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Technical Report

Transformable Heavy Lift Ship

by
Andrew Bloxom
Livia Cohen
Joseph Loeffler

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There is a requirement to efficiently transfer wheeled and tracked vehicles from Sealift ships to Landing Craft Air Cushion (LCAC) vessels at sea. For this mission, NAVSEA has explored using a traditional heavy lift type ship as a Mobile Landing Platform (MLP). Large relative motions between the LCAC, the traditional heavy lift ship, and the Sealift ship limits the effective operational Sea State envelope of this configuration. A transformable heavy lift ship concept was developed to provide the required deck area and LCAC interface while reducing the motions experienced during trials with a traditional heavy lift ship. The concept vessel has a service speed of 18 knots and can transport five LCACs. A unique feature of this vessel is its capability to transform its upper deck into a platform 60 meters wide using deck extensions deployed from both sides. During transit, these extensions would be raised to allow for efficient passage and transit through the Panama Canal. Upon arriving in the operational theater, the ship ballasts down into a mode with reduced waterplane area for enhanced seakeeping characteristics. Then, the extensions would rotate outward to double the breadth of the ship's main working deck and provide a stable platform for the loading of LCACs. Further work is required to support the enhanced motion response characteristics of the ship, detailed design of the transformable platform, and relative motion analysis between the offloading cargo vessel and the ship.

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Abstract

There is a requirement to efficiently transfer wheeled and tracked vehicles from Sealift ships to Landing Craft Air Cushion (LCAC) vessels at sea. For this mission, NAVSEA has explored using a traditional heavy lift type ship as a Mobile Landing Platform (MLP). Large relative motions between the LCAC, the traditional heavy lift ship, and the Sealift ship limits the effective operational Sea State envelope of this configuration.

A transformable heavy lift ship concept was developed to provide the required deck area and LCAC interface while reducing the motions experienced during trials with a traditional heavy lift ship. The concept vessel has a service speed of 18 knots and can transport five LCACs. A unique feature of this vessel is its capability to transform its upper deck into a platform 60 meters wide using deck extensions deployed from both sides. During transit, these extensions would be raised to allow for efficient passage and transit through the Panama Canal. Upon arriving in the operational theater, the ship ballasts down into a mode with reduced waterplane area for enhanced seakeeping characteristics. Then, the extensions would rotate outward to double the breadth of the ship's main working deck and provide a stable platform for the loading of LCACs. Further work is required to support the enhanced motion response characteristics of the ship, detailed design of the transformable platform, and relative motion analysis between the offloading cargo vessel and the transformable heavy lift ship.

Transit Mode, deck folded


Ballasted Mode, deck extended

Acknowledgments

This report is the culmination of work conducted by students hired under the National Research Enterprise Intern Program sponsored by the Office of Naval Research. This program provides an opportunity for students to participate in research at a Department of Navy laboratory for 10 weeks during the summer. The goals of the program are to encourage participating students to pursue science and engineering careers, to further education via mentoring by laboratory personnel and their participation in research, and to make them aware of Navy research and technology efforts, which can lead to future employment.

At the Naval Surface Warfare Center Carderock Division, the single largest employer of summer interns is the Center for Innovation in Ship Design (CISD), which is part of the Ship Systems Integration and Design Department. The intern program is just one way in which CISD fulfils its role of conducting student outreach and developing ship designers.

The student team consisted of:

Andrew Bloxom

Livia Cohen

Joe Loeffler

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Introduction

The Navy of the future looks to reduce its dependency on foreign countries in times of war and peace. In an age of terrorism, the constant threat of enemy attack on ships overseas looms ever present. To minimize that threat, seabasing steps forward as a potential solution to the Navy's logistical support needs for forces deployed around the world. A Sea Base is a collection of self-sustainable vessels, which includes combatants, auxiliaries, and air support to provide an offshore site where re-supply efforts can safely occur. Cargo transfer and refueling operations are essential to the Sea Base mission. The ability to sustain a force on the ground with re-supply efforts in the ocean is vital to the long-term effectiveness of the military during wartime. Key to the functioning of a Sea Base is the use of intermediaries where wheeled and tracked vehicles, cargo containers, and various supplies can be moved from large, slow cargo vessels onto small, fast shuttle type vessels to move the supplies over the horizon and over the beachfront to the troops on the ground. The heavy lift type ship is one intriguing possibility to fill the role of an intermediary within the Sea Base. The heavy lift type ship is able to ballast down and bring its large main deck at or below the waterline.

Traditional heavy lift ships are slow commercial semi-submersible vessels that transport large cargo such as drilling platforms. The M/V Blue Marlin, a commercial heavy lift ship owned and operated by Dockwise is shown below with a large offshore platform on her deck.

Figure 1. M/V Blue Marlin, a commercial heavy lift ship

The defining features of commercial heavy lift ships are their large open deck area and their large payload capacity. The main disadvantages of the commercial style heavy lift ships for the cargo transfer role are:

- Slow transit speeds;
- Susceptibility to weather when loaded; and
- Loading/Offloading operations must be performed in nearly calm water.

In the commercial heavy lift ship, the hull form is not optimized for speed and instead focuses more on allowing for a large cargo capacity. Derivatives of these commercial ships are being studied to serve as intermediaries between large Roll On/Roll Off (RO/RO) vessels and smaller cargo shuttles. The Navy has a potential role for a dedicated semi-submersible ship, capable of performing operations in a variety of environmental conditions. Cargo transfer in higher sea states is required for the Navy ships. While the cargo weight requirements are significantly lower than that of the commercial ships, the required deck area is the same or greater. The goal of this study is to address the three main disadvantages of the traditional heavy lift ship to produce a design that is deployable for trans-oceanic voyages without weather routing and provides good seakeeping characteristics in both the ballasted and unballasted modes. The ship would also be provided with adequate power to reach fleet operational speeds.

The conceptual idea for the transformable ship is that the vessel ballasts down and extends its platform to provide a large beach-like deck to assist in the transfer of Marine Expeditionary Brigade (MEB) vehicles and personnel from Sealift ships to Landing Craft Air Cushion (LCAC) vessels for deployment to the shore. During the transit mode, the extendable platform is retracted into a folded position with LCACs loaded inboard. The design of the ship's hull combined with sponsons near the edges of the expanded platform will improve the ship's seakeeping in higher sea states.

The LCAC is a versatile workhorse of the United States Navy. It is a hovercraft designed to carry wheeled and tracked vehicles, personnel, and cargo from offshore over the beachfront. Currently, it operates primarily in the well deck of amphibious assault ships, where it can come down from its air cushion and load vehicles via the forward and aft ramps equipped onboard. The LCAC reaches speeds up to 40 knots over water and 10 knots over land with a 75 metric ton cargo capacity. The LCAC shown in Figure 2 is loaded with Army Hum-Vees.

Figure 2. A Landing Craft Air Cushion (LCAC) loaded with military vehicles

Definition of Requirements

The requirements summarized here reflect the baseline concept as developed by the Center for Innovation in Ship Design. They are operationally tied to the Seabasing concept wherein the need for a vessel to perform as both a carrier for LCACs and as a Mobile Landing Platform (MLP) is presented.

Cargo Requirements

The transformable heavy lift ship should be able to safely carry 4 to 6 LCACs into the operational theatre. Upon arrival, the vessel would transform into its Mobile Landing Platform mode by extending its side platforms and ballasting down. The LCACs would be loaded with their respective cargo while the heavy lift ship is docked with a larger vessel such as a Large, Medium Speed, Roll-On/Roll-Off ship (LMSR). The vessel in the ballasted mode should provide adequate stability and seakeeping to support the MEB vehicles on deck during the loading operations.

General Requirements

The design of the ship must fulfill several general requirements in order to adequately complete its intended missions.

The ship is to be able to transit through the Panama Canal. This means that the length can be no larger than 294.1 meters, the beam can be no larger than 32.3 meters, and the draft can be no larger than 12 meters.

The ship will primarily be constructed of steel. Furthermore, existing propulsion technology must be employed in the ship. Using existing technology in this aspect ensures no new and unreliable propulsion elements that might affect the plausibility of the design.

The maximum speed of the ship is to exceed 15 knots. It is intended that this ship perform at fleet operational speeds.

When in the transit mode, the aim is to reduce reliance on weather routing. When in the ballasted mode, the ship motions should be minimized. Also, in both modes, the ship should be operational in Sea State 5.

In addition, there should also be accommodations for a 20 crew members and the LCAC crews.

Definition of Design Environment

As stated in the general requirements, the ship is required to be fully operational in Sea State 5. This includes both the transit mode and ballasted loading mode. For the purposes of this report, observational data collected on the wave characteristics will be used to model the design seaway. The characteristics of Sea State 2 to 5 are summarized in the table 1.

Wind Speed (Kts)	Sea State	Significant Wave (m)	Significant Range of Periods (Sec)	Average Period (Sec)	Average Length of Waves (m)
10.75	2	0.6858	1.5 to 6	3	9.0297
15.5	3	1.2954	2 to 7.5	4	16.9926
19	4	2.0828	2.5 to 9.5	5.16	27.432
22.75	5	2.9725	3 to 12	6.125	39.02

Table 1: Observed characteristics of Sea State 2-5.

Figure 3 shows the significant wave height and range of periods for Sea State 2 to 5. The area under these curves roughly represents the total energy in the spectrum. The curve shows the large majority of the energy contained within the range of wave periods of 3-12 seconds. To reduce ship motions, the goal of this design was to produce a hull with a roll period in the ballasted operating mode well outside of this range to avoid exciting the ship near its natural frequency. A design roll period of 15-25 seconds was selected.

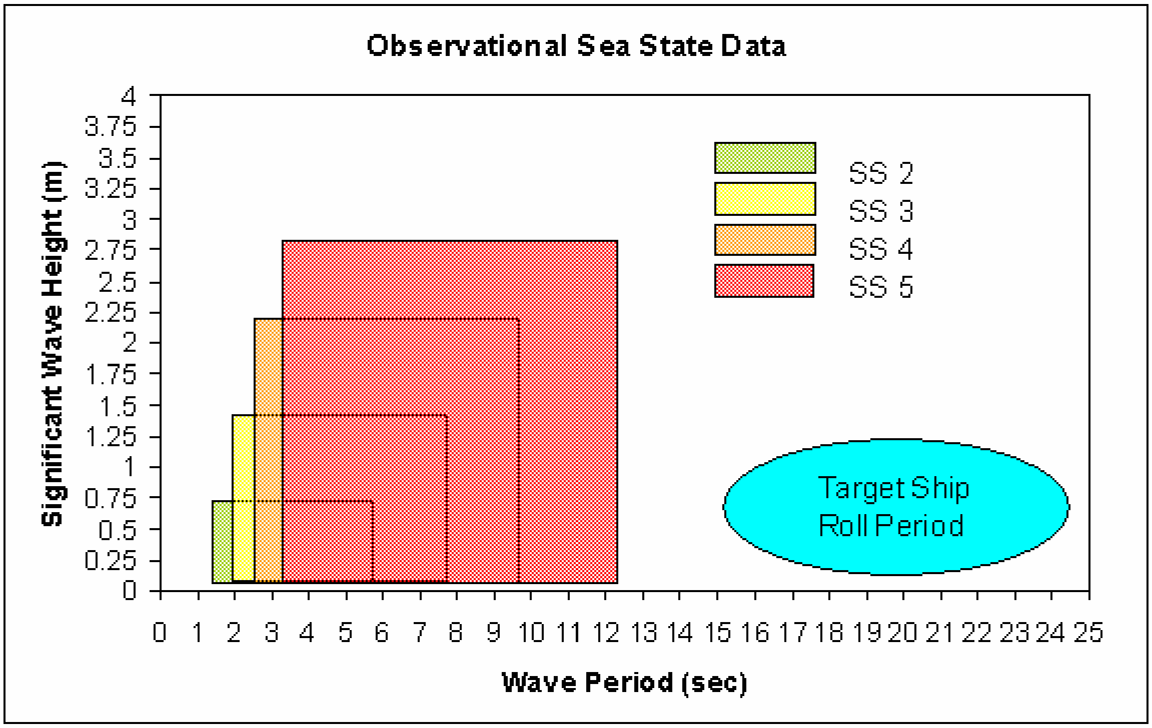


Figure 3. Range of Periods vs. Significant Wave Height for SS 2-5

Concept Development

Hullform

In the initial stages of the design, the team explored a number of potential hull forms to assess their feasibility in respect to the mission requirements. The five main forms included a monohull, transformable monohull with extendable sponsons, a catamaran, a trimaran, and a SWATH hull.

The findings for each concept were: the traditional monohull lacked good ship motions in the ballasted condition. The catamaran showed the ability to reach higher speeds, but the roll motions in the ballasted condition were judged to be too large because of a high metacentric height while submerged. The trimaran and SWATH were both ruled out based on their constrictive geometries. The SWATH does however have good seakeeping characteristics.

The transformable monohull was chosen as the baseline hull form to explore in depth because of a large range of possible configurations that would be compatible with this platform and the possibility of excellent seakeeping characteristics after modifications to the hull to reduce waterplane area in the ballasted mode. The ability to transit the Panama Canal with a load of LCACs was important to the versatility of the vessel, and the transformable concept adheres well to that idea.

Loading Deck

From the initial brainstorming sessions, a loading platform with a stern ramp was considered. Much like the well decks of current the LHD and LPD, the ship would submerge to flood the LCAC launch ramp. Using the Panamax restrictions as a guide, a beamy platform was idealized that could support two LCACs side by side. However, after further consideration of the requirement to carry and load 4 to 6 LCACs, the dual lane stern ramp platform was considered unacceptable from a time and logistic standpoint for loading more than two LCACs at a time.

