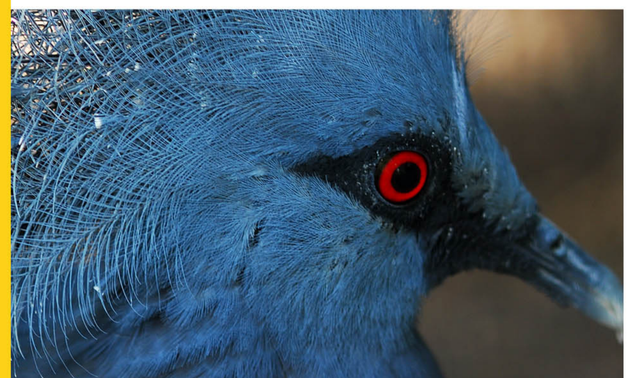

PNG TRIumph

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REGISTRATION NO. 0714

EXECUTIVE SUMMARY

The *PNG TRIumph* is a concept design produced to satisfy the requirements set forth by the World-wide Ferry Safety Association's 2014 Ferry Design Competition. With the aid of industry and faculty mentors, this project was undertaken by five graduate students from the University of British Columbia. This vessel is intended to operate on the 750 nautical mile route between the Papua New Guinean cities of Lae and Kavieng. Safety considerations were of prime importance during the design, with the overcrowded Rabaul Queen capsizing along this route in 2012. The *TRIumph* is intended to be innovative, providing superior stability while maintaining its affordability. Further safety, affordability, and innovation design considerations are detailed below.

Safety

Rules & Regulations

- Designed to Lloyd's Register 100A1 Passenger Ferry Tri specifications
- Compliance with SOLAS 2000 with 2 compartment flooding
- Accommodation spaces designed to MLC 2006 specifications
- Compliance with 2008 IMO Intact Stability Code

Stability

- Increased damage stability redundancy due to mono-tri hybrid design
- Survivability with at least 258% passenger overcrowding

Operational Safety

- Greater sea keeping performance compared to equivalent monohull or catamaran
- Side hull flare improves roll and heave damping
- Higher cross-deck structure height reduces wave slamming impacts
- Large double bottom and cross-deck structure allow for ease of construction and safer maintenance
- Increased manoeuvrability, redundancy, and control during docking with the addition of a bow thruster and twin propeller azimuth drives

Safety Equipment

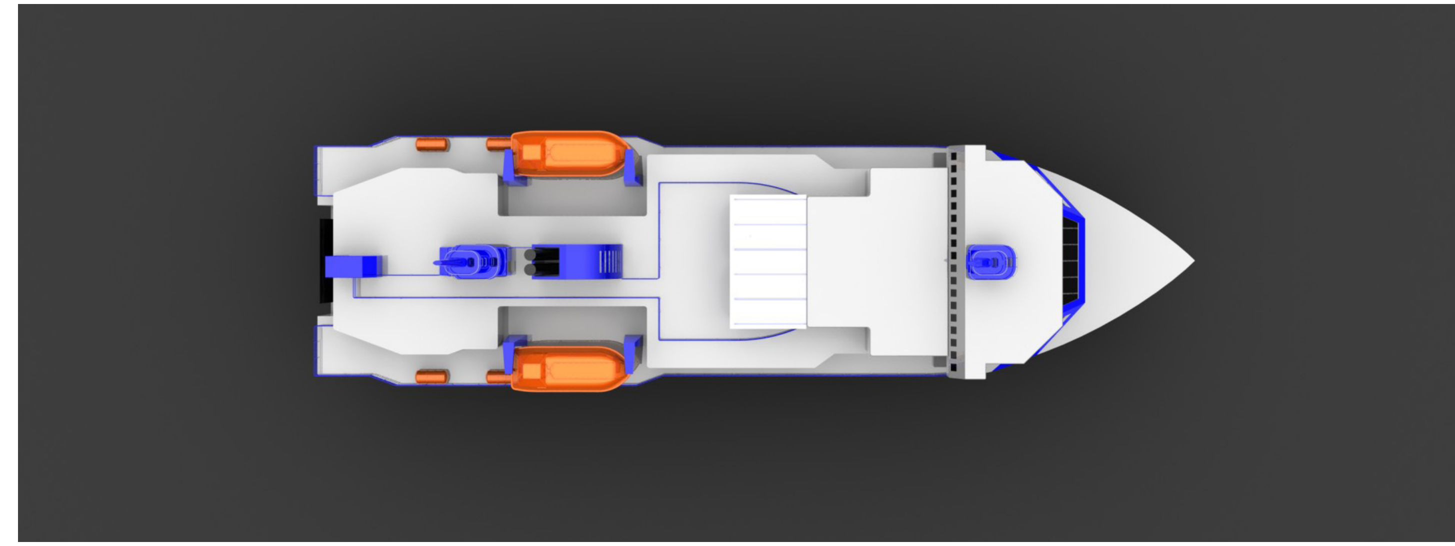
- Quick deployment chute evacuation system allow for evacuation of 215 persons in 11 minutes
- Two 101 person life rafts per side
- Two SOLAS approved fast rescue boats located on car deck for quick launching in emergencies
- One 50 person lifeboat per side
-Easy to follow evacuation routes to muster areas
- Conveniently located life vests under seats and in cabins

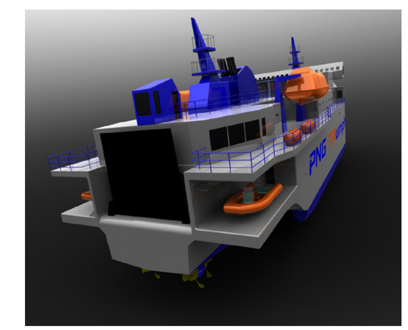
Innovation

- Hull selection feasibility study was done to arrive at superior tri-mono hybrid hull form
- Optimal side hull length and location for increased manoeuvring performance, deck space, and wave cancellation effects
- Excellent stability characteristics allow for ballast-less operation leading to reduced lifecycle costs and maintenance
- Counter-ballast in opposing side hull helps correct heel if a side hull is flooded
- Selected propeller system optimizes for maximum manoeuvrability and efficiency
- Large deck area with a trimaran permits easy future adaptability to other markets while maximizing revenue from cargo
- Longitudinal and transverse hybrid framing system helps reduce cost and weight
- Convenient and pleasing viewing areas located throughout the vessel increasing passenger enjoyment
- Accessible design features larger cabins, restrooms, hallways, and multi-deck lift access
- Modular cabin design for ease in manufacturing
- If acquisition cost permits, solar panels could provide large savings

Affordability

- Hull form uses hard chine, fully-developable geometry to simplify and reduce construction costs as well as allow for production in less-sophisticated shipyards.
- Hybrid framing system designed to reduce man-hours and cost
- Twin propulsion and engine arrangement offers increased efficiency and wider power operating range
- Structure designed with mild steel to minimize material and assembly (ie. welding) costs
- Designed with block construction and pre-outfitting in mind
- Medium speed diesel engines reduce operating costs
- Large deck area permits easy future adaptability to other markets while maximizing revenue from cargo
- Excellent stability characteristics allow for ballast-less operation leading to reduced lifecycle costs and maintenance
- Enclosed free space was minimized throughout the vessel to discourage overcrowding and minimize air conditioning loads





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HULL FORM SELECTION

One of the first major decisions when designing a new ship is the type of hull to use. In the early stages of the *TRIumph* project, well before it had its name or even a conceptual size, it was not immediately apparent that the final vessel would be a trimaran. In fact, many hours were spent discussing the advantages and disadvantages of each hull type.

To fully comprehend the performance benefits of all alternatives a very extensive and thorough analysis would be done. However, as in most environments involving ship design, time was limited. Therefore, as typical with many naval architecture assessments, a qualitative rather than quantitative approach was used in the hull form selection. Unfortunately theses assessments are generally based upon experience, a quality the designers of the *TRIumph* were and still are limited in. Consequently, knowledge of varying hull forms was gathered from a wide variety of published sources (see references list) and correspondence with industry.

Following are the major facts of the three hull types originally considered as well as a comparative table referenced during early design (Andrews, 2001).

Monohull

Advantages

- High carrying capacity
- Versatile in most environments
- Simple to operate, maintain and construct
- Lower building cost
- Easier docking
- Lighter structure
- Good manoeuvrability
- Simple general arrangement (i.e. one machinery space)
- Lower risk (it's been done before)

Limitations

- Higher power requirements at increased speeds
- Poor operability in rough seas
- Requires larger beam for high stability
- Reduced damage stability

Catamaran

Advantages

- Large deck space
- Increased roll Stability
- Decreased resistance at high speeds
- Increased manoeuvrability

Limitations

- Uncomfortable "cork screwing" motion in open seas
- Requires large cross deck structure
- Highest structural weight overall
- Relatively expensive and complicated to construct
- Requires two hull machinery spaces
- More difficult maintenance due to small machinery spaces

Trimaran

Advantages

- Lowest power requirements at medium to higher speeds
- Increased damage and roll stability
- Large carrying capacity and deck space
- Best operability
- Increased comfort in open seas
- Increased weight efficiency compared to catamaran
- One central machinery space
- Increased adaptability

Limitations

- Generally longer, harder to manoeuver and dock
- Requires a cross deck structure (although less stringent than a catamaran)
- More complicated construction compared to monohull

A multi criteria decision matrix of the three hull types considered was formed using preliminary findings and anecdotal evidence provided by industry. This was perceived as the best approach to choosing an optimum hull given the time constraints. Categories were established and weighted by the *TRIumph* designers based upon their respective significance according to the mission profile. The hull types were then ranked in each category on a scale from 1 to 5 and a total weighted score was established for each vessel type. As seen below, major emphasis was put upon affordability, safety and the intact and damage stability of the vessel. Passenger comfort was also given high importance.

The trimaran was determined to be the most ideal hull form to meet competition requirements as well as the standards set by the designers.

ASPECTS	*Monohull*	*Catamaran*	*ACV*	*SES*	*Hydrofoil*	*SWATH*	*HYSWAS*	*WIG*	*Trimaran*
Speed, Power and Endurance	Good	Good[1]	Very Good[2]	Good	Very Good[2]	Good	Good	Very Good	Good
Space and Layout	Good	Good	Average	Good	Poor	Very Good	Poor	Poor	Very Good
Structural Design and Weight	Very Good	Average	Poor	Poor	Very Poor	Average	Poor	Very Poor	Good
Stability	Good	Good	Good	Good	Good[3]	Good	Good	Poor	Very Good
Manueverability	Good	Average	Poor	Good	Good	Average	Good	Poor	Good
Noise, Radar & Magnetic Signatures	Good	Average	Good	Good	Good	Very Good	Good	Good	Very Good
Weapon Placement & Effectiveness	Good	Average	Average	Average	Poor	Good	Average	Poor	Very Good
Construction Cost and Build Time	Very Good	High	Very High	High	Very High	Good	High	Very High	Good
Through Life Costs	Good	Average	Very High	High	Very High	Average	High	Very High	Very Good

1. But bad in deep ocean seaway
2. Very fast but limited to hull borne (slow) speed in seaway and endurance is poor (fuel weight)
3. Very good hull borne but foil borne degraded by wave effects in Deep Ocean

A comparative table of varying vessel types. The reader should focus on the monohull, catamaran and trimaran. (Andrews, 2001)

Multi Criteria Decision Matrix

Requirements	Weight	Mono	Cat	Tri
Cost of Manufacturing	18.5	4.5	2.5	3
Intact Stability	17.5	3	4.5	4
Damage Stability	15.3	3	3	4.5
Passenger Comfort	10.0	3.5	3.5	4
Payload Capacity	7.6	3	4	3.5
Hull Resistance	10.5	4	3	3.5
Manoeuvrability	5.0	3	4	2.5
Maintenance	8.6	4	3	3
Innovation	7.0	2	4	4.5
SCORE	**100**	**345**	**342**	**367**

The trimaran hull form scored the best according to the criteria set by the TRIumph designers.

It is the wholehearted wish of the *TRIumph* team that the reader will come to agree with this statement at the conclusion of this report. To re-enforce this, comparisons were conducted between the *TRIumph* and multiple reference monohulls where possible. No suitable data existed to compare to catamarans.

Nevertheless, the designers feel that a monohull comparison is more valid as it is a more conventional hull type, it is the type currently in service in the PNG region, and it would almost certainly be the hull form selected if not for the trimaran.

Reference Monohulls for Comparison

In terms of general stability, the *TRIumph* was compared to the Robert Allan Ltd. (RAL) designed 50 m RORO ferry and the winner of last year's WFSA competition, the UBC designed *Bangladesh River Ferry*.

In terms of general powering, the *TRIumph* was once again compared to the *RAL RORO*. The UBC ferry was not considered a valid comparison due to the nature of the environments for operation (shallow river vs. deep ocean).

A table of particulars for the three vessels is shown below (please refer to the stability and powering sections to view the comparisons).

Vessel Particulars

	PNG TRIumph	RAL 50m RORO	UBC Bangladesh River Ferry
Vessel Type	Trimaran	Monohull	Monohull
LOA (m)	63.4	53.9	56.7
LWL (m)	60.2	50.2	54.7
Beam (m)	16.5	12.1	12.7
Draught (m)	3.7	3.0	2.4
Midship Area (m2)	29.6	30.6	21.4
Displacement (tonnes)	1174	982	791
Cb	0.55 (main) 0.64 (sides)	0.53	0.47
Cp	0.66 (main) 0.91 (sides)	0.64	0.68
L/B overall	3.65	4.14	4.3
B/T overall	4.46	3.98	5.3
Design Speed (kn)	14	14	10
Passenger Capacity	256	100	500
Auto Capacity	36	20	-

WEIGHTS & VOLUMES

The determination of space and volume requirements is a pivotal problem in the design of passenger ships. This task was tackled in parallel with that of hull form selection. Requirements for the hull and superstructure were treated separately to promote clarity. The hull was split into tanks and machinery spaces. The superstructure was split into categories of crew, passenger, safety, and miscellaneous spaces (see appendices).

It was hypothesised that if the required deck area and volume was identified, the approximate hull parameters could be estimated and guesstimate of the number of vehicles could be made. These estimates of areas and volumes would then partially hint at the feasibility of the potential hull forms in question. Further yet, a completed list of required areas would allow the preliminary design of the general arrangement to begin and promote a more holistic approach to the design process. Essentially, this approach allowed the design team to categorize the "musts" and the "wants" for the project and allowed for the parametric exploration of the design space. As data on many mono hull, catamaran, and trimaran vessels had been accumulated, the design team was free to vary the 3 principle dimensions in order to obtain the required volume and area.

Initial areas and volumes were estimated through the use of coefficients for passenger vessels presented in "Practical Ship Design", independent research, and industry feedback. Spaces were either a function of their required volume or area. Margins were included to compensate for errors and a preliminary volume for the superstructure was calculated. Crew space requirements were ultimately dictated by MLC 2006 guidelines.

Next, areas and volumes for the hull were determined. Machinery and technical spaces were calculated using coefficients presented in Kai Levander's "System Based Ship Design" (SBSD) approach. A preliminary power estimate was found through research of similar vessels and industry feedback. This power estimate was then translated into a volume via appropriate coefficients. The tanks were calculated as per mission requirements.

