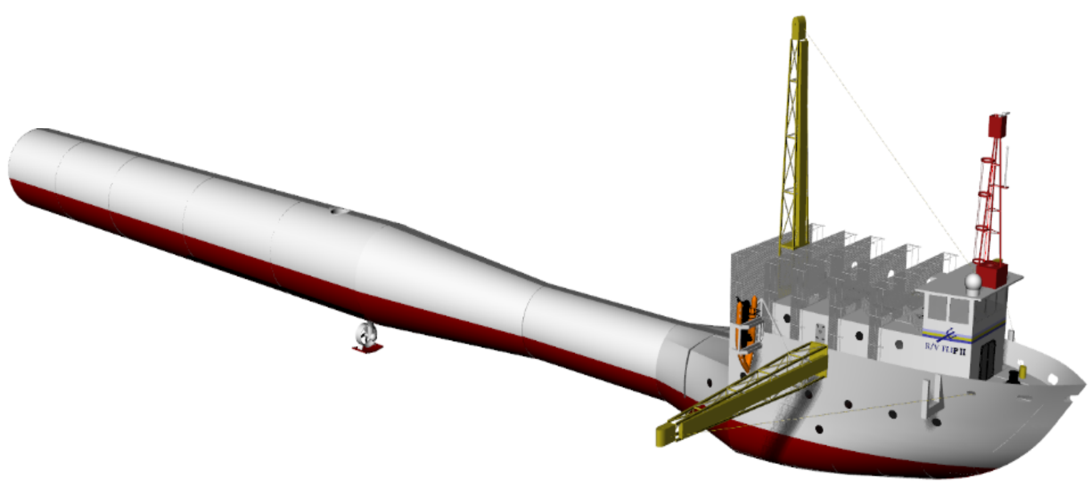
University of Michigan

Naval Architecture and Marine Engineering Department

Research Vessel Floating Instrument Platform II (*R/V FLIP II*)

Dr. James A. Lisnyk Student Ship Competition Design Report

14 June, 2014



Vittorio Bichucher *Harleigh Seyffert*

Phillip Cenzer *Michael Sypniewski*

Jonathan Holbert

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Scripps Institute of Oceanography

Capt. William Gaines	*R/P FLIP* Captain, US Navy Ret.
Tom Golfinos	*R/P FLIP* Officer in Charge
Dr. Gerald D'Spain	

NA&ME Department Faculty:

Dr. Matthew Collette

Dr. Armin Troesch

Dr. Steve Ceccio

Dr. David Singer

Dr. Kevin Maki

Industry Contacts

Mr. Matthew Miller	The Glosten Associates, Inc.
Mr. Paul V. Devlin	Chevron Energy Technology Company
Mr. Dave Wisch	Chevron Energy Technology Company

NA&ME Department Advisory Board

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Lianna Gordon	Swiss Re
Kevin Graney	General Dynamics NASSCO
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Douglas Pearlson	Pearlson Shiplift Corporation
Bruce Rosenblatt	Bruce S. Rosenblatt & Associates
Rick Spaulding	Northrop Grumman Corporation
Robert Tagg	Herbert Software
Robin White	United States Navy
Ronal Yeung	University of California, Berkeley

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1.0 Executive Summary

The *R/P FLIP* is an Office of Naval Research (ONR) owned research platform operated by the Scripps Institution of Oceanography. Constructed in 1962, *R/P FLIP* was initially designed for a single research project but has been in use ever since. Currently, *R/P FLIP* is towed to a research location, trims by ninety degrees, and is moored in position. The exceptional stability in its vertical orientation enables *R/P FLIP* to conduct scientific experiments with minimal wave interference. The scientific community has expressed interest in a redesign of *R/P FLIP.*

The *R/V FLIP II* is an upgraded response to the successes and shortcomings of the *R/P FLIP*. The vessel has self-propulsion and self-mooring capabilities with significant improvements in habitability and scientific capacity. The vessel maintains *R/P FLIP*'s extremely high vertical stability for oceanographic research operations in the Pacific Ocean.

The vessel was designed to operate in the mid-latitude Pacific Ocean. The range of the *R/V FLIP II* is 2200 nautical miles (the distance between San Diego to Hawaii), and the vessel has an endurance time of 45 days without re-supply.

R/V FLIP II is approximately 150 feet longer than the current *R/P FLIP*, totaling an overall length of 450 feet. This increase allows for improvements to the living space and provides more stable operations in the vertical position. The principal characteristics of the vessel are represented in Table 1.

Table 1. Principal Characteristics

Design Characteristics	Value	Design Characteristics	Value
Length Overall	455 ft	Range	2,200 Nm
Waterline Length	440 ft	Installed Power	1,196 kW
Maximum Breadth	36.5 ft	Service Speed	8 knots
Horizontal Sailing Draft	13.5 ft	Horizontal Displacement	3,131 LT
Vertical Draft	300 - 340 ft	Vertical Displacement	4,449 – 4,764 LT
Cost	$40.5 M USD		

The general arrangements optimize the scientific spaces so that different research groups can perform their work concurrently. As requested, the design also significantly enhances the living quarters. A major effort was made to improve privacy and comfort aboard the vessel. The result was a notable increase in laboratory space and habitability onboard *R/V FLIP II.* The design goal was to permit multiple research cruises at once, thereby saving time and increasing revenue. Finally, the complement on *R/V FLIP II* has been increased to 20 (5 crew and 15 scientists).

R/V FLIP II is equipped with three 60ft booms for scientific equipment deployment, and a newly designed deployment area near the vertical water line. The vessel can carry up to 300LT of scientific payload, but 50LT is the design, and recommended, value. *R/V FLIP II* is now capable of self-mooring using an anchor windless winch located at the bow. Three drums are used to store a total of 18,000ft of line. *R/V FLIP II* is capable of using a three-point-moor up to 6,000ft depth.

An extensive trade study on propulsion and design speed was conducted to weigh the benefits and shortcomings of different machinery. Resistance calculations showed that the required power increased drastically for transit speeds over 8 knots, and therefore 8 knots was chosen for *R/V FLIP II*'s design speed. A Thrustmaster TH1500MLR retractable thruster was chosen to decrease maintenance and cost, and to increase efficiency. Moreover, the trade study selected the highest energy to volume and weight ratios generator. *R/V FLIP II*'s power plant will consist of two John Deere 6315S and one John Deere 6068S generator drives. As requested by SCRIPPS scientists, battery packs are also installed onboard *R/V FLIP II* enabling the use of clean, silent power during sensitive acoustic research.

R/V FLIP II's ballasting and flipping sequence was designed for optimal stability throughout the flipping procedure and for minimal accelerations and velocities near the final degrees of the flipping sequence, thus reducing the risk of the vessel plunging and trimming past ninety degrees. The flipping procedure was studied using a model test to ensure its safety. Results show that the vessel goes through its point of instability at a much slower velocity, therefore decreasing the risk of going over ninety degrees.

A thorough seakeeping analysis was performed for *R/V FLIP II* in both the horizontal and vertical positions to ensure that the vessel reacts soundly to wave excitations. A 50ft long bilge keel at midship is necessary for optimal horizontal seakeeping results in roll. Also in horizontal, *R/V FLIP II* does not experience any large motions in heave or pitch. The vertical seakeeping analysis quantified *R/V FLIP II's* heave response when exposed to different sea states. The study showed the success of the design: in the vertical position, *R/V FLIP II's* heave is approximately 3% of the incoming significant wave height for sea state 5.

An extensive structural analysis was performed to assess the structural needs of the vessel. Due to design uniqueness, American Bureau of Shipping (ABS) rules for building and classing steel vessels 2014, and ABS guidelines for the design of offshore structures were used. A minimal number of unique sizes and shapes for the structures of the vessel were used to minimize production costs.

The total cost of *R/V FLIP II* was estimated to be $40.5 M USD, with an operational cost benefit of approximately $125,000 USD per mission when compared to the *R/P FLIP*.

R/P FLIP has been an incredible asset for the Office of Naval Research (ONR) due to its capabilities, but a re-design of the *R/P FLIP* would bring numerous benefits to the scientific community. Scientists are concerned with the lack of habitability, comfort, and space for larger scientific explorations. The *R/V FLIP II* mitigates these concerns and others, proving to be a vessel that is safer, cheaper, and feasible.

2.0 Owner's Requirements

The requirements for this new vessel were developed by Scripps Institute of Oceanography (SIO) and scientists who have closely worked with *R/P FLIP*. In summary, the research vessel shall be proven to be more habitable, efficient, self-sufficient, and cost effective over its lifetime. The detailed requirements for this new research vessel are hereby listed.

2.1 Objective/Purpose

The vessel must be built for the advancement of deep water oceanographic research. It must also possess the characteristic of trimming to ninety degrees.

2.2 Environment/Trade Route

The vessel shall operate mainly off the US West Coast and within the low and mid latitudes of the Pacific Ocean. The vessel shall have the ability to self-moor in depths of up to 6000ft using a three point mooring. The vessel shall have low vertical heave response (less than 5%) in up to 60ft waves, and a medium heave vertical heave response (less than 25%) in 100ft waves.

2.2 Cargo/Capabilities

The vessel shall incorporate a modular design concerning its scientific capabilities. These spaces are required to total more than 600 ft^2. This value includes transition time. The vessel shall include three deployment booms to deploy research instruments in the vertical position. In the horizontal, the booms must be retrieved. A desired feature for the vessel is an improved system for the transfer of passengers and crew by air and water. The capability to deploy and retrieve underwater vehicles shall also be addressed.

2.3 Limitations

The vessel is limited mostly by her mission: for seakeeping purposes, she shall have a low waterplane area in the vertical position. The vessel shall minimize noise while in the vertical position. All efforts should be made to reduce production costs, as previous re-designs for a new *R/P FLIP* were halted due to exceeding budget.

2.4 Dimensional Constraints

The maximum length in the horizontal condition shall be 550 ft. The breadth of the vessel shall be sufficient to support the desired objective. The displacement shall be defined by general arrangements, scientific payload, and required tankage. A major consideration for the vessel is that of clearances: the scientific booms must have a sufficient range of motion.to be retrieved in the horizontal, and fully extended in the vertical

2.5 Speed and Endurance

The vessel shall have a cruising speed of at least 5 knots and have a maximum endurance of 45 days. This value includes transition time. The vessel shall have enough fuel to travel from San Diego to Hawaii.

2.6 Complement

Accommodations and provisions shall be planned for up to 20 passengers (5 crew, 15 researchers) for 45 days without resupply.

2.7 Equipment

The following equipment shall be installed aboard:

- Reverse Osmosis System
- Enough space for a one working class Autonomous Underwater Vehicle (AUV)
- Enough space for a one working class Remotely Operated Vehicle (ROV)
- Auxiliary cranes to assist the deployments of the AUVs or ROVs
- Support Boats to assist operations on vertical
- Necessary equipment (winches, etc.) for the mooring system

2.8 Regulatory Approach

The vessel is to be funded by the United States government, so it shall be US built, flagged, and operated. The vessel shall meet American Bureau of Shipping and United States Coast Guard requirements on research vessels, or similar.

3.0 Primary Design Drivers

Research vessels are an integral part of oceanographic research, taking samples and data that are used for various studies of the oceans' processes, properties, and life. These discoveries have a direct relation to our daily life, since the oceans help to shape the atmosphere's condition. Some of these experiments require minimal interference from the vessel and even the ocean motion itself. Figure 1 presents the conventional naming of each hull section used throughout this report.

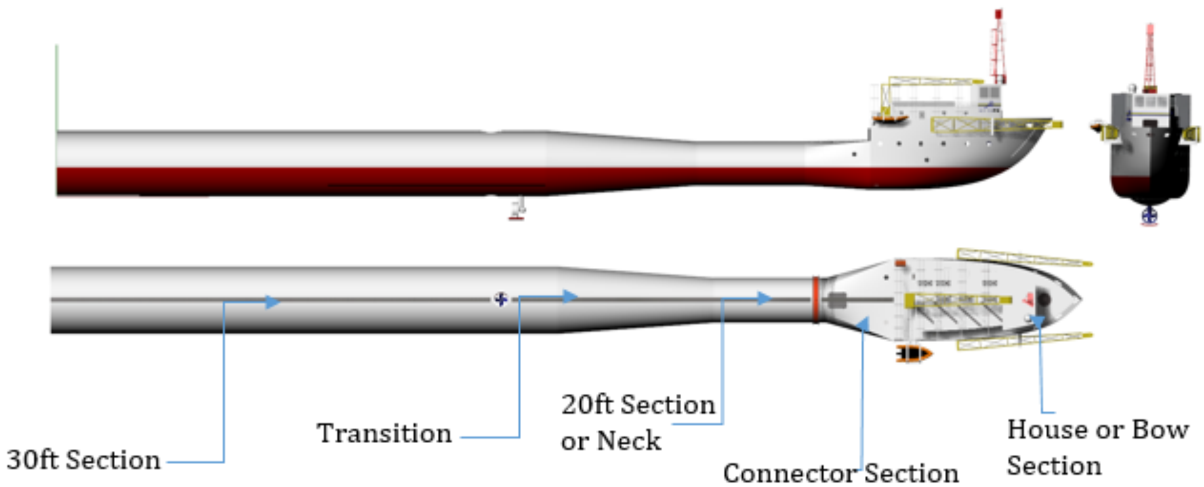


Figure 1. Conventional naming of hull sections

The *R/P FLIP* is an ocean-going stable research platform designed for minimal heave response while in the vertical mode of operation. Hence, the *R/P FLIP*, operated by the Marine Physical Laboratory (MPL) at Scripps Institution of Oceanography, trims to ninety degrees when on station to provide a stable platform due to its small waterplane area. This low motion assists sound and motion-sensitive experiments, such as acoustic and air-sea interaction research.

The *R/P FLIP* averages four research cruises a year. However, even after a major overhaul in 1994, the *R/P FLIP* is still plagued by design and habitability issues; some scientists refuse to use the vessel because of its lack in comfort. The *R/P FLIP* is completely dependent on ocean-going tugs for mooring and its transportation to station, driving up costs for each research cruise. With all these setbacks, there still is large demand for and interest in the *R/P FLIP*'s capabilities. MPL's intentions are to continue using the vessel as long as possible. Motivation certainly exists for an updated *R/P FLIP*, and in the 1980s a new vessel was designed. Lack of funding, however, turned the new design away.

The *R/V FLIP II* is designed to be 150ft longer than its predecessor to allow for more living and scientific space. The cylindrical section of the *R/V FLIP II* is longer than the *R/P FLIP*, which allows more stable operations in the vertical position, and enough volume to add machinery space. Sizing estimates were based off the present geometry as well as comparisons with the sizing estimates for the re-design of the vessel done by The Glosten Associates in the late 1980's. The cylindrical section tapers into a smaller diameter section to further minimize heave response in the vertical position.

The increasing cost of renting ocean-going tugs caused a major push to design a vessel that can safely self-moor and self-propel. The forward section of the vessel needed to account for the extra volume in bringing this equipment aboard. The design allowed extra space in the cylindrical section for the propulsion, and the vessel has extra compartment space for additional propulsion units since maneuverability of the vessel needs improvements. The addition of another thruster is most possibly likely in the next steps of the design. By fixing the current problems and leaving extra space for future changes made during building and future design work, the *R/V FLIP II* will provide an updated, more habitable and stable vessel for sensitive scientific research cruises.

4.0 Hull Design

This section details the hull characteristics, design features, hydrostatics, curves of form, sectional area curves, and floodable length diagram of *R/V FLIP II*.

4.1 Hull Generation

A model was formed using Rhinoceros3D software. *R/P FLIP's* hull was used as a parent vessel since it is a design that can trim to ninety degrees, which is one of the primary challenges of the design. The Glosten Associates' redesign in the late 1980's was also used with the original lines from *R/P FLIP* to help make design decisions. General modifications were made to the hull design in order to improve seakeeping characteristics, increase berthing and scientific lab space, as well as provide the required space for the added propulsion and mooring systems.

The overall length, breadth, and draft of the vessel increased in order to accommodate all of the changes and additions that were necessary: The length of the vessel was augmented by approximately 150 feet and the aft end of the cylindrical diameter enlarged from 20 to 30 feet. Through increasing the size of the cylindrical section, more room was allotted for added machinery, and made the increase in the house section also possible. Simply increasing vertical displacement with an increase in the house without also augmenting the cylinder section could bring the vertical draft too close to the house, both sections saw increased volume. Moreover, increasing the cylinder diameter instead of just the length also helps the vessel maintain a smaller overall length. Keeping a shorter length limited propulsion requirements, since adding length is known to increase propulsion requirements at a higher rate than increasing the beam.

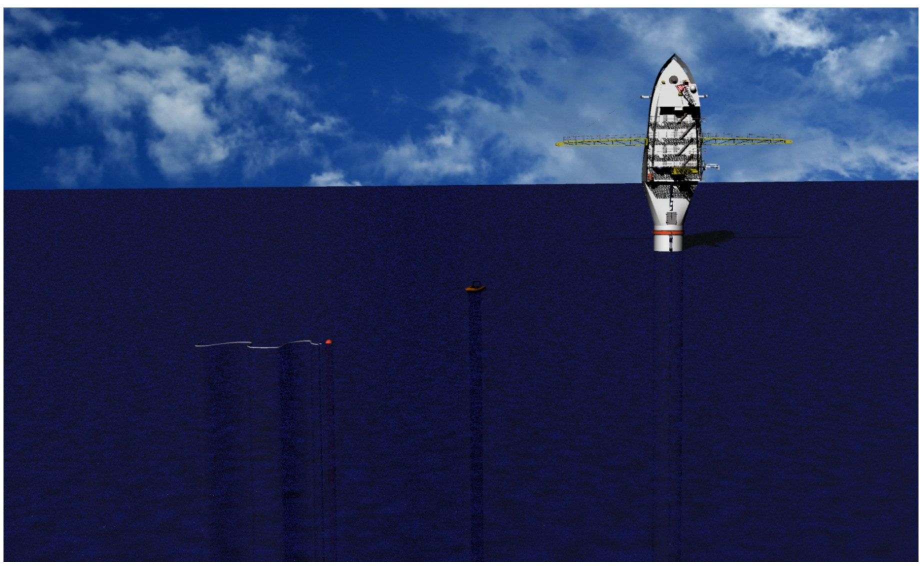


Figure 2. *R/V FLIP II* on vertical during mooring procedure

Increasing the diameter, however, can decrease the natural frequency in the vertical mode of operation (for more detail, see Section 14), yielding a higher risk of experiencing resonant heave responses. The displacement, therefore, must increase at a higher rate to avoid such risk. The design tried to optimize this relation, without having to increase the length by intensive amounts.

The optimal result arrived by increasing the house and connector by approximately 100ft, and the cylindrical section increased by approximately 50ft in length. The length and breadth of the house makes it possible to improve the habitability, as requested by the owners, to increase the air draft in the vertical condition, to increase scientific space, and to account for the added machinery needed for the mooring equipment. Significant improvements were made to the habitability and scientific lab capacity on board and will be detailed in the general arrangements discussion in Section 5**.** The *R/V FLIP II* is approximately 150 feet longer than the current *R/P FLIP*, totaling an overall length of 450 feet. This increase allows for improvements to the living spaces and provides more stable operations in the vertical position. The principal characteristics of the vessel are represented in Table 1.

4.2 Principal Hullform Characteristics

Through conversations with the operators of the *R/P FLIP*, it was determined that some analysis should be conducted in order to improve the horizontal seakeeping performance of the vessel. The bow of the present platform is very blunt and broad, providing poor performance in head seas. Through converting the stations from a “U-shape” to a “V-shape”, the seakeeping performance was theoretically improved. “V-shape” bows normally increase resistance, however, the pitch response in head seas was a major concern. Moreover, transforming the house from a “U-shape” to a “V-shape” decreased the volume inside the house. Therefore, it was beneficial that the length of the house increased significantly, since a considerable amount of space was lost through the narrowing of the stations. Table 2 presents some characteristics of the *R/V FLIP II*.

4.3 Design Features

The *R/V FLIP II* was designed to optimize living and working spaces, providing a better working platform for experiments coupled with more habitable quarters for those onboard. The designed scientific payload is currently 50 LT. The extra scientific payload is limited by stability during flipping. It is possible to bring the scientific payload up to 300 LT.

Table 2. Principal Hullform Characteristics

Principal Characteristics	
LOA (ft)	460
LWL (ft)	440
Maximum B (ft)	36.5
T (ft)	13.5
Trim at Departure (ft) (+ by the stern)	0.02
Displacement (LT)	3131.9
C_B	0.506
C_P	0.725
C_{WP}	0.743
A_{WP} (ft^2)	11950
LCB from AP (ft)	191.5
LCF from AP (ft)	208.3
KB (ft)	8.30
BM_T (ft)	7.42
BM_L (ft)	1717.3
GM_T (ft)	4.24
GM_L (ft)	1714
KM_T (ft)	12.5
KM_L (ft)	1725

Table 3. Design Features

Design Features	
Payload Designed Capacity (LT)	50
Laboratory Space (ft2)	
Berthing Space (ft2)	
Cruise Speed (kts)	8.0
Endurance (days)	45
Complement	15

4.4 Curves of Form

The following four graphs display the curves of form for the *R/V FLIP II*. Figure 3 below presents the data for the displacement, wetted and waterplane areas. It is of interest to note that the sharp change in the wetted area is due to the irregular shape of the connector section of the hullform. The nondimensionalized (prismatic, block, sectional area, and waterplane area coefficients) curves of Figure 3 are plotted in Figure 4. In Figure 5, the hydrostatic curves of form for the longitudinal and vertical centers are presented. The tons per inch immersion as well as the moment to trim one inch (MTI) curves are plotted in Figure 6.

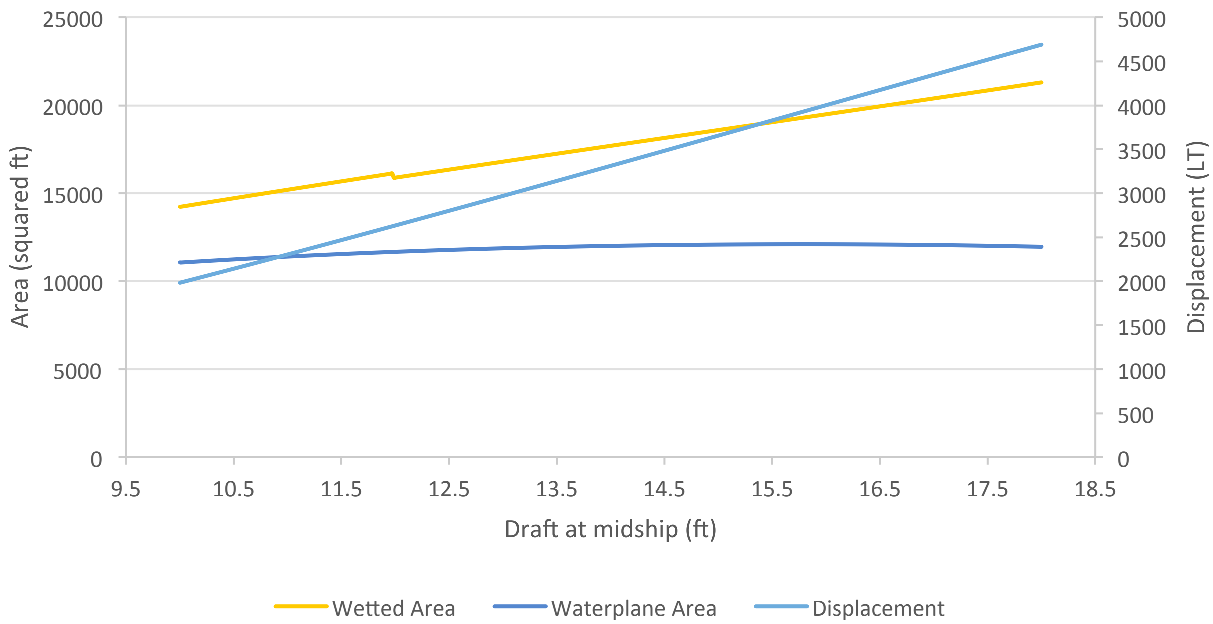


Figure 3. Displacement, wetted and waterplane areas as a function of draft

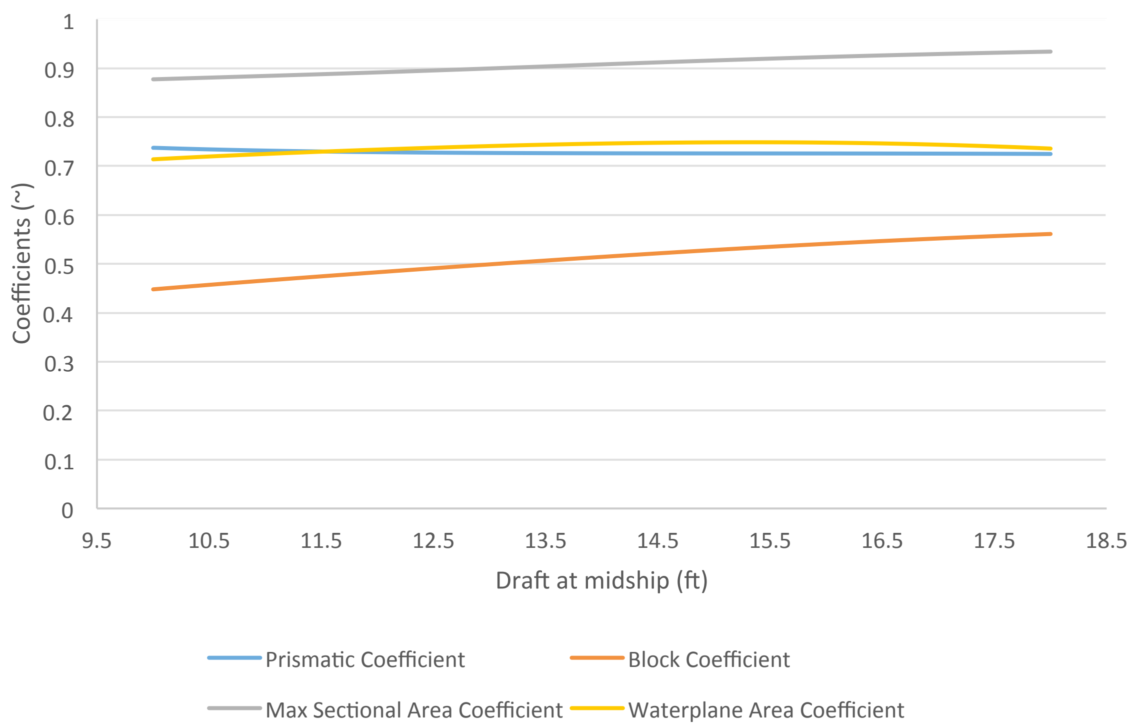


Figure 4. Prismatic, block, sectional area, and waterplane area coefficients

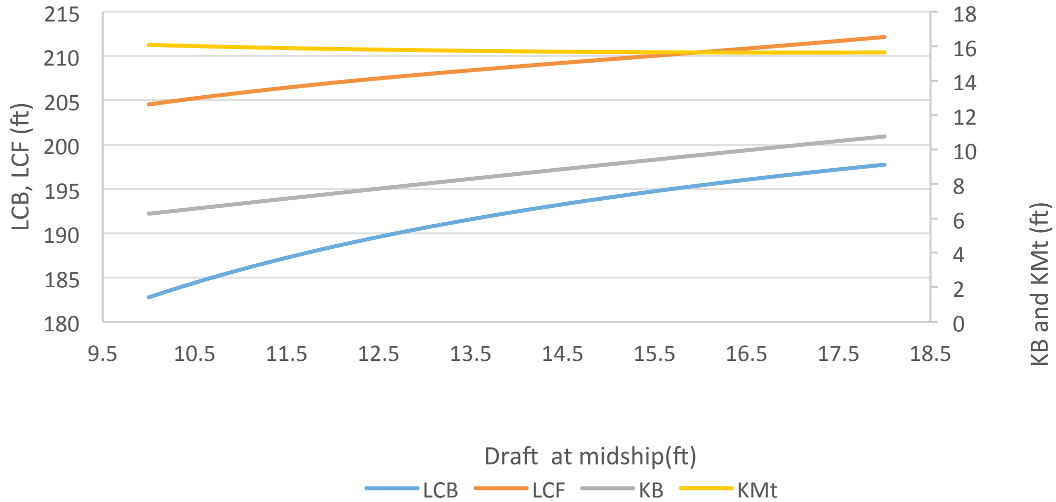


Figure 5. Hydrostatic curves of form for LCB, LCF, KG, and KM_t

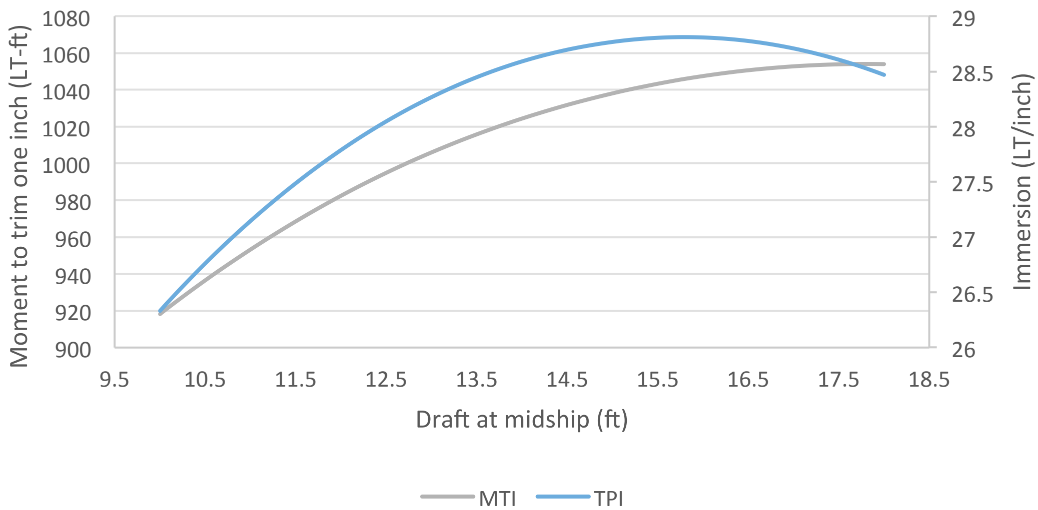


Figure 6. MTI and TPI curve

4.5 Sectional Area and Bonjean Curves

The sectional area curve is shown below in Figure 7**.** Each section of the vessel is evident in the curve.

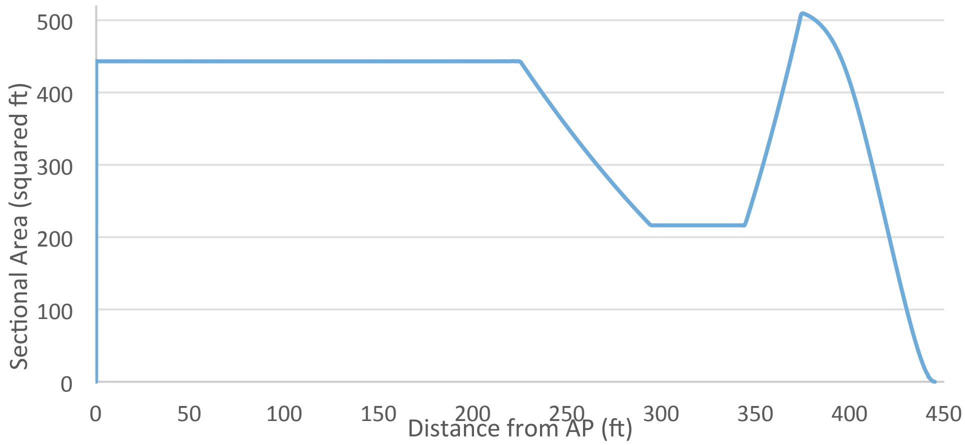


Figure 7. Sectional area curve

Bonjean Curves are plotted in Figure 8. The sectional area for specified stations can be found for given drafts. The locations of each station forward of the aft perpendicular are tabulated in Table 4.

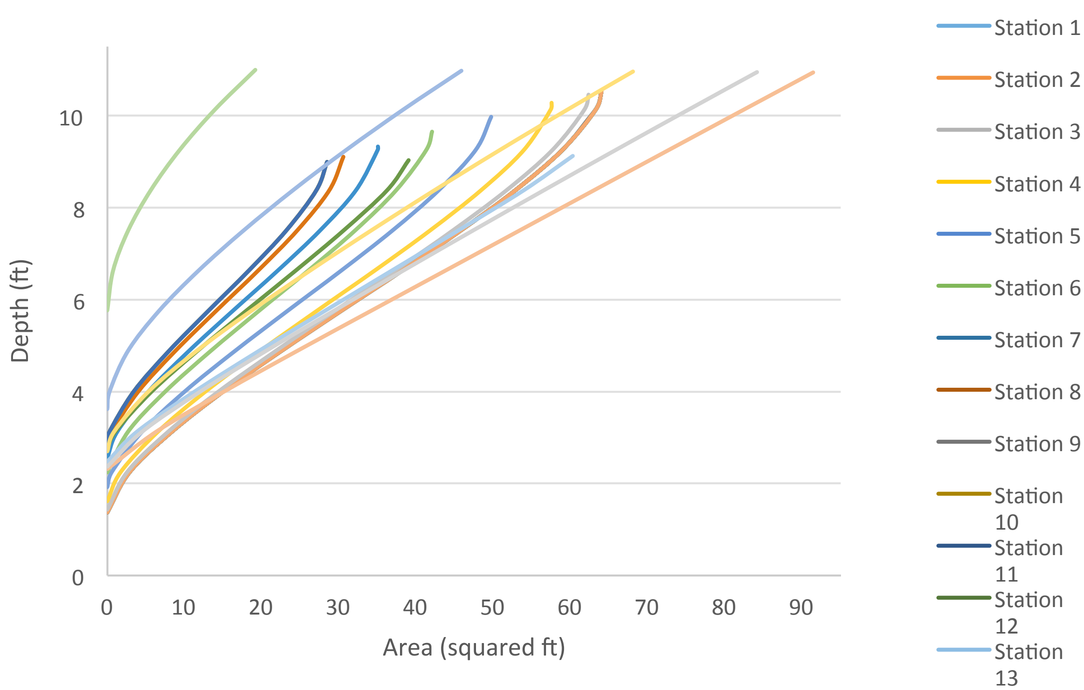


Figure 8. Bonjean curves

Table 4. Station location measured forward of the aft perpendicular

Station	X Location (ft)	Station	X Location (ft)
1	15.17	16	242.67
2	30.33	17	257.83
3	45.50	18	273.00
4	60.67	19	288.17
5	75.83	20	303.33
6	91.00	21	318.50
7	106.17	22	333.67
8	121.33	23	348.83
9	136.50	24	364.00
10	151.67	25	379.17
11	166.83	26	394.33
12	182.00	27	409.50
13	197.17	28	424.67
14	212.33	29	439.83
15	227.50	30	455.00

4.6 Floodable Length

Watertight bulkheads were placed strategically in order to provide an adequate amount of control during the flipping procedure. The bulkheads were also placed such that the vessel passes single compartment floodable length requirements. The floodable length curves were generated with permeability of 100, 98, 95, 85, and 70%. The *R/V FLIP II* passes the 46 CFR Subchapter S requirements (See Stability Section).

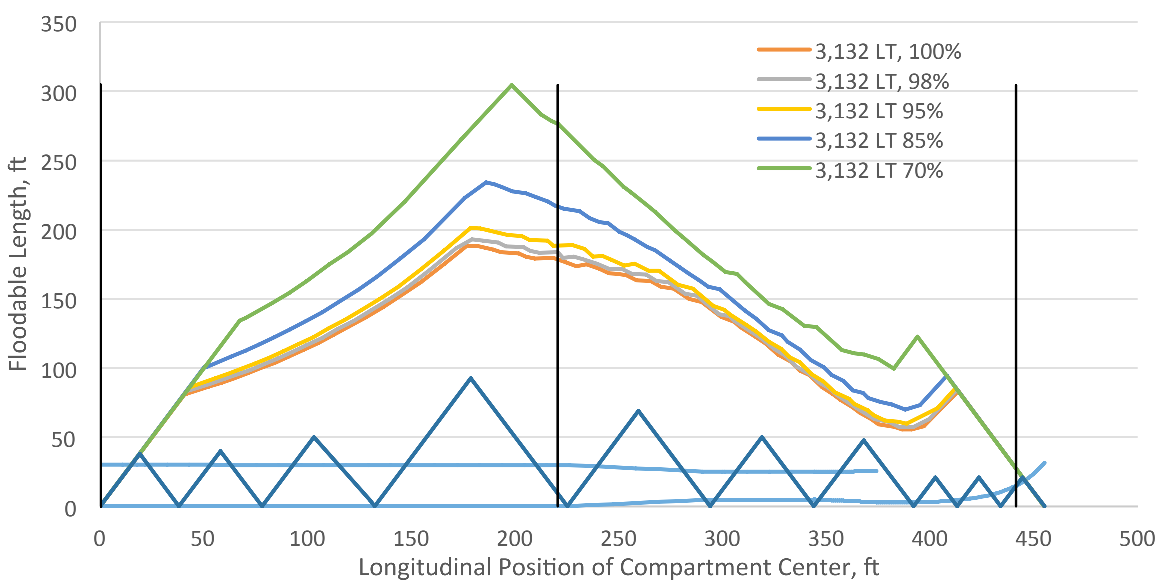


Figure 9. Floodable length curves

4.7 Lines Drawing

The lines drawings can be found in the appendix.

5.0 General Arrangements

In detail, the two primary goals of the arrangements were to provide at least 1,000 ft^2 of scientific lab space and increase the berthing capacity to 20 scientists and crew while also improving the habitability on board.

5.1 Arrangements Overview

The bow section of the *R/V FLIP II*, in comparison with the *R/P FLIP*, was increased in length by approximately 60 feet and in breadth by 12 feet. This added volume provided the space necessary to improve habitability, increase scientific laboratory space, as well as house mooring equipment and power generation equipment.

There are some within the scientific community that choose not to conduct research on board *R/P FLIP* due to its poor habitability. The improvements in the design of the *R/V FLIP II* in the way of crew and scientist comfort will hopefully attract more clients to utilize the unique capabilities the *R/V FLIP II*.

5.1.1 Outboard Profile

The outboard profile drawing displays the hull form and deckhouse. The vertical grating decks, retractable thruster, support boat, and deployment booms are also shown. The outboard profile drawing can be found in the appendix. This drawing also presents *R/V FLIP II's* unique shape with its long 30 foot diameter section. The location of the tunnel thruster can also be seen (aft of the retractable thruster).

5.1.2 Inboard Profile

The inboard profile located in the appendix shows both the vertical and horizontal deck layouts along with the tank arrangements and machinery spaces. A point of emphasis is that *R/V FLIP II* has more deck area on vertical than on horizontal by approximately 1.4 times. This proves the high quality of design for the *R/V FLIP II.*

5.1.3 Summary of Areas

A large effort was put into the designing the general arrangements to be optimal in the vertical condition and operable in horizontal. The main concern with *R/P FLIP* is its poor habitability. The issue was solved by extending the house to 100ft, a 60ft increase for *R/P FLIP.* The total area of *R/V FLIP II* on horizontal is of $4642ft^2$, while on vertical it has a total area of $6659ft^2$. The increase in area on vertical does not account for the outside grating. The grating greatly increases the deck area, allowing for both storage and operating space outside, near to where the experiments are being conducted.

5.1.4 Machinery Spaces

In comparison again to the present platform, the total allotted machinery space was increased from 200 sq. ft. to approximately 900 sq. ft. in the vertical orientation. This increase in space allowed for the addition of another diesel generator set as well as a set of batteries for clean and silent power during scientific research. The generator sets are mounted on trunnions allowing them to stay in the same orientation as the vessel rotates between horizontal and vertical attitudes. *R/P FLIP* has easily de-attachable exhaust pipes for proper orientation in both conditions. *R/V FLIP II* will employ a similar mechanism as it is proven useful in the present vessel.

It is not necessary for the solid state batteries to stay in the vertical position and thus they are hard mounted against the after bulkhead of the main machinery space. A grating deck is located in between the generator sets and the batteries and switchboard such that both can be serviced in the vertical position. The battery set is a new asset that will hopefully become an invaluable asset for this vessel, allowing scientists to conduct sensitive research for an extended period of time.

Detailed images are shown below that display the placement of the machinery equipment. More detailed arrangement drawings are located in the appendix.

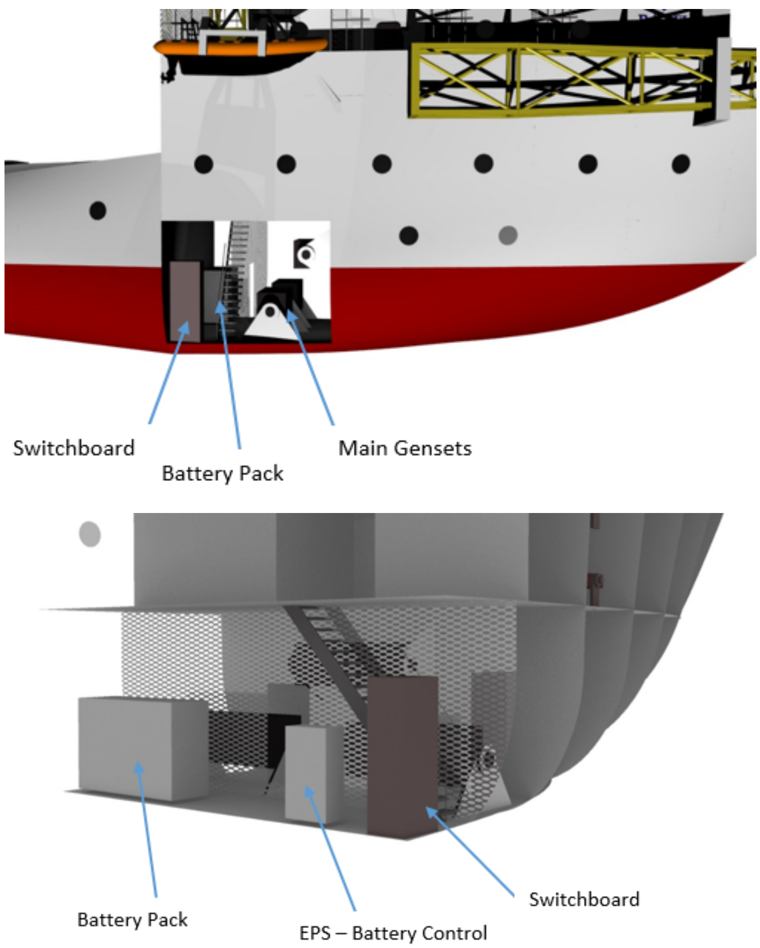


Figure 10. Main machinery rendered view

5.1.5 Habitability Spaces

The present platform has very limited habitability capabilities. There are a total of four berthing spaces with no space dedicated to lounging/relaxation. Moreover, the *R/P FLIP* had four berthing spaces, one with 6 bunks, two with 4 bunks, and one with two bunks. The arrangable space of the *R/V FLIP II* was increased, and a large portion of it dedicated to berthing/habitability. The amount of scientist berths was increased by three and one crew was added to the complement. The general arrangements allowed the crew and scientist berthing to be distributed into a total of 9 different berthing spaces. The crew, the captain, and the chief engineer all have single berth berthing spaces. The other crew shares a berthing space with three bunks. The two senior scientists/principal investigators are allotted their own berths, while others scientists are divided as needed between four berthing spaces: two four-bunk berths, one three-bunk berth and one two-bunk berth. The top bunks in the stacked bunk berthing spaces are accessed via a ladder built into the shell of the ship. Additionally, there is a lounge which is located on deck seven when in the vertical mode of operation that shall be used by the scientists and crew for general activities.

Detailed habitability drawings can be found at the end of this section. The habitability spaces are also shown in the general arrangements drawings in the appendix.

5.1.6 Scientific Laboratory Spaces

The scientific lab space on the current platform consists of one 500 sq. ft. room. *R/V FLIP II*'s new design increased the lab space to a total of 1000 sq. ft. spread over four different laboratories. These spaces are adaptable and can be configured to meet the needs of those who are embarking on a research cruise aboard the *R/V FLIP II*. The four rooms will enhance the experience of the scientists as it will provide quitter and more private space during research experiments. *R/V FLIP II* was designed to enhance the overall quality of the trip. *R/V FLIP II* has improved accommodations, ample research space, and greater adaptability.

5.2 Tank Capacities and Placement

The vessel is equipped with four fuel tanks and one day tank, as well as tanks for lubrication oil, potable water, and waste water. An inboard profile view of the tank arrangements can be seen in the arrangements in the appendix. The fuel tanks are located just aft of the bow section and are split into forward, aft and port, starboard tanks along with a day tank. The four tanks and the day tank hold adequate fuel for the entire 45 day endurance. The lubrication oil tank is sized appropriately for the propulsion and is located in the machinery room. The potable water tank is located under tank 6T, in compartment 6. This tank is sufficient to last 7 days in case the desalination system shuts down.

The waste water has been sized to be roughly half the size of the fresh water tank and can be discharged when needed according to the standard discharge regulations. It is also located beneath tank 6T, aft of the potable water. The main ballast tanks are tanks 1, 2B, 2T, 3B, 3T, 3P, 3S, 4, 6T. These tanks were sized in order to optimize the flipping process.

All tank locations were decided based on convenience and overall system efficiency. All tanks are equipped with baffles, although aside for a weight margin, engineering analysis calculations did not account for them. Each tank designed was given a five percent margin in order to account for fluid expansion due to temperature change. Another five percent margin was added to the tank volumes to account for the required internal structure and baffling.

Table 5 lists the volume of all the tanks. The sections following provide a more detailed breakdown of the volume and weights with images to help visualization.

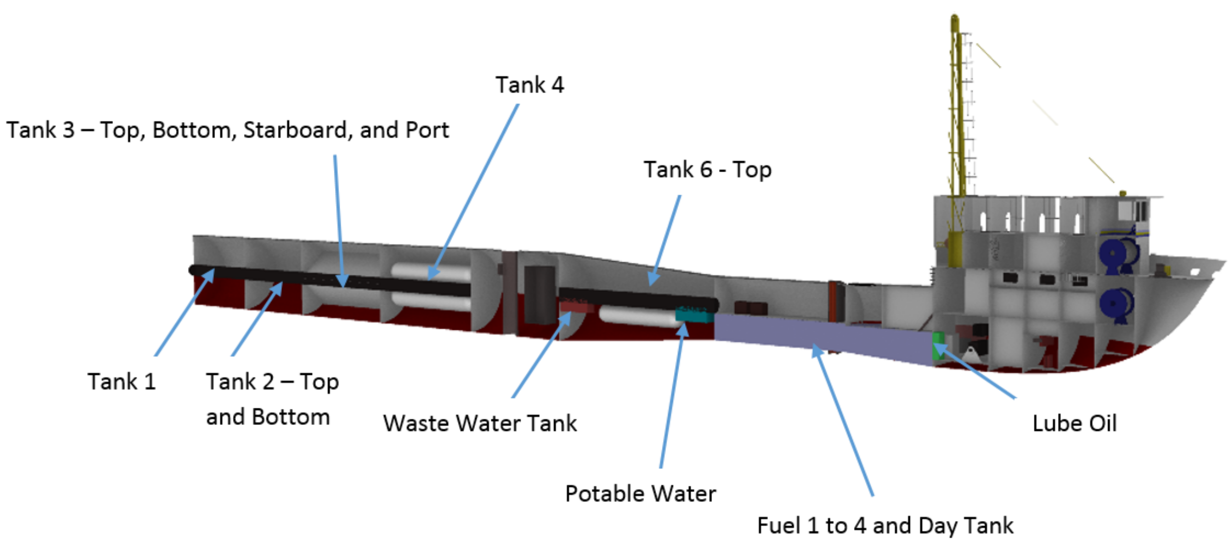


Figure 11. Tank arrangements rendered view

Table 5. Summary of tank volumes

Summary of Tank Volumes	
Space	**Volume (ft^3)**
Fuel Oil Tank No. 1 P	2,881
Fuel Oil Tank No. 1 S	2,881
Fuel Oil Tank No. 2 P	2,537
Fuel Oil Tank No. 2 S	2,537
Fuel Oil Day Tank	678
Lube Oil	95
Potable Water	932
Waste Water	466
Tank 1	22,220
Tank 2T	13,747
Tank 2B	9,648
Tank 3T	8,590
Tank 3B	3,739
Tank 3P	8,454
Tank 3S	8,454
Tank 4	25,392
Tank 6T	15,925
Air Receiver 1	2,278
Air Receiver 2	2,278
Air Receiver 3	2,278
Air Receiver 4	2,278
Air Receiver 5	1,139
Air Receiver 6	1,139
Total	137,685

5.2.1 Fuel Oil

Table 6. Detail fuel oil tanks

Fuel Oil Tanks		
Tank	**100% Volume (ft^3)**	**100% Weight (LT)**
Fuel Oil Tank No. 1 P	2,881	67
Fuel Oil Tank No. 1 S	2,881	67
Fuel Oil Tank No. 2 P	2,537	59
Fuel Oil Tank No. 2 S	2,537	59
Fuel Oil Day Tank	678	14

5.2.2 Lubrication Oil

Table 7. Detail lubrication oil tank

Lubrication Oil Tank		
Tank	**100% Volume (ft^3)**	**100% Weight (LT)**
Lube Oil	95	5

5.2.3 Potable Water

Table 8. Detail potable water tank

Potable Water Tank		
Tank	**100% Volume (ft^3)**	**100% Weight (LT)**
Potable Water	932	24

5.2.4 Ballast Tanks

Table 9. Detail ballast tanks

Ballast Tank Volumes		
Ballast Tanks	**100% Volume (ft^3)**	**100% Weight (LT)**
Tank 1	22,220	635
Tank 2T	13,747	392
Tank 2B	9,648	275
Tank 3T	8,590	245
Tank 3B	3,739	106
Tank 3P	8,454	241
Tank 3S	8,454	241
Tank 4	25,392	725
Tank 6T	15,925	455

5.3 Deck Layouts and allotted space

The first deck of the *R/V FLIP II* is the deck closest to the waterline while in the vertical position. Figure 12 shows a vertical profile of *R/V FLIP II* with its decks locations.

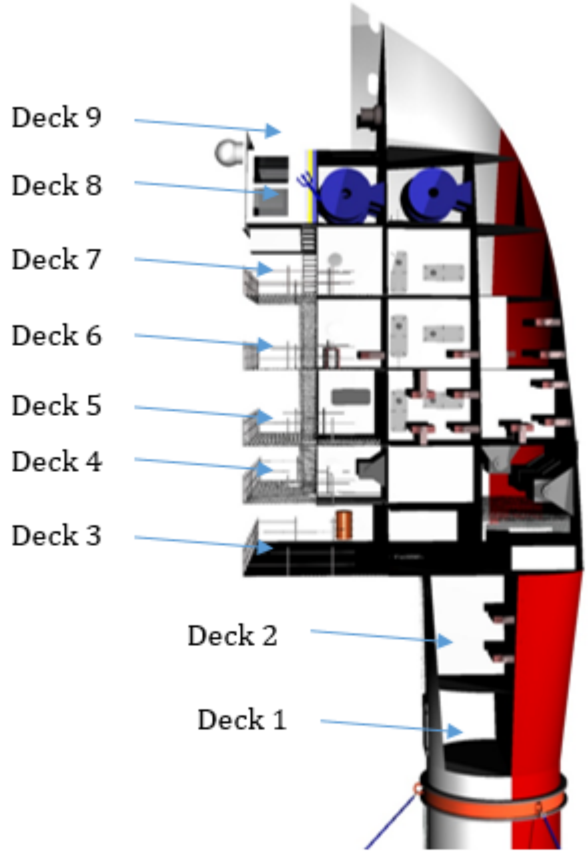


Figure 12. Deck arrangement profile view

Deck 1 is used for the deployment of scientific equipment. It provides *R/V FLIP II* with an area that is near the waterline. This opening can also be used for crew transfer area in non-emergency situations (calm seas). This is an improvement from the current platform, as it only has deployment booms that are high off the water. Finally, Deck 1 can be used to check the condition of the shackles and lines at the mooring ring.

