Calypso Final Report

Pirate Ro-Ro Company

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December 9, 2015

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Abstract

This report presents a concept design for a Ro-Ro vessel, *Calypso*, to be designed by the Pirate Ro-Ro Company to carry Volvo automobiles and TEU ISO containers. The vessel must have at least two ramps to roll cargo on deck, a minimum deadweight of 15000 tons and carry at least 1700 automobiles and 1000 TEUs. The vessel must also fit through the Panama Canal, have a maximum air draft of 37 meters and be able to make a trip from the Port of Gothenburg to the Port of Galveston in 11 days. Our solution presents a design that has an L_{pp} of 175 meters, a breadth of 32 meters and a draft of 7 meters. *Calypso* is able to carry 1,015 TEUs and 1,760 automobiles and has a deadweight capacity of 15,681.80 tons.

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1.0 Introduction

Our design team, Pirate Ro-Ro Company, consists of a project manager, Ben Cain, a hydrostatic analyst, Quentin Henderson, a hydrodynamic analyst, Hunter Myres, a draftsman, Salvatore D'Ambra, and a structural analyst, Kayley Treichel. The project presented to us involves the design of a transatlantic Ro-Ro ship for Rotto Nordic Lines. The intended routes for the desired Ro-Ro ship begin from the Port of Gothenburg in Sweden and ends at Port of Tacoma in North America. Various stops can occur at different ports such as Port of Antwerp in Belgium, Port of Southampton in England, Port of Halifax in Canada, Port of Baltimore and Port of Galveston in the US, and Veracruz Port in Mexico. However, a required deadline of 11 days was established for a direct route starting from Port of Gothenburg to Port of Galveston carrying full cargo. Additionally, a minimum deadweight of 15,000 ton and enough cargo hold to carry at least 1,700 cars and 1,000 TEUs are required. To start the design strategy, we looked at the parent ship and researched average block coefficients and deadweight ratios for Ro-Ro ships. Hull lines were drawn in AutoCAD and hydrostatic properties were calculated using Excel tables.

2.0 Project Schedule

Initially, the project schedule was heavily influenced by the deadlines of the assignment with the majority of tasks being due on one of the five major dates given by the project assignment. However, after being given feedback from the initial project schedule, the schedule was updated to allow more leeway in due dates. All project milestones and assignments are now due before they are expected to be turned in with some of the major assignments being given a full week before their actual due date. The reason for this is to account for unforeseen changes that might warrant last minute updates to the design. See Appendix 1 for the complete Gantt chart that displays the comprehensive project schedule.

3.0 Parent Ship

At first, the *M/V Ark Futura* was selected as the parent ship used because of its similarity to the requirements outlined by the owner. It had an overall length of 183 meters, which was extremely close to our "target" length of 180 meters. However, very little was known about the *M/V Ark Futura*, and eventually it was replaced with the *Grande Argentina*. Figure 3.1 shows the *Grande Argentina*. Information about the *Grande Argentina* was readily available, making it an excellent choice for the parent ship. Most importantly, the displacement of the *Grande Argentina* was found, which was used to base our calculations off of. The deadweight of the *Grande Argentina* was 26,195 tons. She can carry 1,321 TEUs and 3,515 cars. Additionally, taking specifications like fuel consumption, engine power output and fuel capacity from the parent ship will help expedite the design process for the *Calypso*.

Figure 3.1: Parent Ship *Grande Argentina*

4.0 Concept Solution

A Design of the *Calypso* began by making assumptions about the ship based on pre-existing ships. From there, the number of decks needed to carry the required cargo was calculated. The options for the internal ramps and load on/off ramps were then discussed and decided upon in the following subchapter.

4.1 Design Assumptions

The design of the vessel was started by considering a number of Ro-Ro ships to determine if there was an average deadweight ratio and block coefficient. The deadweight ratio is defined by Equation 4.1 and is the deadweight of the ship divided by the displacement of the ship.

$$Deadweight\ Ratio = \frac{DWT}{\Delta} \tag{4.1}$$

Two articles found online gave information for the block coefficient and deadweight ratio for Ro-Ro ships. The first article "Study on Standards for Main Dimensions of the Design Ship" studied Ro-Ro ships and accumulated the block coefficients for all the ships. The average block coefficient was 0.67 which was used for our beginning calculations (Takahashi, 2006). The second article "Selection of Main Dimensions and Calculation of Basic Ship Design Values" studied Ro-Ro ships and collected their deadweight ratios. The article showed the Ro-Ro ships had deadweight ratios between 0.5 and 0.6 (Papanikolaou, 2014). We assumed a deadweight ratio of 0.55 for our ship, along with an overall length of 180, 15,000 ton deadweight, and a breadth of 32 meters.

4.2 Design Calculations

After design assumptions were made, the draft and decks needed for hauling the 1700 automobiles and 1000 TEUs were found. The draft was found by using Equation 4.2, found in the article "Parametric Design" from an academic journal called *Ship Design and Construction* (Parsons, 2003).

$$\left(\frac{B}{T}\right)_{max} = 9.625 - 7.5C_B \tag{4.2}$$

In this equation, the breadth, B, is 32 meters and C_B is 0.67. The C_B of 0.67 is used because of the assumptions and research in Chapter 4.1. This is the initial C_B assumed and will not necessarily be the actual block coefficient of the *Calypso*. By applying Equation 1, this gave a draft of 6.96 meters.

The amount of decks needed was found by roughly estimating the amount of cargo that could be held on each deck. A length of 160 meters was used to create this estimate. This is a conservative estimate because the cargo hold is not 180 meters at each deck of the ship. For the top 5 internal decks that carry automobiles, there are ten lanes at 2.4 meters wide. Each of these decks is capable of holding 320 automobiles, totaling at 1,600 vehicles. There is an additional 3 meters of space on each side of the deck for ramps and air exchange equipment. The bottom deck is capable of holding 7 lanes of double stacked TEUs, totaling at 364 containers. The deck above the bottom deck can stow 10 lanes of double stacked TEUs, totaling at 520 containers. The bottom two decks also offer large clearances so that heavy machinery can be stored, if needed. The third deck from the bottom is capable of holding 131 TEUs and 160 automobiles. With this cargo configuration, the ship is capable of carrying 1,760 automobiles and 1,015 TEUs. This is shown in Figure 4.1.

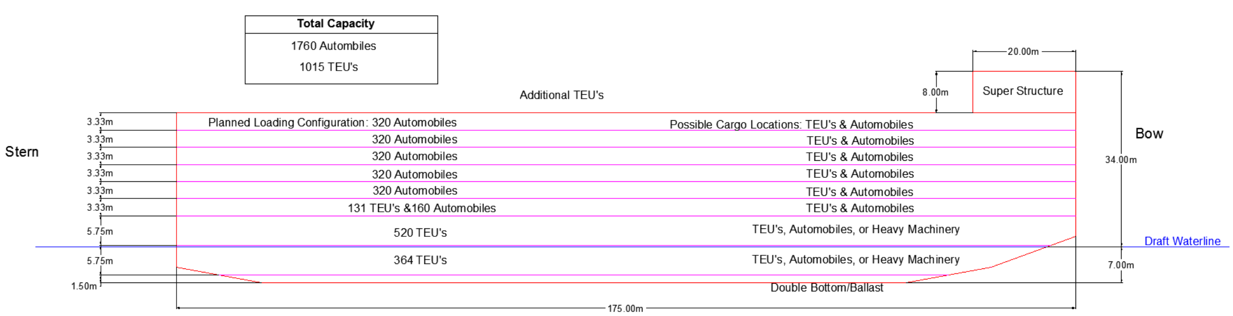

Figure 4.1: Side profile of *Calypso* showing the decks and associated cargo

4.3 Internal Ramps

The internal ramps will be placed at the outer 3 meters of each of the decks. There will be a set of internal ramps for both the port and starboard sides of the ship. As illustrated in Figure 4.2 and Figure 4.3, the port side ramp will start at the bow in the lowest deck and travel to the top deck. The starboard side ramp will start towards the stern in the lowest deck and travel to the top deck. This configuration was chosen in an attempt to decrease loading and offloading times. The ramps are designed to handle one way traffic to ease simultaneous loading and offloading.