Lightship Weight					
Weight Group	Scale by	Value	Unit	Coefficient (tonnes/unit)	Weight (tonnes)
Hull	Volume	1562.10	m^3	-	324.48
Superstructure	Volume	2156.26	m^3	0.070	150.94
Furnished Spaces	Area	503.56	m^2	0.100	50.36
Comfort System	Area	16.43	m^2	0.028	0.46
Machinery	Total Power	2000.00	kW	0.025	50.00
Machinery Outfitting	Total Power	2000.00	kW	0.011	21.00
Ship Outfitting	Volume	5585.82	m^3	0.010	55.86
Electricity & Automation	Volume	5585.82	m^3	0.005	27.93
Car Deck	Volume	1867.47	m^3	0.070	130.72
Total before margin:					**811.75**
Margin (5%):					**40.59**
Total including margin:					**852.33**
Deadweight					
Weight Group	Scale by	Value	Unit	Coefficient (tonnes/unit)	Weight (tonnes)
Crew	Occupancy	15	person	0.1	1.73
Passengers & Luggage	Occupancy	200	person	0.085	17.00
Stores	Occupancy	645	persons*days	0.01	6.45
Trucks	Occupancy	16	vehicle	2.5	40.00
Cars	Occupancy	28	vehicle	1.5	42.00
Fuel Oil	-	63.54	m^3	0.87	55.28
Fresh Water	-	60	m^3	1	60.00
Minor Tanks	-	70.6	m^3	-	0.55
Ballast Water	-	61.77	m^3	1.025	0.00
Misc Tanks	-	-	tonnes	-	10.00
Safety Equipment	-	23.94	tonnes	1	23.94
Total before margin:					**256.94**
Margin (5%):					**12.85**
Total including margin:					**269.79**
Concept Totals					**Weight (tonnes)**
Total before margin:					**1068.69**
Margin (5%):					**53.43**
Total including margin:					**1122.12**

A summary of the tank capacities can be found on page 14 with pertinent calculations in the appendix. Finally, volumes were transformed into a lightship weight through the use of coefficients provided in SBSD and by industry. A preliminary lightship weight breakdown can be seen in the table on the right.

Final Lightship Weight

The final lightship calculation was done using the typical SWBS sections. It should be noticed that group 300 is missing from the table below. This was because the weight coefficient utilised for group 400 includes a weight margin for group 300. The majority of weight is attributed to group 100 as expected. The structural weight was calculated by using the determined scantling weights for a typical web frame around amidship and

Final Lightship Summary				
Weight Group	Weight (tonnes)	LCG (m)	TCG (m)	VCG (m)
100 - Structure	520	28.5	0.00	5.2
200 - Machinery, Mechanical & Propulsion	94	14.8	0.00	3.6
400 - Communication, Command & Surveillance	28	39.3	0.00	9.2
500 - Auxiliary Systems	29	47.8	0.00	4.5
600 - Outfit	132	29.9	0.04	8.0
TOTAL LIGHTSHIP WEIGHT:	803	28.2	0.01	5.6
Note:				
LCG measured as positive forward of frame 0				
TCG measured as positive port of centreline				
VCG measured as positive upward from baseline				

an ordinary frame in way of the machinery space at frame 22 (see strucural design section). These section weights were then extrapolated for the length of the vessel with appropriate margins applied to areas of higher or lower curvature (see appendices for a detailed structural weight calculation). The machinery weights were a function of the selected machinery and coefficients provided by industry. Outfitting weights were largely a function of the calculated cabin weights with additional weight being added for outfitting in machinery spaces via coefficients. A more detailed breakdown of the final lightship weight can be found in the appendices.

Comparing the final lightship with the conceptual lightship weight, it can be seen that there is approximately a 6% difference. The design team was surprised at the accuracy of the various weight coefficients used in the concept design stage. In fact, excluding margins, the final lightship weight was within 1% of conceptual lightship weight. Nevertheless, the design team was cognicent of the fact that these values may still be inaccurate and a more detailed analysis should be done in the next iteration of the design spiral.

HULL FORM DEVELOPMENT

Introduction

This section outlines the design methodology utilised in the development of the *PNG TRIumph*. Sections are broken up into centre hull and side hull development.

Reference Vessels

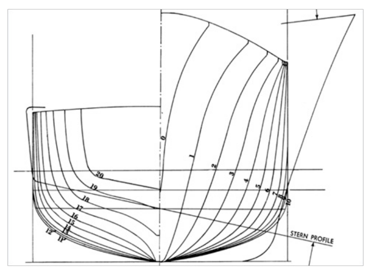
Existing vessels were analysed which provided a base from which to start from. The two main vessels that were examined were the Benchijigua and White Rabbit as seen in the figures below, respectively.

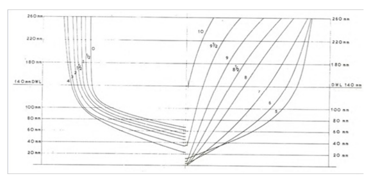
These vessels provided a basis for the development of a long, slender centre hull (L/B =7) while maintaining relatively small outriggers (<6% of total displacement each as outlined by Lloyd's Register). Complete list of design parameters can be found in the appendices.

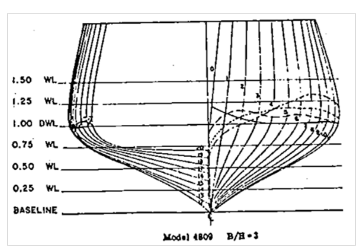
Centre Hull Development

Reference Hull Forms

Several existing hull forms were analysed that were believed to meet the general hull requirements. Due to manufacturing complexities, as well as low block coefficients, the NPL, DD 692 and Series 60 hulls (shown in figures below) were only used as a visual reference.



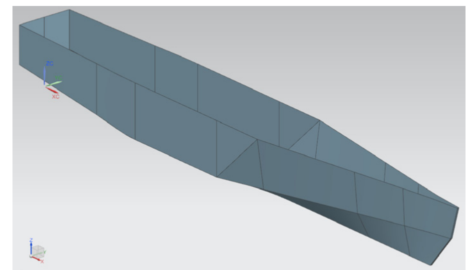


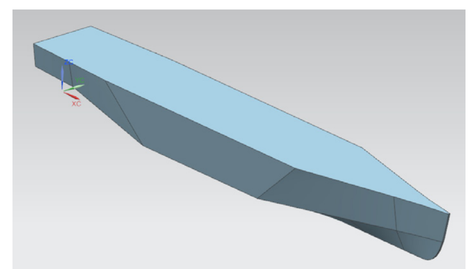


Design Process

The centre hull went through much iteration. In order to reduce manufacturing costs, the initial design involved a wall sided hull form with a single hard chine. These efforts produced a very boxy hull as seen below. The next iteration saw the stem smoothed and the transom brought much closer to the water line. These changes helped to reduce the overall hull resistance but still had several areas with abrupt transitions that were affecting the flow patterns around the vessel.

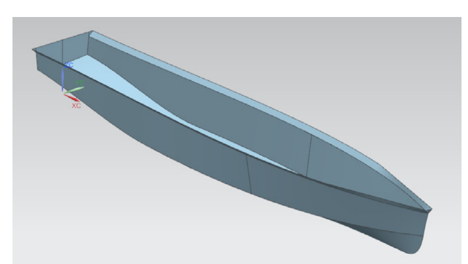
The final iteration of the centre hull created a smooth hull from bow to stern while maintaining a single hard chine. The transom was effectively tapered to reduce drag as well as maximize space for the propeller. The final centre hull can be seen below.

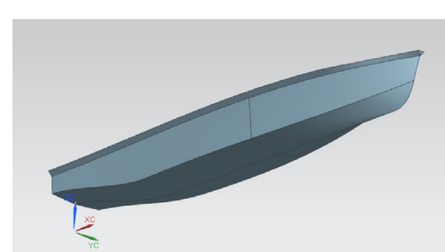




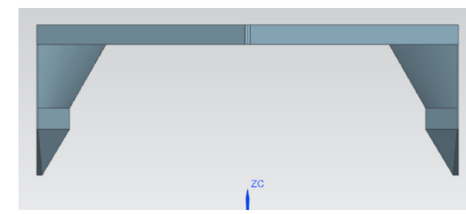
Outrigger Development

The initial outrigger design was conceived using Lloyd's guidelines for maximum displacement (6% each) and length (60% of total) while maintaining a simple, boxy design similar to the initial centre hull design. The initial concept was an asymmetric inboard configuration which can be seen below.

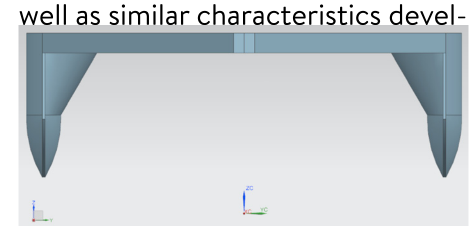




Upon further research, a study illustrating the effects of hull interference for trimarans was utilised (Ackers et al., 1997). Depending on the Froude number at which the vessel would be operating at, plots were developed which illustrate the most effective placement and type of outrigger that should be used. For this scenario (Froude Number of 0.3) the outrigger design was changed to a symmetric shape that was centred at midship. The transverse placement of the outriggers was also chosen to maximise wave cancellation effects.

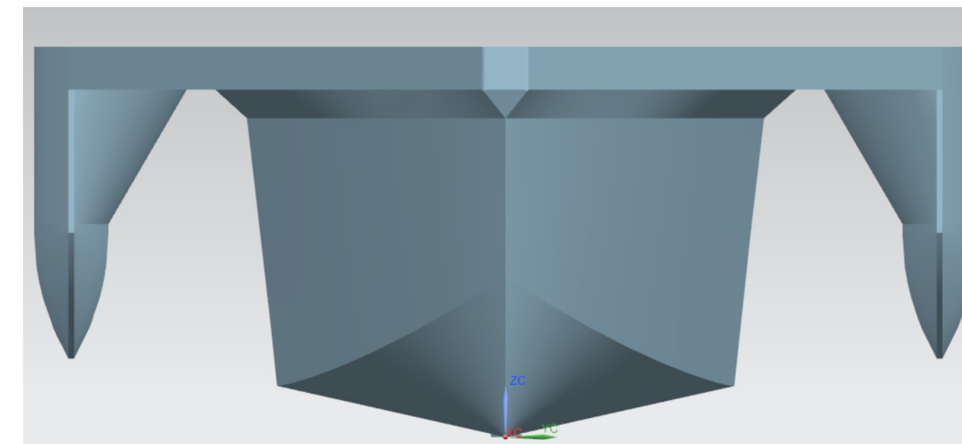


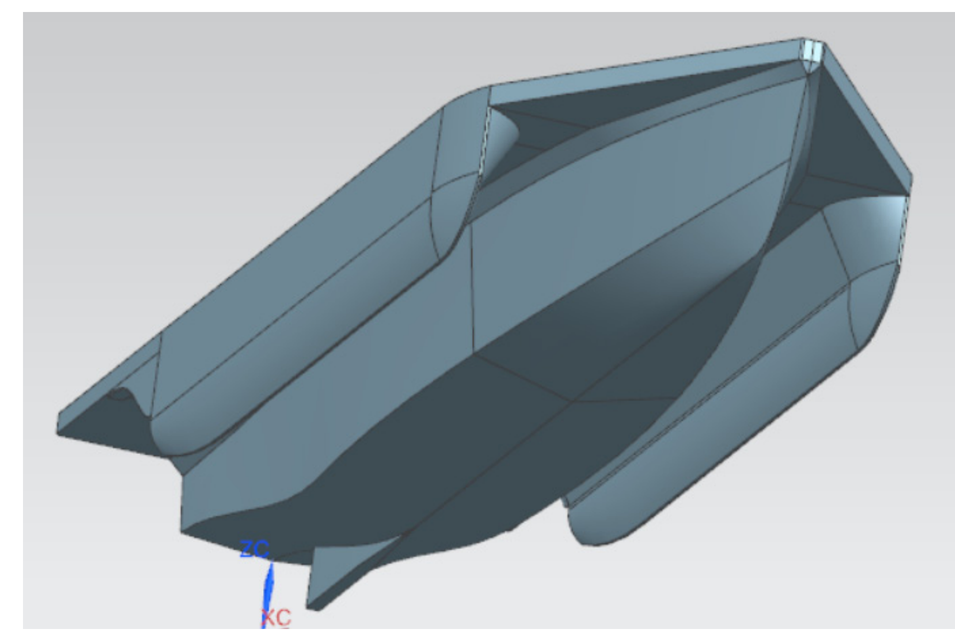
The final outrigger design (shown below) incorporated the information from the aforementioned study as well as similar characteristics developed in the centre hull. The outriggers were smoothed to eliminate hard transitions and the supports were extended closer to the waterline to improve the vessels heeling characteristics.

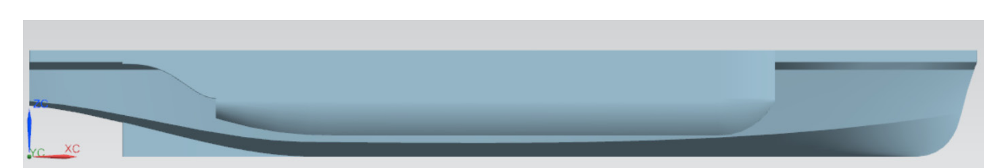


Final Design

The final design of the hull can be seen below. A skeg was added to the centre hull and extra support was added to the stern of the outriggers for structural reasons. The overall beam of the vessel was determined by the vehicle deck requirements and in turn determined the placement of the outriggers. The final beam, waterline length and draft of the hull were 16.5m, 60m and 5.7m, respectively. A complete lines plan can be found in the appendices.







VESSEL OVERVIEW

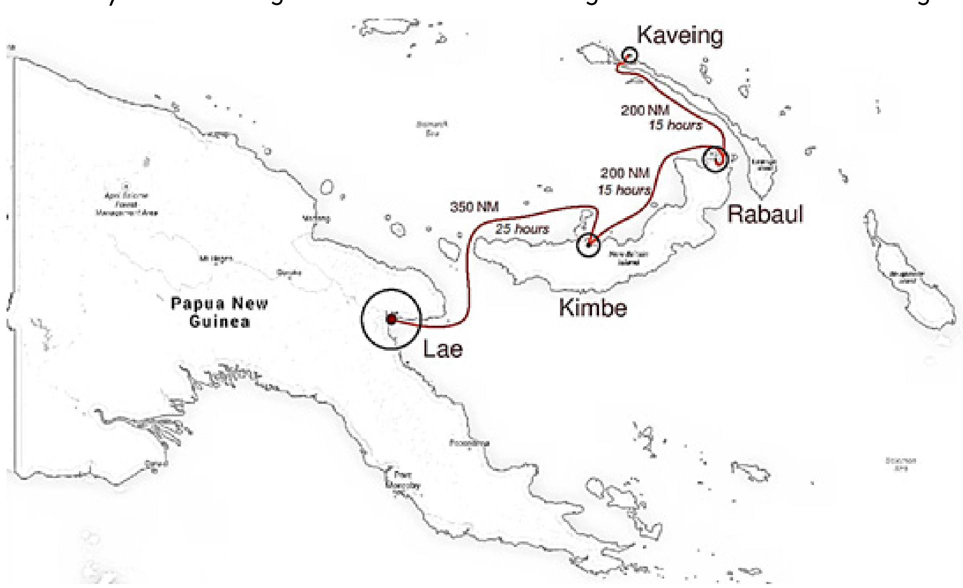
Introduction

The following section outlines the principle particulars and operating profile of the *PNG TRIumph.* Further opportunities for implementation in Indo-Pacific markets are also explored.

Area of Operation

The *TRIumph* will operate between the four Papua New Guinea cities detailed in the figure below. Lae has a population of 100,000, with its constituent province of Morobe having a population of 650,000. City and region populations are illustrated in the figure below through the circle and ring marker diameters, respectively. Distances and approximate transit times with a 14 knot design speed are also detailed.