The deployment bay doors are watertight as required by CFR Title 46. Deck 1 is one of the few compartments that the area on vertical is smaller than the area on horizontal. Future work could assess this issue by introducing a new floor while on vertical (new bulkhead on horizontal). Table 10 summarizes the areas of deck 1. Figure 13 shows a possible usage of the area for the deployment of an autonomous underwater vehicle.

Table 10. Summary of Deck Areas

Deck 1		
Space	Horizontal Deck Area (ft)	Vertical Deck Area (ft)
Deployment Bay	355	180

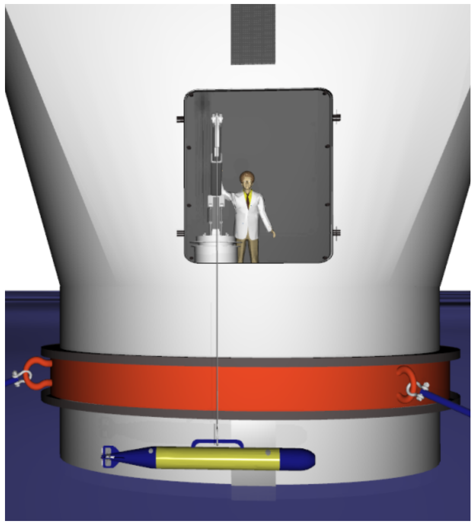


Figure 13. Front view of deployment bay

Deck 2 is in the connector that fairs the cylinder into the bow sections. It contains the sick bay, an improvement not seen in *R/P FLIP*, and a general two person berthing for scientists. In *R/P FLIP*, the scientists must share a berth with other five people, and a two person berthing would be a significant increase in comfort for the crew. This deck is located near the main machinery room. Suggested future work involves assessing the noise levels in this deck and account for the necessary technology to make this a livable and comfortable room for the scientific party. Table 11 summarizes the areas of deck 2. Figure 14 shows a possible usage of the area.

Table 11. Summary of areas: Deck 2

Deck 2		
Space	Horizontal Deck Area (ft)	Vertical Deck Area (ft)
Sick Bay	212	140
Scientists Berth (4)	212	140

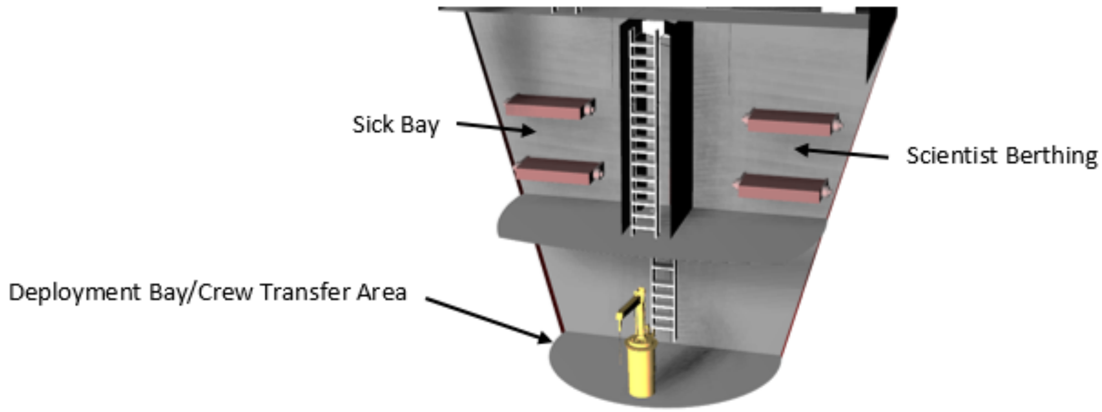


Figure 14. Deployment bay and after berthing compartment

The third deck holds the first and the largest of the lab spaces and the lower floor of the main machinery space that contains the bank of batteries and the lube oil. The third deck also is the first one with outside grating, allowing scientists to be outside while working. This is also the location of the life raft in emergency situations, and the support vessel also sits at this level. The division of scientific space will hopefully allow for different projects to be conducted on board simultaneously.

Table 12. Summary of areas: Deck 3

Deck 3		
Space	Horizontal Deck Area (ft)	Vertical Deck Area (ft)
Lab Space (1)	114	475
Main Machinery (2)	273	474

Deck four comprises of lab space 2 and 3, head 1, the ship workshop, emergency generator, and the top level of the machinery which contains the main three generator sets. This laboratory space is not the most comfortable, due to vibratory noises in the engines, but it is on the same level as the center line boom deployment. Also, being near the power supply may give a cooperative advantage that may not seem noticeable at this point of the design. Deck four also contains the head, and ship workshop. It is expected that Deck 4 will be the busiest, since a lot of small different rooms are present at this level. Adequate hall and ladder sizing will be implemented to allow the crew and scientists to easily move about.

Table 13. Summary of areas: Deck 4

Deck 4		
Space	Horizontal Deck Area (ft)	Vertical Deck Area (ft)
Lab Space (2)	147	167
Lab Space (3)	124	106
Head (1)	56	98
Ship Workshop	114	205
Emergency Genset	72	114
Main Machinery (1)	250	474

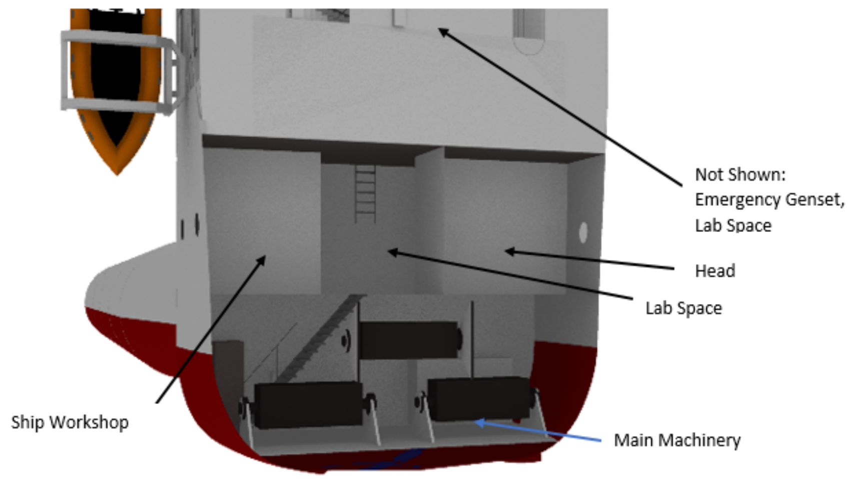


Figure 15. Machinery deck

Deck five consists of the upper-most lab space and three different berthing spaces. This deck contains the new addition of single bunk berthing spaces for the extra comfort of chief scientists, as well as a two bunk and a three bunk berthing space. This deck also contains the laundry space for long research cruises. Since the booms are deployed in deck 6, the lab space at deck 5 may have a comparative advantage when analyzed with different labs.

Table 14. Summary of areas: Deck 5

Deck 5		
Space	Horizontal Deck Area (ft)	Vertical Deck Area (ft)
Lab Space (4)	290	280
Scientists Berth (1)	148	200
Scientists Berth (2)	151	200
Scientists Berth (3)	128	253
Laundry	115	186

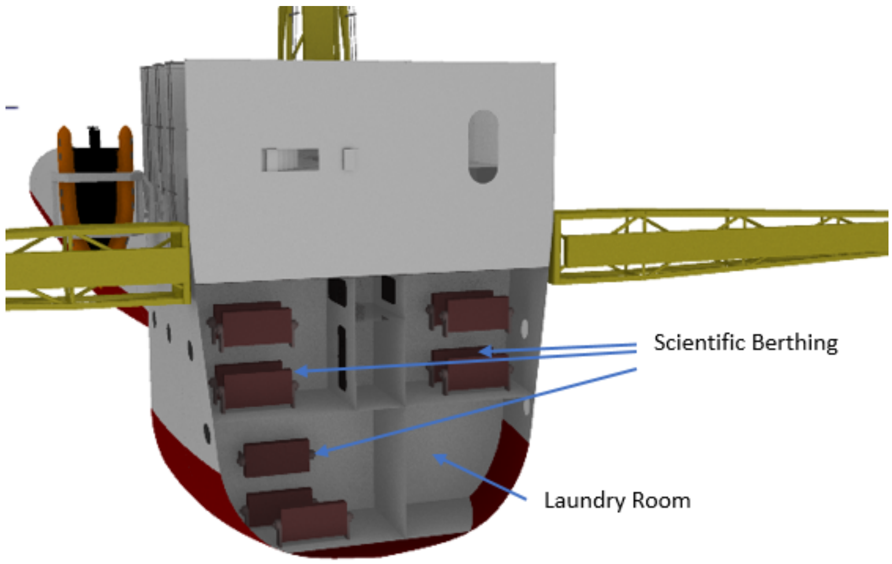


Figure 16. Berthing deck

Deck 6 contains crew berthing and a head for use while in the vertical attitude. Deck 6 is also where the booms will be deployed when on vertical.

Table 15. Summary of areas: Deck 6

Deck 6		
Space	Horizontal Deck Area (ft)	Vertical Deck Area (ft)
Captains Berth	122	110
Chief Engineers Berth	122	110
Chief Scientists Berth (1)	134	185
Chief Scientists Berth (2)	134	185
Crew Berth	126	302
Head (3)	---	61

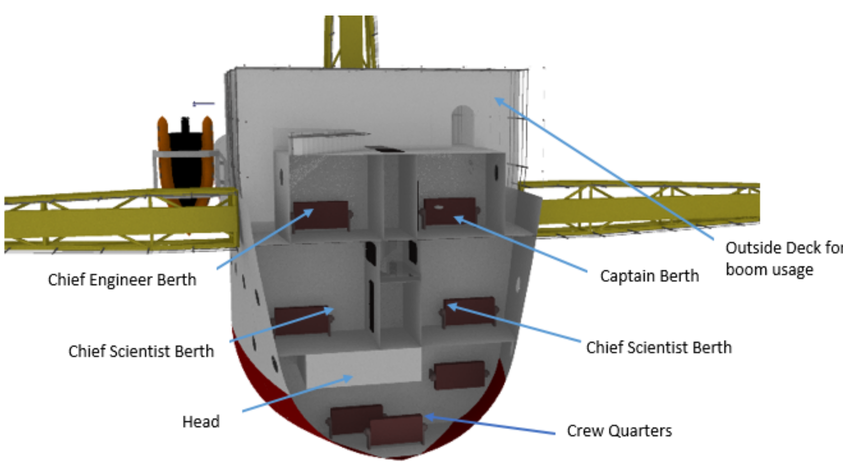


Figure 17. Secondary berthing deck

Deck 7 is where the galley, mess room, lounge, and food stores will be located. Not a lot of human traffic is expected here during normal hours. For meal and rest time, this deck is designed to fit all crew and scientists comfortably. Deck 7 will also contain the last head on the vessel.

Table 16. Summary of areas: Deck 7

Deck 7		
Space	Horizontal Deck Area (ft)	Vertical Deck Area (ft)
Lounge	170	190
Galley	111	170
Mess	113	170
Head (2)	68	65
Food Stores	70	281

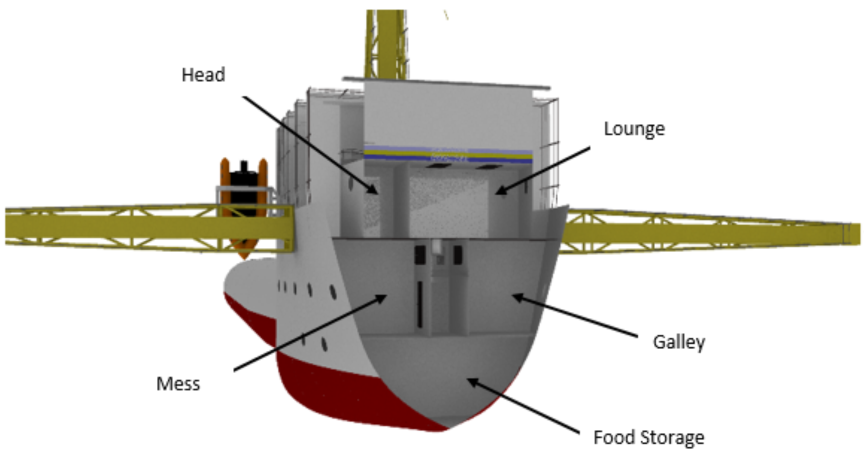


Figure 18. Mess and galley deck

Deck 8 is mainly used for more food stores, and for mooring equipment (lines and drums). The bridge is also located at this deck.

Table 17. Summary of areas: Deck 8

Deck 8		
Space	Horizontal Deck Area (ft)	Vertical Deck Area (ft)
Bridge	212	226
Mooring (1)	218	226
Mooring (2)	209	353
Stores	72	147

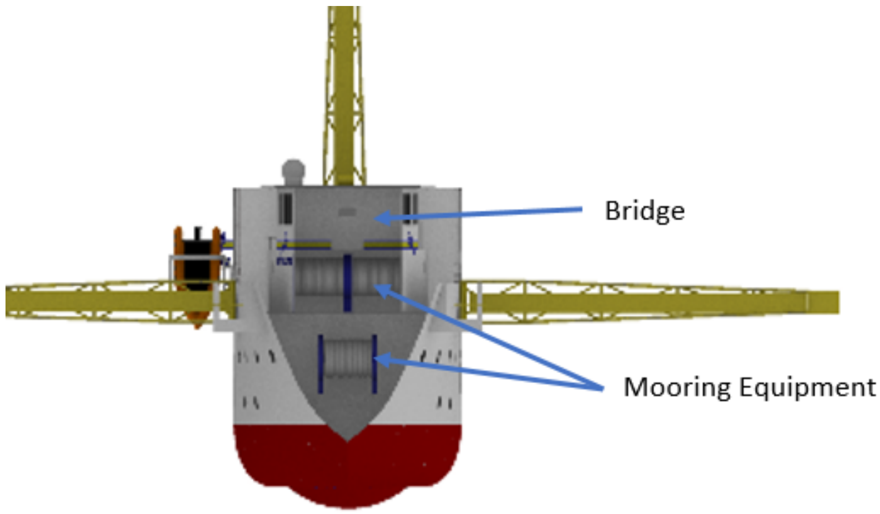


Figure 19. Mooring deck

Deck 9 is where the anchor locker is located. Deck 9 can also be used for emergency crew transfer through helicopter basket drop, since the bow section is not far away from the house, and there is plenty of room for objects to be deployed at that area.

Table 18. Summary of areas: Deck 9

Deck 9		
Space	Horizontal Deck Area (ft)	Vertical Deck Area (ft)
Anchor Locker	---	186

The general arrangements for *R/V FLIP II* were carefully considered throughout the entire design process. One of the *R/P FLIP's* major areas of concern was the habitability issues. This was improved by adding single berth rooms for chief scientists, more heads, and more divided scientific space.

Unfortunately, we do not meet some habitability and manning requirements as stated by CFR 46. However, *R/V FLIP II* is a unique vessel, and special consideration would possibly apply to this vessel. Currently, the major annual cost of *R/P FLIP* is the crew, therefore keeping the crew number low would help the success of the program.

As mentioned previously, *R/V FLIP II* is designed for mainly vertical operation, not horizontal; therefore the total area on vertical is 1.4 times that on horizontal. Currently, the ratio of vertical to horizontal area is 1.5 for *R/P FLIP* including the outer deck grating.

5.4 Manning Estimate

Improved habitability as well as scientific capability were two main design drivers. Following suggestions from the captain of the *R/P FLIP* as well as the scientists that conduct experiments on board, an initial manning estimate was conducted. The captain suggested that he would like to have one more crew member, increasing the number from three to four. Having one captain, a chief engineer, and three cross-trained crew members allows for there to be at least one person available to stand an eight hour watch. The scientists also desired an increase in the size of the scientific party. The berthing capacity for members of the scientific party was increased from 12 to 16. In order to comply with the Title 46 of the Code of Federal Regulations, the crew should be cross-certified as both mates and engineers. The table below summarizes the manning and scientific party of the *R/V FLIP II* in comparison to the *R/P FLIP*.

Table 19. Manning and scientific party comparison between *R/P FLIP* and *R/V FLIP II*

Specification	***R/P FLIP***	***R/V FLIP II***
Crew		
Captain	1	1
Chief Engineer	1	1
Cross Certified Mates/Engineers	2	3
Scientific Party		
Senior Scientists	-	4
Scientists/Researchers	12	11
Total	16	20

6.0 Weights

6.1 Weights Analysis

A preliminary weights analysis was conducted for the *R/V FLIP II*. The overall summary of the departure condition is shown below in Table 20.

Table 20. Preliminary weights analysis in departure condition

Item	Weight (LT)	VCG (ft)	LCG (ft)
Lightship	2,775	12.77	171.9
Deadweight	357	13.29	345.6
Total	**3,132**	**12.83**	**191.7**

The next three pages detail the results of the weights analysis for the departure, arrival, and lightship conditions. The structural weights were estimated based on the total structure needed in order to pass ABS requirements.

The outfit weight was estimated to be comprised of two components. The primary was estimated through the application of a regression presented by Watson and Gilfillan with respect to ships with high density outfit. The second component of the outfit weight was a first principles estimate on the piping system necessary to transfer ballast and compressed air throughout the cylindrical portion of the vessel. An added factor was given to the outfit weight in order to account for the gimballing of the main machinery. This process resulted in a more conservative estimate than scaling the present outfit weight of *R/P FLIP* because as a platform, *R/P FLIP* does not possess the full number of systems that the *R/V FLIP II* will require. The weights of the main machinery and auxiliary systems were supplied by vendors. The weight of the scientific deployment booms was provided by the captain of *R/P FLIP*. Regression models presented by Watson and Gilfillan were also used to determine the crew and provision weights.

For the resulting KG estimate, a one foot margin was added in order to account for future growth and a safety factor. On top of the one foot increase, a 3% margin was also added to the KG for free surface effects. These margins were studied from regression models available from the University of Michigan design spreadsheets. A 10% percent margin was added to the structural weight to account for structural components that are not included in the initial estimate of the hull.

The resulting trim for each condition is presented. The light ship condition includes all that the vessel needs to be ready for service minus any variable loads such as consumables, scientific payload, or fuel stores. The departure condition includes the full weight of the lightship as well as the deadweight which is comprised of the provisions, scientific payload, fuel, water, etc. At the arrival condition, it was assumed that the full scientific payload was installed with 10% of fuel and other consumables remaining, and ballast.

The next three tables present a summary of the weights. The following three present detailed calculations of the weights.

Table 21. Weight analysis results for departure, arrival, and light ship conditions

Condition	Displacement (LT)	GM_t (ft.)	Draft Forward (ft.)	Draft Aft (ft.)	Trim (degrees)
Departure	3,132	2.89	13.48	13.50	0.005
Arrival	3,337	3.81	13.61	14.56	0.239
Light Ship	2,775	3.13	10.39	14.49	1.032

Table 22. Weight margins summary

Weight Margins	
GM_tFuture Growth (ft)	0.5
GM_t Safety Factor (ft)	0.5
Free Surface Effect	1.03 *x* KG
Weight Safety Factor	10%

Table 23. Summary of Load Conditions

Condition	Structure	Ballast Tanks	Main Machinery	Crew, Provisions, and Tanks	Auxiliary Systems and Outfit	Scientific Equipment
Departure	Yes	Yes	Yes	100%	Yes	All Included
Arrival	Yes	Yes	Yes	10%	Yes	All Included
Light Ship	Yes	No	Yes	None	Yes	Only Booms

Full Load Departure Condtition

Structure

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Transom	8.51	0.00	0.00	15.00
Bulkhead 1	13.77	38.00	0.00	15.00
Bulkhead 2	14.77	78.00	0.00	15.00
Bulkhead 3	13.33	128.00	0.00	15.00
Bulkhead 4	14.08	188.00	0.00	15.00
Bulkhead 5	14.92	225.00	0.00	15.00
Bulkhead 6	7.18	294.00	0.00	15.00
Bulkhead 7	6.31	344.00	0.00	15.00
Bulkhead 8	6.20	374.00	0.00	22.68
Bulkhead 9	5.82	392.00	0.00	23.00
Bulkhead 10	5.24	403.00	0.00	23.68
Bulkhead 11	4.33	413.00	0.00	24.74
Bulkhead 12	3.31	424.00	0.00	26.10
Bulkhead 13	2.03	434.00	0.00	28.60
Shell + Stiffening Compartment 1	43.54	19.00	0.00	15.00
Shell + Stiffening Compartment 2	107.05	58.00	0.00	15.00
Shell + Stiffening Compartment 3	132.05	103.00	0.00	15.00
Shell + Stiffening Compartment 4	178.59	150.50	0.00	15.00
Shell + Stiffening Compartment 5	145.62	199.00	0.00	15.00
Shell + Stiffening Compartment 6	299.24	259.50	0.00	15.00
Shell + Stiffening Compartment 7	129.93	319.00	0.00	15.00
Shell + Stiffening Compartment 8	34.66	359.00	0.00	18.00
Shell + Stiffening Compartment 9	51.65	414.50	0.00	20.00
Total Weight	1242.12	204.40	0.00	15.49

Ballast Tanks

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Fixed Ballast	844.00	70.00	-0.08	3.60
Tank 1	0.00	19.00	0.00	---
Tank 2T	0.00	58.00	0.00	---
Tank 2B	0.00	58.00	0.00	---
Tank 3T	0.00	103.00	0.00	---
Tank 3B	0.00	103.00	0.00	---
Tank 3P	0.00	103.00	0.00	---
Tank 3S	0.00	103.00	0.00	---
Tank4T	0.00	154.00	0.00	---
Tank 4B	0.00	154.00	0.00	---
Tank 6T	0.00	259.62	0.00	---
Total Weight	844.00	70.00	-0.08	3.60

Main Machinery

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Retractable Thruster	23.27	213.00	0.00	10.00
Tunnel Thuster	5.00	200.00	0.00	15.00
John Deere 6315S Set (1)	2.47	385.00	8.00	8.44
John Deere 6315S Set (2)	2.47	385.00	-8.00	8.44
John Deere 6068S Set	1.60	387.00	0.00	14.33
Emergency Gen	0.73	388.00	0.00	33.67
Batteries	8.63	376.28	7.17	8.13
Switchboard	0.64	376.18	-13.86	9.80
Total Weight	44.81	273.35	1.18	10.56

Crew and Provision / Tanks

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Fuel Oil Tank No. 1 P	66.74	319.23	4.07	9.91
Fuel Oil Tank No. 1 S	66.74	319.23	-4.07	9.91
Fuel Oil Tank No. 2 P	59.09	360.62	6.98	8.86
Fuel Oil Tank No. 2 S	59.09	360.62	-6.98	8.86
Fuel Oil Day Tank	14.34	370.68	0.00	8.11
Lube Oil	5.00	375.00	0.00	8.94
Potable Water	23.42	284.56	0.00	12.63
Gray Water	0.00	231.97	0.00	12.62
Crew	3.35	401.91	0.00	22.07
Provisions	8.86	401.92	0.00	22.07
Total Weight	306.63	339.14	0.00	10.10

Auxiliary Systems and Outfit

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Small Boat & Davit	0.33	383.60	0.24	36.70
Outfit	387.80	295.00	0.00	16.00
Bilge Keels	2.84	175.00	0.00	5.16
Life raft	0.18	370.00	18.00	36.00
Capstan	7.54	441.00	0.00	32.46
Rope Spools (main deck)	2.92	428.65	0.00	35.71
Rope Spool (01 Deck)	1.36	428.65	0.00	22.72
Chain	36.00	441.65	0.00	25.70
Anchors	1.00	445.00	0.00	30.00
Air Compressor	0.76	186.13	0.00	17.43
4 Primary Air Receivers	60.13	154.09	0.00	15.00
2 Secondary Air Recievers	15.03	258.43	0.00	10.25
Total Weight	515.91	290.54	0.01	16.75

Scientific Equipment

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
BoomsCL	1.43	405.25	0.00	53.13
Boom Starboard	1.43	401.75	-20.00	33.20
Boom Port	1.43	401.75	20.00	33.20
Payload	50.00	383.00	0.00	26.00
Total Weight	54.28	384.57	0.00	27.09

Total Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
3131.97	191.57	0.00	11.48

GM AND TRIM RESULTS

resulting hydrostatic conditions

Design KG	12.83 ft, including design and free surface margins		
GM_T	2.89 ft	**GM_L**	1799.81 ft
Trim	0.02 ft; + by the stern		
T forward	13.48 ft	**T aft**	13.50 ft

Arrival Condtition

Structure

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Transom	8.51	0.00	0.00	15.00
Bulkhead 1	13.77	38.00	0.00	15.00
Bulkhead 2	14.77	78.00	0.00	15.00
Bulkhead 3	13.33	128.00	0.00	15.00
Bulkhead 4	14.08	188.00	0.00	15.00
Bulkhead 5	14.92	225.00	0.00	15.00
Bulkhead 6	7.18	294.00	0.00	15.00
Bulkhead 7	6.31	344.00	0.00	15.00
Bulkhead 8	6.20	374.00	0.00	22.68
Bulkhead 9	5.82	392.00	0.00	23.00
Bulkhead 10	5.24	403.00	0.00	23.68
Bulkhead 11	4.33	413.00	0.00	24.74
Bulkhead 12	3.31	424.00	0.00	26.10
Bulkhead 13	2.03	434.00	0.00	28.60
Shell + Stiffening Compartment 1	43.54	19.00	0.00	15.00
Shell + Stiffening Compartment 2	107.05	58.00	0.00	15.00
Shell + Stiffening Compartment 3	132.05	103.00	0.00	15.00
Shell + Stiffening Compartment 4	178.59	150.50	0.00	15.00
Shell + Stiffening Compartment 5	145.62	199.00	0.00	15.00
Shell + Stiffening Compartment 6	299.24	259.50	0.00	15.00
Shell + Stiffening Compartment 7	129.93	319.00	0.00	15.00
Shell + Stiffening Compartment 8	34.66	359.00	0.00	18.00
Shell + Stiffening Compartment 9	51.65	414.50	0.00	20.00
Total Weight	1242.12	204.40	0.00	15.49

Ballast Tanks

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Fixed Ballast	844.00	70.00	-0.08	3.60
Tank 1	0.00	19.00	0.00	---
Tank 2T	0.00	58.00	0.00	---
Tank 2B	0.00	58.00	0.00	---
Tank 3T	0.00	103.00	0.00	---
Tank 3B	0.00	103.00	0.00	---
Tank 3P	0.00	103.00	0.00	---
Tank 3S	0.00	103.00	0.00	---
Tank4T	0.00	154.00	0.00	---
Tank 4B	0.00	154.00	0.00	---
Tank 6T	443.00	255.00	0.00	19.63
Total Weight	1287.00	133.68	-0.05	3.60

Main Machinery

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Retractable Thruster	23.27	213.00	0.00	10.00
Tunnel Thuster	5.00	200.00	0.00	15.00
John Deere 6315S Set (1)	2.47	385.00	8.00	8.44
John Deere 6315S Set (2)	2.47	385.00	-8.00	8.44
John Deere 6068S Set	1.60	387.00	0.00	14.33
Emergency Gen	0.73	388.00	0.00	33.67
Batteries	8.63	376.28	7.17	8.13
Switchboard	0.64	376.18	-13.86	9.80
Total Weight	44.81	273.35	1.18	10.56

Crew and Provision / Tanks

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Fuel Oil Tank No. 1 P	0.00	319.23	4.07	9.91
Fuel Oil Tank No. 1 S	0.00	319.23	-4.07	9.91
Fuel Oil Tank No. 2 P	6.20	360.62	6.98	8.86
Fuel Oil Tank No. 2 S	6.20	360.62	-6.98	8.86
Fuel Oil Day Tank	14.34	370.68	0.00	8.11
Lube Oil	0.50	375.00	0.00	8.94
Potable Water	23.42	284.56	0.00	12.63
Gray Water	13.36	231.97	0.00	12.62
Crew	3.35	401.91	0.00	22.07
Provisions	0.89	401.92	0.00	22.07
Total Weight	68.25	314.11	0.00	11.55

Auxiliary Systems and Outfit

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Small Boat & Davit	0.33	383.60	0.24	36.70
Outfit	387.80	295.00	0.00	16.00
Bilge Keels	2.84	175.00	0.00	5.16
Life raft	0.18	370.00	18.00	36.00
Capstan	7.54	441.00	0.00	32.46
Rope Spools (main deck)	2.92	428.65	0.00	35.71
Rope Spool (01 Deck)	1.36	428.65	0.00	22.72
Chain	36.00	441.65	0.00	25.70
Anchors	1.00	445.00	0.00	30.00
Air Compressor	0.76	186.13	0.00	17.43
4 Primary Air Receivers	60.13	154.09	0.00	15.00
2 Secondary Air Recievers	15.03	258.43	0.00	10.25
Total Weight	515.91	290.54	0.01	16.75

Scientific Equipment

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
BoomsCL	1.43	405.25	0.00	53.13
Boom Starboard	1.43	401.75	-20.00	33.20
Boom Port	1.43	401.75	20.00	33.20
Payload	50.00	383.00	0.00	26.00
Total Weight	54.28	384.57	0.00	27.09

Total Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
3336.59	188.93	0.00	10.56

GM AND TRIM RESULTS

resulting hydrostatic conditions

Design KG	11.88 ft, including design and free surface margins		
GM_T	3.81 ft	**GM_L**	1644.20 ft
Trim	1.01 ft; + by the stern		
T forward	13.61 ft	**T aft**	14.56 ft

Lightsihp Condtition

Structure

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Transom	8.51	0.00	0.00	15.00
Bulkhead 1	13.77	38.00	0.00	15.00
Bulkhead 2	14.77	78.00	0.00	15.00
Bulkhead 3	13.33	128.00	0.00	15.00
Bulkhead 4	14.08	188.00	0.00	15.00
Bulkhead 5	14.92	225.00	0.00	15.00
Bulkhead 6	7.18	294.00	0.00	15.00
Bulkhead 7	6.31	344.00	0.00	15.00
Bulkhead 8	6.20	374.00	0.00	22.68
Bulkhead 9	5.82	392.00	0.00	23.00
Bulkhead 10	5.24	403.00	0.00	23.68
Bulkhead 11	4.33	413.00	0.00	24.74
Bulkhead 12	3.31	424.00	0.00	26.10
Bulkhead 13	2.03	434.00	0.00	28.60
Shell + Stiffening Compartment 1	43.54	19.00	0.00	15.00
Shell + Stiffening Compartment 2	107.05	58.00	0.00	15.00
Shell + Stiffening Compartment 3	132.05	103.00	0.00	15.00
Shell + Stiffening Compartment 4	178.59	150.50	0.00	15.00
Shell + Stiffening Compartment 5	145.62	199.00	0.00	15.00
Shell + Stiffening Compartment 6	299.24	259.50	0.00	15.00
Shell + Stiffening Compartment 7	129.93	319.00	0.00	15.00
Shell + Stiffening Compartment 8	34.66	359.00	0.00	18.00
Shell + Stiffening Compartment 9	51.65	414.50	0.00	20.00
Total Weight	1242.12	204.40	0.00	15.49

Ballast Tanks

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Fixed Ballast	844.00	70.00	-0.08	3.60
Tank 1	0.00	19.00	0.00	---
Tank 2T	0.00	58.00	0.00	---
Tank 2B	0.00	58.00	0.00	---
Tank 3T	0.00	103.00	0.00	---
Tank 3B	0.00	103.00	0.00	---
Tank 3P	0.00	103.00	0.00	---
Tank 3S	0.00	103.00	0.00	---
Tank4T	0.00	154.00	0.00	---
Tank 4B	0.00	154.00	0.00	---
Tank 6T	0.00	259.62	0.00	---
Total Weight	844.00	70.00	-0.08	3.60

Main Machinery

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Retractable Thruster	23.27	213.00	0.00	10.00
Tunnel Thuster	5.00	200.00	0.00	15.00
John Deere 6315S Set (1)	2.47	385.00	8.00	8.44
John Deere 6315S Set (2)	2.47	385.00	-8.00	8.44
John Deere 6068S Set	1.60	387.00	0.00	14.33
Emergency Gen	0.73	388.00	0.00	33.67
Batteries	8.63	376.28	7.17	8.13
Switchboard	0.64	376.18	-13.86	9.80
Total Weight	44.81	273.35	1.18	10.56

Crew and Provision / Tanks

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Fuel Oil Tank No. 1 P	0.00	319.23	4.07	9.91
Fuel Oil Tank No. 1 S	0.00	319.23	-4.07	9.91
Fuel Oil Tank No. 2 P	0.00	360.62	6.98	8.86
Fuel Oil Tank No. 2 S	0.00	360.62	-6.98	8.86
Fuel Oil Day Tank	0.00	370.68	0.00	8.11
Lube Oil	0.00	375.00	0.00	8.94
Potable Water	0.00	284.56	0.00	12.63
Gray Water	0.00	231.97	0.00	12.62
Crew	0.00	401.91	0.00	22.07
Provisions	0.00	401.92	0.00	22.07
Total Weight	0.00	0.00	0.00	0.00

Auxiliary Systems and Outfit

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
Small Boat & Davit	0.33	383.60	0.24	36.70
Outfit	387.80	295.00	0.00	16.00
Bilge Keels	2.84	175.00	0.00	5.16
Life raft	0.18	370.00	18.00	36.00
Capstan	7.54	441.00	0.00	32.46
Rope Spools (main deck)	2.92	428.65	0.00	35.71
Rope Spool (01 Deck)	1.36	428.65	0.00	22.72
Chain	36.00	441.65	0.00	25.70
Anchors	1.00	445.00	0.00	30.00
Air Compressor	0.76	186.13	0.00	17.43
4 Primary Air Receivers	60.13	154.09	0.00	15.00
2 Secondary Air Recievers	15.03	258.43	0.00	10.25
Total Weight	515.91	290.54	0.01	16.75

Scientific Equipment

Unit	Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
BoomsCL	1.43	405.25	0.00	53.13
Boom Starboard	1.43	401.75	-20.00	33.20
Boom Port	1.43	401.75	20.00	33.20
Payload	0.00	383.00	0.00	26.00
Total Weight	4.28	402.92	0.00	39.84

Total Weight (LT)	LCG (ft) (Fwd AP)	TCG (ft) (+Port)	VCG (ft) (ABL)
2775.34	171.81	0.00	11.37

GM AND TRIM RESULTS

resulting hydrostatic conditions

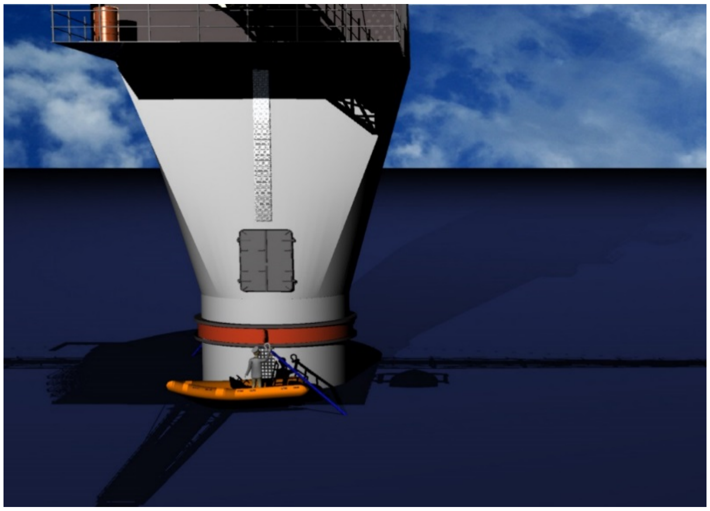
Design KG	12.71 ft, including design and free surface margins		
GM_T	3.13 ft	**GM_L**	1799.92 ft
Trim	4.34 ft; + by the stern		
T forward	10.39 ft	**T aft**	14.49 ft

7.0 Operational Procedures

7.1 Mooring Process

For the mooring process, the three mooring lines attached to the anchor and chain are released while *R/V FLIP II* is horizontal. These lines are each attached to a buoy; the mooring lines themselves are buoyant. *R/V FLIP II* releases all 3 mooring lines and moves to about the center of the 3-point. The flipping process occurs and *R/V FLIP* uses her tunnel thruster and retractable thruster for station keeping. *R/V FLIP*'s small support vessel goes to retrieve the lines on the buoys and they are attached onto *FLIP*'s mooring ring. The mooring ring is an important addition to the *R/V FLIP* because it allows free rotation of the vessel while in the vertical position to rotate with the wind. Presently, the *R/P FLIP* will turn bow into the wind, so it is possible for the mooring lines to tangle if the configuration does not allow for easy yaw motion. However, with the mooring ring, the mooring lines can be set up independently of any wind pattern directions and the *R/V FLIP* can yaw freely.

Future analysis of the mooring configuration includes a more detailed analysis of the process. Questions arose as to how feasible the process of using the small support boat to retrieve the lines is, and whether it would be possible to pull the weight of the lines from the support vessel. The managers of *R/P FLIP* believe that the support from the small vessel would be incredibly valuable and a great addition. The managers also stated that the mooring lines are never highly tensioned, and their current mooring equipment is more than sufficient. Once coming back to horizontal, *R/V FLIP* would use its tunnel thruster and retractable thruster to alleviate tension in one end of the mooring. The support vessel would detach the ropes, and add the buoy at the end of the line. Once *R/V FLIP* is horizontal again, the vessel would retract the lines. However, future work would be necessary to closely consider the effects on the de-mooring process, and what to do with the lines when *R/V FLIP II* is coming back to the horizontal position.



7.2 Flipping Procedure

The flipping procedure is crucial for the success of the *R/V FLIP II* design. Currently, *R/P FLIP*'s rotating procedure has a couple of issues: the vessel can pass 90° trim due to high velocities, and plunging occurs if too much water goes into the tanks too quickly (the vessel flips and then drastically sinks to equilibrium once at 90°). During our interviews with *R/P FLIP* crew and engineers involved with vessel maintenance, possible solutions to both issues were discussed.

The point of instability occurs when the VCB passes the VCG and the vessel wants to go to the upright condition. At the trim angle of the instability point, it is crucial to maintain the VCG and VCB at small differences to decrease the moment arm. A small moment arm leads to small moments, which results into small angular accelerations. Therefore, keeping the VCB higher than the VCG (but with only a small difference) leads to small accelerations. Designing to such requirement would decrease the chance of seeing *FLIP* trimming past 90°. To avoid plunging, *R/P FLIP*'s crew stated that the solution is to not take on water once instability has started. This is accounted in our flipping procedure.

Analytically solving the flipping procedure is a dense and complex motion problem that requires further analysis than the one performed. Therefore, a model test was performed, and results show an improvement in flipping velocities. Computationally, *R/V FLIP II's* current flipping procedure was solved with an iterative method. Assuming quasi-static behavior, the trim as a function of the water intake was calculated, and velocities were calculated numerically. Further, using trial and error, different ballasting sequences were tested. The current results rely on the flipping procedure that resulted into a stable small velocity flipping procedure. Table 24 summarizes the results.

R/V FLIP II is designed with 8 independent ballast tanks. Tank 2 is divided into top and bottom, and tank 3 into top, bottom, port, and starboard. The purpose of the separation is to try to decrease velocities, and to correct for tilt while on vertical if necessary.
To increase buoyancy and stability in the vertical condition, it is crucial to free flood some tanks, instead of flooding them to full capacity. The trial and error method also found that free-flooding tanks decrease the velocity of trimming. Therefore, the first step is to free flood tanks 1 and 3 starboard and port. Next, tanks 2 bottom and 3 bottom are flooded simultaneously. Then, tank 4 must be flooded to its full capacity, then tank 2 top to 50%. At that approximate location, the point of instability occurs.

Finally, once on vertical, tank 2 top should be flooded to 100%, and tank 4 should be adjusted from 100% to approximately 55%. It is important to use tank 2 instead of 4 since

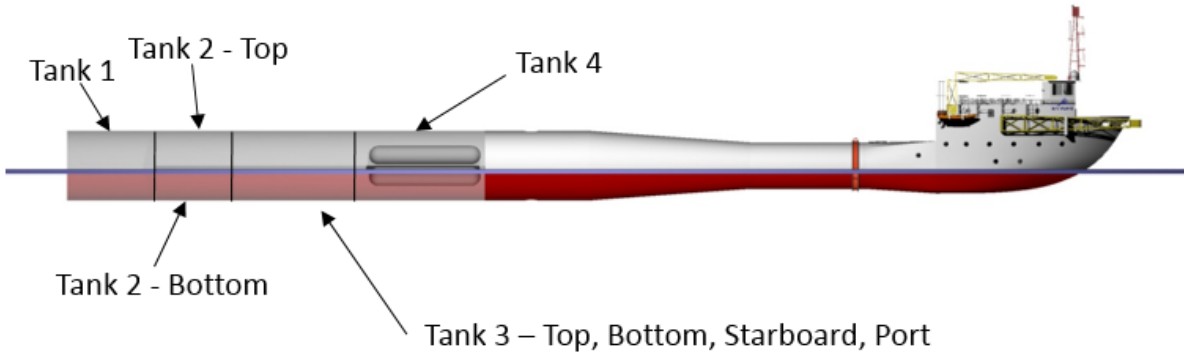


Figure 20 - Ballast tanks arrangements

that lowers the vertical center of gravity, making *R/V FLIP II* a more stable platform. However, it is crucial not to empty tank 4 more than 55%. This could cause *R/V FLIP II* to be unstable, and give room for fatal accidents to occur. Figure 21 shows the flipping procedure graphically.

Table 24. Summary of flipping condition

Sequence No.	Tank Condition	Trim	Draft (ft)
1	Tank 1 – Free Flooding	2°	20.6
	Tank 3P – Free Flooding		
	Tank 3S – Free Flooding		
2	Same as 1	2.5°	26.5
	Tank 2B – Flooded		
	Tank 3B – Flooded		
3	Same as 2	3°	29.9
	Tank 3T – Flooded		
4	Same as 3	5°	41.1
	Tank 4 – Flooded		
5. Point of Instability	Same as 4	15°	93.8
	Tank 2T – 50%		
6. Vertical Operating	Tank 2T – 100%	90°	370
7. Set Vertical Draft	Adjust Tank 4 to a minimum of 55%	90°	330

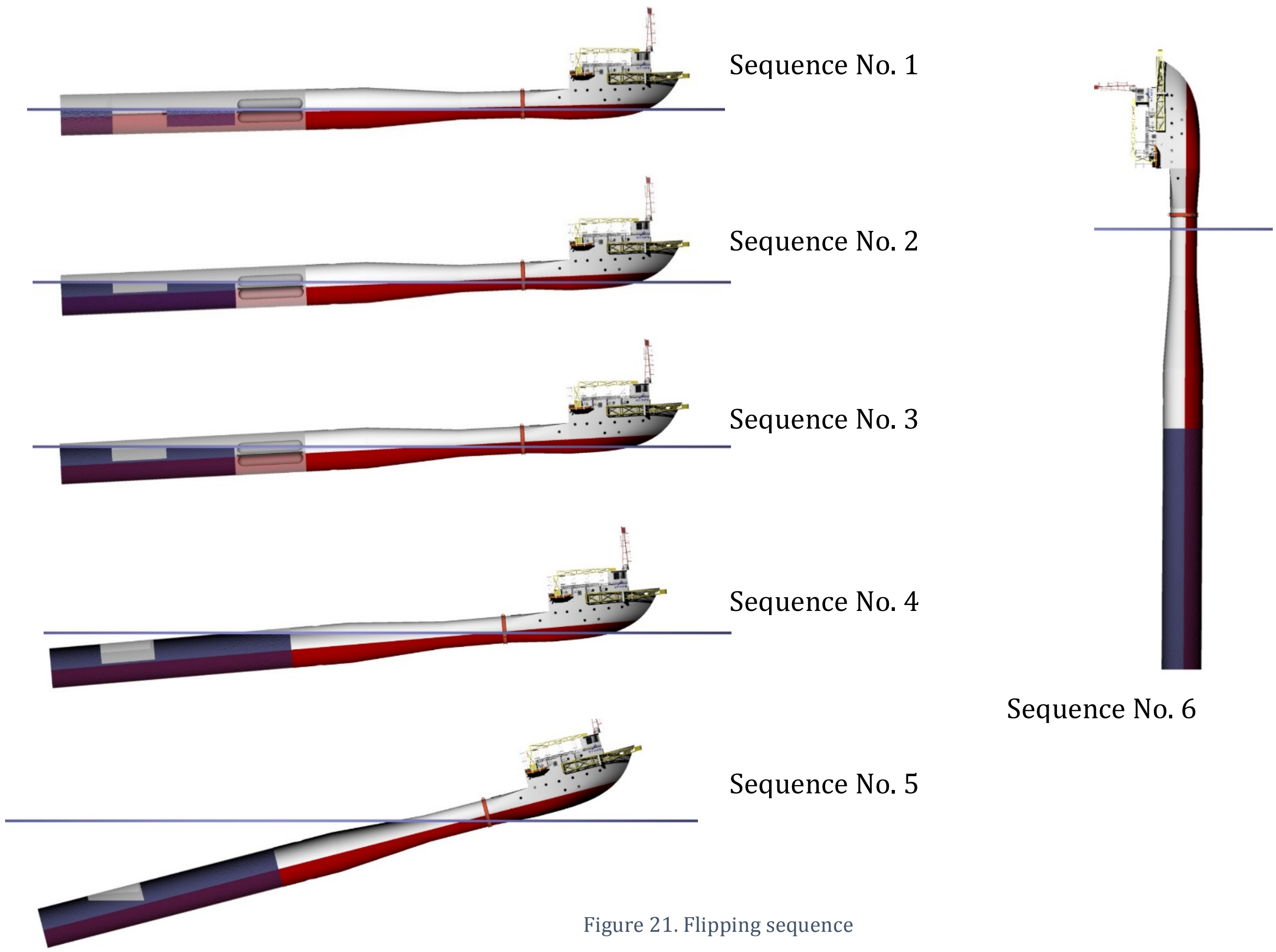


Figure 21. Flipping sequence

7.3 Flipping Velocities

7.3.1 Estimating Flipping Velocities in Quasi-static Mode

Computationally, it is necessary to re-emphasize that the velocity of flipping is a preliminary and crude calculations. The equations of motion, added mass, and damping terms are difficult to solve especially due to time constraints. However, Figure 22 shows the results of our quasi-static analysis of the flipping procedure.

Comparing the results to the *R/P FLIP* results, Figure 23, *R/V FLIP II* shows promising results even for the quasi-static analysis for the velocity during flipping. Assuming a constant flow rate, *R/V FLIP II* has higher initial velocities when compared to *R/P FLIP*, but after a 40° trim, our curve has a decrease in slope. In *R/P FLIP,* the slope remains constant throughout the flipping procedure, which causes the vessel to plunge or go past 90°. It is worth mentioning that time is zero at the first instance when the center of buoyancy is higher than the center of gravity.

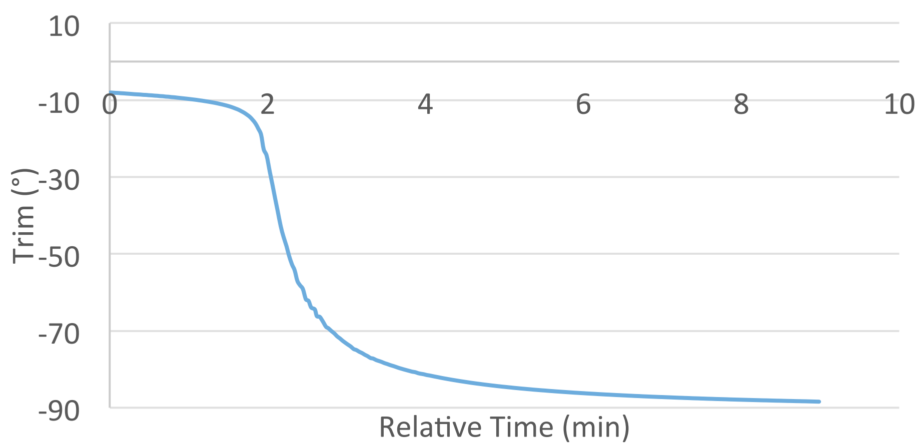


Figure 22. Trimming as a function of relative time from point of instability for *R/V FLIP II*

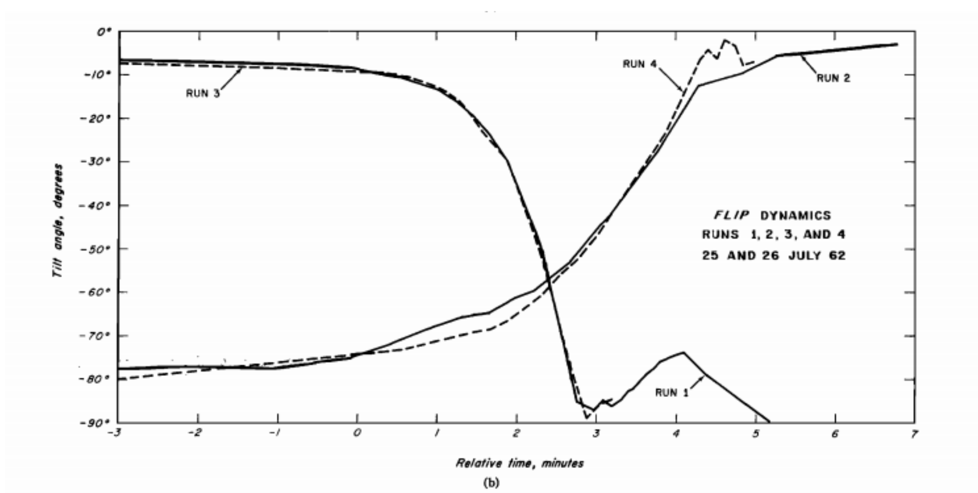


Figure 23. Trimming as a function of relative time from point of instability for *R/P FLIP*

7.3.2 Model Test

A model test was performed at the Marine Hydrodynamics Laboratory at the University of Michigan as a proof of concept. Due to time and financial constraints, the hull was built with PVC pipes, and synthetic foam, and all internal tanks that go through the center of the ballast compartments were also built with PVC. Weights were added across the vessel to achieve the same loading distribution as the *R/V FLIP II*. Moreover, due to the constraints with PVC piping, the designers did their best to have a constant scale ratio. The desired ratio was 1:60 scale model. Table 25 shows the principal dimensions of the model. It is worth emphasizing that one flaw of the design was the model draft. The design draft of *R/V FLIP II* is 13.5ft, however, our model flipped at a full scale draft of 15ft. The longitudinal center of gravity and vertical center of gravity were scaled correctly. The model was just slightly heavier; however attention was given to achieve a load distribution that was similar to that of *R/V FLIP II.*

Table 25. Model principal characteristics

Length (ft)	Beam (ft)	Draft (ft)	Trim (°)	Heel (°)
7.58	0.60	0.25	0.0	0.0

More importantly, the designers also managed to have the ballast tanks at the desired volume scale ratio. However, the permanent ballast that is located from tank 1 to tank 4 could not be allocated, since the weight distribution was already matching that of the vessel. To account for this loss in tank volume, some tanks were not fully flooded, as Table 27 demonstrates.

