was merely a placeholder to derive the general hull particulars. The hull also has very slight tumblehome, which allows for more displacement for waterline heights at mid-depths. The generation III hull was the model used in a majority of the catamaran concepts, and was resized to fit various requirements of the deck arrangement:

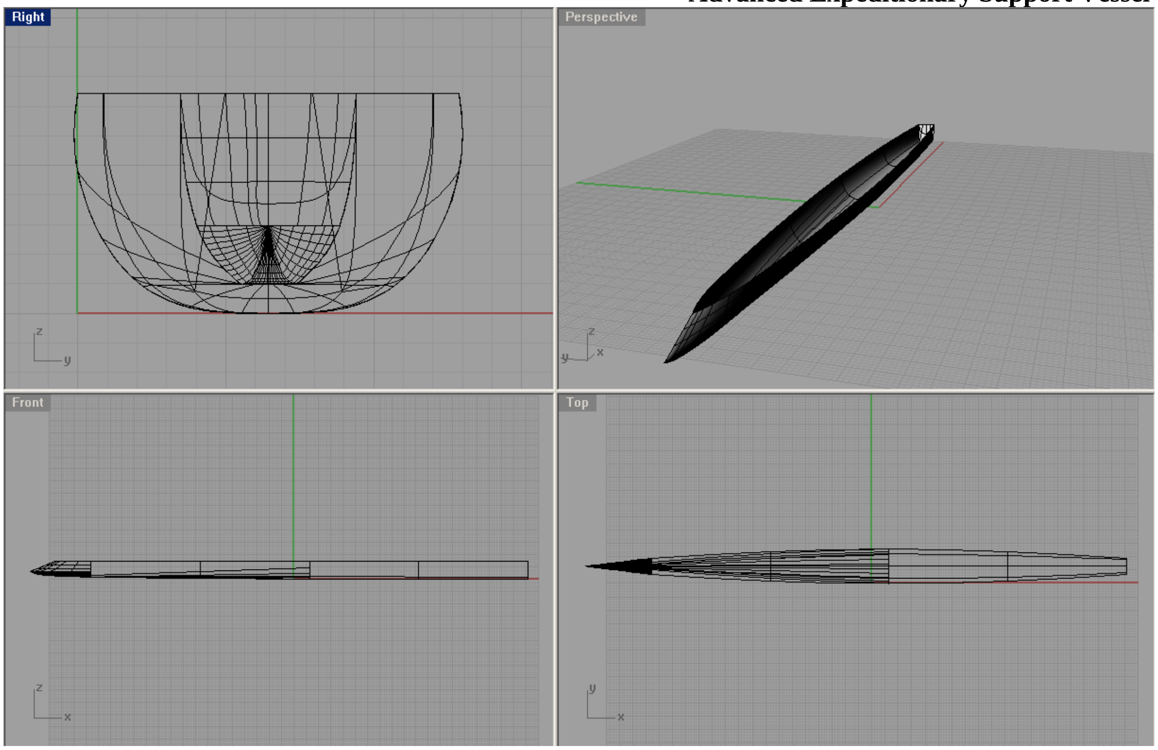


Figure 51: Catamaran Concept Hull Generation III

The initial hope for this hull concept was for it to be about 200 m long and have a 3 m draft, with a displacement of at least 5,000 long tons as a monohull in order to provide a minimum of 10,000 tons when used in a catamaran configuration. The concept hull that was actually modeled came close to this mark: at 203 m long, a 13.1 m beam, and a 3.5 m draft, it displaced 4,732 LT, with a block coefficient of 0.529 and a waterplane coefficient of 0.713. This came very close to the design constraints, though the draft did have to be increased by half a meter to achieve a reasonable displacement mark.

Concept II: The Generation I Catamaran

This catamaran concept was created using the generation I hullform, and mainly served as a demonstrator for the deck sizes of a large-scale catamaran. The ship was 187 m long with a 43 m beam, and displaced 14,184 LT at 3.5 m draft. The concept had a combined 12,470 m of cargo deck area, which was much larger than the estimated 2,000-2,500 square meters of deck space that would be required for each cargo load. Ultimately this concept would have proven to have too much weight in deck steel and cargo to support, and was much larger than would be necessary:

