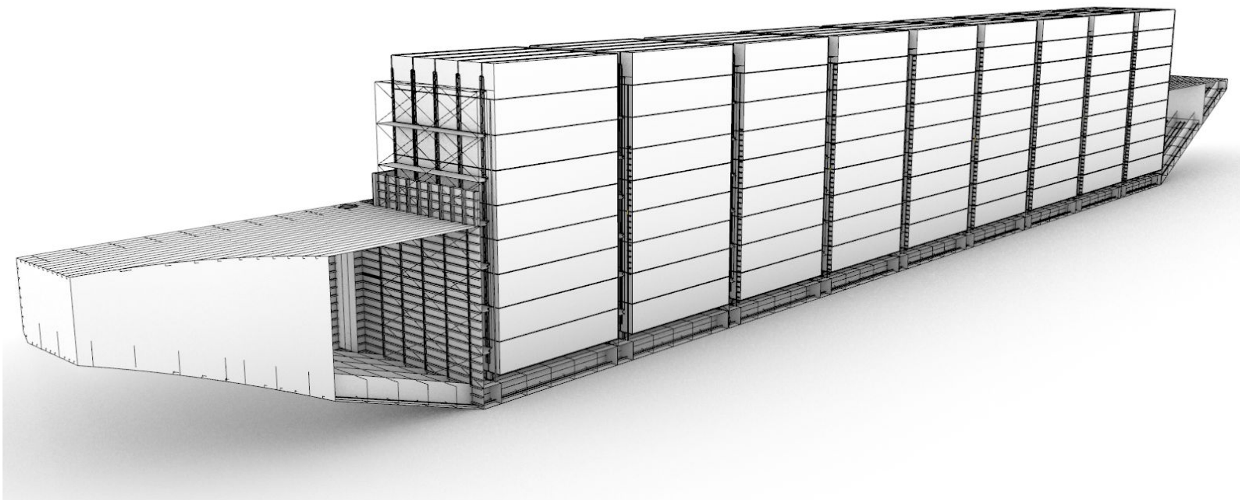
Articulated Tug and Barge: Container Carrying

Focus: Barge Design with Tug Powering Specifics



2019-2020 Dr. James A. Lisnyk Student Ship Design Competition

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Preface

This report is a contribution to the 2020 Dr. James A. Lisnyk Student Ship Design Competition organized by the Society of Naval Architects and Marine Engineers (SNAME) and the American Society of Naval Engineers (ASNE).

The members of the group are all students in their fourth year of either a four-year program in Naval Architecture B.E. being in the Intern or a 3rd Assistant Engineer License Programs, or a four and a half year Naval Architecture B.E. being in the 3rd Mate License Program at the State University of New York (SUNY) Maritime College in New York.

First, we would all like to thank our Advisor, Professor Charles Munsch at SUNY Maritime for directing our efforts time and time again. Special thanks to Robert Hill and Professors George Pietre and David Gerr for assistance throughout the duration of this project.

Last, but not least, we would like to thank family, friends, and others for all the support, patience, and understanding of the rigorous work put into this project over the course of several semesters both in school and at home.

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1. Owner's Requirements

1.1 Introduction

A major national cargo liner operator intends to produce an ATB with container carrying capabilities to ensure quick turn over of cargo.

1.2 Trade Route

Gulf of Mexico- Southeastern Coast of the Continental U.S.

A typical round-trip voyage covers about 2,400 nautical miles in 11 days calling at two ports. Ports of call may vary, but a typical voyage will go from New Orleans, LA to Charleston, SC. The total cargo volume carried on one round trip is loaded at the departure port and discharged at the arrival port.

1.3 Principle Cargo Types - Loading and Discharging Means

1. ISO standard 40' containers in holds loaded and discharged via shore side cranes
2. ISO standard 40' containers on weather deck loaded and discharged via shore side cranes

1.4 Limiting Particulars

	BARGE	**TUG**
LOA	Max 600 ft	Max 200ft
BEAM	Max 100 ft	Max 45 ft
DEPTH	Max 45 ft	Max 45ft
DRAFT	25ft design	21 ft
AIR DRAFT	100ft maximum	140ft maximum

Table 1: Limiting Particulars

1.5 Speed, Range, and DWT

Trial speed at Design Draft- 10 knots

Range- 3,000 nautical miles at 10 knots and 0.90 MCR with 10% fuel remaining.

1.6 Classification

ABS

1.7 Complement

The minimum manning requirement for tug is 7 people. The crew will live on the tug full time since the barge does not require people to live on board. Berthing and hotel services to be provided for up to and including 10 crew members on the tug.

1.8 Special Design Considerations

In developing the design, the following considerations shall be addressed, considering at all times the requirements of applicable regulations and/or industry standards.

- Cargo hold design shall include either hatch covered holds or hatchless holds. The specific design pertaining to each will be addressed and designed according to ABS' Regulations.
- Selection of propulsion and auxiliary plants to have enough power to power both the tug and the barge
- Due to the trade route, the tug should be able to dock without the assistance of other tugs

1.9 Applicable Regulations

SOLAS criteria for enhanced crew safety

SubChapter M Requirements

EPA Emissions Requirements

EEDI Requirements

ABS Rules for Building and Classing Steel Barges: Jan 2020

2. Background and Concept Selection

2.1 Background

Shipping by use of containers has been around for over 60 years. Within the past couple of decades, the demand for container shipping has gone up all over the globe. Many companies that ship containers internationally have used ships to get the cargo from Point A to Point B. However, when it comes to shipping containers nationally, ATB's have been utilized in order to get the cargo into more restrictive areas.

2.2 Concept Selection

With the production of many container carrying vessels, one has to question why a company has decided to make a container carrying articulated tug and barge. A container carrying ATB can go places many large container carrying vessels cannot venture. An ATB has two components, the tug and the barge, meaning the barge is able to be left at the dock while the tug is able to do other work. This ensures maximum utilization of the two separate entities, and maximum optimization of the two separate components.

2.3 Vessel Introduction

As stated previously, an ATB has two components, the tug and the barge. The ATB as a whole will meet a wide range of requirements and functionalities. As seen in the Owner's Requirements, the draft, length, breadth, and depth are maximums, this is to ensure that the ATB can enter the most limiting port. This design consideration will allow the ATB to be able to function in a wide variety of ports of call.

The barge will be the focus of this report, whereas the tug will be mentioned as a power requirement. The tug section of the report will have the minimum power required in order to move the barge, and similar information, but that is all the information that will be given on the tug. The barge, however, will have a complete design and information to go along with it.

2.4 Area of Operation

The area of operation was determined by two major factors:

- Jones Act
- Need for container transportation along the coast

In the United States, container terminals are often located near other shipping hubs such as fuel terminals and dry bulk terminals. The fact that container terminals are located near other hubs or ports, is why New Orleans, LA, to Charleston, SC, was chosen as a route, as seen in *Figure 1*.

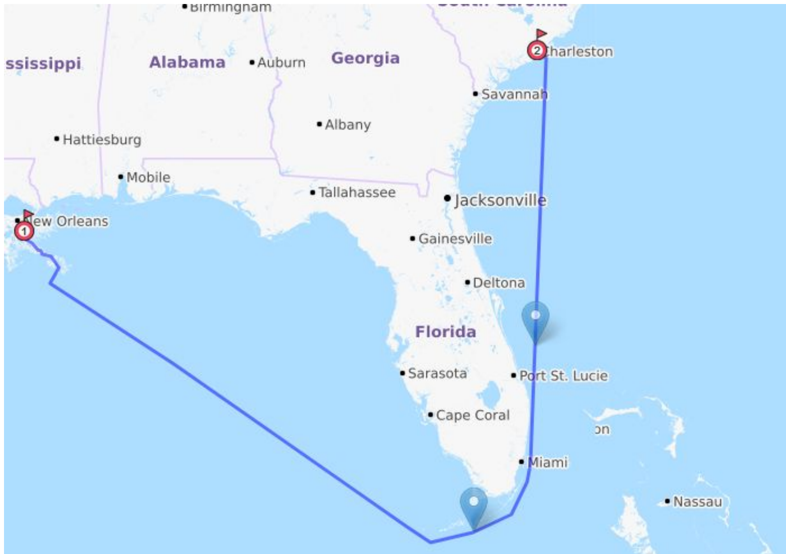

Figure 1: Area of Operation

The two ports chosen each have limiting characteristics due to their locations, so an ATB, when compared to a container carrying vessel, will be able to go where the larger vessel cannot venture. This specific ability to go in shallower waters can be more desirable to the owner since it can go into more restrictive areas.

A round trip between New Orleans and Charleston is about 2,400 nautical miles. The steaming time involved in the trip is approximately 10 days and port time will be around 1 day. Time has been added to the overall steaming time to account for any unplanned events such as weather, accidents, or maintenance. This trip once the steaming and port time is added together is 11 days, this will allow for 33 round trips to allow for a maximized use of the ATB with operation 360 days a year.

3. Tug Specifications

3.1 Manning Estimate

An ATB requires a significantly smaller crew size when compared to larger vessels. A total crew size of seven is required in order to operate an ATB, but more can be utilized. Below in *Table 2*, is a breakdown of the crew and the average cost to employ them on an annual basis.

Crew	Quantity	Cost
Captain	1	$100,000
Chief Mate	1	$85,000
2nd Mate	1	$80,000
Chief Engineer	1	$100,000
Assistant Engineer	1	$75,000
Utility/ Deckhands	2	$40,000

Table 2: Manning Breakdown

The deck department will have three crew members, the engine department will have two crew members, and there will be two utility hands to help out either department. *Table 2*, also shows the average salary depending on their position, this is just an average so the salaries can vary higher or lower depending on the employer.

3.2 Propulsion Plant Trade-Off

Our suggested power plant features three EMD 16E23B sixteen cylinder engines. These are dual-fuel engines and are set up in a diesel-electronic configuration. The engines have the capability to run with up to 95% natural gas to 5% Diesel fuel. Due to the addition of scrubbers along with the usage of low sulfur diesel, our vessel will meet the environmental restrictions on emissions for the foreseeable future. However, despite the advantages of the scrubber system it does have some drawbacks. Since the scrubbers are mounted directly to the engines themselves, the size of the unit nearly doubles. This means that accessing and working on the unit will be slightly more time-consuming. The pros do outweigh the cons, however, as you will be operating with very low SOx and NOx emissions and will have to worry less about exhaust pipe corrosion.

3.3 Major Systems and Engine Equipment

As stated in *Section 3.2*, we have three EMD 16E23B sixteen cylinder engines to serve as our main propulsion generators which together generate up to 12,000 BHP. We also have an additional generator to handle any auxiliary loads. The capacity of that generator is dependent upon the requirements of the equipment installed on the tug, which is up to the owner. This would include bridge electronics, anchor windlass, steering motors, capstans, pumps, and etc.

3.4 Speed and Power Analysis

We calculated the power necessary to move the vessel by computing the barge resistance in Maxsurf: Resistance. Using our barge's characteristics as inputs we determined that in order to make 10 knots the required horsepower is approximately 12,000HP. The speed versus power curve that resulted from this resistance test can be seen in *Appendix A*.

3.5 Endurance Range and Route Trade-Off

Using a specific fuel consumption estimate of 0.054 Gal/hr for diesel fuel, we determined that the fuel consumption for three 4000 BHP engines for our tug at full rpm is 648 Gal/hr. Given our round trip distance is approximately 2,400 nautical miles, this means that our total fuel consumption is 588 tons, roughly 160,000 gallons, required for a roundtrip. Therefore, to be able to make the trip the tug would need at least 588 tons for the main generators but also an additional 15-20 tons allocated for the auxiliary loads like lighting and pump usage. It is important to remember that the 588 tons of fuel is with the tug operating at full rpm for the entire voyage, which will most likely not happen.

4. Barge Principal Characteristics

4.1 Table of Principal Characteristics

Principal characteristics are characteristics that are of the most importance. Below in *Table 3*, the principal characteristics of the barge are listed.

Barge	Value	Units
Length Overall	567	ft
Length Between Perp.	567	ft
Beam	89.5	ft
Design Draft	25	ft
Depth	45	ft
GM(t)	6.9	ft
C_b	.86	-
Cargo Capacity	729	Containers
Displacement	30,822	LT
Complement	0 (Unmanned)	People

Table 3: Barge Principal Characteristics

5. Barge Hull Form Development

All designs end up going through the design spiral, and this design was no different. The start of the design process began with the Owner's Requirements. From there many ideas came and went until we ended up with our final design which is only a Preliminary Design and takes 300 Man Days of work. This project ended up going around the design spiral at least several times before we reached the design we have today. However, the most important part of the spiral however was ensuring that the design met ABS and IMO regulations. In order to complete this project, and make a Complete Design, it would take 60,000 Man Days to complete. These man-days could be spread out over multiple people to ensure the design is checked by different eyes to ensure that it is fit for building.

5.1 Barge Hull Design

A hull design can best be seen by the Lines Plan, which can allow one to have a general idea of how the hull is to be formed. A Lines Plan shows three different projections: body plan, the half breadth plan, and the sheer plan. The body plan allows one to have a view of the vessel's stations. Stations intersect the hull and form a curved line at the point of intersection. These sections are split into two halves, the right half of the body plan being the sections forward of amidships and the after sections being on the left half of the body plan. The half-breadth plan on the other hand shows the vessels water lines as they would appear on the vessel's hull. The water lines have nothing to do with how the vessel actually reacts with what it is floating in, this is just an imaginary plane placed to gain a better understanding of the hull. Lastly, the sheer plan runs from the bow to the stern along a centerline plane. In this view, buttock lines are projected onto this plane to form curved lines along the length of the hull.

The Barge Lines Plan will be attached in *Appendix B*.

6. Barge Hull Curves and Properties

6.1 Hull Form Properties

The hull form varies depending on Archimedes Principle which states, an upward buoyant force is exerted on a body immersed in a fluid, which is equal to the weight of the fluid the body displaces. By using this principle we will be allowed to study the hull and how different variables will affect the buoyancy of the vessel. This will result in the best possible hull form for our vessel within the design characteristics.

6.2 Hydrostatic Curves

Figure 2 depicts the hydrostatic curves for the barge. These curves were taken from Maxsurf: Stability once the barge was loaded and the correct vertical center of gravity was calculated. These curves can show varying hydrostatic properties such as displacement, moment to trim one inch, and the wetted area when compared to different drafts.

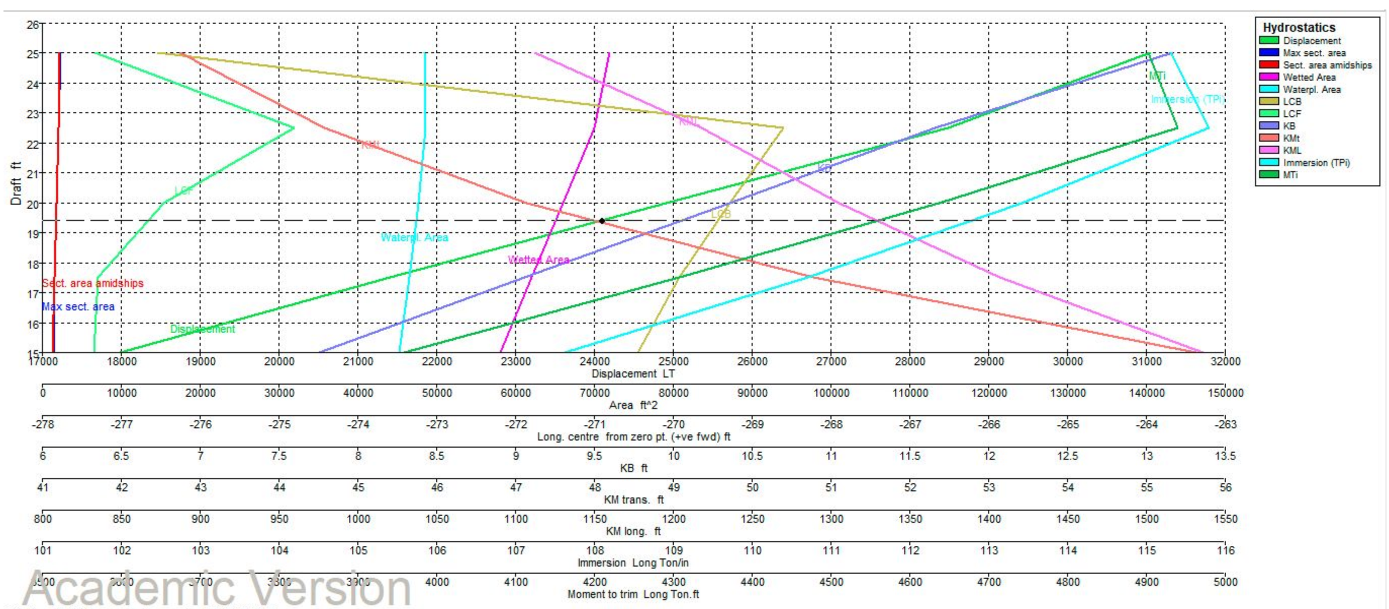

Figure 2: Hydrostatic Curves- Barge

6.3 Curves of Form

Figure 3 shows the Curves of Form which show the coefficients that are necessary to know for the barge at different angles of heel in the Lightship Condition. This was pulled from Maxsurf: Stability once the tanks, compartments, and loads were added to the system.

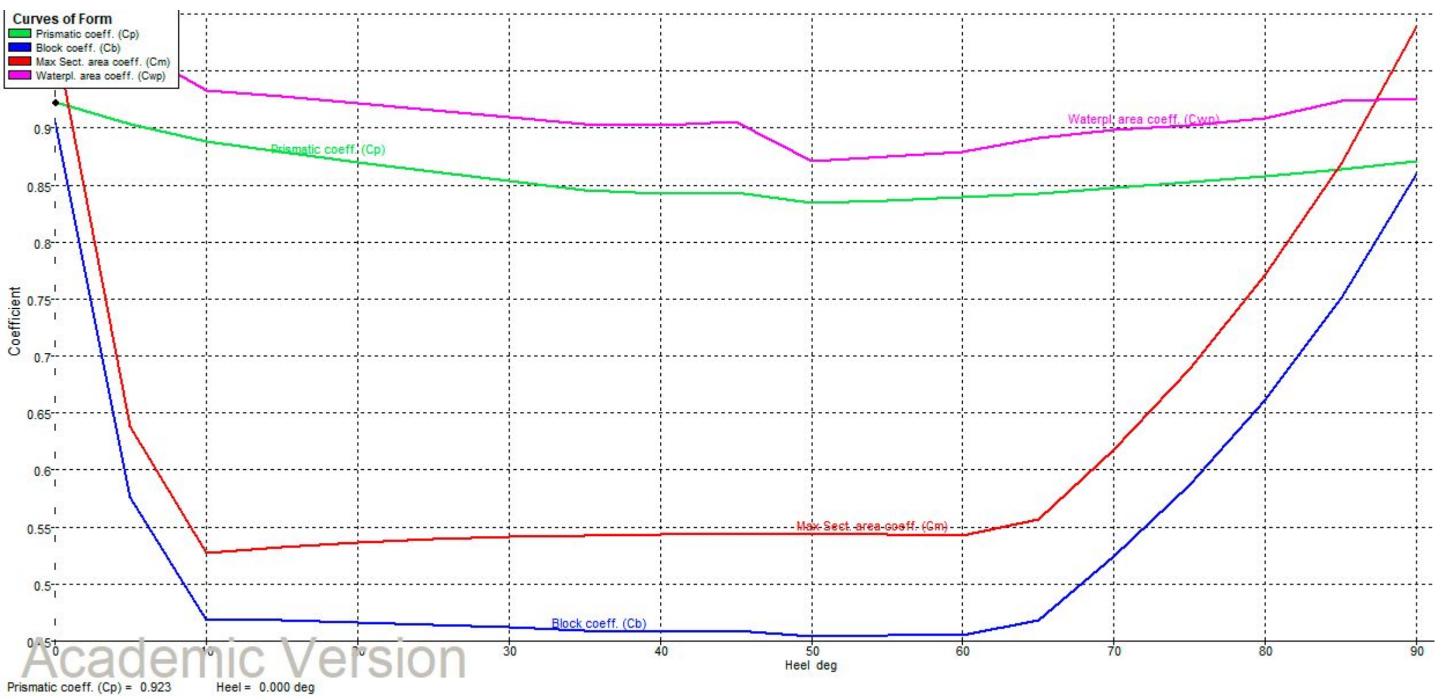

Figure 3: Curves of Form - Barge

6.4 Curves of Area

Figure 4, depicts the Sectional Area Curves for the barge in a loaded condition. The figure shows areas of cross-sections up to the design waterline along the length of the barge. As the bow and the stern are mainly above the design waterline, the midbody is what houses most of the shown area.

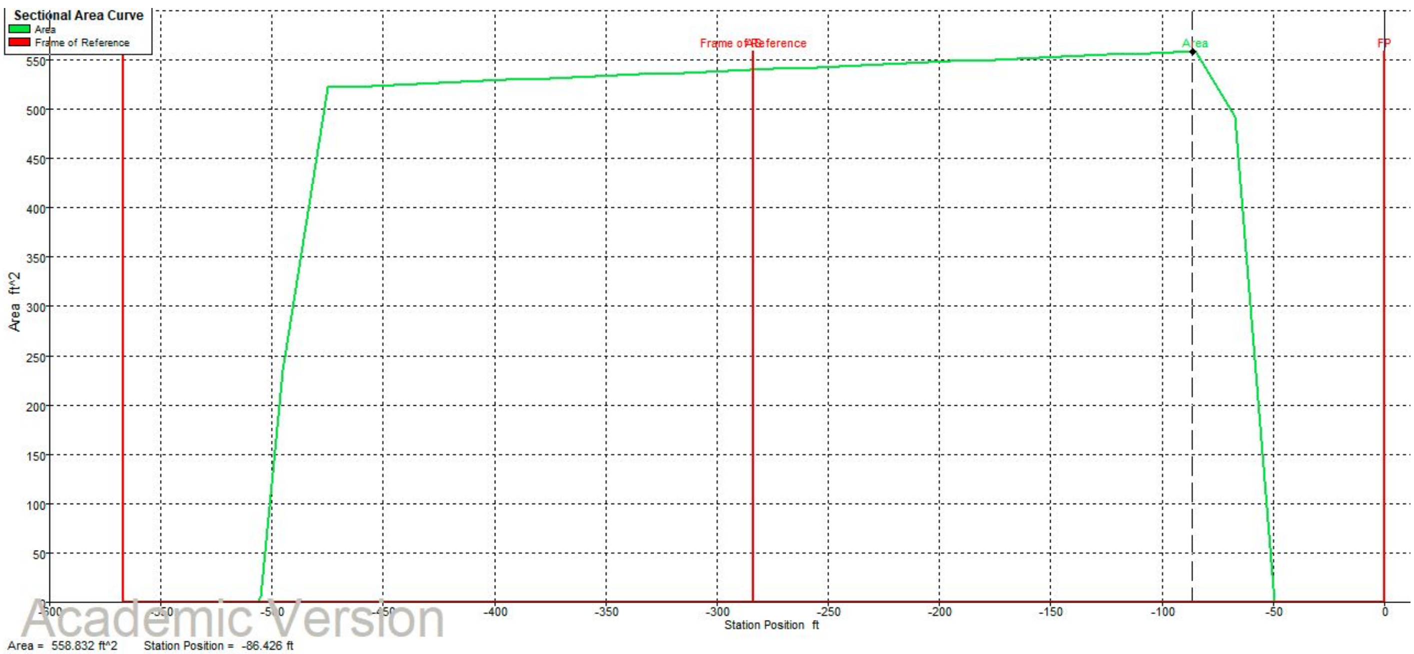

Figure 4: Curve of Area - Barge

6.5 Floodable Length

Figure 5, shows the floodable length curve for the barge. A floodable length curve represents the maximum length that can be flooded along the length of a vessel, in this case the barge. The figure was again pulled from Maxsurf: Stability and was run at different permeabilities. The permeabilities ran were: 85, 90, 95, 98, and 100.

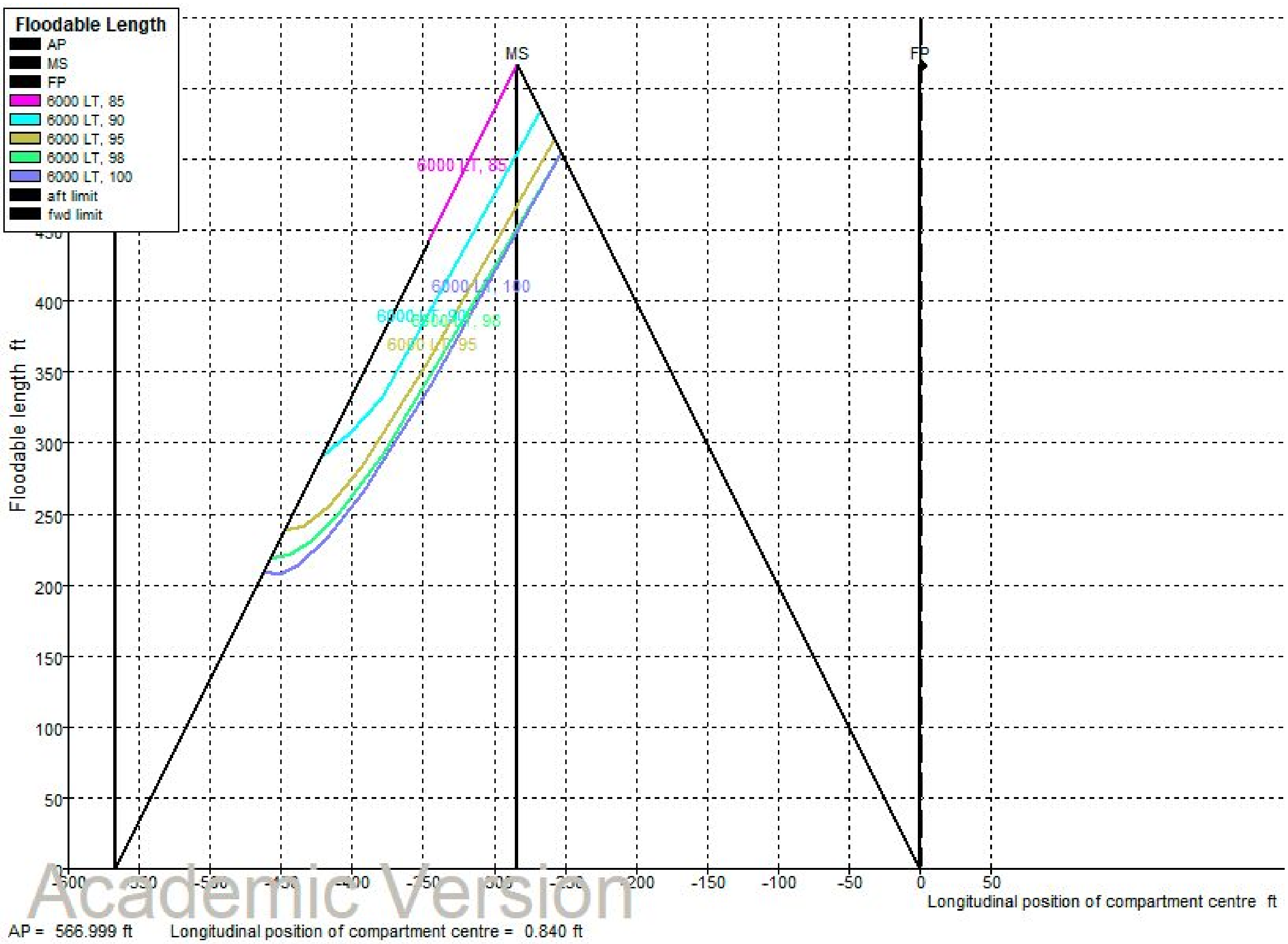

Figure 5: Floodable Length Curve - Barge

6.6 Cross Curves of Stability

Figure 6, shows the Cross Curves of Stability for the barge from Maxsurf: Stability. These curves show the KN values at constant heel angles at different displacements.