Figure 24. Model.

Table 26. PVC pipe for model

Hull Section	Inner Diameter of PVC	Scale Ratio
30ft diameter	6"	60.00
20ft diameter	3.998"	60.03
Man Hole (Tank 1, 2, 3)	1.4"	51.43
Internal Tank (Tank 4)	3"	70.71
	Average Scale Ratio	60.54

Froude scaling was used since the procedure was thought to have little effect from viscous forces. From that assumption, the desired flow rate was found. A small pump with a ball valve was used to achieve the needed flow rate. Equations below demonstrate the calculations. Since the desired time for the *R/V FLIP II's* flipping procedure is one hour, the model was designed to flip in 7 minutes and 44.75 seconds. The desired flow rate is therefore 1.672 in^3/sec.

During the model test, a pitch and roll sensor were installed. With the pitch versus time data, angular velocities and accelerations were found by differentiating the data.

Table 27. Flooding time for each tank

	Ship Volume (ft^3)	Model Volume (in^3)	Discrepancy (in^3)	% of tank (in)	Flow Rate (gal/sec)	Time Flooding (sec)
Tank 1	22220.4	203.2	25.4	87	0.0072381	106.3
Tank 2T	13746.7	106.9	-3.0	103	Flow Rate (in^3/sec)	65.8
Tank 2B	9647.8	106.9	29.8	72		46.2
Tank 3T	8590.1	66.8	-1.9	103	1.672	41.1
Tank 3B	3739.2	66.8	36.9	45		17.9
Tank 3S	8454.2	66.8	-0.8	101		40.5
Tank 3P	8454.2	66.8	-0.8	101		40.5
Tank 4	22317.9	220.5	42.0	81		106.8

$$Fr = \frac{V}{\sqrt{gL}}$$

$$\frac{V_m}{V_s} = \frac{1}{\sqrt{60}}$$

$$\frac{L_m T_m^{-1}}{L_s T_s^{-1}} = \frac{1}{\sqrt{60}}$$

$$T_m = \frac{T_s}{\sqrt{60}}$$

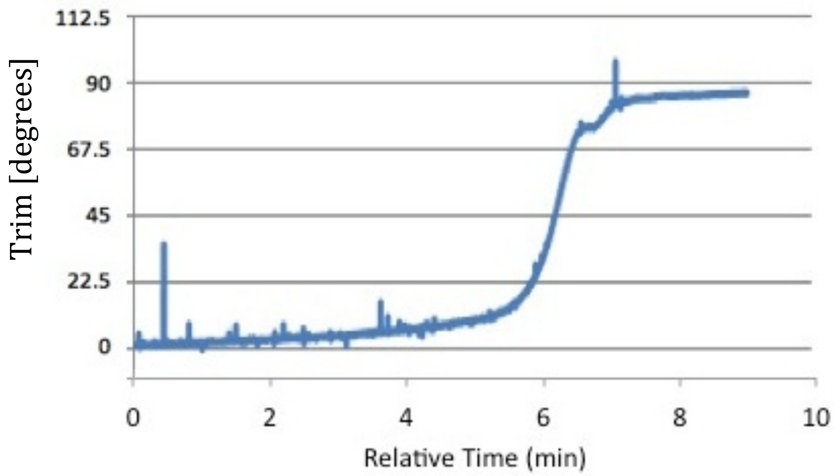


Figure 25. Trim vs. Time

Above shows the results for the model test. The *y*-coordinate is already real size scaled.

Figure 26. Model While Flipping

In summary, the model's flaws are: the lack of a permanent ballast on the aft section, the access shaft was slightly bigger than desired, the air receivers and access shaft had to be modeled as one inside tank 4, and the experiment was performed in a draft of 15ft (instead of the designed 13.5ft). However, this model proves the concept that the velocities decrease towards the end of the flipping procedure, and the crew feels no large accelerations. It also shows that no plunging was seen initially, but more load cases needed to be studied to understand when plunging occurs, and how to properly mitigate it.

7.4 Additional Scientific Payload

R/V FLIP II was designed to carry 50LT of scientific payload. The load location can be found in Table 28.

It was of interest to calculate how much extra scientific payload can be brought aboard for specific research that may require additional weight. It was necessary that this extra load did not interfere with the flipping procedure or the stability of the vessel in horizontal, during flipping, and on vertical.

Table 28. Summary of scientific payload location

Weight (LT)	LCG (ft)	TCG (ft)	VCG (ft)
50	383	0	26

The extra scientific payload was first assumed to be located at the same location as the current payload. The value of the payload then increased until *R/V FLIP* failed flipping or a stability requirement. The first criteria to breakdown was stability during flipping at an extra 250LT located with the designed scientific load. With that weight, the GM_t reaches a negative value during the trimming procedure. For the other longitudinal locations, the same criteria failed. However, the VCG of the extra payload shifted, due to general arrangements set ups. The extra payload decreases with higher LCG, and increases with lower LCG (see below).

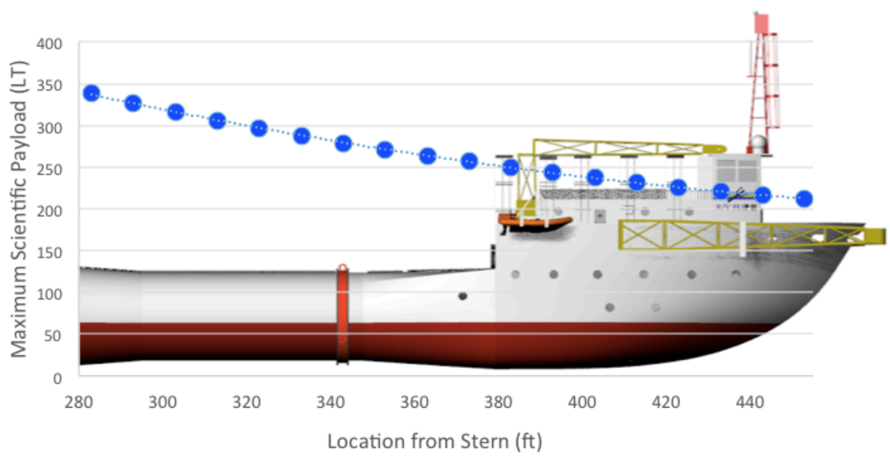


Figure 27. Additional Scientific payload as a function of its LCG

8.0 Structural Design

This section details the design reasoning and calculations regarding the structural strength of *R/V FLIP II*. It reviews: materials, regulations, longitudinal strength, tank and bow compartment structural details, producibility, and future work. Detailed structural drawings for each section of the vessel can be found in the appendix,

8.1 Classification Society Requirements

The preliminary structural design for the vessel was performed according to the regulations for both ABS rules for building and classing steel vessels – 2014, and the ABS guide for buckling and ultimate strength assessment for offshore structures.

8.2 Material

Currently, *R/P FLIP*'s largest maintenance cost is addressing corrosion issues within the ballast tanks. As such, build costs, operating costs, and overall lifecycle costs were reflected while determining the most appropriate material for the construction of *R/V FLIP II*. Titanium and composites would perform exceptionally well against tank corrosion, as well as having better strength values than traditional steel. However, these materials are expensive, and our calculations show an increase in cost in the overall life cycle of the vessel if these materials are used. Furthermore, the owners asked to reduce costs, since past proposals for a new research platform had been shut down due to cost. Steel was found to be the optimal build material. To address corrosion issues, the ballast tanks will be lined with corrosion resistive coatings to act against degradation.

The current research platform was constructed of lower quality steel and has experienced negative consequences in fatigue. Therefore, Grade A36 steel will be used in building *R/V FLIP II* to ensure quality and reduce the probability of complications, since, since the plate exhibits good strength coupled with formability. The steel can be galvanized to provide increased corrosion resistance in the tanks.

8.3 Rules, Regulations, and Guidelines

The structural design guide was taken from "*ABS RULES FOR BUILDING AND CLASSING STEEL VESSELS – 2014.*" According to these application criteria, *R/V FLIP II* falls into a structural special consideration bracket to its (*i*) length to beam ratio, (*iii*) small block coefficient, and (*vii*) unique design and application. In response, the individual compartments were each designed – with a sufficient safety factor – to sustain the largest moments, axial forces, and pressure loads that each experiences.

Figure 28. Structural 3D Drawing for the *R/V FLIP II*

CHAPTER 2 Hull Structures and Arrangements

SECTION 1 Longitudinal Strength

1 Application

Vessels to be classed for unrestricted service, are to have longitudinal strength in accordance with the requirements of this section. Vessels, however, having one or more of the following characteristics will be subject to special consideration:

i) Proportions: $L/B < 5$, $B/D > 2.5$

ii) Length: $L > 500$ m (1640 ft)

iii) Block Coefficient: $C_b < 0.6$

iv) Large deck opening

v) Vessels with large flare

vi) Carriage of heated cargoes

vii) Unusual type or design

Figure 29. ABS rulings on the application of the longitudinal strength section of "*RULES FOR BUILDING AND CLASSING STEEL VESSELS – 2014*"

Because the vessel possess both spar and vessel characteristics, the ABS guidelines for offshore structures was employed in addition to complying with the traditional regulations for steel vessels. Section 8.5 the ABS documents used and their respective locations.

Table 29. ABS documents used and their respective applications

Guideline	Sections	Areas of Concern	To Design
ABS GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES	2, 3, 4	- Cylindrical Compartments	- Tank Structures - Longitudinal Stringers - Ring Stiffeners - Bulkheads
ABS RULES FOR BUILDING AND CLASSING STEEL VESSELS – 2014	3.2.2, 3.2.3., 3.2.9.	- Bow Compartment	- Bow Structure - Bulkheads - Decks

8.4 Longitudinal Strength

Each weight distribution was analyzed in hogging and sagging moments and shears and in calm water. Moreover, the longitudinal stresses were estimated during the flipping procedure in departure and arrival conditions.

For the hogging and sagging conditions, the wave characteristics can be seen in the following sections. The wave length was selected to be equal to the length of the waterline, and the wave height is 1/20 of the length of the waterline. A trochoidal wave was used since its geometrical properties are closer related to the waves seen in the ocean.

Table 30. Wave Characteristics for Longitudinal Stress Analysis

Wave Type	Wave Length	Wave Height
Trochoidal	442ft	23.1ft

The maximum bending moment and shear stress occur in departure condition in hogging. During flipping, maximum bending moments and shear forces were found at a 15° trim. Table 31 summarizes the longitudinal strength results for all conditions analyzed. Figure 30 and Figure 31 present the results for the shear stresses and moments as a function of the length of the vessel for the maximum conditions in calm water, hogging, sagging, and flipping for both departure and arrival. Figure 32 to Figure 36 show the longitudinal moments and forces through the flipping procedure in more detail.

Table 31. Summary of the Structural Loads

Condition		Shear (LT)	Moment (LT-ft. x 1000)
Departure	Calm Water	1981	15.51
Arrival	Calm Water	180.1	12.56
LS	Calm Water	171.1	11.12
Departure	Hogging	711.5	89.77
Arrival	Hogging	632.6	77.70
LS	Hogging	588.7	70.94
Departure	Sagging	611.5	-67.45
Arrival	Sagging	573.3	-66.07
LS	Sagging	573.9	-65.58
Departure	Flipping	622.2	79.64
Arrival	Flipping	569.6	71.29

The results presented in Table 31 are the second iteration of the longitudinal strength calculations. During the first design iteration of the *R/V FLIP II*, our structural loads were calculated to be higher than the ones mentioned in Table 31. Due to an efficient structural design, the weights were distributed more effectively, therefore decreasing the structural loads. During the first iteration, the largest bending moment was 128,698 LT-ft., and the maximum shear force was 966.2LT. These were the values used in the design of each compartment, due to a lack of time, the designers could not update the structural needs.

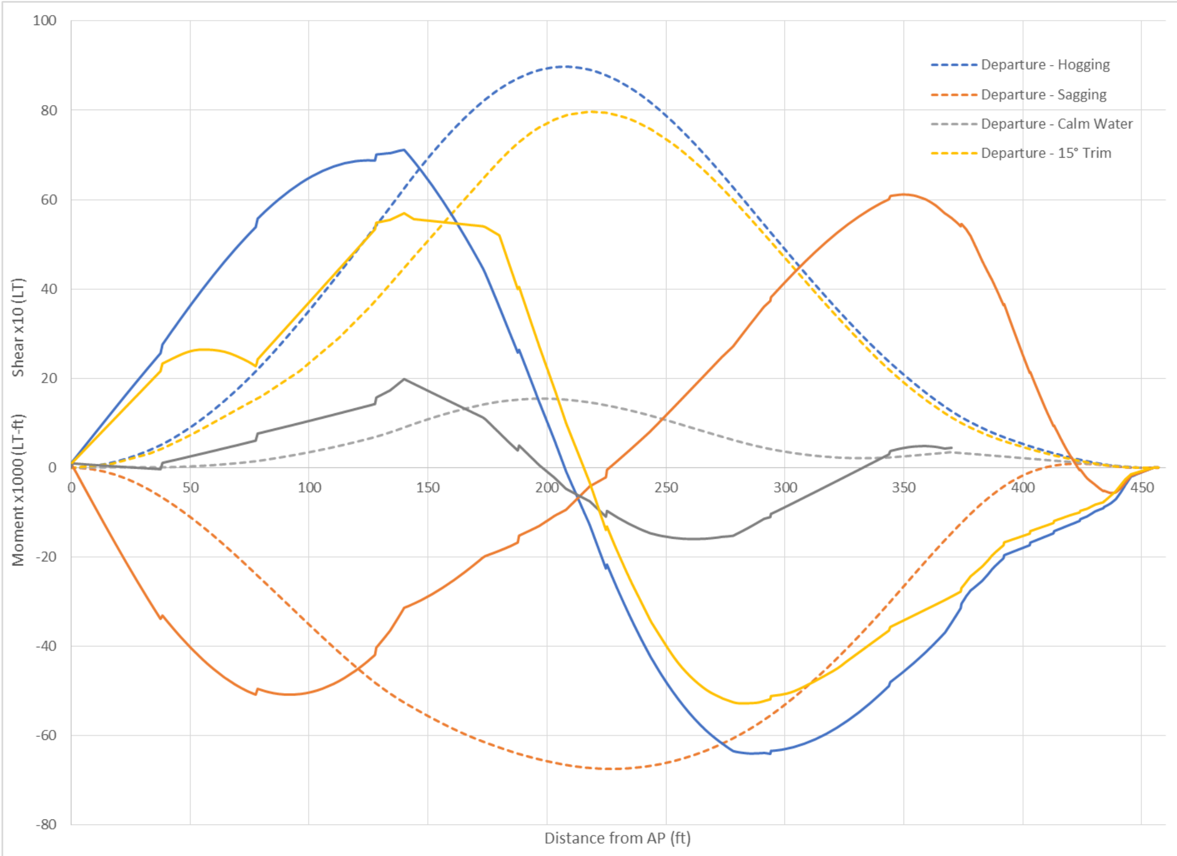


Figure 30. Maximum moments and shear in all conditions

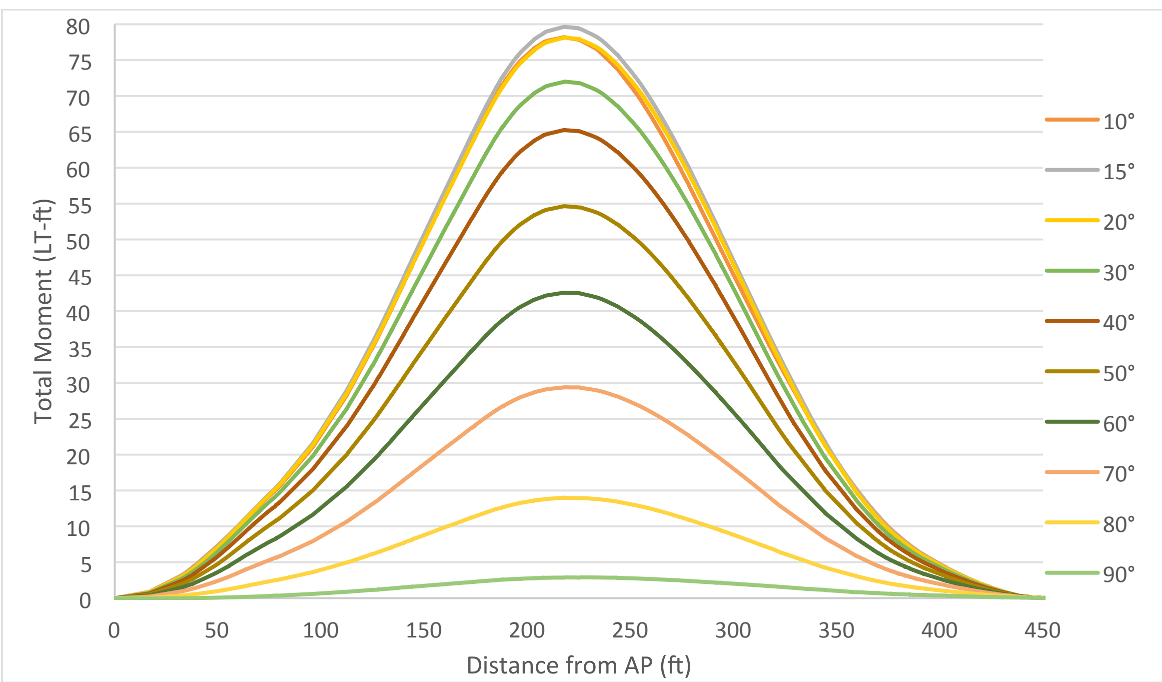


Figure 31. Moments through flipping in departure condition

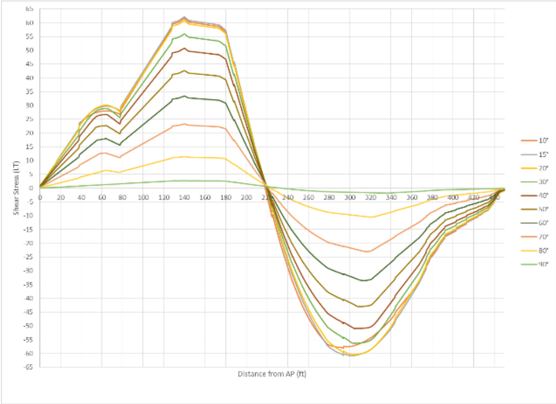


Figure 32. Shear stresses through flipping in departure condition

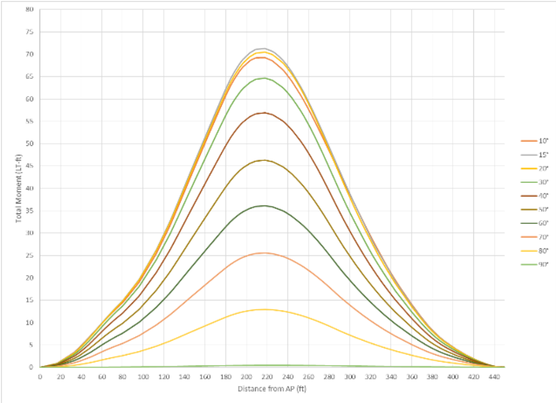


Figure 33. Moments through flipping in arrival condition

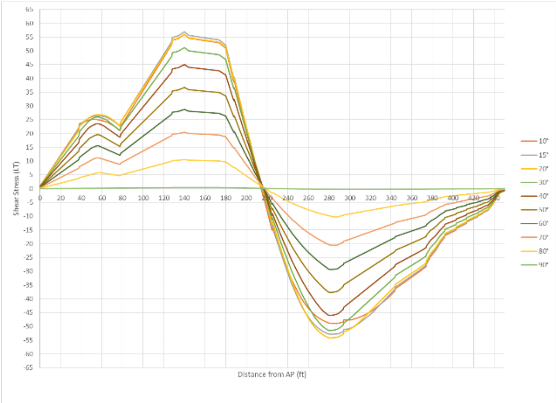


Figure 34. Shear stresses through flipping in arrival condition

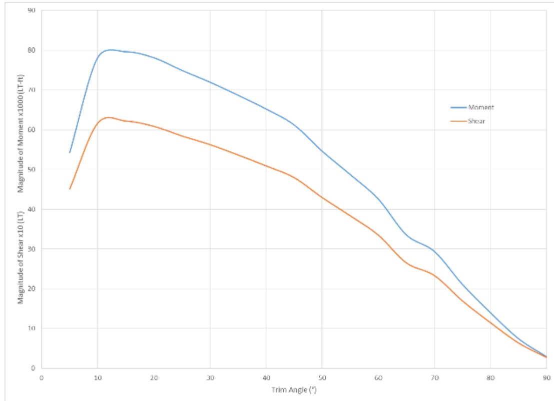


Figure 35. Maximum moment and shear stresses through flipping in departure condition

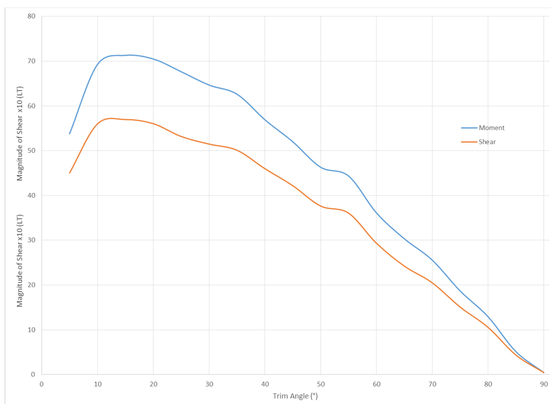


Figure 36. Maximum moment and shear stresses through flipping in arrival condition

8.5 Tank Details

As per ABS guide, tank structures were designed against local shell buckling, bay buckling, and general buckling, in addition to their maximum shear forces and bending moments. A utilization factor for severe weather was used throughout to result in a more robust structure and to withstand the structural challenges provided by the open ocean.

The tank, transition, neck, and connector compartments were designed to Sections 2, 3, and 4 of "*ABS GUIDE FOR BUCKLING AND ULTIMATE STENGTH ASSESSMENT FOR OFFSHORE STRUCTURES.*" Each of these hull sections comply with the criteria detailed in:

- **2.3.** Members Subjected to a Single Action
    - 2.3.1. Axial Tension
    - 2.3.3. Axial Compression
    - 2.3.5. Bending Moment
- **2.5.** Members Subjected to Combined Loads
    - 2.5.1. Axial Tension and Bending Moment
    - 2.5.3. Axial Compression and Bending Moment
- **2.7.** Tubular Members Subjected to Combined Loads and Hydrostatic Pressure

  - 2.7.1. Axial Tension, Bending Moment, and Hydrostatic Pressure
  - 2.7.3. Axial Compression, Bending Moment, and Hydrostatic Pressure
- **2.9.** Local Buckling
  - 2.9.1. Tubular Members Subjected to Axial Compression
  - 2.9.3. Tubular Members Subjected to Bending Moment
  - 2.9.5. Tubular Members Subjected to Hydrostatic Pressure
  - 2.9.7. Plate Elements Subjected to Compression and Bending Moment
- **3.3.** Plate Panels
  - 3.3.1. Buckling State Limit
    - 3.3.1.1. Critical Buckling Stress for Edge Shear
    - 3.3.1.2. Critical Buckling Stress for Uniaxial Compression and In-plane Bending
  - 3.3.3. Ultimate Strength under Combined In-plane Stresses
  - 3.3.5. Uniform Lateral Pressure
- **3.5.** Stiffened Panels
  - 3.5.1. Beam-Column Buckling State Limit
  - 3.5.3. Flexural-Torsional Buckling State Limit
  - 3.5.5. Local Buckling of Web, Flange, and Face Plates
  - 3.5.7. Overall Buckling State Limit
- **4.5.** Curved Panels
  - 4.5.1. Buckling State Limit
  - 4.5.3. Critical Buckling Stress for Axial Compression or Bending Moment
  - 4.5.5. Critical Buckling Stress under External Pressure
- **4.7.** Ring and Stringer-stiffened Shells
  - 4.7.1. Bay Buckling Limit State
  - 4.7.3. Critical Buckling Stress for Axial Compression or Bending Moment
  - 4.7.5. Critical Buckling Stress for External Pressure
  - 4.7.7. General Buckling
- **4.9.** Local Buckling Limit State for Ring and Stringer Stiffeners
  - 4.9.1. Flexural-Torsional Buckling
  - 4.9.3. Web Plate Buckling
  - 4.9.5. Faceplate and Flange Buckling
- **4.11.** Beam-Column Buckling
- **4.13.** Stress Calculations
  - 4.13.1. Longitudinal Stress
  - 4.13.3. Hoop Stress
- **4.15.** Stiffness and Proportions
  - 4.15.1. Stiffness of Ring Stiffeners
  - 4.15.3. Stiffness of Stringer Stiffeners
  - 4.15.5. Proportions of Webs of Stiffeners
  - 4.15.7. Proportions of Flanges and Faceplates

Table 32 details the structural members employed. The calculations used in determining these sizing can be found in the following section.

Table 32. Structural members used throughout the tanks, transition, neck, and connector compartments

Compartment	Shell Thickness (in)	Stringers				Ring Stiffeners			
		No.	d_w (in)	b_f (in)	t_f & t_w (in)	No.	d_w (in)	b_f (in)	t_f & t_w (in)
Tank 1	0.313	36	13.50	4.00	0.375	7	15.00	4.00	0.375
Tank 2	0.688	38	13.50	4.00	0.375	18	22.50	5.25	0.563
Tank 3	0.938	50	13.50	4.00	0.375	12	15.00	4.00	0.375
Tank 4	1.188	48	18.00	4.50	0.438	18	21.00	5.25	0.500
Tank 5	1.188	54	18.00	4.50	0.438	10	21.00	5.25	0.500
Transition	1.250	54	32.00	8.00	0.750	12	15.00	4.00	0.375
Neck	1.188	48	21.00	6.00	0.563	5	15.00	4.00	0.375
Connector	1.188	36	21.00	5.25	0.500	3	15.00	4.00	0.375

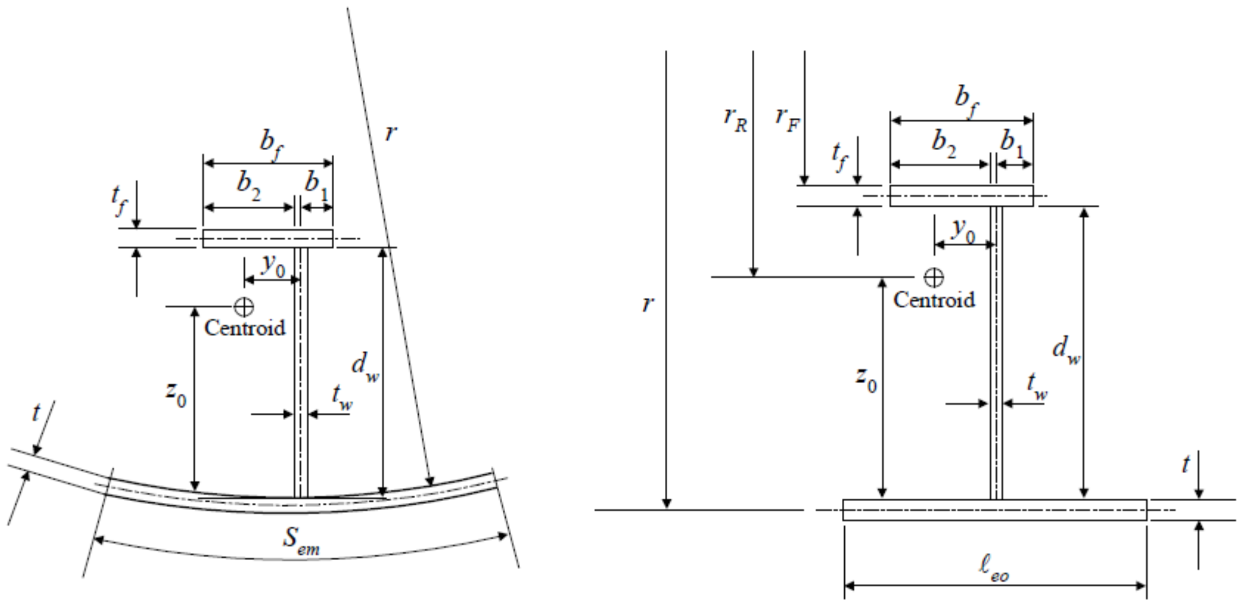


Figure 37. Drawing for reference taken from *"ABS GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES"*

8.7 Bow Details

Continuing forward of the connector compartment, the bow's structure was designed using Chapter 3 from "*ABS RULES FOR BUILDING AND CLASSING STEEL VESSELS – 2014.*" These rules were also used to design the watertight bulkheads, assign minimum plate thicknesses, and structuring the decks:

- **3.2.2.** Shell Plating
  - **3.2.2.3.** Shell Plating Amidships
    - 3.2.2.3.9. Side Shell Plating
    - 3.2.2.3.13. Bottom Shell Plating Amidships
    - 3.2.2.3.17. Minimum Thickness
  - **3.2.2.5.** Shell Plating at Ends

        - 3.2.2.5.1. Minimum Shell Plating Thickness
        - 3.2.2.5.5. Bottom Forward
    - **3.2.2.13.** Bilge Keels
- **3.2.3.** Decks
    - 3.2.3.5. Deck Plating
        - 3.2.3.5.1. Thickness
        - 3.2.3.5.3. Effective Lower Decks
- **3.2.9.** Watertight Bulkheads and Doors
    - 3.2.9.3. Arrangement of Watertight Bulkheads
        - 3.2.9.3.1. Collision Bulkhead
        - 3.2.9.3.3. After-peak Bulkhead
        - 3.2.9.3.5. Machinery Spaces
    - 3.2.9.5. Construction of Watertight Bulkheads
        - 3.2.9.5.1. Plating
        - 3.2.9.5.3. Stiffeners

Calculations for the bow compartment can be found section 8.9

8.6 Producibility

To design for production, all ring stiffeners, bulkhead stiffeners, and longitudinal stringers are made of angle stiffeners. The hull was structured to contain a large portion of the stress within the support members. As such, the exterior plate thicknesses were constrained to a range of 0.3125 inches to 1.25 inches.

To reduce complexity and increase like components, longitudinal stringers and ring stiffeners have only 6 and 3 unique sizes, respectively, throughout the entirety of the vessel's hull. These sizes are shown below in Table 33.

Table 33. Dimensions of the unique structural components

Member	d_w(in)	b_f(in)	t_f & t_w (in)
Stringer #1	9.00	3.00	0.313
Stringer #2	13.50	4.00	0.375
Stringer #3	18.00	4.50	0.438
Stringer #4	21.00	5.25	0.500
Stringer #5	21.00	6.00	0.563
Stringer #6	32.00	8.00	0.750
Ring Stiffener #1	15.00	4.00	0.375
Ring Stiffener #2	21.00	5.25	0.500
Ring Stiffener #3	22.50	5.25	0.563

8.7 Hull Natural Frequency and Vibrations

A preliminary hull natural frequency analysis was conducted in order to compare to the excitations frequencies present in the design. The primary excitations include the high-speed diesel generator sets and the retractable propulsion unit. The University of Michigan Hull Natural Frequencies spreadsheet tool was used in this analysis, which is based on compliance with ABS calculation procedures. The results of this analysis are shown in

Table 34 below. The primary propulsion unit has a blade rate of 1,350 CPM and the high-speed generator set has a frequency of 1,800 CPM.

Table 34. Hull natural frequency estimates

Mode	Natural Frequency Estimates (CPM)	+/- band (CPM)
N_{2v} (2-noded vert.)	80.27	2.01
N_{3v}	144.49	7.22
N_{4v}	200.68	15.05
N_{5v}	260.89	26.09
N_{6v}	357.22	44.65
N_{2h} (2-noded horiz.)	124.42	3.11
N_{3h}	248.85	12.44
N_{4h}	385.31	28.90
N_{5h}	521.78	52.18

As shown, the excitation frequencies lay far outside the range of most excitation modes. The blade rate does fall within the band of the 6^{th} natural mode of the vessel, however this does not cause concern as this can be avoided through further analysis. A detailed analysis of natural frequency of the local structure should be conducted in order to properly compare the excitation provided by the machinery and the structural natural frequency of the bulkheads and decks that they are mounted on. This analysis could be conducted through the use of a finite element model.

8.8 Future Work

Due to the reduction in shear force and bending moment values from the second iteration of longitudinal strength, a second iteration of structural design would further decrease our weight. As adding more permanent ballast would likely be an inefficient use of space and money, future work would probably include resizing the hull so that an optimal size can be yielded. This decrease in length or cylinder diameter would decrease costs and resistance requirements, and possibly further improve vertical sea-keeping characteristics. The change would affect the design as a whole, and further analysis should be performed.

8.9 Detailed Structural Calculations

Tank 1

TANK 1 STATUS: initially sized

Data and Calculations in Table are for Half of Hull.

piece	number	thickness (Note 2.) in	height (length of web) ft	width (of flange) ft	centroid from wall ft	radius from center ft	VCG of struct. ft	*area per piece* in^2	total area in^2	*local self inertia* ft^4	total local inertia ft^4	moment rel. to BL in^2ft	total inertia rel. to center ft^4	percent contrib. to inertia
CIRCULAR ITEMS														
exterior plate	1	0.313				15.000	15.000	*176.715*	176.715	*138.058*	138.058	2650.719	138.058	45.03%
access tunnel	1	0.250				2.500	15.000	*23.562*	23.562	*0.511*	0.511	353.429	0.511	0.17%
LONGITUDINAL ITEMS														
stringer stiffeners	18	0.375	1.125	0.333	0.691	14.309	15.000	*6.561*	118.098	*0.006*	0.112	1771.470	168.032	54.80%
heavy s stiffeners	0	0.500	2.500	1.000	1.607	13.393	15.000	*21.000*	0.000	*0.101*	0.000	0.000	0.000	0.00%
tank dividers	0	0.250	12.500	0.000	6.250	8.750	15.000	*37.500*	0.000	*3.391*	0.000	0.000	0.000	0.00%
TRANSVERSE ITEMS														
ring stiffeners	7	0.375	1.250	0.333	0.756	14.244		*7.124*		*0.008*				
total									318.4		138.7	4775.6	306.6	100.00%

half of hull

Tank depth	30.00 ft	Effective depth while vert.	50.00 ft	Mid-depth	15.00 ft
Tank length	38.00 ft	Pressure	1.43 LT/ft^2	Neutral axis	15.00 ft above BL
				Inertia for whole hull	613.20 ft^4 relative to neutral axis
				SM deck	40.88 ft^3
				SM bottom	40.88 ft^3

VALUES

Total area	4.42 ft^2	BULKHEAD VOLUME			
E (steel)	1928571.43 LT/ft^2	t	0.43 in		
min. yield	2312.32 LT/ft^2	A_bh	706.86 ft^2	Yield Strength	2312.32 LT/ft^2 (248.00 MPa)
Pr	0.60 for steel	V_bh	25.23 ft^3	Ultimate Stength	7841.36 LT/ft^2 (841.00 MPa)
shell btwn stingers	31.42 inches	V_stiffener	0.57 ft^3		
shell bwtn ring stiffene	57.00 inches	reduction	0.67 nd	M(x)	16911.619 LTft
total volume of steel	199.02 ft^3	stiffeners	36.00 stiffeners	Bending Stress	-413.69 LT/ft^2
		V_total	38.90 ft^3		
				V(x)	876.919 LT
				Shear Stress	396.63 LT/ft^2

LOCAL SHELL BUCKLING

phi	0.83 nd
utilization factor	0.67 nd

PROPORTIONS OF WEBS OF STIFFENERS

STRINGERS	d_w	1.13 ft		
	t_w	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		36.00	must be < or	43.32
				0.83
RING STIFFENERS	d_w	1.25 ft		
	t_w	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		40.00	must be < or	43.32
				0.92

PROPORTIONS OF FLANGES AND FACEPLATES

STRINGERS	b_2	0.3330 ft		
	t_f	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		10.66	must be < or	11.55
				0.92
RING STIFFENERS	b_2	0.3330 ft		
	t_f	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		10.66	must be < or	11.55
				0.92

STIFFNESS OF STRINGER STIFFENERS

l	4.75 ft		
A_s	0.0456 ft^2		
v	0.30 nd		
t	0.0260 ft		
s	2.62 ft		
alpha	1.81 nd		
delta	0.6683 nd		
gamma_o	22.08 nd		
i_o	0.0001	must be <	0.0062
			0.0150

STIFFNESS OF RING STIFFENERS

eta	0.6664 nd		
l	4.75 ft		
t	0.0260 ft		
A_s	0.0456 ft^2		
s	2.62 ft		
E	1928571.43 LT/ft^2		
o_o	2312.32 LT/ft^2		
K_theta	0.9927 nd		
z_e	0.4935 ft		
r_e	14.24 ft		
l_eo	0.98 ft must be <= 1		
delta	0.6683 nd		
o_thetaR	247.22 LT/ft^2		
o_theta	818.70 LT/ft^2		
o_x	551.04 LT/ft^2		
i_r	0.0082	must be <	0.0083
			0.99

TANK 1

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

2.3.1	axial tension req.			
	axial tensile pressure	1.431818	LT/ft^2	
	eta	0.6664		
	o_o	2312.32		
	req	0.00	has to be < 1	
2.3.3	axial compression req.			
	axial compressive pressu	1.43	LT/ft^2	
	eta	0.6664	nd	
	k, eff length	1.00	nd	
	L, of member	38.00	ft	
	K, St. Venant	1226.41	ft^4	
	A	4.42	ft^2	
	E	1928571.43	LT/ft^2	
	radius of gyration	11.78	ft	
	o_Eeta	1827958.77	LT/ft^2	
	o_ET	1483516.48	LT/ft^2	
	o_EA	1483516.48	LT/ft^2	
	o_CA	2311.45	LT/ft^2	
	req	0.00	has to be < 1	
2.3.5	bending moment req.			
	o_b	413.69	LT/ft^2	
	o_CB	2312.28	LT/ft^2	
	o_b / n_2 o_SB	0.27	has to be < 1	
4.7.3	critical buckling stress for axial compression or bending moment			
	lambda_xP	1.6147	nd	
	s_e	10.31	inches	
	I_se	3.08	ft^4	
	o_c	38231581.90	LT/ft^2	
	rho_xB	0.7500	nd	
	o_s	500.41	LT/ft^2	
	o_ExB	38232082.31	LT/ft^2	
	o_CxB	2312.28	LT/ft^2	
4.5.3	critical buckling stress for axial compression or bending moment in curved panels			
	z_s	16.74	nd	
	rho_xP	0.3198	nd	
	K_xP	12.63	nd	
	o_CExP	2177.97	LT/ft^2	
	lambda_n	1.8220	nd	
	B_xP	1.27	nd	
	o_ExP	886.87	LT/ft^2	
	o_CxP	865.40	LT/ft^2	
2.5.1	axial tension and bending			
	o_t	1.43	LT/ft^2	
	o_b	413.69	LT/ft^2	
	o_CB	2312.28	LT/ft^2	
	eqn	0.38	has to be < 1	
2.5.3	axial compression and bending			
	o_a	1.43	LT/ft^2	
	o_CA	2311.45	LT/ft^2	
	o_b	413.69	LT/ft^2	
	o_CB	2312.28	LT/ft^2	
	eqn	0.38	has to be < 1	

BAY BUCKLING LIMIT STATE

4.13.3	hoop stress		
	r	15.00	ft
	N_theta	1.00	LT/ft
	N_axial	0.00	LT/ft
	q	1.43	LT/ft^2
	A_R	0.0495	ft^2
	r_R	14.24	ft
	r_F	13.75	ft
	t	0.0260	ft
	t_w	0.0313	ft
	l	4.75	ft
	v	0.3000	nd
	k	0.5000	nd
	alpha	4.87	nd
	G_alpha	0.0127	nd
	omega	0.2053	nd
	A_R mean	0.0549	ft^2
	K_thetaR	0.2748	nd
	K_theta	0.9927	nd
	o_thetaR	247.22	LT/ft^2
	o_theta	818.70	LT/ft^2
4.13.1	longitudinal stress		
	t	0.0260	ft
	r	15.00	ft
	s	2.62	ft
	A_st	0.0456	ft^2
	delta	0.6683	nd
	M	16911.62	LTft
	P	876.92	LT
	o_b	550.69	LT/ft^2
	o_a	0.35	LT/ft^2
	o_x	551.04	LT/ft^2
4.7.1	bay buckling limit state		
	eta	0.6664	nd
	o_o	2312.32	LT/ft^2
	o_ExP	886.87	LT/ft^2
	lambda_m	1.6147	nd
	s_em	1.42	ft
	s	2.62	ft
	t	0.0260	ft
	A_s	0.0456	ft^2
	A	0.1137	ft^2
	A_e	0.0826	ft^2
	phi_B	1.00	nd
	o_CthetaB	2312.32	LT/ft^2
	o_CxB	2312.28	LT/ft^2
	o_theta	818.70	LT/ft^2
	o_x	551.04	LT/ft^2
	req	0.26	has to be < 1

TANK 1

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

4.7.5	criticial buckling stress for external pressure		
	o_o	2312.32	LT/ft^2
	t	0.02604	ft
	r	15.00	ft
	l	4.75	ft
	N_s	36.00	stringers
	I_s	0.00625	ft^4
	g	28.71	nd
	K_p	0.29881	nd
	A_s	0.04556	ft^2
	z_st	14.31	ft
	q_s	408.35	LT/ft^2
	K_theta	0.99	nd
	o_sp	233490.11	LT/ft^2
	o_CthetaR	351.28	LT/ft^2
	o_CthetaB	69873.60	if greater, 2312.315933
4.3.5			
	o_o	2312.32	LT/ft^2
	v	0.30	nd
	E	1928571.43	LT/ft^2
	t	0.02604	ft
	r	15.00	ft
	l	4.75	ft
	z	55.10	nd
	k	0.50	nd
	C_P	0.01209	nd
	A_L	6.96	nd
	q_CEthetaR	0.77	LT/ft^2
	K_theta	0.99	nd
	rho_thetaR	0.80	nd
	o_EthetaR	351.28	LT/ft^2
	DELTA	0.15	nd
	PHI	1.00	nd
	o_CthetaR	351.28	LT/ft^2

BEAM COLUMN BUCKLING

4.11.	E	1928571.43	LT/ft^2
	kL	38.00	ft
	A_T	4.42	ft^2
	I_T	613.20	ft^4
	r_i	11.78	ft
	o_E©	1827958.77	LT/ft^2
	lambda_xE	0.04	if > 0.5 then the following beam buckling sectic

LOCAL BUCKLING LIMIT STATE FOR RING AND STRINGER STIFFENERS

4.9.1	flexural-torsional buckling				
	eta	0.67	nd		
	l	4.75	ft		
	t	0.02604	ft		
	A_s	0.04556	ft^2		
	s	2.62	ft		
	E	1928571.43	LT/ft^2		
	o_o	2312.32	LT/ft^2		I_y
	n	2.00	wave for smallest yield	tw	3.13E-02 ft
	alpha	1.81	nd	dw	1.13E+00 ft
	o_CL	696.45	LT/ft^2	tf	3.13E-02 ft
	I_xf	0.00032	ft^4	bf	3.33E-01 ft
	WARPING const	0.00026	ft^6	Aw	3.52E-02 ft^2
	C_o	4.34	LT	Af	1.04E-02 ft^2
	t_f	0.03125	ft	At	4.56E-02 ft^2
	b_1	0.00000	ft	y_o	3.80E-02 ft
	b_f	0.33	ft	z_o	6.91E-01 ft
	t_w	0.03125	ft	I_yw	3.71E-03 ft^4
	d_w	1.13	ft	I_yf	8.47E-07 ft^4
	z_o	0.69097	ft	I_zw	2.86E-06 ft^4
	y_o	0.03803	ft	I_zf	9.62E-05 ft^4
	u	1.00	nd	I_y	6.39E-03 ft^4
	m	0.64	nd	I_z	3.22E-04 ft^4
	I_y	0.00639	ft^4		
	I_z	0.00032	ft^4		
	I_o	0.02842	ft^4		
	K	0.00001	ft^4		
	o_ET	27666.48	LT/ft^2		
	P_r	0.60	nd		
	o_CT	2265.93	LT/ft^2		
	o_x	551.04	LT/ft^2		
	req	0.36	has to be < 1		

AFT BULKHEAD THICKNESS (RULES FOR BUILDING AND CLASSING STEEL VESSELS)

c	460	nd	c = 460 for collision bh and 525 for watertight
h	50.00	ft	using effective depth instead of horizontal value
Y	35969	psi	
q	0.945		
alpha	1		
k	0.785		
s	31.42	inches	
t	0.428	inches	
	0.257	inches	
THICKNESS	0.428	inches	

Tank 2

TANK 2 STATUS: initially sized

Data and Calculations in Table are for Half of Hull.

piece	number	thickness (Note 2.) in	height (length of web) ft	width (of flange) ft	centroid from wall ft	radius from center ft	VCG of struct. ft	*area per piece* in^2	total area in^2	*local self inertia* ft^4	total local inertia ft^4	moment rel. to BL in^2ft	total inertia rel. to center ft^4	percent contrib. to inertia
CIRCULAR ITEMS														
exterior plate	1	0.688				15.000	15.000	*388.772*	388.772	*303.728*	303.728	5831.581	303.728	60.15%
access tunnel	1	0.250				2.500	15.000	*23.562*	23.562	*0.511*	0.511	353.429	0.511	0.10%
LONGITUDINAL ITEMS														
stringer stiffeners	19	0.375	1.125	0.333	0.691	14.309	15.000	*6.561*	124.659	*0.006*	0.119	1869.885	177.367	35.13%
heavy s stiffeners	0	0.500	2.500	1.000	1.607	13.393	15.000	*21.000*	0.000	*0.101*	0.000	0.000	0.000	0.00%
tank dividers	1	0.250	12.500	0.000	6.250	8.750	15.000	*37.500*	37.500	*3.391*	3.391	562.500	23.329	4.62%
TRANSVERSE ITEMS														
ring stiffeners	18	0.563	1.875	0.438	1.115	13.885		*15.609*		*0.040*				
total									574.5		307.7	8617.4	504.9	100.00%

Tank depth	30.00 ft	Effective depth while verti	312.00 ft		Mid-depth	15.00 ft		
Tank length	40.00 ft	Pressure	8.93 LT/ft^2		Neutral axis	15.00 ft above BL		

half of hull

Inertia for whole hull 1,009.87 ft^4 relative to neutral axis

SM deck 67.32 ft^3

SM bottom 67.32 ft^3

VALUES

Total area	7.98 ft^2	BULKHEAD VOLUME					
E (steel)	1928571.43 LT/ft^2	t	0.82 in				
min. yield	2312.32 LT/ft^2	A_bh	706.86 ft^2	Yield Strength	2312.32 LT/ft^2	248.00	MPa
Pr	0.60 for steel	V_bh	48.53 ft^3	Ultimate Stength	7841.36 LT/ft^2	841.00	MPa
shell btwn stingers	29.76 inches	V_stiffener	0.57 ft^3				
shell bwtn ring stiffene	25.26 inches	reduction	0.67 nd	M(x)	53429.50 LTft		
total volume of steel	489.39 ft^3	stiffeners	38.00 stiffeners	Bending Stress	-793.61 LT/ft^2		
		V_total	62.96 ft^3				

LOCAL SHELL BUCKLING

phi	0.83 nd	V(x)	950.74 LT
utilization factor	0.67 nd	Shear Stress	238.31 LT/ft^2

PROPORTIONS OF WEBS OF STIFFENERS

STRINGERS	d_w	1.13 ft		
	t_w	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		36.00	must be < or	43.32
				0.83
RING STIFFENERS	d_w	1.88 ft		
	t_w	0.0469 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		40.00	must be < or	43.32
				0.92

PROPORTIONS OF FLANGES AND FACEPLATES

STRINGERS	b_2	0.3330 ft		
	t_f	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		10.66	must be < or	11.55
				0.92
RING STIFFENERS	b_2	0.4375 ft		
	t_f	0.0469 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		9.33	must be < or	11.55
				0.81

STIFFNESS OF STRINGER STIFFENERS

l	2.11 ft		
A_s	0.0456 ft^2		
v	0.30 nd		
t	0.0573 ft		
s	2.48 ft		
alpha	0.85 nd		
delta	0.3206 nd		
gamma_o	1.16 nd		
i_o	0.0000	must be <	0.0062
			0.0079

STIFFNESS OF RING STIFFENERS

eta	0.6664 nd		
l	2.11 ft		
t	0.0573 ft		
A_s	0.0456 ft^2		
s	2.48 ft		
E	1928571.43 LT/ft^2		
o_o	2312.32 LT/ft^2		
K_theta	0.7400 nd		
z_e	0.7601 ft		
r_e	13.89 ft		
l_eo	1.45 ft must be <= 1		
delta	0.3206 nd		
o_thetaR	954.97 LT/ft^2		
o_theta	1730.96 LT/ft^2		
o_x	1000.26 LT/ft^2		
i_r	0.0390	must be <	0.0404
			0.97

TANK 2

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

2.3.1	axial tension req.		
	axial tensile pressure	8.93	LT/ft^2
	eta	0.6664	
	o_o	2312.32	
	req	0.01	has to be < 1
2.3.3	axial compression req.		
	axial compressive pressu	8.93	LT/ft^2
	eta	0.6664	nd
	k, eff length	1.00	nd
	L, of member	40.00	ft
	K, St. Venant	2019.74	ft^4
	A	7.98	ft^2
	E	1928571.43	LT/ft^2
	radius of gyration	11.25	ft
	o_Eeta	1505666.99	LT/ft^2
	o_ET	1483516.48	LT/ft^2
	o_EA	1483516.48	LT/ft^2
	o_CA	2311.45	LT/ft^2
	req	0.01	has to be < 1
2.3.5	bending moment req.		
	o_b	793.61	LT/ft^2
	o_CB	2312.31	LT/ft^2
	o_b / n_2 o_SB	0.52	has to be < 1
4.7.3	critical buckling stress for axial compression or bending moment		
	lambda_xP	0.7198	nd
	s_e	21.91	inches
	I_se	6.50	ft^4
	o_c	186011957.21	LT/ft^2
	rho_xB	0.7500	nd
	o_s	2328.37	LT/ft^2
	o_ExB	186014285.57	LT/ft^2
	o_CxB	2312.31	LT/ft^2
4.5.3	critical buckling stress for axial compression or bending moment in curved panels		
	z_s	6.83	nd
	rho_xP	0.7924	nd
	K_xP	5.44	nd
	o_CExP	5055.90	LT/ft^2
	lambda_n	0.7597	nd
	B_xP	1.11	nd
	o_ExP	4462.65	LT/ft^2
	o_CxP	2024.77	LT/ft^2
2.5.1	axial tension and bending		
	o_t	8.93	LT/ft^2
	o_b	793.61	LT/ft^2
	o_CB	2312.31	LT/ft^2
	eqn	0.73	has to be < 1
2.5.3	axial compression and bending		
	o_a	8.93	LT/ft^2
	o_CA	2311.45	LT/ft^2
	o_b	793.61	LT/ft^2
	o_CB	2312.31	LT/ft^2
	eqn	0.73	has to be < 1

