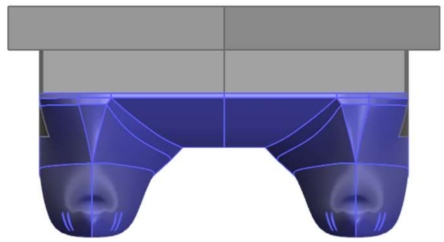
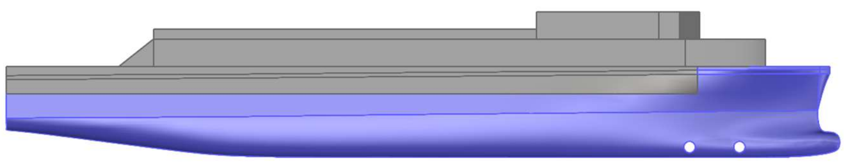
Preliminary Design of a 90m Ro-Pax Ferry





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Dr. James A. Lisnyk Student Ship Design Competition

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Faculty Advisor Statement

By this statement, I certify that the work done for this design competition was completed by the student team members.

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III. Glossary and Abbreviations

ABS	American Bureau of Shipping
Cf	Coefficient of Frictional Resistance
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
Cr	Coefficient of Residuary Resistance
Demi-hull	One individual hull of a catamaran
DWT	Deadweight Tonnage
EEDI	Environmental Efficiency Design Index
FEA	Finite Element Analysis
Fn	Froude Number
IMO	International Maritime Organization
MDO	Marine Diesel Oil
PB	Brake Power
PE	Effective Power
RoPax	Roll-on/Roll-off passenger and vehicle carrying vessel
S	Separation between catamaran demi-hull centerlines
SOLAS	Safety of Life at Sea
SWATH	Small Waterplane Area, Twin Hull
USCG	U.S. Coast Guard

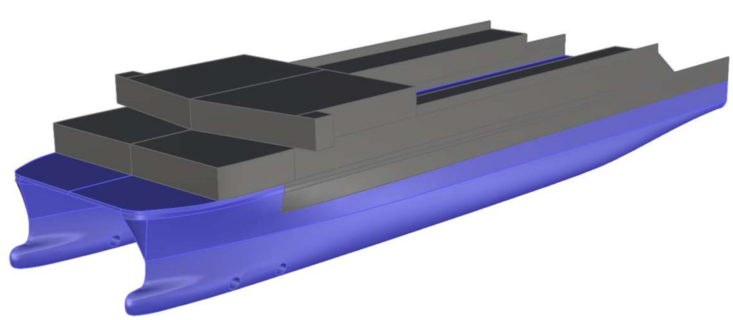
IV. Summary

The following report outlines the preliminary ship design for a RoPax ferry carrying 100 cars (500 lane-meters) and 650 passengers on a voyage short enough to not require staterooms.

Table 1: Principal Particulars

Length Overall (m)	**92**
Waterline Length Between Perpendiculars (m)	90
Beam (m)	25.57
Draft (m)	3
Depth (m)	10
Displacement (t)	2284
Deadweight (t)	750
Service Speed (knots)	18
Installed Power (kW)	5760
Block Coefficient (per demi-hull)	0.59
Vehicle Capacity (lane-meters)	525
Passenger Capacity	650
Crew	16

Figure 1: Rendering of Proposed Ferry Design



V. Concept and Owner's Requirements:

A. Owner's Requirements:

The design task was for a RoPax ferry to carry 100 cars and 650 passengers on a passage short enough to preclude the need for passenger staterooms. A design adaptable for sale into different ferry markets was an added requirement. For the first pass around the design spiral, the team designed a monohull ferry with dual fuel (diesel/methanol) hybrid propulsion. This design could comply with International Maritime Organization (IMO) Environmental Efficiency Design Index (EEDI) Phase III standards only when using methanol fuel derived from "green" sources. Given the limited availability of this fuel and the desire for a design adaptable to various routes, it was decided to examine other hull form concepts that would result in lower power requirements and carbon emissions while utilizing commonly available marine diesel oil (MDO).

Low speed, low displacement catamaran ferry designs offer a higher deadweight tonnage to displacement ratio than monohull ferries, while still retaining superior stability characteristics. These designs offer shallow draft and potentially lesser displacements, resulting in lower hull resistance.

Most of the catamaran ferries currently in service operate at speeds greater than 30 knots. These vessels create significant wave making resistance and thus have large propulsion power plants (>10,000 kW), consuming large amounts of fuel.

The medium speed catamaran design reduces resistance through drastically reduced wave making resistance and reduced structural weight without adding resistance from the slamming forces inherent in high-speed operations. Reduced structural weight produces reduced draft and allows the deadweight to lightship ratio to increase further.

B. Sample Route

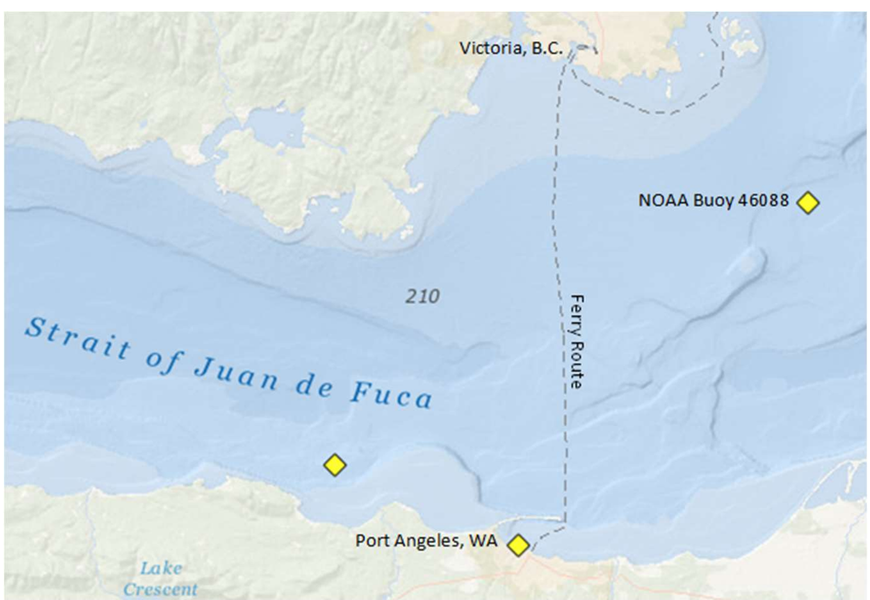
While an adaptable design is desirable, to comply with the requirements of this competition the route of the MV Coho has been chosen as a necessary framework for endurance, seakeeping and economic analysis. This is a private ferry operator which limits the availability of accounting data which could be derived from government operated or subsidized ferry services. The rates charged reflect the real costs of operating on this route and will facilitate cost analysis.

The MV Coho, owned and operated by the Black Ball Ferry Line, carries cars, trucks, and passengers 22.6 nautical miles across the Strait of Juan de Fuca between Port Angeles, Washington and Victoria, British Columbia. It can transport a maximum of 110 cars and 1000 passengers making 2-4 round trips per day, depending on the season. She is a steel monohull vessel powered by two 1,900 kW diesel engines. At a service speed of 15 knots, MV Coho can complete a crossing in 90 minutes.

Launched in 1959, replacement of this aging monohull ferry can bring this ferry route into compliance with the IMO Energy Efficiency Design Index requirements. Lower fuel use and carbon emission can be achieved along with higher service speeds, resulting in more profit for the ferry operator.

The Black Ball Line, founded in 1818 in New York, was the original trans-Atlantic service that sailed on a fixed schedule. Subsequently the Peabody family founded the Puget Sound Navigation Company to ferry passengers and cargo. Most of the routes and facilities were sold to the State of Washington and became the Washington State Ferry System. This single route along with the Black Ball name and distinctive flag were retained.

Figure 2: Map of Black Ball Ferry Route



The route takes the ferry 22.6 miles across the Strait of Juan de Fuca from Port Angeles, Washington to Victoria, British Columbia. The ship loads and unloads through a stern ramp in Port Angeles and with a starboard side, hull opening ramp in Victoria, allowing the through flow of vehicles without reversing or U-turns. The design under consideration in this report has only a stern ramp and would require passenger cars to U-turn on the deck while loading and unloading. Trucks would be reversed onto the ship for loading.

VI. Definition and sizing

A. Definition

Initial design parameters were based on the comparison of existing vessels against requirements for carrying capacity and speed. Comparable vessels were drawn from three main sources—classification society databases, external web research, and catalogs in SNAME Ship Design and Construction I. The overwhelming majority of vessels within this speed and capacity regime appear to be monohulls. Examples of monohulls approximately meeting one or more of these initial design parameters are shown in Table 2.

Table 2: Comparable Monohull Ferry Vessels in Service

Ship Name	L	B	T	Δ	Cars	Pax	DWT	Speed	Power
	[m]	[m]	[m]	[mt]			[mt]	[knots]	[kW]
Queen of Capilano	95.7	21.2	5.8	2500	100	457	602	12	7305
Coho	93.9	21.9	6.2		110	1000	2057	15	5100
Aqua Jewel	96.0	16.6	7.7		160	661	461	18	6358
Veteran	81.1	17.2	6.7		70	200	905	14	5100
M/V Aurora	56.64	20.0	4.2	714	33	250	280	17	2162
Coastal Celebration	160.0	27.8	8.8	10034	310	1600	2350	21	21444
Spirit Vancouver Is.	167.5	26.6	5.3	11681	358	2100		23	21444

Our initial research indicated that multihulls were primarily relegated to routes with much higher service speeds than were desired for this design. In fact, there were very few vessels operating at a 20-knot intended service speed with similar amounts of capacity (monohull or multihull). Monohulls primarily operated at much lower service speeds (10-15 knots) or had significantly larger capacities. Multihulls (with a few notable exceptions) operated at much higher speeds.

Linear regression analysis was performed on the ships in the database, and very rough particulars were determined based on existing vessels. These analyses are shown in Appendix B. Comparison of existing monohulls indicated an approximate LWL in the 90-100 m range, estimated displacements were difficult to come by, however the closest monohull analogue to the expected passenger/ vehicle load and size was the Aqua Jewel, which had a power of 6358 kW. Given the large variance in DWT for number of vehicles and passengers, a 100-vehicle monohull is estimated to have a DWT of at least 678 t. The regression and chart used for this analysis is shown in Figure 3. Papanikolau [1] provides an average ratio for DWT/ displacement for RoPax ferries of 24.5%. Using this ratio against the Queen of Capilano (602 DWT, 2500 t actual displacement) gives an estimated displacement of 2457 t based on DWT and confirms the ratio generally. Given this, we expect monohull displacement to come in around 2767 t.

Figure 3: Length Regression from Car Load – Monohull

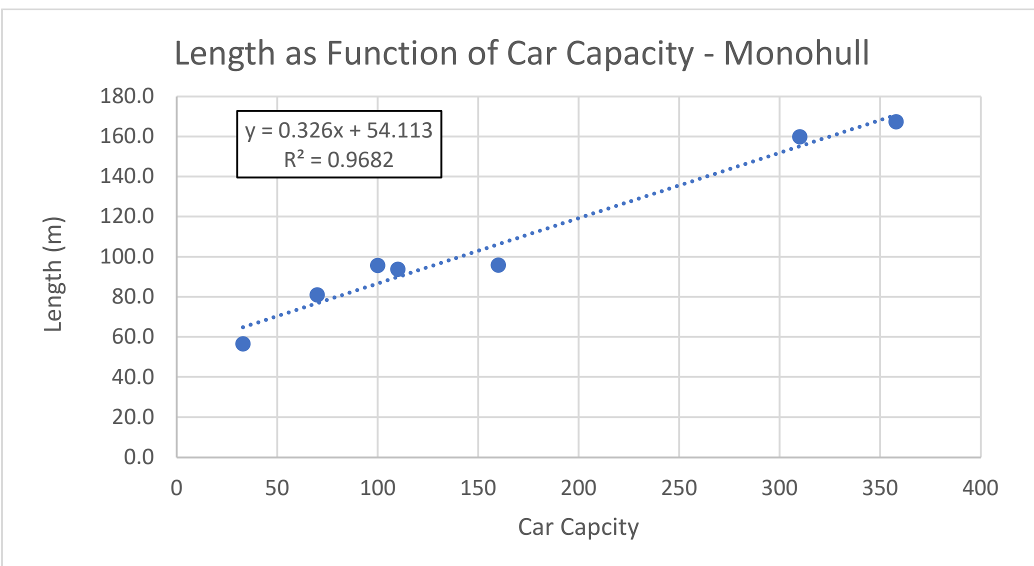
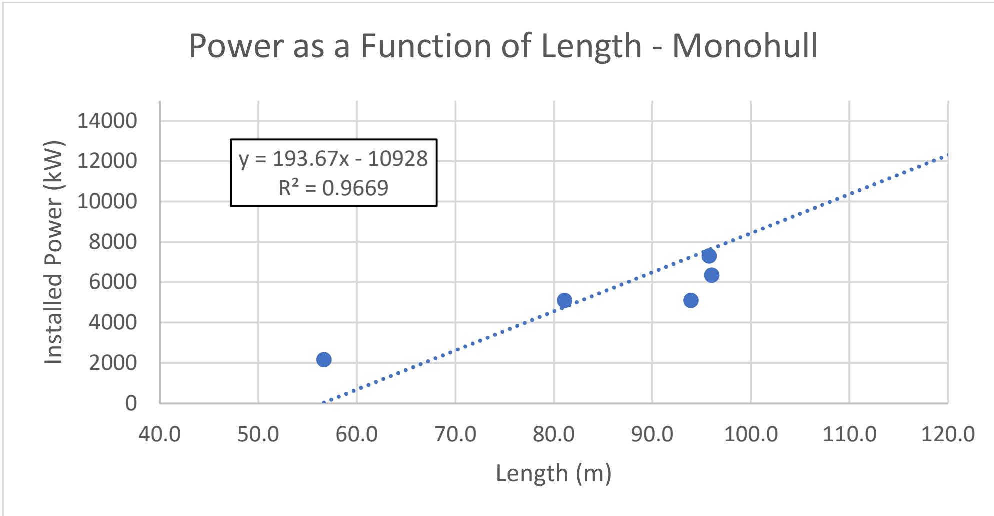


Figure 4: Power Regression from Length - Monohull



It is important to note that due to the extreme paucity of comparable vessels (as well as the large number of potential variables in any comparison), R^2 values were well below generally accepted statistical baselines. Regression values were used mainly to evaluate vessel alternatives, as well as to provide general baselines for initial design. These values were then validated using more analytical methods. Regression values were not used to create design parameters.

In the last 20 years, a small but increasing number of small-medium size, medium speed displacement catamarans have been developed and entered into service across diverse markets. The designs of Sea Transport Inc. and BMT are the best examples of these newer low speed catamaran designs. One of the more notable versions of this design paradigm is the M/V Alfred, operated by Pentland Ferries in Scotland and designed by BMT. This ferry is of a slightly smaller capacity and slightly slower service speed than what is required by the initial owner's requirements, however it has vastly less installed power than comparable monohulls (3348 kW vs the Aqua Jewel's 6358 kW, for example). The Aqua Jewel's higher vehicle capacity number and speed do not entirely explain the difference in installed power.

Ferries are challenging vessels to make meet current EEDI requirements. Small to medium ferries frequently operate out of smaller ports where novel fuel options (LNG, methanol, ammonia) are not readily available. It is therefore of utmost importance to try to keep fueling to a readily available fuel such as diesel. Furthermore, novel fuels are frequently more expensive than their conventional peers. Any improvements to a hull's efficiency will be passed on in significantly lower fuel costs.

Catamarans are generally less efficient per displacement tonne when compared to a monohull. This is due to their greater surface area/displacement ratios (two hulls to carry a comparable weight of cargo), as well as greater residuary resistance due to complex wave interference characteristics between demi-hulls. They do, however, possess an advantage for volume limited vessel types, as a large amount of internal and external volume can be provided relative to a given displacement. Ro-pax ferries (as ferries in general) are volume-limited vessels, making the catamaran hull form a worthwhile option to pursue.

In addition, the long, slender hulls characteristic of catamarans allow for more efficient operation at high Froude numbers relative to a monohull. This is especially applicable for a ferry case such as this, where a 20 kt service speed will place a vessel of our approximate length in a Froude number regime of approximately .30.

Table 3: Table of Comparable Catamaran Ferries in Service

Ship Name	**L**	**B**	**T**	**Δ**	**Cars**	**Pax**	**DWT**	**Speed**	**Power**
	[m]	[m]	[m]	[mt]			[mt]	[knots]	[kW]
Alfred	84.5	22.0	5.3		98	430	550	16	3348
Pentalina	70.6	20.0	5.0	930	80	350	360	17.1	3580
Seascape 1	50.6	16.5	3.2	425	65	250	170	15	1790
Don Nasib	61.2	20.0	5.0	730	93	300	400	17.5	2880
Lite Cat 2	60.6	20.0	4.5		60		340	16	1280
Willem Barentsz	67.8	17.0	5.0	930	65	1300	333	15	3998
Aurora V	56.6	12.0	4.2	714	88	297	280	17.5	2162

A similar regression analysis was performed on the table of comparable catamarans, and indicated an approximate LWL in the 75 m range, with a total displacement of approximately 738 t. The regressions are shown in Figure 5 through Figure 7. Additional DWT regressions are shown in Appendix B. R^2 values for all regressions were extremely low, and indicate large variability from vessel to vessel. This is due to a large amount of variability in construction techniques (aluminum vs steel), as well as varying car carrying configurations and car weight estimations. The displacement estimation is especially suspect. However, broad interpretations can be taken from the regressions.

Figure 5: Length Regression from Car Capacity - Catamaran

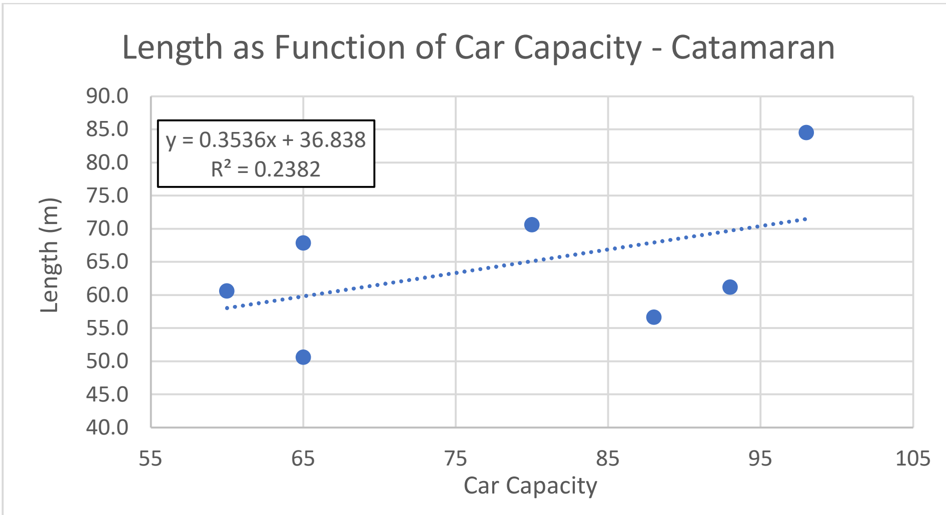


Figure 5 shows a regression of length from car carrying capacity. As mentioned previously, there is a large amount of variance. This could result from varied methods for storing cars (multi-tiered, ramped, etc.). The comparable vessel closest to the intended use case (M/V Alfred) carries 100 cars on a single deck and has a length of 84.5 m. Its passenger capacity is less than the desired capacity for this vessel. This suggests a vessel slightly longer than 85 m is likely to best fit the necessary profile.

Figure 6: Power Regression from Length - Catamaran

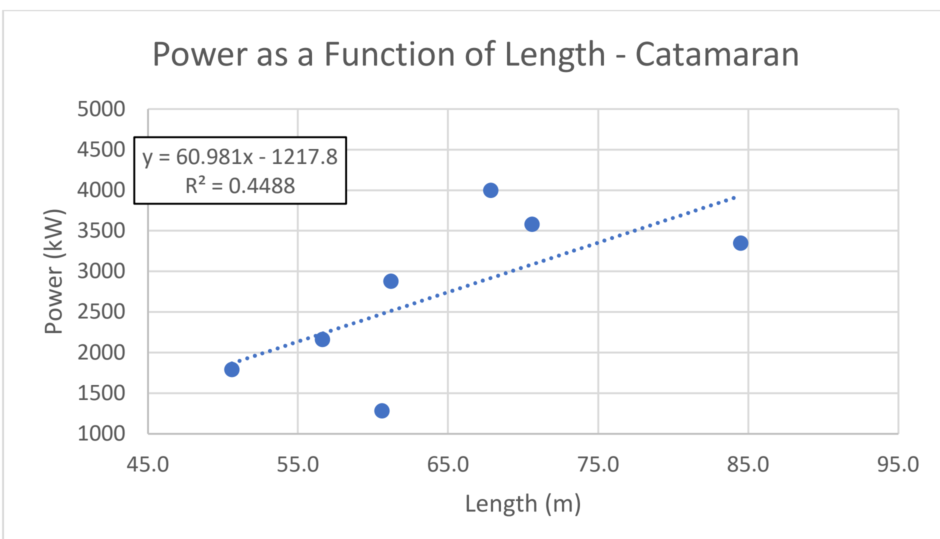
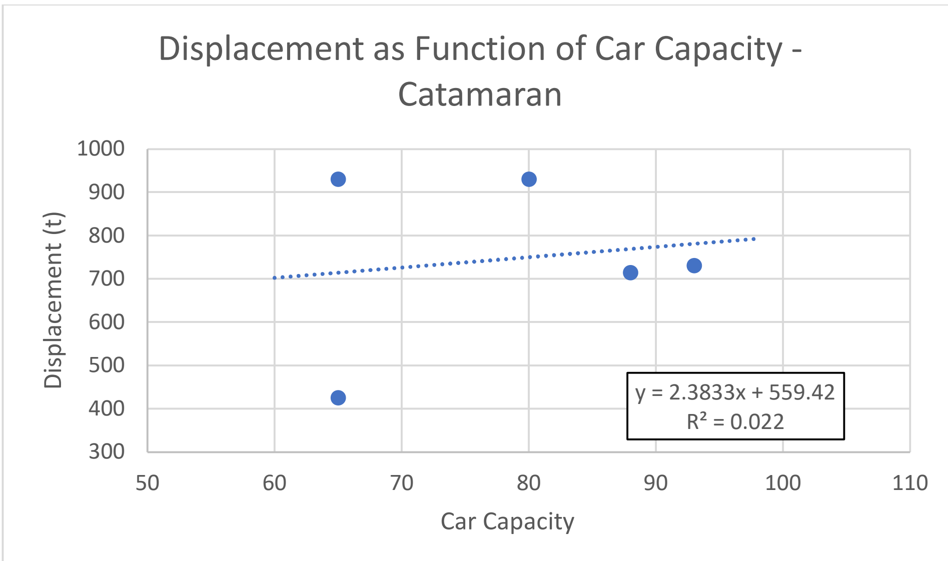


Figure 6 shows a regression of power from length. Variance is less than for length, however the regression still indicates large amounts of statistical noise. This is likely due to the varying speed regimes at which the ferries operate, and the highly variable effects of catamaran hull forms on residuary resistance. There is much greater ability with a catamaran to taper hull form to a particular speed regime. For rough comparison purposes, a 90 m catamaran RoPax ferry would seem to have about 4270 kW of installed power for an average speed of 16.3 kts (the average of the sample group).

Figure 7: Displacement Regression from Car Capacity



The regression shown in Figure 7 (displacement vs car capacity) is statistically useless. However, the displacements are all below 1000 t. When compared against DWT (and this ratio compared against monohull vessels), these displacements indicate that a catamaran RoPax ferry can have a much higher DWT/displacement ratio to a comparable monohull. This suggests a potential strength of catamarans vs monohulls in a RoPax ferry configuration.

It is incredibly difficult to find vessels within this size and speed regime being built as conventionally powered monohulls or catamarans today. The speed requirement for this vessel is in a Froude number range that is well above optimal efficiency. The vast majority of ferries within this size regime are either powered by LNG, operate at much slower speeds, or were designed and built before the advent of contemporary EEDI rules. We believe this is due to the low DWT to displacement ratios of most Ro-Pax ferries. This is the driving consideration behind most EEDI regulations.

We decided to analyze a medium speed/medium size catamaran ferry to determine tradeoffs as compared to monohull.

Advantages of catamaran design:

-Low draft, allows for greater number of ports to be accessed
-High stability
-Redundancy of systems
-High flexibility to tailor displacement to volume needs without compromising stability (reducing power requirements)
-High maneuverability

Disadvantages of catamaran design:

- Higher cost of construction
-More limited loading/unloading options (drive through much more difficult)
-Greater beam
-Potential for deleterious seakeeping characteristics
-High resistance for comparable volume when compared to monohull

Advantages of monohull design:

- Large number of existing vessels allows for ease in estimation
- Known behaviors and technology
- Simpler ramp configuration
-Existing infrastructure generally supports monohull loading configurations

Disadvantages of monohull design:

-High stability requirements necessitate high displacement
-Complex vehicle loading ramp configuration to maximize vehicle storage space
-Vehicles must be stored in enclosed spaces
-Relatively high draft to displacement ratio
- High speeds at this size regime (~100m) requires novel fuel sources to meet EEDI
-Low maneuverability using conventional propulsion

Unlike their high-speed cousins, medium- low speed catamaran vessels can be built from steel, reducing cost. While displacement is a concern in all vessels, and especially in catamarans, a non-planing vessel will have a more forgiving speed/displacement regime and can therefore get away with a steel hull.

Given the (deserved) focus on reduced emissions in contemporary shipbuilding, EEDI and efficiency are the most crucial deciding factors in choosing a hull form. With the choice to maintain a non-novel fuel supply, the hull must operate significantly more efficiently than existing hull forms in order to meet EEDI requirements. Although novel-fuel sources are viable options to decrease the vessel's overall environmental impact, these fuels are significantly more expensive per unit energy, placing a further premium on hull efficiency. For these reasons, the optimal hull form to pursue for this application appears to be a medium speed catamaran.

B. Sizing

Initial sizing of the catamaran hull was achieved using regressions from the database of comparable ferries and a parametric excel spreadsheet. The predominant factor in the design was the size of the Ro-Ro deck. Standard vehicle sizes were taken from Ship Design and Construction, Vol II [1]. These sizes and weights are shown in Table 4. Adjustments were made to some of the values, due to changes in average vehicle dimensions over the past 20 years. For example, a Honda Accord (a four-door sedan that would once have been considered a large vehicle) is 4.9 m long by 1.9 m wide, with a weight of 1.6 mt [2]. Comparatively, the smallest Ford F-150 has an overall length of 5.3 m, a width (excluding mirrors) of 2.03 m, and a weight of 2.12 mt. Given the proliferation of light trucks and SUV's (which currently outsell cars by a margin of 3-1 in the US), it is a necessity that more space be allocated per vehicle in order to achieve a 100-vehicle capacity [3]. The dimensions of a Honda Accord were used to roughly represent the median vehicle in the vessel's market (USA/Canada).

Table 4: Typical Vehicle Size

Type of Vehicle	Length [m]	Breadth [m]	Height [m]	Weight [mt]
Passenger Car	5	2.3	2.4	1.7
Bus / Small Lorry	12.3	3.2	4.2	17
Truck	18.7	3.2	4.8	28

Using the tables of comparable vessels, as well as a parametric mathematical model of car length, beam, and height on a single vehicle deck, a set of guiding principal particulars was determined for a catamaran ferry. The results of this analysis are shown in

Table 5. Particulars were driven by a need for at least 500 lane meters of car space (100 cars of 5 m length), with each lane between 2.5 and 3.5 m wide (to allow loading for some combination of trucks and buses to be carried as well). Expected DWT is based on a worst-case loading of 10 trucks, 66 cars, and 650 passengers at 200 kg/ passenger.

Table 5: Guiding Principal Particulars, Catamaran

Length	90 m
Beam	25 m
Draft	3 m
Displacement	2300 t
DWT	750 t

As the structure, weight estimates, and powering were changed, the particulars of the vessel were updated to arrive at our final preliminary estimates.

VII. Hull Forms and Curves of Form

A. Initial Form Decisions

Hull models were developed using the Maxsurf design suite. Due to the vessel's catamaran configuration, demi-hull form can be almost entirely separated from most of the vessel's operational needs. Carrying capacity and stability are both functions of total vessel beam and length and are not reliant on the shape of the individual demi-hulls. The primary concern in this design is the shape of the hull to minimize resistance for optimal fuel efficiency.

Initial form characteristics were grossly generalized by Fn. For the purposes of initial design, low Froude numbers are generally those that are under 0.15, while high Fns are those over 0.25 [4, p. 81]. With these considerations in mind, the vessel is well within the range of what could be considered a high Fn vessel. As Fn increases, frictional resistance increases linearly, while residuary resistance increases exponentially. Therefore, residuary resistance quickly becomes the dominant force of resistance for high Fn vessels. The primary intention in developing each demi-hull form is to reduce wave making resistance without compromising frictional resistance.

Semi-SWATH hull forms have been effectively used to reduce the amount of resistance and improve seakeeping abilities of catamaran vessels [1, pp. 45-8]. A typical semi-SWATH vessel configuration utilizes a very fine forward entry and small forward waterplane (similar to a conventional SWATH vessel) while gradually transitioning to a full aft waterplane characteristic of traditional catamarans. Semi-SWATH hulls generally incorporate round bilges, although the sterns of more modern vessels can include hard chines to improve directional stability (obviating the need for skegs in otherwise directionally unstable multi-hulls) and simultaneously reducing manufacturing costs [1, pp. 45-8]. This design methodology results in a bulbous bow, along with an almost “delta” shape to the hull, with full waterline beam not being achieved until midship.

For this preliminary design, the complexity of a round bilge to chine transition was not considered. In future design refinements, the implementation of this design choice would likely result in reduction of wetted surface area, and therefore improved efficiency.

The fundamental concerns in initial hull design are as follows:

-Minimizing beam and increasing slenderness of the demi-hulls to reduce residuary resistance.

-Fine entry at the bow, with most immersed volume carried well below waterplane

-Limited parallel midsection to reduce pressure concentrations at shoulders of hull. Significant parallel midbody is not necessary to preserve volume, as all major volume is carried above the demi-hulls

-Smooth transitions between all major regions of the hull to minimize resistance.

B. Specific Hull Shape Considerations

The interactions between catamaran demi-hulls and the resulting wave generation are not easily modeled using empirical methods. CFD analysis is generally the best method for optimizing the design of multihull vessels. However, a systematic series of tank tests were carried out at the University of Southhampton in 1994 by A.F. Molland, et al [5]. These tank tests utilized demi-hulls of varying length/displacement ratios and beam/draft ratios. The demi-hulls were then configured in differing demi-hull separation/length ratios. Ultimately, the results of these tank tests were expressed as non-dimensionalized residuary resistance coefficients. Vessel parameter values necessary for comparison are shown in Table 6 below.

Table 6: Parameters of Catamaran Ferry Hull for Comparison with Molland Values

Initial Hull Form Parameters	
$L/\nabla^{1/3}$ (Per Demi-hull)	8.68
B/T Ratio (Per Demi-hull)	2.357
Separation/Length (S/L)	.2034
Froude Number	0.32

Table 7: Notation and Main Parameters of Molland Models [5]

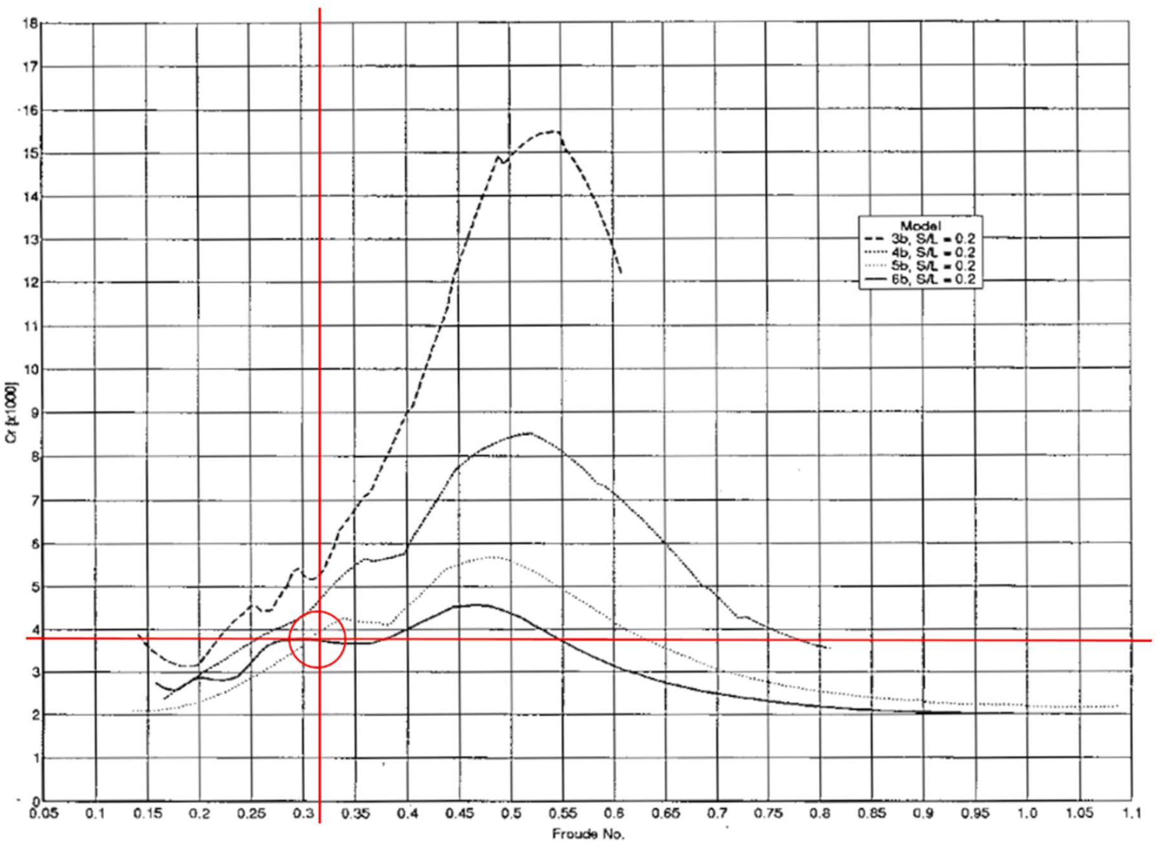
$L/\nabla^{1/3}$	B/T			C_P
	1.5	2.0	2.5	
6.3		3b		0.693
7.4	4a	4b	4c	0.693
8.5	5a	5b	5c	0.693
9.5	6a	6b	6c	0.693

*Where 3b, 4a, 4b, 4c, etc. are model names.

Rather than attempt to design to the hull forms shown in Table 7, an initial hull form was developed from the table of guiding principal particulars, and then confirmed by comparison against the Molland values.

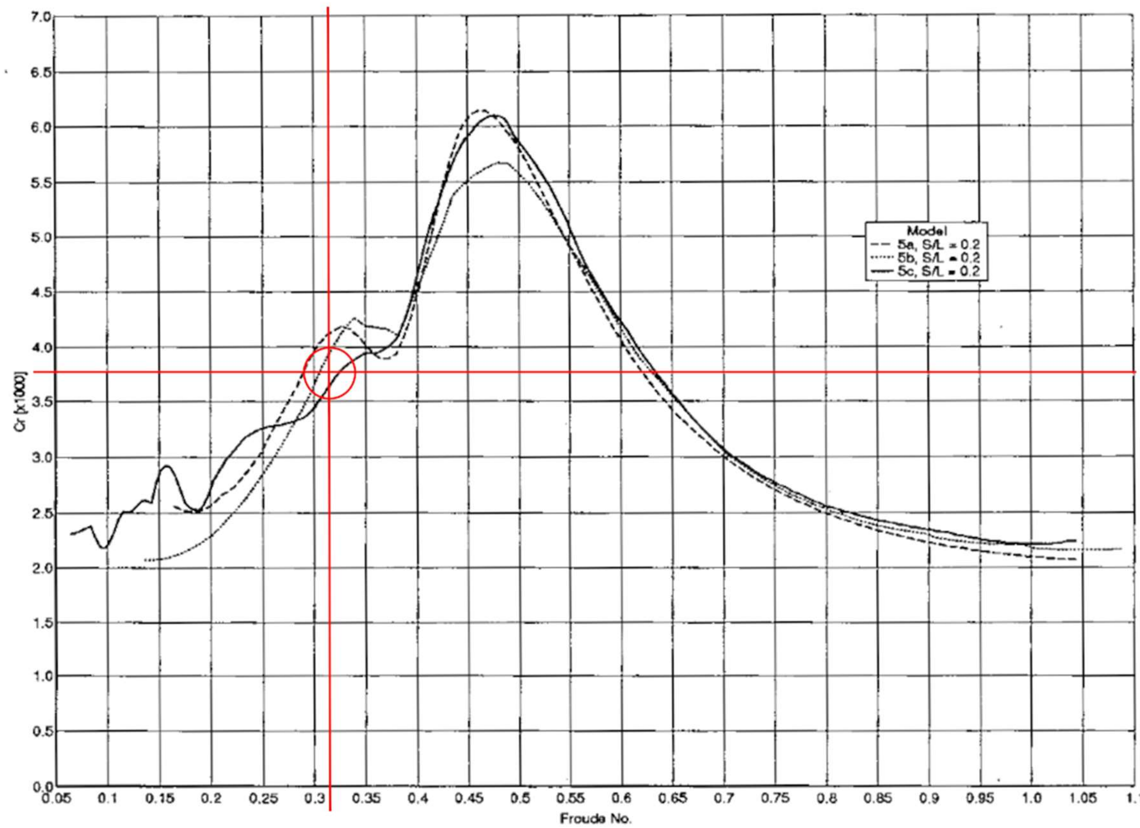
The closest Molland reference hull-forms to the guiding parameters shown in Table 6 were the 5 and 6 series b and c hulls, with the 5c reference hull-form closest to the initial design. Numeric series vary demi-hull L/∇ ratio, while letter series denote variance in demi-hull B/T ratio. All hull forms were tested at varying S/L ratios. Since beam of this vessel is constrained by a need to easily access a variety of restricted ports, no special consideration was given to the variance of S/L. The initial parameter of 0.2 was considered constrained, although a comparison between S/L ratios for hull 5c is shown in Figure 11.

Figure 8: Residuary Resistance for b Series Models; S/L = 0.2



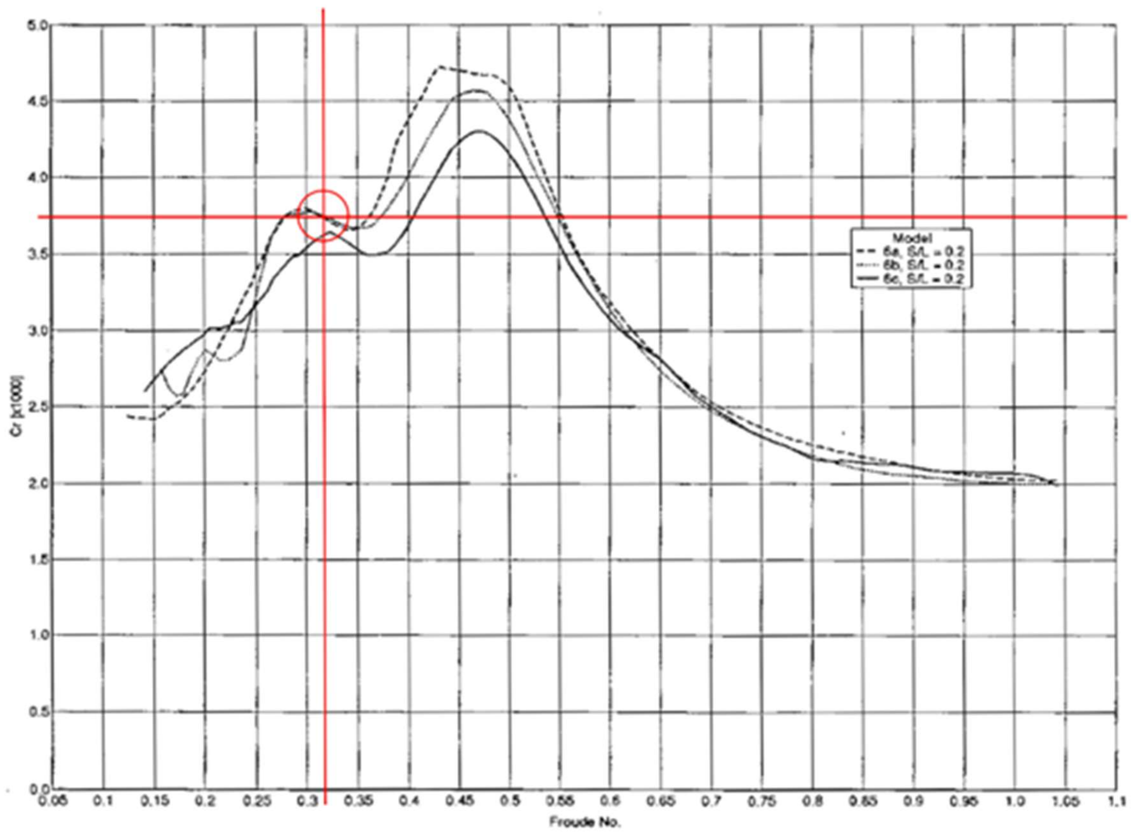
Molland does not provide a chart comparing c series hulls against one another, so an initial comparison of demi-hull B/T ratio was performed using the b series hulls. Residuary resistance coefficients for these hulls are shown in Figure 8. The red cross indicates the approximate location of the initial guiding parameters at maximum Froude number for this vessel. Residuary coefficients of the 5 and 6 series hulls approximately intersect at this location, although the 5 series appears to achieve lower resistance values at Fns below 0.32, while the 6 series seems to be privileged above 0.32. This indicates that the 5 series L/∇ ratio (8.5) is best for the expected operating envelope of this vessel.

Figure 9: Residuary Resistance for Models 5a, 5b, and 5c; S/L = 0.2 [5]



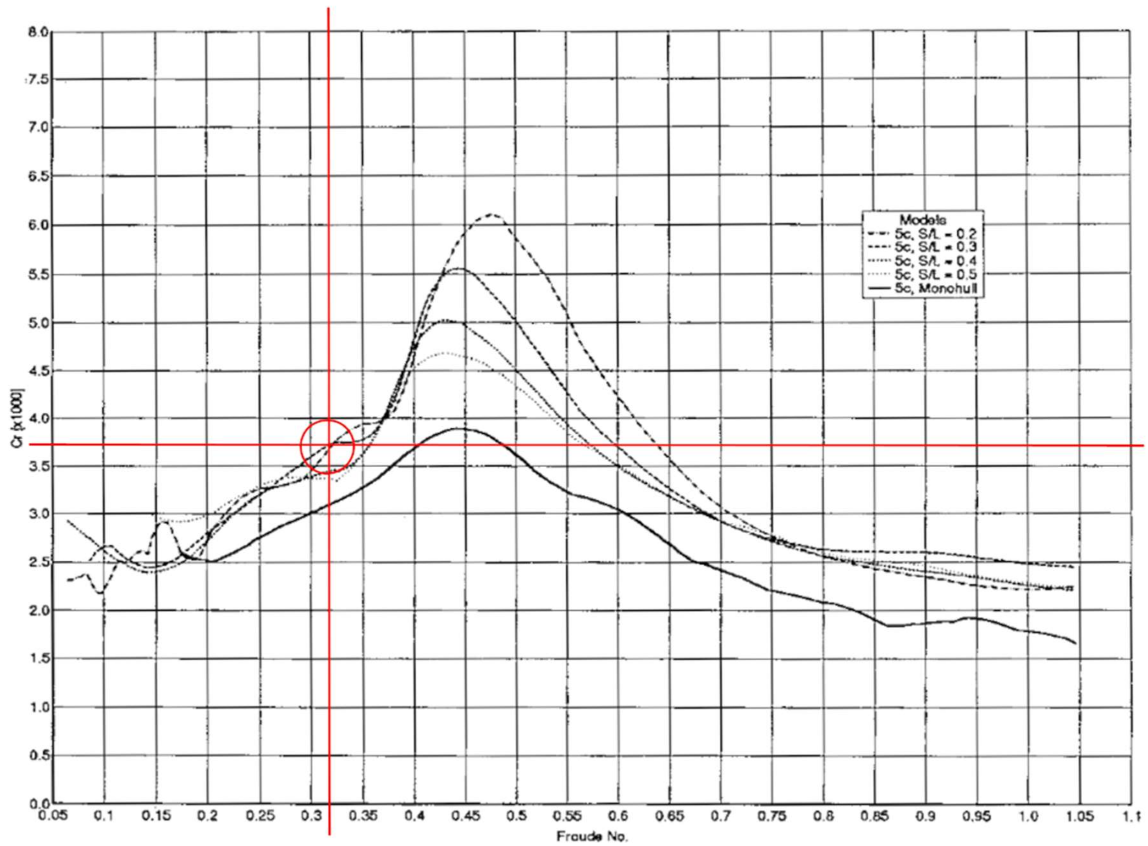
Comparison between 5 series demi-hull B/T ratios are shown in Figure 9. In this case, the higher B/T ratio of the c series hull is privileged over the b series until a Fn of approximately 0.28. Current design parameters place this hull design between the b and c series, and this suggests that counterintuitively, increasing beam of the demi-hulls while reducing draft could improve efficiency to some degree. Although optimization of the hull form is outside the scope of this preliminary design, this indicates that there are further efficiency gains to be made with this hull form. Given current parameters, it is anticipated that CFD will provide a Cr of approximately $3.750*10^{-3}$ for this hull shape.