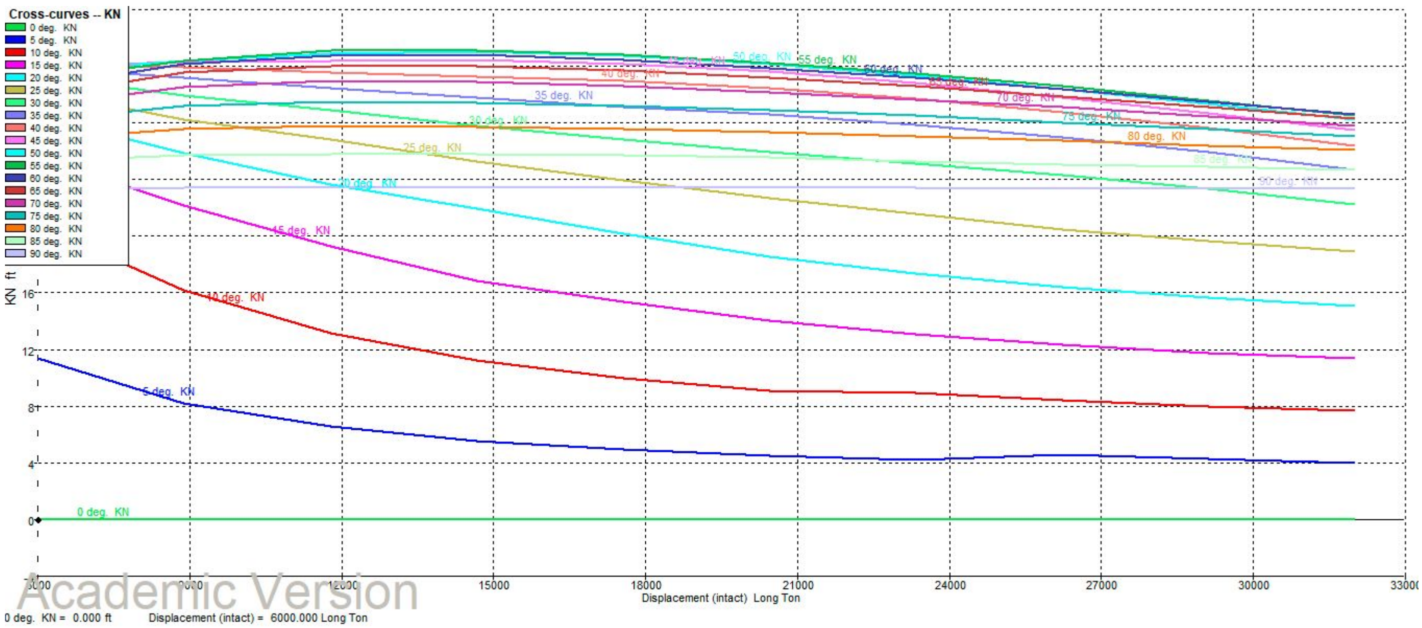

Figure 6: Cross Curves of Stability - Barge

7. Barge General Arrangement

7.1 General Arrangement

A general arrangement provides the basic layout of the vessel, this can include tank plans and capacities, cargo areas, crew berths, and engine room location and layout.

Since the design is an ATB all housing will solely be on the tug since the barge is unmanned, and the same will go for any major machinery that is not used to power the barge. The barge will house generators to power equipment on the barge as well as locations for bilge pumps to pump out any water in the open holds.

7.2 Tank Capacity Arrangement

A tank capacity and arrangements show the tanks and compartments as well as their capacities. *Appendix C* will show the capacity of the tanks, the cargo capacity for the holds, and their locations.

7.3 General Arrangement: Plan View

The General Arrangement Plan View will show the barge from a birds-eye-view. This will allow someone to look down at the barge and see how the barge is laid out on the deck. The Plan View can be seen in *Appendix D*.

7.4 General Arrangement: Profile View

Attached in *Appendix E* is the Profile View of the Barge. The profile view will allow one to see the barge from the side. This can show how high the cargo will be stacked as well as the deck coamings around the cargo hold.

7.3 General Arrangement: Midsection View

The Mid Section View is taken from midships and shows a cutout of the barge. One can see the double bottom as well as the holds and how containers are stacked with the cell guides. This can be seen in *Appendix F*.

7.4 Machinery Arrangement

The main generators for the barge and fire pumps are shown in the proposed machinery layout attached in *Appendix G;* the generator sizing can be seen in *Section 14* of this report. As per IMO, since the barge is technically an open cargo hold barge, it requires a minimum of 3 bilge pumps with at least 66.6 GPM flow rate. Our calculations told us that our required flow rate on our particular barge must not be less than 526 GPM; so using a comfortable extra allowance for the pump, we sized our pumps to be 660 GPM. Since the bilge pumps are not local to the machinery space, they are not represented in the *Appendix G*, the pumps that are visible *in Appendix G* are the fire pumps. The fire pumps were chosen based on ABS requirements stating that the fire pumps could not have a capacity of less than 792 GPM. To ensure adequate pressure at the nozzle all over the barge, we sized our pumps to be capable of 740 GPM.

8. Barge Structural Design

We based our design on the requirements set forth in the *ABS Steel Barges* published in January 2020. We reviewed each applicable chapter of the rules and performed all required calculations to obtain our required minimum thickness values and appropriate section modulus calculations to ensure our barge would have the proper strength for our design and its purpose.

Below in *Figure 7*, you will see two (2) views of our designed barge in its loaded configuration for service. As indicated in *Section 10*, we have designed our barge to carry 729 FEU's with 125 of those slots being reefer in Hold 5.

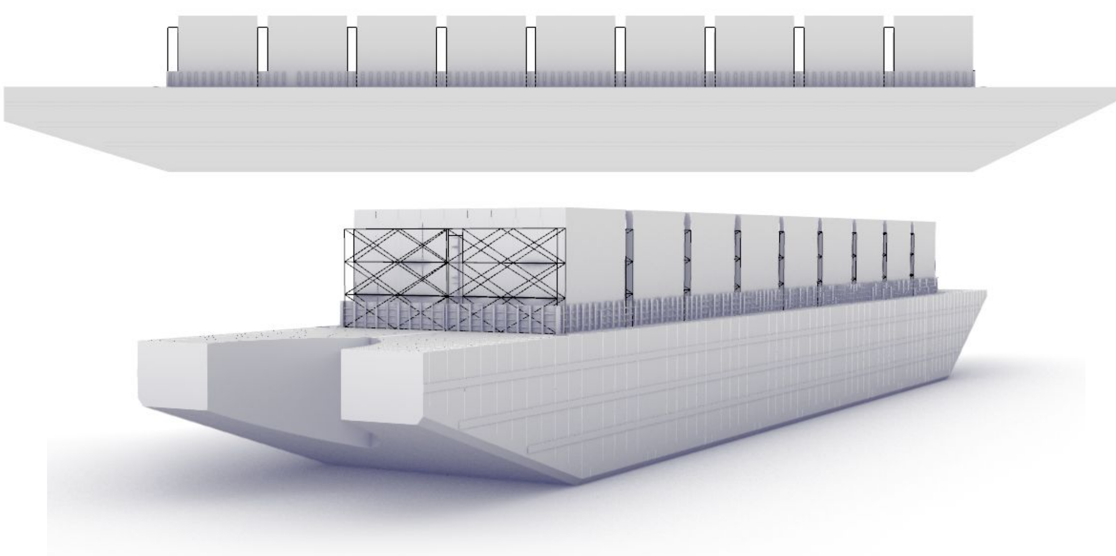

Figure 7: Barge Views

8.1 Rules and Regulations

To ensure that we followed the rules and regulations set forth by ABS, we prepared an excel database. This database included each applicable rule and its calculation and went through each chapter performing each applicable calculation. These calculations were then stored and saved so the data was easily accessible for modification and recalculations in the event there were changes to the design and the need to recalculate arisen.

8.2 Midbody Structure

We went through and calculated the minimum shell plating thickness, main framing properties, the longitudinal and watertight bulkheads, and all applicable members of the barge according to the ABS rules based on our dimensions of the vessel and ABS interpretation of how those values are modified for the calculations.

The most important calculation was one of the first calculations listed, and that was the calculation to determine our required section modulus for our current design. This calculation required the completion and results from some additional members prior to its calculation, which we prepared via excel to ensure our sizing of the barge members was adequate.

The Longitudinal Hull Girder Strength [SMr] calculation is derived by the following formula.

$$SM_R = KSM_b \quad \text{cm}^2 - \text{m}\left(\text{in}^2 - \text{ft}\right)$$

To complete this calculation, we had to calculate and identify the other variables in the equation, specifically K and SMb. To obtain these values we calculated our Still-Water Bending Moment via excel.

We built an excel table to calculate our Lightship Weight per foot and also calculated a distributed cargo loading plan per hold. This allowed the cargo load weight to be distributed across the barge in specific holds to properly measure the Still-Water Bending Moment. These calculations can be seen in *Table 4* below.

Flat Bottom Barge		
L	567.00	ft
B	89.50	ft
D	45.00	ft
T	25.00	ft
C_B	0.858	ft
Δ	31,100.36	LT
FP	-26.25	ft
⊗	-255.00	ft
AP	-484.00	ft

Steel Density		
ρ =	490.00	lb / ft^3

Salt Water Density		
ρ =	35.00	ft^3 / LT

40 ft Container		
L	40.00	ft
B	8.00	ft
H	8.00	ft
Weight	67,200.00	lbs
Weight	30.00	LT
Weight per end (LT) =		15

Collision Bulkhead from FP		
Between	21.5'	34'
Using	30	ft
Location	-30	ft

Hold	WT per Hold	Hold Length	WT per ft
1	1080	40	27.00
2	3510	85	41.29
3	4050	85	47.65
4	4590	85	54.00
5	4860	85	57.18
Total Cargo WT	18,090.00		

Midbody							Centroid				
ITEM	thickness (in)	b (in)	h (in)	A = bh (in^2)	Quantity	Σ A * Q	h from keel (ft)	Yi (in)	A*Yi	A*Yi^2	i_o = bh^3 / 12
Box Girder Upper Plate	1.7500	96.000	1.750	168.000	1.000	168.000	44.93	539.13	90,573.00	48,830,168.63	42.88
Box Girder Side Shell	1.7500	1.750	120.000	210.000	2.000	420.000	39.85	478.25	100,432.50	48,031,843.13	252,000.00
Box Girder Bottom Plate	1.7500	96.000	1.750	168.000	1.000	168.000	34.93	419.13	70,413.00	29,511,848.63	42.88
Box Girder Upper Stiffener	1.2500	1.250	4.000	5.000	3.000	15.000	44.69	536.25	2,681.25	1,437,820.31	6.67
Box Girder Side Stiffener 5	1.0000	3.000	1.000	3.000	2.000	6.000	43.04	516.50	1,549.50	800,316.75	0.25
Box Girder Side Stiffener 4	1.0000	3.000	1.000	3.000	2.000	6.000	41.37	496.50	1,489.49	739,524.83	0.25
Box Girder Side Stiffener 3	1.0000	3.000	1.000	3.000	2.000	6.000	39.71	476.49	1,429.48	681,133.88	0.25
Box Girder Side Stiffener 2	1.0000	3.000	1.000	3.000	2.000	6.000	38.04	456.49	1,369.46	625,143.88	0.25
Box Girder Side Stiffener 1	1.0000	3.000	1.000	3.000	2.000	6.000	36.37	436.48	1,309.45	571,554.85	0.25
Box Girder Lower Stiffener	1.2500	1.250	4.000	5.000	3.000	15.000	34.69	416.25	2,081.25	866,320.31	6.67
Side Shell	1.2500	1.250	370.800	463.500	1.000	463.500	17.50	210.00	97,335.00	20,440,350.00	5,310,653.22
Longitudinal Bulkhead	1.2500	1.250	396.000	495.000	1.000	495.000	17.50	210.00	103,950.00	21,829,500.00	6,468,660.00
Side Shell Stiffener 6	0.5000	9.000	4.000	6.250	2.000	12.500	31.00	372.00	2,325.00	864,900.00	48.00
Side Shell Stiffener 7	0.5000	9.000	4.000	6.250	2.000	12.500	29.00	348.00	2,175.00	756,900.00	48.00
Side Shell Stiffener 8	0.5000	9.000	4.000	6.250	2.000	12.500	27.00	324.00	2,025.00	656,100.00	48.00
Side Shell Stiffener 9	0.5000	8.000	4.000	5.750	2.000	11.500	25.00	300.00	1,725.00	517,500.00	42.67
Side Shell Stiffener 10	0.5000	8.000	4.000	5.750	2.000	11.500	23.00	276.00	1,587.00	438,012.00	42.67
Side Shell Stiffener 11	0.5000	8.000	4.000	5.750	2.000	11.500	21.00	252.00	1,449.00	365,148.00	42.67
Side Shell Stiffener 13	0.5000	7.000	4.000	5.250	2.000	10.500	17.00	204.00	1,071.00	218,484.00	37.33
Side Shell Stiffener 14	0.5000	7.000	4.000	5.250	2.000	10.500	15.00	180.00	945.00	170,100.00	37.33
Side Shell Stiffener 15	0.5000	7.000	4.000	5.250	2.000	10.500	13.00	156.00	819.00	127,764.00	37.33
Side Shell Stiffener 16	0.5000	7.000	4.000	5.250	2.000	10.500	11.00	132.00	693.00	91,476.00	37.33
Side Shell Stiffener 17	0.3750	7.000	4.000	3.984	2.000	7.969	9.00	108.00	430.31	46,473.75	37.33
Side Shell Stiffener 18	0.3750	7.000	4.000	3.984	2.000	7.969	7.00	84.00	334.69	28,113.75	37.33
Side Shell Stiffener 20	0.3750	7.000	4.000	3.984	6.000	23.906	3.33	40.00	159.36	6,373.73	37.33
Side Shell Stiffener Bilge Angle	0.5000	4.000	9.000	6.250	1.000	6.250	1.05	12.60	78.75	992.25	243.00
Inner Bottom Plate	1.2500	441.000	1.250	551.250	1.000	551.250	4.75	57.00	31,421.25	1,791,011.25	71.78
Inner Bottom Plate Upper Stiffener	0.4375	4.000	6.000	4.184	16.500	69.029	4.25	51.00	213.36	10,881.53	72.00
Wing Tank Deck 1	0.5000	96.000	0.500	48.000	1.000	48.000	20.98	251.76	12,084.48	3,042,388.68	1.00
Wing Tank Deck 1 Stiffeners	0.4375	4.000	6.000	4.184	3.000	12.551	20.65	247.80	1,036.69	256,892.90	72.00
Wing Tank Deck 2	0.5000	96.000	0.500	48.000	1.000	48.000	6.98	83.76	4,020.48	336,755.40	1.00
Wing Tank Deck 2 Stiffeners	0.4375	4.000	6.000	4.184	3.000	12.551	6.65	79.80	333.85	26,641.29	72.00
Side Girders	0.5000	0.500	60.000	30.000	5.000	150.000	2.50	30.00	900.00	27,000.00	9,000.00
Bottom Longitudinals	0.5000	4.000	8.000	5.750	15.000	86.250	0.31	3.72	21.39	79.57	170.67
Bottom Plate	1.2500	516.000	1.250	645.000	1.000	645.000	0.03	0.36	232.20	83.59	83.98
Bilge Plate	1.2500	1.250	12.600	15.750	1.000	15.750	1.05	12.60	198.45	2,500.47	208.37
			1/2 Sums =	2,961.00		3,572.97			540,892.65	184,148,097.36	12,041,942.69

Table 4: Still Water Bending Moment

This is our initial table, which we used to calculate the area, centroid and moment of inertia for each member. We utilized these values to calculate the height of our neutral axis, our inertia ref, and our inertia at the neutral axis. Once we had these values we were then able to calculate the SM of our keel and SM of our deck at the current sizing of the members, as seen below in *Figure 8*.

Midbody		
Total Area =	7,145.95	in^2

H of NA	inches	ft
	182.67	15.22

Inetia, ref =	392,380,080.10
Inetia, NA =	153,926,349.55

SM keel	842,638	in^3
	70,220	ft-In^2

SM deck	430,771	in^3
	35,898	ft-In^2

SM Req'd	49,763		ft-In^2
H36	0.72	35,829	ft-In^2
H40	0.68	33,839	ft-In^2

Figure 8: Section Modulus Calculation

Once that was completed, we then prepared an estimated Lightship Weight calculation table where we assigned each member its own line and broke the vessel up by the bow, midship and stern. From there, we calculated the weight of each section by multiplying the thickness of the member by the breadth and the height in ft and then multiplied that by the density of steel at 490 lb/ft^3, which was then converted to long tons.

Once each appropriate section was calculated, we then interpolated the weight as an even distribution across each section of the barge for our lightship weight distribution, as seen in *Table 5*.

	Total LT	Length	LT / ft
Bow	542	77	7.04
Midbody	5,617	407	13.80
Stern	606	83	7.30
	6,765		

Table 5: Lightship Weight Calculation

From there we moved onto preparing the cargo load distribution table to calculate the cargo weight distribution and calculate our full load VCG, as seen in *Table 6*.

Cargo Balanced Load

Δ Keel [ft]	Tier	Hold 5	Moment	Hold 4	Moment	Hold 3	Moment	Hold 2	Moment	Hold 1	Moment	Hold 5	Hold 4	Hold 3	Hold 2	Hold 1	Total
11.25	1	30	6075	30	6075	25	5062.5	25	5062.5	15	1518.75	18	18	18	18	9	81
19.75	2	30	10665	30	10665	25	8887.5	25	8887.5	15	2666.25	18	18	18	18	9	81
28.25	3	30	15255	30	15255	25	12712.5	25	12712.5	15	3813.75	18	18	18	18	9	81
36.75	4	30	19845	30	19845	25	16537.5	25	16537.5	15	4961.25	18	18	18	18	9	81
45.25	5	30	24435	30	24435	25	20362.5	25	20362.5	15	6108.75	18	18	18	18	9	81
53.75	6	30	29025	30	29025	25	24187.5	20	19350	15	7256.25	18	18	18	18	9	81
62.25	7	30	33615	25	28012.5	25	28012.5	20	22410	10	5602.5	18	18	18	18	9	81
70.75	8	30	38205	25	31837.5	25	31837.5	15	19102.5	10	6367.5	18	18	18	18	9	81
79.25	9	30	42795	25	35662.5	25	35662.5	15	21397.5	10	7132.5	18	18	18	18	9	81
			219915		200812.5		183262.5		145822.5		45427.5	4860	4590	4050	3510	1080	18090
												162	162	162	162	81	729

Σ Cargo	18090
Σ Containers	729

Cargo	Σ Moments	795240
	Σ Weight	18090
	VCG	43.96

Lightship	Weight	6765
	Moment	152214
	VCG	22.50

Full Load	Weight	24855
	Moment	947454
	VCG	38.12

Table 6: Vertical Center of Gravity Calculation

We arranged *Table 6* to calculate the moment of each container separately to account for varying loads in each hold and position independently. We then utilized the SUMPRODUCT function within excel to calculate the number of containers per tier and each projected container weight to approximate our cargo load weight.

Once this was completed we were able to utilize that data and combined with our Lightship projections were able to calculate a full load VCG of 38.12ft, a container weight of 18,090 LTs, and a total carrying capacity of 729 containers.

Once our lightship weight per ft and cargo weight per ft were calculated, we then established an excel database to calculate our buoyancy, weight, shear, and bending moment to prepare our load, shear, and bending moment graphs. As our vessel is designed to carry FEU's, we established Hold 1 to carry 1 bay of FEU's and Holds 2 to 5 to hold two bays of FEU's with a five (5) ft transverse walkway between them for container access.

This established our Hold dimensions to eighty-five (85) ft overall between watertight bulkheads, our design called for five (5) cargo holds. We equipped Hold 1 and the forward part of Hold 2, to be able to hold TEU's if needed and added additional pillars to hold one and two for the accommodation of TEU's. The additional pillars can be seen in the top-down view below showing Hold 1 and Hold 2 forward, with the additional row of pillars in the middle, as seen in *Figure 9*.

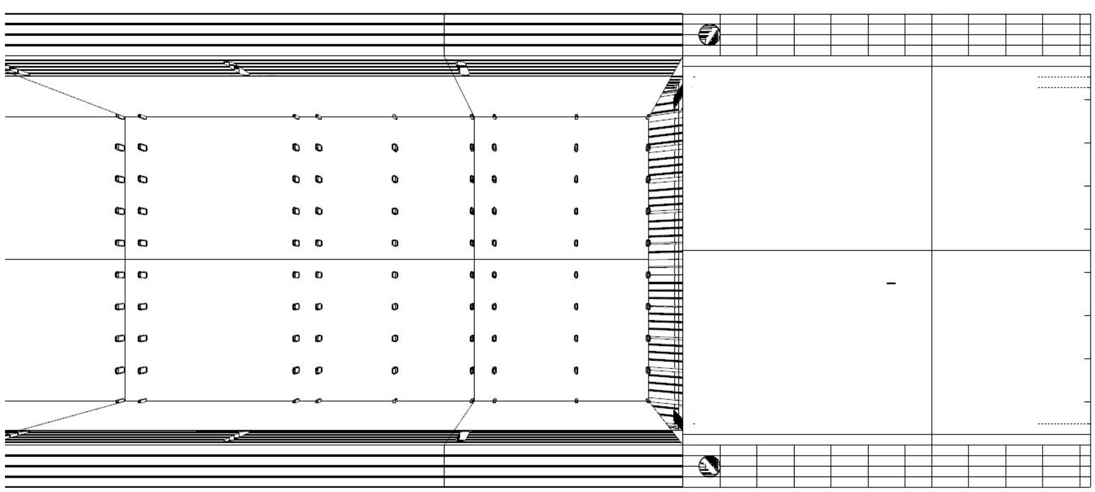

Figure 9: Hold View

We based our pillar dimensions on the corner casting size of the containers to ensure the entire casting corner would be resting on the pillar and fully supported when they are between containers and sharing a double load.

We determined the weight per casting based on a max load FEU of 30 LT's at a tier height of nine (9) containers. We determined the single point load is 151,200 lbs, while a shared load is 302,400 lbs as seen in the below Equation.

$$X_A = \left(\frac{\sigma_y}{F.S} * \frac{1}{Load} \right)^{-1}$$

We then calculated safety factor calculations based on the yield strength of steel of 36,000 psi of two (2), three (3), and four (4), as seen in *Table 7*.

Piller Sizing					
Steel	σ_y		Single Point	Double Point	Stack Height
A36	36,000	[psi]	151200	302400	9
F.S =	2	18000			
F.S =	3	12000			
F.S =	4	9000			

Table 7: Pillar Sizing

By utilizing the above formula, we then calculated the required pillar size to pass each safety factor margin.

X Sectional Area for Shared Load				Nominal Size	Check	
F.S =	2 =	16.80	[in^2]	4.125" x 5.5"	22.69	[in^2]
F.S =	3 =	25.20	[in^2]	5" x 5.625"	33.75	[in^2]
F.S =	4 =	33.60	[in^2]	6" x 7.5"	45.00	[in^2]

X Sectional Area for Single Load				Nominal Size	Check	
F.S =	2 =	8.40	[in^2]	3" x 3.75"	11.25	[in^2]
F.S =	3 =	12.60	[in^2]	3" x 3.5"	17.02	[in^2]
F.S =	4 =	16.80	[in^2]	3.75" x 6"	22.50	[in^2]

Table 8: Sectional Area

Our calculations determined that even utilizing a safety factor of four (4), the largest pillar needed would be a 6" x 7.5", which would give us a cross-sectional area of 33.6 in^2. As initially stated our pillars were based on the size of the corner castings of the container and to ensure full coverage of each casting per container on a shared load, as seen in *Table 8*.

That sizing was determined to be a 7"x 16" pillar, giving a cross-sectional area of 112, over three (3) times greater than the required cross-sectional area if utilizing a safety factor of four (4), which is above and beyond what is required, as seen in *Figure 10*.

Selected Pillar	7" x 16"	112	[in^2]
This was selected to fit the size of both corner castings of the containers equally.			

Figure 10: Pillar Sizing

To support the pillars, we placed transverse solid floors under the center of each pillar and doubler plate, as seen below under the corner of each container and also in the midpoint of hold one and two in the event TEU's are carried.

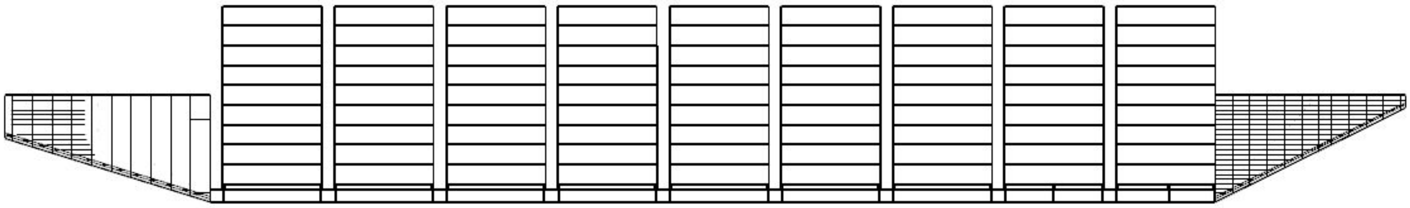

Figure 11: FEU Capability

We determined the height of our solid floors and side girders on the minimum required height from ABS for the double bottom calculation as seen in the Equation below.

$$d_{DB} = 0.384B + 4.13\sqrt{d} \quad \text{in}$$

Based on our barge characteristics, we determined our minimum double bottom height to be 52.6 inches, which is 4.38 ft. We set the double bottom height to 60 inches, 5 ft, for our calculations.

Once the height was determined, we then moved on to calculating the minimum thickness of the side girders. The minimum thickness calculated was .39 inches, which is greater than ⅜ plate. This equated to us using the ⅛ plate as it was the next appropriate size for these members.

The next calculations, which were completed were for calculating the side shell plating, bottom shell plating, shell plating at the ends, bottom forward plating, and the bilge plating. We set the bilge plating to equal the bottom plating for calculation and weight purposes and also for ease of transition during the building process. The following minimum thicknesses are as follows in *Figure 12*.