With a range of 1,000 nautical miles, the vessel is capable of travelling between any two of the four cities. However, this is dependent on the port facilities and replenishment capability of each city. Based on population, it is likely that Kaveing will not be visited during each excursion. Excluding

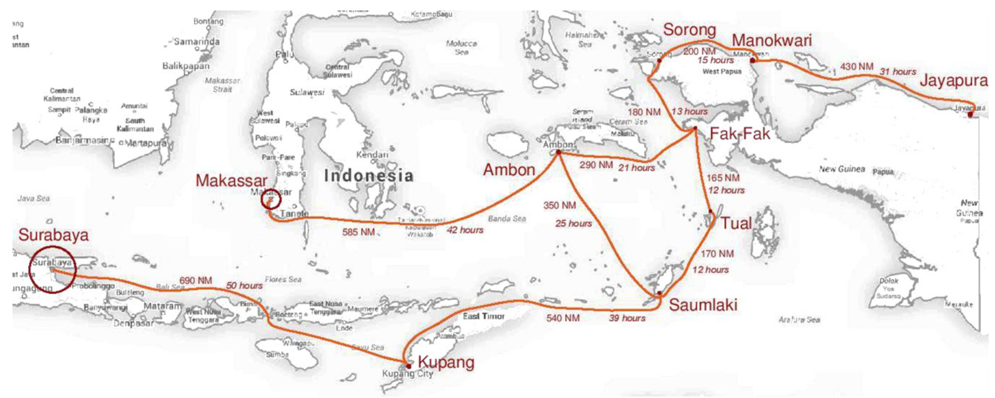


the Kaveing arm, the *TRIumph* would be able to sail twice weekly along the Lae to Rabaul route, with ample time allotted at port. This is similar to the former Rabaul Queen, which sailed from Lae to Rabaul twice weekly.

Further Opportunities for Implementation

The South Pacific contains numerous developing island nations and there are diverse opportunities for a safe and affordable ferry. These nations range from Indonesia, with a population of 240,000,000 to Niue, with a population under 1,500. A trimaran offers a stable, safe design which may be utilized across a broad range of ferry capacities. The *TRIumph* is viewed as suitable for overnight voyages between cities supporting regions with populations between 100,000 to 300,000. The *TRIumph's* capacity would exceed or be insufficient for populations outside of this range.

The adjacent figures show potential *TRIumph* routes for Indonesia and are based off of existing ferry routes. The vessel likely has too large of a capacity for much of the sparsely populated south pacific. Western Indonesia has the population base to support the *TRIumph* and routes from the metropolitan centres of Surabaya and Makassar are shown. The *TRIumph* has multiple implementation opportunities beyond Papua New Guinea and it is highly suitable for nation archipelagos such as Indonesia and the Philippines.



Classification and Regulation

The ferry will operate solely within PNG territorial waters and will likely require subsidy from the PNG government. Due to this relationship, it is logical that the *TRIumph* will be registered under Papua New Guinea and will thus be subject to its regulations.

The vessel will be built according to Lloyd's Register, ✠100A1 Passenger Ferry Tri regulations. Lloyd's Register was selected due to its large presence within the South Pacific. The nearest office located in Cairns, Queensland, a distance of 840 NM.

The safety aspects of the *TRIumph* were developed in accordance to SOLAS and IMO Intact Stability regulations. Last, the crew space was designed to meet MLC 2006 accommodation and lavatory requirements.

Table of Ship Particulars

Particular	Unit	Main Hull	Side Hull	Overall
Length Overall	m	-	-	63.4
Length WL	m	60.2	36	60.2
Beam WL	m	8.59	1.3	16.5
Draft	m	3.57	2.2	3.7
Outrigger Offset	m	-	2.65	-
Depth	m	6.82	-	-
Midship Area	m^2	25.64	2	-
Waterplane Area	m^2	406.25	45.32	-
LCB (amidship)	%	-1.42%	-0.82%	-1.34%
Cruise Speed	knots	-	-	14
Maximum Speed	knots	-	-	18
Wetted Surface	m^2	681.04	160.98	1003
% WS	%	67.90%	16.05%	100.00%
Displacement	tonnes	1040.33	67.26	1174.85
% Displacement	%	88.50%	5.72%	100.00%
L/B	-	7.01	27.69	3.65
B/T	-	2.41	0.59	4.46
Cb	-	0.55	0.64	-
Cm	-	0.84	0.7	-
Cp	-	0.66	0.91	-
Cw	-	0.79	0.97	-
Fr	-	0.3	0.38	-
KB	m	-	-	2.19
KG	m	-	-	5.59
GM	m	-	-	3
Economy Seating	-	-	-	122
Premium Seating	-	-	-	54
Cabins	-	-	-	20 x 4
Automobile Capacity	-	-	-	36
Crew Capacity	-	-	-	16

GENERAL ARRANGEMENT

The following sections detail the major considerations during the General Arrangement (GA) development.

Class Separation

An important consideration in the GA design was establishing adequate separation between the different fare grades. This was to ensure that facilities provided for higher-fare passengers are not utilized by the lower fare grades. The passengers were divided into economy, premium, and cabin classes. Cabin and premium classes were provided with combined common areas to minimize duplication of facilities, floor space, and operating costs. Economy class was provided with its own facilities and will be separated during normal operation. Economy class will be most prone to overcrowding and it was thus desirable to compartmentalize it from other ship areas to minimize the risk of overcrowding throughout the vessel.

Safety

Passenger overcrowding risks decreasing the metacentric height to unsafe and unstable levels. To decrease this effect, the major passenger areas were placed on the lowest superstructure deck. The economy class, which will be most prone to overcrowding, was entirely constrained to this deck. This ensures that during overcrowding events, the cumulative passenger weight will be at minimal distance from the water. A small enclosed free space was allotted to economy to decrease the area available for overcrowding. Last, a minimum of two means of egress were provided throughout the vessel. These were distributed for easily navigable pathways to the liferafts and lifeboats during an emergency.

Accessibility

The vessel was designed to allow for universal passenger access, regardless of mobility issues. Two of the twenty passenger cabins were modified to accommodate wheelchair patrons. These cabins have minimum 1525 mm clearances to allow for wheelchair manoeuvring throughout. A central lift was provided to allow for disabled passenger movement between decks.

Affordability

Enclosed free space was minimized throughout the vessel to decrease air conditioning loads and thus operating expenses. To decrease construction costs, modularized cabins were utilized and complex geometry, such as curvature, was minimized to increase manufacturability.

The following section details the design selection of safety areas and equipment in the *PNG TRIumph*.

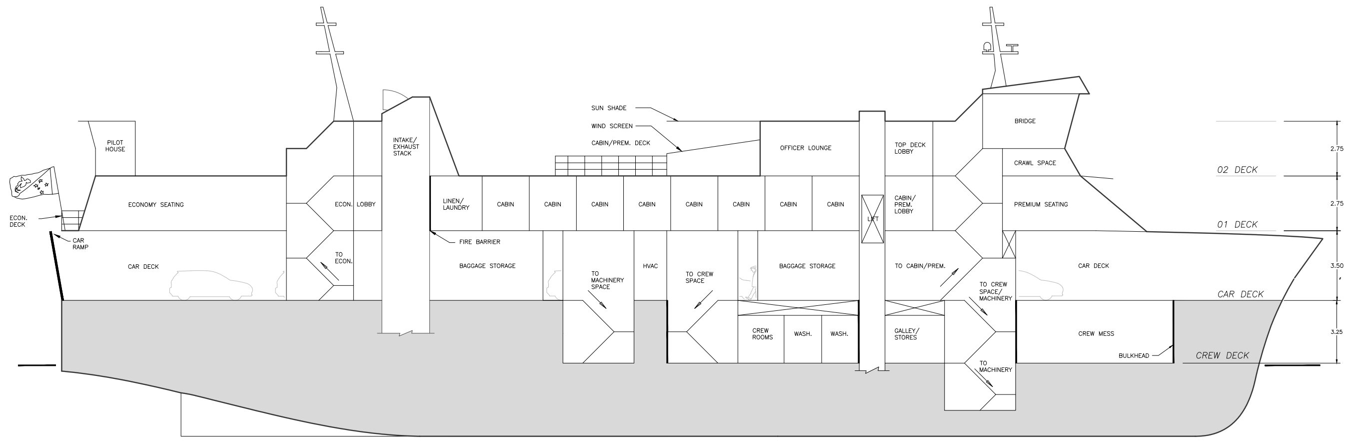
Safety Equipment and Areas

The International Convention for the Safety of Life at Sea (SOLAS) governed the selection of safety equipment for the concept design as well as specific design features.

- Lifeboats/Liferafts placed on main passenger deck to provide minimal travel distance to evacuation points. Lifeboat, liferaft, and the fast-response vessels' size and capacities are detailed in the adjacent table. The fast response vessels were placed on the car deck to facilitate rapid launching.
- Passenger evacuation routes to muster areas indicated on drawings. Muster area of 125 m^2, exceeding SOLAS requirements of 0.35 m^2 per passenger.
- Designated storage area available for over 300 lifejackets of 60 mm x 30 mm x 7.5 mm packaged dimension in addition to those under passenger seats and within cabins. Stored lifejackets will be provided in infant, child, and adult sizes. Lifejackets will also be stowed on the bridge, in the engine control room, and in crew accommodation.
- The concept design must carry at minimum 12 lifebuoys on both sides of the ship and on all open decks extending to the vessel's sides. One lifebuoy on each side of the ship is fitted with a 30 m buoyant lifeline complying with requirements of the code. Six lifebuoys, equally distributed on both sides of the vessel, have self-igniting lights while two of these are also equipped with self-activating smoke signals with lights. Each lifebuoy is marked in block capitals of the Roman alphabet with *PNG Triumph* and Papua New Guinea, the port of registry of the ship.

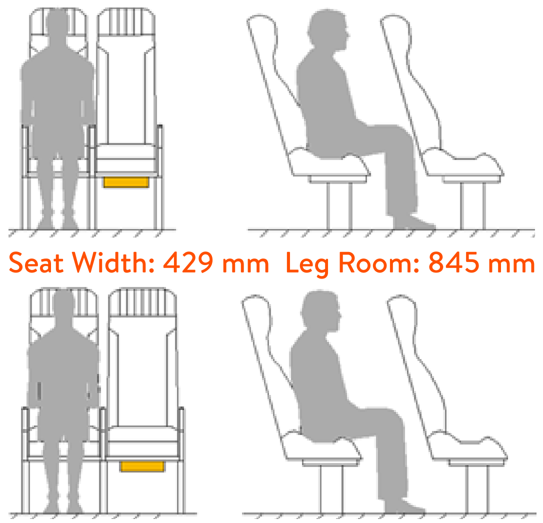
Major Safety Equipment

Equipment	Quantity (per side)	Dimensions (weight) L x W x H	Passengers Capacity	Launching System
Lifeboat (partially	2 (1)	8.1 x 3.1 x2.96 (4195 kg)	100	Hydraulic Davit
Fast Rescue Boat	2 (1)	6 x 2.45 x 1.254 (785 kg)	6	Slewing Arm Davit
Liferafts (self righting)	8 (4)	1.45 x 0.8 x 0.74 (266 kg)	404	Marine Evacuation System



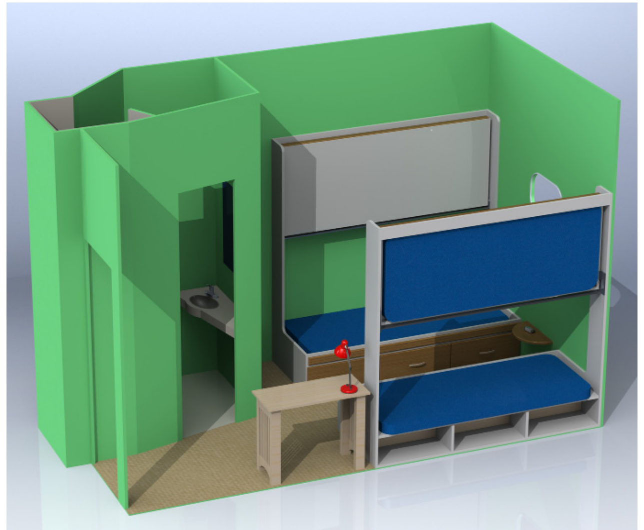
The ferry will be loaded and unloaded over the stern for maximum safety and efficient use of deck space. Passengers are located on the two decks above the main car deck, and crew are located on a lower deck situated above the deepest load waterline. Officers are located on the upper deck close to the Bridge. 'Tween deck heights for lower, car, 01 and 02 decks are 2.4, 3.5, 2.75 and 2.75 metres respectively.

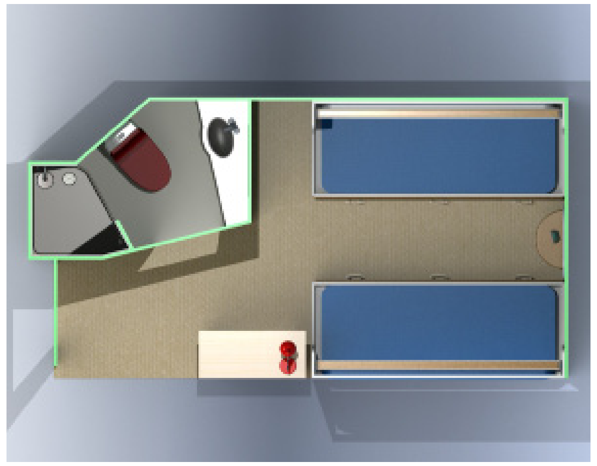
Seating differences between Economy (top) and Premium (bottom). Spacing is based on European train standards with lifejackets to be located under each seat.