Figure 10: Residuary Resistance for Models 6a, 6b, and 6c; S/L = 0.2 [5]



Since the demi-hull form is between the 5 and 6 series in L/∇ ratio, a similar comparison is shown for the 6 series in Figure 10. In this case, the efficiency gains from increasing B/T ratio are even more pronounced, especially as Froude number decreases from vessel maximum speed. There is a pronounced hump in the residuary resistance at Froude numbers less than 0.32 that appears to be potentially minimized by making this adjustment. Given current parameters, it is anticipated that CFD will provide a Cr of approximately $3.750*10^{-3}$ for this hull shape.

Figure 11: Residuary Resistance for Model 5c, Varying S/L Ratio

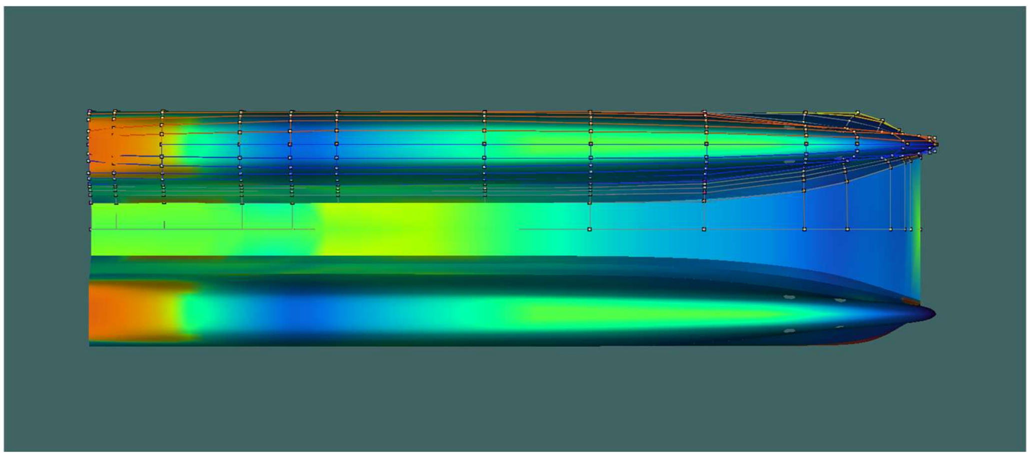


Although variance of S/L ratio is not practicable for this vessel, a comparison of 5c hulls at various S/L ratios is shown in Figure 11. This comparison does provide general guidance as to the use of catamaran form factors for general use for high-efficiency ferries in congested areas. Interestingly, the C_R curve for an S/L ratio of 0.2 roughly intersects that of an S/L ratio of 0.3 in this speed regime. For Froude numbers under 0.32, there may actually be a slight advantage to an S/L ratio closer to 0.2. Markedly reduced resistance does not appear to occur until an S/L ratio of 0.4, at which point the gains will likely be more than offset by the reduction in hull length for a given carrying capacity. Again, given established parameters, it is anticipated that CFD will indicate a Cr of approximately $3.750*10^{-3}$ for this hull shape.

C. Final Hull Fairing

Initial hull modelling and fairing was performed using Bentley's Maxsurf Naval Architecture software. Demi-hulls were designed with roughly symmetrical inboard and outboard sections. Topsides were modelled as separate surfaces from immersed portions of the hull to allow for larger areas of low curvature and decrease ultimate cost.

Figure 12: Underside of Hull Model with Net and Longitudinal Curvature



As mentioned in (B), hard chines aft of midships will likely improve ultimate efficiency and maneuverability of the vessel. At this stage of the design process however, the additional modelling complexity and extra complicating parameters do not justify their inclusion. Figure 12 shows the very fine entry and long taper to max waterline beam of the demi-hulls. Predominant consideration was given to ensuring well faired sections below the waterline for the purposes of CFD.

Figure 13: Front Elevation of Hull with Net and Transverse Curvature

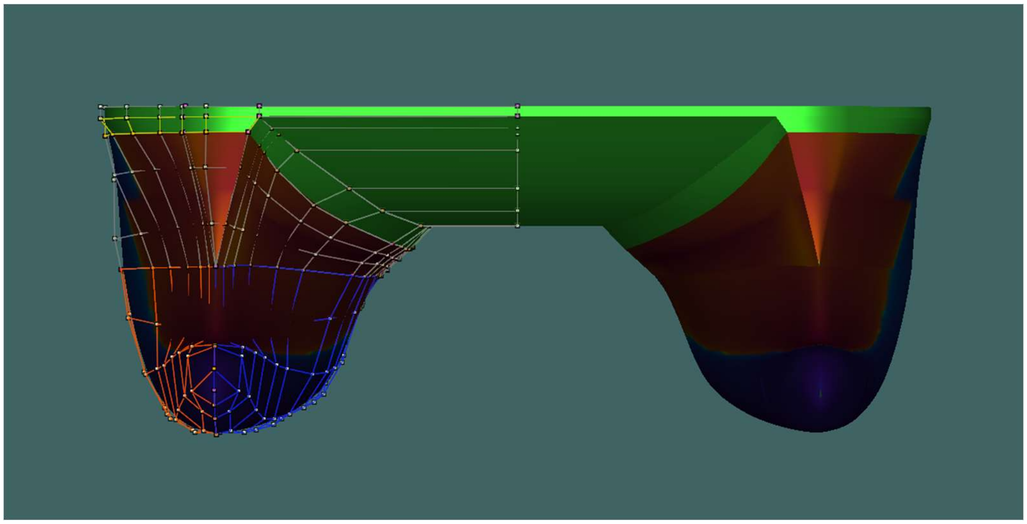


Figure 14: Axonometric View of Hull with Net and Longitudinal Curvature

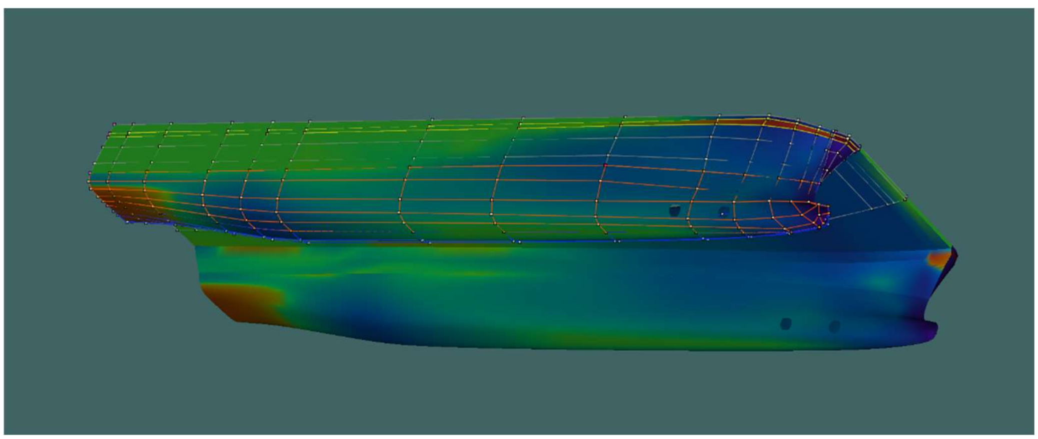


Figure 14 shows the faired hull. There remains space for further improvements to reduce resistance, however the waterline shape contains most intended design principles, and is sufficient for obtaining initial powering requirements and design parameters.

VIII. Area and Volumes

The demi hulls are each divided into eight watertight compartments by seven transverse bulkheads. The foremost bulkhead is spaced in accordance with SOLAS regulations for a collision bulkhead. Each engine is enclosed in its own watertight compartment on the tank top. There is a double bottom structure containing salt water ballast tanks. The aft peak ballast tank and tankage for MDO, lube, fresh and black water is located on the tank top deck. In order to meet two compartment flooding requirements, the bow thrusters are separated by a bulkhead.

Table 8: Summary of Areas and Volumes

Tank/Space	Area [m2]	Volume [m3]
Vehicles	2,463	7,390
Passengers	1,400	4,241
Machinery	1,443	4,376
Peak Tanks	243	525
Engine Rooms	309	927
Bow Thruster Rooms	96.4	337
General Tank Top Rooms	344	1,031
Salt Water Ballast Tanks	653	848
Fresh Water	16.0	16.0
Black Water	40.2	80.4
Marine Diesel Oil	61.1	122
Lube Oil	1.65	1.65
Waste Oil	0.83	0.83
Bilge Tanks	27.2	27.2

IX. General Arrangement

A. Tank Top Deck

The propulsion machinery and tankage are located on this deck. Two engines in each demi hull are staggered fore and aft into separate compartments. Shaft alleys extend aft and shaft generators are located on the inboard propulsion engines. Marine diesel oil, lube oil, fresh water, and black water tanks are located forward of the engine compartments. The bow thruster rooms are located forward of the black water tanks and aft of the fore peak ballast tank.

B. Machinery Deck

The hotel load generators, chillers and HVAC equipment is located on the machinery deck. In the bow, the fore peak tank extends upward into this deck. At the stern is the steering gear room. While some of the machinery deck will be filled with electric and pipe outfit, there is ample free space on the machinery deck for crew quarters or other uses.

C. Main Deck

The main deck is the roll-on deck. In the stern, offset to port, there is an 89.9 square meter hydraulically deployed ramp providing passenger and automotive loading. Most of this deck is occupied by automotive parking. The 525 lane-meters of parking area can accommodate up to 72 cars and 9 articulated trucks. Access to the upper decks is provided by 4 sets of stairs and a lift. The outboard areas are reserved for structure and mechanicals. The deck is wide enough for cars to drive on and turn around. Trucks will be reversed into the central parking slots. There is an anchor chain locker in the forward center of the main deck.

D. Passenger Deck

There are 650 seats arrayed around the outboard areas of this deck. The aft central area of the deck is absent to allow headspace for truck parking. In the forward central area, there is a food service with dining table seating for 32 with attendant areas for food preparation and service. Five bathrooms are located in this forward section with four more aft of the passenger seating. The electric room, crew mess, sick bay and information desk are located in the forward center section. Three stairways and a lift allow access to the upper bridge deck. The anchor and windlass are located at the bow forward of passenger spaces.

The passenger deck is divided into fire barrier compartments with fire doors at the bulkheads. There are four marine evacuation slides located in passenger areas fore and aft.

E. Bridge Deck

The upper deck of the ship contains seating for 100 passengers in an enclosed section at the center. The aft areas contain outside bench seating for another 160 passengers. Engine mechanicals, air intake and exhaust, occupy the outboard aft areas. Forward of the enclosed passenger seating is the bridge and a set of restrooms.

Life rafts and rescue boats are located on the outboard aft portions of the bridge deck. These outside areas will be used as a muster location in case of emergency.

The open-air portions of this deck could enclose any additional seats fitted if there is a need for more passengers on board. Ship stability will not be sufficiently adversely affected to prohibit this design change. The current ferry on this route, the MV Coho, has seating for 1000 passengers. During peak summer season, the 350 additional seats may be required.

X. Structural Design

A. ABS Requirements and Scantling Sizing

The structural design of the ship is in accordance with the American Bureau of Shipping, Requirements for Building and Classing SWATH Vessels [6] and Rules for Building and Classing Marine Vessels [7]. As this design exceeds 90 meters in length, the rules for larger SWATH vessels were applied. A spreadsheet was created to transform the equation-based rules into plate thicknesses and section moduli for structural components. Design dimensions were then compared to these values to ensure compliance with relevant class regulations.

The design includes transverse frames spaced at 1.25 meters with sufficient longitudinal girder structures to create the necessary midship section modulus. Stringers are spaced at 0.75 meters throughout ship and are placed longitudinally on the hull, decks, and longitudinal bulkheads, and vertically on the transverse bulkheads. Additional longitudinal girders are placed to create reinforced shaft alleys and machinery support structures in the double bottom.

The hulls of the ship and bridging structure up to and including the Roro deck are designed in steel. The superstructure is designed in aluminum. Since this is a catamaran design, the use of aluminum to reduce weight high in the vessel has little effect on the stability. The weight reduction allows for an improved deadweight to lightship ratio, reducing power requirements. There will be a dielectric connection between the steel hull forms and the superstructure to prevent galvanic corrosion.

The SWATH design envisions wave slamming forces affecting the bow and wet deck areas. Design pressures were calculated which guided the thickness of plating and size of structural members. In many cases these values are greater in the bow than in the after portions of the vessel. While the rules envision high speed designs with significant wave slamming, our low-speed design may not produce these forces to the same degree. Nonetheless, the SWATH design rules were used to guide the sizing of these components. Additional weight reduction might be achieved by a more accurate estimation of these forces in a lower speed vessel.

To further validate this design, the rules for SWATH vessels over 90 meters require that the bridging structure between the demi-hulls be subjected to an ABS acceptable finite element analysis (FEA). This process would determine whether the bridge deck can endure forces unique to multihull vessels. Yawing, pinching, and twisting forces will stress the bridge deck in ways not present in monohull vessels. In this early pass around the design spiral, the goal of the structural calculations was to determine an estimate for the lightship weight. If this design was subjected to FEA analysis, the wet deck – Roro deck connection and the haunch structures may require significant structural additions, possibly increasing the steel weight of the vessel by a few percentage points.

It has been difficult to find structural drawings of this type of low-speed catamaran to compare sizing of structural members and validate the design choices. Ship Design and Construction, Volume II [8], does include a midship section from a SWATH vessel with similar transverse web frames, hull and deck plating and longitudinal members. The sizes and spacing of these components in the design presented in this paper are close enough to build confidence that the scantling sizing is suitable.

Table 9: ABS Required Structural Scantlings

Structural Part	Required Section Modulus [cm^3]	Design Dimensions Web, Flange [mm]	Design Section Modulus [cm^3]	Δ Section Modulus [cm^3]	Material
Demi-Hull Transverse Frames	589.34	350x8, 100x8	602.98	13.64	Steel
Frame Wet Deck Bow->0.2L	180.53	220x6,100x5	207.37	26.84	Steel
Frame Wet Deck 0.2L->Transom	131.79	200x6, 60x5	138.6	6.84	Steel
Frame In Haunch Bow->0.2L	150.23	220x6, 60x5	162.27	12.04	Steel

Frame In Haunch 0.2L->Transom	126.62	210x6, 60x5	138.79	12.17	Steel
Frame Out Haunch Bow->Transom	135.97	220x6, 50x5	150.66	14.69	Steel
Tank Top Deck Beams	296.63	280x8, 200x6	306.34	9.71	Steel
Machinery Deck Beams	296.63	280x8, 200x6	306.34	9.71	Steel
Roro Deck Beams	395.50	300x8, 220x6	430.06	34.56	Steel
Passenger Deck Beams	244.68	260x8, 220x6	267.67	24.99	Aluminum
Bridge Deck Beams	244.68	260x8, 220x6	267.67	24.99	Aluminum
Tank Top Girders	771.55	400x8, 100x8	827.43	55.88	Steel
Machinery Deck Girders	771.55	300x10, 250x8	810.41	38.87	Steel
Roro Deck Girders	1,175.69	350x8, 250x8	1,204.15	28.45	Steel
Baseline to Tank Top Stringers	30.78	140x8 Bulb Plate	32.50	1.72	Steel
Tank Top - Machinery Stringers	21.31	120x8 Bulb Plate	23.60	2.29	Steel
Machinery to Roro Stringers	7.10	80x6 Bulb Plate	8.15	1.05	Steel
Roro to Passenger Stringers	9.47	100x6 Bulb Plate	12.70	2.26	Aluminum
Main To Bridge Deck Stringers	16.58	120x6 Bulb Plate	18.50	0.24	Aluminum

Table 10: ABS Required Plating Thicknesses

Plating Area	**Required Thickness [mm]**	**Design Thickness [mm]**	**Material**
Wet Deck Bow->0.2L	6.17	7.0	Steel
Wet Deck 0.2L->Transom	5.28	6.0	Steel
Inboard Haunch	5.63	6.0	Steel

Bow->Transom			
Outboard Haunch Bow->Transom	5.36	6.0	Steel
Lower Hull Bow->0.2L	7.67	8.0	Steel
Lower Hull 0.2L->Transom	6.78	7.0	Steel
Double Bottom, Collision, and Watertight Bulkheads	5.51	6.0	Steel
Tank Top Deck C&W Bulkheads	4.5	5.0	Steel
Machinery Deck C&W Bulkheads	3.90	4.0	Steel
Double Bottom Tank Bulkheads	5.71	6.0	Steel
Tank Top Tank Bulkheads	4.84	5.0	Steel
Tank Top Strength Deck	5.12	6.0	Steel
Machinery Deck	6.61	7.0	Steel
Wet Deck	7.62	8.0	Steel
Roro Deck By Loading Rules	6.32	7.0	Steel
Roro Deck By SWATH Rules	6.61	7.0	Steel
Passenger Deck	9.48	10	Aluminum
Bridge Deck Open or Enclosed	10.72	11	Aluminum

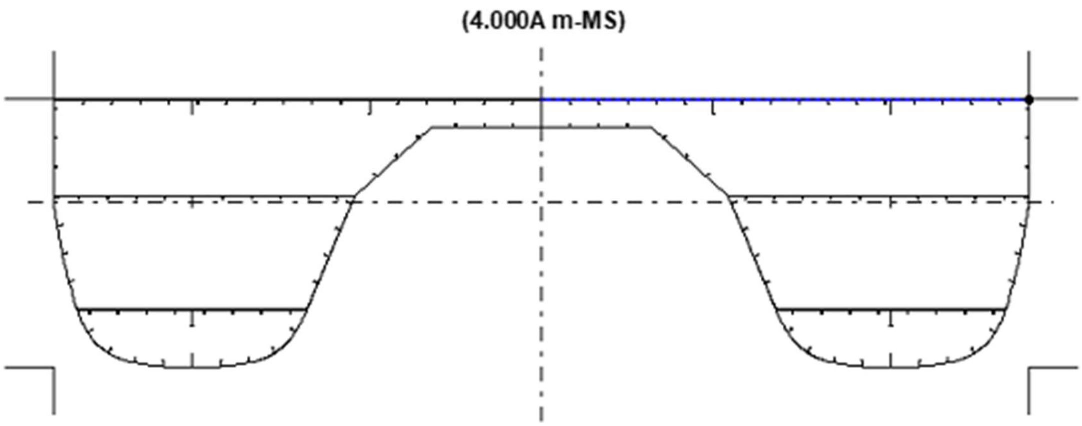
Table 11: ABS Required Bulkhead Stiffeners

Bulkhead Stiffeners	**Required Section Modulus [cm^3]**	**Bulb Plate Steel**	**Design Section Modulus [cm^3]**	**Δ Section Modulus [cm^3]**
Collision & Watertight				
Double Bottom	120.24	220 x 12	122.0	1.76
Tank Top Deck	89.17	200 x 11	92.3	3.13
Machinery Deck	44.77	160 x 9	47.9	3.13

Tank Bulkheads				
Double Bottom	77.08	200 x 9	77.7	0.62
Tank Top	40.08	160 x 8	43.9	3.82

B. Midship Section Strength Assessment

Figure 15: Midship Section



A midship section was created in HECSALV software based on the plate thickness and scantling dimensions derived from ABS requirements [6]. This design software output values for moment of inertia, section modulus and extreme fiber distance. The ship model created in Maxsurf was subjected to still water, hogging and sagging calculations to determine bending moments for 10 load conditions. These bending moments were used to calculate the midsection bending stresses at the Roro deck and the keels. These values were compared with the allowable stress for mild steel and were found to be well below the stresses that would cause failure. Factors of safety varied from 2.6 to 9.3 for various bending scenarios and locations.

Table 12: Midship Strength Analysis Results

Material Yield	234	MPa		
Allowable FOS	2.3			
Material Allowable	102	MPa		
			Actual FOS	**OK?**
Still water Deck Stress	25.24	MPa	9.3	OK
Still water Bottom Stress	50.47	MPa	4.6	OK

Hogging Deck Stress	45.53	MPa	5.1	OK
Hogging Bottom Stress	91.06	MPa	2.6	OK
Sagging Deck Stress	25.41	MPa	9.2	OK
Sagging Bottom Stress	50.82	MPa	4.6	OK

XI. Resistance, Speed, and Initial Power Analysis

A. Initial Determination of Resistance

Due to the complex nature of residuary resistance in catamaran hull forms, there is no good method of numerically estimating resistance with the standard methodologies used in monohulls. Holtrop and Mennen's used method of analysis and estimation is based on a regression analysis of monohull vessels and was of very limited use in this design. Very generalized coefficients of residuary resistance were calculated using Molland et. Al [5]. These values were compared against values generated by CFD software.

B. CFD Analysis

CFD analysis was performed using the Orca3D Simerics Plugin. Hull models developed in Maxsurf Modeler were exported to Rhino3D for minimal processing. An early visual showing pressure concentrations is shown in Figure 16. The slender hull forms show comparatively little pressure past the bow bulb. Since the hull form lacks any noticeable shoulder, wave generation is consistent along the length of the hull. As expected, the catamaran hull form generates significant interference between the hulls, with a very large high-pressure area in the wake zone.

Figure 16: Early Model CFD Analysis at 20 kts

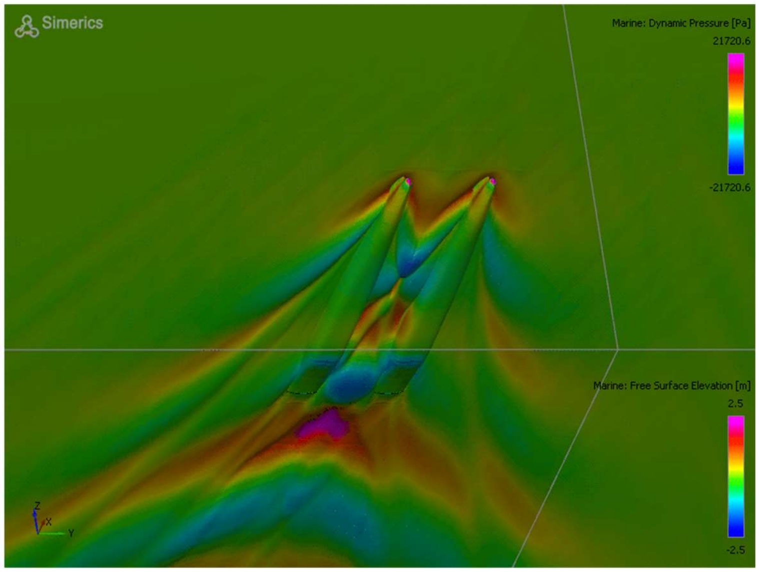


Figure 17: CFD Calculated Resistance Coefficients

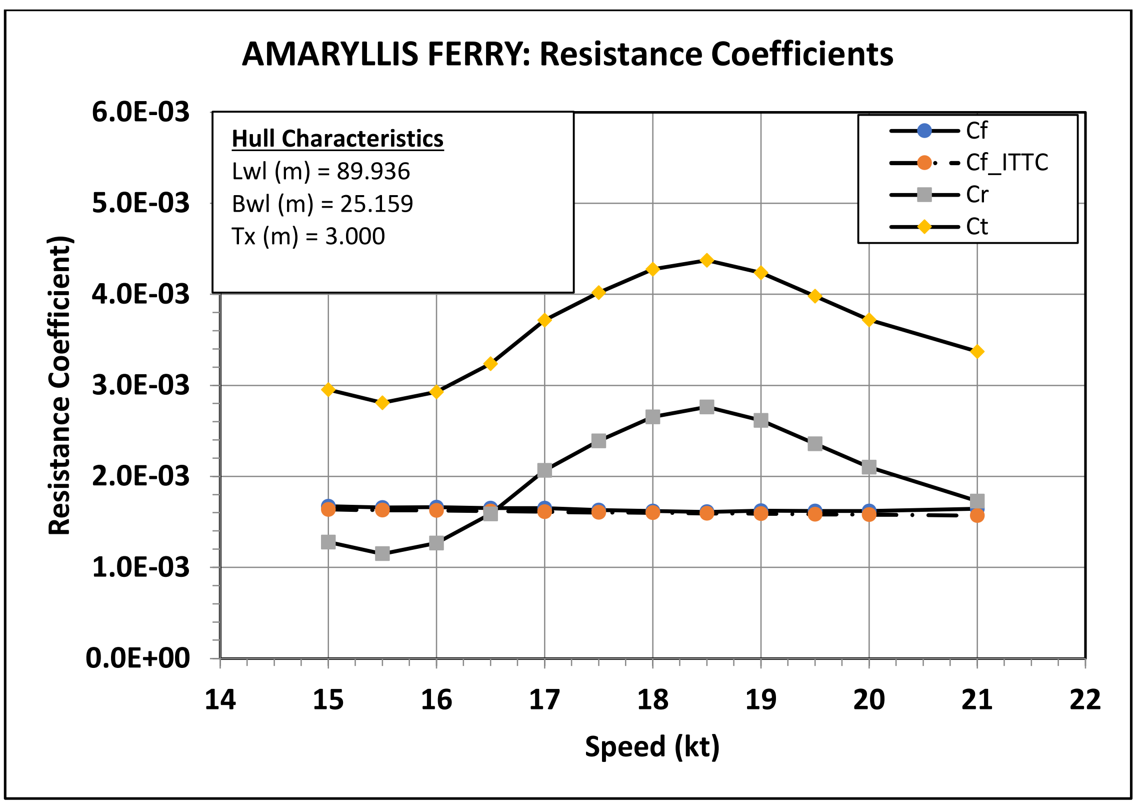
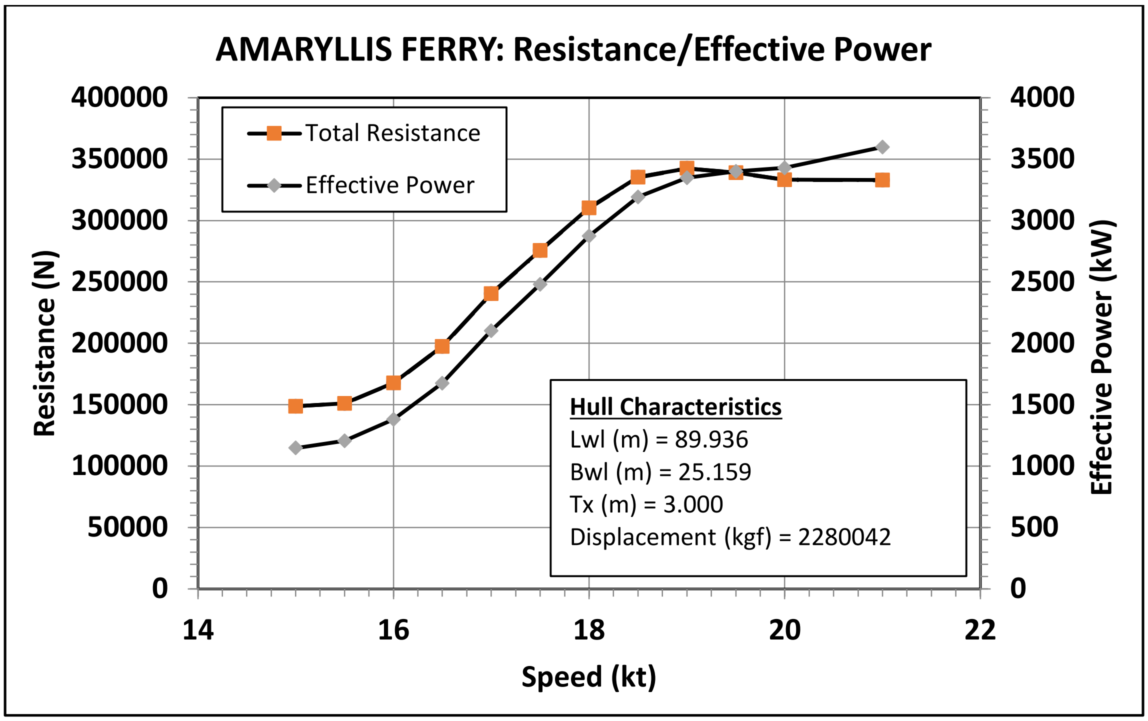


Figure 18 shows resistance at various operational speeds as calculated by Orca 3D CFD. There is a very distinct contour to the Cr curves that holds ramifications for powering. The current hull form shows a large increase in residuary resistance in the 16-18.5 kt realm due to positive wave interference. Interestingly, at speeds below approximately 16.5 kts, the amount of residuary resistance drops below that of frictional resistance due to negative wave interference. This effect occurs again above 18.5 kts. As currently designed, this places vessel resistance at top speed in a pronounced dip, while cruising speed is expected to be near the top of the curve. This results in a very flat speed/power curve in the expected operational envelope.

Figure 18: Bare Hull Resistance VS Effective Power



Bare hull resistance and effective power curves are shown in Figure 18. As expected, speed/power ratios are relatively flat in the 15 kt region, increase rapidly through 18 kts, and level off through 21 kts. Detailed results are shown in Appendix G.

C. Power Analysis

To maximize the benefits of the catamaran hull form, draft must be kept to minimum. This limits the size of possible propellors. While high speed catamarans frequently utilize waterjets to mitigate these low draft effects, waterjets are dramatically less efficient than propellors (especially at speeds below 35-40 kts). The need to maintain the highest possible efficiency ruled out consideration of waterjets for this design. Although single propellers are generally more efficient, overloading a single propellor will result in severe losses in efficiency. To prevent overloading, four propellers were used in the design (2 per demi-hull). Per CFD analysis, a bare hull speed of 18 kts requires an effective power of 2872.7 kW. Assuming an initial estimating ratio of 50% bare hull EHP to total BHP leads to a total BHP for the vessel of 5745.4 kW. Divided between four engines, an initial estimate of 1436 kW per engine is obtained.

XII. Propulsion plant selection

A. Power Plant Tradeoffs

The selection of the power plant was guided by a combination of power requirements, weight, emissions, fuel consumption, fuel availability and IMO/EPA/EU compliance. Wartsila, Yanmar and MTU have designed and marketed ferry specific, high speed diesel engines that are lightweight compared with other marine diesel power plants. The power to weight ratio of the high-speed diesels average 2.7 times that of medium speed marine diesel engines.

Table 13:Power to Weight Ratio Comparison

Model	**Manufacturer**	**Power [kW]**	**Weight [mt]**	**Power/weight [kW/mt]**	**Speed**
6EY26W	Yanmar	1,471	18.5	80	medium
20 8L20	Wartsila	1,480	10.5	141	medium
6L250	GE	1,498	15.9	94	medium
			average	**105**	**medium**
3512C	Caterpillar	1450	7.488	194	High
16V 2000 M72	MTU	1440	4.3	335	High
KTA38-DM	Cummins	1119	4.22	265	High
12AYEMGT	Yanmar	1340	4.78	280	High
14 16V	Wartsila	1340	3.8	353	High
			average	**285**	**High**

The 1436 kW initial estimated power requirement per engine of this ferry design eliminated the Wartsila and Yanmar engines with a maximum power of 1340 kW. The inclusion of a reduction gear in the MTU engine provides additional weight savings and design simplicity over the other manufacturers. The MTU engine is compliant with IMO Tier II, EPA 2, and EU IIIA emissions requirements and is acceptable to ABS and other major classification societies.

Table 14:Comparison of High-Speed Marine Diesel Engines

	MTU 16V 2000 M72	Yanmar 12AYEM-GT	Wartsila 14 16V
Power [kW]	1440	1340	1340
Weight [kg]	4300	4780	3800
IMO Compliance	Tier II	Tier II	Tier III w/ NOx
Fuel Consumption [l/hr]	361	350	323
Reduction Gear	Yes – ZF5000	No	No

The MTU 16V 2000 M72 was selected for further analysis.

B. Specified Powerplant Analysis

NavCad Design suite was used to further refine powering predictions

Table 15: Specific Powerplant Analysis

NavCad Powering Estimates – MTU 16V 2000 M72				
Speed (kts)	PE TOTAL (kW)	RPM Engine	PB Eng (kW)	Load Engine (%)
5	90.5	683	38.7	2.7
9	524.6	1228	215.6	15
13	1198.6	1656	472.8	32.8
15	1807.2	1902	709.9	49.3
17	2587.1	2148	1012.8	70.3
+ 18.00 +	3047.3	2270	1191.2	82.7
19	3557.4	2392	1388.9	96.4
20	4119.7	2514	1607.2	111.6

XIII. EEDI Analysis

Figure 19:IMO Energy Efficiency Design Index Formula

$$\frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}**\right)}{f_i \cdot f_c \cdot f_l \cdot Capacity \cdot f_w \cdot V_{ref} \cdot f_m}$$

A primary goal in the design of this ferry is to achieve compliance with IMO Energy Efficient Design Index (EEDI) Phase III requirements while using commonly available marine diesel oil as fuel. While this goal could more easily be achieved using liquified natural gas (LNG), the limited availability of this fuel makes it unsuitable for the Port Angeles to Victoria route. The lower speed, lower resistance and the higher dead weight load to lightship ratio allows a higher cargo to propulsive power ratio. The intermittent use of shaft generators reduces the size of electric generators, which cover only hotel, not bow thruster, power loads. Replacing compressor driven air conditioning equipment with marine chillers provides further reductions in electric demand and utilization of recovered waste heat from the propulsion engines. Both of these systems improve the EEDI index of this design. Our attained EEDI value is 39.6, below the required EEDI value of 42.7.

XIV. Electric Load Analysis

The electric requirements of the vessel are separated into four operating scenarios; Maneuvering, Underway, Emergency and Docked. The electric power requirements of the vessel will be supplied completely by two diesel gensets while in all modes except Maneuvering and Emergency. While approaching the dock using the four bow thrusters, two of the main engines will be decoupled from the propeller shafts and be designated to operate shaft generators to accommodate the heavy load of the electric bow thrusters. Similarly, for emergency situations two of the main engines will be dedicated to shaft generators.

Bilge, ballast and fire pump sizing and electric requirements are based on the ABS Marine Vessel Rules for Bilge Pimp Sizing [6]; US Coast Guard Review of Bilge and Ballast Systems (46 CFR 5.50-50(d) [9]; and SOLAS Chapter II-1, Regulation 35-1 3.9 Chapter 6 Section 5 11.5.4. Hydraulic pump electrical requirements are based on flow rates for operating steering gear and Roro ramps, with redundancies for emergency situations.

Lighting loads are estimated from commercial standards for passenger and industrial environments. Food service electrical loads are estimated from a Consolidated Edison estimate of 0.67 kW/m2 for a 144 m2 service area.

The HVAC systems are based on chillers and heaters operated on recovered waste heat from main engines. The adsorption chillers provide an 85% power savings over operating traditional compressor chiller devices. The heaters will operate using waste heat from the engine coolant and will require minimal loads to operate pumps. Air circulators will provide chilled and heated air to the passenger and crew spaces.

The provision of power will be from two 250 kW diesel gensets, 2 intermittently operated 700 kW shaft generators and a 100-kW emergency backup generator. Total generating capacity of 2000 kW will cover the highest demand Emergency Scenario of 1514 kW.

Table 16: Electric Load Analysis

Component		**Number**	**Load [kW]**	**Operating Mode [kW}**			
			Each	Maneuvering	Underway	Emergency	Docked
Bow Thrusters		4	275.4	1101.6		1101.6	
Lighting							
Passenger Spaces			25.8	25.8	25.8	25.8	25.8
Crew & Machinery			30.3	30.3	30.3	30.3	30.3
Emergency Lights			10			10	
Navigation			10	10	10	10	10
Pumps							
Hydraulic Oil		2	76.8	153.6	76.8	153.6	76.8
Fuel		4	1.0	4.0	4.0	4.0	
Lube Oil		4	1.0	4.0	4.0	4.0	
Potable Water		2	2.0	4.0	4.0	4.0	4.0
CHT		2	4.0			8.0	8.0
Bilge		2	16.8	16.8	33.6	16.8	
Fire Pumps		2	22.3			44.6	
Ballast		8	5.0			40	20
HVAC							
Chillers (90 tons)		2	2.3	4.6	4.6		2.3
Heaters		2	2.0	4.0	4.0		2.0
Air Circulators		20	0.3	5.0	5.0	5.0	5.0

Food Service		1	96.5	48.2	96.5	19.3	96.5
Bridge Equipment		1	15	15	15	15	
Anchor Windlass		1	22	=		22	
Mooring Windlass		2	8.0	16			16
			TOTAL	**1458.2**	**356.6**	**1514**	**318.2**

XV. Major mechanical systems

A. Hull Equipment

Four bow thrusters, two per demi hull, are specified in this design. The sizing of the bow thruster is based on the beam windage area of the vessel. Wartsila provides formula for electric demand for bow thrusters in ferries. [10] Power demand ranges from 0.54-0.96 kW per square meter of beam windage area. The bow thrusters are sized at a mid-point value of 0.72 kW/m^2. Given a windage area of 1530 m^2, the total demand is 1102 kW divided into four 275 kW thrusters. Based on a brochure from PT Marine for transverse thrusters, the design specifies four 275BTM thrusters with a tunnel diameter of 1110 mm [11].

B. HVAC

A typical compressor driven HVAC system would be the largest non-maneuvering consumer of electricity. In order to reduce power demand for the air conditioning, this design specifies the use of waste heat recovery marine absorption chillers. This will result in an 85% reduction in electric demand compared to a similarly sized compressor/condenser system. Waste heat from the engine exhaust and the engine cooling water jacket will pass through a heat exchanger heating a hot water loop and providing thermal energy to the absorption chiller’s generator. Cooling load demand, based on heat transfer calculations of passenger compartment window and surface area and passenger occupancy total 40 tons. In order to provide redundancy, two Heinen & Hopman SWM-60 absorption chillers providing 50 tons of cooling capacity per unit, are located port and starboard on the mid machinery deck [12]. In cold weather the engine heat recovery loop will provide hot water to radiators in the air handling units.

Figure 20: Exhaust Heat Recovery System

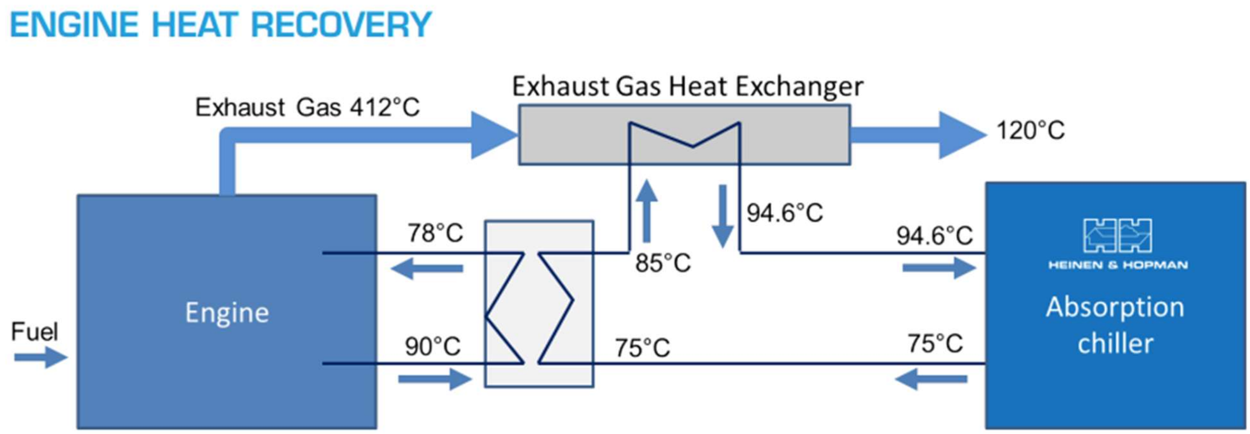
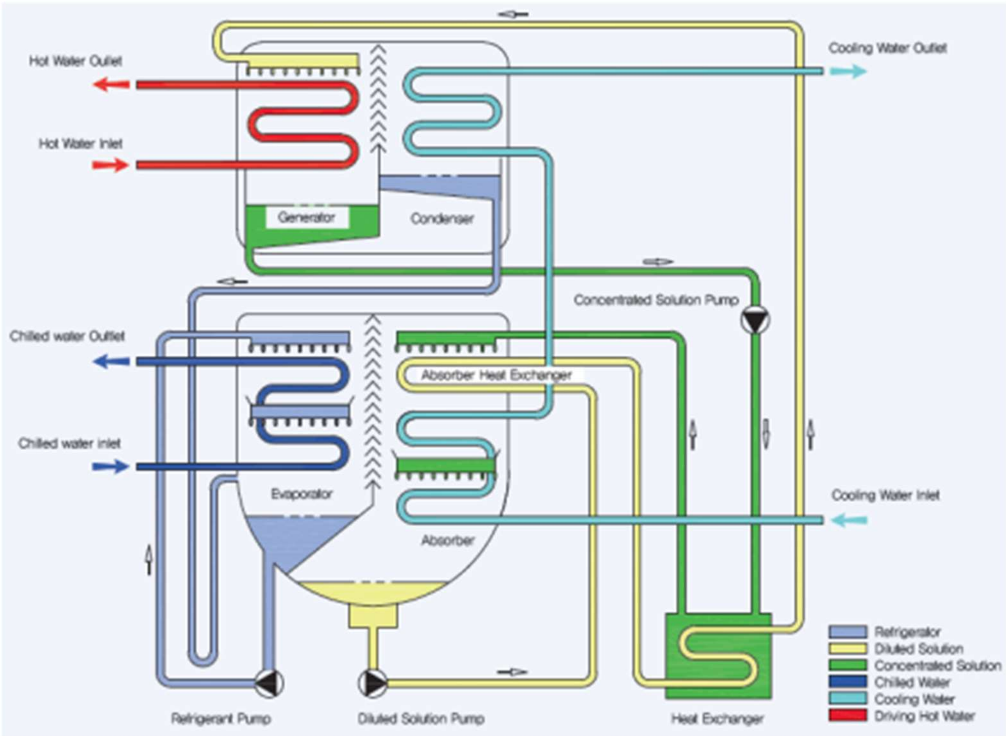


Figure 21: Typical Absorption Marine Chiller



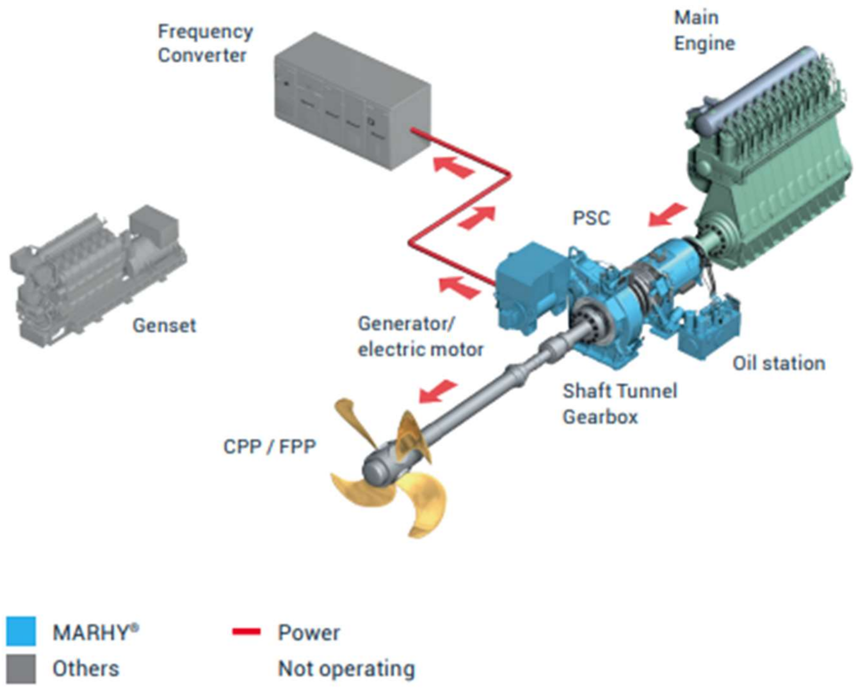
C. Pumps

Bilge and ballast pumps have been sized in accordance with ABS Marine Vessel Rules for Bilge System Sizing and US Coast Guard Review of Bilge and Ballast Systems (46CFR 56.50-50(d)). Based on these criteria the main bilge lines should be 4.58 inches in diameter. The design calls for five-inch pumps in each demi hull with crossover piping between. This will yield a flow rate of 750 GPM per pump. Fire pump sizing is in accordance with SOLAS Chapter II-1, Regulation 35-1 3.9 Chapter 6 Section 5 11.5.4. This regulation requires a minimum of two fire pumps with a capacity of 4/3 the flow rate of the ballast system. The design specifies two 1000 GPM pumps producing a pressure of 43.5 psig. Hydrants shall be located in the engine rooms, shaft tunnels, at the steering gear, on the main deck, in the accommodations, and at the bow for anchor washing. Hydraulic pumps are sized according to flow rates demanded by the steering gear and the Roro ramp. At a pressure of 320 BAR, 144 l/min are required. For redundancy, a pair of Kawasaki K3VL60 piston pumps are specified [13].