Using the transformable monohull concept, a new platform idea was forged that would start out with a beam at Panamax restrictions, then extend out to effectively double the working area of the deck. Heeling the ship over two degrees to immerse one side of the platform would turn the entire working deck into a beach like platform for the LCACs to ride up on and come off cushion for loading and unloading.

A major design issue was the design and mechanical operation of a large extendable platform. One of the biggest problems arose in the extension process. Three main designs were considered: folding the platforms down against the main hull, folding the platforms up above the working deck, or sliding the platforms in and out transversely within the deck structure. Hydraulic actuators, electric motors, linear actuators, buoyancy driven extension, and cable-pulley systems were all analyzed for the mechanical actuation during this phase.

Ship Particulars

The ship has a length overall of 200 meters, a depth of 14 meters, and an effective breadth that varies from 14 meters to 28 meters depending upon the ballast condition. The unique hull design provides has two different beam magnitudes. The transit mode beam is 28 meters. This is the largest physical beam of the ship. In the deep ballast condition, the beam at the waterline is only14 meters. The ship has a draft of 6.5 meters when in the transit mode. These characteristics allow for passage through the Panama Canal.

When in the loading/unloading mode (when the ship is ballasted), the ship has a draft of 13.5 meters. At this draft, the ship can heel or trim to allow the loading and unloading of LCACs. Figure 4 provides a visual summary of the vessel's dimensions.

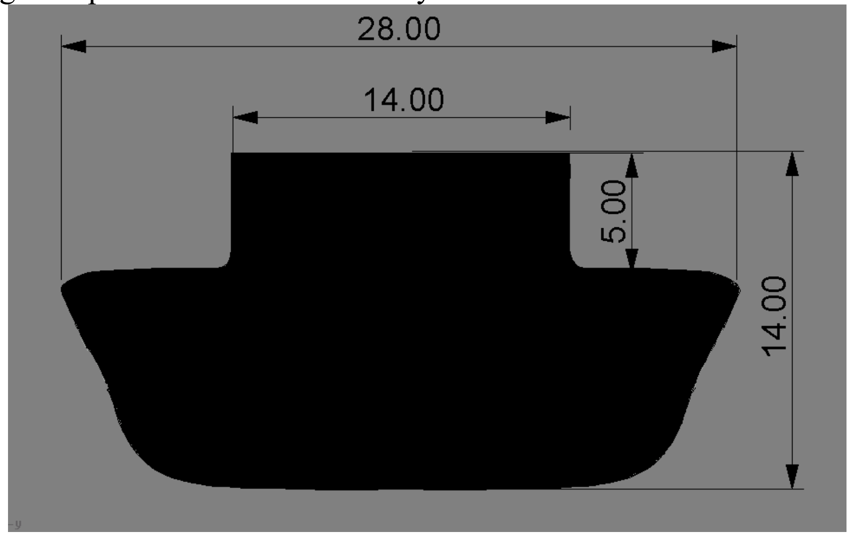


Figure 4. Ship Dimensions

The non-transformable working deck is 16 meters in beam, as it is slightly larger than the beam of the center part of the hull. When transformed, the deck has a beam of 60 meters and a length of 150 meters to allow adequate area for LCAC operations.

General Arrangements

Hull

The hull of the transformable heavy lift ship was specially designed to meet the requirements of two separate modes of operation. In order to fulfill transit speeds, the main lower hull was designed to be long and slender to reduce resistance and achieve the desired speed. Above the main lower hull was a reduced waterplane area section that is a part of the main hull girder. While ballasted, the ship has reduced waterplane area for improved motion characteristics.

Transformable Platform

The deck consists of one main central platform hinged to four more steel platforms to allow the deck to fold. A detailed hinge mechanism attaching the platform to the main deck has not been developed.

Much of the deck is a high-risk area as it lacks a definite locking system once the transformation is complete. A series of pins would lock the deck in place. However, the strength and size required for such pins and connectors has not yet been calculated.

The deck is moved by a series of hydraulic actuators on each side. These actuators will push directly up to fold the platform, and pull down to expand it. As the vessel ballasts down, the buoyancy of the sponsons pushes the outer deck edges outboard. Once the deck has been fully expanded, it will then need to be locked in place at both the hinge at the main deck connection and at the mid-extension hinge. These hinges and locking mechanisms will experience heavy loading in higher sea states as waves wash onto the submerged side of the deck, and as wheeled and tracked vehicles traverse the platform during loading/unloading operations. The hinges and connectors would be sized accordingly to support these types of loads. The hydraulic actuators have been researched in order to validate the possibility of using them for this type of application. Using the weight of the transformable platform estimated to be 840 tonnes, actuators were found that could be grouped to lift the weight of the platform.

When the vessel is ballasted down in the operational mode, two types of loads will be placed on the platform structures. One side, high out of the water will experience loads as if it were a cantilever. It will need strength to support both the weight of the platform, vehicles moving on top, and any loads associated with a ramp placed on it from the offloading cargo ship. The other side of the platform will be partially submerged in the water to allow the LCAC to sail up on the main deck. During roll motions and wave passage, large dynamic loads will be placed on this platform imparted to the structure by the water.

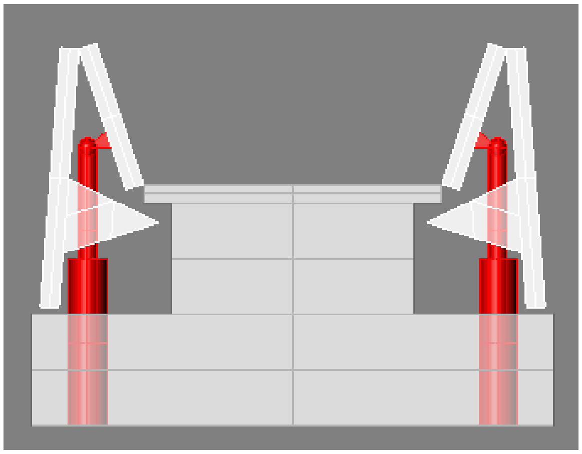


Figure 5. View of folded transformable deck moved by hydraulic actuators.

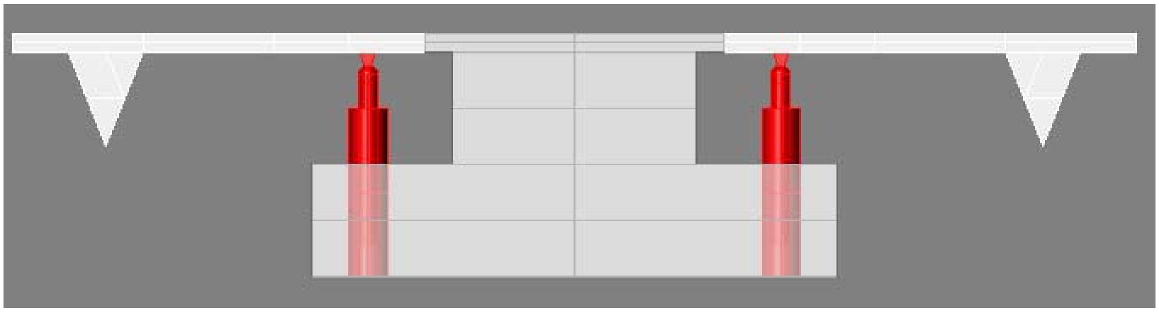


Figure 6. View of the extended transformable platform held in place by hydraulic actuators.

Ballasting Arrangement

Conventional heavy lift ships require long periods of time for ballasting operations due to smaller pump rooms and instabilities when submerging the main deck. The transformable heavy lift ship addresses this problem by reducing ballast volume requirements due to waterplane area reduction, then breaking the system into four subsections, each containing a high volumetric flow rate pump rated at 10,000 m^3/h. With a total enclosed ballast volume on the order of 20,000 m^3, this operation has the capability to be performed in approximately half of an hour. Additionally, with four pump rooms, the system acquires a level of redundancy that ensures the safety of operations in the event of single or double pump failure.

Ballast Tanks

Detailed ballast tank arrangements have not yet been developed, however, it should be noted that there is sufficient volume in the hull for the tanks required to ballast down the vessel. This required volume is 19,000 m^3.

Fuel Tanks

The individual fuel tank arrangements have not been detailed, but sufficient volume is available for the 1,670 m3 needed for a 10,000 nm endurance fuel load. This volume was calculated after performing an endurance fuel calculation with a SFC of 0.188 kg/kW-hr and dividing the total fuel load by the density of diesel fuel, which was found to be 0.82 t/m^3.

Main Propulsion, Engine Room, and Electric Plant

A diesel-electric configuration has been chosen for the transformable heavy lift ship to support the ship. The primary reason for this decision was to simplify the machinery arrangements and create a ship that could power all systems from a single source. The integrated electric drive is comprised of a number of key components.

Two 6,000 kW rated diesel prime movers connected to generators provide the main energy to the propulsors. An auxiliary diesel generator set may be required, but has not been established in this design. These generator sets route the power through various power management, conversion, and distribution equipment before reaching its destination. Frequency converters are the final stage before the propulsors and allow the benefit of variable speed propeller characteristics.

Figure 7 is a representation of a common diesel-electric integrated drive system.

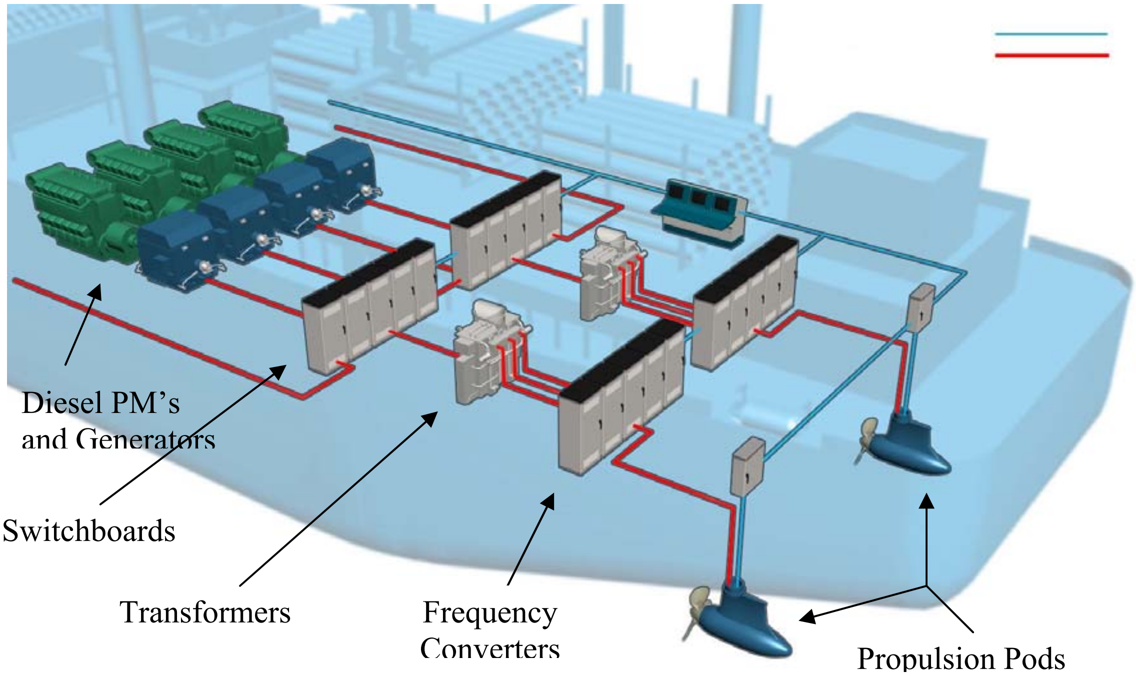


Figure 7. Main Propulsion Equipment Schematic.

Podded Propulsion

In using the integrated electric drive, additional losses in efficiency are accrued between the prime mover and the propellers in the various power management systems. Propulsion pods will help to reduce this effect by the increase in efficiency they gain as a result of their forward facing propellers, elimination of shafting, struts, appendages, and the rudders.

They have increased functionality in their ability to vector thrust through their 360 degrees of rotation. Additionally, new model propulsion pods are becoming more reliable and have the capability to be service without dry docking the ship. Current models are made rated up to 30 MW. Two 6 MW rated propulsion pods would be sufficient and are available commercially.

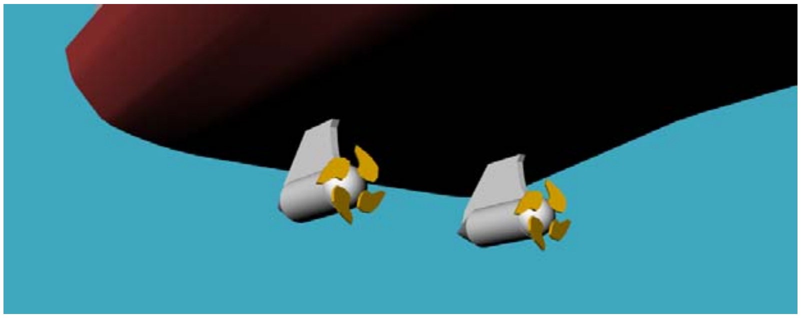


Figure 8. View of propulsion pods looking aft.