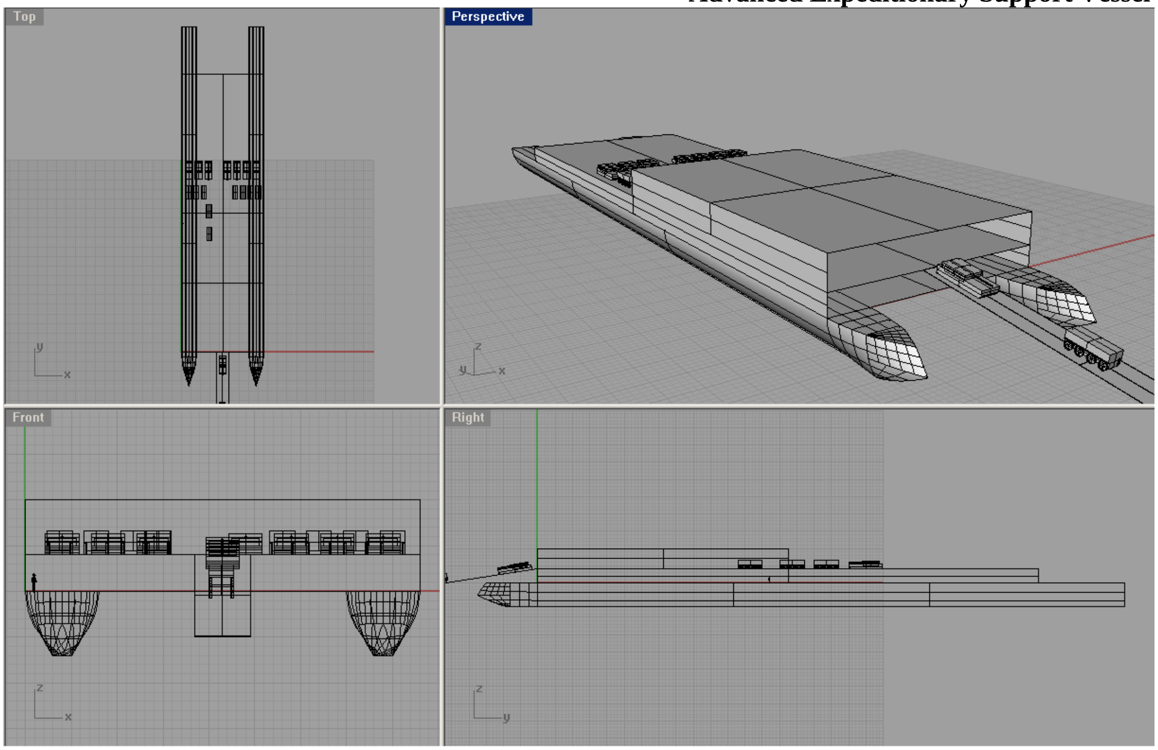


Figure 52: Generation I Catamaran

Concept III: The Generation II Catamaran

After creating the oversized generation I catamaran concept, a much smaller concept was explored using the generation II hullform. This ship was 129 m long with a 42 m beam, and only displaced 5,110 LT at a 3.5 m draft. The concept had 6448 square meters of deck area, including the area required to land a Ch-53 helicopter on the stern. This concept was dismissed due to its very low displacement, which may not have even been able to support the lightship weight of the vessel, much less a full cargo load:

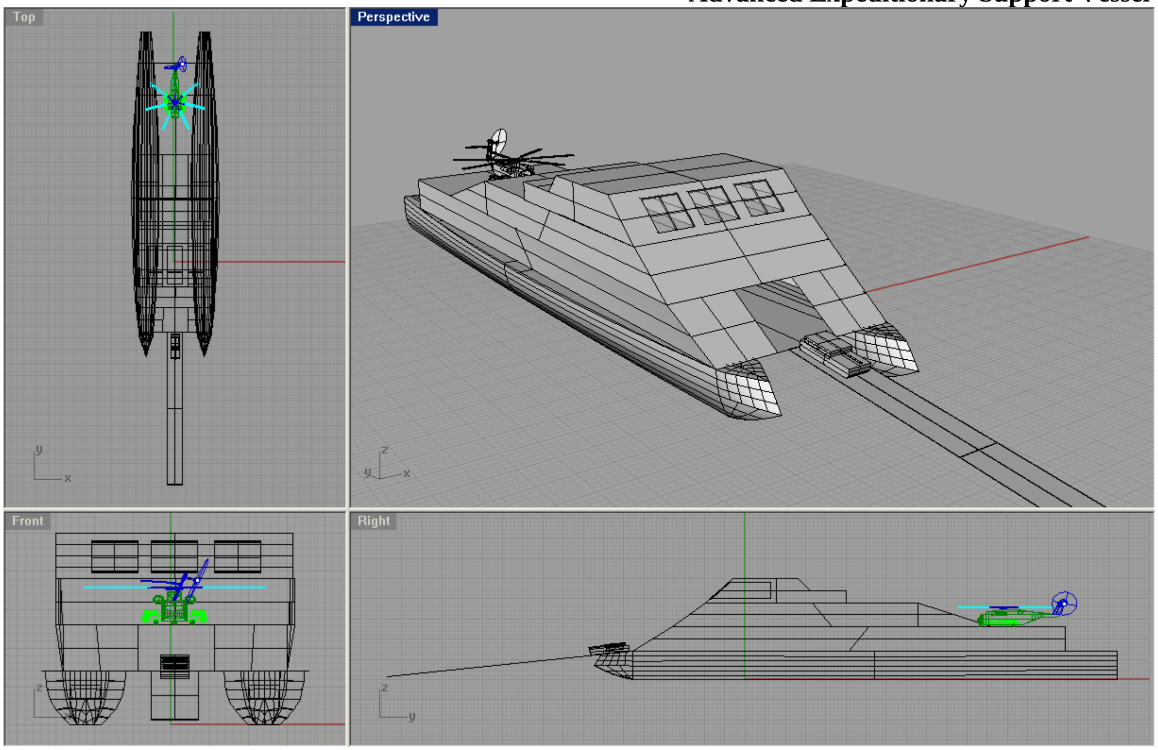


Figure 53: Generation II Catamaran

Concept IV: The Generation III Catamaran

The generation III hullform was used in four separate ship concepts, with each catamaran concept design possessing its own unique deck and cargo arrangements. The first concept was on the same scale as the generation one catamaran, measuring 205 m long with a 43 m beam, and displacing 9,635 LT at a 3.5 m draft. As seen in Figure #, different cargoes, including tanks, Stryker vehicles, TEU's, and the CH-53 helicopter, were loaded on deck to visualize the space requirements. Like the Gen. I concept, this ship far exceeded our deck space requirements with 14,680 m of open deck area. Another factor that pushed this ship out of consideration was the relatively low displacement compared to the high deck areas and cargo loads; again, like the Gen. I ship that preceded it, the displacement would not have been able to support the ship lightweight and load requirements:

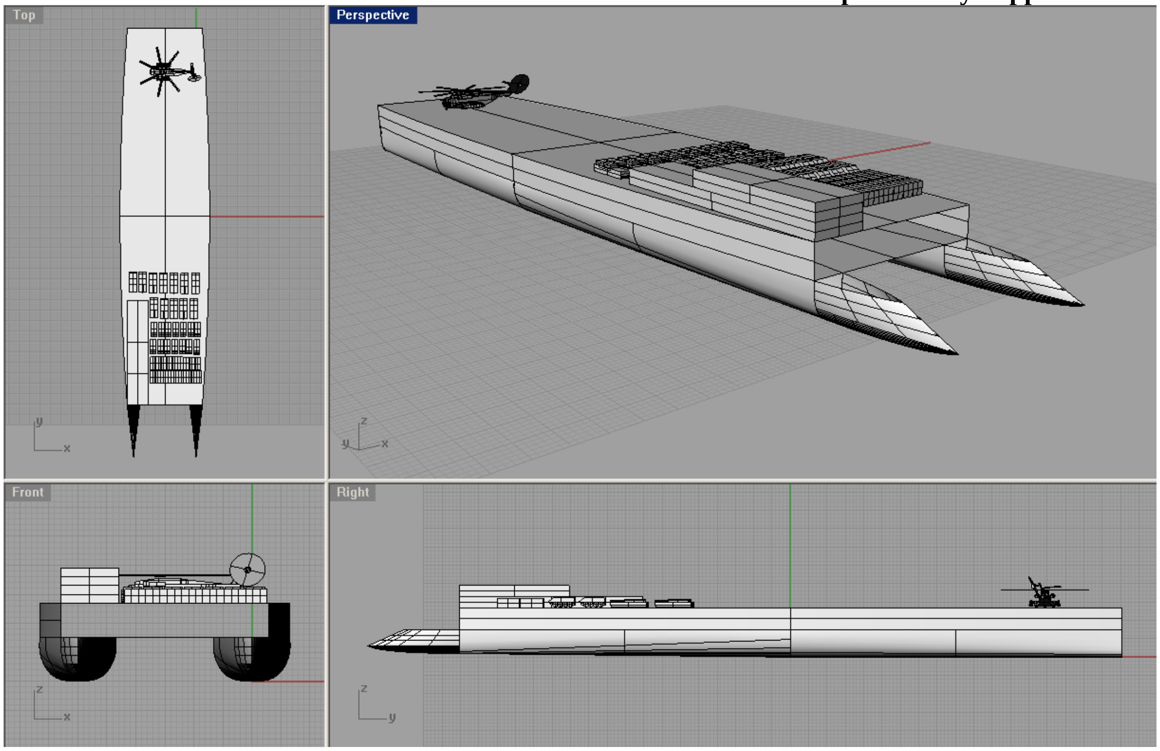


Figure 54: Generation IV Catamaran Design

It should be noted that were this ship to be taken into serious consideration as a design, much of the deck area would be given towards other ship needs, including crew spaces, ammo lockers, electronics bays, and other necessary functions. However, even with these spaces accounted for, the ship would have displaced far too much to float at a sensible draft, and would still have had an excess of deck space.

The next design of catamaran was more refined than any that had preceded it, and was the basis for the final catamaran concepts that were taken into consideration. This design was on the same scale as the ship that preceded it, displacing 9,632 LT at 205 m long and a 43 m beam. The concept had a dedicated helicopter bay and heli-pad, as well as a Ro-Ro deck that could be configured for different types of cargo. The helicopter bay was on the same level as a troop deck, with the combined area measuring 3810 square meters; the heli-pad was adjacent to the bay, and located in front of the deckhouse to allow for easier loading of troops from the stern of the ship onto the troop deck. The Ro-Ro deck provided 6196 square meters of space for either vehicles or TEU's, and was open to the stern for loading via ramp. While this concept faced improvements in deck space area and utilization of a helicopter hangar, it was still too large to be practical from a weights and structures standpoint:

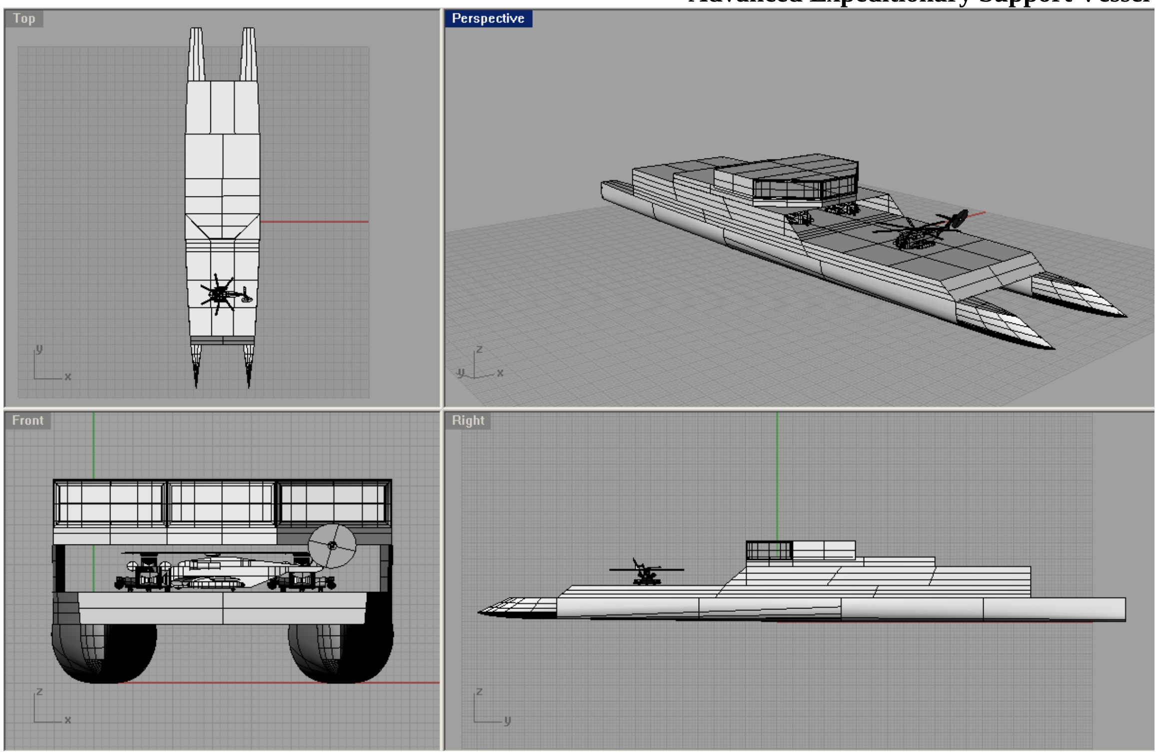


Figure 55: Another Gen. IV Catamaran Design

The final catamaran concept that was placed into consideration alongside the trimaran concept went through two phases, with the deck arrangements changing slightly between them. The first concept phase was 184 m long, with a 37 m beam and a draft of 3.5 m, at which it displaced 8083 tons. The ship decks were broken into five separate compartments: Personnel Deck(1200 m^2), Flex Deck(800 m^2), Ro-Ro Deck(1700 m^2), and Helicopter Bay(700 m^2). The Flex-Deck was supposed to be configurable to hold numerous cargoes: troops, TEU's, vehicles, or pallets. The idea was to have an elevator deck that effectively separated the Flex-Deck into two compartments, with the bottom compartment housing the cargo and the upper compartment containing seats for personnel transfer. The personnel section of the Flex-Deck could be raised for the trip from CONUS to the seabase, to allow for taller cargoes, and then could be lowered to allow for personnel to load at the seabase and transfer to shore. The deckhouse was not modeled, but was going to be added in at a later date if the concept was accepted as our design and further refined. The helicopter pad was at the stern of the ship, and relied on a series of columns to support the weight of the helicopter. This concept was ultimately rejected because of one major problem: structural soundness. After talking with a naval architect experienced with structures, it appeared that the long, slender form of the ship would have been unable to withstand the loads of a ship in motion. The ship had no true strength deck, and no support between the demihulls for a majority of its length. This would have causes major vibration problems throughout the ship as well as serious deficiencies in the hull-girder strength. Because of these pressing structural issues, the concept had to go through a second phase of refinement. The following figure shows phase one of the concept:

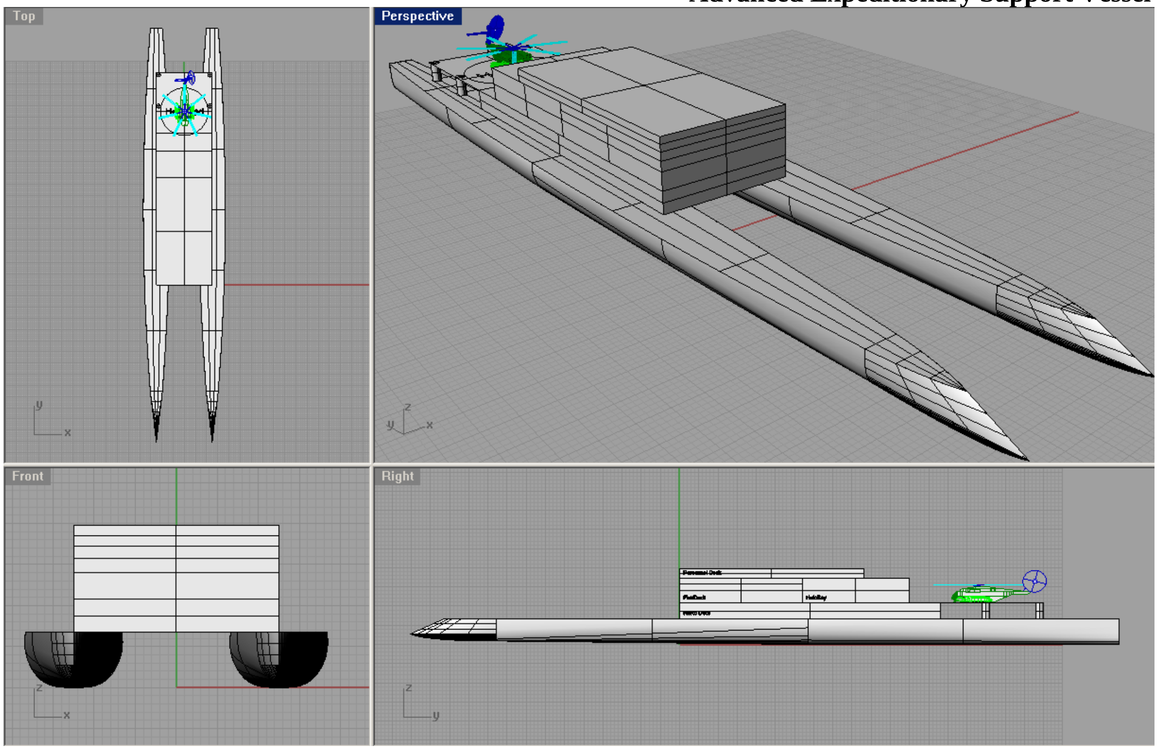


Figure 56: Generation IV Phase 1

The second phase of the ship was shortened to 165 m, with a 37 m beam and an initial draft of 3.5 m. However, this draft produced a displacement of only 7,273 LT and was believed to be too low for the structure and loads that were being considered. Therefore, the draft was raised to 4 m, which produced a satisfactory displacement of 8,695 LT. The deck arrangements were changed to provide a smooth transition between hull and Ro-Ro deck, which allowed for a strength deck to run a majority of the hull length. The deck spaces were reconfigured as follows: Ro-Ro deck (4312 m^2), Personnel deck (2028 m^2), and Crew Quarters (1576 m^2). The other spaces on the ship were committed to a deckhouse area and a Helo-bay, which was configured to fit two CH-53 helicopters in a folded configuration. The Flex-Deck was dropped in favor of larger personnel and Ro-Ro decks, which were expected to handle the lost capacity for both troops and cargo. The major factor for this change was the requirement for human habitability in ship spaces, namely the fact that it would be more efficient to outfit a dedicated space for personnel rather than trying to outfit lights, heat, water, and head facilities in a deck that has to carry cargo as well. Had the catamaran concept been chosen, these arrangements may have changed again due to other requirements that come up father along the design process:

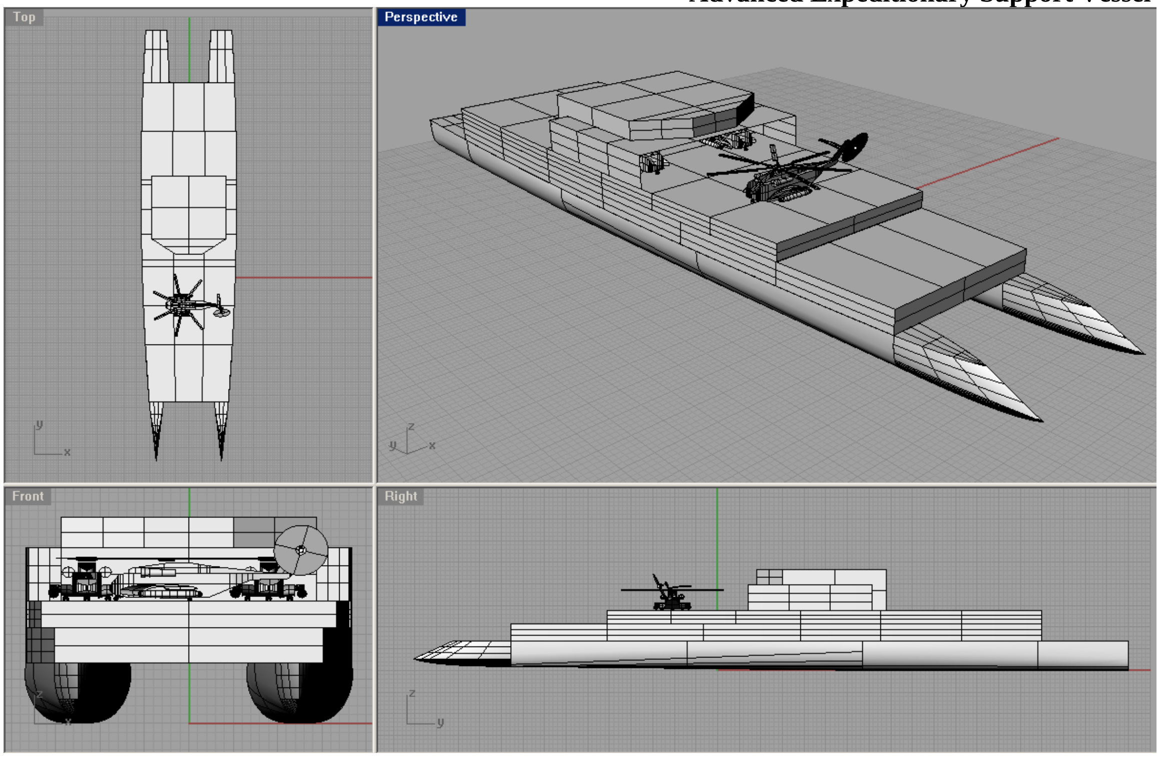


Figure 57: Generation V Phase II