Design of a Common Modular - SWAS(S)H for Offshore and Harbour Support Vessels

Akula Nidarshan

Master Thesis

presented in partial fulfillment
of the requirements for the double degree:
“Advanced Master in Naval Architecture” conferred by University of Liege
"Master of Sciences in Applied Mechanics, specialization in Hydrodynamics, Energetics and Propulsion” conferred by Ecole Centrale de Nantes
developed at West Pomeranian University of Technology, Szczecin
in the framework of the

“EMSHIP”
Erasmus Mundus Master Course
in “Integrated Advanced Ship Design”

Ref. 159652-1-2009-1-BE-ERA MUNDUS-EMMC

Supervisor: Prof. Zbigniew Sekulski, West Pomeranian University of Technology Szczecin, Poland

Prof. André Hage, Design Naval & Transport and University of Liège

Reviewer: Prof. Robert Bronsart, University of Rostock

Szczecin, January 2016

DEDICATION

To

Mr. Karnthi Kumar Boina, Naval Architect and Ocean Engineer
The only reason I joined EMship, because you kept preaching about it.

&

Audry Cooper
My oh my, you are such a pain in my life,
I wouldn’t have survived EMship without you.

&

La Mujer en Rojo
For being my “friend”, when I was 100% sure I didn’t need one.
Finally someone made me “try” to be a less “frightening” person ;)

DECLARATION OF AUTHORSHIP

I declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research. Where I have consulted the published work of others, this is always clearly attributed. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work. I have acknowledged all main sources of help. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. I cede copyright of the thesis in favour of the West Pomeranian University of Technology, Szczecin, Poland.

Date: 15 JANUARY 2016

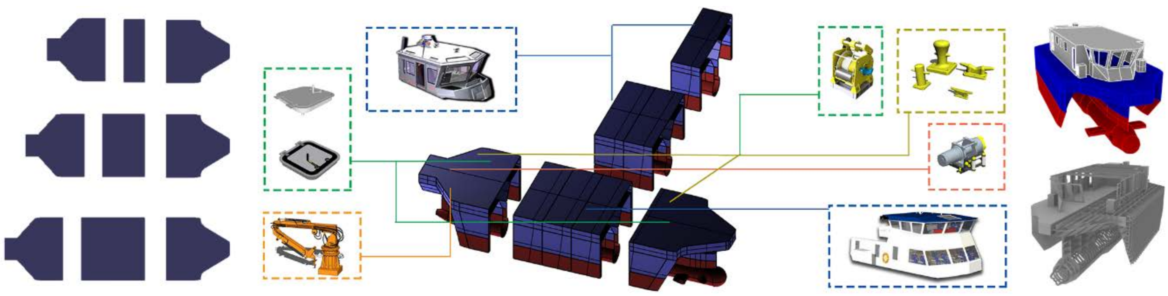
AKULA Nidarshan

ABSTRACT

Design of a Common Modular – SWAS(S)H for Offshore and Harbour Support Vessels

Safety and Environmental sustainability as the key aspects, the thesis predominantly focuses on European shipbuilding business of Windfarm, Harbour and Offshore Support Vessels. The thesis proposes use of SWATH concept to design a Trimaran like Small Water-plane Area Single (Stabilized) Hull popularly termed as SWAS(S)H. As described in literature, the excellent sea-keeping characteristics of this design make it an ideal choice for vessel types selected, but the design present itself with many drawbacks. The objective of this thesis is to eliminate or minimise the effects of these shortcomings.

The first task of this thesis was to design a hull that is not only practical and efficient technically but also economically. To ensure economic and practical feasibility, thesis developed the concept of common modular hull, improving productivity with reduction in production time and cost. Based on market research, it was decided to build modular hulls of lengths 18m, 21m and 24m. The idea being that the forward and aft modules of combined length 15m, are common to all hulls, while parallel middle body like modules of lengths 3m can be added to extend the length of the vessels from 18m to 24m. This resulted in total of five (5) vessel types of three (3) different hull lengths.



A common scantling structure for all the hulls was designed using DNV-GL HSC for the longest vessel length of 24m. The same scantlings are used for all the three hull lengths to ensure modular continuity. The below mentioned optimisation methodology was used with major focus on increasing the operational speed from 14-17 knots to 20 knots while reducing the fuel consumption & emissions, to an extent which is comparable to currently operational catamarans.

OPTIMISATION METHEDOLOGY				
S. No.	**Design Element**	**Software(s) Used**		**Logic/Code**
1	Ship Design/Modelling	Rhino 3DM/AutoCAD/Maxsurf Modeler		Class Rules
2	Sea-keeping	Maxsurf Motion Advanced		3D Panel Method
3	Resistance	Optimisation	Maxsurf & modeFrontier	Potential Flow
		Validation	FineMARINE	RANSE
			Towing Tank Test	ITTC 78
4	Adv. Hybrid DE Plant	MS Excel (Mathematical Model)		MAN Turbo Guide

The 18m hull was selected for towing tank test to facilitate largest model size with good scaling factor to ensure better results. The resistance of 18m mathematical model hull was successfully validated by towing tank test and with validated mathematical model, the thesis proved a reduction in resistance and power consumption in range of 21% to 25% for the three hull lengths. In conclusion, this thesis provides a design that has power consumption in range of less than 10% variance from the currently operational catamarans, while having superior stability and sea-keeping characteristics.

INTERNSHIP

Design Naval & Transports S.A.
Rue de la Belle Jardinière, 256 | 4031 Liège-Angleur
Belgium | TVA BE 880.074.961 | RPM Liège
Email: info@dn-t.be

INTERNSHIP SUPERVISOR **PROF. ANDRÉ HAGE**
INTERNSHIP PERIOD **1ST JULY TO 5TH NOVEMBER 2015**

The objective of this internship was to design a *Common Modular – Small Water-plane Area Single (Stabilised) Hull, CM-SWAS(S)H* with an intent to be used for three different types of vessels. This hull is to designed to accommodate the vessel size ranging from 18 m to 24 m. Work includes numerical simulation for resistance and stability, optimise the design for resistance reduction by way of bow modification and design of advanced hybrid diesel electric propulsion system. The results for resistance to be validated by way of Towing Tank test at University of Liège, Belgium. The vessel types targeted: Wind-farm Support Vessel, Pilot Boats, Police and Customs Patrol Crafts.

DELIVERABLES

a) Concept Design of CM-SWAS(S)H – Report,
b) Towing tank model test for resistance,
c) Master thesis defence at West Pomeranian University of Technology (ZUT), Szczecin,
d) Publish paper as per internship supervisor's preference

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND NOTATIONS

Please note that most technical notations and abbreviations are defined in the main report or the specific annexures for each chapter. The most commonly used abbreviations and noations are mentioned below:

IMO	International Maritime Organisation
UNFCCC	United Nations Framework Convention on Climate Change
DNV-GL	Det Norske Veritas - Germanischer Lloyd
ITTC	International Towing Tank Convention
ULg	University of Liege
ECN	Ecole Centrale de Nantes
L_{WL}	Length at waterline
L_{BP}	Length between perpendiculars
B	Beam
C_B	Block coefficient
D	Depth
Fn	Froude number
T	Draught/ Draft
L/B	Length-beam ratio
ρ	Water density
Δ	Displacement (weight)
TCG	Transversal centre of gravity
LCG	Longitudinal centre of gravity
VCG	Vertical centre of gravity
KT	Thrust coefficient
KQ	Torque coefficient
A_E/A_0	Blade Area Ratio
C	Chord length of the propeller
n	Shaft Speed
Rn	Reynolds number
R_T	Total resistance

T	Thrust
t	Thrust deduction factor
τ	Thrust loading
V_A	Advanced velocity
V_R	Resultant velocity
V_S	Ship/Service Velocity
w	Wake fraction
FO	Fuel Oil
LO	Lubricating Oil
FW	Fresh Water
SW	Sea Water
AC	Alternating Current
DC	Direct Current

Today, the two major concerns of Maritime Industry are Safety and Environmental sustainability. The European Shipbuilding business is being predominantly governed by Wind-farm, Harbour, Offshore Support Vessels and Yacht/Cruise/Pleasure Craft, this project will focus on design of a safe and eco-friendly common modular vessel that can cater to Wind-farm, Harbour Support Vessels (mainly Pilot, Police/Custom Patrol Boats) and Wind-farm Crew Transfer vessels for 18-24 m segment.

Pilot Boats, Police/Custom Patrol Boats and Wind-farm Support Vessels are designed and operated with an intent to carry personnel at shortest possible time while ensuring safety and comfort of personnel on board, in addition one of the most quintessential requirement is the safety during embarkation and disembarkation to/ from these crafts. Conventionally Mono-Planing Hulls are used for Pilot Boats, Police/Custom Patrol Boats and in latest trends Catamarans and/or SWATH (small water-plane area twin hulls) for wind-farm support vessels. The relative advantages and disadvantages of the same are the mentioned in table 1.1/1.2.

TABLE OF COMPARISON BETWEEN MONO-HULL AND SWATH			
S. NO.	**ELEMENT**	**PLANING MONO-HULL**	**SWATH**
1	**RESISTANCE**	Low	**HIGHER** (Frictional Resistance due to large wetted surface area)
2	**STABILITY**	Good	Excellent
3	**SEA-KEEPING**		
	Calm Waters	Good	Excellent
	Higher Sea-States	Poor	Excellent
4	**MANOEUVRING**	Good	Good
	In port / wind-fame area	Average	Average (As high course stability)
5	**OPERATIONAL EASE**		
	Deck Area	Small	Large
	Ease of Deck Work	Average	Excellent
	Embarkation/ Disembarkation	Poor	Excellent

Table 1.1 Comparison of Planing Mono-hull and Catamaran/ SWATH

TABLE OF COMPARISON BETWEEN MONO-HULL AND SWATH			
S. NO.	**ELEMENT**	**PLANING MONO-HULL**	**SWATH**
6	**STRUCTURAL DESIGN**		
	Weight and Complexity	Lower	**HIGHER**
	Class Rule Availability	Widely Available	**LIMITED**
7	**FINANANCIAL ASPECTS**		
	Production/Initial Cost	Low	**HIGHER**
	Operational & Maintenance Cost	Low	**HIGHER** (cost due to high fuel consumption and complex maintenance)

Table 1.2 Comparison of Planing Mono-hull and SWATH (continued from Table 1.1)

Now we compare the vessels in terms of values in numbers and as per practical application, please note that the data mentioned in table 1.3 represents vessels of different sizes but intended for same operation and similar values of deck area.

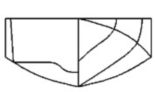
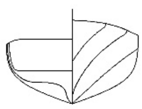
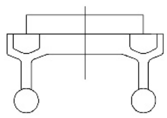
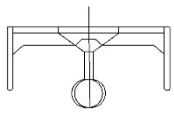
COMPARISON OF DIFFERENT HULL FORMS					
S. No.	**ELEMENT**				
1	Vessel Type	**PLANING**	**SEMI-PLANING**	**SWATH**	**SWAS(S)H**
2	Main Dimensions	26 m x 5.8 m	23 m x 8 m	25 m x 13 m	20 m x 12 m
3	Displacement	75 t	80 t	125 t	70 t
4	Propulsion Power	2300 kW	1600 kW	1800 kW	1300 kW
5	Max Speed	20 Knots	20 Knots	14 Knots	15 Knots
6	Wetted Surface Area	125 m^2	100 m^2	314 m^2	198 m^2
7	Operation Limit for Boarding	$h_{1/3} < 1.0$ m	$h_{1/3} = 1.0$ m	$h_{1/3} = 2.5$ m	$h_{1/3} = 2.0$ m
8	Vertical Acceleration at $h_{1/3} = 2.5$m	≈ 1.0 m/s^2	≈ 0.6 m/s^2	≈ 0.2 m/s^2	≈ 0.2 m/s^2

Table 1.3 Comparison of Planing & Semi-Planing Mono-hull, SWATH, SWAS(S)H hull form

A quick glance through the tables 1.1, 1.2 and 1.3 shows that, while the operational characteristics of SWATH are superior and unmatchable, the design, construction and operation calls for very high investment as compared to a planing mono-hull.

Another very important factor that makes SWAS(S)H hull ideal for crew transfer vessel is the ability to operate at high wave height with low value of vertical acceleration. This provides high passenger/personnel comfort, which means that when crew arrives at destination of operation the crew fatigue is least and the ability to efficiently operate is higher.

To evaluate the constraints at hand let us try to take a detailed look at disadvantage and a possible solution for each of the elements. Later the author will try to combine all the solutions in the best/most optimised manner to propose the new concept hull form.

Note*: Hydrostatic stability is an integral and relative parameter that gets affected as we optimise other design parameters, hence while proposing the solution for each element we will discuss how to counter the instability effects that might be introduced by optimising these relative elements.*

1.1 Resistance And Stability

High resistance means high installed operating power thus higher emissions. The operational profile of the vessels selected requires them to operate mostly in near coast region. In accordance to UNFCCC Copenhagen 2009, all EU nations have pledged to reduce the CO_2 emissions to a tune of 30% by 2020 and 40% by 2030, ***excluding offsets***. To solve this, the first thought that comes to mind is use of LNG as operating fuel. This presents us with two constraints:

1) While LNG, the Green Fuel of future does solve the problem of SO_X and NO_X, its ability to reduce greenhouse gasses like CO_2 is limited to 20-25% as compared to MDO,
2) In addition, at this point installation of LNG power plant on small vessels like Harbour and Wind-farm support vessels is limited due to large size of installation.

This requires us to look for alternate means of resistance reduction. The major reason for high resistance in SWATH is the large wetted surface area, which causes the increase in the frictional resistance component. In an effort to reduce the wetted surface area, instead of using twin hull, it is proposed to use a trimaran like multihull design with single submerged hull stabilised by two outriggers. This concept is popularly known as Small Water-plane Area Single (Stabilised) Hull - SWAS(S)H. This reduction in hull while reducing the resistance will adversely affect the displacement and stability. To take care of the displacement the design will increase, in an optimised manner the size of the central tube and the strut. And the stability will balanced out by optimising the outriggers, attached passive fin stabilizers and introduction of trim tanks.

1.2 Sea-Keeping And Pitch Instability

The concept of small water plane area combined with smaller length of the crafts reduces the lifting force acting due to the pressure of the wave, especially at high seas states, making this an excellent design for the required operations of the vessel types selected. On the other hand the drawback of pitch instability in terms of two steady-value phenomenon trim and sinkage, this can be controlled or eliminated by selecting correct design of fin stabilisers. Here in addition to the passive fin stabilisers used on outriggers, the central tube will also be provided with two passive stabilisers.

The forward end of central strut and the outriggers will be provided with spray rail system at operating draught line, this not only helps in reduction of spray resistance but also provides a lifting force at the forward end, reducing the pitch instability.

1.3 Structure And Stability

The advantage of SWATH Hull is high beam to length ratio (B/L), while it provides larger deck area for a given length it introduces complexity in structure. While the longitudinal bending loads do not influence the structure to large extent, the transverse and torsional loads call for the use of mixed framing system, instead of using the convention longitudinal or transverse system. This not only increases the complexity but also the structural weight and thus the lightship displacement. For SWATH vessels like this, it is important to keep the lightship displacement lower, this is to allow movement of cargo in and out of the vessel, as the movement of weight in and out of these vessels is supercritical for the stability. Thus the author proposes use Aluminium alloy for both hull and superstructure to reduce the structural weight and to provide flexibility in movement of weight in and out of the vessel, two/four small trim tanks will be provided, this will also ensure higher stability.

The Class rules for approval are limited to very few classification societies (most comprehensive is DNV-GL), but limited to SWATH only. We can use conservative approach and design the new concept hull and then carry out FEM based structural optimisation/ analysis to prove the structural integrity and compensate for unavailability of Class Rules.

1.4 Financial Aspects

A solution is as good as no solution, if it is not commercially viable. In this section author proposes the use of ideas that can help in reduction of both initial and operational investment.

1.4.1 Production Cost

The construction of multi-hull ships, in general calls for high cost of production due to the complex structure, in addition the introduction of aluminium alloy increases the raw material and welding cost of the project as well. To reduce this, the author proposes the use of common modular hull (CMH) i.e. not only the superstructure is made in modules that can be added or removed to modify the capability/features as needed, but the hull is designed in modular manner that can accommodate for the weight and stability parameter change by addition of small modules in parallel middle body. In addition this hull will be designed (in shape/structure/displacement) in such a manner that it can accommodate for all three vessel types with common hull, hence the name common modular hull. This will not only help in reduction in production man hours but also the design man hours thus reducing the overall production cost.

To reduce the welding cost of aluminium, the directly extruded stiffened panels will be used. These panels are manufactured in sizes up to 6m x 6m with the desired size of plate and stiffeners. As the welding at web-flange-plate is reduced the relative load bearing strength will increase thus the structure can be optimised to reduce the sizing of stiffened panel. This again results in relative reduction of weight and cost of the production.

1.4.2 Operational And Maintenance Cost

The optimisation for resistance as stated above, helps in reducing the fuel consumption and thus the operational cost. To reduce the fuel consumption to even larger extent the design proposes the use of Advanced Hybrid Diesel Electric System. The electric propulsion eliminates the gear box and thus enabling the design and operation of the propeller always at highest efficiency RPM with an accuracy of ±5 RPM. As the propeller efficiency extracted increases, the power load on engine and the corresponding fuel consumption can be reduced.

In a slender body hull like this the maintenance procedures/time becomes complex and critical. Another advantage of the electric propulsion system is elimination of extra auxiliary engine dedicated for electrical supply and the mechanically moving parts like gearbox, connecting shafts, etc. the reduction of moving mechanical parts not only reduces the wear and tear but also eliminates the use of access lubricating oil and the cleanliness issues associated and thus provides easy maintenance procedure and less maintenance cost.

The electric system that operates for both AC/DC system. AC as it is a more viable solution in current market and DC to accommodate for use of battery operation in emergency condition thus eliminating emergency diesel engine and more importantly providing the future scope to include ***Solar Power Charged Batteries***. The vessel will be installed with Siemens EcoProp like system which is a modification of ELFA system used on European Bus Transport System to reduce emission.

1.5 SUMMARY OF PROBLEMS AND SOLUTION

The table 1.4 summarises all the limitations and solutions proposed in above sections.

LIMITATION OF SWATH VS PROPOSED SOLUTION			
S. NO.	**ELEMENT**	**LIMITAION IN SWATH**	**PROPOSED SOLUTION**
1	**RESISTANCE**	**HIGHER** (Frictional Resistance due to large wetted surface area)	Reduction In Wetted Surface Area with Single Stabilised Tube
			Bow Hull Optimisation
			Spray rails at draught line
2	**STABILITY**	**EXCELLENT**	Maintained as excellent using
			Outriggers With Passive Fin Stabilisers
			Central Tube With Passive Fin Stabilisers
			Trim Tanks
3	**SEA-KEEPING**	**PITCH INSTABILITY**	Passive Fin Stabilisers
			Spray Rails
			Trim Tanks
4	**STRUCTURAL DESIGN**		
	Weight and complexity	**HIGHER**	Use Of Aluminium
			Modular Hull
	Class Rule availability	**LIMITED**	FEM Based Analysis and Optimisation
5	**FINANANCIAL ASPECTS**		
	Production/Initial cost	**HIGHER**	Common Modular Hull
			Extruded Stiffened Panel
	Operational & Maintenance cost	**HIGHER**	Resistance reduction
			Advanced Hybrid Diesel Electric System

Table 1.4 Summary of constraints of SWATH and proposed solutions

1.6 THE CONCEPT

Amalgamating all the solutions proposed above, the idea of advanced hybrid diesel electric propelled **C**ommon **M**odular-**S**mall **W**ater-plane **A**rea **S**ingle **(S**tabilised**) H**ull **CM-SWAS(S)H** is proposed. The vessels will be designed for different configurations for three hull lengths ranging from 18-24m. The figure 1.1 depicts the concept for easy understanding.

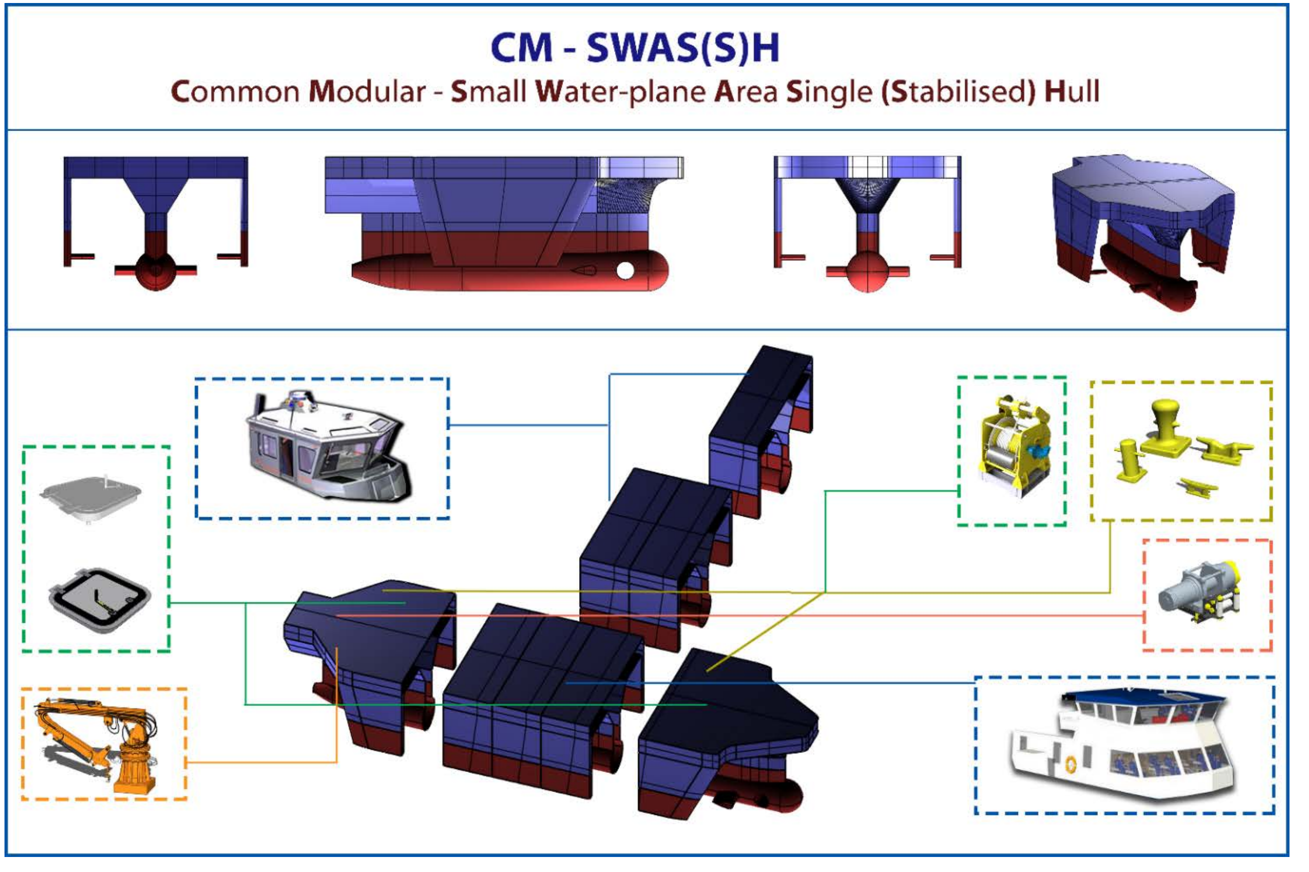


Figure 1.1 The Concept: Common Modular-Small Water-plane Area Single (Stabilised) Hull

CHAPTER 2 - PROBLEM DEFINITION

As any design process, this concept also required multiple iterations as the design of the vessel evolved. For the purpose of this master thesis work, the problem is divided and defined in sections as displayed in figure 2.1:

1. Concept Design of CM-SWAS(S)H based on owners requirement (defined by Market Survey),
2. Optimisation of bow for resistance in calm waters,
3. Design of Advanced Hybrid AC/DC Diesel Electric System,
4. Validation of resistance results by way of towing tank test.

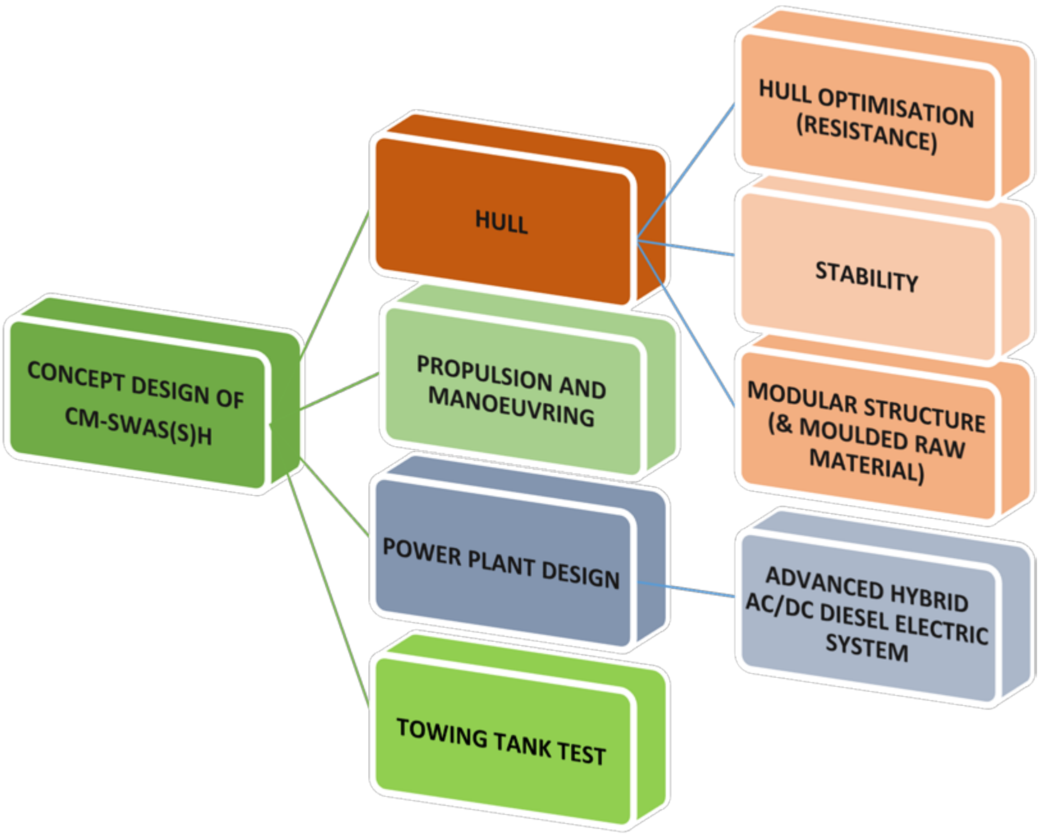


Figure 2.1 Project structure for the proposed concept design

2.1 Owners Requirement

Define the requirements of all the vessel as per general market requirement, this is done based on the data survey of the Port and Wind-farm industry.

2.2 Hull Form

The basic design of general arrangement and tank plan to accommodate for all of owners requirement.

2.3 Structural Design

Based on the general arrangement and operating draught condition design the structure of the vessel. Since there are no Class rules available dedicated to his kind of special ships, a conservative approach is used and the class rules for SWATH vessels form the guidelines.

2.4 Resistance Check And Bow Optimisation

The basic models are created in Rhino 3D and were evaluated for resistance in Maxsurf (Potential Flow) with modeFrontier (MOGA) and FineMARINE (RANSE). Since the major contribution of resistance for this hull is due to frictional component, the results of the final optimised hull were first validated with FineMARINE and then the towing tank test was carried out.

2.5 Stability

The design of outriggers, passive fin stabilisers (if needed) and trim tanks to ensure the stability of the vessel. Standard IMO stability criteria using the GZ-Curve is used to confirm the stability, this again is carried out using Maxsurf Stability Enterprise.

2.6 Propulsion And Manoeuvring

The work in this section is based on Class/Owners requirements. While the design is done for high efficiency, the work of this master thesis did not focus on optimisation for maximum efficiency.

2.7 Marine Power Plant

The standard AC diesel electric system was selected based on power requirement and was modified to Advanced Hybrid system with PTO/PTI (power take off/take in) units to accommodate for both AC/DC system.

2.8 TOWING TANK TEST

This involved the preparation of foam/resin/wood based scaled down model to be tested at towing tank to validate the numerical model resistance results of the 18 m hull.

2.9 WORK FLOW

The brief overview of workflow intended for this thesis is explained the figure 2.2:

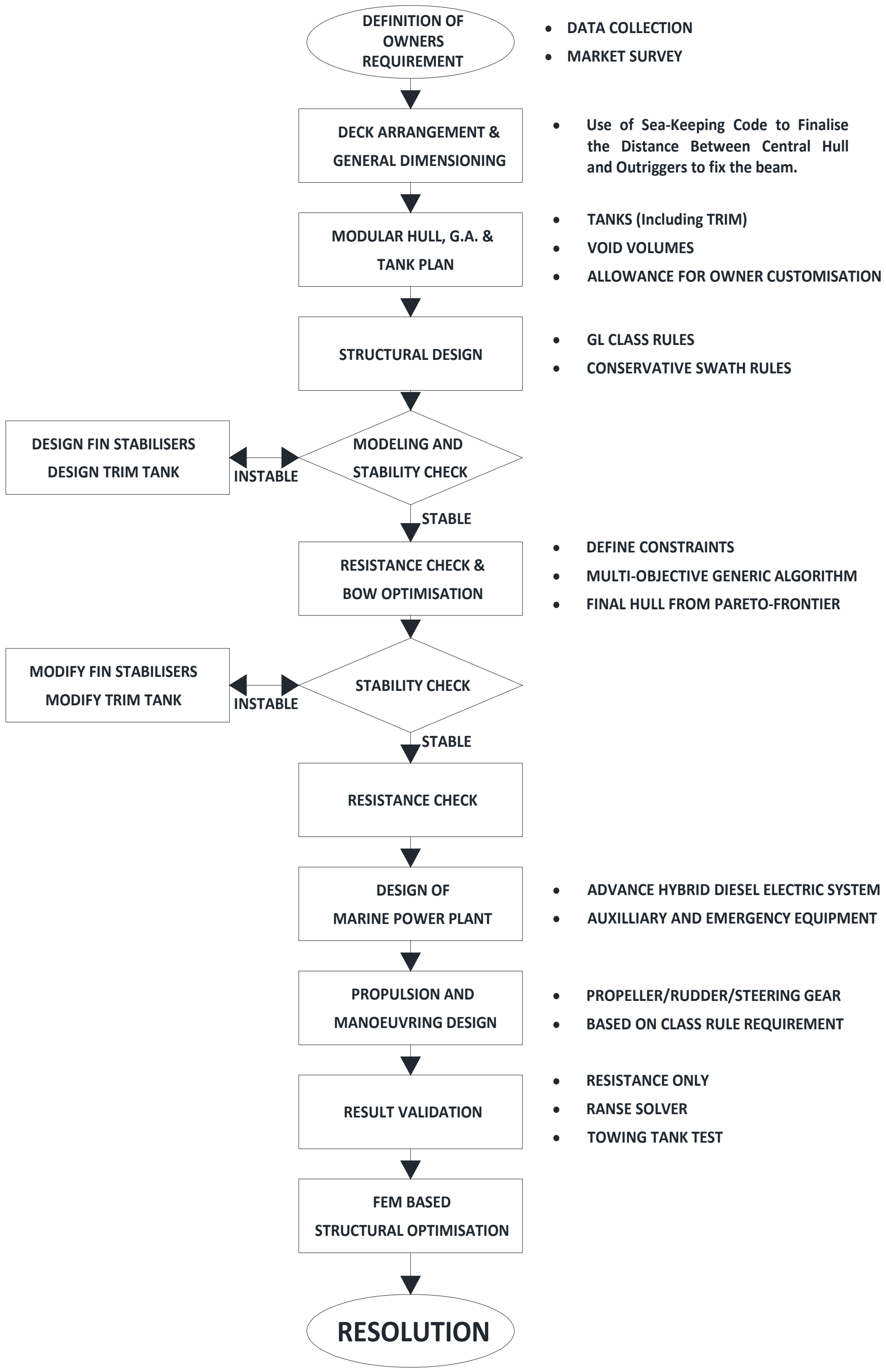


Figure 2.2 Project work flow chart

CHAPTER 3 - OWNERS & TECHNICAL SPECIFICATION

The owner’s requirement is defined based on the market survey of most common vessel size and requirements. The data collection based on market survey for Port and Wind-farm industry showed that the majority of vessels in operation are in the range of 18-28 m length. It should be noted that most Classification Society Rules for vessels less than equal to 24 m length are different from those with length greater than 24m. As the concept proposes the use of common modular hull, it was finalised that the vessels will be designed for lengths ranging from 18-24 m.

It total seven (7) configurations of vessels with three different types and sizes will be designed in common modular hull form, the details of the same are given in table 3.1.

VESSEL TYPE AND LENGTH COVERED UNDER THE CM-SWAS(S)H CONCEPT					
S. NO.	**VESSEL TYPE**	**NO. OF VESSELS**		**L.O.A. (approx.)**	**PERSONNEL (+ CREW)**
1	WINDFARM SUPPORT (WS)	3	1	24 m	12 (+3)
2			1	21 m	10 (+2)
3			1	18 m	6 (+2)
4	PILOT BOAT (PB)	2	1	21 m	10 (+2)
5			1	18 m	6 (+2)
6	CUSTOM / PATROL BOAT (CPB)	2	1	21 m	10 (+2)
7			1	18 m	6 (+2)

BASIC OWNERS REQUIREMENTS FOR ALL VESSELS			
S.NO.	**ELEMENT**	**QUANTITY/VALUE**	**VESSEL TYPE**
1	Max. Operating Speed	20 Knots	All Vessels
2	Endurance	48 Hrs	All Vessels
3	Fresh Water	0.5 m^3	18 m Vessel
		1.5 m^3	21 m – 24 m Vessel
4	Cargo/Free Deck Area	10 m^2	18 m Vessel
		35 m^2	21 m Vessel
		60 m^2	24 m Vessel
5	Winch	0.5 to 5 T at 2m	All Vessel
6	Saloon/Lavatory/Galley	To accommodate all Personnel and Crew	All Vessels Accordingly
7	Cabins	1 - 2 Personnel Cabin 1 - Captain’s Cabin	24 m WS Vessel

Table 3.1 Vessel type and length configuration including basic owner’s requirements

3.1 MULTI-HULL DIMENSIONING PRINCIPLE

The standard design process involves data collection for parameters like Length/Beam (L/B), Beam/Draft (B/T) etc. to estimate the initial dimensioning of vessels, since this is a concept hull and no such data is available, we will be using the Multi-Hull Characteristic parameters as proposed in technical paper title "Multihulls: Some results of development and new technical solutions" by Dubrovsky *Viktor Anatolievich, SaintPetersburg* [1]. The same in comparison with mono-hull are mentioned in table 3.2.

CHARACTERISTIC PARAMETERS AND RATIOS FOR MULTI-HULL				
S. NO.	**PARAMETERS**	**NOTATION**	**MULTI-HULL**	**MONO-HULL**
1	Overall Breadth/Length Ratio	B_m/L	0.30 - 1.00	0.10 - 0.20
2	Hull Depth/Overall Length	D/L	0.10 - 0.25	0.07 - 0.20
3	Depth/Length Ratio	H/L	0.10 - 0.30	0.07 - 0.10
4	One Hull Breadth/Draft Ratio	B_1/T	0.50 - 2.50	2.00 - 4.00
5	One Hull Length/Breadth Ratio	L/B_1	3.00 - 30.00	3.00 – 10.00

Table 3.2 Typical characteristic parameters for multi-hull vessels

As we intend to design a modular hull, parameters like beam, draft, and depth is kept same for all vessels, while the longitudinal dimensions (outrigger, central tube, deck, LOA etc.) will change for different vessels, it was also necessary to analyse sea-keeping and resistance characteristics of the vessel with change in distance between the outrigger and the central hull.

3.2 Beam Selection – Resistance And Sea-keeping Characteristics

In order to use the multihull dimensioning rule it's necessary that we fix some dimensions based on the requirements of the owner. In this case the most important factor is the length of the vessel. Keeping in mind the consideration of good hydrodynamic characteristics it was decided to check the variations based on the change of vessel beam. This will allow us to freeze two dimensions one based on owners requirement and the other based on hydrodynamic properties making it a more practical design. Hence it was decided to check resistance based on beam variation to ensure that there is no generated wave interference between the central and outer hulls. Also as per literature study we know that the sea-keeping characteristics of this type of hulls are excellent, in order to ensure that this property translates into the real design also, we decided to carry out preliminary sea-keeping analysis. When we use the length of the vessels and the multi-hull ratios we get a beam variation from 8.0 m to 11.5 m. Hence the analysis was carried out on this hull beams. These tests were carried out on 24 m hull only as the effect would be maximum on the longest hull.