3-2-2 Shell Plating		
Side Shell Plating Amidships [min t] =	0.58	[in]
Bottom Shell Plating [min t] =	0.53	[in]
Shell Plating at Ends [min t] =	0.41	[in]
Bottom Forward Plating [min t] =	0.64	[in]
Immersed Bow Plating [min t] =	0.55	[in]
Bildge Plating = Bottom Shell Plating [min t] =	0.53	[in]

Figure 12: Shell Plating

We set these as our baseline thickness in our spreadsheet initially for a place holder, which were modified after determining our required SM so that the vessel would pass and have enough strength to operate safely.

We then calculated the SM for the deck longitudinals, and the bottom and side longitudinals, using the ABS Formula below.

$$SM = 0.0041chs\ell^2 \quad \text{in}^3$$

This resulted in a calculated minimum SM required of 4.88 in^3, we chose an angle stiffener of 4" x 4" x ½", which provided us an offered SM of 5.25 in^3. Which passes the minimum required SM calculation.

We then calculated our bottom and side longitudinals utilizing the formula found in 3.5.

$$SM = 0.0041chs\ell^2 \quad \text{in}^3$$

where

c = 1.34 for bottom longitudinals

= 1.25 for side longitudinals

We varied *c* constant based on which member we were calculating and we calculated a minimum SM of 29.42 in^3 for the bottom longitudinals and a minimum SM of 26.44 in^3 for the uppermost side longitudinal.

For these we selected an 8"x 6"x ½" for the bottom longitudinal offering an SM of 30.62 in^3 and a 9"x 4"x 1/2" for the highest side longitudinal. We prepared the *Figure 13* and broke the side longitudinals into groups of 4 to resize them in accordance with the decreasing required SM due to the height decreasing from the deck to the keel.

Side Shell		SM_{SIDE}			off
1	52.64	26.44	Group 1	9x4x1/2	27.50
2	50.64	25.43			
3	48.64	24.43			
4	46.64	23.42			
5	44.64	22.42	Group 2	8x4x1/2	23.32
6	42.64	21.42			
7	40.64	20.41		No Stiff	
8	38.64	19.41			
9	36.64	18.40	Group 3	7x4x1/2	18.81
10	34.64	17.40			
11	32.64	16.39			
12	30.64	15.39			
13	28.64	14.38	Group 4	7x4x3/8	14.84
14	26.64	13.38		No Stiff	
15	24.64	12.37			
16	22.64	11.37			
17	20.64	10.37	Group 5	5x5x3/8	11.22
18	18.64	9.36			
19	16.64	8.36			
20	14.64	7.35			

Figure 13: Side Shell Plating

Please note, that lines 7 and 14 are highlighted yellow indicating there is no stiffener at that height, as that is the intersection line for the wing tanks on the port and starboard side of the vessel. Additionally, the side longitudinals do not start on the midbody until number six (6), as numbers one (1) through five (5) is replaced by the box girder, as seen in *Figure 14* below. The following figure provides the required SM for each individual stiffener along with the selected stiffener for that group and the selected stiffener with the offered SM to the right of it.

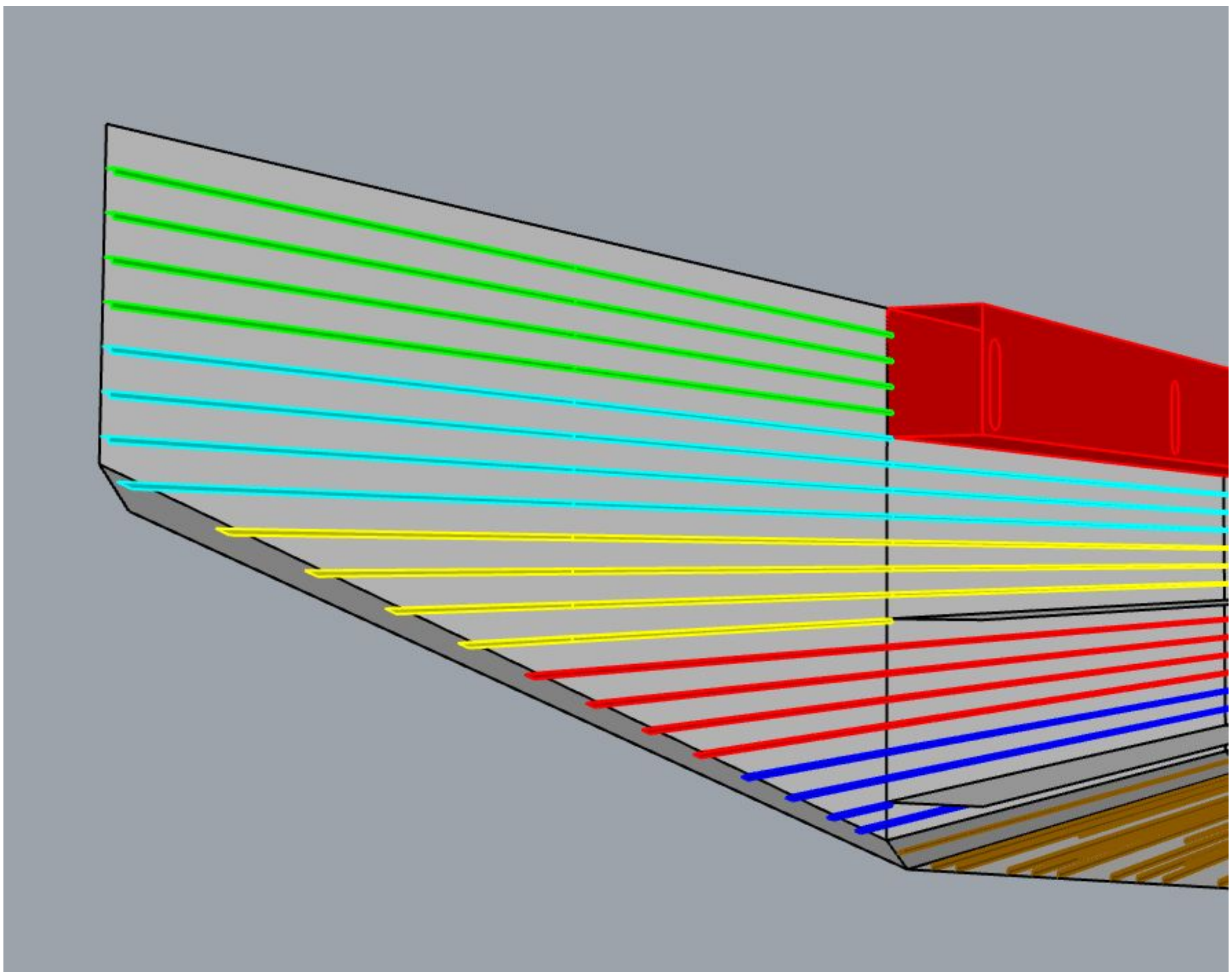

Figure 14: Side Shell Stiffeners

Figure 14 displays a visual layout of the side shell stiffeners grouped by color, along with the box girder shown in red, the wing tank decks in grey, and the bottom longitudinals in brown.

The next calculation we completed was to determine the thickness of our watertight bulkheads utilizing the formula in Section 3-2-6 in the below Equation.

$$t = sk\sqrt{qh}/c + 0.06 \quad \text{in.}$$

For this equation, we utilized the value of 525 as designated for the constant *c* per the rules. This formula gave us a minimum thickness value of 0.36 inches. We utilized ⅜ plate as it was the next nominal size utilizing ⅛ plate increments.

Once we completed the thickness of our watertight bulkheads, we then calculated the SM of the stiffeners that we would need to use to reinforce the plating. In the same Section 3-2-6, it provides you with the minimum SM required for the stiffeners, as seen in the below Equation.

$$SM = 0.0041chs\ell^2Q \quad \text{in}^3$$

For this Equation we utilized the value of 0.56 for the constant *c*, as the stiffeners have both ends attached. This equation provided us with a minimum SM required of 5.00 in^3. We chose a 4” x 4”x 1/2” stiffener which offered an SM of 5.24 in^3, as seen below in *Figure 15*.

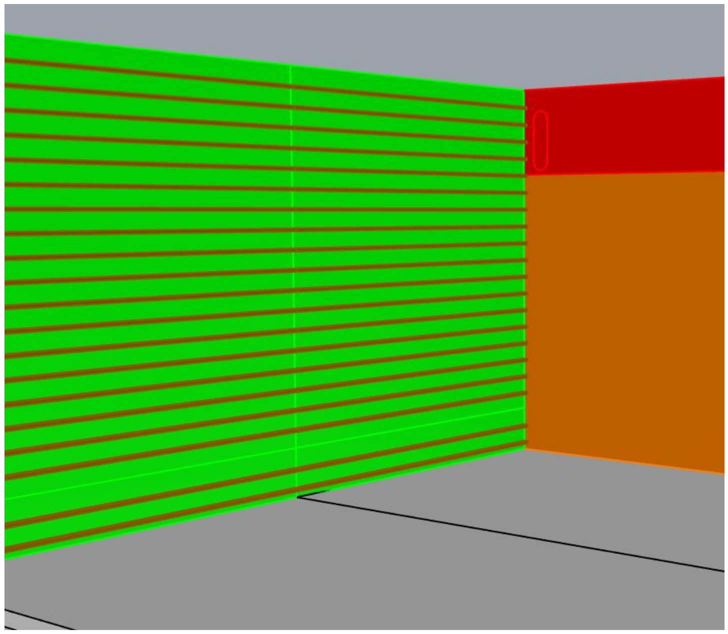

Figure 15: Stiffeners on Watertight Bulkhead

In this figure, you can see the watertight bulkhead (green), the box girder (red), and the longitudinal bulkhead (orange) along with the bottom plate (gray). The missing stiffener seen near the bottom is the intersection with the inner bottom (not shown) and the watertight bulkhead.

We then moved to Section 5-1-2 to calculate the required minimum thickness for our side girders and solid floors, utilizing the below Equations.

$$t = 0.000432L + 0.18 \quad \text{in.}$$

$$t = 0.000432L + 0.236 \quad \text{in.}$$

Utilizing these equations we calculated the minimum thickness for our side girders was 0.39 inches and the solid floors had a minimum thickness of 0.44 inches. Based on that information we set our design thickness to ½ plate. As seen in *Figure 16* below. The solid floors are shown in purple, while the side girders are displayed in yellow.

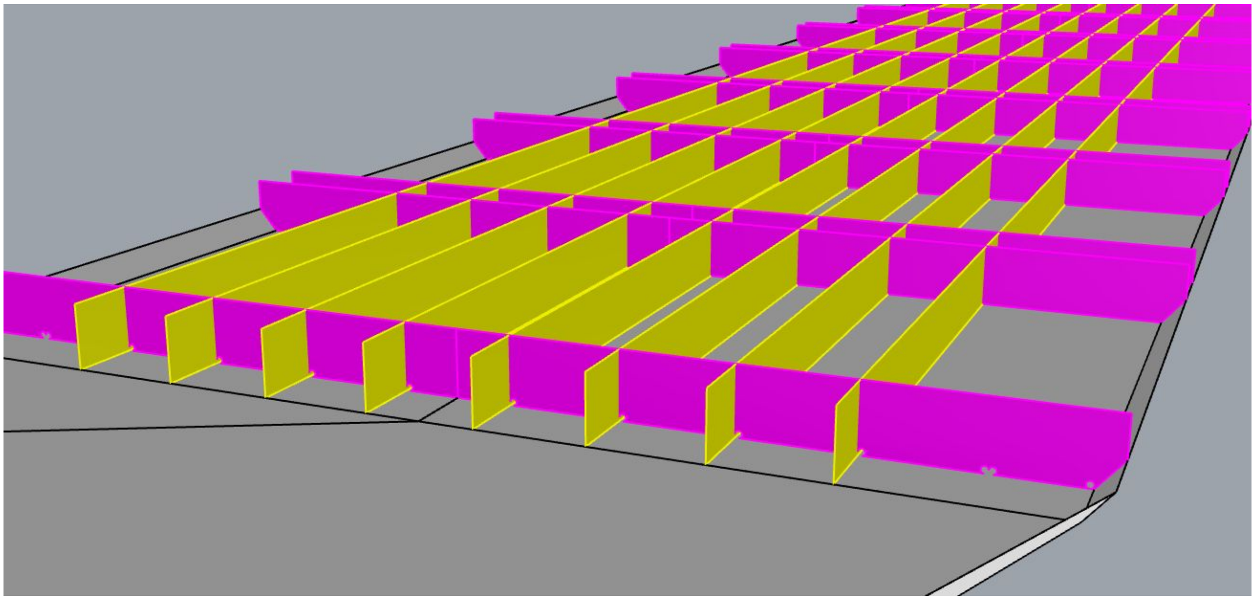

Figure 16: Solid Floors

Once we determined the design thickness of the solid floors, we needed to determine their spacing for distribution throughout the barge. Utilizing the same section as the solid floors, we utilized the provided Equation under 5.7.1 for the spacing calculation of the solid floors forward of 0.3L from amidships.

$$S = 0.00625L + 4.43 \quad \text{in.}$$

With S denoting the spacing of the floors in ft, our calculation determined that the floors must be spaced no more than 3.4 ft throughout the forward half of the barge or 0.3L. This is equivalent to 144.6 ft forward of amidships.

In *Figure 17* below, you can see the solid floors in purple with the associated transverse web frames in blue and yellow. The solid floors are separated from the transverse web frames as they were placed directly under the pillar supports to support the container loads.

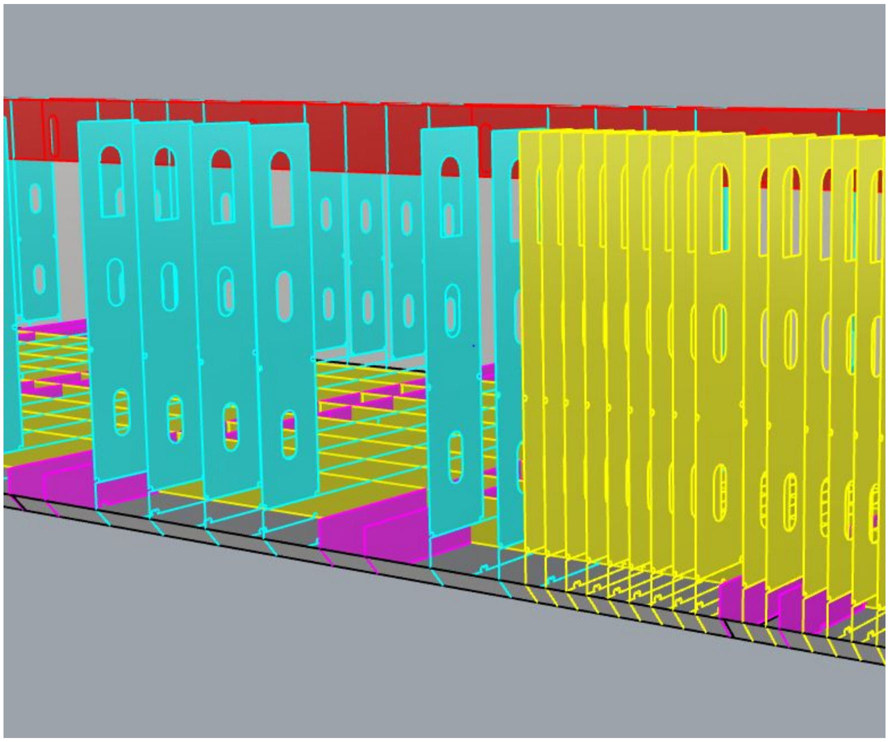

Figure 17: Web Frames

The color variation between the transverse web frame denotes the point of the midbody where we transition from an 8 ft spacing to a 3 ft spacing. Which is 144.6 ft forward of amidships to be within the maximum spacing allowed as calculated earlier, being less than 3.4 ft.

We then calculated our bottom longitudinals and our inner bottom longitudinals utilizing the same section of the rules 5-1-2 utilizing the below Equation.

$$SM = 0.0041chs\ell^2 \text{ in}^3$$

This provided us with a minimum SM required for the bottom longitudinals of 15.67 in^3, which we selected a stiffener sizing of 7” x 4”x 7/16”. This provided us with an offered SM of 17.18 in^3.

To calculate our inner-bottom longitudinals, we multiplied the bottom longitudinal SM by 85%, as the rule states they are not to be less than that value. That calculation yielded a required SM of 13.32 in^3. This enabled us to utilize a stiffener sizing of 6” x 4” x 7/16” yielding an offered SM of 14.47 in^3. In *Figure 18* below, you can see the placement of the bottom longitudinals, the inner bottom longitudinal and the side girder longitudinal all denoted by the color brown.

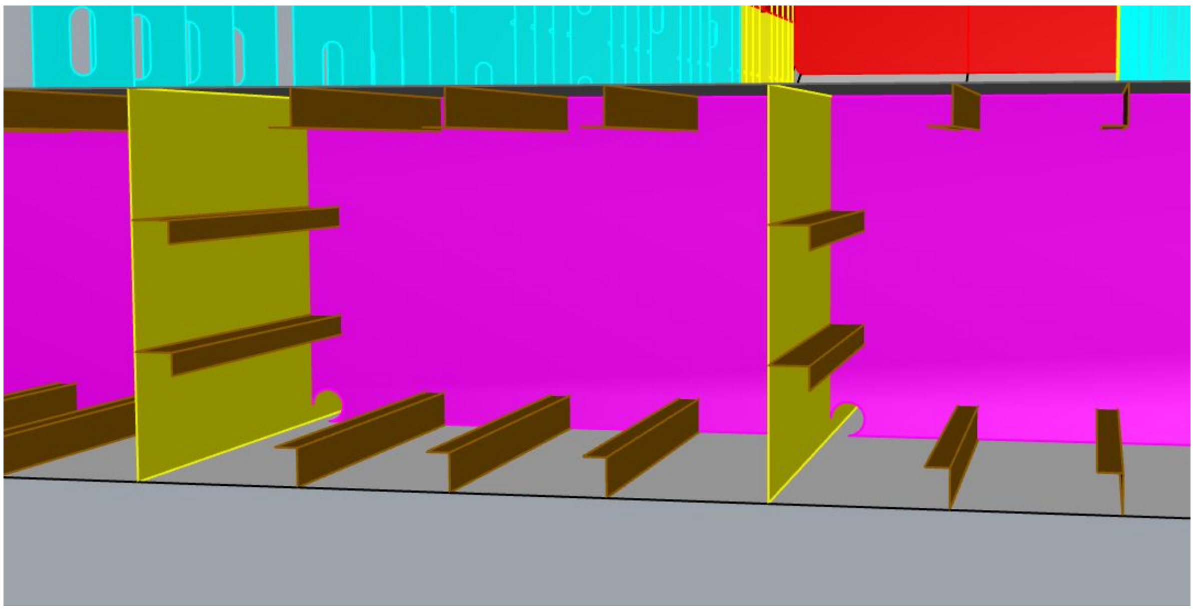

Figure 18: Inner-Bottom Longitudinals

We then moved to calculate our inner bottom thickness utilizing the below Equation.

$$t = 0.000445L + 0.009s - 0.02 \quad \text{in.}$$

This calculation provided us a minimum thickness required of 0.41 in. There are two applicable sub-rules which pertain to our configuration in this calculation which is as follows:

Where there is no ceiling under hatchways, except for barges intended for the exclusive carriage of containers on the inner-bottom, the required thickness is to be increased by 2 mm (0.08 in.).

This increases our required minimum thickness to 0.49 in, which would require ½ plate and the second sub-rule indicates the following

> For barges regularly engaged in trades where the cargo is handled by grabs or similar mechanical appliances, or where heavy bulk cargoes are carried, it is recommended that flush inner-bottom plating be adopted throughout the cargo space and that the plating requirements be suitably increased, but the increase need not exceed 5 mm (0.20 in.). It is also recommended that the minimum thickness be not less than 12.5 mm with 610 mm (0.50 in. with 24 in.) frame spacing and 19 mm with 915 mm (0.75 in. with 36 in.) frame spacing with intermediate thicknesses obtained by interpolation.

As we have a spacing of 24 in as indicated, the recommended minimum thickness is 0.50 in, which is in line with our findings from the first sub-rule and we set our initial thickness to ½ plate for the inner bottom.

We then moved on to calculate our box girder and box girder stiffeners with an initial sizing of the box girder at an 8' x 10' ft box and set our stiffeners to be 1" x 12" inch flat stock as a preliminary design. As seen in the below *Figure 19.*

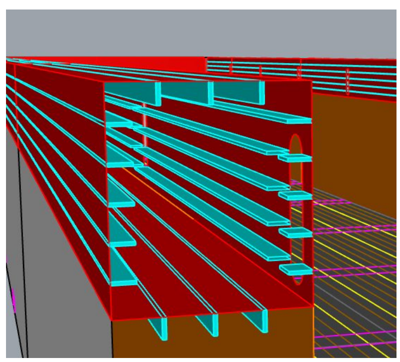

Figure 19: Box Girders

We also established wing tanks in the midbody and we set that equally distant from the bottom of the box girder and the keel for even distribution, we set their thickness to an initial value of ½ plate until we finalize our required SM calculations to determine what plating needed to be increased. For the stiffener sizing for the wing tanks, we utilized the same stiffeners used for the inner bottom of 6" x 4" x 7/16" as seen in *Figure 20* below.

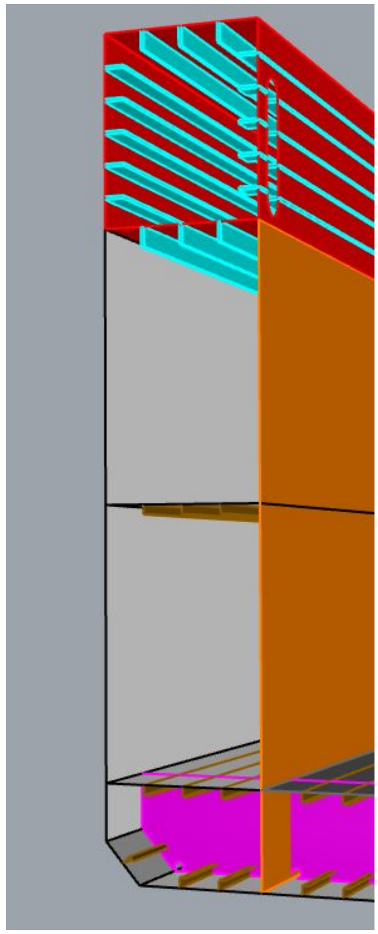

Figure 20: Wing Tank Stiffeners

All the above calculations were established as the minimum required and were modified and increased we needed to meet the required SM for our design which will be discussed in the coming pages in greater detail.

We designed this vessel to hold the containers via cell guides and designed them with 6” x 6” x 1/2” angles, at the top of the guides we designed tapered guides to assist the containers sliding into the guides to increase loading times and limit damages from the containers striking the top of the cell guides. If a container were to strike the tops of the cell guides, this could flatten and damage them. The cell guide tops can be seen in *Figure 21* below.

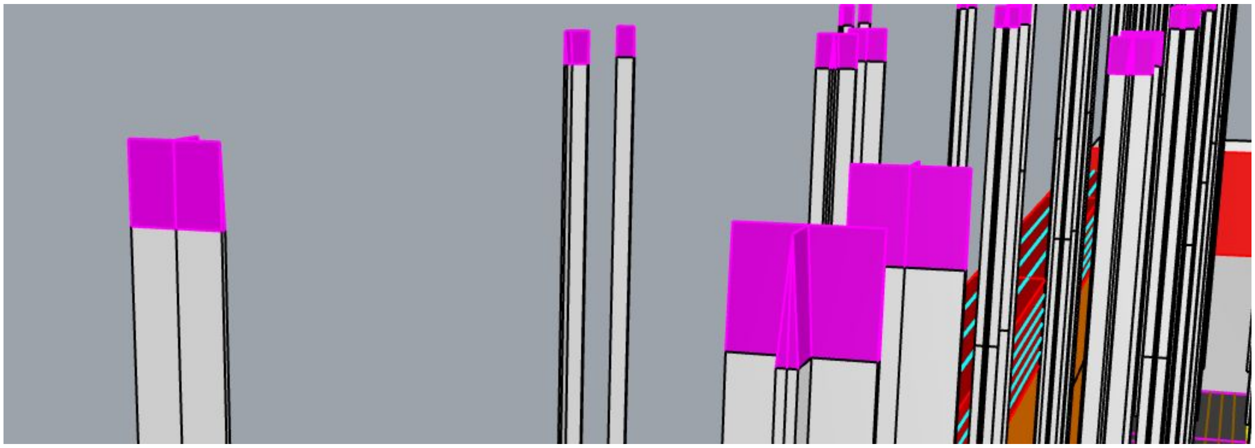

Figure 21:Cell Guide Top

We then designed an associated lattice structure support for the cell guides and also added transverse walkways to allow access to the containers for the loading, inspection, and required hook up for reefer connections. These can be seen in the below-rendered image for clarity of the cell guide structure system in *Figure 22.*

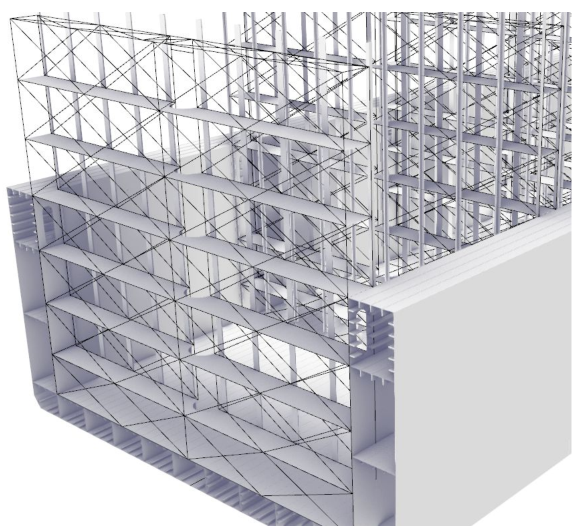

Figure 22: Cell Guides and Transverse Walkways

We then established a coaming around the container holds 8’ ft off the deck and added both vertical and horizontal stiffeners to support the coaming. We placed a top flange on the coaming in the event anything was dropped or struck the coaming. This top flange would assist in providing additional strength to prevent damage sustained to the coaming.