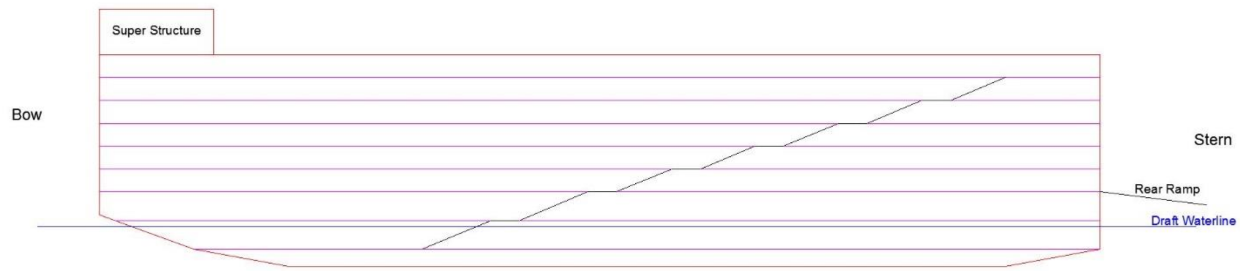

Figure 4.2: Port side view of *Calypso* with internal ramps shown

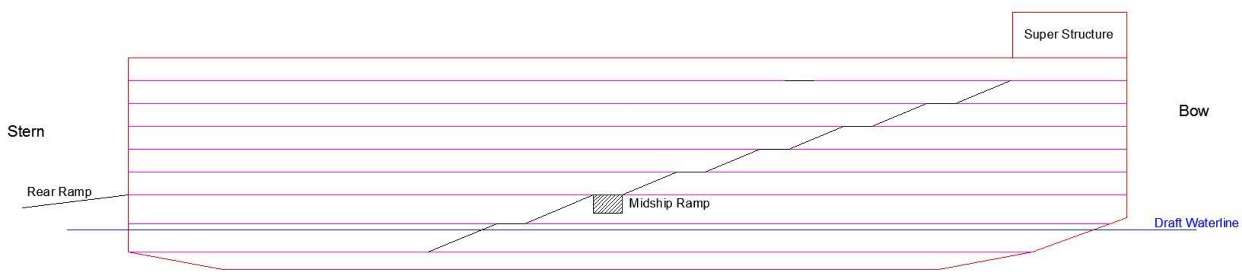

Figure 4.3: Starboard side view of *Calypso* with internal ramps shown

4.4 Load On/Off Ramps

The *Calypso* will feature two off-loading and on-loading ramps located in the stern and midship section of the ship, as shown in Figure 4.4. The rear main ramp will have a width of 7 meters and total length of 18 meters to allow for uncertainty in the draft and port dock height. The rear ramp will come in two sections that can be folded against the ship as seen in Figure 4.5. The midsection ramp has a width of 4 meters and total length of 10 meters to adjust for draft and port heights. Both ramps will feed directly into the third deck from the bottom at a height of 13 meters from the keel. The main rear ramp will be capable of handling both heavy machinery and automobile traffic, but the midsection ramp will be restricted to automobile traffic only. The locations of these two ramps will enable the vehicles to be transferred on and off of the *Calypso* efficiently.

Figure 4.4: External ramp configuration (“RORO Roll On Roll Off”, 2010)

Figure 4.5: Foldable rear ramp (“Quarter Ramp”, 2012)

5.0 Table of Offsets

A table of offsets for the vessel was created by first starting with the body plan. Knowing that the midship section would be the same for most of the ship’s length, it was constructed first. This was done by creating several possible midship sections and comparing the midship coefficient to the assumed block coefficient of the vessel. A midship coefficient greater than the assumed block coefficient was desired so that once the bow was accounted for, the actual block coefficient of the vessel would be close to the assumed value. The midship section extends from station 0.75 to station 8 of the ship to increase the cargo hold space in the ship.

By looking at parent ships, the bow and stern were constructed. Since the stern of the ship needed to be wide enough to accommodate a large loading ramp, the aft perpendicular narrowed only a small amount and the ship does not extend past the aft perpendicular. A table of offsets

(Table 5.1) was extracted from the body plan. A half breadth and sheer plan were also constructed from this data.

Table 5.1: Table of Offsets

Table of offsets for Calypso. All dimensions are given in meter.													
Station Number	Waterline Numbers												
	Keel	0.5	1	2	3	4	5	6	7	8	9	10	11
A.P.	0.00	0.00	0.00	0.00	11.64	13.15	14.06	14.71	15.03	15.35	15.68	16.00	16.00
0.25	0.00	0.00	0.00	8.66	12.88	14.28	14.97	15.56	16.00	16.00	16.00	16.00	16.00
0.5	0.00	4.89	11.90	14.35	15.69	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
0.75	0.00	12.07	14.36	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
1	0.00	12.07	14.36	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
2	0.00	12.07	14.36	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
3	0.00	12.07	14.36	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
4	0.00	12.07	14.36	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
5	0.00	12.07	14.36	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
6	0.00	12.07	14.36	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
7	0.00	12.07	14.36	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
8	0.00	12.07	14.36	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
9	0.00	0.00	11.48	14.49	15.38	15.79	16.00	16.00	16.00	16.00	16.00	16.00	16.00
9.25	0.00	0.00	1.07	4.03	7.36	12.44	14.81	15.55	15.91	16.00	16.00	16.00	16.00
9.5	0.00	0.00	0.00	1.31	2.67	6.10	10.68	14.05	14.92	15.46	15.84	16.00	16.00
9.75	0.00	0.00	0.00	0.00	1.37	3.38	6.21	9.47	11.91	12.92	13.80	14.23	14.32
F.P.	0.00	0.00	0.00	0.00	0.00	1.29	2.67	5.94	9.12	10.34	11.44	11.90	11.90

Station Intervals: 17.5 meters
Waterline Intervals: 3 meters
Buttock Intervals: 2.67 meters

6.0 Hull Lines

The hull lines based on the table of offsets for *Calypso* are shown in the following sections. Autocad was used to construct the hull lines.

6.1 Body Plan

Figure 6.1 shows the body plan of *Calypso*. Stations are shown in green with intervals of 17.5 meters, waterlines are shown in blue with intervals of 3 meters, and buttocks are shown in red with intervals of 2.67 meters. Stations 1-8 are identical, showing the extent of the midship section of the ship. Aft perpendicular, fore perpendicular, and station 9 were constructed by observation of parent ships. The designated water line is at 7 meters, which gives a volume of 27816.95 m^3. The volume is known by using AutoCAD to get the area of the waterplanes and then applying Simpson's first rule (an integration technique) from the keel to the designated water line. Further discussion of the designated water line is in Chapter 8 and 9.1.

Ultimately, a bulbous bow would be implemented to reduce resistance due to the water. Since computational fluid dynamics is needed to optimize the design, we did not include it in our initial hull lines.