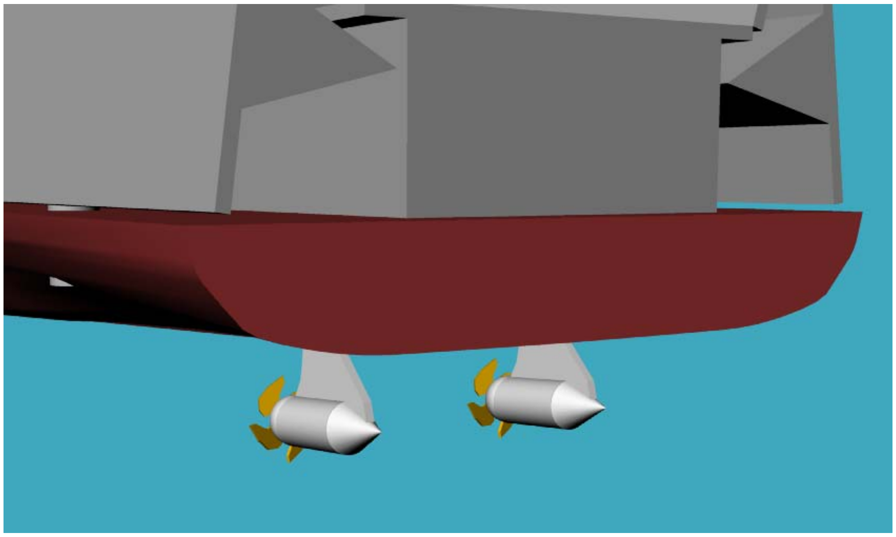


Figure 9. View of propulsion pods looking forward.

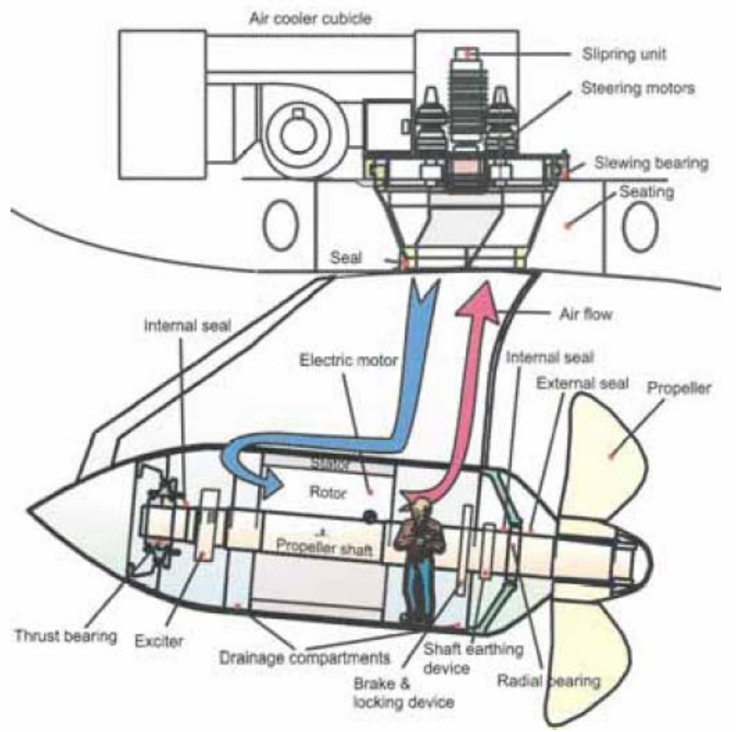


Figure 10. A schematic of the inner working and layout of the Mermaid Propulsion Pod.

Dynamic Positioning System

During LCAC operations in the open ocean, a dynamic positioning system will be utilized to provide good station keeping qualities for the ship. The LCAC lacks precise maneuverability, and the benefits of a dynamic positioning system installed on the transformable heavy lift ship are required. The main components of the system are: retracting azimuthing thrusters forward, position and weather sensors, and operator control equipments. A dynamic positioning system has the ability to be run autonomously or by the hand of a trained operator. A schematic of the components included in such a system is shown below in Figure 11.

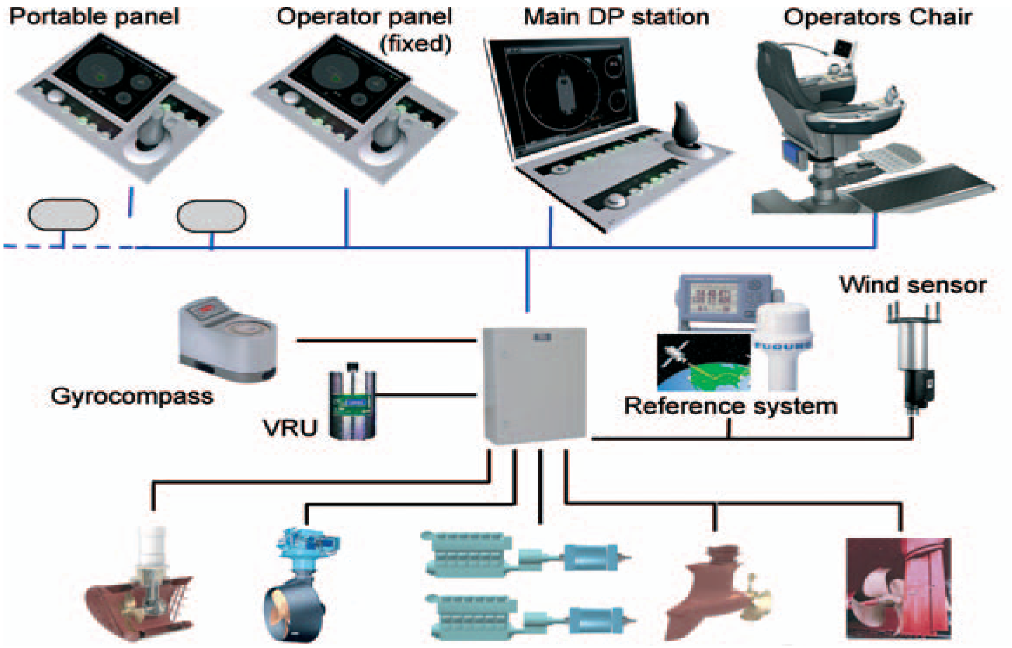


Figure 11. Dynamic Positioning System components.

The two retracting azimuthing thrusters mounted forward of midships are shown in the figure below. They rotate into position when the ship is ballasted down, and retract within the hull for minimized resistance in the transit mode.

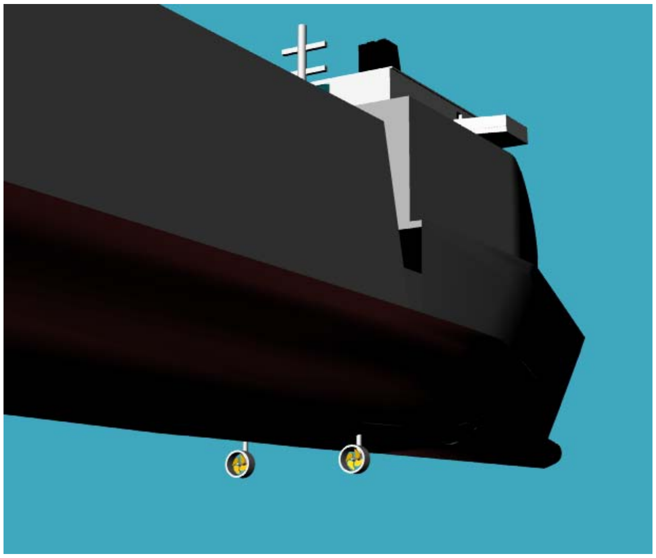


Figure 12. View of the forward thrusters.

Superstructure
The superstructure is located above the forecastle deck on the bow of the ship. It contains the bridge deck, control rooms, crew's quarters, and other spaces vital to the crew.

Navigation Bridge
The main bridge houses both the navigation bridge facing forward and the LCAC control tower facing aft, overlooking the landing platform. A series of centrally mounted consoles provides the necessary interfaces for ship control, engine control, and navigation information display. The ballasting operation station looks aft over the transformable deck. The main pump rooms controls are located here and this location allows for good visibility of the submerged depth and deck angle. The dynamic positioning station is located next to the ballast station and looks aft as well. From this vantage point, LCAC operations are controlled and relative motions are assessed.

LCAC Loading and Unloading Operations

When the deck is folded, there is enough space on the central platform to carry five LCACs. This arrangement can be seen in Figure 13 below.

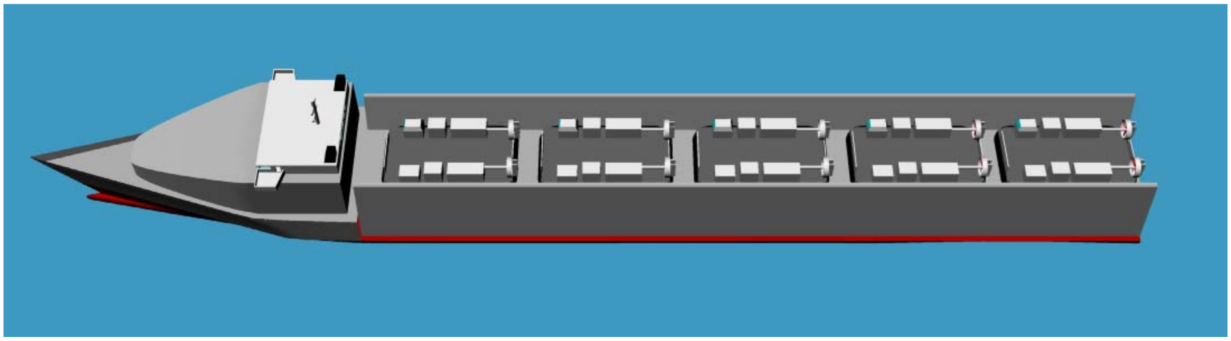


Figure 13. LCACs secured to center deck in transit mode.

Once the heavy lift ship ballasts and transforms, its working deck measures 150 meters in length and 60 meters in beam. To facilitate the process of LCACs landing on the deck, the heavy lift ship has the capability both to list and to trim by the stern.

When the transformable heavy lift ship is listing, it allows for another ship to unload in a med moor configuration. A med moor configuration can be seen in Figure 14, which shows the transformable heavy lift ship perpendicular to another ship. When the ship is listing, there is enough room for more than the original five LCACs to sail up onto the deck at once.

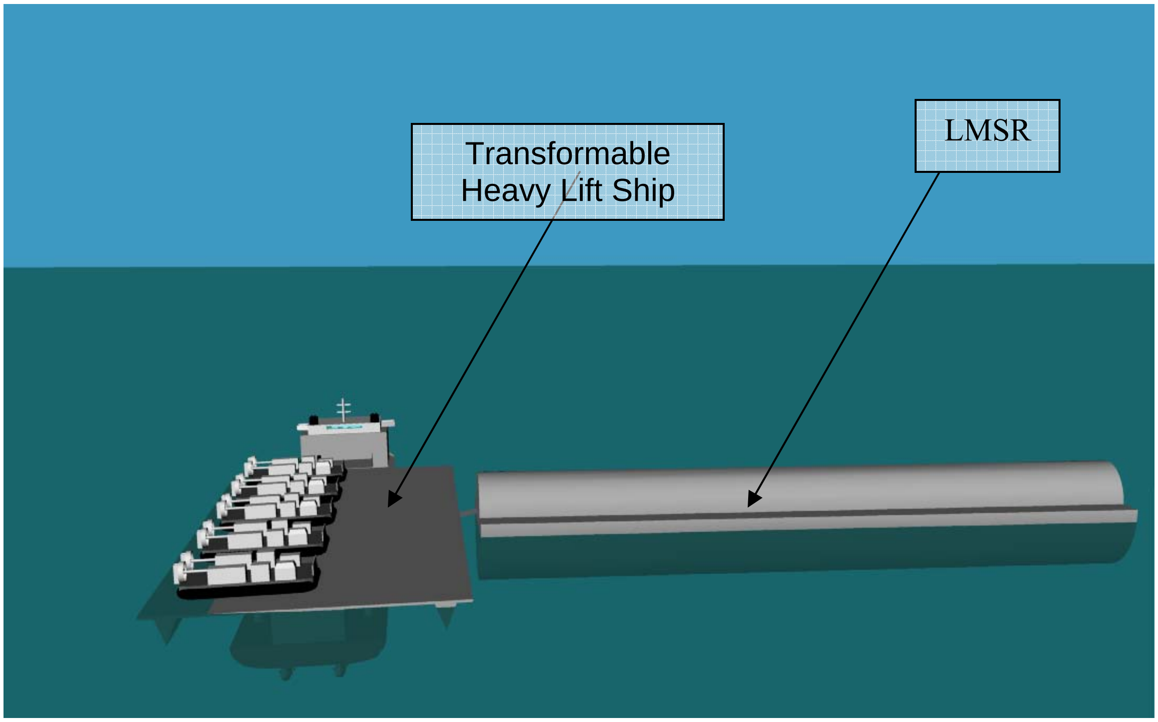


Figure 14. Ship heeled for transverse landing of LCACs with med moor unloading with LMSR.

When the transformable heavy lift ship is trimmed by the stern, it allows for another ship to unload in a skin-to-skin configuration. A skin-to-skin configuration can be seen in Figure 15 below. It shows both ships arranged parallel to each other, having the port side of one ship parallel to the starboard side of another ship. In trimming by stern, there is space for three LCACs to sail up at once.