We did not make the coaming continuous in our calculation and have breaks in the coaming between each hold for access to the transverse walkway for access to the container rows. The breaks in the coaming for access to transverse walkways are not shown in the below image *Figure 23.*

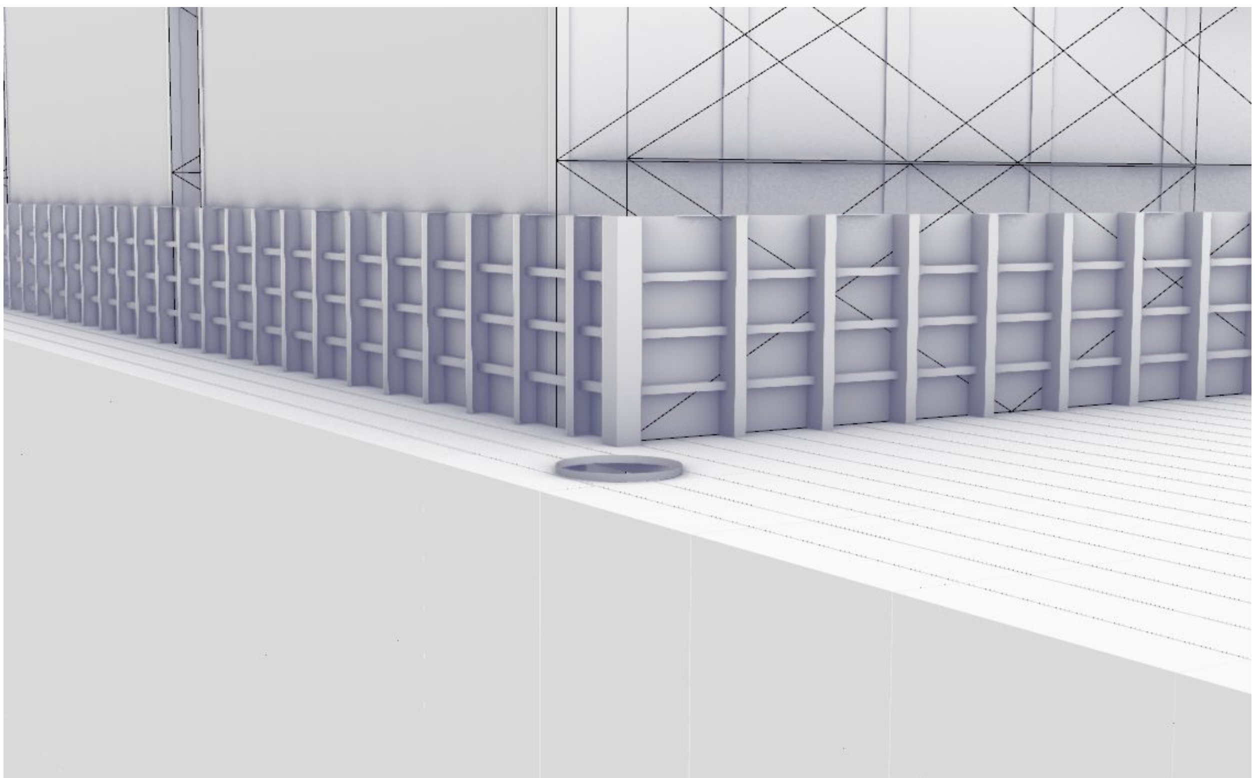

Figure 23: Coaming

8.3 Bow Structure

To start our bow structuring, we utilized the majority of the calculations that were previously done for the midships. These included the side shell longitudinals, the side girders, the transverse web frames, the bottom plating, side shell plate, deck plating were all carried forward.

The specific calculation required in the bow section was for the placement and thickness of our collision bulkhead. Following Section 3-2-6 Formula 3.1 for the Collision Bulkhead we determined the placement of the bulkhead was to be no less than twenty-four (24) ft and no more than thirty-nine (39) from the FP. The FP was determined to be twelve (12) ft from the headlog giving us bounds of thirty-six (36) and fifty-one (51) ft from our zero point (measuring from the headlog).

Utilizing those bounds we placed the Collision Bulkhead at negative forty (-40) ft from the zero mark.

We utilized the below Equation of the same chapter as the watertight bulkheads to determine the minimum thickness of the collision bulkhead.

$$t = sk\sqrt{qh}/c + 0.06 \quad \text{in.}$$

Constant *c* varied as a factor of 460 for a collision bulkhead and 525 for a watertight bulkhead in the equation. The watertight bulkheads (green) and collision bulkhead (red) can be seen below in *Figure 24*. The notches in the watertight bulkhead top corners denote the intersection point with the box girder.

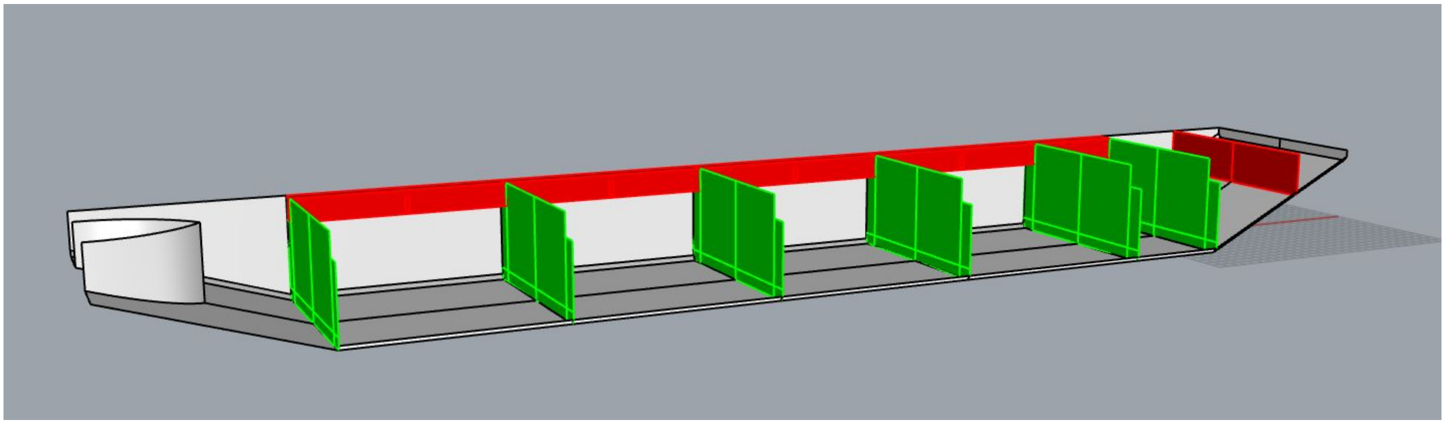

Figure 24: Watertight Bulkheads

In the above Figure, you can see the collision bulkhead (red) in the bow structure and the watertight bulkheads (green) separating each cargo hold.

8.4 Stern Structure

The stern structure of the barge utilized the same calculations from the midship and just extended them into the stern of the barge, we did not have any specific calculations for the stern. We took consideration into the deck and notch area due to the additional stress and forces that would be exerted from the tug on that point and chose to use a 1-inch plate for those members, as seen in *Figure 25* below.

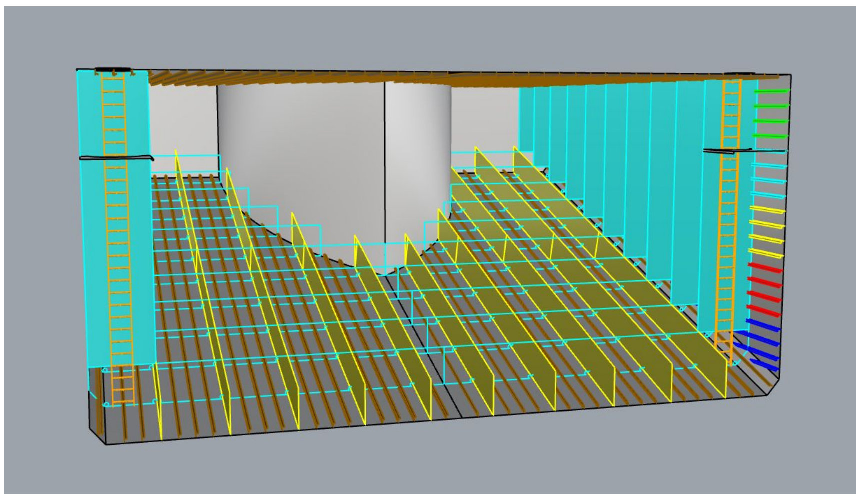

Figure 25: Stern Structure

You are able to see the side girders (yellow), transverse web frames (blue), bottom and side longitudinals (brown, yellow, red, green and light blue) and the ladder and ladder platform from the hatch access on the deck to get to the box girder and stern structure.

The bow has the same access point and design.

9. Barge Weight Estimate

9.1 Lightship Weight Estimate

Once the minimum size and SM calculations were completed, we were able to develop a lightship weight estimate by multiplying the thickness, breadth, and height in feet and multiplying it by the density of framing steel per ft. Which is 490 lb/ft^3, we then divided it by 2240lb to convert it to long tons. We did this for each flat plate member of the barge. For the stiffener weight, we took the weight per foot for the established stiffener size and multiplied it by the total length of the stiffener and acquired each associated weight with each stiffener member. Below you will see an example of the spreadsheet that was created to perform these calculations in *Figure 26*.

Stiffeners	Weight per Ft [lbs]	LT Conversion per ft
9"x4"x1/2"	21.5	0.010
8"x6"x1/2"	23.0	0.010
8"x4"x1/2"	19.6	0.009
7"x4"x1/2"	17.9	0.008
7"x4"x3/8"	13.6	0.006
6"x6"x3/4"	28.7	0.013
6"x4"x7/16"	10.5	0.005
5"x5"x3/8"	12.3	0.005
4"x4"x1/2"	12.8	0.006

Bow	Size	Length	QTY	Total Length	LT
Side Shell Stiffener 1-4	9"x4"x1/2"	72	8	576	5.5
Side Shell Stiffener 5-8	8"x4"x1/2"	58	8	464	4.1
Side Shell Stiffener 9-12	7"x4"x1/2"	42	8	336	2.7
Side Shell Stiffener 13-16	7"x4"x3/8"	25	8	200	1.2
Side Shell Stiffener 17-20	5"x5"x3/8"	9.2	8	73.6	0.4
Bildge Angle Stiffener	9"x4"x1/2"	77	2	154	1.5
Deck Stiffener	4"x4"x1/2"	77	42	3234	18.5
Bottom Stiffener	8"x6"x1/2"	86	22	1892	19.4
Collision Horiz Stiffeners	4"x4"x1/2"	89.5	10	895	5.1
Collision Vert Stiffeners	4"x4"x1/2"	19.8	11	217.8	1.2
					59.6

Midbody						
ITEM	thickness (in)	b (in)	h (in)	Quantity	LT	LT* Q
Coaming Longitudinal	1.000	4,878.000	96.000	1.000	59.281	59.281
Coaming Top Flange Longitudinal	1.000	4,878.000	12.000	1.000	7.410	7.410
Box Girder Upper Plate	1.750	96.000	4,878.000	1.000	103.742	103.742
Box Girder Side Shell	1.750	4,878.000	120.000	2.000	129.678	259.355
Box Girder Bottom Plate	1.750	96.000	4,878.000	1.000	103.742	103.742
Box Girder Upper Stiffener	1.250	4,878.000	4.000	3.000	3.088	9.263
Box Girder Side Stiffener 5	1.000	4,878.000	3.000	2.000	1.853	3.705
Box Girder Side Stiffener 4	1.000	4,878.000	3.000	2.000	1.853	3.705
Box Girder Side Stiffener 3	1.000	4,878.000	3.000	2.000	1.853	3.705
Box Girder Side Stiffener 2	1.000	4,878.000	3.000	2.000	1.853	3.705
Box Girder Side Stiffener 1	1.000	4,878.000	3.000	2.000	1.853	3.705
Box Girder Lower Stiffener	1.250	4,878.000	4.000	3.000	3.088	9.263
Side Shell	1.250	4,878.000	540.000	1.000	416.821	416.821
Longitudinal Bulkhead	1.250	4,878.000	396.000	1.000	305.669	305.669
Inner Bottom Plate	1.250	441.000	4,878.000	1.000	340.404	340.404
Wing Tank Deck 1	0.500	96.000	4,878.000	1.000	29.641	29.641
Wing Tank Deck 2	0.500	96.000	4,878.000	1.000	29.641	29.641
Side Girders	0.500	4,878.000	60.000	5.000	18.525	92.627
Bottom Plate	1.250	516.000	4,878.000	1.000	398.296	398.296
Bilge Plate	1.250	33.000	4,878.000	1.000	25.472	25.472
					Σ =	2,209.153

Figure 26: Stiffener Weight Calculation

The sum of these weights fed into our lightship weight distribution calculation to establish a distributed weight curve for the lightship and interpolated the weight over the bow and stern section.

Once that was completed, we prepared our spreadsheet with the lightship weight distribution and the cargo weight distribution by hold to establish our maximum bending moment, which is required to determine our SMreq.

We set our weight distributions as constant and utilized solver within excel to adjust ballast weight, draft and trim to achieve 0 on our final shear and bending moment calculations. This enabled the solver to analyze and change each of the allowed variables until it found the correct condition to satisfy the criteria.

This became a little trial and error due to once the max bending moment was calculated, it provided us with our SMreq, which we were able to compare to our current SM calculated, which was discussed and shown on Pages 22 and 23.

With this comparison, we were able to make live changes to the thickness of each member to modify our current section modulus to bring it to pass the SM Req calculation. We linked each spreadsheet so as we resized the thickness on each member that adjusted the weight calculations on the following tab in the spreadsheet, which then changed the lightship weight distribution and required us to run a solver again to resolve for the most optimal conditions.

9.2 Full Load Weight Estimate

Once the optimal condition was satisfied, we found there was significant ballast needed to adjust our trim to even keel as we initially established an even loading plan for the container weight across each hold.

This caused us to have a negative six (-6) ft trim down by the bow, which is not an ideal way to transit. As all of our cells were linked, we were then able to go into our cargo loading plan spreadsheet and adjust the weight of each individual container for each tier and row and modify the recommended weight and rerun solver to reconfigure the trim and draft due to the LCB of the cargo shifting.

As we were bow down initially, we modified our loading plan to account for all 125 potential reefers we would carry would be confined to Hold Five (5) in the stern and then set an ascending load plan by weight moving forward, the heaviest containers would be located in the stern with the light containers being held in the forward most holds.

We utilized the excel function SUMPRODUCT to multiply each row by each tier for each specific container to get an exact cargo weight per hold, which fed back into our max bending moment spreadsheet and enabled us to adjust each individual container to achieving our designed trim while maintaining 0 on our shear and bending moment calculation.

We finalized our loading plan leaving us with a 19.5ft draft, with a +0.6ft trim up in the bow. We choose to leave a slight bow positive trim, as we are carrying reefers and they will be powered by onboard generators with a fuel tank, we projected throughout the voyage the reduction in fuel weight will allow us to settle on an even keel and avoid any negative bow trim.

Images of these tables and calculations can be found below in *Figure 27*.

Cargo Balanced Load

Δ Keel [ft]	Tier	Hold 5	Moment	Hold 4	Moment	Hold 3	Moment	Hold 2	Moment	Hold 1	Moment	Hold 5	Hold 4	Hold 3	Hold 2	Hold 1	Total
11.25	1	30	6075	30	6075	25	5062.5	25	5062.5	15	1518.75	18	18	18	18	9	81
19.75	2	30	10665	30	10665	25	8887.5	25	8887.5	15	2666.25	18	18	18	18	9	81
28.25	3	30	15255	30	15255	25	12712.5	25	12712.5	15	3813.75	18	18	18	18	9	81
36.75	4	30	19845	30	19845	25	16537.5	25	16537.5	15	4961.25	18	18	18	18	9	81
45.25	5	30	24435	30	24435	25	20362.5	25	20362.5	15	6108.75	18	18	18	18	9	81
53.75	6	30	29025	30	29025	25	24187.5	20	19350	15	7256.25	18	18	18	18	9	81
62.25	7	30	33615	25	28012.5	25	28012.5	20	22410	10	5602.5	18	18	18	18	9	81
70.75	8	30	38205	25	31837.5	25	31837.5	15	19102.5	10	6367.5	18	18	18	18	9	81
79.25	9	30	42795	25	35662.5	25	35662.5	15	21397.5	10	7132.5	18	18	18	18	9	81
			219915		200812.5		183262.5		145822.5		45427.5	4860	4590	4050	3510	1080	18090
												162	162	162	162	81	729

Σ Cargo	18090
Σ Containers	729

Cargo	Σ Moments	795240
	Σ Weight	18090
	VCG	43.96

Lightship	Weight	6712
	Moment	151030
	VCG	22.50

Full Load	Weight	24802
	Moment	946270
	VCG	38.15

Figure 27: Cargo Balanced Load Calculation

This calculation shows the weight of each row on containers based on tier and hold position and provides the total cargo weight of each hold with the total sum of all the weights. Our final cargo weight projection for this design is 18,090 LT.

We also utilized this table to calculate our cargo VCG and then full load VCG by adding the moments and dividing by the total weight as can be seen above.

The second Figure shown below, *Figure 28*, is our results of our calculations solving for the mean draft of the barge along with the trim and amount of ballast needed, while ensuring our shear and bending moments were accounted for correctly.

Hold 5 LS Fwd	392.0	-114.0		392.0	0.00	13.7	13.7	89.5	19.59	1	50.09	36.42							-847.25			240,854	13.7
			0.0										42.26	0.00	50.09	0.00	7.83	0.00		-847.25	0.00		
Hold 5 Cargo Fwd	392.0	-114.0		392.0	57.18	13.7	70.8	89.5	19.59	1	50.09	-20.76							-847.25			240,854	13.7
			85.0										70.85	6,022.18	50.21	4,267.80	-20.64	-1,754.38		-1,724.44	-146,577.55		
Hold 5 Cargo Aft	477.0	-199.0		477.0	57.18	13.7	70.8	89.5	19.68	1	50.33	-20.52							-2,601.63			94,277	13.7
			0.0										42.26	0.00	50.33	0.00	8.07	0.00		-2,601.63	0.00		
Hold 5 LS Aft	477.0	-199.0		477.0	0.00	13.7	13.7	89.5	19.68	1	50.33	36.65							-2,601.63			94,277	13.7
			5.0										12.61	63.05	50.33	251.66	37.72	188.61		-2,507.32	-12,536.62		
Station 22	482.0	-204.0		482.0	0.00	11.5	11.5	89.5	19.69	1	50.34	38.79							-2,413.02			81,740	11.5
			42.5										10.49	445.68	50.40	2,141.91	39.91	1,696.23		-1,564.90	-66,508.38		
Station 23	524.5	-246.5		524.5	0.00	9.4	9.4	89.5	19.73	1	50.46	41.03							-716.79			15,232	9.4
			42.5										8.36	355.40	25.23	1,072.19	16.87	716.79		-358.39	-15,231.73		
Station 24	567.0	-289.0		567.0	0.00	7.3	7.3	89.5	0.00	1.0	0.00	-7.30							0.00			0	7.3
														25,281.36	=	25,281.36							
																			0.00			269,061	= Max BM

LS Weight Step down line 45 - 51 =	2.12
Mean Draft 19.5	feet
Trim Bow up 0.6	feet
BALLEST IN WING TANK 5 PS	0.00
LT/ft for Ballast	0.00
Height of ST 1 Above BL 10.11	feet
Station 1 Draft 9.10	feet
LCF from Bow 278.00	feet
LOA 567.00	feet

Figure 28: Mean Draft Calculation

The following charts are the graphs resulting from our calculations, specifically our Load, Shear and Moment graphs, as seen below in *Figures 29* to *31*.

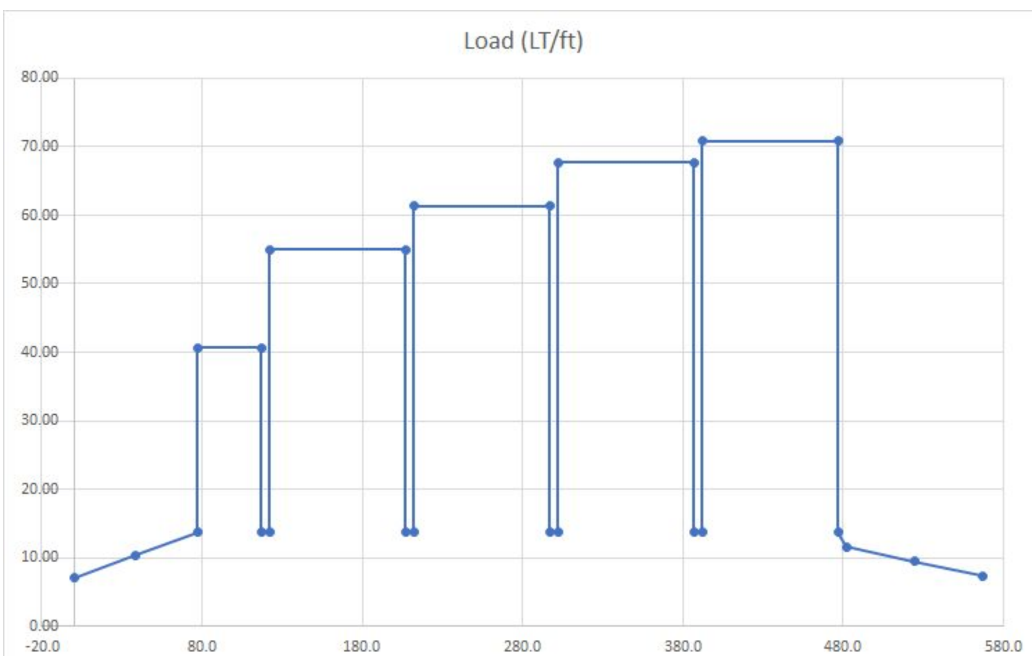

Figure 29: Load Diagram

Figure 30: Shear Diagram

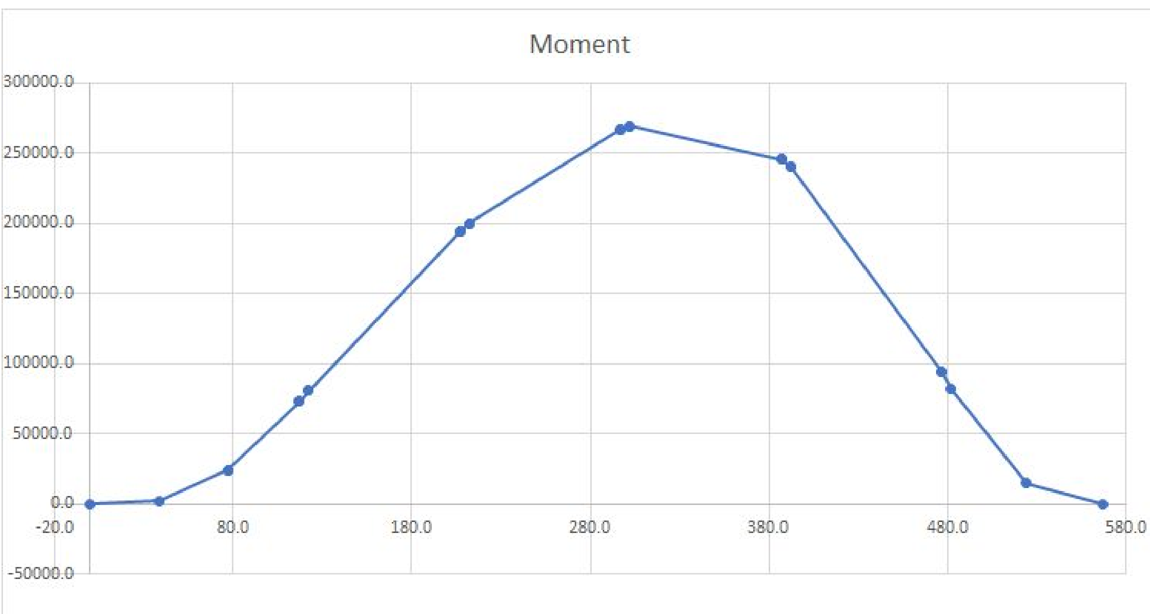

Figure 31: Moment Diagram

These graphs visually confirm our excel calculations and as they are inline and display an image and data consistent with what we projected to see.

The final values we found for our barge indicate a lightship weight of 6,647LT, with a cargo weight of 18,090 LT. This results in a total weight of 24,737 LT prior to the inclusion of any machinery or fuel storage. We estimated about 50 tons of fuel will be needed for the machinery and a machinery weight of 15LT.

We set up a conditional statement within excel, to notify us upon completion of the solver if the calculated SM passed the SMreq due to the bending moment. As indicated earlier, as we had each spreadsheet linked it enabled us to make modifications and changes very quickly to ensure all criteria were met and passed. Due to the size of the barge and the weight of the cargo and the max bending moment being encountered we chose to go with H36 Steel which enabled us to reduce the SMreq by 72% due to the inclusion of High Strength Steel. The following images is the chart showing the calculated SM vs the SMreq and showing how our calculated value passes the requirement for H36 calculations in *Table 9.*

SM keel	842,638	in^3
	70,220	ft-In^2

SM deck	430,771	in^3
	35,898	ft-In^2

SM Req'd	49,729		ft-In^2
H36	0.72	35,805	ft-In^2
H40	0.68	33,816	ft-In^2

Table 9: Section Modulus Calculation

The second image shows the final sizing result needed to pass the SMreq utilizing H36 Steel, *Figure 32*.

Midbody	
ITEM	thickness (in)
Box Girder Upper Plate	1.7500
Box Girder Side Shell	1.7500
Box Girder Bottom Plate	1.7500
Box Girder Upper Stiffener	1.2500
Box Girder Side Stiffener 5	1.0000
Box Girder Side Stiffener 4	1.0000
Box Girder Side Stiffener 3	1.0000
Box Girder Side Stiffener 2	1.0000
Box Girder Side Stiffener 1	1.0000
Box Girder Lower Stiffener	1.2500
Side Shell	1.2500
Longitudinal Bulkhead	1.2500
Side Shell Stiffener 6	0.5000
Side Shell Stiffener 7	0.5000
Side Shell Stiffener 8	0.5000
Side Shell Stiffener 9	0.5000
Side Shell Stiffener 10	0.5000
Side Shell Stiffener 11	0.5000
Side Shell Stiffener 13	0.5000
Side Shell Stiffener 14	0.5000
Side Shell Stiffener 15	0.5000
Side Shell Stiffener 16	0.5000
Side Shell Stiffener 17	0.3750
Side Shell Stiffener 18	0.3750
Side Shell Stiffener 20	0.3750
Side Shell Stiffener Bilge Angle	0.5000
Inner Bottom Plate	1.2500
Inner Bottom Plate Upper Stiffener	0.4375
Wing Tank Deck 1	0.5000
Wing Tank Deck 1 Stiffeners	0.4375
Wing Tank Deck 2	0.5000
Wing Tank Deck 2 Stiffeners	0.4375
Side Girders	0.5000
Bottom Longitudinals	0.5000
Bottom Plate	1.2500
Bilge Plate	1.2500

Figure 32: Final Stiffener Sizing

Additional photos and renderings of the barge can be found in *Appendix H*.

9.3 Arrival Condition Weight Estimate

The only difference between the departure and arrival conditions is the fuel weight. At the end of the route, the fuel will be about 5 tons, which is 44 tons less than what the barge started with. This will give an overall weight of 24,850LT.

10. Barge Cargo Carrying Plan

The barge is constructed to carry containers, more specifically forty-foot-equivalent units, FEU's, and twenty-foot-equivalent, TEU's, in cargo holds. The barge has five holds that have watertight bulkheads fore and aft of the hold bounds. *Figure 33* shows the proper terminology for container stowage as well as numbering.