NOTE: Please note though mentioned in this section, these tests were carried out on the optimised hull.

3.2.1 Resistance Analysis – Potential Flow Slender Body

Referring to the results of the resistance analysis in table 3.3, it can be seen that there is very little variation in the resistance by changing the beam and when translated in terms of power this variation further decreases to a very small value. Considering we are taking only 60% hull efficiency for power calculations this variation in resistance is deemed negligible. Hence based on the deck are requirement it was decided to select the 9.0 m beam.

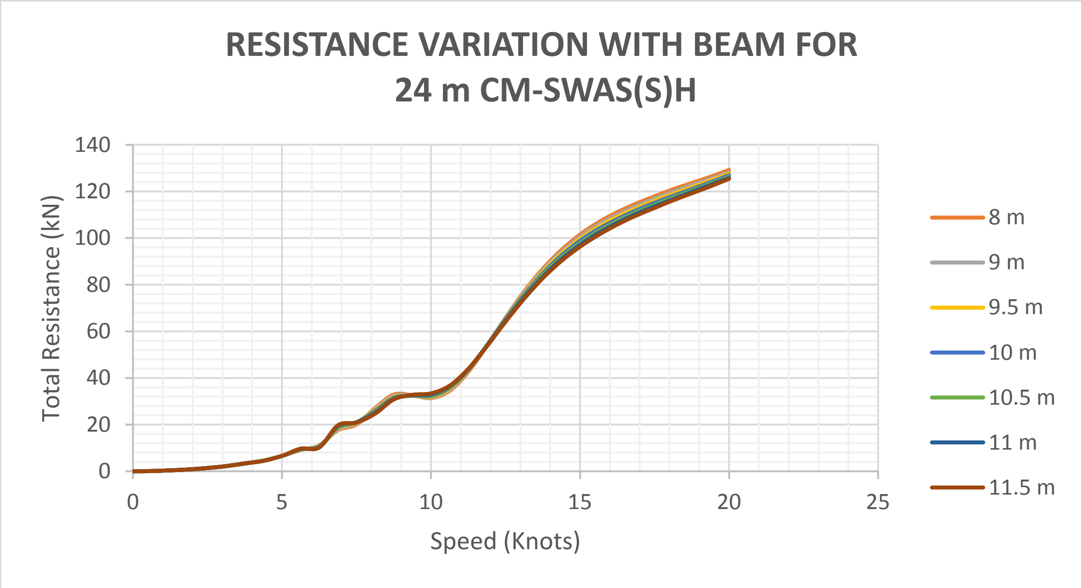


Figure 3.1 Resistance values for different beam dimensions 24 m hull

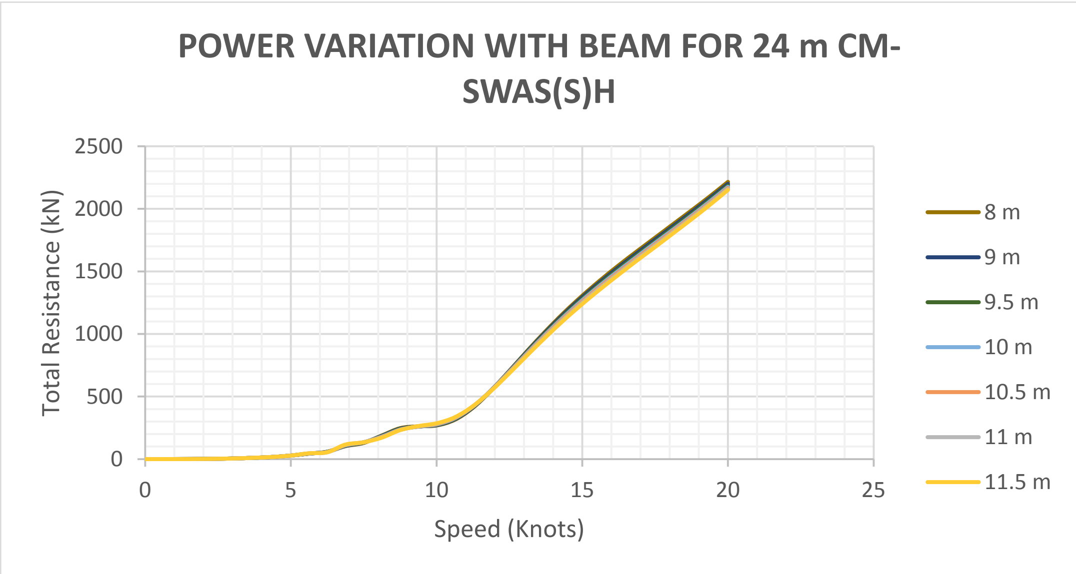


Figure 3.2 Power values for different beam dimensions for 24 m Hull

RESISTANCE VARIATION WITH BEAM FOR 24m CM-SWAS(S)H							
SPEED (Knots)	**BEAM (meters) / RESISTANCE (kN)**						
	8 m	**9 m**	**9.5 m**	**10 m**	**10.5 m**	**11 m**	**11.5 m**
20	129.2	128.2	127.5	126.9	126.3	125.8	125.4
POWER VARIATION WITH BEAM FOR 24m CM-SWAS(S)H							
SPEED (Knots)	**BEAM (meters) / POWER (kW)**						
	8 m	**9 m**	**9.5 m**	**10 m**	**10.5 m**	**11 m**	**11.5 m**
20	2215.08	2199.01	2186.68	2175.94	2165.20	2157.21	2150.42

Table 3.3 Resistance and power values for different beam dimensions for 24 m hull

3.2.2 SEA-KEEPING – POTENTIAL FLOW 3D RADIATION AND DIFFRACTION

The Sea-keeping analysis again were carried out for the same beam of the vessels, encounter frequency from 0.2 rad/sec to 30 rad/sec. Again the variation were very limited. And the resulting graphs are shown in figure 3.3 and 3.4, for details value please refer to the Annex -4.

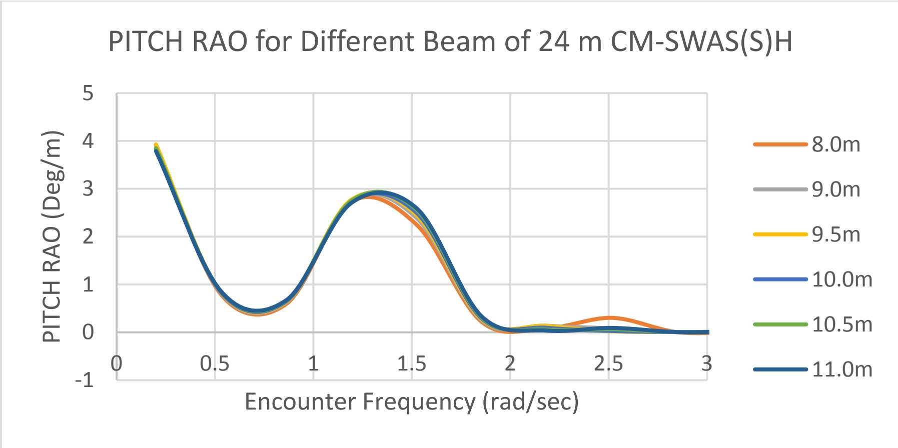


Figure 3.3 Pitch RAO for different beam dimensions for 24 m hull (till 3 rad/sec only)

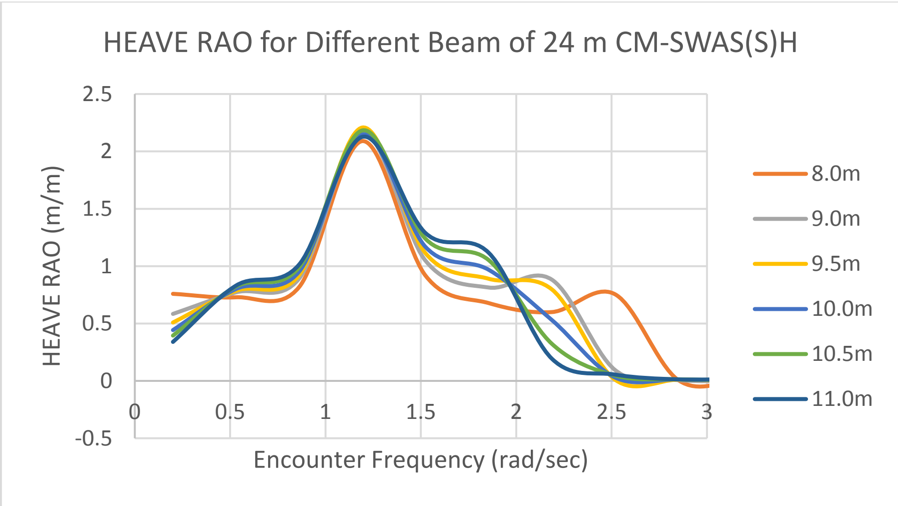


Figure 3.4 Heave RAO for different beam dimensions for 24 m hull (till 3 rad/sec only)

From the RAO results of pitch and heave it can be concluded that the natural period of the vessel at both heave and pitch is at 5.2 secs and in pitch RAO there is a hike of values at 2 different periods and smaller being 5.2 secs (wavelength λ=43m) and larger being more than 30 secs. Since there are really less number of waves with higher periods than 25 secs the larger one is not of our concern.

However, the smaller one lies in the time period of most occurring waves and hence further study on this wave period is required.

It could be seen that at this natural period the phase angle of pitch is just 11 degrees and heave is just 4 degrees which shows that the vessel is almost in phase with the wave so slamming of the vessel is less likely to occur. And also it can be seen that the L_{WL}/λ is equal to 0.5 at natural period, so this hike of pitch is just because it's aligning to the wave. Hence this motion is safe even in natural period.

Also waves of 5.2 secs are more seen near the port region and hence the wave height of such waves is really less as it is near the port region so it won't be much of a big issue. Anyhow as this vessel is meant to work in a sea state of higher wave height and wave period it could be seen from the heave and pitch RAO that the vessel either moves along the wave or else the motion is negligible which make it best suited as an offshore support vessel.

Since it is a potential flow solver and the values of roll RAO are inaccurate without the viscous damping coefficient the results of the same are not discussed but are available the in Annex-4 for review.

3.3 DIMENSIONS AND TECHNICAL SPECIFICATIONS

Based on the Multi-Hull dimensioning principle listed in Table 3.2, results of resistance and sea-keeping characteristics shown in figure 3.4, owners requirement for deck area and facilities, the dimensions were fixed as listed in the Table 3.4.

PRINCIPAL DIMENSIONS OF PROPOSED HULLS					
S. NO.	**PARAMETERS**	**VALUE (m)**	**S. NO.**	**PARAMETER**	**VALUE (m)**
1	LENGTH OVER ALL (LOA) 1	24.0	7	MAX. OUTRIGGER WIDTH	0.50
2	LENGTH OVER ALL (LOA) 2	21.0	8	MIN. OUTRIGGER WIDTH	0.35
3	LENGTH OVER ALL (LOA) 3	18.0	9	DESIGN DRAFT (T)	3.2
4	BEAM AT DESIGN DRAFT(B)	9.00	10	LIGHT SHIP DRAFT (T')	2.1
5	OVERALL BEAM (B_m)	9.50	11	DEPTH (D)	5.75
6	FENDER WIDTH	0.25	12	MAX TUBE DIAMETER	2.6

Table 3.4 Principal dimensions of proposed hulls

Once the dimensions were finalised, the next step was to finalise the complete technical specification and list of facilities for all the vessels.

Note: The final specifications of all the vessels are mentioned in Annex-1.

CHAPTER 4 - GENERAL ARRANGEMENT, TANK & LINES PLAN

The preliminary goal of any ship designer is to express the entire specification of the desired vessel graphically in terms of General Arrangement. This section presents the general arrangement drawings of all vessel configuration(s). Prior to starting the general Arrangement the first step(s) are to define the Class Rules/Notation that will be followed, the axis system, frame spacing and position of collision bulkhead.

4.1 CLASSIFICATION RULES AND NOTATION

The vessel will be designed as per the class rules under DNV-GL HSC, 2012 section, as

✠ 100 A5 HSDE RSA (200) "Transfer Vessel" **✠ MC AUT**

In DNV - GL rules, the notation above is divided into following representations:	
✠	The Maltese Cross means Hull, machinery and/or special equipment (e.g. refrigerating installation) have been constructed :under the supervision of and in accordance with the Rules of DNV-GL at the shipyard and/or at subcontractors supplying construction components/hull sections – with certification by DNV-GL of components and materials requiring inspection, subject to the GL Construction Rules As for example, hull, which has been constructed under supervision as stated in 2.3, and for which proof of subdivision and damage stability has been furnished, one of the two markings, shown on the left are assigned.
100 A5	The ship's hull fully complies with the requirements of the Construction Rules of DNV-GL or other rules considered to be equivalent.
HSDE	Notation for craft which have been constructed by using elements of Part 3 – Special Craft, Chapter 1 – High Speed Craft and which are not subject to the IMO HSC Code. Details regarding rule application are specified in the Class Certificate.
RSA (200)	This area of service is restricted, in general, to trade along the coast, provided that the distance to the nearest port of refuge as well as the offshore distance do not exceed 200 nautical miles. This applies also to trade in the North Sea and within enclosed seas, such as the Mediterranean, the Black Sea and waters with similar seaway conditions. Trade to Iceland, Spitsbergen and the Azores is exempted.
MC	MC means that the machinery including electrical installations complies with the requirements of the Construction Rules of DNV-GL or other rules considered to be equivalent.
AUT	The machinery installation is fitted with equipment for unattended machinery spaces, so that it does not require to be operated and/ or maintained for periods of at least 24 hours.

Table 4.1 Description of class notation followed

The operating Froude No. (F_n) for all the vessels were calculated as per the equation below and are mentioned in table 4.2.

$$F_n = \sqrt{\frac{V}{g * L_{WL}}}$$

OPERATING FROUDE NUMBER				
S. No.	**VESSEL LENGTH**	**OPERATING SPEED**	**L_{WL}**	**F_n**
1	18 m	20 knots (10.28 m/sec)	15.5 m	0.834
2	21 m	20 knots (10.28 m/sec	18.5 m	0.763
3	24 m	20 knots (10.28 m/sec	21.5 m	0.708

Table 4.2 Operating Froude number for all hull lengths

4.2 Axis System, Frame Spacing And Collision Bulkhead

The section details of the general axis system used and the special considerations that have been made to finalise the frame spacing and collision bulkhead position.

4.2.1 Axis System

The design axis system for all purposes will remain same during the project:

AXIS SYSTEM		
DIRECTION	**AXIS**	**ZERO REFERENCE POINT**
Longitudinal	X-Axis	0 point at Aft Perpendicular Centre Line of Rudder Stock
Athwart	Y-Axis	0 point at Centre Line along the length of the Vessel (Port Side as Positive and Starboard Side as Negative)
Vertical	Z-Axis	0 point at Keel of the Vessel

Table 4.3 Axis system followed for vessel design

4.2.2 Frame Spacing And Collision Bulkhead

To initiate the design, a conservative approach is followed to fix the frame spacing. This rule to approximate the frame spacing is taken from GL Rules High Speed Crafts: Yacht and Boats less than 24 m, Part 3, Section 1, Chapter 3, Hull Structure B. Glass Fibre Reinforced Plastic Hulls, 5.8. In practical scenario also, for aluminium hulls the frame spacing is not more than 500 mm. We could have taken any other value (let's say 380-450mm) also, all it will do is change the structural calculation with plate thickness and stiffener size to match the required section modulus based on the calculated bending moment and shear force. As future work we intended to do structural optimisation we took this as a starting reference.

$$Frame\ Spacing\ (s) = 1.2 * (0.35 + 0.005 *\ L_{wl})$$

And the collision bulkhead should be located at from forward perpendicular (FP) at a minimum length of 5% of length at water line to maximum of 3 m from FP i.e.:

$$Minimum\ Distance\ from\ FP = 0.05 *\ L_{wl}$$

$$Maximum\ Distance\ from\ FP = (0.05 *\ L_{wl}) + 3$$

Since the hull is modular in design, it is essential that, same frame spacing and position be followed for collision bulkhead. Hence a careful calculation of all hull lengths was carried out to arrive final values. The table 4.4 shows the values for different vessels.

FRAME SPACING & COLLISION BULKHEAD (CB)				
24 m - CM-SWAS(S)H				
S. No.	**PARTICULAR**	**FORMULA**	**VALUE**	**UNITS**
1	Frame Spacing	1.2*(0.35+0.005L)	0.534	m
2	CB Min Dist. From FP	0.05 L	0.950	m
3	CB Max Dist. From FP	0.05 L +3	3.950	m
21 m - CM-SWAS(S)H				
S. No.	**PARTICULAR**	**FORMULA**	**VALUE**	**UNITS**
1	Frame Spacing	1.2*(0.35+0.005L)	0.516	m
2	CB Min Dist. From FP	0.05 L	0.800	m
3	CB Max Dist. From FP	0.05 L +3	3.800	m
18 m - CM-SWAS(S)H				
S. No.	**PARTICULAR**	**FORMULA**	**VALUE**	**UNITS**
1	Frame Spacing	1.2*(0.35+0.005L)	0.498	m
2	CB Min Dist. From FP	0.05 L	0.800	m
3	CB Max Dist. From FP	0.05 L +3	3.800	m

Table 4.4 Frame spacing and position of collision bulkhead for all vessel lengths

Based on the values shown table 4.4 it was finalised that the frame spacing will be based on the smallest i.e. 18 m vessel while the minimum distance of collision bulkhead will be based on the longest i.e. 24 m vessel. The selected values are listed in the table 4.5.

SELECTED FRAME SPACING & COLLISION BULKHEAD POSITION				
S. No.	**PARTICULAR**	**REMARK**	**VALUE**	**UNITS**
1	Frame Spacing		0.50	m
2	CB Dist. From FP	From FP	1.00	m

Table 4.5 Selected frame spacing and position of collision bulkhead for modular hull

4.3 SPECIAL CONSIDERATIONS

With the basic details finalised, the next step was to list any special arrangements that were to be incorporated in the vessel design. Some of the major special consideration are mentioned here from sub-sections 4.3.1 to 4.3.4:

4.3.1 EMBARKATION / DISEMBARKATION

The pilot boat and the police/custom patrol boats are provided with one side ladder on both Port and Starboard side while the wind-farm Support Vessel is provided with an additional access point in forward to embark/disembark when the vessel positions itself to the windmill tower.

4.3.2 SINGLE AND TWO TIER SUPER STRUCTURE

All the vessels are designed in such a manner that they can accommodate the modular superstructure, which can either be single tier or two tier, in case of two tier structure the second tier will be completely dedicated as the navigation deck. The two tier system is provided to increase the open deck area to ease the operational movement and in special case as deck cargo area.

4.3.3 SINGLE OR TWO CABIN SYSTEM

The 24 m wind-farm support vessel is provided with an option of additional cabin for crew, this is done to accommodate the special owner’s requirement that has been observed as the current trend with wind-farm support vessels

4.3.4 SINGLE ANCHOR OR TWO ANCHOR SYSTEM

As per class rules and calculation it has been found that all the vessels will need only one number anchor (though of different specification as per vessel). But as we will be providing a special access point for wind-farm support vessel in forward end, two anchors (one each port and starboard) of 100% capacity are provided as forward anchors.

4.4 TANK CAPACITIES

Post Engine, Generator and Stability Calculations, the tank capacities were computed based on an endurance of 48 Hours of operation and fully loaded condition of cargo and crew. The same have been mentioned in the table 4.6.

TANK CAPACITIES							
S. NO.	TANK TYPE	18 m		21 m		24 m	
		P.P.C.	WSV	P.P.C.	WSV	P.P.C.	WSV
1	FUEL OIL (F.O.)	5 t	7 t	9 t	10 t	-	12 t
2	F.O. TRIM TANK	5 t	5 t	5 t	5 t	-	5 t
3	LUBE OIL	1 t	1 t	1.5 t	1.5 t	-	2 t
4	FRESH WATER	1.2 t	1.2 t	1.2 t	1.2 t	-	1.2 t
5	WASTE WATER	0.8 t	0.8 t	0.8 t	0.8 t	-	0.8 t
NOTE : P.P.C. : Pilot, Police/Custom Patrol Boat, WSV : Wind-farm Support Vessel							

Table 4.6 Tank capacities for all vessel configurations

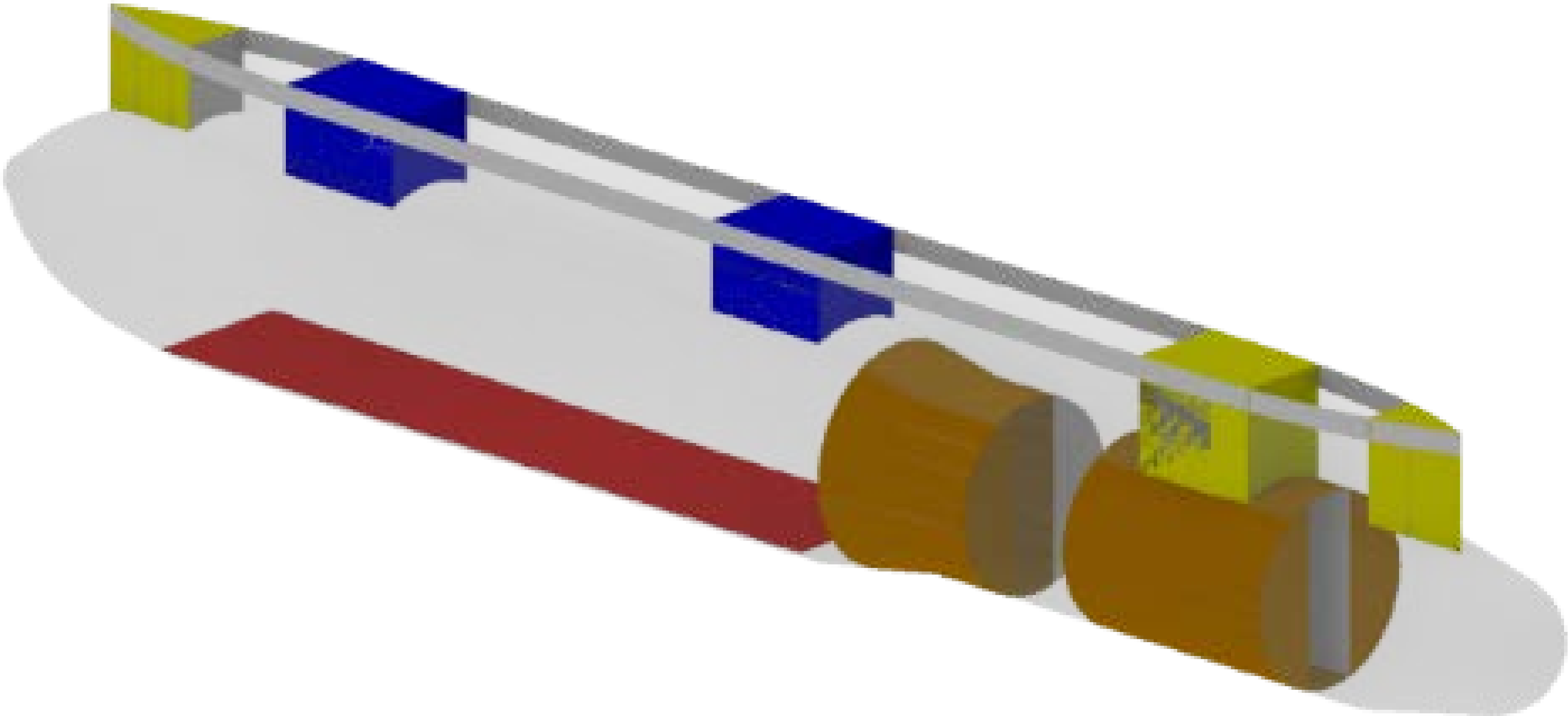


Figure 4.1 Tank Plan of 18m vessel to illustrate the arrangement of trim tanks

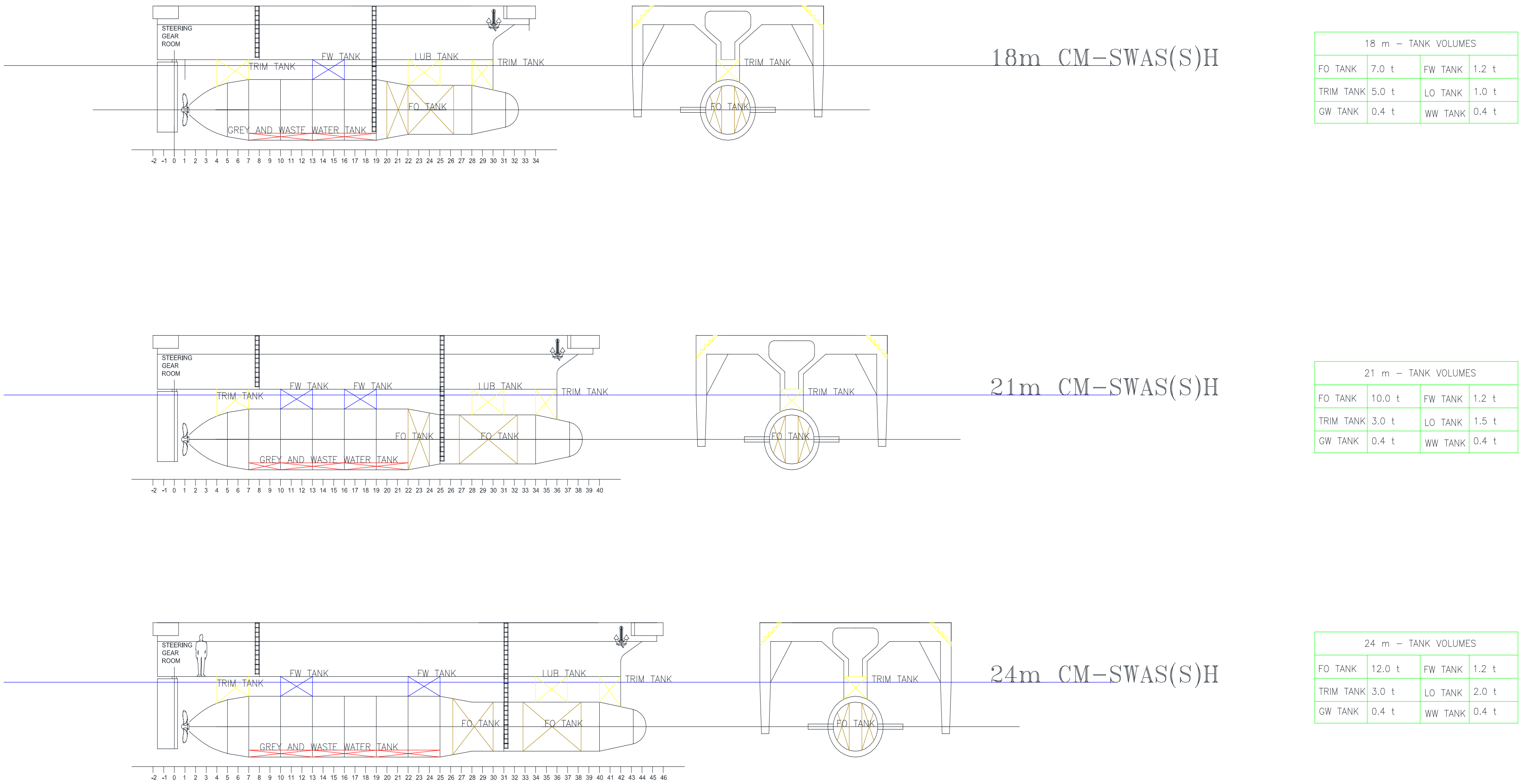


Figure 4.2 Tank plan for all three hulls, for detailed plan refer Annex – 1

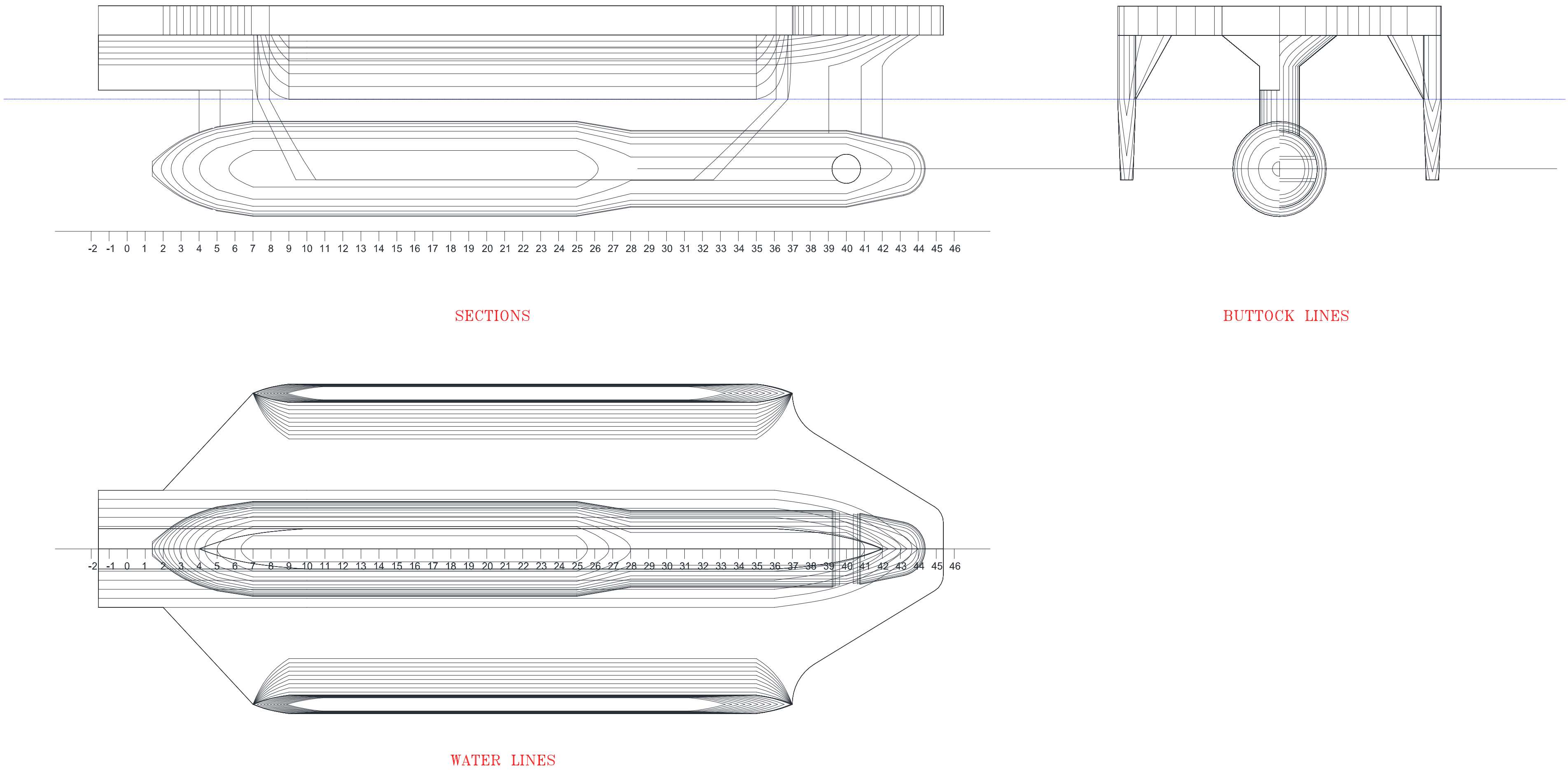


Figure 4.3 Lines plan for 24 m CM - SWAS(S)H, for detailed plan refer Annex – 1

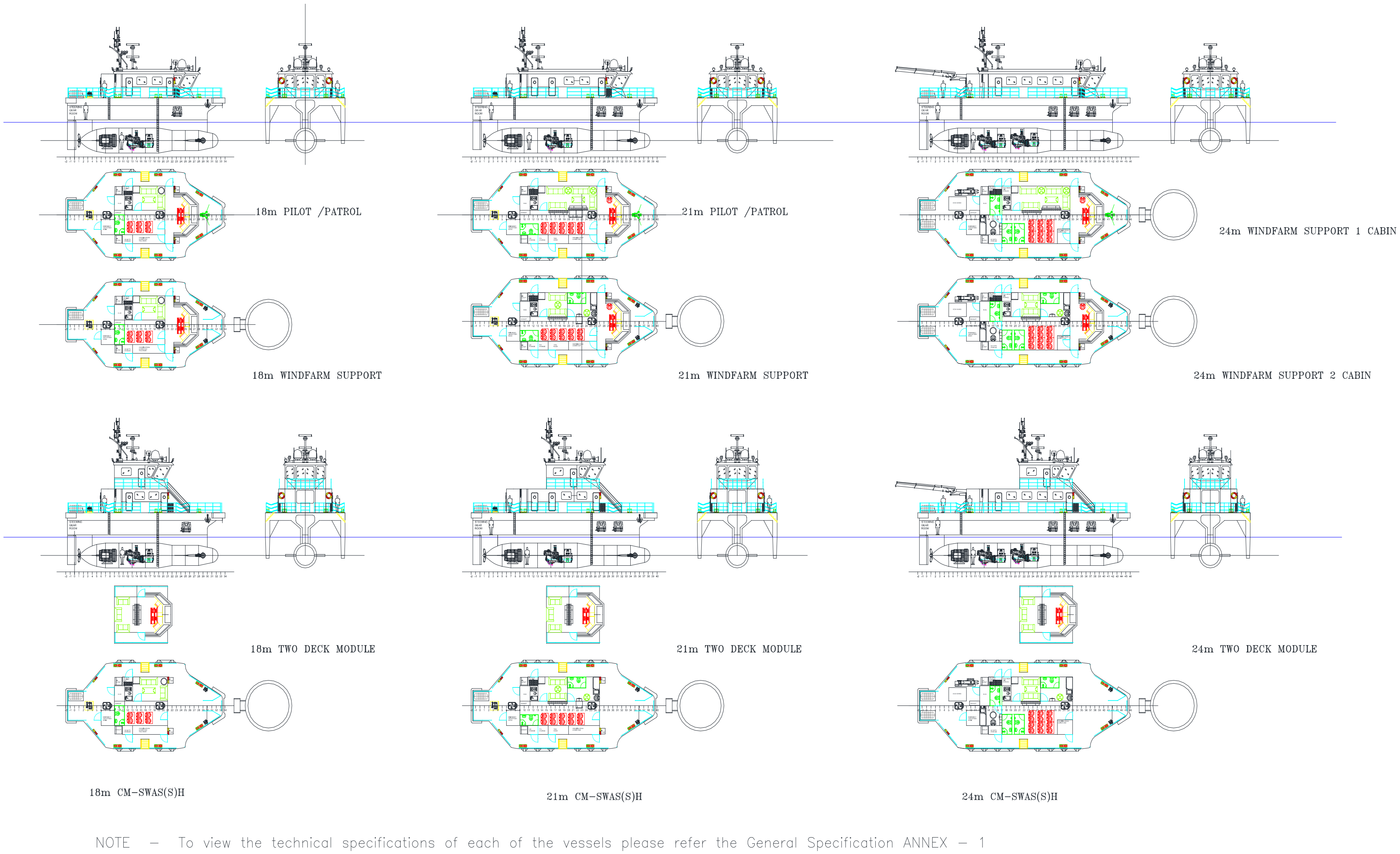


Figure 4.4 General arrangement plan for 6 different vessels, for detailed plan refer Annex – 1

CHAPTER 5 - STRUCTURAL DESIGN

In Chapter 4, mentions the class notation and the details of the rules that will be followed, it should be noted that based on study of multiple Classification Societies member of IACS it was found that there are no specific rules for special hull forms like CM-SWAS(S)H. Hence is was decided to use a conservative approach and use the class rules for SWATH and Trimaran Hulls as applicable. Since as future work we intend to carry out FEM based structural optimisation, the effects of this conservative approach will be nullified.