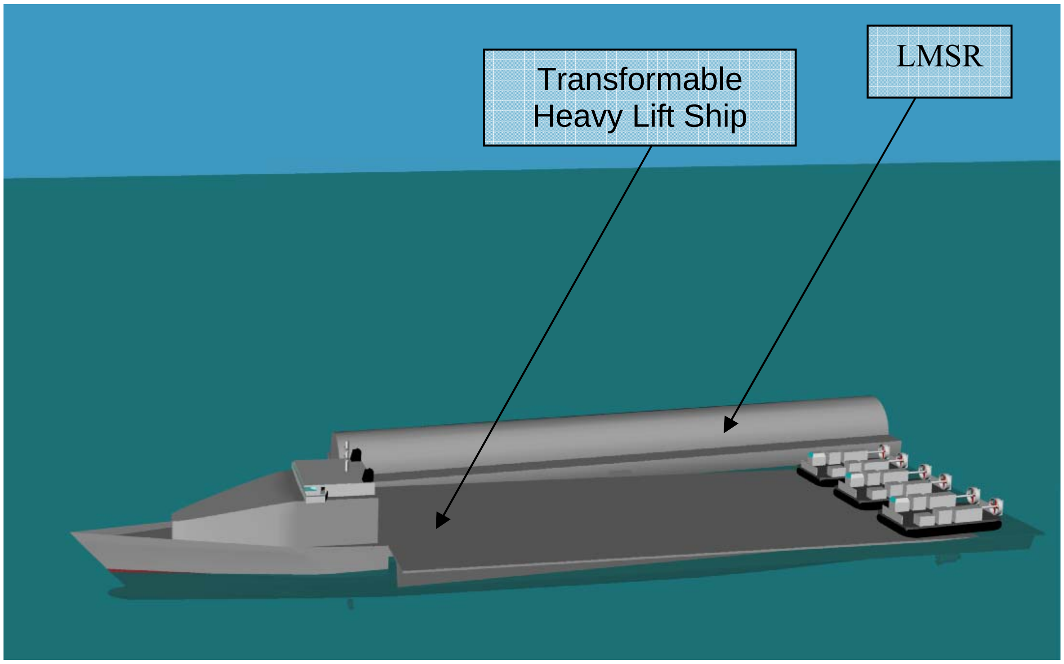


Figure 15. Ship trimmed by the stern to allow skin to skin unloading of the LMSR.

Weights Estimates

Ship Work Breakdown Structure

The ship weight estimates provided here have been gathered from a variety of data sources. The main SWBS groups compromising the lightship weight and the deadweight tonnage will be defined, and the estimating procedure for each will be detailed in the following sections. The following table presents an overall summary of ship weights.

SWBS Summary	tonnes
100 Structures	9597.3
200 Propulsion	1346
300 Electric Plant	1100
400 Command and Control	27
500 Auxiliary Systems	1005.6
600 Outfit/Furnishings	1103.7
700 Armament	1
Total Lightship	14179.6
Total Lightship w/ 10% Design Margin	15597.56
Diesel Fuel (10,000 nm range)	1700
5 LCACs (fully loaded)	900
Miscellaneous (crew, stores, etc.)	52
Deadweight	2652
Full Load Displacement	18249.56

Table 2: Ship Work Breakdown Structure.

SWBS 100 - Hull Structures

The primary hull structure weight estimate utilized data collected over a range of naval ships that plots the primary structural weight against the total enclosed volume of the vessel. The enclosed volume of the transformable heavy lift ship hull and superstructure was estimated to 51,780 m^3. By looking at the data trends, primary structural density for combatants and amphibious ships remained constant as the total enclosed volume increased. For auxiliaries, the data showed a slight decrease in structural density as the total enclosed volume increased. Ultimately, a value of 2.27 kg/ m^3 was estimated as the structural density of the transformable heavy lift ship based upon where a heavy lift type ship would fit in with the data considering a large portion of the enclosed volume includes the ballast tanks. Figure 16 shows this data in English units.

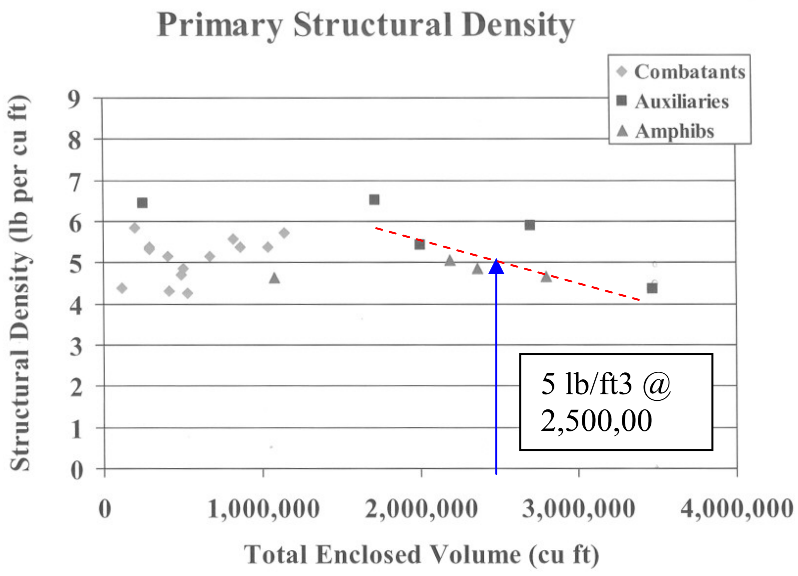


Figure 16. Historical structural weight estimation data gathered on various ships of the U.S. Naval Fleet.

Also included in the SWBS 100 section is the weight of the transformable deck including the associated steel structure, actuators, connectors, and hinges. Actuator weights were determined from vendor data. The other primary weights of the transformable platform were estimated based on volumetric estimates of the amount of steel required and a density of 7.85 t/ m^3 for steel. Altogether, the SWBS 100 group accounted for 63.5% of the total lightship weight of the vessel.

SWBS 200 - Propulsion

Weight estimates for the propulsion plant of the transformable heavy lift ship were made using vendor data. The engines and propulsors were sized according to the resistance and powering estimates outlined in Section 10. The 200 group includes the two main diesel engines, two azimuthing podded propulsors, lubricating oils, operating fluids, repair parts, and the intake and exhaust ventilation casings.

SWBS 300 - Electric

The electric plant weight estimates were made by observing vendor data trends for similarly sized components, and through a scaling of the electric plant weights from the Joint High Speed Sealift concept ship. More research in this area is required to develop a more accurate estimate that better reflects the specific components to be installed on the transformable heavy lift ship. The main equipment is the propulsion and ship service generators, cabling, power management, and frequency control systems.

Scaling Weights from the JHSS

The following three sections of the SWBS breakdown are strictly scaled weight estimates from the Joint High Speed Sealift concept ship design data. The JHSS is over 300 meters in length and 34,500 tonnes in displacement. It carries nearly 1700 troops and their respective vehicles. The missions are fundamentally different, but the sizes are relatively similar. While this method of estimation introduces a significant level of uncertainty, no weight report data was made available from heavy lift type ships. Assumptions and estimation methods will be discussed in each individual section.

SWBS 400 - Command & Control

The main command and control requirements for the transformable heavy lift ship are less than for the larger JHSS. It was decided that 60% of the JHSS command and control weight would be reasonable considering the LCAC operations control equipment, dynamic positioning system, radar, navigation, communications, power control, and ballasting control equipment.

SWBS 500 - Auxiliary Systems

The subgroups for the 500 group include climate control, freshwater/seawater systems, mechanical handling, and special purpose systems. Due to the large troop compliment carried on the JHSS, large amounts of climate control and ventilation were required. The transformable heavy lift ship has only a single superstructure, with much less internal volume and machinery spaces. With this in mind, it was estimated that the ship would require 40% of the auxiliary systems requirements.

SWBS 600 - Outfit/Furnishings

The 600 group weight estimates were estimated to be 60 percent of the JHSS. Significant areas of difference arose in the hull compartmentation, living spaces, working spaces, and stowage spaces. Weight areas such as the preservatives and coverings section were more relevant as they are mainly based on ship size.

SWBS 700 - Armament

The transformable heavy lift ship has a standard light defensive armament typical of a Military Sealift Command vessel and weight to match. This light armament does not provide for any major weapons systems, and includes small personal firearms and equipment related to the personal safety of the crew when entering narrow passages or foreign ports.

Deadweight

The deadweight estimate includes five fully loaded LCACs at 180 tonnes each, diesel fuel for a 10,000 nautical mile endurance range, and the additional weight of the crew, stores, and other miscellaneous cargo.

Stability

Ballasted

In the ballasted mode, the transverse metacentric height is 0.396 meters. This gives the ship a roll period of 15.7 seconds. As seen in Figure 3, this falls within the target roll period. The achieved roll period is outside the periods of concentrated energy for Sea State 5. Thus, a decrease in ship motions is expected; however, the amount of reduction needs to be determined by analysis.

Due to the direct relationship between GM and roll period, a low GM was required in order to achieve the desired roll period. However, a low GM presents stability problems. To address this issue, two sponsons have been placed on the outer bottom edge of the right and left part of the transformed deck (not interfering with deck space). These will provide the additional stability that is needed when in the ballasted mode. The sponsons are parallel to the monohull and located at an equal distance from the centerline. They extend the length of the transformable deck (150 meters) and are approximately 5 meters in width (taken at the largest measurement). There is a predetermined area that they must fit in to, as they need to be small enough so the deck can fold up and fit through the Panama Canal. It should be noted that the sponsons are permanently fixed to the bottom side of the deck. They move as the deck transforms, but they do not move in relation to the deck. The exact shape of the sponsons requires further work.

In the ballasted mode, it is also important to consider loading conditions. The tonnes per centimeter immersion is 22.1. Given the weight of the LCACs and the additional machinery that will be loaded onto the ship in the ballasted mode, it is concluded that this value is sufficient (the freeboard is large enough to accommodate the additional weight being loaded).

Unballasted

In the unballasted mode, the aim is to ensure the ability for a transoceanic passage as well as the ability to transit in Sea State 5. This will reduce weather routing and permit the transformable heavy lift ship to complete its missions in variable weather conditions.

The transverse metacentric height is 3.8 meters. The righting arm curve is shown in Figure 17. A slightly larger plateau at the peak of the GZ curve is observed, due to the distinctive geometry of the ship. The maximum GZ is 2.1 meters and it occurs at an angle of approximately 26 degrees.

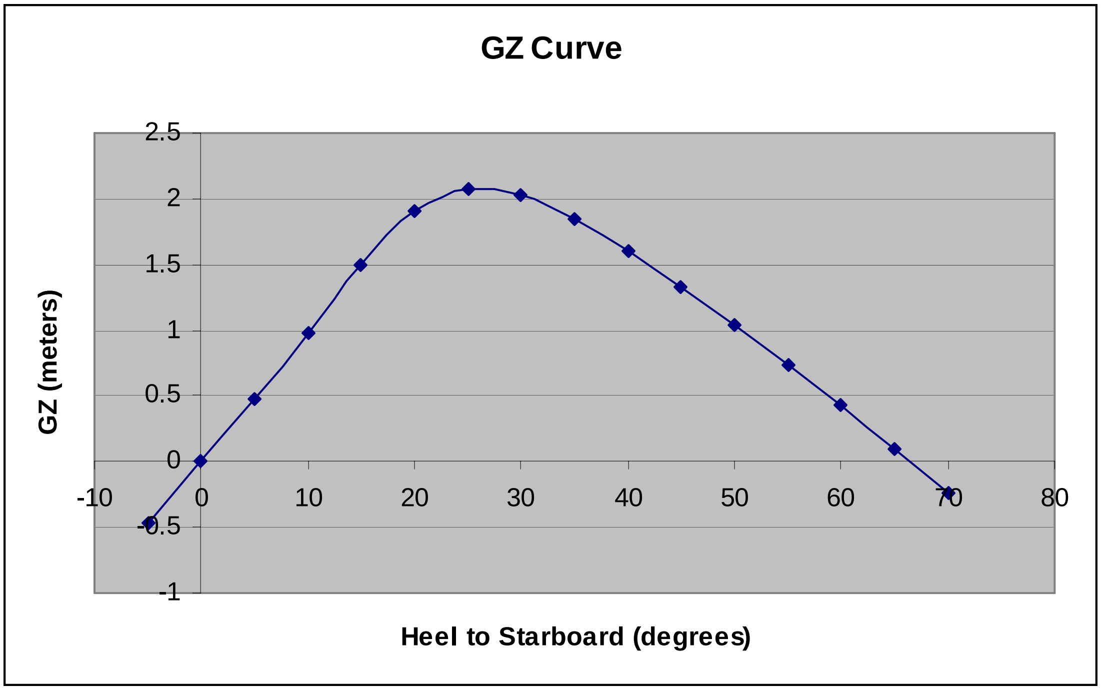


Figure 17. The righting arm curve, GZ vs. angle of heel.

Resistance and Powering

Preliminary powering estimates were performed using Watson's Method, which stands as a modification to the Admiralty Coefficient Approach. This method provides a simple estimation of the required shaft power.

$$Ps(kW) \equiv \frac{5.0 \quad \Delta^{2/3} \quad V^{3} \quad \left[40 - 0.017L + 400(k-1) - 12C_b\right]}{15000 - 110n\sqrt{L}}$$

This is mostly a frictional model based on the idea that P ≈ V3 where,

n = propeller revolutions per second obtained from U of M's Propeller Optimization Program (POP)

V = ship's speed in meters per second

L = ship's length in meters

Cb = block coefficient

Δ= displacement in metric tons

$$k \equiv 1.04 + 0.8(\frac{V_k}{\sqrt{L_f}} - 0.5)$$

Where,

Vk = speed in knots

Lf = length in feet

Then shaft horsepower was converted into required installed brake horsepower, Pb, by taking into account a liberal 95% electric drive efficiency, as well as 15% service margins. The results are shown below in Figure 18.