D. Electric Generators

Electric loads will be met by two systems. Two 250 kW Caterpillar C9.3 marine generators fueled with marine diesel oil will provide for continuous hotel loads [14]. They will be placed on the mid-machinery deck, one each on the port side and starboard side. A single 100 kW Caterpillar C7.1 generator will be located on the starboard side of the Roro deck to serve as an emergency backup generator [15] [16]. During docking maneuvers and in emergency situations, two of the main propulsion engines will be decoupled from the propeller shafts and will generate electricity to power the four bow thrusters. A pair of 700 kW Marhy marine hybrid drive systems have been chosen for this design. These consist of a remotely engaged propeller shaft clutch which disconnects the propulsion engine from the propeller shafts and engages a generator gearbox. This gearbox diverts power into a generator. The shaft generators will operate in PTO mode only and will not be used as a redundant propulsion system [17].

Figure 22: Marhy PTO Shaft Generator System



E. Anchor and Windlass

Ground tackle has been sized according to ABS Regulations for Design and Classification of SWATH vessels [6]. These calculations generate an equipment number of 1109 which specifies an anchor weighing 3540 kg and 19 shots of 60 mm chain weighing 42,180 kg. The maximum load on the anchor windlass will be 73,890 kg. The chain locker will be 104 m^3 based on the Germanischer Lloyd formula [18].

XVI. Mission specific equipment and outfitting

A. Outfitting

The outfitting for this ferry will include 650 passenger seats on the main passenger deck, 32 seats in the dining area, an additional 160 seats inside the bridge deck, and room for 100 more passengers on benches in the outside area of the bridge deck. Four stairways will bring passengers from the Roro deck to the passenger deck and three stairways will provide access from the passenger deck to the bridge deck. Two elevators will provide handicap access to all passenger decks. There will be food and beverage service with table seating in the forward area of the passenger deck with attendant food preparation and serving spaces.

To comply with United States Coast Guard rules, 14 inflatable life rafts with a capacity of 50 persons each and two davit launched fast rescue boats will be mounted on the exterior section of the bridge deck [19]. There will be lifejackets stored in lockers around the passenger and bridge decks, sufficient to provide for all passengers, crew, and staff. There will be 16 life buoys arrayed on the roro and bridge decks. These appliances will comply with SOLAS regulations concerning lifesaving equipment [20].

B. Roro Ramp

A single hydraulic ramp is fitted to the stern for loading both automotive traffic and passengers. When deployed it will extend 3.75 meters aft of the transom and has an area of 65.8 square meters. It will be lifted and lowered by a set of direct acting hydraulic rams [21]. The port outboard area will be segregated with railings to separate pedestrian passenger boarding from car and truck loading.

Figure 23:Example Hydraulic Lift RoRo Ramp

XVII. Weight Estimates

Structural steel and aluminum weight of 975 metric tons has been generated from a Maxsurf model summation of all structural parts. Accommodations outfit weight has been estimated using a set of formulae found in Schneekluth and Bertram [22]. Machinery weight is the summation of all machines selected to be installed on the vessel.

Table 17: Itemized Weight Estimate

Group	**Item**	**Weight [mt]**
Structure	Steel & Aluminum	975.550
Outfit	Accommodations	254.000
	Stern Ramp	36.000
	Anchors & Chain	49.280
	HVAC Chillers	5.194
	Other Outfit (pumps, pipes, wiring, etc.)	101.500
Machinery	Main Engines & Gearboxes	17.200
	Hotel Load Generators	2.244
	Emergency Generator	1.522
	Propulsion Shafts	48.700
	Propellers	5.206
	Bow Thrusters	11.200
Contingency	5% Lightship Contingency	75.380
	TOTAL LIGHTSHIP	**1582.976**

The weight estimates are in accordance with historical data assembled by Strohbusch (1971), Schneekluth (1985) and updated by Papanikolaou [4] in table 2.1. This ferry design complies with the ranges of data for Passenger Ro-Ro, ferries/ RoPax shown in this table for ferries between 85 and 120 meters of length.

Table 18: Weight Estimate Ratio Comparisons

	DWT/Δ	Structural/Lightship	Outfit/Lightship	Machinery/Lightship
Range [%]	16-33	56-66	23-28	11-18
Design [%]	32.0	61.6	28.2	10.2

XVIII. Trim and Intact Stability Analysis

Trim and intact stability analysis was performed using the MaxSurf design suite. Since the vessel's primary route is between the US and Canada, the design was inspected in relation to both USCG intact stability requirements as defined in 46 CFR Subchapter S, as well as intact stability requirements imposed by Transport Canada. Both USCG and Transport Canada incorporate IMO IS 2008, therefore intact stability was primarily analyzed with regards to IMO regulation.

Loading conditions were analyzed for lightship, as well as a matrix that included all possible permutations of 0%, 50%, and 100% cargo; as well as 10%, 50%, and 100% consumables. For the purposes of this report, results for 0% cargo and 10% consumables will be included as a worst-case arrival condition, while 100% cargo and 100% consumables will be treated as a worst-case departure condition. 50% cargo and 50% consumables will be analyzed as an intermediate condition. These load cases are shown in conjunction with results in Appendix F.

Downflooding points were taken to be the two aft doors for passenger access, as well as a forward door on the focsle space. The ro-ro deck and focsle compartment were treated as non-buoyant volumes, as the gunwales of the hull are 3 m above the main deck.

The catamaran has a very small draft relative to the size of propellors, and for passenger comfort must be kept near 0 trim. Draft was therefore kept approximately at design draft for all load cases except worst-case arrival condition.

Due to the catamaran hull form's high beam to draft ratios, intact stability did not present issues at any of the primary loading conditions. MaxSurf Stability was used to calculate intact stability compliance

A. IMO 2008 IS Code- MSC.267(85)

A summary of applicable IMO 2008 IS regulations is presented below.

2.2.1 specifies a minimum area under the righting lever curve of 0.055 metre-radians up to 30° angles of heel (a value greater than or equal to 0.055 metre-radians), and either between 30° and 40° or between 30° and minimum angle of down flooding, whichever is less (a value greater than or equal to 0.09 metre-radians).

2.2.2 specifies that a righting lever greater than or equal to 0.2 m must be maintained for an angle of at least 30°

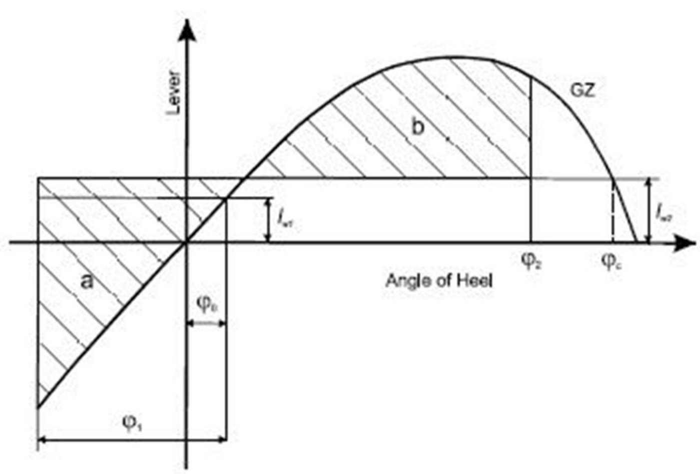
2.2.3 specifies that a maximum righting lever shall occur at an angle greater than 25°. A final criterion is applied that specifies a minimum initial GM greater than or equal to 0.15 m.

2.2.2 and 2.2.3 present a challenge for large beam to draft ratio vessels (such as catamarans). MSC.1/Circ. 1281 provides an alternative test whereby the max righting lever (GZ) should occur at an angle greater than or equal to 15° [23]. The area under the curve of righting arm levers should be greater than 0.070 metre-radians to an angle of 15° (when max righting lever occurs at 15°), and 0.055 metre-radians when max righting lever occurs at 30°. For angles between, values are to be interpolated based on equation. For ease of calculations, the worst case of 0.070 metre-radians was assumed.

2.2.4 specifies a minimum initial GM_0 greater than 0.15 m

2.3 provides a mechanism for analyzing severe wind and rolling criterion. Essentially, the criteria requires calculation of the area under GZ curve assuming an initial heel due to wind and wave action. Roll back from the heel is then calculated, assuming wind and wave action is released. Figure 24 graphically shows the criterion, whereby area a (area under GZ curve from heel due to rollback) must be less than area B.

Figure 24: IMO IS 2008 Severe Wind and Rolling Criterion [23]



3.1.1 specifies a maximum heel (10°) due to passenger crowding to one side of the vessel. The magnitude of the heeling arm was derived from the relocation of all passengers to the centroid of one-half of the vessel's passenger deck.

3.1.2 specifies a maximum

B. USCG 46 CFR Subchapter S

The main intended route for this vessel is between ports in the United States and Canada. 46 CFR 71.75-5 requires any US flagged vessel on an international voyage to have a SOLAS Passenger Ship Safety Certificate. Per USCG CFR 171.001/171.050 (c), a vessel issued a SOLAS Passenger Ship Safety Certificate must meet IMO Res. MSC.216(82) instead of any regulations contained elsewhere in the CFR. This exempts the vessel from the requirements of 46 CFR 170.170 and 170.173 (Weather Criteria, and Criterion for vessels of unusual proportion and form) [24]. Additionally, a vessel that complies with 2008 IS Code is exempt from 171.050 (Passenger heel requirements for a mechanically propelled or a non-self-propelled vessel) [25]. The vessel was analyzed for Subchapter S and passed, however as the requirements are not regulatory requirements, they will not be included in this report.

C. Transport Canada TP 7301

Transport Canada manages safety of vessels in Canadian waters, and in TP 15415 states that IMO IS 2008 is incorporated into Transport Canada regulations. TP 7301 specifies several acceptable modifications to the 2008 IS Code for near-shore vessels that are unable to meet the standards of the 2008 IS Code. As these modifications all relax the requirements of the 2008 IS Code, none were applied to this design.

D. Results

Table 19: Intact Stability Results

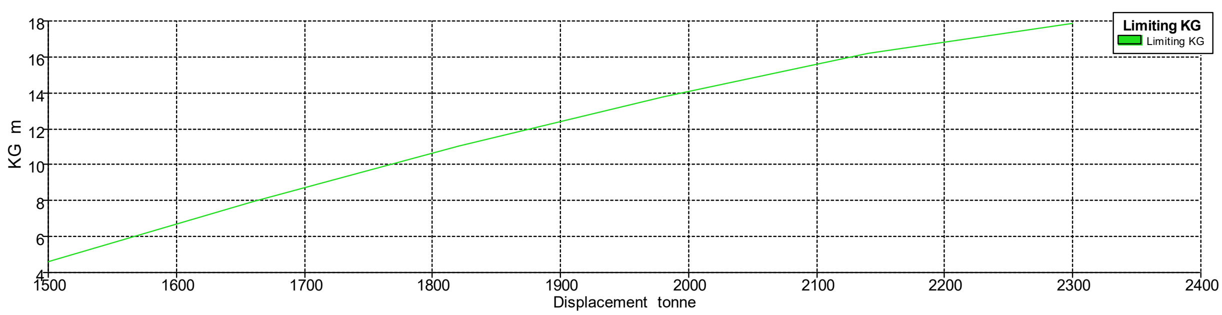
Intact Stability IS Code 2008					
Criteria	Condition				
	Arrival	Intermediate	Departure	Required	Result
2.2.1: GZ Area 0-30 (m*deg)	181.03	174.08	165.93	3.1513 m*deg	PASS
2.2.1: GZ Area 0-40 (m*deg)	242.25	233.44	217.23	5.1566 m*deg	PASS
2.2.1: GZ Area 30-40 (m*deg)	61.22	59.36	51.30	1.7189 m*deg	PASS
2.2.2 GZ Area Angle > 30 Deg (m*deg)	6.73	6.58	6.178	0.2 m*deg	PASS
2.2.4: Initial GMt (m)	39.26	36.56	34.38	0.150 m	PASS
2.3: Severe Wind and Rolling Ratio of Roll Area to Rollback (%)	457%	435%	365%	100 %	PASS
2.2.3: Alt Angle of Max GZ (deg)	18.2	20	20	15 deg	PASS
2.2.3: Alt Area of GZ Eq to Angle of max GZ (m*deg)	93.78	101.88	96.95	0.07 m*deg	PASS
3.1.1: Passenger Crowding Angle of Eq (deg)	0.4	0.4	0.4	10 deg	PASS
3.1.2: Turn Angle of Eq (deg)	0.1	0.1	0.2	10 deg	PASS

Table 19 shows the results of intact stability at a worst-case arrival, intermediate, and worst-case departure condition. A breakdown of each of these loading conditions is shown in Appendix F. With the exception of 2.2.3 (alternate angle of max GZ), at least a 300% margin is available for all conditions. 2.2.3 should be able to be solved by utilizing ballast, if necessary, at lower displacements. This should provide adequate intact stability for all possible loading conditions.

Table 20: Limiting KG at Selected Displacements

Displacement (intact) tonne	Draft Amidships m	Trim (+ve by stern) m	LCG m	TCG m	VCG m	Limit KG m	min. GM m	Criterion	Name
1500	2.221	0.000	-41.211	0.000	4.584	4.584	50.098	267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ
1660	2.390	0.000	-41.617	0.000	7.947	7.947	43.253	267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ
1820	2.554	0.000	-42.024	0.000	11.014	11.014	37.246	267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ
1980	2.713	0.000	-42.439	0.000	13.760	13.760	32.078	267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ
2140	2.868	0.000	-42.865	0.000	16.214	16.214	27.624	267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ
2300	3.017	0.000	-43.300	0.000	17.844	17.844	24.432	267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40

Figure 25: Graph of Limiting KG vs Displacement



XIX. Damage Stability Analysis

Damage stability analysis was conducted using both probabilistic and deterministic methods. 46 CFR 171.001 states that any vessel issued a SOLAS Passenger Ship Safety Certificate must meet the applicable requirements of IMO Res. MSC.216(82) rather than USCG damage stability and subdivision requirements laid out in 46 CFR Part 171. Resolution MSC.216(82) initially laid out concepts for probabilistic damaged stability, which were later clarified in MSC.421(98) (IMO Explanatory Notes to the SOLAS Chapter II-1 Subdivision and Damage Stability Regulations). These explanatory notes were then revised once more in MSC.421(98) Rev.1. These notes make up what will hereafter be called IMO Probabilistic Damage Stability 2020.

Although not required, the vessel was analyzed for USCG 46 CFR Part 171 compliance. Abbreviated notes will be made on these regulations, however extended calculations will not be provided. 46 CFR Part 171 includes regulations for subdivision size, as well as deterministic damaged stability.

Deterministic damaged stability was calculated with the use of MaxSurf Stability, while GHS was used to analyze IMO Probabilistic Damage Stability 2020.

A. Subdivision Requirements

46 CFR 171.060 specifies general watertight subdivision requirements. Since the ferry is intended for an international voyage, it falls under requirements for Type I subdivision

B. Probabilistic Damage Stability

Probabilistic damage stability analysis was conducted for three loading conditions, per MSC.429(98)/Rev.1 (IMO Probabilistic Damage Stability 2020). The formula for calculating probabilistic damage stability depends on calculation of a required index, and comparison against an attained index. This is tested at three drafts, corresponding to a light draft, an intermediate draft, and a heavy draft. In all cases, a test trial VCG was utilized to bring attained and required index in close proximity. In all cases, the attained index was greater than required for VCGs that are beyond any possible loading condition of the vessel.

Figure 26: GHS Model

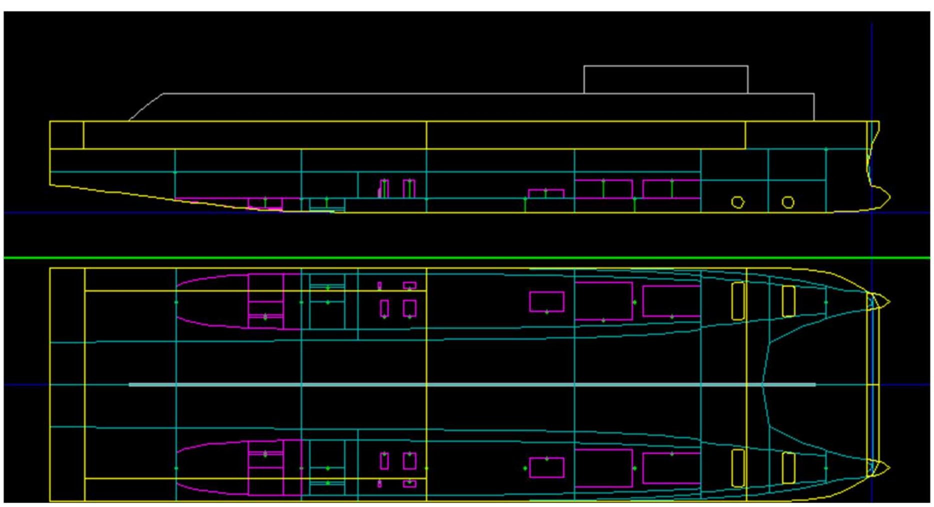


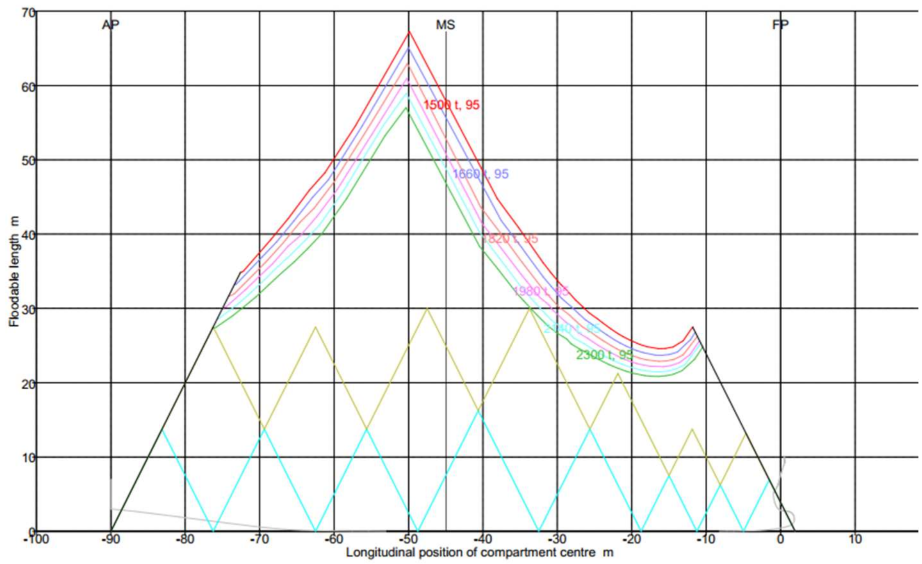
Figure 27: Probabilistic Damage Stability Analysis Results

Probabilistic Damaged Stability Per SOLAS 2020 – Variable Trial VCG				
	Trial VCG (m)	Required Index	Attained Index	Pass/Fail
dl	28	0.755	0.821	PASS
dp	26	0.755	0.844	PASS
ds	25	0.755	0.850	PASS

C. Floodable Length Curves

Floodable length curves for the vessel are shown in Figure 28. An additional bulkhead was added behind the collision bulkhead to ensure the vessel met two compartment standards, however because it is a catamaran, these requirements are likely overly onerous and can be relaxed for some level of weight reduction. Floodable length is calculated by removing buoyancy across the entire beam of the vessel. In a catamaran, this amounts to assuming that both hulls are penetrated from baseline to waterline simultaneously. In a vessel of 25.5 m beam with approximately 11 m of separation between the two hulls, this would be an exceptionally unlikely occurrence. This is reinforced by the probabilistic damage stability results shown in **Error! Reference source not found.**. Prior to adding the additional forward bulkhead, the vessel still passed with trial VCGs of 25 m.

Figure 28: Floodable Length Curves



XX. Endurance and Bunkering

A. Fuel

Operating at 85% load, four MTU 16V 2000 M72 main engines will burn 0.986 metric tons of fuel per hour [26]. The Caterpillar C9.3 generators will consume 0.123 metric tons of fuel per hour at full hotel load [27]. The total consumption for each hour of ferry operations will total 1.109 metric tons per hour. With a 15% safety factor this gives a total consumption rate of 1.44 metric tons per 22.6 nautical mile trip. The trip frequency varies from four trips per day in winter to eight in the summer months. The ship will carry 116 mt of marine diesel oil when all tanks are full. This will provide 84 total trips per bunker period and an endurance of 1820 nautical miles. Given these parameters the following table shows the required refueling periods for the ship under various seasonal operating scenarios.

Table 21:Fuel Bunkering Periods

	Seasonal Scenario		
	Winter	Spring & Fall	Summer
	4 trips/day	6 trips/day	8 trips/day
Fuel Burn/day [mt]	5.77	8.65	11.53

Bunker Period [days]	20	13	10

B. Lube Oil

The MTU 16V 2000 M72 main engines do not require a through flow lube system. The oil change interval is every 1500 hours with an oil volume of 113 liters per engine [26]. For the Caterpillar C9.3 gensets, the oil change interval is every 500 hours and the volume is 30 liters per engine [27]. With a total lube oil capacity of 3136 liters, the ship will carry 5 oil changes for the main propulsion engines and 30 for the generators. The waste oil tank holds 782 liters and every 1500 hours oil changes will generate 632 liters. The waste oil will need to be discharged 5 times per lube oil bunkering period.

Table 22:Lube and Waste Oil Periods

	Seasonal Scenario		
	Winter	Spring & Fall	Summer
	4 trips/day	6 trips/day	8 trips/day
Lube Oil Fill [days]	1650	1110	825
Waste Oil Discharge [days]	330	220	165

XXI. Seakeeping Analysis

A. Sea State

The sea state assessment comes from data collected at the New Dungeness Buoy Station 46088, located in the Strait of Juan de Fuca 17 NM northeast of Port Angeles [28]. It lies within 5 NM east of the path of the ferry route under consideration and is representative of the conditions that will be experienced by the ferry design. December has historically been the most severe sea state conditions of the year, with a significant wave height of 3.5 meters. Waves of this size would require that this ferry design be assessed at Sea Stage 6 on the Beaufort scale. Winds of 21-26 knots, with waves varying between 3 and 4 meters are characteristic of this sea state. Long waves are beginning to form. White foam crests are very frequent and there will be some airborne spray.

Figure 29: Mean and Standard Deviation Plot of Significant Wave Height [28]

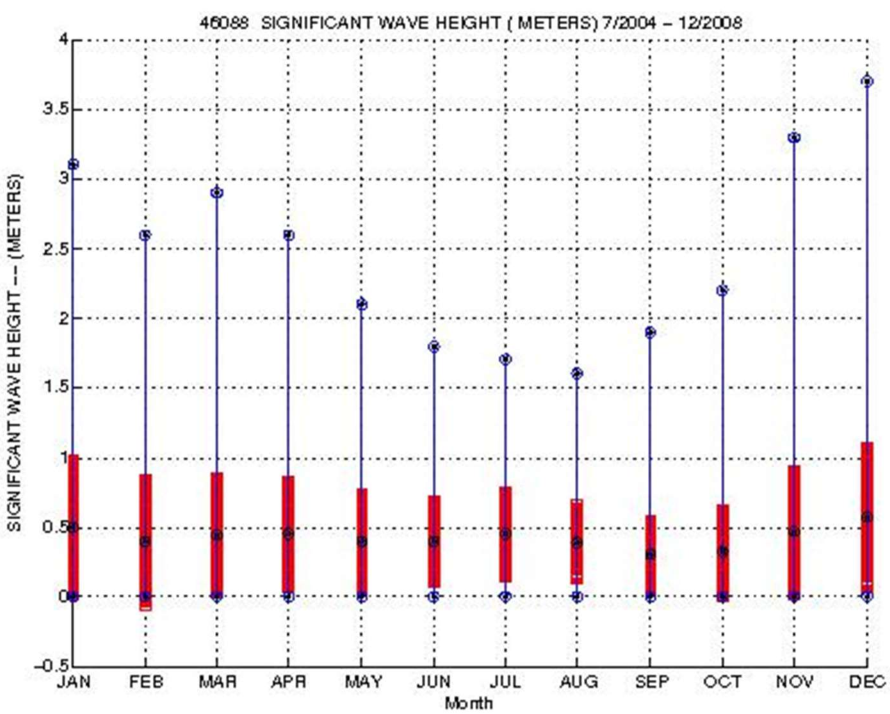
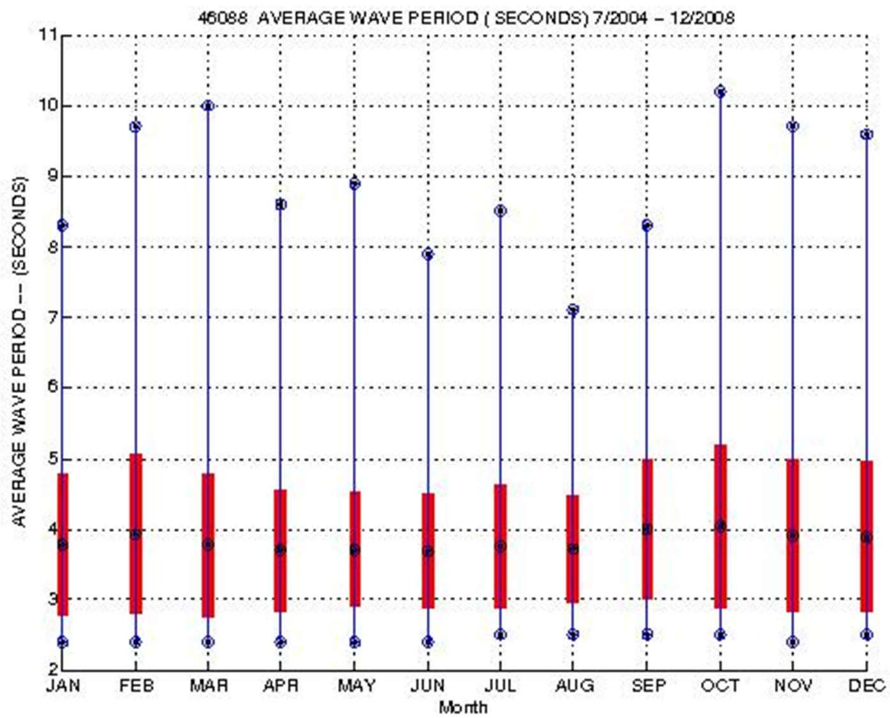


Figure 30: Mean Standard Deviation for Average Wave Period [29]



B. Criteria

The American Bureau of Shipping publishes a "Guide for Passenger Comfort on Ships" which, along with Motion Sickness Index data from a MaxSurf model, form the criteria for assessing the seakeeping ability of this design [30].

Table 23: Maximum Root Mean Square Acceleration Level

Notation	Frequency Range	Acceleration Measurement	Maximum RMS Level
COMF	1-80 hz	Frequency rated RMS	71.5 mm/s2
COMF +	0.1-0.5 hz	Motion Sickness Dose Value	30 m/s2
	1-80 hz	Frequency rated RMS	71.5 mm/s2

The Motion Sickness Index (MSI) rates the percentage of passengers who will experience motion sickness during a given exposure time. The MaxSurf model shows criteria by wave encounter frequency.

C. Model Results

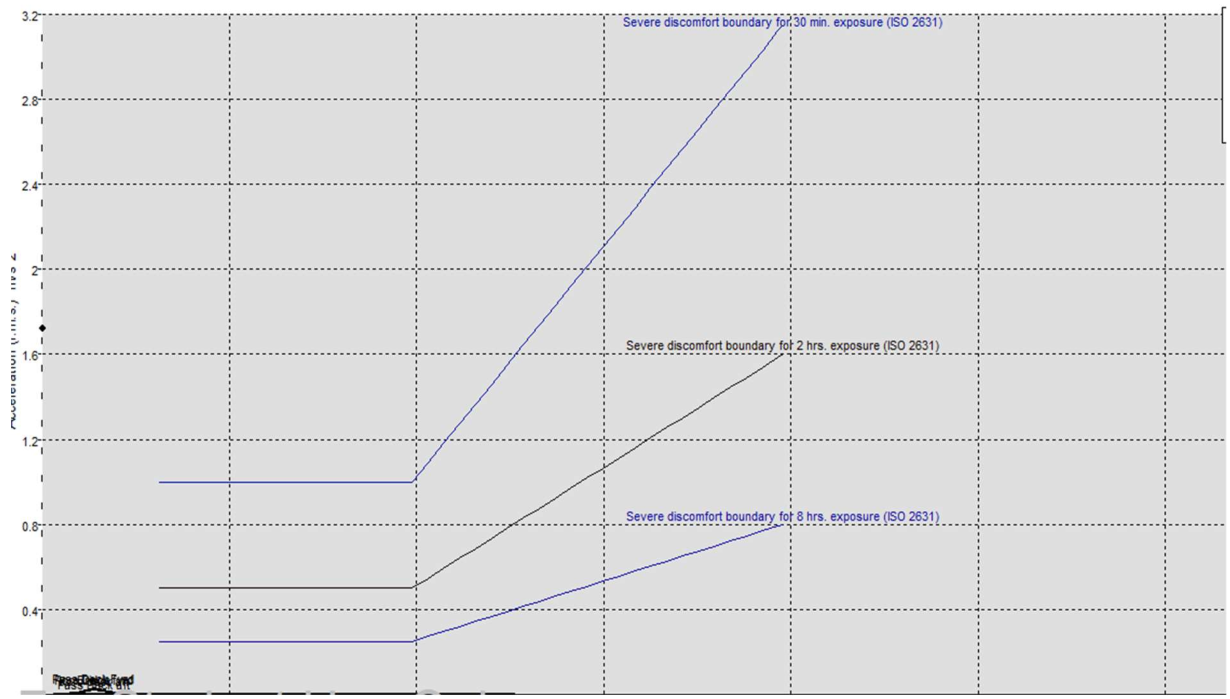
While ABS requires that these data be collected from a ship in trials or service, these values can be compared to those generated by the MaxSurf Motions to assess the suitability of this design to the intended seaway. The table below shows two wave approach directions, a head sea and the worst-case scenario of a 45-degree rear quartering sea. Five locations on the ship were modelled.

Table 24: Maximum RMS Accelerations at 20 knots for Sea Stage 6

Location	Heave (mm/s2)	Pitch (mm/s2)	Roll (mm/s2)
Head Sea			
Roro Deck Aft	28	2.0	0
Roro Deck Bow	47	2.0	0
Passenger Deck Bow	59	1.0	0
Passenger Deck Aft	5.0	1.0	0
Bridge Deck	47	5.0	0
45-degree Rear Quarter	**Heave (mm/s2)**	**Pitch (mm/s2)**	**Roll (mm/s2)**
Roro Deck Aft	29	2.0	1.0
Roro Deck Bow	44	2.0	1.0
Passenger Deck Bow	50	1.0	1.0
Passenger Deck Aft	11	1.0	1.0
Bridge Deck	44	5.0	3.0

The graph below represents the worst-case scenario, a 45-degree rear quartering sea. MSI discomfort limits are displayed along with the calculated MSI values for five locations on the ship. The comfort limits are clearly shown, the results of the model for this design are all clustered at the lower left of the graph, demonstrating that the design in sea state 6 does not approach limits for the Motion Sickness Index.

Figure 31: MSI Limits and Calculated Values at 20 knots in a Rear Quartering Sea



D. Conclusions

The ship is within ABS acceleration limits of 71.5 mm/s2 in all cases tested and at maximum speed during seat state 6 and in all five locations examined on the ship. The catamaran design exhibits some heave and pitch motions, but even in a beam sea, almost zero rolling acceleration. The Motion Sickness Index generated by the model shows that all locations on the ship are far below threshold values that would generate motion sickness, regardless of the incident wave direction. Absolute vertical displacement of the locations examined indicate that at sea state 6 there will be no sea water breaching the transom or bow, with the Roro deck remaining dry.

XXII. Crew manning estimates

The crewing requirements for this ferry will include deck crew, engineering crew and a small service staff. Since there are no staterooms the only necessary service personnel will be those operating the food service. The current one-way passage requires 90 minutes at a service speed of 15 knots. The design under consideration will increase service speed to 18 knots, reducing voyage time by 75 minutes. Eight trips per day can be performed by a single crew in 10 hours. The estimated crew compliment is shown in the following table.

Table 25: Crew and Service Staff

Position	Number
Master	1
Deck Officers	6
Chief Engineer	1
Engineers	6
Total Crew	14
Food Service Staff	6
Total on Ship	20

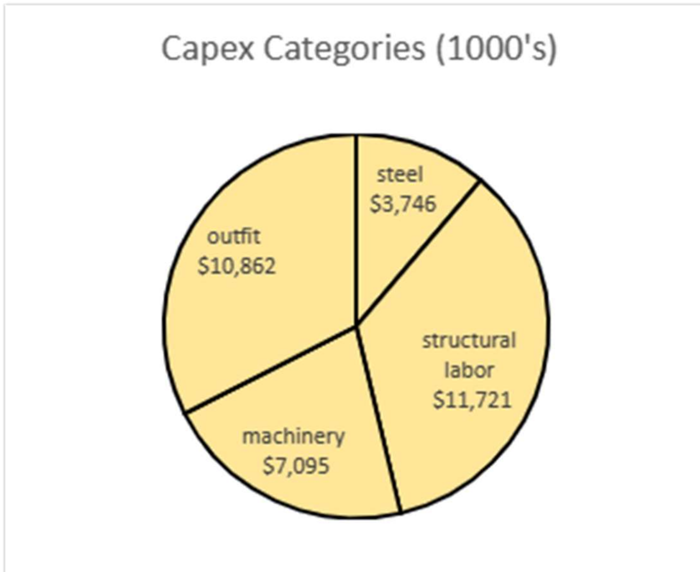
XXIII. Cost, Rates and Profit Analysis

A. Capital Expenditure

Two methods for estimating the cost of construction have been used for this design. The initial parametric model is based on “Preliminary Ship Cost Estimation” by J. Carreyette . This method is based on structural steel weight and outfit weight. The cost of labor, materials and outfit were inflated to present day values. This paper envisions estimating the cost of construction of monohull vessels made exclusively of steel. It represents labor costs in England during the 1970’s. While labor costs have been inflated, there are discrepancies between construction of ships in developed economies and manufacturing in lower labor cost environments. The design being considered has both steel hull construction and aluminum superstructure. The labor costs of aluminum manufacturing can be highly variable depending on shipyard experience and equipment. The most of aluminum material is higher than similar structures built of steel. For these reasons, the cost estimate may not be accurate and presents some risk.

Using the parametric model and the Carreyette method, the estimated capital cost of this design is $33.42 million. This is based on a length of 90 meters, a structural weight of 951 metric tons of steel, 446 metric tons of outfit, a block coefficient of 0.62 and a total propulsive power of 5760 horsepower. These are the principal inputs into the Carreyette estimation method. Labor costs were estimated at $20.43/hr for tradesmen with an overhead of 100%. Labor costs are below market rates for developed economies, but are representative of costs in lower wage nations.

Figure 32: Breakdown of Capital Expenses



The second approach to cost estimation was to examine build costs of currently operating low speed catamaran ferries. The Sea Transport company in Australia has designed dozens of this type of ferry and overseen construction in various locations, both in Australia and in lower labor cost nations. There is limited information related to the build costs of these ferries. A regression analysis was attempted relating ferry length to cost with inconclusive results. From the available data, most of these ferries cost around $20 million in 2023 U.S. dollars, independent of length for ships from 60 to 85 meters. This may be a result of variable labor costs and skill levels. These costs are lower than the Carreyette estimate derived from the parametric model.

Table 26: Length, Deadweight Tonnage and Build Cost of Comparable Catamarans

Ferry Name	Length [m]	Dead Weight [mt]	Build Cost [2023 1000's US$]
Lite Cat 2	60.6	340	10.35
Galleons Passage	73.9	477	22.09
Pentalina	68.9	475	22.08
Ivete Sangalo	49	unknown	23.55

Alfred	84.5	550	19.18

Considering what the other low speed catamarans cost to build, there is confidence that this design can be built in a low labor cost environment for less than the Carreyette method estimate. The value generated by this method has been used in all calculations of annualized capital expenses and is likely a conservative estimate.

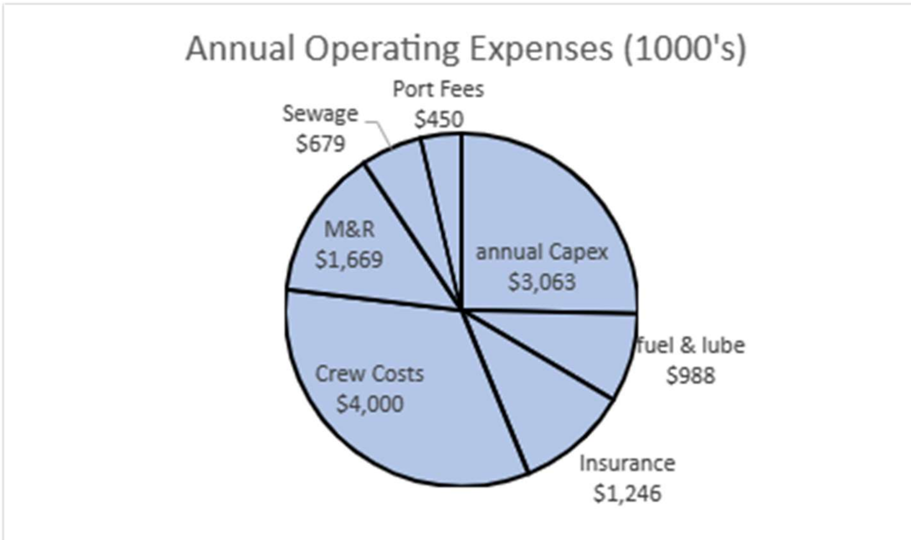
B. Operating Expenses

Annual operating expenses were estimated from the sum of annualized capital expenses, fuel and lube oil usage, crewing costs, insurance, maintenance and repair, port fees, and sewage pump fees. Annualized capital expenses are derived from the total build cost of the vessel and its 25-year expected service life. Considering the advanced age of the ferry currently in use, this may underestimate the vessel's service life.

Port fees are assigned because the catamaran design may require alteration of the current Victoria facilities. As the current ferry has a starboard side loading ramp and the design under consideration has only a stern ramp, dock reconstruction will be necessary.

Fuel and lube oil consumption is based on engine and genset manufacturer data. Crewing costs assume an average of $80,000/year for 20 crew members with a 100% overhead allowance. Insurance has been estimated from a Drewry Maritime Research Ship Operating Costs Annual Review from 2012, inflated to 2023 $US [31]. Maintenance and repair costs are derived from the same paper and similarly inflated. Sewage disposal fees are from estimates for disposing of sewage in the Port of Seattle for the Washington State Ferry System. The total annual cost of operating this ferry design across the Strait of Juan de Fuca is $9.03 million

Figure 33: Annual Operating Expenses



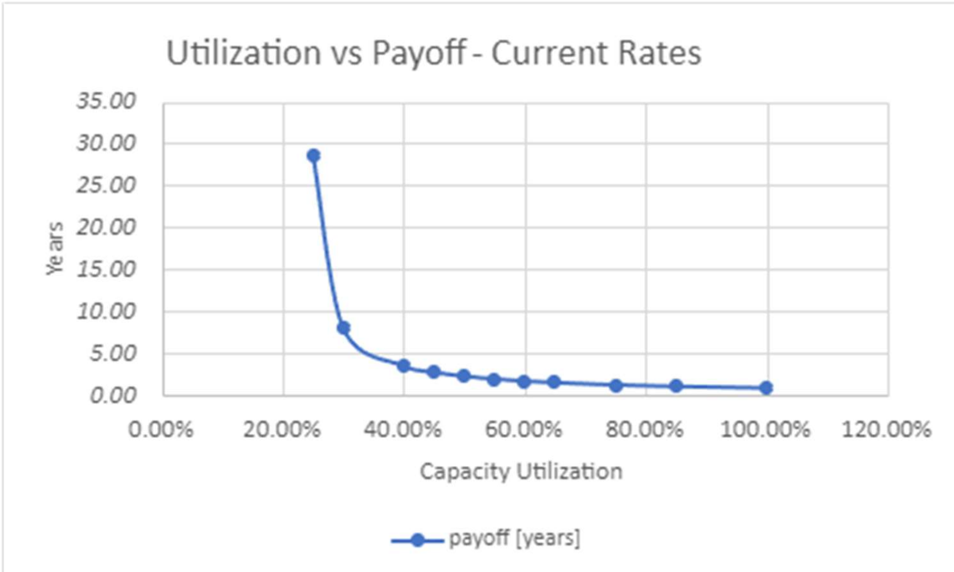
C. Rates

Based on the operating and construction expenses of this design, the parametric model dictates a required rate of $0.83 per passenger for each nautical mile of the 22.6 nautical mile route. For automotive traffic, the required rate is $0.62 per lane meter per nautical mile. The 2024 Black Ball Ferry line rates listed on the website yield $0.97/ passenger-NM and $2.26/ lane meter-NM. The ferry schedule varies from 4 trips per day in winter months to 8 trips per day in summer months, with 6 trips per day during spring and fall.

D. Profit Analysis

Assuming an 8% interest rate, this design will achieve positive cash flow in approximately 7 years with the current 30% utilization rate. This utilization rate is based on the current load of about 400,000 passengers per year and assuming a similar utilization rate for the automotive capacity [32]. This does not include any income that might be made by leasing or operating the food service, government subsidies for covering this route, increases in ferry rates over time, or changes in capacity utilization. After the payoff period operating on the Port Angeles to Victoria route, assuming constant expenses and rates, the total profit per year is $6.55 million, and the cumulative profit after 25 years will be $114.8 million.

Figure 34: Payoff Period and Capacity Utilization



XXIV. Passenger Risk Assessment

A. Passenger and Ship Safety

There are inherent risks to taking passengers and vehicles on board an oceangoing vessel. The physical ability of passengers varies and the design under consideration requires pedestrian boarding vessel via the Roro ramp. While this process can be acceptable to both ambulatory and handicapped customers, the incline of the ramp could present problems for both groups. Slip/fall injuries can be a cause of passenger injury. Adequate makings, railings and non-skid surfaces should guide movements to prevent injury and mitigate the risk of passengers going overboard. Separation of passenger and vehicle loading physically or temporally is necessary to prevent car/truck strike accidents with pedestrians. Loading vehicles can be accident prone, even with guidance from experienced crew members. Backing trucks onto the vessel requires competent operators and an orderly plan for queuing and loading. Pedestrian and motorized loading risks can be mitigated with adequate crew training and staffing. As the ferry currently in service provides multiple ramps with drive-through capabilities, this design would require new dockside arrangements for waiting vehicles. Provision of life saving equipment will be required to meet SOLAS regulations and secure passenger safety in cases of passengers overboard and ship wide emergencies.

There is a risk of collision and allision with the ship. Docking maneuvers and port operations can place the vessel at risk of collision with stationary objects and other ships. Proper crew training and carefully designed port facilities and schedules can mitigate these risks. Restricting operations to weather conditions appropriate for the vessel design will reduce the danger of collisions and groundings. In the worst case of the ship sinking and requiring abandonment, life preserving equipment in adequate amounts will be included in the safety gear on the vessel. This will include life jackets for all passengers and crew, inflatable lifeboats with enough capacity to carry all persons on board, and a rescue boat.