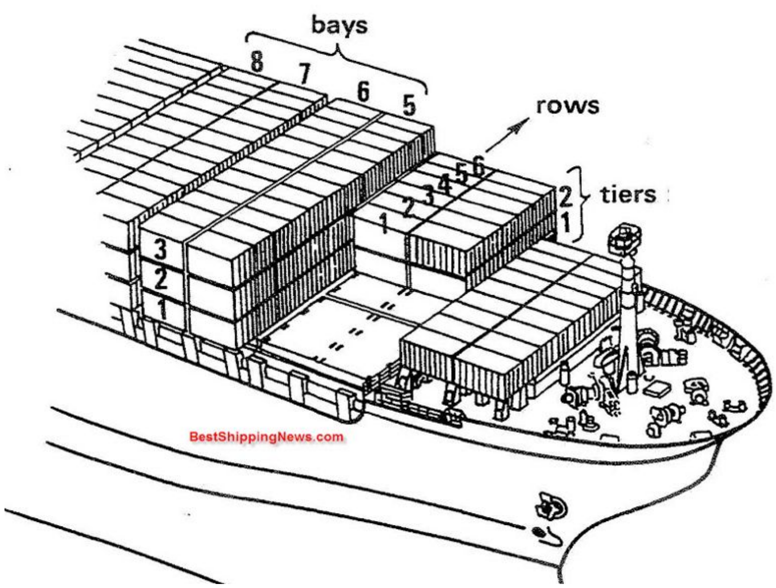

Figure 33: Container Stowage

The barge was designed to carry 729 containers, as seen in the hold breakdown in *Table 10*. Hold 1 to 4 will only carry non-reefer containers, whereas Hold 5 will have the ability to carry a total of 125 reefer containers out of its total capacity where the rest will be non-reefer containers.

Hold	Bay(s)	Rows	Tiers	Total Containers
Hold 1	1	9	9	81
Hold 2	2	9	9	162
Hold 3	2	9	9	162
Hold 4	2	9	9	162
Hold 5	2	9	9	162

Table 10: Container Stowage Breakdown by Hold

Holds 1 and 2 were also designed to be able to carry TEUs. Two TEUs are able to be carried in a place where one FEU would normally be. In order to allow this, pillars were added to the deck of Hold 1 and the fore section of Hold 2, the cell guides will support the ends of each container, as stated in the Structure section of this report. However, in the center where the two containers meet, twist locks, or pillars will be utilized to ensure the TEU's are properly secured.

With a capacity of 729 containers, we were able to maximize the amount of cargo carried via the barge without affecting visibility and the need for additional support. The profile of the barge can be seen in *Figure 34* below. By only stacking 9 tiers high with a wheelhouse height of 100ft, we are able to see 800ft past the barge to allow for maximum visibility during transit. This will also not require any additional support for the containers since we are not stacking more than nine tiers high.

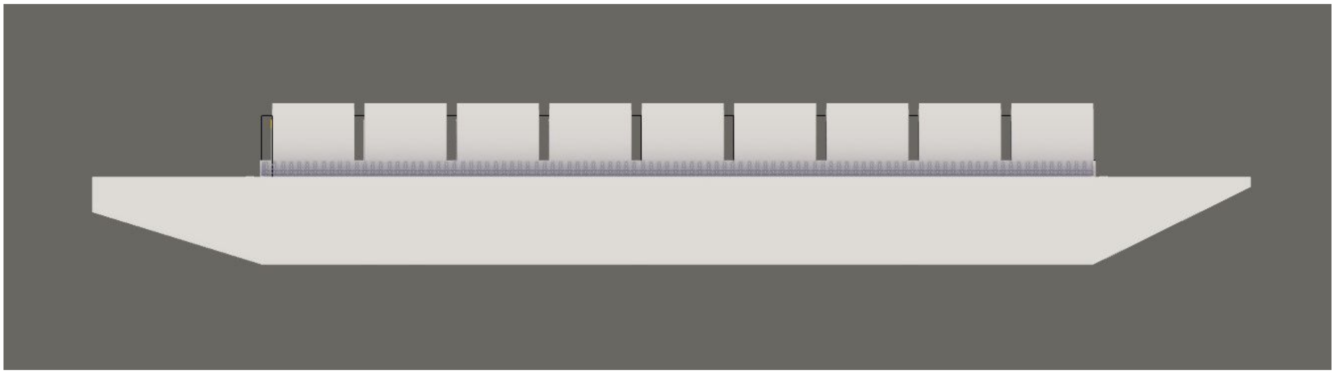

Figure 34: Profile View of Cargo Capacities

To secure the cargo, cell guides will be utilized in order to ensure that the containers are transported safely during transit. The cell guide structure can be seen in *Figure 35* below and are spaced so FEU's can be carried without additional structure or support. According to the American Bureau of Shipping's *Guide for Certification of Container Securing Systems*, September 2019, cell guides can be utilized to stack containers vertically without the need for other securing methods.

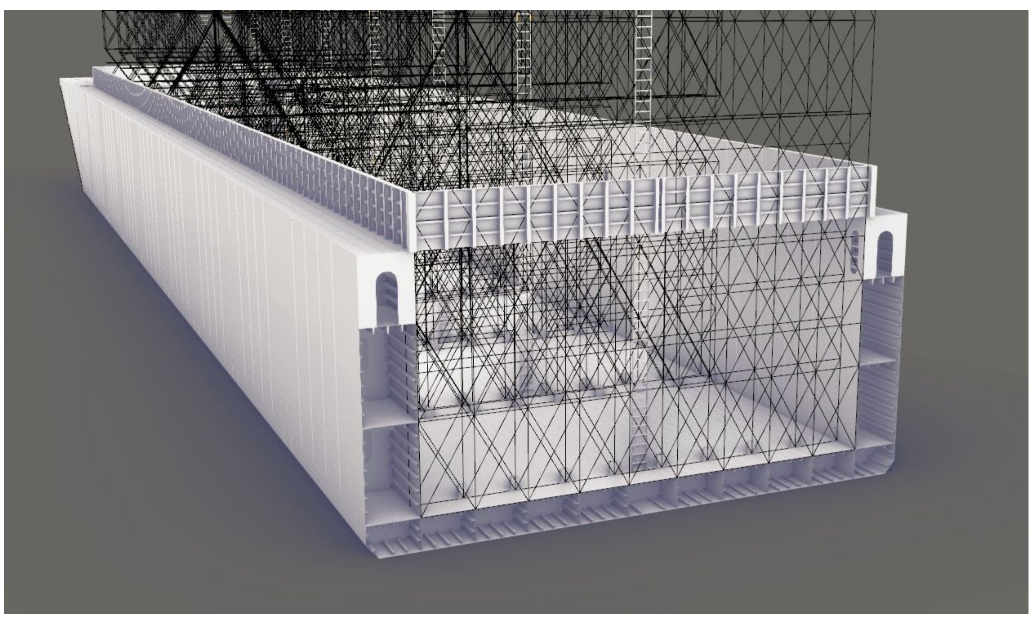

Figure 35: Cell Guide Structure

Cell guides are able to ensure the movement of containers is not only limited in the transverse direction, but also the longitudinal direction as well. This is important to know when stacking containers more than a couple tiers high to ensure not only the cargo is safe, but the crew as well when transiting between the stacks.

11. Barge Cost Estimate

Cost estimation is an important aspect of any design project, and being able to design around a certain cost is a key element in a project. If the cost for a certain object exceeds the budget, often it is redesigned instead of built. Through a cost analysis, the most efficient design is chosen if it meets the owner's requirements and financial needs.

11.1 Cost of Steel

The significant costs of any design project are materials, outfitting, and labor. In the case of a vessel, the hull will be made of steel which will make up a majority of the material cost. Depending on the type of steel utilized and the type of steel, the costs can vary. In order to calculate the Required Freight Rate, the average cost was taken in order to complete the calculation.

11.2 Required Freight Rate

A required freight rate (RFR) is the price at which a certain cargo is delivered from one point to another to ensure one breaks even. The ATB has been designed to carry 729 containers overall, with 125 of those being reefer containers. An RFR has been calculated at different capacities to show the price depending on capacity, as seen in *Table 11*.

Total Containers	Percent Capacity	RFR Per Round Trip	RFR per Container
729	50%	$556,259	$2,000
729	60%	$556,259	$1,700
729	70%	$556,259	$1,500
729	80%	$556,259	$1,300
729	90%	$556,259	$1,150
729	95%	$556,259	$1,100

Table 11: Required Freight Rate by Capacity

In the industry of shipping containers, railroad cars are able to carry approximately 400 containers at $1,800 or more per container. This method of transportation has been utilized for years, and this would be our competition. This capacity is about half of what the ATB has been designed to carry, so we can allow for a more competitive pricing and carrying capacity. We are able to ship containers at less than $1800 if we are at 60% capacity or greater, beating out the competition. This allows the ATB to compete not only in the shipping industry but also in the rail industry as well making it a front runner for those that need to ship containers.

12. Barge Trim and Intact Stability

12.1 Criteria

The criteria used in Maxsurf: Stability was under the *IMO Guidelines 267(85)*. However, a specific guideline for intact stability was used under the category for Container Vessels more than 100m in length. This allowed us to determine if the barge was able to meet the IMO Criteria at our different loads and weights.

12.2 Required GM Curve

A Required GM Curve shows different GM's at different drafts (ft). *Figure 36* displays the required GM curve for the barge, taken from Hecsalv.

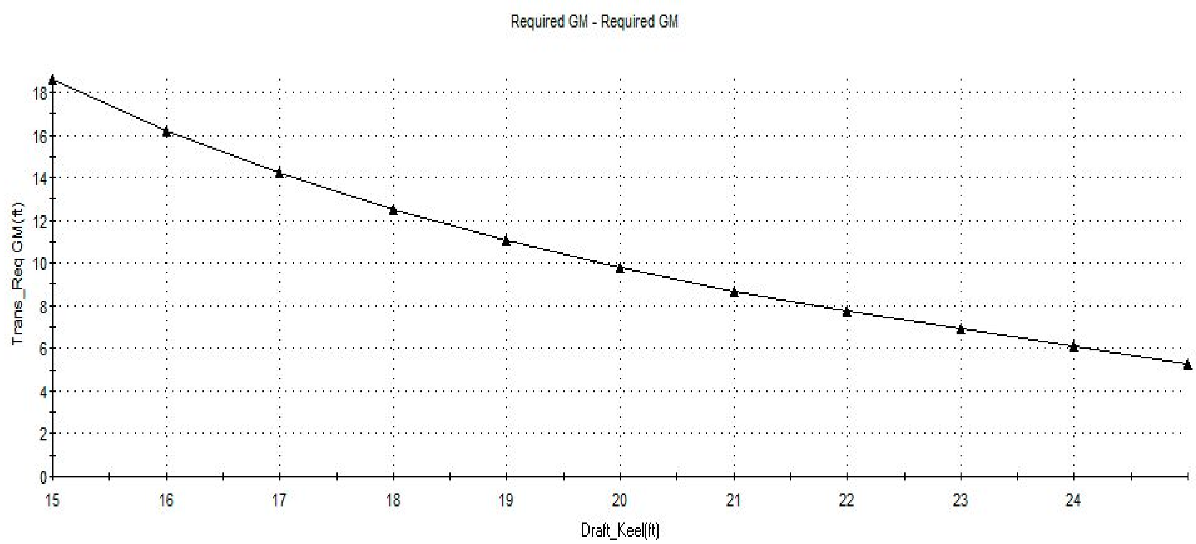

Figure 36: Intact Required GM

12.3 Lightship Condition

The Lightship Condition was run in Maxsurf: Stability with only the barge weight which was mainly steel; the lightship weight was calculated in *Section 9.1*. The breakdown of the weight put into Maxsurf: Stability can be seen in *Figure 37* below.

Item Name	Quantity	Unit Mass Long Ton	Total Mass Long Ton
Lightship	1	6740.000	6740.000
Hold 5 SW	0%	552.597	0.000
Hold 1 PW	0%	270.193	0.000
Hold 1 SW	0%	270.193	0.000
Hold 2 PW	0%	555.674	0.000
Hold 2 SW	0%	555.674	0.000
Hold 3 PW	0%	552.597	0.000
Hold 3 SW	0%	552.597	0.000
Hold 4 PW	0%	552.597	0.000
Hold 4 SW	0%	552.597	0.000
Hold 5 PW	0%	552.597	0.000
Fuel Tank P	0%	27.312	0.000
Fuel Tank S	0%	27.312	0.000
Total Loadcase			**6740.000**

Figure 37: Load Condition - Lightship

To better understand the stability of the barge, a Large Angle Stability analysis was done to determine the Maximum GZ curve for the Barge in the Lightship Condition. The analysis was run from a heel angle of 0 degrees to 90 degrees in increments of 5 degrees, and at a 0.6ft trim by bow. The trim by bow was stated previously and all analysis' will be run with this trim. The GZ curve can be seen in *Figure 38* below.

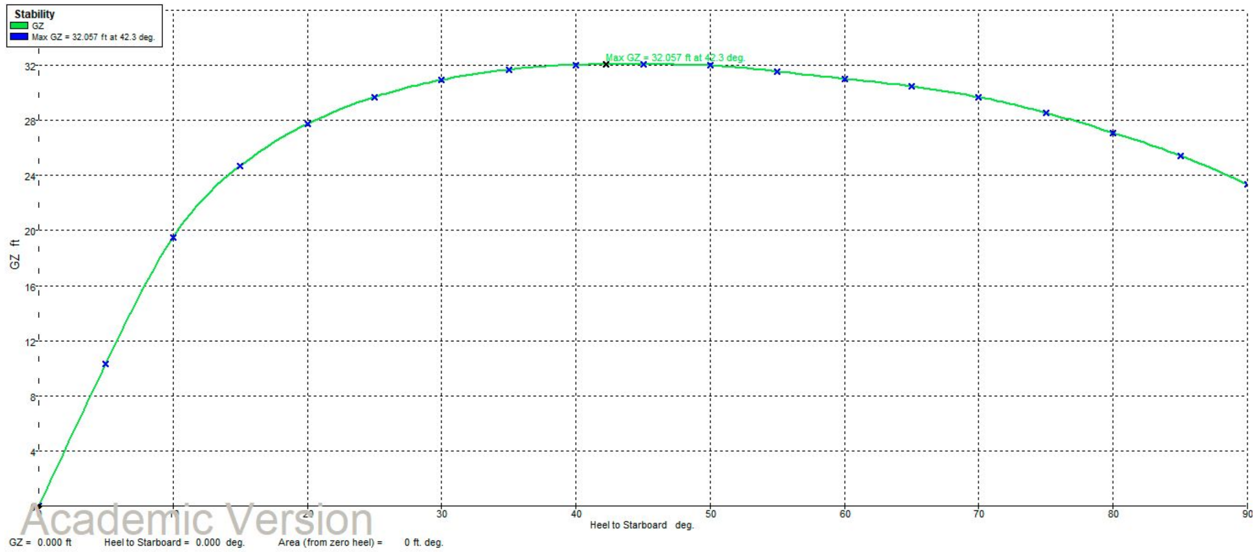

Figure 38: Maximum GZ Curve - Lightship

Figure 38, shows the GZ Curve which starts at a steep slope and then starts to even out until the Maximum GZ was reached. The maximum GZ was determined to be 32ft at an angle of 42 degrees, and after the Maximum GZ is reached, the curve gradually slopes downward until 90 degrees is reached.

12.4 Full Load Departure Condition

The Full Load Departure Condition was run in Maxsurf: Stability and included the weight of the barge, cargo, fuel, and machinery; this was calculated in *Section 9.2*. The breakdown of the weights put into Maxsurf Stability can be seen in *Figure 39* below.

Item Name	Quantity	Unit Mass Long Ton	Total Mass Long Ton
Lightship	1	6740.000	6740.000
Hold 1 PW	**0%**	270.193	0.000
Hold 1 SW	**0%**	270.193	0.000
Hold 2 PW	**0%**	555.674	0.000
Hold 2 SW	**0%**	555.674	0.000
Hold 3 PW	**0%**	552.597	0.000
Hold 3 SW	**0%**	552.597	0.000
Hold 4 PW	**0%**	552.597	0.000
Hold 4 SW	**0%**	552.597	0.000
Hold 5 PW	**0%**	552.597	0.000
Hold 5 SW	**0%**	552.597	0.000
Hold 1	1	1080.000	1080.000
Hold 2	1	3510.000	3510.000
Hold 3	1	4050.000	4050.000
Hold 4	1	4590.000	4590.000
Hold 5	1	4860.000	4860.000
Fuel	1	0.000	0.000
Machinery	1	15.000	15.000
Fuel Tank P	**98%**	27.312	26.766
Fuel Tank S	**98%**	27.312	26.766
Total Loadcase			**24898.532**

Figure 39: Load Condition - Departure

To better understand the stability of the barge, a Large Angle Stability analysis was done to determine the Maximum GZ curve in the Full Load Departure Condition. It was run from a heel angle of 0 degrees to 90 degrees in increments of 5 degrees, and at a 0.6ft trim by bow, again this was designed to be head up. The GZ curve can be seen in *Figure 40* below.

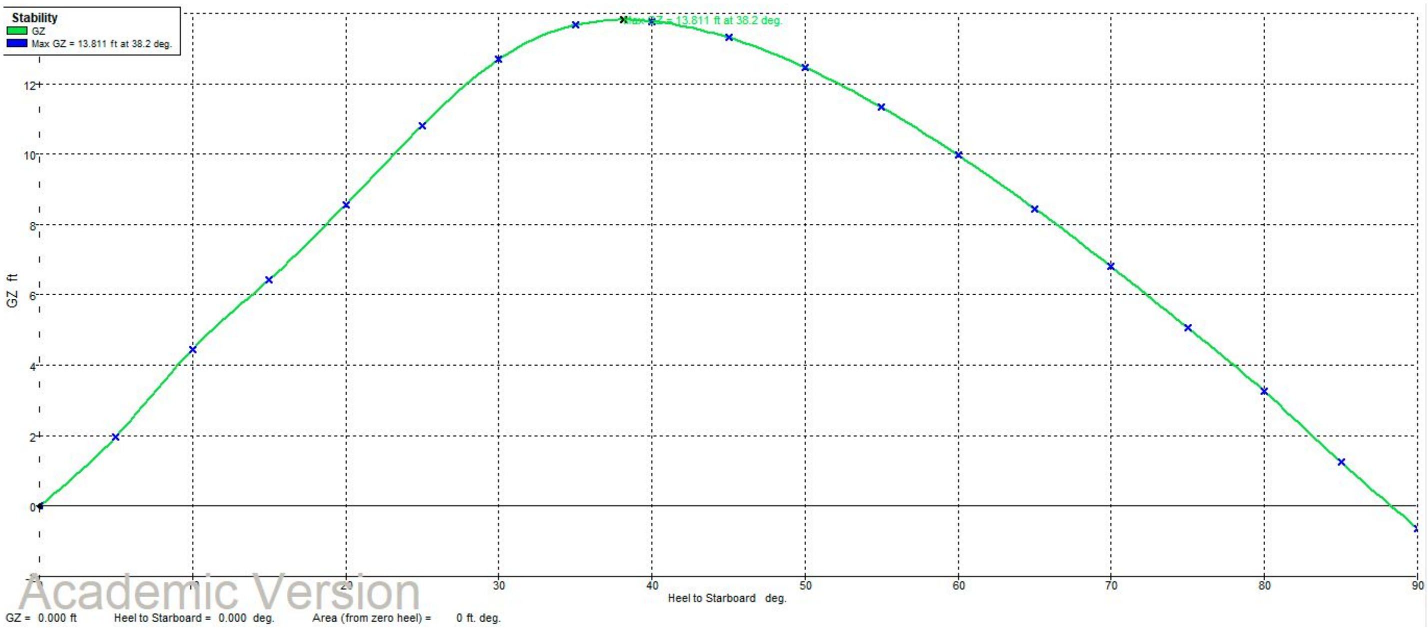

Figure 40: Maximum GZ Curve - Departure

Figure 40, shows the GZ Curve which starts at a steep slope and then comes to a peak right before the Maximum GZ is reached. The maximum GZ was determined to be 14ft at an angle of 38 degrees. After the Maximum GZ was reached, the slope of the curve sharply went down until it reached 90 degrees.

12.5 Arrival Condition

The Arrival Condition was run in Maxsurf: Stability and contained the weight of the barge, cargo, machinery, and 10% of the fuel remaining for the machinery. The breakdown of the weights put into Maxsurf: Stability can be seen in *Figure 41*.

Item Name	Quantity	Unit Mass Long Ton	Total Mass Long Ton
Lightship	1	6740.000	6740.000
Hold 1 PW	**0%**	270.193	0.000
Hold 1 SW	**0%**	270.193	0.000
Hold 2 PW	**0%**	555.674	0.000
Hold 2 SW	**0%**	555.674	0.000
Hold 3 PW	**0%**	552.597	0.000
Hold 3 SW	**0%**	552.597	0.000
Hold 4 PW	**0%**	552.597	0.000
Hold 4 SW	**0%**	552.597	0.000
Hold 5 PW	**0%**	552.597	0.000
Hold 5 SW	**0%**	552.597	0.000
Hold 1	1	1080.000	1080.000
Hold 2	1	3510.000	3510.000
Hold 3	1	4050.000	4050.000
Hold 4	1	4590.000	4590.000
Hold 5	1	4860.000	4860.000
Fuel	1	0.000	0.000
Machinery	1	15.000	15.000
Fuel Tank P	9.15%	27.312	**2.500**
Fuel Tank S	9.15%	27.312	**2.500**
Total Loadcase			**24850.000**

Figure 41: Load Condition - Arrival

To better understand the stability of the barge, a Large Angle Stability analysis was done to determine the Maximum GZ curve in the Arrival Condition. It was run from a heel angle of 0 degrees to 90 degrees in increments of 5 degrees, and at a 0.6ft trim by bow. The GZ curve can be seen in *Figure 42* below.

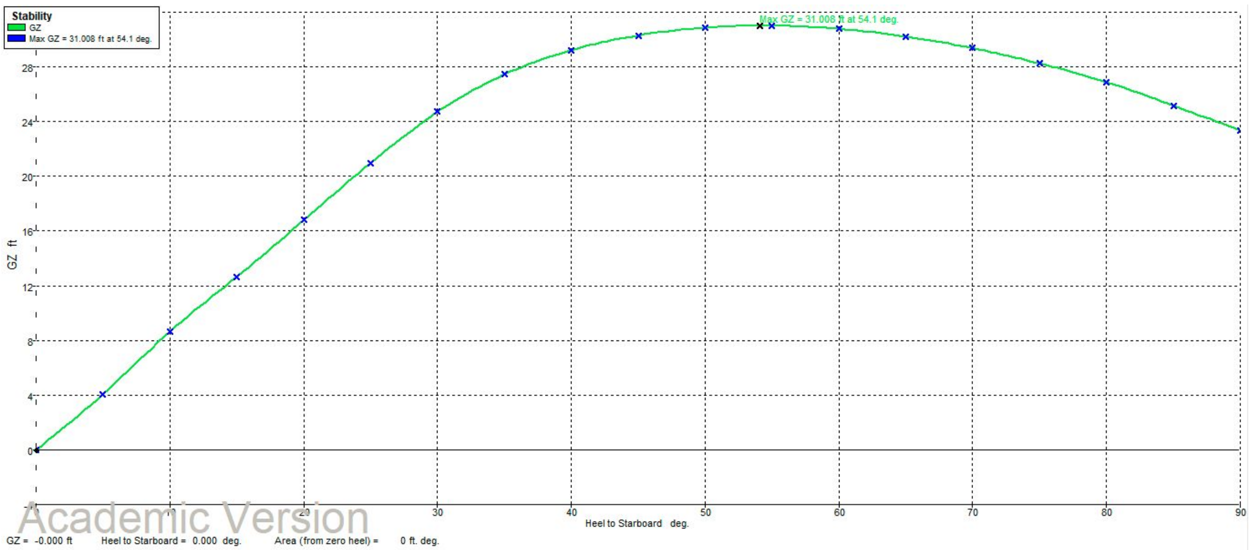

Figure 42: Maximum GZ Curve - Arrival

Initially the slope of the curve gently rises until it evens out to reach the Maximum GZ. The Maximum GZ was determined to be 31ft at an angle of 54 degrees. Once the Maximum GZ was reached, the curve gently sloped downward until it reached 90 degrees.

13. Barge Damage Stability Analysis

13.1 Required GM

A Required GM Curve shows different GM's at different drafts (ft). *Figure 43* displays the required GM curve for the barge, taken from Hecsalv.

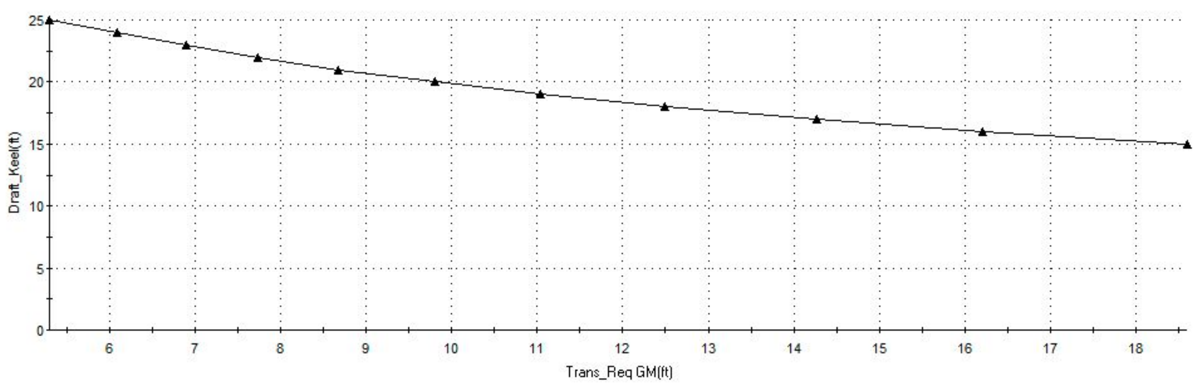

Figure 43: Damage Required GM

13.2 Lightship Condition

As stated in Section 12.3, we ran the Lightship condition at the weights in *Figure 37*. However, this time we damaged empty tanks and compartments in order to determine if the vessel would stay afloat if more than 20% of the breadth was damaged. Below in *Figure 44*, shows the Maximum GZ curve for the Lightship Condition. This curve was run with the same heel angles and trim as set previously.