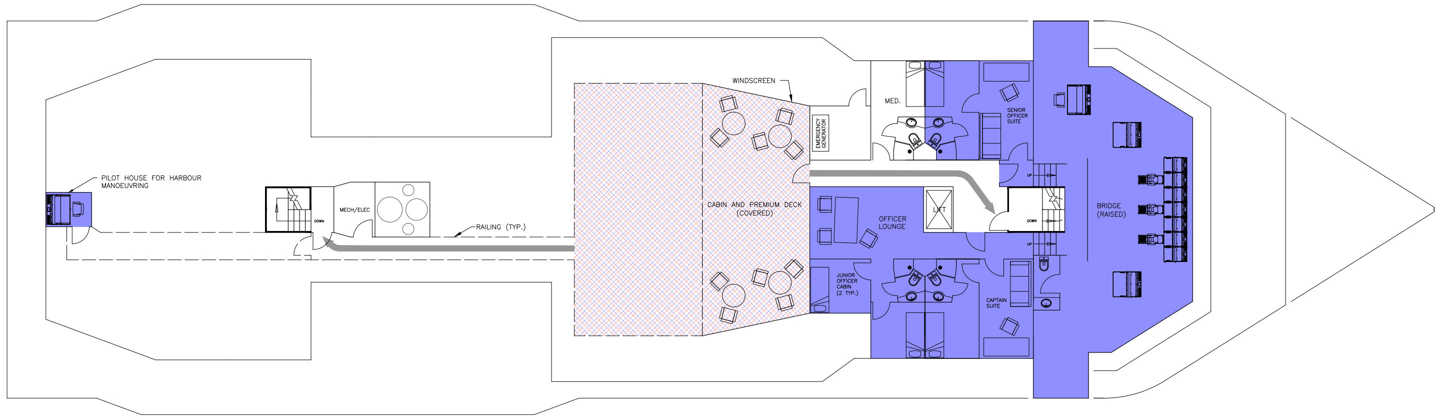
Seat Width: 429 mm Leg Room: 845 mm

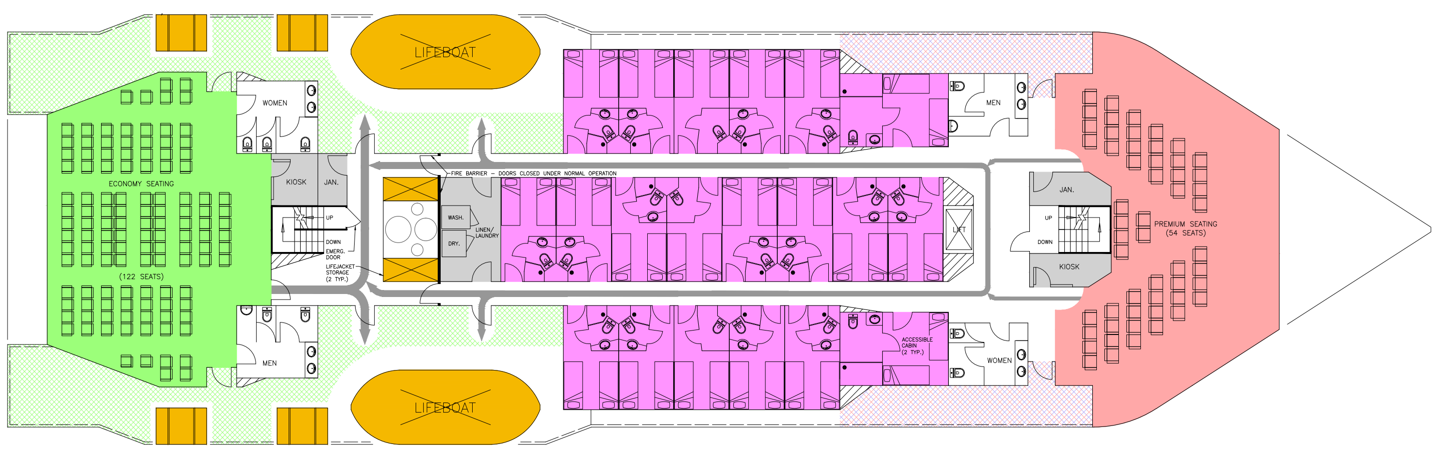
Seat Width: 509 mm Leg Room: 945 mm

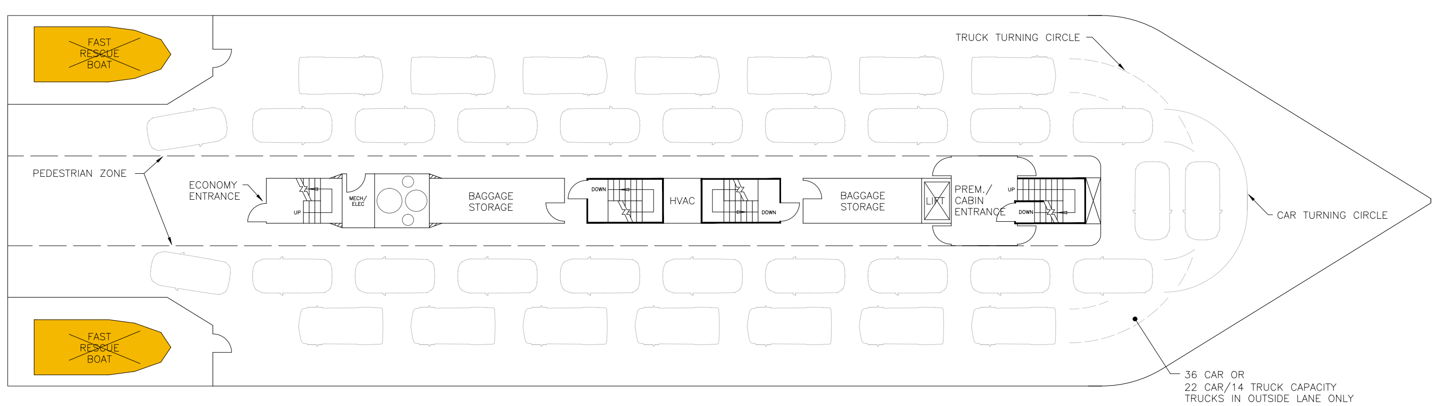




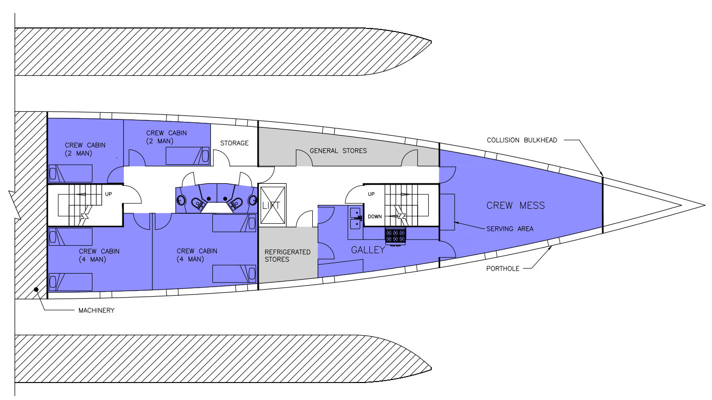
Cabins were modeled from reference drawings provided by STX Finland. Each cabin has a 9.3 m^2 area and contains a wet-unit. Two Pullman beds were included to provide cabin accommodation versatility. Four lifejackets to be included within each cabin.







CABINS
PREMIUM
ECONOMY
CABIN/PREMIUM DECK SPACE
CREW
SERVICE
SAFETY
ECONOMY DECK SPACE



02 Deck:

- Bridge wings to aid in navigation and manoeuvring
- Aft pilot house for stern navigation and docking
- Isolated medical/first-aid facilities.
- Separated officer quarters, with officer lounge, two single rooms, and two double room single occupancy cabins
- 60 m^2 of exposed and 50 m^2 of covered external deck area for premium and cabin classes. All shielded with windscreen and accessible via stairs or lift

01 Deck:

- 18 standard and two accessible cabins.
- 54 premium seats and 122 economy seats.
- Separate kiosks for economy and premium classes. Kiosks to be stocked via general and refrigerated stores on Crew Deck.
- 1:20 and 1:14 toilet ratios for economy and premium classes, respectively.
- 100 m^2 and 40 m^2 external deck space for economy and premium/cabin classes, respectively. Majority of premium/cabin class deck space on 02 Deck. Majority of deck space shielded from oncoming wind.

Car Deck:

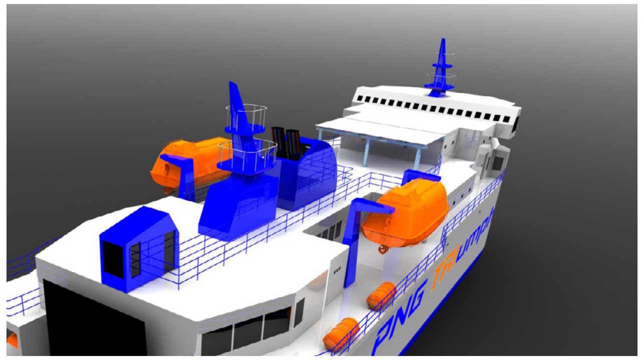
- 36 vehicle capacity of varying car/truck configurations. Deck can withstand truck loads in both inner and outer lanes.
- Two accessible parking stalls near bow with easy access to lift.
- Separate entrances for cabin/premium and economy classes.
- Separate stairways for crew access into hull.
- 70 m^3 of enclosed passenger luggage storage.

Crew Deck:

- Two four-person and two two-person crew cabins of size meeting MLC 2006.
- Two contained wet units, per MLC 2006 requirements.
- Refrigerated and General Stores, with lift access for supplying kiosks.
- Crew galley and crew mess, with mess forward of side hulls to provide surrounding view.

Superstructure Development

The superstructure was modelled in 3D CAD software SolidWorks using the general arrangement as reference. Each deck was modelled separately and brought together to form the final product. "Safety orange" was chosen as one of the main exterior colours to highlight the safety equipment and demonstrate how safety was at the forefront of the vessel during design



RESISTANCE & POWERING

Although the trimaran has superior stability to most ship types, it also has the ability to provide lower powering requirements with increased deck space, especially at higher speeds.

At lower speeds, frictional resistance dominates and it is here where a monohull would have an advantage due to its decreased surface area compared to a trimaran. As speeds increase, residuary resistance, which is mainly composed of wave making resistance, tends to dominate. The slender hull forms of the trimaran provide very little wave resistance and this large reduction can overcome the penalty for increased surface area. In this instance, the *PNG TRIumph* will be travelling at a design speed of 14 knots to limit fuel consumption. This equates to a Froude number of roughly 0.3 which is in the approximate region when trimaran ships have decreased powering requirements over monohulls.

Effective Power

Analyzing a trimaran hull form for resistance is not as simple as a monohull or catamaran counterpart. Many of the programs used for resistance analysis cannot detect the presence of the three separate hulls and the standard regression series developed to find effective power have been almost exclusively for monohulls. Therefore, the *TRIumph* was treated as three isolated hulls wherein the resistance of each was determined and summed to find the total effective power required.

Side Hull

The side hulls are very slender and unorthodox compared to conventional ship hulls and using a standard regression series would provide inaccurate results.

It has been shown experimentally and theoretically that very slender hulls with a B/L ratio of less than 6% have little to no wave making resistance and total resistance consists almost entirely of friction (Zhang, 1997). The side hulls of the *TRIumph* have a B/L ratio of 3.6%. Consequently, residual resistance was estimated as 20% of the frictional resistance. This is most likely high but done to provide a margin for uncertainties. The bare hull friction resistance was determined using the ITTC 57 method. A standard roughness correlation of 0.0004 was also introduced into the calculation.

Main Hull

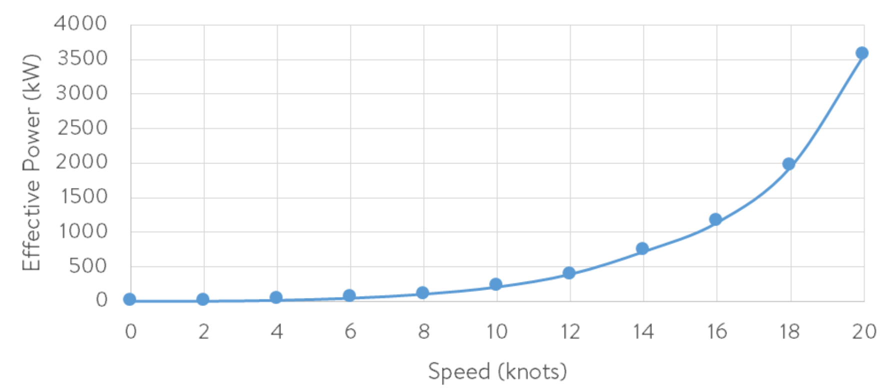
Fortunately, the main hull of the *TRIumph* conforms to more conventional hulls and fell within the constraints of the Holtrop and Mennen regression series. This series has been used extensively over the years and is known for its robustness in providing accurate results for resistance predictions. The particulars of the main hull were imported into the naval architecture software NAVCAD where the analysis was completed. The ITTC 57 method was once again used to predict the frictional resistance component.

Total Bare Hull Effective Power

The total bare hull effective power is shown in the graph below. It is important to note that appendages, fouling and wind drag have not yet been accounted for. It should also be noted that the wave interference effects between the three hulls have not yet been accounted for. There is no reliable method to determine them without proper model testing. As mentioned earlier in hull form development, the side hulls are located to provide maximum wave cancellation effects, which could potentially reduce residuary resistance as much as 60% (Ackers, et al., 1997). In the final design, the overall resistance could well be lower than as calculated at this stage. At the design speed (14 knots) the effective power required is just over 700 kW.

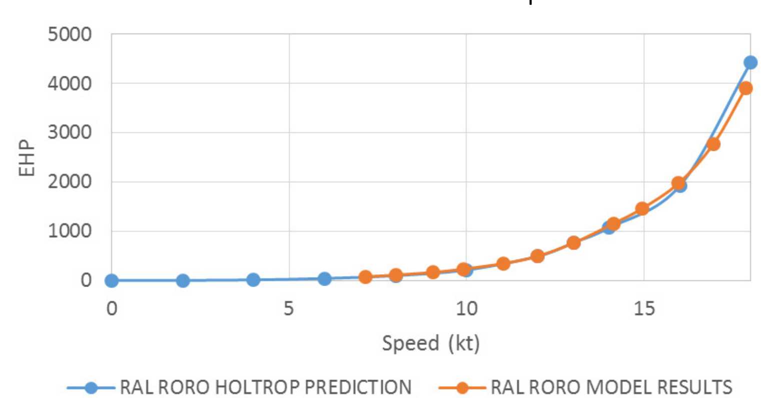
PNG TRIumph vs. A Monohull

The same Holtrop and Mennen methodology used for the *PNG TRIumph*



PNG TRIumph bare hull effective power.

was applied to the RAL 50m RORO reference vessel (hard chine monohull similar to the centre hull of the TRIumph) using the NAVCAD software. The results of which were compared to the actual model tests of the vessel conducted in May of 1980 (B.C. Research, 1980). The two analyses are shown in the graph below and are in very good agreement with one another providing some level of confidence to the trimaran prediction. This also provides some



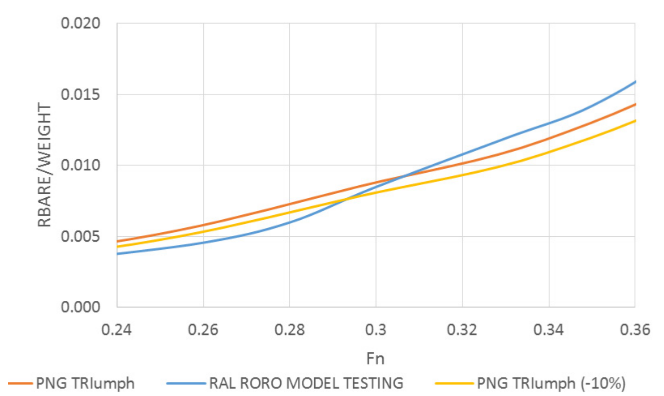
A comparison between the Holtrop and Mennen prediction (NAVCAD) and model test results for RAL 50m RORO.

confidence in a comparison of the two vessels to one another. Although this is not a perfect comparison, the resistance characteristics of the *TRIumph* vs. a monohull can be explored with some validity.

The comparison of the resistance characteristics between the *TRIumph* and the RAL 50 m RORO is shown in the graph below. The comparison was done on a non-dimensional basis of bare hull resistance divided by weight displacement vs. Froude number. The results are predominantly what is to be expected with the monohull providing lower power requirements at reduced vessel speed and the trimaran providing better resistance characteristics at increased speeds. At the design Froude number of 0.3 the monohull has a very slight advantage, but it can be reasoned that the resistance is essentially the same with uncertainties. If the *PNG TRIumph* resistance was decreased by 10% due to side hull placement and wave cancellation effects, the resistance would actually be noticeably lower than the monohull. A 10% reduction in total resistance for the trimaran equates to about a 30% reduction in residuary resistance, half of the reduction originally designed for. It is therefore entirely possible that the *PNG TRIumph* would have better resistance characteristics than an equivalent monohull at the chosen design speed and especially at higher speeds above 14 knots.

Total Effective Power

Additional effects must be considered in the total effective power analysis. Surface fouling can drastically increase frictional resistance, especially at the higher water temperatures predominant in the PNG region. The geometry of the superstructure was also considered and a margin for wind drag at 15 knots was introduced. An appendage drag of 10% was estimated to account for the propellers, bow thruster tunnel and other extremities. Finally, a 5% margin was included to account for uncertainties and less than optimum conditions. At the design speed of 14 knots, the total effective resistance is 143 kN requiring 1033 kW of effective power and 161 kN of thrust.



A resistance comparison between the PNG TRIumph and the RAL 50m RORO monohull.

Propulsion Arrangement

The *PNG TRIumph* is outfitted with a twin shaft propulsion system consisting of 2 Schottel STP 1010 azimuth Z-drives powered by 2 MAK 6M 20C engines.