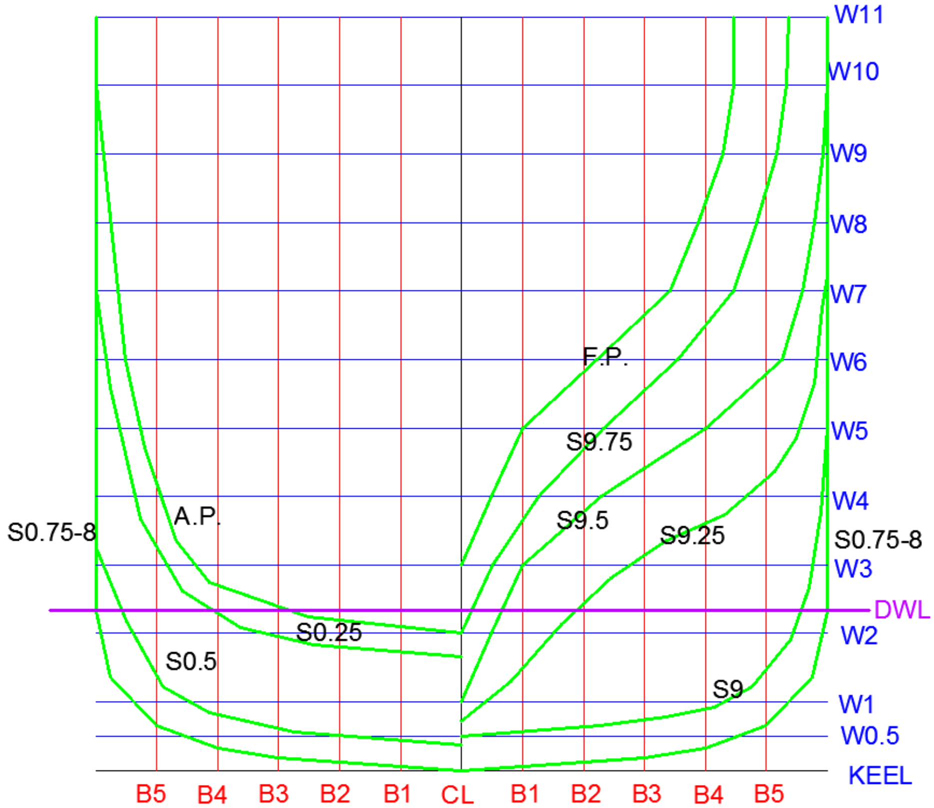

Figure 6.1: Body plan of *Calypso*

6.2 Sheer Plan

Figure 6.2 shows the sheer plan of *Calypso*. Stations are shown in green with intervals of 17.5 m, waterlines are shown in blue with intervals of 3 m, and buttocks are shown in red with intervals of 2.67 m. A larger print of the sheer plan is included in Appendix 2.

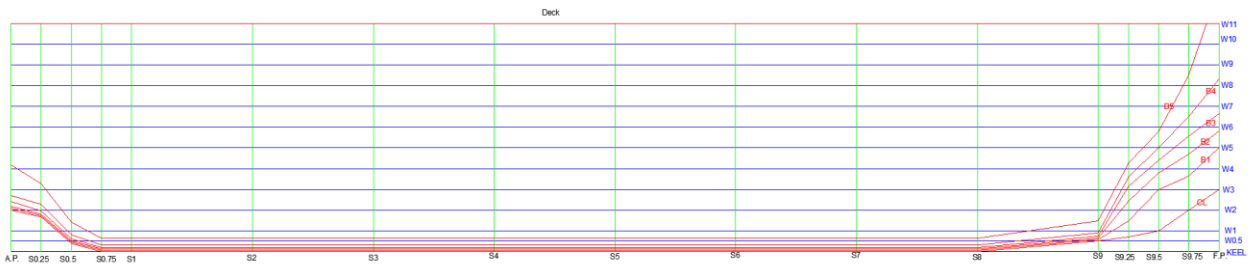

Figure 6.2: Sheer plan of *Calypso*

6.3 Half-Breadth Plan

Figure 6.3 shows the half breadth plan of *Calypso*. Stations are shown in green with intervals of 17.5 m, waterlines are shown in blue with intervals of 3 m, and buttocks are shown in red with intervals of 2.67 m. A larger print of the half breadth plan is included in Appendix 3.

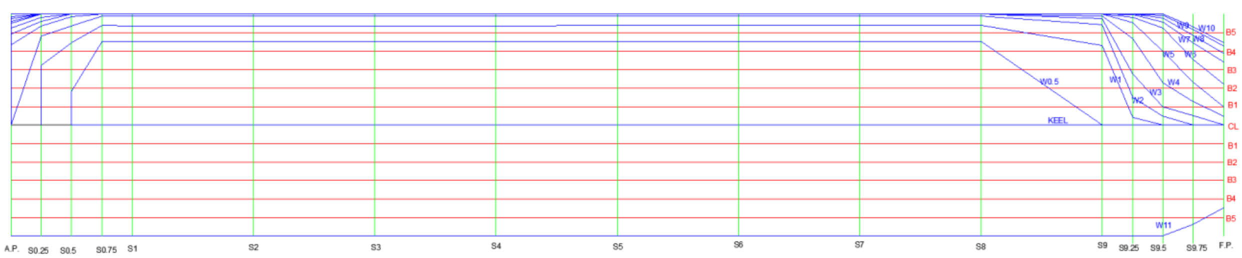

Figure 6.3: Half-Breadth plan of *Calypso*

7.0 Sesam GeniE Drawing

The Sesam GeniE drawings were especially important because they gave the group our first look of the ship's dimensions in a three dimensional view. First, the table of offsets was converted into their X,Y and Z coordinates by knowing the ship's overall dimensions. From this, the data points were easily entered into the Sesam GeniE program using the "add polyline" tool. With the basic structure of the hull outlined, the "cover curve" tool was used to create a hull surface between the polylines plotted. Figures 7.1, 7.2, 7.3, and 7.4 show the Sesam drawing of *Calypso*.