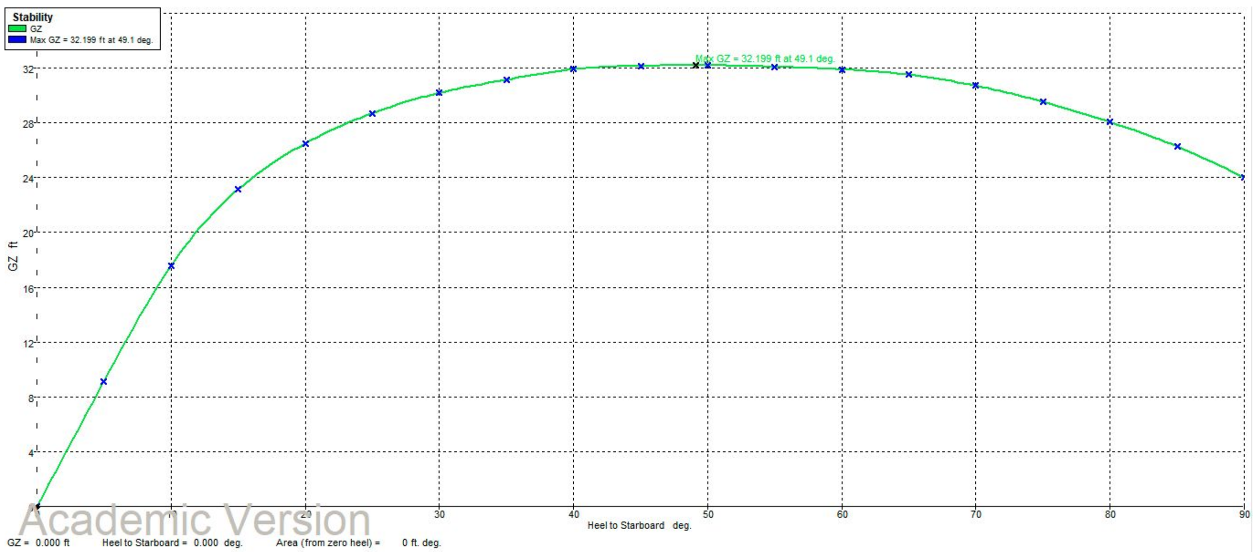

Figure 44: Damage Maximum GZ Curve - Lightship

After completing the analysis, a maximum GZ was determined to be 31ft at an angle of 49 degrees. To determine the above curve, we damaged Hold 4, Hold 4C (Void), and Hold 4 P/S Wing Tanks. So the entirety of the barge across Hold 4 was damaged and was still able to stay upright after the analysis was run.

13.3 Full Load Condition

As stated in Section 12.4, we ran the Full Load condition at the weights in *Figure 39*. However, this time we damaged empty tanks and compartments in order to determine if the vessel would stay afloat if more than 20% of the breadth was damaged. *Figure 45*, shows the Maximum GZ curve for the Departure Condition. This curve was run with the same heel angles and trim as set previously.

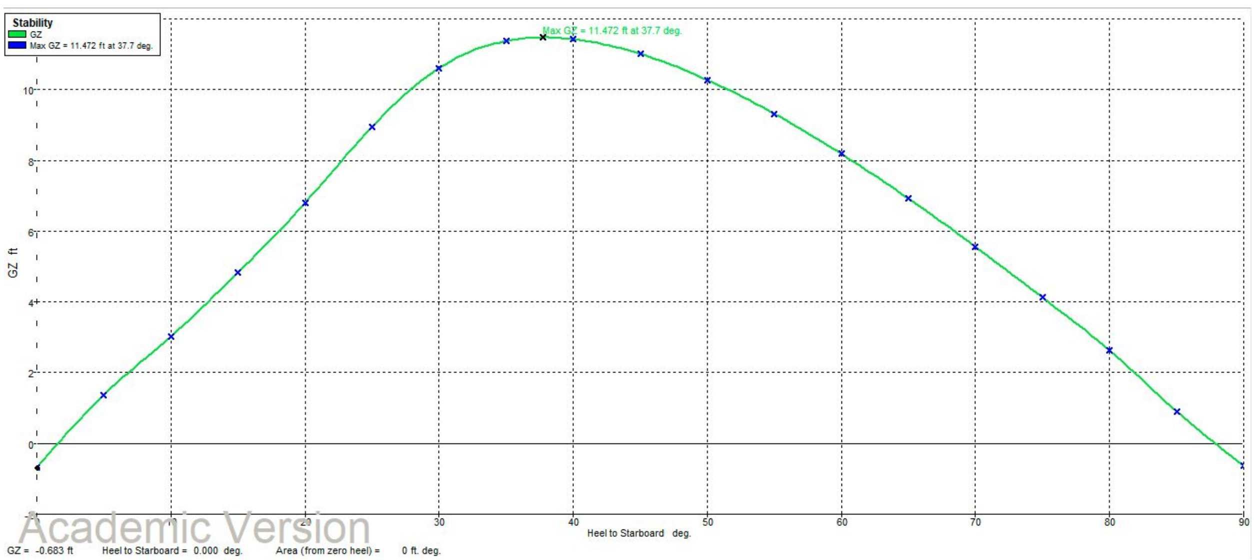

Figure 45: Damage Maximum GZ Curve - Departure

After completing the analysis, a maximum GZ was determined to be 11ft at an angle of 38 degrees. Although that angle is not ideal, it is still able to survive damage at the set conditions. To determine the above curve, we damaged Holds 1 and 2, Hold 2C (Void), and Hold 1 P/S wing Tanks, and Hold 2 Port Wing Tank.

13.4 Arrival Condition

As stated in Section 12.5, we ran the Arrival condition at the weights in *Figure 41*. However, this time we damaged empty tanks and compartments in order to determine if the vessel would stay afloat if more than 20% of the breadth was damaged. *Figure 46*, shows the Maximum GZ curve for the Arrival Condition. This curve was run with the same heel angles and trim as set previously.

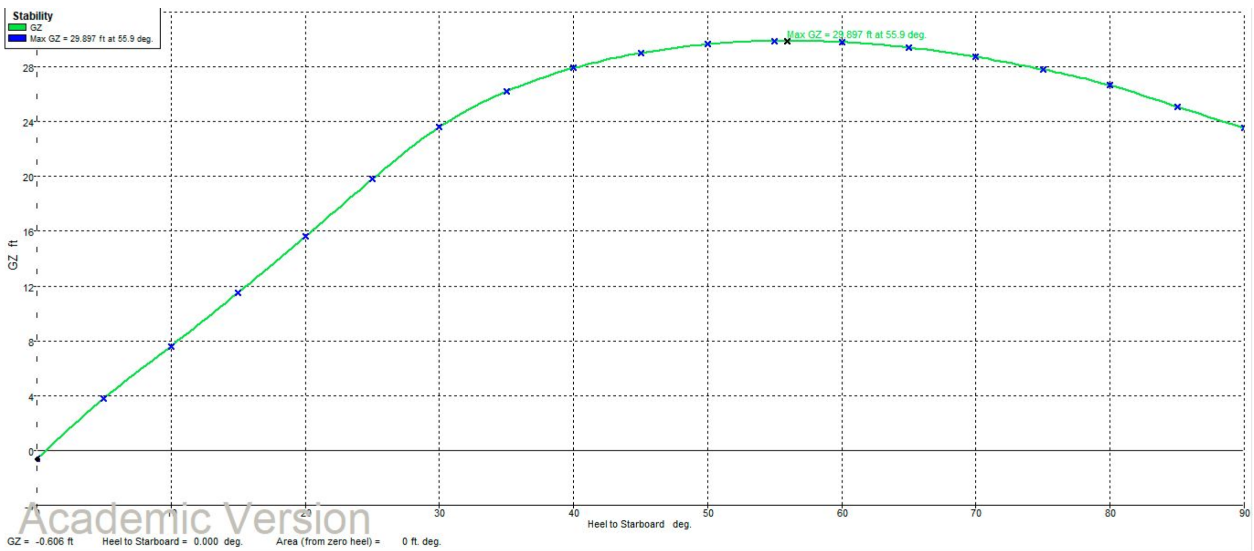

Figure 46: Damage Maximum GZ Curve - Arrival

After completing the analysis, a maximum GZ was determined to be 30ft at an angle of 56 degrees. Although that angle is not ideal, it is still able to survive damage at the set conditions. To determine the above curve, we damaged Hold 2, Hold 2C (Void), and Hold 2 Port Wing Tank.

14. Barge Electrical Load Analysis

ATBs require unique analysis when it comes to electrical load, due to the fact that both vessels have their own separate loads but can share sources of power. The unmanned nature of the barge means that it will not contain any hotel or bridge-related loads, making the refrigerated containers the main load to be accounted for. Many of the other components on the barge such as fire pumps and anchoring equipment will only occasionally, rather than continuously draw power.

An EPLA or Electric Power Load Analysis has a standard in which loads are grouped and calculated depending on the operating condition of the vessel. The total electrical load will be determined in the following conditions: at anchor, ashore, cruising, functional, and in an emergency. The rated kW draw produced by each component is multiplied by a factor of usage in each condition and the generator must be able to supply enough power to handle the highest estimated load. Our barge will have 2 generators, one main and one standby which will both have the capacity to take on the full electrical load for the barge if need be.

14.1 Barge Electrical Load Analysis

The electrical load of the unmanned barge has been broken down into the following components:

COMPONENTS	ESTIMATED POWER DRAW (kW)
Bilge Pumps (3)	34
Fire Pumps (3)	56
Anchor Windlass Hydraulic Power Unit	140
Refrigerated Containers	525
Lighting	2.5
Emergency Lighting	1.5
TOTAL DRAW	731.5

Table 11: Rated Electrical Load Analysis

The requirements for both bilge and fire pump capacities were taken from International Maritime Organization publications for open-top container vessels. When choosing the pumps for the barge, it was again essential to consider the nature of an open container barge. The vessel is completely vulnerable to the elements, rain and debris can very easily find its way into the barge, especially in a foul weather situation. For this reason a self-priming, semi-trash pump was selected. If the bilges need to be pumped in an emergency situation these pumps have a 660 GPM rating and could handle pumping water even if it is contaminated with debris. Three of these pumps will be distributed across the unmanned barge. The selected fire pump has a 740 GPM rating and meets IMO standards for an open container vessel. IMO also requires 3 fire pumps for this type of ship. The electrical load calculations for our pumps can be found in the tables below.

BILGE PUMPS	
660	GPM
15	HP
11.18	kW
# OF PUMPS	3
TOTAL kW :	33.54

Table 12: Bilge Pump EPLA

FIRE PUMPS	
740	GPM
25	HP
18.6	kW
# OF PUMPS	3
TOTAL kW :	55.8

Table 13: Fire Pump EPLA

The main lighting load was calculated by evenly spacing 4ft led lights across the total distance of passageways in the barge assuring that all passageways were illuminated to ABS standard. The only requirement of ABS was that the lighting must be adequate for work in all crew areas. The total lighting load was calculated to be 3kW The emergency lighting was assumed to be a fraction of the main lighting, which was already an almost negligible load. The emergency lighting load was estimated on the high end assuming that half of the lights were also emergency lights, a load of 1.5 kW was then assumed. It is important to note that emergency lighting is not a separate fixture from the main lighting, it is just a fraction of the main lights that remain on in emergency situations when the kW load must be reduced. The barge lighting electrical draw calculations can be seen in the table below:

SELECTED MODEL			
TYPE	4	FT. LEDS	
WATTS	15	EACH	
HP	0.02	EACH	
VOLTAGE	120	TO	277
PASSAGEWAYS			
TRANSVERSE PEEWAYS		72	FT
# OF PEEWAYS		30	_
LIGHT SPACING		16	FT
LIGHT LENGTH		4	FT
TOTAL LENGTH		20	FT
AMOUNT OF LIGHTS		108	UNITS
BOX GIRDERS		500	FT
# OF BOX GIRDERS		2	_
AMOUNT OF LIGHTS		50	UNITS
TOTAL POWER NEEDED		3.16	HP
TOTAL POWER IN kW		2.35	kW
TOTAL E-LIGHTING		1.175	kW

Table 14: Lighting EPLA

The anchor windlass hydra power pack electrical draw was calculated based on sample anchor windlass kW loads from ships of a similar size. These specifications are shown below:

FULL LOAD	150 HP
125% FULL LOAD (MAY BE OVERLOADED AT START OF HOIST)	188 HP
MAX kW DRAW	140.19 kW

Table 15: Anchor Windlass EPLA

For the refrigeration containers an estimated 7 kW load and 60% utilization factor were selected based on common industry practice to calculate the total kilowatt draw from our refrigeration containers. This produced a total draw of 525 kW. The calculations for our refrigeration container electrical load is displayed in the table below:

kW per Reefer	7	kW
# of Reefers	125	-
Total kW Load	875	kW
Utilization 60%	525	kW

Table 16: Refrigeration Container Electrical Load Calculations

Once all of the rated kW loads were determined for each of the components of the barge, the utilization factor in each condition of the vessel was determined using a sample NAVSEA publication about standard EPLAs which is listed in the references. In the table below you can see the full Electric Power Load Analysis for the unmanned barge:

COMPONENTS	ESTIMATED DRAW (kW)	anchor factor	anchor	shore factor	shore	Cruising factor	cruising	functioning factor	functioning	emergency factor	emergency
Bilge Pumps (3)	34	0.1	3.4	0.1	3.4	0.1	3.4	0.1	3.4	0	0
Fire Pumps (3)	56	0.2	11.2	0.2	11.2	0.2	11.2	0.4	22.4	0.4	22.4
Anchor Windlass Hydraulic Power Unit	140	0.9	126	0	0	0	0	0	0	0	0
Refrigerated Containers	525	0.9	472.5	0.9	472.5	0.9	472.5	0.9	472.5	0	0
Lighting	2.5	0.9	2.25	0.9	2.25	0.9	2.25	0.9	2.25	0	0
Emergency Lighting	1.5	0	0	0	0	0	0	0	0	0.9	1.35
TOTAL DRAW	**759**	**TOTAL kW DRAW:**	**615.35**	**TOTAL kW DRAW:**	**489.35**	**TOTAL kW DRAW:**	**489.35**	**TOTAL kW DRAW:**	**500.55**	**TOTAL kW DRAW:**	**23.75**

Table17: Final EPLA for Barge Components in Different Conditions

Based on the EPLA above, the highest kilowatt load is during the anchoring condition as this is the only condition that includes both the refrigeration containers as well as the anchor windlass system in its load. In order to account for this load of 615.35 kW, along with increased start up load, as well as the possibility of a higher than 60% refrigeration container utilization factor, we have decided to select a generator with a generously higher kW load than suggested by the EPLA.

As seen in the figure below, we have chosen two 760kW Northern Lights Marine Generators. A large amount of extra kW between the two generators was designed so that each generator is equipped to handle the required load completely independent of the other. This means that even in a situation where the main generator is lost, the standby generator, which has the same kilowatt rating can kick on and the barge will still be fully operable. See the chosen generator specifications below:

Northern Lights M12812H23 Series Marine Generator	
60 Hz @ 1800 rpm	760 kW
50 Hz @ 1500 rpm	660 kW
Cylinders:	V-12
Displacement:	1479 cid (24.24 ltr)
Aspiration:	Turbo and Aftercooled
60 Hz @ 1800 rpm	760 kW

Table 18: M12812H23 Specifications

14.2 Barge Generator Fuel Estimates

The calculation for the fuel consumption of the barge generators can be seen below. We estimated the GPM based on roughly a ¾ load condition, as the heaviest load condition we analyzed in our EPLA was roughly .8 of the generators overall rating. The table that was used to estimate the generator GPM can also be found below:

Gen Size	760	kW
Highest Load	615.35	kW
3/4 Load	40	GPH
gal/day	960	gal
Convert to LT	3.6	LT/day
15% S.F	4.2	LT/day
Single Leg	5	days
Fuel for single	20.9	tons
Round Trip	10	days
Fuel for RT	41.8	tons

Table 19: Barge Generator Fuel Consumption

Generator Size (kW)	1/4 Load (gal/hr)	1/2 Load (gal/hr)	3/4 Load (gal/hr)	Full Load (gal/hr)
20	0.6	0.9	1.3	1.6
30	1.3	1.8	2.4	2.9
40	1.6	2.3	3.2	4
60	1.8	2.9	3.8	4.8
75	2.4	3.4	4.6	6.1
100	2.6	4.1	5.8	7.4
125	3.1	5	7.1	9.1
135	3.3	5.4	7.6	9.8
150	3.6	5.9	8.4	10.9
175	4.1	6.8	9.7	12.7
200	4.7	7.7	11	14.4
230	5.3	8.8	12.5	16.6
250	5.7	9.5	13.6	18
300	6.8	11.3	16.1	21.5
350	7.9	13.1	18.7	25.1
400	8.9	14.9	21.3	28.6
500	11	18.5	26.4	35.7
600	13.2	22	31.5	42.8
750	16.3	27.4	39.3	53.4
1000	21.6	36.4	52.1	71.1
1250	26.9	45.3	65	88.8
1500	32.2	54.3	77.8	106.5
1750	37.5	63.2	90.7	124.2
2000	42.8	72.2	103.5	141.9
2250	48.1	81.1	116.4	159.6

Table 19: GPM Estimation Chart

In the chart above, as mentioned previously, the ¾ load gal/hr estimate was used as it is the closest representation of the highest electrical load condition that was calculated in our EPLA. The condition with the highest kW draw was anchoring, likely due to the fact that it was the only condition that accounted for the 140 kW Hydraulic Anchor Windlass Unit. The load on the generator in this condition is estimated at 615.35 kW which is roughly 80% of the total kW rating of the generators, considering most of the other conditions don't come anywhere close to this load, it was well within reason to estimate using 75% load. We used the 750 kW estimation for our generators, as it was the closest to the 760 kW rating of the barge generators. The overall estimation for fuel consumption round trip for the unmanned barge is roughly 42 tons.

15. Barge Seakeeping Analysis

15.1 Wave Statistics

For our initial analysis, we selected four different NOAA buoys along our route from the historical data for each individual buoy provided from the *National Buoy Data Center*. The buoy with the most severe roll motion was chosen to represent the most concerning seas that the vessel would encounter. The buoy that had the most challenging wave action was Buoy 41004 southeast of Charleston. The buoy data is shown in *Table 20*.

Buoy Number	Location	Latitude and Longitude
Buoy 41004	41NM Southeast of Charleston, SC	32°30'2" N 79°5'58" W

Table 20: Buoy Location Overview A

Figure 47 below shows the annual data for wave height (meters) versus the wave period (seconds). The wave height of 1 meter and a wave period of 4.0-4.99 seconds had the highest percentage of occurrences at 43.6%. During this wave period, wave height of 1 meter was more likely to occur than any other height and period.

Buoy 41004 - Charleston

	PERCENT FREQUENCY OF SIGNIFICANT WAVE HEIGHT(METERS) VS AVERAGE WAVE PERIOD(SECONDS)														
	WAVE HEIGHT														
WAVE PERIOD	0.2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	TOT %
< 3.0																0.0
3.0 - 3.9	0.002	0.061														6.3
4.0 - 4.9	0.004	0.343	0.089													43.6
5.0 - 5.9	0.003	0.179	0.125	0.040	0.001											34.8
6.0 - 6.9	0.001	0.062	0.023	0.018	0.009	0.001										11.4
7.0 - 7.9	0.002	0.0180	0.006	0.002	0.002	0.001										3.1
8.0 - 8.9	0.001	0.003	0.002	0.001	0.001											0.8
9.0 - 9.9																0.0
10.0 - 11.0																0.0
>= 11.0																0.0
																100.0
TOTAL %	1.300	66.600	24.500	6.100	1.300	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.0

Figure 47: 41004 Wave Statistics A

In order to determine any issues with the operability of the vessel, another seakeeping analysis was conducted for harsher sea conditions. Buoy 46001 in the western Gulf of Alaska was chosen due to the notoriety of the winter wave patterns in this area. The buoy data is found in *Table 21*.

Buoy Number	**Location**	**Latitude and Longitude**
Buoy 46001	175NM Southeast of Kodak, AK	56°13'56" N 147°56'57" W

Table 21: Buoy Location Overview B

The wave statistics for this buoy are found below in Figure 48. When compared to the wave height and period for the Charleston buoy, there are more instances of higher wave heights for a longer wave period. These statistics are the average data for the winter months - December, January, and February - in order to test the most severe wave motion available.

PERCENT FREQUENCY OF SIGNIFICANT WAVE HEIGHT(METERS) VS AVERAGE WAVE PERIOD(SECONDS)

Buoy 46001 - Gulf of Alaska

	WAVE HEIGHT															
WAVE PERIOD	0.2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	TOT %
< 3.0																0.0
3.0 - 3.9																0.0
4.0 - 4.9		0.002	0.005													0.7
5.0 - 5.9		0.008	0.047	0.023	0.001											7.9
6.0 - 6.9		0.006	0.076	0.125	0.051	0.003										26.1
7.0 - 7.9		0.002	0.045	0.101	0.111	0.060	0.01									32.9
8.0 - 8.9		0.002	0.014	0.039	0.059	0.051	0.036	0.013	0.001							21.5
9.0 - 9.9		0.002	0.003	0.009	0.016	0.02	0.014	0.011	0.007	0.002						8.4
10.0 - 11.0		0.002	0.002	0.002	0.002	0.004	0.004	0.003	0.003	0.003						2.5
>= 11.0																0.0
																100.0
TOTAL %	0.000	2.400	19.200	29.900	24.000	13.800	6.400	2.700	1.100	0.500	0.000	0.000	0.000	0.000	0.000	100.0

Figure 48: 46001 Wave Statistics B

The preliminary analysis of the barge hull was conducted using MAXSURF Motions. The results of the analysis produced the RAO curves and Polar Plots necessary to find the most problematic speed and heading combinations for the barge.

15.2 RAO Curves

An RAO, response amplitude operator, is a set of statistics that are used to determine the likely behavior of a ship when operating underway. An RAO looks at the six motions of the vessel: surge, sway, heave, roll, pitch, and yaw, when a wave passes the vessel. The displacements, accelerations, and velocities for any given location on the barge can be found by looking at the six motions of the vessel. For the Maxsurf: Motions analysis, two locations were selected; a location directly on the bow and another location representing the tug wheelhouse.

Two RAO curves were analyzed at 0 knots. The first RAO curve that was selected showed Roll and Heave RAO in Beam Seas. Beam seas occur when the sea is approximately at a right angle to the course of the vessel. A heading of 0 degrees when steering means that wave action would encounter the barge from an angle of 90 degrees. *Figure 49* shows the resulting graph of the RAO at a speed of 0 knots and a heading of 90 degrees. The natural period found from the RAO graph was determined to be 0.4 radians per second. The frequency, ω, of the waves can be found using the below equation. The result of this equation showed that the period of the wave at its highest point at 13.9 seconds.

$$Period = \frac{2\pi}{\omega}$$

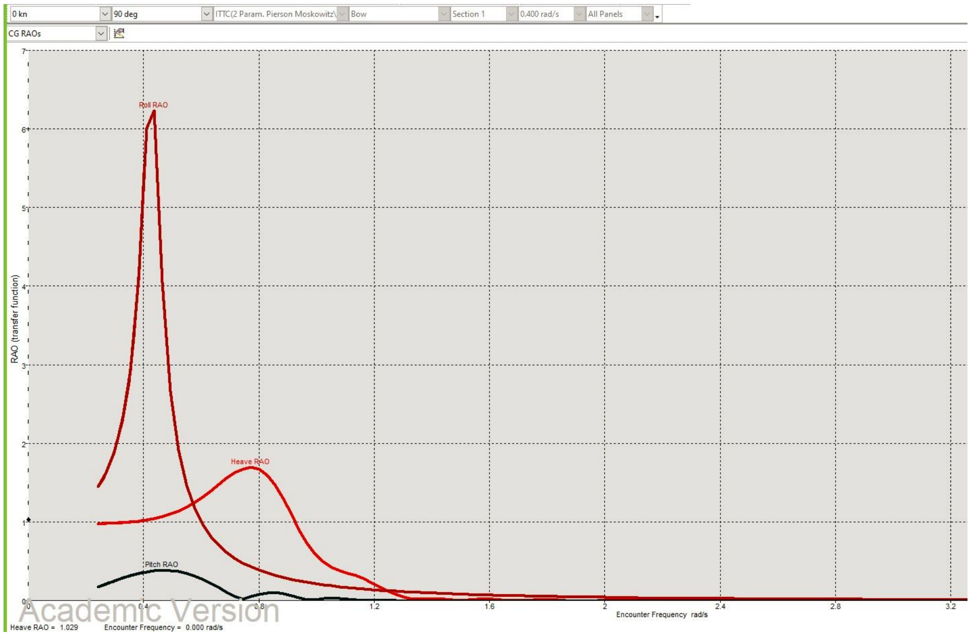

Figure 49: RAO Curve (0 knots, 90-degree heading), Beam Seas

When looking at the Beam Sea RAO graph, *Figure 49*, the Heave RAO, *Figure 50*, is well below the Roll RAO. The Heave RAO has an encounter frequency of about 0.6 rad/s at its highest point when compared to Roll RAO which has an encounter frequency of about 0.42 rad/sec at its highest point. This shows that when the vessel is underway and waves encounter the vessel at an angle of 90 degrees abaft the heading, the vessel is more likely to roll than heave in that situation.

The second RAO graph, *Figure 50*, that was selected shows Pitch and Heave RAO in Head Seas. Head seas occur when the motion of the ocean is against that of the vessel's heading. At a heading of 0 degrees, head seas encounter the vessel at 180 degrees. *Figure 49* shows the resulting graph of the vessel at a speed of 0 knots and a heading of 180 degrees. Again, using *Equation 1*, the period of the vessel was determined to be about 16 seconds when the frequency was 0.4 rad/s.

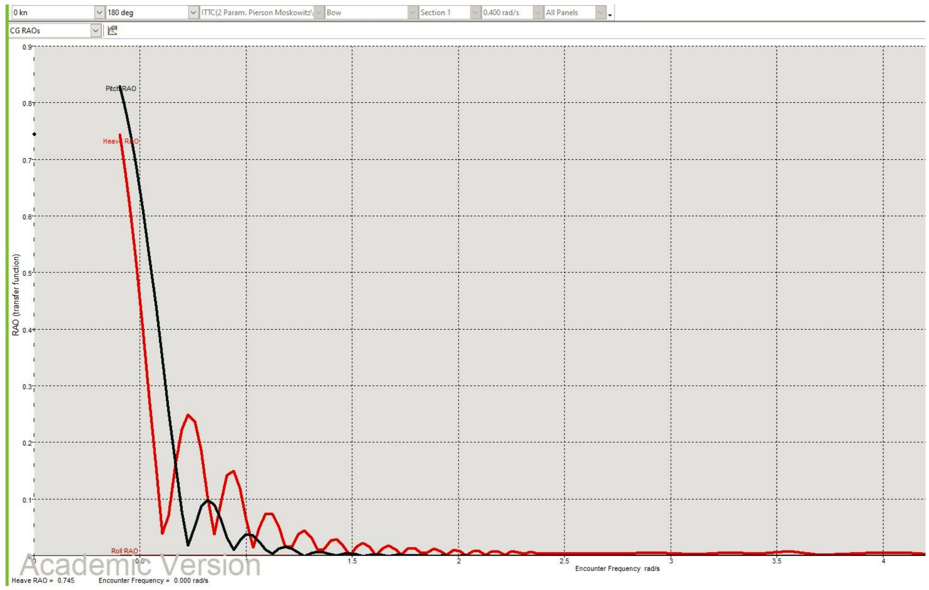

Figure 50: RAO Curve (0 knots, 180-degree heading), Head Seas

When looking at the Head Sea RAO graph in *Figure 50*, the Pitch and Heave RAO curves are very similar when looking at their height and shape. The Pitch RAO is above the Heave RAO, however, after reaching the respective maximum point, both curves fall in unison. After the fall, both curves repeat the parabolic motion with a decrease in amplitude as more waves are encountered until the vessel stops pitching and heaving. This shows that when a vessel encounters a wave, it is more likely to pitch than heave, but both will occur and fade almost simultaneously.