To limit the structural weight of the vessel to be as minimum as possible it was decided to use aluminium alloy for both main hull and superstructure. Furthermore to have even lesser weight it was decided to use ***Aluminium alloy 5083, H116***, this is due to the fact that as per DNV-GL Class rules for Special Ships-High Speed Crafts 2012, Chapter 1, Part 3, Section 3, Table C3.2.1 with an un-welded yield strength of H116 is 215 MPa as compared to 125 MPa for H111 for the same weight. For detailed properties of welded/un-welded yield and tensile strength refer to Annex-2. Considering the high beam to length (B/L) ration and the fact that for multi-hulls the transverse loads play dominant role. It was decided to use a mixed framing system in place of convention longitudinal or transverse framing system.

5.1 CONCEPT OF MODULARITY

The structural design involves the study of two levels of modularity one for the modularity of hull and the other for modularity of raw material in terms of stiffened panels. Both aspects have been explained below.

5.1.1 COMMON MODULAR HULLS

Employing the logic of Parallel Middle Body (PMB), used in mono hulls we designed the hull is such a manner that middle body of the vessel remains the same for 3m length in 18m LOA vessel and is termed as module. Thus when designing the 21m and 24 m LOA vessel we add one or two modules of this 3m length to the hull respectively. The concept image can be seen in the figure 5.1:

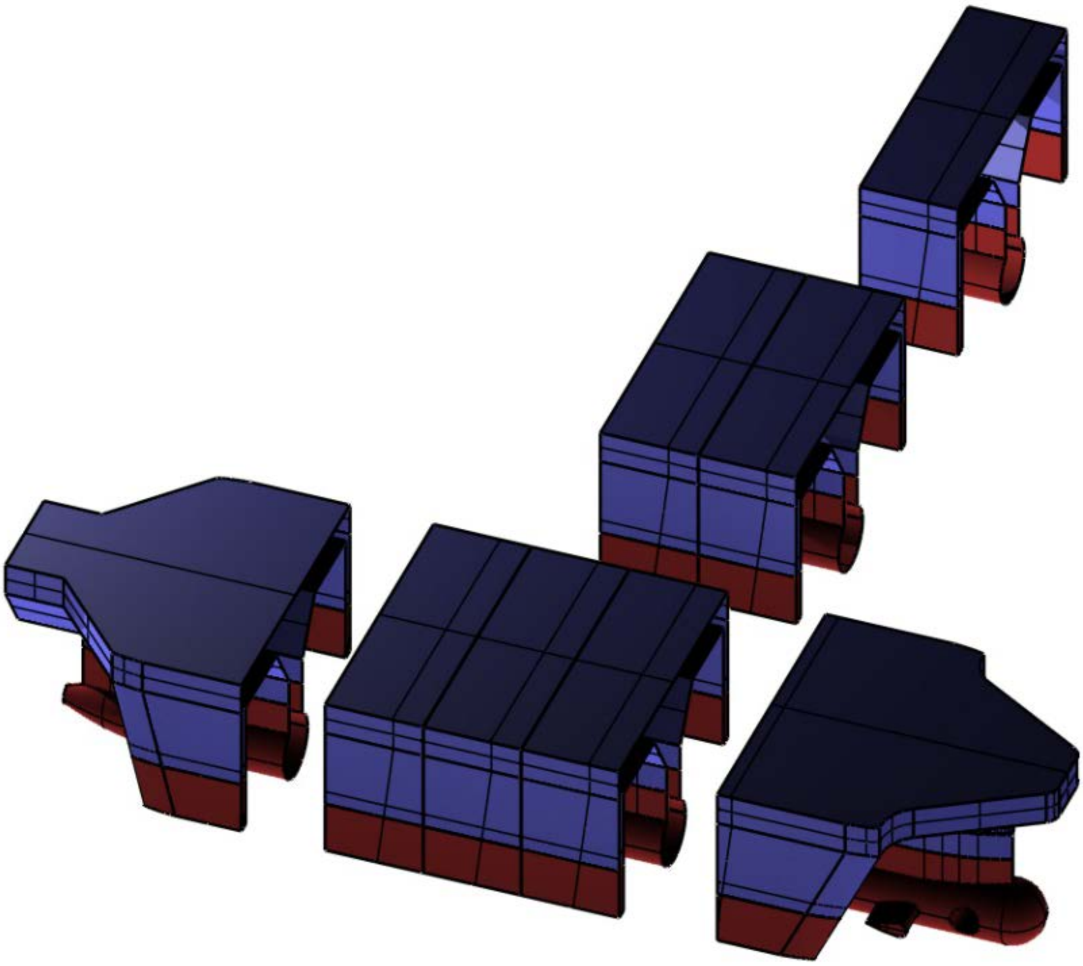


Figure 5.1 The concept of modular hull

5.1.2 Moulded Stiffened Panels Of Aluminium

We try to emphasise the use of extruded stiffened panels, as these panels are available in size of 6m x 6m (source : *Abeking & Rasmussen Schiffs- und Yachtwerft Aktiengesellschaft*) that can be easily used for any vessel size. The cost of welding is reduced as these are extruded panels which are then stir welded to form blocks. In addition since the stiffeners are part of the extruded plates the initial residuary stress induced due to welding is also minimised. This not only increases the strength of stiffened panel but also reduces the building time and cost. Since we have proposed the use of modular hull these moulded stiffened panel further ease the production for all vessel sizes.

The sample images of this kind of stiffener plans is provided in figure 5.2. It should be noted that these specimen images are from the samples available at University of Liege (ULg) Laboratory provided courtesy of ***Abeking & Rasmussen Schiffs- und Yachtwerft Aktiengesellschaft (A&R)*** for academic research purposes.

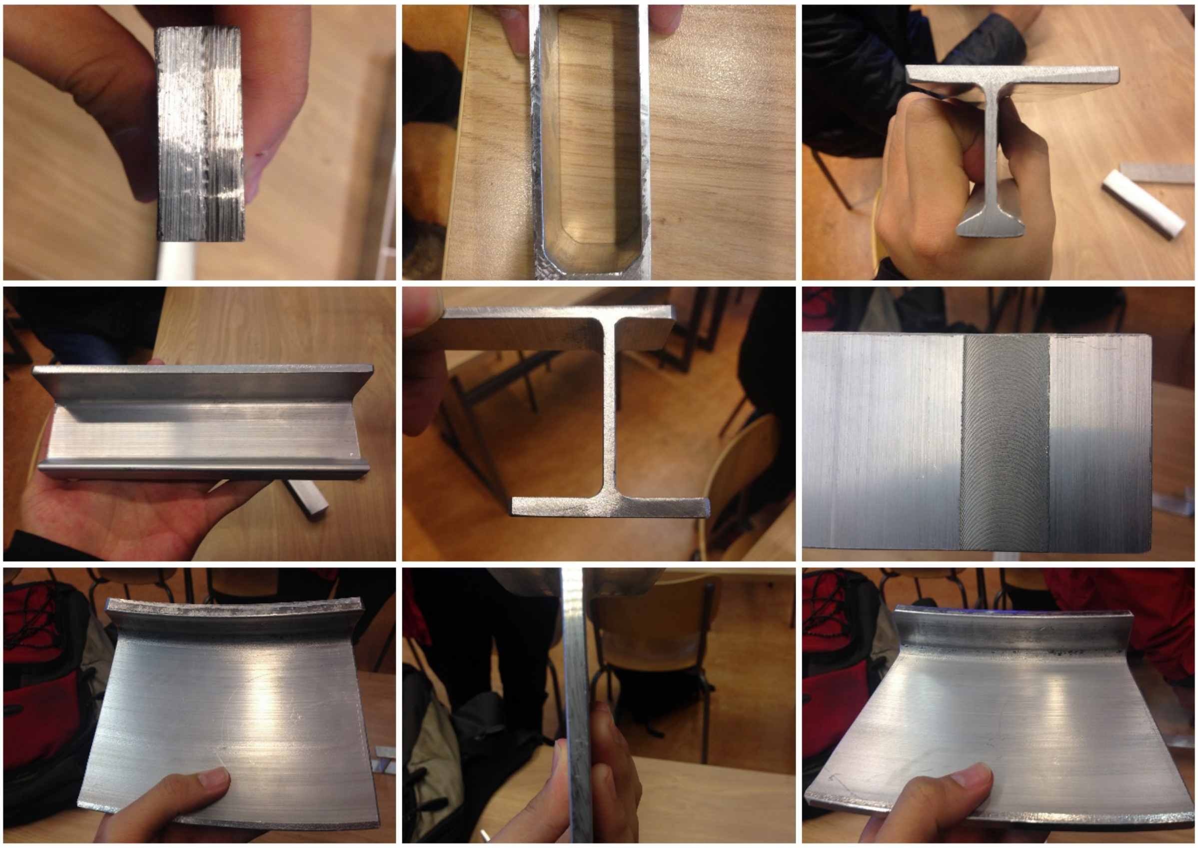


Figure 5.2 Sample images of moulded stiffened panels

Source: Abeking & Rasmussen Schiffs- und Yachtwerft Aktiengesellschaft (A&R)

5.1.3 MODULARITY EFFECT OF STRUCTURAL DESIGN

The major concern with a modular hull is the structural design and its continuity for all hull shapes and sizes. Hence we decided to design all the vessels with same structure i.e. we carry out structural calculation for the longest 24m LOA hull as it will be under the maximum expected load and use this hull for all the vessel lengths by removing sections of blocks of 3m length. As we have already arrived at a stiffener spacing of 500mm (refer Table 4.5), to achieve modularity it was very important to make sure that the ordinary frames, strong frames and water-tight bulkheads are placed at distance that are multiples of both 0.5 m, 1.5m and 3.0 m respectively. Based on these limiting constrains the structural calculation as per class rules was carried out.

5.2 STRUCTURAL CALCULATION

As the first step of any calculation it was required to check the use and applicability of the rules. Since we have decided to use the Special Ships-High Speed Crafts rule, as per Classification Rules DNV-GL, Chapter 1, Section 3, Structural details the applicability condition is given as

$$Vessel\ Velocity\ (V), knots\ \geq 7.16 * Displacement\ (\Delta)^{\frac{1}{6}}$$

5.2.1 Load Calculation

In following section(s) we will discuss the consideration and most important equations that are used for the purpose of structural calculation. Based on these equations, the detailed calculation were carried out on spread sheets and the same (including the abbreviations) can be referred in Annex-2.

$$Material\ Factor\ (k) = \frac{100}{R_{p0.2}}$$

$$Vertical\ Acceleration\ at\ LCG\ (a_{CG}) = c_{HSC} * c_{RW} * \frac{V}{\sqrt{L}}$$

$$Longitudinal\ Distribution\ of\ Vertical\ Acceleration\ (a_V) = k_V *\ a_{CG}$$

$$Transverse\ Acceleration\ (a_t) = 2.5 * \frac{H_s}{L} * \left(1 + 5 * \left(1 + \frac{V_X}{6 * \sqrt{L}}\right)^2 * \frac{r}{L}\right)$$

$$Limisting\ Significant\ Wave\ Height\ (H_{sm}) = 5 * \frac{a_{CG}}{V} * \frac{L^{1.5}}{6 + 0.14 * L}$$

Due the limitation imposed by vertical acceleration at LCG and based on vessels geometry, the significant wave height is then calculated as:

$$H_s = \frac{10.9 * a_{CG} * K_{cat} * K_H}{{K_F}^2}$$

As stated earlier one of the major advantages of small water plane are design is reduced or very limited heave motion of vessel due to wave action, which also plays important role while calculating for section C 3.3.3.4 Limitation imposed by global loads. As per sub-section C 3.3.3.4.3 For SWATH craft, the global loads as given in C3.4.3 are not depending on ship motions. Refer figure 5.3 for load notations.

$$Beam\ Side\ force\ (F_Q) = 12.5 * T * \Delta^{\frac{2}{3}} * d * L_s$$

$$d = 1.55 - 0.75 * \tanh\left(\frac{\Delta}{11000}\right)$$

$$L_S = 2.99 * \tanh(\lambda) - 0.725$$

$$\lambda = \frac{0.137 * A_{lat}}{T * \Delta^{\frac{1}{3}}}$$

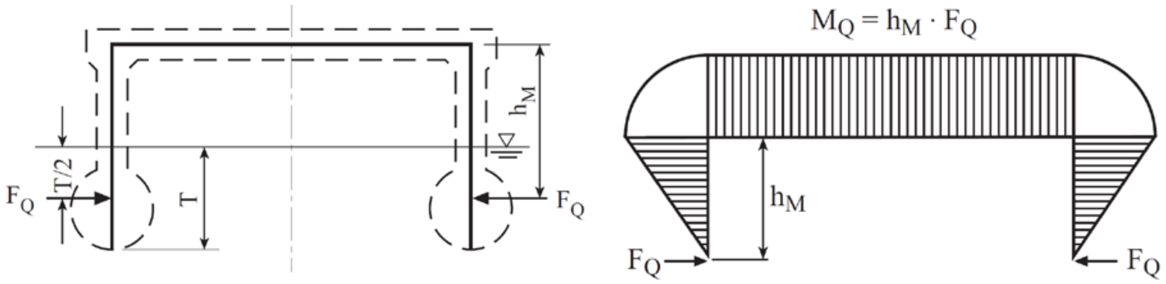


Figure 5.3 Beam loads and bending moment principle of SWATH Vessel, Source: DNV-GL Rules

$$Lateral\ Pressure\ (P_Q) = \frac{F_Q}{A_{lat}}$$

$$Bending\ Moment\ (M_Q) = h_m * F_Q$$

$$Impact\ Pressure\ on\ Bottom\ Hull\ (p_{sl}) = 100 * T * K_1 * K_2 * K_3 * a_{CG}$$

$$Impact\ Pressure\ on\ Wet\ Deck\ (p_{sl}) = 3 * K_2 * K_3 * K_{WD} * V_X * V_{sl} * \left(1 - 0.85 * \frac{H_A}{H_s}\right)$$

$$Sea\ Pressure\ on\ Bottom\ and\ Side\ Shell\ (p_s) = 10 * \left(T_0 + 0.75 * S - \left(1 - 0.25 * \frac{S}{T}\right) * z\right)$$

$$Sea\ Pressure\ on\ Deck\ House\ (p_s) = K_{su} * \left(1 + \frac{x_1}{2 * L * C_B + 0.1}\right) * (1 + 0.045 * L - 0.38 * z_1)$$

$$Pressure\ acting\ on\ Deck\ (p_d) = p * (1 + 0.4 * a_v)$$

5.2.2 OVERALL STRENGTH AND PLATING

After calculating the pressure and load acting, the next step is to calculate overall strength of the structure by calculating the longitudinal bending strength and the plate thickness based on the bending strength:

$$Longitudinal\ Stress\ (\sigma_{bl}) = \left|\frac{M_{bl}}{I_y} * (z - z_0) * 10^{-3}\right|$$

$$Plating\ Thickness\ (t) = 22.4 * \mu * s * \sqrt{\frac{P}{\sigma_{am}}}$$

5.2.3 OVERALL STRENGTH AND ORDINARY STIFFENERS

To calculate the stiffener scantling we must calculate the section modulus and the shear area as per the following equations. These equations are then used for different section to evaluate the scantling at each section:

$$Section\ Modulus\ (Z) = 1000 * \frac{l^2 * s * p}{m * \sigma_{am}}$$

$$Shear\ Area\ (A_t) = 5 * \frac{l * s * p}{\tau_{am}}$$

5.2.4 PRIMARY SUPPORTING MEMBERS

The primary supporting members (floors, frames, beams) are to form continuous transverse frames. In general, the stiffened frame spacing is not to exceed:

$$S = 1200 + 10 * L$$

$$Section\ Modulus\ (Z) = 1000 * \frac{S^2 * b * p}{m * \sigma_{am}}$$

$$Shear\ Area\ (A_t) = 5 * \frac{S * b * p}{\tau_{am}}$$

5.2.5 BULKHEAD STRUCTURE

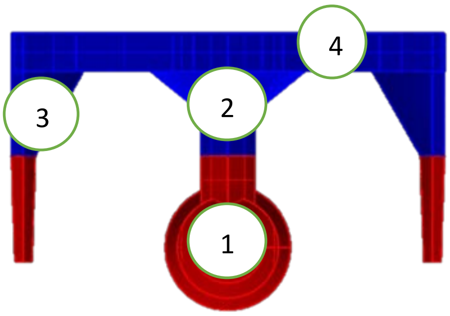
The proof of buckling strength of longitudinal and transverse bulkhead structures is carried out as per the same guidelines as stated earlier for ordinary and primary members, with the distinction of plating thickness which is given by:

$$Bulkhead\ Plating\ Thickness\ (t) = 22.4 * f_m * \mu * s * \sqrt{\frac{p_{sb}}{\sigma_{am}}}$$

5.3 Structural Details

The most critical step of structural design is selecting the right scantling, here it should be noted that different sizes and shapes of scantling can provide based on the required strength as calculated from the equation and rules stated above, but we have to arrive at a scantling that eases the production and at the same time provides minimum lightship weight. In order to arrive at right shape and size have divided the hull structure into four segments and for each segment the scantlings have been selected accordingly. The segments are divided as below:

1. Central tube,
2. Central strut,
3. Outrigger,
4. Deck,
5. Superstructure,
6. Bulkheads.



In this sub-section(s) we will discuss the required scantlings and any special consideration(s) that have been taken into account for final selection.

5.3.1 Central Tube

The tube is treated as the bottom shell, provided with one central bottom girder and to side girders, one both Starboard and Port side each. The transverse frames are divided into two elements, one at strong frames of 1.5m apart and one at each ordinary frame at 0.5m. While the entire tube is not provided with double bottom, at intermittent section, there are double bottom tanks provided for bilge and waste water tanks.

The details of required and selected scantlings are provided in the table 5.1.

DETAILS OF CENTRAL TUBE SCANTLINGS				
S. NO.	ELEMENT	SCANTLING REQUIRED	SCANTLING PROVIDED	
			VALUES	SHAPE AND SIZE
1	Outer Plate Thickness	6.258 mm	8 mm	-
2	DB Plate Thickness	6.258 mm	8 mm	-
3	Bow Plate Thickness	6.524 mm	8 mm	-
4	Central Girder	53.309 cm^3	249.63 cm^3	T 300x10 + 40x10
5	Side Girder	53.309 cm^3	249.63 cm^3	T 300x10 + 40x10

Table 5.1 Details of central tube scantlings

5.3.2 Central Strut

The scantling selection for central strut is done using the side shell criteria. The structure is predominantly supported by transverse frames with longitudinal at each side spaced at 0.5m each. The details of required and selected scantlings are provided in the table 5.2.

DETAILS OF CENTRAL STRUT SCANTLINGS				
S. NO.	ELEMENT	SCANTLING REQUIRED	SCANTLING PROVIDED	
			VALUES	SHAPE AND SIZE
1	Plate Thickness	2.173 mm	4 mm	-
2	Longitudinal Member	6.429 cm^3	13.51 cm^3	T 40x10 + 40x10
3	Transverse Frame	130.4 cm^3	140.84 cm^3	T 200x10 + 40x10

Table 5.2 Details of central strut scantlings

5.3.3 OUTRIGGERS

The outriggers are considered as outer hulls of a Triamaran and provided with mixed transverse and longitudinal members. To ease the welding/production instead of profiles (T, L, Bulb etc.), the transverse members are provided as plates with perforation holes to reduce the weight while ensuring the required strength.

The details of required and selected scantlings are provided in the table 5.3.

DETAILS OF OUTRIGGER SCANTLINGS				
S. NO.	ELEMENT	SCANTLING REQUIRED	SCANTLING PROVIDED	
			VALUES	SHAPE AND SIZE
1	Plate Thickness	2.173 mm	4 mm	-
2	Longitudinal Member	6.429 cm^3	13.51 cm^3	T 40x10 + 40x10
3	Transverse Member	130.4 cm^3	140.84 cm^3	T 200x10 + 40x10

Table 5.3 Details of outrigger scantlings

5.3.4 DECK

The lower deck and upper deck calculations were based on the weather deck criteria with cargo loading. The lower and upper deck were provided with similar scantlings as per the rule requirements.

The details of required and selected scantlings are provided in the table 5.4.

DETAILS OF DECK SCANTLINGS				
S. NO.	ELEMENT	SCANTLING REQUIRED	SCANTLING PROVIDED	
			VALUES	SHAPE AND SIZE
1	Upper Deck Plate	3.816 mm	8 mm	-
2	Lower Deck Plate	3.816 mm	8 mm	-
3	Longitudinal Member	19.822 cm^3	37.90 cm^3	T 80x10 + 40x10
4	Transverse Member	158.9 cm^3	205.51 cm^3	T 200x10 + 80x10

Table 5.4 Details of deck scantlings

5.3.5 SUPERSTRUCTURE

The single structural calculation based on single deck system is done and the scantling is provided accordingly. It can be seen from the table 5.5 that the required thickness for the superstructure is taken 0.4 mm higher than the required, this is done taking into consideration the two deck system of modularity.

DETAILS OF SUPERSTRUCTURE SCANTLINGS				
S. NO.	ELEMENT	SCANTLING REQUIRED	SCANTLING PROVIDED	
			VALUES	SHAPE AND SIZE
1	Plate Thickness	5.646 mm	6 mm	-
2	Longitudinal Member	4.821 cm^3	15.19 cm^3	T 40x10 + 40x10
3	Transverse Member	142.4 cm^3	189.98 cm^3	T 200x10 + 80x10

Table 5.5 Details of superstructure scantlings

5.3.6 BULKHEADS

The vessel is provided with one collision bulkhead, and 3/4/5 engine room bulkheads, depending upon the length of the vessel. Since we are using mixed framing, which is predominantly transverse, the thickness of these bulkhead is taken slightly higher than the rule requirement, this also helps us in minimizing the longitudinal scantlings.

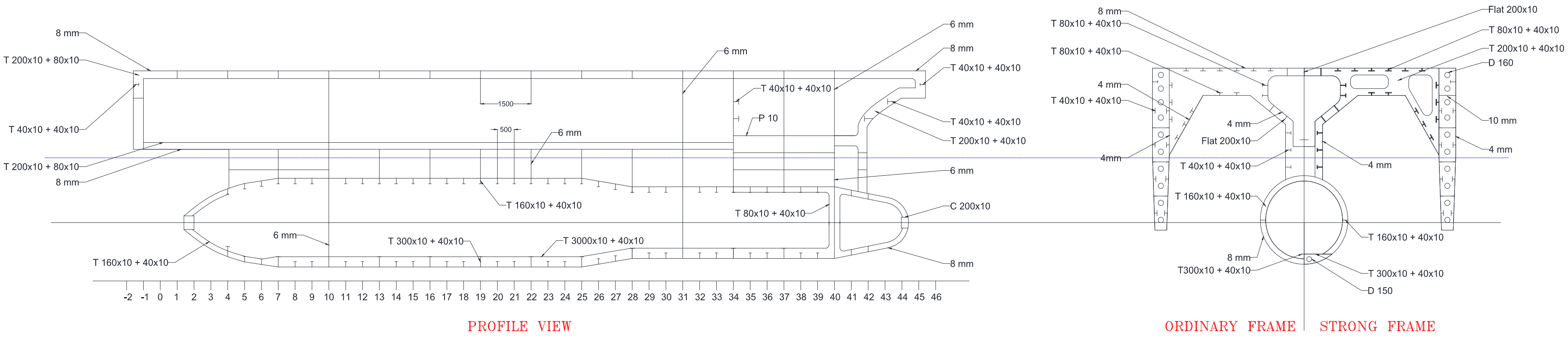
The details of required and selected scantlings are provided in the table 5.6.

DETAILS OF BULKHEAD SCANTLINGS				
S. NO.	ELEMENT	SCANTLING REQUIRED	SCANTLING PROVIDED	
			VALUES	SHAPE AND SIZE
1	Collision Bulkhead Plate	4.685 mm	6 mm	-
2	Other Bulkhead Plate	4.062 mm	6 mm	-

Table 5.6 Details of bulkhead scantlings

It should be noted, though in most ship designs it’s a practice to use bulb profiles at stiffening elements, we have used T- bars as we have proposed the use of rolled stiffened panels of aluminium and it had been indicated that these rolled panels of 6m x 6m are produced best with T-bars to have minimum defects.

Based on the design, we first created the preliminary two dimensional structure which can be referred in the structural plan. Though FEM based structural optimisation is not carried out as part of this master thesis, a detailed structural model was designed, that can be later used for structural analysis and optimisation the structural elements, the same can be referred in figure 5.4 to figure 5.8.



18 m			
LOADED SHIP		LIGHT SHIP	
DISPL. (t)	79.34 (t)	DISPL. (t)	63.97 (t)
LCG (m)	8.10 (m)	LCG (m)	7.50 (m)
VCG (m)	2.10 (m)	VCG (m)	2.60 (m)
TCG (m)	0.00 (m)	TCG (m)	0.00 (m)

21 m			
LOADED SHIP		LIGHT SHIP	
DISPL. (t)	99.76 (t)	DISPL. (t)	77.56 (t)
LCG (m)	9.50 (m)	LCG (m)	8.90 (m)
VCG (m)	2.00 (m)	VCG (m)	2.75 (m)
TCG (m)	0.00 (m)	TCG (m)	0.00 (m)

24 m			
LOADED SHIP		LIGHT SHIP	
DISPL. (t)	118.6 (t)	DISPL. (t)	93.39 (t)
LCG (m)	11.50 (m)	LCG (m)	11.0 (m)
VCG (m)	1.85 (m)	VCG (m)	2.95 (m)
TCG (m)	0.00 (m)	TCG (m)	0.00 (m)

MIXED FRAMING SYSTEM FRAME SPACING : 500 mm STRONG FRAME : 1500 mm

Figure 5.4 Common Modular structure plan for 24 m CM-SWAS(S)H, for detailed plan refer Annex – 2

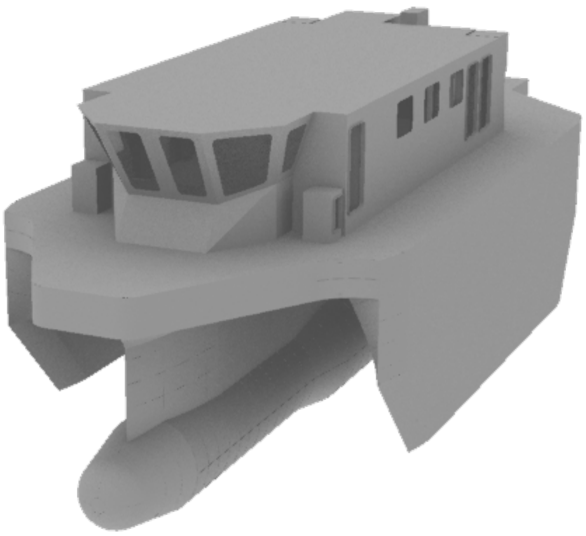


Figure 5.5 General hull overview with superstructure

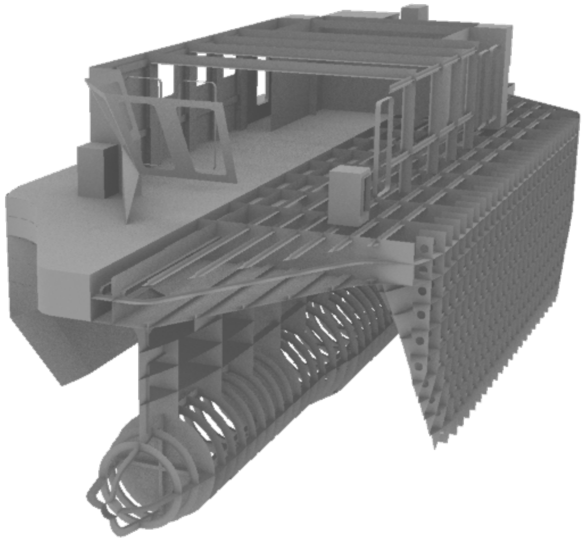


Figure 5.6 Structural design forward view detailing the stiffened panels

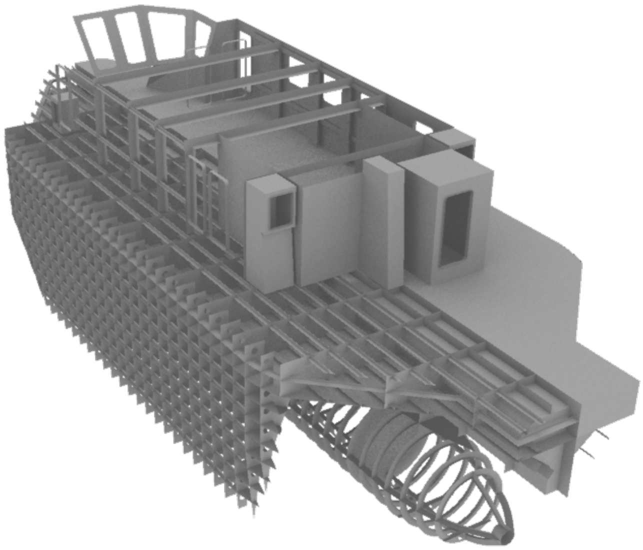


Figure 5.7 Structural design aft view detailing the stiffened panels

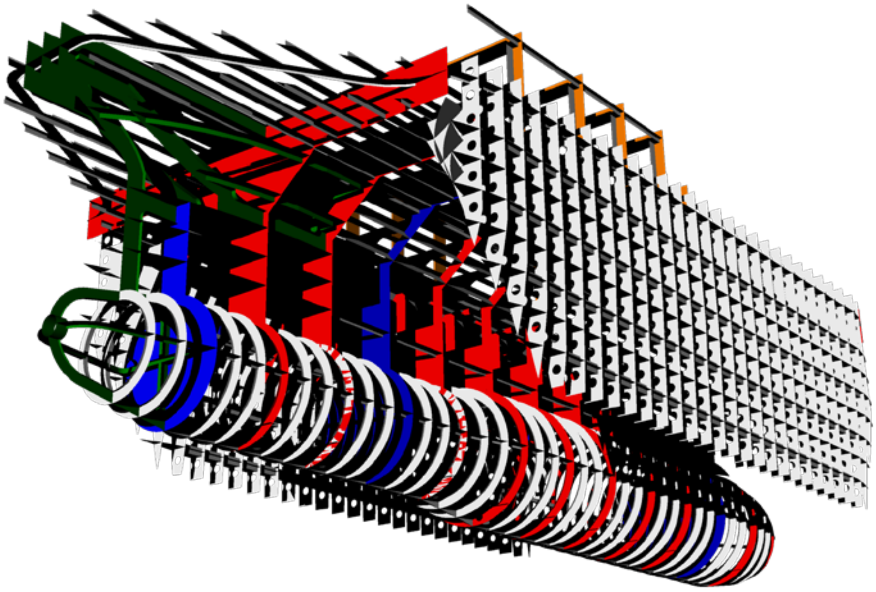


Figure 5.8 Bottom - 3D Illustration of structural model
Red - Strong Frames, Blue - Water Tight Bulkheads

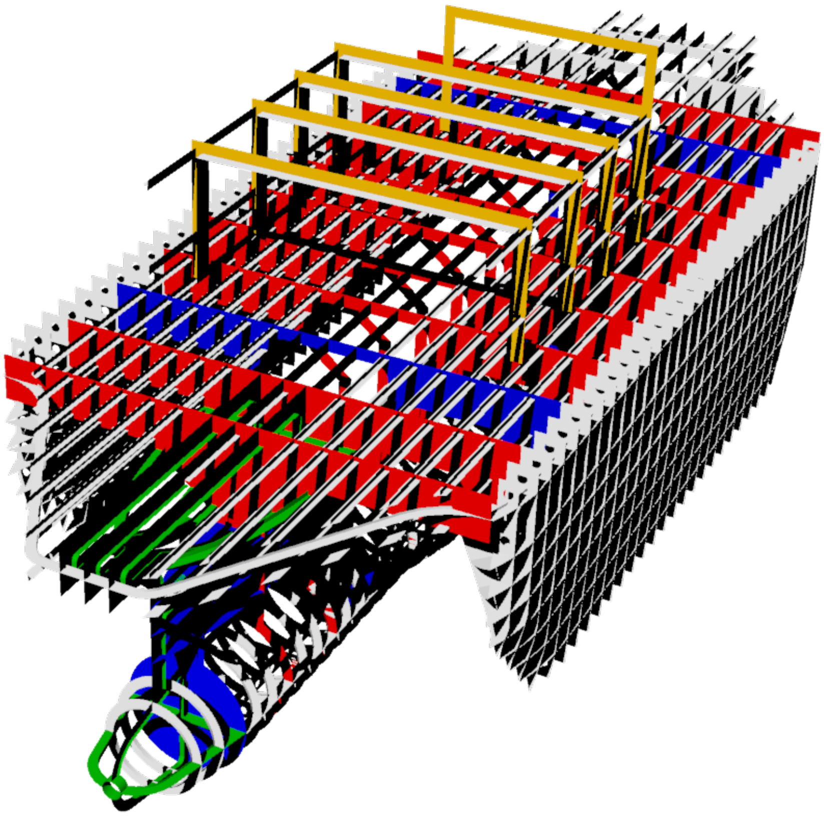


Figure 5.9 Top - 3D Illustration of structural model
Red - Strong Frames, Blue - Water Tight Bulkheads

CHAPTER 6 - HULL FORM OPTIMISATION FOR RESISTANCE

Safety based design is one aspect, in addition we have to ensure the practicality of design and its implementation. Hence it becomes essential that we employ certain measures that can increase the practical feasibility of design, as discussed in earlier chapters high resistance offered by this design leads to high fuel consumption and higher emission.

Today, European maritime industry faces a problem that is to achieve environmental protection during the economic slowdown. Thus, it requires an integrated solution of multi-dimensional nature. The idea is to provide a ship design that not only reduces emissions but at the same time provides a practical solution that can be implemented in current volatile market.

In accordance to UNFCCC Copenhagen 2009, all EU nations have pledged to reduce the CO_2 emissions to a tune of 30% by 2020 and 40% by 2030, ***excluding offsets***. To solve this, the first thought that comes to mind is use of LNG as operating fuel. This presents us with two constraints:

1. While LNG, the Green Fuel of future does solve the problem of SO_X and NO_X, its ability to reduce greenhouse gasses like CO_2 is limited to 20-25% as compared to MDO,
2. In addition, at this point installation of LNG power plant on small vessels like Harbour and Wind-farm support vessels is limited due to large size of installation.

Hence we evaluate all the possible methods that can help us reduce fuel oil consumption. The figure 6.1 shows in a broad spectrum the methods of reducing fuel oil consumption.

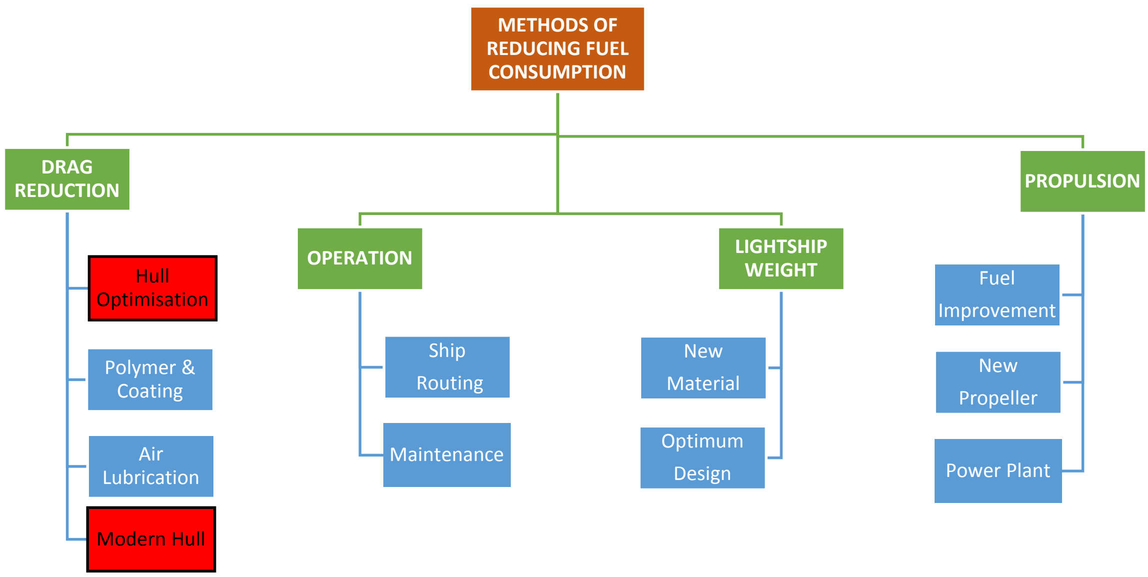


Figure 6.1 Method of fuel reduction by drag reduction, Source: Marine Insight, July, 2012

The design process involves some of the aspects of all four elements. To reduce drag we will use a modern hull with hull form optimisation. The operation and propulsion parameters will be controlled by power plant design for high efficiency and low maintenance. While the lightship weight will be controlled by structural optimisation.