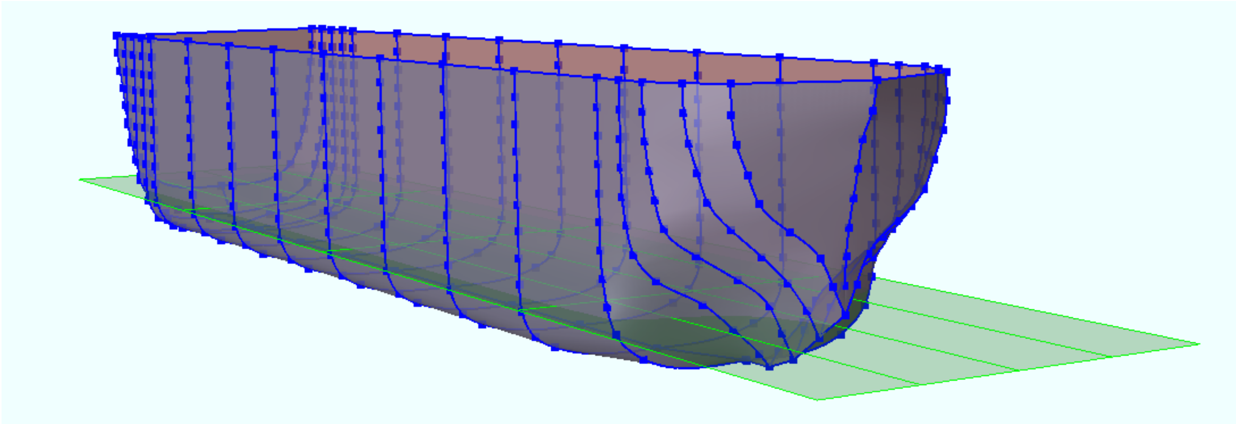

Figure 7.1: Starboard side view of the *Calypso*

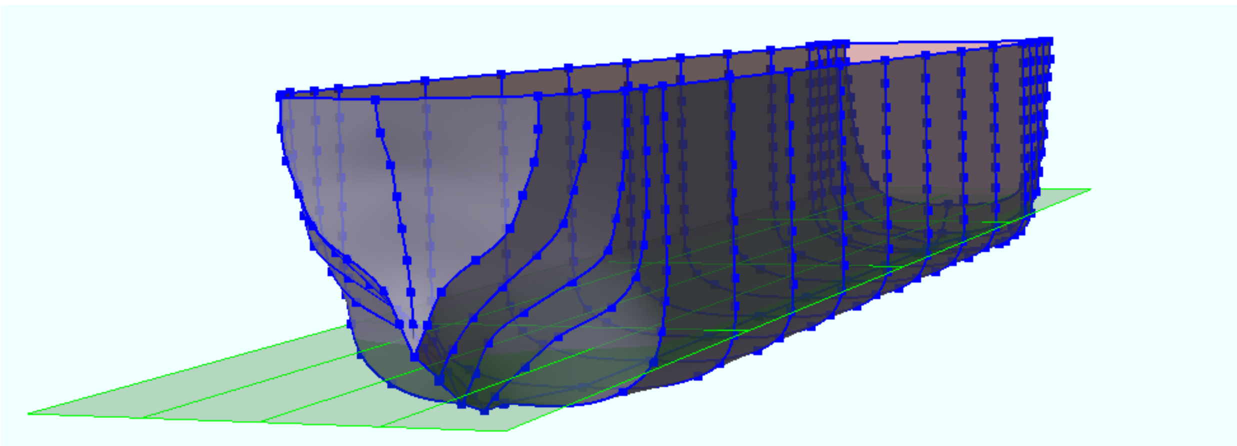

Figure 7.42 Port view of the *Calypso*

8.0 Curves of Form

After the hull lines were constructed, coefficients for the ship at varying drafts were defined. The area of the waterplane at each draft was extracted from the hull line drawings in Autocad. Simpson's first rule was used to calculate the volume of the ship at different drafts given the area at each waterplane. The drafts are 9 meters, 7 meters (DWL), 6 meters, 3 meters and 1.5 meters. Figure 8.1 shows the block coefficient, water plane coefficient, midship coefficient, prismatic coefficient and vertical prismatic coefficient for the drafts. As seen below, the water plane coefficient and the prismatic coefficient are closer to 1 than the other coefficients. The high waterplane coefficient indicates the ship is rectangular along the waterplanes. The high prismatic coefficient relates to the ship resembling a cylinder.

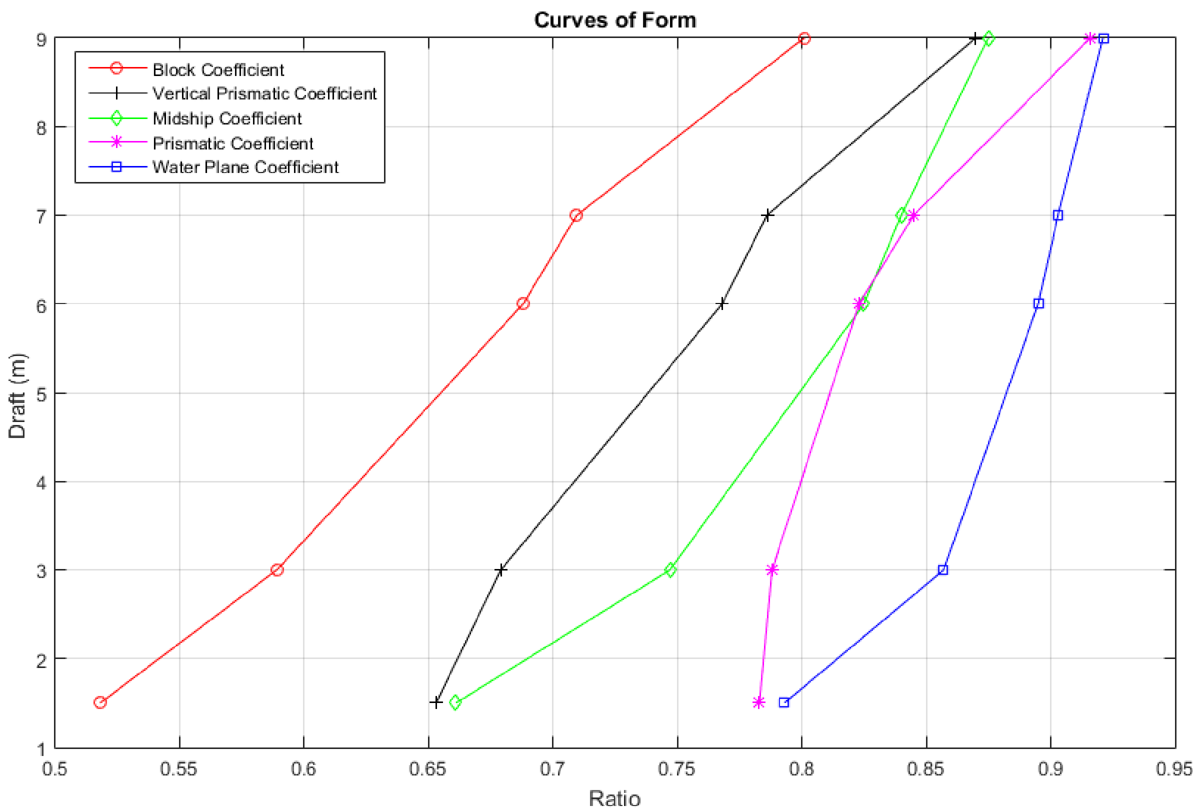

Figure 8.1: Curves of form for *Calypso*

9.0 Hydrostatic Properties

The hydrostatic properties for three conditions were calculated. These conditions are full load condition, ballast condition and light ship condition. Simpson's first rule was used to evaluate the integrals when calculating waterplane areas and the volume of the ship.The center of gravity, $\overline{KG}$, was estimated for each condition by taking the moment about the keel using the approximate weight distribution. The approximate weight distribution was obtained by considering the weight of all of the decks and structural elements associated with the ship. The weight of all of these elements were obtained by calculating their volume and multiplying by the density of steel, 7.8 ton/m^3. The weight of the engine and superstructure were also taken into account. For ballast condition, the weight of the water in the ballast tank is also considered. Full load condition is affected by the distribution of cargo. The tables used to calculate the hydrostatic properties for all conditions are included in Appendix 4. Hand calculations for the $\overline{KG}$ values are shown in Appendix 5. It is noted that the center of buoyancy for each condition is a lower than what would be expected. Calculations were reviewed multiple times but no error was found.

9.1 Lightship Condition

The displacement of the ship at lightship is 12830.57 ton. This is known by subtracting the deadweight of the ship from the displacement at full load condition. The volume of the ship (assuming saltwater) at lightship condition is 12517.63 m^3. The rest of the hydrostatic properties were calculated and are shown in Table 9.1.

Table 9.1: Hydrostatic Properties at Lightship Condition

Lightship Condition	
L (m)	175
Draft (m)	3.75
Displacement (ton)	12830.57
Volume (m^3)	12517.63
$\overline{BM_L}$ m)	3107.52
$\overline{BM_T}$ (m)	24.89
$\overline{KG}$ (m)	19.61
$\overline{KB}$ (m)	0.794
$\overline{GM_T}$ (m)	6.07
$\overline{GM_L}$ (m)	3088.42
Radius of Gyration (m)	24.28
Rolling Period (s)	19.77
TPC (ton/cm)	46.76
MCTC (ton*m/cm)	2264.56

9.2 Ballast Condition

The ballast tank size is 22 meters wide by 1.5 meter high by 160 meters long. This is capable of carrying approximately 5280 m^3 of liquid and can hold 5412 tons of salt water. The displacement of the ship at ballast condition is 18242.57 tons. The volume of the ship (assuming saltwater) is 17797.63 m^3. The rest of the hydrostatic properties were calculated and are shown in Table 9.2.