BAY BUCKLING LIMIT STATE

4.13.3	hoop stress		
	r	15.00	ft
	N_theta	1.00	LT/ft
	N_axial	0.00	LT/ft
	q	8.93	LT/ft^2
	A_R	0.1084	ft^2
	r_R	13.89	ft
	r_F	13.13	ft
	t	0.0573	ft
	t_w	0.0313	ft
	l	2.11	ft
	v	0.3000	nd
	k	0.5000	nd
	alpha	1.46	nd
	G_alpha	0.5277	nd
	omega	0.7454	nd
	A_R mean	0.1265	ft^2
	K_thetaR	0.3572	nd
	K_theta	0.7400	nd
	o_thetaR	954.97	LT/ft^2
	o_theta	1730.96	LT/ft^2
4.13.1	longitudinal stress		
	t	0.0573	ft
	r	15.00	ft
	s	2.48	ft
	A_st	0.0456	ft^2
	delta	0.3206	nd
	M	53429.50	LTft
	P	950.74	LT
	o_b	999.01	LT/ft^2
	o_a	1.25	LT/ft^2
	o_x	1000.26	LT/ft^2
4.7.1	bay buckling limit state		
	eta	0.6664	nd
	o_o	2312.32	LT/ft^2
	o_ExP	4462.65	LT/ft^2
	lambda_m	0.7198	nd
	s_em	2.28	ft
	s	2.48	ft
	t	0.0573	ft
	A_s	0.0456	ft^2
	A	0.1877	ft^2
	A_e	0.1760	ft^2
	phi_B	1.00	nd
	o_CthetaB	2312.32	LT/ft^2
	o_CxB	2312.31	LT/ft^2
	o_theta	1730.96	LT/ft^2
	o_x	1000.26	LT/ft^2
	req	0.96	has to be < 1

TANK 2

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

4.7.5	criticial buckling stress for external pressure			
	o_o	2312.32	LT/ft^2	
	t	0.05729	ft	
	r	15.00	ft	
	l	2.11	ft	
	N_s	38.00	stringers	
	I_s	0.00625	ft^4	
	g	5.34	nd	
	K_p	0.25908	nd	
	A_s	0.04556	ft^2	
	z_st	14.31	ft	
	q_s	2194.24	LT/ft^2	
	K_theta	0.74	nd	
	o_sp	425108.78	LT/ft^2	
	o_CthetaR	2453.66	LT/ft^2	
	o_CthetaB	**110774.19**	if greater,	2312.315933
4.3.5				
	o_o	2312.32	LT/ft^2	
	v	0.30	nd	
	E	1928571.43	LT/ft^2	
	t	0.05729	ft	
	r	15.00	ft	
	l	2.11	ft	
	z	4.92	nd	
	k	0.50	nd	
	C_P	0.00624	nd	
	A_L	1.63	nd	
	q_CEthetaR	15.83	LT/ft^2	
	K_theta	0.74	nd	
	rho_thetaR	0.80	nd	
	o_EthetaR	2453.66	LT/ft^2	
	DELTA	1.06	nd	
	PHI	1.00	nd	
	o_CthetaR	**2453.66**	LT/ft^2	

LOCAL BUCKLING LIMIT STATE FOR RING AND STRINGER STIFFENERS

4.9.1	flexural-torsional buckling					
	eta	0.67	nd			
	l	2.11	ft			
	t	0.05729	ft			
	A_s	0.04556	ft^2			
	s	2.48	ft			
	E	1928571.43	LT/ft^2			
	o_o	2312.32	LT/ft^2		I_y	
	n	2.00	wave for smallest yield	tw	3.13E-02	ft
	alpha	0.85	nd	dw	1.13E+00	ft
	o_CL	7191.18	LT/ft^2	tf	3.13E-02	ft
	I_xf	0.00032	ft^4	bf	3.33E-01	ft
	WARPING const	0.00026	ft^6	Aw	3.52E-02	ft^2
	C_o	48.74	LT	Af	1.04E-02	ft^2
	t_f	0.03125	ft	At	4.56E-02	ft^2
	b_1	0.00000	ft	y_o	3.80E-02	ft
	b_f	0.33	ft	z_o	6.91E-01	ft
	t_w	0.03125	ft	I_yw	3.71E-03	ft^4
	d_w	1.13	ft	I_yf	8.47E-07	ft^4
	z_o	0.69097	ft	I_zw	2.86E-06	ft^4
	y_o	0.03803	ft	I_zf	9.62E-05	ft^4
	u	1.00	nd	I_y	6.39E-03	ft^4
	m	0.64	nd	I_z	3.22E-04	ft^4
	I_y	0.00639	ft^4			
	I_z	0.00032	ft^4			
	I_o	0.02842	ft^4			
	K	0.00001	ft^4			
	o_ET	152557.99	LT/ft^2			
	P_r	0.60	nd			
	o_CT	2303.90	LT/ft^2			
	o_x	1000.26	LT/ft^2			
	req	**0.65**	has to be < 1			

BEAM COLUMN BUCKLING

4.11.	E	1928571.43	LT/ft^2
	kL	40.00	ft
	A_T	7.98	ft^2
	I_T	1009.87	ft^4
	r_i	11.25	ft
	o_E©	1505666.99	LT/ft^2
	lambda_xE	**0.04**	if > 0.5 then the following beam buckling sectic

AFT BULKHEAD THICKNESS (RULES FOR BUILDING AND CLASSING STEEL VESSELS)

c	525	nd	c = 460 for collision bh and 525 for watertight
h	312.00	ft	using effective depth instead of horizontal value
Y	35969	psi	
q	0.945		
alpha	1		
k	0.785		
s	29.76	inches	
t	0.824	inches	
	0.249	inches	
THICKNESS	**0.824**	inches	compare to the thickness of the forward tank

Tank 3

TANK 3 STATUS: initially sized

Data and Calculations in Table are for Half of Hull.

piece	number	thickness (Note 2.) in	height (length of web) ft	width (of flange) ft	centroid from wall ft	radius from center ft	VCG of struct. ft	*area per piece* in^2	total area in^2	*local self inertia* ft^4	total local inertia ft^4	moment rel. to BL in^2ft	total inertia rel. to center ft^4	percent contrib. to inertia
CIRCULAR ITEMS														
exterior plate	1	0.938				15.000	15.000	*530.144*	530.144	*414.175*	414.175	7952.156	414.175	59.61%
access tunnel	1	0.250				2.500	15.000	*23.562*	23.562	*0.511*	0.511	353.429	0.511	0.07%
LONGITUDINAL ITEMS														
stringer stiffeners	25	0.375	1.125	0.333	0.691	14.309	15.000	*6.563*	164.063	*0.006*	0.156	2460.938	233.427	33.60%
heavy s stiffeners	0	0.500	2.500	1.000	1.607	13.393	15.000	*21.000*	0.000	*0.101*	0.000	0.000	0.000	0.00%
tank dividers	2	0.250	12.500	0.000	6.250	8.750	15.000	*37.500*	75.000	*3.391*	6.782	1125.000	46.658	6.72%
TRANSVERSE ITEMS														
ring stiffeners	12	0.375	1.250	0.333	0.756	14.244		*7.124*		*0.008*				
total									792.8		421.6	11891.5	694.8	100.00%

half of hull

Tank depth	30.00 ft	Effective depth while verti	50.00 ft	Mid-depth	15.00 ft
Tank length	50.00 ft	Pressure	1.43 LT/ft^2	Neutral axis	15.00 ft above BL
				Inertia for whole hull	1,389.54 ft^4 relative to neutral axis
				SM deck	92.64 ft^3
				SM bottom	92.64 ft^3

VALUES

Total area	11.01 ft^2	BULKHEAD VOLUME					
E (steel)	1928571.43 LT/ft^2	t	0.82 in				
min. yield	2312.32 LT/ft^2	A_bh	706.86 ft^2	Yield Strength	2312.32 LT/ft^2	248.00 MPa	
Pr	0.60 for steel	V_bh	48.53 ft^3	Ultimate Stength	7841.36 LT/ft^2	841.00 MPa	
shell btwn stingers	22.62 inches	V_stiffener	0.57 ft^3				
shell bwtn ring stiffene	46.15 inches	reduction	0.67 nd	M(x)	97727.66 LTft		
total volume of steel	603.66 ft^3	stiffeners	50.00 stiffeners	Bending Stress	-1054.96 LT/ft^2		
		V_total	67.52 ft^3				
				V(x)	966.25 LT		
				Shear Stress	175.51 LT/ft^2		

LOCAL SHELL BUCKLING

phi	0.83 nd
utilization factor	0.67 nd

PROPORTIONS OF WEBS OF STIFFENERS

STRINGERS	d_w	1.13 ft		
	t_w	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		36.00	must be < or	43.32
				0.83
RING STIFFENERS	d_w	1.25 ft		
	t_w	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		40.00	must be < or	43.32
				0.92

PROPORTIONS OF FLANGES AND FACEPLATES

STRINGERS	b_2	0.3333 ft		
	t_f	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		10.67	must be < or	11.55
				0.92
RING STIFFENERS	b_2	0.3330 ft		
	t_f	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		10.66	must be < or	11.55
				0.92

STIFFNESS OF STRINGER STIFFENERS

l	3.85 ft		
A_s	0.0456 ft^2		
v	0.30 nd		
t	0.0781 ft		
s	1.88 ft		
alpha	2.04 nd		
delta	0.3095 nd		
gamma_o	22.42 nd		
i_o	0.0018	must be <	0.0063
			0.2953

STIFFNESS OF RING STIFFENERS

eta	0.6664 nd		
l	3.85 ft		
t	0.0781 ft		
A_s	0.0456 ft^2		
s	1.88 ft		
E	1928571.43 LT/ft^2		
o_o	2312.32 LT/ft^2		
K_theta	0.9936 nd		
z_e	0.4935 ft		
r_e	14.24 ft		
l_eo	1.69 ft must be <= l		
delta	0.3095 nd		
o_thetaR	182.27 LT/ft^2		
o_theta	273.15 LT/ft^2		
o_x	1351.60 LT/ft^2		
i_r	0.0079	must be <	0.0083
			0.95

TANK 3

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

2.3.1	axial tension req.			
	axial tensile pressure	1.43	LT/ft^2	
	eta	0.6664		
	o_o	2312.32		
	req	0.00	has to be < 1	
2.3.3	axial compression req.			
	axial compressive pressu	1.43	LT/ft^2	
	eta	0.6664	nd	
	k, eff length	1.00	nd	
	L, of member	50.00	ft	
	K, St. Venant	2779.09	ft^4	
	A	11.01	ft^2	
	E	1928571.43	LT/ft^2	
	radius of gyration	11.23	ft	
	o_Eeta	960845.98	LT/ft^2	
	o_ET	1483516.48	LT/ft^2	
	o_EA	960845.98	LT/ft^2	
	o_CA	2310.98	LT/ft^2	
	req	0.00	has to be < 1	
2.3.5	bending moment req.			
	o_b	1054.96	LT/ft^2	
	o_CB	2312.29	LT/ft^2	
	o_b / n_2 o_SB	0.68	has to be < 1	
4.7.3	critical buckling stress for axial compression or bending moment			
	lambda_xP	0.4275	nd	
	s_e	28.04	inches	
	I_se	7.47	ft^4	
	o_c	42148910.82	LT/ft^2	
	rho_xB	0.7500	nd	
	o_s	3647.32	LT/ft^2	
	o_ExB	42152558.14	LT/ft^2	
	o_CxB	2312.29	LT/ft^2	
4.5.3	critical buckling stress for axial compression or bending moment in curved panels			
	z_s	2.89	nd	
	rho_xP	0.9308	nd	
	K_xP	4.26	nd	
	o_CExP	12748.50	LT/ft^2	
	lambda_n	0.4414	nd	
	B_xP	1.07	nd	
	o_ExP	12652.48	LT/ft^2	
	o_CxP	2210.89	LT/ft^2	
2.5.1	axial tension and bending			
	o_t	1.43	LT/ft^2	
	o_b	1054.96	LT/ft^2	
	o_CB	2312.29	LT/ft^2	
	eqn	0.97	has to be < 1	
2.5.3	axial compression and bending			
	o_a	1.43	LT/ft^2	
	o_CA	2310.98	LT/ft^2	
	o_b	1054.96	LT/ft^2	
	o_CB	2312.29	LT/ft^2	
	eqn	0.97	has to be < 1	

BAY BUCKLING LIMIT STATE

4.13.3	hoop stress		
	r	15.00	ft
	N_theta	1.00	LT/ft
	N_axial	0.00	LT/ft
	q	1.43	LT/ft^2
	A_R	0.0495	ft^2
	r_R	14.24	ft
	r_F	13.75	ft
	t	0.0781	ft
	t_w	0.0313	ft
	l	3.85	ft
	v	0.3000	nd
	k	0.5000	nd
	alpha	2.28	nd
	G_alpha	0.0264	nd
	omega	0.4500	nd
	A_R mean	0.0549	ft^2
	K_thetaR	0.6078	nd
	K_theta	0.9936	nd
	o_thetaR	182.27	LT/ft^2
	o_theta	273.15	LT/ft^2
4.13.1	longitudinal stress		
	t	0.0781	ft
	r	15.00	ft
	s	1.88	ft
	A_st	0.0456	ft^2
	delta	0.3095	nd
	M	97727.66	LTft
	P	966.25	LT
	o_b	1351.45	LT/ft^2
	o_a	0.15	LT/ft^2
	o_x	1351.60	LT/ft^2
4.7.1	bay buckling limit state		
	eta	0.6664	nd
	o_o	2312.32	LT/ft^2
	o_ExP	12652.48	LT/ft^2
	lambda_m	0.4275	nd
	s_em	1.88	ft
	s	1.88	ft
	t	0.0781	ft
	A_s	0.0456	ft^2
	A	0.1928	ft^2
	A_e	0.1928	ft^2
	phi_B	1.00	nd
	o_CthetaB	2312.32	LT/ft^2
	o_CxB	2312.29	LT/ft^2
	o_theta	273.15	LT/ft^2
	o_x	1351.60	LT/ft^2
	req	0.65	has to be < 1

TANK 3

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

4.7.5	criticial buckling stress for external pressure			
	o_o	2312.32	LT/ft^2	
	t	0.07813	ft	
	r	15.00	ft	
	l	3.85	ft	
	N_s	50.00	stringers	
	I_s	0.00625	ft^4	
	g	13.55	nd	
	K_p	0.27304	nd	
	A_s	0.04557	ft^2	
	z_st	14.31	ft	
	q_s	865.22	LT/ft^2	
	K_theta	0.99	nd	
	o_sp	165060.48	LT/ft^2	
	o_CthetaR	2518.27	LT/ft^2	
	o_CthetaB	45755.41	if greater,	2312.315933
4.3.5				
	o_o	2312.32	LT/ft^2	
	v	0.30	nd	
	E	1928571.43	LT/ft^2	
	t	0.07813	ft	
	r	15.00	ft	
	l	3.85	ft	
	z	12.04	nd	
	k	0.50	nd	
	C_P	0.01519	nd	
	A_L	2.92	nd	
	q_CEthetaR	16.50	LT/ft^2	
	K_theta	0.99	nd	
	rho_thetaR	0.80	nd	
	o_EthetaR	2518.27	LT/ft^2	
	DELTA	1.09	nd	
	PHI	1.00	nd	
	o_CthetaR	2518.27	LT/ft^2	

LOCAL BUCKLING LIMIT STATE FOR RING AND STRINGER STIFFENERS

4.9.1	flexural-torsional buckling				
	eta	0.67	nd		
	l	3.85	ft		
	t	0.07813	ft		
	A_s	0.04557	ft^2		
	s	1.88	ft		
	E	1928571.43	LT/ft^2		
	o_o	2312.32	LT/ft^2		I_y
	n	2.00	wave for smallest yield	tw	3.13E-02 ft
	alpha	2.04	nd	dw	1.13E+00 ft
	o_CL	11981.87	LT/ft^2	tf	3.13E-02 ft
	I_xf	0.00032	ft^4	bf	3.33E-01 ft
	WARPING const	0.00026	ft^6	Aw	3.52E-02 ft^2
	C_o	162.62	LT	Af	1.04E-02 ft^2
	t_f	0.03125	ft	At	4.56E-02 ft^2
	b_1	0.00000	ft	y_o	3.81E-02 ft
	b_f	0.33	ft	z_o	6.91E-01 ft
	t_w	0.03125	ft	I_yw	3.71E-03 ft^4
	d_w	1.13	ft	I_yf	8.48E-07 ft^4
	z_o	0.69107	ft	I_zw	2.86E-06 ft^4
	y_o	0.03810	ft	I_zf	9.65E-05 ft^4
	u	1.00	nd	I_y	6.40E-03 ft^4
	m	0.64	nd	I_z	3.23E-04 ft^4
	I_y	0.00640	ft^4		
	I_z	0.00032	ft^4		
	I_o	0.02843	ft^4		
	K	0.00001	ft^4		
	o_ET	41881.91	LT/ft^2		
	P_r	0.60	nd		
	o_CT	2281.68	LT/ft^2		
	o_x	1351.60	LT/ft^2		
	req	0.89	has to be < 1		

BEAM COLUMN BUCKLING

4.11.	E	1928571.43	LT/ft^2
	kL	50.00	ft
	A_T	11.01	ft^2
	I_T	1389.54	ft^4
	r_i	11.23	ft
	o_E©	960845.98	LT/ft^2
	lambda_xE	0.05	if > 0.5 then the following beam buckling sectic

AFT BULKHEAD THICKNESS (RULES FOR BUILDING AND CLASSING STEEL VESSELS)

c	525	nd	c = 460 for collision bh and 525 for watertight
h	50.00	ft	using effective depth instead of horizontal value
Y	35969	psi	
q	0.945		
alpha	1		
k	0.785		
s	22.62	inches	
t	0.292	inches	
	0.213	inches	
THICKNESS	0.292	inches	compare to the thickness of the forward tank

Tank 4

TANK 4 STATUS: initially sized
Data and Calculations in Table are for Half of Hull.

piece	number	thickness (Note 2.) in	height (length of web) ft	width (of flange) ft	centroid from wall ft	radius from center ft	VCG of struct. ft	*area per piece* in^2	total area in^2	*local self inertia* ft^4	total local inertia ft^4	moment rel. to BL in^2ft	total inertia rel. to center ft^4	percent contrib. to inertia
CIRCULAR ITEMS														
exterior plate	1	1.188				15.000	15.000	*671.515*	671.515	*524.621*	524.621	10072.731	524.621	61.60%
access tunnel	1	0.250				2.500	15.000	*23.562*	23.562	*0.511*	0.511	353.429	0.511	0.06%
LONGITUDINAL ITEMS														
stringer stiffeners	24	0.438	1.500	0.375	0.900	14.100	15.000	*9.844*	236.250	*0.016*	0.394	3543.750	326.566	38.34%
heavy s stiffeners	0	0.500	2.500	1.000	1.607	13.393	15.000	*21.000*	0.000	*0.101*	0.000	0.000	0.000	0.00%
tank dividers	0	0.250	12.500	0.000	6.250	8.750	15.000	*37.500*	0.000	*3.391*	0.000	0.000	0.000	0.00%
TRANSVERSE ITEMS														
ring stiffeners	18	0.500	1.750	0.438	1.050	13.950		*13.125*		*0.030*				
total									931.3		525.5	13969.9	851.7	100.00%

half of hull

Tank depth	30.00 ft	Effective depth while verti	222.00 ft	Mid-depth	15.00 ft
Tank length	52.00 ft	Pressure	6.36 LT/ft^2	Neutral axis	15.00 ft above BL
				Inertia for whole hull	1,703.40 ft^4 relative to neutral axis
				SM deck	113.56 ft^3
				SM bottom	113.56 ft^3

VALUES

Total area	12.94 ft^2	BULKHEAD VOLUME			
E (steel)	1928571.43 LT/ft^2	t	0.57 in		
min. yield	2312.32 LT/ft^2	A_bh	706.86 ft^2	Yield Strength	2312.32 LT/ft^2 — 248.00 MPa
Pr	0.60 for steel	V_bh	33.58 ft^3	Ultimate Stength	7841.36 LT/ft^2 — 841.00 MPa
shell btwn stingers	23.56 inches	V_stiffener	0.85 ft^3		
shell bwtn ring stiffene	32.84 inches	reduction	0.67 nd	M(x)	122927.94 LTft
total volume of steel	816.43 ft^3	stiffeners	48.00 stiffeners	Bending Stress	-1082.49 LT/ft^2
		V_total	60.92 ft^3		

LOCAL SHELL BUCKLING

phi	0.83 nd	V(x)	767.59 LT
utilization factor	0.67 nd	Shear Stress	118.68 LT/ft^2

PROPORTIONS OF WEBS OF STIFFENERS

STRINGERS	d_w	1.50 ft	
	t_w	0.0365 ft	
	o_o	2312.32 LT/ft^2	
	E	1928571.43 LT/ft^2	
		41.14	must be < oı 43.32
			0.95
RING STIFFENERS	d_w	1.75 ft	
	t_w	0.0417 ft	
	o_o	2312.32 LT/ft^2	
	E	1928571.43 LT/ft^2	
		42.00	must be < oı 43.32
			0.97

PROPORTIONS OF FLANGES AND FACEPLATES

STRINGERS	b_2	0.3750 ft	
	t_f	0.0365 ft	
	o_o	2312.32 LT/ft^2	
	E	1928571.43 LT/ft^2	
		10.29	must be < oı 11.55
			0.89
RING STIFFENERS	b_2	0.4375 ft	
	t_f	0.0417 ft	
	o_o	2312.32 LT/ft^2	
	E	1928571.43 LT/ft^2	
		10.50	must be < oı 11.55
			0.91

STIFFNESS OF STRINGER STIFFENERS

l	2.74 ft	
A_s	0.0684 ft^2	
v	0.30 nd	
t	0.0990 ft	
s	1.96 ft	
alpha	1.39 nd	
delta	0.3518 nd	
gamma_o	9.49 nd	
i_o	0.0017	must be < 0.0164
		0.1007

STIFFNESS OF RING STIFFENERS

eta	0.6664 nd	
l	2.74 ft	
t	0.0990 ft	
A_s	0.0684 ft^2	
s	1.96 ft	
E	1928571.43 LT/ft^2	
o_o	2312.32 LT/ft^2	
K_theta	0.8452 nd	
z_e	0.7000 ft	
r_e	13.95 ft	
l_eo	1.90 ft must be <= l	
delta	0.3518 nd	
o_thetaR	614.86 LT/ft^2	
o_theta	814.46 LT/ft^2	
o_x	1300.52 LT/ft^2	
i_r	0.0285	must be < 0.0298
		0.96

TANK 4

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

2.3.1	axial tension req.		
	axial tensile pressure	6.36	LT/ft^2
	eta	0.6664	
	o_o	2312.32	
	req	0.00	has to be < 1
2.3.3	axial compression req.		
	axial compressive pressu	6.36	LT/ft^2
	eta	0.6664	nd
	k, eff length	1.00	nd
	L, of member	52.00	ft
	K, St. Venant	3406.80	ft^4
	A	12.94	ft^2
	E	1928571.43	LT/ft^2
	radius of gyration	11.48	ft
	o_Eeta	926990.21	LT/ft^2
	o_ET	1483516.48	LT/ft^2
	o_EA	926990.21	LT/ft^2
	o_CA	2310.93	LT/ft^2
	req	0.00	has to be < 1
2.3.5	bending moment req.		
	o_b	1082.49	LT/ft^2
	o_CB	2312.30	LT/ft^2
	o_b / n_2 o_SB	0.70	has to be < 1
4.7.3	critical buckling stress for axial compression or bending moment		
	lambda_xP	0.3539	nd
	s_e	35.28	inches
	I_se	11.02	ft^4
	o_c	77944624.18	LT/ft^2
	rho_xB	0.7500	nd
	o_s	4674.88	LT/ft^2
	o_ExB	77949299.06	LT/ft^2
	o_CxB	**2312.30**	LT/ft^2
4.5.3	critical buckling stress for axial compression or bending moment in curved panels		
	z_s	2.48	nd
	rho_xP	0.9439	nd
	K_xP	4.19	nd
	o_CExP	18547.02	LT/ft^2
	lambda_n	0.3634	nd
	B_xP	1.05	nd
	o_ExP	18460.54	LT/ft^2
	o_CxP	**2242.80**	LT/ft^2
2.5.1	axial tension and bending		
	o_t	6.36	LT/ft^2
	o_b	1082.49	LT/ft^2
	o_CB	2312.30	LT/ft^2
	eqn	1.00	has to be < 1
2.5.3	axial compression and bending		
	o_a	6.36	LT/ft^2
	o_CA	2310.93	LT/ft^2
	o_b	1082.49	LT/ft^2
	o_CB	2312.30	LT/ft^2
	eqn	1.00	has to be < 1

BAY BUCKLING LIMIT STATE

4.13.3	hoop stress		
	r	15.00	ft
	N_theta	1.00	LT/ft
	N_axial	0.00	LT/ft
	q	6.36	LT/ft^2
	A_R	0.0911	ft^2
	r_R	13.95	ft
	r_F	13.25	ft
	t	0.0990	ft
	t_w	0.0365	ft
	l	2.74	ft
	v	0.3000	nd
	k	0.5000	nd
	alpha	1.44	nd
	G_alpha	0.5405	nd
	omega	0.7525	nd
	A_R mean	0.1054	ft^2
	K_thetaR	0.5636	nd
	K_theta	0.8452	nd
	o_thetaR	**614.86**	LT/ft^2
	o_theta	**814.46**	LT/ft^2
4.13.1	longitudinal stress		
	t	0.0990	ft
	r	15.00	ft
	s	1.96	ft
	A_st	0.0684	ft^2
	delta	0.3518	nd
	M	122927.94	LTft
	P	767.59	LT
	o_b	1300.01	LT/ft^2
	o_a	0.50	LT/ft^2
	o_x	**1300.52**	LT/ft^2
4.7.1	bay buckling limit state		
	eta	0.6664	nd
	o_o	2312.32	LT/ft^2
	o_ExP	18460.54	LT/ft^2
	lambda_m	0.3539	nd
	s_em	1.96	ft
	s	1.96	ft
	t	0.0990	ft
	A_s	0.0684	ft^2
	A	0.2627	ft^2
	A_e	0.2627	ft^2
	phi_B	1.00	nd
	o_CthetaB	2312.32	LT/ft^2
	o_CxB	2312.30	LT/ft^2
	o_theta	814.46	LT/ft^2
	o_x	1300.52	LT/ft^2
	req	0.55	has to be < 1

TANK 4

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

4.7.5	critical buckling stress for external pressure		
	o_o	2312.32	LT/ft^2
	t	0.09896	ft
	r	15.00	ft
	l	2.74	ft
	N_s	48.00	stringers
	I_s	0.01641	ft^4
	g	4.08	nd
	K_p	0.25694	nd
	A_s	0.06836	ft^2
	z_st	14.10	ft
	q_s	2424.68	LT/ft^2
	K_theta	0.85	nd
	o_sp	310636.82	LT/ft^2
	o_CthetaR	4914.88	LT/ft^2
	o_CthetaB	81079.25	if greater, 2312.315933
4.3.5			
	o_o	2312.32	LT/ft^2
	v	0.30	nd
	E	1928571.43	LT/ft^2
	t	0.09896	ft
	r	15.00	ft
	l	2.74	ft
	z	4.81	nd
	k	0.50	nd
	C_P	0.01062	nd
	A_L	1.61	nd
	q_CEthetaR	47.95	LT/ft^2
	K_theta	0.85	nd
	rho_thetaR	0.80	nd
	o_EthetaR	4914.88	LT/ft^2
	DELTA	2.13	nd
	PHI	1.00	nd
	o_CthetaR	4914.88	LT/ft^2

LOCAL BUCKLING LIMIT STATE FOR RING AND STRINGER STIFFENERS

4.9.1	flexural-torsional buckling					
	eta	0.67	nd			
	l	2.74	ft			
	t	0.09896	ft			
	A_s	0.06836	ft^2			
	s	1.96	ft			
	E	1928571.43	LT/ft^2			
	o_o	2312.32	LT/ft^2		I_y	
	n	2.00	wave for smallest yield	tw	3.65E-02	ft
	alpha	1.39	nd	dw	1.50E+00	ft
	o_CL	20120.92	LT/ft^2	tf	3.65E-02	ft
	I_xf	0.00054	ft^4	bf	3.75E-01	ft
	WARPING const	0.00086	ft^6	Aw	5.47E-02	ft^2
	C_o	317.28	LT	Af	1.37E-02	ft^2
	t_f	0.03646	ft	At	6.84E-02	ft^2
	b_1	0.00000	ft	y_o	3.75E-02	ft
	b_f	0.38	ft	z_o	9.00E-01	ft
	t_w	0.03646	ft	I_yw	1.03E-02	ft^4
	d_w	1.50	ft	I_yf	1.51E-06	ft^4
	z_o	0.90000	ft	I_zw	6.06E-06	ft^4
	y_o	0.03750	ft	I_zf	1.60E-04	ft^4
	u	1.00	nd	I_y	1.67E-02	ft^4
	m	0.70	nd	I_z	5.51E-04	ft^4
	I_y	0.01671	ft^4			
	I_z	0.00055	ft^4			
	I_o	0.07256	ft^4			
	K	0.00003	ft^4			
	o_ET	116699.16	LT/ft^2			
	P_r	0.60	nd			
	o_CT	2301.32	LT/ft^2			
	o_x	1300.52	LT/ft^2			
	req	0.85	has to be < 1			

BEAM COLUMN BUCKLING

4.11.	E	1928571.43	LT/ft^2
	kL	52.00	ft
	A_T	12.94	ft^2
	I_T	1703.40	ft^4
	r_i	11.48	ft
	o_E©	926990.21	LT/ft^2
	lambda_xE	0.05	if > 0.5 then the following beam buckling sectic

AFT BULKHEAD THICKNESS (RULES FOR BUILDING AND CLASSING STEEL VESSELS)

c	525	nd	c = 460 for collision bh and 525 for watertight
h	222.00	ft	using effective depth instead of horizontal value
Y	35969	psi	
q	0.945		
alpha	1		
k	0.785		
s	23.56	inches	
t	0.570	inches	
	0.218	inches	
THICKNESS	0.570	inches	compare to the thickness of the forward tank

Tank 5

TANK 5 STATUS: initially sized

Data and Calculations in Table are for Half of Hull.

piece	number	thickness (Note 2.) in	height (length of web) ft	width (of flange) ft	centroid from wall ft	radius from center ft	VCG of struct. ft	*area per piece* in^2	total area in^2	*local self inertia* ft^4	total local inertia ft^4	moment rel. to BL in^2ft	total inertia rel. to center ft^4	percent contrib. to inertia
CIRCULAR ITEMS														
exterior plate	1	1.188				15.000	15.000	*671.515*	671.515	*524.621*	524.621	10072.731	524.621	58.81%
access tunnel	0	0.250				2.500	15.000	*23.562*	0.000	*0.511*	0.000	0.000	0.000	0.00%
LONGITUDINAL ITEMS														
stringer stiffeners	27	0.438	1.500	0.375	0.900	14.100	15.000	*9.844*	265.781	*0.016*	0.443	3986.719	367.387	41.19%
heavy s stiffeners	0	0.500	2.500	1.000	1.607	13.393	15.000	*21.000*	0.000	*0.101*	0.000	0.000	0.000	0.00%
tank dividers	0	0.250	12.500	0.000	6.250	8.750	15.000	*37.500*	0.000	*3.391*	0.000	0.000	0.000	0.00%
TRANSVERSE ITEMS														
ring stiffeners	10	0.500	1.750	0.438	1.050	13.950		*13.125*		*0.030*				
total									937.3		525.1	14059.5	892.0	100.00%

half of hull

Tank depth	30.00 ft	Effective depth while verti	170.00 ft	Mid-depth	15.00 ft
Tank length	45.00 ft	Pressure	4.87 LT/ft^2	Neutral axis	15.00 ft above BL
				Inertia for whole hull	1,784.02 ft^4 relative to neutral axis
				SM deck	118.93 ft^3
				SM bottom	118.93 ft^3

VALUES

Total area	13.02 ft^2	BULKHEAD VOLUME			
E (steel)	1928571.43 LT/ft^2	t	0.57 in		
min. yield	2312.32 LT/ft^2	A_bh	706.86 ft^2	Yield Strength	2312.32 LT/ft^2 — 248.00 MPa
Pr	0.60 for steel	V_bh	33.58 ft^3	Ultimate Stength	7841.36 LT/ft^2 — 841.00 MPa
shell btwn stingers	20.94 inches	V_stiffener	0.85 ft^3		
shell bwtn ring stiffene	49.09 inches	reduction	0.67 nd	M(x)	128698.48 LTft
total volume of steel	665.70 ft^3	stiffeners	54.00 stiffeners	Bending Stress	-1082.10 LT/ft^2
		V_total	64.34 ft^3		

LOCAL SHELL BUCKLING

phi	0.83 nd	V(x)	333.98 LT
utilization factor	0.67 nd	Shear Stress	51.31 LT/ft^2

PROPORTIONS OF WEBS OF STIFFENERS

STRINGERS	d_w	1.50 ft		
	t_w	0.0365 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		41.14	must be < or	43.32
				0.95
RING STIFFENERS	d_w	1.75 ft		
	t_w	0.0417 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		42.00	must be < or	43.32
				0.97

PROPORTIONS OF FLANGES AND FACEPLATES

STRINGERS	b_2	0.3750 ft		
	t_f	0.0365 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		10.29	must be < or	11.55
				0.89
RING STIFFENERS	b_2	0.4375 ft		
	t_f	0.0417 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		10.50	must be < or	11.55
				0.91

STIFFNESS OF STRINGER STIFFENERS

l	4.09 ft		
A_s	0.0684 ft^2		
v	0.30 nd		
t	0.0990 ft		
s	1.75 ft		
alpha	2.34 nd		
delta	0.3958 nd		
gamma_o	31.84 nd		
i_o	0.0049	must be <	0.0164
			0.3005

STIFFNESS OF RING STIFFENERS

eta	0.6664 nd		
l	4.09 ft		
t	0.0990 ft		
A_s	0.0684 ft^2		
s	1.75 ft		
E	1928571.43 LT/ft^2		
o_o	2312.32 LT/ft^2		
K_theta	0.9786 nd		
z_e	0.7000 ft		
r_e	13.95 ft		
l_eo	1.90 ft must be <= 1		
delta	0.3958 nd		
o_thetaR	463.91 LT/ft^2		
o_theta	722.11 LT/ft^2		
o_x	1318.53 LT/ft^2		
i_r	0.0294	must be <	0.0298
			0.99

TANK 5
ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

2.3.1	axial tension req.		
	axial tensile pressure	4.87	LT/ft^2
	eta	0.6664	
	o_o	2312.32	
	req	0.00	has to be < 1
2.3.3	axial compression req.		
	axial compressive pressu	4.87	LT/ft^2
	eta	0.6664	nd
	k, eff length	1.00	nd
	L, of member	45.00	ft
	K, St. Venant	3568.03	ft^4
	A	13.02	ft^2
	E	1928571.43	LT/ft^2
	radius of gyration	11.71	ft
	o_Eeta	1288145.55	LT/ft^2
	o_ET	1483516.48	LT/ft^2
	o_EA	1288145.55	LT/ft^2
	o_CA	2311.32	LT/ft^2
	req	0.00	has to be < 1
2.3.5	bending moment req.		
	o_b	1082.10	LT/ft^2
	o_CB	2312.28	LT/ft^2
	o_b / n_2 o_SB	0.70	has to be < 1
4.7.3	critical buckling stress for axial compression or bending moment		
	lambda_xP	0.3158	nd
	s_e	35.15	inches
	I_se	11.01	ft^4
	o_c	34968069.21	LT/ft^2
	rho_xB	0.7500	nd
	o_s	4671.49	LT/ft^2
	o_ExB	34972740.69	LT/ft^2
	o_CxB	2312.28	LT/ft^2
4.5.3	critical buckling stress for axial compression or bending moment in curved panels		
	z_s	1.96	nd
	rho_xP	0.9583	nd
	K_xP	4.12	nd
	o_CExP	23075.55	LT/ft^2
	lambda_n	0.3234	nd
	B_xP	1.05	nd
	o_ExP	23186.57	LT/ft^2
	o_CxP	2256.97	LT/ft^2
2.5.1	axial tension and bending		
	o_t	4.87	LT/ft^2
	o_b	1082.10	LT/ft^2
	o_CB	2312.28	LT/ft^2
	eqn	1.00	has to be < 1
2.5.3	axial compression and bending		
	o_a	4.87	LT/ft^2
	o_CA	2311.32	LT/ft^2
	o_b	1082.10	LT/ft^2
	o_CB	2312.28	LT/ft^2
	eqn	1.00	has to be < 1

BAY BUCKLING LIMIT STATE

4.13.3	hoop stress		
	r	15.00	ft
	N_theta	1.00	LT/ft
	N_axial	0.00	LT/ft
	q	4.87	LT/ft^2
	A_R	0.0911	ft^2
	r_R	13.95	ft
	r_F	13.25	ft
	t	0.0990	ft
	t_w	0.0365	ft
	l	4.09	ft
	v	0.3000	nd
	k	0.5000	nd
	alpha	2.15	nd
	G_alpha	0.0727	nd
	omega	0.4817	nd
	A_R mean	0.1054	ft^2
	K_thetaR	0.5553	nd
	K_theta	0.9786	nd
	o_thetaR	463.91	LT/ft^2
	o_theta	722.11	LT/ft^2
4.13.1	longitudinal stress		
	t	0.0990	ft
	r	15.00	ft
	s	1.75	ft
	A_st	0.0684	ft^2
	delta	0.3958	nd
	M	128698.48	LTft
	P	333.98	LT
	o_b	1318.16	LT/ft^2
	o_a	0.37	LT/ft^2
	o_x	1318.53	LT/ft^2
4.7.1	bay buckling limit state		
	eta	0.6664	nd
	o_o	2312.32	LT/ft^2
	o_ExP	23186.57	LT/ft^2
	lambda_m	0.3158	nd
	s_em	1.75	ft
	s	1.75	ft
	t	0.0990	ft
	A_s	0.0684	ft^2
	A	0.2411	ft^2
	A_e	0.2411	ft^2
	phi_B	1.00	nd
	o_CthetaB	2312.32	LT/ft^2
	o_CxB	2312.28	LT/ft^2
	o_theta	722.11	LT/ft^2
	o_x	1318.53	LT/ft^2
	req	0.55	has to be < 1

TANK 5

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

4.7.5	criticial buckling stress for external pressure			
	o_o	2312.32	LT/ft^2	
	t	0.09896	ft	
	r	15.00	ft	
	l	4.09	ft	
	N_s	54.00	stringers	
	I_s	0.01641	ft^4	
	g	8.11	nd	
	K_p	0.26379	nd	
	A_s	0.06836	ft^2	
	z_st	14.10	ft	
	q_s	1220.86	LT/ft^2	
	K_theta	0.98	nd	
	o_sp	181094.02	LT/ft^2	
	o_CthetaR	3366.86	LT/ft^2	
	o_CthetaB	48659.28	if greater,	2312.315933
4.3.5				
	o_o	2312.32	LT/ft^2	
	v	0.30	nd	
	E	1928571.43	LT/ft^2	
	t	0.09896	ft	
	r	15.00	ft	
	l	4.09	ft	
	z	10.76	nd	
	k	0.50	nd	
	C_P	0.01796	nd	
	A_L	2.72	nd	
	q_CEthetaR	28.37	LT/ft^2	
	K_theta	0.98	nd	
	rho_thetaR	0.80	nd	
	o_EthetaR	3366.86	LT/ft^2	
	DELTA	1.46	nd	
	PHI	1.00	nd	
	o_CthetaR	3366.86	LT/ft^2	

LOCAL BUCKLING LIMIT STATE FOR RING AND STRINGER STIFFENERS

4.9.1	flexural-torsional buckling					
	eta	0.67	nd			
	l	4.09	ft			
	t	0.09896	ft			
	A_s	0.06836	ft^2			
	s	1.75	ft			
	E	1928571.43	LT/ft^2			
	o_o	2312.32	LT/ft^2		I_y	
	n	2.00	wave for smallest yield	tw	3.65E-02	ft
	alpha	2.34	nd	dw	1.50E+00	ft
	o_CL	22983.28	LT/ft^2	tf	3.65E-02	ft
	I_xf	0.00054	ft^4	bf	3.75E-01	ft
	WARPING const	0.00086	ft^6	Aw	5.47E-02	ft^2
	C_o	356.94	LT	Af	1.37E-02	ft^2
	t_f	0.03646	ft	At	6.84E-02	ft^2
	b_1	0.00000	ft	y_o	3.75E-02	ft
	b_f	0.38	ft	z_o	9.00E-01	ft
	t_w	0.03646	ft	I_yw	1.03E-02	ft^4
	d_w	1.50	ft	I_yf	1.51E-06	ft^4
	z_o	0.90000	ft	I_zw	6.06E-06	ft^4
	y_o	0.03750	ft	I_zf	1.60E-04	ft^4
	u	1.00	nd	I_y	1.67E-02	ft^4
	m	0.70	nd	I_z	5.51E-04	ft^4
	I_y	0.01671	ft^4			
	I_z	0.00055	ft^4			
	I_o	0.07256	ft^4			
	K	0.00003	ft^4			
	o_ET	51588.80	LT/ft^2			
	P_r	0.60	nd			
	o_CT	2287.44	LT/ft^2			
	o_x	1318.53	LT/ft^2			
	req	0.86	has to be < 1			

BEAM COLUMN BUCKLING

4.11.	E	1928571.43	LT/ft^2
	kL	45.00	ft
	A_T	13.02	ft^2
	I_T	1784.02	ft^4
	r_i	11.71	ft
	o_E©	1288145.55	LT/ft^2
	lambda_xE	0.04	if > 0.5 then the following beam buckling sectic

AFT BULKHEAD THICKNESS (RULES FOR BUILDING AND CLASSING STEEL VESSELS)

c	525	nd	c = 460 for collision bh and 525 for watertight
h	170.00	ft	using effective depth instead of horizontal value
Y	35969	psi	
q	0.945		
alpha	1		
k	0.785		
s	20.94	inches	
t	0.457	inches	
	0.205	inches	
THICKNESS	0.457	inches	compare to the thickness of the forward tank

Transition

TRANSITION TO NECK STATUS: initially sized

Data and Calculations in Table are for Half of Hull.

piece	number	thickness (Note 2.) in	height (length of web) ft	width (of flange) ft	centroid from wall ft	radius from center ft	VCG of struct. ft	*area per piece* in^2	total area in^2	*local self inertia* ft^4	total local inertia ft^4	moment rel. to BL in^2ft	total inertia rel. to center ft^4	percent contrib. to inertia
CIRCULAR ITEMS														
exterior plate	1	1.250				10.000	10.000	*471.239*	471.239	*163.625*	163.625	4712.389	163.625	28.60%
access tunnel	1	0.250				2.500	10.000	*23.562*	23.562	*0.511*	0.511	235.619	0.511	0.09%
LONGITUDINAL ITEMS														
stringer stiffeners	27	0.750	2.666	0.667	1.600	8.400	10.000	*29.994*	809.838	*0.158*	4.264	8098.380	401.118	70.11%
heavy s stiffeners	0	0.500	1.500	1.000	1.050	8.950	10.000	*15.000*	0.000	*0.026*	0.000	0.000	0.000	0.00%
tank dividers	1	0.250	7.500	0.000	3.750	6.250	10.000	*22.500*	22.500	*0.732*	0.732	225.000	6.836	1.19%
TRANSVERSE ITEMS														
ring stiffeners	12	0.375	1.250	0.333	0.756	9.244		*7.124*		*0.008*				
total									1327.1		169.1	13271.4	572.1	100.00%

half of hull

Tank depth	20.00	ft
Tank length	69.23	ft
Effective depth while verti	125.00	ft
Pressure	3.58	LT/ft^2
Mid-depth	10.00	ft
Neutral axis	10.00	ft above BL
Inertia for whole hull	1,144.18	ft^4 relative to neutral axis
SM deck	114.42	ft^3
SM bottom	114.42	ft^3

VALUES

Total area	19.26	ft^2
E (steel)	1928571.43	LT/ft^2
min. yield	2312.32	LT/ft^2
Pr	0.60	for steel
shell btwn stingers	13.96	inches
shell bwtn ring stiffene	63.90	inches
total volume of steel	1367.95	ft^3

BULKHEAD VOLUME

t	0.46	in
A_bh	314.16	ft^2
V_bh	11.96	ft^3
V_stiffener	1.56	ft^3
reduction	0.67	nd
stiffeners	54.00	stiffeners
V_total	68.20	ft^3

Yield Strength	2312.32	LT/ft^2	248.00	MPa
Ultimate Stength	7841.36	LT/ft^2	841.00	MPa
M(x)	124476.96	LTft		
Bending Stress	-1087.92	LT/ft^2		
V(x)	-866.90	LT		
Shear Stress	-94.06	LT/ft^2		

LOCAL SHELL BUCKLING

phi	0.83	nd
utilization factor	0.67	nd

PROPORTIONS OF WEBS OF STIFFENERS

STRINGERS	d_w	2.67	ft	
	t_w	0.0625	ft	
	o_o	2312.32	LT/ft^2	
	E	1928571.43	LT/ft^2	
		42.66	must be < or	43.32
				0.98
RING STIFFENERS	d_w	1.25	ft	
	t_w	0.0313	ft	
	o_o	2312.32	LT/ft^2	
	E	1928571.43	LT/ft^2	
		40.00	must be < or	43.32
				0.92

PROPORTIONS OF FLANGES AND FACEPLATES

STRINGERS	b_2	0.6667	ft	
	t_f	0.0625	ft	
	o_o	2312.32	LT/ft^2	
	E	1928571.43	LT/ft^2	
		10.67	must be < or	11.55
				0.92
RING STIFFENERS	b_2	0.3330	ft	
	t_f	0.0313	ft	
	o_o	2312.32	LT/ft^2	
	E	1928571.43	LT/ft^2	
		10.66	must be < or	11.55
				0.92

STIFFNESS OF STRINGER STIFFENERS

l	5.33	ft	
A_s	0.2083	ft^2	
v	0.30	nd	
t	0.1042	ft	
s	1.16	ft	
alpha	4.58	nd	
delta	1.7185	nd	
gamma_o	226.97	nd	
i_o	0.0273	must be <	0.1579
			0.1731

STIFFNESS OF RING STIFFENERS

eta	0.6664	nd	
l	5.33	ft	
t	0.1042	ft	
A_s	0.2083	ft^2	
s	1.16	ft	
E	1928571.43	LT/ft^2	
o_o	2312.32	LT/ft^2	
K_theta	0.9822	nd	
z_e	0.4935	ft	
r_e	9.24	ft	
l_eo	1.59	ft must be <= l	
delta	1.7185	nd	
o_thetaR	249.68	LT/ft^2	
o_theta	337.51	LT/ft^2	
o_x	1399.39	LT/ft^2	
i_r	0.0079	must be <	0.0083
			0.95

TRANSITION TO NECK
ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

2.3.1	axial tension req.		
	axial tensile pressure	3.58	LT/ft^2
	eta	0.6664	
	o_o	2312.32	
	req	0.00	has to be < 1
2.3.3	axial compression req.		
	axial compressive pressu	3.58	LT/ft^2
	eta	0.6664	nd
	k, eff length	1.00	nd
	L, of member	69.23	ft
	K, St. Venant	2288.36	ft^4
	A	18.43	ft^2
	E	1928571.43	LT/ft^2
	radius of gyration	7.88	ft
	o_Eeta	246522.66	LT/ft^2
	o_ET	1483516.48	LT/ft^2
	o_EA	246522.66	LT/ft^2
	o_CA	2307.11	LT/ft^2
	req	0.00	has to be < 1
2.3.5	bending moment req.		
	o_b	1087.92	LT/ft^2
	o_CB	2312.20	LT/ft^2
	o_b / n_2 o_SB	0.71	has to be < 1
4.7.3	critical buckling stress for axial compression or bending moment		
	lambda_xP	0.2015	nd
	s_e	36.72	inches
	I_se	9.05	ft^4
	o_c	11521566.89	LT/ft^2
	rho_xB	0.7500	nd
	o_s	5513.22	LT/ft^2
	o_ExB	11527080.11	LT/ft^2
	o_CxB	2312.20	LT/ft^2
4.5.3	critical buckling stress for axial compression or bending moment in curved panels		
	z_s	1.24	nd
	rho_xP	0.9772	nd
	K_xP	4.05	nd
	o_CExP	56541.60	LT/ft^2
	lambda_n	0.2046	nd
	B_xP	1.03	nd
	o_ExP	56945.96	LT/ft^2
	o_CxP	2289.78	LT/ft^2
2.5.1	axial tension and bending		
	o_t	3.58	LT/ft^2
	o_b	1087.92	LT/ft^2
	o_CB	2312.20	LT/ft^2
	eqn	1.00	has to be < 1
2.5.3	axial compression and bending		
	o_a	3.58	LT/ft^2
	o_CA	2307.11	LT/ft^2
	o_b	1087.92	LT/ft^2
	o_CB	2312.20	LT/ft^2
	eqn	1.00	has to be < 1

BAY BUCKLING LIMIT STATE

4.13.3	hoop stress		
	r	10.00	ft
	N_theta	1.00	LT/ft
	N_axial	0.00	LT/ft
	q	3.58	LT/ft^2
	A_R	0.0495	ft^2
	r_R	9.24	ft
	r_F	8.75	ft
	t	0.1042	ft
	t_w	0.0625	ft
	l	5.33	ft
	v	0.3000	nd
	k	0.5000	nd
	alpha	3.34	nd
	G_alpha	0.0832	nd
	omega	0.2980	nd
	A_R mean	0.0579	ft^2
	K_thetaR	0.6358	nd
	K_theta	0.9822	nd
	o_thetaR	249.68	LT/ft^2
	o_theta	337.51	LT/ft^2
4.13.1	longitudinal stress		
	t	0.1042	ft
	r	10.00	ft
	s	1.16	ft
	A_st	0.2083	ft^2
	delta	1.7185	nd
	M	124476.96	LTft
	P	-866.90	LT
	o_b	1399.19	LT/ft^2
	o_a	0.20	LT/ft^2
	o_x	1399.39	LT/ft^2
4.7.1	bay buckling limit state		
	eta	0.6664	nd
	o_o	2312.32	LT/ft^2
	o_ExP	56945.96	LT/ft^2
	lambda_m	0.2015	nd
	s_em	1.16	ft
	s	1.16	ft
	t	0.1042	ft
	A_s	0.2083	ft^2
	A	0.3295	ft^2
	A_e	0.3295	ft^2
	phi_B	1.00	nd
	o_CthetaB	2312.32	LT/ft^2
	o_CxB	2312.20	LT/ft^2
	o_theta	337.51	LT/ft^2
	o_x	1399.39	LT/ft^2
	req	0.67	has to be < 1

TRANSITION TO NECK

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

4.7.5	criticial buckling stress for external pressure			
	o_o	2312.32	LT/ft^2	
	t	0.10417	ft	
	r	10.00	ft	
	l	5.33	ft	
	N_s	54.00	stringers	
	I_s	0.15793	ft^4	
	g	4.35	nd	
	K_p	0.25740	nd	
	A_s	0.20829	ft^2	
	z_st	8.40	ft	
	q_s	1961.77	LT/ft^2	
	K_theta	0.98	nd	
	o_sp	184974.39	LT/ft^2	
	o_CthetaR	3169.56	LT/ft^2	
	o_CthetaB	48427.96	if greater,	2312.315933
4.3.5				
	o_o	2312.32	LT/ft^2	
	v	0.30	nd	
	E	1928571.43	LT/ft^2	
	t	0.10417	ft	
	r	10.00	ft	
	l	5.33	ft	
	z	25.97	nd	
	k	0.50	nd	
	C_P	0.04773	nd	
	A_L	4.58	nd	
	q_CEthetaR	42.02	LT/ft^2	
	K_theta	0.98	nd	
	rho_thetaR	0.80	nd	
	o_EthetaR	3169.56	LT/ft^2	
	DELTA	1.37	nd	
	PHI	1.00	nd	
	o_CthetaR	3169.56	LT/ft^2	