This chapter will focus on the hull form optimisation of the SWAS(S)H design keeping in mind the modularity constraints. The figure 6.2 illustrates the steps to be followed to achieve the hull form optimisation:

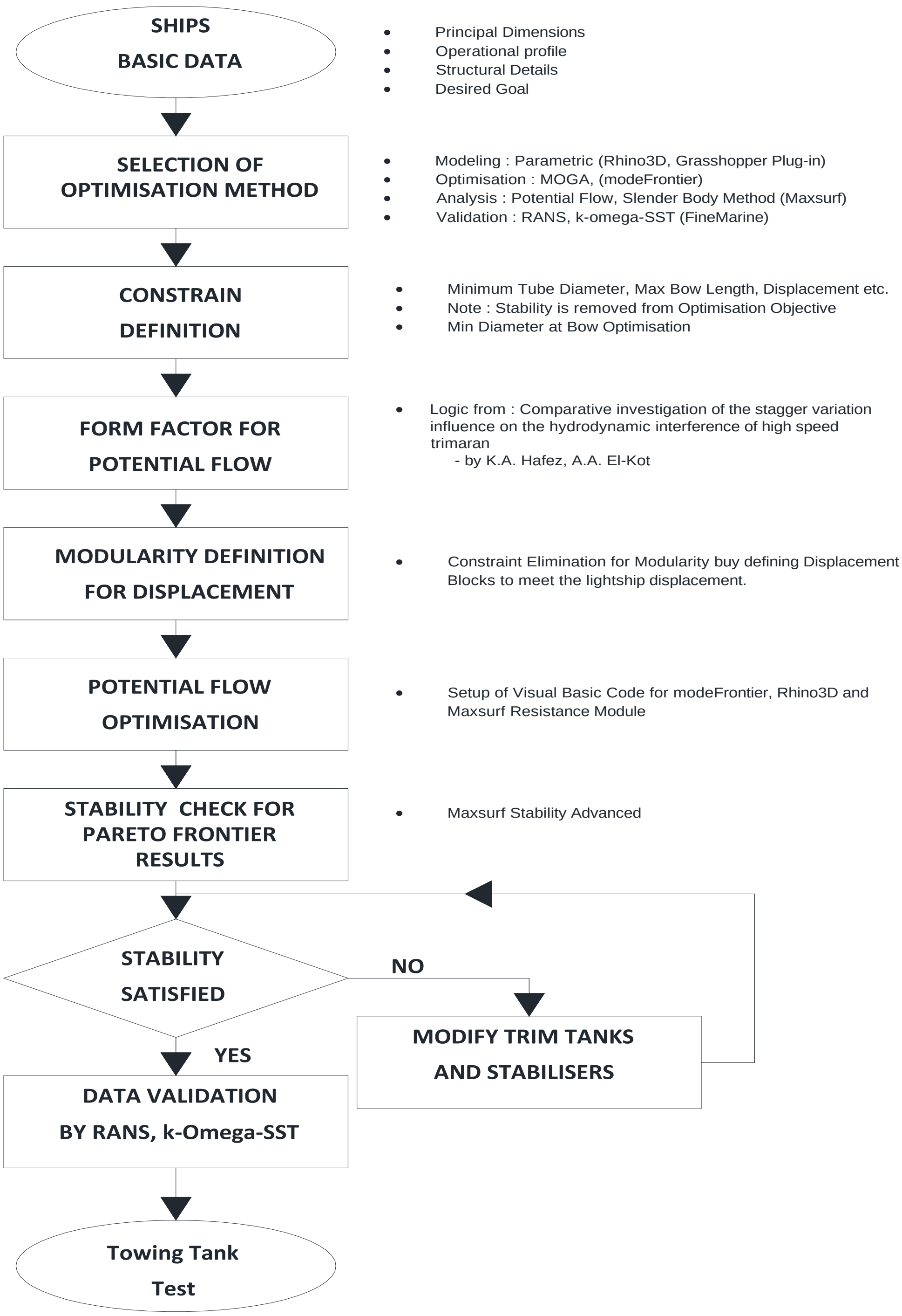


Figure 6.2 Flow chart for hull form optimisation for calm water resistance

6.1 Introduction to Base Hull

The base hull, here on referred as Chica-Caliente is an SWAS(S)H vessel design from the collaborative work as part of Ship Design Project EMship at University of Liege (ULg) by Akula Nidarshan, Martin P.W. & Xu Cheng, 2014.

The vessel was designed as a Pilot vessel of 15.5 m to operate at max service speed of 25 knots. The figure 6.3 and 6.4 depict the general arrangement and tank plan of the original vessel.

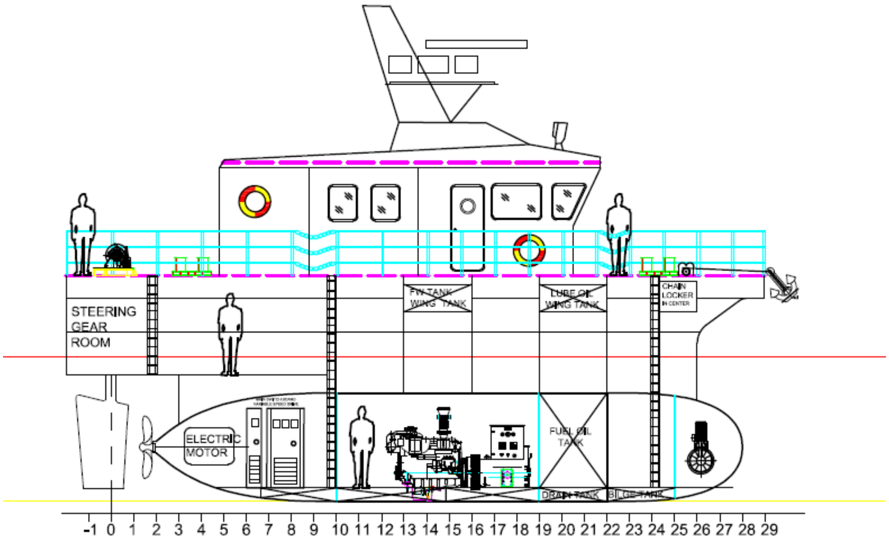


Figure 6.3 Longitudinal plan of Chica-Caliente

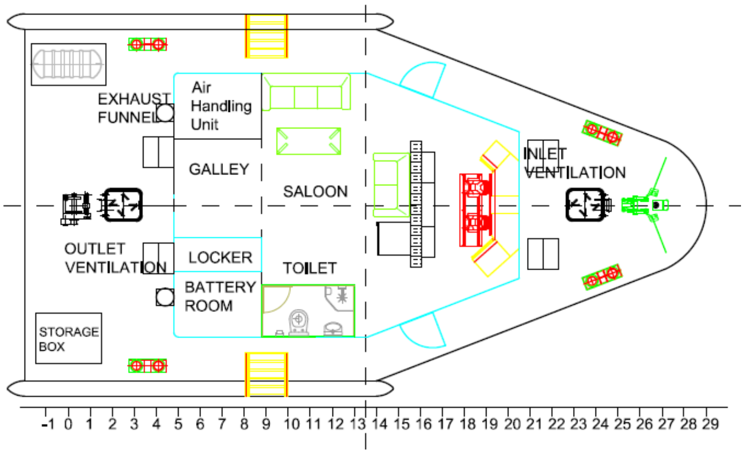


Figure 6.4 Deck plan of Chica-Caliente

The design presented itself with many errors in stability and resistance prediction by potential flow method. As part of this thesis work, the first step was to rectify the potential flow error and the general arrangement. It was then decided to increase the minimum length of the vessel to 18 m. Hence while doing the analysis, first using the hull form of Chica-Caliente base hulls were designed for 18, 21 and 24 m length. In this thesis these new base hulls will be referred Chica-Caliente.

as of optimisation, the model setup plays a critical role as it not only depends on the accuracy and robustness but also the compatibility between the tools to be used and the time for results convergence based on the support (hardware/software) at hand.

6.2 SELECTION OF OPTIMISATION ENVIRONMENT

As the first step of optimisation, the model setup plays a critical role as it not only depends on the accuracy and robustness but also the compatibility between the tools to be used and the time for results convergence based on the support (hardware/software) at hand.

Based on the practical work carried out in the past, we have selected specific models and methods based on the software availability.

6.2.1 MODELLING

As part of optimisation it was necessary to use a tool with ability to modify the model parameters automatically using inputs from an optimisation process. There are basically two major types of modelling approaches

1. Parameter Free – Topology optimisation and Adjoint Simulation
2. Parameter Based – Partially Parametric and Fully Parametric

The parameter free modelling is mostly limited to concept and fine tuning stages of design. While more time consuming parametric modelling provides good results from initial to final design stage. Furthermore we selected fully parametric modelling as it provides for high quality CAD geometry and allows for both local and global changes in modelling.

6.2.2 RESISTANCE OPTIMISATION

As we intended to optimise only the central hull for a limited length of bow it was decided to use potential flow code, using a slender body method. Maxsurf Resistance Module was selected as the desired tool as it has been auto-calibrated for both Small Water-plane area and Trimaran hulls. This gave us the advantage of running faster simulation and avoiding initial convergence test for panel mesh.

6.2.3 OPTIMISATION ALGORITHM

Considering the multi-objective nature of optimisation we could only had two options either to go for Weighted Simplex or Multi objective genetic algorithm (MOGA). From the practical experience at Ecole Centrale de Nantes (ECN), we had already established that while weighted simplex has faster convergence, MOGA presents much higher robustness and accuracy. And as we had already selected a potential flow optimisation approach higher time of computation over MOGA was an acceptable approach. modeFrontier with auto DOE (design of experiment) was selected the working tool.

6.2.4 MATHEMATICAL VALIDATION

As we know that the design has higher resistance due to large wetted surface area and thus the viscous drag, something that is considered constant in potential flow and is extrapolated using ITTC formula. Hence it we decided that before validating the results with towing tank test a RANS based mathematical validation was an appropriate approach. There are two main models that are employed industry wide for RANS analysis:

1. k-epsilon,
2. k-omega-SST.

While both provide acceptable results, we chose k-omega-SST based on the results obtained from practical work carried out at ECN as part of EMship.

DETAILS OF SOFTWARE AND MODELS USED			
S. NO.	**SOFTWARE**	**METHOD/LOGIC**	**MODEL**
1	Rhino3dM Modelling + Grasshopper Plug-in	Parameter Based	Fully Parametric
2	Maxsurf (Panel Method)	Potential Flow	Slender Body
3	modeFrontier	MOGA	Automated DOE
2	Fine Marine	RANSE	k-Omega SST

Table 6.1 Details of resistance optimisation software and model used.

6.3 CONSTRAINT DEFINITION

Once the optimisation environment and the preliminary modelling is finished, we define the constraints that are going to limit the optimisation algorithm, some of these constrains also act as the desired optimisation outputs. While the objective of the thesis is to minimise resistance at 20 knots speed, it should be noted that harbour support vessels also operate at lower speed of around 5knots, hence an additional optimisation constraint of resistance at 5knots was introduced into the environment. Here we need to take a note that since we are going to design three different vessels, constraints for all three need to be considered. Based on the general arrangements and structural calculation we know the principal dimensions, lightship weight, stability and sea-keeping characteristics for all three vessels. The same under consideration are mentioned in table 6.2.

OPTIMISATION CONSTRAINTS				
S. NO.	**PARAMENTER**	**LOA - 18 m**	**LOA - 21 m**	**LOA - 24 m**
1	Resistance at Speed (Operating)	21.875 knots	21.875 knots	21.875 knots
2	Resistance at Speed (Low Op.)	5 knots	5 knots	5 knots
3	Constant Overall Length	18 m	21 m	24 m
4	Constant Waterline length	13	16	19
5	Minimum Displacement (m^3)	78	95	114
6	Minimum Value of LCG	Not considered	Not considered	Not considered
7	GM_{min} greater than	Not considered	Not considered	Not considered
8	Min. Tube Diameter at ER	2.6	2.6	2.6
9	Min. Tube Diameter at Bow	2.1	2.1	2.1
10	Maximum Bow length	6.7	8.2	9.7
11	Constant Tube Length	15.5	18.5	21.5

Table 6.2 Optimisation constraints for all three vessels

While it can be seen that the optimisation constraints and objective combined for all three vessels represent a total of 33. But if we pay close attention we can see that we should be taking into consideration the modularity of vessels that is some variables, like diameters of tube, length and displacement can be regulated/eliminated by carefully defining the optimisation logic code. Hence we used a simpler approach, that is we will only optimise one hull form and the constraints that are applicable to other two vessels will be considered in the form of relative equations. As the wetted surface are of 24m vessel will be the largest we will be optimising only the 24m hull and will represent the respective values of 21m and 18m hull as equation.

6.3.1 STABILITY

We know from the basic theory that Trimaran hulls provide greater stability characteristics and as we will be optimising only the bow part of the central tube, it was decided that instead of considering/ testing stability of each optimised model as part of the environment we will test the stability of only the models that from the part of the pareto frontier. In case the stability of the vessel requires improvement we will modify the trim tanks and distribution of other tanks to achieve the desired objective.

6.3.2 LENGTHS – LOA, LWL, OVERALL TUBE LENGTH AND BOW LENGTH

Considering the modularity we know that the difference in length of the three vessel is increment of 3m, hence instead of considering all three vessels at the same time we can simply use the difference in lengths and consider only one vessel.

6.3.3 DISPLACEMENT

The length variables are easier to eliminate as the single numerical value. While the displacement of the vessels depends lightship weight and the endurance which further control the tank capacities. Hence it was decided to add a term called displacement module.

A ***displacement module*** represents set underwater volume of length Xm which when removed from 24m hull will affect the bow length of 21m vessel by Xm and will still be able to provide the desired displacement for 21m vessel. The same will be done for the 18m vessel with 24m vessel by removing two such displacement modules.

Logic of displacement module, considering that Δ_1, Δ_2 and Δ_3 represent minimum displacement required for vessel of LOA 24m, 21m and 18m respectively and let Δ_{dm} be the displacement of displacement module of length Xm. We then eliminate the displacement constraint as:

$$\Delta_2 \geq \Delta_1 - \Delta_{dm}$$

$$\Delta_3 \geq \Delta_1 - 2 * \Delta_{dm}$$

When know from the initial weight estimation that

$$\Delta_2 = 95\, m^3$$

$$\Delta_3 = 79\, m^3$$

Thus the conditions above can be represented as

$$\Delta_1 = \Delta_3 + 2 * \Delta_{dm}$$

and

$$\Delta_1 = \Delta_2 + \Delta_{dm}$$

As we know the values of Δ_1, Δ_2 and Δ_3 from the two equation above we can calculate the minimum value of Δ_{dm} and the length X for displacement module.

The figure 6.5 depicts the concept of displacement module:

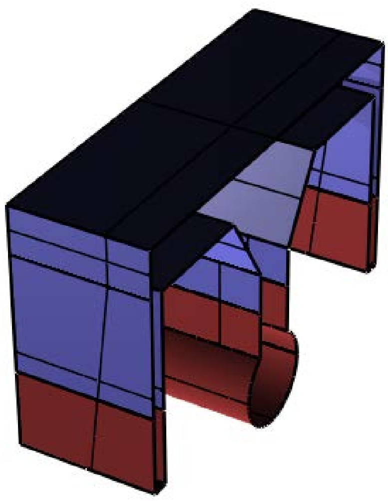


Figure 6.5 Displacement Module of 3m

Implementing all the factors we can then define the new constraints as:

SELECTED OPTIMISATION OBJECTIVE AND CONSTRAINTS		
S. NO.	**PARAMENTER**	**LOA - 24 m**
1	Resistance at Speed (Operating)	21.875 knots
2	Resistance at Speed (Low Op.)	5 knots
3	Constant Overall Length	24 m
4	Constant Waterline length	19 m
5	Minimum Displacement (m^3)	118 tonne
6	Min. Tube Diameter at ER	2.6 m
7	Min. Tube Diameter at Bow	2.1 m
8	Maximum Bow length	9.7
9	Constant Tube Length	21.5 m
10	Length of displacement module	3 m
11	Volume of displacement module	20 tonne

Table 6.3 Details of selected optimisation objectives and constraints

6.4 FORM FACTOR FOR POTENTIAL FLOW

We intend to use Maxsurf Resistance package as the resistance calculation program, which uses a potential flow logic with slender body method, this is based on the work of Tuck et al. and Couser et al. and we can only estimate the wave making resistance of the vessel. Using this data we need to extrapolate the viscous resistance via ITTC 78 formula with for factor (1+k). While we have Hultrop and Molland formula for mono-hull and catamaran respectively, there is no empirical formula to evaluate the form factor for Trimaran Hulls. In such condition the best way to find the form factor is using the towing tank model test, which is this case in not a viable option as it will require us to carry out multiple towing tank tests.

According to the paper titled "*Comparative investigation of the stagger variation influence on the hydrodynamic interference of high speed trimaran by K.A. Hafez, A.A. El-Kot*"[4] in cases like this we can evaluate the calm water viscous resistance of the non-interfered trimaran hulls by calculating the form effect applied to the calm water friction resistance of the individual hulls, and then use the following equations:

$$C_{f-tri} = \frac{1}{A_{S-tri}} * \left[A_{S-Tube} * C_{f-tube} + 2 * A_{S-out} * C_{f-out}\right]$$

Where,

$$C_{f-tube} = \frac{0.075}{(log_{10}R_{e-tube} - 2)^2}$$

$$C_{f-out} = \frac{0.075}{(log_{10}R_{e-out} - 2)^2}$$

and

$$Wetted\ Surface\ area\ of\ Trimaran = A_{S-tri} = A_{S-tube} + 2 * A_{S-out}$$

Then to modify this formula to implement the effect of form factor, we treat the tube and outriggers as mono-hull and use Hultrop equation for form factor to calculate the coefficient of viscous resistance using the modified formula below:

$$C_{V-tri} = \frac{1}{A_{S-tri}} * [A_{S-Tube} * C_{V-tube} + 2 * A_{S-out} * C_{V-out}]$$

$$C_{V-tri} = \frac{1}{A_{S-tri}} * \left[A_{S-Tube} * (1+k)_{tube} * C_{f-tube} + 2 * A_{S-out} * (1+k)_{out} * C_{f-out}\right]$$

The coefficient potential flow wave making resistance is given by:

$$C_{W-tri} = \frac{1}{A_{S-tri}} * [A_{S-Tube} * C_{w-tube} + 2 * A_{S-out} * C_{w-out}]$$

The coefficient of residuary resistance is given as:

$$C_{R-tri} = C_{W-tri} + \frac{1}{A_{S-tri}} * \left[A_{S-Tube} * k_{tube} * C_{f-tube} + 2 * A_{S-out} * k_{out} * C_{f-out}\right]$$

And the sum of the calm water total resistance coefficients of the non-interfered trimaran hulls is calculated using the equation:

$$C_{T-tri} = \frac{1}{A_{S-tri}} * [A_{S-Tube} * C_{T-tube} + 2 * A_{S-out} * C_{T-out}]$$

Furthermore the resistance can be calculated as:

$$R_{T-tri} = \frac{1}{2} * \rho * A_{S-tri} * U^2$$

6.5 Potential Flow Optimisation And Pareto Frontier

To setup a potential flow optimisation environment, we have to form a bridge between Rhino3D for parametric modelling, Maxsurf Resistance for resistance, power and displacement analysis, modeFrontier for optimisation algorithm.

6.5.1 Parametric Modelling

Rhino3DM in itself is just a modelling tool, to enable parametric modelling we added as extra plugin Grasshopper, an open source plugin that allows us to enter mathematical equations that modify the central tube boundary.

While setting up equations it was decided to use a ***symmetry approach***, i.e. the central tube will be symmetrical about the buttock plane at the centre line of the vessel, waterline plane at 1.3m above the zero point and any division along the plane that passes through the intersection of the earlier mentioned buttock and waterline plane. This is done to ensure continuity for modular hulls. In addition this enables us to modify only one boundary of the tube, which when revolved about longitudinal axis passing through Y = 0 and Z = 1.3m will result in central tube formation. The constraint definition had provided us with length of engine room and the maximum length of the bow we will optimise. The length of bow for 24m vessel is 9.7m, which was divided into two equations of ellipse.

The modification algorithm for the two sections is given as:

For 21.5m $\geq X_a \geq$ 17.0m, the conditions and equations are

Section one denoted by a suffix “a”,

At X_a= 21.5m,

$$Z_a = 1.3m$$

$$Length\ of\ Forward\ bow\ section\ (a_a) = 4.5m$$

$$Z_a \geq 1.3m$$

for

$$X_{a2} \geq X_{a1},\ always\ Z_{a2} \geq Z_{a1},$$

$$Z_a = \sqrt{\left(1 - \frac{{X_a}^2}{{a_a}^2}\right) * {b_a}^2}$$

For 17m $\geq X_b \geq$ 11.8m, the conditions and equations are

Section two denoted by a suffix “b”,

At X_b = 17m

$$Z_b = Z_a$$

At X_b = 11.8m

$$Z_b = 2.6m$$

$$Length\ of\ Aft\ bow\ section\ (a_b) = 5.2m$$

For

$$X_{b2} \geq X_{b1},\ always\ Z_{b2} \geq Z_{b1},$$

$$Z_b = \sqrt{\left(1 - \frac{{X_b}^2}{{a_b}^2}\right) * {b_b}^2}$$

When entered in modeFrontier environment for section "a", b_a will be DOE and will vary from 1.3m to 2.6m and the same way for section "b", b_b will be DOE and will vary from Z_a at 17m to 2.6m. These values thus imported to Rhino3DM Grasshopper for hull form modification. The exact logic of optimisation can be found in the figure 6.6 indicating the concept of the equations.

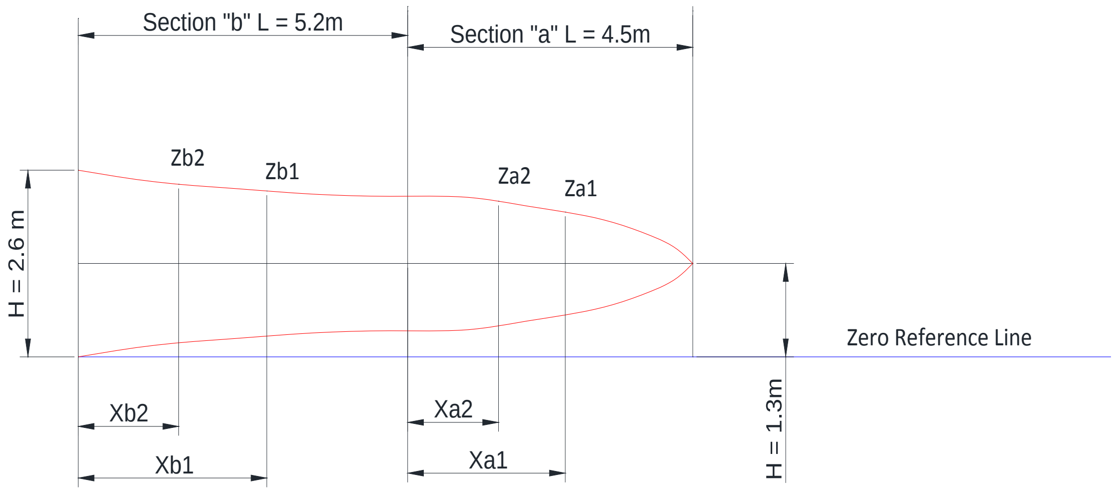


Figure 6.6 Concept of optimisation equations for central tube by symmetry approach

6.5.2 Resistance Analysis

Maxsurf Resistance Module is used to evaluate the resistance using the slender body method, which is a potential flow technique. The advantage of using Maxsurf is that the solver is pre-calibrated auto mesh system for both small water plane area and trimaran hull so we don't have check for mesh convergence and has the ability to directly import Rhino3DM model but at the same time the biggest constraint is integration with modeFrontier.

Again from the paper titled "Comparative investigation of the stagger variation influence on the hydrodynamic interference of high speed trimaran by K.A. Hafez, A.A. El-Kot" [4] we was learned about the best possible tools to integrate Maxsurf results. The excerpt for this paper is mentioned below for ready reference.

"Maxsurf CAD package and its downstream analysis modules provide direct automation support that allows the interested user to create, modify and 50analyse many design models over a minimum time span. None of the Maxsurf modules but include an embedded environment to write or record macros, but they accept their interface via the conventional programming languages, e.g., Visual C++©, Visual Basic©, Visual FORTRAN©, Java©, or Microsoft Windows Scripting©, Host©, etc. Also, all Maxsurf modules have the ability to interface spreadsheet applications like Microsoft Office©, other CAD systems like Autodesk AutoCAD©, and other graphing systems like SigmaPlot©, to either get more design details or to get more visualization quality."

Based on the above stated approach we selected Visual Basic© and Microsoft Office Excel© to right a proprietary code that automatically imports the model from Rhino3DM, and runs the analysis. The results of the analysis are then plotted using spread sheet and exported to modeFrontier for output of resistance and displacement for generating the pareto frontier.

6.5.3 OPTIMISATION ENVIRONMENT AND RESULTS

As stated earlier the environmental setup requires us to add special Visual Basic Patches to form interface between different modellers and solvers. A simple schematic of the plan is shown in the figure 6.7.

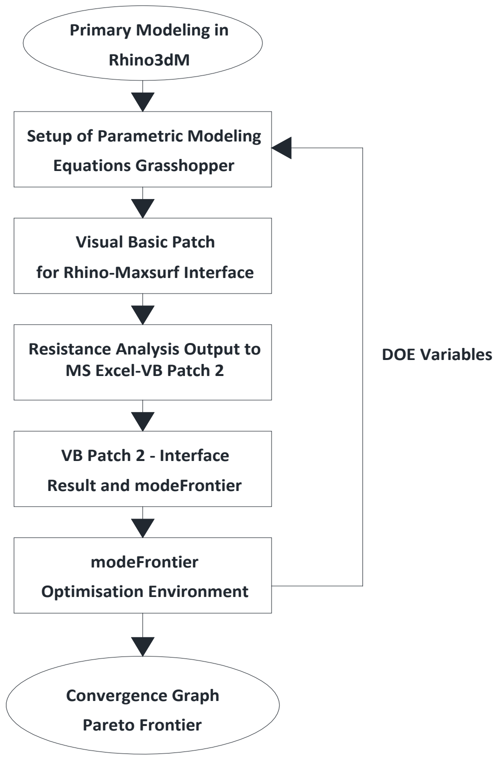


Figure 6.7 Optimisation environment and interfacing data flow

For detailed plan and process of modeFrontiner setup kindly refer to Annex-3. It should be noted that some parts of this Annexure are from Optimisation Lab Work of Akula Nidarshan and Nikhil Mathew as part of Ecole Centrale de Nantes (ECN) EMship studies.

Once the convergence was achieved for global minima of resistance, the pareto frontier was plotted using MS Excel and the final design with least resistance was selected for further analysis. The figure 6.8 shows the pareto frontier resulted:

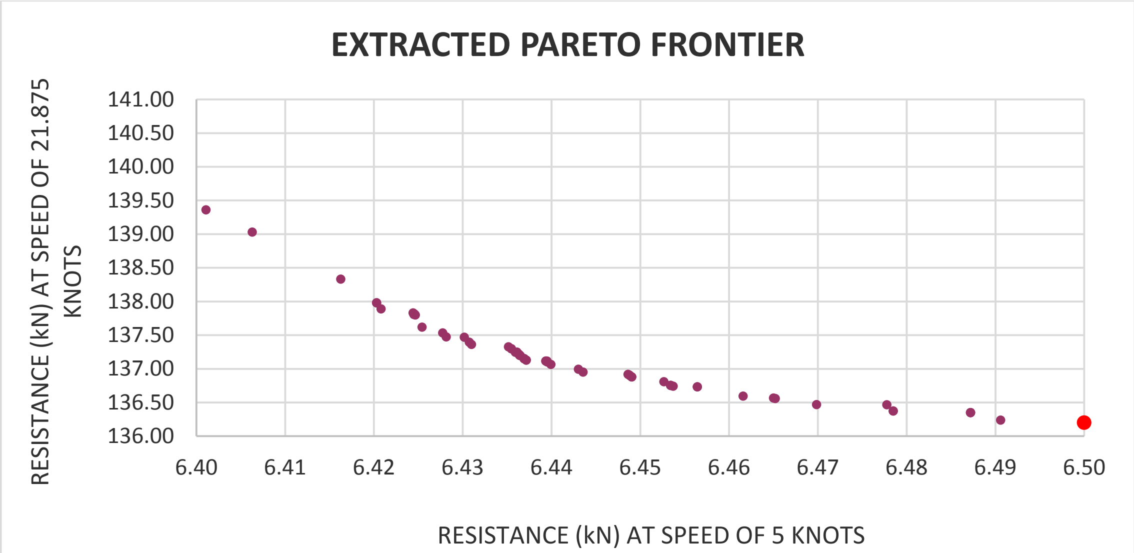


Figure 6.8 Extracted Pareto frontier showing selected variant in red dot

Though the model is optimised for two different operating speeds, considering the fact that the vessels will majorly operate at speed of 20 knots, we selected the model with least resistance at 21.875 knots this speed. The detailed values of Pareto Frontier can be seen in Annex-3.

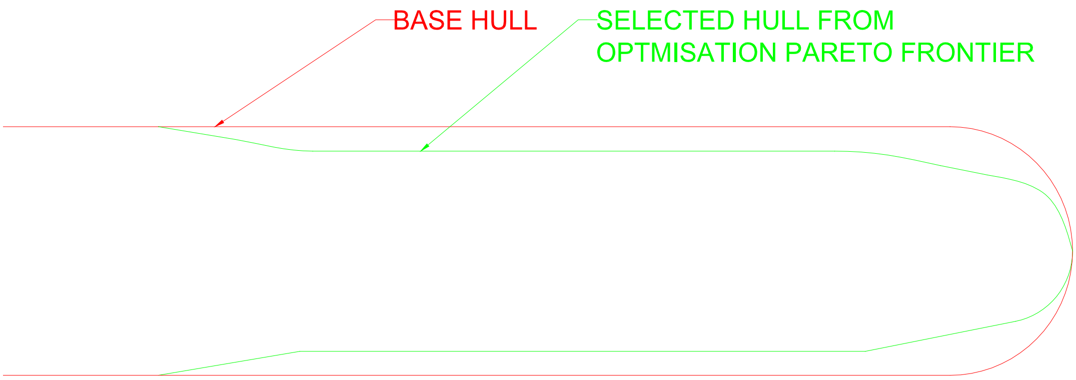


Figure 6.9 Comparison of Base and Selected hull from optimisation Pareto frontier

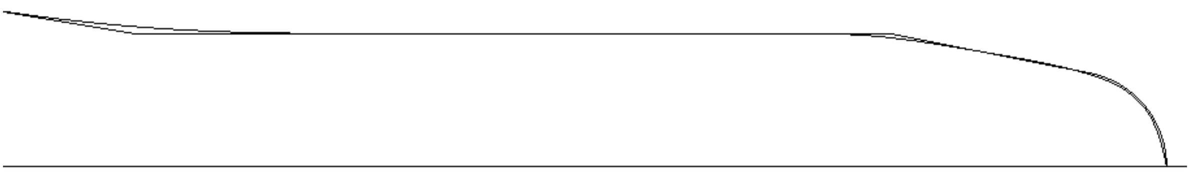


Figure 6.10 Comparison of Optimised Hull and Fine Tuned Hull

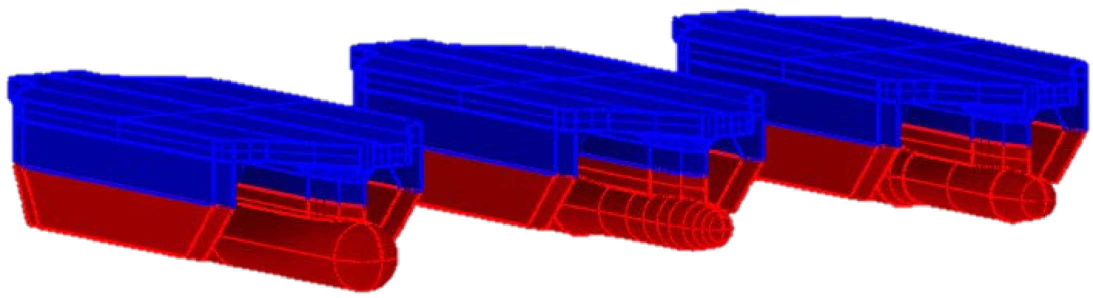


Figure 6.11 Comparison of three Hulls Left to Right: Base Hull, Optimised Hull and Fine Tuned Hull

Based on this results the selected model showed a lot of curvature in bow part, as can be seen in the figure 6.11. This curvature is not the best solution from modularity point of view hence a fine tuning using manual distortion method was carried out. In the resistance graph figure 6.12, it can be seen that the direct optimised model and fine-tuned model have very less variation in the resistance which is considered acceptable based on design requirements.

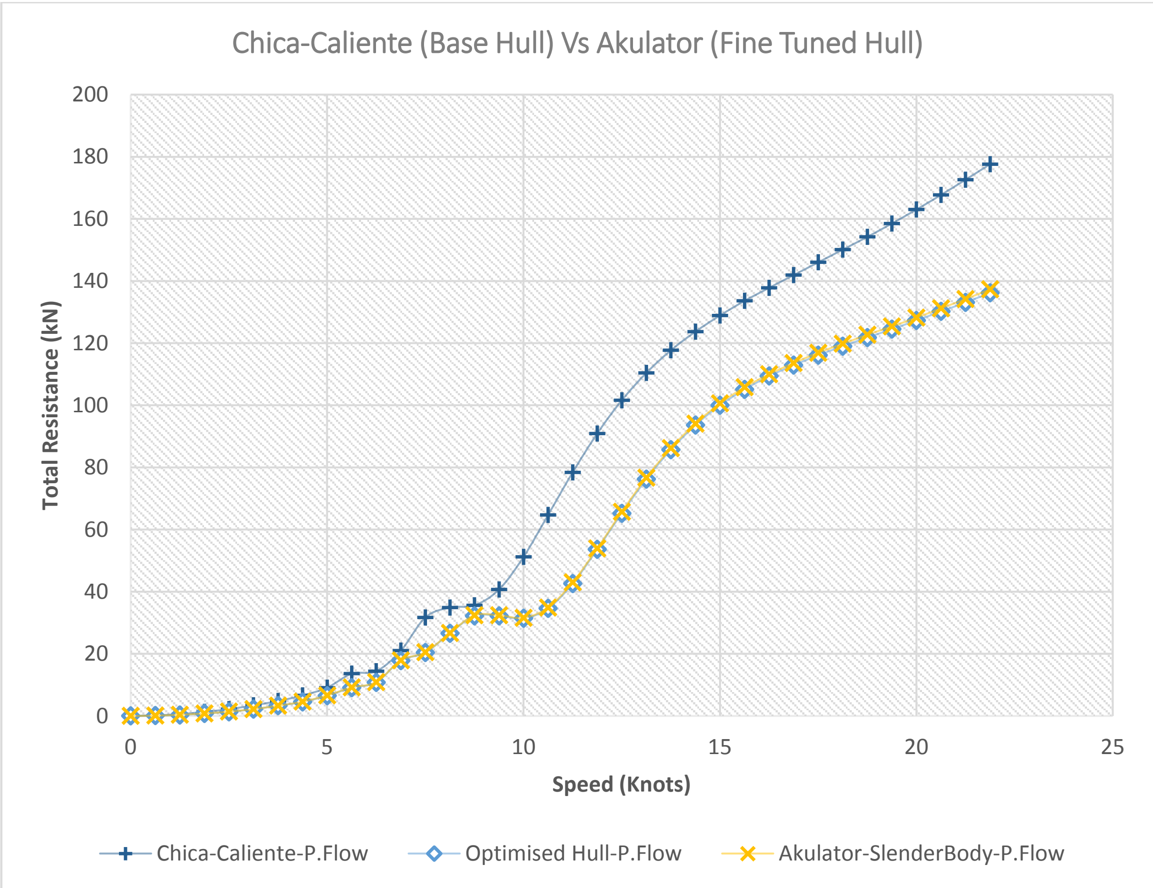


Figure 6.12 Graphical Comparison of resistance between Base Hull, Optimised Hull and Fine Tuned

RESISTANCE COMPARISON BETWEEN THREE HULLS				
S. NO.	**SPEED (Knots)**	**Base Hull (Chica-Caliente)**	**Optimised Hull**	**Fine Tuned Hull (Akulator)**
1	5	9.1 kN	6.5 kN	6.6 kN
2	20	163.0 kN	127.3 kN	128.2 kN
3	21.875	177.6 kN	136.2 kN	137.3 kN

Table 6.4 Resistance comparison between Base, Optimised and Fine Tuned Hull

With fine-tuned model as final hull for modularity, we then designed the final hull forms of all the three vessel lengths. Before we could finalise these values it was required that we first validate the potential flow results.