Fire is a risk when operating any ship, especially when carrying automobiles and trucks. There is a risk that some trucks will be carrying flammable or hazardous materials. The risk of fire spreading and destroying the ship will be mitigated by a firefighting system compliant with relevant SOLAS regulations and crew trained to fight fires.

B. Structure and Weight Estimate

ABS design and class requirements stipulate the use of a Finite Element Analysis to determine the structural integrity of the bridging structure between the demi hulls. There are moments and loads which are specific to catamaran designs that are not present in monohull arrangements. These are moments generated by prying and squeezing of the hulls, yaw moments splitting the hulls apart, pitch torsional moments as one hull rises while the other falls, and the longitudinal bending moment. The following loading forces must also be considered in this FEA analysis: side force applied by wave motions and lateral movement of the ship, transverse vertical shear on the longitudinal plane and longitudinal vertical shear in the transverse direction.

An FEA analysis has not been performed on the bridging structure of this design. This may necessitate additional structural elements between the wet and Roro decks to reinforce this area against the moments and forces. This will affect, and likely increase, the structural and lightship weight of the vessel producing follow on effects on draft, resistance, and power requirements.

C. Powering and Resistance

Powering requirements have been estimated using Simerics computational fluid dynamics (CFD) and verified using NavCad and the Holtrop method. The design maximum speed of 20 knots places the ship on a plateau in the speed/power curve. This has given some confidence that the resistance and power requirements of the vessel are appropriate for this operational speed. It has been observed from a series of CFD simulations that lowering the speed to 18 knots results in dramatically reduced power requirements and certain compliance with EEDI Phase III regulations.

D. Port Facilities and Roro Loading

The current Black Star Ferry Line ship plying this route loads automotive traffic through a stern ramp and side ramp. Our ferry design specifies only a stern ramp. This arrangement will require an upgrade to the current port facilities and backing trucks on or off the ship. Port facility upgrades are costly and not included in the build cost of the vessel. The design envisions either rebuilding the traffic ramp at the Victoria terminus to accept stern loading or the inclusion of a complex Roro ramp that can accommodate straight loading at one port and right angle loading at the other. Adding a side ramp to our design is problematic as there is insufficient vertical clearance to drive trucks under the passenger deck and off the side of the ship. Either the complex ramp or upgrades to port facilities will add cost to this project.

E. Economic Considerations

Our build costs estimates are based on the Carreyette method of estimation and checked against a regression analysis of build costs of similar low speed catamaran designs. These may result in inaccurate estimates of construction costs. The Carreyette method was developed for steel monohull vessels and may have limited application to twin hull catamarans. Additionally, our design incorporates a steel structure from the Roro deck to the baseline and an aluminum superstructure. Aluminum materials and welding are more expensive than steel and vary considerably depending on the experience and skills of the shipyard. The build cost estimate may be increased or decreased by these uncertainties.

Assumptions have been made regarding the interest rate environment and capacity utilization of this ferry route. The parametric model assumes an interest rate of 8%. This rate could vary depending on current rates and the creditworthiness of the borrower. The model assumes a capacity utilization of 50% or greater. If that figure falls to 25% for an extended duration, this design is no longer profitable and will lose money year over year. As the Black Ball Ferry Line Is a private company occupancy rates are not available to the public, so the risk to economic viability due to unknown capacity utilization is difficult to assess.

F. Oil and Fuel Spills

Ferry operations, especially bunkering operations, present a risk of oil and fuel entering the water. Collisions and allisions also may present a risk of spills. These risks can be mitigated with careful and professional fueling operations. Spill response kits will be included in the safety gear present on the ship to deal with smaller spills.

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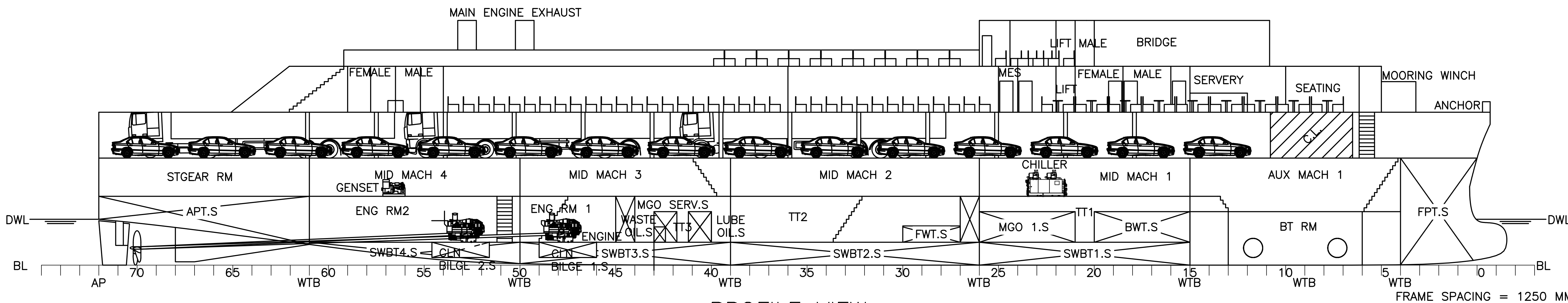
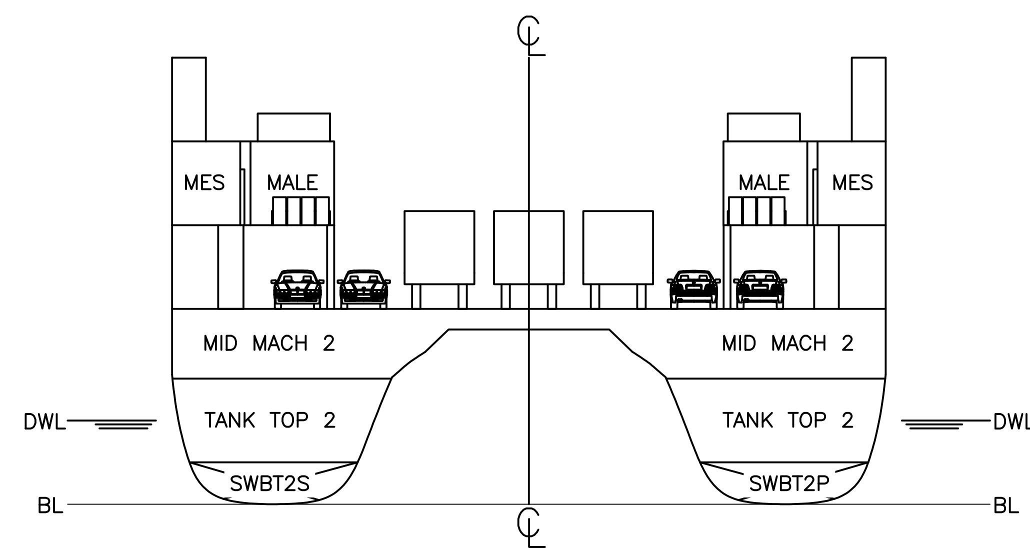
Appendix A: General Arrangement and Lines Plan



PROFILE VIEW

PRINCIPAL PARTICULARS	
LOA	92.0 m
LBP	90.0 m
B	25.57 m
T	3.0 m
D	10.0 m
DISPLACEMENT	2282 MT
DEADWEIGHT	730 MT
DESIGN SPEED	18 kt
INSTALLED POWER	5760 kW
CB (DEMI-HULL)	0.59
CAR LANES	525 m
PASSENGERS	650
CREW	18



MIDSHIP

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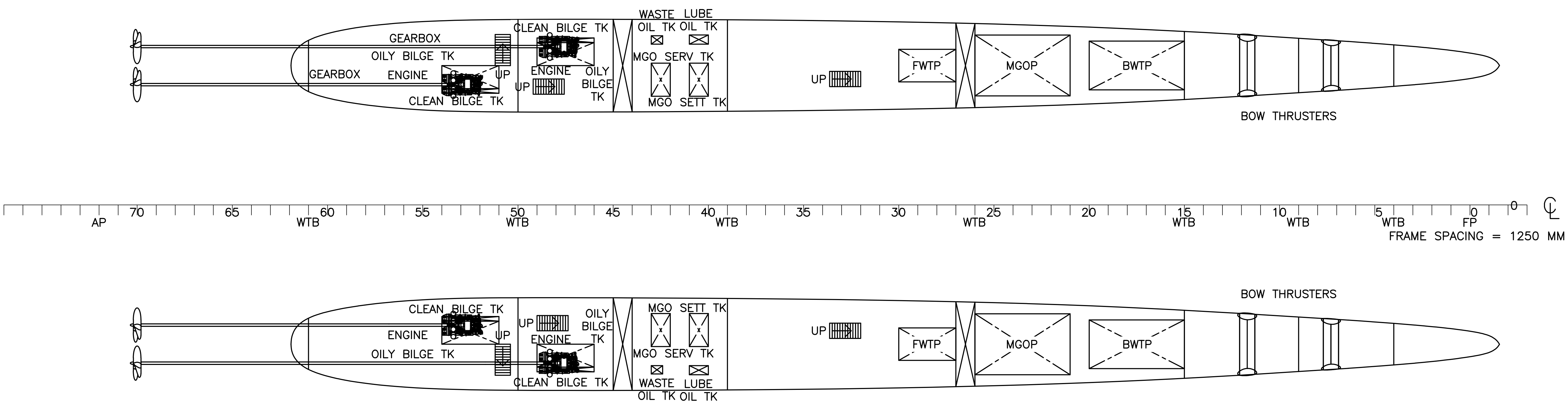

TANK TOP

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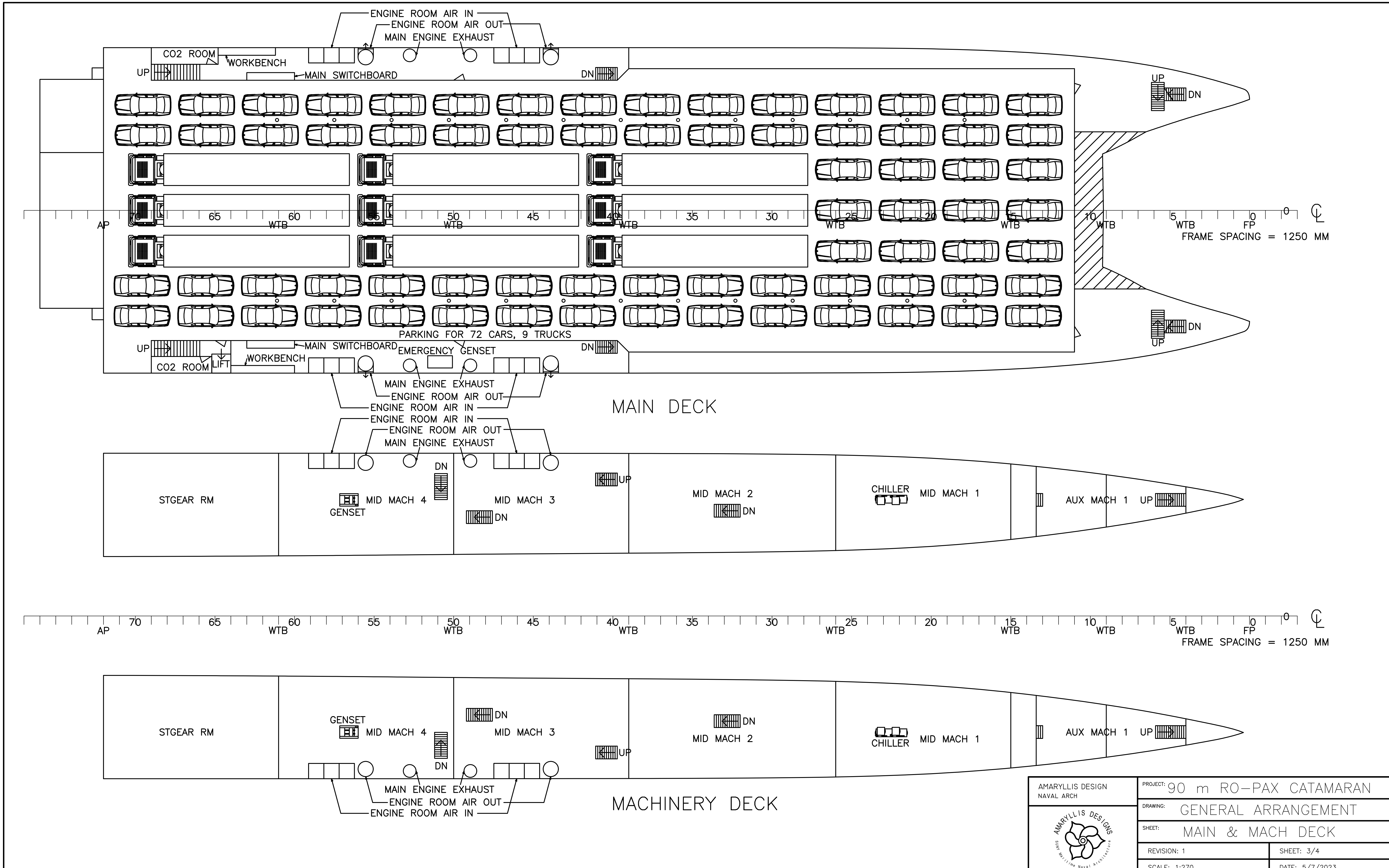
ENGINE ROOM AIR IN
ENGINE ROOM AIR OUT
MAIN ENGINE EXHAUST
CO2 ROOM
WORKBENCH
MAIN SWITCHBOARD
UP
DN
LIFT
EMERGENCY GENSET
PARKING FOR 72 CARS, 9 TRUCKS
AP
WTB
FP
FRAME SPACING = 1250 MM
MAIN DECK
STGEAR RM
MID MACH 4
GENSET
MID MACH 3
MID MACH 2
CHILLER
MID MACH 1
AUX MACH 1
MACHINERY DECK
AMARYLLIS DESIGN
NAVAL ARCH
PROJECT: 90 m RO-PAX CATAMARAN
DRAWING: GENERAL ARRANGEMENT
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SHEET: 3/4
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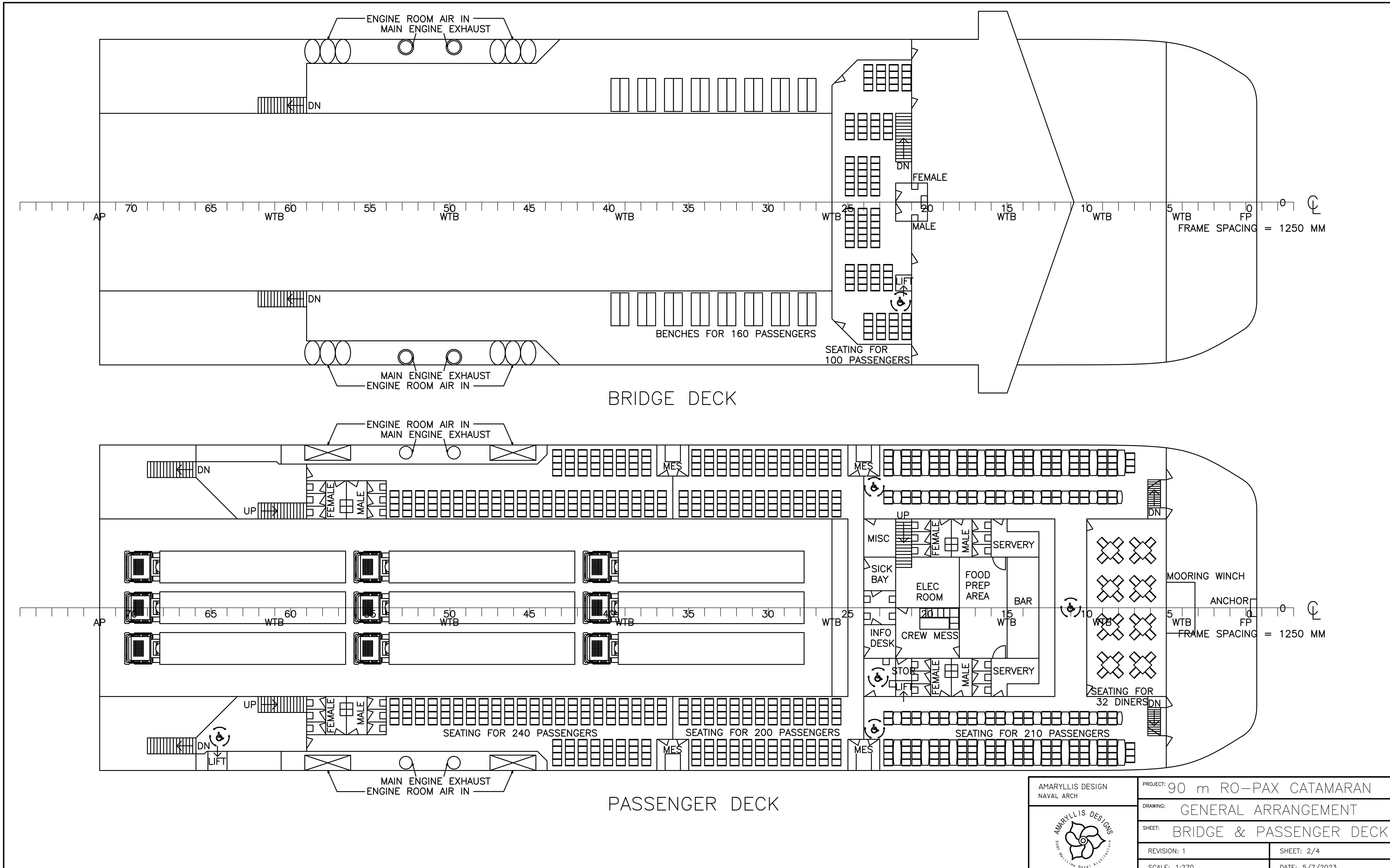


ENGINE ROOM AIR IN
MAIN ENGINE EXHAUST
DN
BENCHES FOR 160 PASSENGERS
SEATING FOR 100 PASSENGERS
FEMALE
MALE
LIFT
AP
WTB
FP
FRAME SPACING = 1250 MM
BRIDGE DECK
MES
UP
MISC
SICK BAY
ELEC ROOM
FOOD PREP AREA
SERVERY
BAR
INFO DESK
CREW MESS
STOR
MOORING WINCH
ANCHOR
SEATING FOR 32 DINERS
SEATING FOR 240 PASSENGERS
SEATING FOR 200 PASSENGERS
SEATING FOR 210 PASSENGERS
PASSENGER DECK
AMARYLLIS DESIGN
NAVAL ARCH
AMARYLLIS DESIGNS
PROJECT: 90 m RO–PAX CATAMARAN
DRAWING: GENERAL ARRANGEMENT
SHEET: BRIDGE & PASSENGER DECK
REVISION: 1
SHEET: 2/4
SCALE: 1:270
DATE: 5/7/2023

⁎WATER BALLAST TANK (100% FULL)

NAME		POSITION (FRAME)	CAPACITY m^3	WEIGHT M.T.	LCG m	TCG m	VCG m
FPT	P	−1.5−4	54.09	55.44	−2.78	−9.12	3.31
	S	−1.5−4	54.09	55.44	−2.78	9.12	3.31
SWBT1	P	15−26	79.86	81.85	−25.85	−9.14	0.83
	S	15−26	79.86	81.85	−25.85	9.14	0.83
SWBT2	P	26−39	108.33	111.04	−40.74	−9.16	0.84
	S	26−39	108.33	111.04	−40.74	9.16	0.84
SWBT3	P	39−50	84.86	86.99	−55.14	−9.07	0.86
	S	39−50	84.86	86.99	−55.14	9.07	0.86
SWBT4	P	50−61	45.78	46.93	−67.59	−9.29	1.04
	S	50−61	45.78	46.93	−67.59	9.29	1.04
APT	P	61−72	231.16	236.94	−83.92	−8.96	3.51
	S	61−72	231.16	236.94	−83.92	8.96	3.51

⁎BILGE TANK (100% FULL)

NAME		POSITION (FRAME)	CAPACITY m^3	WEIGHT M.T.	LCG m	TCG m	VCG m
CLN1	P	46−49	1.09	1.09	−59.38	−10.81	1.00
	S	46−49	1.09	1.09	−59.38	10.81	1.00
CLN2	P	51−54	1.09	1.09	−65.63	−7.48	1.00
	S	51−54	1.09	1.09	−65.63	7.48	1.00
OILY1	P	46−49	5.38	4.91	−59.38	−9.90	1.00
	S	46−49	5.38	4.91	−59.38	9.90	1.00
OILY2	P	51−54	5.38	4.91	−65.63	−8.39	1.00
	S	51−54	5.38	4.91	−65.63	8.39	1.00

⁎MARINE GAS OIL TANK (98% FULL)

NAME		POSITION (FRAME)	CAPACITY m^3	WEIGHT M.T.	LCG m	TCG m	VCG m
MGO	P	21−26	46.55	39.10	−29.38	−9.15	2.48
	S	21−26	46.55	39.10	−29.38	9.15	2.48
SETT	P	40−41	5.42	4.55	−50.63	−8.22	2.48
	S	40−41	5.42	4.55	−50.63	8.22	2.48
SERV	P	42−43	5.42	4.55	−54.00	−8.22	2.48
	S	42−43	5.42	4.55	−54.00	8.22	2.48

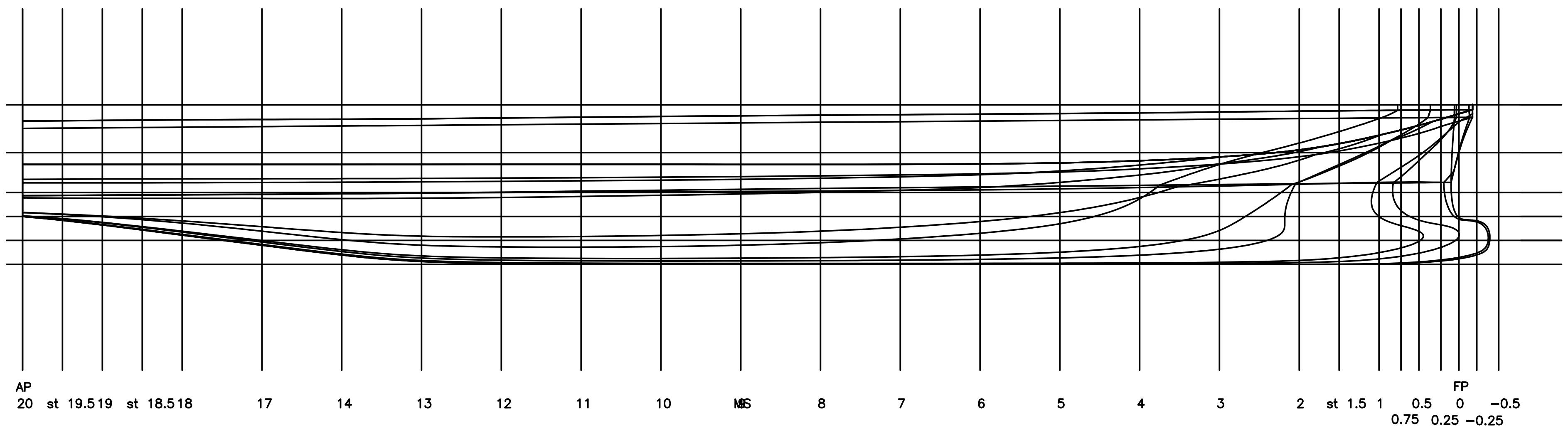
⁎LUBE OIL TANK (98% FULL)

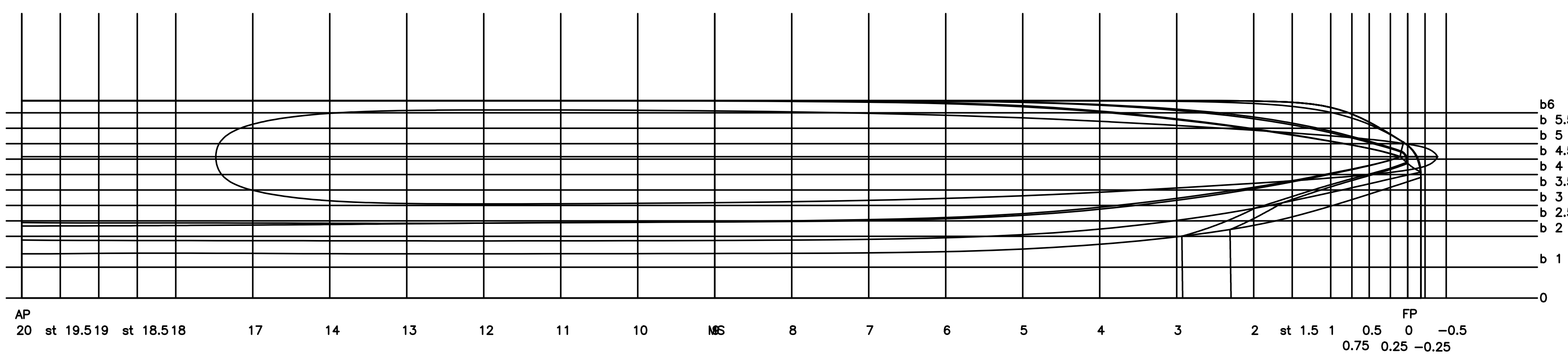
NAME		POSITION (FRAME)	CAPACITY m^3	WEIGHT M.T.	LCG m	TCG m	VCG m
LUBE	P	40−41	1.40	1.29	−50.63	−10.85	2.48
	S	40−41	1.40	1.29	−50.63	10.85	2.48
WASTE	P	42.5−43	0.41	0.38	−53.88	−10.85	1.99
	S	42.5−43	0.41	0.38	−53.88	10.85	1.99

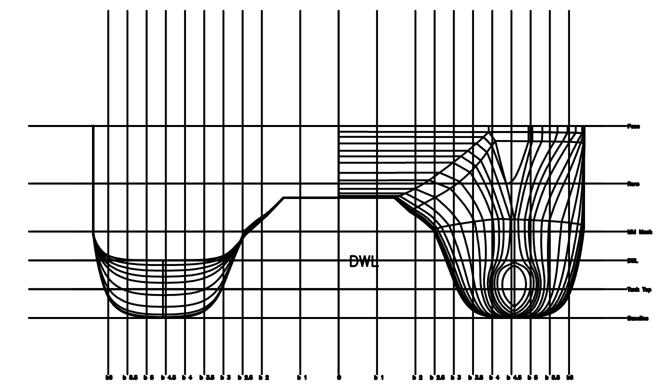
⁎WATER HOLDING TANK (100% FULL)

NAME		POSITION (FRAME)	CAPACITY m^3	WEIGHT M.T.	LCG m	TCG m	VCG m
FWT	P	27−30	8.00	8.00	−35.63	−9.14	2.03
	S	27−30	8.00	8.00	−35.63	9.14	2.03
BWT	P	15−20	40.00	40.00	−21.88	−9.15	2.50
	S	15−20	40.00	40.00	−21.88	9.15	2.50

AMARYLLIS DESIGN NAVAL ARCH	PROJECT: 90 m RO−PAX CATAMARAN
	DRAWING: GENERAL ARRANGEMENT
	SHEET: CAPACITY PLAN
	REVISION: 1 — SHEET: 4/4
	SCALE: 1:360 — DATE: 5/7/2023







AMARYLLIS DESIGN NAVAL ARCH	PROJECT: 90 m RO–PAX CATAMARAN	
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	SHEET: LINES PLAN	
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Appendix B: Initial Design: Vessel DWT Regressions

Figure 35: DWT as Function of Car Capacity - Monohull

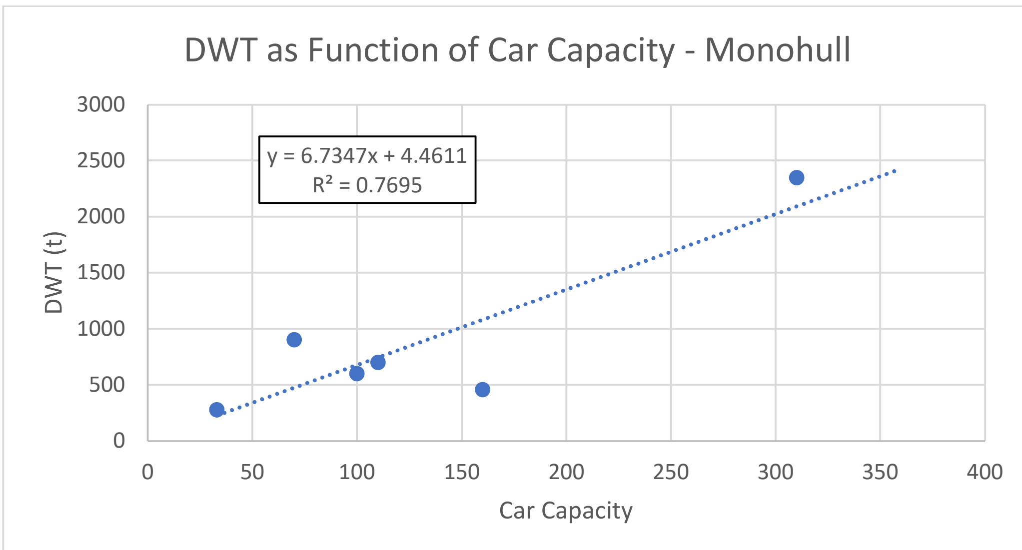
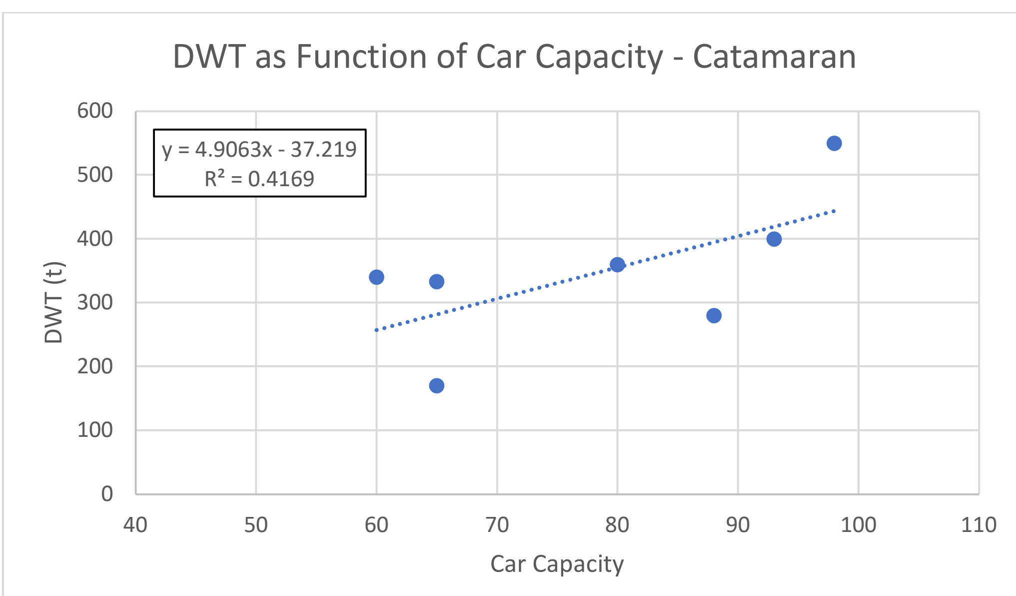


Figure 36: DWT as Function of Car Capacity - Catamaran



Appendix C: Economic Parametric Models

1. Design Inputs/Economic Outputs

	Design Inputs			Financial Outputs	
Length BP	90.0	[meters]	Total CapEx	$33,423,635.29	
Weight of Steel	3020	[tonnes]	Annualized CapEx	$3,062,691.45	
Weight of Outfit	446	[tonnes]	Annual Opex	$9,032,224.48	
Propulsion	5760	[kW]	Total Annual Costs	$12,094,915.93	
Block Coeff (Cb)	0.62			Required Rates	
Fuel Burn Rate	1.321	[mt/hour]	Min Passenger Rate	$18.75	[per passenger]
Number of Crew	20	[persons]	Min Lane-meter Rate	$14.02	[per lane meter]
Operating Days/Year	350	[days]			
Trips/day	6	[trips]	Min Rate/ Pass-nm	$0.8296	
Distance/trip	22.6	[nm]	Min Rate/ Lane-m-nm	$0.6204	
Occupancy	30%				
MARR	8%				

2. Capital Expenses

Capital Expenditure Cost Estimates

The methods and values in this` sheet are derived from "Preliminary Ship Cost Estimation" by J. Carryette, 1977, The Royal Institute of Naval Architects Adapted With Inflation

Design Outputs		
Total CapEx	$	32,181,249.76
Annualized CapEx		$2,946,306.29

Inputs		
Length BP	90	[meters]
Weight of Steel	2071.106552	[tonnes]
Weight of Outfit	446	[tonnes]
Propulsion	5760	[hp]
Block Coeff (Cb)	0.62	

4295.232 [kW]

		Inflation Rate	Years (1977-2023)
Inflation Since 1977	Materials	3.00%	46
	Labor	3.50%	46
	Machinery	1.00%	46

Steel Cost		
Weight of Steel		2071.106552
B'		1241
Steel Materials	$	2,569,355.53

Steel Construction Labor			
A' or K value		6814	
Weight of Steel		2071.106552	[mt]
Length BP		90	[m]
Block Coeff (Cb)		0.425675263	
Steel Labor Cost	$	11,655,247.79	

Outfit Costs		
C'		81338.75314
Weight of Outfit		446
Oufit Labor	$	4,748,109.76
Outfit Materials		$6,113,604.14
Total Outfit Costs	$	10,861,713.90

Machinery Costs			
F' Machinery Labor		3143	
G' Machinery Material		2710	
E' Machinery Combined		5853	
Propulsion		5760	[hp]
Machinery Costs	$	7,094,932.53	

Labor Costs	$	20,212,848.47
Material Costs		$11,968,401.30
Total Costs	$	32,181,249.76

interest		8%	
period		25	years
used value	$	(5,000,000.00)	
Annualized Cost		$2,946,306.29	

Tables Adapted From Carryette - Appendix II

Values Used

Table II — Values of A'

Average Wage Rate of Direct Labor

per hour		1977 $/hr		2023 $/hour	Overheads 75%	100%	125%
£	1.60	$ 2.80	$	13.63	5962	6814	7665
£	2.00	$ 3.50	$	17.03	7453	8517	9582
£	2.40	$ 4.20	$	20.44	8943	10221	11498

Table III — Values of B'

Average Price of Shipbuilding Steel

per mt		1977 $/mt		2023 $/mt	Wastage + Welding Rods 7.50%	10%	12.50%
£	150.00	$ 262.50	$	1,022.45	1213	1241	1268
£	200.00	$ 350.00	$	1,363.27	1618	1654	1690
£	250.00	$ 437.50	$	1,704.08	2022	2068	2113

Table IV — Values of C'

Average Wage Rate of Direct Labor

per hour		1977 $/hr		2023 $/hour	Overheads 75%	100%	125%
£	1.60	$ 2.80	$	13.63	71118	81339	91559
£	2.00	$ 3.50	$	17.03	10437.5	11938	13437.5
£	2.40	$ 4.20	$	20.44	12525	14325	16125

Table V — Values of D' — Outfit Materials

Date				
1975	£	1,500.00	$	2,625.00
1976	£	1,725.00	$	3,018.75
1977	£	2,011.00	$	3,519.25
2023	£	7,832.93	$	13,707.63

Table VI — Values of F'

Average Wage Rate of Direct Labor

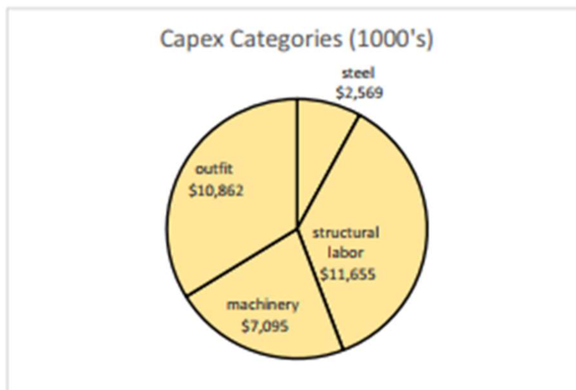
per hour		1977 $/hour		2023 $/hour	Overheads 75%	100%	125%
£	1.60	$ 2.80	$	13.63	2751	3143	3535
£	2.00	$ 3.50	$	17.03	3439	3929	4418
£	2.40	$ 4.20	$	20.44	4127	4714	5302

Categories	
Steelwork	**Outfit**
Hull	Structural forgings
Superstructure	castings
bulkheads	smithwork
bulwarks	sheet iron work
machinery seats	carpentry
	piping outside ER
Machinery	electrics outside ER
Main and auxilary	painting
generators	deck coverings
ER electrics	insulation
ER pumps	accomodation
ER piping	windows
compressors	doors
Aux Boilers	firefighting
Funnel	galley
Shafting	refrigeration
Propellers	HVAC
Thrusters	accomodation
Stabilizers	steering gear
	anchors
	cables
	deck machinery
	derricks and cranes
	hatch covers
	lifesaving appliances
	nautical instruments
	bridge consoles
	stores
	sundries

Table VII	**Values of G'**	**Machinery Materials**
Date	G'	
1975	£ 735.00	$ 1,286.25
1976	£ 845.00	$ 1,478.75
1977	£ 980.00	$ 1,715.00
2023	£ 1,548.85	$ 2,710.49

steel	$ 2,569,355.53
structural labor	$ 11,655,247.79
machinery	$ 7,094,932.53
outfit	$ 10,861,713.90
Total CapEx	$ 32,181,249.76

steel	$ 2,569
structural labor	$ 11,655
machinery	$ 7,095
outfit	$ 10,862
Total CapEx	$ 32,181



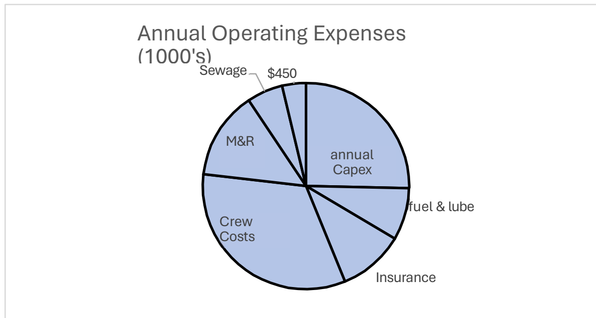
Methods of Outfit Weight Estimation

Outfit Weight	Schneekluth and Bertram				
k	0.045				Volume
converted volume	3755.051991 m3	coeff	0.282472787		8675.5
outfit weight	168.9773396 mt				3279
					1339
					13293.5
Outift weight	Schneekluth and Bertram			gross tonnage	3755.052
	975 mt				
c	1.6				
weight of outfit	156.0 mt				
Outfit Weight	Schneekluth and Bertram				
area of pass/bridge	1539.43				
weight accomodations	254.00595 mt				
	for accomodations				
Total Outfit weight	410.0				

3. Annual Operating Expenses

Design Inputs Output Value

Fuel Burn Rate		[mt/hour]	**Total Annual Opex**	
Number of Crew	**1.321363233**			**$ 9,032,224.48**
Operating Days/Year	**20**	[persons]		
Trips/day				
Distance/trip	**350**			



Operating Parameters

Days Operating/year	350	
Trips/day	6	
Distance/trip	22.6	[nm]
Vessel Speed Vk	18	[knots]
Total Trips	2100	
Total Miles	47460	
Total Hours	2636.666667	

Fuel and Lube Oil

Fuel Burn Rate		1.321363233	[mt/hour]	1136.37238
Fuel per year		3483.994391	[mt]	
Fuel MGO Cost	$ 270.00		[$/ton]	
Total Fuel Cost	$ 940,678.49		[$/year]	
Lube Oil Cost	$ 1,000.00		[$/ton]	
Lube Oil Burn Rate		0.018	[tons/hour]	
Total Lube Oil Cost	$	47,460.00		
Total Fuel and Lube Costs	$	988,138.49		

Insurance Costs

P&I	$	704,000.00	these values from VSL Cost Estimate 2012 inflated 28% to 2023 values
Supplemental P&I	$	128,000.00	
P&I Deductible	$	160,000.00	
Hull Insurance Premium	$	177,536.00	
Hull Deductible	$	12,800.00	
VSL Guarantee Premium	$	64,000.00	
Total Insurance Costs	$	1,246,336.00	

Crew Costs

Number of Crew 25 [persons]
Avg Salary/ Crew $ 80,000.00 [$/person]

Overhead 100%
Crew Costs $ 160,000.00 [$/person]

Total Crew Costs $ 4,000,000.00

Port Fees $ 450,000.00
Sewage Pumpout $679,013.99

Maintenance and Repair

M&R $	704,000.00	these values from VSL Cost Estimate 2012 inflated 28% to 2023 values
SS&E $	128,000.00	
Misc Operating Expense $	160,000.00	
Edible Stores $	177,536.00	

Chemicals $ 12,800.00 **Lube Oil**
Lubricating Oil $ 64,000.00

SSH Drydocking $ 384,000.00

Intermediate DD/UWILD 38,400.00
Total Annual M&R $ 1,668,736.00

Total Annual OpEx **$** **9,032,224.48**

		oil change intervals		
total lube oil	3136 liters		total volume mains	
waste oil cap	782 liters	1500		632 liters
Main engines	113 liters	1500 hours		
Gensets	30.0 liters	500 hours		
changes/bunker	5.0			

At 4 trips/day
1 day
2 days
3 days
4 days
5 days
6 days
1 week
weeks
4 weeks

Fuel Requirements

Trip Distance	22.6 [nm]
Burn Rate	1.321363233 [mt/hour]
Bunkering Rate	100 [m3/hour]
Total Fuel	116.07 mt

Gensets	Cat C9.3 Marine Gensets
Number	2
Power	250 kW
Fuel Burn at Full Power	35.4 gal/hr
	134.003514 l/hr
	0.123283233 mt/hr

annual Capex $3,062,691.45
fuel & lube $ 988,138.49

Insurance	$	1,246,336.00					
Crew Costs	$	4,000,000.00	Trips	Fuel Burned + 15%	Volume		
M&R	$	1,668,736.00	1	1.717111521 [mt]	1.476715908 [m3]		
Sewage		$679,013.99	2	3.434223042 [mt]	2.953431816 [m3]		
Port Fees	$	450,000.00	4	6.868446085 [mt]	5.906863633 [m3]		
Total Annual Costs	$	12,094,915.93	8	13.73689217 [mt]	11.81372727 [m3]		
			12	20.60533825 [mt]	17.7205909 [m3]		
			16	27.47378434 [mt]	23.62745453 [m3]		
	in $1000		20	34.34223042 [mt]	29.53431816 [m3]		
annual Capex		$3,063	24	41.21067651 [mt]	35.4411818 [m3]		
fuel & lube		$988	28	48.07912259 [mt]	41.34804543 [m3]		
Insurance		$1,246	56	96.15824518 [mt]	82.69609086 [m3]		
Crew Costs		$4,000	112	192.3164904 [mt]	165.3921817 [m3]		
M&R		$1,669		m3	mt	Range	Miles/wk
Sewage		$679		108.255814	81.9273696	1638.547392	1120
Port Fees		$450					
Total Annual Costs		$12,095					

VSL Annual Operating Expenses Estimates 2012 and 2023
inflation 2012-2023 28.00%

Fuel Expenses	**2012**	**2023**
Fuel $/ton MGO	$ 6,789,000.00	$ 8,689,920.00
Aux Fuel $/ton MGO	$ 420,000.00	$ 537,600.00
Cylinder Oil	$ 150,000.00	$ 192,000.00
Fuel Testing	$ 6,000.00	$ 7,680.00
	Fuel Totals	**$ 9,427,200.00**
Operational Expenses		
Labor	$ 4,200,000.00	$ 5,376,000.00
Labor (OT)	$ 1,600,000.00	$ 2,048,000.00
Relief Officers	$ 55,000.00	$ 70,400.00
Misc Crew Expense	$ 10,000.00	$ 12,800.00
Transportation	$ 40,000.00	$ 51,200.00
	Labor Totals	**$ 7,558,400.00**
Maintenance		
M&R	$ 550,000.00	$ 704,000.00
SS&E	$ 100,000.00	$ 128,000.00
Misc Operating Expense	$ 125,000.00	$ 160,000.00
Edible Stores	$ 138,700.00	$ 177,536.00
Chemicals	$ 10,000.00	$ 12,800.00
Lubricating Oil	$ 50,000.00	$ 64,000.00
	Operating Sub Total ex labor	**$ 1,246,336.00**