BEAM COLUMN BUCKLING

4.11.	E	1928571.43	LT/ft^2
	kL	69.23	ft
	A_T	19.26	ft^2
	I_T	1144.18	ft^4
	r_i	7.71	ft
	o_E©	235912.13	LT/ft^2
	lambda_xE	0.10	if > 0.5 then the following beam buckling sectic

LOCAL BUCKLING LIMIT STATE FOR RING AND STRINGER STIFFENERS

4.9.1	flexural-torsional buckling				
	eta	0.67	nd		
	l	5.33	ft		
	t	0.10417	ft		
	A_s	0.20829	ft^2		
	s	1.16	ft		
	E	1928571.43	LT/ft^2		
	o_o	2312.32	LT/ft^2	I_y	
	n	2.00	wave for smallest yield	tw	6.25E-02 ft
	alpha	4.58	nd	dw	2.67E+00 ft
	o_CL	103766.78	LT/ft^2	tf	6.25E-02 ft
	I_xf	0.00525	ft^4	bf	6.67E-01 ft
	WARPING const	0.02611	ft^6	Aw	1.67E-01 ft^2
	C_o	624.47	LT	Af	4.17E-02 ft^2
	t_f	0.06250	ft	At	2.08E-01 ft^2
	b_1	0.00000	ft	y_o	6.67E-02 ft
	b_f	0.67	ft	z_o	1.60E+00 ft
	t_w	0.06250	ft	I_yw	9.87E-02 ft^4
	d_w	2.67	ft	I_yf	1.36E-05 ft^4
	z_o	1.59965	ft	I_zw	5.42E-05 ft^4
	y_o	0.06668	ft	I_zf	1.54E-03 ft^4
	u	1.00	nd	I_y	1.61E-01 ft^4
	m	0.70	nd	I_z	5.30E-03 ft^4
	I_y	0.16075	ft^4		
	I_z	0.00530	ft^4		
	I_o	0.69838	ft^4		
	K	0.00027	ft^4		
	o_ET	100666.80	LT/ft^2		
	P_r	0.60	nd		
	o_CT	2299.57	LT/ft^2		
	o_x	1399.39	LT/ft^2		
	req	0.91	has to be < 1		

AFT BULKHEAD THICKNESS (RULES FOR BUILDING AND CLASSING STEEL VESSELS)

c	525	nd	c = 460 for collision bh and 525 for watertight
h	125.00	ft	using effective depth instead of horizontal value
Y	35969	psi	
q	0.945		
alpha	1		
k	0.785		
s	13.96	inches	
t	0.287	inches	
	0.170	inches	
THICKNESS	0.287	inches	compare to the thickness of the forward tank

Neck

NECK STATUS: initially sized

Data and Calculations in Table are for Half of Hull.

piece	number	thickness (Note 2.) in	height (length of web) ft	width (of flange) ft	centroid from wall ft	radius from center ft	VCG of struct. ft	*area per piece* in^2	total area in^2	*local self inertia* ft^4	total local inertia ft^4	moment rel. to BL in^2ft	total inertia rel. to center ft^4	percent contrib. to inertia
CIRCULAR ITEMS														
exterior plate	1	1.188				10.000	10.000	*447.677*	447.677	*155.443*	155.443	4476.770	155.443	42.59%
access tunnel	0	0.250				2.500	10.000	*23.562*	0.000	*0.511*	0.000	0.000	0.000	0.00%
LONGITUDINAL ITEMS														
stringer stiffeners	24	0.563	1.750	0.500	1.069	8.931	10.000	*15.188*	364.500	*0.035*	0.838	3645.000	202.717	55.54%
heavy s stiffeners	0	0.500	1.500	1.000	1.050	8.950	10.000	*15.000*	0.000	*0.026*	0.000	0.000	0.000	0.00%
tank dividers	1	0.250	7.500	0.000	3.750	6.250	10.000	*22.500*	22.500	*0.732*	0.732	225.000	6.836	1.87%
TRANSVERSE ITEMS														
ring stiffeners	5	0.375	1.250	0.333	0.756	9.244		*7.124*		*0.008*				
total									834.7		157.0	8346.8	365.0	100.00%

half of hull

Tank depth	20.00 ft	Effective depth while verti	55.77 ft	Mid-depth	10.00 ft
Tank length	50.00 ft	Pressure	1.60 LT/ft^2	Neutral axis	10.00 ft above BL
				Inertia for whole hull	729.99 ft^4 relative to neutral axis
				SM deck	73.00 ft^3
				SM bottom	73.00 ft^3

VALUES

Total area	11.59 ft^2	BULKHEAD VOLUME			
E (steel)	1928571.43 LT/ft^2	t	0.29 in		
min. yield	2312.32 LT/ft^2	A_bh	314.16 ft^2	Yield Strength	2312.32 LT/ft^2 — 248.00 MPa
Pr	0.60 for steel	V_bh	7.51 ft^3	Ultimate Stength	7841.36 LT/ft^2 — 841.00 MPa
shell btwn stingers	15.71 inches	V_stiffener	0.79 ft^3		
shell bwtn ring stiffene	100.00 inches	reduction	0.67 nd	M(x)	78189.64 LTft
total volume of steel	594.00 ft^3	stiffeners	48.00 stiffeners	Bending Stress	-1071.10 LT/ft^2
		V_total	32.82 ft^3		
				V(x)	-862.36 LT
				Shear Stress	-148.78 LT/ft^2

LOCAL SHELL BUCKLING

phi	0.83 nd
utilization factor	0.67 nd

PROPORTIONS OF WEBS OF STIFFENERS

STRINGERS	d_w	1.75 ft	
	t_w	0.0469 ft	
	o_o	2312.32 LT/ft^2	
	E	1928571.43 LT/ft^2	
		37.33	must be < o: 43.32
			0.86
RING STIFFENERS	d_w	1.25 ft	
	t_w	0.0313 ft	
	o_o	2312.32 LT/ft^2	
	E	1928571.43 LT/ft^2	
		40.00	must be < o: 43.32
			0.92

PROPORTIONS OF FLANGES AND FACEPLATES

STRINGERS	b_2	0.5000 ft	
	t_f	0.0469 ft	
	o_o	2312.32 LT/ft^2	
	E	1928571.43 LT/ft^2	
		10.67	must be < o: 11.55
			0.92
RING STIFFENERS	b_2	0.3330 ft	
	t_f	0.0313 ft	
	o_o	2312.32 LT/ft^2	
	E	1928571.43 LT/ft^2	
		10.66	must be < o: 11.55
			0.92

STIFFNESS OF STRINGER STIFFENERS

l	8.33 ft	
A_s	0.1055 ft^2	
v	0.30 nd	
t	0.0990 ft	
s	1.31 ft	
alpha	6.37 nd	
delta	0.8142 nd	
gamma_o	283.00 nd	
i_o	0.0329 must be <	0.0349
		0.9421

STIFFNESS OF RING STIFFENERS

eta	0.6664 nd	
l	8.33 ft	
t	0.0990 ft	
A_s	0.1055 ft^2	
s	1.31 ft	
E	1928571.43 LT/ft^2	
o_o	2312.32 LT/ft^2	
K_theta	0.9996 nd	
z_e	0.4935 ft	
r_e	9.24 ft	
l_eo	1.55 ft must be <= l	
delta	0.8142 nd	
o_thetaR	114.77 LT/ft^2	
o_theta	161.32 LT/ft^2	
o_x	1386.45 LT/ft^2	
i_r	0.0051 must be <	0.0083
		0.62

NECK

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

2.3.1	axial tension req.		
	axial tensile pressure	1.60	LT/ft^2
	eta	0.6664	
	o_o	2312.32	
	req	0.00	has to be < 1
2.3.3	axial compression req.		
	axial compressive pressu	1.60	LT/ft^2
	eta	0.6664	nd
	k, eff length	1.00	nd
	L, of member	50.00	ft
	K, St. Venant	1459.98	ft^4
	A	11.59	ft^2
	E	1928571.43	LT/ft^2
	radius of gyration	7.94	ft
	o_Eeta	479432.98	LT/ft^2
	o_ET	1483516.48	LT/ft^2
	o_EA	479432.98	LT/ft^2
	o_CA	2309.64	LT/ft^2
	req	0.00	has to be < 1
2.3.5	bending moment req.		
	o_b	1071.10	LT/ft^2
	o_CB	2312.02	LT/ft^2
	o_b / n_2 o_SB	0.70	has to be < 1
4.7.3	critical buckling stress for axial compression or bending moment		
	lambda_xP	0.2381	nd
	s_e	34.96	inches
	I_se	6.19	ft^4
	o_c	4311357.88	LT/ft^2
	rho_xB	0.7500	nd
	o_s	6340.25	LT/ft^2
	o_ExB	4317698.13	LT/ft^2
	o_CxB	2312.02	LT/ft^2
4.5.3	critical buckling stress for axial compression or bending moment in curved panels		
	z_s	1.65	nd
	rho_xP	0.9671	nd
	K_xP	4.08	nd
	o_CExP	40684.48	LT/ft^2
	lambda_n	0.2424	nd
	B_xP	1.04	nd
	o_ExP	40774.67	LT/ft^2
	o_CxP	2280.84	LT/ft^2
2.5.1	axial tension and bending		
	o_t	1.60	LT/ft^2
	o_b	1071.10	LT/ft^2
	o_CB	2312.02	LT/ft^2
	eqn	0.98	has to be < 1
2.5.3	axial compression and bending		
	o_a	1.60	LT/ft^2
	o_CA	2309.64	LT/ft^2
	o_b	1071.10	LT/ft^2
	o_CB	2312.02	LT/ft^2
	eqn	0.98	has to be < 1

BAY BUCKLING LIMIT STATE

4.13.3	hoop stress		
	r	10.00	ft
	N_theta	1.00	LT/ft
	N_axial	0.00	LT/ft
	q	1.60	LT/ft^2
	A_R	0.0495	ft^2
	r_R	9.24	ft
	r_F	8.75	ft
	t	0.0990	ft
	t_w	0.0469	ft
	l	8.33	ft
	v	0.3000	nd
	k	0.5000	nd
	alpha	5.37	nd
	G_alpha	0.0017	nd
	omega	0.1862	nd
	A_R mean	0.0579	ft^2
	K_thetaR	0.6223	nd
	K_theta	0.9996	nd
	o_thetaR	114.77	LT/ft^2
	o_theta	161.32	LT/ft^2
4.13.1	longitudinal stress		
	t	0.0990	ft
	r	10.00	ft
	s	1.31	ft
	A_st	0.1055	ft^2
	delta	0.8142	nd
	M	78189.64	LTft
	P	-862.36	LT
	o_b	1386.31	LT/ft^2
	o_a	0.14	LT/ft^2
	o_x	1386.45	LT/ft^2
4.7.1	bay buckling limit state		
	eta	0.6664	nd
	o_o	2312.32	LT/ft^2
	o_ExP	40774.67	LT/ft^2
	lambda_m	0.2381	nd
	s_em	1.31	ft
	s	1.31	ft
	t	0.0990	ft
	A_s	0.1055	ft^2
	A	0.2350	ft^2
	A_e	0.2350	ft^2
	phi_B	1.00	nd
	o_CthetaB	2312.32	LT/ft^2
	o_CxB	2312.02	LT/ft^2
	o_theta	161.32	LT/ft^2
	o_x	1386.45	LT/ft^2
	req	0.73	has to be < 1

NECK

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

4.7.5 criticial buckling stress for external pressure

o_o	2312.32	LT/ft^2	
t	0.09896	ft	
r	10.00	ft	
l	8.33	ft	
N_s	48.00	stringers	
I_s	0.03490	ft^4	
g	27.47	nd	
K_p	0.29671	nd	
A_s	0.10547	ft^2	
z_st	8.93	ft	
q_s	383.35	LT/ft^2	
K_theta	1.00	nd	
o_sp	38723.52	LT/ft^2	
o_CthetaR	1813.84	LT/ft^2	
o_CthetaB	12027.68	if greater,	2312.315933

4.3.5

o_o	2312.32	LT/ft^2
v	0.30	nd
E	1928571.43	LT/ft^2
t	0.09896	ft
r	10.00	ft
l	8.33	ft
z	66.94	nd
k	0.50	nd
C_P	0.07660	nd
A_L	7.74	nd
q_CEthetaR	22.45	LT/ft^2
K_theta	1.00	nd
rho_thetaR	0.80	nd
o_EthetaR	1813.84	LT/ft^2
DELTA	0.78	nd
PHI	1.00	nd
o_CthetaR	1813.84	LT/ft^2

LOCAL BUCKLING LIMIT STATE FOR RING AND STRINGER STIFFENERS

4.9.1 flexural-torsional buckling

eta	0.67	nd		
l	8.33	ft		
t	0.09896	ft		
A_s	0.10547	ft^2		
s	1.31	ft		
E	1928571.43	LT/ft^2		
o_o	2312.32	LT/ft^2		I_y
n	2.00	wave for smallest yield	tw	4.69E-02 ft
alpha	6.37	nd	dw	1.75E+00 ft
o_CL	121841.63	LT/ft^2	tf	4.69E-02 ft
I_xf	0.00163	ft^4	bf	5.00E-01 ft
WARPING const	0.00324	ft^6	Aw	8.20E-02 ft^2
C_o	475.92	LT	Af	2.34E-02 ft^2
t_f	0.04688	ft	At	1.05E-01 ft^2
b_1	0.00000	ft	y_o	5.56E-02 ft
b_f	0.50	ft	z_o	1.07E+00 ft
t_w	0.04688	ft	I_yw	2.09E-02 ft^4
d_w	1.75	ft	I_yf	4.29E-06 ft^4
z_o	1.06944	ft	I_zw	1.50E-05 ft^4
y_o	0.05556	ft	I_zf	4.88E-04 ft^4
u	1.00	nd	I_y	3.57E-02 ft^4
m	0.65	nd	I_z	1.64E-03 ft^4
I_y	0.03566	ft^4		
I_z	0.00164	ft^4		
I_o	0.15768	ft^4		
K	0.00008	ft^4		
o_ET	27042.74	LT/ft^2		
P_r	0.60	nd		
o_CT	2264.86	LT/ft^2		
o_x	1386.45	LT/ft^2		
req	0.92	has to be < 1		

BEAM COLUMN BUCKLING

4.11.

E	1928571.43	LT/ft^2
kL	50.00	ft
A_T	11.59	ft^2
I_T	729.99	ft^4
r_i	7.94	ft
o_E©	479432.98	LT/ft^2
lambda_xE	0.07	if > 0.5 then the following beam buckling sectic

AFT BULKHEAD THICKNESS (RULES FOR BUILDING AND CLASSING STEEL VESSELS)

c	525	nd	c = 460 for collision bh and 525 for watertight
h	55.77	ft	using effective depth instead of horizontal value
Y	35969	psi	
q	0.945		
alpha	1		
k	0.785		
s	15.71	inches	
t	0.230	inches	
	0.179	inches	
THICKNESS	0.230	inches	compare to the thickness of the forward tank

Connector

CONNECTOR STATUS: initially sized

Data and Calculations in Table are for Half of Hull.

piece	number	thickness (Note 2.) in	height (length of web) ft	width (of flange) ft	centroid from wall ft	radius from center ft	VCG of struct. ft	*area per piece* in^2	total area in^2	*local self inertia* ft^4	total local inertia ft^4	moment rel. to BL in^2ft	total inertia rel. to center ft^4	percent contrib. to inertia
CIRCULAR ITEMS														
exterior plate	1	1.188				10.000	10.000	*447.677*	447.677	*155.443*	155.443	4476.770	155.443	44.98%
access tunnel	0	0.250				2.500	10.000	*23.562*	0.000	*0.511*	0.000	0.000	0.000	0.00%
LONGITUDINAL ITEMS														
stringer stiffeners	25	0.500	1.750	0.438	1.050	8.950	10.000	*13.125*	328.125	*0.030*	0.744	3281.250	183.270	53.04%
heavy s stiffeners	0	0.500	1.500	1.000	1.050	8.950	10.000	*15.000*	0.000	*0.026*	0.000	0.000	0.000	0.00%
tank dividers	1	0.250	7.500	0.000	3.750	6.250	10.000	*22.500*	22.500	*0.732*	0.732	225.000	6.836	1.98%
TRANSVERSE ITEMS														
ring stiffeners	3	0.375	1.250	0.333	0.756	9.244		*7.124*		*0.008*				
total									798.3		156.9	7983.0	345.5	100.00%

Tank depth	30.00 ft	Effective depth while verti	5.77 ft
Tank length	30.03 ft	Pressure	0.17 LT/ft^2

half of hull

Mid-depth	15.00 ft	
Neutral axis	10.00 ft above BL	
Inertia for whole hull	691.10 ft^4 relative to neutral axis	
SM deck	34.55 ft^3	
SM bottom	69.11 ft^3	
Yield Strength	2312.32 LT/ft^2	248.00 MPa
Ultimate Stength	7841.36 LT/ft^2	841.00 MPa
M(x)	36756.70 LTft	
Bending Stress	-1063.72 LT/ft^2	
V(x)	-732.92 LT	
Shear Stress	-132.21 LT/ft^2	

VALUES

Total area	11.09 ft^2
E (steel)	1928571.43 LT/ft^2
min. yield	2312.32 LT/ft^2
Pr	0.60 for steel
shell btwn stingers	15.08 inches
shell bwtn ring stiffene	90.08 inches
total volume of steel	341.52 ft^3

BULKHEAD VOLUME

t	0.23 in
A_bh	314.16 ft^2
V_bh	6.03 ft^3
V_stiffener	0.68 ft^3
reduction	0.67 nd
stiffeners	50.00 stiffeners
V_total	28.82 ft^3

LOCAL SHELL BUCKLING

phi	0.83 nd
utilization factor	0.67 nd

PROPORTIONS OF WEBS OF STIFFENERS

STRINGERS	d_w	1.75 ft		
	t_w	0.0417 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		42.00	must be < or	43.32
				0.97
RING STIFFENERS	d_w	1.25 ft		
	t_w	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		40.00	must be < or	43.32
				0.92

PROPORTIONS OF FLANGES AND FACEPLATES

STRINGERS	b_2	0.4375 ft		
	t_f	0.0417 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		10.50	must be < or	11.55
				0.91
RING STIFFENERS	b_2	0.3330 ft		
	t_f	0.0313 ft		
	o_o	2312.32 LT/ft^2		
	E	1928571.43 LT/ft^2		
		10.66	must be < or	11.55
				0.92

STIFFNESS OF STRINGER STIFFENERS

l	7.51 ft		
A_s	0.0911 ft^2		
v	0.30 nd		
t	0.0990 ft		
s	1.26 ft		
alpha	5.97 nd		
delta	0.7330 nd		
gamma_o	239.18 nd		
i_o	0.0267	must be <	0.0298
			0.8958

STIFFNESS OF RING STIFFENERS

eta	0.6664 nd		
l	7.51 ft		
t	0.0990 ft		
A_s	0.0911 ft^2		
s	1.26 ft		
E	1928571.43 LT/ft^2		
o_o	2312.32 LT/ft^2		
K_theta	0.9969 nd		
z_e	0.4935 ft		
r_e	9.24 ft		
l_eo	1.55 ft must be <= l		
delta	0.7330 nd		
o_thetaR	11.86 LT/ft^2		
o_theta	16.64 LT/ft^2		
o_x	682.27 LT/ft^2		
i_r	0.0006	must be <	0.0083
			0.07

CONNECTOR

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

2.3.1	axial tension req.			
	axial tensile pressure	0.17	LT/ft^2	
	eta	0.6664		
	o_o	2312.32		
	req	0.00	has to be < 1	
2.3.3	axial compression req.			
	axial compressive pressu	0.17	LT/ft^2	
	eta	0.6664	nd	
	k, eff length	1.00	nd	
	L, of member	30.03	ft	
	K, St. Venant	1382.20	ft^4	
	A	11.09	ft^2	
	E	1928571.43	LT/ft^2	
	radius of gyration	7.90	ft	
	o_Eeta	1316055.95	LT/ft^2	
	o_ET	1483516.48	LT/ft^2	
	o_EA	1316055.95	LT/ft^2	
	o_CA	2311.34	LT/ft^2	
	req	0.00	has to be < 1	
2.3.5	bending moment req.			
	o_b	1063.72	LT/ft^2	
	o_CB	2312.06	LT/ft^2	
	o_b / n_2 o_SB	0.69	has to be < 1	
4.7.3	critical buckling stress for axial compression or bending moment			
	lambda_xP	0.2287	nd	
	s_e	34.94	inches	
	I_se	5.58	ft^4	
	o_c	4967013.44	LT/ft^2	
	rho_xB	0.7500	nd	
	o_s	6578.66	LT/ft^2	
	o_ExB	4973592.10	LT/ft^2	
	o_CxB	2312.06	LT/ft^2	
4.5.3	critical buckling stress for axial compression or bending moment in curved panels			
	z_s	1.52	nd	
	rho_xP	0.9703	nd	
	K_xP	4.07	nd	
	o_CExP	44008.66	LT/ft^2	
	lambda_n	0.2327	nd	
	B_xP	1.03	nd	
	o_ExP	44191.95	LT/ft^2	
	o_CxP	2283.28	LT/ft^2	
2.5.1	axial tension and bending			
	o_t	0.17	LT/ft^2	
	o_b	1063.72	LT/ft^2	
	o_CB	2312.06	LT/ft^2	
	eqn	0.98	has to be < 1	
2.5.3	axial compression and bending			
	o_a	0.17	LT/ft^2	
	o_CA	2311.34	LT/ft^2	
	o_b	1063.72	LT/ft^2	
	o_CB	2312.06	LT/ft^2	
	eqn	0.98	has to be < 1	

BAY BUCKLING LIMIT STATE

4.13.3	hoop stress		
	r	10.00	ft
	N_theta	1.00	LT/ft
	N_axial	0.00	LT/ft
	q	0.17	LT/ft^2
	A_R	0.0495	ft^2
	r_R	9.24	ft
	r_F	8.75	ft
	t	0.0990	ft
	t_w	0.0417	ft
	l	7.51	ft
	v	0.3000	nd
	k	0.5000	nd
	alpha	4.84	nd
	G_alpha	0.0138	nd
	omega	0.2068	nd
	A_R mean	0.0579	ft^2
	K_thetaR	0.6218	nd
	K_theta	0.9969	nd
	o_thetaR	11.86	LT/ft^2
	o_theta	16.64	LT/ft^2
4.13.1	longitudinal stress		
	t	0.0990	ft
	r	10.00	ft
	s	1.26	ft
	A_st	0.0911	ft^2
	delta	0.7330	nd
	M	36756.70	LTft
	P	-732.92	LT
	o_b	682.26	LT/ft^2
	o_a	0.02	LT/ft^2
	o_x	682.27	LT/ft^2
4.7.1	bay buckling limit state		
	eta	0.6664	nd
	o_o	2312.32	LT/ft^2
	o_ExP	44191.95	LT/ft^2
	lambda_m	0.2287	nd
	s_em	1.26	ft
	s	1.26	ft
	t	0.0990	ft
	A_s	0.0911	ft^2
	A	0.2155	ft^2
	A_e	0.2155	ft^2
	phi_B	1.00	nd
	o_CthetaB	2312.32	LT/ft^2
	o_CxB	2312.06	LT/ft^2
	o_theta	16.64	LT/ft^2
	o_x	682.27	LT/ft^2
	req	0.19	has to be < 1

CONNECTOR

ABS REQUIREMENTS FROM "GUIDE FOR BUCKLING AND ULTIMATE STRENGTH ASSESSMENT FOR OFFSHORE STRUCTURES - 2004"

4.7.5 critical buckling stress for external pressure

o_o	2312.32	LT/ft^2	
t	0.09896	ft	
r	10.00	ft	
l	7.51	ft	
N_s	50.00	stringers	
I_s	0.02978	ft^4	
g	21.67	nd	
K_p	0.28684	nd	
A_s	0.09115	ft^2	
z_st	8.95	ft	
q_s	426.26	LT/ft^2	
K_theta	1.00	nd	
o_sp	42938.97	LT/ft^2	
o_CthetaR	2026.48	LT/ft^2	
o_CthetaB	12898.05	if greater,	2312.315933

4.3.5

o_o	2312.32	LT/ft^2
v	0.30	nd
E	1928571.43	LT/ft^2
t	0.09896	ft
r	10.00	ft
l	7.51	ft
z	54.31	nd
k	0.50	nd
C_P	0.06838	nd
A_L	6.91	nd
q_CEthetaR	25.15	LT/ft^2
K_theta	1.00	nd
rho_thetaR	0.80	nd
o_EthetaR	2026.48	LT/ft^2
DELTA	0.88	nd
PHI	1.00	nd
o_CthetaR	2026.48	LT/ft^2

BEAM COLUMN BUCKLING

4.11.

E	1928571.43	LT/ft^2
kL	30.03	ft
A_T	11.09	ft^2
I_T	691.10	ft^4
r_i	7.90	ft
o_E©	1316055.95	LT/ft^2
lambda_xE	0.04	if > 0.5 then the following beam buckling sectic

LOCAL BUCKLING LIMIT STATE FOR RING AND STRINGER STIFFENERS

4.9.1 flexural-torsional buckling

eta	0.67	nd		
l	7.51	ft		
t	0.09896	ft		
A_s	0.09115	ft^2		
s	1.26	ft		
E	1928571.43	LT/ft^2		
o_o	2312.32	LT/ft^2	I_y	
n	2.00	wave for smallest yield	tw	4.17E-02 ft
alpha	5.97	nd	dw	1.75E+00 ft
o_CL	119249.76	LT/ft^2	tf	4.17E-02 ft
I_xf	0.00099	ft^4	bf	4.38E-01 ft
WARPING const	0.00212	ft^6	Aw	7.29E-02 ft^2
C_o	495.75	LT	Af	1.82E-02 ft^2
t_f	0.04167	ft	At	9.11E-02 ft^2
b_1	0.00000	ft	y_o	4.38E-02 ft
b_f	0.44	ft	z_o	1.05E+00 ft
t_w	0.04167	ft	I_yw	1.86E-02 ft^4
d_w	1.75	ft	I_yf	2.64E-06 ft^4
z_o	1.05000	ft	I_zw	1.05E-05 ft^4
y_o	0.04375	ft	I_zf	2.91E-04 ft^4
u	1.00	nd	I_y	3.03E-02 ft^4
m	0.70	nd	I_z	9.99E-04 ft^4
I_y	0.03032	ft^4		
I_z	0.00100	ft^4		
I_o	0.13168	ft^4		
K	0.00005	ft^4		
o_ET	26256.34	LT/ft^2		
P_r	0.60	nd		
o_CT	2263.44	LT/ft^2		
o_x	682.27	LT/ft^2		
req	0.45	has to be < 1		

AFT BULKHEAD THICKNESS (RULES FOR BUILDING AND CLASSING STEEL VESSELS)

3.2.9.5

c	525	nd	c = 460 for collision bh and 525 for watertight
h	5.77	ft	using effective depth instead of horizontal value
Y	35969	psi	
q	0.945		
alpha	1		
k	0.785		
s	15.08	inches	
t	0.113	inches	
	0.175	inches	
THICKNESS	0.175	inches	compare to the thickness of the forward tank

Bow

BOW
Data and Calculations in Table are for Half of Hull.

piece	number	thickness (Note 2.) in	height (vert) ft	width (horizontal) ft	vertical centroid ft	*area per piece* in^2	total area in^2	moment rel. to BL in^2ft	*local self inertia* ft^4	total local inertia ft^4	total inertia rel. to center ft^4	percent contrib. to inertia
LONGITUDINAL-HORIZONTAL												
bottom plating	1	0.313	2.50	15.00	2.50	56.25	56.25	*140.625*	0.000022076	*0.000022076*	97.688	21.41%
1st deck	1	0.188	1.82	13.12	1.82	29.51325	29.51325	*53.714*	0.000004170	*0.000004170*	55.758	12.22%
2nd deck	1	0.188	17.33	15.23	17.33	34.2585	34.2585	*593.768*	0.000004840	*0.000004840*	0.229	0.05%
top deck	1	0.188	28.22	18.04	28.22	40.581	40.581	*1144.993*	0.000005733	*0.000005733*	27.626	6.05%
top of deckhouse	1	0.188	38.22	14.02	38.22	31.536	31.536	*1205.148*	0.000004456	*0.000004456*	86.735	19.01%
deck stringers	20	0.313	0.75	0.25	18.17	3.75	75	*1362.601*	0.000915895	*0.018317905*	105.974	23.22%
LONGITUDINAL-VERTICAL												
exterior plate	1	0.313	27.697	6.250	18.856	103.86375	103.86375	*1958.403*	46.109	*46.109*	46.321	10.15%
wall on 1st deck	0	0.250	13.334	2.500	8.487	40.002	0	*0.000*	4.116	*0.000*	0.000	0.00%
wall on 2nd deck	0	0.250	12.989	2.500	23.827	38.967	0	*0.000*	3.805	*0.000*	0.000	0.00%
wall of deckhouse	1	0.188	10.000	14.016	33.215	22.5	22.5	*747.338*	1.302	*1.302*	35.996	7.89%
wall stiffeners	0	0.313	0.50	0.25	26.29	2.8125	0	*0.000*	0.000034644	*0.000000000*	0.000	0.00%
total			64.0	75.40			393.50	7206.59			456.3	100.00%

half of hull

Tank depth	38.22 ft	Effective depth while verti	0.00 ft	Mid-depth	19.11 ft
Tank length	81.00 ft	Pressure	0.00 LT/ft^2	Neutral axis	18.31 ft above BL
				Inertia for whole hull	912.66 ft^4 relative to neutral axis
				SM deck	45.86 ft^3
				SM bottom	49.83 ft^3

VALUES

Total area	5.47	ft^2
E (steel)	1928571.43	LT/ft^2
min. yield	2312.32	LT/ft^2
Pr	0.60	for steel
shell btwn wall stringer		inches
shell bwtn deck stringer	45.24	inches
total volume of steel	295.13	ft^3

Yield Strength	2312.32 LT/ft^2	248.00	MPa
Ultimate Stength	7841.36 LT/ft^2	841.00	MPa
M(x)	17976.12 LTft		
Bending Stress	-391.98 LT/ft^2		
V(x)	-494.46 LT		
Shear Stress	-180.95 LT/ft^2		

LOCAL SHELL BUCKLING

phi	0.83	nd
utilization factor	0.67	nd

PROPORTIONS OF WEBS OF STIFFENERS

STRINGERS

d_w	0.75	ft
t_w	0.0260	ft
o_o	2312.32	LT/ft^2
E	1928571.43	LT/ft^2
	28.80	must be < or 43.32
		0.66

PROPORTIONS OF FLANGES AND FACEPLATES

STRINGERS

b_2	0.2500	ft
t_f	0.0260	ft
o_o	2312.32	LT/ft^2
E	1928571.43	LT/ft^2
	9.60	must be < or 11.55
		0.83

ABS REQUIREMENTS FROM "RULES FOR BUILDING AND CLASSING STEEL VESSELS - 2014"

2.1.3.7	M_t	17976.12
	f_p	1631.52
	SM_min	11.01801878

BULKHEAD WEIGHTS

thickness	0.257	in
ft^3/ft^2	0.028324729	ft
density	0.21875	LT/ft^3
weight/area	0.006196034	LT/ft^2
area of bulkhead 1	1000	ft^2
area of bulkhead 2	940	ft^2
area of bulkhead 3	846	ft^2
area of bulkhead 4	699	ft^2
area of bulkhead 5	534	ft^2
area of bulkhead 6	328	ft^2

9.0 Resistance and Powering

9.1 Resistance Calculations

The addition of propulsion is one of the significant improvements that the *R/V FLIP II* possesses in comparison to the platform that it is designed to replace. A preliminary calm water resistance analysis was conducted in order to size the primary propulsion. This analysis included the effects of frictional as well as wave making resistance. The decomposition of the resistance coefficients can be seen below.

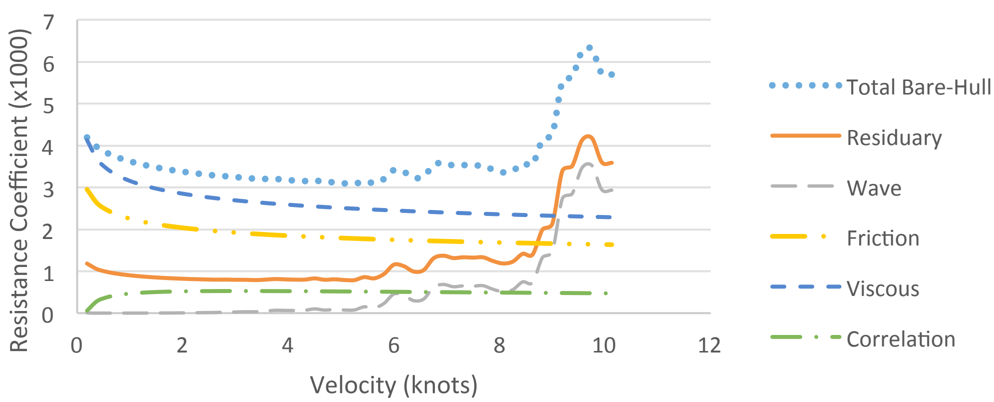


Figure 38. Decomposition of resistance coefficients

Due to the large amount of transverse frontal area caused by the presence of the deckhouse and external deck grating, an air drag resistance estimate was conducted. This analysis included a 30-knot headwind and an estimated drag coefficient of 1.28 as defined by D.W. Taylor in 1943. Due to the fact that the vessel will be slow moving and will not possess a vast amount of installed power, a 30-knot head wind was used in order to provide that the vessel will be able to maintain heading in a storm. In most circumstances, the relative wind will not be head on nor at magnitudes of 30 knots. The overall resistance is plotted below.

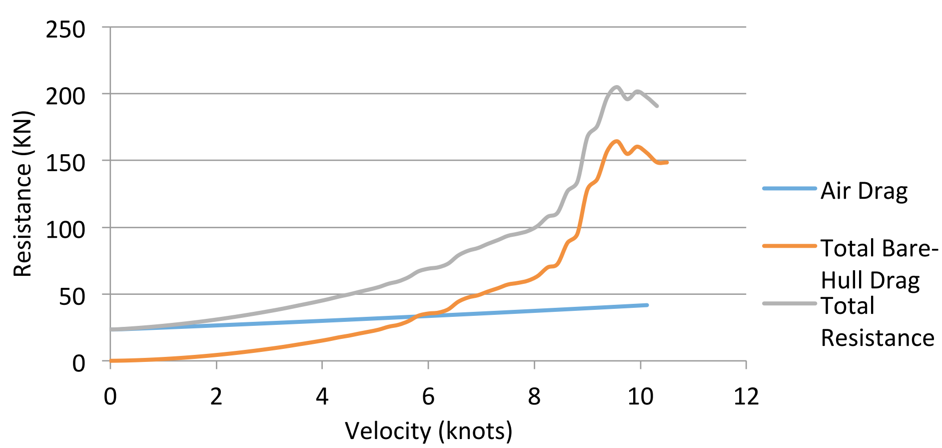


Figure 39. Resistance as a function of speed

9.2 Powering

Following the determination of the overall resistance on the vessel due to air and sea interaction, the installed propulsion power requirement was calculated. The following efficiencies listed in Table 35 were used to plot a graph of the installed power requirement. This plot can be seen below in Figure 41.

Table 35. Efficiencies of propulsion system

Efficiency or Margin	Value
Electrical System Efficiency	90%
Propeller Efficiency	60%
Service Margin	30%

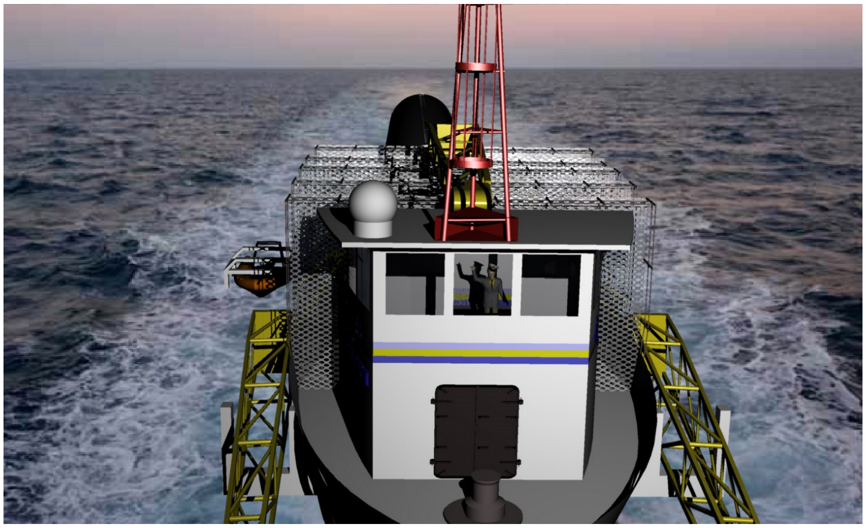


Figure 40. Rendered view of the *R/V FLIP II* in transit

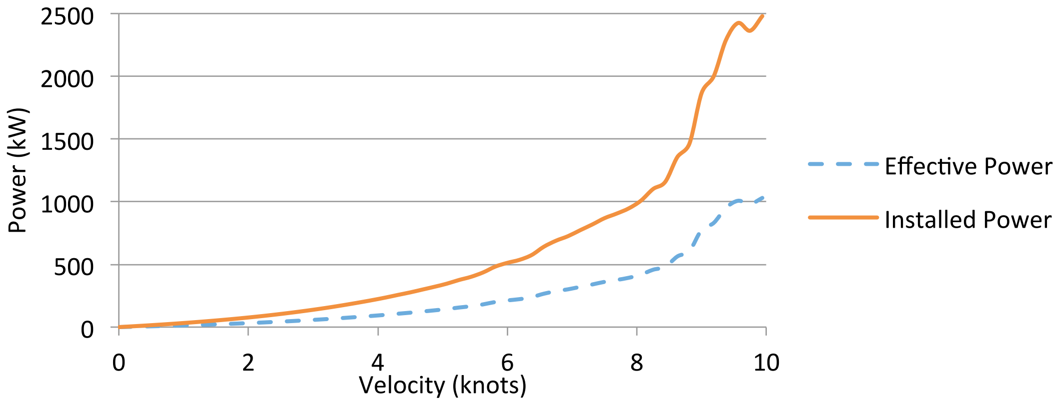


Figure 41. Installed power requirement as a function of speed taking into account system efficiencies

A speed of eight knots was chosen as the service speed for the vessel requiring approximately 968 kW of installed power. Eight knots is faster than the present *R/P FLIP* is towed at and at speeds greater than this value, the wave drag has a much greater effect on the overall resistance of the vessel. Through conversation with Dr. Gerald D'Spain of the Marine Physical Laboratory at Scripps Institute of Oceanography, it was learned that most marine mammal strikes occur on vessels operating at speeds greater than eight knots. As marine mammal observation is a component of the *R/V FLIP II*'s scientific research profile, mammal strikes are events to be avoided. A more detailed description of the transit speed selection is given in the Trade Study section of the report.

The range of the vessel was chosen to allow for it to travel from San Diego, CA to Hawaii and back in a single scientific mission with an endurance of 45 days without resupply. This resulted in a total range of approximately 4,400 nautical miles. Traveling at 8 knots in perfect conditions, it would take just less than 12 days to arrive on station. Assuming the vessel then operates for 34 days on station and then returns back to California, the total weight of required fuel was estimated to be 266LT. This was assumed to be the most demanding mission profile. The power required while in transit is approximately 1,027 kW and 900 kW while conducting research on station. The calculation of the total required fuel weight follows the equations presented below. A ten percent margin was added to the specific fuel consumption in order to account for reduction in fuel efficiency as the machinery ages. A five percent service margin was also added to the value of total required fuel weight.

$$Transit\ Fuel\ Weight = sfc * \frac{Range}{Speed} * Power\ Demand$$

$$Station\ Fuel\ Weight = sfc * Endurance\ on\ Station * Power\ Demand$$

$$Total\ Fuel\ Weight = Transit\ Fuel\ Weight + Station\ Fuel\ Weight$$

9.3 Maneuvering

A preliminary maneuvering analysis was conducted on the *R/V FLIP II* utilizing two different methods. The first analysis used the University of Michigan Maneuvering Prediction program, which is a regression based program that uses a data set of 72 different model tests. The results were assumed to need further engineering work due to the fact that the vessels tested have different geometric ratios and coefficients.

A second analysis was based on slender-body maneuvering theory. This method is based on the added mass coefficients of the vessel. These values were gathered from running SHIPMO in the low frequency spectrum. SHIPMO is a FORTRAN based program written at the University of Michigan that applies strip theory and ideal fluid assumptions in order to analyze vessel motions. Table 36 shows the coefficients estimations based on linear slender-body maneuvering theory.

Table 36. Estimations of linear maneuvering coefficients based on slender-body maneuvering theory

Standard Notation	Slender-Body Theory	Added-Mass Theory
Y_v	$-U_1 m_T$	0
$-Y_r$	$U_1 x_T m_T$	$U_1 m_{11}$
$-N_v$	$U_1 (m^s_{33} + x_T m_T)$	$U_1 (m_{33} - m_{11})$
N_r	$U_1 (m^s_{35} - (x_T)^2 m_T)$	$U_1 m_{35}$

The results of each analysis are tabulated below in Table 37. Neither of the analysis methods result in a turning diameter that meets the ABS criteria of 5*LWL. Thus, through future iterations of the design, the addition of a chain operated rudder or another maneuvering aid such as another retractable thruster should be investigated. Maneuvering capability is not only necessary for operation in harbor but also for the deployment of mooring lines.

Further, the relative location of the center of pressure to the propulsion unit causes the negative value on the turning diameter. Meaning that turning the helm to starboard would move the vessel to port. The regression method is not able to capture this result due to its regression equations.

Table 37. Summary of maneuvering results

Analysis Method	Course Stability Result	Turning Diameter Result
Maneuvering Prediction Program Regressions	Controls-fixed Stable	55 * LWL
Slender-Body Maneuvering Theory	Controls-fixed Stable	- 89 * LWL

10.0 Electrical Generation

This section of the report details the electrical generation requirements of the *R/V FLIP II*. An overview of the electrical load analysis is presented as well as the operational modes inspected. Following this, the generator selection is documented, and the one-line diagram is shown in the appendix.

10.1 Electrical Load Analysis

Five operational modes were examined: in transit, mooring retrieval, on station moored or drifting and station keeping, and shore power. The loads were calculated by either an estimation based on similar ships or a direct input from the given equipment's manufacturer. A summary of the electrical load analysis is displayed below in Table 38.

Table 38. Summary of the electrical loads in the 5 modes of operation examined

Load Description	In Transit (kW)	Moored (kW)	Station-keeping (kW)	Mooring Retrieval (kW)	Shore Power (kW)
Retractable Thruster	928	0	49	49	0
Tunnel Thruster	0	0	335	335	0
Misc. 480V and 120 V Loads	92	104	104	123	22
Total	1020	104	488	507	22
Percent of Installed Power	85%	9%	41%	42%	1%

In addition to fulfilling the power requirements for propulsion and auxiliary systems, a UPS has also been installed for use during sensitive acoustic experiments. These experiments require not only a silent source of power (i.e. not running a generator) but also need a clean electrical signal. The UPS system is capable of supplying 96 kW at peak power, but these sensitive research experiments hardly ever require more than 10 kW. At a constant electrical load of 10 kW, the system can supply battery power for up to 22 hours without recharging. The ability to run completely silent provided by the UPS is one that *R/P FLIP* does not have, and it is a clear advantage of the new design.

10.2 Generator Selection

Caterpillar, GM, and John Deere generator drives were compared against a combination of metrics, most notably (1) power output per unit area, (2) power per unit volume, and (3) power output per unit weight. These metrics were deemed the most important due to the minimal amount of space for machinery allocation within the bow. For reasons of acoustic and vibrational disturbances, the power plants could not be positioned below the waterline in the vertical orientation, limiting their placement to the bow region.

10.2.1 Quantity and Power Outputs

The set of generators were chosen based upon the results from the electrical load analysis, such that engines will be able to shut down in accordance to the varying operational electrical load requirements. This procedure was adopted to minimize energy waste and therefore possess the greatest long term cost benefits.

10.2.2 Selection

John Deere generator drives were chosen and paired with ABB generators. This combination possessed the highest power density and out ranked GM and Caterpillar in the other prescribed metrics. An overview of the electrical generation plants is shown below in Table 39.

Table 39. Electrical power generation plants

Generator Drive	Generator	Number Installed	Power Output (kW)
John Deere 6135S	ABB AMG 0315	2	832
John Deere 6068S	ABB AMG 0280	1	195
John Deere 4045T	ABB AMG 0200	1	73
Total		4	**1100**

For station keeping and mooring retrieval, one of each the 6135S and 6068S generator drives can be used as the only sources of power. While moored or drifting on station, the 6068S generator set can solely provide the power demand. And dependent on the wind forces experienced, the transit condition requires anywhere from one of the 6135S engines to the entire set.

10.3 One-Line Diagram

In the appendix, the overall electrical framework of *R/V FLIP II* electrical one-line diagram is presented. The primary switchboard is fed a supply of power from the primary gensets, the UPS, the emergency genset, or the shore power connector. From there power is transformed up to 690V for propulsion requirements and transformed down to 120V for Navigation Electronics and ship-wide outlets. The generators supply 480V and feed directly into the respective bus that powers auxiliary machinery, scientific loads, lighting, the galley and mess, and the HVAC system.

10.4 Electrical Load Analysis

The next page presents a detailed calculation of the electrical power output. The designers did not include during trimming electrical loads. However, most equipment will be expected to be off during the procedure, therefore producing enough loads for the air compressors to act.

The Cool Kidz, Inc
Ann Arbor, Michigan

ELECTRICAL LOAD ANALYSIS
Client: ONR and Scripps Institution of Oceanograpy
Vessel: R/V FLIP II

4/23/2014
By: MJS

SWITCHBOARD SUMMARY

Circuit Number or Ckt Bkr Position	Load Description	Voltage E	Unit kW	Connected kW	In Transit DF	In Transit kW	Mooring Retrieval DF	Mooring Retrieval kW	On Station (Drifting/Moored) DF	On Station (Drifting/Moored) kW	On Station (DP) DF	On Station (DP) kW	In Port (Shore Pwr) DF	In Port (Shore Pwr) kW	Remarks
PROPULSION BUS	Retractable Thruster	690	1000	977	0.95	928.15	0.05	48.85	0	0	0.05	48.85	0	0	
	Tunnel Thruster	690	670	670	0	0	0.5	335	0	0	0.5	335	0	0	
	690V Bus Sub-Totals	690		1647		928.15		383.85		0		383.85		0	
	120V/480V Bus Sub-Totals	480		573.5		91.25		122.5		103.35		103.35		2.5	
	TOTALS			2220.5		1019.4		506.35		103.35		487.2		2.5	
	Total Generator kW	1027													
	Emergency Generator kW	73													
	Battery Power Supplied kW	96													
	Total Available Power kW	1196													
Percent of Total Ship Service Generator Capacity				186%		85%		42%		9%		41%		0%	

120V/480V 3 PHASE - SHIP SERVICE BUS SUMMARY

Circuit Number or Ckt Bkr Position	Load Description	Voltage E	Unit kW	Connected kW	In Transit DF	In Transit kW	Mooring Retrieval DF	Mooring Retrieval kW	On Station (Drifting/Moored) DF	On Station (Drifting/Moored) kW	On Station (DP) DF	On Station (DP) kW	In Port (Shore Pwr) DF	In Port (Shore Pwr) kW	Remarks
	Air Compressor No. 1	480	30	30	0	0	0	0	0	0	0	0	0	0	
	Air Compressor No. 2	480	30	30	0	0	0	0	0	0	0	0	0	0	
	Crane (Centerline)	480	20	20	0	0	0	0	0	0	0	0	0	0	
	Crane (Port)	480	20	20	0	0	0	0	0	0	0	0	0	0	
	Crane (Starboard)	480	20	20	0	0	0	0	0	0	0	0	0	0	
	Mess Area Power Panels	480	50	50	0.1	5	0.1	5	0.1	5	0.1	5	0	0	
	HVAC	480	35	35	0.75	26.25	0.75	26.25	0.75	26.25	0.75	26.25	0	0	
	Hydraulic Pump No. 1	480	25	25	0	0	0.25	6.25	0	0	0	0	0	0	
	Hydraulic Pump No. 2	480	25	25	0	0	0.25	6.25	0	0	0	0	0	0	
	Laboratory UPS 120kVA System	120	96	96	0	0	0	0	0.1	9.6	0.1	9.6	0	0	
	Lighting	480	40	40	0.5	20	0.5	20	0.75	30	0.75	30	0	0	
	Mooring Winch	480	40	40	0	0	1	40	0	0	0	0	0	0	
	Range and Galley Misc.	480	25	25	0.25	6.25	0	0	0.25	6.25	0.25	6.25	0	0	
	Sewage Transfer	480	5	5	0	0	0	0	0	0	0	0	0.5	2.5	
	Ship Electronics	120	30	30	0.5	15	0.5	15	0.25	7.5	0.25	7.5	0	0	
	Water Generation	480	7.5	7.5	0.5	3.75	0.5	3.75	0.5	3.75	0.5	3.75	0	0	
	Water Heater	480	50	50	0.3	15	0	0	0.3	15	0.3	15	0	0	
	Welding Machine	480	25	25	0	0	0	0	0	0	0	0	0	0	
	480V Bus Totals			573.5		91.25		122.5		103.35		103.35		2.5	

EMERGENCY BUS POWER SUMMARY

Circuit Number or Ckt Bkr Position	Load Description	Voltage E	Unit kW	Connected kW	In Transit DF	In Transit kW	Mooring Retrieval DF	Mooring Retrieval kW	On Station (Drifting/Moored) DF	On Station (Drifting/Moored) kW	On Station (DP) DF	On Station (DP) kW	In Port (Shore Pwr) DF	In Port (Shore Pwr) kW	Remarks
	HVAC	480	20	20	0.5	10	0.5	10	0.5	10	0.5	10	0	0	
	Lighting	480	25	25	0.5	12.5	0.5	12.5	0.5	12.5	0.5	12.5	0	0	
	Range and Galley Misc.	480	25	25	0.2	5	0.2	5	0.2	5	0.2	5	0	0	
	Ship Electronics	120	30	30	0.25	7.5	0.25	7.5	0.25	7.5	0.25	7.5	0	0	
	Water Generation	480	7.5	7.5	0.5	3.75	0.5	3.75	0.5	3.75	0.5	3.75	0	0	
	Water Heater	480	50	50	0.1	5	0.1	5	0.1	5	0.1	5	0	0	
	Emergency Bus Totals			157.5		43.75		43.75		43.75		43.75		0	

11.0 Propulsion Machinery Trade Study

The purpose of this trade study is to determine the most effective primary propulsion unit and electrical power generation system for the *R/V FLIP II* design. The study analyzes characteristics of the primary components contained in the propulsion and the power generation systems. The analysis is designed to address the general concepts of system component selection. The results of this report will be used as the basis for the selection of the primary propulsion and power generation equipment.