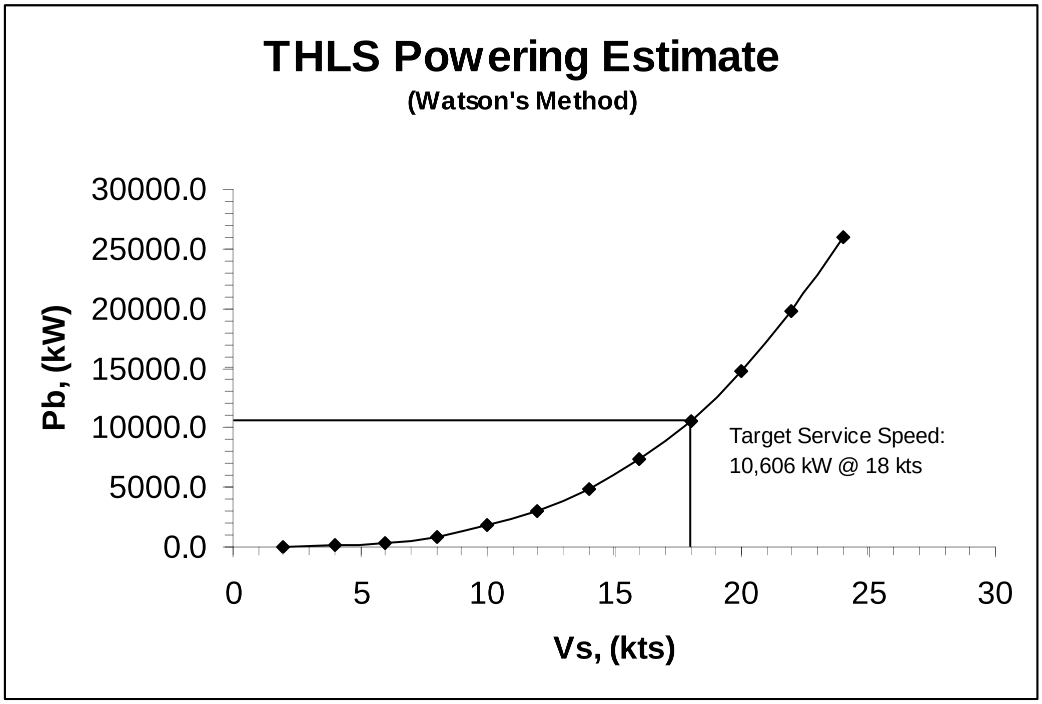


Figure 18. Powering estimate for the transformable heavy lift ship using Watson's Method, a modification of the Admiralty Coefficient Approach.

The estimate shows that at the service speed of 18 knots, the ship will require 10,606 kW of brake power. Based on the analysis of the powering requirements and research on medium speed diesels engines, two engines rated at 6,000 kW each have been chosen for the ships main propulsion engines in the integrated electric drive system.

The speed while in the ballasted mode is 0 knots. An idle ship will allow for easier sailing of LCACs onto the ship's deck while the vessel maintains a station using the dynamic positioning system.

Conclusions

Summary

A transformable heavy lift ship concept was developed to provide the required deck area and LCAC interface while reducing the motions experienced during trials with a traditional heavy lift ship. The concept vessel has a service speed of 18 knots and can transport five LCACs. A unique feature of this vessel is its capability to transform its upper deck into a platform 60 meters wide using deck extensions deployed from both sides. During transit, these extensions would be raised to allow for efficient passage and transit through the Panama Canal. Upon arriving in the operational theater, the ship would ballast down into a mode with reduced waterplane area for enhanced seakeeping characteristics, and the extensions would rotate outward to double the breadth of the ships main working deck and provide a stable platform for the loading of LCACs.

Further Work

The team recommends the following work in support of the Transformable Heavy Lift Ship concept. It has been divided into three levels of risk in relation to the overall effectiveness of the design.

High Risk Issues

The exact mechanical operation of the transformable platform needs to be worked out from strength of materials and kinematic point of view. The strength issues arise in the deck hinges, actuators, and other connectors. A detailed locking mechanism design is also needed to hold the extended platform in place, and another to lock it while folded in transit mode.

A seakeeping analysis in the ballasted mode is required to validate the benefits of the predicted increase in the ship's natural roll. Additionally, the effect of the sponsons should be taken into account in order to capture their effect on the roll motions as well in higher sea states.

Relative ship motions between cargo ship and the transformable heavy lift ship are a critical issue for the offloading of wheeled and tracked vehicles in high sea states. The proper mooring configuration must be determined to minimized the relative ship motions and allow a ramp from the cargo ship to remain fast on the transformable platform.

Medium Risk Issues

Structural and hull girder stress arising from the cutouts below the main deck could be an issue. The effective breadth of the strength deck is reduced by cutting outboard sections of the hull for reduced waterplane area. A structural model made to analyze stress concentrations in these regions can point to the best structural scantlings for this unique hullform.

Detailed weight estimates that include a more in depth estimation of specific weights to be installed onboard the ship will be needed. Additionally, the rough scaling from the Joint High Speed Sealift introduces a level of uncertainty that is unacceptable to a comprehensive weight estimate.

Improved powering estimates should be performed to better reflect the hullform as it stands at the end of the ten-week project. The preliminary Watson’s Method came along with a number of assumptions that could severely affect the output for powering data.

References

“Focus on Propulsion Pods.” Genova: Studio di Ingegneria Navale e Meccanica, June 2004.

"Heavy Lift Ships." 06 Sep 2006 . GlobalSecurity.org. 31 Jul 2007 <http://www.globalsecurity.org/military/systems/ship/heavy-lift.htm>.

"High Speed Sealift." 07 July 2006. GlobalSecurity.org. 31 Jul 2007 <http://www.globalsecurity.org/military/systems/ship/hss.htm>.

“High Speed Sealift SWBS” 12 February, 2007. CISD Sharedrive.

Joint High Speed Sealift (JHSS) - SWBS, Center for Innovation in Ship Design Share Drive

"Landing Craft, Air Cushion (LCAC)." FAS Military Analysis Network. 14 Feb. 2000. Federation of American Scientists. 22 May 2007 <http://www.fas.org/man/dod-101/sys/ship/lcac.htm>.

"Landing Craft, Air Cushioned - LCAC." United States Navy - Fact File. 30 Dec. 2003. United States Navy. 30 May 2007 <http://www.navy.mil/navydata/fact_display.asp?cid=4200&tid=1500&ct=4>.

Lamb, Thomas. Ship Design and Construction, Vol II. 4. Jersey City: Sheridan Books, 2004.

Moore, John, ed. Jane's Fighting Ships: 1987-88. London: Jane's Company Limited, 1987.

"Pierson - Moskowitz Sea Spectrum." 19 Apr 2007. Resolute Weather. 30 Jul 2007 <http://www.oceandata.com/support/Sea%20State%20Table.htm>.

"Poscon DP." 2002. Rolls-Royce. 31 Jul 2007 <http://www.rolls-royce.com/marine/downloads/automation/pcdp_fact.pdf>.

"Positioning Systems." 13 Aug 2002. ABB. 31 Jul 2007 <http://www.abb.com/cawp/seapr035/b61a6236467cbd37412567f6004fcd94.aspx>.

Project Guide for Azipod Propulsion Systems. Finland: ABB Oy, 2004.

"Propulsion." Rolls-Royce. 31 Jul 2007 <http://www.rolls-royce.com/marine/downloads/propulsion/prop_broc.pdf>.

Seabase to Treeline Connector Innovation Cell Naval Research Enterprise Intern Program Final Report, NSWCCD-20-TR-2005/05 August 2005

"Saturn." Nijhuis Pompen. 31 Jul 2007 <http://82.150.137.74/pompen/1/index.php?option=displaypage&Itemid=64&op=page&SubMenu=>.

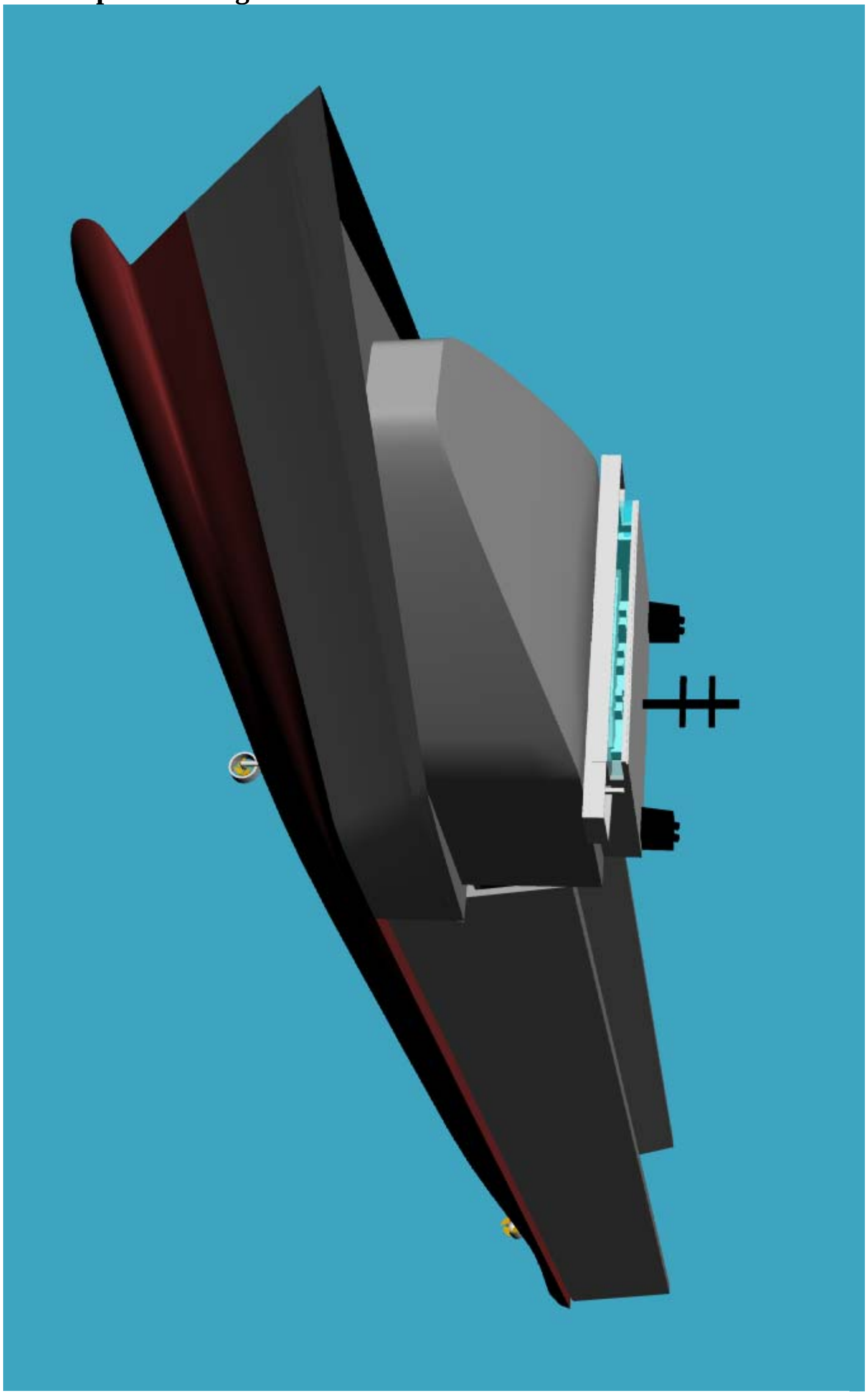
"S.E.M.T. Pielstick PA6 STC and PA6B STC." 2003. Rolls-Royce. 31 Jul 2007 <http://www.rolls-royce.com/marine/downloads/gas_diesel/pielstickpa6_fact.pdf>.

Van Dorn, William G. Oceanography and Seamanship. New York: Dodd, Mead, & Co, 1974.

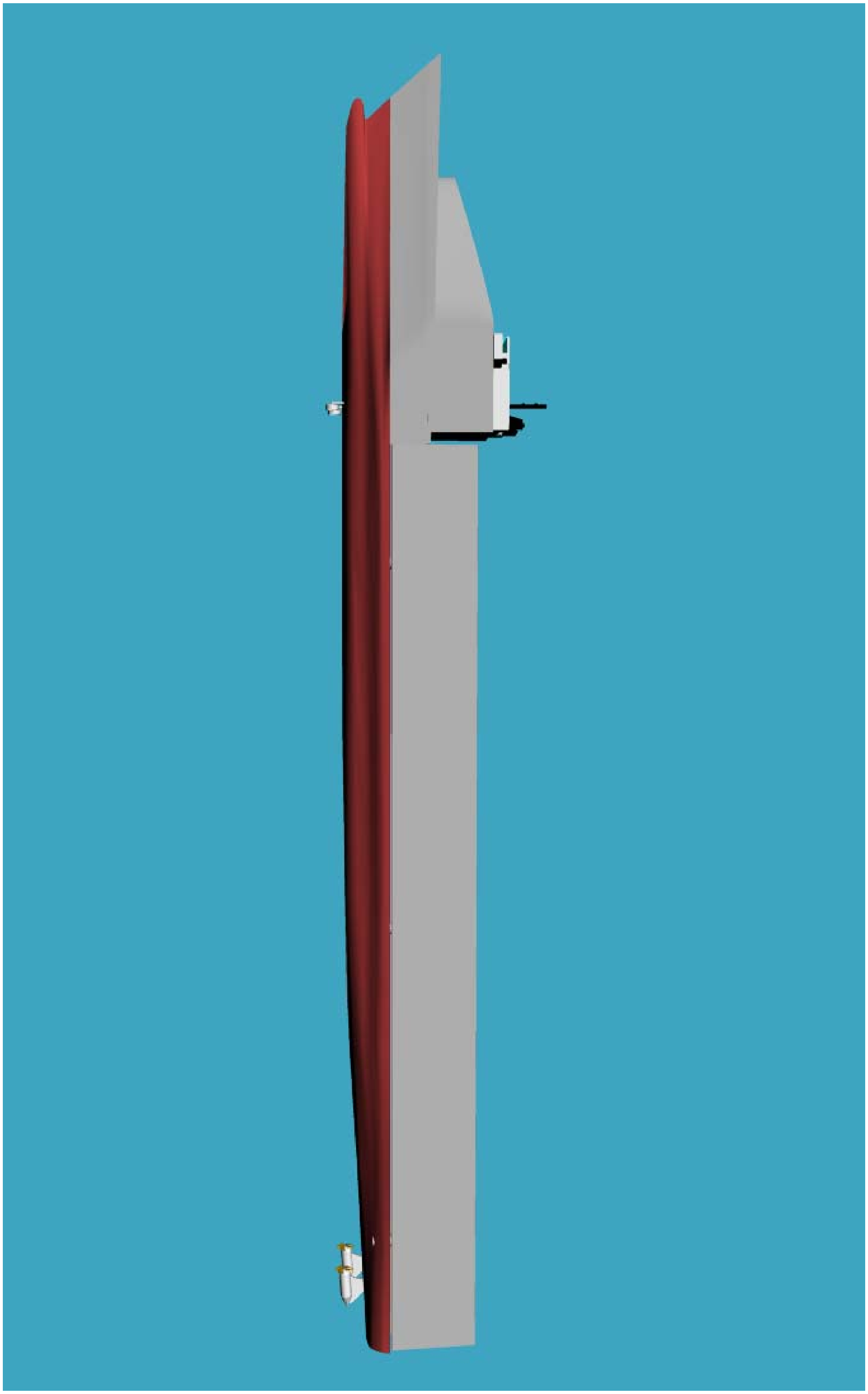
Van Hoorn, Frank: “A Conceptual Design of a Convertible Heavy Lift (CHL) Ship”, presented to the Golden Gate Section of the ASNE, June 1993.