Drydocking		
SSH Drydocking	$ 300,000.00	$ 384,000.00
Intermediate DD/UWILD	$ 30,000.00	$ 38,400.00
DD/Overhaul total		**$ 422,400.00**
Insurance Costs		
P&I	$ 530,000.00	$ 678,400.00
Supplemental P&I	$ 180,000.00	$ 230,400.00
P&I Deductible	$ 590,000.00	$ 755,200.00
Hull Insurance Premium	$ 500,000.00	$ 640,000.00
Hull Deductible	$ 250,000.00	$ 320,000.00
VSL Guarantee Premium	$ 50,000.00	$ 64,000.00
	Insurance Totals	**$ 2,688,000**

Total Annual Operating Expenses $ 21,342,336

		EHP Fuel mt/h	$y = 19.015x^2 - 246.76x + 923.93$ $y =$ $0.0067x^2 - 0.0866x + 0.324$		
	PE total (kW)	**PP total (kW)**	**Speed (kt)**	**PE total (kW)**	[mt/hr]
8 trips/day	60.0	120.1	5.000	60.0	0.021063602
	101.0	202.0	6.000	101.0	0.035435319
	156.4	312.9	7.000	156.4	0.054893082
	228.2	456.4	8.000	228.2	0.08007099
	318.1	636.3	9.000	318.1	0.111628359
	428.5	857.0	10.000	428.5	0.150342211
	562.1	1124.2	11.000	562.1	0.197220371
	722.8	1445.6	12.000	722.8	0.253610034
	915.7	1831.3	13.000	915.7	0.321282288
	1146.7	2293.4	14.000	1146.7	0.402343495
1 week	1424.6	2849.2	15.000	1424.6	0.499865143
2 weeks	1762.5	3525.0	16.000	1762.5	0.618425473
	2163.8	4327.7	17.000	2163.8	0.759243853
	2616.6	5233.1	18.000	2616.6	0.918090005
	3120.1	6240.2	19.000	3120.1	1.094772276
	3705.8	7411.6	20.000	3705.0	1.3

hours/trip

Bunker

trips/1500 hrs 1.13

days 1659.292035 days 1327.433628

days 1106.19469 days

Speed (kt)	Fv	Rbare (N)
5.000	0.203	23338.3
6.000	0.244	32718.4
7.000	0.284	43443.6
8.000	0.325	55448.7
9.000	0.366	68712.9
10.000	0.406	83288.9
11.000	0.447	99326.6
12.000	0.487	117082.4
13.000	0.528	136914.6
14.000	0.569	159211.8
15.000	0.609	184615.4
16.000	0.650	214128.2
17.000	0.690	247422.2
18.000	0.731	282565.5
19.000	0.772	319210.1
20.000	0.812	360173.2

Total Trips/bunker

67.59840498 1527.723953

		Bunker period fuel	Oil Change Interval
	4trips/day	16.89960124	331.8584071
	6trips/day	#DIV/0!	221.2389381
2850	8trips/day	8.449800622	165.9292035

days 829.6460177 d

4. Income Projections

Estimated Gross Income Based on Average Rates, Trip Length and % Capacity

miles/ trip	hours/trip	max pass	max cars	Trips/ day	Days/yr
22.6	1.25	650	100	6	350

	Passenger Rate $/NM	Lane Meter Rate/NM	profit multiplier		
Actual	$ 0.97	$ 2.26	2	interest rate	8%
RFR Rates	$ 0.83	$ 0.62			

Current Black Ball ferry Rates

Passenger $/NM	L-m $/NM	average pass $/hour
0.973	2.257	$ 17.60

average car$/hou	Actual Pass/yr
$ 40.80	400000

rate 8%

Actual Rates	% capacity	income miles/ trip	income hours/trip	Annual Gross Income	Net Income	payoff [yrs]	pass/yr	
100%	**100%**	$ 39,800.00	$ 19,400.00	$ 62,160,000.00	$ 50,065,084.07	0.713184549	1365000	
85%	85%	$ 33,830.00	$ 16,490.00	$ 52,836,000.00	$ 40,741,084.07	0.882058992	1160250	
75%	75%	$ 29,850.00	$ 14,550.00	$ 46,620,000.00	$ 34,525,084.07	1.047429807	1023750	
65%	65%	$ 25,870.00	$ 12,610.00	$ 40,404,000.00	$ 28,309,084.07	1.289179563	887250	
60%	60%	$ 23,880.00	$ 11,640.00	$ 37,296,000.00	$ 25,201,084.07	1.45741069	819000	
55%	55%	$ 21,890.00	$ 10,670.00	$ 34,188,000.00	$ 22,093,084.07	1.676207858	750750	
50%	50%	$ 19,900.00	$ 9,700.00	$ 31,080,000.00	$ 18,985,084.07	1.972453143	682500	
45%	45%	$ 17,910.00	$ 8,730.00	$ 27,972,000.00	$ 15,877,084.07	2.396252707	614250	
40%	40%	$ 15,920.00	$ 7,760.00	$ 24,864,000.00	$ 12,769,084.07	3.053071326	546000	
30%	30%	$ 11,940.00	$ 5,820.00	$ 18,648,000.00	$ 6,553,084.07	6.812649301	409500	actual utilization
25%	25%	$ 9,950.00	$ 4,850.00	$ 15,540,000.00	$ 3,445,084.07	19.44834134	341250	
20%	20%	$ 7,960.00	$ 3,880.00	$ 12,432,000.00	$ 337,084.07	#NUM!	273000	
15%	15%	$ 5,970.00	$ 2,910.00	$ 9,324,000.00	$ (2,770,915.93)	-8.776964674	204750	
10%	10%	$ 3,980.00	$ 1,940.00	$ 6,216,000.00	$ (5,878,915.93)	-4.871128556	136500	
5%	5%	$ 1,990.00	$ 970.00	$ 3,108,000.00	$ (8,986,915.93)	-3.384356949	68250	

RFR Rates * Profit	% capacity	income miles/ trip	income hours/trip	Annual Gross Income	Net Income	payoff [yrs]	pass/yr	
full ferry	**100%**	$ 38,396.56	$ 38,800.00	$ 81,056,386.43	$ 68,961,470.50	0.513836677	1365000	
85%	85%	$ 32,637.07	$ 32,980.00	$ 68,897,928.46	$ 56,803,012.53	0.626512142	1160250	
75%	75%	$ 28,797.42	$ 29,100.00	$ 60,792,289.82	$ 48,697,373.89	0.733791226	1023750	
65%	65%	$ 24,957.76	$ 25,220.00	$ 52,686,651.18	$ 40,591,735.25	0.885417467	887250	
60%	60%	$ 23,037.94	$ 23,280.00	$ 48,633,831.86	$ 36,538,915.93	0.987449069	819000	
55%	55%	$ 21,118.11	$ 21,340.00	$ 44,581,012.53	$ 32,486,096.61	1.116075096	750750	
50%	50%	$ 19,198.28	$ 19,400.00	$ 40,528,193.21	$ 28,433,277.29	1.283261111	682500	
45%	45%	$ 17,278.45	$ 17,460.00	$ 36,475,373.89	$ 24,380,457.96	1.50942683	614250	
40%	40%	$ 15,358.62	$ 15,520.00	$ 32,422,554.57	$ 20,327,638.64	1.832529363	546000	
30%	30%	$ 11,518.97	$ 11,640.00	$ 24,316,915.93	$ 12,222,000.00	3.208044745	409500	actual utilization
25%	25%	$ 9,599.14	$ 9,700.00	$ 20,264,096.61	$ 8,169,180.68	5.151662172	341250	
20%	20%	$ 7,679.31	$ 7,760.00	$ 16,211,277.29	$ 4,116,361.36	13.62523557	273000	
10%	10%	$ 3,839.66	$ 3,880.00	$ 8,105,638.64	$ (3,989,277.29)	-6.665515083	136500	
5%	5%	$ 1,919.83	$ 1,940.00	$ 4,052,819.32	$ (8,042,096.61)	-3.729769677	68250	

They represent averages of the ferries examined and are NOT the required rates for our ferry design.

Trip Distance	22.6 NM
Avg Passenger Cost	$22.00
Lane Meter Cost	$51.00

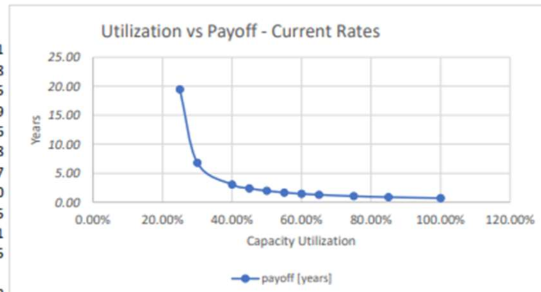
cash flow diagram

year	income-expediture	total profit
1	-$42,455,860	-$42,455,860

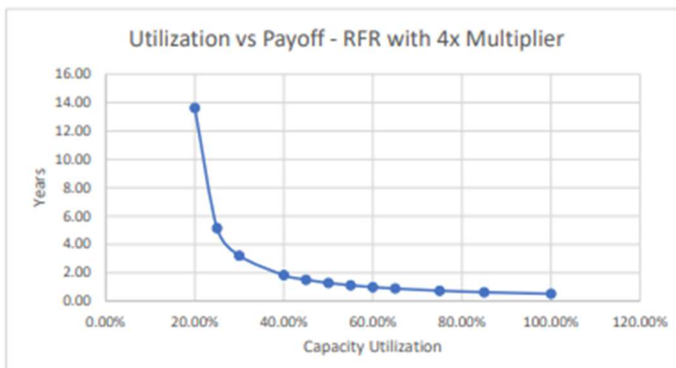
Required Pass Rate	$18.75		
Required LM Rate	$14.02		
	85.00%	50%	30%
Gross Income/yr	$ 52,836,000.00	$ 31,080,000.00	$ 18,985,084.07
Opex/ yr	$12,094,915.93	$ 12,094,915.93	$ 12,094,915.93
Profit/yr	$40,741,084.07	$ 18,985,084.07	$ 6,890,168.14
Payoff Capex	0.88	1.78	0.00

2	$6,553,084	-$35,902,776
3	$6,553,084	-$29,349,692
4	$6,553,084	-$22,796,608
5	$6,553,084	-$16,243,523
6	$6,553,084	-$9,690,439
7	$6,553,084	-$3,137,355
8	$6,553,084	$3,415,729
9	$6,553,084	$9,968,813
10	$6,553,084	$16,521,897
11	$6,553,084	$23,074,981
12	$6,553,084	$29,628,065
13	$6,553,084	$36,181,149
14	$6,553,084	$42,734,233
15	$6,553,084	$49,287,317
16	$6,553,084	$55,840,401
17	$6,553,084	$62,393,485
18	$6,553,084	$68,946,569
19	$6,553,084	$75,499,654
20	$6,553,084	$82,052,738
21	$6,553,084	$88,605,822
22	$6,553,084	$95,158,906
23	$6,553,084	$101,711,990
24	$6,553,084	$108,265,074
25	$6,553,084	$114,818,158

% capacity	payoff [years]	
100.00%		0.71
85.00%		0.88
75.00%		1.05
65.00%		1.29
60.00%		1.46
55.00%		1.68
50.00%		1.97
45.00%		2.40
40.00%		3.05
30.00%		6.81
25.00%		19.45
20.00%	#NUM!	
15.00%		-8.78
10.00%		-4.87



% capacity	payoff [years]
100.00%	0.51
85.00%	0.63
75.00%	0.73
65.00%	0.89
60.00%	0.99
55.00%	1.12
50.00%	1.28
45.00%	1.51
40.00%	1.83
30.00%	3.21
25.00%	5.15
20.00%	13.63
10.00%	-6.67



Appendix D: Structural Calculations

1. Design Pressures

Design Pressures

IAW SWATH Requirements, Wave Impact Slamming Pressures 3-2 Section 2.3

Design Pressures				
		from	to	
Design Area Medium	Adm	0.0324	29.2896	[m^2]
Design Area Large	Adl	29.2896	129.6	[m^2]
Reference Area	Ar	129.6		[m^2]
Breadth	B	27		[m]

Slamming Pressures			
	n	6.9	
Long Impact Load Factor	Lp	see table	[m]
Fore & Aft Length of Box	Lb	80	[m]
Frame Spacing	s	1.25	[m]

Longitudinal Impact Load Distribution Factors				
from SWATH 3-2 Figure 1				
	Bow	Bow-20%	20%-30%	30%-stern
Wet Deck	1	1	0.73	0.73
Inboard Haunch	0.7	0.7	0.59	0.59
Outboard Haunch	0.59	0.59	0.59	0.59
Inboard Strut	0.47	0.47	0.4	0.4
Outboard Strut	0.4	0.4	0.4	0.4

Maximum Slamming Pressure (P_{max}) [KN/m^2]				
	Bow	Bow-20%	20%-30%	30%-stern
Wet Deck	783.77	783.77	572.15	572.15
Inboard Haunch	548.64	548.64	462.42	462.42
Outboard Haunch	462.42	462.42	462.42	462.42
Inboard Strut	368.37	368.37	313.51	313.51
Outboard Strut	313.51	313.51	313.51	313.51

Panel Size [m^2]				
	Width	Bow-20%	20%-30%	30%-stern
Wet Deck	6.23	7.79	7.79	7.79
Inboard Haunch	1.75	2.19	2.19	2.19
Outboard Haunch	1.19	1.49	1.49	1.49

Kdl (applies to all panels)					
	Kd	Kn	20%-30%	30%-stern	Ad/Ar
Wet Deck	0.31	0.42			0.048055556
Inboard Haunch	0.36	0.42			0.013510802
Outboard Haunch	0.39	0.42			0.009166667

Design Pressures (P_{des}) [KN/m^2]					
	Bow	Bow-20%	20%-30%	30%-stern	
Wet Deck	566.61	566.61	413.62	413.62	
Inboard Haunch	471.48	471.48	397.39	397.39	
Outboard Haunch	426.76	426.76	426.76	426.76	

2. Plating Thicknesses

Deck Plating

IAW SWATH Requirements 3-2 Section 3 Operational Loads

Material Factor		
Al alloy	m	
5083	1.23	
5086	1.46	
5454	**1.62**	**used in design**
5456	1.23	
6061-T-6	1.75	

Platform Decks			
material factor	m	1	mild steel
deck beam spacing	s_b	750	mm
	k	1	ar > 2
between deck height	h roro	3	
	h main	3	
	h bridge	3	
	h mid mach	3	
	h tank top	1.5	
	c	254	
	a	1.5	mm

Nominal Deck Loads from 3-2 Section 3.1		
Crew Spaces	4510	N/m^2
Work Areas	9020	N/m^3
Storage Areas	13000	N/m^4

Roro deck				
Rules for Building and Classing Marine Vessels Part 5C Specific Vessel Types; 5C-10-2 Section 11.3.2				
	k	8.05		
	n	1		
	C	1.1		
static wheel load	W	**16.35**	KN	30,000 kg truck 18 wheels
	W	4.56	KN	1860 kg car 4 wheels
wheel imprint long	a	50		
wheel imprint trans	b	300		
length of plate panel	l	2250	mm	
longitudinal spacing	s	750	mm	
	l/s	3		
	K	0.185187378		
Roro Deck Plate thick	t roro	6.32	mm	comp Roro decks 12 mm

Deck Plate Thickness					
IAW SWATH Requirements 3-5 Section 2.2 Deck Plating page 52					
		Steel	Aluminum		
Roro by load	t roro	6.32		mm	roro deck loading procedures
Roro by SWATH rules	t roro	6.61		mm	weather deck thickness- SWATH rules
main deck	t main	5.85	9.48	mm	encl. platform decks: accom spaces- SWATH rules
bridge deck open	t bridge	6.61	10.72	mm	weather deck thickness- SWATH rules
bridge deck enclosed	t bridge	6.61	10.72	mm	encl. platform deck -SWATH rules
mid machinery deck	t mid mach	6.61		mm	encl. platform deck- SWATH rules
Tank Top strength deck	t tank top	5.12		mm	encl. platform deck- SWATH rules
hgs		4.29		m	
weather deck		7.62		mm	

Longitudinal Compressive Stress				
	E	2.06E-05	N/mm^2	
Net Plate Thickness	t_b	7.92		after deductions in 3-2-A4/3.3.3 Table 1A or 1B
panel short side	s	750	mm	
panel long side	l	2250	mm	
	c	1.3		plating stiffened with floors or deep girders
stress ratio				
Stillwater bending mom	M_{sw}		kN-m	
wave bending moment	M_w	2.46E+11	kN-m	
Moment of inertia Hull girder	I_n	33922	cm^4	
neutral axis to considered pt	y	0.185	m	
	Q	1		ordinary steel
	C_s	1.00E+05		

3. Shell Framing

Shell Framing

IAW SWATH Requirements 3-5 Section 2.5.2 page 57

Transverse Frames					
IAW SWATH Requirements 3-5 Section 2.5.2 page 57					
	C	877			
vertical distance-middle of l to deck at side					at forward perp. Middle of l to bulklhead deck
					aft of amidships-middle of l to 2/3 distance to bulkhd deck
					btw fwd perp and amidhsips h interpolated between above
		2.1			not less than 2.1 m
transverse frame spacing	s	1.25	m		
span between heels	l	8	m	dbl bottom	
			m	mid machine	
			m	roro	
design stress clear of tanks	sigma b	250	N/mm^2		
yield stress for steel	sigma y	500	N/mm^2		
Required Sectional Modulus for Frames	**SM**	**589.34**	**cm^3**		

Design Section Modulus		
length of shell plate	225	mm
shell plate thickness	0.8	mm
Top Flange width	10	cm
Top Flange Thickness	0.8	mm
Web Height	35	cm
Web Thickness	0.8	mm
Total Depth	36.6	cm
Area	216	
Cy	32.5537	
Ix	19629.39	
Design Section Modulus	**602.98**	**cm^3**

4. Web Frames & Stringers

Web Frames and Side Stringers

Web Frames & Side Stringers

	C	877		
middle of l to deck at side	h bl-tt	6.5	m	
	h tt-mm	4.5	m	
	h mm-rr	1.5	m	
	h rr-mn	2	m	
	h mn-br	3.5	m	
frame spacing	s	2.25	m	
	l bl-tt	0.5	m	
	l tt-mm	1.5	m	
	l mm-rr	1.5	m	
	l rr-mn	2	m	
	l mn-br	1.5	m	
design stress clear tanks	sigma b	200	N/mm^2	
steel yield stress	sigma y	400	N/mm^2	
design stress	sigma d	181.5	N/mm^2	aluminum
Material Yield Stress	sigma y	330	N/mm^2	aluminum

	C	877	
supported breadth	b	0.75	m
length	l	1.2	m
mid l to deck at side	h bl-tt	6.5	m
	h tt-mm	4.5	m
	h mm-rr	1.5	m
	h rr-mn	2	m
	h mn-br	3.5	m
design stress clr tks	sigma b	200	N/mm^2

Transverse Frames Required SM				
Baseline to tank top	16.03	cm^3	0.98	in^3
tank top to mid mach	99.90	cm^3	6.10	in^3
mid mach to roro	33.30	cm^3	2.03	in^3
roro to main	78.93	cm^3	4.82	in^3
main to bridge	77.70	cm^3	4.74	in^3
Transverse Frame Spacing At 1.2 m - Stiffener Spacing 35 cm				
supported breadth	b	0.35	m	

Required Bulb Plate Size

	Section Modulus [c	Mass [kg/m]	Delta SM
100 x 7	14.5	7.13	0.13
100 x 6	12.7	7.33	2.75
60 x 5	6.91	4.42	3.59
60 x 5	6.91	4.42	2.49
80 x 6	8.15	5.07	0.41

Stringer Required Section Modulus SM - Steel

Baseline to tank top	14.37	cm^3	0.88	in^3
tank top to mid mach	9.95	cm^3	0.61	in^3
mid mach to roro	3.32	cm^3	0.20	in^3
roro to main	4.42	cm^3	0.27	in^3
main to bridge	7.74	cm^3	0.47	in^3

Required Bulb Plate 30%-stern

length of shell plate	750
shell plate thickness	0.6
Top Flange width	5
Top Flange Thickness	0.6
Web Height	5
Web Thickness	0.6
Total Depth	6.2
Area	456
Cy	5.84
Ix	136.02
Section Modulus	23.27

Transverse Frame Spacing At 1.2 m- Stiffener Spacing 75 cm - Final Design Spacing

						Required Bulb Plate Size	Section Modulus	Mass	Delta SM	
	Side Stringer Required Section Modulus SM						cm3	kg/m		
Baseline to tank top	**30.78**	**cm^3**	**1.88**	**in^3**	**33.92**	**140 x 8**	**32.50**	**25.5**	**1.72**	steel
tank top to mid mach	**21.31**	**cm^3**	**1.30**	**in^3**	**23.48**	**120 x 8**	**23.60**	**9.57**	**2.29**	steel
mid mach to roro	**7.10**	**cm^3**	**0.43**	**in^3**	**7.83**	**80 x 6**	**8.15**	**5.07**	**1.05**	steel
roro to main	**9.47**	**cm^3**	**0.58**	**in^3**	**10.44**	**100 x 6**	**12.70**	**7.33**	**2.26**	
main to bridge	**16.58**	**cm^3**	**1.01**	**in^3**	**18.26**	**120 x 6**	**18.50**	**7.6**	**0.24**	

Alternate Transverse Frame Spacing At 5 m- Stiffener Spacing 75 cm

length	1.25	m				Required Bulb Plate Size	Section Modulus	Mass	Delta SM
Web Frames and Side Stringer Required Section Modulus SM							cm3	kg/m	
Baseline to tank top	33.40	cm^3	2.04	in^3		220 x 10	113	25.5	79.60
tank top to mid mach	23.12	cm^3	1.41	in^3		180 x 11.5	76.8	19.8	53.68
mid mach to roro	7.71	cm^3	0.47	in^3		140 x 6.5	27.3	9.58	19.59
roro to main	10.28	cm^3	0.63	in^3		140 x 10	39.8	13.5	29.52
main to bridge	17.99	cm^3	1.10	in^3		180 x 9	61.8	16.9	43.81

5. Deck Beams & Girders

Deck Beams, Transverses, Girder

IAW SWATH Requirements 3-5 Section 2.3 page 54

The minimum requirements for stiffening and framing members on the Strength Deck, and on any internal Platform Decks, related to local load

Conditions				
	C	584.7		
height tank top	h tank top	3	m	
height mid machine	h mid mach	3	m	
height roro	h roro	4	m	
height main	h main	3	m	
height bridge	h bridge	3	m	
spacing of beams	s	0.75	m	
beam span tank top	l tt	7.043	m	
beam span mid mach	l mm	7.043	m	
beam span roro	l roro	7.043	m	
beam span passenger	l main	5.81	m	
beam span bridge	l bridge	5.81	m	
design stress	sigma d	220	N/mm^2	steel
Material Yield Stress	sigma y	400	N/mm^2	steel
design stress	sigma d	181.5	N/mm^2	aluminum
Material Yield Stress	sigma y	330	N/mm^2	aluminum

This design calls for transverse frames every 2.25 meters and a girder to split each long span with support from a bulkhead or stanchion every other frame.

Bulb Plates Required			
	SM	kg/m	delta SM
80 x 7	9.24	5.73	-287.385
100 x 7	14.5	7.13	-282.125
120 x 7	21	8.58	-374.501

Beam Required Section Moduli								
		Required		Required		Design	delta SM	
tank top	SM tt	296.6254	cm^3	18.101	in^3	306.337	9.712	cm^3
mid machine	SM mm	296.6254	cm^3	18.101	in^3	306.337	9.712	cm^3
roro	SM roro	395.5005	cm^3	24.135	in^3	430.057	34.556	cm^3
passenger	SM main	244.6759	cm^3	14.931	in^3	269.665	24.989	cm^3
bridge	SM bridge	244.6759	cm^3	14.931	in^3	269.665	24.989	cm^3

Beam Designs

Tank Top		
Steel		
length of deck plate	75	cm
deck plate thickness	0.06	cm
Top Flange width	20	cm
Top Flange Thickness	0.06	cm
Web Height	28	cm
Web Thickness	0.08	cm
Total Depth	28.12	cm
Area	7.94	cm^3
Cy	19.891	
Ix	6093.390	
Section Modulus	306.337	cm^3

Mid Machine		
Steel		
length of deck plate	75	cm
deck plate thickness	0.06	cm
Top Flange width	20	cm
Top Flange Thickness	0.06	cm
Web Height	28	cm
Web Thickness	0.08	cm
Total Depth	28.12	cm
Area	7.94	cm^3
Cy	19.891	
Ix	6093.390	
Section Modulus	306.337	cm^3

Roro		
Steel		
length of deck plate	75	cm
deck plate thickness	0.06	cm
Top Flange width	22	cm
Top Flange Thickness	0.06	cm
Web Height	30	cm
Web Thickness	0.08	cm
Total Depth	30.12	cm
Area	8.22	cm^3
Cy	20.875	
Ix	8977.226	
Section Modulus	430.057	cm^3

Passenger/Bridge		
Aluminum		
length of deck plate	75	cm
deck plate thickness	0.06	cm
Top Flange width	22	cm
Top Flange Thickness	0.06	cm
Web Height	26	cm
Web Thickness	0.08	cm
Total Depth	26.12	cm
Area	7.9	cm^3
Cy	18.305	
Ix	4936.221	
Section Modulus	269.665	cm^3

Deck Girder Conditions			
	C	584.7	
height tank top	h tank top	3	m
height mid machine	h mid mach	3	m
height roro	h roro	4	m
height main	h main	3	m
height bridge	h bridge	3	m
supported deck breadth	m tt	4.2	m
	m mm	4.2	m
	m roro	4.8	m
	m main	9	m
	m bridge	9	m
Length btwn supports	l	4.8	m
design stress	sigma d	220	N/mm^2

Deck Girder Designs			
	TT deck	MM deck	RoRo
length of deck plate	120	120	120
shell plate thickness	0.8	0.8	0.8
Top Flange width	10	25	25
Top Flange Thickness	0.8	0.6	0.8
Web Height	40	30	35
Web Thickness	0.8	1	0.8
Total Depth	41.6	31.4	36.6
Area	136	141	144
Cy	34	24.457	27.747
Ix	28132.49	19820.761	33411.670
Section Modulus	827.43	810.418	1204.145

Deck Girder SM						delta SM
tank top	SM tt	771.55	cm^3	47.083	in^3	55.877
mid mach	SM mm	771.55	cm^3	47.083	in^3	38.869
roro	SM roro	1175.69	cm^3	71.745	in^3	28.451
main	SM main	1653.32	cm^3	100.891	in^3	
bridge	SM bridge	1653.32	cm^3	100.891	in^3	

Girder Proportions Required

Steel		
Depth Clear of Tanks	279.8	mm
Depth in way of tanks	398.4	mm
web thickness no tanks	4.00	mm
web thick with tanks	4.00	mm

Aluminum		
Depth Clear of Tanks	322.6	mm
Depth in way of tanks	459.8	mm
web thickness no tanks	6.51	mm
web thick with tanks	6.51	mm

6. Shell Plating

Shell Plating

IAW SWATH Requirements 3-5 Section 2.6 page 59

The plating, beams and supporting structures (i.e., girders, floors, side stringers etc.) of the wet deck, haunch and strut external surfaces are to comply with the following requirements for wave impact.

Conditions					
	u	1	for steel		
	Uw	235	N/mm^2		
Deck Beam Spacing	s	2.5	m		
	k	1			
Equivalent Head in SW	h				
	Bow	Bow-20%	20%-30%	30%-stern	
Wet Deck	56.38	56.38	41.16	41.16	
Inboard Haunch	46.91	46.91	39.54	39.54	
Outboard Haunch	42.46	42.46	42.46	42.46	
Inboard Strut	N/A	N/A	N/A	N/A	
Outboard Strut	N/A	N/A	N/A	N/A	
	n	10.05	KN/m^2		
ordinary strength steel	J	3.04			

Design Pressures (P_{des}) [kN/m^2]				
	Bow	Bow-20%	20%-30%	30%-stern
Wet Deck	566.61	566.61	413.62	413.62
Inboard Haunch	471.48	471.48	397.39	397.39
Outboard Haunch	426.76	426.76	426.76	426.76
Inboard Strut	N/A	N/A	N/A	N/A
Outboard Strut	N/A	N/A	N/A	N/A

Required Shell Plate Thickness [mm]				
	Bow	Bow-20%	20%-30%	30%-stern
Wet Deck	6.17	6.17	5.28	5.28
Inboard Haunch	5.63	5.63	5.17	5.17
Outboard Haunch	5.36	5.36	5.36	5.36
Inboard Strut	N/A	N/A	N/A	N/A
Outboard Strut	N/A	N/A	N/A	N/A
Bottom Plating +1.5mm (Drydock)	7.67	7.67	6.78	6.78

Design Shell Plate Thickness [mm]				
	Bow	Bow-20%	20%-30%	30%-stern
Wet Deck	7.00	7.00	6.00	6.00
Inboard Haunch	6.00	6.00	6.00	6.00
Outboard Haunch	6.00	6.00	6.00	6.00
Inboard Strut	N/A	N/A	N/A	N/A
Outboard Strut	N/A	N/A	N/A	N/A
Bottom Plating +1.5mm (Drydock)	8.00	8.00	7.00	7.00

Watertight Tank and Bulkheads

Watertight and Tank Bulkheads
IAW SWATH Requirements 3-5 Section 3.2 page 63

Conditions				
	m	1		Steel
stiffener spacing	s	750	mm	
	k	1		AR const.
	q	0.5875		Steel
Steel Yield Strength	Y	400	N/mm^2	
collision and tank blkhds	C	254		
other watertight blkhds	C	290		
Collision & watertight blkhds	a	1.5	mm	
Tank bulkheads	a	2.5	mm	
effective pressure head				
double bottom C&W	h	6	m	
3rd Deck C&W	h	4	m	
2nd Deck C&W	h	3	m	
double bottom tank	h	6.5	m	
3rd Deck Tank	h	4.67	m	

Tank Bulkhead Plate Thickness Requirements			
double bottom C&W	t	5.51	mm
3rd Deck C&W	t	4.50	mm
2nd Deck C&W	t	3.90	mm
double bottom tank	t	5.71	mm
3rd Deck Tank	t	4.84	mm

Stiffeners and Beams			
	C	877	
stiffeners spacing	s	0.75	m
span	l	2.25	m
design stress	sigma b	180	N/mm^2
yield stress	sigma y	400	N/mm^2

Watertight Bulkheads			
dbl btm	h	6.5	m
3rd deck	h	4.82	m
2nd deck	h	2.42	m

Tank Bulkheads			
dbl btm	h	4.167	m
3rd deck	h	2.167	m

Required Stiffener and Beam SM

Collison & Watertight					
dbl btm	**SM**	**120.24**	cm^3	**7.34**	in^3
3rd Deck	**SM**	**89.17**	cm^4	**5.44**	in^4
2nd Deck	**SM**	**44.77**	cm^4	**2.73**	in^4

Tank Bulkheads					
dbl btm	**SM**	**77.08**	cm^3	**4.70**	in^3
3rd Deck	**SM**	**40.08**	cm^4	**2.45**	in^3

Required Bulb Plate					
	SM [cm^3]	**Mass [kg/m]**	**Depth**	**Web t**	**Delta SM**
220 x 12	**122**	27.2	220	12	1.76
200 x 11	**92.3**	22.6	200	11	3.13
160 x 9	**47.9**	13.97	160	9	3.13
200 x 9	**77.7**	18.57			0.62
160 x 8	**43.9**	12.72			3.82

Girders and Webs Conditions			
	C	877	
sum of half lengths of stfnrs			
double bottom	b	6	m
3rd Deck	b	10	m
2nd Deck	b	12	m
length between supports	l	4	m
design bending stress	sigma a	180	N/mm^2

Effective Pressure Head

Watertight Bulkheads			
dbl btm	h	6.5	m
3rd Deck	h	4.82	m
2nd Deck	h	2.42	m

Tank Bulkheads			
dbl btm	h	4.167	m
3rd Deck	h	2.167	m

Required Section Modulus for Girders and Webs					
Collison & Watertight					
dbl btm	**SM**	**3040**	**cm^3**	**185.53**	**in^3**
3rd Deck	**SM**	**3757**	**cm^3**	**229.29**	**in^3**
2nd Deck	**SM**	**2264**	**cm^3**	**138.15**	**in^3**

Tank Bulkheads					
dbl btm	**SM**	**1949**	**cm^3**	**118.93**	**in^3**
3rd Deck	**SM**	**1689**	**cm^3**	**103.07**	**in^3**

Minimum Proportions of Stiffening and Framing Members

IAW SWATH Requirements 3-5 Section 3.3 page 66

length of unsupported span 2 m

Watertight Bulkheads		
Steel		
Minimum Depth	166.66	mm
Minimum Web Thickness	5.00	mm
Aluminum		
Minimum Depth	192	mm
Minimum Web Thickness	7.38	mm

Tank Bulkheads		
Steel		
Minimum Depth	290	mm
Minimum Web Thickness	8.7	mm
Aluminum		
Minimum Depth	334	mm
Minimum Web Thickness	9.51	mm

7. Ground Tackle

Anchoring and Mooring Equipment
IAW SWATH Requirements 2-2 Section 7
IAW Rules for Building and Classing High Speed Craft 3-5-1 Table 1A

Conditions			
	k	1	
	m	2	
	n	0.1	
Avg B of Strut/haunch	S	10	m
d from load line to deck	a	4	m
Breadth	B'	27	m
height roro deck	h1	4	m
height passenger deck	h2	3	m
height bridge deck	h3	3	m
Profile Area	A	1530	m^2
Equipment Number	EN	1109.22	

Anchor			
Numeral	Number	Weight	
U25	2	3540	kg

Chain					
Length	522.5	m	Link Dia	60	mm
Shot Length	27.5	m	Weight/shot	2220	kg
Num shots	19	ordinary strength steel			
Weight of Chains	42180	kg	Per chain	21090	kg
Total Weight	49260	kg			
Volume	103.455	m^3			

Germanischer Lloyd formula from SOTRA anchor and Chain
https://www.sotra.net/?produkter=recomended-volume-of-chain-locker

Totals				
Total Weight	24630	kg		
Max Windlass Load	73890	kg	73.89	mt

Appendix E: Areas and Volumes Summary

Tank / Space	Area [m^2]	Volume [m^3]
Vehicle (Main)	1647.118	4941.353
Vehicle (Upper)	816.075	2448.225
Passenger (Forward Upper)	281.389	844.166
Passenger (Middle Upper)	202.187	606.560
Passenger (Aft Upper Starboard)	119.892	359.676
Passenger (Aft Upper Port)	119.892	359.676
Passenger (Dining)	93.747	281.240
Passenger (Bridge)	133.920	401.758
Passenger (Bridge Bench Port)	224.573	673.720
Passenger (Bridge Bench Starboard)	224.573	673.720
Machinery (Forward Main Port)	50.507	151.521
Machinery (Forward Main Starboard)	50.507	151.521
Machinery (Aft Main Port)	62.494	187.482
Machinery (Aft Main Starboard)	62.494	187.482
Steering Gear Room (Port)	109.308	327.924
Steering Gear Room (Starboard)	109.308	327.924
Mid Machinery 4 (Port)	108.203	324.609
Mid Machinery 4 (Starboard)	108.203	324.609
Mid Machinery 3 (Port)	106.619	319.856
Mid Machinery 3 (Starboard)	106.619	319.856
Mid Machinery 2 (Port)	138.826	416.478
Mid Machinery 2 (Starboard)	138.826	416.478
Mid Machinery 1 (Port)	91.816	275.448
Mid Machinery 1 (Starboard)	91.816	275.448
Auxiliary Machinery (Port)	54.272	184.739
Auxiliary Machinery (Starboard)	54.272	184.739
Aft Peak Tank (Port)	109.308	225.686
Aft Peak Tank (Starboard)	109.308	225.686
Engine Room 2 (Port)	72.568	217.704
Engine Room 2 (Starboard)	72.568	217.704
Engine Room 1 (Aft Port)	41.075	123.225

Engine Room 1 (Aft Starboard)	41.075	123.225
Engine Room 1 (Forward Port)	40.865	122.596
Engine Room 1 (Forward Starboard)	40.865	122.596
Tank Top 2 (Port)	104.437	313.311
Tank Top 2 (Starboard)	104.437	313.311
Tank Top 1 (Port)	67.379	202.136
Tank Top 1 (Starboard)	67.379	202.136
Bow Thruster Room (Port)	48.202	168.707
Bow Thruster Room (Starboard)	48.202	168.707
Forepeak (Port)	12.230	36.690
Forepeak (Starboard)	12.230	36.690
Saltwater Ballast Tank 1 (Port)	67.379	78.483
Saltwater Ballast Tank 1 (Starboard)	67.379	78.483
Saltwater Ballast Tank 2 (Port)	104.437	140.222
Saltwater Ballast Tank 2 (Starboard)	104.437	140.222
Saltwater Ballast Tank 3 (Port)	81.941	109.532
Saltwater Ballast Tank 3 (Starboard)	81.941	109.532
Saltwater Ballast Tank 4 (Port)	72.569	95.761
Saltwater Ballast Tank 4 (Starboard)	72.569	95.761
Fresh Water Tank (Port)	8.000	8.00
Fresh Water Tank (Starboard)	8.000	8.00
Black Water Tank (Port)	20.1	40.2
Black Water Tank (Starboard)	20.1	40.2
Marine Gas Oil Tank (Port)	25.125	50.25
Marine Gas Oil Tank (Starboard)	25.125	50.25
Marine Gas Oil Settling Tank (Port)	2.711	5.421
Marine Gas Oil Settling Tank (Starboard)	2.711	5.421
Marine Gas Oil Service Tank (Port)	2.711	5.421
Marine Gas Oil Service Tank (Starboard)	2.711	5.421
Lube Oil Tank (Port)	0.825	1.65
Lube Oil Tank (Starboard)	0.825	1.65
Waste Oil Tank (Port)	0.4125	0.4125
Waste Oil Tank (Starboard)	0.4125	0.4125
Clean Bilge Tank (Forward Port)	1.151	1.15125
Clean Bilge Tank (Forward Starboard)	1.151	1.15125
Clean Bilge Tank (Aft Port)	1.151	1.15125

Clean Bilge Tank (Aft Starboard)	1.151	1.15125
Oily Bilge Tank (Forward Port)	5.660	5.660
Oily Bilge Tank (Forward Starboard)	5.660	5.660
Oily Bilge Tank (Aft Port)	5.660	5.660
Oily Bilge Tank (Aft Starboard)	5.660	5.660

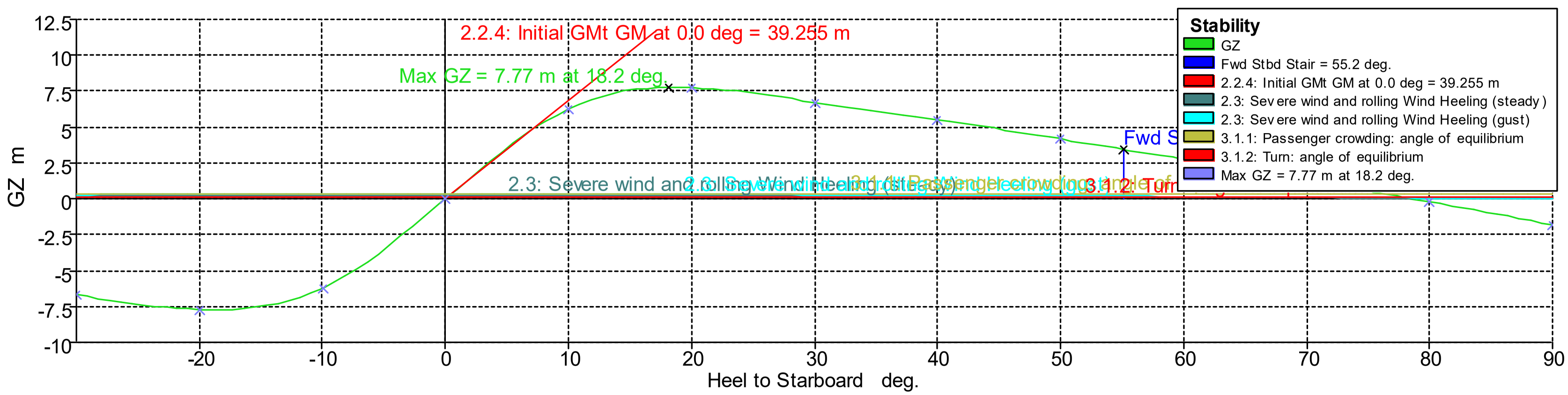
Appendix F: Intact Stability Load Conditions and Results

Stability 24.00.00.722, build: 722
Model file: C:\Users\Howie Waffler\sunymaritime.edu\Super Seniors Ship Design 1 - General\Ship Design 3\ENGR 461_SUPER SENIORS_HULL MODEL-FERRY_CATAMARAN 90m_REV06.2 (High precision, 115 sections, Trimming on, Skin thickness not applied). Long. datum: FP; Vert. datum: Baseline.
Analysis tolerance - ideal(worst case): Disp.%: 0.01000(0.100); Trim%(LCG-TCG): 0.01000(0.100); Heel%(LCG-TCG): 0.01000(0.100)

Loadcase - 0% Cargo, 10% Consumables
Damage Case - Intact
Free to Trim
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)
Fluid analysis method: Use corrected VCG

Ballasting	Item Name	Fluid type	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m	FSM Type
0	Lightship		1	1582.976	1582.976			-42.695	-0.024	7.331	0.000	
0	Subtotal Lightship				1582.976			-42.695	-0.024	7.331	0.000	
0												
0	FPT.P	Sea Water	0%	55.448	0.000	54.095	0.000	-4.853	-6.103	0.025	0.000	Maximum
0	FPT.S	Sea Water	0%	55.448	0.000	54.095	0.000	-4.853	6.103	0.025	0.000	Maximum
0	SWBT1.P	Sea Water	0%	81.859	0.000	79.863	0.000	-25.769	-9.153	0.000	0.000	Maximum
0	SWBT1.S	Sea Water	0%	81.859	0.000	79.863	0.000	-25.769	9.153	0.000	0.000	Maximum
0	SWBT2.P	Sea Water	100%	111.052	111.052	108.343	108.343	-40.742	-9.162	0.837	0.000	Maximum
0	SWBT2.S	Sea Water	100%	111.052	111.052	108.343	108.343	-40.742	9.162	0.837	0.000	Maximum
0	SWBT3.P	Sea Water	50%	86.986	43.493	84.864	42.432	-55.010	-9.064	0.514	251.302	Maximum
0	SWBT3.S	Sea Water	50%	86.986	43.493	84.864	42.432	-55.010	9.064	0.514	251.302	Maximum
0	SWBT4.P	Sea Water	0%	46.929	0.000	45.784	0.000	-62.511	-6.103	0.096	0.000	Maximum
0	SWBT4.S	Sea Water	0%	46.929	0.000	45.784	0.000	-62.511	6.103	0.096	0.000	Maximum
0	APT.P	Sea Water	0%	198.339	0.000	193.501	0.000	-76.499	-6.102	1.353	0.000	Maximum
0	APT.S	Sea Water	0%	198.339	0.000	193.501	0.000	-76.499	6.102	1.353	0.000	Maximum
0	Subtotal Ballast		26.62%	1161.225	309.089	1132.902	301.550	-44.758	0.000	0.746	502.603	
0												
0	MGO 1.P	Diesel	0%	39.900	0.000	47.500	0.000	-29.375	-9.152	1.500	0.000	Maximum
0	MGO 1.S	Diesel	0%	39.900	0.000	47.500	0.000	-29.375	9.152	1.500	0.000	Maximum
0	MGO SETT.P	Diesel	67.87%	3.605	2.447	4.292	2.913	-50.625	-8.372	2.179	0.516	Maximum
0	MGO SETT.S	Diesel	67.87%	3.605	2.447	4.292	2.913	-50.625	8.372	2.179	0.516	Maximum
0	MGO SERV.P	Diesel	98%	2.163	2.120	2.575	2.523	-53.375	-8.372	2.480	0.000	Maximum
0	MGO SERV.S	Diesel	98%	2.163	2.120	2.575	2.523	-53.375	8.372	2.480	0.000	Maximum
0	Subtotal MGO		10%	91.336	9.133	108.733	10.872	-51.902	0.000	2.319	1.033	
0												
0	FWT.P	Fresh Water	10%	7.599	0.760	7.599	0.760	-35.625	-9.143	1.550	3.033	Maximum