11.1 Phase 1 – Design Transit Speed

Prior to sizing the prime mover, the design transit speed of the vessel must be selected. Once this value is known, the total drag on the hullform can be estimated and size of the required propulsion system can be determined.

11.1.1 Analysis

Two main factors were used to determine the design transit speed of the *R/V FLIP II*. These factors were based on the hullform resistance as well as the time necessary for the vessel to arrive on station. Transit speeds within the range from six to twelve knots were analyzed. The *FLIP* platform is towed at speeds ranging from five to seven knots and sometimes up to ten knots. Selecting a transit speed within this range was determined to be sufficient.

The required installed power was estimated for the *R/V FLIP II* at a variety of speeds from zero to fifteen knots. The particulars of the analysis can be found in more detail in the Resistance and Powering section of the design report. In Table 40 below, the resulting required installed power data can be found for a variety of speeds. Also tabulated is the power required to increase the transit speed from one value to the next. This information was used to determine the optimum speed for operation.

The second metric was based off the total time required for the vessel to travel to and from station. The maximum range of 2,200 nautical miles was used in this calculation as well as the total allotted endurance of 45 days. Assuming ideal conditions, the total time required for the vessel to reach position at 2,200 nautical miles was calculated and then divided by the total endurance.

Table 40. Transit Speed Analysis

Transit Speed (knots)	Power Required (kW)	Difference in Power (kW)	% of Endurance in Transit
6	512	-	33
7	757	245	29
8	**968**	**211**	**25**
9	1,867	899	22
10	2,476	609	20
11	3,046	570	18
12	5,441	2,395	16

11.1.2 Discussion

Based on the analysis above, the design transit speed was set to eight knots. This selection was primarily determined by the large increase in required installed power after eight knots; at this point the wave drag resistance component begins to dominate and increases considerably with speed. Selecting a transit speed of eight knots surpasses the speed at which the current *R/P FLIP* is usually towed, allowing the scientists and researchers to arrive on station sooner. While meeting with scientists and engineers that often perform research on *FLIP*, Dr. Gerald D'Spain, Associate Research Scientist at the University of California, San Diego Marine Physical Laboratory, stated that most marine mammal ship strikes occur at speeds just above eight knots. These were the main decision factors utilized in selecting the design transit speed of eight knots.

11.2 Phase 2 – Propulsion Unit Selection

This section of the trade study aims to determine the optimal propulsion unit to incorporate into the *R/V FLIP II* design. Many different primary propulsion systems were initially considered, including conventional, water-jet, swing-down thruster, retractable thruster, and podded propulsion. Due to the unique space and functionality limitations inherent in the *R/V FLIP II* design, retractable thrusters were selected as the most applicable to this project. The use of a retractable thruster allows the propulsion unit to be contained within the hull when not in use. This prevents the thruster having any negative effects on clearances or the deployment of scientific arrays. The thruster, if placed properly, can also be used for primary propulsion in the horizontal and for rotational control in the vertical attitude.

11.2.1 Analysis

Four different retractable thrusters were analyzed in this section of the trade study, produced by Wartsila, Thrustmaster, Schottel, and Rolls-Royce. The principal characteristics of these units are shown below in Table 41. The data used to populate this table was found on the vendor websites.

Table 41. Retractable Thruster Data

Thruster Model	Rated Power (kW)	Height (ft.)	Footprint (ft^2)	Weight (LT)	Maximum Prop D (ft.)
Wartsila LMT 175	1000	25.26	117	19.68	5.58
Thrustmaster (TH1500MLR)	932-1,305	19.83	113	23.27	6.17
Schottel (SRP 550 ZSV)	650-1000	24.60	94.3	19.5	5.41
Rolls-Royce (UL 1401)	1200	21.71	115.8	23.62	6.56

With the data in Table 41, the four retractable thruster models were analyzed and compared based on a series of weighted metrics. These results are shown in Table 42. The main metrics were: how close the rated power of the thruster was to the required installed power, what volume was required, the weight, and relative propeller efficiency based on maximum propeller diameter. Each thruster was given a score, ranking either one, two, or three representing poor, average, and good, respectively. Each metric was also given a weighting factor from one to five, as some have greater implications on the design than others.

The metric comparing how close the rated power of the retractable thruster is to the required installed power was given a weight of three. It is important to match the size of the size of the installed propulsion to the power required because oversizing can lead to unnecessary capital and lifetime costs.

A weight factor of two and a half was given to the scores of the required volume comparison. The required volume, especially the height of the units can have a considerable impact on the arrangements of the vessel. Due to the limitations on arrangable space in the cylindrical afterbody, the shape and total required volume of the propulsion unit must be thoroughly analyzed.

The weight of each unit was used as a metric with a scale factor of two. A lower weight factor was used for this category because the weights of these units do not deviate greatly from each other and are a small portion of the total displacement.

Having the maximum propeller diameter for each retractable thruster option allowed for the comparison of propeller efficiency. This is based on the assumption that with increased propeller diameter the open water efficiency of the propeller increases as well. Due to the implications on required fuel and cost a weight factor of four was given to this metric.

Table 42. Thruster Selection Results

System	Rated Power Weight = 3		Volume Req'd Weight = 2.5		Weight Weight = 2		Propeller Efficiency Weight = 4	
	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Wartsila Retractable LMT 175	3	9	1	2.5	3	6	2	8
Thrustmaster (TH1500MLR)	3	9	3	7.5	1	2	3	12
Schottel (SRP 550 ZSV)	3	9	2	5	3	6	2	8
Rolls-Royce (UL 1401)	1	3	1	2.5	1	2	3	12

11.2.2 Discussion

The analysis shown in Table 42 leads to the conclusion that the Thrustmaster TH1500MLR retractable thruster is the most applicable to the *R/V FLIP II* design. This thruster model has the smallest height requirement, which is beneficial for the arrangements of the vessel. Thrustmaster products are also designed and built in the United States, which is useful when product support is needed as well as beneficial for an Office of Naval Research sponsored vessel.

11.3 Phase 3 – Power Generation

Propulsive power requirements being determined, the selection of generators may proceed. This final section of the trade study is based on values for the power required during transit, as they will be far greater than any power requirements on station.

11.3.1 Analysis

A number of generator companies were surveyed, and among them, Caterpillar and John Deere were the main competitors selling marine products in the power range of interest. Beyond the 968 kW of required propulsive power, hotel loads in transit shall need to be provided, roughly estimated at 50 kW. Clean power for instrumentation and other research equipment shall be provided by a Tripp Lite uninterruptable power supply. Being that these research loads have been accounted for here, they shall not be considered as a part of the primary supplied loads.

In the selection of a generator set, the following metrics were considered: specific fuel consumption (SFC), mechanical complexity, power density, and EPA tier approval. The SFC was of principal concern as it is proportional to the operational fuel costs over the vessel's life cycle. When compared to the other metrics, these fuel costs shall have the greatest impact on producing a competitive design. In addition, increasing the mechanical complexity – measured by an engine's number of cylinders – shall cause a rise in overhaul and maintenance costs. The power density was calculated as the ratio of a generator's projected floor area to its power output. The total deck space aboard the vessel is minimal and should be reserved for research and habitability requirements. The last metric, EPA tier approval, is required to fulfill current environmental regulations without penalization. Higher tiers of approval will meet regulations for a longer period of time. Table 43 details the metrics described and the weights applied to them.

Table 43. Generator Selection Results

	Specific Fuel Consumption Weight = 5		Mechanical Complexity Weight = 3		Power Density Weight = 2		EPA Tier Approval Weight = 2	
	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Caterpillar C7.1	1	5	2	6	2	4	3	6
Caterpillar C18	2.5	12.5	2	6	2.5	5	2	4
John Deere 6068A & ABB 280	2	10	2	6	1.5	3	3	6
John Deere 6068S & ABB 280	3	15	2	6	1	2	3	6
John Deere 6315A & ABB 280	2	10	2	6	2	4	2	4
John Deere 6315S & ABB 315	3	15	2	6	3	6	2	4

11.3.2 Discussion

After performing the analysis, the John Deere 6315S drive and ABB AMG 0315BS04 generator were selected as the best genset candidate and deliver 416 kW of power. To supply the 1,018 kW required, two of the John Deere 6315S sets and one John Deere 6068S with an ABB AMG 0280AS04 shall be used, providing a total of 1,027 kW for propulsion and hotel loads in transit.

11.4 Conclusion

In conclusion, the selected design speed for the *R/V FLIP II* was 8 knots. This speed was selected after communications with the current operators of the *R/P FLIP* as well as investigating how the required effective power increases with speed. The required installed power to transit at a speed of 8 knots is 968 kW. After performing an analysis on four different available thruster units that can provide this power, the Thrustmaster of Texas retractable thruster model TH1500MLR was selected. The electrical power required was found to be 1,018 kW and will be generated by integrated system of two John Deere 6315S generator drives and one John Deere 6068S generator drive, all paired with ABB generators.

12.0 Auxiliary Equipment

12.1 Air Compressors

For the deballasting procedure, it was necessary to determine the amount of compressed air that was required to blow out the tanks and return *R/V FLIP II* to the horizontal position. Tank 2T is the main driver for ballasting and deballasting *R/V FLIP II*, so that is the tank the calculations were based on. For a conservative estimate, we considered how much compressed air at 250 psi would be necessary to completely blow out tank 2T at its vertical immersed hydrostatic pressure (136 psi) and then blow out the rest of the tanks at near-atmospheric pressure (16 psi). We considered this an adiabatic process and found the amount of compressed air it would take to blow out these tanks, as shown below:

Table 44. Compressed air calculations

		PV^1.4 = constant	
Tank	V2 [ft^3]	P1 [psi]	V1 [ft^3]
1	26860.48	16	3770.380488
2T	17665.8	135.347	11396.80431
2B	17665.8	16	2479.731845
3T	5300	16	743.9560495
3B	5300	16	743.9560495
3P	5300	16	743.9560495
3S	5300	16	743.9560495
5T	7924	16	1112.284479
5B	7924	16	1112.284479
5P	7924	16	1112.284479
5S	7924	16	1112.284479
		Total Volume	25071.87876

Based off of this, we chose ballast tanks that contain a total of 11,500 cubic feet of air at 250 psi. The selected air compressor for this process was the Yanmar C185. It has a maximum rating of 350 psi and has a flowrate capacity of 3,000 ft^3/hour. This allows all of the air tanks to be filled in less than four hours.

12.2 Air Receivers

A total of six air receivers were designed to contain the compressed air that will be used for the blowing of the ballast tanks. These six receivers can hold up to 11,500 ft^3 of air at 250 psi. A five percent structural margin was applied to the internal volume calculations. The four primary air canisters were designed to be 40 feet long with an eight-foot diameter and are located in Tank 4. The two smaller air receivers measuring 30 feet in length with a 6.5-foot diameter are placed in the bottom of Tank 6. Further analysis should include detailed design of the air receivers in order to comply with the requirements of USCG pressure vessel codes. The drawing below shows the arrangements of the air receivers in Tanks 4 and 6. The air compressors will be located in the auxiliary machinery space in Tank 7.

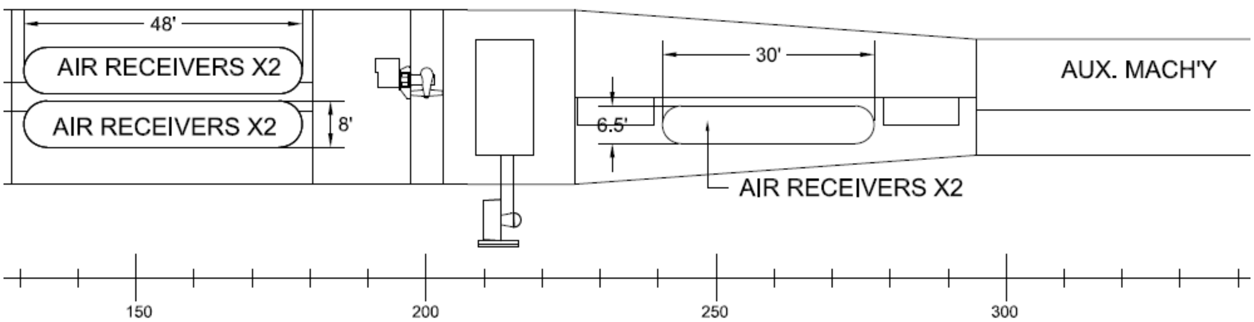


Figure 42. Detail air receiver arrangements

12.3 Mooring Line Equipment

The *R/V FLIP II* will be moored using a 3-point mooring system with mooring line lengths of twice the mooring depth. Each mooring line uses 12 tons of chain and a 750 lb anchor. To size the mooring line, we looked at the maximum loads that we expected to see based off of what the current vessel experiences and sized from there. We chose from the following Samson ropes:

Table 45. Summary of Air Compression

Type	Diameter	Est. Vol. Per 100 ft (ft^3)	Weight per 100 ft (lbs)	AVG. Strength (lbs)	Est. Vol. For 36,000 ft (ft^3)	Weight for 36,000 ft (lbs)
AmSteel	1”	0.694	21.8	109,000	250	7848
Quantum-8	1 1/4”	1.085	35.9	114,000	391	12924
Quantum-12	**1 1/8”**	**0.879**	**25.5**	**105,000**	**316**	**9180**
Turbo-75	1 1/16”	0.784	28.4	113,000	282	10224
Turbo-EPX	1 1/16”	0.784	31.4	113,000	282	11304

The current vessel has mooring lines that see upwards of 70,000 lb of tension. We chose the Quantum-12 rope with 105,000 lb strength because with newer lines made of different material than the old mooring lines. We picked a mooring winch and capstan based off of the mooring line weights, plus the weight of the anchor and chain, plus factors for added mass and drag. We chose the Markey VEP-32-80 Capstan-Windlass, which has a maximum pull strength of 125,000 lbs and pulls at 33 ft/min at 31,900 lbs. Although the initial speed of the pulling rope is small, the pulling speed increases quadraticly.as the load decreases.

12.4 Rigid Inflatable Boat

A Zodiac Pro Racing 550 was selected as the assisting small craft for the *R/V FLIP II*. This boat will be used to gather mooring lines, assist in crew transfer, as well as be used as a platform for scientific equipment deployment. The small boat will be held by a four-point control davit, which rotates as the ship changes orientation. Winches built into the davit will allow for the small boat to be raised and lowered.

12.5 Scientific Deployment Booms

The *R/V FLIP II* is designed to have three scientific deployment booms. These booms are 60 feet long and are located on port, starboard, and centerline positions on the vessel. In the horizontal attitude the booms are held in stowed positions. Once the vessel is on station and in the vertical position, the booms are deployed. Three Warn Industries winches have been selected for use in lowering the booms into position. These winches have a max rating of 2.5 LT and the booms weigh 1.4 LT without any scientific equipment deployed on them. Once the booms are in the deployed position stays will be attached and the safety railing will be erected.

12.6 Tunnel Thruster

For use in the vertical condition, the *R/V FLIP II* was equipped with a tunnel thruster. This tunnel thruster has placed just aft of the retractable thruster and its axis will be in a vertical orientation while the vessel sits horizontal. The propulsive mechanism and blades will be located closer to the top end of the tunnel while in the horizontal position. This is to avoid the effects of sloshing and water slamming inside the tunnel as the vessel interacts with waves. The tunnel thruster was sized such that the vessel will be able to remain on station in an ocean current of up to 1.5 knots. The 62-inch L-drive tunnel thruster was selected with a power range of 521-671 kW. While in the vertical condition, the tunnel thruster will primarily be used in order to keep the vessel in the center of the mooring array while the lines are being gathered as well as for translational control in station keeping or drifting.

12.7 Liferaft

A 25 person Survivetec Zodiac liferaft was selected to be installed on the *R/V FLIP II*. This liferaft meets SOLAS A requirements as well as 46 CFR Subchapter W.

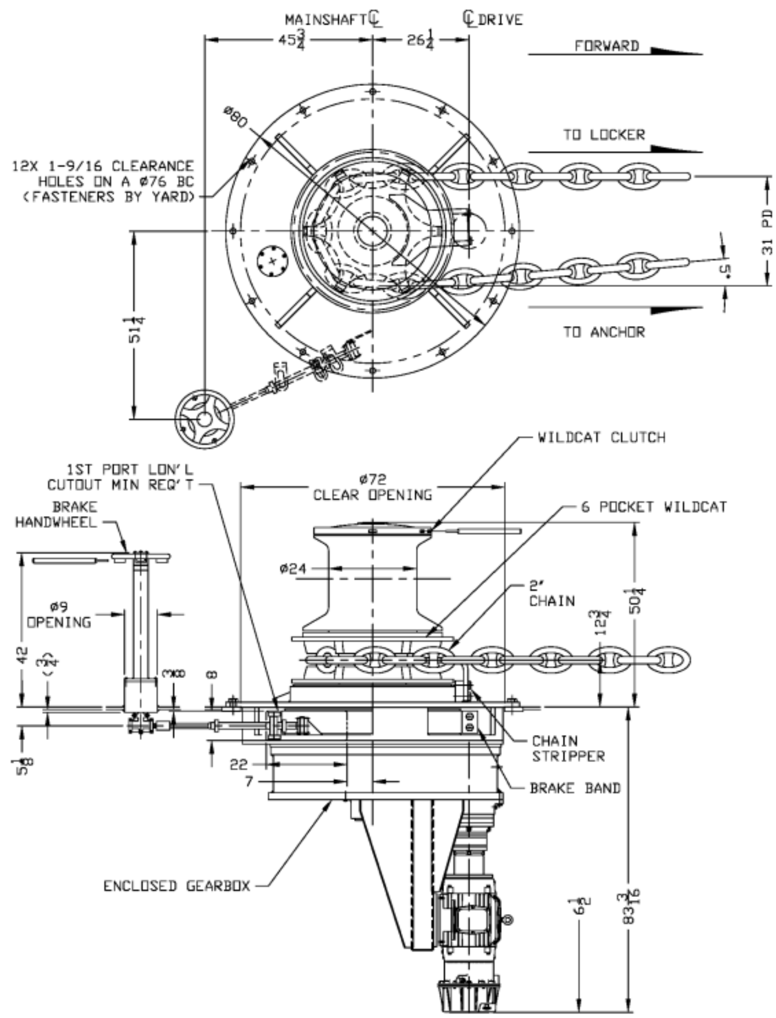


Figure 43. 2D Drawing of capstan windlass winch

13.0 Stability Analysis

The following section describes the stability of *R/V FLIP II* during its operational procedures. It includes intact stability while on 0° trim, and damaged stability at 0° and 90° trim. The stability during the flipping procedure is also assessed. Table 46 summarizes the weights used during the stability calculations.

Table 46. Summary of weights used in stability calculations

Condition	Total Weight (LT)	LCG (ft)	TCG (ft)	VCG (ft)
Departure	3131.9	191.57	0	12.83
Arrival	3398.4	190.74	0.01	14.33
Lightship	2774.66	168.04	0.02	12.68

13.1 Intact Stability on Horizontal

When on horizontal, *R/V FLIP II* is designed to meet the Title 46 - Code of Federal Regulations (CFR), Subchapter U (Oceanographic Research Vessels), § 190.03 – Subdivision and Stability. The requirement states that "*Each vessel must comply with the applicable requirements in Subchapter S of this chapter.*"

Moreover, Subchapter S, Part 170, Subpart E – Intact Stability Criteria, §170.165 states that "*A vessel (…) is permitted to comply with the applicable criteria contained in the 2008 IS Code as an alternative to the requirements of §170.170 and §170.173 of this part.*" Therefore, *R/V FLIP II* is designed to meet the International Maritime Organization 2008 Code on Intact Stability for a passenger vessel. For all cases analyzed, free surface effects were included. *R/V FLIP II* passes all requirements with safe margins for all loading conditions.

As seen from Figure 44, the stability analyses conducted show *R/V FLIP II* is stable to 180°. Moreover, the transverse metacentric height at 0° heel remains above 2ft for all loading conditions, and the angle of maximum GZ at high angles of heel gives plenty of margin to meet all requirements. The maximum GZ for each loading condition can be found in Table 47 together with the metacentric height (GMt), and the angle of maximum GZ.

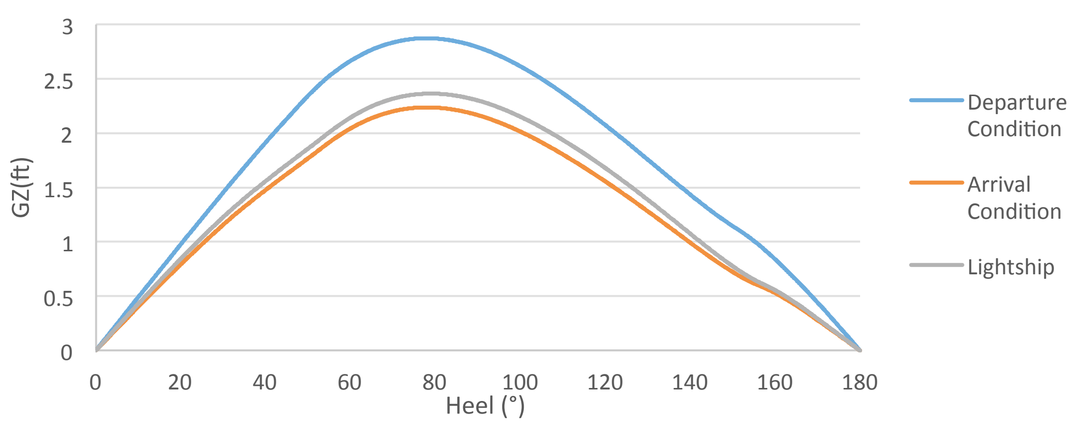


Figure 44. GM_t curves for three loading conditions

Table 47. Maximum GM_t for each loading condition

Loading Condition	Trim (°)	Angle of Max GZ (°)	Max GZ (ft)	GMt at 0° (ft)
Departure	0.0	77.8	2.87	2.8
Arrival	0.2	77.9	2.23	2.3
Lightship	1	78.9	2.36	2.5

13.2 Damage Stability on Horizontal

A damage stability assessment in horizontal was performed to determine if the vessel met the United States Coast Guard requirements for oceanographic vessels in damage conditions. Since the full load case scenario was considered the worst case, the analysis was conducted in that condition.

Although only single compartment flooded was necessary in USCG requirements, *R/V FLIP II* passes the requirements for two and three compartments flooded for the bow compartments. The design team deemed necessary to analyze USCG requirements for these conditions since the distance between bulkheads is quite small. Therefore, there is a small probability that damage would occur at only one compartment. There were a total of 19 damaged cases that are detailed in Table 49. For each case, Table 50 presents the summary of the results for all damaged cases; *R/V FLIP II* passes all requirements imposed by the USCG with safe margins.

In more detail, damage stability was analyzed according to the Title 46 of the CFR, Subchapter S, §173.080 – Damage stability for oceanographic research vessels. According to the paragraph, *R/V FLIP II* must comply with Title 46 of the CFR, Subchapter S, §171.080 damage stability requirements as a category Z vessel for a single compartment vessel.

The same chapter also specified R/V FLIP II compartment permeability. Table 48 presents these results and tables present the requirements stated in the CFR. CFR regulations also state the longitudinal and transversal penetration lengths. The value used is higher in our calculations, since the damage was assumed to be extended fully across a compartment.

Table 48. Permeability (%)

Spaces and tanks	Permeability
Cargo, coal, stores	60%
Accommodations	95%
Machinery	85%
Tanks	95%

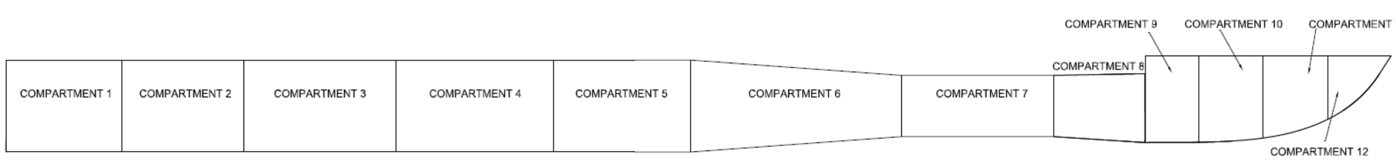


Table 49. Summary of damaged cases

	Damage Cases																		
Compartment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	X																		
2		X																	
3			X																
4				X															
5					X														
6						X													
7							X												
8								X					X				X		
9									X				X	X			X	X	
10										X				X	X		X	X	X
11											X				X	X		X	X
12												X				X			X

Table 50. Summary of damage stability results

Damage Stability Analysis				
Damage Case	Trim (°)	Angle of Max GZ	GZ (ft)	GMt (ft)
1	0.61	80	2.42	2.36
2	0.46	80	2.47	2.35
3	0.39	80.9	2.46	2.25
4	0.15	78.2	2.73	2.60
5	0.03	77.7	2.89	2.81
6	-0.23	76.3	2.98	2.86
7	-0.24	76.4	2.91	2.80
8	-0.36	80	2.90	2.64
9	-0.35	79.1	2.54	2.55
10	-0.35	75.5	2.47	2.58
11	-0.11	70.9	2.54	2.71
12	0	73.6	2.78	2.75
13	-0.87	83.6	2.60	2.52
14	-0.86	79.1	2.06	2.42
15	-0.56	67.3	2.04	2.52
16	-0.12	65.5	2.49	2.71
17	-1.67	85.5	2.08	2.46
18	-1.26	38.7	1.37	2.31
19	-0.58	52.1	1.96	2.52

The worst case occurs when compartment 9, 10, and 11 are flooded. A -1.26° trim by the bow translates to an approximate 10ft difference in draft from the aft perpendicular to the forward perpendicular. The maximum GZ at that condition is only 1.37ft. For the single compartment flooding, however, the worst case occurs when flooding tank 1. A 0.61° trim corresponds to an approximate 4.8ft difference in draft from the aft perpendicular to the forward perpendicular. The maximum GZ at this damage condition is 2.42ft that occurs at 80° heel, and the transverse metacentric height is 2.36ft

13.3 Intact Stability at 90° Trim

As mentioned previously, tank 4 is used for ballast in the vertical position in order to achieve the desired vertical draft. Moreover, it is assumed that while the VCB is above the VCG on vertical, *R/V FLIP II* is stable. It is of interest, therefore, to find the minimum tank volume that will still result in the VCB equaling the VCG.

It is crucial that further analyses of vertical stability be performed. After concluding the report, the authors were pointed to rules pertaining the stability of ocean platform. *R/V FLIP II* may fit in that criteria, and the current results should be taken as preliminary.

First, it is crucial to re-emphasize that during the flipping procedure, tank 2T will continue to be filled until its full capacity. Then, de-ballasting tank 4 begins. However, once tank 4 is at 50% capacity, the VCB will equal the VCG in the vertical condition, and *R/V FLIP II* will lose its balance and could flip to horizontal unexpectedly. Therefore, the point of intact stability on vertical occurs at the loading condition where tanks 1, 3P, 3S are free flooded, tanks 2T, 2B, 3T, 3B are at full loading capacity, and tank 4 is at 50% capacity.

Table 51. Summary of tank capacities and stabilities in vertical

Tank 1, Tank 3P, and Tank 3S	Free-flooded
Tank 2T, Tank 2B, Tank 3T, and Tank3B	Full Capacity
Tank 4	50%
VCB	191.6 ft
VCG	191.6 ft
GMt	0.3 ft

This point should be avoided at all costs. It is advised by the designers to have tank 4 at 55% of its full capacity at all times to avoid accident that could lead to loss of human life.

13.4 Damage Stability at 90° Trim – Minimum Draft

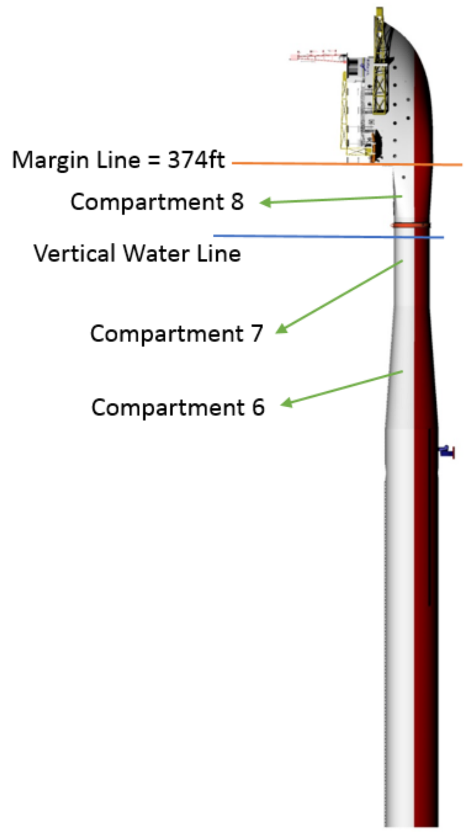
It is crucial to present the crew with operational procedures if a single compartment floods. The only damage stability condition analyzed was that the waterline must not pass the margin line, set to be at the beginning of the bow section. Moreover, since compartments are being flooded, *R/V FLIP II* VCB will increase, therefore increasing the GM_t.

Since tank 4 is used for vertical draft, two damage stabilities were assessed, at minimum draft and at maximum draft.

For the minimum draft, flooding additional single compartments does not increase the vertical water line to be above the margin line. Flooding compartment 6, brings the waterline at the same level of the margin line, and it should be further studied in the future of the design. However, the overall stability is not compromised. The vertical center of buoyancy is higher than the vertical center of gravity, putting the transversal metacentric height to be positive, making *R/V FLIP II* a stable platform when on vertical.

Table 52. Summary of damage stability results at minimum vertical draft

Compartment Flooded	Permeability	Equilibrium Draft (ft)
Vertical Draft	-	301.5
Tank 4	95%	336
Tank 5	85%	369
Compartment 6	95%	374
Compartment 7	95%	336
Compartment 8	95%	336



13.5 Damage Stability at 90° Trim – Maximum Draft

For the maximum draft, however, flooding tank 5 (engine room), and compartment 6 (transition from 30ft diameter tube to 20ft) passes the only requirement on the margin line. Therefore, if the crew founds itself sinking at maximum draft, it is crucial that tank 4, or other tank, are emptied to account for the extra water coming aboard due to flooding.

For both conditions, the worst-case scenario is the flooding of compartment 6. For future work, it is of interest to subdivide compartment 6 into two, and place a watertight bulkhead in between. The designers will then need to re-evaluate the engineering analysis present in this report.

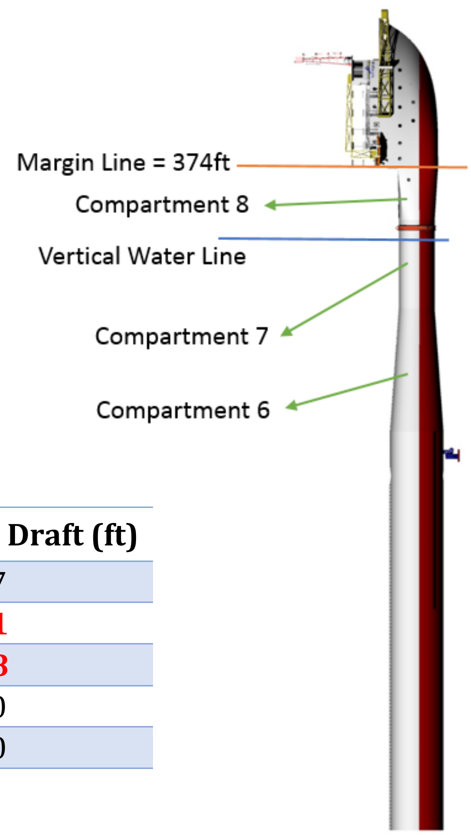


Table 53. Summary of damage stability results at maximum vertical draft

Compartment Flooded	Permeability	Equilibrium Draft (ft)
Vertical Draft	---	337
Tank 5	85%	**381**
Compartment 6	95%	**388**
Compartment 7	95%	370
Compartment 8	95%	370

13.6 Stability during flipping

R/V FLIP II is not expected to flip during storms, and the crew and scientists shall conglomerate on the center line of the vessel, and the vessel's bow is shall be pointing towards the wind. Given all the assumptions, *R/V FLIP II* stability through flipping was analyzed by analytically finding the metacentric height. If the metacentric height was positive at all angles of trim, the flipping procedure was deemed stable.

First, it is worth emphasizing that the VCG on vertical will have the same value as the LCG in horizontal. Therefore, we transformed our VCG, and VCG to an inertial coordinate system that does not rotate with the vessel. Finally, we tracked the GMt to check for its range during flipping.

$$VCB_{intertial} = LCB * \sin(\alpha) + VCB * \cos(\alpha)$$

$$VCG_{intertial} = LCG * \sin(\alpha) + VCB * \cos(\alpha)$$

Where LCB, VCB, LCG, and VCG are the parameters in a coordinate system that trims with the vessel and it is attached to the transom (Figure 45); α is the trim angle.

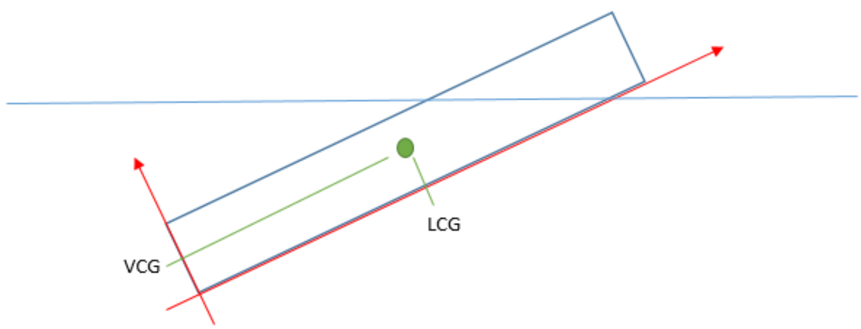


Figure 45. Diagram of LCG in reference to ship's coordinate system

$$GM_t = VCB - VCG + \frac{I_t}{V}$$

Where I_t is the moment of inertia of the waterplane area, and V is the underwater volume.

Figure 46 presents some interesting results. First, the GMt initially decreases to approximately 0.7ft, and remains fairly constant until 60° trim. However, the GMt never goes below zero, therefore *R/V FLIP II* is stable throughout flipping.

Until approximately 20° of trim, the ratio of the moment of inertia to the underwater volume is crucial to the stability of the vessel, since the value of the vertical center of buoyancy minus the vertical center of gravity is negative, or too small. Moreover, the angle where the difference becomes positive (~10°) is near the point of instability. It is reassuring to know, however, that our GMt is always positive after that point. Moreover, it is also worth emphasizing how, near the end of our flipping process, there is a huge spike in the value of GMt, which is completely auto-correlated to the significant increase in KB. Table 54 presents the numbers in detail of the flipping stability procedure.

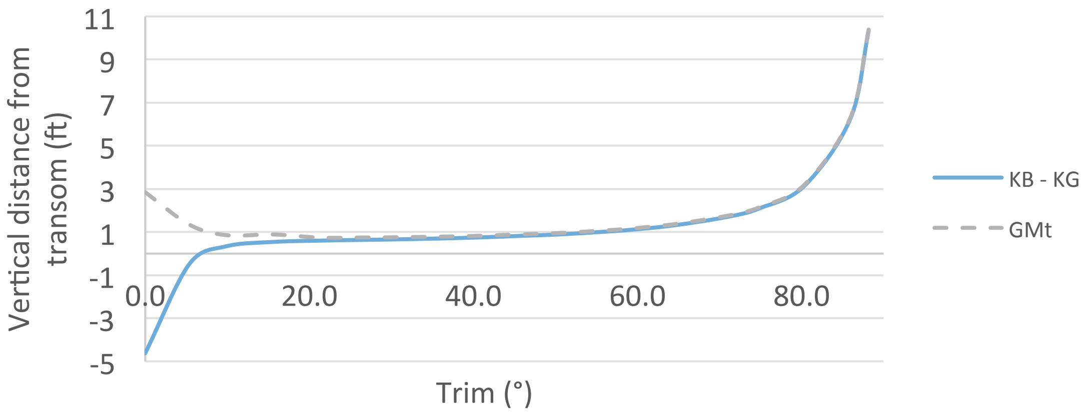


Figure 46. GM_t during flipping procedure

Table 54. Summary of stability during flipping

Trim (°)	KB (ft)	LCB (ft)	Kbeff (ft)	KG (ft)	LCG (ft)	Kgeff (ft)	It (ft^4)	Displacement (LT)	BM_t (ft)	GM_t (ft)
0.0	8.3	191.7	8.3	12.9	191.7	12.9	817355	3130	7.48	**2.84**
5.4	13.3	170.0	29.2	13.8	170.1	29.7	281672	4415	1.83	**1.34**
9.8	14.3	166.7	42.6	13.9	166.7	42.2	82641	4551	0.52	**0.86**
15.7	14.5	166.2	59.1	14.0	166.1	58.5	54559	4572	0.34	**0.89**
21.3	14.6	166.2	74.0	14.0	165.9	73.4	21657	4575	0.14	**0.74**
26.5	14.6	166.1	87.1	14.0	165.9	86.5	17627	4577	0.11	**0.75**
29.1	14.6	166.1	93.6	14.1	165.8	93.0	16134	4578	0.10	**0.75**
35.5	14.6	166.2	108.3	14.1	165.8	107.6	13535	4580	0.08	**0.78**
40.9	14.7	166.2	120.0	14.1	165.7	119.2	11988	4581	0.08	**0.83**
46.1	14.7	166.3	129.9	14.1	165.7	129.1	10904	4583	0.07	**0.90**
50.4	14.7	166.3	137.5	14.1	165.6	136.7	10187	4584	0.06	**0.95**
56.4	14.7	166.4	146.6	14.1	165.5	145.6	9435	4588	0.06	**1.08**
59.2	14.7	166.4	150.4	14.1	165.5	149.3	9147	4589	0.06	**1.16**
64.5	14.7	166.6	156.7	14.1	165.4	155.3	8703	4594	0.05	**1.36**
71.0	14.7	166.8	162.5	14.1	165.2	160.8	8308	4601	0.05	**1.76**
74.9	14.7	167.1	165.1	14.2	165.1	163.0	8135	4609	0.05	**2.15**
80.4	14.7	167.7	167.8	14.2	164.6	164.7	7966	4628	0.05	**3.20**
86.0	14.7	169.7	170.3	14.3	163.4	164.0	7873	4686	0.05	**6.32**
88.2	14.7	172.3	172.7	14.4	162.0	162.3	7588	4764	0.05	**10.39**

14.0 Seakeeping

The seakeeping analysis for the *R/V FLIP II* for the horizontal orientation was conducted using Shipmo. Shipmo was developed at the University of Michigan by Professors Troesch and Beck and uses slender body theory to predict linear seakeeping coefficients. *R/V FLIP II*'s underwater geometry was defined in Shipmo using 19 stations that best quantified the change in geometry along *R/V FLIP II*'s length. A bilge keel on port and starboard was added at amidships moving 50 feet aft. Before the bilge addition, preliminary analyses showed the *R/V FLIP II* experiencing large roll motion. An ITTC sea spectrum was chosen with significant wave heights and wave modal periods defined from *R/V FLIP II*'s operating range (low and mid latitudes Pacific Ocean). Table 55 presents these values.

Table 55. Sea state definitions

Sea State	Significant Wave Height [ft]	Modal Period [sec]
SS2	0.89	7.50
SS3	2.89	7.50
SS4	6.17	8.80
SS5	10.66	9.70
	60.00	24.80
	100.00	36.59

14.1 Heave motion in horizontal operation

Response amplitude operators (RAO's) for *R/V FLIP II* for 3 different degrees of motion for the different sea states and vessel speeds were created. These RAO's allow us to better understand the nature of *R/V FLIP II*'s horizontal motion, and to recognize the different dynamical quirks. The RAO's for heave and pitch are shown below for sea states 2-5 for *R/V FLIP II* at 8 knots.

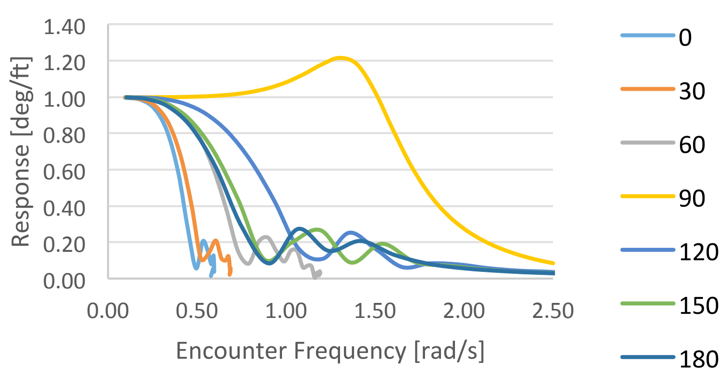


Figure 47. Heave RAO, SS2, 8 knots

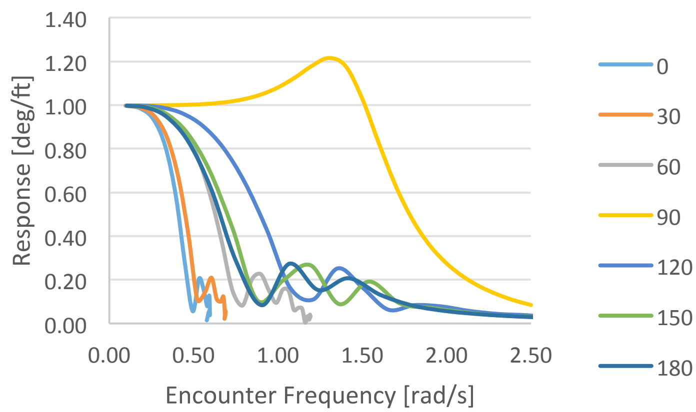


Figure 48. Heave RAO, SS3, 8 knots

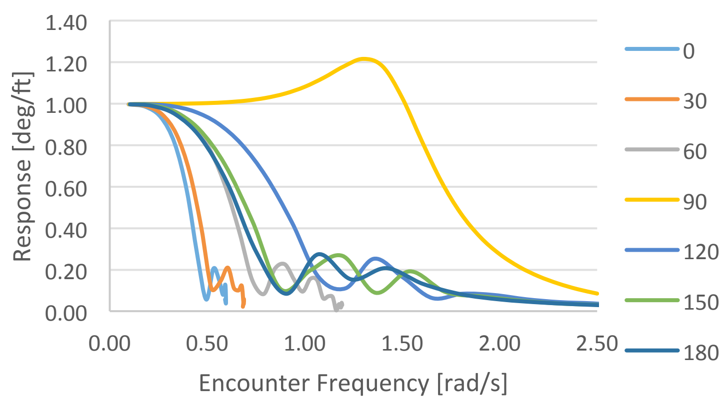


Figure 49. Heave RAO, SS4, 8 knots

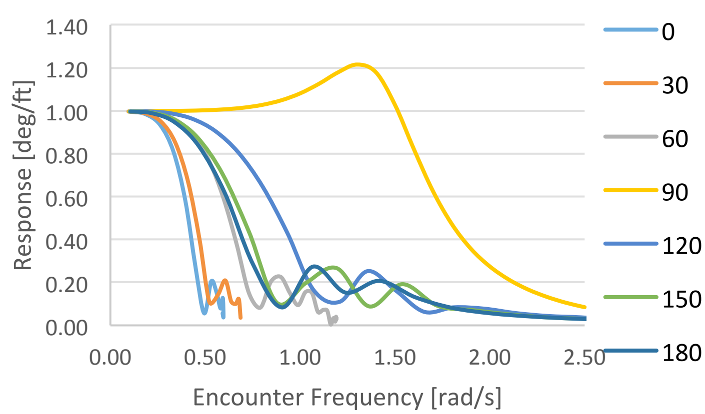


Figure 50. Heave RAO, SS5, 8 knots

14.2 Pitch motion in horizontal operation

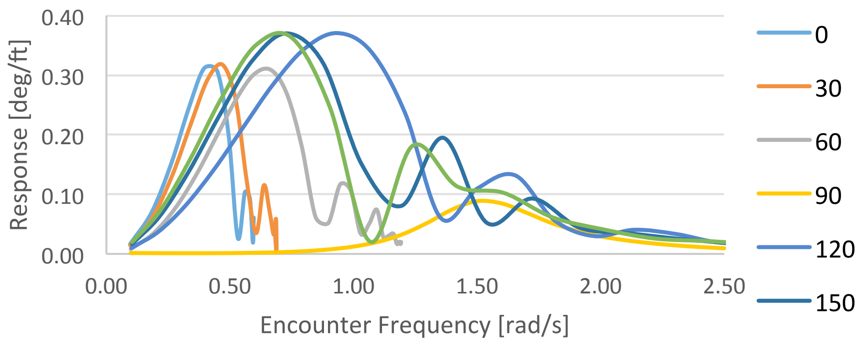


Figure 51. Pitch RAO, SS2, 8 knots

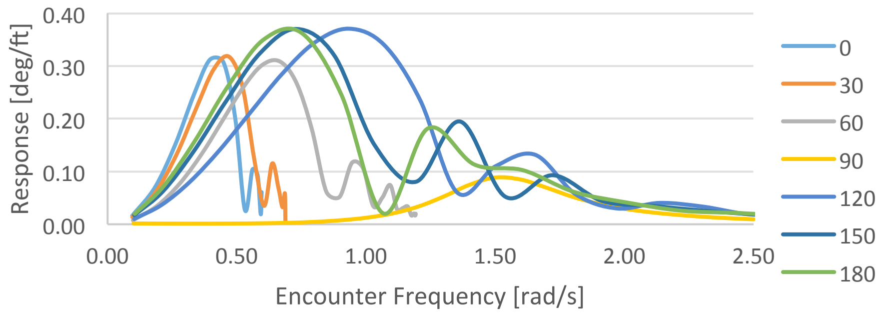


Figure 52. Pitch RAO, SS3, 8 knots

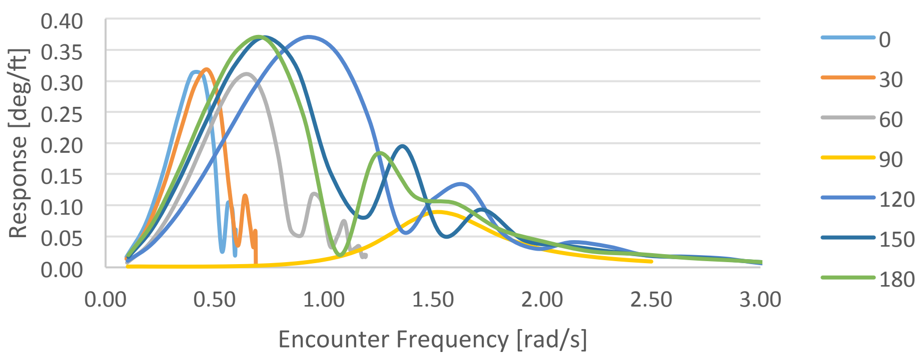


Figure 53. Pitch RAO, SS4, 8 knots

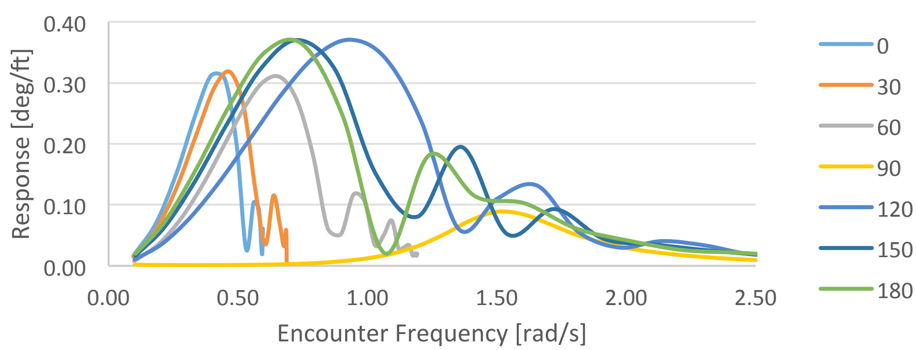


Figure 54. Pitch RAO, SS5, 8 knots

14.3 Heave and pitch polar plots

The polar plot below shows *R/V FLIP II*'s significant heave motion for sea state 5. *R/V FLIP II* experiences the largest heave motion at beam seas, since that is when the equivalent length of the vessel is the smallest compared to the incoming wavelength. Further, there will be minimal cancellation of the wave forces and *R/V FLIP II* will experience the largest heave motion. *R/V FLIP II* experiences small pitch angles due to its long length versus the equivalent wavelengths.

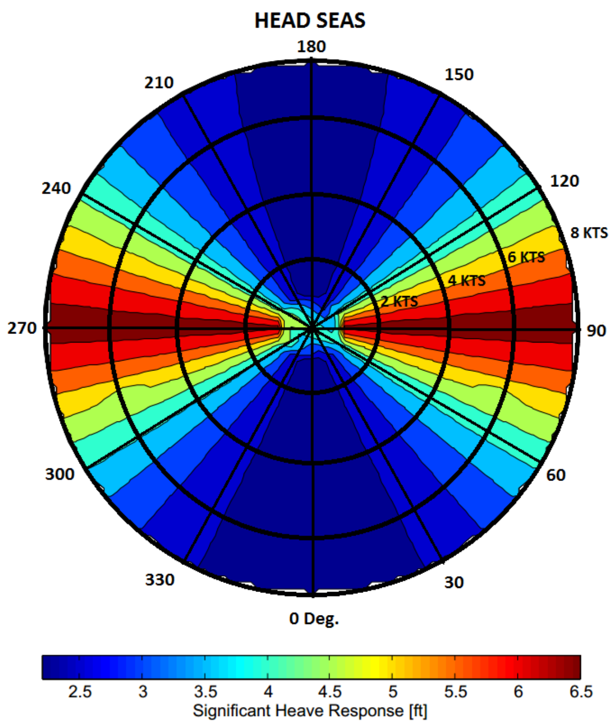


Figure 56. Significant Heave Response

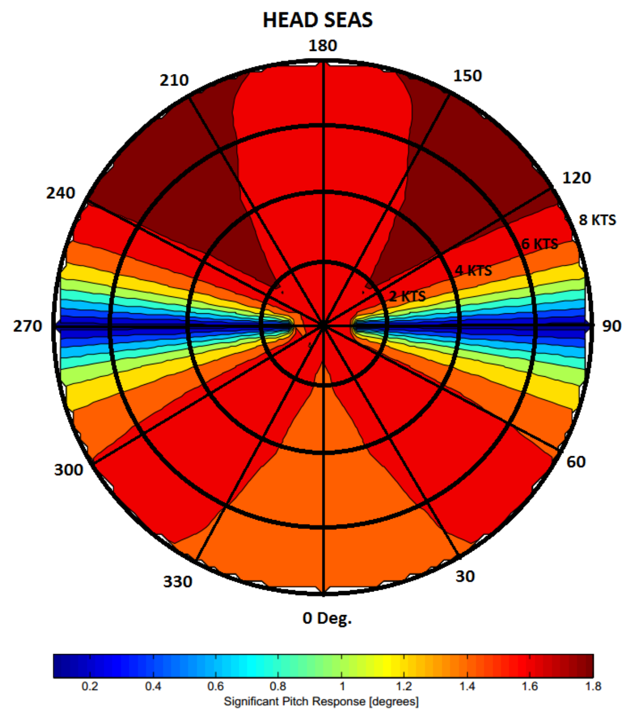


Figure 55. Significant Pitch Response

14.4 Roll Motion in Horizontal Operation

A RAO was constructed for *R/V FLIP II*'s roll motions, which are certainly the most interesting due to *FLIP*'s cylindrical geometry. This was the most concerning section because a cylinder has little reserve buoyancy and generates very little damping due to waves. It must be recognized that Shipmo uses linear theory, which does not consider viscous damping, which is an important factor in roll damping calculations. At this stage of the design, Shipmo was the best idea but that in future stages of the design spiral, a model test or CFD model would probably be necessary to fully model the vessel's roll motion.