Appendices

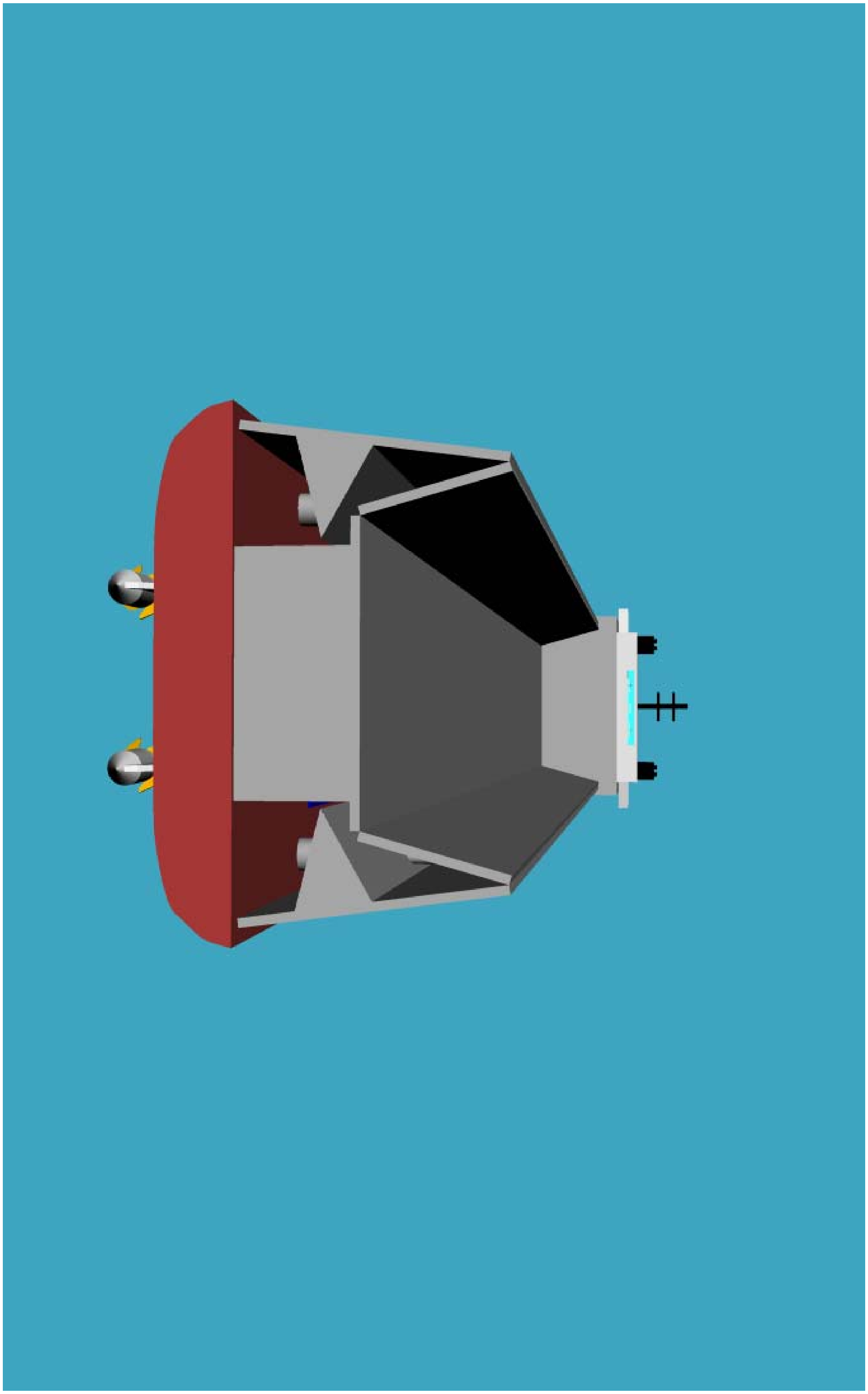
3-D Ship Renderings



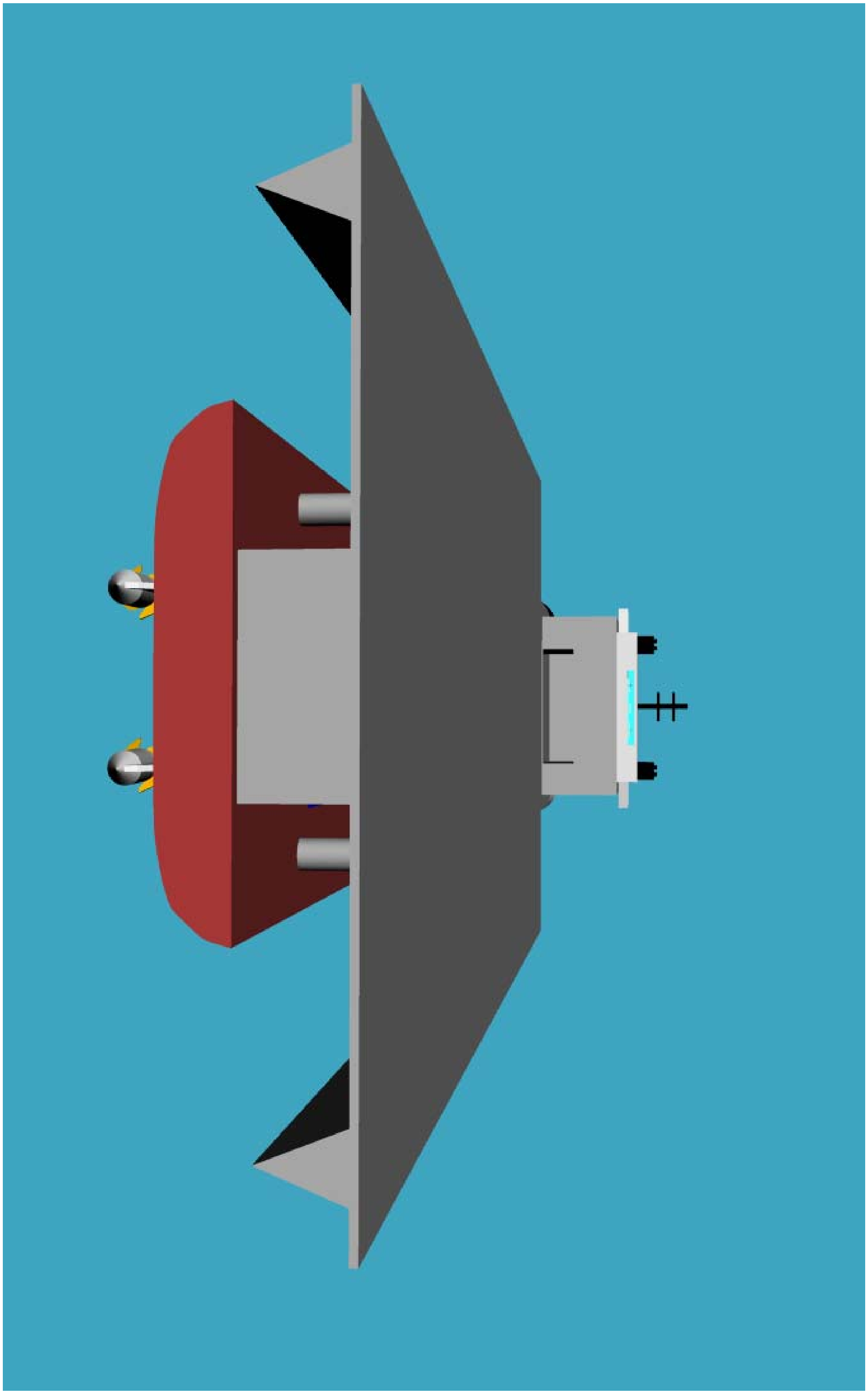
Perspective view of ship in transit mode