Ballasting	Item Name	Fluid type	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m	FSM Type
0	FWT.S	Fresh Water	10%	7.599	0.760	7.599	0.760	-35.625	9.143	1.550	3.033	Maximum
0	LUBE OIL.P	Lube Oil	10%	1.311	0.131	1.425	0.142	-50.625	-10.852	1.600	0.021	Maximum
0	LUBE OIL.S	Lube Oil	10%	1.311	0.131	1.425	0.142	-50.625	10.852	1.600	0.021	Maximum
0	Subtotal Consumables		10%	17.820	1.782	18.048	1.805	-37.832	0.000	1.557	6.107	
0												
0	BWT.P	Custom 3	95%	38.594	36.664	38.594	36.664	-21.875	-9.125	2.450	17.879	Maximum
0	BWT.S	Custom 3	95%	38.594	36.664	38.594	36.664	-21.875	9.125	2.450	17.879	Maximum
0	WASTE OIL.P	Slops	98%	0.130	0.128	0.143	0.140	-53.875	-10.852	1.990	0.000	Maximum
0	WASTE OIL.S	Slops	98%	0.130	0.128	0.143	0.140	-53.875	10.852	1.990	0.000	Maximum
0	OILY BILGE 1.P	Slops	98%	4.909	4.811	5.377	5.269	-59.625	-9.898	0.990	0.000	Maximum
0	OILY BILGE 1.S	Slops	98%	4.909	4.811	5.377	5.269	-59.625	9.898	0.990	0.000	Maximum
0	CLN BILGE 1.P	Fresh Water	100%	1.094	1.094	1.094	1.094	-59.625	-10.806	1.000	0.000	Maximum
0	CLN BILGE 1.S	Fresh Water	100%	1.094	1.094	1.094	1.094	-59.625	10.806	1.000	0.000	Maximum
0	OILY BILGE 2.P	Slops	98%	4.911	4.813	5.379	5.272	-66.375	-8.389	0.990	0.000	Maximum
0	OILY BILGE 2.S	Slops	98%	4.911	4.813	5.379	5.272	-66.375	8.389	0.990	0.000	Maximum
0	CLN BILGE 2.P	Fresh Water	100%	1.086	1.086	1.086	1.086	-66.364	-7.481	1.003	0.000	Maximum
0	CLN BILGE 2.S	Fresh Water	100%	1.086	1.086	1.086	1.086	-66.364	7.481	1.003	0.000	Maximum
0	Subtotal Waste		95.8%	101.449	97.192	103.345	99.050	-31.948	0.000	2.095	35.758	
0												
0	Vehicle Load		0	387.000	0.000			-49.775	0.000	8.500	0.000	User Specified
0	Passenger Load		0	130.000	0.000			-31.761	0.000	10.500	0.000	User Specified
0	Stores		0	1.000	0.000			-26.625	4.825	11.000	0.000	User Specified
0	Subtotal Cargo				0.000			0.000	0.000	0.000	0.000	
0												
0	Total Loadcase				2000.172	1363.029	413.278	-42.529	-0.019	6.031	545.501	
0	FS correction									0.273		
0	VCG fluid									6.303		



Heel to Starboard deg	-30.0	-20.0	-10.0	0.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
GZ m	-6.694	-7.711	-6.233	0.019	6.270	7.747	6.728	5.519	4.165	2.750	1.303	-0.221	-1.802
Area under GZ curve from zero heel m.deg	180.0149	107.1299	33.8081	0.0000	34.1805	107.8937	181.0282	242.2485	290.7944	325.3801	345.6907	351.1628	341.0738
Displacement t	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Draft at FP m	0.459	2.393	3.004	2.726	3.005	2.394	0.465	-1.821	-4.701	-8.868	-16.281	-37.048	n/a
Draft at AP m	-1.862	0.179	2.037	2.738	2.037	0.179	-1.866	-4.459	-8.104	-13.952	-25.391	-58.601	n/a
WL Length m	89.670	89.671	91.931	88.482	91.931	89.671	89.671	89.692	89.770	89.960	90.611	90.932	90.957
Beam max extents on WL m	13.081	13.094	24.643	25.052	24.643	13.094	13.082	13.105	13.574	12.446	10.948	10.143	10.000
Wetted Area m^2	1128.079	1121.884	1413.528	1509.825	1415.113	1122.915	1128.955	1152.062	1211.896	1286.854	1343.724	1382.739	1428.630
Waterpl. Area m^2	624.777	603.733	900.386	1000.028	900.774	603.729	624.611	621.851	637.504	668.501	663.506	633.625	583.273
Prismatic coeff. (Cp)	0.748	0.747	0.730	0.721	0.730	0.747	0.748	0.738	0.704	0.650	0.603	0.563	0.525
Block coeff. (Cb)	0.524	0.524	0.366	0.583	0.366	0.524	0.524	0.510	0.475	0.453	0.507	0.519	0.406
LCB from zero pt. (+ve fwd) m	-42.357	-42.373	-42.471	-42.526	-42.473	-42.374	-42.347	-42.330	-42.288	-42.231	-42.153	-42.078	-42.019
LCF from zero pt. (+ve fwd) m	-48.039	-48.575	-45.738	-47.769	-45.719	-48.574	-48.037	-48.944	-49.769	-50.547	-50.887	-50.274	-49.099
Max deck inclination deg	30.0247	20.0420	10.0182	0.0075	10.0182	20.0420	30.0249	40.0172	50.0142	60.0132	70.0125	80.0087	90.0000
Trim angle (+ve by stern) deg	-1.4769	-1.4093	-0.6157	0.0075	-0.6156	-1.4098	-1.4836	-1.6787	-2.1655	-3.2328	-5.7800	-13.4677	n/a

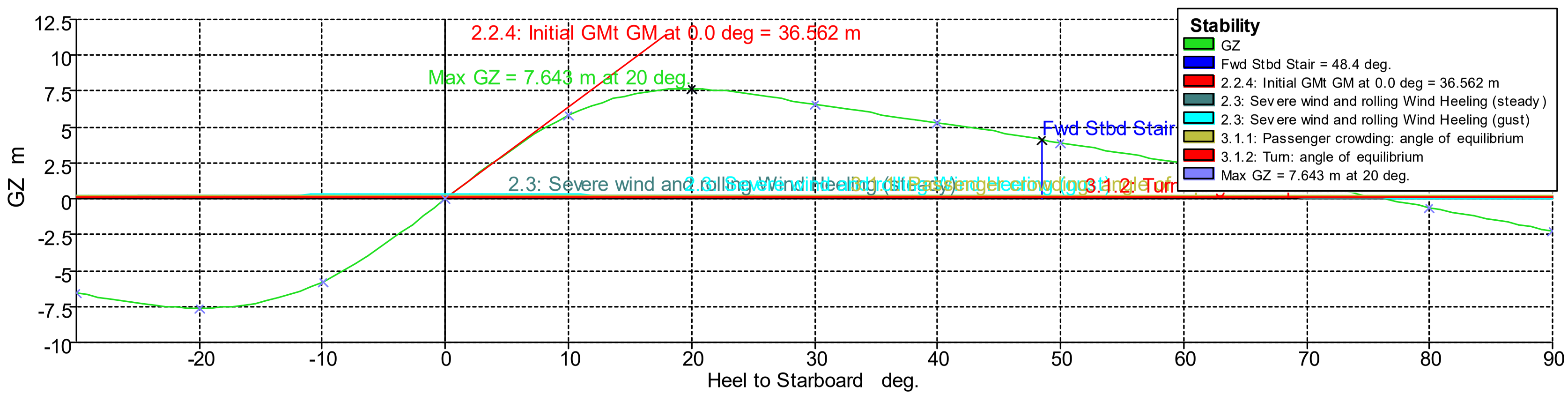
Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30	3.1513	m.deg	181.0282	Pass	+5644.56
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40	5.1566	m.deg	242.2485	Pass	+4597.83
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40	1.7189	m.deg	61.2203	Pass	+3461.60
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater	0.200	m	6.728	Pass	+3264.00
267(85) Ch2 - General Criteria	2.2.4: Initial GMt	0.150	m	39.255	Pass	+26070.00
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Area1 / Area2 shall not be less than (>=)	100.00	%	457.29	Pass	+357.29
3.1 Passenger Ships	3.1.1: Passenger crowding: angle of equilibrium	10.0	deg	0.4	Pass	+96.24
3.1 Passenger Ships	3.1.2: Turn: angle of equilibrium	10.0	deg	0.1	Pass	+99.01
267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ	15.0	deg	18.2	Pass	+21.21
267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ Area	0.0700	m.deg	93.7780	Pass	+133868.55

Key point	Type	Immersion angle deg	Emergence angle deg	Freebd at 0.0 deg m	Freeboard at 10.0 deg m	Freeboard at 20.0 deg m	Freeboard at 30.0 deg m	Freeboard at 40.0 deg m	Freeboard at 50.0 deg m	Freeboard at 60.0 deg m
Margin Line (immersion pos = -19.417 m)		26.7	n/a	4.185	1.894	0.424	-0.218	-0.906	-1.646	-2.395
Deck Edge (immersion pos = -19.417 m)		27.7	n/a	4.261	1.969	0.495	-0.152	-0.848	-1.598	-2.357
Aft Stbd Stair	Downflooding point	Not immersed in + range	0	4.263	3.114	2.898	2.636	2.347	2.064	1.827
Aft Port Stair	Downflooding point	Not immersed in + range	0	4.263	6.491	9.549	12.358	14.846	16.959	18.665
Fwd Stbd Stair	Downflooding point	55.2	0	4.273	2.317	1.154	0.962	0.686	0.274	-0.255
Fwd Port Stair	Downflooding point	Not immersed in + range	0	4.273	5.658	7.732	10.579	13.049	15.007	16.399
Aft Air Intake Stbd	Downflooding point	75.9	0	11.331	9.456	8.303	7.043	5.611	4.065	2.481
Aft Air Intake Port	Downflooding point	Not immersed in + range	0	11.331	13.896	17.047	19.825	22.042	23.647	24.617
Fwd Air Intake Stbd	Downflooding point	75.9	0	11.331	9.456	8.303	7.043	5.611	4.065	2.481
Fwd Air Intake Port	Downflooding point	Not immersed in + range	0	11.331	13.896	17.047	19.825	22.042	23.647	24.617

Loadcase - 50% Cargo, 50% Consumables
Damage Case - Intact
Free to Trim
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)
Fluid analysis method: Use corrected VCG

Ballasting	Item Name	Fluid type	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m	FSM Type
0	Lightship		1	1582.976	1582.976			-42.695	-0.024	7.331	0.000	
0	Subtotal lightship				1582.976			-42.695	-0.024	7.331	0.000	
0												
0	FPT.S	Sea Water	0%	55.448	0.000	54.095	0.000	-4.853	6.103	0.025	0.000	Maximum
0	FPT.P	Sea Water	0%	55.448	0.000	54.095	0.000	-4.853	-6.103	0.025	0.000	Maximum
0	SWBT1.P	Sea Water	0%	81.859	0.000	79.863	0.000	-25.769	-9.153	0.000	0.000	Maximum
0	SWBT1.S	Sea Water	0%	81.859	0.000	79.863	0.000	-25.769	9.153	0.000	0.000	Maximum
0	SWBT2.P	Sea Water	50%	111.052	55.526	108.343	54.172	-40.739	-9.163	0.486	270.143	Maximum
0	SWBT2.S	Sea Water	50%	111.052	55.526	108.343	54.172	-40.739	9.163	0.486	270.143	Maximum
0	SWBT3.P	Sea Water	100%	86.986	86.986	84.864	84.864	-55.135	-9.068	0.856	0.000	Maximum
0	SWBT3.S	Sea Water	100%	86.986	86.986	84.864	84.864	-55.135	9.068	0.856	0.000	Maximum
0	SWBT4.P	Sea Water	0%	46.929	0.000	45.784	0.000	-62.511	-6.103	0.096	0.000	Maximum
0	SWBT4.S	Sea Water	0%	46.929	0.000	45.784	0.000	-62.511	6.103	0.096	0.000	Maximum
0	APT.P	Sea Water	0%	198.339	0.000	193.501	0.000	-76.499	-6.102	1.353	0.000	Maximum
0	APT.S	Sea Water	0%	198.339	0.000	193.501	0.000	-76.499	6.102	1.353	0.000	Maximum
0	Subtotal Ballast		24.55%	1161.225	285.023	1132.902	278.072	-49.526	0.000	0.712	540.285	
0												
0	MGO 1.P	Diesel	43.06%	39.900	17.181	47.500	20.453	-29.375	-9.152	1.931	28.000	Maximum
0	MGO 1.S	Diesel	43.06%	39.900	17.181	47.500	20.453	-29.375	9.152	1.931	28.000	Maximum
0	MGO SETT.P	Diesel	98%	3.605	3.533	4.292	4.206	-50.625	-8.372	2.480	0.000	Maximum
0	MGO SETT.S	Diesel	98%	3.605	3.533	4.292	4.206	-50.625	8.372	2.480	0.000	Maximum
0	MGO SERV.P	Diesel	98%	2.163	2.120	2.575	2.523	-53.375	-8.372	2.480	0.000	Maximum
0	MGO SERV.S	Diesel	98%	2.163	2.120	2.575	2.523	-53.375	8.372	2.480	0.000	Maximum
0	Subtotal MGO		50%	91.336	45.667	108.733	54.366	-34.891	0.000	2.067	56.000	
0												
0	FWT.P	Fresh Water	50%	7.599	3.800	7.599	3.800	-35.625	-9.143	1.750	3.033	Maximum
0	FWT.S	Fresh Water	50%	7.599	3.800	7.599	3.800	-35.625	9.143	1.750	3.033	Maximum
0	LUBE OIL.P	Lube Oil	50%	1.311	0.656	1.425	0.713	-50.625	-10.852	2.000	0.021	Maximum
0	LUBE OIL.S	Lube Oil	50%	1.311	0.656	1.425	0.713	-50.625	10.852	2.000	0.021	Maximum
0	Subtotal Consumables		50%	17.820	8.910	18.048	9.024	-37.832	0.000	1.787	6.107	
0												
0	WASTE OIL.P	Slops	50%	0.130	0.065	0.143	0.071	-53.875	-10.852	1.750	0.004	Maximum

Ballasting	Item Name	Fluid type	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m	FSM Type
0	WASTE OIL.S	Slops	50%	0.130	0.065	0.143	0.071	-53.875	10.852	1.750	0.004	Maximum
0	BWT.P	Custom 3	50%	38.594	19.297	38.594	19.297	-21.875	-9.125	2.000	17.879	Maximum
0	BWT.S	Custom 3	50%	38.594	19.297	38.594	19.297	-21.875	9.125	2.000	17.879	Maximum
0	OILY BILGE 1.P	Slops	0%	4.909	0.000	5.377	0.000	-59.625	-9.898	0.500	0.000	Maximum
0	OILY BILGE 1.S	Slops	0%	4.909	0.000	5.377	0.000	-59.625	9.898	0.500	0.000	Maximum
0	CLN BILGE 1.P	Fresh Water	0%	1.094	0.000	1.094	0.000	-59.625	-10.806	0.500	0.000	Maximum
0	CLN BILGE 1.S	Fresh Water	0%	1.094	0.000	1.094	0.000	-59.625	10.806	0.500	0.000	Maximum
0	OILY BILGE 2.P	Slops	98%	4.911	4.813	5.379	5.272	-66.375	-8.389	0.990	0.000	Maximum
0	OILY BILGE 2.S	Slops	98%	4.911	4.813	5.379	5.272	-66.375	8.389	0.990	0.000	Maximum
0	CLN BILGE 2.P	Fresh Water	100%	1.086	1.086	1.086	1.086	-66.364	-7.481	1.003	0.000	Maximum
0	CLN BILGE 2.S	Fresh Water	100%	1.086	1.086	1.086	1.086	-66.364	7.481	1.003	0.000	Maximum
0	Subtotal Waste		49.8%	101.449	50.523	103.345	51.452	-32.349	0.000	1.764	35.767	
0												
0	Vehicle Load		0.5	387.000	193.500			-49.775	0.000	8.500	4.250	User Specified
0	Passenger Load		0.5	130.000	65.000			-31.761	0.000	10.500	5.250	User Specified
0	Stores		0.5	1.000	0.500			-26.625	4.825	11.000	0.000	User Specified
0	Subtotal Cargo				259.000			-45.209	0.009	9.007	9.500	
0												
0	Total Loadcase				2232.099	1363.029	392.913	-43.446	-0.016	6.424	647.659	
0	FS correction									0.290		
0	VCG fluid									6.714		



Heel to Starboard deg	-30.0	-20.0	-10.0	0.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
GZ m	-6.551	-7.613	-5.772	0.016	5.803	7.643	6.579	5.312	3.914	2.468	0.965	-0.615	-2.246
Area under GZ curve from zero heel m.deg	173.3138	101.2301	30.9072	0.0000	31.2110	101.8825	174.0832	233.4434	279.7063	311.6288	328.8576	330.6679	316.3882
Displacement t	2232	2232	2232	2232	2232	2232	2232	2232	2232	2232	2232	2232	2232
Draft at FP m	0.778	2.695	3.129	2.889	3.131	2.694	0.782	-1.410	-4.171	-8.155	-15.207	-34.875	n/a
Draft at AP m	-1.360	0.648	2.406	3.008	2.404	0.649	-1.362	-3.927	-7.528	-13.295	-24.423	-56.509	n/a
WL Length m	89.741	89.740	91.941	90.077	91.941	89.739	89.742	89.785	89.893	90.159	90.788	90.932	90.953
Beam max extents on WL m	13.285	13.228	24.863	25.150	24.862	13.228	13.286	13.472	13.576	12.450	10.863	10.125	9.997
Wetted Area m^2	1201.920	1192.896	1506.895	1625.563	1508.649	1193.972	1202.885	1234.566	1299.692	1369.333	1418.669	1462.778	1514.988
Waterpl. Area m^2	621.862	624.719	941.905	1056.862	942.264	624.723	621.693	614.242	630.841	657.861	637.031	589.235	541.257
Prismatic coeff. (Cp)	0.763	0.763	0.738	0.716	0.738	0.763	0.763	0.745	0.704	0.656	0.612	0.574	0.537
Block coeff. (Cb)	0.542	0.543	0.382	0.579	0.382	0.543	0.542	0.521	0.479	0.473	0.522	0.531	0.424
LCB from zero pt. (+ve fwd) m	-43.284	-43.299	-43.410	-43.455	-43.402	-43.306	-43.282	-43.255	-43.203	-43.144	-43.073	-42.996	-42.950
LCF from zero pt. (+ve fwd) m	-49.269	-48.758	-46.227	-49.518	-46.204	-48.761	-49.273	-50.478	-51.327	-52.158	-51.988	-51.194	-49.341
Max deck inclination deg	30.0210	20.0359	10.0102	0.0759	10.0103	20.0358	30.0211	40.0157	50.0138	60.0135	70.0128	80.0088	90.0000
Trim angle (+ve by stern) deg	-1.3610	-1.3033	-0.4604	0.0759	-0.4628	-1.3013	-1.3647	-1.6021	-2.1362	-3.2687	-5.8469	-13.5163	n/a

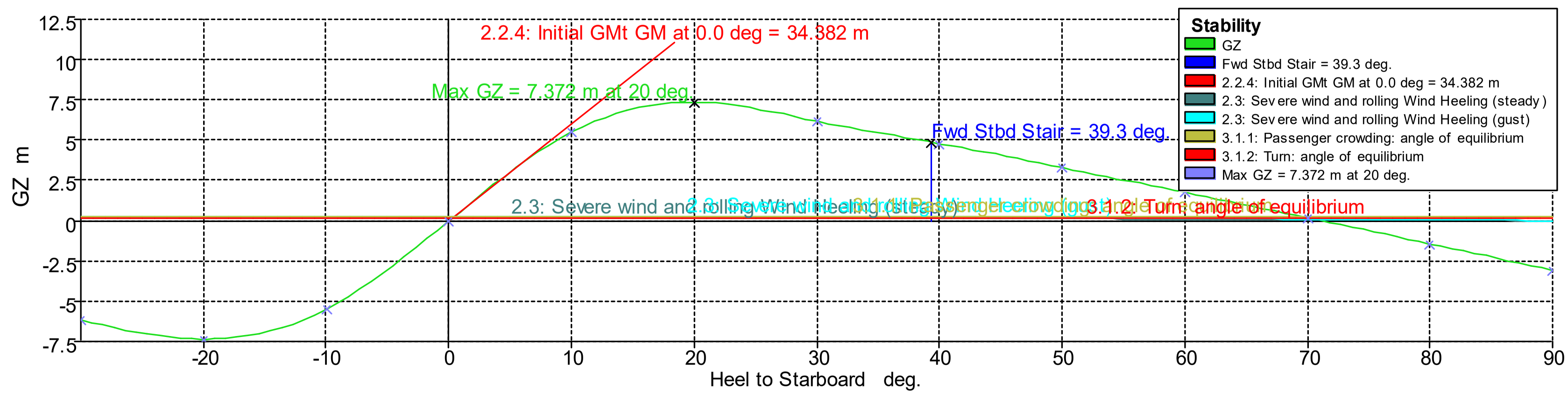
Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30	3.1513	m.deg	174.0832	Pass	+5424.17
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40	5.1566	m.deg	233.4434	Pass	+4427.08
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40	1.7189	m.deg	59.3602	Pass	+3353.38
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater	0.200	m	6.579	Pass	+3189.50
267(85) Ch2 - General Criteria	2.2.4: Initial GMt	0.150	m	36.562	Pass	+24274.67
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Area1 / Area2 shall not be less than (>=)	100.00	%	434.59	Pass	+334.59
3.1 Passenger Ships	3.1.1: Passenger crowding: angle of equilibrium	10.0	deg	0.4	Pass	+96.26
3.1 Passenger Ships	3.1.2: Turn: angle of equilibrium	10.0	deg	0.1	Pass	+98.80
267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ	15.0	deg	20.0	Pass	+33.33
267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ Area	0.0700	m.deg	101.8827	Pass	+145446.69

Key point	Type	Immersion angle deg	Emergence angle deg	FreeBd at 0.0 deg m	FreeBd at 10.0 deg m	FreeBd at 20.0 deg m	FreeBd at 30.0 deg m	FreeBd at 40.0 deg m	FreeBd at 50.0 deg m	FreeBd at 60.0 deg m
Margin Line (immersion pos = -17.56 m)		21.8	n/a	3.916	1.720	0.112	-0.530	-1.244	-1.994	-2.744
Deck Edge (immersion pos = -18.488 m)		22.9	n/a	3.992	1.795	0.183	-0.464	-1.186	-1.945	-2.706
Aft Stbd Stair	Downflooding point	Not immersed in + range	0	4.003	2.774	2.470	2.213	1.948	1.697	1.496
Aft Port Stair	Downflooding point	Not immersed in + range	0	4.003	6.151	9.121	11.936	14.447	16.592	18.334
Fwd Stbd Stair	Downflooding point	48.4	0	4.104	2.180	0.863	0.678	0.366	-0.068	-0.610
Fwd Port Stair	Downflooding point	Not immersed in + range	0	4.104	5.520	7.442	10.295	12.730	14.665	16.044
Aft Air Intake Stbd	Downflooding point	73.7	0	11.080	9.137	7.890	6.635	5.220	3.700	2.148
Aft Air Intake Port	Downflooding point	Not immersed in + range	0	11.080	13.577	16.634	19.418	21.652	23.282	24.283
Fwd Air Intake Stbd	Downflooding point	73.7	0	11.080	9.137	7.890	6.635	5.220	3.700	2.148
Fwd Air Intake Port	Downflooding point	Not immersed in + range	0	11.080	13.577	16.634	19.418	21.652	23.282	24.283

Loadcase - 100% Cargo, 100% Consumables
Damage Case - Intact
Free to Trim
Specific gravity = 1.025; (Density = 1.025 tonne/m^3)
Fluid analysis method: Use corrected VCG

Ballasting	Item Name	Fluid type	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m	FSM Type
0	Lightship		1	1582.976	1582.976			-42.695	-0.024	7.331	0.000	
0	Subtotal Lightship				1582.976			-42.695	-0.024	7.331	0.000	
0												
0	FPT.S	Sea Water	0%	55.448	0.000	54.095	0.000	-4.853	6.103	0.025	0.000	Maximum
0	FPT.P	Sea Water	0%	55.448	0.000	54.095	0.000	-4.853	-6.103	0.025	0.000	Maximum
0	SWBT1.P	Sea Water	0%	81.859	0.000	79.863	0.000	-25.769	-9.153	0.000	0.000	Maximum
0	SWBT1.S	Sea Water	0%	81.859	0.000	79.863	0.000	-25.769	9.153	0.000	0.000	Maximum
0	SWBT2.P	Sea Water	27.08%	111.052	30.075	108.343	29.341	-40.726	-9.156	0.303	270.143	Maximum
0	SWBT2.S	Sea Water	29.79%	111.052	33.087	108.343	32.280	-40.728	9.158	0.326	270.143	Maximum
0	SWBT3.P	Sea Water	0%	86.986	0.000	84.864	0.000	-48.801	-6.103	0.001	0.000	Maximum
0	SWBT3.S	Sea Water	0%	86.986	0.000	84.864	0.000	-48.801	6.103	0.001	0.000	Maximum
0	SWBT4.P	Sea Water	0%	46.929	0.000	45.784	0.000	-62.511	-6.103	0.096	0.000	Maximum
0	SWBT4.S	Sea Water	0%	46.929	0.000	45.784	0.000	-62.511	6.103	0.096	0.000	Maximum
0	APT.P	Sea Water	0%	198.339	0.000	193.501	0.000	-76.499	-6.102	1.353	0.000	Maximum
0	APT.S	Sea Water	0%	198.339	0.000	193.501	0.000	-76.499	6.102	1.353	0.000	Maximum
0	Subtotal Ballast		5.44%	1161.225	63.161	1132.902	61.621	-40.727	0.437	0.315	540.285	
0												
0	MGO 1.P	Diesel	98%	39.900	39.102	47.500	46.550	-29.375	-9.152	2.480	0.000	Maximum
0	MGO 1.S	Diesel	98%	39.900	39.102	47.500	46.550	-29.375	9.152	2.480	0.000	Maximum
0	MGO SETT.P	Diesel	98%	3.605	3.533	4.292	4.206	-50.625	-8.372	2.480	0.000	Maximum
0	MGO SETT.S	Diesel	98%	3.605	3.533	4.292	4.206	-50.625	8.372	2.480	0.000	Maximum
0	MGO SERV.P	Diesel	98%	2.163	2.120	2.575	2.523	-53.375	-8.372	2.480	0.000	Maximum
0	MGO SERV.S	Diesel	98%	2.163	2.120	2.575	2.523	-53.375	8.372	2.480	0.000	Maximum
0	Subtotal MGO		98%	91.336	89.509	108.733	106.559	-32.189	0.000	2.480	0.000	
0												
0	FWT.P	Fresh Water	100%	7.599	7.599	7.599	7.599	-35.625	-9.143	2.000	0.000	Maximum
0	FWT.S	Fresh Water	100%	7.599	7.599	7.599	7.599	-35.625	9.143	2.000	0.000	Maximum
0	LUBE OIL.P	Lube Oil	98%	1.311	1.285	1.425	1.397	-50.625	-10.852	2.480	0.000	Maximum
0	LUBE OIL.S	Lube Oil	98%	1.311	1.285	1.425	1.397	-50.625	10.852	2.480	0.000	Maximum
0	Subtotal Consumables		99.71%	17.820	17.768	18.048	17.991	-37.794	0.000	2.069	0.000	
0												

Ballasting	Item Name	Fluid type	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m	FSM Type
0	BWT.P	Custom 3	10%	38.594	3.859	38.594	3.859	-21.875	-9.125	1.600	17.879	Maximum
0	BWT.S	Custom 3	10%	38.594	3.859	38.594	3.859	-21.875	9.125	1.600	17.879	Maximum
0	WASTE OIL.P	Slops	10%	0.130	0.013	0.143	0.014	-53.875	-10.852	1.550	0.004	Maximum
0	WASTE OIL.S	Slops	10%	0.130	0.013	0.143	0.014	-53.875	10.852	1.550	0.004	Maximum
0	OILY BILGE 1.P	Slops	0%	4.909	0.000	5.377	0.000	-59.625	-9.898	0.500	0.000	Maximum
0	OILY BILGE 1.S	Slops	0%	4.909	0.000	5.377	0.000	-59.625	9.898	0.500	0.000	Maximum
0	CLN BILGE 1.P	Fresh Water	0%	1.094	0.000	1.094	0.000	-59.625	-10.806	0.500	0.000	Maximum
0	CLN BILGE 1.S	Fresh Water	0%	1.094	0.000	1.094	0.000	-59.625	10.806	0.500	0.000	Maximum
0	OILY BILGE 2.P	Slops	20%	4.911	0.982	5.379	1.076	-66.375	-8.389	0.600	0.982	Maximum
0	OILY BILGE 2.S	Slops	20%	4.911	0.982	5.379	1.076	-66.375	8.389	0.600	0.982	Maximum
0	CLN BILGE 2.P	Fresh Water	20%	1.086	0.217	1.086	0.217	-66.322	-7.483	0.605	0.009	Maximum
0	CLN BILGE 2.S	Fresh Water	20%	1.086	0.217	1.086	0.217	-66.322	7.483	0.605	0.009	Maximum
0	Subtotal Waste		10%	101.449	10.144	103.345	10.333	-32.479	0.000	1.364	37.749	
0												
0	Vehicle Load		1	387.000	387.000			-49.775	0.000	8.500	0.000	User Specified
0	Passenger Load		1	130.000	130.000			-31.761	0.000	10.500	0.000	User Specified
0	Stores		1	1.000	1.000			-26.625	4.825	11.000	0.000	User Specified
0	Subtotal Cargo				518.000			-45.209	0.009	9.007	0.000	
0												
0												
0	Total Loadcase				2281.558	1363.029	196.504	-42.716	-0.003	7.259	578.035	
0	FS correction									0.253		
0	VCG fluid									7.513		



Heel to Starboard deg	-30.0	-20.0	-10.0	0.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
GZ m	-6.174	-7.367	-5.484	0.000	5.487	7.372	6.178	4.791	3.289	1.753	0.182	-1.437	-3.072
Area under GZ curve from zero heel m.deg	165.9934	96.8522	29.2882	0.0000	29.2898	96.9542	165.9273	220.6279	261.1586	286.3686	296.0869	289.8410	267.2997
Displacement t	2282	2282	2282	2282	2281	2282	2282	2282	2282	2282	2282	2282	2282
Draft at FP m	1.230	3.073	3.358	3.110	3.360	3.071	1.230	-0.855	-3.478	-7.223	-13.766	-31.989	n/a
Draft at AP m	-1.563	0.476	2.289	2.909	2.287	0.478	-1.563	-4.169	-7.829	-13.698	-25.055	-57.777	n/a
WL Length m	89.863	89.845	91.948	88.875	91.948	89.845	89.863	89.933	90.086	90.488	90.925	90.965	90.991
Beam max extents on WL m	13.439	13.301	24.898	25.149	24.898	13.301	13.439	13.882	13.574	12.440	10.942	10.120	9.996
Wetted Area m^2	1224.490	1211.419	1529.895	1636.080	1529.896	1212.526	1225.397	1264.905	1330.191	1398.179	1451.461	1498.312	1551.825
Waterpl. Area m^2	601.465	626.602	946.229	1043.880	946.594	626.670	601.447	592.558	608.803	632.699	615.888	569.512	528.945
Prismatic coeff. (Cp)	0.743	0.749	0.733	0.733	0.733	0.749	0.743	0.718	0.670	0.624	0.583	0.547	0.512
Block coeff. (Cb)	0.520	0.523	0.373	0.574	0.373	0.523	0.520	0.497	0.455	0.453	0.498	0.495	0.402
LCB from zero pt. (+ve fwd) m	-42.478	-42.510	-42.649	-42.696	-42.642	-42.519	-42.483	-42.447	-42.400	-42.331	-42.245	-42.177	-42.139
LCF from zero pt. (+ve fwd) m	-49.860	-48.424	-45.977	-48.959	-45.954	-48.424	-49.862	-51.196	-52.202	-53.083	-52.978	-52.270	-50.708
Max deck inclination deg	30.0358	20.0577	10.0222	0.1277	10.0224	20.0576	30.0358	40.0271	50.0232	60.0214	70.0192	80.0125	90.0000
Trim angle (+ve by stern) deg	-1.7774	-1.6527	-0.6808	-0.1277	-0.6828	-1.6502	-1.7774	-2.1088	-2.7680	-4.1155	-7.1494	-15.9887	n/a

Code	Criteria	Value	Units	Actual	Status	Margin %
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 30	3.1513	m.deg	165.9273	Pass	+5165.36
267(85) Ch2 - General Criteria	2.2.1: Area 0 to 40	5.1566	m.deg	217.2279	Pass	+4112.62
267(85) Ch2 - General Criteria	2.2.1: Area 30 to 40	1.7189	m.deg	51.3007	Pass	+2884.51
267(85) Ch2 - General Criteria	2.2.2: Max GZ at 30 or greater	0.200	m	6.178	Pass	+2989.00
267(85) Ch2 - General Criteria	2.2.4: Initial GMt	0.150	m	34.382	Pass	+22821.33
267(85) Ch2 - General Criteria	2.3: Severe wind and rolling				Pass	
	Area1 / Area2 shall not be less than (>=)	100.00	%	365.35	Pass	+265.35
3.1 Passenger Ships	3.1.1: Passenger crowding: angle of equilibrium	10.0	deg	0.4	Pass	+95.84
3.1 Passenger Ships	3.1.2: Turn: angle of equilibrium	10.0	deg	0.2	Pass	+98.18
267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ	15.0	deg	20.0	Pass	+33.33
267(85) Ch2 - General Criteria	MSC 1281 Alt Max GZ Area	0.0700	m.deg	96.9542	Pass	+138406.05

Key point	Type	Immersion angle deg	Emergence angle deg	Freeboard at 0.0 deg m	Freeboard at 10.0 deg m	Freeboard at 20.0 deg m	Freeboard at 30.0 deg m	Freeboard at 40.0 deg m	Freeboard at 50.0 deg m	Freeboard at 60.0 deg m
Margin Line (immersion pos = -14.774 m)		19.1	n/a	3.815	1.564	-0.151	-0.794	-1.524	-2.285	-3.050
Deck Edge (immersion pos = -14.774 m)		19.5	n/a	3.891	1.638	-0.079	-0.729	-1.466	-2.236	-3.012
Aft Stbd Stair	Downflooding point	Not immersed in + range	0	4.073	2.858	2.585	2.337	2.079	1.833	1.638
Aft Port Stair	Downflooding point	Not immersed in + range	0	4.073	6.236	9.234	12.059	14.576	16.725	18.472
Fwd Stbd Stair	Downflooding point	39.3	0	3.902	1.973	0.537	0.321	-0.024	-0.478	-1.038
Fwd Port Stair	Downflooding point	Not immersed in + range	0	3.902	5.313	7.114	9.937	12.337	14.252	15.611
Aft Air Intake Stbd	Downflooding point	74.2	0	11.122	9.191	7.957	6.708	5.295	3.778	2.230
Aft Air Intake Port	Downflooding point	Not immersed in + range	0	11.122	13.631	16.700	19.488	21.725	23.357	24.360
Fwd Air Intake Stbd	Downflooding point	74.2	0	11.122	9.191	7.957	6.708	5.295	3.778	2.230
Fwd Air Intake Port	Downflooding point	Not immersed in positive range	0	11.122	13.631	16.700	19.488	21.725	23.357	24.360

Appendix G: Probabilistic Damage Stability

Damage Stability Analysis
GHS DAMSTAB2 Wizard version 18.90
GHS DAMSTAB2 Library version 18.90

Probabilistic Damage

RoPax 90m Ferry

STARBOARD-side Probabilistic Passenger SOLAS 2020

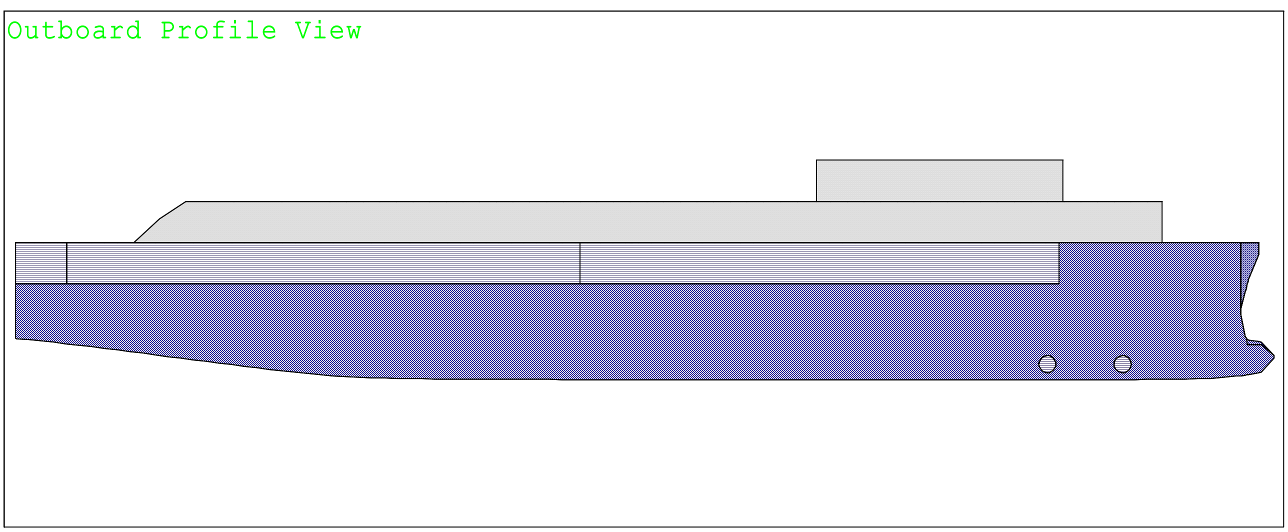
Including Heeling Moments:
Calculated wind heeling moments
650 passengers crowding
0 METRIC TONS-METERS Life-boat moment

Including Intermediate Stages of Flooding
Intermediate flooding tanks are considered flooded for
de/activating critical points with tank references and
and flooded permeability overrides.

If garage space () damaged then TZrange=20, TGZmax=0.20.

Variable Trial VCG

Condition Graphic



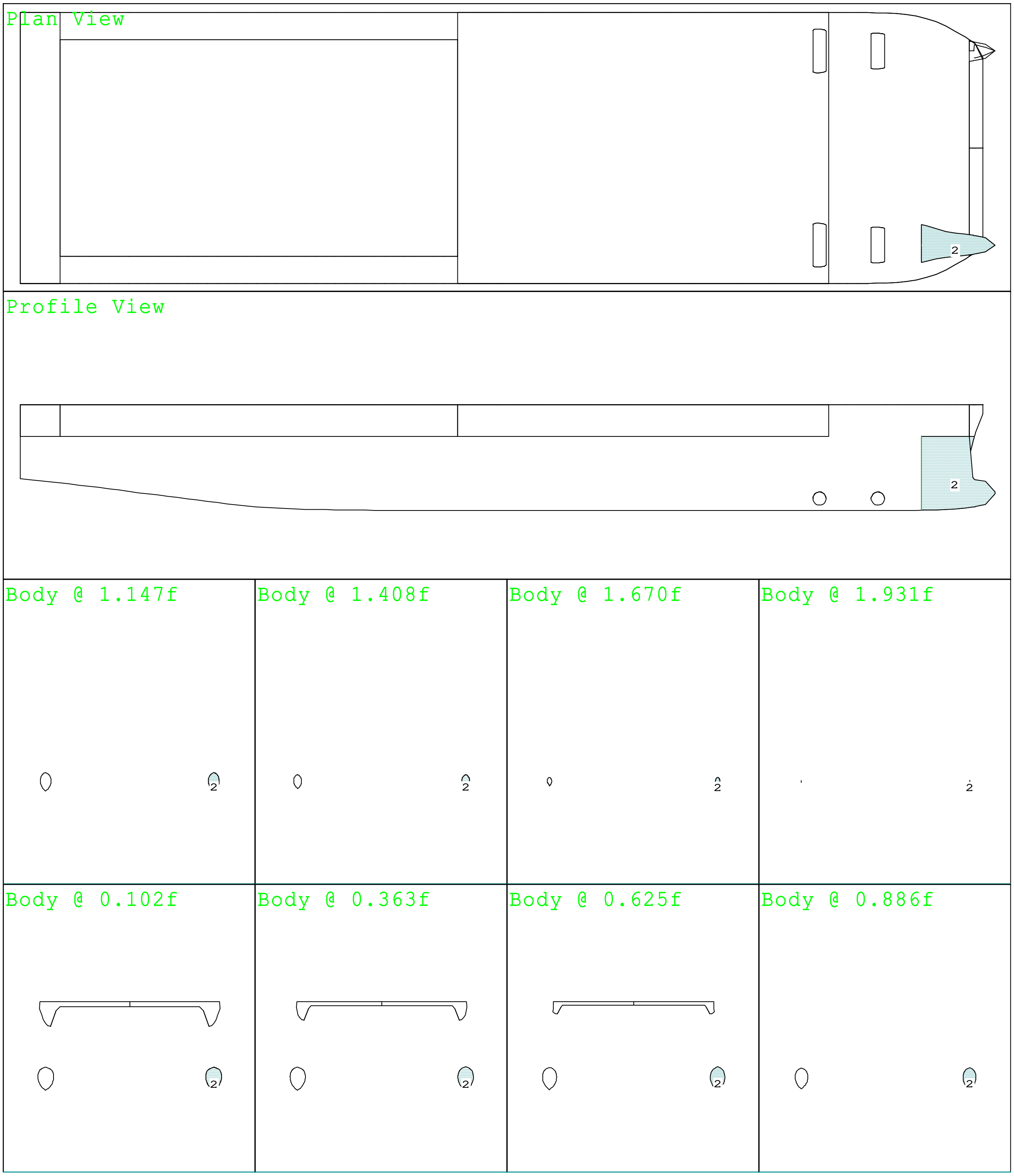
DIVISION definitions

Division	Fwd End	Aft End	Wing	HBhd	Parts
1	1.941f	0.092f			FPT.S
2	0.092f	5.000a			FPT.S FOCSLE.S
3	5.000a	11.250a			BT_RM_1A.S AUXMACH_1B.S FOCSLE.S
4	11.250a	13.750a			BT_RM_1B.S AUXMACH_1A.S FOCSLE.S
5	13.750a	18.750a			BT_RM_1B.S AUXMACH_1A.S
6	18.750a	32.500a			SWBT1.S BWT.S TT_1.S MID_MACH_1.S
7	32.500a	48.750a			SWBT2.S FWT.S TT_2.S MID_MACH_2.S
8	48.750a	56.250a			SWBT3.S MGO_SETT.S MGO_SERV.S WASTE_OIL.S LUBE_OIL.S TT3.S MID_MACH_3.S
9	56.250a	62.500a			SWBT3.S OILY_BILGE_1.S CLN_BILGE_1.S ENG_RM_1.S MID_MACH_3.S
10	62.500a	76.250a			SWBT4.S OILY_BILGE_2.S CLN_BILGE_2.S MID_MACH_4.S ENG_RM_2.S
11	76.250a	90.000a			APT.S STGEAR.S

Distances in METERS.