6.6 DATA VALIDATION USING RANS SOLVER

Major contributor to the resistance values of this design is due to the frictional component and hence it was decided to validate the results with a solver based on Reynolds Averaged Navier Stokes Equation (RANSE) before validating it with towing tank test. For this purpose FineMarine© was chosen due to licence availability at DN&T, Liege. The modelling was done in Rhino3dM and a parasolid export was carried out in order to import the model into FineMarine©.

The foam model to be tested in towing tank presented the constraint of producing 24m hull as the scaling effect causes the strut to be very small and thus impractical to produce on the model maker. Even though we have optimised the 24m hull, the idea of result validation if acceptable will be valid for all the three vessel lengths. Hence it was decided to run the RANS analysis and the towing tank test on 18m hull.

Once the model is imported, we need to check continuity of surfaces in HEXPRESS and then prepare the project setup which involves following basic steps:

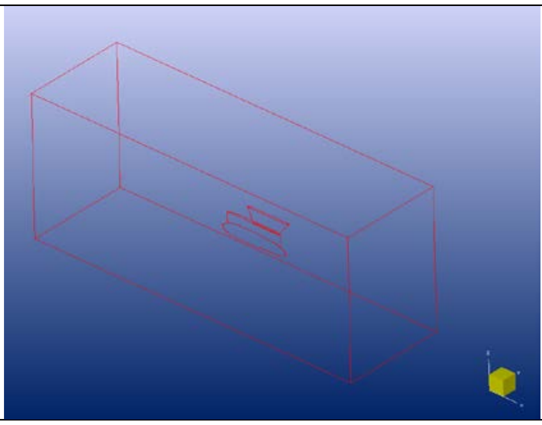
1. Define Domain,
2. Grid/Boundary Condition Definition,
3. Initial Meshing,
4. Free Surface Mesh,
5. Global Refinement and Surface Refinement,
6. Mesh Snapping,
7. Mesh Optimisation,
8. Viscous Layer Generation,
9. Defining Motion Parameters,
10. Setting-up Computational Controls – Series / Parallel.

The major parameters and values entered in the program are mentioned in table 6.7 for detailed setup process kindly refer to Annex-3.

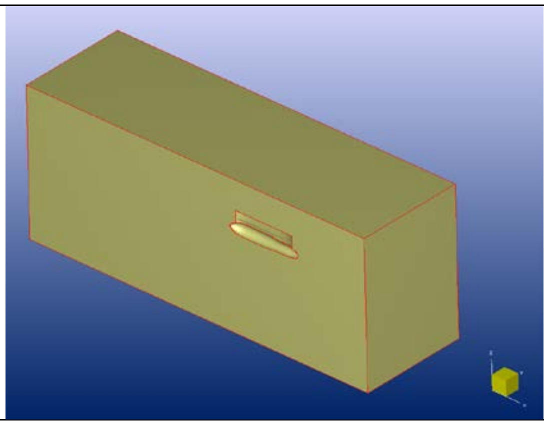
MESH DEFINITION					
S. No.	**ELEMENT**	**VALUE**	**S. No.**	**ELEMENT**	**VALUE**
1	X – Axis	20	4	Z – Axis	10
2	Y – Axis	06	5	No. of Cells	1200
3	N_b Cells	4,397,433	6	N_b Vertices	5,167,773
VISCOUS LAYER PARAMETERS					
GLOBAL			**SURFACE**		
S. No.	**ELEMENT**	**VALUE**	**S. No.**	**ELEMENT**	**VALUE**
1	First Layer Thickness	1e-005	1	First Layer Thickness	3.08e-004
2	Stretching Ratio	1.2	2	Stretching Ratio	1.2
3	Inflate Viscous Layer	Fixed No.	3	No. of Layers	20
FLOW MODEL					
S. No.	**ELEMENT DESCRIPTION**			**VALUE**	
1	Turbulence Model			k-omega-SST	
2	Reference Length			15.5 m	
3	Reference Velocity			10.28 m/s	
4	Reynolds Water			1.4808E+008	
5	Froude			0.83367	

Table 6.5 Mesh definition and flow model details

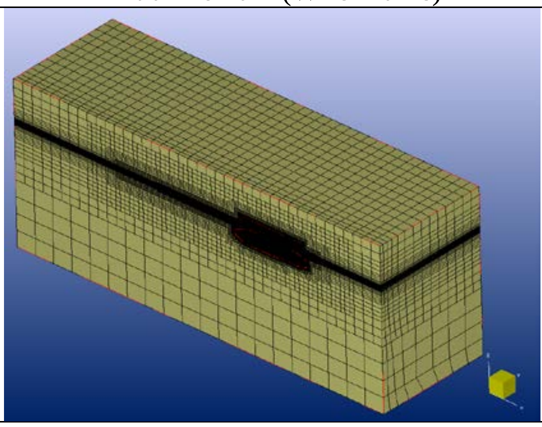
The figure 6.13 shows the mesh definition and figure 6.14 free surface elevation for the 20 knots vessel speed.



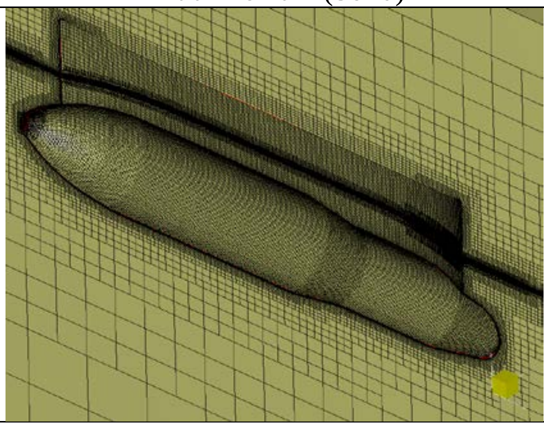
Initial Domain (Wire Frame)



Initial Domain (Solid)



Initial Mesh



Final Optimised Mesh

Figure 6.13 Figures detailing the FineMarine© mesh system

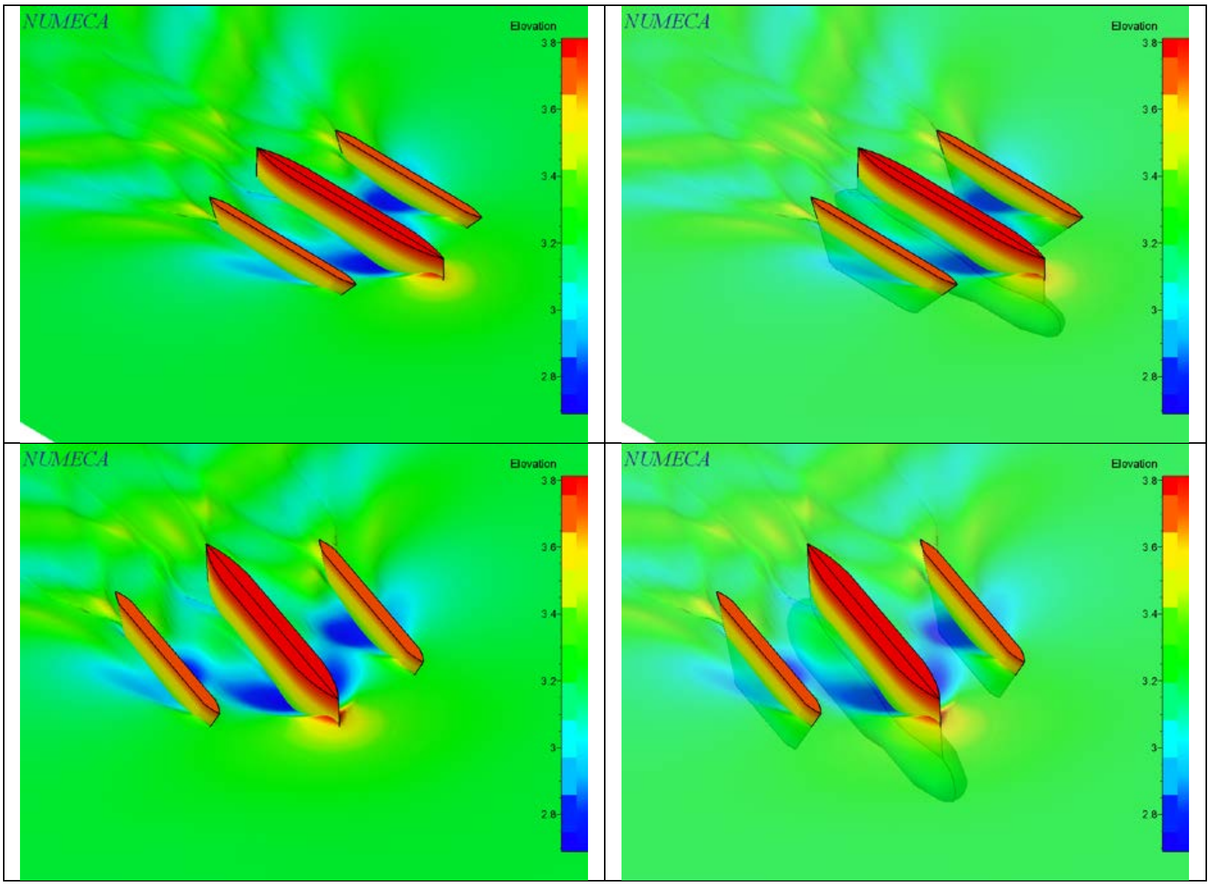


Figure 6.14 Free surface elevation at 20 knots

The graph in the figure 6.15 shows the comparison of potential flow and RANS based analysis for 18m vessel.

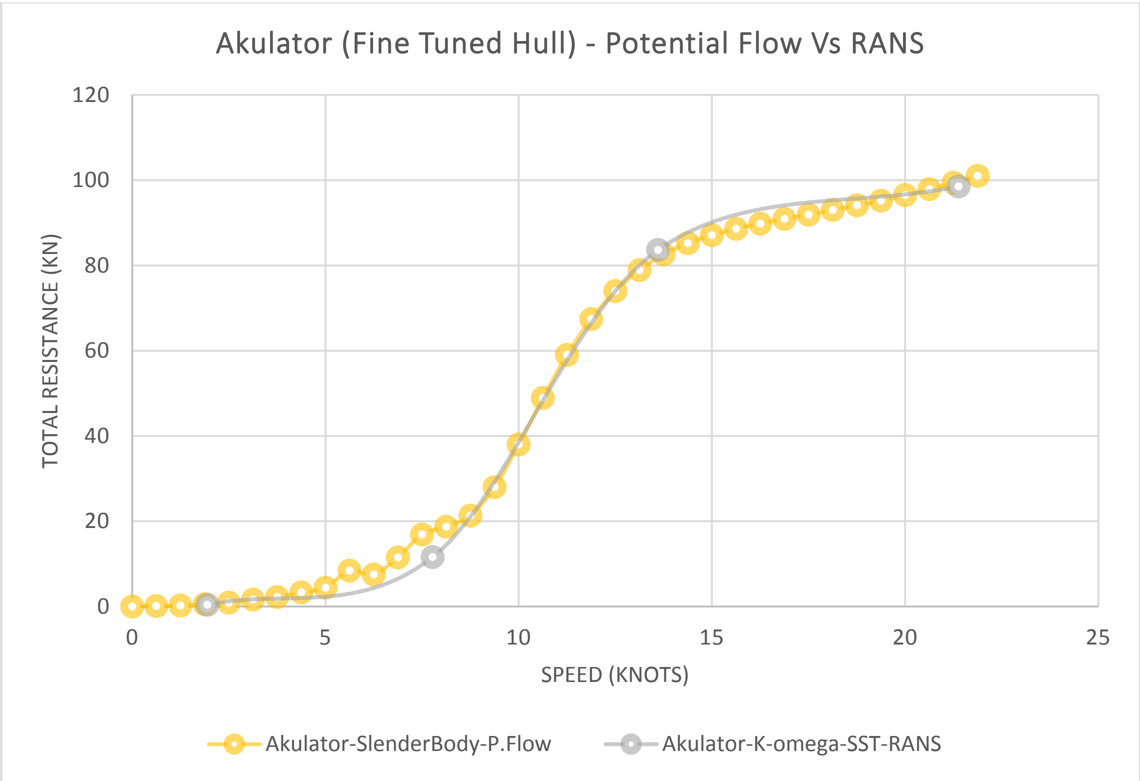


Figure 6.15 Resistance Comparison: Akulator (Fine Tuned Hull) – Potential Flow Vs RANS

RESULT COMPARISON OF POTENTIAL FLOW VS RANSE FOR 18m LOA HULL				
S. NO.	**SPEED (Knots)**	**POTENTIAL FLOW (kN)**	**RANS (kN)**	**% DEVIATION**
1	13.60	82.6	83.61	1.23 %
2	21.38	99.4	98.55	0.85 &

Table 6.6 Resistance comparison of Potential Flow Vs RANSE Solver

As it can be seen that the error at high/operating speeds is less than 1.5% which as per industry standards are considered acceptable, thus for further validation we carried out the towing tank test.

6.7 DATA VALIDATION USING TOWING TANK TEST

Any innovative design can only be evaluated in true sense based on its experimental results. In order to validate the mathematical model, we decided to prepare a Foam, Resin, Wood and PVC based 1:13 scale model to be tested at University of Liege (ULg) towing tank.

As explained earlier the Foam model to be tested in towing tank presented the constraint of producing 24m hull as the scaling effect causes the strut to be very small and thus making it impractical to produce on the model maker. Even though we have optimised the 24m hull, the idea of result validation if acceptable will be valid for all the three vessel lengths. Hence it was decided to carry out the towing tank test on 18m hull. The figures 6.16 to 6.21 show various stages of model preparation. The model test was carried out with Roll and Yaw motion arrested. The results of the towing tank experiment were then extrapolated using the ITTC 78 formula. The equations for the same are mentioned below and the form factor (1+k) was calculated from the graph (Refer Annex-3). The detailed spread sheet of model scaling, extrapolation, graphs and form factor calculations are presented in Annex-3.

ITTC Formulation

$$Fourde\ No.(F_n) = \frac{V}{\sqrt{gL}}$$

$$Reynolds\ No.(R_e) = \frac{V}{L * \nu}$$

$$C_F = \frac{0.075}{(Log_{10}(R_e) - 2)^2}$$

$$\frac{C_T}{C_F} = (1 + k) + \alpha * \frac{{F_n}^n}{C_F}$$

Plotting the graph for above equation on a spread sheet and using regression analysis we obtained the value of (1+k) and α. Then using the form factor and scaling factor the values of model test were extrapolated to full scale ship. The results of the same are plotted in figure 6.22 and tabulated in table 6.9.

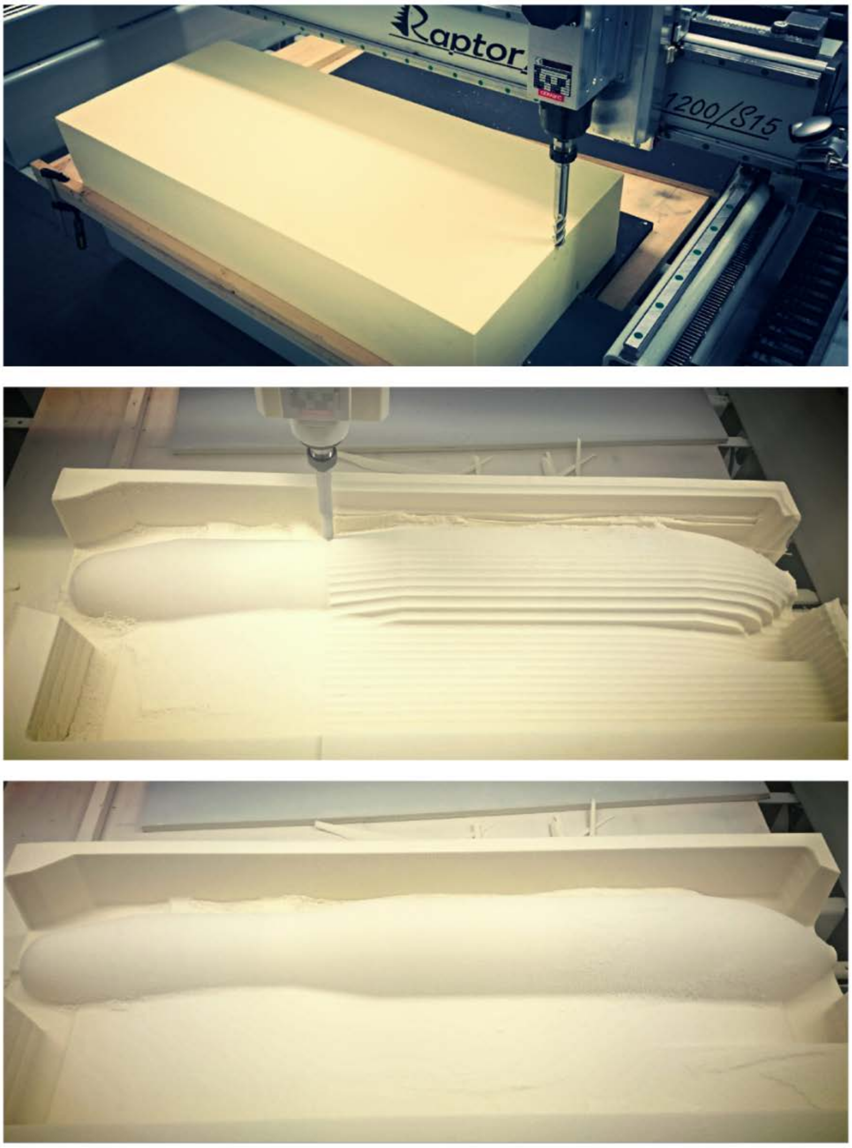


Figure 6.16 Central hull prepared on CNC milling machine

Figure 6.17 Foam based central hull

Figure 6.18 Central Hull, Outriggers (coated with resin and painted) along with Wooden Deck

Figure 6.19 Left to Right: Model comparison of Chica-Caliente and Akulator Hull

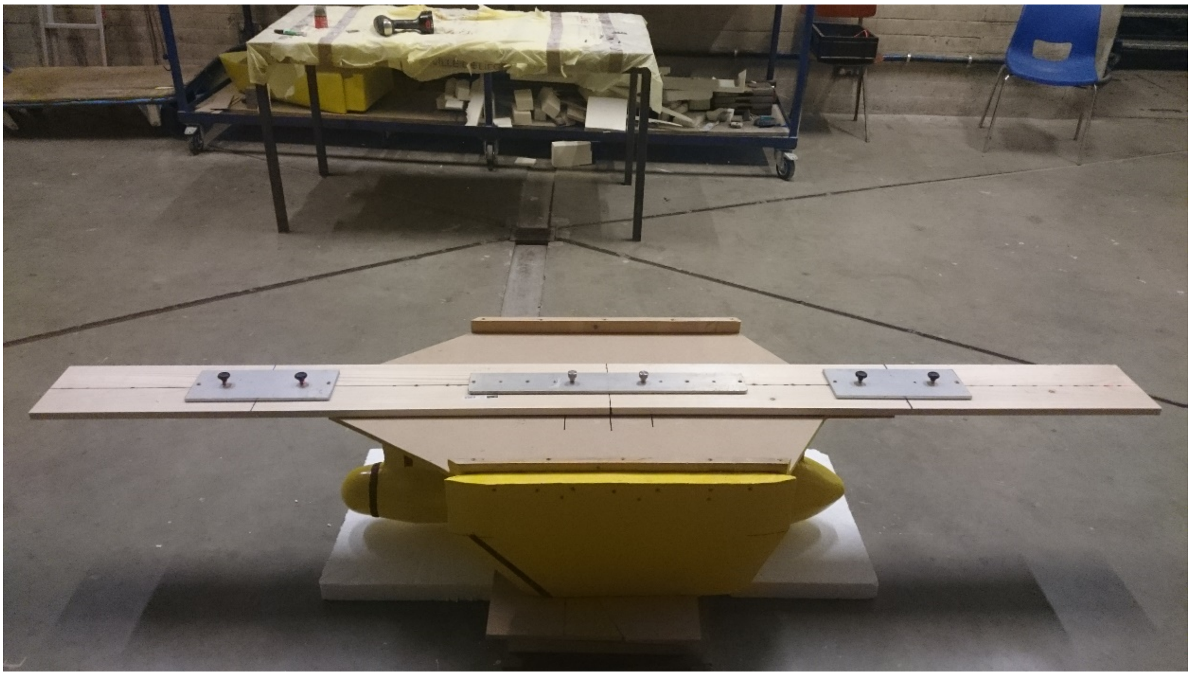


Figure 6.20 Extra wooden plank attached to deck to connect trim guides

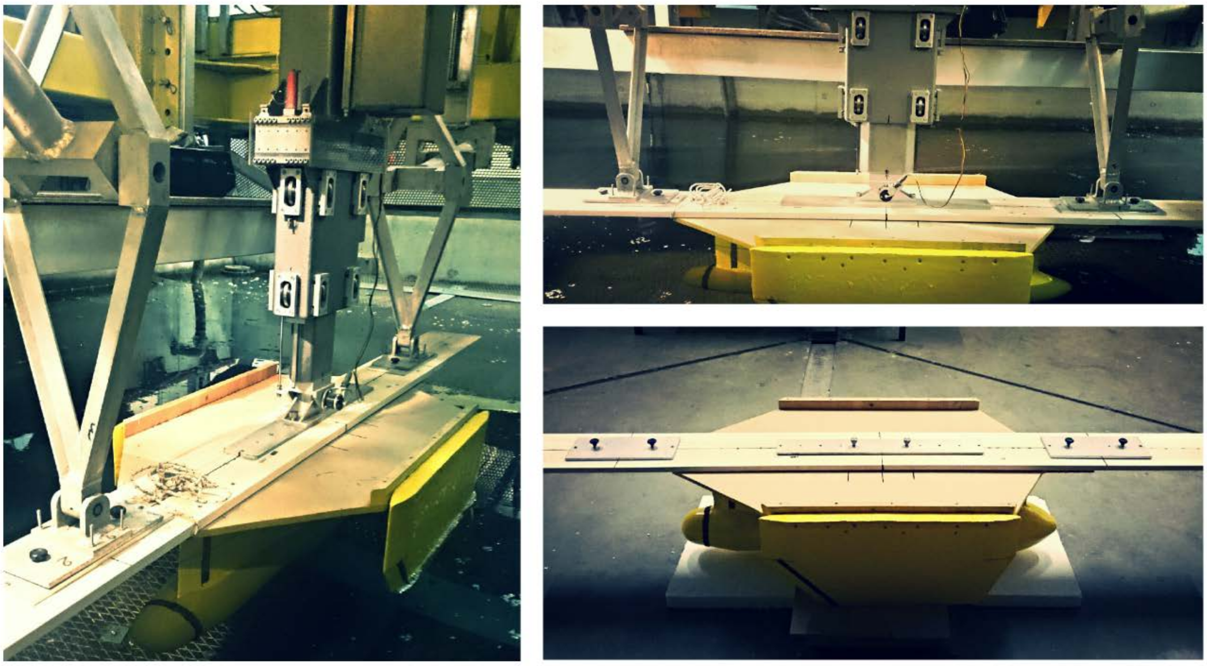


Figure 6.21 Final arrangement of model on carriage

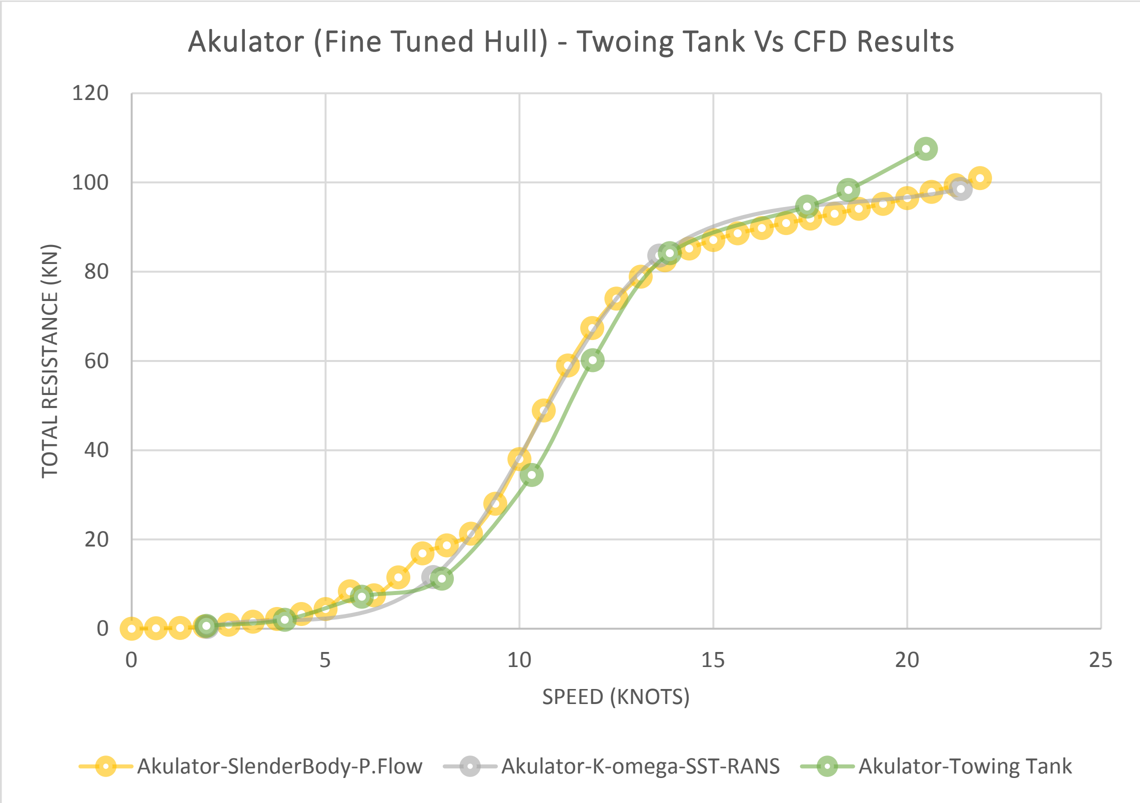


Figure 6.22 Resistance comparison Akulator (Fine-Tuned hull) towing tank test Vs CFD results

RESULT COMPARISON OF POTENTIAL FLOW VS TOWING TANK FOR 18m LOA HULL				
S. NO.	**SPEED (Knots)**	**POTENTIAL FLOW (kN)**	**TOWING TANK (kN)**	**% DEVIATION**
1	13.878	82.6	84.16889488	1.86
2	17.418	91.9	94.59014702	2.84
3	18.483	94.1	98.34487473	4.32
4	20.481	97.9	107.5404989	8.96

Table 6.7 Resistance comparison of Potential Flow and Towing Tank Experiment

Again it can be seen that the results deviation between potential flow and towing tank experiment are 1.5-9% which is under the acceptable range as per industry standards.

6.8 Final Results

With the mathematical models validated, for the next step all the three hulls were modified as per fine-tuned hull keeping in mind the modularity concept. The figures 6.23 to 6.25 show the modified concept of modular hull, where it can be seen that instead of having just one module of 3 m we now have two modules of 1.5 m each one where max diameter of tube is 2.1m and other with 2.6 m.

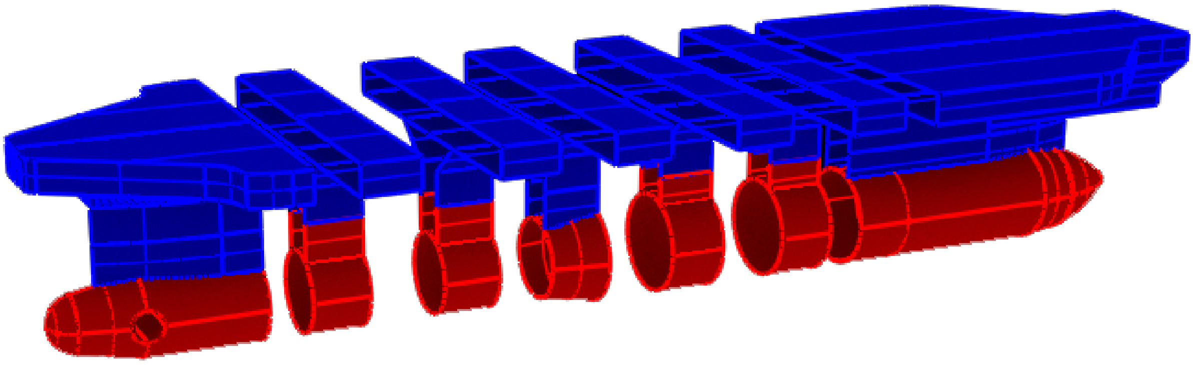


Figure 6.23 Central strut: Fine-tuned modular hull

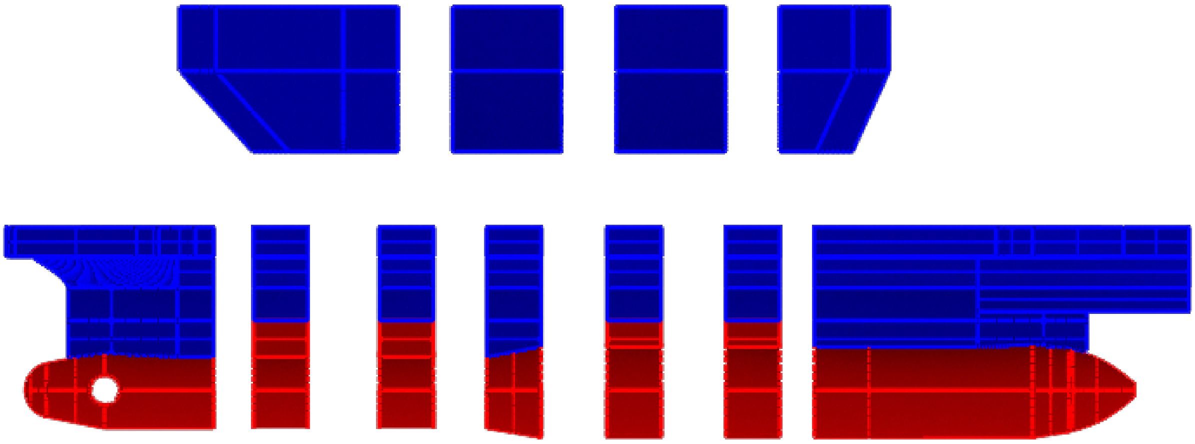


Figure 6.24 Fine-tuned modular hull: Profile view showing modules of outrigger and central hull

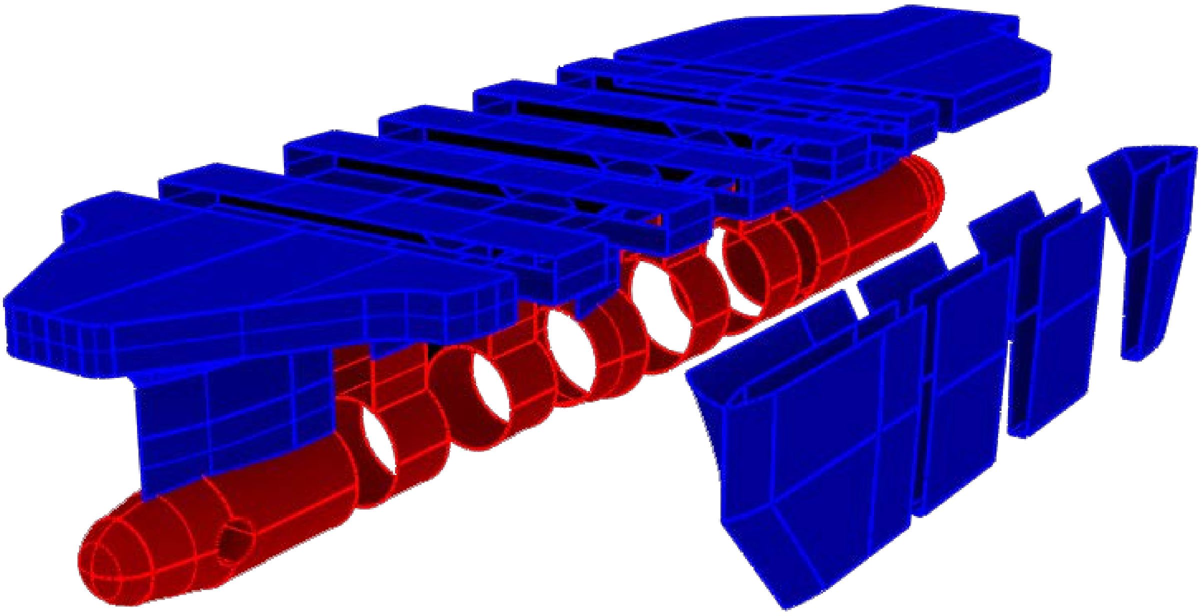


Figure 6.25 Fine-tuned modular hull: ISO view showing modules of outrigger and central hull

Post modification and fine tuning the final resistance results of all the three hull lengths are shown in the figure 6.26 to figure 6.28. It should be noted that to arrive at power calculations the hull efficiency was considered as 60% only, this is to take into account the effect of appendages, effects of real life variables such as marine growth, painting, wind and wave directions etc. and more importantly the deviation that has been observed between the potential flow and experimental results.