Why Twin Shaft?

The predominant reason for the twin shaft setup is redundancy. A passenger ship travelling along an ocean going route has the potential for all kinds of trouble. If there are problems with one shafting system, due to engine failure or another reason, there is still the possibility of reaching the desired destination or shelter of some kind, albeit at a slower speed. This is especially important in the PNG region where the infrastructure to provide help to stranded ships may not be satisfactory. Additional benefits include increased manoeuvrability, increased propulsion efficiency (pertaining to a reduced propeller thrust and size requirement) as well as increased adaptability. The vessel can run at a wider range of vessel speeds without sacrificing engine efficiency since there are two smaller engines instead of one larger more powerful engine. These benefits, especially in regards to safety, were considered to outweigh the additional costs and maintenance compared to a single shaft system.

Why Z-drives?

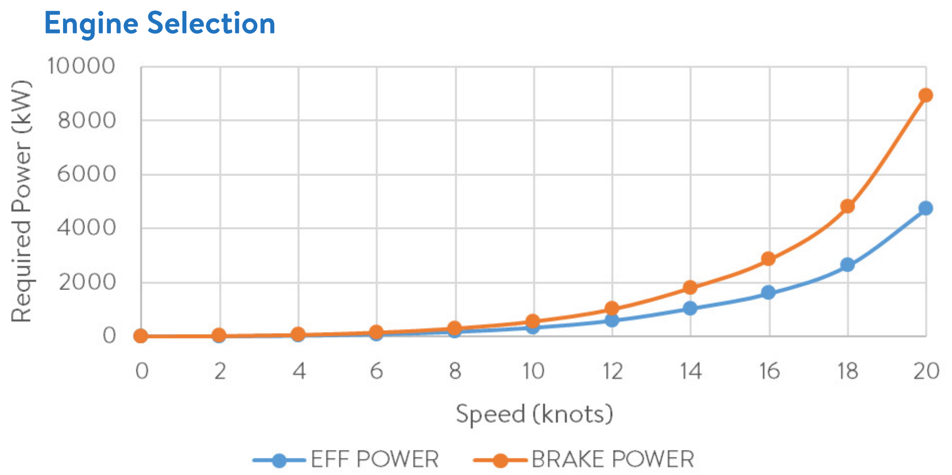
Trimarans generally have reduced manoeuvrability when compared to monohull counterparts due to their increased length and the presence of side hulls, both of which increase hydrodynamic forces. Although the side hulls of the TRIumph are located amidship, which is optimum for manoeuvrability in trimarans (Zhang, 1997), it was decided that additional steps need be taken to increase turning and reaction ability of the vessel. Doing so would undoubtedly help with positioning while docking and diminish some of the challenges associated with stern loading, particularly in rougher conditions. Therefore, z-drives were a natural choice for the *PNG TRIumph* and with assistance from distinguished manufacturer Schottel, 2 STP 1010 azimuth thrusters were chosen. As seen below, each azimuthing drive actually contains twin propellers which rotate in the same direction, one pulling and the other pushing.

These particular z-drives have increased efficiency when compared to conventional azimuthing drives. To put it in perspective, if a STP azimuth were to require 1000 kW of input power, a conventional open propeller azimuth would require about 1100 kW. This equates to a fuel savings of almost $150,000 per year in the case of a twin shaft system with medium speed diesels running 4275 hours at design condition. Although the purchase cost of a STP is roughly 25 % higher according to industry correspondence, the increased efficiency would help offset the capital cost, especially in the case of the TRIumph which would operate at its design speed for the better part of its life. There was insufficient time to allow for an in depth comparison between the STP azimuth drive and a traditional rudder and propeller combination. However, information gathered from industry representatives states that the STP efficiency and drag would be similar and final installed costs would only be slightly higher. Manoeuvrability would of course be increased and the use of the azimuthing drives actually allows for a reduction in the installed power and costs of the bow thruster because of this. At this stage in the design cycle, findings indicated that the use of 2 STP azimuthing drives is justifiable. However, a more in depth analysis would have to be incorporated if the vessel were to ever be built. If this study were to conclude a conventional propeller and rudder system more appropriate, there should be no problem outfitting the *PNG TRIumph* with such a system. The particulars of the STP propellers fitted on the *PNG TRIumph* are shown in the table below.

SCHOTTEL STP 1010 TWIN PROPELLER	
D (mm)	2050
BAR	0.35
Z	3
Input RPM	900
Prop RPM	273.1
P/D (FIXED)	0.923
η_0 (Design Point)	0.616
DP Thrust/unit (kN)	80.58

Brake Power

The required engine brake power for the *PNG TRIumph* is shown in the graph below. At design speed (14 knots), the required power is 1800 kW or approximately 1.7 times the effective power of 1030 kW with a shaft efficiency of 95%.



The required effective and brake power of the PNG TRIumph.

A comparison was done between two engines which were found to be suitable candidates for the *TRIumph*. The medium speed MAK 6M 20C and the high speed CAT 3512C. Medium speed diesels have better fuel consumption but are also generally larger/heavier and more expensive up front. A simple economic analysis (shown below), with help from industry for pricing details, found that the capital cost payback period for the medium speed MAK was 4 years. This is relatively low when compared to the lifetime of the vessel and large savings on fuel costs would be incurred in the future. Another added benefit of a medium speed engine is less maintenance costs over engine lifetime. Therefore the PNG TRIumph is equipped with 2 MAK 6M 20C engines outputting 1080 kW at 900 rpm. Incidentally, the required input for the STP azimuths is 900 rpm; a gearbox is not necessary saving costs and increasing efficiency.

Note, the engines were sized based upon 85% load which is necessary for fixed pitch propeller setups and medium speed diesels. It is important because the propeller load and available engine power curve (for a medium speed) is very close. There needs to be extra reserve to account for non-optimum conditions; this will also ensure that speed requirements can be met under a wider range of operating conditions.

Bow Thruster

A bow thruster was deemed necessary to help stabilize the ship when loading by counteracting against varying wind and wave conditions. The Schottel STT 110 transverse thruster met the 20 kN thrust requirement with a tunnel diameter of 815 mm and an overall weight of 890 kg. It will be powered by the *TRIumph's* main auxiliary generators requiring just over 200 ekW which is relatively low because of the added manoeuvrability from the azimuthing drives. A Schottel thruster was implemented to allow for a propulsion package from a single manufacturer potentially saving costs on installation and maintenance.

Engine	MAK 6M 20C	CAT 3512C
Engine Type	Medium speed	High Speed
L (m)	4.05	2.63
W (m)	1.56	2.04
H (m)	2.10	2.11
Weight (tonnes)	10.90	7.40
SFC (g/kWh)	190	201
Installed kW	1080	1040
Engine cost ($/kW)	650	325.00
Capitital Cost ($)	702,000	338,000
Fuel/yr (t)	1624.50	1718.55
Cost per tonne ($/t)	950	950
Fuel cost/year ($)	1,543,275	1,632,622
MAK Payback (yrs)	**4.07**	

Medium and high speed diesel engine comparison.

Auxiliary Powering and Electrical Load

There was insufficient time and data to conduct a complete electrical load analysis for the vessel. However, using first order approximations (Gerr, 2009) and data from reference vessels, the total maximum required electrical load was estimated to be 490 ekW not including the bow thruster unit (roughly 700 ekW with it). The HVAC load for all required spaces accounts for 250 kW and if its use was limited, there would be potential for large cost savings.

There are 3 CAT ACERT C18 (400 ekW) generators aboard the *PNG TRIumph*, mainly for redundancy. In general, the required electrical load of the ship will be less than the total estimated maximum, roughly 70% or 350 ekW without the bow thruster. Consequently, only 1 of the CAT C18 generators will be supplying the ship in most instances, while running at an optimum range of reduced fuel consumption. In occasional instances where extra power is required, such as when the bow thruster unit is needed and the HVAC load is unusually high, 2 of the generators will be running in parallel to supply the ship. There will always be one generator in reserve in case another fails which is not uncommon. This ensures that the *TRIumph* will always have enough power to supply all required electrical loads which is very important on ocean going vessels.

The emergency auxiliary load was estimated at 95 ekW. The CAT C4.4 (100 ekW) generator will provide for the required emergency electrical loads including but not limited to bilge/fire pump loads, emergency lighting, and emergency navigation/communication. Note, the engine and auxiliary generators are all of the same manufacturer (CAT/MAK) which once again allows for savings on installation and maintenance costs.

MACHINERY ARRANGEMENT

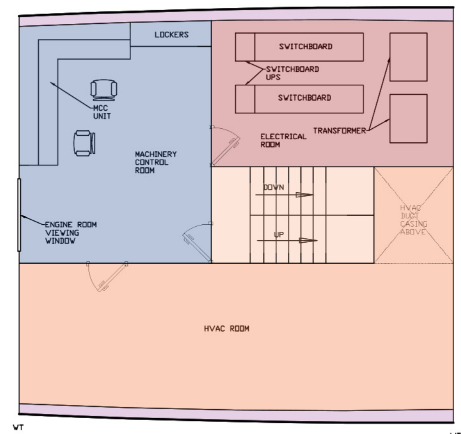
Steering Flat (1)
- 2x Z-Drive Pods
  - -Schottel STP 1010 Twin Propeller

Service Spaces (2/4.2/6)
- Refueling Accessories **(2)**
  - -Refueling connection point with hose
- Electrical Room **(4.2)**
  - -Transformers and Switchboards
- Lift Service Room **(6)**

Engine Room (3)
- 2x Main Engines
  - -MAK 6M 20C (1080 kW @ 900 rpm output)
- 3x Auxiliary Generators
  - -CAT C18 ACERT (400 ekW @ 1500 rpm, 50 hz)
- 2x Engine Room Receivers
- 2x Starting Air Compressors

Auxiliary Machinery Space (2)
- 3x Pumps
  - -Bilge, Ballast/ Bilge and Fire

Air Handling Space (4.2)
- HVAC units for entire ship
- HVAC Duct Casing



Mezzanine

Emergency Generator
- 1x CAT C4.4 (99 ekW) generator is located on the roof directly behind the main stack

Void Space/Cofferdams
- Minimum 800mm clearance for ease of access
- Double Bottom 1300mm to allow for manufacturing of hard chine hull

Domestic Machinery Space (4)
- 2x Fresh Water Pumps
- Fresh Water Hydrophore
- 2x Hot Water Tanks
  - -Vertical Tanks with 350 gal. capacity each
- Hot Water Circulation Pump
- Reverse Osmosis Unit

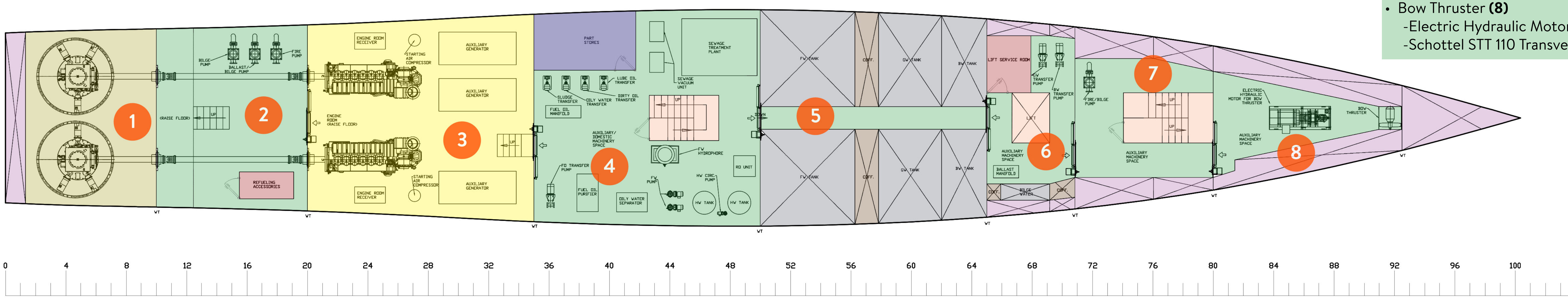
Engineering Rooms (4/4.2)
- Parts Store **(4)**
- Machinery Control Room **(4.2)**

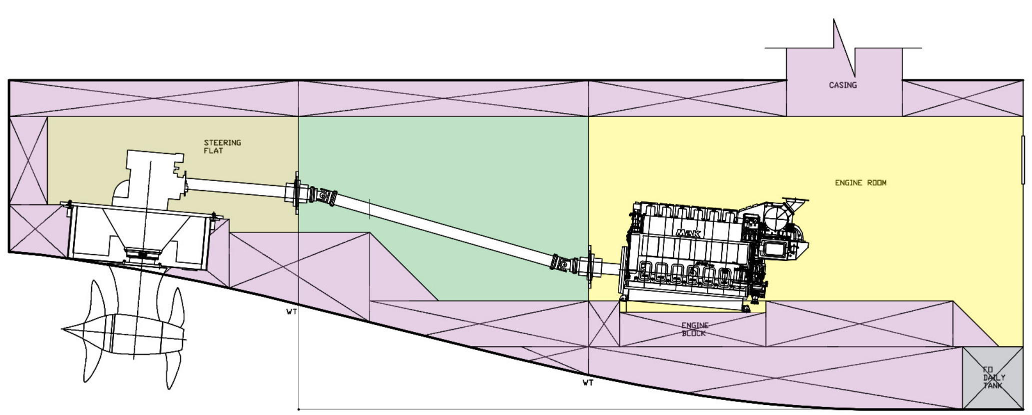
-MCC Unit
-Lockers
-Engine Room Viewing Window

Tanks (4/5/6)
- 2x Fresh Water Tank
- 2x Grey Water Tanks
- 2x Black Water Tanks
- Bilge Water Tank **(6)**
- Tanks In Double Bottom (not shown) **(4)**
  - -2x Fuel Oil Tanks
  - -Waste Oil Tank
  - -Lube Oil Tank
  - -Sludge Tank
  - -Fuel/Oil Overflow

Auxiliary Machinery Space (4)
- Oily Water Separator
- Fuel Oil Purifier
- 5x Transfer Pumps
  - -Sludge, Oily Water, Dirty Water, Lube Oil, Fuel Oil
- Sewage Vacuum Unit
- Sewage Treatment Plant
  - -Wartsila ST25-C
- Fuel Oil Manifold

Auxiliary Machinery Space (6/7/8)
- Transfer Pumps **(6)**
  - -Grey Water, Black Water
- Fire/Bilge Pump **(7)**
- Bow Thruster **(8)**
  - -Electric Hydraulic Motor
  - -Schottel STT 110 Transverse





Note:

1.) All engines and generators run on Marine Diesel Oil (MDO) and meet IMO Tier II requirements.

2.) All machinery arrangement items are drawn to scale.

Shaft Configuration (1/2)
- Due to alignment difficulties, both the main engines and the Z-drive pods have been tilted to a maximum 5 degrees. Two sets of Cardan joints were used to accommodate the addition angle change of 11 degrees.

Fire Pumps (2/7)
- Two fire pumps were installed in the machinery space and were placed a minimum of 2 water tight bulkheads apart in case of flooding. The secondary fire pump is dual purpose with bilge pumping capabilities.

Means of Egress
- A dedicated main stairwell for the machinery space is situate in water tight zone 4. This allows for easy access between the control room and the main machinery space.
- A secondary stairwell is located in water tight zone 7. This stairwell is to be used as a backup as it is shared with the crew quarters above.
- Additional means of egress have been provided in order to meet the code requirements. Emergency escape hatches are locate in water tight zones 1, 2, 3, 6 and 8.
- The lift does not open to the machinery space but can be accessed at this level for repairs

Water Treatment (4)

A sewage treatment plant and RO unit were installed on this vessel despite increasing the initial cost of the vessel. This was justified with 3 reasons:

1. It was determined that it was not feasible to rely on the ports for proper disposal sites that could handle raw sewage as well as being able to provide potable water.
2. It allows for smaller tank sizes since the water is being treated which also means it is more sustainable over longer trips (doesn't have to stop as often).
3. If the vessel starts operating in different waters, the addition of these two plants makes it more versatile.