Table 9.2: Hydrostatic Properties at Ballast Condition

Ballast Condition	
L (m)	175
Draft (m)	5
Displacement (ton)	18242.57
Volume (m^3)	17797.63
$\overline{BM_L}$ m)	2461.56
$\overline{BM_T}$ (m)	22.40
$\overline{KG}$ (m)	13.99
$\overline{KB}$ (m)	1.14
$\overline{GM_T}$ (m)	9.55
$\overline{GM_L}$ (m)	2448.71
Radius of Gyration (m)	21.86
Rolling Period (s)	14.19
TPC (ton/cm)	48.68
MCTC (ton*m/cm)	2552.62

9.3 Full Load Condition

The displacement of the ship at full load condition is 28512.37 ton. The volume of the ship (assuming saltwater) is 27816.95 m^3. The remaining hydrostatic properties were calculated in Excel and are shown in Table 9.1. The $\overline{KG}$ value of 15.51 is made assuming the cargo distribution shown in Chapter 4.2.

Table 9.1: Hydrostatic Properties at Full Load Condition

Full Load Condition	
L (m)	175
Draft (m)	7
Displacement (ton)	28512.37
Volume (m^3)	27816.95
$\overline{BM_L}$ m)	1595.65
$\overline{BM_T}$ (m)	14.9
$\overline{KG}$ (m)	15.51
$\overline{KB}$ (m)	1.629
$\overline{GM_T}$ (m)	1.018
$\overline{GM_L}$ (m)	1581.77
Radius of Gyration (m)	14.54
Rolling Period (s)	28.89
TPC (ton/cm)	51.82
MCTC (ton*m/cm)	2577.09

10.0 Static Stability Curve

The static stability curve for *Calypso* is shown in the following subchapters for three loading conditions. When the heel angle (φ) is less than 5°, Equation 10.1 can be used to calculate the righting arm, $\overline{GZ}$. When the heel angle is between 5° and 20°, Scribanti's formula for large angles of inclination (Equation 10.2) must be used.

$$\overline{GZ} = \overline{GM}\sin(\varphi) \tag{10.1}$$

$$\overline{GZ} \approx \left(\overline{GM_T} + \frac{1}{2}\overline{BM_T}tan^2(\varphi)\right) * \sin(\varphi) \tag{10.2}$$

10.1 Lightship Condition

The $\overline{GM}$ is found by extending a line parallel to the initial linear portion of the curve. On this line, a heel angle of 1 radian will give a $\overline{GZ}$ approximately equal to $\overline{GM}$. At 1 radian, $\overline{GZ}$ is 6.10 which is almost equivalent to the $\overline{GM}$ calculated through hydrostatics (6.07 meters). The static stability curve for lightship condition is shown in Figure 10.1.

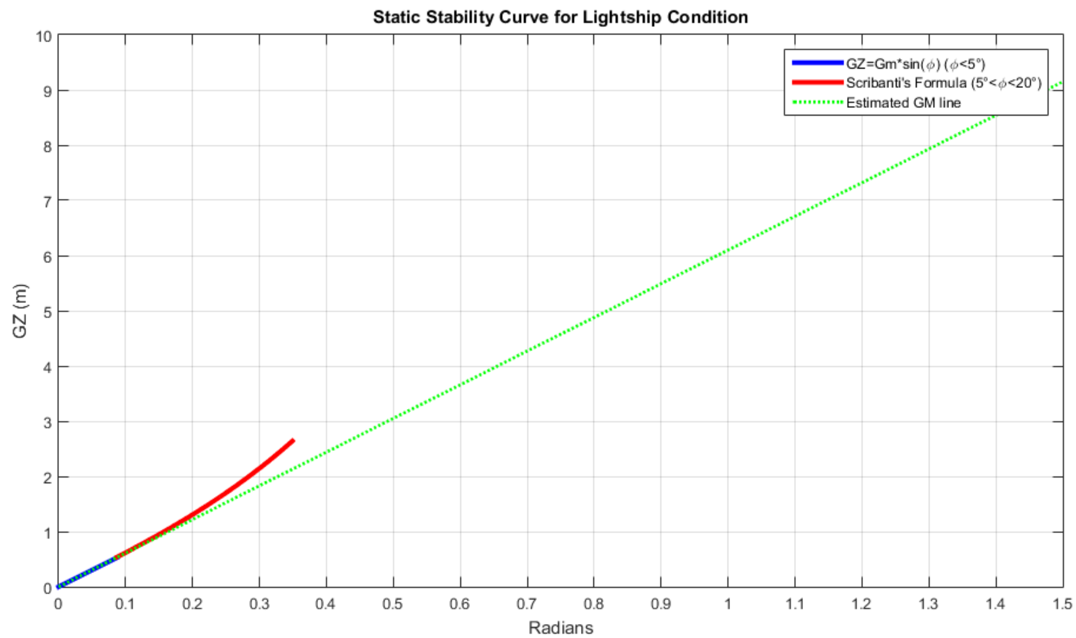

Figure 10.1: Static Stability Curve for Lightship Condition

10.2 Ballast Condition

At 1 radian, $\overline{GZ}$ and $\overline{GM}$ are 9.50 which is almost equivalent to the $\overline{GM}$ calculated through hydrostatics (9.55 meters). The static stability curve for ballast condition is shown in Figure 10.2.

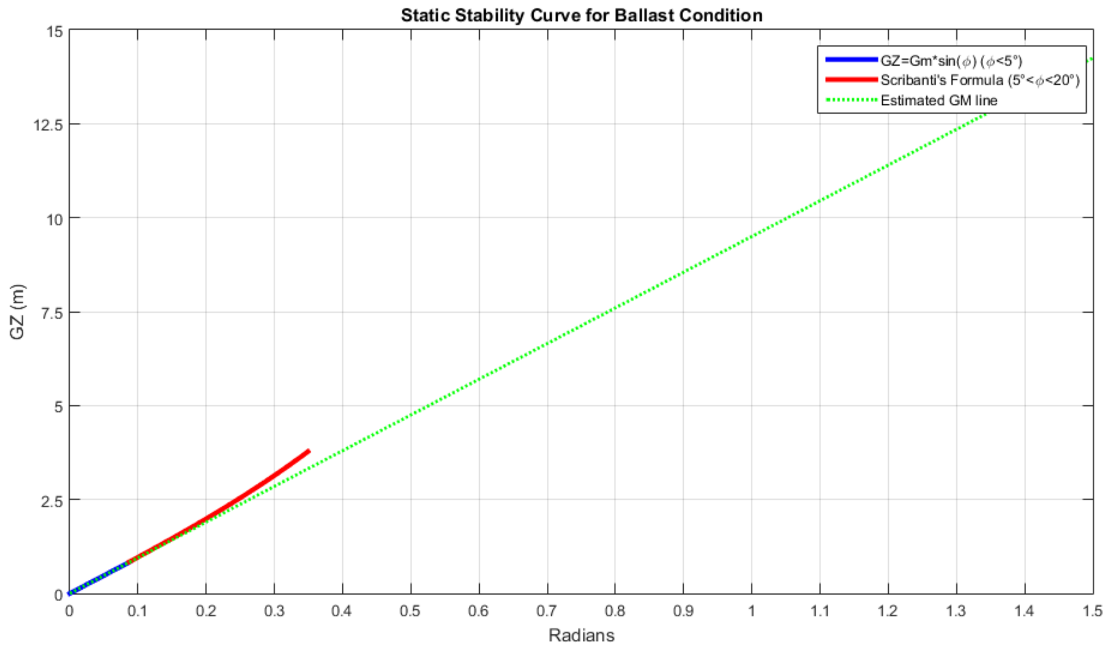

Figure 10.2: Static Stability Curve for Ballast Condition

10.3 Lightship Condition

At 1 radian, $\overline{GZ}$ and $\overline{GM}$ are 1.00 which is close to the $\overline{GM}$ calculated through hydrostatics (1.018 meters). The static stability curve for full load condition is shown in Figure 10.3.