RESISTANCE COMPARISON FOR HULL OPTIMISATION			
VESSEL TYPE	RESISTANCE (KN)		
	CHICA-CALIENTE (BASE HULL)	AKULATOR (FINE TUNED HULL)	% REDUCTION
18 m CM-SWAS(S)H	122.40	96.50	21.16
21 m CM-SWAS(S)H	141.30	114.50	18.97
24 m CM-SWAS(S)H	163.00	128.20	21.35

Table 6.8 Resistance comparison for the all hulls post optimisation and fine tuning

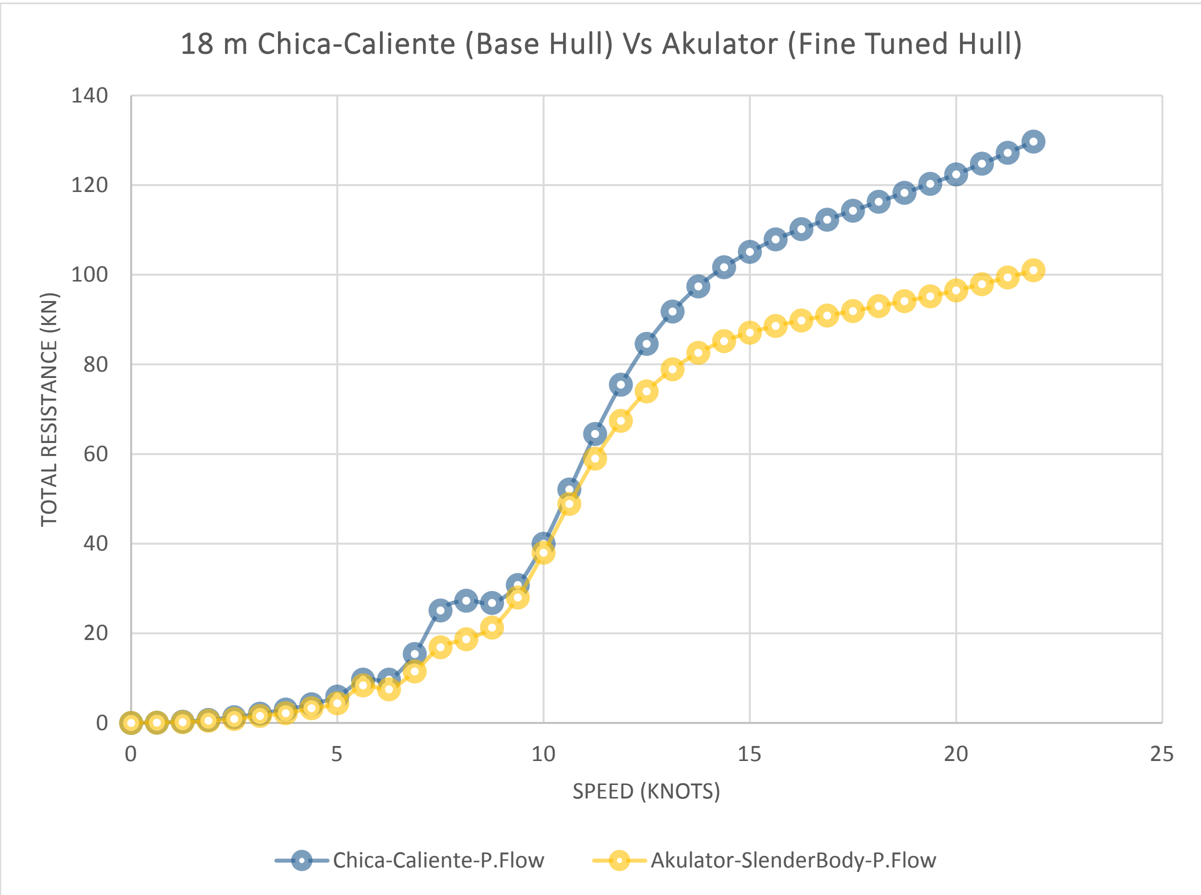


Figure 6.26 Resistance comparison: 18 m Chica-Caliente (Base Hull) Vs Akulator (Fine Tuned Hull)

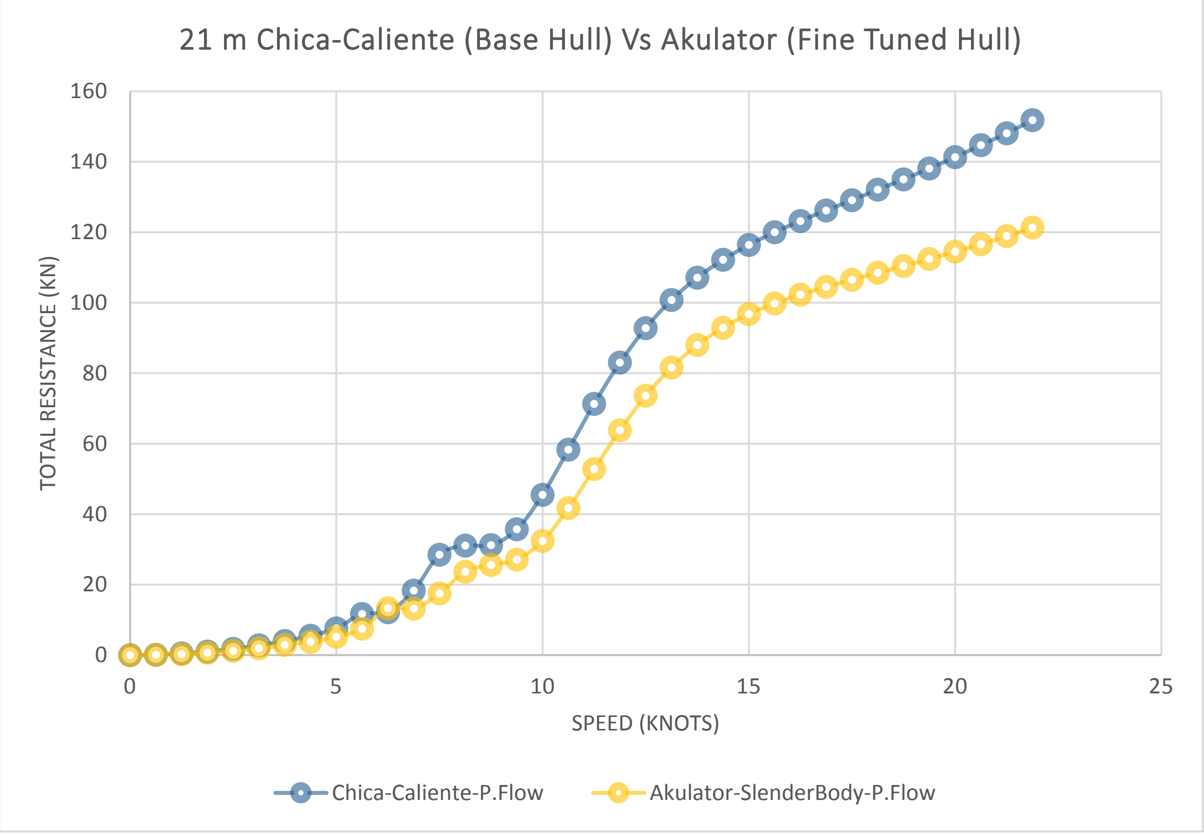


Figure 6.27 Resistance comparison: 21 m Chica-Caliente (Base Hull) Vs Akulator (Fine Tuned Hull)

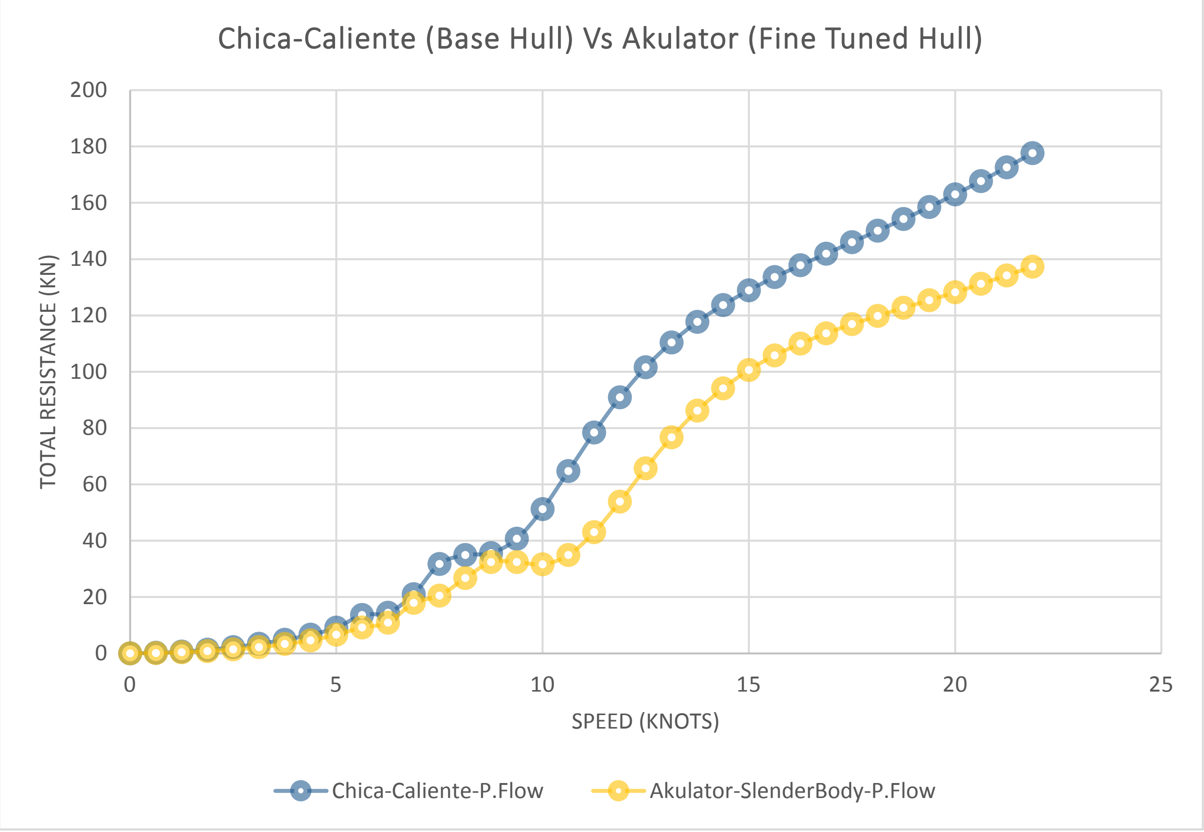


Figure 6.28 Resistance comparison: 24 m Chica-Caliente (Base Hull) Vs Akulator (Fine Tuned Hull)

CHAPTER 7 - ANCHOR, PROPULSION & MANOEUVRING

The chapter deals with calculation and specification of propulsion and manoeuvring equipment like rudder, propeller, bow thruster and steering gear. These equipment/elements are selected based on the guidelines and requirements stated by owners and Class/IMO/other regulatory authority. While this thesis will not deal with detailed design and optimisation of these equipment's/elements, they will be selected for each of the vessel specifically based on the above stated criteria.

7.1 ANCHOR

The anchors are selected as per the DNV-GL Class rules 2012, for Special Ships-High Speed Crafts, Chapter 1, Part 3, Section 6, Sub-section 5.2 Multi-Hull Craft. The first Step is to calculate the Equipment Number EN (refer figure 7.1 for reference):

$$EN = K_m * \Delta^{\frac{2}{3}} + 2 * [\, a * B + \sum_i (b_i * h_i * Sin\,\theta_i) - S_t] + 0.1 * A$$

Where, for craft with one mid hull and 2 · n non-identical lateral hulls (N = 2 · n + 1):

$$K_m = \frac{(B_0 * T_0)^{\frac{2}{3}} + 2 * \sum_{i=1}^{n} (B_1 * T_1)^{\frac{2}{3}}}{(B_0 * T_0 + 2 * \sum_{i=1}^{n} B_1 * T_1\,)}$$

Δ	: Maximum displacement in tonne
a	: Distance from summer load waterline to the upper deck at side (m)
h_i	: Height of the deck houses having actual breadth greater than B/4 (m)
θ_i	: Angle of Inclination
A	: Area of deck houses above summer load waterline (m2)
S_t	: Transverse Area of the tunnels existing between hull and waterline
B_0, T_0	: Breadth and draught of the middle hull (m)
B_1, T_1	: Breadth and draught of lateral hulls (m)
N	: Total number of craft hulls
n	: Number of lateral hulls on one side

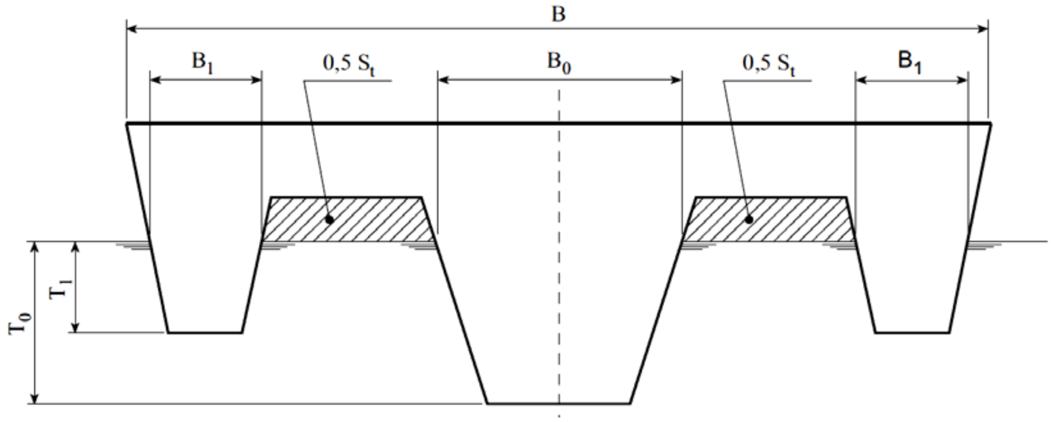


Figure 7.1 Transverse area of tunnel existing between hull and water line

Once the equipment number is calculated, and the number and mass of HHP anchor is finalised, the next step is to select the anchor cable and windlass based on proof/break load and pull duty. All anchor cable and windlass calculations are for K3 grade steel stud less link chain. The same are calculated in "kN" using the formula below:

$$Proof\ Load\ (PL) = 13.73 * d^2 * (44 - 0.08 * d) * 10^{-3}$$

$$Breaking\ Load\ (BL) = 2 * PL$$

The windlass is to be able to supply, for at least 30 minutes, a continuous duty pull P_C, in N, corresponding to the grade K3 of the chain cables, given by the following formula:

$$P_c = 47.5 * d^2$$

where,

d – Diameter of cable selected from Table C6.5.1 Equipment of Class Rules

The detailed calculations based on the above stated principle are listed in Annex-5.

The table 7.1 list the major characteristics of all the anchors selected:

DETAILS OF THE ANCHORS SELECTED				
S. NO.	**PARAMENTER**	**LOA - 18 m**	**LOA - 21 m**	**LOA - 24 m**
1	Equipment Number (EN)	59.1	64.5	68.5
2	Anchor Cable Diameter (mm)	8.5	9.5	9.5
3	Proof Load (kN)	42.97	53.58	53.58
4	Breaking Load (kN)	85.94	107.16	107.16
5	Pull Duty of Windlass (N)	3431.88	4286.88	4286.88
6	Chain cable length (m)	82.5	82.5	82.5
7	Mass of Anchor (kg)	60	67	67

Table 7.1 Details of the selected anchors

7.2 PROPELLER

The driving force and at the same time one of the major source for ship vibrations, the selection places very critical role in the efficiency of operation for a vessel. The Wageningen propeller being the most suitable profile for most vessel types, it was decided to select ***Bronze made Fixed Pitch Wageningen B Series propeller*** for all vessels but based on the configuration best suited for each vessel specifically.

As explained earlier chapters, the vessel uses a diesel electric propulsion system, which gives us the unique advantage of running the propeller at a speed that provides maximum efficiency. But efficiency is not the only factor, Back Cavitation also plays very critical role in selection process. Thus after finalising the diameter, various configurations of propeller profiles were tested for back cavitation based on Burrill's cavitation chart and then the configuration with maximum efficiency was selected.

The flow chart in figure 7.2 shows the work flow of propeller selection:

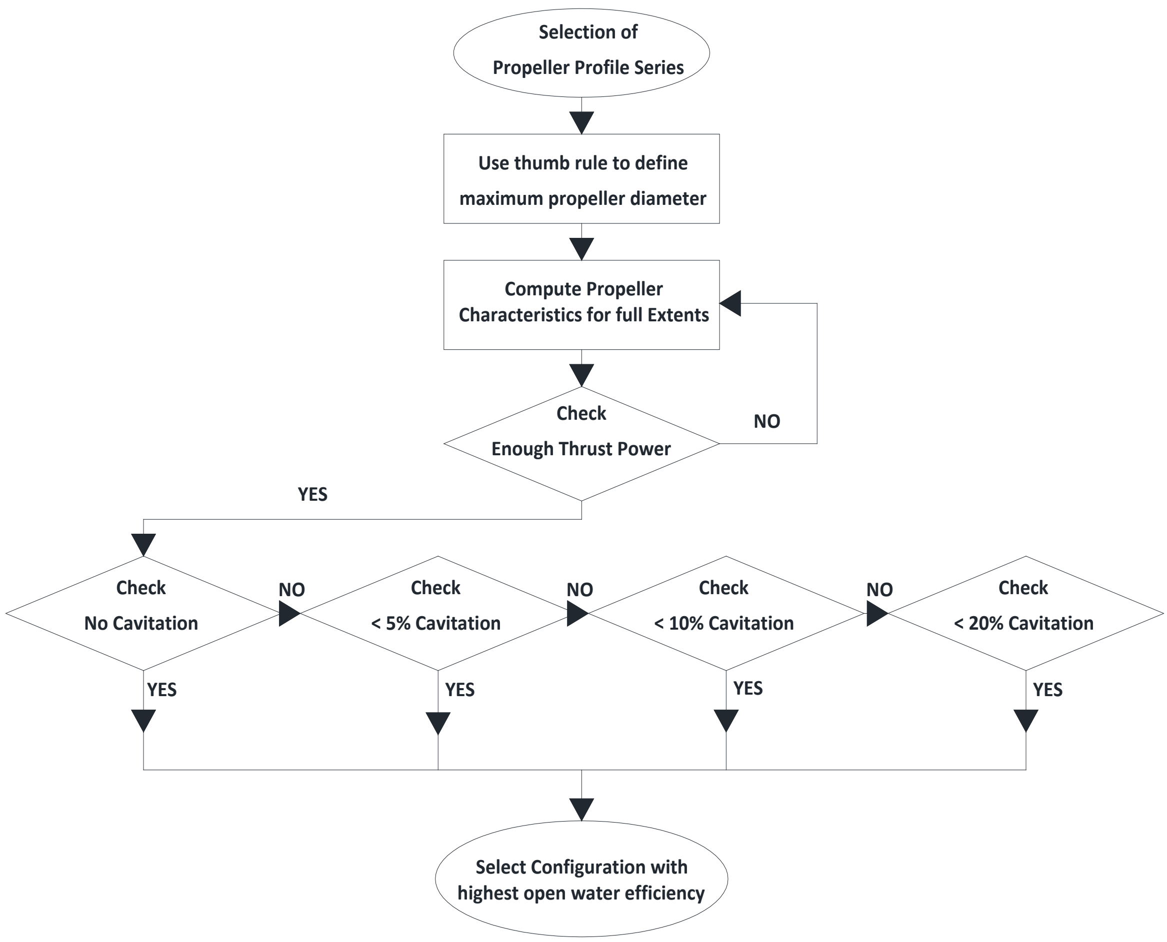


Figure 7.2 Flow chart for propeller selection for electrically driven propeller

7.2.1 PROPELLER SELECTION

Once the resistance of all the vessels was finalised and validated with Potential Flow and RANSE solves, the next step was to finalise the diameter of the propeller. For the design it is evident that the rules for propeller clearances do not limit the diameter of propeller to a large extent. The maximum possible diameter considering keel clearance is approximately 2.6 m in loaded condition but considering the light ship condition and to ensure 100% propeller immersion the maximum diameter is limited to 2 m.

Based on the design thumb rule of it is said that the maximum diameter of the propeller is estimated by the rule:

$$D_{max} = \frac{2}{3} * \; Loaded/Design\, Draft\ (T)$$

At a design draft of 3.2m,

$$D_{max} = 2.13\ m\ (approximately)$$

Considering this diameter was selected as 2.0 m and propeller.

To evaluate the characteristics such as number of blades, BAR, P/D ratio, the propeller design were analysed for thrust, torque, efficiency and cavitation, based on the equation mentioned below in conjunction with KT and KQ curves:

$$wake\ fraction\ (w) = \ 0.5\ C_B - 0.05 = 0.3795$$

$$Velocity\ of\ Advance\ (V_A), \frac{m}{s} = (1 - w) * V$$

$$Thrust\ Coefficient\ (K_T) = \frac{T}{\rho * n^2 * D^4}$$

$$Advance\ Ratio\ (J) = \frac{V * A}{n * D}$$

For potting KT and KQ curves the equations are as follows:

$$KT = \sum_{n=1}^{39} Cn(J)^{S_n} * \left(\frac{P}{D}\right)^{tn} * \left(\frac{A_E}{A_0}\right)^{un} * (Z)^{vn}$$

$$KQ = \sum_{n=1}^{47} Cn(J)^{S_n} * \left(\frac{P}{D}\right)^{tn} * \left(\frac{A_E}{A_0}\right)^{un} * (Z)^{vn}$$

The above equations are for Wageningen B-Series were represented for Reynolds No. (R_n) = $2x10^6$, for other Reynolds numbers with in the range of $2x10^6$ to $2x10^9$ we use the equation as follows:

$$KT\ (R_n) = KT\ (R_n = 2 * 10^6) + \ \Delta KT(R_n)$$

$$KQ\ (R_n) = KQ\ (R_n = 2 * 10^6) + \Delta KQ(R_n)$$

To eliminate the unknown quantity rotation per second (n):

$$\frac{K_T}{J^2} = \frac{T}{\rho * D^2 * V * A^2}$$

After plotting the curve of K_T as a function of J, we find the value of J using non-liner solver. Then using that value of J, the rotation per second is calculated as"

$$n = \frac{V * A}{J * D}$$

And the open water efficiency as:

$$\eta_0 = \frac{J * K_T}{2 * \pi * K_Q}$$

To optimise the calculation, it was decided to use the extents of Wageningen B Series as mentioned in the table 7.2 :

Extents of Waganingen B-Series Propeller																
No. of Blades (Z)	**BLADE AREA RATIO A_E/A_0**															
2	0.30															
3		0.35			0.50			0.65			0.80					
4			0.40			0.55			0.70			0.85			1.00	
5				0.45			0.60			0.75						1.05
6					0.50			0.65			0.80					
7						0.55			0.70			0.85				

Table 7.2 Extents of Waganingen B-Series propeller

Based on the extents mention for different P/D ratios, a total of 200 propeller configurations were obtained. These configurations were then tested to evaluate the ability to provide the required thrust based on the efficiency as assumed and mentioned below.

Two major considerations were made to limit the propeller variables further i.e.:

Range of Developed is,

PE ≤ Developed PT ≤ 1.3 PE;

Propeller Efficiency (η_0) = 50% or higher.

7.2.2 Developed Thrust And Cavitation Test

The 200 propellers configurations were tested for various RPM. All operating speeds of these 200 propellers which satisfied the condition of

$$1.1\ \mathrm{PE} \leq \text{Developed PT} \leq 1.3\ \mathrm{PE}$$

were then tested for back cavitation. This was carried out using the Burrill's Cavitation Test, using the equations as mentioned below:

Cavitation number

$$Cavitation\ Number\ (\sigma_{0.7R}) = \frac{\mathrm{P}_{atm} - \mathrm{P}_{v} + \rho g h}{0.5 * \rho * \left[{V_A}^2 + (0.7 * \pi * n * D)^2\right]}$$

Thrust loading on blades:

$$Thrust\ Loading\ on\ Blade\ (\tau) = \frac{\frac{T}{A_P}}{0.5 * \rho * [{V_A}^2 + (0.7 * \pi * n * D)^2]}$$

The equation for Burrill's Cavitation Chart are as follows:

For 5% back cavitation $\tau = 0.11104 * Ln(\sigma) + 0.27104$

For 10% back cavitation $\tau = 0.1412 * Ln(\sigma) + 0.3506$

For 20% back cavitation $\tau = 0.1722 * Ln(\sigma) + 0.4494$

For 30% back cavitation $\tau = 0.1822 * Ln(\sigma) + 0.4985$

The final Burrill's charts in figure 7.3 to 7.5 depict the result of cavitation test for all the three propeller.

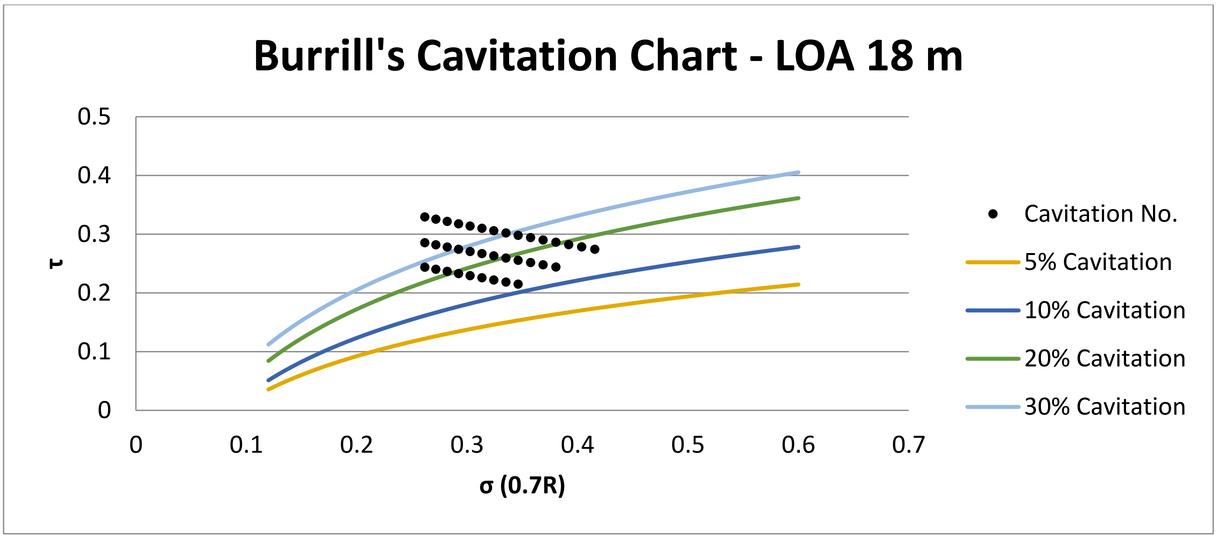


Figure 7.3 Burrill's cavitation chart for 18 m LOA vessel

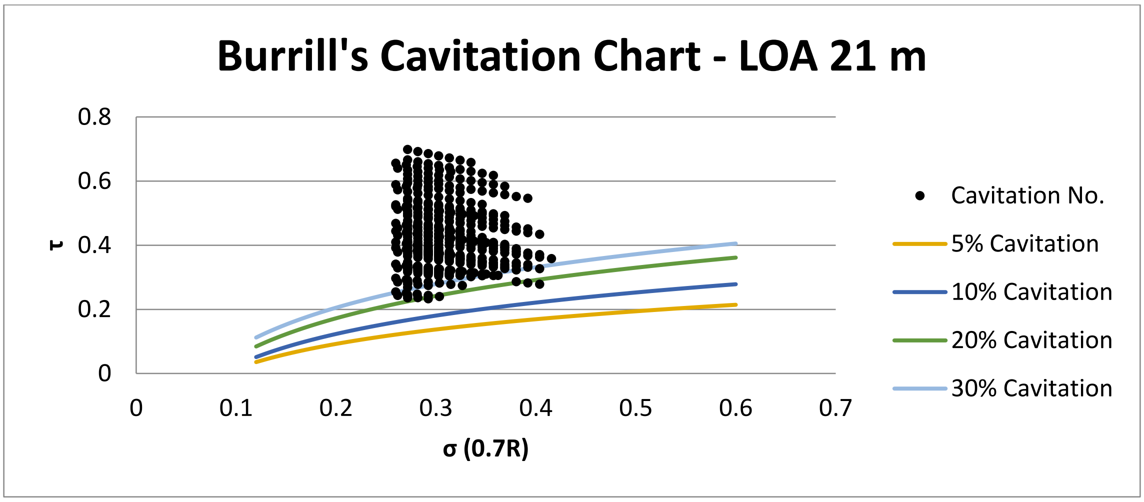


Figure 7.4 Burrill's cavitation chart for 21 m LOA vessel

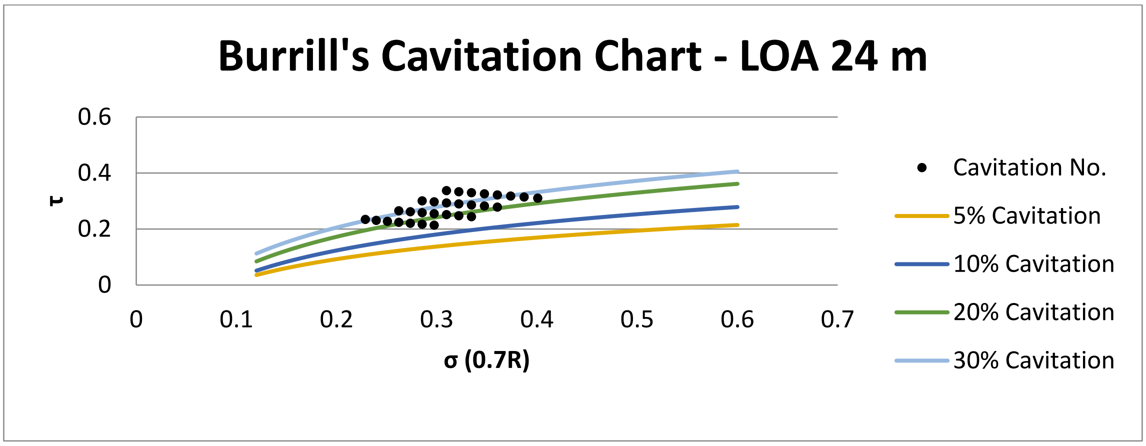


Figure 7.5 Burrill's cavitation chart for 24 m LOA vessel

A closer look at the charts will show that for all the three vessel lengths there were no propeller configurations with less than 10% back cavitation. For all there were 4 to 5 propellers which had less than 20% back cavitation. Based on that the final configuration for all the propellers was selected and the same are mention in the table 7.3:

DETAILS OF THE FIXED PITCH PROPELLERS SELECTED				
S. NO.	**PARAMENTER**	**LOA - 18 m**	**LOA - 21 m**	**LOA - 24 m**
1	Propeller Diameter (D), m	2.0	2.0	2.0
2	No. of Blades (Z)	5	5	5
3	Ratio A_E/A_0	1.05	1.05	1.05
4	Pitch/Diameter Ration (P/D)	1.2	1.4	1.1
5	RPM	341	313.5	407.2
6	Open Water Efficiency (η_0)	68.7	66.1	63.09
7	Back Cavitation	<20%	<20%	<20%
8	Propeller Type	Fixed Pitch	Fixed Pitch	Fixed Pitch
9	Material	Bronze	Bronze	Bronze

Table 7.3 Details of the selected propeller configurations

7.3 RUDDER, STEERING GEAR AND BOW THRUSTER

7.3.1 RUDDER AND RUDDER STOCK

The manoeuvrability of the vessel primarily depends upon the shape and size of rudder, for high speed multihulls this becomes even more critical. Keeping this in mind the selection was based on practical approach which supersedes the Class and IMO requirement. Hence the design was based on "Boat Mechanical Systems Handbook - by Dave Gerr". An aluminium rudder was selected to keep the weight as low as possible.

As per the hand book many High-Speed Displacement Power Multihulls reach high speeds without planing. Such craft are usually round bilged with quite slender hulls and can be powered to go much faster than comparable displacement mono-hulls. Rather than determining the rudder area directly, a good rule for rudder (with a propeller directly ahead of rudder) is that the rudder be entirely under the hull (i.e. not project beyond the transom), with clearance between the top of the rudder and the underside of the hull as close as practical. The rudder blade span or height should be 90 to 95 percent of the maximum hull draft. The mean width of the rudder blade is then 60 percent of the height. It’s common for such rudders to be nearly perfect rectangles; however, they can be trapezoidal, in which case the chord at the tip is usually roughly 60 to 65 percent of the chord at the root. Balance is 17 percent. For further rudder calculations (for the rudder stock, steering gear, etc.), we then calculate the area of the rudder multiplying the span times the mean chord.

<u>Note:</u> As it is evident from the General Arrangement that all the vessels have same draft and the hull clearance. Hence based on the explanation above it was decided to select a common rudder for all the vessels.

The governing equations and criteria are mentioned below

$$Minimum\ Blade\ Span\ (R_h) = 0.90 * Draft\ (T)$$

$$Maximum\ Blade\ Span\ (R_h) = 0.95 * Draft\ (T)$$

$$Minimum\ Blade\ Chord\ (C_h) = 0.60 * Draft\ (T)$$

$$Maximum\ Blade\ Span\ (C_h) = 0.35 * Draft\ (T)$$

and the detailed calculation can be seen in Annex-5.

$$Rudder\ Plate\ Thickness\ (t), mm = 2.54 + \frac{Stiffener\ Spacing\ (S) * Speed\ (Knots)}{666}$$

$$Max. Stiffener\ Spacing\ for\ Aluminium\ Rudder = 101.6 + (\ t * 32)$$

$$Force\ on\ Rudder, kg = \ Lift\ Coeff.(C_L) * \left(Propeller\ Factor\ (P_f) * Speed\ \right)^2 \ * \ Area * 52.55$$

$$Twisting\ Moment\ (TM) = Force\ Center * Twisting\ Arm$$

$$Bending\ Moment\ (BM) = Force\ Center * Bending\ Arm$$

$$Combined\ Moment\ (CM) = BM + \ \sqrt{BM^2 + TM^2}$$

$$Diameter\ of\ Solid\ Rudder\ Stock, mm = \ \sqrt[3]{\frac{16 * CM * 1000}{\pi * \left(\frac{UTS}{SF}\right)}}$$

Where,

UTS : Ultimate Tensile Strength of Material in N/mm^2

SF : Safety Factor

Based on the calculations, a parabolic section rudder was selected and the main particulars of the rudder and rudder stock selected are mentioned in the table 7.4.

RUDDER AND RUDDER STOCK DETAILS			
ALUMINIUM RUDDER			
Blade Span	R_h	2.6	m
Chord	C_h	0.95	m
Rudder Shape		Rectangle	
Rudder Profile		Parabolic Section	
Plate Thickness		12	mm
Max Stiffener Spacing Aluminium	S_{max}	485.6	mm
Weight of Rudder		157.092	kg
RUDDER STOCK			
Rudder Stock Diameter		200	mm
Length of Rudder Stock		500	mm
Weight of Rudder Stock		41.626	kg
TOTAL WEIGHT OF RUDDER		**198.718**	**Kg**

Table 7.4 Details of rudder and rudder stock selected

It should be noted that for the rudder selected, the stiffener thickness should and is kept same as the plate thickness.

7.3.2 Steering Gear And Bow Thruster System

As per IMO SOLAS and Class rules a work boat should be supplied with a redundant steering gear system. That is if the 100% system fails the redundant system should be able to provide 50% operation. The condition states that in 100% operation the Rudder should be able to turn 35^o on one side to 35^o on other side. Should be able to turn 35^o on one side to 30^o on other side within 28 sec at full ahead speed. At 50% operation condition turning the rudder over from 15° on one side to 15° on the other side in not more than 60 seconds with the ship on summer load waterline and running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater. The two applicable system that meet the size and load criteria are shown in figure 7.6:

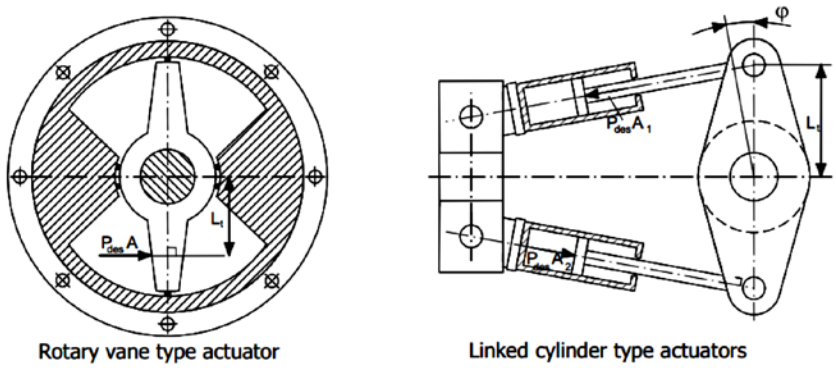


Figure 7.6 Steering gear actuators types, Source: DNV-GL Class Rules 2012

Considering the space constrain and the method of actuation the vessel will be provided with electrically actuated hydraulically operated rotary-vane steering gear system, with rudder stock diameter as 200 mm. Based on the specification above a Rolls Royce steering gear of following specification was selected:

STEERING GEAR DETAILS			
S. NO.	**PARAMETER**	**VALUE**	**UNITS**
1	Type	RV 550-2	
2	Max. Stock Diameter	370	mm
3	Max. Working Torque	568	kNm
4	Max. Rudder Angle	2 x 71.5	
5	Weight	3500	kg
6	Max. Radial Load	1400	kN
7	Max. Axial Load	500	kN

Table 7.5 Details of steering gear

A common electrically operated bow thruster as per DP1 requirement of 48kN thrust capacity is required. Based on DP1 requirement and space availability we have selected electrically operated Rolls Royce TT-CP Transverse thruster. The specification can be seen in table 7.6.

BOW THRUSTER DETAILS			
S. NO.	**PARAMETER**	**VALUE**	**UNITS**
1	Version	ICE/DPN/DPD	
2	Diameter	1100	mm
3	Drive	Electric	
4	Max. Power	350	kW

Table 7.6 Specification of bow thruster

CHAPTER 8 - ADVANCED HYBRID - MARINE POWER PLANT

In earlier chapters we learned that there are different methods to decrease fuel consumption and thus the emissions. This chapter will deal with the operational parameters for fuel reduction i.e.:

1. Power plant design,
2. Maintenance profile

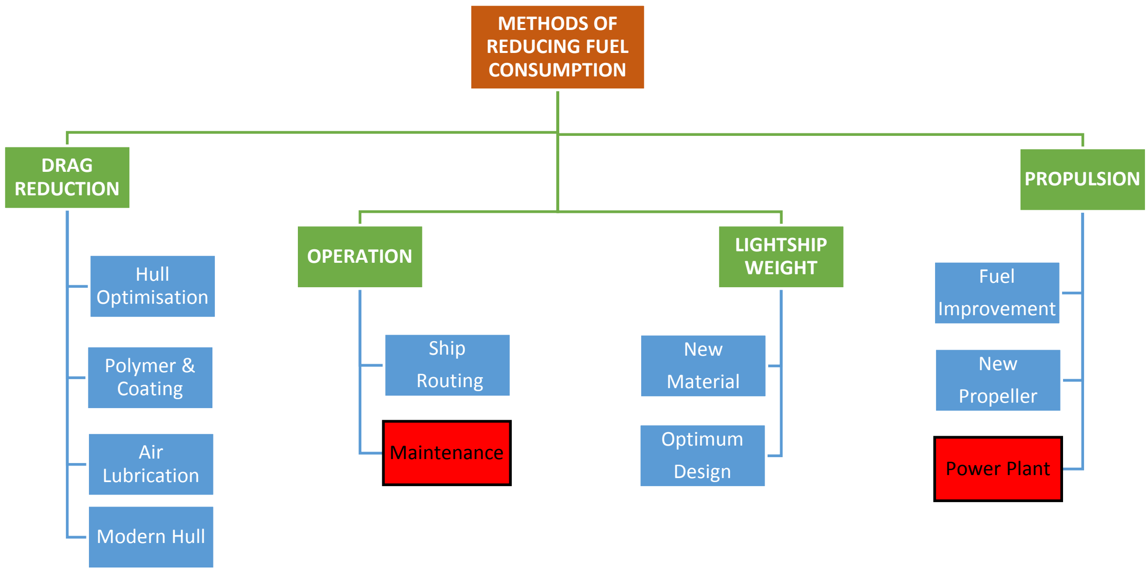


Figure 8.1 Method of reducing fuel consumption by power plant, Source: Marine Insight, July 2012

The Marine power plant is designed on the principle of Advanced Hybrid Diesel Electric System popularly known as ELFA that is being employed in the Diesel Electric buses in European countries. We know that the transmission losses in diesel electric system are higher than that in direct drive, but due to the fact that diesel electric system allows us to operate both propeller and engine at maximum efficiency, the overall efficiency of the with Diesel Electric System is higher. In order to further enhance the efficiency we will use AC-DC units. In addition the system will use battery as source of power for propulsion during emergency conditions.