Profile view of ship in transit mode

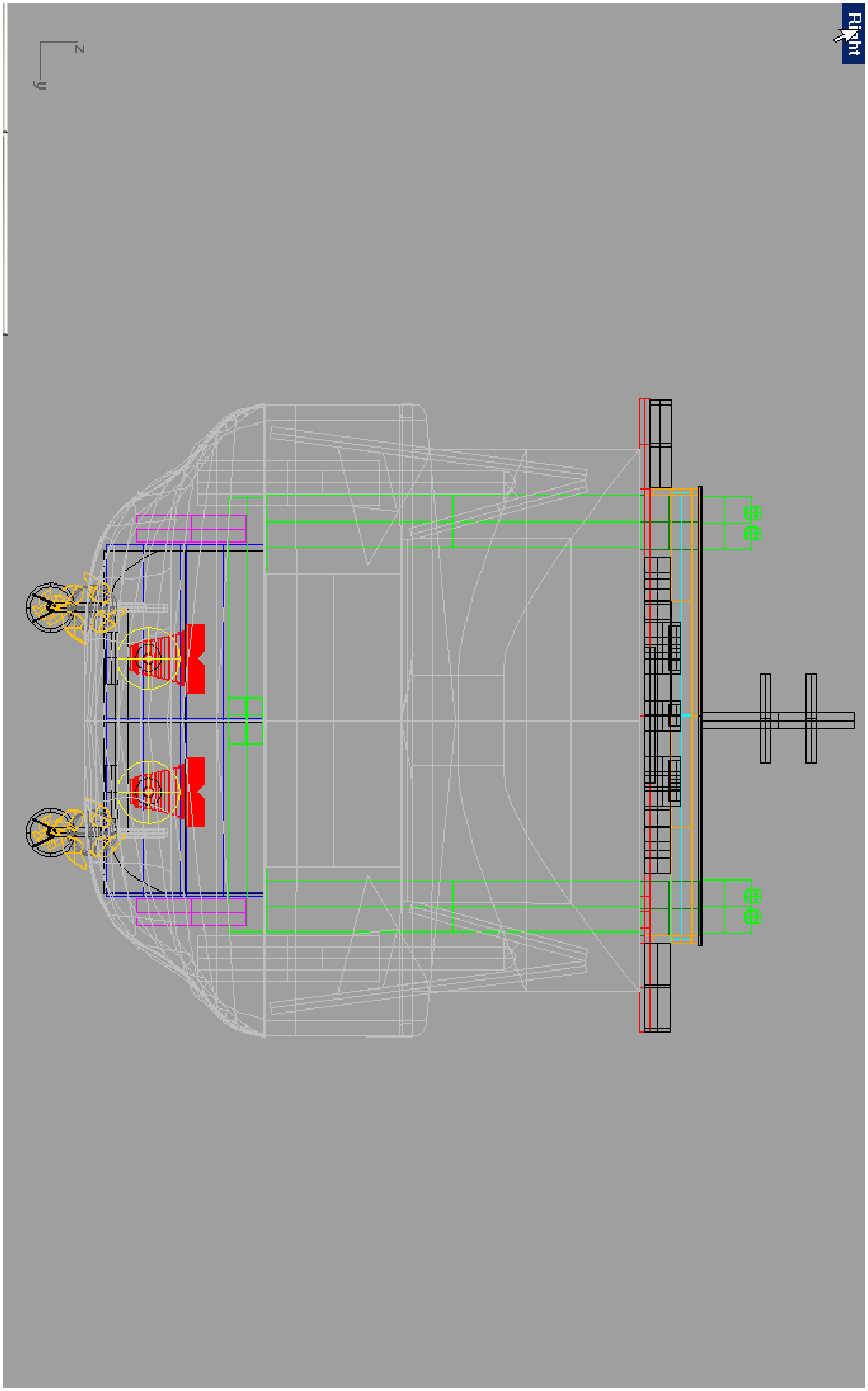


Body plan view of ship in transit mode

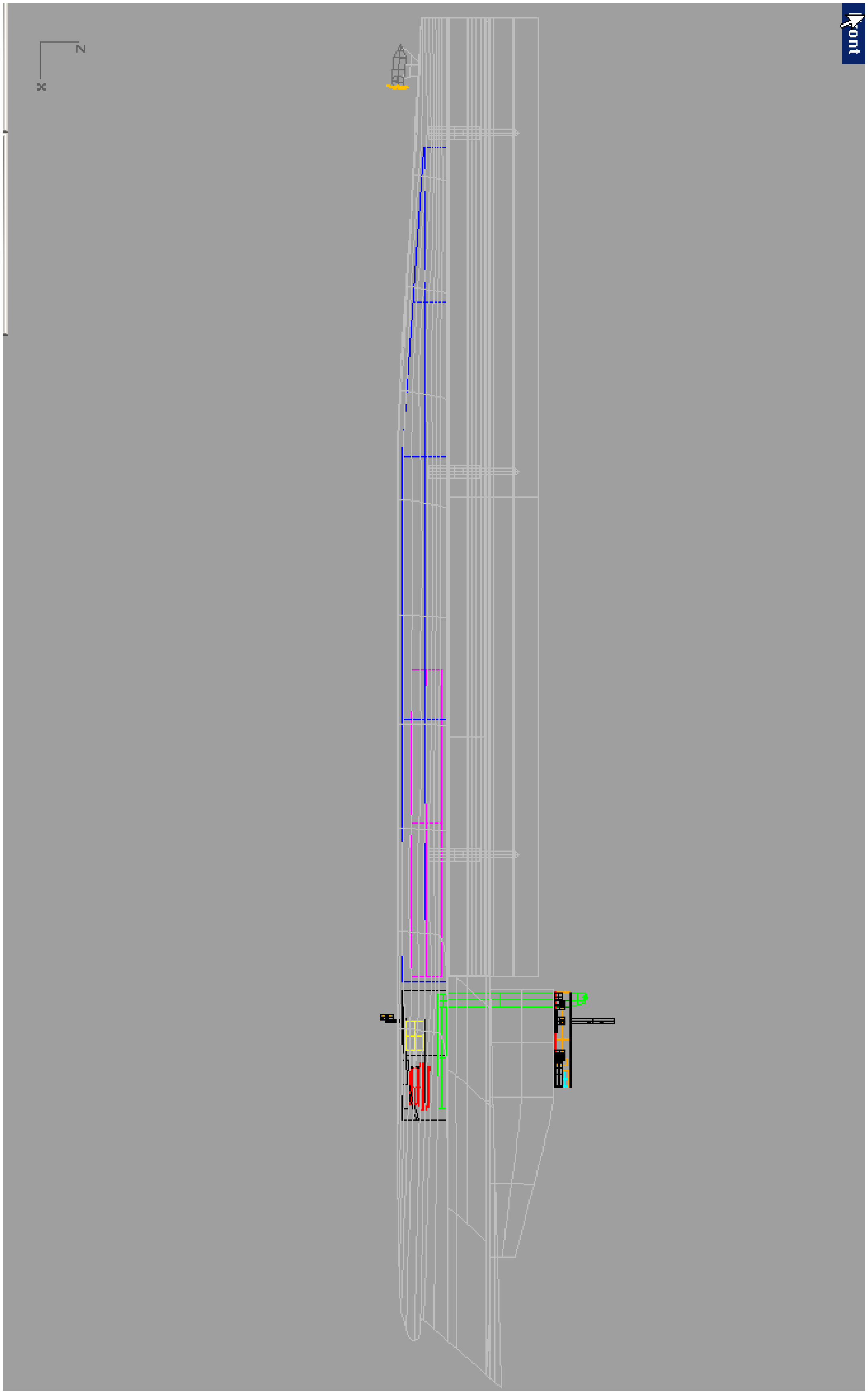


Body plan view of ship in ballasted mode (transformed)