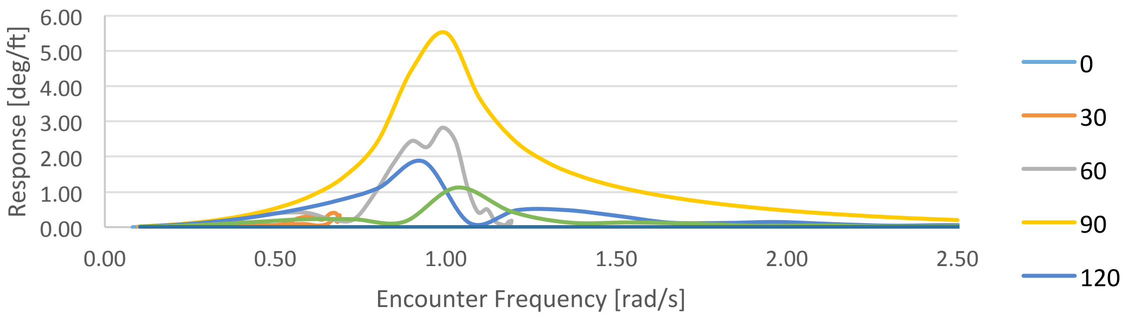


Figure 57. Roll RAO, SS2, 8 knots

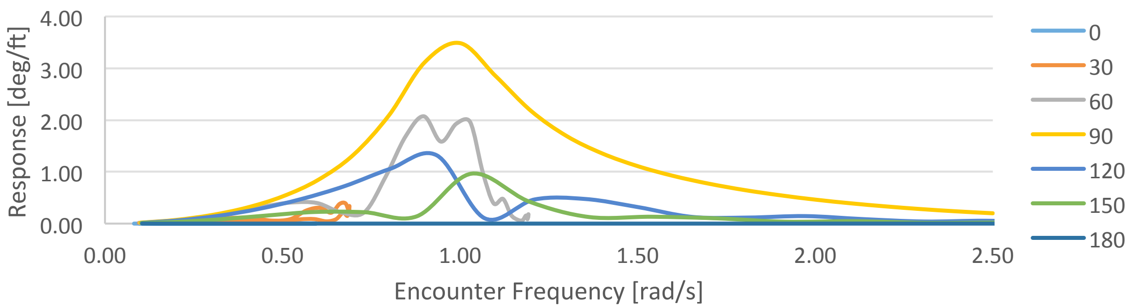


Figure 58. Roll RAO, SS3, 8 knots

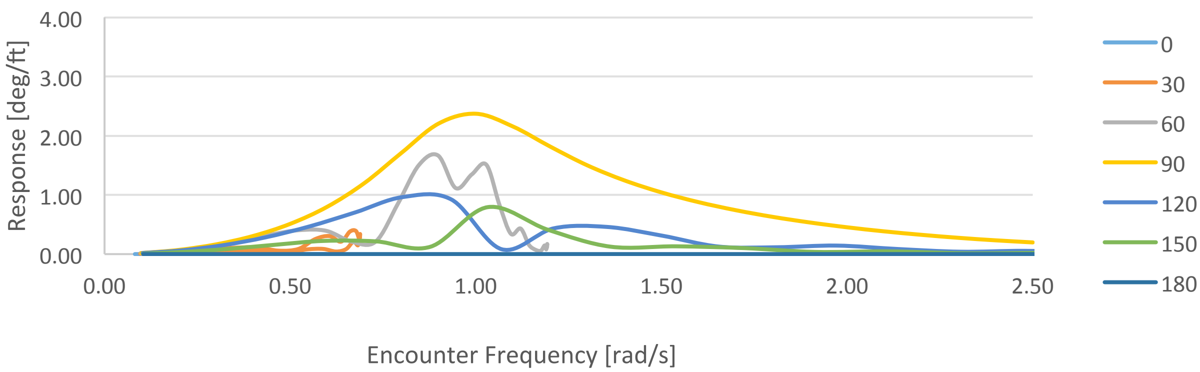


Figure 59. Roll RAO, SS4, 8 knots

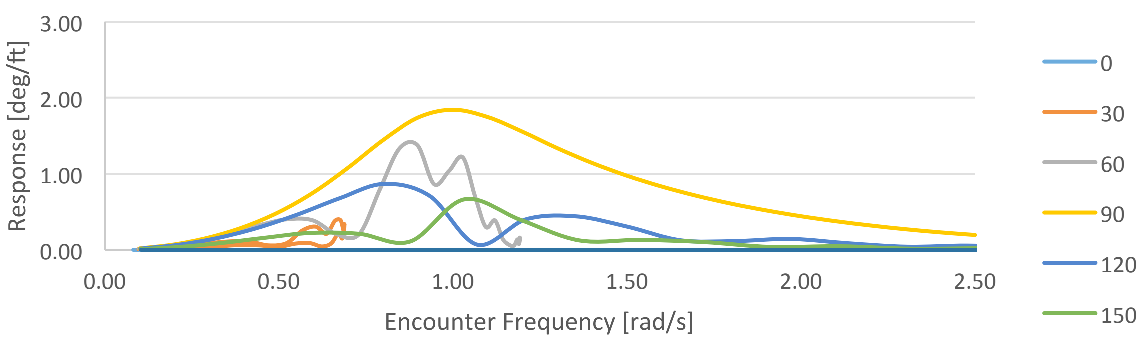


Figure 60. Roll RAO, SS5, 8 knots

Clearly, the maximum roll motions occur in beam seas, but it is interesting to note that the RAO for *R/V FLIP II* was greater at lower sea states than at higher ones. Bilge keels are designed to dampen large roll motions and are therefore more effective for larger amplitudes than smaller amplitudes. Drag is a function of velocity squared so more drag is "felt" at higher velocities and this parallels to the effectiveness of bilge keels. At low roll motions, the bilge keels are not as effective, so the vessel rolls more.

Another interesting aspect from *R/V FLIP II*'s roll RAO is that the roll goes to nearly zero at the roll frequency for seas at 120°. For a wave coming in at 120° at the roll natural frequency, the equivalent wavelength is essentially the waterline length of the *R/V FLIP II*. Therefore, the wave excitation is nearly entirely cancelled out and very little roll motion is experienced. To check this, the Froude-Krylov and diffracted forces on the vessel as calculated by Shipmo were plotted as a function of encounter frequency to determine what was happening at the resonant point to cause almost zero roll motion for 120° wave heading.

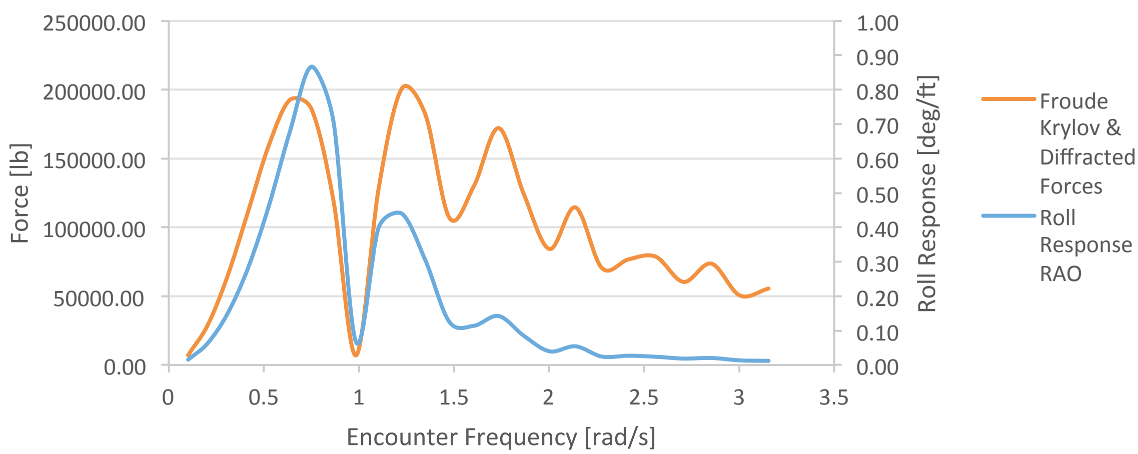


Figure 61. Forces on *FLIP* & Roll Response

The *R/V FLIP II*'s roll natural frequency occurs at about 1 rad/s. Clearly at this point, the sum of the Froude-Krylov and Diffracted forces drops sharply, resulting in negligible roll motion. This explained why the vessel's roll motion RAO's were so unusual and also gave a good example of why Shipmo was the optimal choice for an analysis tool. The quirks were all due to *R/V FLIP II*'s unique geometry, and they were studied and understood.

14.5 Roll motion polar plot

A polar plot of the vessel's significant roll response was also made to highlight the response in different conditions for sea state 5. As expected, the largest roll motions occur in beam and stern-quartering seas.

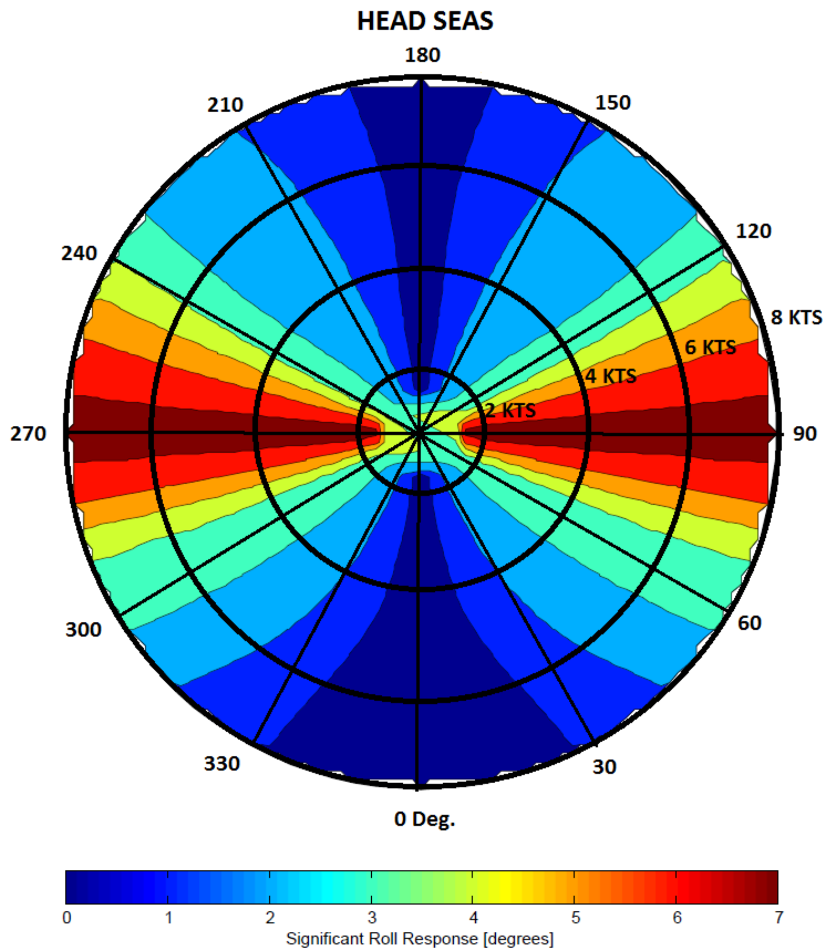


Figure 62. Roll Polar Plot

14.6 Significant motions and accelerations

As a final analysis, the *R/V FLIP II*'s significant and RMS motions and accelerations were plotted as a function of wave heading at sea state 5 and 8 knots, as shown below:

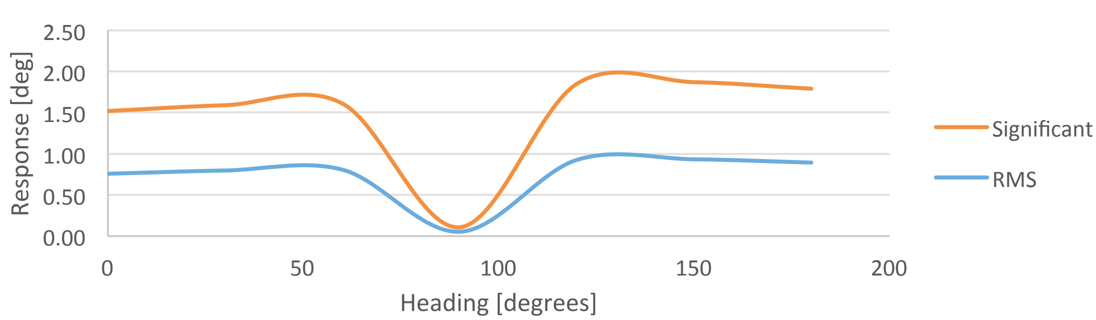


Figure 63. Significant and RMS Pitch Response

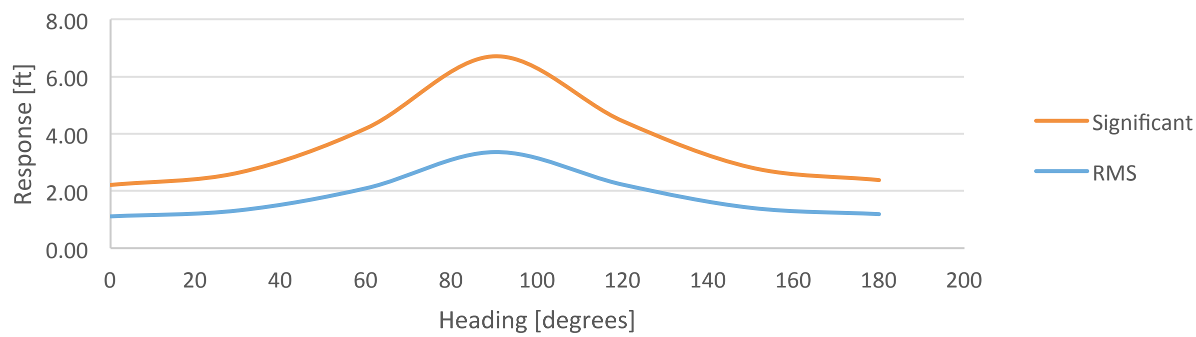


Figure 64. Significant and RMS Heave Motion

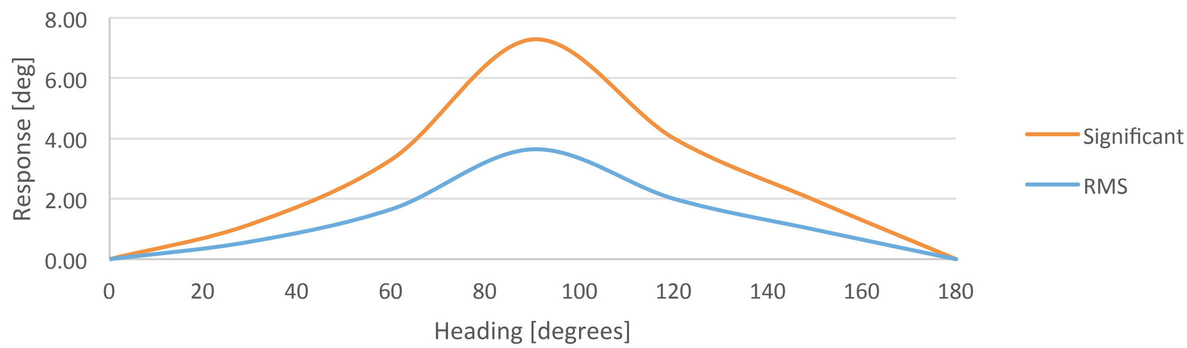


Figure 65. Significant and RMS Roll Response

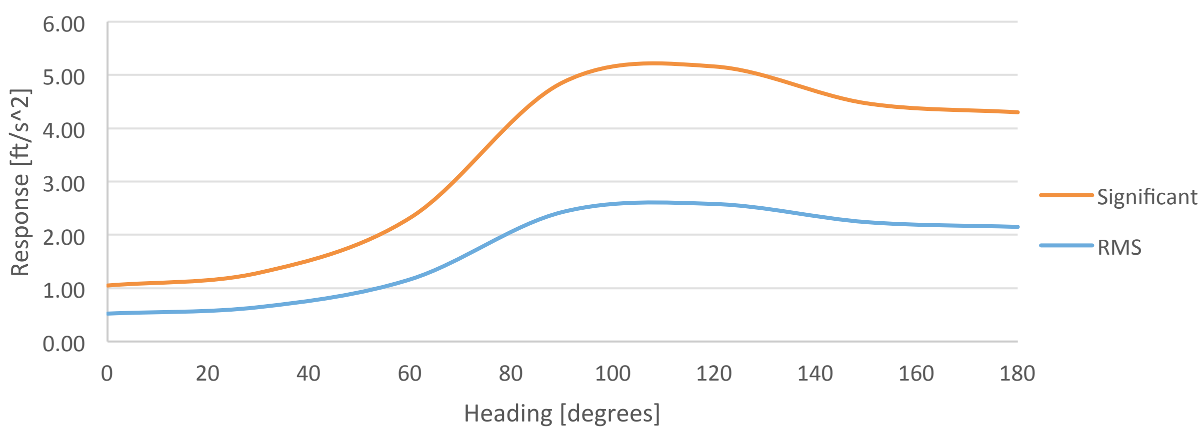


Figure 66. Significant and RMS Vertical Acceleration

14.7 Requirements

The *R/V FLIP II* passed all requirements, as stated by General Operability Limiting Criteria for Ships (Nordforsk, 1987). Table 56 presents the results.

Criteria for Accelerations and Roll (NORDFORSK, 1987)			
Description	RMS Vertical Acceleration	RMS Lateral Acceleration	RMS Roll Motion
Light Manual Work	0.20 g	0.10 g	6.0°
Heavy Manual Work	0.15 g	0.07 g	4.0°
Intellectual Work	0.10 g	0.05 g	3.0°
Transit Passengers	0.05 g	0.04 g	2.5°
Cruise Liner	0.02 g	0.03 g	2.0°

Seakeeping performance criteria for human effectiveness - Limiting Criteria with regard to accelerations (vertical and lateral) and roll motion (NORDFORSK, 1987).

General Operability Limiting Criteria for Ships (NORDFORSK, 1987)			
Description	Merchant Ships	Navy Vessels	Fast Small Craft
RMS of vertical acceleration at FP	0.275 g ($L \leq$ 100 m) 0.050 g ($L \geq$ 330 m)	0.275 g	0.65 g
RMS of vertical acceleration at Bridge	0.15 g	0.20 g	0.275 g
RMS of lateral acceleration at Bridge	0.12 g	0.10 g	0.10 g
RMS of Roll	6.0 deg	4.0 deg	4.0 deg
Probability of Slamming	0.03 ($L \leq$ 100 m) 0.01 ($L \geq$ 300 m)	0.03	0.03
Probability of Deck Wetness	0.05	0.05	0.05

General Operability Limiting Criteria for Ships (NORDFORSK, 1987).

Figure 67. Seakeeping Criteria for *R/V FLIP*

Table 56. Requirements for RMS motions and accelerations

8 KNOTS	SS2	SS3	SS4	SS5	Requirement
RMS Vertical Acceleration	0.01 g	0.02 g	0.05 g	0.08 g	< 0.28 g
RMS Lateral Acceleration	0.01 g	0.02 g	0.03 g	0.05 g	< 0.12 g
RMS Roll	0.90°	1.70°	2.67°	3.64°	< 6.00°

14.8 Vertical seakeeping

FLIP's vertical seakeeping response was analyzed to determine what heave response comes from the incoming wave excitation, as based off the analysis from the ONR report *HEAVE AND ROLL RESPONSE OF FREE FLOATING BODIES* OF CYLINDRICAL SHAPE by Berteaux, Goldsmith and Schott from WHOI. This part analytically calculated *FLIP*'s heave equation of motion using *FLIP*'s underwater geometry, as shown below:

$$RAO = \sqrt{\frac{(\rho g A_{WP} e^{-kT} - \omega^2 \rho C_m V e^{-kT})^2 + (\omega^2 C e^{-kT})^2}{(\rho g A_{WP} - M\omega^2)^2 + (\omega^2 C)^2}}$$

$$C = \frac{4}{3\pi} \rho C_D A_{WP} \omega$$

$$C_D = 6\pi^2 \left(\frac{D}{T}\right)^{-1} \frac{1}{KC} \left(\frac{1}{4\pi\beta}\right)^{0.5}$$

$$\beta = \frac{D^2 f}{\nu}$$

$$KC = \frac{2\pi A}{D}$$

with the following variable definitions:

A_{WP}	waterplane area
C_m	added mass coefficient
V	underwater volume
T	vertical draft
KC	Keulegan-Carpenter number
D	Waterplane diameter of cylinder
f	wave frequency [cycles/sec]
μ	dynamic viscosity of water
ν	kinematic viscosity of water
A	amplitude of wave excitation (1 ft)

The drag coefficient C_D is for a vertical cylinder in heave and is defined by Telionis in the 1981 publication *Unsteady Viscous Flows*. The RAO normalizes the incoming wave forces by the restorative forces on *FLIP* due to buoyancy and the damping due to drag.

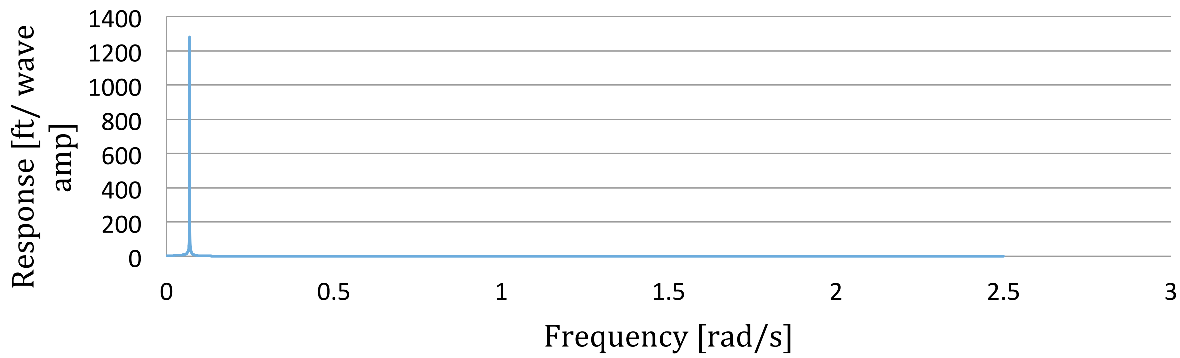


Figure 68. Vertical Heave RAO

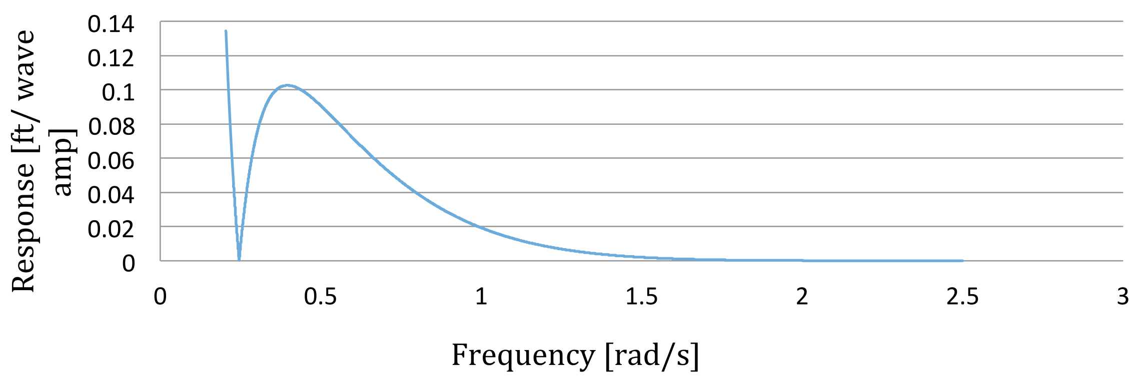


Figure 69. Zoomed Heave RAO

It should be noted that the RAO is based upon the Keulegan-Carpenter number, which is a nonlinear function of the wave amplitude. It would appear that this makes the RAO nonlinear, however, the drag coefficient becomes constant for large Keulegan-Carpenter numbers, as shown below from theoretical and experimental results from Troesch and Thiagarajan's paper *Hydrodynamic Damping Estimation and Scaling for Tension Leg Platforms*:

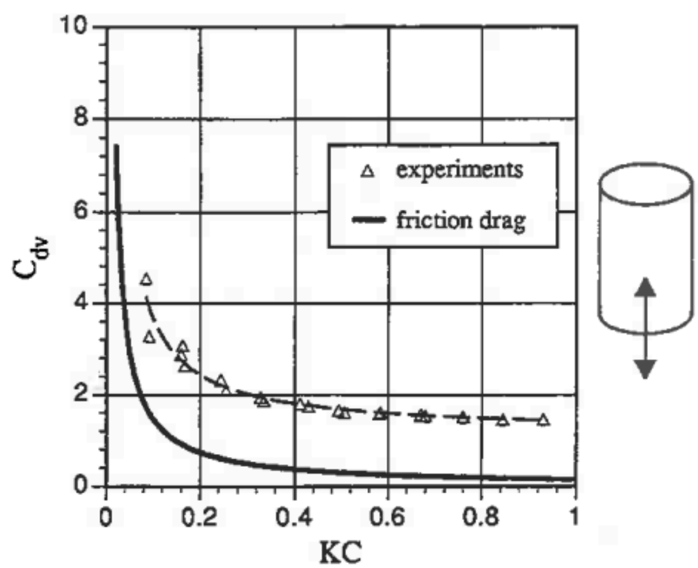


Figure 3. Drag coefficient (C_{dv}) for a vertical cylinder vs. KC; $\beta = 89236$

In the vertical attitude, *R/V FLIP II* has 2 frequencies that excite large excitation, as shown below:

Table 57. Summary of resonance responses on vertical

1st Excitation Point		2nd Excitation Point	
Period	Wave Length	Period	Wave Length
29 sec	4315 ft	15.9 sec	1298 ft

In linear theory, the first excitation point of the vessel corresponds to a swell. However, it is crucial to further study the possibility of adding some heave damping mechanism, (such as a parachute or skirt) on the vessel while on vertical. Once in a fifty-year time frame, the *R/P FLIP's* experienced a resonant response in a storm; the crew stated that the vessel heaved like an elevator, and they had to evacuate. Therefore, for safety purposes, vertical heave damping mechanisms should be further studied.

The second excitation point for *R/V FLIP II* is larger than *R/P FLIPs* excitation period. Therefore, *R/V FLIP* II seakeeping characteristics on vertical are farther out of the rage of "expected" waves. We then found the significant heave response for *R/V FLIP II*'s vertical motion when excited by different sea states. This is helpful statistically because it shows how the vessel is likely to respond, rather than just comparing the largest maximum response or the average response.

Table 58. Vertical heave response of the R/V FLIP II

Sea State	Significant Wave Height [ft]	Modal Period [sec]	*FLIP* Significant Heave Response (Amp) [ft]	% of Significant Wave Height
SS2	0.89	7.50	0.015	0.52 %
SS3	2.89	7.50	0.044	0.72 %
SS4	6.17	8.80	0.136	2.20 %
SS5	10.66	9.70	0.279	2.62 %
	60.00	24.80	2.66	4.43 %
	100.00	36.59	19.18	19.18 %

The seakeeping analysis showed that the *R/V FLIP II* exhibits minimal heave in the vertical orientation due to wave excitation and that the vessel has sufficient seakeeping attributes in the horizontal. A future analysis would include a method that includes viscous effects to better model the roll motion. Future work would also include research into heave damping, possibly a disc at the base of the cylinder that could be deployed in the vertical position. Such an appendage would increase the drag and added mass of the vertical *R/V FLIP II*, putting the exciting frequencies at even longer waves and out of the expected range of wavelengths.

15.0 Risk Assessment

Risk is inherent in engineering and design. It cannot be fully eliminated from a design, however through detailed analysis it can be mitigated. Discussed below are five primary risks that have been identified in the preliminary design of the *R/V FLIP II*. Future analysis should be conducted in order to address the risk in the following portions of the design.

15.1 Flipping Motions

The ability of the vessel to ballast to and from the vertical attitude is a necessary process as stated in the owner's requirements. The ability to do this safely and effectively during each scientific mission is critical to the vessel's success. Due to the fact that there is a point throughout the flipping procedure that the vessel is instable, it is of necessary importance to thoroughly analyze these motions. The present analysis has focused on three characteristics of the flipping process. The first characteristic is the location of the point of instability. The location of this point has a direct effect on the motions of the vessel, by pushing the point of instability further on in the flipping sequence the total distance that the vessel has to travel until its final equilibrium is decreased. This allows for reduction in the time spent under high rotational velocities. These velocities have been calculated using a quasi-static analysis assuming a constant fill rate. This is the second point of focus that has risk associated with it. The risk with using a quasi-static analysis is that the dynamic effects are lost. The fill rate (will most likely not be constant) and the accelerations present in the initial period of the process are difficult to determine. Detailed analyses should be conducted in future design iterations in order to track the point of instability as well as the velocities and accelerations experienced while flipping. Further analysis should also investigate the possibility of the vessel plunging into the water due to flipping at too fast of a rate. The third part of the flipping analysis that has risk associated with it is the determination of the stability of the vessel throughout the process. Currently, the stability of the vessel while flipping is defined solely by the analysis of the metacentric height. This present analysis does not take into effect the changing free surfaces, external wind and current forces, or any other external force that may cause the vessel to lose its stability throughout the process. Detailed numerical simulations or model tests should be included in the next phase of the design in order to better address the risk associated with the motions experienced during the flipping procedure.

15.2 Seakeeping

Risk exists in a seakeeping analysis because no theoretical model can exactly predict motions in random seas, mainly because the different degrees of freedom are coupled and mostly nonlinear in nature. Shipmo was used for the horizontal seakeeping because it allows more options for defining geometry and gives more output data for further analysis of the data and results. However, there exists a risk in using Shipmo because it is a linear approximation, which makes assumptions that are obviously not true in reality. The different assumptions and approximations allow for a much easier solution of the difficult equations of motion, but must still be considered seriously. A linear approximation can be an issue for *R/V FLIP II* geometry because the majority of the hull form is cylindrical. Therefore, any roll damping inherent in the geometry due to *R/V FLIP II* will be from viscous effects, which are not considered in Shipmo. We certainly saw this to be the case when we allowed Shipmo to calculate *R/V FLIP II*'s roll damping and showed *R/V FLIP II* rolling nearly 700°. Once we added bilge keels, this allowed Shipmo to calculate a more reasonable roll damping coefficient through linear approximations, but it is still important to realize that these results must be verified in future stages of the design. Shipmo provides a reasonable approximation and starting point for the horizontal seakeeping of *R/V FLIP II*. But it would be necessary to further benchmark these results, particularly the roll results, perhaps through a model test or CFD analysis, as future work.

15.3 Controllability and Maneuvering

The present results on the maneuvering characteristics of the *R/V FLIP II* have yielded results that fall short of ABS requirements. Without improvements to the maneuvering capability of the vessel, a tug will be necessary for assistance in the harbor adding to the operational costs. This lack of maneuverability can be cause for danger while at sea, not allowing the vessel to react and change course in time to avoid a possible collision. Further iterations of the design should include the addition of a rudder or possibly a transverse tunnel thruster in order to improve maneuvering capabilities and reduce this risk. Modifying the current placement of the thruster could also improve the maneuvering characteristics as well as re-considering the use of two offset retractable thrusters. Another analysis method should be conducted in order to properly determine the maneuvering characteristics of the *R/V FLIP II*. This analysis type should not be a regression based on linear theory. Methods such as model testing in a maneuvering basin would be most adequate for a design of this unique nature.

15.4 Mooring

The ability for the *R/V FLIP II* to conduct a self-mooring operation is a large improvement with regards to the previous platform. However, there exists risk in the current mooring analysis and plan. A detailed mooring analysis was not conducted for this stage of the preliminary design. The lines were selected based on the loads experienced by the *R/P FLIP* and the same was done for the anchor and chain. Through the use of mooring analysis or other analytical methods, the mooring line and equipment should be specifically selected for this vessel. The design also did not mature to the level that required the analysis of the equipment and clearances necessary while deploying or retrieving.

Another source of risk in the current mooring plan involves the necessity to place the small boat in the water and collect the lines to be connected to the mooring ring. An analysis regarding the power required to tow the ends of the lines to the *R/V FLIP II* was not conducted. This operation is also limited by wind and wave conditions, and depending on the circumstances and in certain circumstances the vessel would not be able to attach to its moorings. However, certain risks were mitigated throughout the mooring process due to engineering decisions made early on in the design process. The decision to not have the mooring lines attached until the vessel is stable in the vertical operating position reduces the risk associated with having any external forces on the body during the flipping procedure. Also, the addition of the mooring ring allows the vessel to rotate both intentionally and unintentionally without the danger of the mooring lines crossing or being tangled.

15.5 General Arrangements

The current edition of the general arrangements of the *R/V FLIP II* has worked to improve the ability to traverse the decks of the vessel while in the vertical attitude. Through the addition of a centerline stairwell located within the hull of the vessel, the scientists and crew do not have to go outside in order to move throughout the ship. This is of importance, especially in times of distress or when the vessel is experiencing a large storm. An aspect of the general arrangements that should be addressed in the next iteration of the design is its performance when compared against the ABS guidance notes on Alternative Design and Arrangements for Fire Safety. The current arrangements have only one primary stairwell and there are many watertight doors that must be opened and passed through in the event of an emergency.

Another aspect of the general arrangements that may pose risk is the location of the emergency generator. As common with most vessels, the emergency generator is located above the calm waterline in both horizontal and vertical conditions. However, while in the vertical attitude, the generator is located 52 feet above the calm waterline. In the event of a storm with large wave heights, the *R/V FLIP II* will not heave much with respect to the wave and the deck that the emergency generator is located on may be subject to excessive wave loading.

These risks associated with the current design of the general arrangements could be mitigated through further analysis and design iterations. Special consideration should be given to how one is able to move throughout the decks and compartments in both attitudes. The arrangements need also to be analyzed in their performance in the event of an emergency.

16.0 Cost

This section of the report details the cost components of *R/V FLIP II*. The build cost is formulated from direct steel prices and labor rates, regression of similar categories, and inflation corrections from past reports. The operating cost comparison examines the relative costs of using the independent *R/V FLIP II* versus its current dependent counterpart, *R/P FLIP*.

16.1 Build Cost

Using current steel plate and beam prices (www.worldsteelprices.com – 2014), the structure costs shown in Table 59 were calculated using the catalog of structural members detailed in the Appendix below. An additional factor of 1.2 was used to account for a portion of the fabrication costs incurred by the cylindrical compartments.

Table 59. Material cost estimate

Item	Cost	Units
A36 Steel Plates	$714.00	USD/tonne
A36 Steel Beams	$774.00	USD/tonne
Percent of Rod and Waste	15%	-
Cost of Plates	~$539,000.00	USD
Cost of Beams	~$484,000.00	USD
Material Costs	**~$1,176,00.00**	**USD**

Due to the difficulty in gathering direct product cost information from the engine manufacturers, propulsion and electrical generation costs were regressed using the equations below developed from a database of containerships.

$$Engine\ Cost\ in\ USD = 1.03^{9} \times \left(5395 \times \frac{P_{installed}^{0.82}}{1000000}\right)$$

Although not the same type of ship, engine costs were assumed to be similar. However, the cost of engine acquisitions will be larger than this value due to the number of generator sets being installed. As for propulsion, a correction factor of 1.5 was used to account for the implementation of an azimuth drive instead of a traditional propeller. Again, a regression based in weight was used to estimate the 5 LT tunnel thruster's cost at $1.6 M USD. This regression calculation is shown below in the equation below.

$$Tunnel\ Thruster\ Cost\ in\ USD = 1.03^{9} \times (0.273 + 0.199 \times W_{tunnel\ thruster})$$

The navigation and electronics, auxiliary systems, and deck machinery costs were taken from a report compiled by Glosten Associates in 1991 and corrected for an inflation of 72% (http://data.bls.gov/cgi-bin/cpicalc.pl). Extra costs were appended to deck machinery and auxiliary systems to account for the RIB workboat and mooring devices.

The outfitting costs were acquired through the weight-based regression shown in equation below. As a high-density outfit was assumed in the Weights Section, this should provide a conservative estimate. Painting costs include an addition for the interior curing of tanks 1 through 4 for corrosion protection.

For ship assembly charges, a labor rate of $30 per hour was used. The number of build hours was calculated from a regression formula.

$$Structure\ man\ hours = 180 \times W_{Structure}^{\frac{2}{3}} \times \frac{L_{BP}^{\frac{1}{3}}}{C_B} = 204{,}000\ hours$$

$$Outfit\ man\ hours = 1627 \times W_{Outfit}^{\frac{2}{3}} = 88{,}400\ hours$$

$$Machinery\ man\ hours = 83.84 \times P_{installed}^{0.82} = 28{,}000\ hours$$

These equations result in an estimated 320,400 required man-hours to construct *R/V FLIP II*. After applying a 10 percent margin for complexity and extra fabrication costs, the labor charges total to $11.5 M USD.

Finally, an overhead of 85 percent and a shipyard profit of 8 percent were used to achieve the final estimated build cost of $40.5 M USD. The individual costs are shown below in Table 60.

Table 60. Cost estimate breakdown by category

Component	Cost in Millions (USD)
Structure	1.5
Electrical Generation and Distribution	2.5
Propulsion	2.5
Navigation and Electronics	1.0
Auxiliary Systems	3.0
Outfitting and Painting	5.0
Deck Machinery	1.5
Ship Assembly	11.5
Overhead	9.0
Subtotal	**37.5**
Shipyard Profit	8%
Total	**40.5**

16.2 Operating Cost Comparison

Since 1985, *R/P FLIP* has performed 114 missions. By extrapolating the number of missions performed back to 1962 using the same frequency of missions since 1985, the result is an additional 94 missions. *R/P FLIP* has always relied on ocean going tugs for towing and mooring assistance. In addition to towing fees, *R/P FLIP* cannot retrieve its chains and anchors after completing a mission. The chains and anchors are sheared away when the tug retrieves the nylon mooring lines. This equates to a $45,000 loss for each trip that *R/P FLIP* is required to moor, roughly 75 percent of its missions.

Figure 70 shows the daily rate for attaining an ocean going tug (www.marcon.com). After considering every rate and adjusting for inflation, the daily cost of an ocean going tug is calculated to be roughly $19,500. To use a more conservative estimate by removing Maritrans, the mean rate is still approximately $15,000 per day.

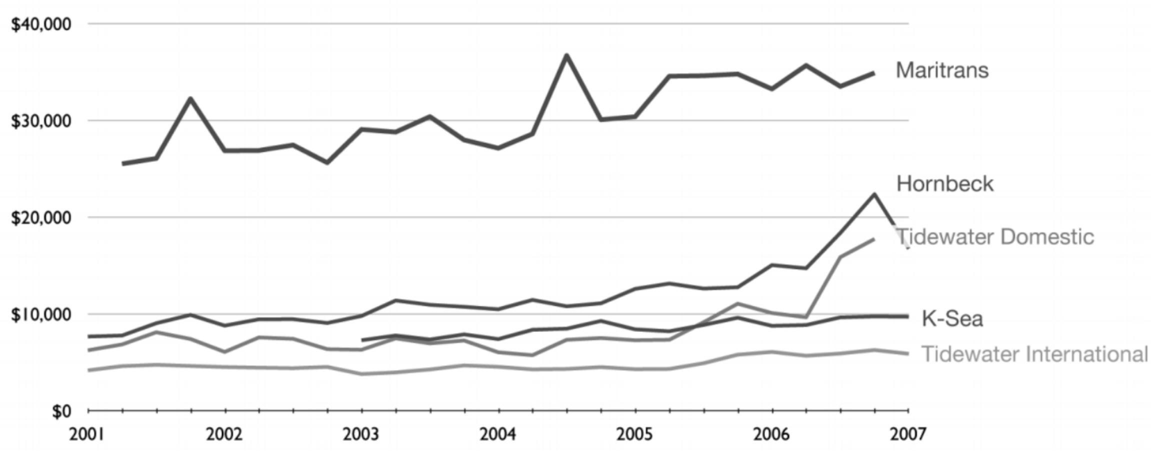


Figure 70. Average daily rates for ocean going tugs (www.marcon.com)

These are the current costs of *R/P FLIP* being dependent on external entities. Examining the relative costs of using the independent *R/V FLIP II*, the engine maintenance and overhaul, additional crew requirement, and fuel consumption costs must be considered.

At maximum resistance, *R/V FLIP II* requires 968 kW of power dedicated to propulsion. Using this ceiling value, the engines will consume 1,375 gallons of fuel per day (181 g/kWh). Current California fuel prices are $3.75 per gallon (www.psmfc.org). At these rates, the daily fuel costs of operating *FLIP* II are $5,200.

The current crew will need to be cross-trained in a couple of disciplines. In addition, there is a requirement for another engineer because of the added propulsion, engines, mooring, and ABS regulations. According to indeed.com, another engineer will cost roughly $80,000 per year.

Yearly engine maintenance costs were estimated at $5,000 per engine (www.safety.cat.com). Overhaul costs occurring every 10,000 hours will incur costs of approximately $5,000 per cylinder (www.yatchforums.com).

Finally, mooring equipment and propulsion maintenance were estimated to be $15,000 per year and to have overhaul costs of $75,000 every 10,000 hours.

Because these calculations are meant to be a comparison and not a determination of operating costs, similar categories between the two ships are neglected. Therefore, the following equations can adequately reflect the relative costs of operating either vessel:

$$Cost\ of\ R/P\ FLIP = tug\ fees + mooring\ losses = 2t\left(\frac{\$15{,}000}{day}\right) + 0.75\frac{moor}{trip}\left(\frac{\$45{,}000}{moor}\right)$$

$$Cost\ of\ R/V\ FLIP = fuel\ costs + engineer\ cost + overhaul\ cost + maintenance\ cost$$

$$= 2t\left(\frac{\$5{,}200}{day}\right) + \left(\frac{\frac{\$80{,}000}{year}}{4.1\frac{trips}{year}}\right) + 2t\left(\frac{\$300}{day}\right) + 3\ engines\left(\frac{\frac{\$5{,}000}{\frac{engine}{year}}}{4.1\frac{trips}{year}}\right)$$

Seeing as *R/P FLIP* has been through the Panama Canal and has performed missions off the coast of Hawaii, *R/V FLIP II* was designed with a range of 2,200 nautical miles. At a cruising speed of 8 knots, this range requires 12 days of transit in each direction. In the analysis shown in Table 61, a transit time of 6 days is used.

Table 61. Relative cost benefit of *R/V FLIP II* assuming a 6 day transit time to station

Platform/Vessel	Fuel/Tug Costs	Mooring Costs	Maint. Costs	Per trip total
R/P FLIP	$180,000	$45,000	-	$213,750
R/V FLIP II	$62,400	-	$28,000	$90,400
Savings	$117,600	$45,000	- $28,000	**~$125,000**

Figure 71 shows the relative operating costs of *R/P FLIP* and *R/V FLIP II* as a function of transit days to station. In each case, the increased independence of *R/V FLIP II* results in operational cost benefits, even with transit times of a single day to station. Only when the daily rate for tugs drops below $5,100 does the cost benefit vanish.

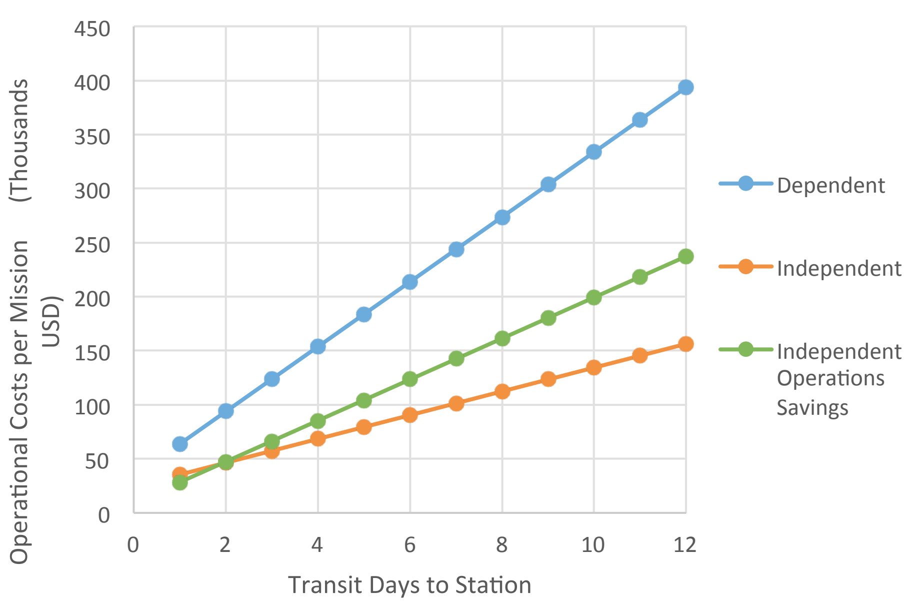


Figure 71. Comparative operating costs at a daily tug rate of $15,000 USD

Appendix: Cost calculations

ECONOMIC PARAMETERS

	parameters	
Profit	8.0%	per cent (enter as decimal)
Direct Labor Rate (Bur. Labor Stat.)	$30.00	$ wages plus add'l compensation/hour
Overhead Rate	85.0%	per cent direct labor (enter as decimal)
Steel Cost	$744.00	$ per tonne
Wastage and Welding Rod	15.7%	per cent steel (calculated by algorithm)
	change if desired	

SHIP CHARACTERISTICS

	enter data in boxes			
LBP	138.70	meters	138.684	
Cb	0.515			
Structural Steel Weight	1,200.0	tonnes		
Outfit Weight	400.0	tonnes		
Installed Propulsion Power	1,200.0	kW		
Number of Propellers	1	[enter 1 or 2]		
Propeller RPM	375.0	RPM		
Fixed Pitch (0) or CRP (1)	1	[enter 0 or 1]		
Bow and/or Stern Thruster No.	1	with thrust	5.0	tonnes each
Vessel Displacement	4,200.0	tonnes		
Fin Stabilizers: no (0); yes (1)	0	[enter 0 or 1]		

COST CATEGORY	Material Cost	Labor hours	Labor Cost
	Million $US	hours	Million $US
Structural	1.03	204,319	6.13
Outfit and Hull Engineering	4.27	88,345	2.65
Machinery	2.36	28,079	0.84

	Million $US	Complexity Factor	
Total Labor Cost	9.62	1.2	for additional fabrication
Total Material Cost	7.66	1	
Overhead	8.18	1.1	for additional fabrication
Add on for CRP Propeller(s), if installed	0.42	1.5	for azimuth drive
Add on for Thruster(s), if installed	1.65	1	
Add on for Anti-Roll Fin Stabilizers, if installed	0.00	1	
Profit	2.20	1	
Appended Shipyard Costs	0.00	1	
TOTAL SHIPYARD BILL		32.69	
Owner's Added Costs	0.00		
TOTAL SHIP CAPITAL COST	32.69	**Million US$**	

piece	thickness (in)	area (ft^2)	length (if app.) (ft)	no.	volume (ft^3)	weight of plate (LT)	weight of beams (LT)
tank 1 shell	0.313	2.454	38.0	1	93.3	20.4	-
tank 2 shell	0.688	5.400	40.0	1	216.0	47.2	-
tank 3 shell	0.938	7.363	50.0	1	368.2	80.5	-
tank 4 shell	1.188	9.327	52.0	1	485.0	106.1	-
tank 5 shell	1.188	9.327	45.0	1	419.7	91.8	-
transtition shell	1.250	6.545	69.2	1	453.1	99.1	-
neck shell	1.188	6.218	50.0	1	310.9	68.0	-
connector shell	1.188	6.218	30.0	1	186.7	40.8	-
bow shell	-	2.947	81.0	1	238.7	52.2	-
tank 1 stringers	0.375	0.046	38.0	36	62.3	-	13.6
tank 2 stringers	0.375	0.046	40.0	38	69.3	-	15.1
tank 3 stringers	0.375	0.046	50.0	50	113.9	-	24.9
tank 4 stringers	0.438	0.068	52.0	48	170.6	-	37.3
tank 5 stringers	0.438	0.068	45.0	54	166.1	-	36.3
transtition stringers	0.750	0.208	69.2	54	778.7	-	170.3
neck stringers	0.563	0.098	50.0	48	234.3	-	51.3
connector stringers	0.500	0.091	30.0	36	98.5	-	21.6
bow stringers	0.313	0.026	81.0	40	84.4	-	18.5
tank 1 ring stiffeners	0.375	0.049	89.5	7	31.0	-	6.8
tank 2 ring stiffeners	0.563	0.108	87.2	18	170.2	-	37.2
tank 3 ring stiffeners	0.375	0.049	89.5	12	53.1	-	11.6
tank 4 ring stiffeners	0.500	0.091	87.7	18	143.8	-	31.5
tank 5 ring stiffeners	0.500	0.091	87.7	10	79.9	-	17.5
transtition ring stiffeners	0.375	0.049	58.1	12	34.5	-	7.5
neck ring stiffeners	0.375	0.049	58.1	5	14.4	-	3.1
connector ring stiffeners	0.375	0.049	58.1	3	8.6	-	1.9
aft collision bulkhead	-	-	-	1	25.2	5.5	-
aft collision bulkhead st.	-	-	12.5	36	13.7	-	3.0
bulkhead 1-2	-	-	-	1	48.5	10.6	-
bulkhead 1-2 st.	-	-	12.5	38	14.4	-	3.2
bulkhead 2-3	-	-	-	1	48.5	10.6	-
bulkhead 2-3 st.	-	-	12.5	50	19.0	-	4.2
bulkhead 3-4	-	-	-	1	33.6	7.3	-
bulkhead 3-4 st.	-	-	12.5	48	27.3	-	6.0
bulkhead 4-5	-	-	-	1	33.6	7.3	-
bulkhead 4-5 st.	-	-	12.5	54	30.8	-	6.7
bulkhead 5-transition	-	-	-	1	12.0	2.6	-
bulkhead 5-transition st.	-	-	12.5	54	56.2	-	12.3
bulkhead transition-neck	-	-	-	1	7.5	1.6	-
bulkhead transition-neck st.	-	-	10.0	48	25.3	-	5.5
bulkhead neck-conn.	-	-	-	1	6.0	1.3	-
bulkhead neck-conn. st.	-	-	10.0	36	22.8	-	5.0
bulkhead bow 1	-	-	-	1	21.4	4.7	-
bulkhead bow 2	-	-	-	1	20.1	4.4	-
bulkhead bow 3	-	-	-	1	18.1	4.0	-
bulkhead bow 4	-	-	-	1	15.0	3.3	-
bulkhead bow 5	-	-	-	1	11.4	2.5	-
foreward collision bulkhead	-	-	-	1	7.0	1.5	-
bulkhead bow stiffeners	-	-	-	-	-	-	6.6
						673.6	**558.5**

17.0 Conclusion

The *R/V FLIP II* was designed as a self-propelled and self-mooring capable replacement to the *R/P FLIP* operated by Scripps Institute of Oceanography. With respect to the platform presently in use, considerable improvements have been made to the habitability on board the vessel as well as its scientific capacity. The flipping procedure is of utmost importance for the vessel, allowing it to transform into an extremely stable spar-like platform with limited heave response. Current analysis suggests that the motions experienced throughout the flipping process have been improved: the rotational velocity of the vessel has been decreased towards the end of the flipping procedure providing a "smoother" transition into the vertical attitude. A leaner and more efficient structure was designed through the application of ABS Steel Vessel Rules, Offshore Structures guide, and design for production techniques. This structural design aims to mitigate the structural discontinuities and bending observed on the present platform. Another notable improvement is the addition of batteries on board for use as a silent power source while extremely sensitive experiments are being conducted on board. These batteries are integrated in an adaptable power generation system that can match the varying electrical load demands. Sufficient seakeeping performance was achieved in the horizontal condition, passing all vessel and crew safety criteria. In the vertical attitude, the vessel passes the requirements for both operability and survivability set forth by the owners, with very minimal heave response in comparison to a conventional vessel. As a result of the independent nature of the *R/V FLIP II*, lifetime operational costs have been reduced due to the elimination of reliance on ocean going tug boats for towing and mooring assistance. Table 62 below summarizes the design and its principal characteristics.