15.3 Polar Plot Analysis

A polar plot is a plot of magnitude versus a phase angle. In the case of this analysis, polar plots were used in order to determine what speeds and headings are compatible and incompatible with the comfort and operation of the barge. We will be looking at three different polar plots in this analysis: Roll Motion, Relative Vertical Motion at the bow, and Lateral Acceleration at the tug wheelhouse.

The first polar plot, Roll Motion, as seen in *Figure 51*, shows the degrees of roll motion of the vessel. The vessel was analyzed at 5 different speeds to show the possible roll motion results that can occur at any vessel speed and heading, including anchorage. The shapes of the Roll Motion curves are similar from 4 knots to 10 knots. As the speed increases at a 60-degree wave heading, the likelihood of a roll motion increases, with 0 knots having a Roll Motion of 2.8 and 10 knots having a Roll Motion of 5.2. At the design speed of 10 knots, the RMS Roll Amplitude is in a period of sustained roll motion from a 45 degree heading to a 60 degree heading. This shows that between the wave headings of 45 degrees and 60 degrees in relation to the vessel, the vessel is more likely to experience rolls than at any other speed and heading.

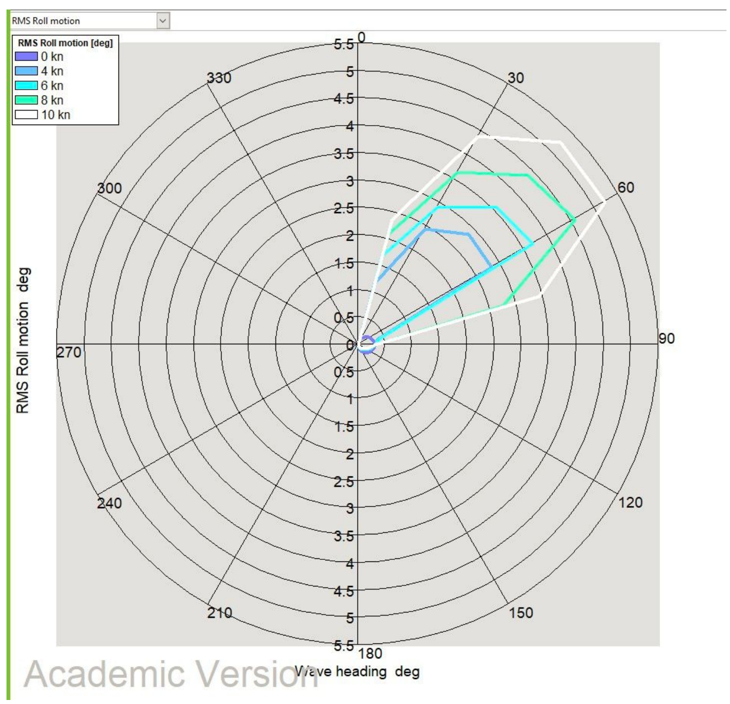

Figure 51: Roll Motion Polar Plot

Overall for the Roll Motion, the wave headings to take into consideration are between 45 and 60 degrees in relation to the vessel's heading. At these wave headings, the vessel is at the most likely to experience roll motion which can decrease speed, and possibly damage cargo.

The next polar plot is the Relative Vertical Motion plot at the bow, as shown in *Figure 52***.** This polar plot shows the vertical motion at the bow of the barge. The specific polar plot selected in

Figure 52 is for an average wave period of 4.5 seconds, due to the wave statistics for the Charleston buoy having the highest frequency of wave periods happening in the period range between 4.0-4.99 seconds. Five different speeds were used at different wave headings to determine the vertical motion behavior of the bow, accounting for multiple conditions including anchorage. As shown in the polar plot below, the most concerning heading for the vessel at a wave period of 4.5 seconds is between 90 degrees and 135 degrees relative to the ship's heading. The most concerning speed for the vessel is 0 knots, or anchorage. If the vessel is anchored in an area with wave patterns similar to those experienced at the Charleston buoy, care should be taken or the ship should be rotated in order to avoid this encounter.

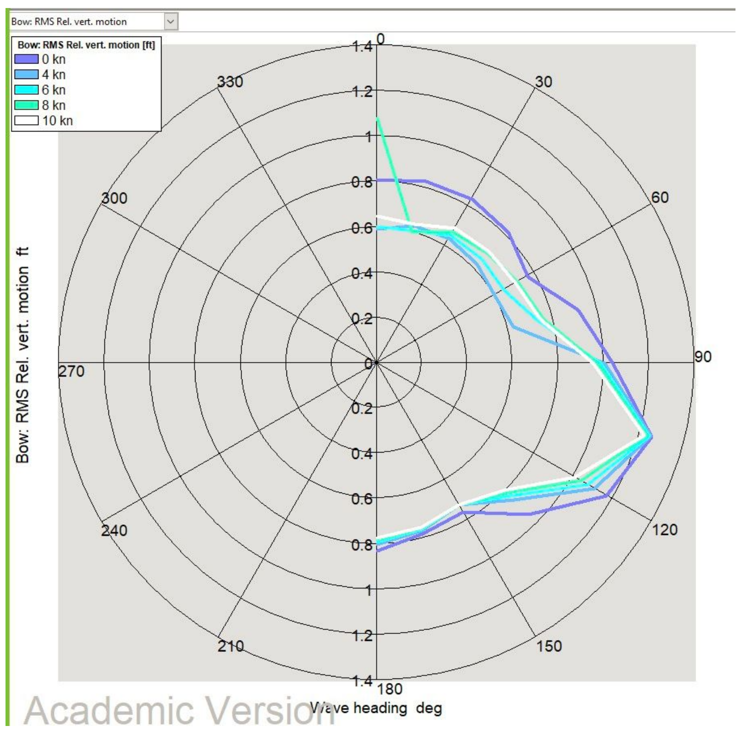

Figure 52: Relative Vertical Motion Polar Plot (Bow)

The problematic headings and speeds are important to know when the vessel is underway in order to ensure that the vessel is not only transiting safely, but that the crew can work in a safe environment. The vessel would be able to change their heading in order to accommodate for the least amount of probable vertical motion, which is when the wave heading is 30 to 60 degrees or 150 to 180 degrees in relation to the vessel's heading.

The final polar plot that was acquired from the Maxsurf: Motions data is the Lateral Acceleration plot at the tug wheelhouse, *Figure 53*. This plot shows the lateral acceleration motion the vessel will experience from the position of the tug wheelhouse. This location is important for the seakeeping analysis because it is the raised location above where the tug connects to the barge. The connection point for the ATB pin is vital for the ATB to function as a unit. If there is increased lateral motion at that point due to a high lateral acceleration above the connection, the interconnecting mechanisms could malfunction and cause damage due to repeated metal fatigue from excessive strain on the pin. Due to the fact that the ATB is designed to transport container cargo, the wheelhouse also has to have a vantage point of 800ft forward of the bow and is resultantly the highest point of the ATB.

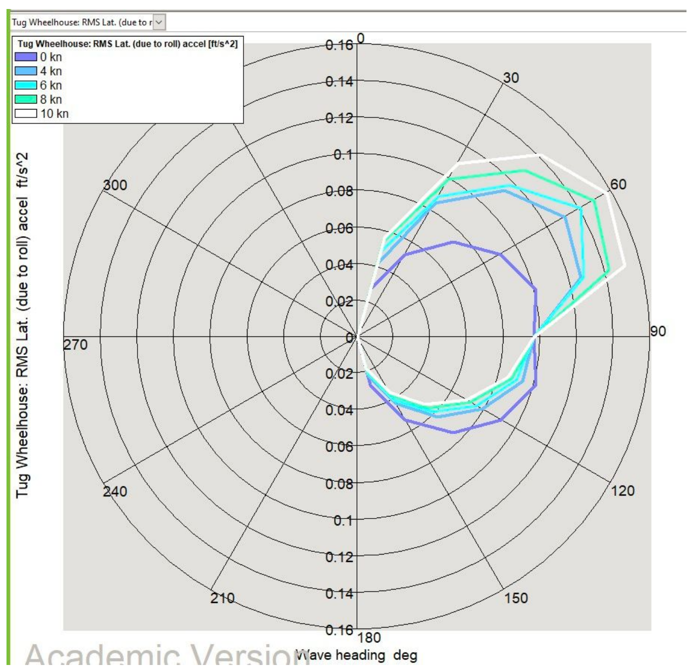

Figure 53: Lateral Acceleration Polar Plot (Tug Wheelhouse)

The highest point on the vessel tends to experience the six possible motions of the vessel more frequently than the rest of the vessel, therefore it is important to determine the possible consequences that may occur from any problematic headings and speeds. This location was analyzed at five different speeds ranging from 0 knots to the design speed of 10 knots. When looking at the plot, the area of interest ranges from 30 degrees to 75 degrees. At speeds greater than 0 kts, a majority of the lateral motion is felt between 45 degrees to 75 degrees. At 10 knots the likelihood of coming into lateral motion is slim because the acceleration is less than 0.16 ft/s^2.

15.4 Analysis

The seakeeping analysis for the ATB focused on the reliability and performance of the barge. The barge was evaluated based on three criteria; roll, lateral acceleration at the bridge, and relative vertical motion at the bow. As stated previously, the Charleston buoy was selected for the route-specific seakeeping analysis due to the fact that it had the highest percentage of heavier sea conditions. Based on the Polar Plots that were obtained from the Maxsurf: Motions results, we selected the headings and speeds that showed the most concerning responses from the barge.

The roll evaluation of the barge showed that the vessel performs as expected; with slightly lower operability at the design speed than at lower speeds. The heading that shows the most significant challenge for the seaworthiness of the barge is 60 degrees at 10 knots. The owner should keep this heading in mind when planning the voyage of the ship and minimize the frequency of encountering these sea conditions. However, if these sea conditions are encountered, the owner should reduce speed to adjust for the roll motion. The barge averages an operability percentage of 97.6% at its design speed of 10 knots. Any reduction in speed will increase the operability percentage, although it is not necessary for the comfort or operation of the vessel.

The relative vertical motion of the bow shows the ability of the vessel to navigate seas without encountering excessive water on deck. Due to the large freeboard of the vessel, the barge achieves an operability of 98.6% in the benign areas that it is intended to run. To ensure that the barge can operate outside of the designated area of operability, we also tested another location that is well known for being some of the roughest seas in the world - the Gulf of Alaska. The barge continues to operate with high levels of operability even in more severe areas, with operability of 89.3% when testing on average winter statistics for December, January, and February.

The last evaluation that was completed for the barge was the analysis of the lateral acceleration at the wheelhouse. This analysis is especially important for the ATB in order to determine if there are any potential issues associated with the articulated pin between the Tug and the Barge units. The analysis was completed for the maximum allowable acceleration of half a G, or 16 ft/s. The barge was found to have an average operability percentage of 75.3% for the most concerning headings.

16. Risk Assessment

With any transportation of cargo, there is always a risk for something to go wrong. These risks can be human or naturally caused and there are ways to limit these, however, there is still always a risk. For human risks, proper training and rest must be in effect for safe work practices and ensure the people know how to operate the ship and equipment properly. For natural risks, weather and the integrity of the hull should constantly be watched in order to avoid a disaster. The comprehensive breakdown of each risk and their corresponding likelihood and risk impact can be found in *Figure 54*.

Human risks can consist of crew error, terrorism attacks, onboard fires, economics, and pirate attacks. Crew errors include grounding, navigational incidents, crew negligence, and any improper usage of shipboard machinery that can result in damage to the vessel or other crew members. Collisions and allisions are one of the most frequent results of navigational incidents.

Terrorism attacks - while most likely not a big risk consideration due to the fact that the vessel is not intended for governmental use - are still a possibility for a US-flagged ship. Any terrorism attacks that target the ship can cause a loss of cargo, human lives, and the ship. In addition to terrorism attacks, pirate attacks can result in the same damage to the vessel. The low freeboard at the stern of the vessel, specifically the tug portion of the ATB, can make the ship a likely target for a possible pirate attack, however, the area the vessel operates in is a low-risk area for piracy.

A major concern on any ocean-going vessel is the possibility of an onboard fire, which can result in the loss of human lives and potentially fatal interactions with any dangerous cargo. A fire is particularly dangerous for the crew on a container ship, due to the high probability of improperly labeled Hazardous Material (HAZMAT) containers stored on the vessel.

The profit of the vessel is dependent on the economy and a poor economy can affect the staffing and cargo demands for the ship. Potential cargo operations and port delays can result in demurrage and a loss of revenue

Natural risks to the vessel can consist of weather-related incidents and can cause structural failure if the ship is improperly built or maintained. A structural failure can cause the loss of cargo and hull failure. Weather casualties can result in structural damages, the potential loss of the ship, and the potential loss of the crew. The area in which the vessel is intended to operate experiences Hurricane Season which causes increased wind speeds and larger wave patterns.

Risks can be mitigated by following STCW rest and work hour regulations in order to ensure that the crew is functioning properly. In regards to the crew, proper training should be required or provided in order to minimize any chances of human error. Natural risks can be minimized by using Navtex and other alert systems and equipment in order to ensure that any weather patterns or incidents are appropriately handled.

RISK	SEVERITY	LIKELIHOOD	RISK IMPACT	RECOMMENDED ACTION(S)
Crew Error: Grounding	Generally unacceptable	Possible	High	Use Navigational Equipment to properly Navigate
Crew Error: Navigational Accident	Generally unacceptable	Possible	High	Use Navigational Equipment to properly Navigate
Terrorist Attack: Lost of Life	Generally unacceptable	Not likely	Medium	Ensure Crew knows what to do in situation, drills
Terrorist Attack: Loss of Cargo and/or Ship	Generally unacceptable	Not likely	High	Ensure Crew knows what to do in situation, drills
Onboard Fire: Loss of Life	Generally unacceptable	Possible	High	Drill to ensure Crew knows how to handle different fire situations
Onboard Fire: Risk of Cargo Exploding/Damage	Tolerable	Possible	Medium	Drill to ensure Crew knows how to handle different fire situations
Pirate Attack: Loss of Cargo and Vessel	Generally unacceptable	Not likely	Medium	Ensure Crew knows what to do in situation, drills
Pirate Attack: Loss of Life	Generally unacceptable	Not likely	Medium	Ensure Crew knows what to do in situation, drills
Weather: Structural Damage	Tolerable	Possible	Medium	Ensure structure is up to standard and if not, fix it
Weather: Loss of Vessel	Generally unacceptable	Not likely	Medium	Ensure structure is up to standard and if not, fix it
Weather: Loss of Life	Generally unacceptable	Not likely	Medium	Ensure Crew knows how to properly disembark the vessel is needed, drill
Weak Structure: Loss of Cargo over Side	Tolerable	Possible	Medium	Ensure structure is up to standard and if not, fix it
Weak Structure: Failure of Hull/ Loss of Vessel	Generally unacceptable	Not likely	Medium	Ensure Crew knows how to properly disembark the vessel is needed, drill

Figure 54: Risk Analysis

17. Conclusion

The overall design of the barge is only partially complete as stated previously. This is a Preliminary Design and will require many more hours to get to the Final Design. However, we were able to gain an understanding of the structure, powering, cargo capacity, and any additional requirements for the barge.

We were able to gain an insight into the stability when running both intact and damage analysis' on the barge. For both intact and damage stability, the barge was run at a lightship. Departure, and arrival condition to be able to compare between the intact and damage stability.

A weight estimate was also done on the barge in order to determine the lightship weight, departure weight, and arrival weight. These weights would be necessary to know along with the hydrostatics to determine not only the draft of the barge, but the VCG as well.

We also were able to size pumps and generators for the barge in order to power the electrical components such as lighting and any equipment needed to operate a container carrying barge.

Lastly, we were able to not only analyze the cost of the barge, but also the risk assessment. The cost was important in order to gain an understanding of what we need to charge to beat the competition, in this case railways. After the RFR was calculated, we determined that at 60% capacity, we could charge a price that would beat our competition. When looking at the risk assessment, we determined that the largest risk to our operation would be human error and this can be mitigated by ensuring proper rest.

18. References

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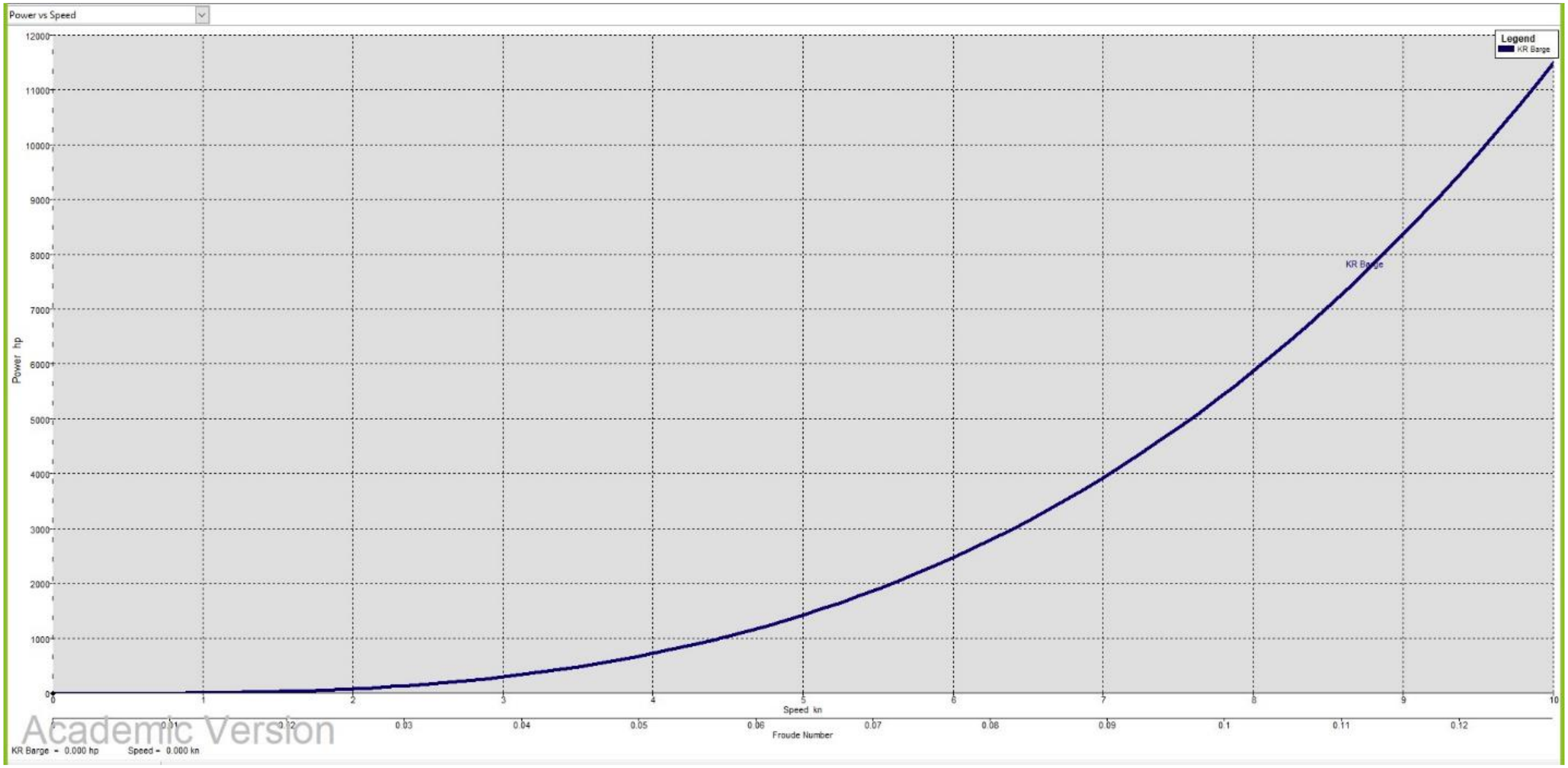
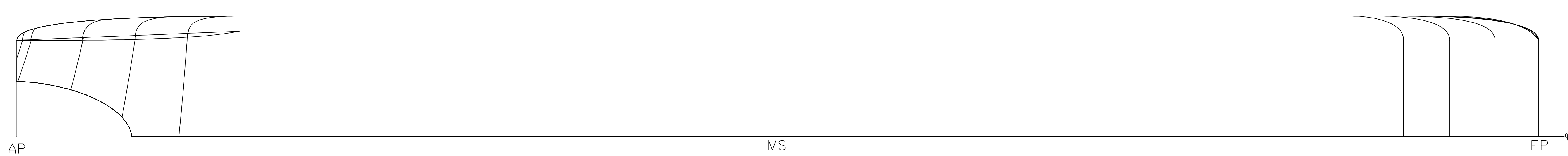
19. Programs Utilized

- Maxsurf: Modeler, Motions, Stability
- AutoCAD 2019, 2020
- Rhino 6.0
- Excel
- Hecsalv 8.1 and Ship Project Editor
- GHS

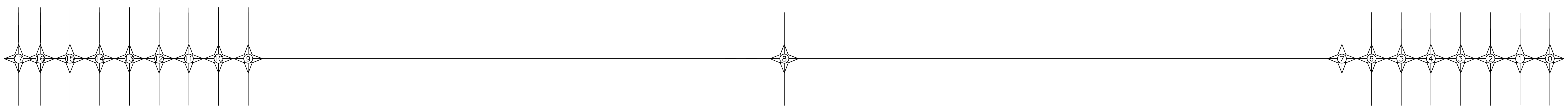
Appendix A: Speed versus Power Curve

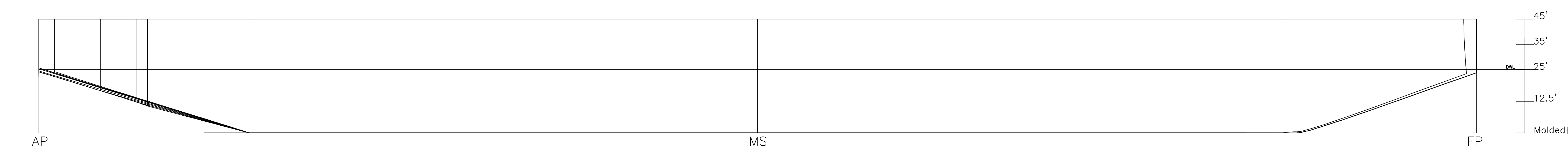


Appendix B

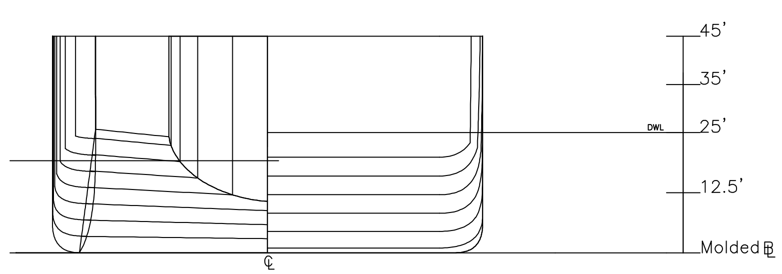


Breadth Plan





Sheer Plan



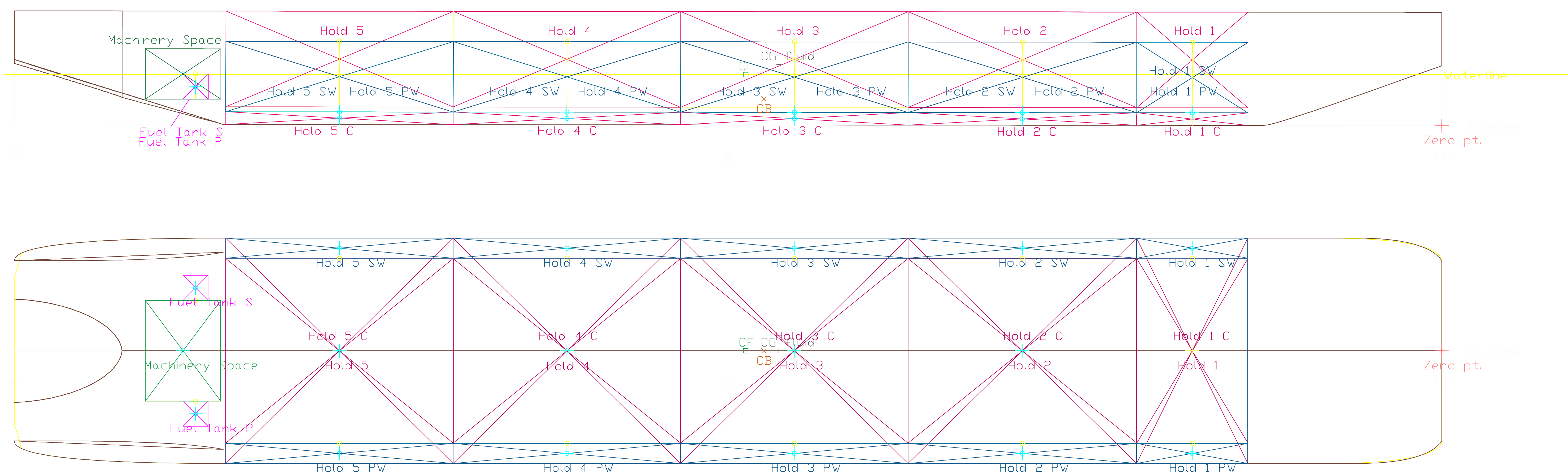
Body Plan

Waterline Spacing List	Buttock Spacing List
WL 1: 30 ft	Buttock 1: 8 ft
WL 2: 24 ft	Buttock 2: 16 ft
WL 3: 18 ft	Buttock 3: 24 ft
WL 4: 12 ft	Buttock 4: 32 ft
WL 5: 6 ft	Buttock 5: 40 ft

Station Spacing List	
Station 0: 0.0ft	Station 9: −484.0ft
Station 1: −11.0ft	Station 10: −495.0ft
Station 2: −22.0ft	Station 11: −506.0ft
Station 3: −33.0ft	Station 12: −517.0ft
Station 4: −44.0ft	Station 13: −528.0ft
Station 5: −55.0ft	Station 14: −539.0ft
Station 6: −66.0ft	Station 15: −550.0ft
Station 7: −77.0ft	Station 16: −561.0ft
Station 8: −283.5.0ft	Station 17: −567.0ft

PRINCIPAL CHARACTERISTICS		
LOA: 567	DWL: 25ft	
LBP: 567ft	Depth: 45ft	
Beam: 89.5ft		
TITLE:		DATE:
LINES PLAN: BARGE		04/07/20
PROJECT:	DWG Name:	DRAWN BY:
Ship Design	Barge Lines	L. McCord