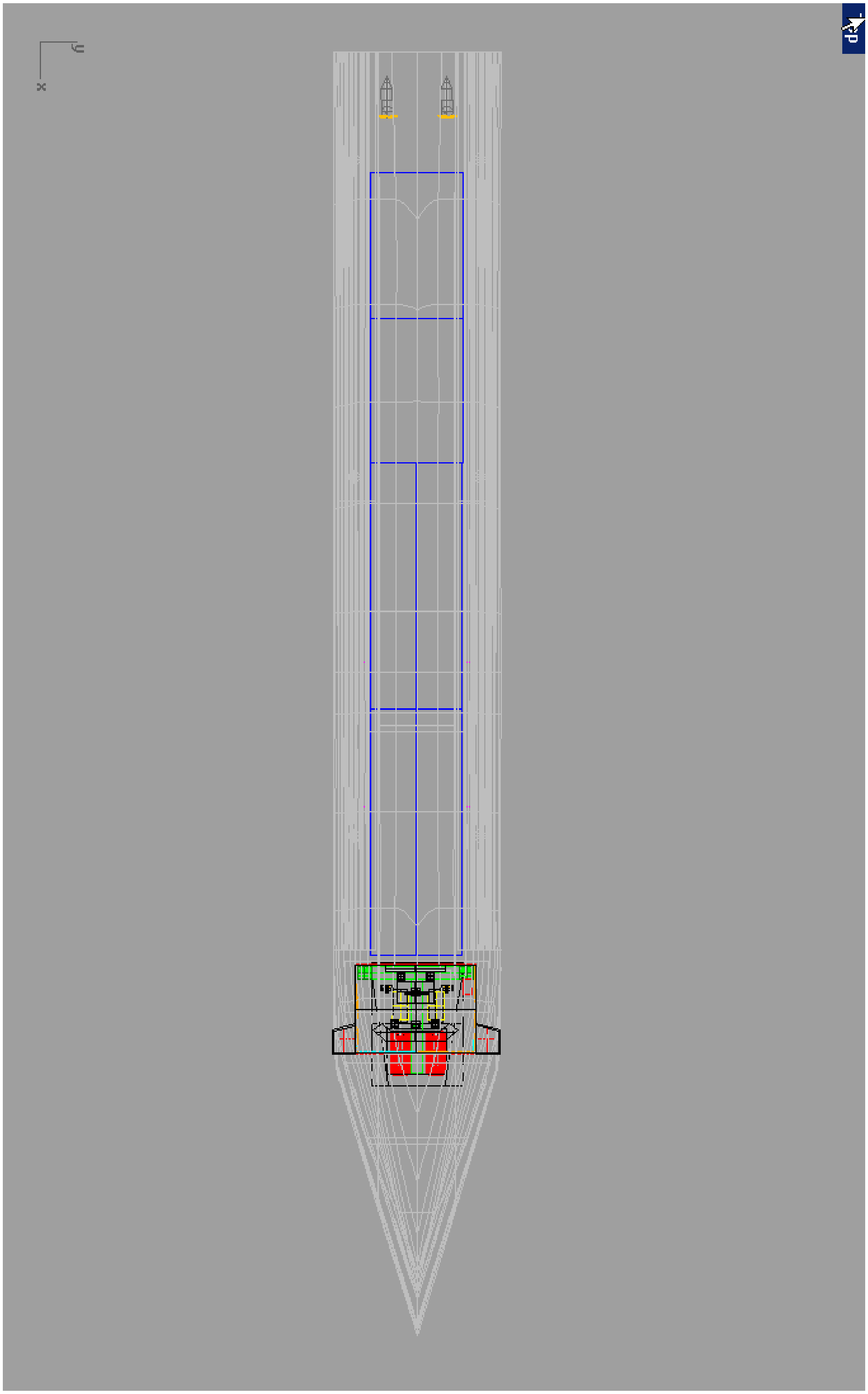
13.2 General Arrangements



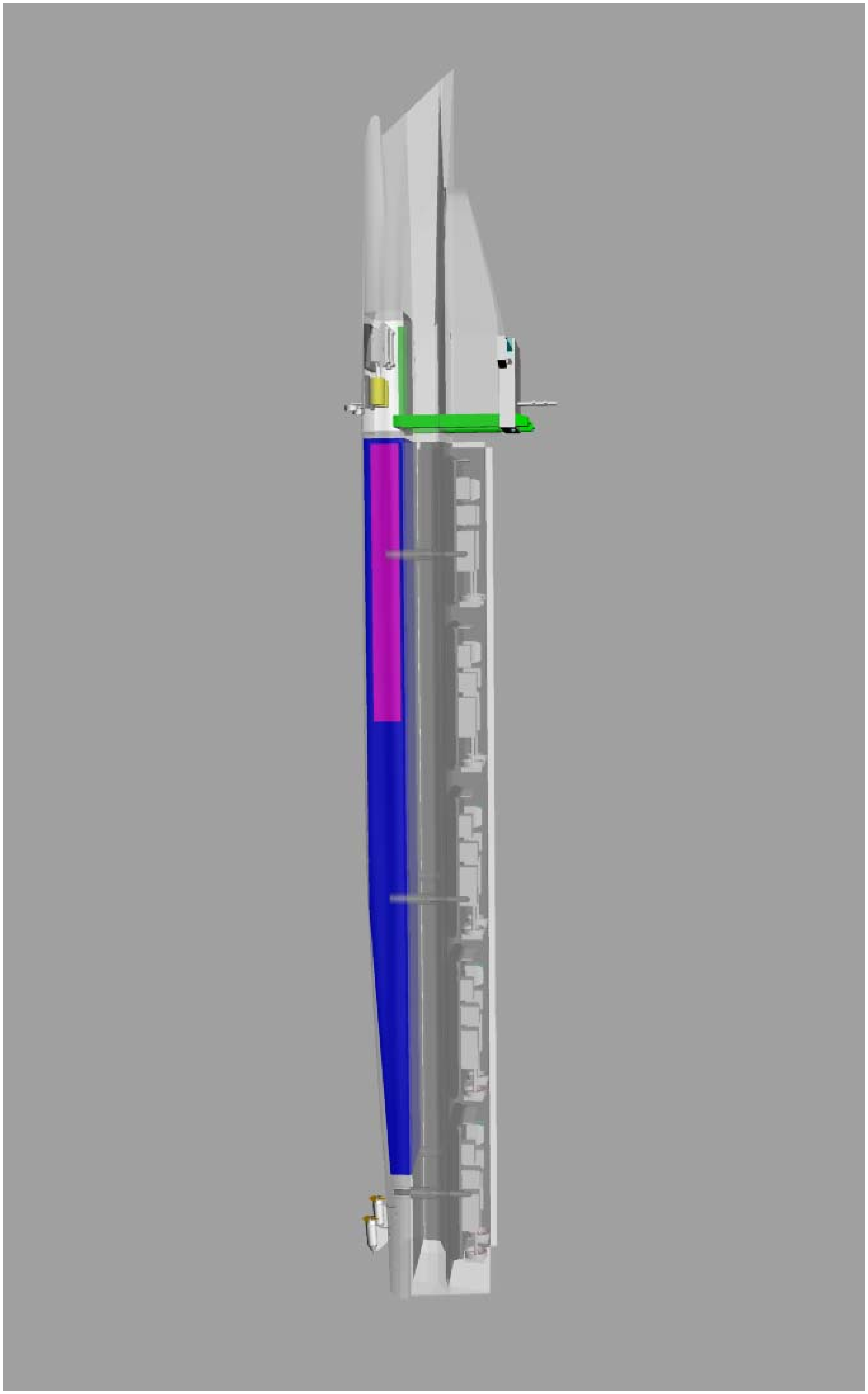
Body plan view of ship in transit mode



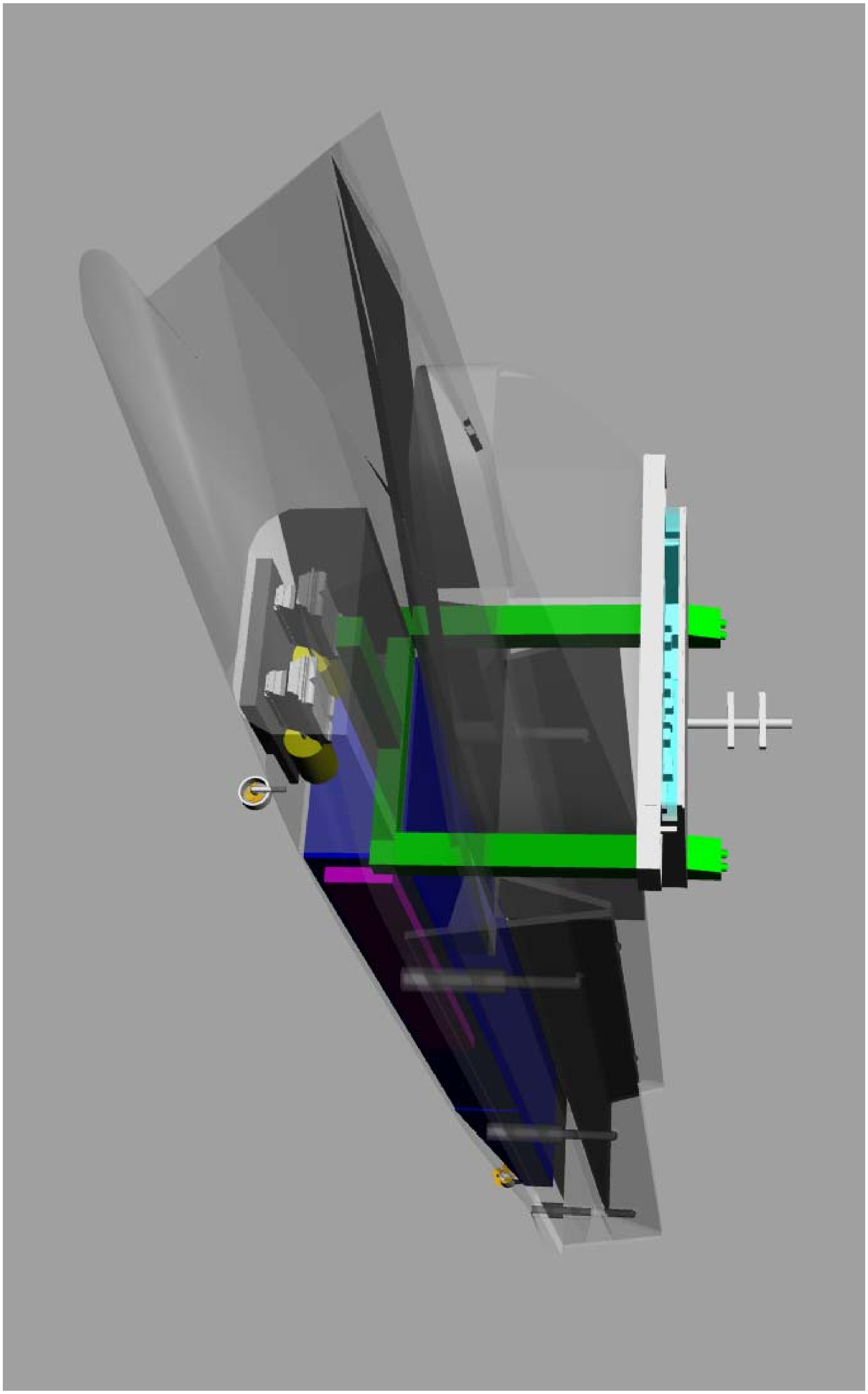
Profile view of ship in transit mode



View of ship in transit mode



Profile view of ship in transit mode



Perspective view of ship in transit mode

13.3 Weight Spreadsheet

SWBS Weight Estimate

				(from AP)	
Item	Mass (tonnes)	VCG (m)	mi x kgi	LCG (m)	mi x kgi
SWBS 100 Structures					
SWBS 100-149 (Primary Hull Structure)	7549.3	7	52845.1	115	868169.5
SWBS 150-190 (Superstructure/Misc)	2048	17	34816	170	348160
SWBS 200 Propulsion Plant					
SWBS 230 (Prime Movers)	126	4	504	150	18900
SWBS 240 (Propulsors)	600	5	3000	6	3600
SWBS 250 (Support Systems)	250	13	3250	165	41250
SWBS 260 (Fuel and Oil Systems)	70	4	280	145	10150
SWBS 270 (Special Purpose)	300	3	900	160	48000
SWBS 300 Electric Plant					
SWBS 310 (Electric Power Generation)	350	4	1400	145	50750
SWBS 320 (Power Distribution)	600	8	4800	100	60000
SWBS 330 (Lighting System)	80	14	1120	175	14000
SWBS 340 (Support System)	20	6	120	150	3000
SWBS 350 (Special Purpose)	50	6	300	150	7500
SWBS 500 Auxilliary Systems					
SWBS 510 (Climate Control)	563.8	7	3946.6	175	98665
SWBS 520 (Seawater Systems)	144.5	4	578	100	14450
SWBS 530 (Fresh Water Sytems)	98.1	2	196.2	130	12753
SWBS 540 (Fuels/Lubricants)	20	3	60	130	2600
SWBS 550 (Air/Gas+Misc Fluids)	50.03	8	400.24	165	8254.95
SWBS 560 (Ship Control Systems)	121.3	8	970.4	170	20621
SWBS 570 (Underway Repl Syst)	37.4	14	523.6	165	6171
SWBS 580 (Mech handling syst)	242	10	2420	180	43560
SWBS 590 (Special Purpose)	114.9	13	1493.7	140	16086
SWBS 600 Outfit/Furnishings					
SWBS 610 (Ship Fittings)	23.73	12	284.76	180	4271.4
SWBS 620 (Hull Compartmentation)	213.5	5	1067.5	100	21350
SWBS 630 (Preservatives/Coverings)	518.5	6	3111	115	59627.5
SWBS 640 (Living Spaces)	184	17	3128	175	32200

SWBS 650 (Service Spaces)	25	13	325	175	4375
SWBS 660 (Working Spaces)	26.3	5	131.5	150	3945
SWBS 670 (Stowage Spaces)	154.4	8	1235.2	185	28564
SWBS 690 (Special Purpose)	15	3	45	160	2400

KG	8.646619
LCG	122.2817

SWBS Summary	tonnes
100 Structures	9597.3
200 Propulsion	1346
300 Electric Plant	1100
400 Command and Control	27
500 Auxilliary Systems	1005.6
600 Outfit/Furnishings	1103.7
700 Armament	1
Total Lightship	14179.6
Total Lightship w/ 10% Design Margin	15597.56
Diesel Fuel (10,000 nm range)	1370
5 LCACs (fully loaded)	900
Miscellaneous (crew, stores, etc.)	45.4
Deadweight	2315.4
Full Load Displacement	17912.96

13.4 Powering Analysis

Reference: 2. Watson, D. G. M., "Estimating Preliminary Dimensions in Ship Design," Transactions Institute of Engineers and Shipbuilders of Scotland, 1962.

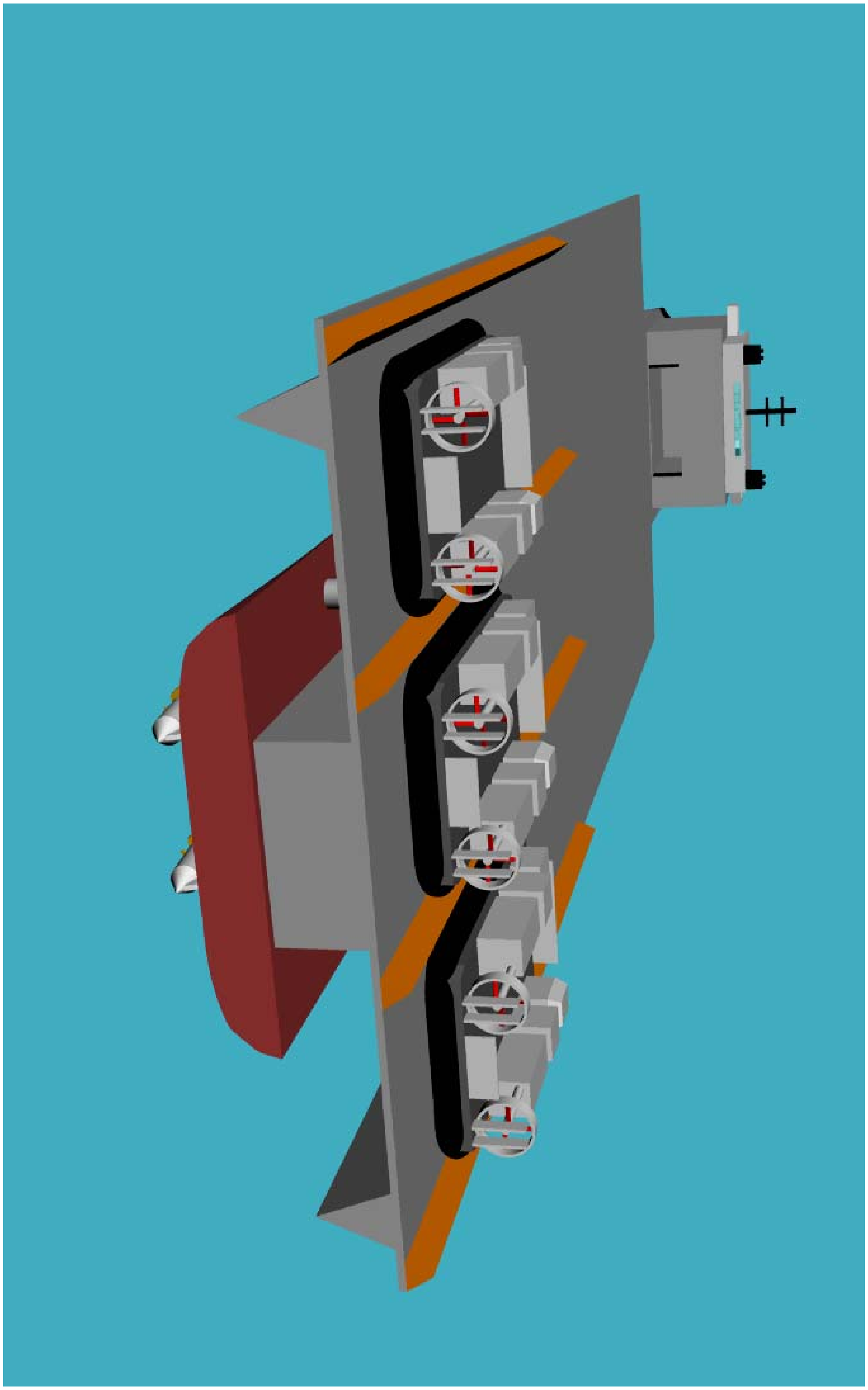
Ship Data

	input data			calculated data	
Vk	18.0	knots	V	9.259	m/s
L	208.6	m	Lf	684.4	ft
B	25.43	m	Bf	83.4	ft
T	5.50	m	Tf	18.0	ft
Bulbous bow	1	yes(1);no(0)	B/T	4.624	
Number props	2	1 or 2 only	Vk/sqrt(Lf)	0.688	
□s□b	0.970		Fn	0.205	
Propeller N	271.9	rpm	Propeller n	4.532	rps
Service margin					
Ms	15.0%		Displacement	17612.1	t
□g	0.995		Displacement	17336.9	LTSW
Water density					
□	1.025	t/m3	Volume	17097.0	m3 molded
Cb	0.586				

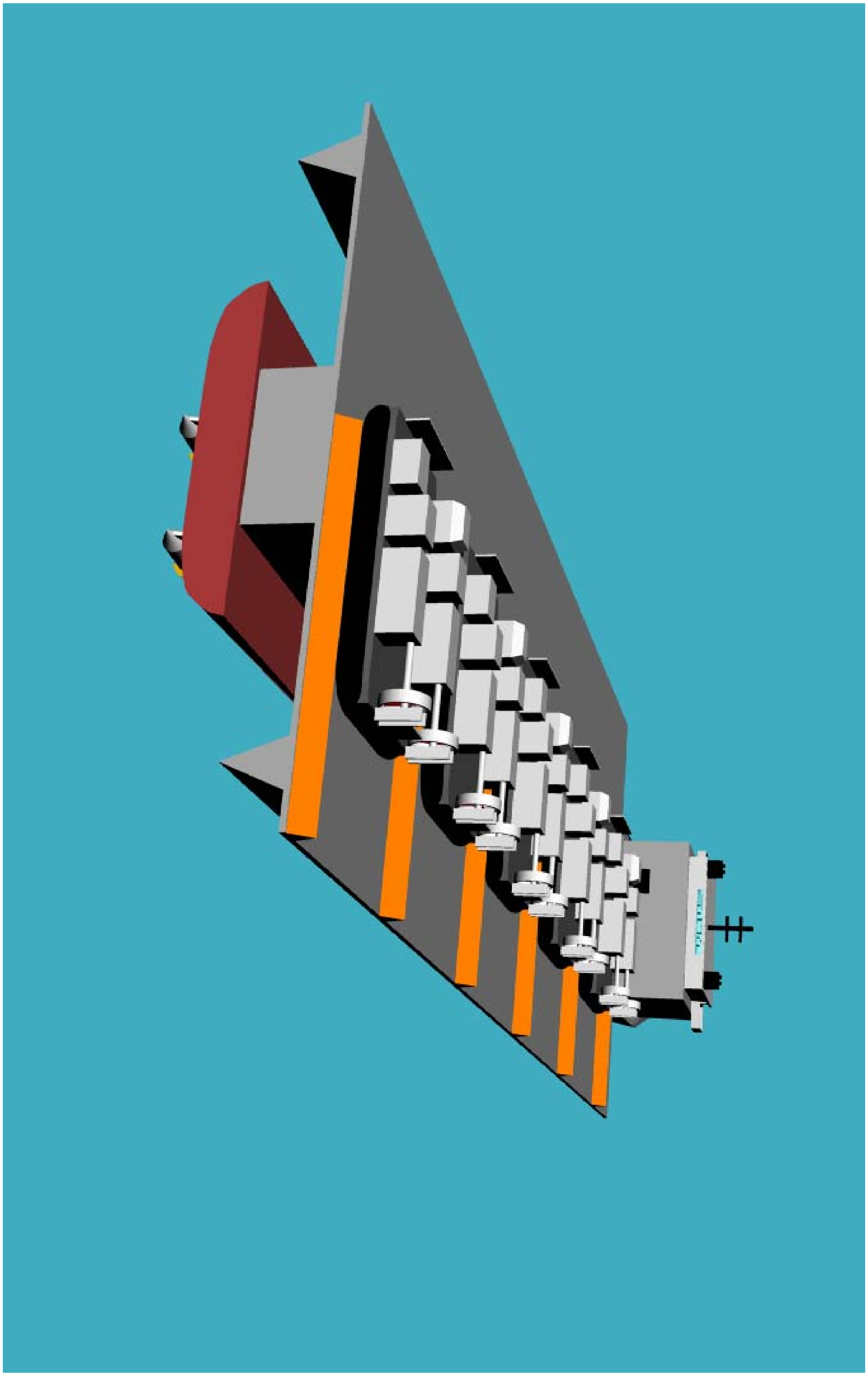
Vs (kts)	Pe (kW)
2	14.0
4	112
6	379
8	901.6
10	1768.8
12	3073.5
14	4912.7
16	7387.1
18	10606
20	14683.7
22	19742.6
24	25913.7

By varying the ship speed in the first entry, a preliminary power curve was created.

13.5 Working Deck Arrangements



Working Deck, LCACs shown after ship is trimmed by stern



Working Deck, LCAC's shown after ship has heeled