Division 1

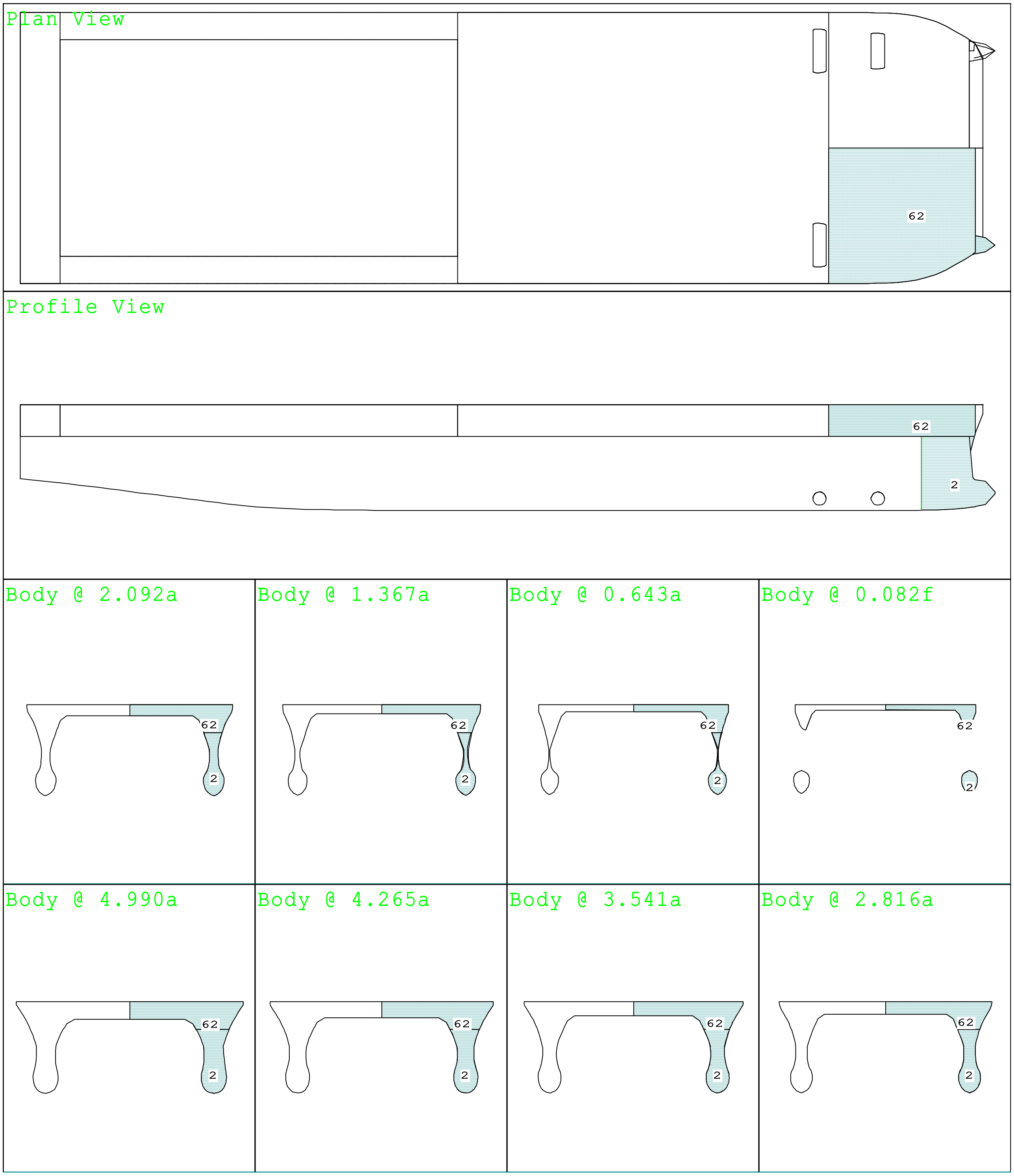
Condition Graphic - Draft: -99.000 Trim: zero Heel: zero



Tanks
2 FPT.S..........100% SEA WATER Intact

Division 2

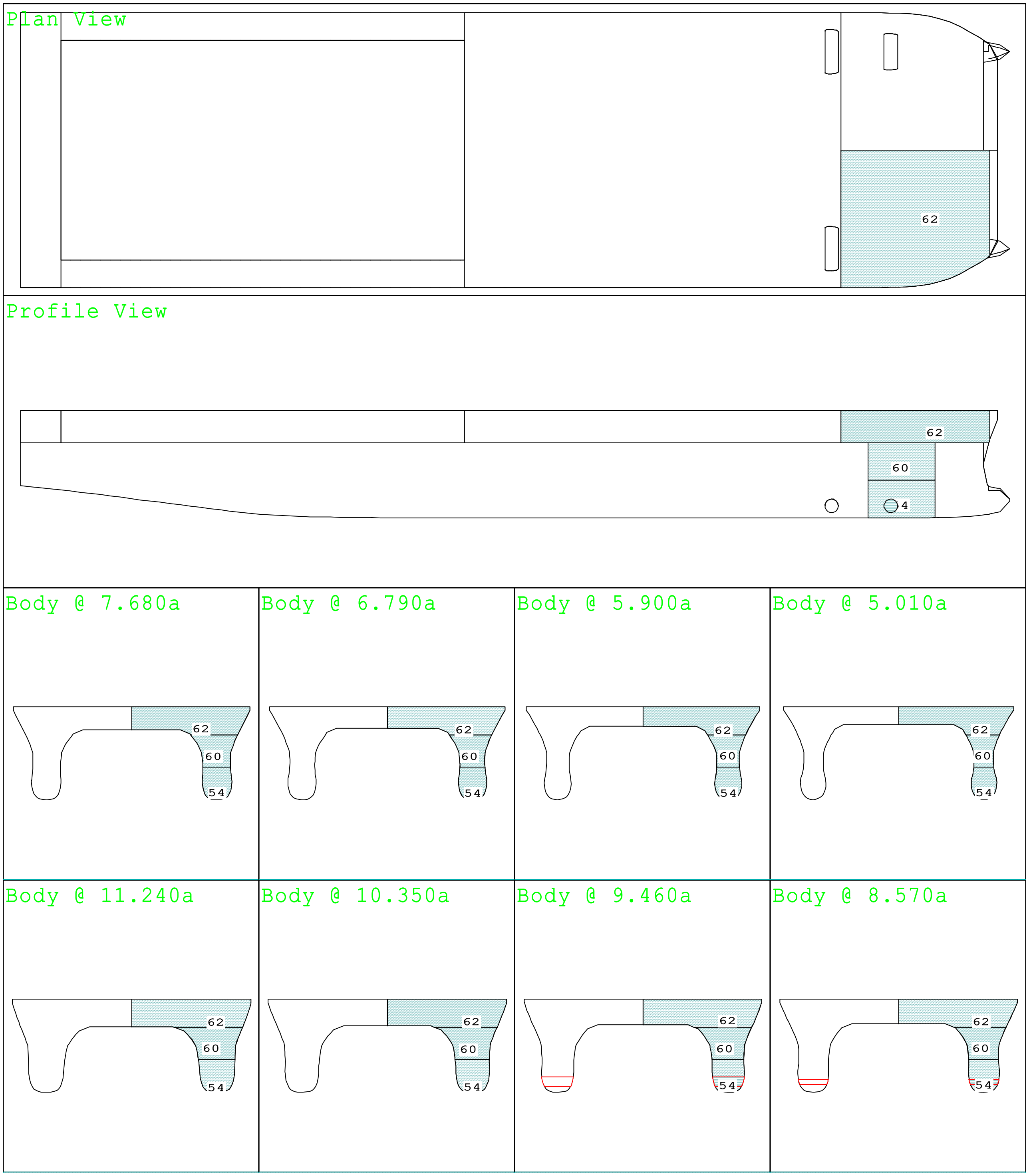
Condition Graphic - Draft: -99.000 Trim: zero Heel: zero



Tanks	
	2 FPT.S....100% SEA WATER Intact 62 FOCSLE.S.100% SEA WATER Intact

Division 3

Condition Graphic - Draft: -99.000 Trim: zero Heel: zero

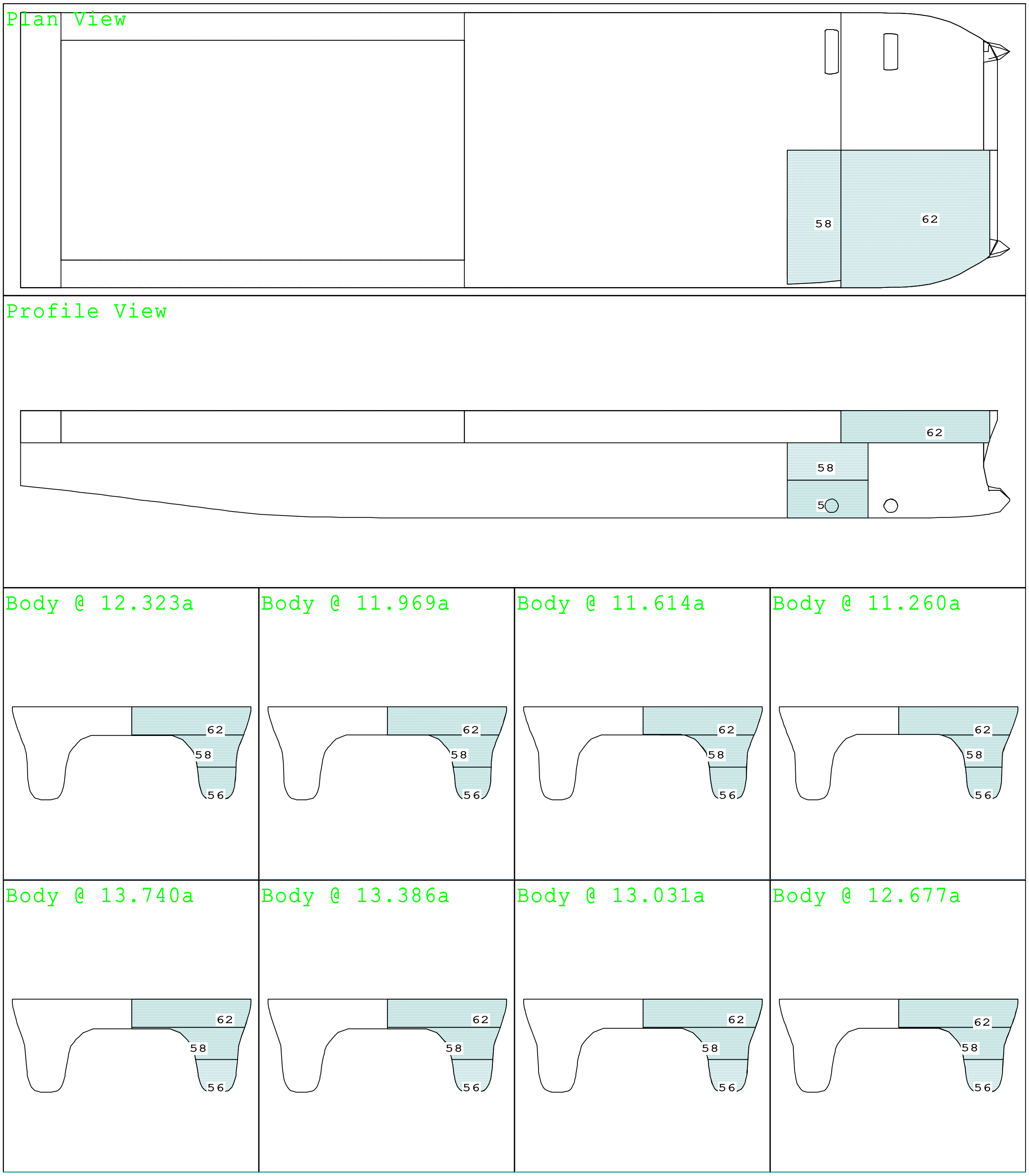


Tanks

54 BT_RM_1A.S...100% SEA WATER Intact
60 AUXMACH_1B.S.100% SEA WATER Intact
62 FOCSLE.S.....100% SEA WATER Intact

Division 4

Condition Graphic - Draft: -99.000 Trim: zero Heel: zero

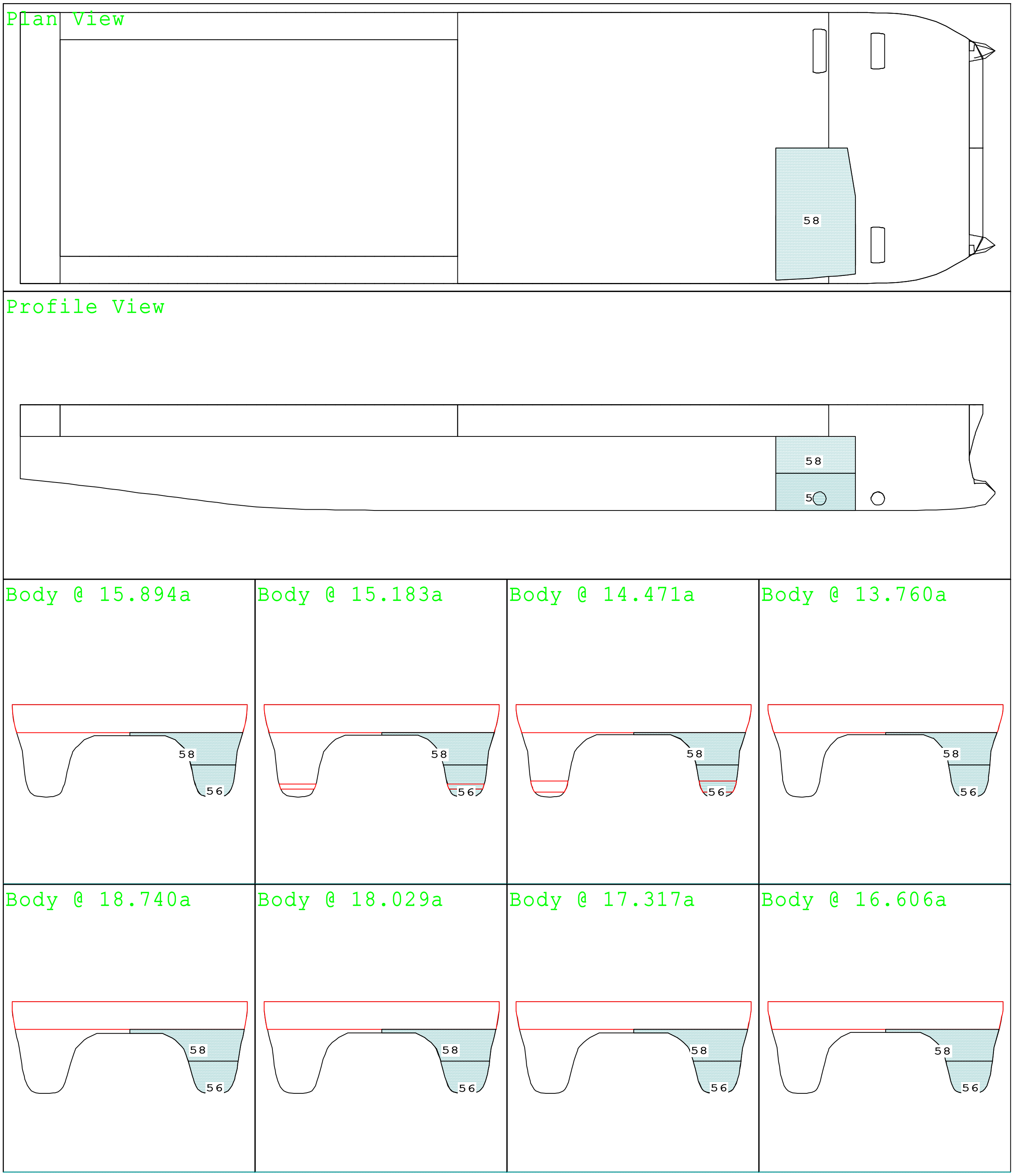


Tanks

58 AUXMACH_1A.S.100% SEA WATER Intact
56 BT_RM_1B.S...100% SEA WATER Intact 62 FOCSLE.S.....100% SEA WATER Intact

Division 5

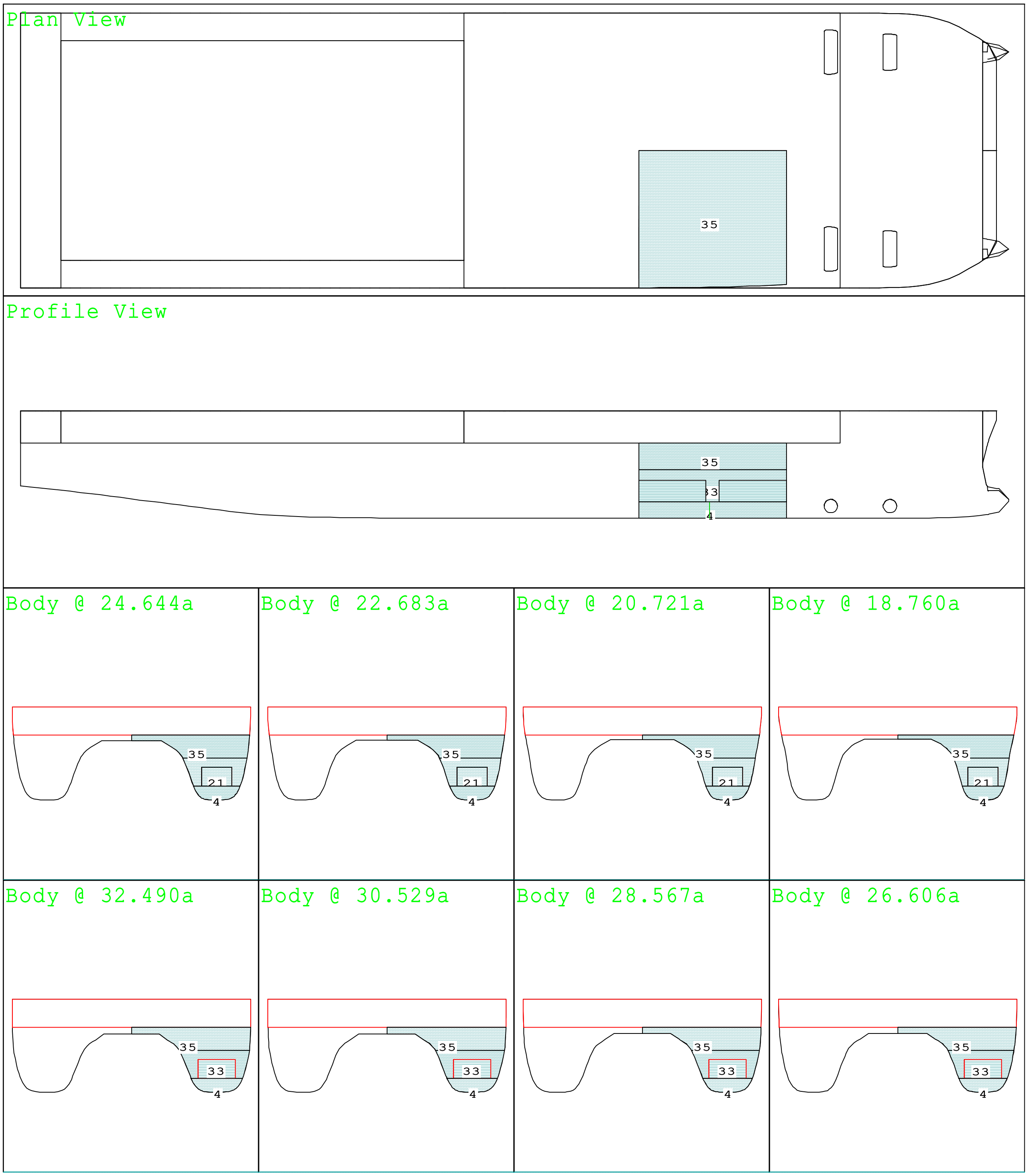
Condition Graphic - Draft: -99.000   Trim: zero   Heel: zero



Tanks
56 BT_RM_1B.S...100% SEA WATER Intact58 AUXMACH_1A.S.100% SEA WATER Intact

Division 6

Condition Graphic - Draft: -99.000 Trim: zero Heel: zero

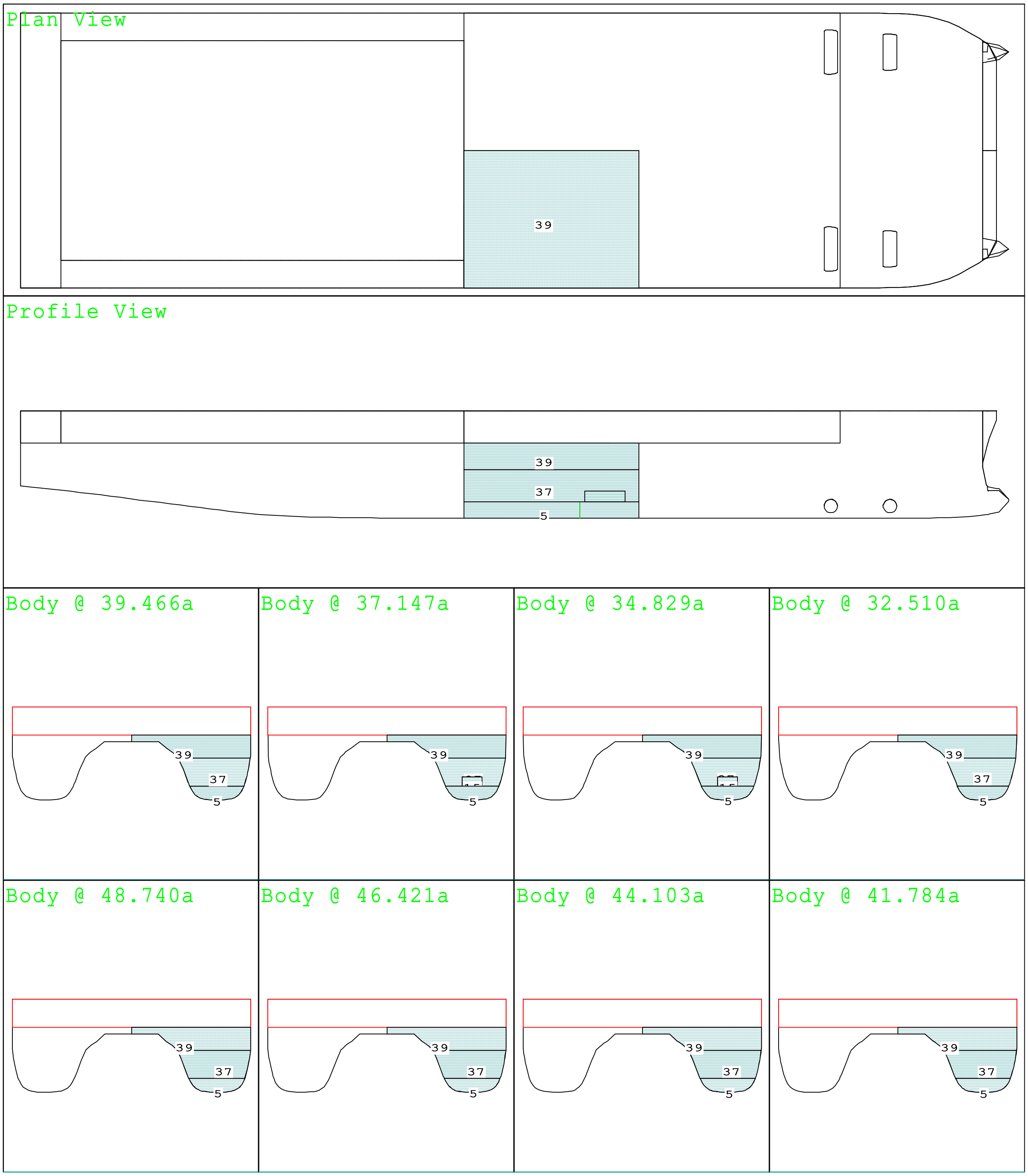


Tanks

21 BWT.S........100% SEA WATER Intact
35 MID_MACH_1.S.100% SEA WATER Intact
4 SWBT1.S......100% SEA WATER Intact
33 TT_1.S.......100% SEA WATER Intact

Division 7

Condition Graphic - Draft: -99.000 Trim: zero Heel: zero

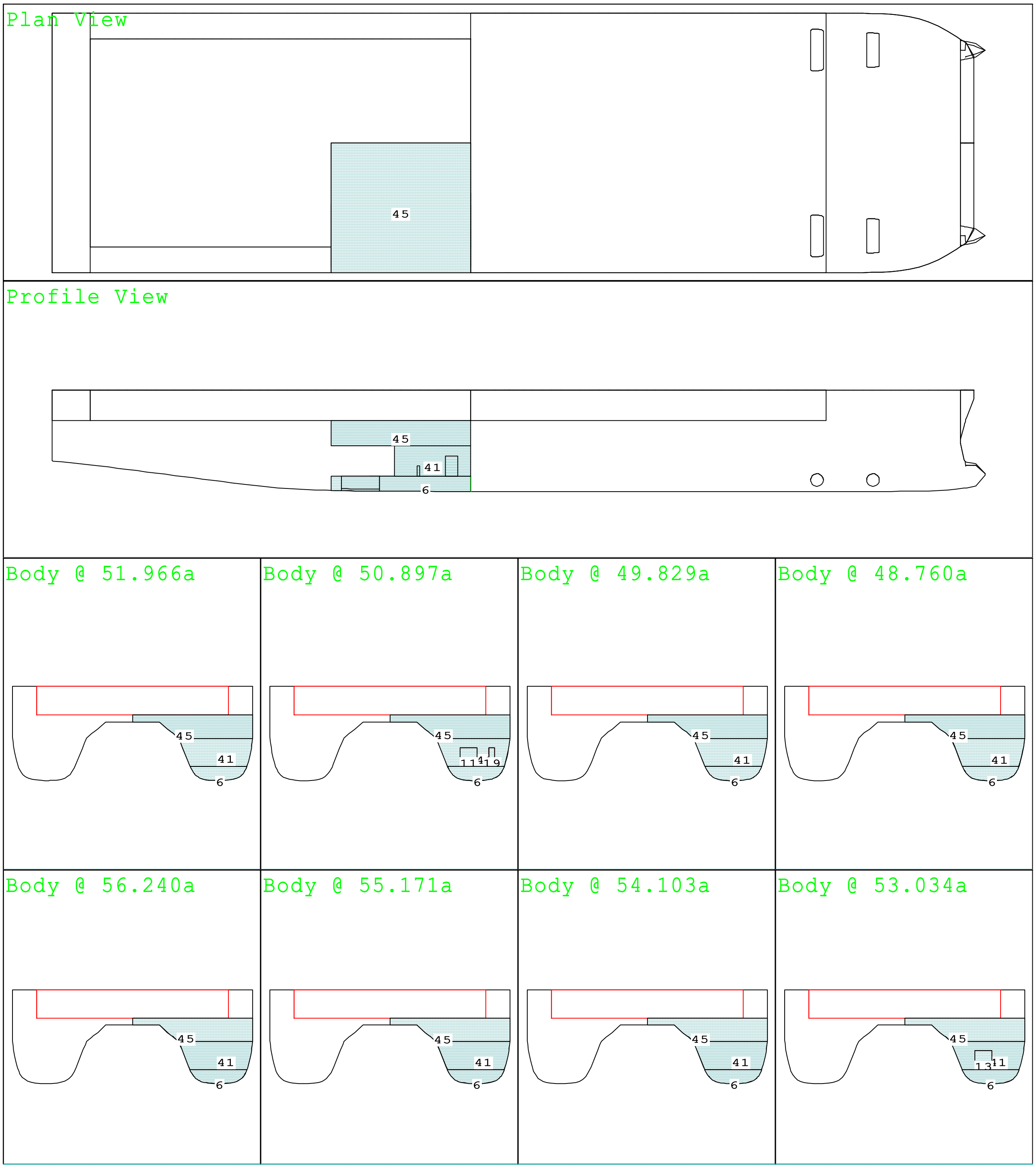


Tanks

15 FWT.S........100% SEA WATER Intact
39 MID_MACH_2.S.100% SEA WATER Intact
5 SWBT2.S......100% SEA WATER Intact
37 TT_2.S.......100% SEA WATER Intact