STRUCTURAL DESIGN

Introduction

This section presents a summary of the structural design of the PNG *TRIumph*. The general goal is to showcase the design methodology. The *TRIumph* features a hybrid framing system with 600mm secondary frame and 2400mm primary web spacing.

Rules and Regulations

To determine the structural design of the *PNG TRIumph*, Lloyd's Register rules for the Classification of Trimaran Ships were utilised. These rules were created through use of design studies, model testing, simulation, and a demonstrator in the form of the *RV Triton*. The majority of structural calculations can be found in the appendices.

Scantling Determination

The size and operational envelope of the *PNG TRIumph* helps determine the primary, secondary, and tertiary loads which in turn govern the strength requirements and subsequently the acceptance criteria for the vessel. Scantlings were determined using the following methodology:

A. Calculate plate thicknesses
B. Calculate section modulus
C. Assess hull bending strength
D. Check with required section modulus
E. Determine major scantlings

Part A: Calculated Plate Thickness

A selective summary of the calculated plate thicknesses is given in the following table. It should be noted that the superstructure was also considered effective in the section modulus calculations as it extends longer than 0.4 times the length of the vessel. All plating thicknesses can be found in the midship section drawing.

Effective Plating - Summary

Location	Thickness (mm)
Keel Plate	13
Bottom Shell	11
Bilge	13
Turn of Bilge	8
Side Shell	7
Sheerstrake	8.5
Mach. Space	6.5
Wet Deck	7
Car Deck Floor	9.5
Car Deck Shell	6.5
1st Deck Floor	6
1st Deck Shell	6

Part B: Calculated Section Modulus

Detailed hull section-modulus calculations can be found in the appendices.; a summary of the results are given in the table below.

Calculated Section Modulus

Property$_{ABOUT}$	Value	Units
N.A. Height $_{KEEL}$	6.19	m
Second Moment$_{KEEL}$	24.21	m^4
Second Moment$_{NA}$	7.55	m^4
Section Modulus$_{DECK}$	2.12	m^3
Section Modulus$_{KEEL}$	2.44	m^3

Part C: Hull Bending Strength

Much like a monohull, a trimaran's structural design is largely governed by longitudinal bending moments acting in head seas. Wave and still water bending moments were calculated using LR empirical formulae to obtain the minimum required section modulus. The aforementioned calculations can be found in **Appendix ##**. According to LR, the minimum section modulus is:

$$Z_{min} = f_1 k_L C_1 L^2 B (C_b + 0{,}7) \times 10^{-6}\ m^3$$

Z_{MIN} = 0.4349 m^3 **OKAY**

It was found that the calculated section modulus easily meets the required section modulus.

Part E: Major Scantlings

Global and local design loads were calculated in order to determine scantlings for the *PNG TRIumph*. Major global design loads consisted of hull girder loads and cross-deck loads. The major local governing load was the wheel loading from vehicles. All selected scantlings according to the governing equations are showcased in the midship section drawing to the right. Detailed calculations are left for the appendices. A pair of the rule formulas utilised are shown below.

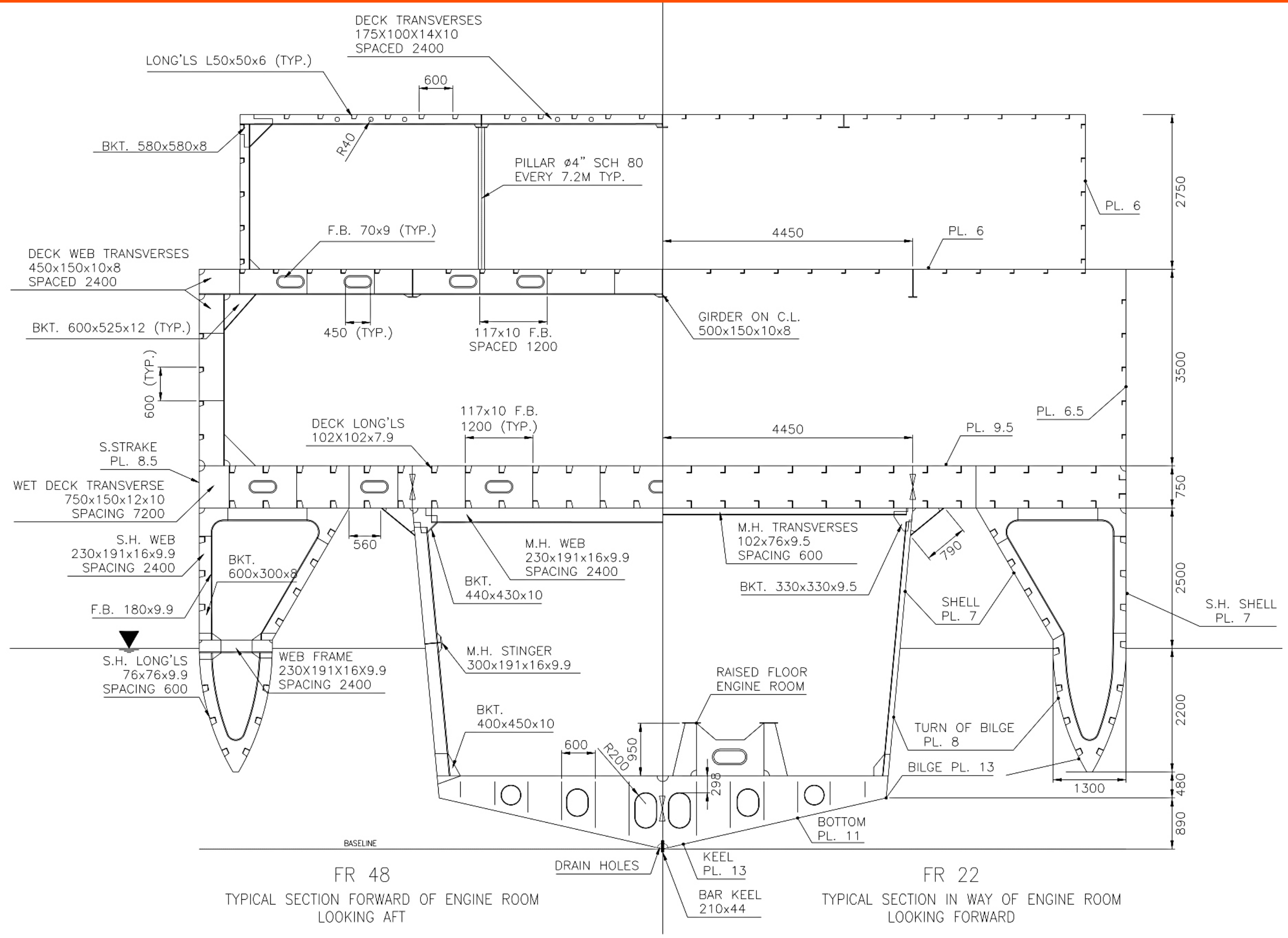
$$Z = \frac{c_z \delta_f P_{des} S l_e^2}{f_\sigma \sigma_{yd}} 10^3\ cm^3$$

Inertia:

$$I = \frac{c_I \delta_f P_{des} S l_e^2}{f_\sigma E} 10^5\ cm^4$$

Midship Drawing & Design Decisions

Following scantling selection, a midship section drawing was completed (see above and appendices). The left hand side of the drawing shows a typical web frame section forward of the engine room looking aft. The right hand side shows a typical section in way of



the engine room with raised floors. Consideration was given to ease of manufacturing and maintenance of the vessel. For example, a double bottom height of 1300mm allows ample room for maintenance, ease of manufacturing, and plenty of volume for tanks. Curvature throughout the *TRIumph* has also been kept to a minimum in order to reduce manufacturing time and man-hours while being mindful of the vessel's resistance performance. A large cross-deck height of 750mm, apart from a manufacturability and maintenance standpoint, also permits a high safety factor which was especially important as the class dataset available on this most important structural member is small.

A hybrid framing system with transversely framed side shells and double bottom and longitudinally framed decks was selected to reduce construction man-hours and maximise stability. Although a transversely framed hull is heavier, it is relatively easier to construct in areas of increased curvature. It was noted that steel is relatively cheap compared to labour.

Furthermore, longitudinally framed decks are lighter and simpler from a manufacturing standpoint (block construction) due to their box-like geometry.

Conclusions

The *PNG TRIumph's* structural design methodology with select major scantlings was presented. The appendices contain detailed design calculations and a higher resolution midship drawing. In sum, the TRIumph features include:

- Transversely framed side shell and double bottom
- Longitudinally framed decks
- Primary web spacing 2400mm
- Secondary spacing 600mm
- Designed for easy manufacturing
- Easily adaptable to block construction and pre-outfitting

DEADWEIGHT & TANKAGE

Deadweight Estimates

Passengers

Passenger deadweight was calculated for both normal and overcrowded operation to ensure a safe voyage. In both cases, a passenger weight of 75 kg/person was used, as required by the 2008 Intact Stability Code, while a choice of VCG, [1 m above deck] per person (standing passenger) or [0.3 m above seat] per person (sitting passenger). Each passenger was assumed to be standing for the calculations of the deadweight as this produced the most unfavourable conditions in terms of overall vessel VCG.

Normal Operation

The *PNG TRIumph* will carry 200 passengers under typical operation. However, its maximum occupancy is 80 cabin passengers, 54 premium passengers, and 122 economy passengers. The maximum capacity of each area was used to compute passenger deadweight as this represents the worst-case for the vessel VCG. All premium and cabin passengers were located on their 02 Deck lounge for the VCG determination. This is a highly implausible scenario, however it presents the greatest detriment to the vessel VCG. The weights and associated centroids for each passenger area are shown in the table below.

Element	Number of Elements	Mass [tonnes]	LCG [m]	TCG [m]	VCG [m]
Normal operation					
Economy	122	9.15	5.6	0	11.12
Cabin & Premium in Lounge	134	10.05	29.8 2	0	14.07

Overcrowded Operation

Overcrowding was limited to the economy class region of the vessel. The higher fares of premium and cabin classes make it unlikely that overcrowding will be tolerated within these classes. Cabin capacity was conservatively assumed at 100% and should thus account for any minor overcrowding within these classes. The overcrowded vessel included the maximum occupancy detailed above in addition to extra passengers within the economy zone. A crowding factor of four persons per square metre was used, as specified in the 2008 Intact Stability Code. This resulted in a 158% passenger excess compared to maximum occupancy operation. The weight and associated centroid for the group of extra passengers considered to overcrowd the economy seating area as well as its surrounding decks is shown in the table above.

Element	Number of Elements	Mass [tonnes]	LCG [m]	TCG [m]	VCG [m]
Overcrowded Operation					
-	-	-	-	-	-
Extra Overcrowding Economy	429	32.18	6.2	0	10.62

Cargo

The design cargo load was 22 automobiles and 14 trucks, symmetrical about the centreline. Generic sizes and weights for both automobile and truck were based on common vehicle imports in Papua New Guinea. The vehicle dimensions and weights are detailed in the table below.

Considerations were made for the scenario where vehicles were misplaced and loaded on either the port or starboard sides only. The weight breakdown and associated centroids for both cases are detailed below.

	Dimensions [m³]	Mass [kg]
Automobile	4.5 × 2.2 × 2	1500
Truck	4.92 × 2.25 × 2.23	2500

Typical automobile and truck seen in Papua New Guinea.

Element	Number of Elements	Mass [tonnes]	LCG [m]	TCG [m]	VCG [m]
Full Cargo Load					
Truck	14	35	29.37	0	7.32
Automobile	22	33	30.7 5	0	7.32

Element	Number of Elements	Mass [tonnes]	LCG [m]	TCG [m]	VCG [m]
Misplaced Cargo Load					
Truck	7	17.5	29.3 7	5.58	7.32
Automobile	10	15	30.7 5	3.35	7.32

Tankages

The *TRIumph's* tanks were designed based on its operational requirements. Namely, the holding tanks have storage capacities to allow for a vessel range of 1,000 NM. Ballasting was not included in the ferry design to limit any complications and management expenses associated with ballast tanks. If ballast becomes necessary during design refinement, additional space is available in both the outriggers and double bottom. The table below details the tanks on board the vessel as well as their capacities and associated properties. Detailed calculations can be found in the appendices.

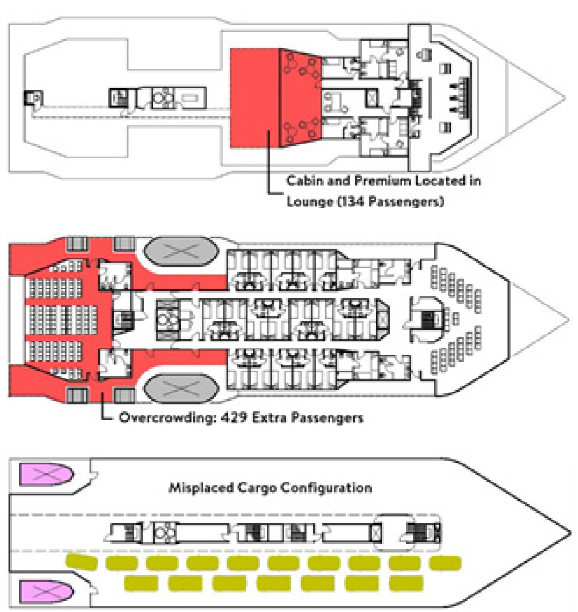
TANK DESCRIPTION	S.G.	GROSS VOLUME [m³]	LCG [m]	TCG [m]	VCG [m]	FS AREA INERTIA [m⁴]	RISE IN VCG [m]
Fresh Water Tank							
Hot Water Tank 1	1	1.394	27.733	3.209	1.983	0.034	0.000
Hot Water Tank 2	1	1.394	29.194	3.209	1.983	0.034	0.000
Fresh Water Tank P	1	30	31.886	-2.286	2.501	20.213	0.017
Fresh Water Tank S	1	30	31.886	2.286	2.501	20.213	0.017
Combined Rise in VCG							**0.035**
Fuel Oil Tanks							
Fuel Oil Day Tank	0.89	1.93	20.375	0	0.687	0.204	0.000
Fuel Oil Overflow Tank	0.89	2.5	28.5	1.843	0.855	1.035	0.001
Fuel Oil Tank S	0.89	31.77	24.027	1.633	0.837	34.461	0.026
Fuel Oil Tank P	0.89	31.77	24.027	-1.633	0.837	34.461	0.026
Combined Rise in VCG							**0.053**
Minor Tanks							
Black Water Tank P	1.25	2	38.056	-2.04	2.486	7.598	0.0081
Black Water Tank S	1.25	2	38.056	2.04	2.486	7.598	0.0081
Grey Water Tank P	1	32	35.816	-2.112	2.486	11.432	0.0097
Grey Water Tank S	1	32	35.816	2.112	2.486	11.432	0.0097
Lube Oil Tank	0.92	0.5	28.777	0.45	0.972	0.052	0.0000
Waste Oil Tank	0.9	2.5	28.5	-1.843	0.855	1.035	0.0008
Sludge Tank	0.95	0.14	28.777	-0.45	1.208	0.052	0.0000
Bilge Tank	0.975	3	40.526	-2.948	2.485	0.045	0.0000
Combined Rise in VCG							**0.0365**
Total Rise in VCG							**0.1242**

INTACT STABILITY

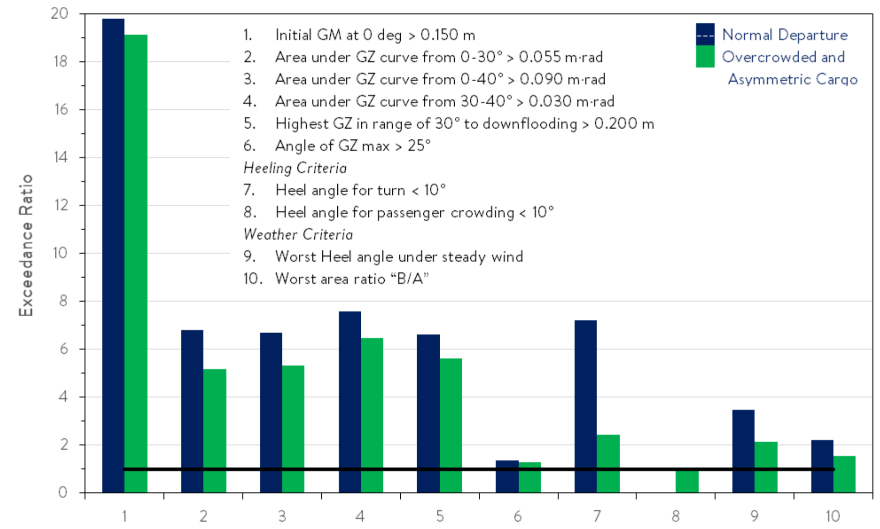
The intact stability of the vessel was assessed according to the International Code on Intact Stability. Four separate loading conditions were analyzed in accordance with regulations. These conditions were:

1. Departure with cargo
2. Departure without cargo
3. Arrival with cargo
4. Arrival without cargo

Overcrowding was added to the full cargo scenarios as this represents a likely detriment to stability. An additional loading scenario of misplaced cargo, economy, overcrowding, and all premium/cabin passengers on the upper deck was evaluated as a worst-case scenario. This scenario is illustrated in the figures below.