The System will be designed to operate with both AC and DC power. Conventionally a pure constant AC-DC rectifier is used in this kind rectification, but here we have proposed a Pulsated DC rectification to minimise the rectification losses. This complete system is easy to install, operate, and can be expanded or modified as per owners needs as it comprises of standardised modules which can be freely arranged on board in the design stage to offer a flexible layout with the best use of space.

8.1 Principle Of Hybrid Diesel Electric System

The system will provide the right propulsion mode for the right situation. Since the drives are always running within their optimum range they have a longer service life. The system will provide three different types of drive mode i.e.:

- Diesel Electric mode – Alternating Current (AC) Mode,
- Battery mode – Direct Current (DC) Mode,
- Hybrid mode – AC/DC Mode.

To understand why we propose a use of Advanced Hybrid Diesel Electric system compared pure battery electric or pure diesel system, we will understand the principle of operation and compare the general properties with the conventional existing systems. The figure 8.2 depicts the basic principle of operation of an Advanced Hybrid AC-DC Diesel Electric System.

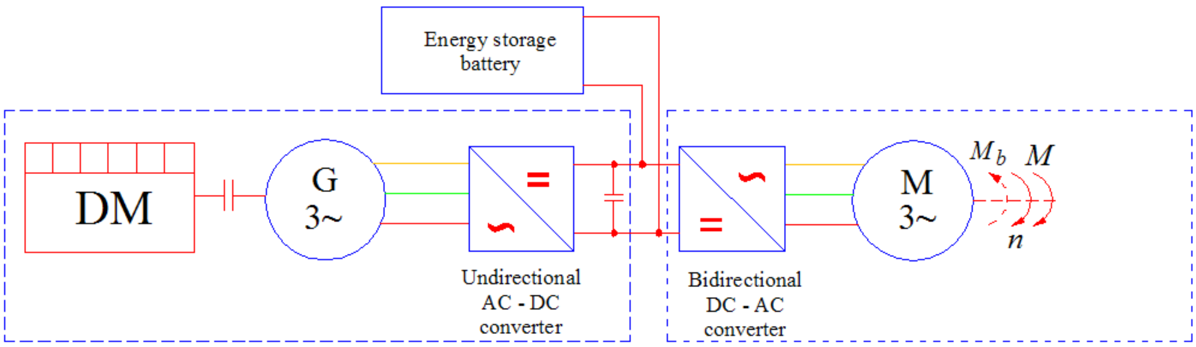


Figure 8.2 Basic layout of Advanced Hybrid AC-DC diesel electric system

As it can be seen the system is divided into three parts:

1. Power Generation and Conversion System,
2. Energy Storage System (In this design it consists of battery terminals and a small generator),
3. Transmission System.

And they function differently during different modes of operation.

Diesel Electric Mode – AC: The diesel engine (DM) with generator (G) generates AC power which is directly supplied to AC propulsion motor (M) to rotate the propeller shaft. In case of low loads DM is run at full load and the AC power is converted into DC by unidirectional AC-DC converter and stored in DC battery.

Battery Mode – DC: During low loads the diesel engine (DM) is stopped with power being supplied by Storage Battery. Since the storage battery is DC system a bi-directional DC-AC converter converts the DC supply from battery to AC before it is supplied to the AC propulsion motor (M).

Hybrid Mode – AC/DC: The hybrid mode operation is when the vessel is operating at full loads during such operations the Diesel engine operates at full load and to supply the additional power the storage batter is used. This enables us to select the best size of engine so that we don't have to select an oversized engine and then operate it at lower loads, especially in cases where the exact kW engine is not available.

DISADVANTAGES OF PURE DIESEL AND PURE BATTERY ELECTRIC SYSTEM	
DIESEL INTERNAL COMBUSTION ENGINE	**BATTERY ELECTRIC SYSTEM**
High energy consumption: resources, independent of foreign oil High emission, air pollution, global warming High maintenance cost Environmental hazards and noisy	Recharging takes much longer time than refuelling gasoline – unless infrastructure for instantly replaceable battery cartridges are available Battery pack takes space and weight of the vehicle which otherwise can be utilised for other equipment.
ADVANTAGES OF HYBRID ELECTRIC SYSTEM	
Optimize the fuel economy	Reduced maintenance because ICE operation is optimized, less hazardous material
• Optimize the operating point of ICE • Stop the ICE if not needed (ultra-low speed and stops) • Recover the kinetic energy at braking • Reduce the size (hp/kW and volume) of ICE	• Fewer tune ups, longer life cycle of ICE • Fewer oil changes • Fewer fuel filters, antifreeze, radiator flushes or water pumps • Fewer exhaust repairs or muffler changes
Reduce emissions	Quiet Operation
• Minimize the emissions when ICE is optimized in operation • Stop the ICE when it's not needed • Reduced size of ICE means less emissions	• Ultra low noise at low speed because ICE is stopped • Quiet motor, motor is stopped when vehicle comes to a stop, with engine already stopped

Table 8.1 Comparison between ICE, Battery and hybrid system

Note: To prepare the concept design of this power plant, we have used "Diesel-electric Propulsion Plants – A brief guideline how to engineer a diesel-electric propulsion system - by MAN Turbo" [15] as the basic guideline. But it is to be noted that we may or may not use the equipment by MAN Turbo.

Now to estimate the efficiency, the first step is to make basic reference point, the figure 8.3 depicts the practical efficiency data as described by MAN engines.

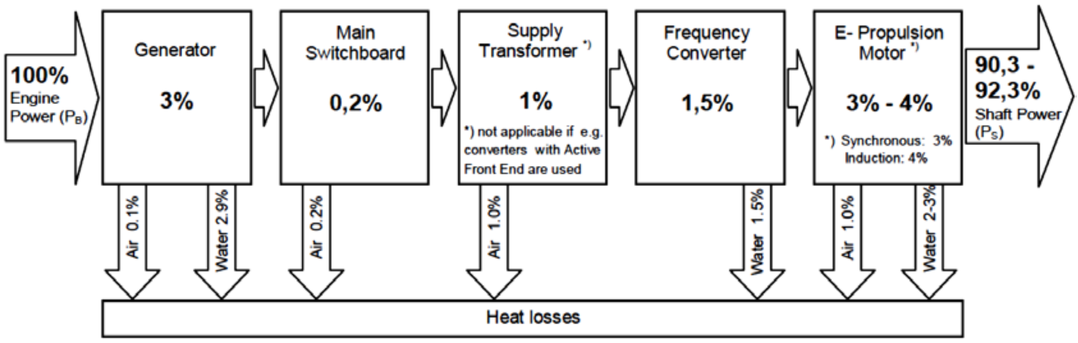


Figure 8.3 Hybrid electric power plant efficiency, Source: MAN Turbo [15]

The figure 8.4 shows the basic workflow for design of a diesel electric power plant, which is followed during the model based design.

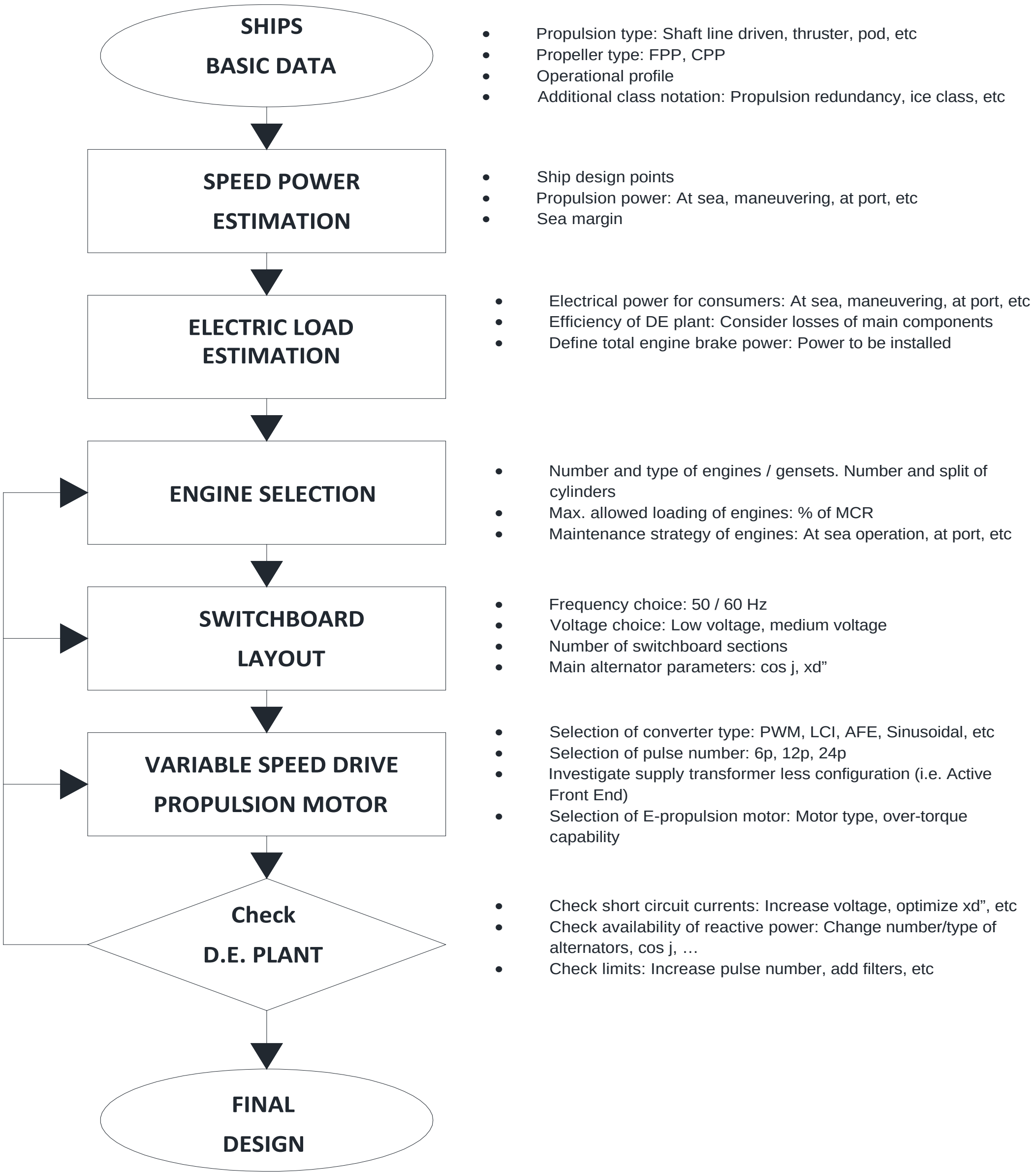


Figure 8.4 Diesel electric system design work flow, Source: MAN Turbo [15]

8.2 Electrical Circuits

To select the right equipment we must first work out the load estimation, but for load estimation to work right we must first prepare a circuit plan, this way we can we know the primary elements, the load and their respective efficiency that need to be taken into account. Based on the design shown in figure 8.2 Basic layout of Advanced Hybrid AC-DC Diesel Electric System, there are two components that have been added in addition to the conventional hybrid diesel electric system i.e.

1. Unidirectional Pulsating AC-DC rectification,
2. Bi-Directional DC-AC convertor.

Here we will explain the circuitry of the two elements before we finalise the layout.

Unidirectional Pulsating AC-DC rectification: This system will employ a bridge rectification with capacitor filter. First a step-down transformer lowers the magnitude of AC voltage (440 VAC) to desired DC voltage of 30 VDC considering rectification losses and the desired output at battery being 26.5 VDC. The 4 diode bridge converts the phase of AC to positive phase wave form. The rectified DC at this point is still in wave form to convert it into pulsating DC we use a capacitor of 4700μF as smoothing element which works as a temporary storage that charges to its full capacity storing the extra energy and discharging slowly till the next cycle.

Assuming n_1 and $n_2$to be number of coils on High voltage side and low voltage side, the step down coil ratio is given as:

$$\frac{n_1}{n_2} = \frac{High\ Voltage\ Value}{Low\ Voltage\ Value} = \frac{440}{30} = \frac{22}{1}$$

The figure 8.5 shows the working principle of an AC-DC rectification system that is used in the unidirectional convertor.

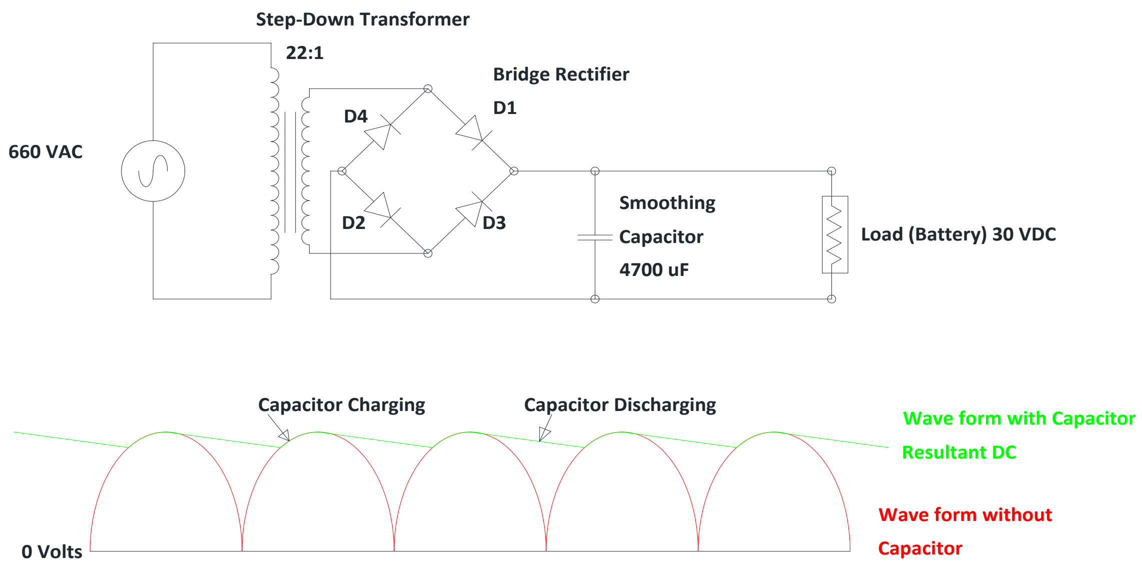


Figure 8.5 Unidirectional bridge wave pulsating AC-DC rectification circuit

Bidirectional DC-AC convertor: Selecting the propulsion motor of same voltage as generator supply i.e. 660 VAC, we will use a step-up transformer for coil ratio 1:22. The circuit also uses two (2) PNP and two (2) NPN transistor in addition to four (4) controlling resistances and two (2) capacitors acting as filtering elements. The system operates with same principle as the residentially used invertors, to have a higher operating capacity the capacitors and resistance are selected accordingly. In this case the values are same as shown in figure 8.5, rectification system.

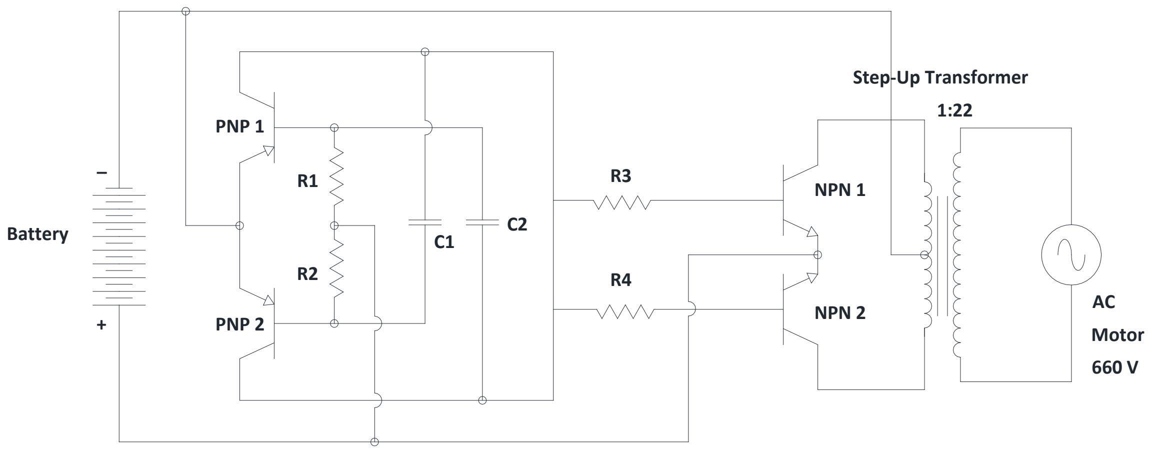


Figure 8.6 Bidirectional DC-AC convertor circuit

8.3 Electric Load Estimation

With Basic ship data, resistance and propulsion power already finalised, as the next step the electrical load estimation was needed to be done to enable us to carry out engine selection. During this estimation process it is very critical to consider all the energy losses and efficiency factors. Since this design is an advanced hybrid diesel electric system, In addition to the efficiency shown in figure 8.5, the efficiency of energy storage (battery) system needed to be taken into account:

$$\eta_{PT} = \frac{P_T}{P_{Batt,int}}$$

$$\eta_{PT} = \frac{Torque\ (T_o) * Shaft\ Speed\ (\omega_o)}{P_{Batt,int}}$$

Which can be further expanded taking into consideration the effect of engine efficiency:

$$\eta_{PT} = \frac{T_o * \omega_o}{P_{Engg,Fuel} + \frac{P_{Batt,out}}{\eta_{Batt}(P_{Batt,out}) * \eta_{Batt,Chg} * \eta_{Gen}}}$$

$$\eta_{PT} = \frac{T_o * \omega_o}{P_{Engg,Fuel} + \frac{P_{Batt,out} * \eta_{Batt}(P_{Batt,out}) * \eta_{Batt,DisChg}}{\eta_{Gen}}}$$

Where,

$$\eta_{Batt,Chg} = \frac{E^-{}_{Batt,int}}{E^-{}_{Batt,out}}$$

$$\eta_{Batt,DisChg} = \frac{E^+{}_{Batt,out}}{E^+{}_{Batt,int}}$$

$$\eta_{Gen} = -\frac{E^-{}_{Batt,out}}{E_{fuel,extra}}$$

Taking into account all the factors above, the electric load estimation is carried out for Sailing, harbour, manoeuvring and Emergency system is calculated. The detailed calculation can be seen in Annex-5. The final values for all the vessels is mentioned in the table 8.2.

Note: The electrical load is done for one type of vessel for each length. We have taken into account the vessel with highest number of loads/consumers to do carry out this estimation.

SUMMARY OF ELECTRIC LOAD ESTIMATION							
PILOT / POLICE / CUSTOM PATROL BOAT/ WINDFARM SUPPORT VESSEL							
S. NO.	PARAMENTER	LOA - 18 m		LOA - 21 m		LOA - 24 m	
		kW	kVA	kW	kVA	kW	kVA
1	Sailing Condition	1608	2412.7	1909	2863.1	2049	3073.4
2	Harbour Condition	31.14	46.70	39.61	59.41	48.08	72.118
3	Manoeuvring Condition	1607	2410.9	1909	2863.5	2051	3077.2
4	Emergency Condition	18.97	28.45	18.97	28.45	18.97	28.45

Table 8.2 Summery of electrical load estimation for all vessels

8.4 ADVANCED HYBRID AC – DC MARINE POWER PLANT LAYOUT

One critical aspect is the right layout with the selected equipment. We design the final layout of the power plant taking into account all the voltages and frequencies. At this time we have to select the operating layout of equipment so that the engine room spaces can be utilised to the best possible way and the wiring/terminals can be minimised, this not only helps in having more working space but also minimises the heat losses in wiring. The figure 8.7 shows the common layout for all vessels, the number of engines, gen-sets and battery terminals are different in different vessels and the same is illustrated in the common layout.

In the figure 8.7 it can be observed that power consumers are carefully grouped based on sailing, manoeuvring and harbour condition. This provides higher efficiency as dedicated bus blocks and lines can be installed thus reducing the heat and conversion losses over multiple lines.

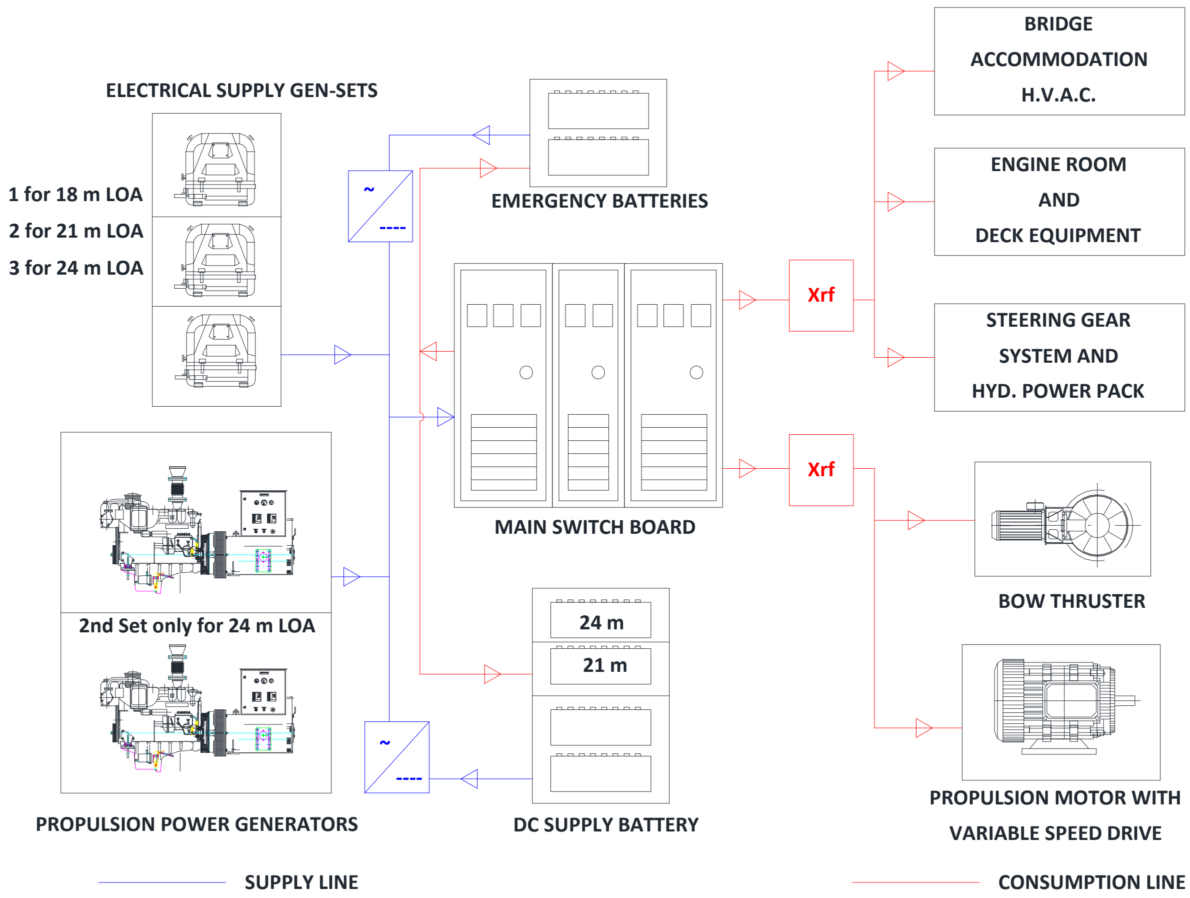


Figure 8.7 Advanced hybrid AC-DC marine power plant layout

8.5 Summary Of Equipment Details

Based on the load estimation, layout and the space requirement it was decided to select continuous duty MTU engines for patrol and harbour support vessel. Even though they are commercially expensive than other engine brands they are more compact and light weight, this gives us the advantage of low light ship weight and sizing of the central tube for easy installation and maintenance.

The details of engine, gen-set, battery and motor model selected are given in the table 8.3.

DETAILS OF MAIN DIESEL ELECTRIC ENGINE							
PILOT / POLICE / CUSTOM PATROL BOAT							
S. NO.	PARAMENTER	LOA - 18 m		LOA - 21 m		LOA - 24 m	
1	Model	16V 2000 M93		16V 2000 M94		-	
2	Rated Power (Max.)	1490	kW	1839	kW	-	-
3	Speed (Max.)	2450	rpm	2450	rpm	-	-
4	Length (L)	2.285	m	2.310	m	-	-
5	Width (W)	1.295	m	1.295	m	-	-
6	Height (H)	1.390	m	1.390	m	-	-
7	Mass (dry)	3380	kg	3380	kg	-	-
WINDFARM SUPPORT VESSEL							
S. NO.	PARAMENTER	LOA - 18 m		LOA - 21 m		LOA - 24 m	
1	Model	16V 2000 M93		16V 2000 M94		10V 2000 M93	
2	Rated Power (Max.)	1490	kW	1839	kW	1020	kW
3	Speed (Max.)	2450	rpm	2450	rpm	2450	rpm
4	Length (L)	2.285	m	2.310	m	1.545	m
5	Width (W)	1.295	m	1.295	m	1.130	m
6	Height (H)	1.390	m	1.390	m	1.230	m
7	Mass (dry)	3380	kg	3380	kg	2240	kg

Table 8.3 Main diesel electric engine, Source: MTU Diesel Electric Engine Program

DETAILS OF GENERATING SET FOR ELECTRICAL SUPPLY							
PILOT / POLICE / CUSTOM PATROL BOAT							
S. NO.	PARAMENTER	LOA - 18 m		LOA - 21 m		LOA - 24 m	
1	Model	FG-P55-3 P		FG-P55-3 S		-	
2	Rated Power (Max.)	45	kW	50	kW	-	-
3	Speed (Max.)	1800	rpm	1800	rpm	-	-
4	Length (L)	1.68	m	1.68	m	-	-
5	Width (W)	0.76	m	0.76	m	-	-
6	Height (H)	1.336	m	1.336	m	-	-
7	Mass (dry)	797	kg	797	kg	-	-
8	Frequency	60	Hz	60	Hz		
WINDFARM SUPPORT VESSEL							
S. NO.	PARAMENTER	LOA - 18 m		LOA - 21 m		LOA - 24 m	
1	Model	FG-P55-3 P		FG-P55-3 S		FG-P55-3 S	
2	Rated Power (Max.)	45	kW	50	kW	50	kW
3	Speed (Max.)	1800	rpm	1800	rpm	1800	rpm
4	Length (L)	1.68	m	1.68	m	1.68	m
5	Width (W)	0.76	m	0.76	m	0.76	m
6	Height (H)	1.336	m	1.336	m	1.336	m
7	Mass (dry)	797	kg	797	kg	797	kg
8	Frequency	60	Hz	60	Hz	60	Hz

Table 8.4 Generating set for electrical supply, Source: FG Wilson

The main reason we selected the ABB HRX motor series is due to the fact that these motors are air cooled and come with inbuilt variable speed drive, which means no need of cooling water lines and excessive space requirements. They also come in both 60 Hz and 50 Hz variants.

DETAILS OF PROPULSION MOTOR							
PILOT / POLICE / CUSTOM PATROL BOAT							
S. NO.	**PARAMENTER**	**LOA - 18 m**		**LOA - 21 m**		**LOA - 24 m**	
1	Model/Type	ABB HRX 2P		ABB HRX 10P		-	
2	Rated Power (Max.)	1500	kW	2000	kW	-	-
3	Speed (Max.)	3600	rpm	720	rpm	-	-
4	Length (L)	1.65	m	1.55	m	-	-
5	Width (W)	1.06	m	1.30	m	-	-
6	Height (H)	1.12	m	1.34	m	-	-
7	Mass (dry)	347	kg	382	kg	-	-
8	Frequency	60	Hz	60	Hz		
WINDFARM SUPPORT VESSEL							
S. NO.	**PARAMENTER**	**LOA - 18 m**		**LOA - 21 m**		**LOA - 24 m**	
1	Model/Type	ABB HRX 2P		ABB HRX 10P		ABB HRX 8P	
2	Rated Power (Max.)	1500	kW	2000	kW	2200	kW
3	Speed (Max.)	3600	rpm	720	rpm	900	rpm
4	Length (L)	1.65	m	1.55	m	1.98	m
5	Width (W)	1.06	m	1.30	m	2.00	m
6	Height (H)	1.12	m	1.34	m	1.90	m
7	Mass (dry)	347	kg	382	kg	461	kg
8	Frequency	60	Hz	60	Hz	60	Hz

Table 8.5 Propulsion motor selected, Source: ABB HRX Maine Propulsion Motors

The emergency power is provided with the use of battery terminal, based on the electrical load and the space available in emergency battery room. A Parallel System battery configuration is installed in all the vessels with same battery specification. Based on the load requirement of each vessel the number of batteries in parallel is increased.

COMMON SPECIFICATIONS OF THE BATTERY SELECTED			
S. NO.	**PARAMETER**	**VALUE**	**UNITS**
1	Nominal Battery Voltage	26.5	Volts
2	Battery Capacity Range	180	Ah
3	Nominal Battery Power	5	kWh
4	Battery Monitoring	Integrated	
5	Battery Terminal	M8	
6	Masterbus Powering	YES	
7	Max. Dimensions (incl. terminals/grip handles), L x W x H	622 x 197 x 355	mm
8	Weight	58	kg

VESSEL SPECIFIC DETAILS OF BATTERY CONFIGURATION							
PILOT / POLICE / CUSTOM PATROL BOAT							
S. NO.	**PARAMENTER**	**LOA - 18 m**		**LOA - 21 m**		**LOA - 24 m**	
1	Required Load	38	kW	40	kW	-	-
2	Required Load	46	kVa	60	kVa	-	-
3	Number of Battery Terminals	8	m	8	m	-	-
4	Total Load Provided	40	kW	40	kW	-	-
5	Total Load Provided	60	kVa	60	kVa	-	-
6	Total Mass	464	kg	464	kg	-	-
WINDFARM SUPPORT VESSEL							
S. NO.	**PARAMENTER**	**LOA - 18 m**		**LOA - 21 m**		**LOA - 24 m**	
1	Required Load	38	kW	40	kW	49	kW
2	Required Load	46	kVa	60	kVa	72	kVa
3	Number of Battery Terminals	8	m	8	m	10	M
4	Total Load Provided	40	kW	40	kW	50	kW
5	Total Load Provided	60	kVa	60	kVa	75	kVa
6	Total Mass	464	kg	464	kg	580	Kg

Table 8.6 Battery configuration, Source: Mastervolt MLI Ultra 24/5000 - LiFePO4

One of the first impressions a person makes is that the shape of the vessel may not provide a good stability characteristics. On the contrary the vessel design actually provides excellent hydrostatic intact and damage stability. When it comes to damage stability the vessel design inherently provides increased stability as the underwater volume increases, provided the design depth of the vessel is carefully selected based on the size of the biggest compartment that can get damaged.

This chapter discusses the stability characteristics of the three hulls for 10% Lightship and 100% loaded ship in both intact and damage condition. These characteristics will be evaluated based on IMO and DNV-GL stability criteria for Multi-Hull high speed crafts by using the GZ curves.

It will also discuss the use and design of trim tanks and passive fin stabilisers. These tests are carried out using Maxsurf Stability Advanced Module.

9.1 Special Consideration For Stability

9.1.1 GZ Curve Dipping / Flat Lining And Outrigger Flaring

While conducting the intact stability test it was observed that the righting arm (GZ) curve exhibited flat lining and a dip at angles of heel less than 60°, refer the figure 9.1 at 10° to 20° for flat lining and 40° to 60° for curve dipping.

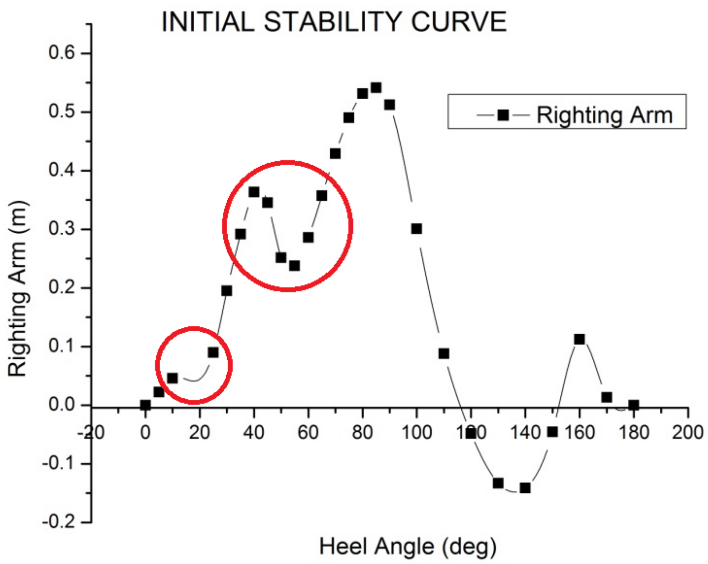


Figure 9.1 Initial GZ Curves exhibiting flat lining and curve dipping

Source: Ship Design Project EMship at ULg, Work of Akula Nidarshan, Martin P.W. & Xu Cheng

While the result shown in figure 9.1 is for base hull Chica-Caliente, a similar trend was observed during all the current design as well. Due to this it was found that the vessel did not meet the stability criteria. The heeling angles of the vessel due to beam wind and high speed turning exceeded the criteria. It was realised that this occurred because when the ship heels, one of the outrigger would begin to emerge from the water, causing the loss of water-plane area and inertia. Unlike mono-hulls, the increase of water-plane area at the centre hull due to heeling has little influence on the total transverse inertia of the water-plane because of the narrow beam.

Since the outer hull did not present any flaring, there was little compensation to the water-plane area from the immersed outriggers. This caused the GZ curve to flat line until the watertight cross structure touches the water at a higher heel angle.

Referring to PhD Thesis work titled Design and Hydrodynamic Performance of Trimaran Displacement Ships by Junwu Zhang, Department of Mechanical Engineering, University College London, 1997.

It was found that this flat lining or curve dipping can eliminated by three design approaches

1. Increase the beam or length of the outriggers.
2. Increasing the beam of the vessel, i.e. by increasing the span of the outriggers.
3. Increase the flare of the outriggers, refer to figure 9.2.

It was clear that if we length/beam of outriggers would mean an increase in the displacement of the vessel for the same design draft, this will cause an increase in weight and powering.

While increasing the beam dose not adversely affect the resistance performance of the ship, it causes some increase to metacentric heightGM which is not desirable for the rolling motion. Although the absolute value of GM would still be extremely low, but considering the fact that this vessel beam was converged upon using the sea-keeping analysis, this too was not a desirable option.

Increasing the flare of the outriggers however tends to overcomes most of the undesirable features. There would be no increase in GM, and as far as calm water resistance is concerned there will be no increase in resistance and will impose a very little increase in lightship weight weights. Thus, the outrigger flaring was used to make the ship meet the stability criteria. The final outrigger flaring angle was arrived at 30^{o} based on the damaged stability criteria.

The flare on the outriggers is only in the inner side above the design waterline, this to compensate for the water-plane area losses of the other outrigger due the heel of the ship to enable stability requirements.