Appendix C

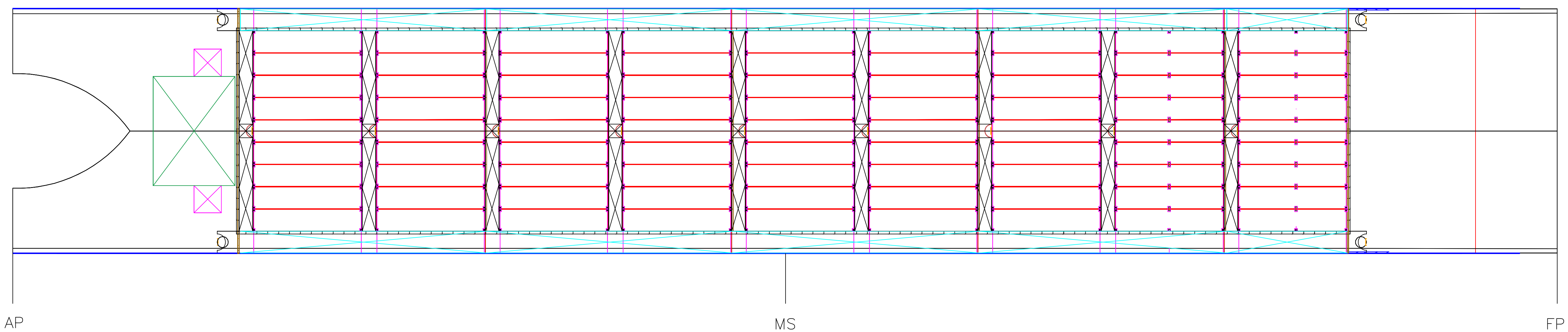


Hold and Void Capacities	
Hold 1: 81 Containers	Hold 1 C: 526 LT
Hold 2: 162 Containers	Hold 2 C: 934 LT
Hold 3: 162 Containers	Hold 3 C: 934 LT
Hold 4: 162 Containers	Hold 4 C: 934 LT
Hold 5: 162 Containers	Hold 5 C: 934 LT

Liquid Capacities	
Hold 1 PW: 270 LT	Hold 1 SW: 270 LT
Hold 2 PW: 556 LT	Hold 2 SW: 556 LT
Hold 3 PW: 553 LT	Hold 3 SW: 553 LT
Hold 4 PW: 553 LT	Hold 4 SW: 553 LT
Hold 5 PW" 553 LT	Hold 5 SW: 553 LT
Fuel Tank P: 27 LT	Fuel Tank S: 27 LT

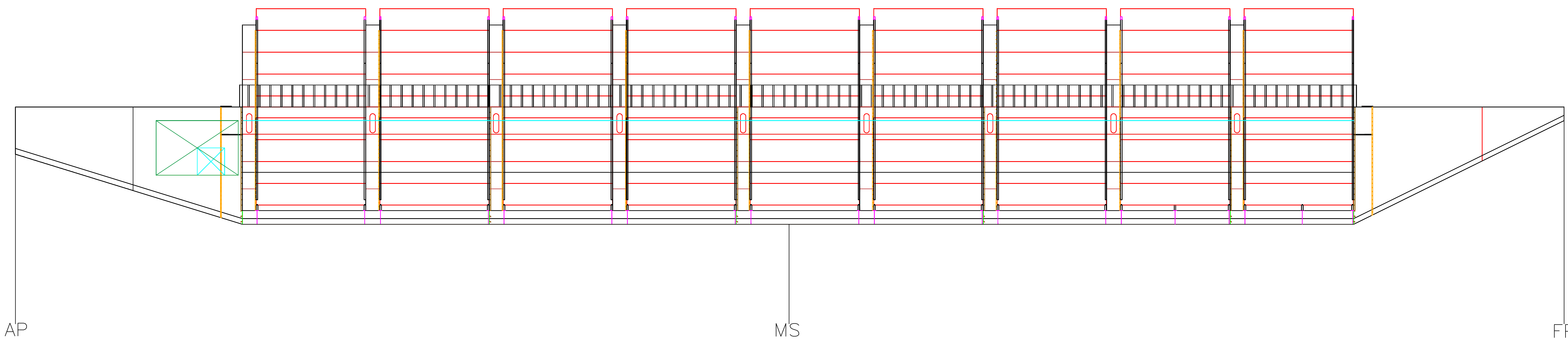
PRINCIPAL CHARACTERISTICS		
LOA: 567	DWL: 25ft	
LBP: 567ft	Depth: 45ft	
Beam: 89.5ft		
TITLE: Capacity Plan: Plan & Profile		DATE: 04/20/20
PROJECT: Ship Design	DWG Name: Barge Tanks	DRAWN BY: L. McCord

Appendix D



PRINCIPAL CHARACTERISTICS		
LOA: 567 DWL: 25ft LBP: 567ft Depth: 45ft Beam: 89.5ft		
TITLE:		DATE:
GENERAL ARRANGEMENT: PLAN		04/20/20
PROJECT:	DWG Name:	DRAWN BY:
Ship Design	GA Barge	L. McCord

Appendix E

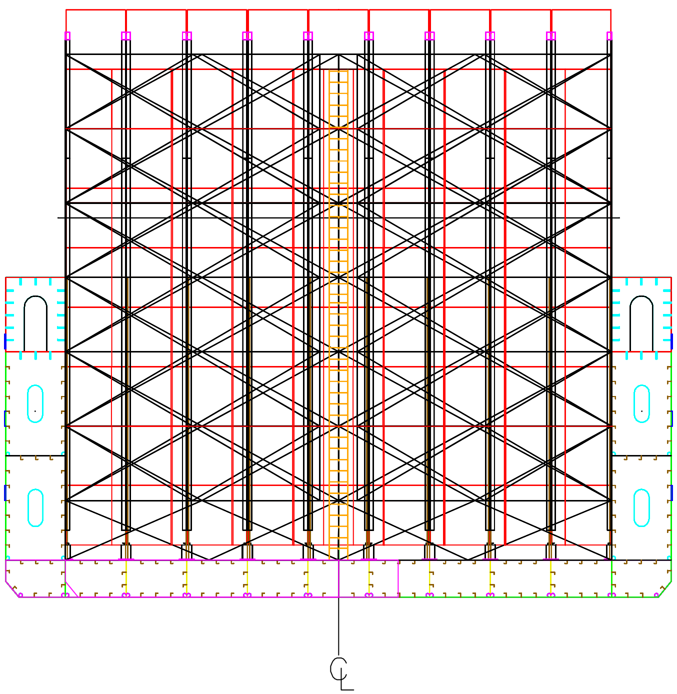


PRINCIPAL CHARACTERISTICS

LOA:	567	DWL:	25ft
LBP:	567ft	Depth:	45ft
Beam:	89.5ft		

TITLE:		DATE:
GENERAL ARRANGEMENT: PROFILE		04/20/20
PROJECT:	DWG Name:	DRAWN BY:
Ship Design	GA Barge	L. McCord

Appendix F



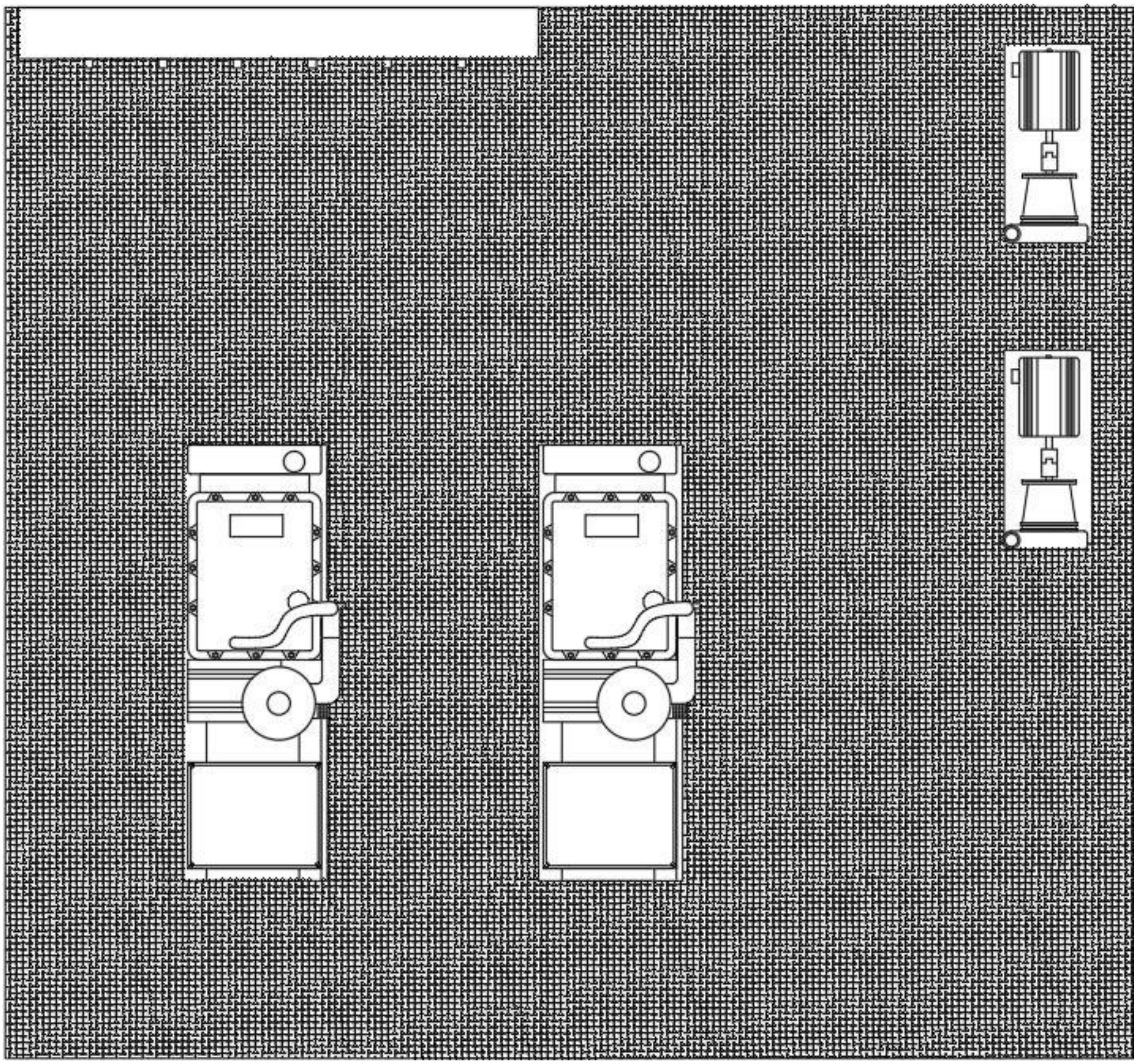
PRINCIPAL CHARACTERISTICS

LOA:	567	DWL:	25ft
LBP:	567ft	Depth:	45ft
Beam:	89.5ft		

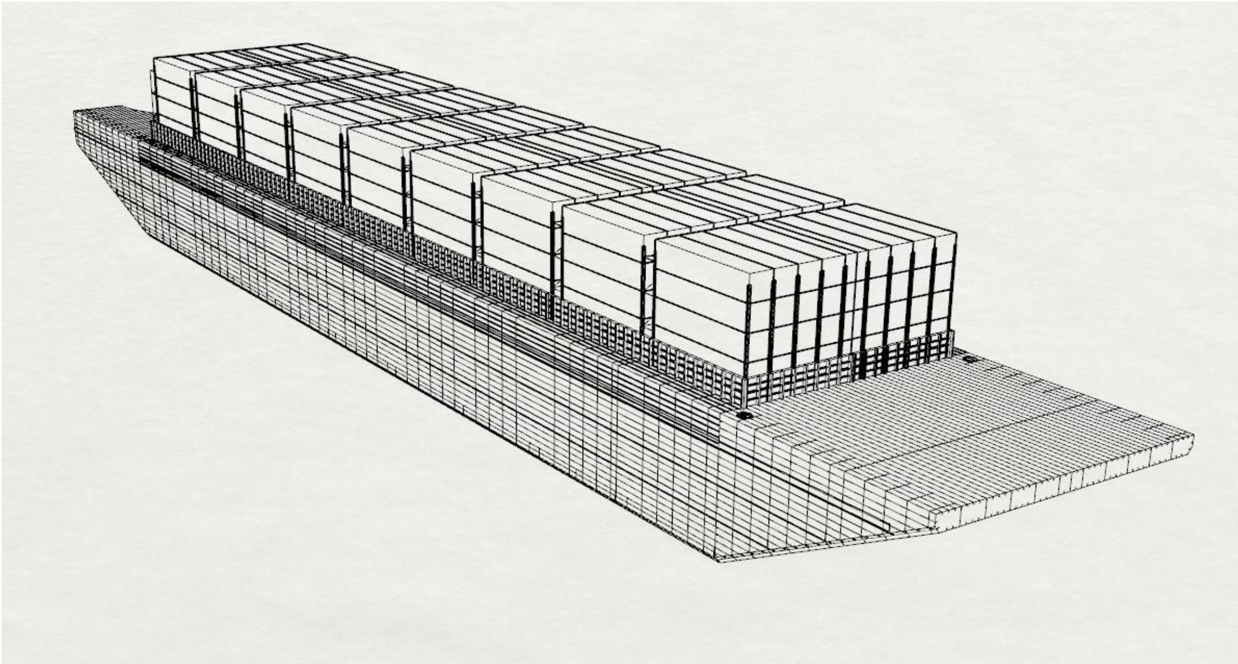
TITLE:	DATE:
GENERAL ARRANGEMENT: Midbody	04/20/20

PROJECT:	DWG Name:	DRAWN BY:
Ship Design	Barge GA	L. McCord

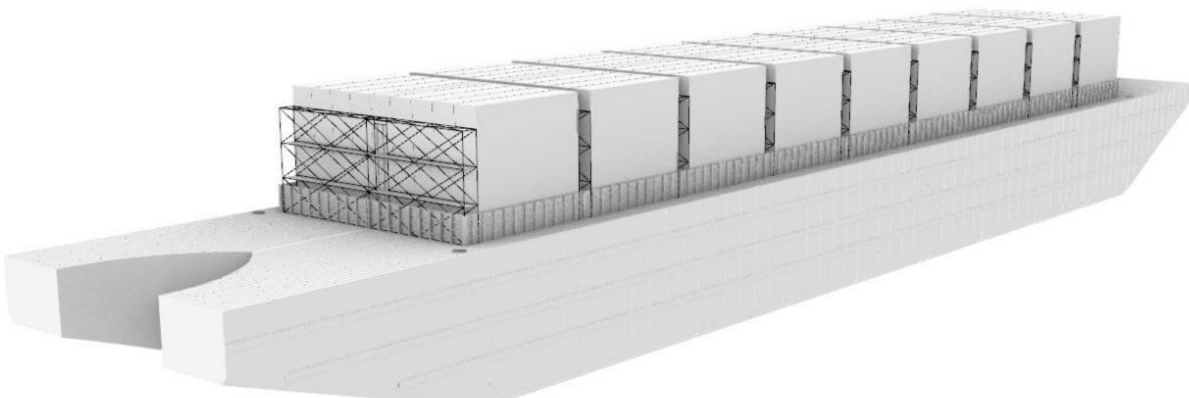
Appendix G: Barge Machinery Space Arrangement



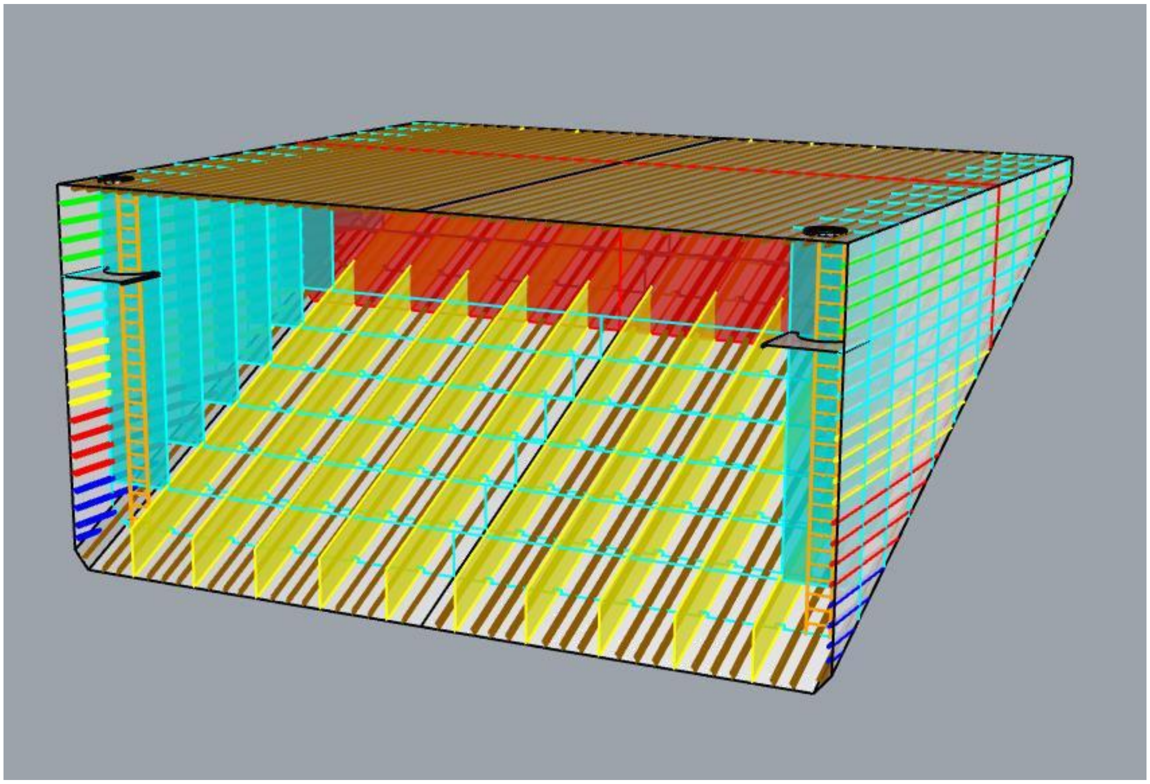
Appendix H: Alternate Barge Views from Rhino



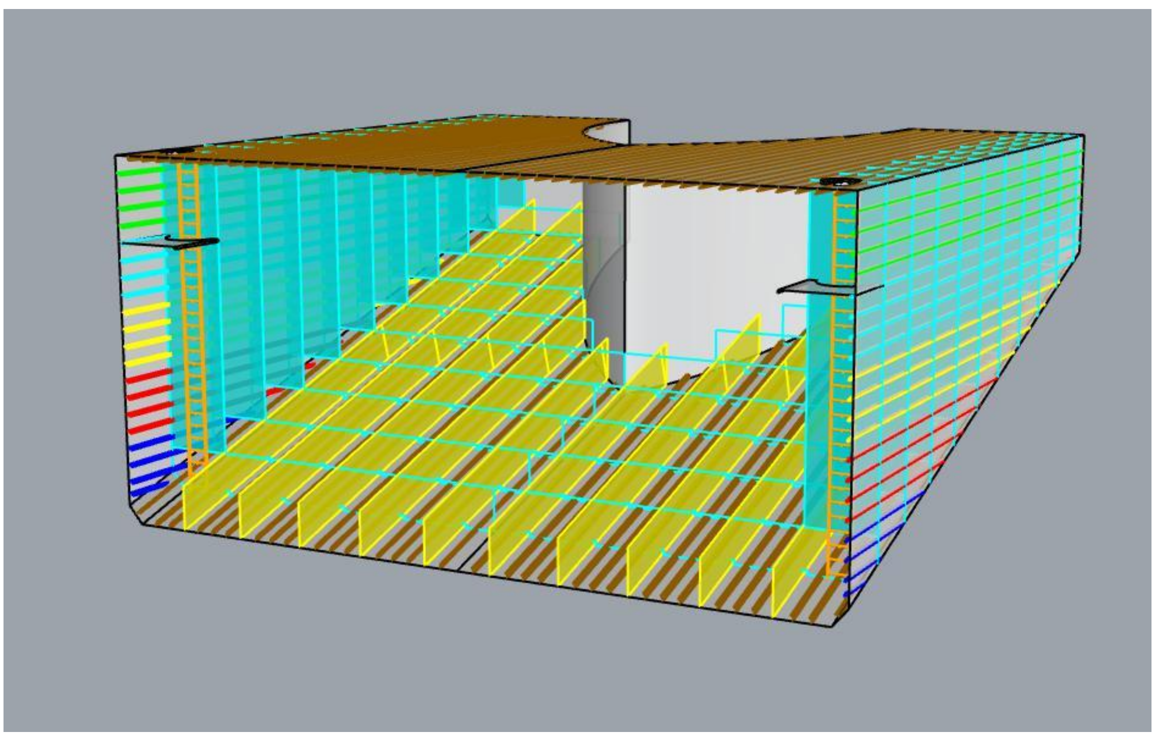
Above: Bow View



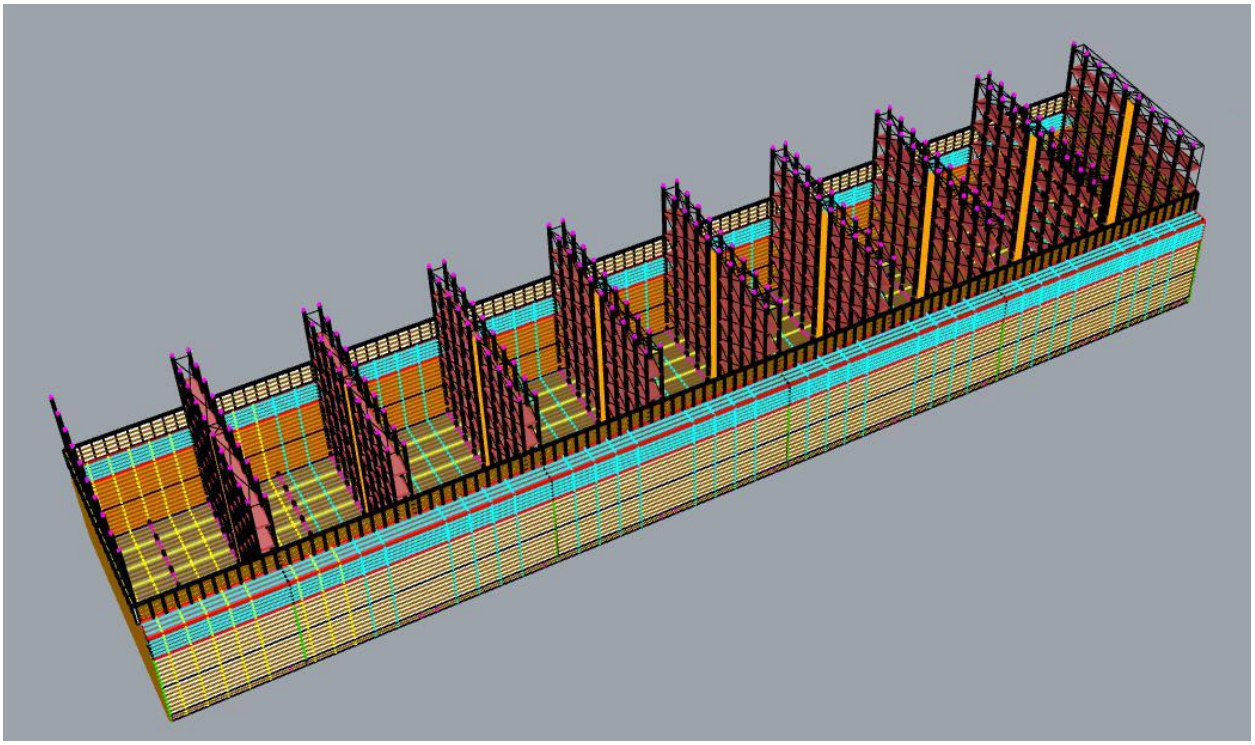
Above: Stern View



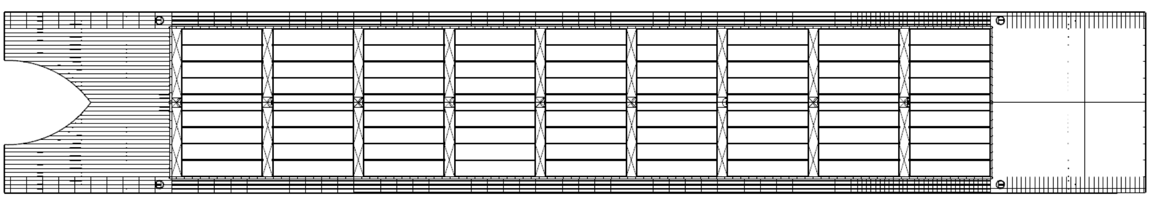
Above: Internal Bow View



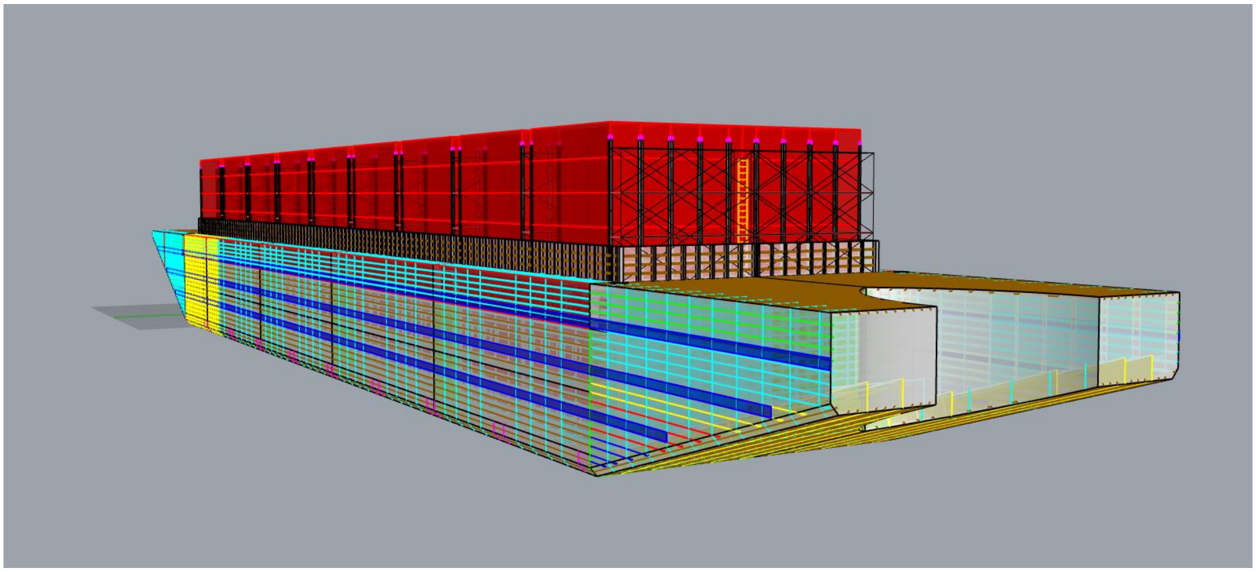
Above: Internal Stern View



Above: Hold Spacing and Cell Guides



Above: Plan View of Barge



Above and Below: Stern Layerd View