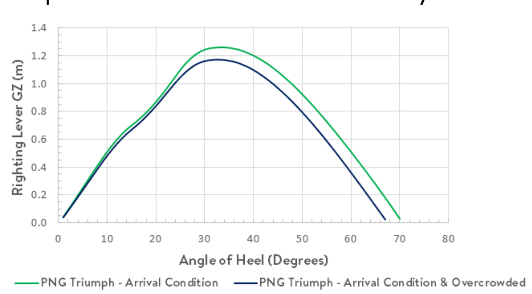
The following bar chart details the *TRIumph's* compliance with 2008 IS Code criteria. The two scenarios presented are departure with cargo and the worst-case overcrowding and asymmetric cargo arrival condition. Data is presented as a ratio over the minimum requirement. Additional scenarios and data may be found in the appendices.



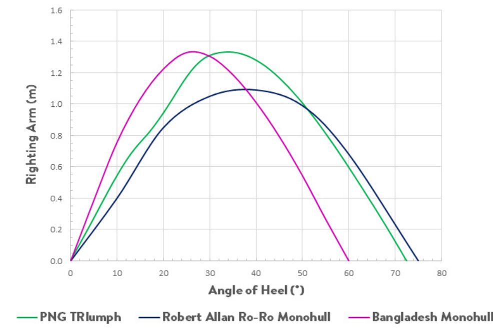
The TRIumph meets 2008 IS regulations as seen in the figure above, where a ratio below one indicates noncompliance. For the overcrowded and asymmetrically loaded condition, minimum requirements are met for passenger crowding heel angle. This could be improved over baseline through decreasing the asymmetry of cargo loading. The figure also illustrates the minor effect of overcrowding and poor cargo loading on stability. This is also illustrated in the righting arm curve below, where a vessel overcrowded by 429 persons only loses 18% reserve energy.

Monohull versus Trimaran Stability

The *TRIumph's* stability was compared to two monohulls of similar displacement. These were namely the Bangladeshi concept of last year's submission and the Robert Allan concept ferry, with displacements of 755 and 855 tonnes, respectively. Additional vessel parameters may be found in the appendices. The righting arm curves of the three ferries at loaded departure conditions are detailed in the following figure.

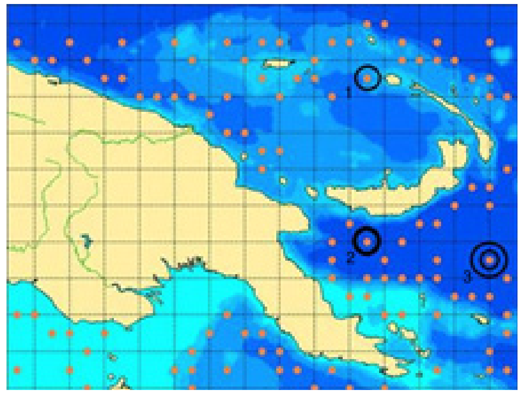


The *TRIumph*, which does not require ballast, has greater stability than both the monohulls, having 13% and 18% more reserve energy than the Robert Allan and Bangladeshi ferries, respectively. The vessel will have a similar maximum righting arm to the Bangladeshi monohull. In addition, its GZ curve has a lower initial slope, which will provide a more comfortable ride compared to the Bangladeshi ferry.

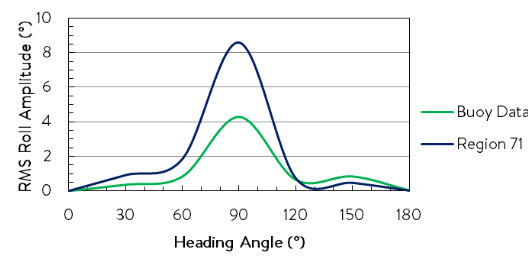


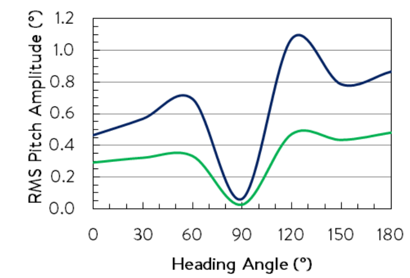
Seakeeping

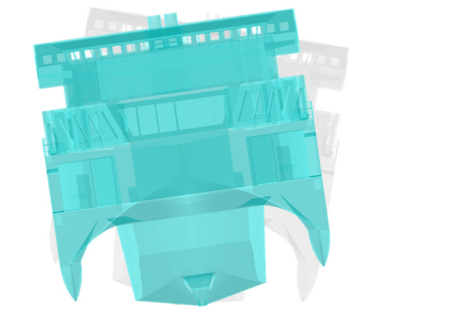
The figure below illustrates three points in Papua New Guinea waters where wave statistics were obtained. Point three had the highest energy waves, with a 1.2 m significant wave height and a 7.1 second peak period. The vessel may operate across the South Pacific, represented by Lloyd's Register Region 71. Much of this area is less sheltered than Papua New Guinean waters. The *TRIumph's* response to both wave data sets was evaluated to assess seakeeping characteristics under typical and expanded operations.

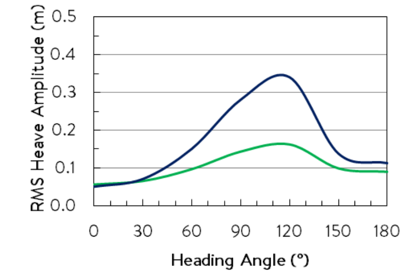


Roll, Heave, and Pitch responses were obtained for the two data sets and are presented above and to the right. The responses are in regards to heading angle relative to waves and were assessed with Paramarine at the design speed of 14 knots and long-crested seas.



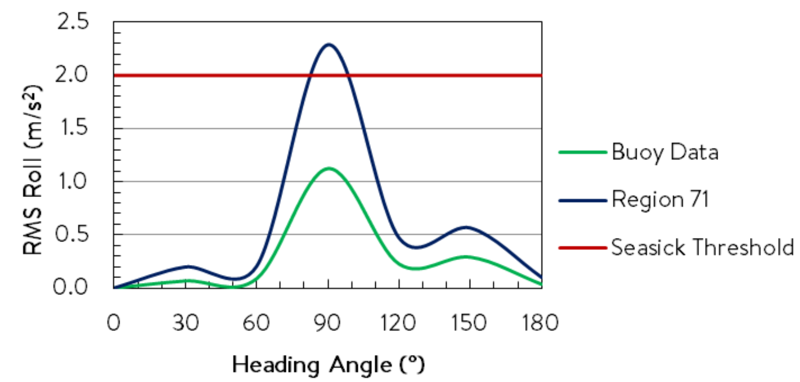






The *TRIumph* exhibits generally favourable seakeeping characteristics at headings other than beam seas. The seakeeping responses must be verified with model tests to validate the above results. In general, a trimaran has favourable seakeeping responses over an equivalent monohull. Exceptions includ pitch response in following seas. As such, although roll amplitudes are large for beam seas, the trimaran is not expected to perform unfavourably compared to a monohull (Zhang, 1997). It is recommended that for further design iterations the effect of bilge keels along the internal side hull edges be investigated. These have been found to reduce roll amplitudes by up to 25% (Pastoor et al, 2004).

The figure below details the roll accelerations experienced by a passenger near the vessel sides. Under the wave conditions analyzed, the horizontal line details what headings will lead to a roll acceleration greater than 2 m/s^2. When this occurs at a period under 10 seconds, per Lloyd's, this typically leads to seasickness for non-acclimatized patrons. Thus, within Papua New Guinea seas, seasickness is unlikely at all headings, however care must be taken in rougher seas.



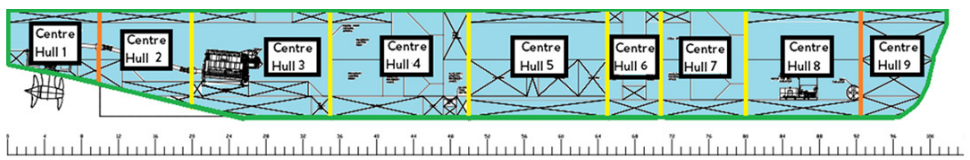
DAMAGE STABILITY

Governing Rules and Regulations

SOLAS dictates a probabilistic damage stability analysis be performed on all passenger ships. However, for the conceptual design, SOLAS 90 deterministic two-compartment rules were followed. Although superceded, these rules could be implemented quickly to evaluate concept-level vessel survivability. A probabilistic analysis should be done in the future to confirm the vessel complies with the latest SOLAS regulations for passenger ships.

Watertight Bulkheads

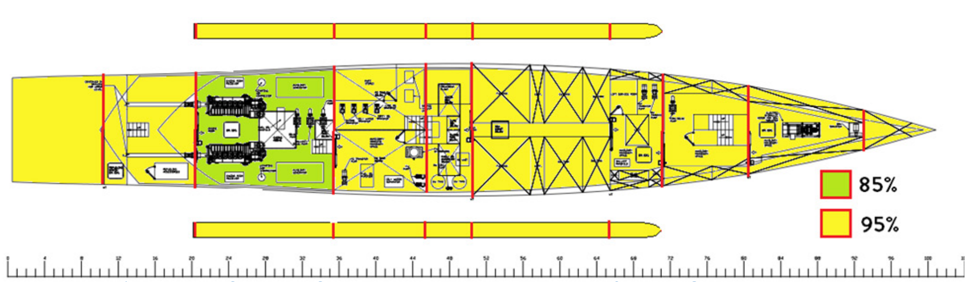
The centre hull was divided into nine watertight compartments with sealed bulkheads (shown below in yellow and orange) which connect to the watertight deck. The bulkheads shown in yellow are aligned with watertight bulkheads in the sidehulls, creating six extra watertight compartments per side hull as shown in the following figure.



Centre Hull Cross-Section up to Watertight Deck illustrating Watertight Bulkheads

Watertight Compartment Permeability

The figure below shows the watertight compartments and their permeability delimited by sealed bulkheads (in red). It is important to note that a compartment aft of each side hull, which has a 95% permeability, cannot be seen in the figure below as it is above the waterline.



Design Waterline Section Showing the Permeability of each Compartment between Watertight Bulkheads

Evaluated Damage Cases

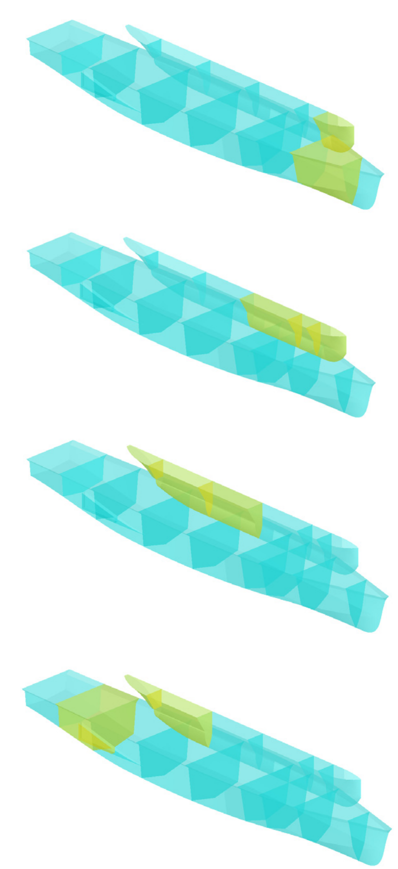
The starboard outrigger was omitted in all of the figures below to provide a clearer view of the damage cases analyzed. The starboard side hull remained intact in the analyzed cases. It is assumed that with machinery, tank, and general arrangement symmetry, starboard-side damage would react symmetrically to port-side hull damage.

The three loading conditions analyzed were arrival, arrival with overcrowding, and arrival with overcrowding and asymmetric cargo. All of the eight damage cases were survivable under the above loading conditions and exceeded SOLAS 90 minimum criteria. The most critical was **Damage Case 1** and its performance against SOLAS 90 is detailed in the table at right. Additional data for the other cases are shown in the appendix.

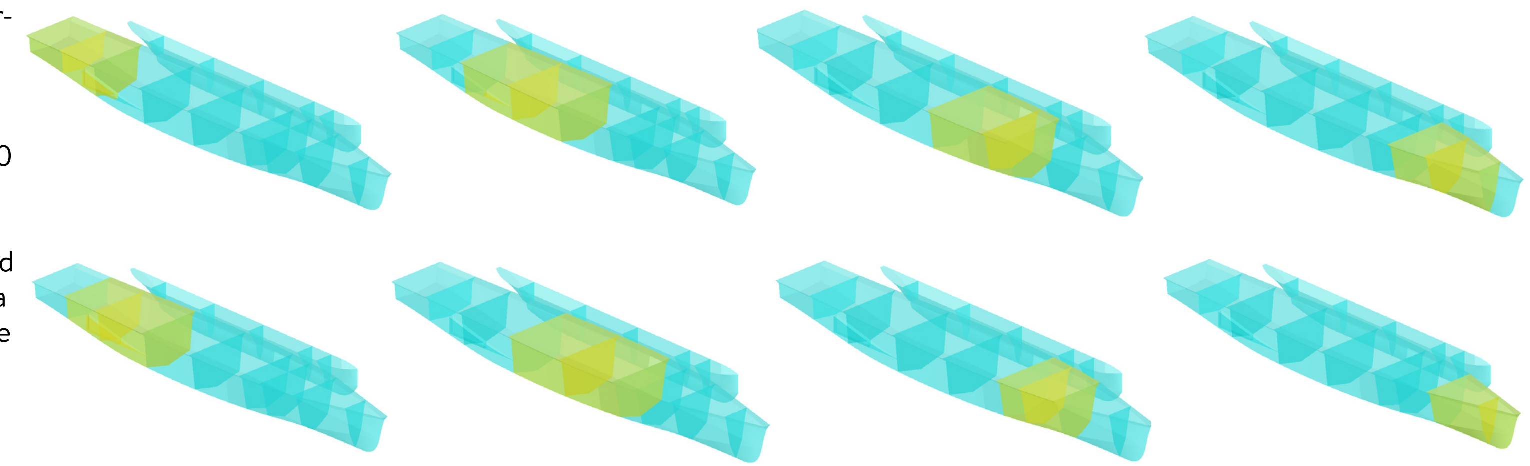
Side Hull Damage Cases

Additional damage cases were analyzed where side and main hull damage occurred in tandem. These cases are shown at right, with both forward and aft damage cases passing SOLAS 90 criteria. The most critical, but survivable damage was found to be flooding of the three aft compartments of a single side hull. The similar case of three adjacent forward compartments was also analyzed but was found to be more stable. Righting lever curves for three aft compartment and full outrigger flooding are shown below. These are compared with the intact righting lever curve under the similar 'arrival with overcrowding' load condition. Hydrostatic values for these cases are shown in the appendix.