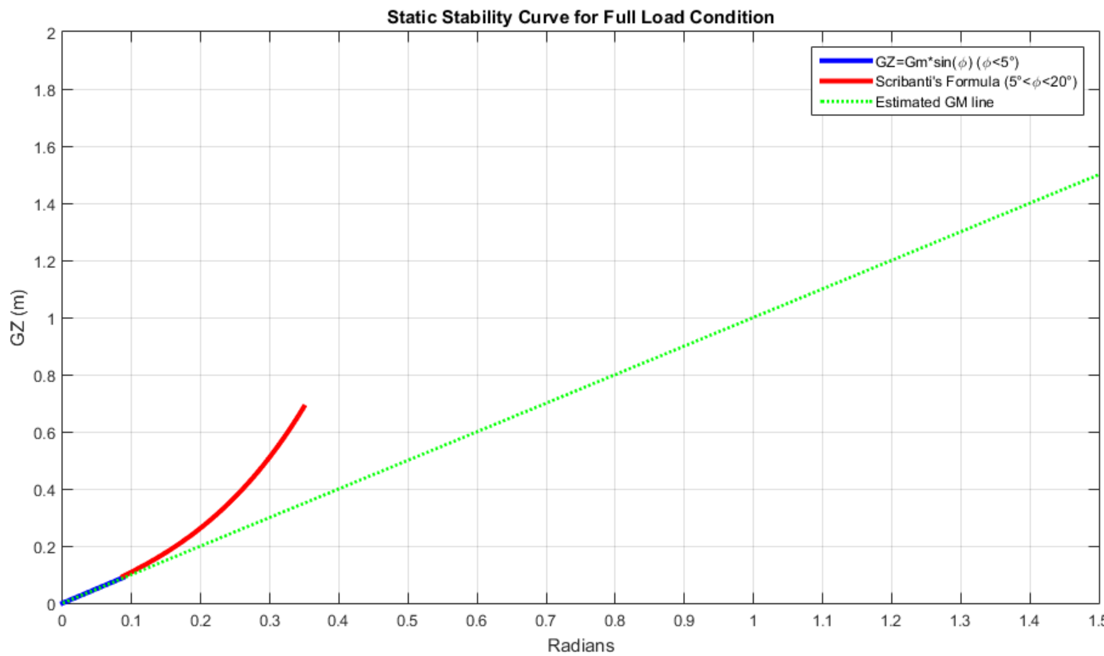

Figure 10.3: Static Stability Curve for Full Load Condition

11.0 Damage Stability

The damage stability for *Calypso* was determined using the constant buoyancy method. This method involves assuming that the amount of volume lost in the damaged compartment is the same as the volume gained by parallel sinkage of the ship. The trim and list of the ship are calculated for each damage condition and the stability and safety of the ship when damaged is assessed. For *Calypso*, three bulkheads were placed at Stations 1, 2 and Station 9. This is shown in Figure 11.1. The damage stability analysis of the aft compartment is shown in Table 11.1. The process for generating the values in Table 11.1 is shown in Appendix 5.

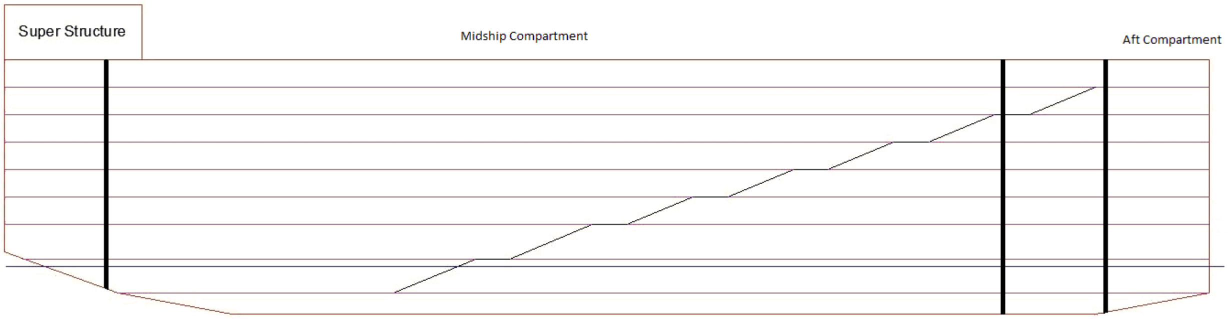

Figure 11.1: *Calypso* with bulkhead positions

Table 11.1: Damage Stability for Aft compartment

Parallel Sinkage (m)	0.856
Volume Lost (m^3)	4617.2
$\overline{BB'}$ (m)	0.554
Y_F' (m)	0
X_F' (m)	87.98
I_t (m^4)	414475.93
i_t (m^4)	31692.50
I_t' (m^4)	387537.30
$\overline{BM_T'}$ (m)	13.93
I_L (m^4)	43809996.56
i_L (m^4)	55509.77
I_L' (m^4)	41941982.41
$\overline{BM_L'}$ (m)	1507.79
$\overline{GM_L'}$ (m)	1494.43
$\overline{GM_T'}$ (m)	0.574
Trim angle (rad)	-0.00738
List angle (rad)	0
Trim (m)	-1.292

The total trim due to damage in the aft compartment is 1.292 meters. This is well below the margin line of the ship, so it will still float if the compartment is damaged.

For Ro-Ro ships, there must be a balance between safety and amount of cargo the ship can carry. Multiple bulkheads would increase the safety of the ship if it was damaged, but also restrict the cargo carrying capacity of the ship. In order to maximize the cargo carrying space, a collision bulkhead was placed coinciding with Station 9. Table 11.2 was constructed by using the same process as for Table 11.1.

Table 11.2: Damage Stability for Midship compartment

Parallel Sinkage (m)	59.88
Total Volume (m^3)	41519.1
$\overline{BB'}$ (m)	42.43
Y_F' (m)	0
X_F' (m)	64.11
I_t (m^4)	414475.93
i_t (m^4)	379099.62
I_t' (m^4)	92241.25
$\overline{BM_T'}$ (m)	3.32
I_L (m^4)	43809996.56
i_L (m^4)	41284516.15
I_L' (m^4)	8262168.996
$\overline{BM_L'}$ (m)	297.020
$\overline{GM_L'}$ (m)	325.54
$\overline{GM_T'}$ (m)	31.83
Trim angle (rad)	0.09034
List angle (rad)	0
Trim (m)	15.81

As shown in Table 11.2, the parallel sinkage for the midship compartment is more than the entire height of the ship. The total trim due to damage in this compartment is 15.81. Additional bulkheads must be added in order for the vessel to still float if the midship compartment is damaged. However, doing so will reduce the amount of cargo the ship can carry.

Further research was conducted into ways to increase the stability of the ship after damage without filling valuable cargo space with bulkheads. In an article out of *Marine Technology and SNAME News*, Pawlowski (1999) found that adding at least one buoyant deck above the waterline will increase the stability of a damaged Ro-Ro vessel. To create a buoyant deck, the girders below the deck are sealed off with a second deck and a chamber is created. The space this chamber occupies is not used for storage because of the protruding girders and stiffeners. The weight of the ship is slightly increased and the additional deck plating increases the strength of the deck and ship.

12.0 Structural Hull Design

The structural elements for *Calypso* were determined according to the guidelines specified by ABS. The structural elements related to the decks, inner bottom and hull of the ship were modeled in Sesam GeniE and are shown in Figure 12.1. These elements make up the bulk of the weight of the lightship. The center of gravity of the ship was calculated using the tool in GeniE and gave a $\overline{KG}$ of 19.9 meters. This is close to the hand calculated lightship $\overline{KG}$ which gives validity to the hydrostatic properties calculated for full load and ballast conditions. Some structural elements of the ship are missing in the GeniE model and it does not account for the engine, fuel or superstructure. If the missing elements were added to the model, the $\overline{KG}$ would come out closer to the hand calculated value.