Division 8

Condition Graphic - Draft: -99.000 Trim: zero Heel: zero



Tanks

```
                                           13 MGO_SERV.S...100% SEA WATER Intact41 TT3.S........100% SEA WATER Intact
 6 SWBT3.S......100% SEA WATER Intact17 WASTE_OIL.S..100% SEA WATER Intact45 MID_MACH_3.S.100% SEA WATER Intact
11 MGO_SETT.S...100% SEA WATER Intact19 LUBE_OIL.S...100% SEA WATER Intact
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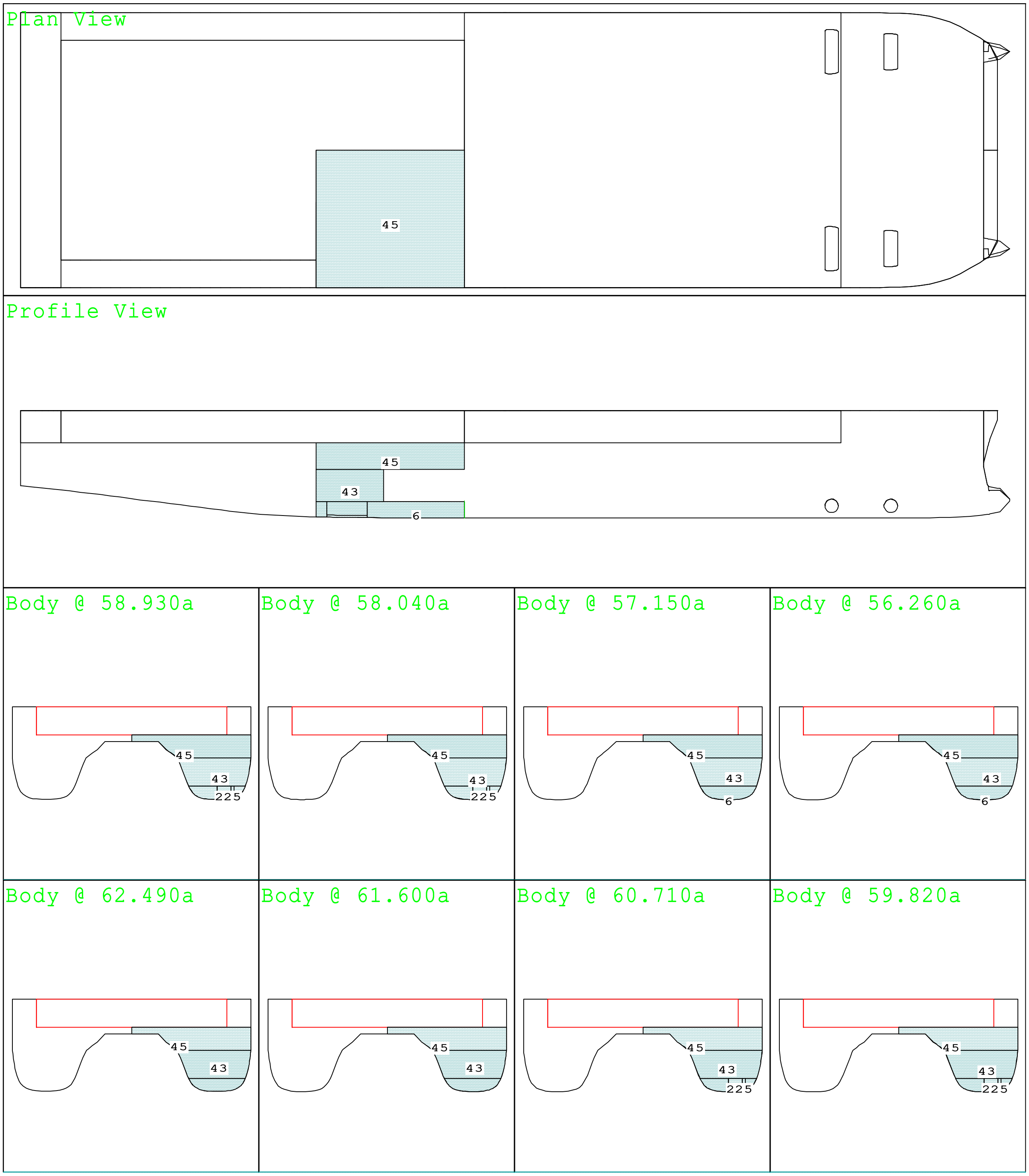
Division 9

Condition Graphic - Draft: -99.000 Trim: zero Heel: zero

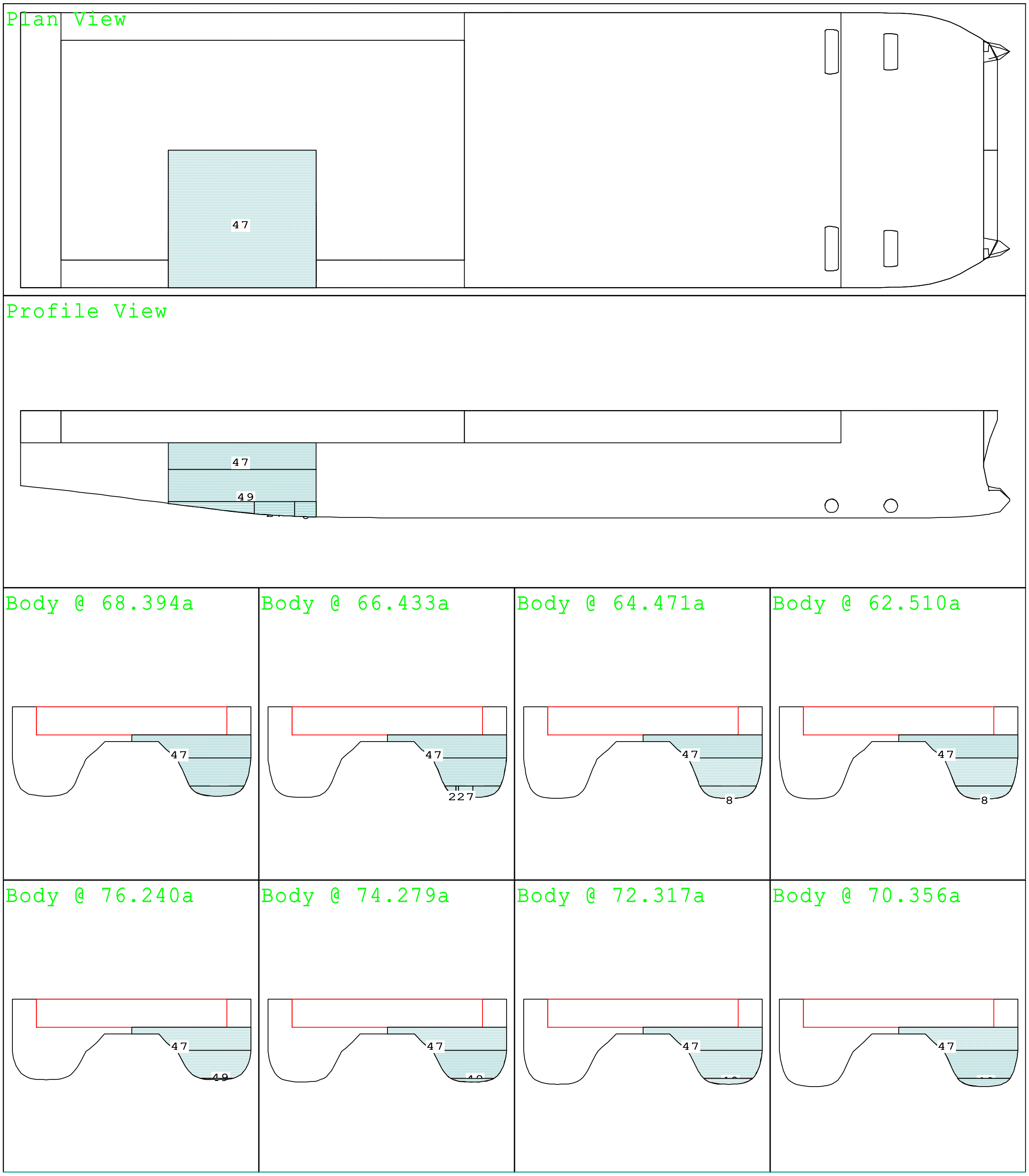


Tanks

	23 OILY_BILGE_1.S.100% SEA WATER	43 ENG_RM_1.S.....100% SEA WATER
6 SWBT3.S........100% SEA WATER	25 CLN_BILGE_1.S..100% SEA WATER	45 MID_MACH_3.S...100% SEA WATER

Division 10

Condition Graphic - Draft: -99.000 Trim: zero Heel: zero

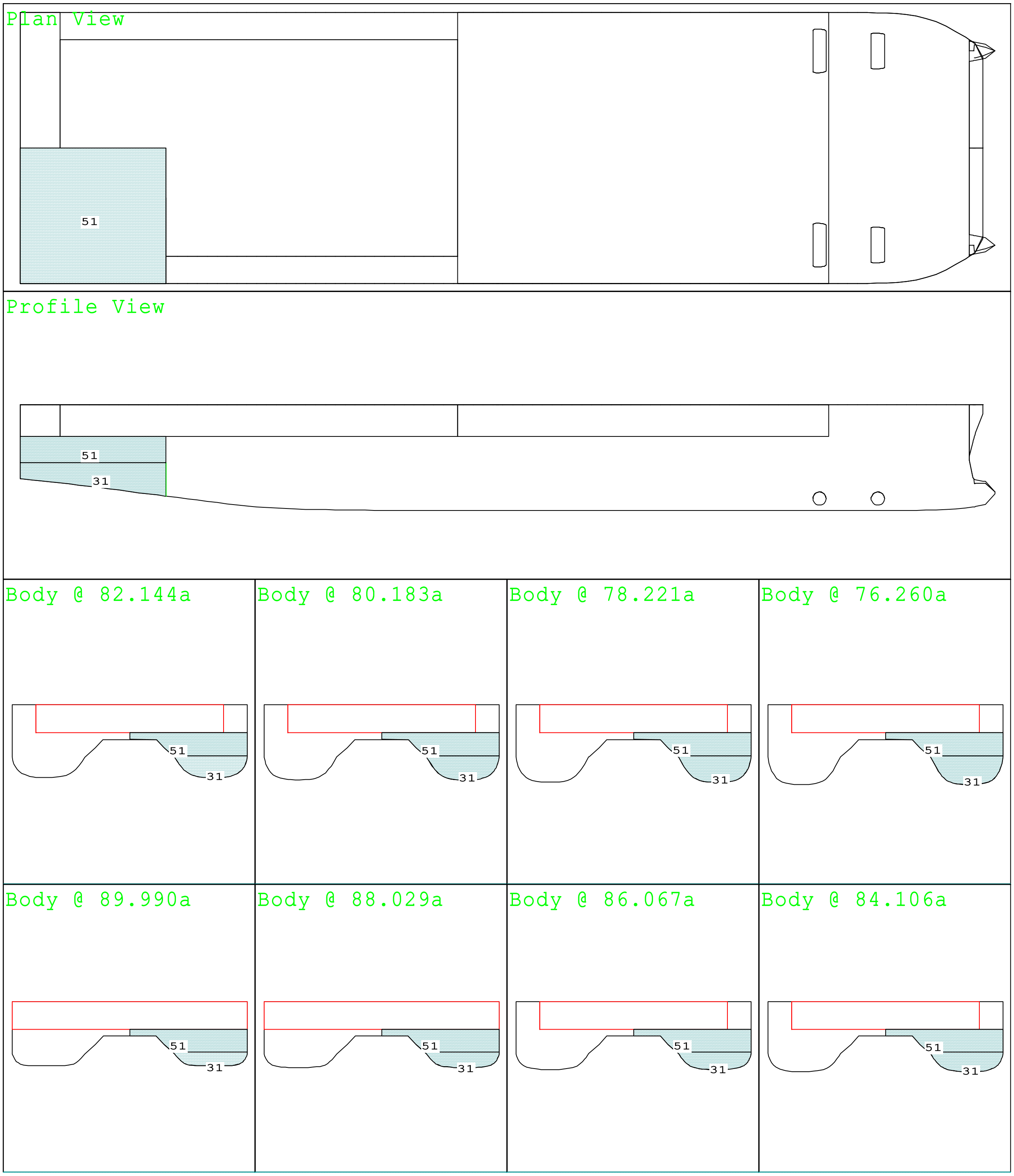


Tanks

	27 OILY_BILGE_2.S.100% SEA WATER	47 MID_MACH_4.S...100% SEA WATER
8 SWBT4.S........100% SEA WATER	29 CLN_BILGE_2.S..100% SEA WATER	49 ENG_RM_2.S.....100% SEA WATER

Division 11

Condition Graphic - Draft: -99.000 Trim: zero Heel: zero



Tanks

31 APT.S....100% SEA WATER Intact 51 STGEAR.S.100% SEA WATER Intact

Downflooding Points

	Critical Points		LCP	TCP	VCP
(1)	Aft Stbd Stair	FLOOD	73.750a	11.057s	10.000
(2)	Aft Port Stair	FLOOD	73.750a	11.057p	10.000
(3)	Fwd Stbd Stair	FLOOD	6.250a	7.843s	10.000
(4)	Fwd Port Stair	FLOOD	6.250a	7.843p	10.000
(5)	Aft Air Intake Stbd	FLOOD	73.895a	12.785s	14.067
(6)	Aft Air Intake Port	FLOOD	73.895a	12.785p	14.067
(7)	Fwd Air Intake Stbd	FLOOD	73.895a	12.785s	14.067
(8)	Fwd Air Intake Port	FLOOD	73.895a	12.785p	14.067
(9)	Aft Mech Door Stbd	FLOOD	62.500a	10.226s	7.000
(10)	Aft Mech Door Port	FLOOD	62.500a	10.226p	7.000

Distances in METERS.

Light-service draft (dl)

WEIGHT STATUS

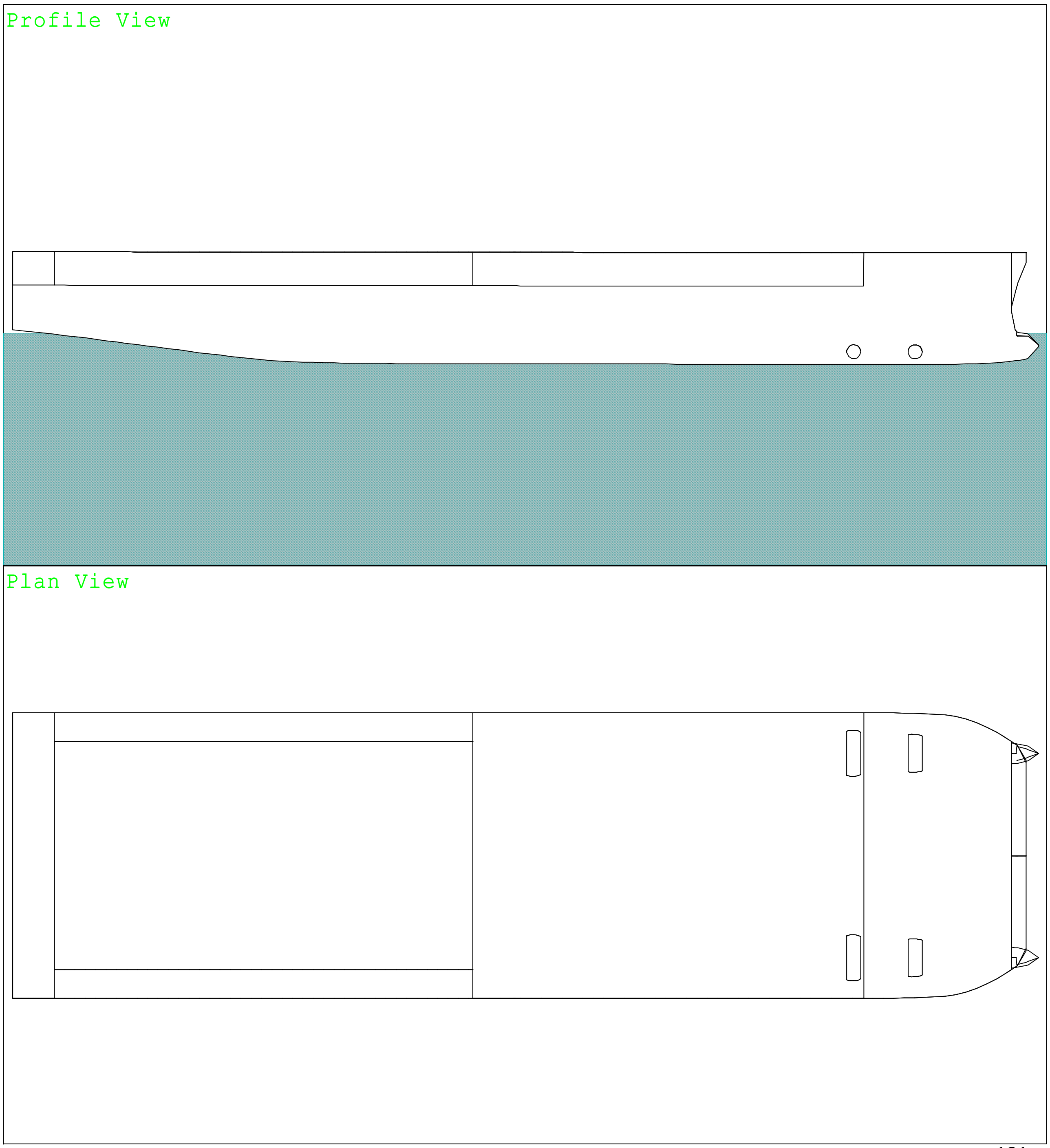
Trim: Fwd 0.07 deg., Heel: zero

Part	Weight(MT)	LCG	TCG	VCG
WEIGHT	1,999.60	42.530a	0.000	28.000

Distances in METERS.

Draft at LCF: 2.754
Draft at mid subdivision length: 2.758

Condition Graphic - Draft: 2.809 @ 0.000 Trim: fwd 0.07 deg. Heel: zero



Light-service draft (dl)

Executing DAMSTAB /sdi421P /side:STARBOARD /L:-1.941,90 /B:25.57 /DLL:3 /N:650,0 /macro:PROBSURV

PROBABILISTIC DAMAGE STABILITY MSC.421(98)
Passenger Vessel Version
Subdivision length: 91.941 Terminals: 1.941f, 90.000a
Breadth: 25.570 Draft: 2.758
Subdivision load line draft: 3.000

Divisions	P	Smin	P*S*V	A	Depth	Trim	Heel	Range	MaxRA
None	0.00000	1.000	0.000	0.000	2.809	0.07f	0.00	20.71	2.590
1	0.01112	1.000*	0.011	0.011	2.983	0.24f	0.46s	20.31	2.368
2	0.01502	1.000*	0.015	0.026	2.983	0.24f	0.46s	20.31	2.366
3	0.02199	1.000*	0.022	0.048	3.078	0.33f	0.80s	20.00	2.116
4	0.00385	1.000*	0.004	0.052	3.215	0.46f	1.40s	19.19	1.822
5	0.01451	1.000*	0.015	0.067	3.215	0.46f	1.40s	19.36	1.822
6	0.08659	1.000*	0.087	0.153	3.540	0.74f	3.23s	17.01	1.240
7	0.11184	0.990*	0.111	0.264	3.530	0.59f	5.35s	15.37	1.178
8	0.03069	1.000*	0.031	0.294	2.905	0.00	2.36s	18.46	2.088
9	0.02199	1.000*	0.022	0.316	2.845	0.05a	2.08s	18.72	2.210
10	0.08659	1.000*	0.087	0.403	2.637	0.34a	2.55s	18.24	2.243
11	0.11807	1.000*	0.118	0.521	2.696	0.13a	0.71s	19.92	2.480
		1-division damage:		**0.521**	**Probability of damage:**			**0.522**	
1+2	0.02493	1.000*	0.025	0.546	2.983	0.24f	0.46s	20.31	2.366
2+3	0.02624	1.000*	0.026	0.572	3.305	0.57f	1.43s	19.14	1.843
3+4	0.01459	0.994*	0.015	0.587	3.686	0.95f	2.93s	15.65	1.151
4+5	0.01233	1.000*	0.012	0.599	3.215	0.46f	1.40s	19.19	1.822
5+6	0.03667	0.000*	0.000	0.599	5.080	2.58f	10.50s	4.41	0.067
6+7	0.06053	0.000*	0.000	0.599	-7.048	0.42a	179.82s	0.00	
7+8	0.04856	0.584*	0.028	0.627	3.980	0.91f	11.21s	8.28	0.375
8+9	0.03390	1.000*	0.034	0.661	2.926	0.06a	3.52s	17.37	1.882
9+10	0.04237	0.991*	0.042	0.703	2.649	0.53a	5.43s	15.42	1.589
10+11	0.06078	0.945*	0.057	0.761	2.092	1.24a	6.22s	12.74	1.158
		2-division damage:		**0.240**	**Probability of damage:**			**0.361**	
1+2+3	0.01295	1.000*	0.013	0.774	3.305	0.57f	1.43s	19.14	1.843
2+3+4	0.00581	0.947*	0.006	0.779	4.082	1.40f	4.23s	12.85	0.769
3+4+5	0.01932	0.994*	0.019	0.798	3.686	0.95f	2.93s	15.65	1.151
4+5+6	0.01029	0.000*	0.000	0.798	5.080	2.58f	10.49s	1.79	0.028
5+6+7	0.00320	0.000*	0.000	0.798	-7.026	0.40a	179.78s	0.00	
6+7+8	0.00233	0.000*	0.000	0.798	-7.004	0.42a	179.56s	0.00	
7+8+9	0.01197	0.000*	0.000	0.798	4.097	1.00f	14.64s	3.63	0.077
8+9+10	0.01623	0.864*	0.014	0.812	2.715	0.63a	8.30s	12.72	1.180
9+10+11	0.00362	0.000*	0.000	0.812	-7.324	0.92a	178.95s	0.00	
		3-division damage:		**0.052**	**Probability of damage:**			**0.086**	
1+2+3+4	0.00189	0.947*	0.002	0.814	4.083	1.40f	4.23s	12.85	0.769
2+3+4+5	0.00508	0.947*	0.005	0.819	4.082	1.40f	4.23s	12.85	0.769

continued next page

Light-service draft (dl)

Divisions	P	Smin	P*S*V	A	Depth	Trim	Heel	Range	MaxRA
3+4+5+6	0.01163	0.000*	0.000	0.819	-5.658	0.82f	178.29s	0.00	
4+5+6+7	0.00073	0.000*	0.000	0.819	-5.393	0.97f	177.66s	0.00	
5+6+7+8	0.00000	0.000*	0.000	0.819	-6.961	0.39a	179.48s	0.00	
6+7+8+9	0.00011	0.000*	0.000	0.819	-7.004	0.42a	179.56s	0.00	
7+8+9+10	0.00437	0.000*	0.000	0.819	-7.075	0.55a	179.35s	0.00	
8+9+10+11	0.00076	0.000*	0.000	0.819	-7.324	0.92a	178.95s	0.00	
		4-division damage:		**0.007**		**Probability of damage:**		**0.025**	
1+2+3+4+5	0.00203	0.947*	0.002	0.821	4.083	1.40f	4.23s	12.85	0.769
2+3+4+5+6	0.00323	0.000*	0.000	0.821	-5.589	0.89f	178.20s	0.00	
3+4+5+6+7	0.00045	0.000*	0.000	0.821	-5.089	1.23f	177.23s	0.00	
4+5+6+7+8	0.00000	0.000*	0.000	0.821	-5.122	1.08f	176.82s	0.00	
5+6+7+8+9	0.00000	0.000*	0.000	0.821	-6.961	0.39a	179.48s	0.00	
6+7+8+9+10	0.00000	0.000*	0.000	0.821	-7.001	0.51a	179.17s	0.00	
7+8+9+10+11	0.00000	0.000*	0.000	0.821	-7.259	0.96a	178.45s	0.00	
		5-division damage:		**0.002**		**Probability of damage:**		**0.006**	
1+2+3+4+5+6	0.00086	0.000*	0.000	0.821	-5.589	0.89f	178.20s	0.00	
2+3+4+5+6+7	0.00000	0.000*	0.000	0.821	-4.962	1.35f	177.05s	0.00	
3+4+5+6+7+8	0.00000	0.000*	0.000	0.821	-4.718	1.41f	176.19s	0.00	
4+5+6+7+8+9	0.00000	0.000*	0.000	0.821	-5.122	1.08f	176.82s	0.00	
5+6+7+8+9+ 10	0.00000	0.000*	0.000	0.821	-6.935	0.46a	179.04s	0.00	
6+7+8+9+10+ 11	0.00000	0.000*	0.000	0.821	-7.154	0.91a	178.13s	0.00	
		6-division damage:		**0.000**		**Probability of damage:**		**0.001**	

Attained index in this condition: **0.821** **Total probability of damage:** **1.000**
Required index: **0.755**
Values marked with * computed by macro.

Distances in METERS. Angles in deg.

Intermediate draft (dp)

WEIGHT STATUS

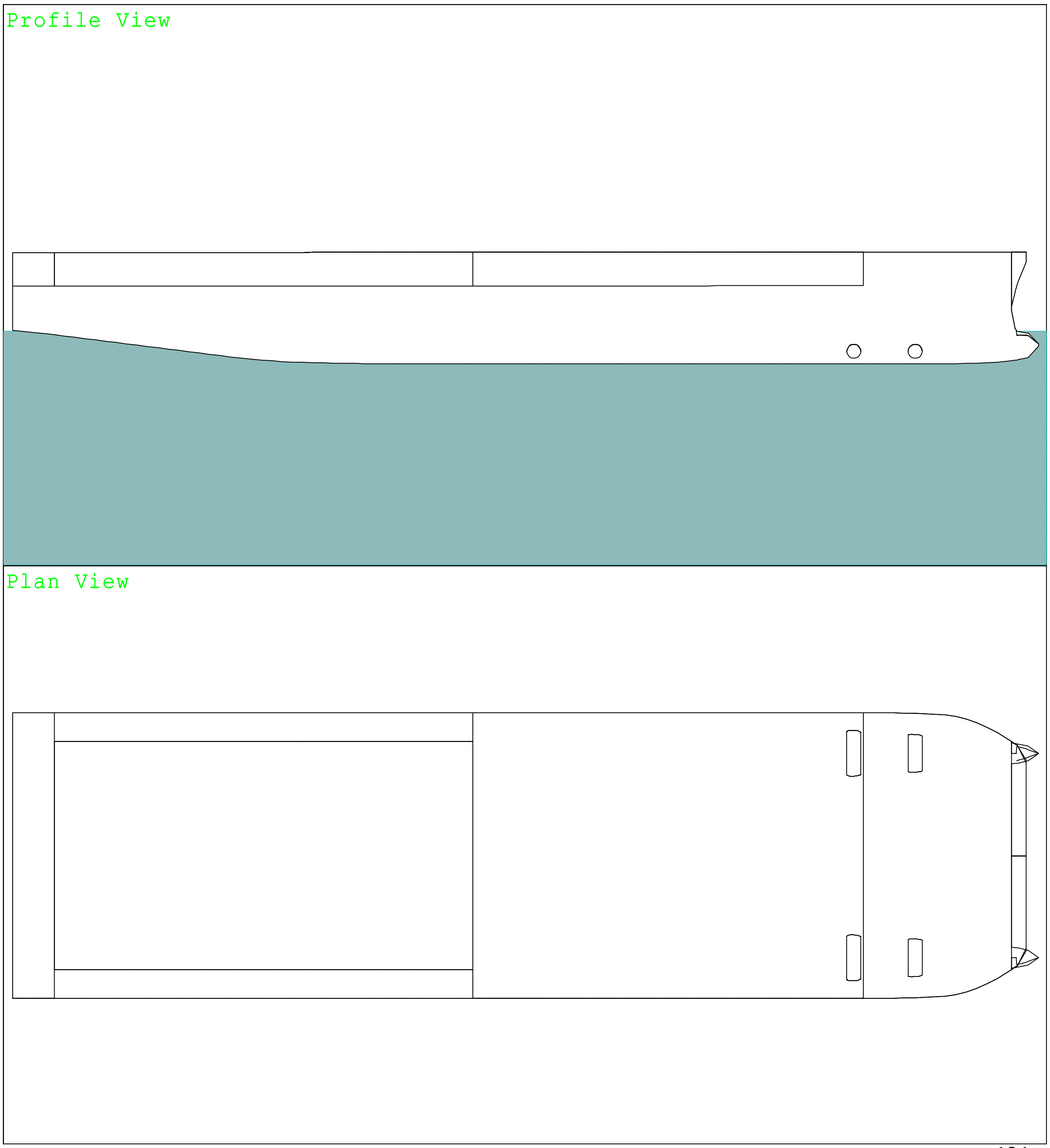
Trim: Aft 0.01 deg., Heel: zero

Part	Weight(MT)	LCG	TCG	VCG
WEIGHT	2,232.08	43.446a	0.000	26.000

Distances in METERS.

Draft at LCF: 2.975
Draft at mid subdivision length: 2.974

Condition Graphic - Draft: 2.966 @ 0.000 Trim: aft 0.01 deg. Heel: zero



Intermediate draft (dp)

Executing DAMSTAB /sdi421P /side:STARBOARD /L:-1.941,90 /B:25.57 /DLL:3 /N:650,0 /macro:PROBSURV

PROBABILISTIC DAMAGE STABILITY MSC.421(98)
Passenger Vessel Version
Subdivision length: 91.941 Terminals: 1.941f, 90.000a
Breadth: 25.570 Draft: 2.974
Subdivision load line draft: 3.000

Divisions	P	Smin	P*S*V	A	Depth	Trim	Heel	Range	MaxRA
None	0.00000	1.000	0.000	0.000	2.966	0.01a	0.00	22.53	2.689
1	0.01112	1.000*	0.011	0.011	3.135	0.15f	0.43s	22.16	2.487
2	0.01502	1.000*	0.015	0.026	3.135	0.15f	0.43s	22.15	2.487
3	0.02199	1.000*	0.022	0.048	3.235	0.25f	0.77s	21.81	2.244
4	0.00385	1.000*	0.004	0.052	3.379	0.38f	1.37s	20.94	1.960
5	0.01451	1.000*	0.015	0.067	3.379	0.38f	1.37s	21.29	1.960
6	0.08659	1.000*	0.087	0.153	3.735	0.68f	3.25s	19.07	1.410
7	0.11184	1.000*	0.112	0.265	3.717	0.52f	5.42s	17.21	1.329
8	0.03069	1.000*	0.031	0.296	3.076	0.07a	2.40s	20.25	2.169
9	0.02199	1.000*	0.022	0.318	3.010	0.12a	2.08s	20.53	2.276
10	0.08659	1.000*	0.087	0.404	2.792	0.43a	2.77s	19.86	2.318
11	0.11807	1.000*	0.118	0.522	2.792	0.30a	1.12s	21.34	2.532
		1-division damage:		**0.522**	**Probability of damage:**			**0.522**	
1+2	0.02493	1.000*	0.025	0.547	3.135	0.15f	0.43s	22.15	2.487
2+3	0.02624	1.000*	0.026	0.573	3.453	0.47f	1.36s	20.99	1.992
3+4	0.01459	1.000*	0.015	0.588	3.837	0.84f	2.81s	17.38	1.320
4+5	0.01233	1.000*	0.012	0.600	3.379	0.38f	1.37s	20.94	1.960
5+6	0.03667	0.772*	0.028	0.629	5.062	2.16f	8.95s	9.94	0.317
6+7	0.06053	0.000*	0.000	0.629	-6.901	0.40a	179.69s	0.00	
7+8	0.04856	0.587*	0.029	0.657	4.151	0.78f	11.50s	10.00	0.416
8+9	0.03390	1.000*	0.034	0.691	3.096	0.13a	3.67s	19.05	1.986
9+10	0.04237	1.000*	0.042	0.733	2.797	0.64a	5.83s	16.92	1.610
10+11	0.06078	0.851*	0.052	0.785	2.127	1.51a	7.31s	9.09	1.162
		2-division damage:		**0.263**	**Probability of damage:**			**0.361**	
1+2+3	0.01295	1.000*	0.013	0.798	3.453	0.47f	1.36s	20.99	1.992
2+3+4	0.00581	0.982*	0.006	0.804	4.201	1.24f	3.95s	14.85	0.961
3+4+5	0.01932	1.000*	0.019	0.823	3.837	0.84f	2.81s	17.38	1.320
4+5+6	0.01029	0.000*	0.000	0.823	5.063	2.17f	8.95s	5.18	0.168
5+6+7	0.00320	0.000*	0.000	0.823	-6.838	0.35a	179.59s	0.00	
6+7+8	0.00233	0.000*	0.000	0.823	-6.837	0.41a	179.33s	0.00	
7+8+9	0.01197	0.000*	0.000	0.823	4.254	0.82f	14.58s	6.09	0.140
8+9+10	0.01623	0.770*	0.012	0.836	2.862	0.76a	8.98s	9.92	1.276
9+10+11	0.00362	0.000*	0.000	0.836	-7.283	1.09a	178.69s	0.00	
		3-division damage:		**0.050**	**Probability of damage:**			**0.086**	
1+2+3+4	0.00189	0.982*	0.002	0.837	4.201	1.24f	3.95s	14.85	0.961
2+3+4+5	0.00508	0.982*	0.005	0.842	4.201	1.24f	3.95s	14.85	0.961

continued next page

Intermediate draft (dp)

Divisions	P	Smin	P*S*V	A	Depth	Trim	Heel	Range	MaxRA
3+4+5+6	0.01163	0.000*	0.000	0.842	-5.434	0.90f	178.19s	0.00	
4+5+6+7	0.00073	0.000*	0.000	0.842	-5.103	1.09f	177.45s	0.00	
5+6+7+8	0.00000	0.000*	0.000	0.842	-6.740	0.33a	179.16s	0.00	
6+7+8+9	0.00011	0.000*	0.000	0.842	-6.838	0.41a	179.33s	0.00	
7+8+9+10	0.00437	0.000*	0.000	0.842	-6.970	0.62a	179.10s	0.00	
8+9+10+11	0.00076	0.000*	0.000	0.842	-7.283	1.09a	178.69s	0.00	
		4-division damage:		**0.007**		**Probability of damage:**		**0.025**	
1+2+3+4+5	0.00203	0.982*	0.002	0.844	4.201	1.24f	3.95s	14.85	0.961
2+3+4+5+6	0.00323	0.000*	0.000	0.844	-5.357	0.97f	178.10s	0.00	
3+4+5+6+7	0.00045	0.000*	0.000	0.844	-4.757	1.38f	176.97s	0.00	
4+5+6+7+8	0.00000	0.000*	0.000	0.844	-4.764	1.23f	176.43s	0.00	
5+6+7+8+9	0.00000	0.000*	0.000	0.844	-6.740	0.33a	179.16s	0.00	
6+7+8+9+10	0.00000	0.000*	0.000	0.844	-6.840	0.54a	178.79s	0.00	
7+8+9+10+11	0.00000	0.000*	0.000	0.844	-7.192	1.16a	177.96s	0.00	
		5-division damage:		**0.002**		**Probability of damage:**		**0.006**	
1+2+3+4+5+6	0.00086	0.000*	0.000	0.844	-5.357	0.97f	178.10s	0.00	
2+3+4+5+6+7	0.00000	0.000*	0.000	0.844	-4.616	1.50f	176.79s	0.00	
3+4+5+6+7+8	0.00000	0.000*	0.000	0.844	-4.282	1.61f	175.70s	0.00	
4+5+6+7+8+9	0.00000	0.000*	0.000	0.844	-4.763	1.23f	176.43s	0.00	
5+6+7+8+9+10	0.00000	0.000*	0.000	0.844	-6.715	0.45a	178.54s	0.00	
6+7+8+9+10+11	0.00000	0.000*	0.000	0.844	-7.020	1.08a	177.45s	0.00	
		6-division damage:		**0.000**		**Probability of damage:**		**0.001**	
		Attained index in this condition:		**0.844**		**Total probability of damage:**		**1.000**	
		Required index:		**0.755**					
		Values marked with * computed by macro.							
Distances in METERS.									Angles in deg.

Deepest draft (ds)

WEIGHT STATUS

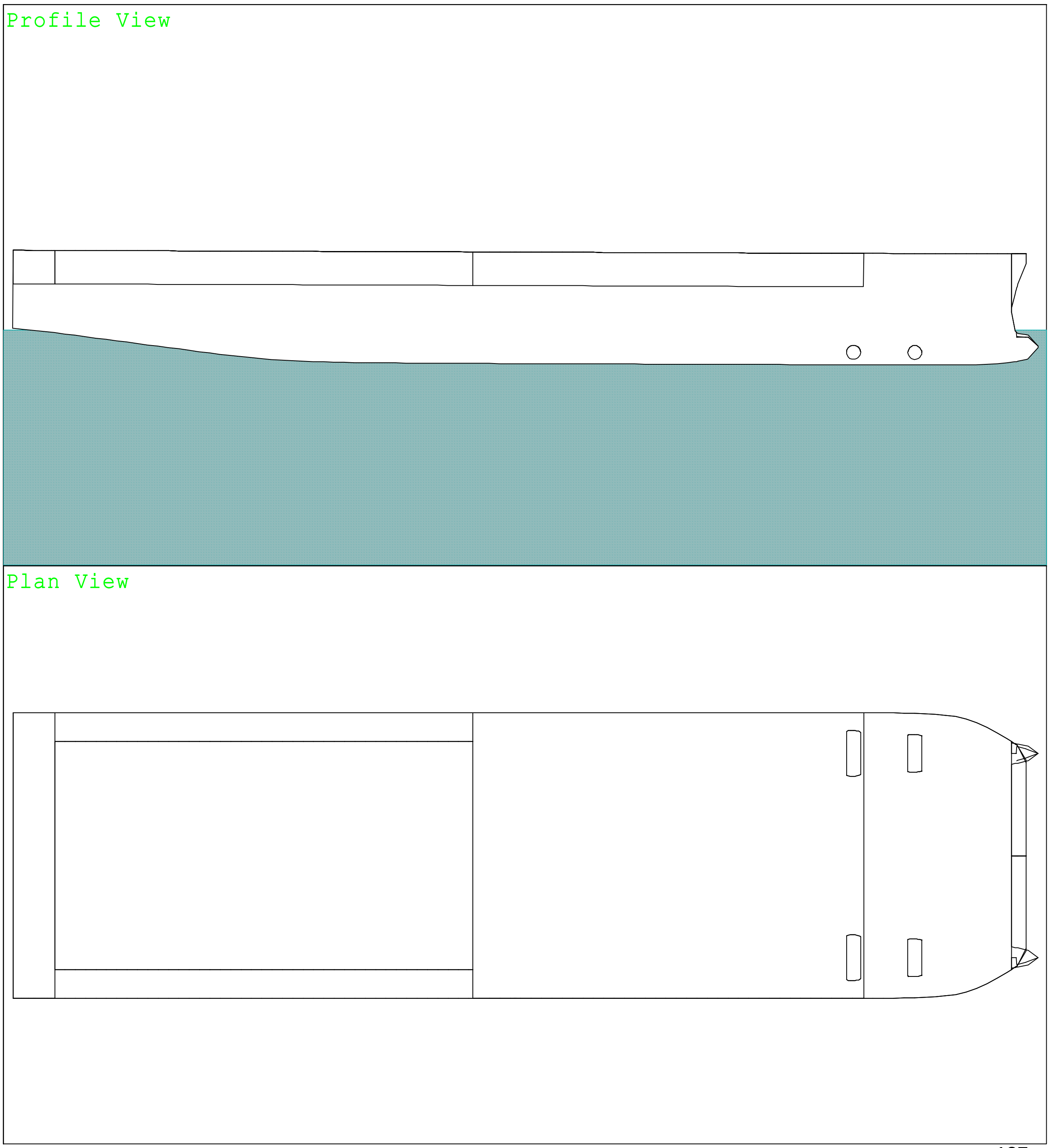
Trim: Fwd 0.21 deg., Heel: zero

Part	Weight(MT)	LCG	TCG	VCG
WEIGHT	2,281.59	42.716a	0.000	25.000

Distances in METERS.

Draft at LCF: 3.022
Draft at mid subdivision length: 3.039

Condition Graphic - Draft: 3.199 @ 0.000 Trim: fwd 0.21 deg. Heel: zero



Deepest draft (ds)

Executing DAMSTAB /sdi421P /side:STARBOARD /L:-1.941,90 /B:25.57 /DLL:3 /N:650,0 /macro:PROBSURV

PROBABILISTIC DAMAGE STABILITY MSC.421(98)
Passenger Vessel Version
Subdivision length: 91.941 Terminals: 1.941f, 90.000a
Breadth: 25.570 Draft: 3.039
Subdivision load line draft: 3.000

Divisions	P	Smin	P*S*V	A	Depth	Trim	Heel	Range	MaxRA
None	0.00000	1.000	0.000	0.000	3.199	0.21f	0.00	23.54	2.744
1	0.01112	1.000*	0.011	0.011	3.381	0.39f	0.45s	23.14	2.538
2	0.01502	1.000*	0.015	0.026	3.380	0.39f	0.45s	23.10	2.538
3	0.02199	1.000*	0.022	0.048	3.496	0.50f	0.83s	22.66	2.282
4	0.00385	1.000*	0.004	0.052	3.652	0.64f	1.48s	21.39	1.995
5	0.01451	1.000*	0.015	0.067	3.652	0.64f	1.48s	22.19	1.997
6	0.08659	1.000*	0.087	0.153	4.035	0.97f	3.49s	19.82	1.459
7	0.11184	1.000*	0.112	0.265	3.969	0.76f	5.45s	18.17	1.403
8	0.03069	1.000*	0.031	0.296	3.307	0.15f	2.38s	21.26	2.258
9	0.02199	1.000*	0.022	0.318	3.239	0.09f	2.05s	21.56	2.362
10	0.08659	1.000*	0.087	0.404	3.017	0.22a	2.68s	20.97	2.434
11	0.11807	1.000*	0.118	0.522	3.045	0.05a	0.95s	22.52	2.649
		1-division damage:		**0.522**		**Probability of damage:**		**0.522**	
1+2	0.02493	1.000*	0.025	0.547	3.381	0.39f	0.45s	23.10	2.538
2+3	0.02624	1.000*	0.026	0.573	3.726	0.73f	1.45s	21.54	2.022
3+4	0.01459	1.000*	0.015	0.588	4.153	1.16f	3.03s	17.37	1.319
4+5	0.01233	1.000*	0.012	0.600	3.652	0.64f	1.48s	21.39	1.995
5+6	0.03667	0.772*	0.028	0.629	5.386	2.50f	9.19s	10.77	0.379
6+7	0.06053	0.000*	0.000	0.629	-6.767	0.29a	179.63s	0.00	
7+8	0.04856	0.640*	0.031	0.660	4.363	0.96f	11.12s	11.47	0.494
8+9	0.03390	1.000*	0.034	0.694	3.324	0.08f	3.62s	20.10	2.092
9+10	0.04237	1.000*	0.042	0.736	3.021	0.43a	5.61s	18.15	1.782
10+11	0.06078	0.888*	0.054	0.790	2.423	1.20a	6.66s	9.93	1.500
		2-division damage:		**0.268**		**Probability of damage:**		**0.361**	
1+2+3	0.01295	1.000*	0.013	0.803	3.726	0.73f	1.45s	21.54	2.022
2+3+4	0.00581	0.979*	0.006	0.809	4.539	1.58f	4.22s	14.67	0.948
3+4+5	0.01932	1.000*	0.019	0.828	4.153	1.16f	3.03s	17.37	1.319
4+5+6	0.01029	0.000*	0.000	0.828	5.385	2.49f	9.19s	4.28	0.112
5+6+7	0.00320	0.000*	0.000	0.828	-6.675	0.21a	179.49s	0.00	
6+7+8	0.00233	0.000*	0.000	0.828	-6.692	0.29a	179.23s	0.00	
7+8+9	0.01197	0.000*	0.000	0.828	4.449	0.97f	13.86s	7.64	0.235
8+9+10	0.01623	0.804*	0.013	0.841	3.090	0.55a	8.60s	10.44	1.462
9+10+11	0.00362	0.000*	0.000	0.841	1.429	2.75a	16.34s	0.00	
		3-division damage:		**0.051**		**Probability of damage:**		**0.086**	
1+2+3+4	0.00189	0.979*	0.002	0.843	4.539	1.58f	4.22s	14.67	0.948
2+3+4+5	0.00508	0.979*	0.005	0.848	4.539	1.58f	4.22s	14.67	0.948

continued next page

Deepest draft (ds)

Divisions	P	Smin	P*S*V	A	Depth	Trim	Heel	Range	MaxRA
3+4+5+6	0.01163	0.000*	0.000	0.848	-5.211	1.10f	178.07s	0.00	
4+5+6+7	0.00073	0.000*	0.000	0.848	-4.851	1.30f	177.25s	0.00	
5+6+7+8	0.00000	0.000*	0.000	0.848	-6.561	0.19a	179.01s	0.00	
6+7+8+9	0.00011	0.000*	0.000	0.848	-6.693	0.29a	179.24s	0.00	
7+8+9+10	0.00437	0.000*	0.000	0.848	-6.854	0.52a	179.06s	0.00	
8+9+10+11	0.00076	0.000*	0.000	0.848	-7.162	0.97a	178.72s	0.00	
		4-division damage:		**0.007**		**Probability of damage:**		**0.025**	
1+2+3+4+5	0.00203	0.979*	0.002	0.850	4.539	1.58f	4.22s	14.67	0.948
2+3+4+5+6	0.00323	0.000*	0.000	0.850	-5.124	1.17f	177.96s	0.00	
3+4+5+6+7	0.00045	0.000*	0.000	0.850	-4.454	1.64f	176.71s	0.00	
4+5+6+7+8	0.00000	0.000*	0.000	0.850	-4.479	1.45f	176.15s	0.00	
5+6+7+8+9	0.00000	0.000*	0.000	0.850	-6.561	0.19a	179.01s	0.00	
6+7+8+9+10	0.00000	0.000*	0.000	0.850	-6.690	0.42a	178.67s	0.00	
7+8+9+10+11	0.00000	0.000*	0.000	0.850	-7.063	1.04a	177.95s	0.00	
		5-division damage:		**0.002**		**Probability of damage:**		**0.006**	
1+2+3+4+5+6	0.00086	0.000*	0.000	0.850	-5.124	1.17f	177.96s	0.00	
2+3+4+5+6+7	0.00000	0.000*	0.000	0.850	-4.288	1.78f	176.49s	0.00	
3+4+5+6+7+8	0.00000	0.000*	0.000	0.850	-3.918	1.90f	175.30s	0.00	
4+5+6+7+8+9	0.00000	0.000*	0.000	0.850	-4.478	1.46f	176.15s	0.00	
5+6+7+8+9+10	0.00000	0.000*	0.000	0.850	-6.528	0.30a	178.35s	0.00	
6+7+8+9+10+11	0.00000	0.000*	0.000	0.850	-6.859	0.94a	177.34s	0.00	
		6-division damage:		**0.000**		**Probability of damage:**		**0.001**	

Attained index in this condition: 0.850 **Total probability of damage: 1.000**
Required index: 0.755
Values marked with * computed by macro.

Distances in METERS. Angles in deg.

Appendix H: NavCad Powering Results

Propulsion

9 May 2024 08:27 AM
HydroComp NavCad 2020 [Premium]

Project ID
Description **90m RoPax Ferry**
File name **Catamaran Hull Model 5.2.hcnc**

Analysis parameters

Hull-propulsor interaction		
Technique:	[Calc]	Prediction
Prediction:		Holtrop
Reference ship:		
Max prop diam:		2250.0 mm
Corrections		
Viscous scale corr:	[On]	Custom
Rudder location:		Behind propeller
Friction line:		ITTC-57
Hull form factor:		1.000
Corr allowance:		0.000363
Roughness [mm]:	[Off]	0.00
Ducted prop corr:	[Off]	
Tunnel stern corr:	[Off]	

System analysis	
Cavitation criteria:	10% cav line
Analysis type:	Free run
CPP method:	
Engine RPM:	
Mass multiplier:	
RPM constraint:	
Limit [RPM/s]:	
Water properties	
Water type:	Salt
Density:	1026.00 kg/m3
Viscosity:	1.18920e-6 m2/s

Prediction method check [Holtrop]

Parameters	FN [design]	CP	LWL/BWL	BWL/T
Value	0.31	0.71	12.69	2.36
Range	0.06··0.80	0.55··0.85	3.90··14.90	2.10··4.00

Prediction results [System]

	HULL-PROPULSOR				ENGINE			FUEL PER ENGINE	
SPEED [kt]	PETOTAL [kW]	WFT	THD	EFFR	RPMENG [RPM]	PBENG [kW]	LOADENG [% rated]	VOLRATE [L/h]	MASSRATE [t/h]
2.00 !	5.4	0.0804	0.0949	0.9856	268	2.6	0.2	---	---
5.00	90.5	0.0795	0.0949	0.9856	683	38.7	2.7	---	---
9.00	524.6	0.0786	0.0949	0.9856	1228	215.6	15.0	---	---
13.00	1198.6	0.0781	0.0949	0.9856	1656	472.8	32.8	---	---
15.00	1807.2	0.0779	0.0949	0.9856	1902	709.9	49.3	---	---
17.00	2587.1	0.0778	0.0949	0.9856	2148	1012.8	70.3	---	---
+ 18.00 +	3047.3	0.0777	0.0949	0.9856	2270	1191.2	82.7	---	---
19.00	3557.4	0.0776	0.0949	0.9856	2392	1388.9	96.4	---	---
20.00	4119.7	0.0776	0.0949	0.9856	2514	1607.2	111.6	---	---
21.00	4736.6	0.0775	0.0949	0.9856	2636	1846.8	128.2	---	---

	CO2	EFFICIENCY			THRUST	
SPEED [kt]	CO2ENG [t/h]	EFFO	EFFOA	MERIT	THRPROP [kN]	DELTHR [kN]
2.00 !	---	0.6705	0.6309	0.42053	1.44	5.20
5.00	---	0.6756	0.6350	0.44041	9.72	35.19
9.00	---	0.6764	0.6352	0.43914	31.30	113.30
13.00	---	0.7003	0.6573	0.39568	49.50	179.22
15.00	---	0.7016	0.6584	0.39268	64.69	234.20
17.00	---	0.7028	0.6594	0.38999	81.71	295.82
+ 18.00 +	---	0.7033	0.6598	0.38873	90.90	329.07
19.00	---	0.7038	0.6602	0.38754	100.53	363.95
20.00	---	0.7043	0.6606	0.3864	110.60	400.40
21.00	---	0.7048	0.6610	0.3853	121.11	438.44

	POWER DELIVERY							
SPEED [kt]	RPMPROP [RPM]	QPROP [kN·m]	QENG [kN·m]	PDPROP [kW]	PSPROP [kW]	PSTOTAL [kW]	PBTOTAL [kW]	TRANSP
2.00 !	35	0.56	0.09	2.1	2.1	8.5	10.5	---
5.00	88	3.68	0.54	34.6	35.6	142.5	154.7	367.9
9.00	159	11.87	1.68	200.3	206.5	825.9	862.6	118.8
13.00	214	19.44	2.73	442.2	455.9	1823.6	1891.3	78.2
15.00	246	25.46	3.56	665.6	686.2	2744.9	2839.4	60.1
17.00	278	32.24	4.50	951.5	980.9	3923.6	4051.2	47.8
+ 18.00 +	294	35.90	5.01	1119.9	1154.5	4618.2	4764.8	43.0
19.00	309	39.74	5.54	1306.6	1347.0	5388.0	5555.4	38.9
20.00	325	43.77	6.10	1512.2	1559.0	6235.8	6428.7	35.4
21.00	341	47.97	6.69	1737.6	1791.4	7165.6	7387.2	32.4

Propulsion

9 May 2024 08:27 AM
HydroComp NavCad 2020 [Premium]

Project ID
Description **90m RoPax Ferry**
File name **Catamaran Hull Model 5.2.hcnc**

Prediction results [Propulsor]

	CAVITATION								
SPEED [kt]	SIGMAV	SIGMAN	SIGMA07R	TIPSPEED [m/s]	MINBAR	PRESS [kPa]	CAVAVG [%]	CAVMAX [%]	PITCHFC [mm]
2.00 !	**257.49**	**136.74**	**25.48**	**4.08**	**0.071**	**0.78**	**2.0**	**2.0**	**1915.7**
5.00	**41.11**	**21.01**	**3.93**	**10.41**	**0.144**	**5.31**	**2.0**	**2.0**	**1897.8**
9.00	**12.67**	**6.50**	**1.21**	**18.71**	**0.231**	**17.09**	**2.0**	**2.0**	**1899.9**
13.00	**6.06**	**3.57**	**0.66**	**25.23**	**0.269**	**27.03**	**2.2**	**2.2**	**1969.3**
15.00	**4.55**	**2.71**	**0.50**	**28.99**	**0.314**	**35.33**	**3.4**	**3.4**	**1974.0**
17.00	**3.54**	**2.12**	**0.39**	**32.73**	**0.365**	**44.62**	**5.3**	**5.3**	**1978.2**
+ 18.00 +	**3.16**	**1.90**	**0.35**	**34.59**	**0.395**	**49.64**	**6.6**	**6.6**	**1980.2**
19.00	**2.84**	**1.71**	**0.31**	**36.45**	**0.426**	**54.90**	**8.1**	**8.1**	**1982.0**
20.00	**2.56**	**1.55**	**0.28**	**38.31**	**0.461**	**60.40**	**10.1 !**	**10.1**	**1983.8**
21.00	**2.32**	**1.41**	**0.26**	**40.16**	**0.499**	**66.14 !**	**12.4 !!**	**12.4**	**1985.5**

	PROPULSOR COEFS								
SPEED [kt]	J	KT	KQ	KT/J2	KQ/J3	CTH	CP	RNPROP	
2.00 !	**0.7287**	**0.1641**	**0.02839**	**0.30899**	**0.07335**	**0.78684**	**1.1908**	**1.51e6**	
5.00	**0.7148**	**0.1705**	**0.02872**	**0.33379**	**0.078639**	**0.85**	**1.2766**	**3.84e6**	
9.00	**0.7163**	**0.1699**	**0.02863**	**0.33107**	**0.077903**	**0.84307**	**1.2647**	**6.90e6**	
13.00	**0.7678**	**0.1478**	**0.02579**	**0.25073**	**0.056984**	**0.63848**	**0.92507**	**9.36e6**	
15.00	**0.7712**	**0.1463**	**0.02559**	**0.246**	**0.055801**	**0.62644**	**0.90588**	**1.08e7**	
17.00	**0.7742**	**0.1450**	**0.02542**	**0.24184**	**0.054765**	**0.61583**	**0.88906**	**1.22e7**	
+ 18.00 +	**0.7757**	**0.1444**	**0.02534**	**0.23992**	**0.05429**	**0.61095**	**0.88135**	**1.29e7**	
19.00	**0.7770**	**0.1438**	**0.02526**	**0.23812**	**0.053844**	**0.60636**	**0.8741**	**1.35e7**	
20.00	**0.7783**	**0.1432**	**0.02519**	**0.23639**	**0.053418**	**0.60197**	**0.86719**	**1.42e7**	
21.00	**0.7795**	**0.1427**	**0.02511**	**0.23475**	**0.053014**	**0.5978**	**0.86063**	**1.49e7**	

Propulsion

9 May 2024 08:27 AM
HydroComp NavCad 2020 [Premium]

Project ID
Description **90m RoPax Ferry**
File name **Catamaran Hull Model 5.2.hcnc**

Hull data [Total for catamaran: Displ 2256.32 t; WidthOA 25.393 m]

General		(per demi-hull)
Configuration:		Catamaran
Chine type:		Round/multiple
Length on WL:		89.937 m
Max beam on WL:	[LWL/BWL 12.693]	7.085 m
Max molded draft:	[BWL/T 2.362]	3.000 m
Displacement:	[CB 0.575]	1128.16 t
Wetted surface:	[CS 5.247]	1650.041 m2
Keel-to-keel spacing:	[S/LWL 0.204]	18.308 m
ITTC-78 (CT)		**(per demi-hull)**
LCB fwd TR:	[XCB/LWL 0.520]	46.776 m
LCF fwd TR:	[XCF/LWL 0.450]	40.491 m
Max section area:	[CX 0.804]	17.100 m2
Waterplane area:	[CWP 0.831]	529.465 m2
Bulb section area:		1.700 m2
Bulb ctr below WL:		1.300 m
Bulb nose fwd TR:		91.942 m
Imm transom area:	[ATR/AX 0.000]	0.000 m2
Transom beam WL:	[BTR/BWL 0.000]	0.000 m
Transom immersion:	[TTR/T 0.000]	0.000 m
Half entrance angle:		9.00 deg
Bow shape factor:	[BTK flow]	-1.0
Stern shape factor:	[EX flat]	-2.0

Planing		(per demi-hull)
Proj chine length:		0.000 m
Proj bottom area:		0.000 m2
LCG fwd TR:	[XCG/LP 0.000]	0.000 m
VCG below WL:		0.000 m
Aft station (fwd TR):		0.000 m
Deadrise:		0.00 deg
Chine beam:		0.000 m
Chine ht below WL:		0.000 m
Fwd station (fwd TR):		0.000 m
Deadrise:		0.00 deg
Chine beam:		0.000 m
Chine ht below WL:		0.000 m
Propulsor type:		Propeller
Max prop diameter:		2250.0 mm
Shaft angle to WL:		0.00 deg
Position fwd TR:		0.000 m
Position below WL:		0.000 m
Transom lift device:		Flap
Device count:		0
Span:		0.000 m
Chord length:		0.000 m
Deflection angle:		0.00 deg
Tow point fwd TR:		0.000 m
Tow point below WL:		0.000 m
Foil assist (planing)		**(total)**
Foil count:		0
Total planform area:		0.000 m2
LCE fwd TR:		0.000 m
VCE below WL:		0.000 m
Lift-drag ratio:		0.0
Lift fraction (design):		0.00
Design speed:		0.00 kt

Propulsor data

Propulsor			
Count:		2	
Propulsor type:		Propeller series	
Propeller type:		FPP	
Propeller series:		B Series	
Propeller sizing:		By power	
Reference prop:			
Blade count:		4	
Expanded area ratio:		0.4605	[Size]
Propeller diameter:		2250.0 mm	[Keep]
Propeller mean pitch:	[P/D 0.9875]	2221.8 mm	[Size]
Hub immersion:		1850.0 mm	
Engine/gear			
Drive line:		Standard	
Gear input:		Single engine	
Engine data:		Generic diesel	
Rated RPM:		2250 RPM	
Rated power:		1440.0 kW	
Primary fuel:		MGO	
Secondary fuel:		None	
Gear efficiency:		0.970	
Load correction:		On	
Gear ratio:		7.732	[Size]
Shaft efficiency:		0.970	

Propeller options	
Oblique angle corr:	Off
Shaft angle to WL:	0.00 deg
Added rise of run:	0.00 deg
Propeller cup:	0.0 mm
KTKQ corrections:	Standard
Scale correction:	Full ITTC
KT multiplier:	1.000
KQ multiplier:	1.000
Blade T/C [0.7R]:	Standard
Roughness:	Standard
Cav breakdown:	Off
Design condition [By power]	
Max prop diam:	2250.0 mm
Design speed:	18.00 kt
Reference power:	1440.0 kW
Design point:	1.000
Reference RPM:	2250.0 RPM
Design point:	1.050

Appendix I: Owner's Requirements

OWNER'S REQUIREMENTS FOR A ROPAX FERRY

Introduction
A ferry operator in the Puget Sound intends to replace an aging Ro-Pax ferry with a more modern and fuel-efficient version. The ferry will have capacity for 100 four wheeled vehicles and 650 passengers. Due to the limited trip length, no staterooms are required. The maximum operational speed is 20 kts.

Ferry Route
From Port Angeles, WA to Victoria, British Columbia.

A one-way trip along this route is approximately 20 NM. At a service speed of 20 kts, this will result in a one-way trip length of approximately one hour, not including cargo loading and unloading times.

The vessel will run a maximum of eight one-way trips per day during the summer and four one-way trips per day during the winter. At each stop, the vessel will either fully load or unload all cargo.

Vehicle and Passenger Cargo
The vehicle deck will be capable of supporting 100 four-wheeled cars, SUVs, and light trucks. Assuming an average vehicle length of five meters, the ferry's main deck will therefore have 500 lane-meters of vehicle space.
There will be structural capacity for loading and transporting a limited number of straight and/or articulated heavy trucks. Heavy trucks will replace space occupied by four-wheeled vehicles—heavy trucks will not be carried in addition to the 100 four-wheeled vehicles.
Seating will be provided for 650 passengers on the main deck with provision for food and beverage service. No passenger cabins are necessary, given the length of route.

Loading and Discharging
Passengers and vehicles (cars and trucks) will be loaded via roll-on/roll-off ramps at the stern of the vessel. Vehicles will be driven or towed onto the ferry. Passengers will arrive in vehicles or on foot. No other cargo is to be carried.

Limiting Particulars
LOA: Minimum length based on vehicle deck area requirements.
Beam: Minimum beam to accommodate sufficient lanes on the vehicle deck.
Draft: Consideration for depth of harbor at ferry dock
Air Draft: Consideration for bridges and other air draft restrictions
Tonnage: Minimize to reduce draft, wetted surface area, crewing, and resistance.

Speed, Range, DWT
Trial Speed at design draft – 20 knots
Range – In excess of 1250 NM (allows for refueling once per week).

Classification
American Bureau of Shipping (ABS) classification

Registry
USA or Canada

Complement
Minimum crew necessary to comply with registry, operational, and regulatory requirements.

Special Design Considerations

- Ro-ro ramp design restrictions due to the configuration of the ferry docks in Port Angeles and Victoria.
- Selection of propulsion plant and generators to minimize carbon emissions for EEDI compliance.
- Waste heat recovery system to supply HVAC energy.
- Structural capacity for vehicle loading on Main deck
- Maneuverability for docking without the aid of tugs.
- Does not need to be Jones Act compliant as route crosses an international border.
- Capacity for electric car charging.
- Fire suppression system suitable for lithium battery fires.
- Open deck for trucks carrying hazardous cargos.
- Utilization of commonly available fuel.

Applicable Regulations

- Canadian Transportation Agency's Ferry Accessibility for Persons with Disability Code of Practice
- International Convention for the Prevention of Pollution from Ships (MARPOL)
- International Convention for the Safety of Life at Sea (SOLAS)
- International Load Line Convention (LLC)
- International Maritime Dangerous Goods (IMDG) Code
- International Maritime Organization (IMO)
- Transport Canada (TC)
- United States Coast Guard (USCG)