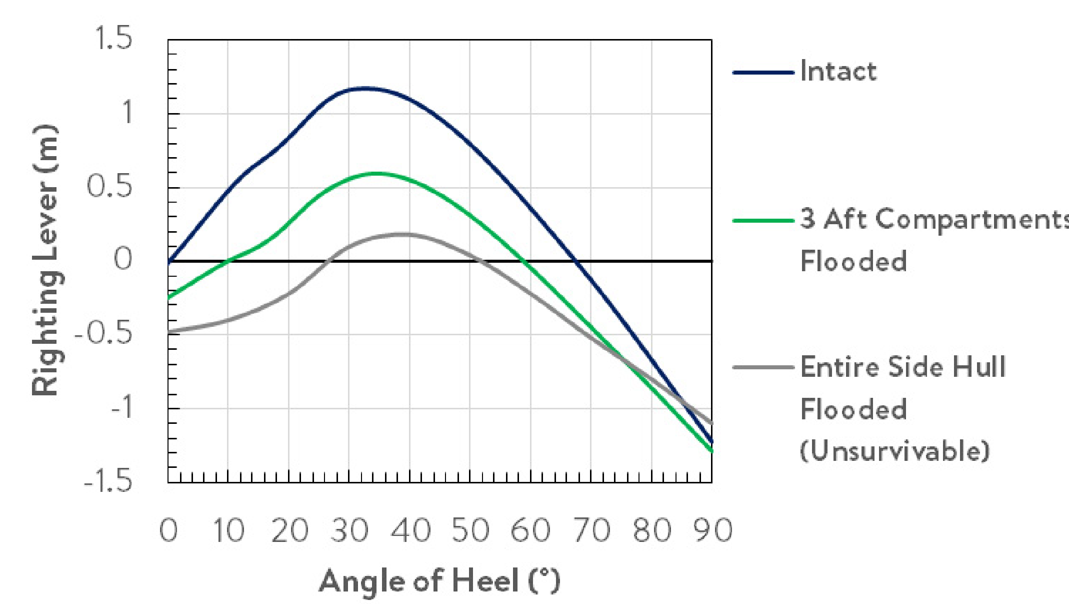
Side hull flooding greater than the cases shown at right would result in vessel capsize. Ballasting of the opposite side hull would increase the roll period caused by disturbances. This would likely increase the amount of time until capsize, however such damage would render the vessel lost. During further stages of this design, the effect of a watertight deck within the side hulls but above the waterline should be analyzed. This would limit buoyancy loss upon side hull compromise.



Main Hull Damage Cases 1 to 8



				Damage Case #1			
SOLAS 90 - 2 Compartment Flooding				ARRIVAL w/ PASSENGER OVERCROWDING		ARRIVAL w/ PASSENGER OVERCROWDING w/ MISPLACED CARGO	
Evaluation Criteria				Attained	Result	Attained	Result
Margin line emergence	>	0.000	*m*	0.419	PASS	2.485	PASS
Righting lever range past equilibrium	>	15.0	*degrees*	66.516	PASS	65.989	PASS
Equilibrium angle	<	12.0	*degrees*	0.122	PASS	2.574	PASS
Area under GZ curve	>	0.015	*m-rad*	0.372	PASS	0.264	PASS
Maximum righting lever	>	0.100	*m*	1.249	PASS	1.203	PASS



COST ANALYSIS

Introduction

A preliminary cost estimate was done using an SWBS and PODAC formulas. Industry correspondence helped refine the analysis and provided a more realistic estimate for shipyards outside North America. During the analysis, it was noticed that the material cost formulae were outdated, therefore a necessary correction was applied to compensate for the increase in material costs over the last decade. In sum, material costs were doubled from initial PODAC estimates.

Operational costs for the vessel were broken into categories of crew, fuel, and maintenance. Crew costs were estimated through research of industry wages in PNG. It should be noted that the GDP for PNG is less than $3,000 and therefore the crew wages do not play a role in the annual operational costs.

Fuel costs were based on an assumed weekly schedule developed by the design team. This amounted to 1 roundtrip per week with an average dock time of 3 hours per port. Further assuming an annual utilisation of 80%, this surmounted to approximately 7000 annual operating hours and 42 roundtrips per year. Taking specific fuel rates for the main engines and auxiliary generators into account, the total amount of fuel needed per year is approximately 2,520 tonnes. MDO was taken as $900/tonne. Maintenance costs for any vessel are difficult to predict. Maintenance figures for the *TRIumph* are referenced to Washington State Ferries (WSF). The design team feels this is a sound reference as WSF has several ferries which operate in proximity to the proposed annual hours for the *TRIumph*.

A *fully burdened* hourly labour rate of $35 was assumed for construction in Singapore or China. The final costs assume a 10% material overhead and a 100% labour overhead. These assumptions were obtained from interviews with industry professionals and experienced faculty.

System Number	Title	Weight (LT)	Labor Man Hours	Material Dollars	Labor Dollars
100	Hull	520	$123,468	$832,000	$4,321,383
200	Propulsion M/C	94	$29,106	$3,790,000	$1,018,701
300	Electrical	14	$10,947	$700,000	$383,130
400	Command & Comm.	14	$13,819	$1,120,000	$483,655
500	Auxilliary M/C	29	$1,493	$600,000	$52,250
600	Outfit	132	$21,477	$2,650,000	$751,681
	Total:	803	$200,309	$9,692,000	$7,010,799

Vessel Annual Operating Expenses	
Crew Expenses	$13,858
Fuel Expenses	$1,927,167
Annual Maintenance	$481,792
Total:	***$2,422,817***

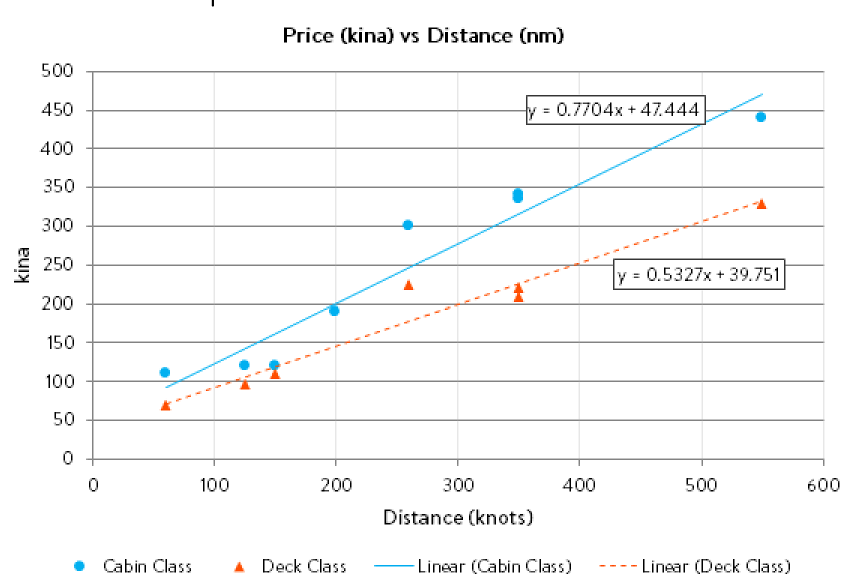
Item	Cost
Material Dollars (x2)	$9,692,000
Labour Dollars	$7,010,799
Material Overhead (10%)	$969,200
Labour Overhead (100%)	$7,010,799
Profit	$2,468,280
Total Vessel Cost	**$27,151,078**

Papua New Guinea Statistics		
Conversion Rate	2.67	kina/$US (Apr. 2014)
Average Hourly Rate	0.99	$US/hr
Annual Average Earnings	2897.00	$US
Annual Average Hours	2937.00	Hours
Vessel Annual Days	292.00	Days
Vessel Annual Hours	7008.00	Hours
Vessel Annual Round Trips	42.00	Roundtrips
Fuel Per Round Trip	50.98	tonnes
MDO Price	900.00	$US/tonne

As seen above, the total cost of the vessel is approximately $27 Million. It should be noted that at this early stage in the design process, any cost estimation will have large uncertainty. Nevertheless, the above figure was *within range* according to industry correspodance.

Revenue Generation

In order to get a realisitic picture of the potential revenue of the *TRIumph*, research was conducted to obtain ticket prices and cargo rates for vessels operating in the PNG region. The aforementioned prices for a total of 4 vessels, including the Rabaul Queen, were found. These prices were extrapolated as a function of distance and class. The graph below showcases the analysis with best fit lines providing the necessary formulae needed to calculate ticket prices.



Cargo rates for cars and trucks were obtained by researching average cargo to ticket rate ratios found in ferries throughout the world. The appropriate data for all ticket prices can be found in the appendices.

Class	Max Capacity	Revenue Per Trip$_{100}$
Economy	122	$20,064
Premium	54	$10,763
Cabin	80	$18,734
Car	22	$12,880
Truck	14	$12,294
	Total:	$74,734
	Annual Total:	***$3,138,833.69***

Revenue Per Trip$_{80}$
$16,051
$8,610
$14,987
$10,304
$9,835
$59,787
$2,511,066.96

Revenue Per Trip$_{60}$
$12,038
$6,458
$11,240
$7,728
$7,376
$44,840
$1,883,300.22

The figures above and to the right showcase potential revenues based on the aforementioned ticket and cargo fares for 100%, 80%, and 60% fully loaded. It can be seen that assuming the fuel, maintenance, and crew costs are correct (total annual operating costs of $2.4 million) , the vessel starts to generate positive revenue at approximately 75% fully loaded for all trips of the year.

Given the lack of high demand in the region and high fuel costs, it is hypothesised that the vessel will need to operate on a subsidy. Therefore, the vessel will be deemed a “service” rather than a “business venture”.

The Potential for Solar

Solar power was also proposed (to take advantage of the large amount of sunshine in the PNG region) to try and offset the large electrical loads of the vessel (air conditioning). Due to time constraints, a first order analysis was conducted. The findings indicate that approximately 200 kW of power could be provided by such a setup. But the high complexity and large acquisition costs dictate that a more detailed analysis is needed before a final decision can be made.

CONCLUSIONS & RECOMMENDATIONS

With increasingly higher levels of overcrowding on ferries, capsizing has become more and more common around the world in the past few decades, especially in developing countries. The *PNG TRIumph* was designed to address the resounding issue of safety while keeping affordability in the foreground.

The design utilizes a trimaran hull form that has addressed the major safety concerns associated with overcrowding-induced capsizing while maximizing vehicle payload. With two-compartment flooding, the vessel meets SOLAS 90 with full cargo and 250% passenger overcrowding capacity, in addition to meeting the International Code on Intact Stability, 2008. The vessel also meets Lloyd's Register regulations regarding safety equipment on board.

Affordability was addressed at all stages of the design. Decisions made to implement components with higher initial costs were justified with improved performance and/or safety features. The twin propeller azimuth drives used in conjunction with medium speed diesel engines provide a significantly more efficient propulsion system and decrease risk of damage associated with stern docking due to improved manoeuvrability. Improved efficiency in the propulsions system is crucial as increasing fuel costs are becoming the major expenses behind owning and operating a vessel. Other features directly affecting affordability include minimized indoor space to minimize air conditioning power consumption, hybrid-framing structure, modular cabin design and the minimal need for ballast which will lower ongoing maintenance costs.

As this is a conceptual design, there are many aspects that were not fully addressed and that require further work. Major tasks required to move forward are outlined below.

- The implementation of bilge keels on the side hulls and an evaluation of their influence on seakeeping motions
- Effect of an above-waterline watertight deck within the side hulls to improve stability under extensive side hull damage
- A probabilistic analysis should be conducted for damage stability to confirm that the vessel complies with the latest SOLAS regulations for passenger ships
- A CFD analysis of the hull form as well as air drag analysis on the superstructure
- An in-depth economical comparison between the equipped azimuthing drives versus a conventional rudder and propeller shafting arrangement
- A total ship electrical load analysis should be done to properly size the auxiliary generators
- In depth analysis of the manufacturability of this design
- Complete solar panel analysis to offset electrical loads (air conditioning)
- Optimisation of the scantlings to further reduce the lightship weight
- Model testing to determine wave interference effects and more accurate powering requirements and seakeeping motions

References

Ackers, B., Michael, T., Tredennick, O., Landen, H., Miller III, E., Sodowsky, J., & Hadler, J. (1997). An Investigation of the Resistance Characteristics of Powered Trimaran Side-hull Configurations. SNAME Transactions.

Andrew, D. (2001). Adaptability - The Key to Modern Warship Design. Warship 2001 Conference - Future Surface Warships. RINA.

Andrews, D. J., & Zhang, J. W. (1995). The Configuration for the Frigate of the Future. Naval Engineers Journal.

B.C. Research. (1980). Model test on a 50 m RO-RO Ferry Designed by Robert Allan ltd. for B.C. Ferry Corporation.

Blanchard, T., & Chunhua, G. E. (2007). Rules for the Classification of Trimarans. Journal of Naval Engineering.

Carr, B., & Dvorak, R. (n.d.). Investigation of Trimaran Interference Effects. Glen Cove, NY: Webb Institute.

Fernandez, R. P. (2012). Seakeeping in Navigation - Example in Trimaran Ships. International Journal for Traffic and Transport Engineering.

Gerr, D. (2009). Boat Mechanical Systems Handbook.

Hebblewhite, K., K, S. P., & J, D. L. (2007). A Case Study: Theoretical and Experimental Analysis of Motion Characteristics of a Trimaran Hull Form. SAOS.

Lamb, T. (2003). Ship Design and Construction. SNAME.

Levander, K. (2000). System Based Ship Design. Department of Marine System Design NTNU.

McDonald, T. P. (2010). A Library Based Approach for Exploring Style in Preliminary Ship Design. University College London.

Mizine, I., & Karafiath, G. (n.d.). Wave Interference In Design of Large Trimaran Ship.

Okumoto, Y., Takeda, Y., Mano, M., & Okada, T. (2009). Design of Ship Hull Structures: A Practical Guide for Engineers. Springer-Verlag.

Pastoor, W., Van't Veer, R., & Harmsen, E. (2004). Seakeeping Behaviour of Frigate-type Trimaran. RINA International Conference on the Design and Operation of Trimaran Ships. London.

Tupper, E. C. (1996). Introduction to Naval Architecture. Butterworth Heinemann.

Ungaro, A., Pino, E., Viviani, M., & Dattola, R. (2004). Global Strength Assessment of Trimaran Hull Multi Purpose Frigate. Design and Operation of Trimaran Ships.

Watson, D. G. (1998). Practical Ship Design. Elsevier.

Xu, M., & Zhang, S.-l. (2010). A Numerical Study on Side Hull Optimization for Trimaran. Journal of Hydrodynamics.

Zhang, J. (1997). Design and Hydrodynamic Performance of Trimaran Displacement Ships. University College London.