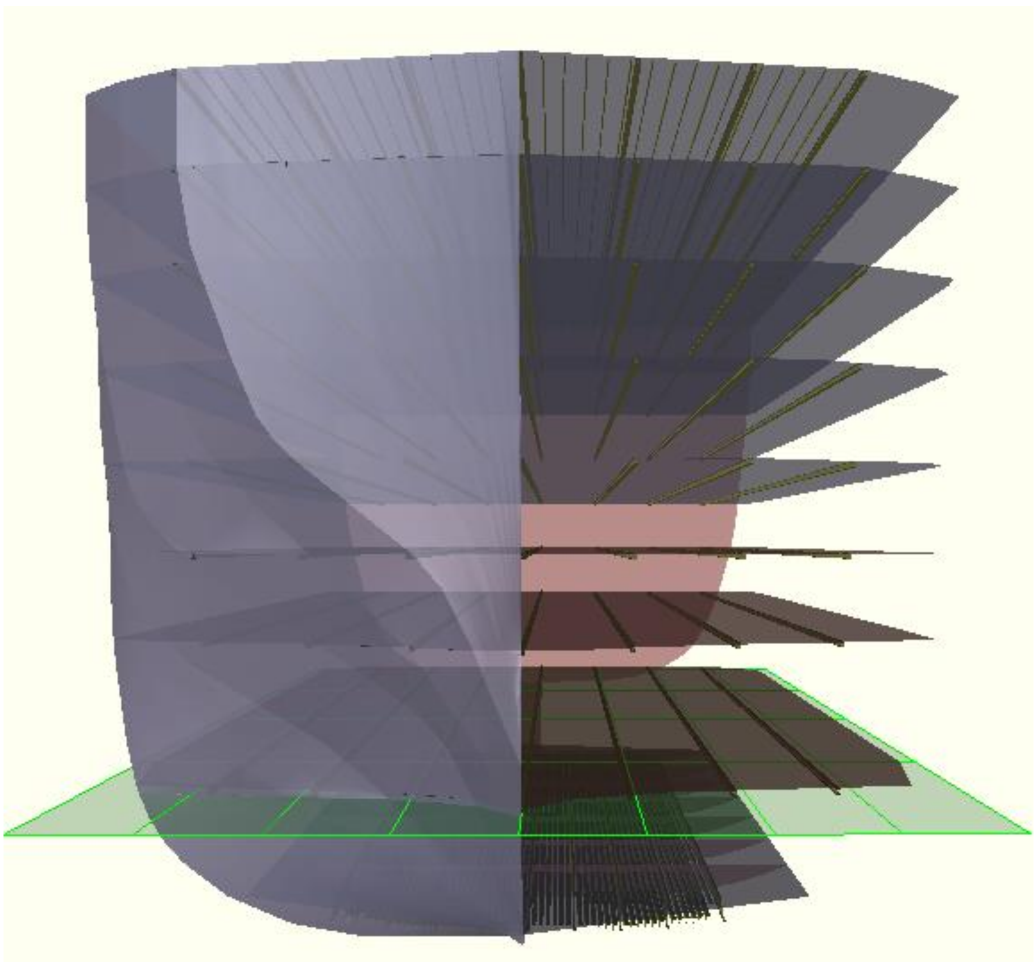

Figure 12.1: Bow view of structural elements of *Calypso*

Since *Calypso* was classified with the American Bureau of Shipping, their rules and regulations were used as the main design parameter for the structural elements of the ship. All of the structural elements were taken from Part 3 of the "Rules for Building and Classing Steel Vessels 2012" from the ABS, and were a function of the ship's overall dimensions. Other parts of the structural design came from the design solution, such as the buoyant decks found on two of the decks. A midship section is included in Figure 12.2 and a table of structural element dimensions is in Appendix 7.

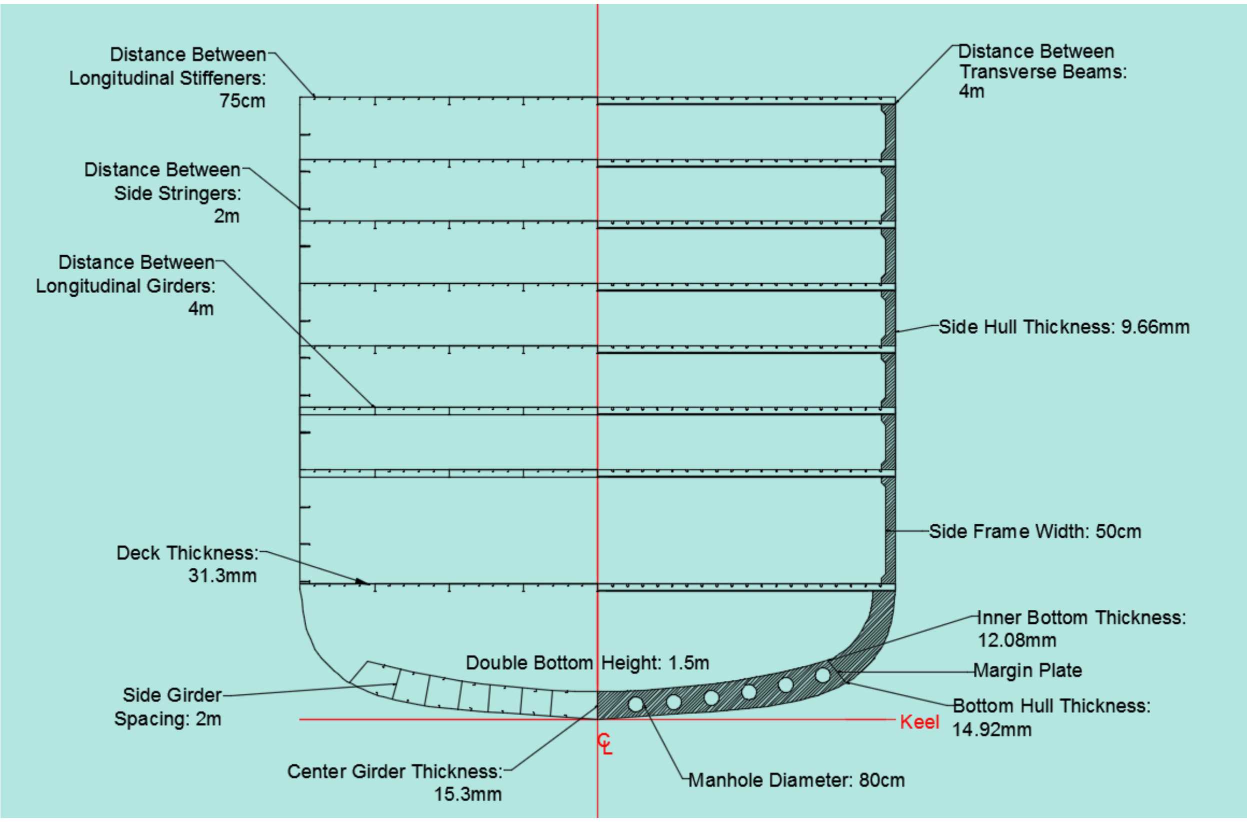

Figure 12.2: Midship section drawing of *Calypso*

13.0 Ship Resistance and Powering

The resistance of the ship was needed to determine what type of engine should be used for *Calypso*. The following subchapters show the results of this analysis.

13.1 Ship Resistance

To help the selection of an engine for the *Calypso*, the effective horsepower needed to be calculated for the ship at its operational speed, 21 knots. Since the effective horsepower is a function of the total resistance R_T, it first needed to be found. Knowing the Froude number of the ship at various velocities, and that the prismatic coefficient is equal to 0.859, a relationship for the coefficient of residual resistance C_R was utilized, as a function of the Froude's number.