Table 62. Summary of *R/V FLIP II* main characteristics

Design Characteristic	Value
Length Overall	455 ft
Maximum Breadth	36.5 ft
Horizontal Sailing Draft	13.5 ft
Vertical Draft	300-340 ft
Horizontal Displacement	3,131 LT
Vertical Displacement	4,449 – 4,764 LT
Range	2,200 Nm
Installed Power	1,196 kW
Accommodation	5 crew
	15 scientists
Laboratory Space	1,000 ft^2
Scientific Payload	50 -350 LT
Service Speed	8 knots
Cost	$40.5 M USD

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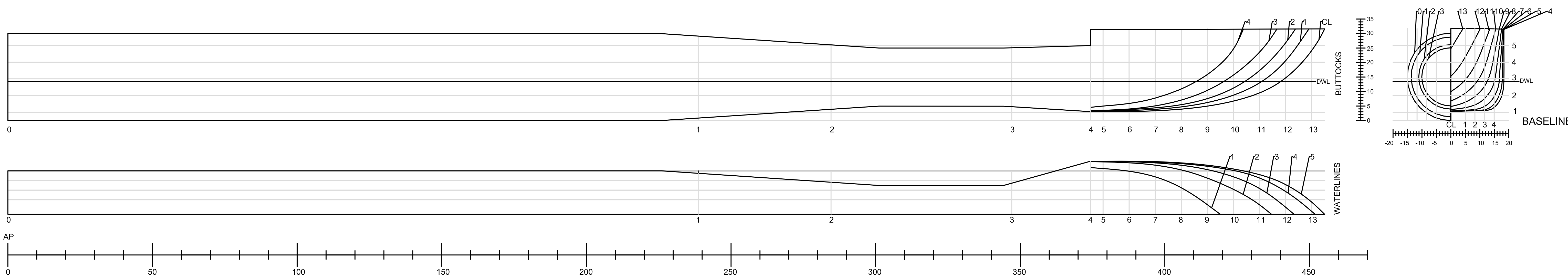
19.0 Appendix

Detailed arrangements and structural drawings as well as the *R/V FLIP II* one line diagram can be found on the following pages.



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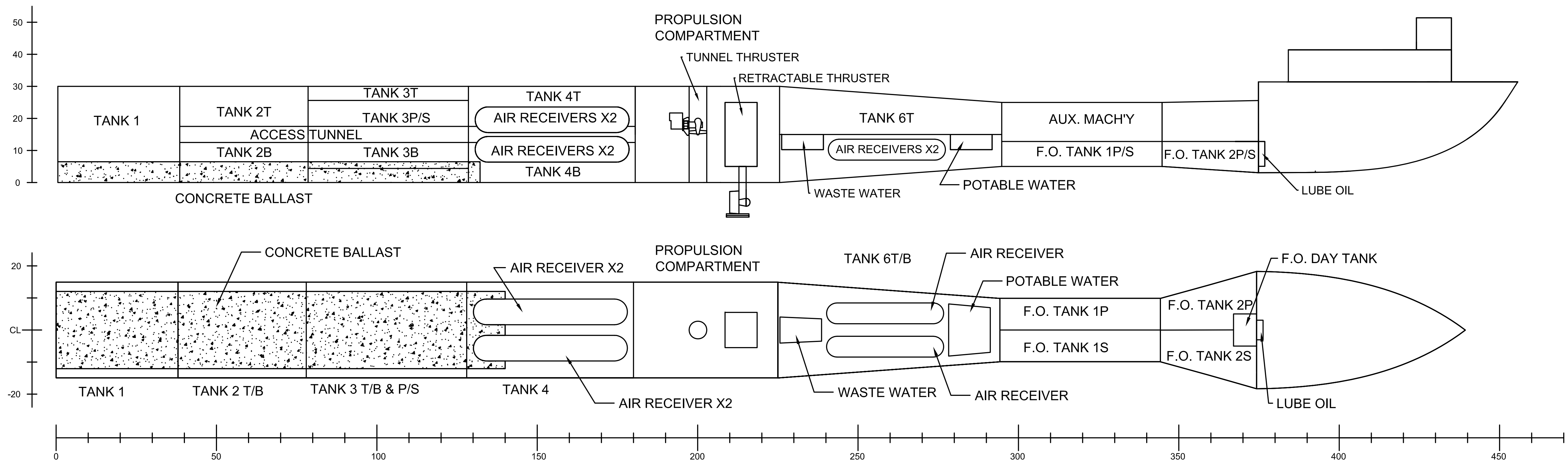

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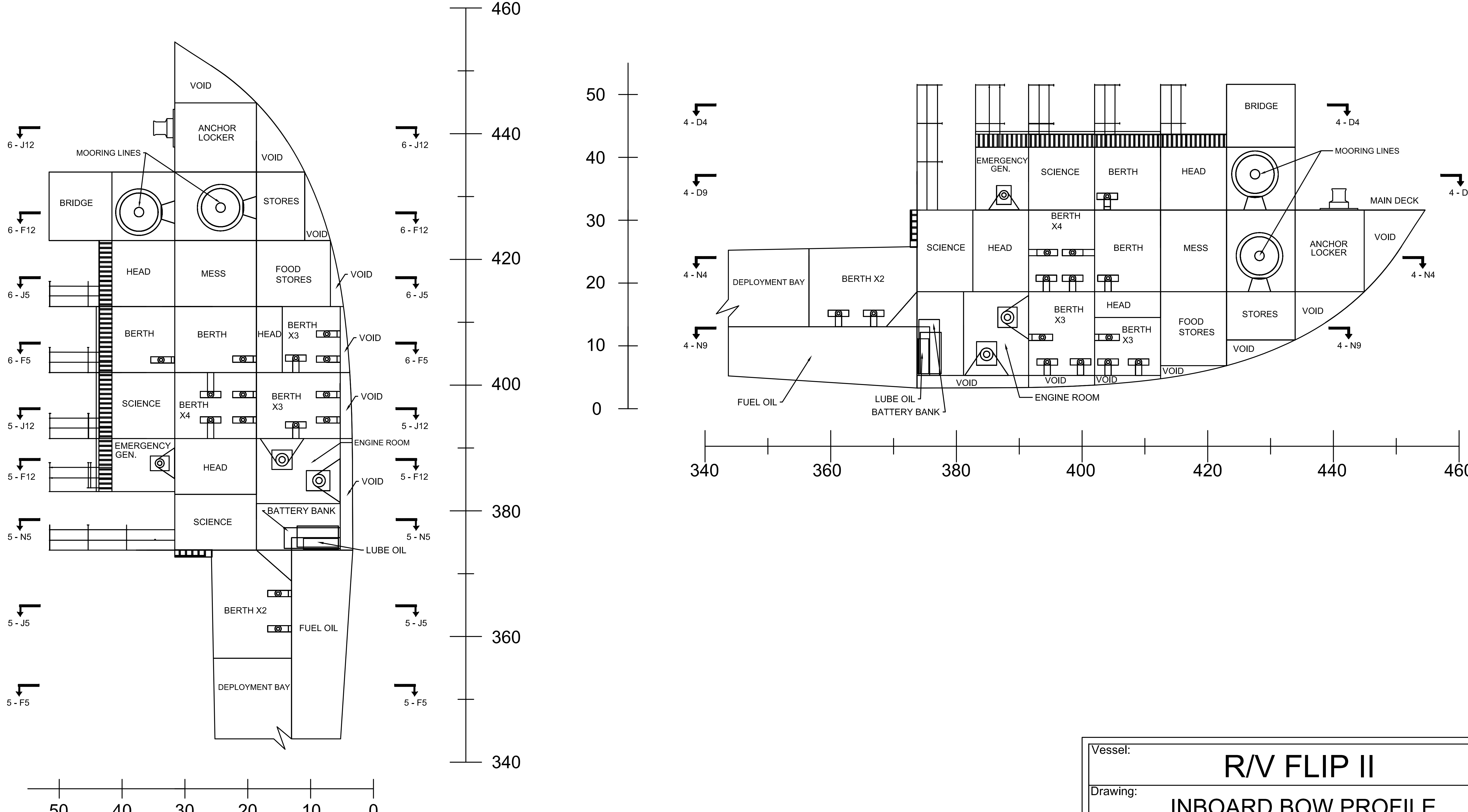

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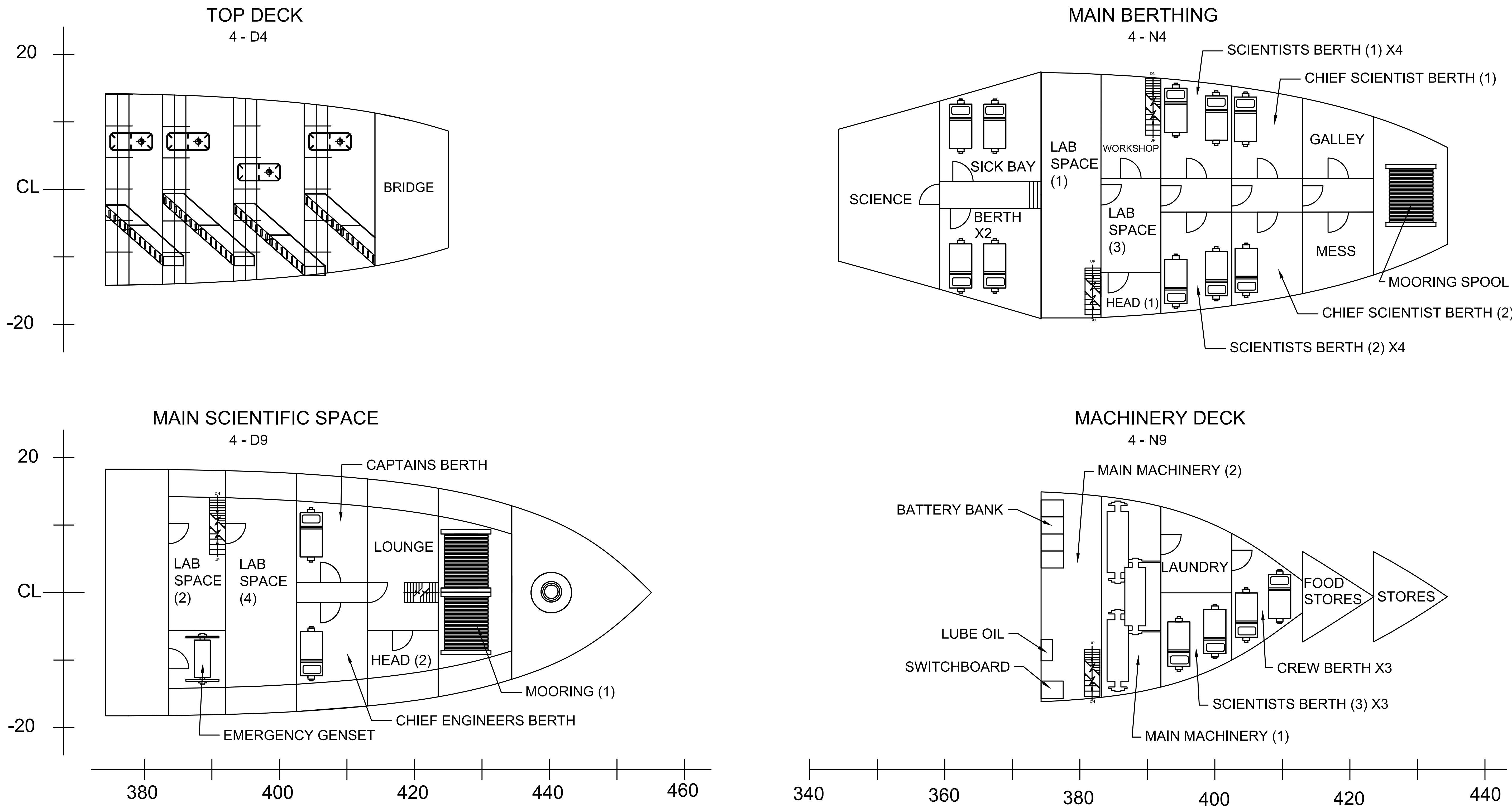

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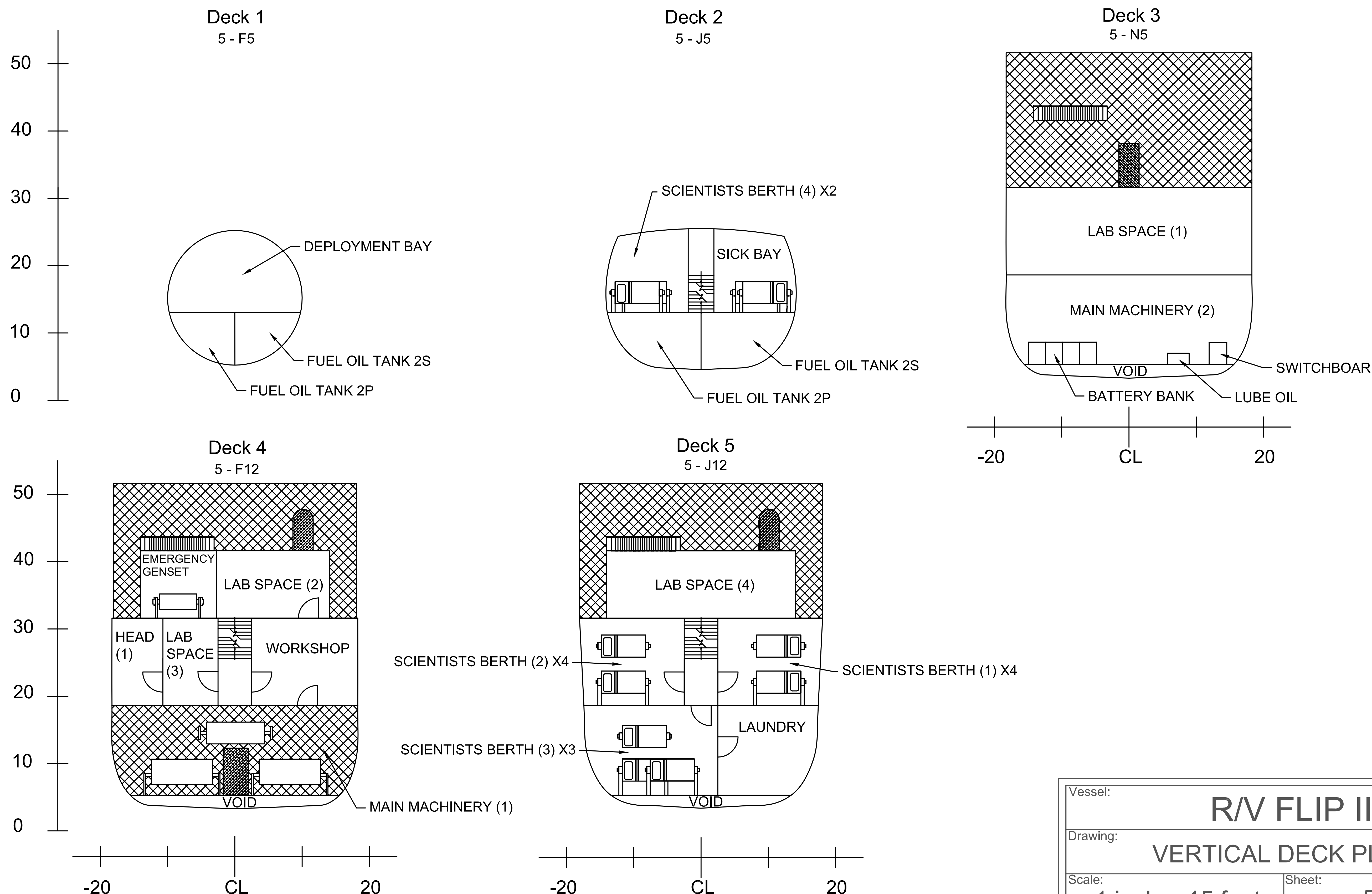

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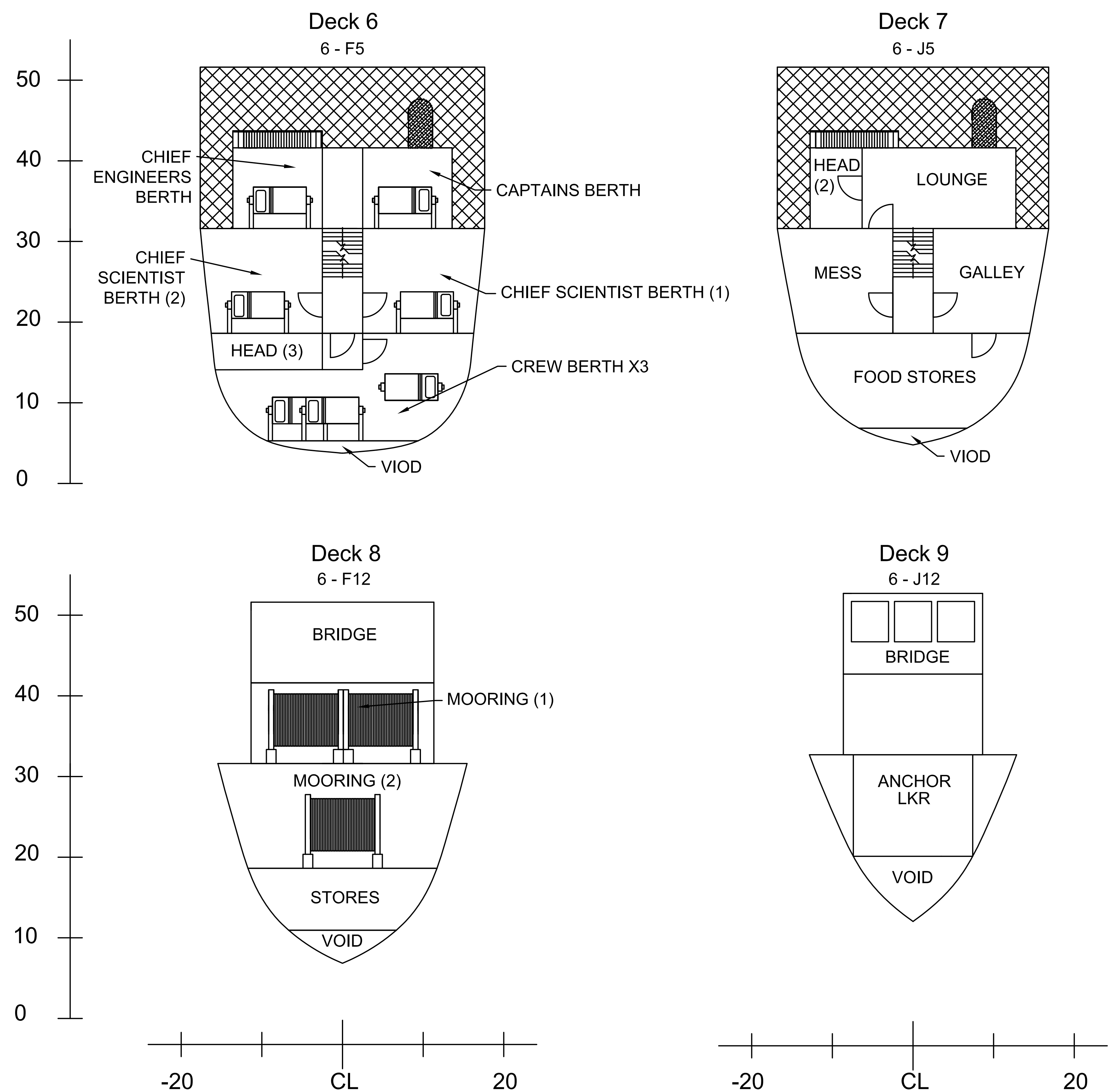

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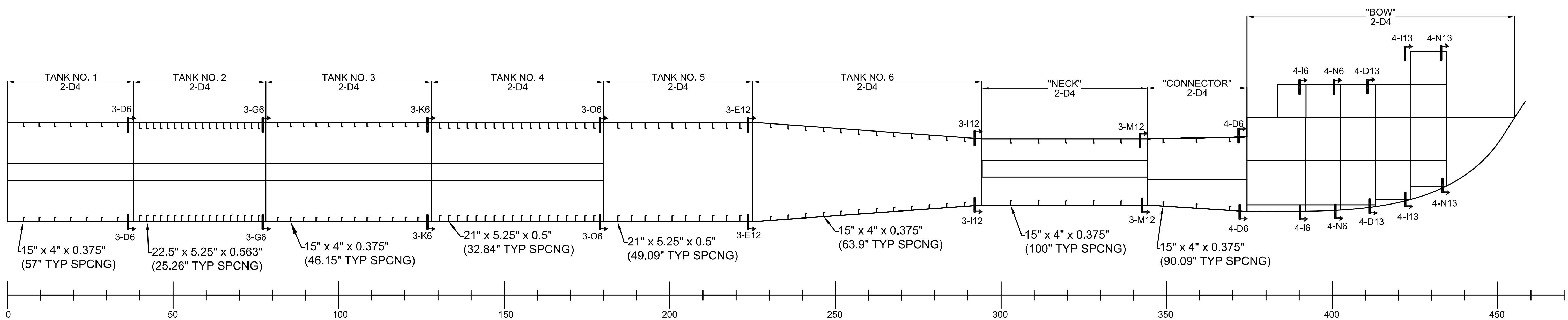

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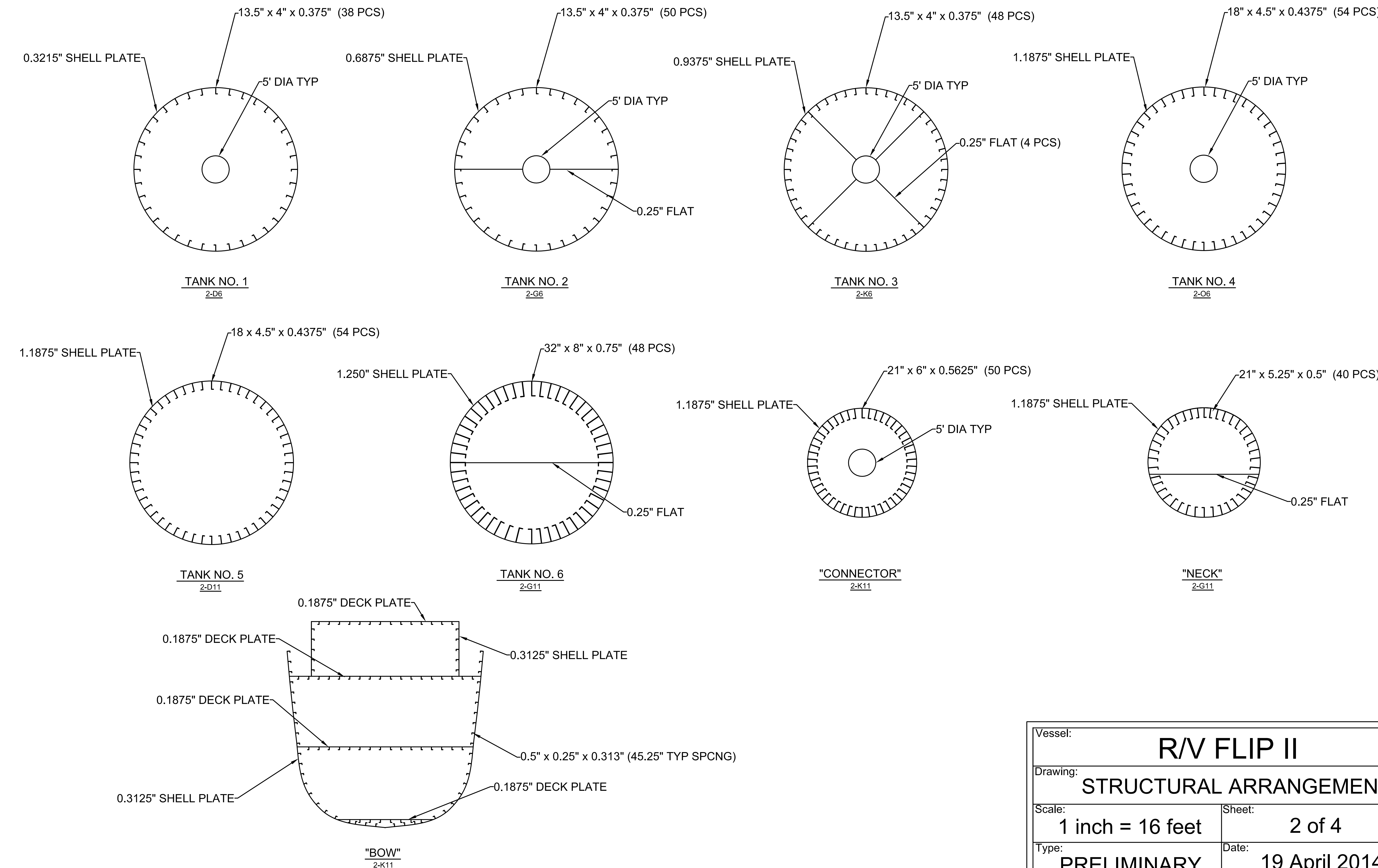

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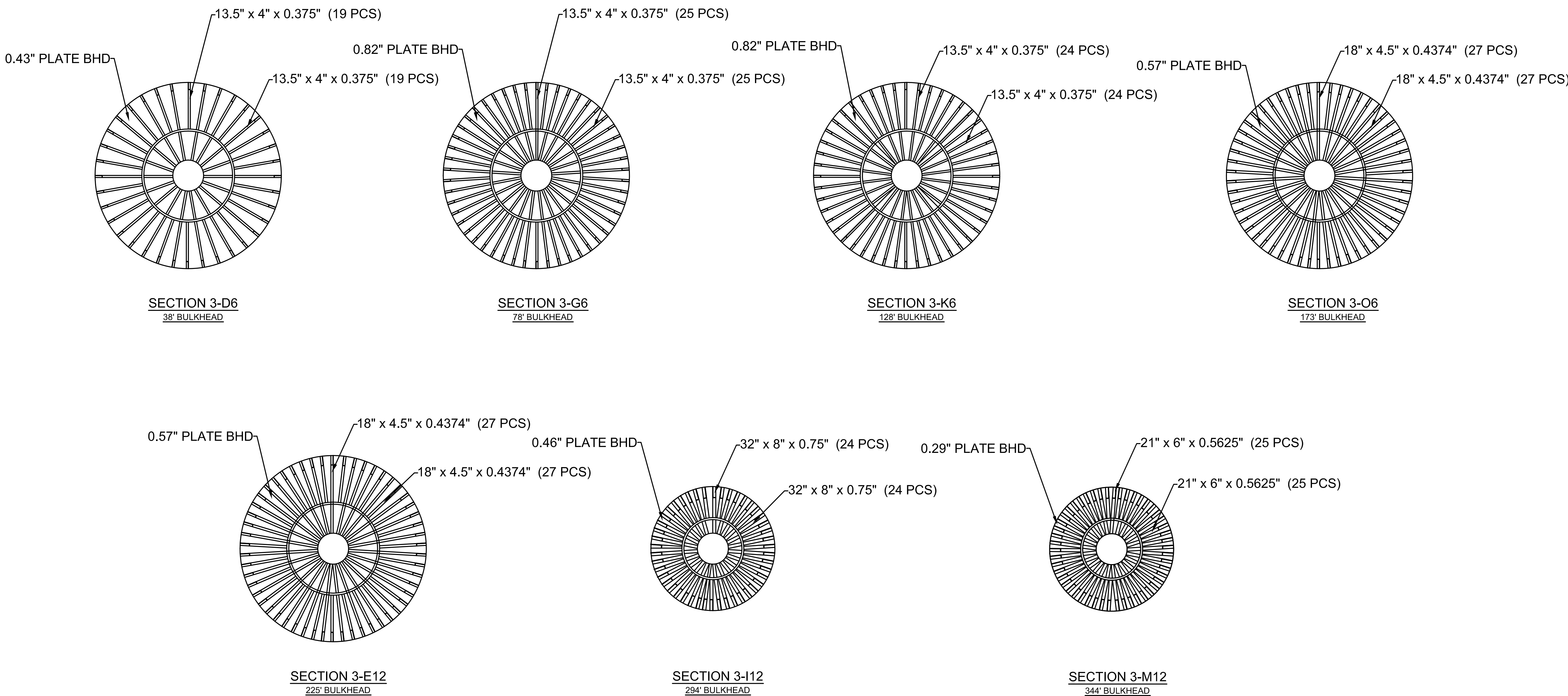

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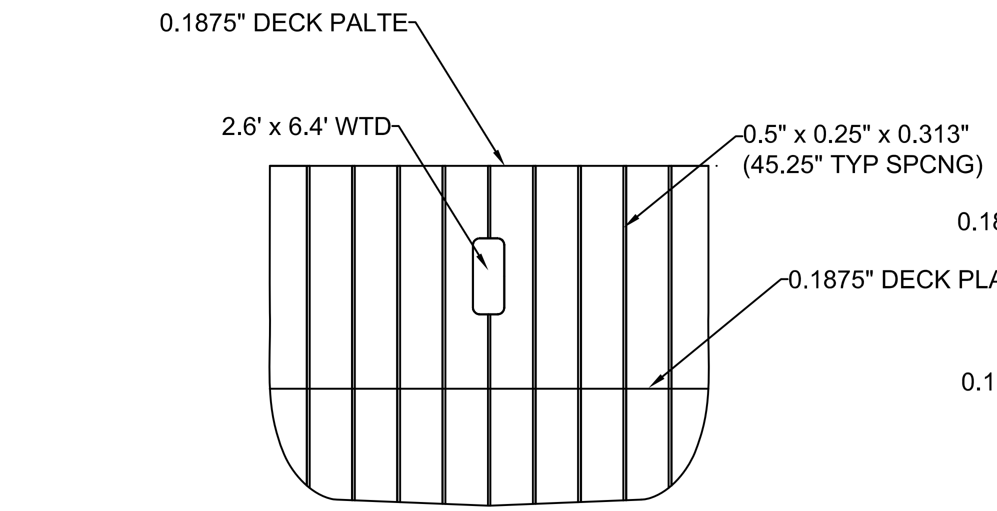

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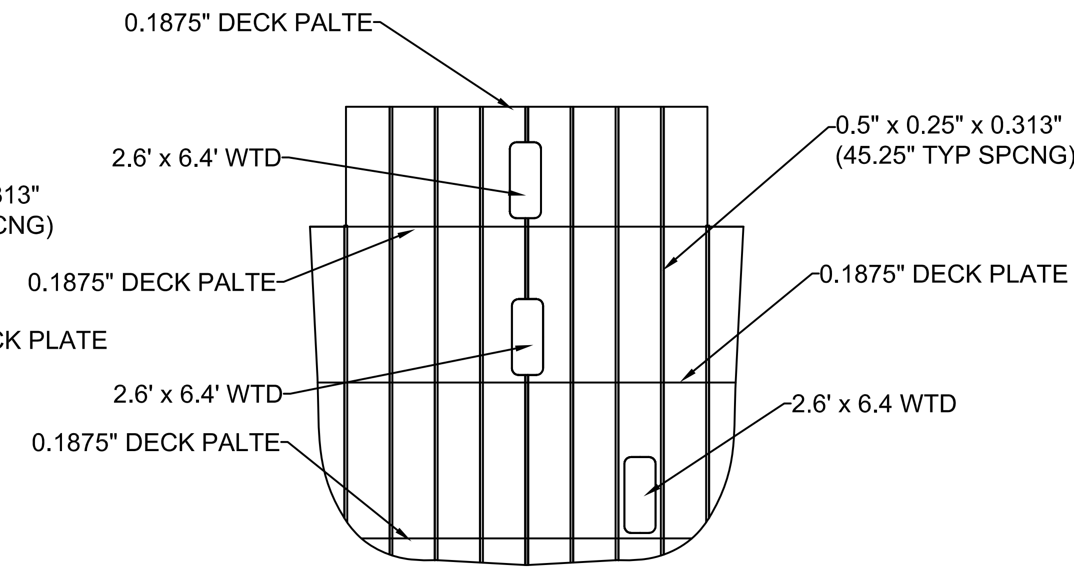

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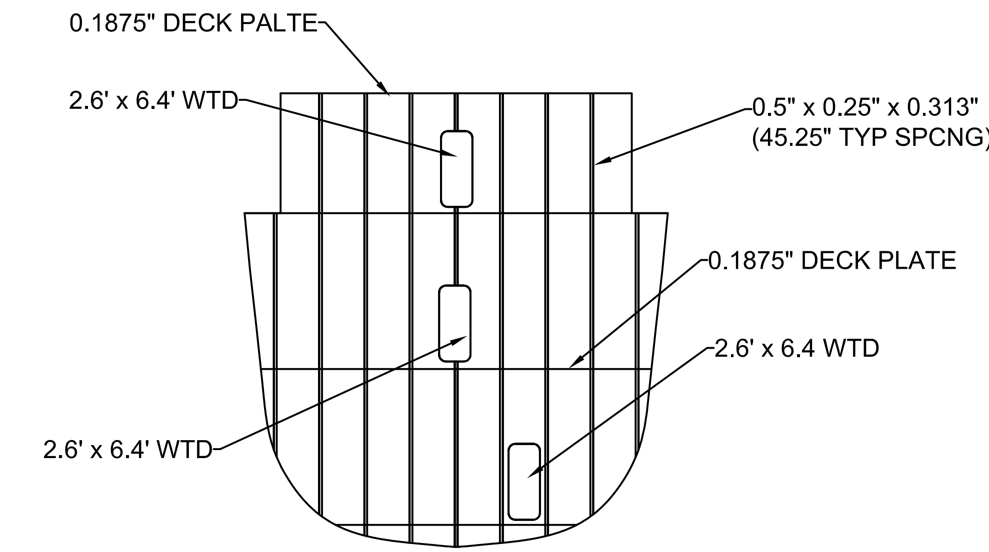

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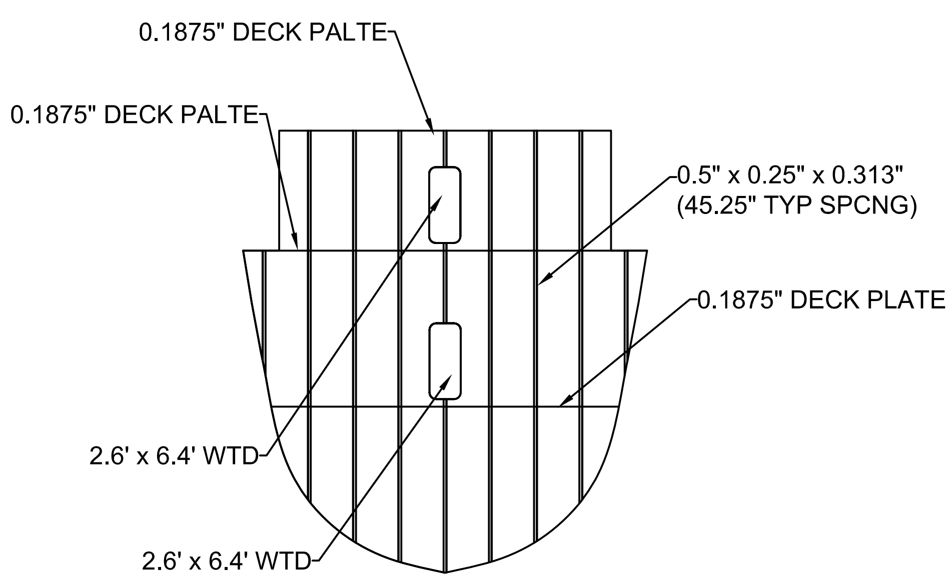

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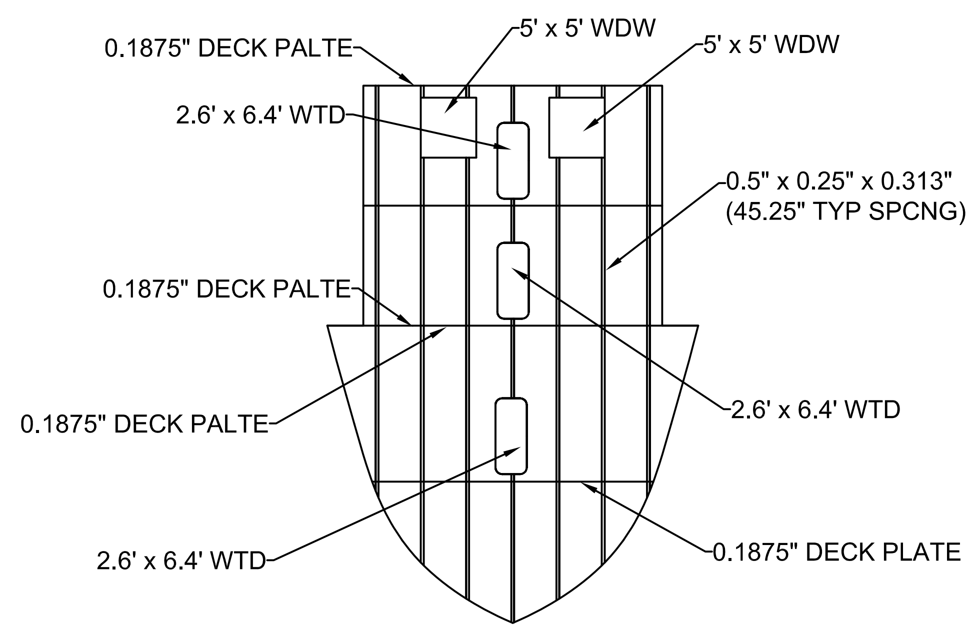

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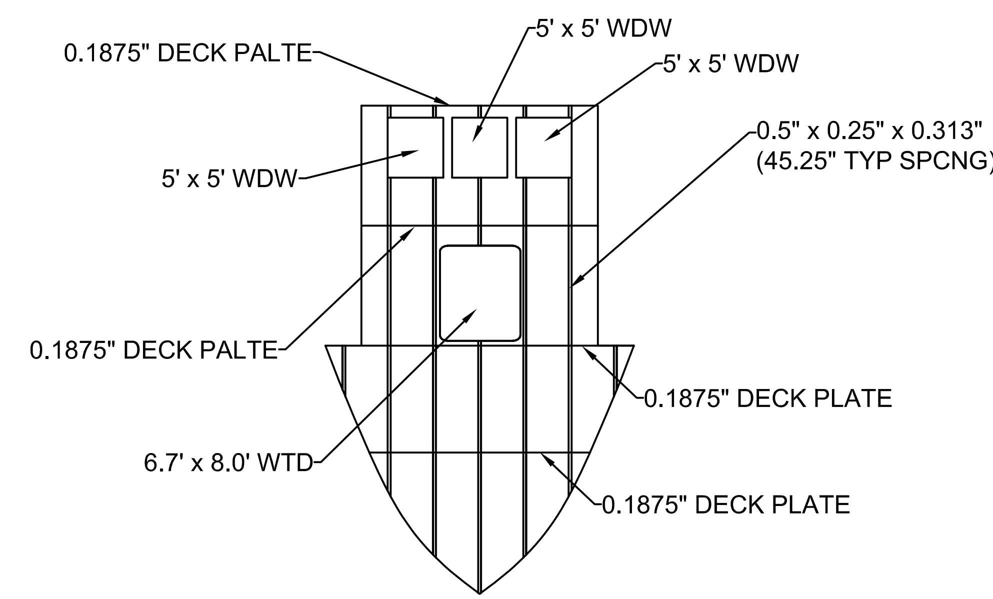

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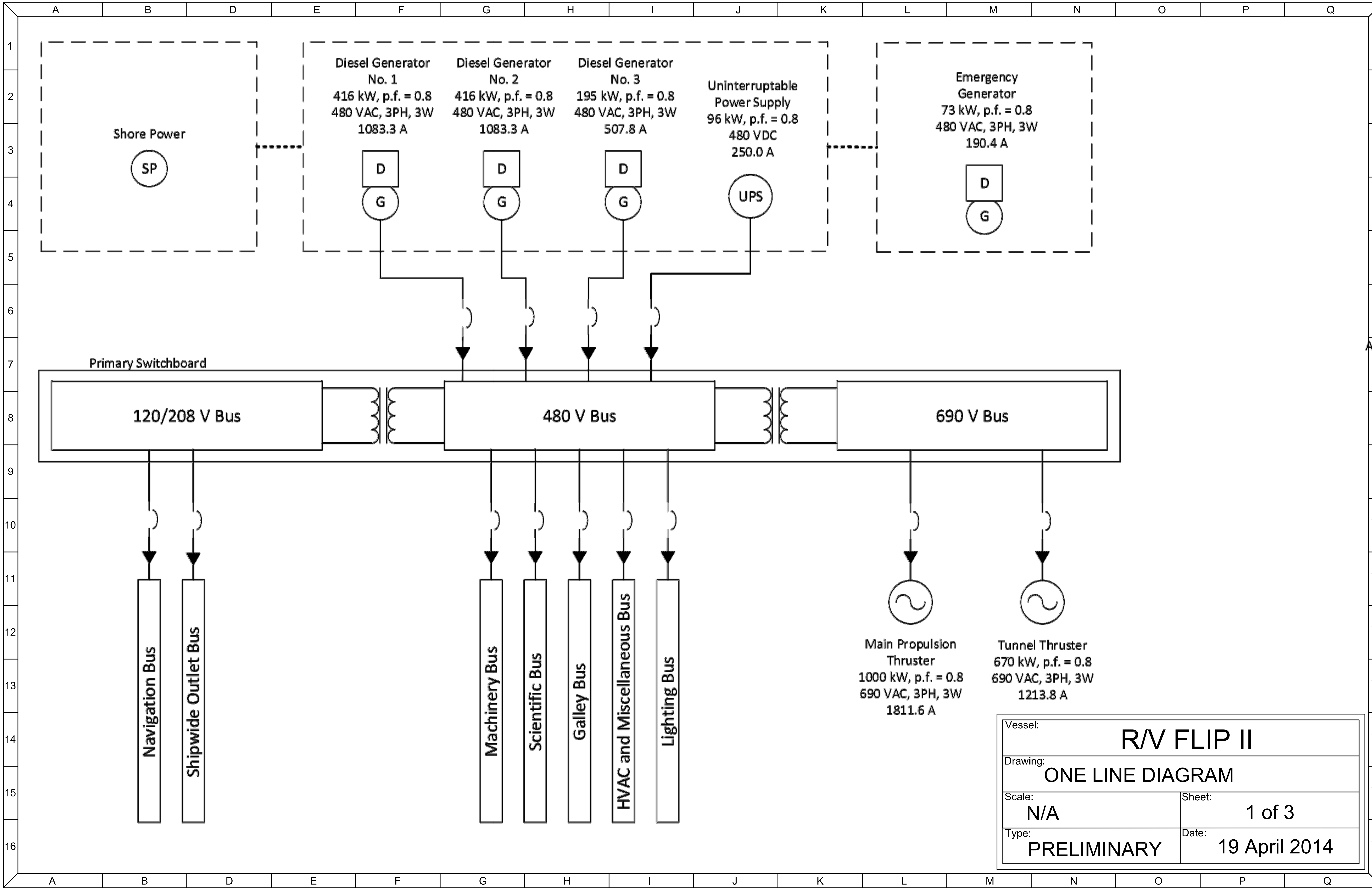

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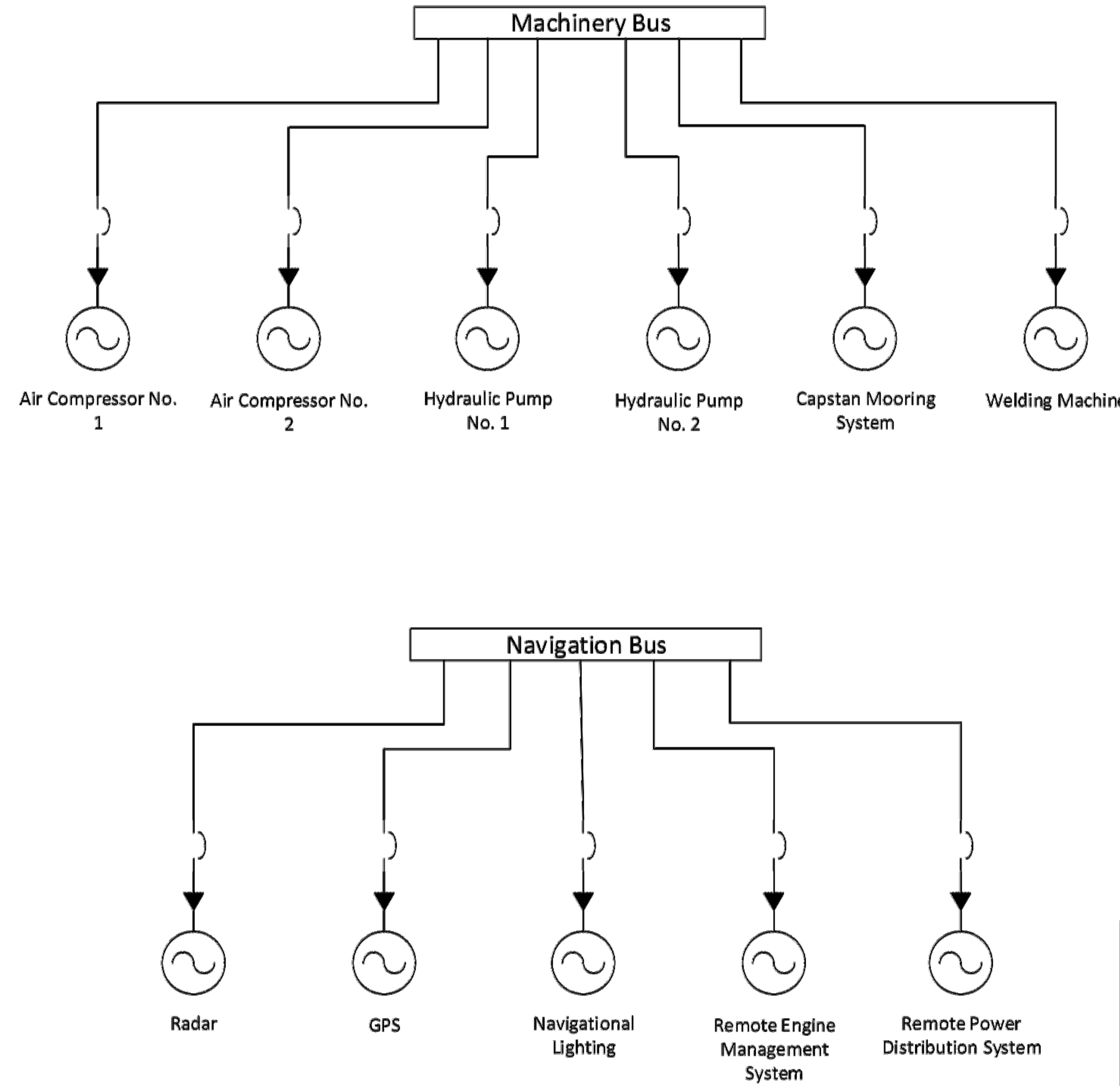

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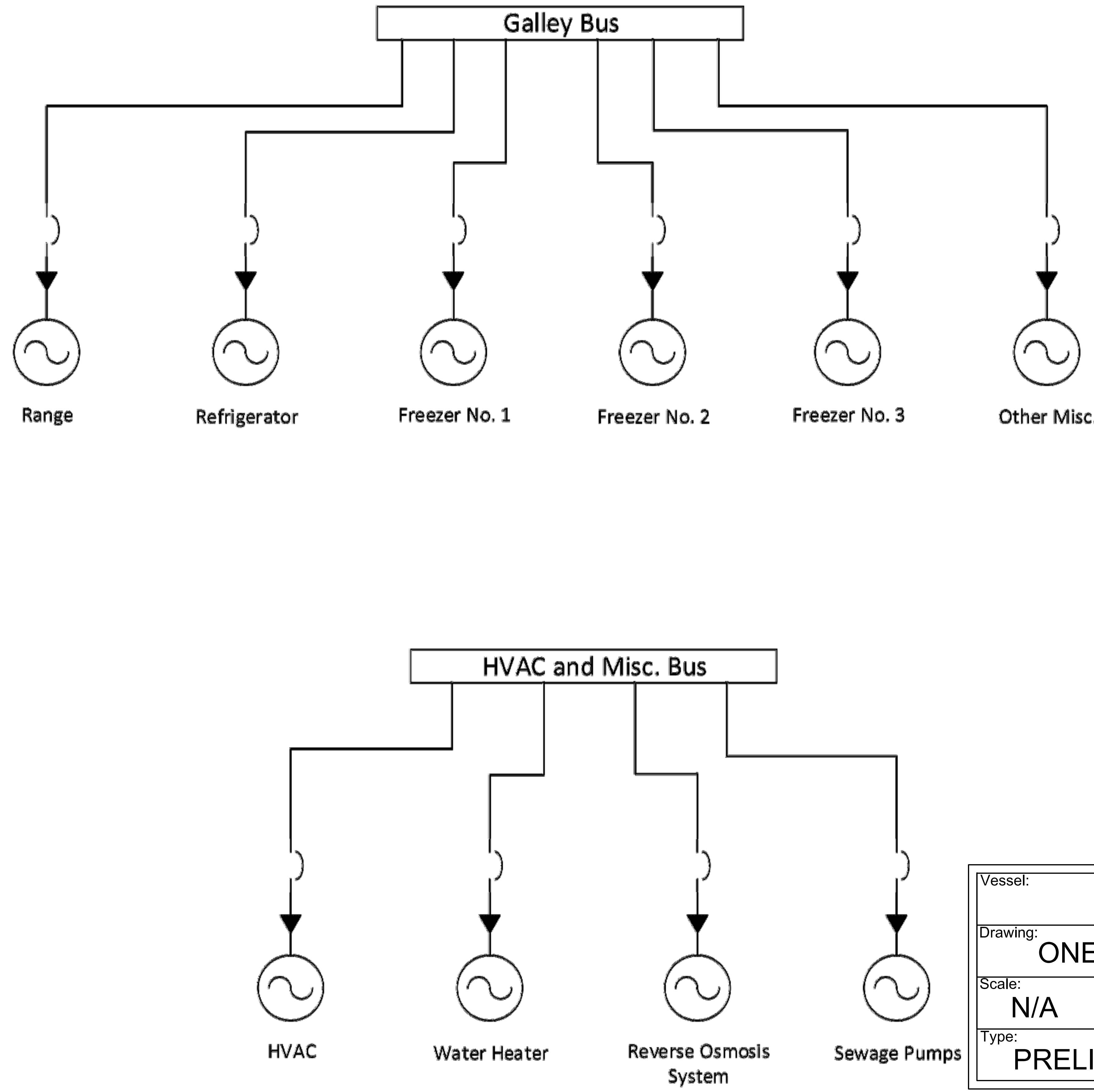

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