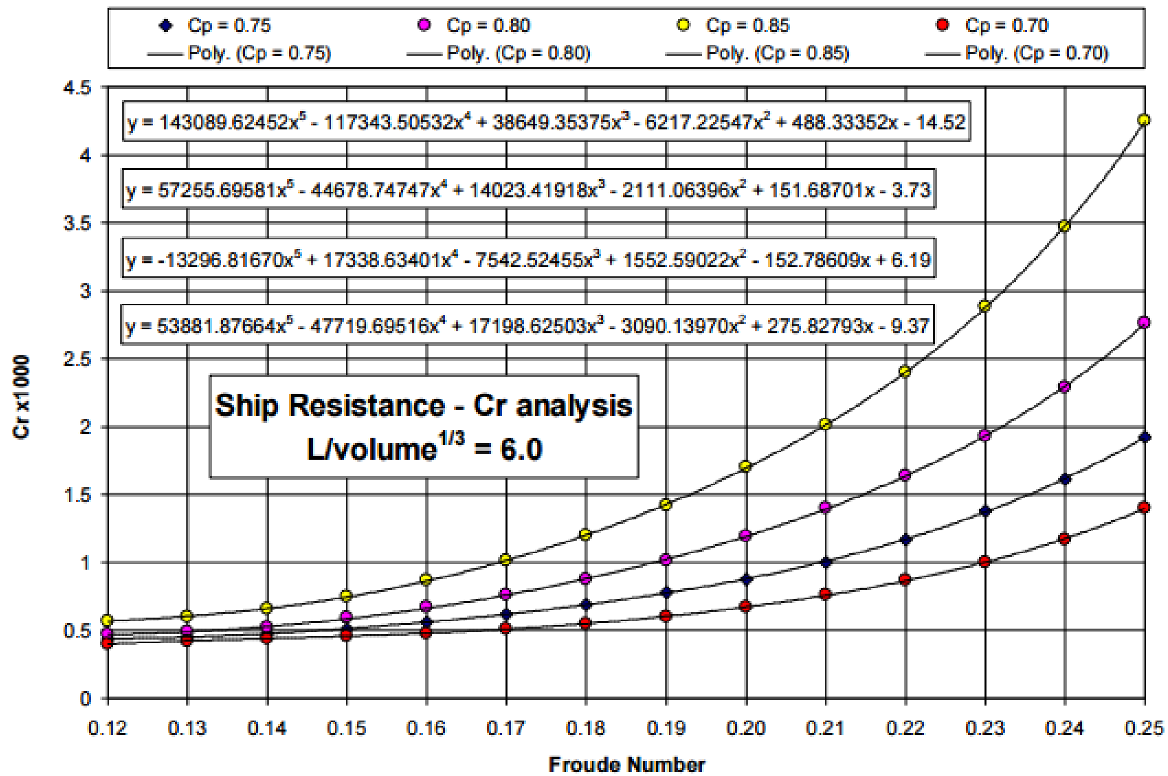

Figure 13.1: The graph used to find the residual coefficient C_R (Kristensen, 2012)

Knowing C_R, the next step was to utilize the ITTC 1957 equation for the coefficient of frictional resistance C_F, seen as Equation 14.1.

$$C_F = \frac{0.075}{\log(R_e - 2)^2} \tag{13.1}$$

Equation 13.2 shows the total coefficient of resistance is defined as the sum of the frictional and residual friction coefficients. Finally, with C_T known, the total resistance of the ship was calculated using Equation 13.3. Note that like all of the previous calculations, this was done for multiple speeds, including the designed operational speed of 21 knots.

$$C_T = C_f + C_R \tag{13.2}$$

$$R_T = \frac{1}{2} C_T \rho v^2 S \tag{13.3}$$

Here, v is the velocity of the ship, S is the wetted surface area of the ship and ρ is the density of the fluid the ship is floating in (assumed to be salt water). Here, the wetted surface area of the ship was calculated using Sesam GeniE. Finally, with the total resistance of the ship, the effective horsepower could be calculated using Equation 13.4.

$$EHP = \frac{R_T v_p}{745.7 \frac{W}{hp}} \tag{13.4}$$

The effective horsepower needed for a design speed of 21 knots is 48254.62. This is assuming an engine with an efficiency of 70%. The table for this calculation is included in Appendix 6.

13.2 Powering

With the minimum amount of horsepower known from the ship resistance calculations, an appropriate engine could then be selected. The MAN B&W S80ME-C8.2 eight cylinder slow speed diesel engine was chosen because it is capable of providing 48276.80 horsepower at 84 RPMs (see Figure 13.2). This is just above the horsepower necessary to power the ship under the speed requirement of 21 knots. The low operating shaft RPMs eliminates the need for a reduction gear box, which otherwise would be necessary to prevent cavitation on the propeller.

Figure 13.2: MAN B&W S80ME-C8.2

14.0 MARPOL Regulations

In addition to the details provided in the previous chapters, certain IMO regulations must be met. These include MARPOL rules related to the protection of fuel tanks, emissions of NO_x, emissions of SO_x, and the energy efficiency design index.

Marine diesel engines installed on a ship that was fabricated on or after January 1st of 2011 must be in accordance to the following regulations regarding NO_x Emmisions (measured as total weighted emission of NO_2):

1. 14.4 g/kWh when n is less than 130 rpm (n = rotations per minute of the crankshaft)
2. $44 \cdot n^{(-0.23)}$ g/kWh when n is 130 or more but less than 2,000 rpm

3. 7.7 g/kWh when n is 2,000 rpm or more

Ships must take necessary precautions to ensure that fuels are not used in exclusive economic zones and pollution control zones if the sulfur content of the fuels by mass exceeds 3.50% for ships built before January 18th of 2014 and 0.50 % for ships constructed before January 1st of 2020.

EEDI is the indication of energy efficiency by CO_2 Emissions measured in grams per cargo carried (ton mile). The EEDI of a ship can be calculated using the flowing equation:
EEDI = (CO_2 from propulsion system＋CO_2 from auxiliary －CO_2 emission reduction) / (DWT x Speed). For RO-RO vessels however, the required EEDI is not considered.

15.0 Superstructure and Manning

The superstructure for *Calypso* is 8 meters tall, 20 meters long, and 32 meters wide, yielding a total of 1,920 m^2 of functional space. It consists of 3 floors to accommodate a crew of 12 and it is located at the bow of the ship to provide a better field of vision for navigation. Extra cabins are included to accommodate visiting members. Additionally, it will deliver eveyday comodoties such as a kitchen, reading and meeting rooms, a gym, and a few TV rooms.

16.0 Registration and Classification

Calypso is registered in the United States of America and is designed to the American Bureau of Shipping classification.

17.0 References

American Bureau of Shipping (2012). *Rules for Building and Classing Steel Vessels*. Retrieved from http://ww2.eagle.org/content/eagle/en/rules-and-resources/rules-and-guides.html

Kristensen, H. O., & Lützen, M. (2012). Prediction of Resistance and Propulsion Power of Ships. *Clean Shipping Currents*, *1*(6).

Parsons, Michael G. (2003). "Parametric Design." *Ship Design and Construction:*11-1-1-50. Print.

Papanikolaou, A. (2014). Selection of Main Dimensions and Calculation of Basic Ship Design Values. In *Ship Design- Methodologies of Preliminary Design* (1st ed., p. 70). New York, NY: Springer Netherlands.

Pawlowski, M. (1999). Subdivision of RO/RO ships for enhanced safety in the damaged condition. *Marine Technology and SNAME News*, *36*(4), 194

Quarter Ramp. (2012). Retrieved December 1, 2015, from http://www.ttsgroup.com/Articles/Quarter-Ramp/

RORO (Roll On Roll Off). (2010). Retrieved December 1, 2015, from http://www.exship.com/roll_on_roll_off.aspx

Takahashi, H., Gotō, A., Abe, M., & Kokudo Kōtsūshō Kokudo Gijutsu Seisaku Sōgō Kenkyūjo. (2006). *Study on standards for main dimensions of the design ship =: Senpaku no shuyō shogen no kijun ni kansuru kenkyū*. S.l.: s.n..