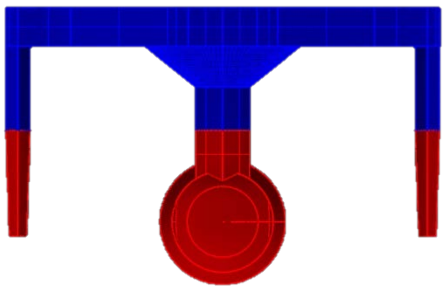
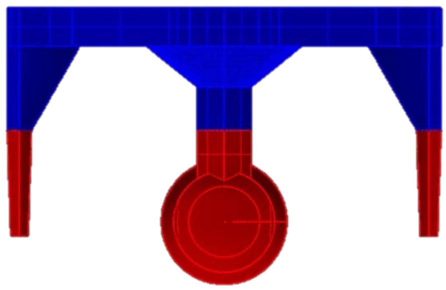
UNFLARED AND FLARED OUTTER HULLS	
	
NO FLARE ON OUTTER HULLS	**10.3^{O} FLARE ON INSIDE OF OUTTER HULLS**

Figure 9.2 Comparison of geometry flared and Non-flared hull

9.1.2 LONGITUDINAL STABILITY AND TRIM TANKS

As explained earlier in these vessels, the movement of load (consumables/cargo) plays a very critical role. To provide flexibility to operate and to eliminate this drawback it was decided to provide four (4) trim tanks in the central strut, two forward and two aft. This not only gives the operator the flexibility but also provides greater control over the stability characteristics of the vessel. While providing a trim tank does resolve the constraint, it causes the increase in light ship weight with no other potential gain. Industry research revealed that in some design of smaller vessels, instead of water trim tanks, fuel oil trim tanks are used. The advantage of this is that during some conditions when movement of load is not a constraint these tanks can be used for fuel supply. Plus when connected with primary fuel oil supply tanks, give greater control as the fuel can be transferred not only between trim tanks but also between supply tanks. The capacity of these tanks was arrived at using the stability test with desired displacement and centre of gravity. The figure 9.3 shows the tank plan including the trim tank setup.

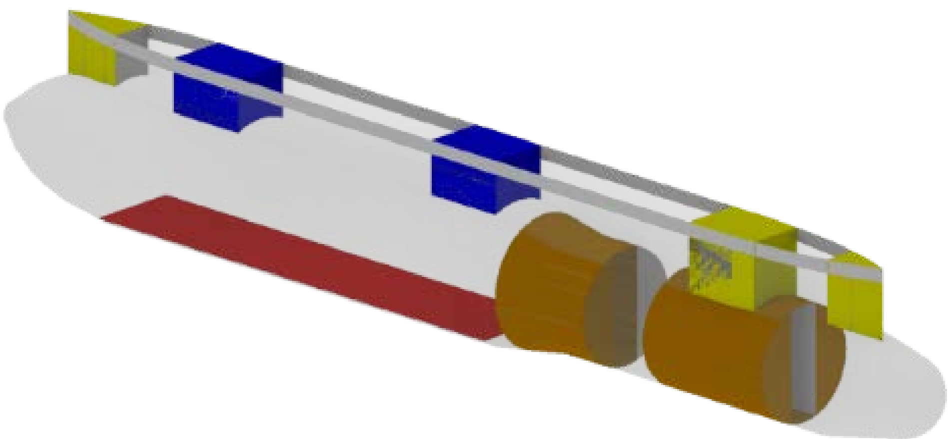


Figure 9.3 Tank Plan of 18m vessel illustrating the arrangement of trim tanks

in forward and aft of central strut

The details of the lightship and loaded ship conditions are mentioned in table 9.1.

18 m - CM-SWAS(S)H			**18 m - CM-SWAS(S)H**		
LIGHTSHIP CONDITION			**LOADED SHIP CONDITION**		
ELEMENT	**VALUE**	**UNIT**	**ELEMENT**	**VALUE**	**UNIT**
DRAFT	2.3	m	DRAFT	3.2	m
DISPLACEMENT	63.97	tonne	DISPLACEMENT	79.34	tonne
LCG	7.5	m	LCG	8.1	m
VCG	2.6	m	VCG	2.1	m
TCG	0	m	TCG	0	m
21 m - CM-SWAS(S)H			**21 m - CM-SWAS(S)H**		
LIGHTSHIP CONDITION			**LOADED SHIP CONDITION**		
ELEMENT	**VALUE**	**UNIT**	**ELEMENT**	**VALUE**	**UNIT**
DRAFT	2.3	m	DRAFT	3.2	m
DISPLACEMENT	77.56	tonne	DISPLACEMENT	99.76	tonne
LCG	8.9	m	LCG	9.5	m
VCG	2.75	m	VCG	2	m
TCG	0	m	TCG	0	m
24 m - CM-SWAS(S)H			**24 m - CM-SWAS(S)H**		
LIGHTSHIP CONDITION			**LOADED SHIP CONDITION**		
ELEMENT	**VALUE**	**UNIT**	**ELEMENT**	**VALUE**	**UNIT**
DRAFT	2.3	m	DRAFT	3.2	m
DISPLACEMENT	93.39	tonne	DISPLACEMENT	118.6	tonne
LCG	11	m	LCG	11.5	m
VCG	2.95	m	VCG	1.85	m
TCG	0	m	TCG	0	m

Table 9.1 Light ship and loaded ship operating parameters

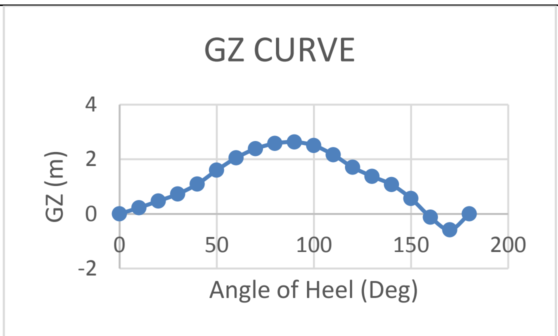
9.2 INTACT STABILITY

The design was tested for stability where vessel should oblige with IMO (International Maritime Organization) rules as one of the most important thing is about the minimum stability criteria. The applicable IMO code is IMO Resolution A.749 (18) Code on Intact Stability for All Types of Ships covered by IMO Instruments adopted on 4th of November 1993. The code requires that the GZ curve should meet 6 general minimum stability criteria:

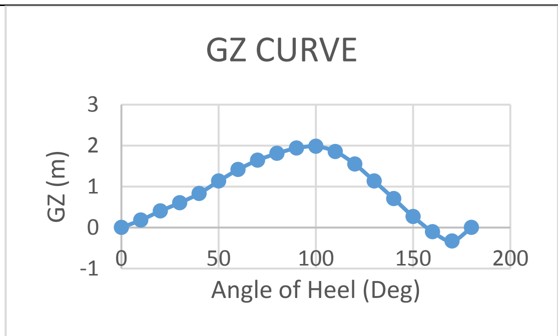
1. The area under the righting lever curve (GZ curve) should not be less than 0.055 meters-radian up to 300 angle of heel. (1 meter-radian = 57.3 meter degrees)
2. The area under GZ curve should not be less than 0.09 meter radian up to 400 or the angle of flooding if this angle is less than 400
3. The area under GZ curve between the angles of heel of 300 and 400, or between 300 and if this angle is less than 400, should not be less than 0.03 meter-radian

4. The righting lever GZ should be at least 0.2 meters at a heel angle equal to or greater than 300
5. The maximum righting lever should occur at an angle of heel not less than 250 and preferably exceeding 300
6. The initial metacentric height GM should not be less than 0.15 meters

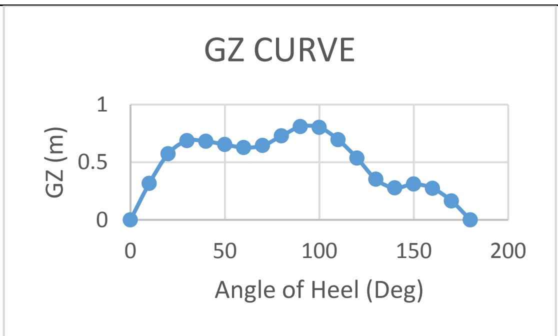
In addition to this the vessel was also tested for DNV-GL HSC and ISO stability criteria for Multi-Hulls. The graphs in figure 9.4 show that as indicated in literature, all the three vessels show that three pass all stability criteria and the superior characteristics. In addition it can be seen that 21 m and 24 m hulls actually have no negative GZ at any angle. Literature study has shown that in ideal ballast condition (in this case fuel oil trim tanks) and underwater fin keel or bulb keel (as in sail boats) also show no negative GZ condition. The same can be referred in article "MODERN SAILBOAT DESIGN: Quantifying Stability" by Charles Doane 16 May 2013.



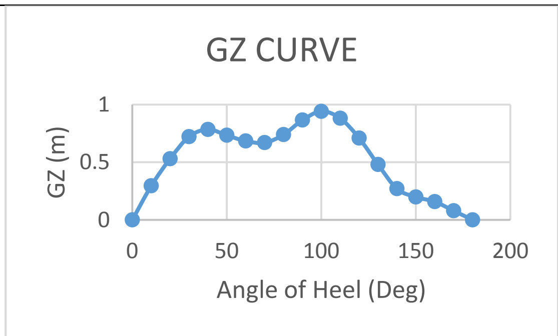
18 m Loaded Hull



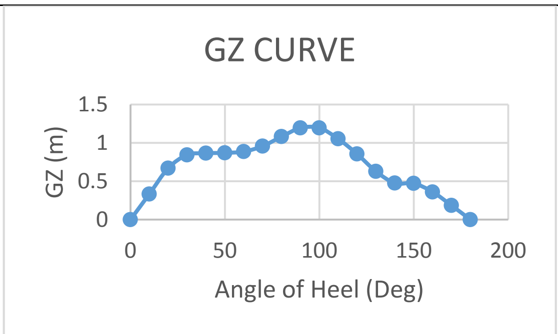
18 m Light Hull



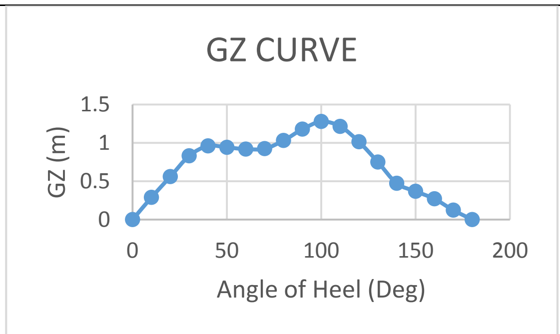
21 m Loaded Hull



21 m Light Hull



24 m Loaded Hull



24 m Light Hull

Figure 9.4 GZ curves for loaded and light ship condition for three hulls

The detailed report on stability test values and percentage margin of clearance can be referred in Annex-4.

9.3 Damage Stability

Guided by IMO rules we determined the extent of damage that needs to be evaluated and this in conjunction with DNV-GL's minimum requirements for sub-division resulted in the determining the number of water tight transverse bulkheads needed to meet the damage stability criteria. In addition to central hull, the outrigger sub-division was also determined by similar criteria.

As evident from design, we can see that the outriggers have a very limited volume that can be flooded, in to that we have subdivided the outriggers with very small compartments to ensure minimum flooding. Hence it was decided that instead of doing standard probabilistic damage study we can consider the worst case scenario in which 50% of outriggers and the two adjacent (with one of them, as the largest) compartment of central hull is flooded at the same time. Based on the compartment time the permeability was selected from Classification rules as mention in Annex-2.

The results of all the damage conditions are illustrated in figure 9.5 to 9.7.

It can be seen that the stability in damaged condition is even superior, this is due to the fact that when the compartments are damaged and loaded the draft of the vessel increases to much higher value, not high enough to sink the hull till deck level. In this case the VCG of the vessel become even lower and this improving the stability characteristics.

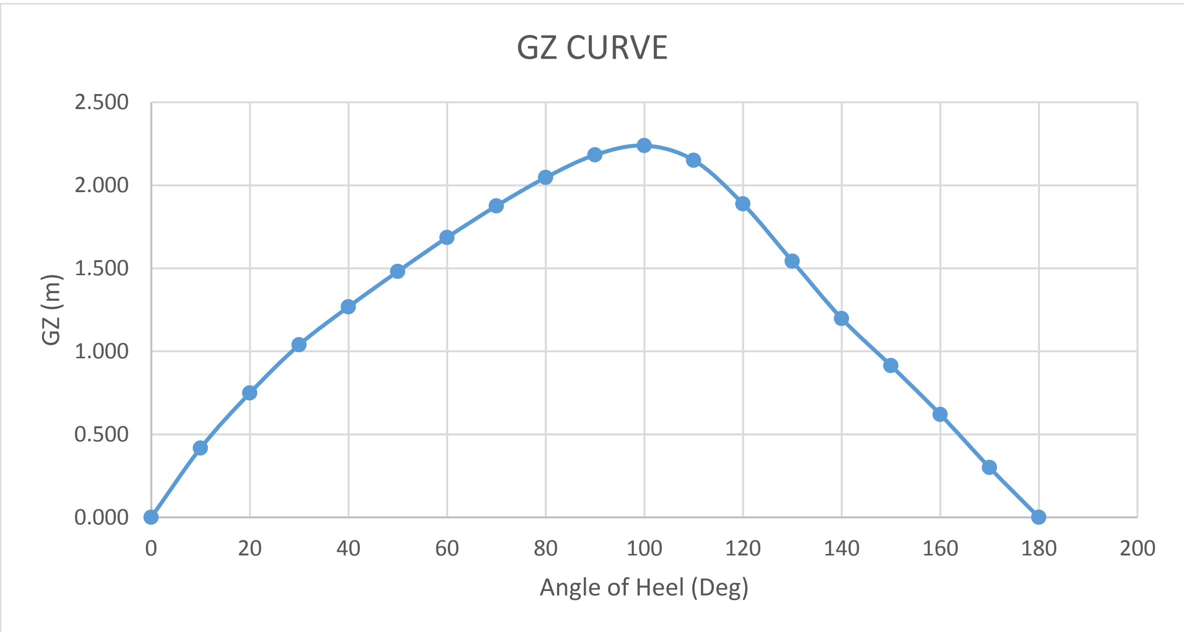


Figure 9.5 GZ Curve 18 m - 2 CENTRAL COMPARTMENT + 50% OUTRIGGER

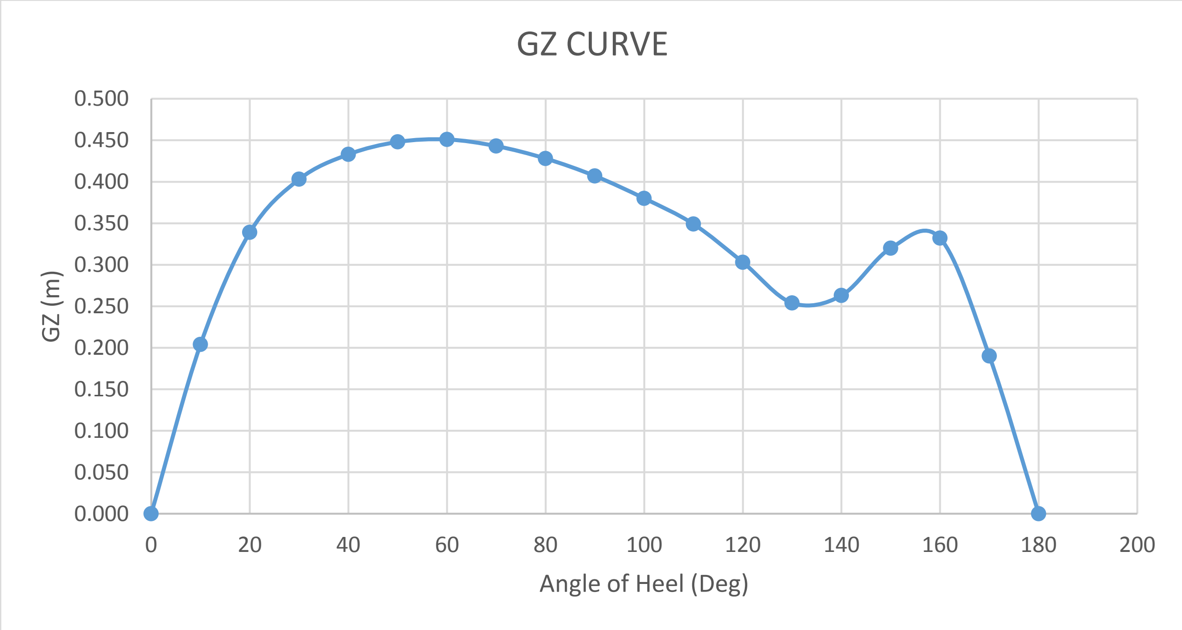


Figure 9.6 GZ Curve 21 m Loaded Hull - 2 CENTRAL COMPARTMENT + 50% OUTRIGGER

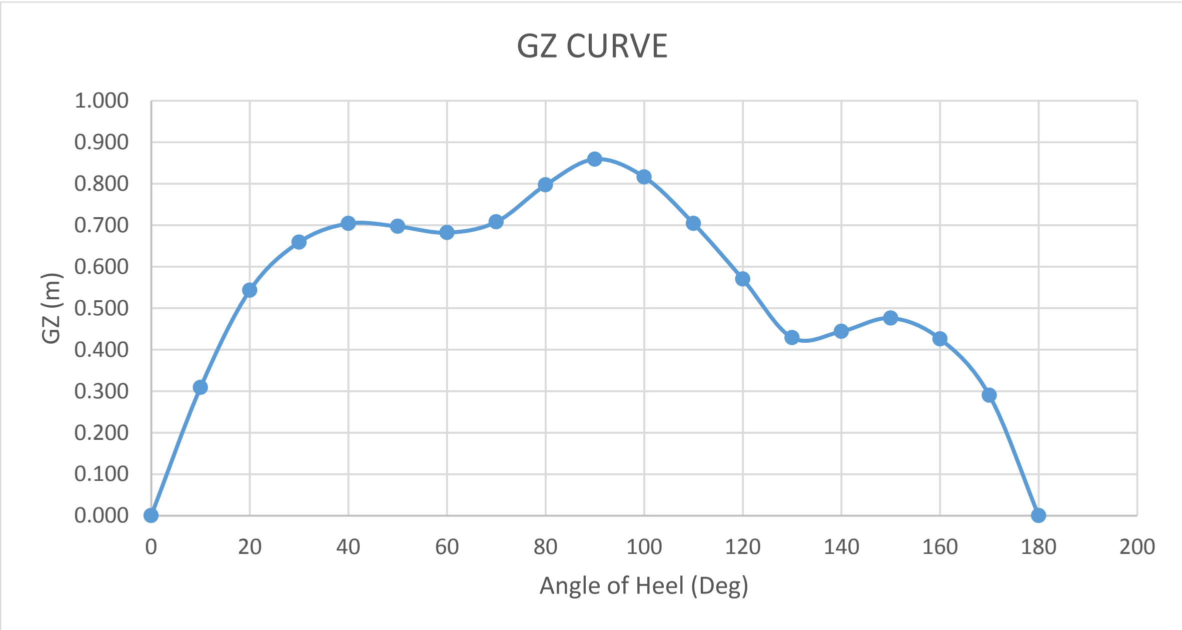


Figure 9.7 GZ Curve 24 m Loaded Hull - 2 CENTRAL COMPARTMENT + 50% OUTRIGGER

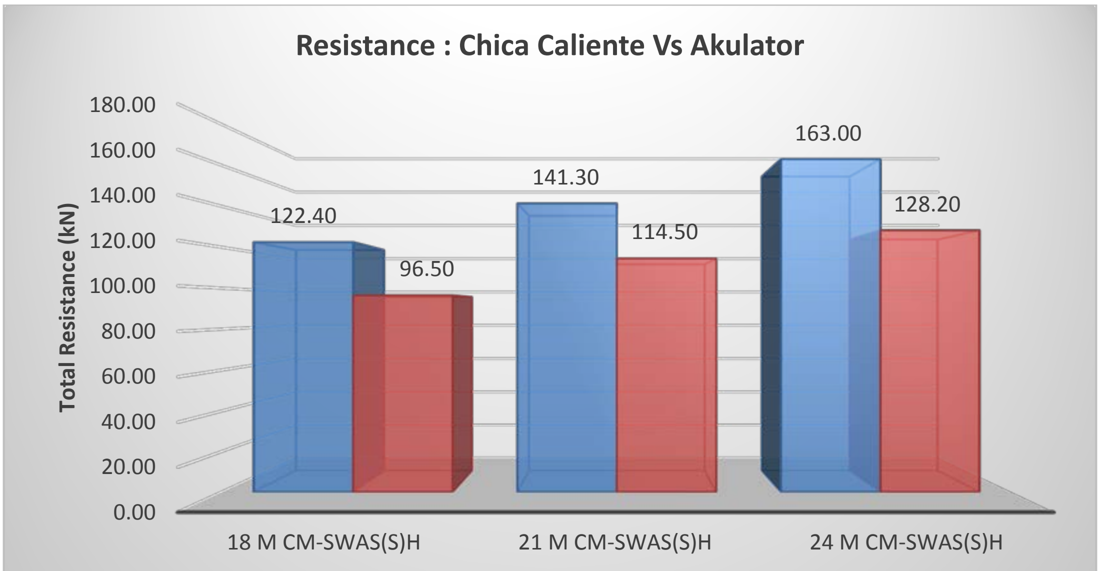
CHAPTER 10 - CONCLUISON AND SCOPE FOR IMPROVEMENT

10.1 CONCLUSION

The objective of this master thesis was to design an eco-friendly safe ship for that can be practically implemented in current market scenario. To do the author proposed use of SWAS(S)H form and then optimise the hull for resistance to reduce the power consumption to values that are comparable to currently operating trimaran. In addition to reduce the production cost the author proposed the use of modular hull, to increase the productivity and reduce production cost making the design more practical.

The design of modular hull was successfully completed in accourdance to the class rules with resistance optimisation that meets industry standards. The combined effect of tests carried out on mathematical and physical model estimate that we have a feasibility of a common modular design which can be practically implemented in current market.

After successfully validating the mathematical model for resistance with towing tank experiment, it is evaluated that the optimisation of hull has reduced the resistance in the range of 18-21% for the three hulls combined with the efficiency of advanced hybrid DE system we have also managed to reduce the total installed power in the range of 21-23%. The same can be seen in the table 10.1 and figure 10.1 and 10.2.



	18 m CM-SWAS(S)H	21 m CM-SWAS(S)H	24 m CM-SWAS(S)H
Chica-Calient	122.40	141.30	163.00
Akulator	96.50	114.50	128.20

Figure 10.1 Resistance reduction at operating speeds for the three hulls

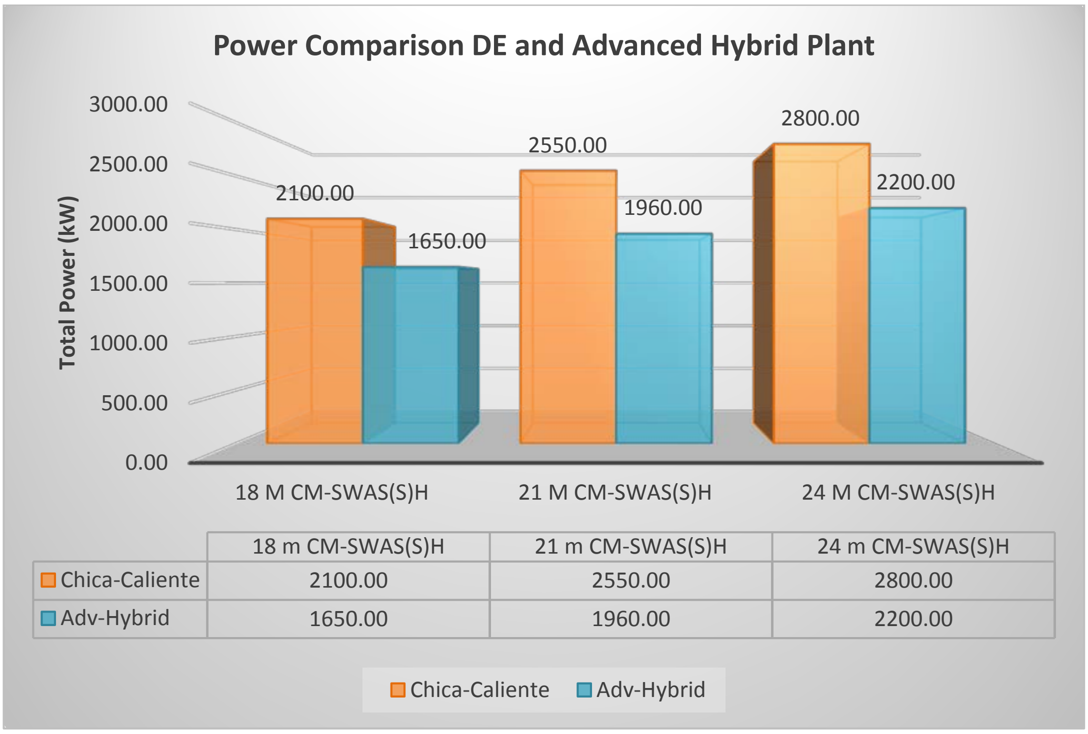


Figure 10.2 Installed power consumption reduction at operating speeds for the three hulls

RESULT COMPARISON OF BASE AND OPTIMISED HULLS							
S. NO.	HULL LOA	RESISTANCE OPTIMISATION			POWER OPTIMISATION (KW)		
		BASE (kN)	FINAL (kN)	% REDUCTION	BASE (kW)	FINAL (kW)	% REDUCTION
1	18 m	122.40	96.50	21.16	2100.00	1650.00	21.43
2	21 m	141.30	114.50	18.97	2550.00	1960.00	23.14
3	24 m	163.00	128.20	21.35	2800.00	2200.00	21.43

Table 10.1 Resistance and Power Comparison for Base and Optimised Hull

The final resolution drawn is that the design not only presents excellent stability and sea-keeping characteristics but has a resistance magnitude in the range of currently operating catamarans with a deviation of less than 9% as seen in the table 10.2.

POWER COMPARISON FOR ADVANCED HYBRID POWER PLANT			
VESSEL TYPE	Power (kW)		
	CM*	Adv-Hybrid	% Deviation
18 m CM-SWAS(S)H	1540.00	1650.00	7.14
21 m CM-SWAS(S)H		1960.00	
24 m CM-SWAS(S)H	2015.00	2200.00	9.18
*CM : DAMEN CATAMARAN : **19.7 m** : Fast Crew Supplier® 2008; **25.6 m** : Fast Crew Supplier® 2610			

Table 10.2 Power comparison of currently operating Catamarans and Akulator hulls

10.2 SCOPE FOR IMPROVEMENT

While the practical feasibility of design can be confirmed with the results obtained it is recommended to carry out the RANS based sea-keeping analysis so that an accurate prediction of rolling characteristics can be obtained. In addition it is suggested to carry out a FEM based structural analysis and optimisation to further improve structural design, is will not only reduce the cost of raw material but will also provide the designer to accommodate more owner specific features. Additionally we can also design the fin stabilisers and spray rails to more effectively reduce the resistance of the hulls, making them even more economical to operate.

CHAPTER 11 - ACKNOWLEDGEMENTS

I would first like to thank my friend Mr. Kranthi Kumar Boina, for encouraging me to join EMship. I would especially like to thank Lloyds Register Foundation for providing me the scholarship that proved to be of great assistance for supporting my studies.

While EMship is a technical study program, the effort that goes into organising oneself from the point of view of administrative works and Erasmus mobility, is enormous. Stating that it is more difficult than the studies would actually be an understatement. The author would like to thank and express his utmost gratitude towards Ms. Christine Reynders and Ms. Emna Belaid for their continued support during entire duration of this course.

Apart from EMship lectures, a great deal of learning takes place in the group work and studies that form intrinsic part of the course. I would specially like to thank Mr. Nikhil Mathew, Mr. Binoy Pilakkat and Mr. Noufal P. Najeeb for providing proper guidance at all times. Special thanks to my dearest friend Mr. Manuel Perez, who’s friendship is one of the best take away from this program.

Special thanks to Prof. Andre Hage and staff of DN&T for providing the dream internship that the author could have hoped for. The constant support, both at professional and personal level from EMship co-ordinator Prof. Philippe Rigo is greatly appreciated.

Last but not the least, the ever co-operating and encouraging thesis supervisor one could wish for, Prof. Zbigniew Sekulski. Thanks for his constant feedback on project progress and suggestions for improvement, which contributed to a large extent towards the successful completion of this master thesis.

iR. AKULA Nidarshan
akula@greenexponent.com

CHAPTER 12 - REFERENCE & BIBLIOGRAPHY

[1] Victor A. Dubrovsky, [2009]. *Multihulls: some results of development and new technical solutions*, Saint-Petersburg, Navigation and Marine Sciences 2009, RC: 629.511; 629.5.01/.08

[2] DNV-GL Rules [2012] for *Classification and Construction, 1 – Ship Technology, 3 – Special Craft, 1 – High Speed Craft*.

[3] Apostolos D. Papanikolaou, [2011].*Holistic Ship Design Optimization: Merchant and Naval Ships*, Vol 5, No 9, http://www.shipjournal.co/index.php/sst/article/view/48/182, January 21th, 2011.

[4] K.A. Hafez , A.A. El-Kot, [2012] *Comparative investigation of the stagger variation influence on the hydrodynamic interference of high speed trimaran*, Department of Naval Architecture and Marine Engineering, Faculty of Engineering, Alexandria University, Alexandria, Egypt.

[5] Vasileios Georgiadis, Kyle Miller, and Leon Faison.[2008] *Design and Assessment of a Super-High Speed, Hybrid Hydrofoil/SWATH Crew Boat, Innovative Ship Design Lab*, Massachusetts Institute of Technology.

[6] Luc Bordier [2012], *Shape optimization of a ship based on CFD simulations*, DCNS RESEARCH, STAR Global Conference 2012.

[7] *Urban buses: alternative powertrains for Europe, A fact-based analysis of the role of diesel hybrid, hydrogen fuel cell, trolley and battery electric powertrains, McKinsey & Company*[2011]

[8] Brizzolara S, [2011]. *Hydrodynamic Design and Assessment by CFD Methods of a Hybrid Hydrofoil / SWATH hull for a Super High Speed* USV. ONRG-N62909-10-1-7116 final report, Office of Naval Research Global, US Navy.

[9] Brizzolara S, [2004] *Parametric Optimization of SWAT-Hull Forms by a Viscous-Inviscid Free Surface Method Driven by a Differential Evolution Algorithm.* Proceedings 25th Symposium on Naval Hydrodynamics, St. John‟s, Newfoundland and Labrador, vol. V, 47-64.

[10] Hoerner, S.F, [1992] *Fluid-Dynamic Drag*. Great Britain: L.A. Hoerner.

[11] Brizzolara S, [2013]. *Super-cavitating (SC) Surface-Piercing (SP) Hydrofoils: Design and Optimization Methods*. ONRG-N62909-11-1-7007 final report. Office of Naval Research Global, US Navy.

[12] Vernengo G., Brizzolara S. [2012]. *A Reformulated Lifting Line Theory for Supercavitating Hydrofoil Design.* Proceedings of the Eighth International

Symposium on Cavitation (CAV 2012). Research Publishing Services. ISBN: 978-981-07-2826-7, doi:10.3850/978-981-07-2826-7 281.

[13] Kuiper, G. [1992]: *"The Wageningen Propeller Series", Wageningen*, The Netherlands: Maritime Research Institute Netherlands, Nº. 92-001

[14] J. P. Ghose and R. P. Gokarn [2004] *"Basic Ship Propulsion"*, Allied Publishers Pvt. Limited, 1st Edition, pp. 1-564

[15] Man Diesel and Turbo [2012]: *"Basic principles of ship propulsion"*, Man Diesel and Turbo, pp. 1-45

[16] H. W. Lerbs, L. C. Burrill, J. D. Van Manen, L. Mazarredo, A. Silverleaf, M. S. Plesset, H. B. Lindgren and R. Brard [1960], *"Propeller cavitation committee report"*, pp. 1-467

[17] Bernitsas, M. M., Ray, D. and Kinley, P. [1981] *"KT, KQ and Efficiency Curves for the Wageningen B-Series Propellers"*, Department of Naval Architecture amd Marine Engineering, College of Engineering, The University of Michingan Ann Arbor, Michigan 48109, USA, Nº. 237 May 1981, pp 1-102

[18] D. G. M. Watson [1998]: *"Pratical Ship Design", Elsevier Ocean Engineering Book* Series, Vol. 1, Elsevier Science Ltd., pp. 1-536

[19] Kari Valkeejärvi [2006] *"The Ship's Electrical Network, Engine Control and Automation"*, Marine Technology, Wärtsilä Corporation

[20] Apostolos Papanikolaou [2014] *"Ship Design – Methodologies of Preliminary Design"*, Springer Dordrecht Heidelberg New York London, 1st Edition, pp. 1-628

[21] MTU [2015] *"Marine Power Products Guide"*, Catalogue for Propulsion Engine, June 2015

[22] Molland, A. F., Turnock, S. R. and Hudson, D. A. [2011] *"Ship Resistance and Propulsion – Pratical Estimation of Propulsive Power"*, Cambridge University Press, 1st Edition, pp 1-568

[23] Sahoo, P. K. [2014] *"Propulsion of Ships"*, EMShip Université de Liége and Florida Institute of Technology College of Engineering Department of Marine and Enviromental Systems, pp 96-186

[24] A. Olivieri, F. Pistano, A. Avanzini and F. Stern [2001] *"Towing Tank Experiments of Resistance, Sinkage and Trim, Boundary Layer, Wake, and Free Surface low Around a Naval Combatant Insean 2340 Model"*, IIHR Technical Report Nº 421, pp. 1-43

[25] M. Gad-el-Hak [1987]: *"The Water Towing Tank as an Experimental Facility – An Overview"*, Experiments in Fluids, Vol. 5, pp. 289-297

ANNEXURES

ANNEX – 1

GENERAL SPECIFICATIONS OF ALL VESSELS

GENERAL SPECIFICATION – 18 m PILOT / PATROL/CUSTOM BOAT			
GENERAL		**DECK LAYOUT**	
HULL MATERIAL	Aluminium 5083, H116	ANCHOR EQUIPMENT	1 x 60 kg HHP with chain and line
SUPERSTRUCTURE	Aluminium 5083, H116	FENDERING	Rubber "D" type and heavy duty foam filled
BASIC FUNCION	Crew and Pilot/Custom/Patrol Duties	DECK CRANE / WINCH	Aft Winch 0.5 T @ 2 m
CLASSIFICATION RULES	DNV - GL 100 A5 HSDE RAS (200), Transfer Vessel + MC AUT	MOB RECOVERY SYSTEM	Electrically operated elevation platform
DIMENSIONS		**LIFE SAVING EQUIPMENT**	
LENGTH O.A.	18.0 m	LIFE BUOY	4
LENGTH W.L.	13.0 m	LIFE JACKETS	8
BEAM O.A.	9.50 m	LIFE RAFT	1 x 16
DEPTH	5.75 m	FIRE EXTINGUISHER	Hand fire extinguishers Fixed Fi-Fi system
DRAUGHT	3.20 m	EPIRB + SART	-
CAPACITIES		**AUXILLIARY EQUIPMENT**	
FUEL OIL	5 tonne	ENGINE ROOM VENTILATION	6380 m3/hr in engine room
FUEL OIL TRIM TANK	5 tonne	GENERAL SERVICE PUMP	Electrically driven, 400V, Azcue CA 50
LUBE OIL	1 tonne		
FRESH WATER	1.2 tonne	**ACCOMMODATION**	
WASTE WATER	0.8 tonne	LOUNGE / GALLEY	6 People
CREW	2	TOILETS	2
INDUSTRIAL PERSONNEL	6	SEATING AREA	6
		CABINS	-
PERFORMANCE		AIR CONDITIONING	49000 BTU
SERVICE SPEED	20 Knots		
MAX. RANGE	700 nm at Max Speed	**NAUTICAL AND COMMUNICATION**	
		SEARCH LIGHT	1x 1000W 230V
DIESEL ELECTRIC SYSTEM		COMPASS	Magnetic
PROPULSION	1 x MTU 1490 kW	ECHO SOUNDER	
TOTAL POWER	1790 kW	VHF + VHF HAND HELD	
PROPELLER	Fixed Pitch 5 Blade 2.0 D	RADAR + GPS + NAVTEX	
BOW THRUSTER	1 x 48 kW	AIS + MF/HF	
ELECTRICAL NETWORK	24V d.c. 230V/400V 50 Hz a.c.	IMMERSAT / V-SAT WIFI SYSTEM + CCTV	
EMERGENCY BATTERY	68 kVA		

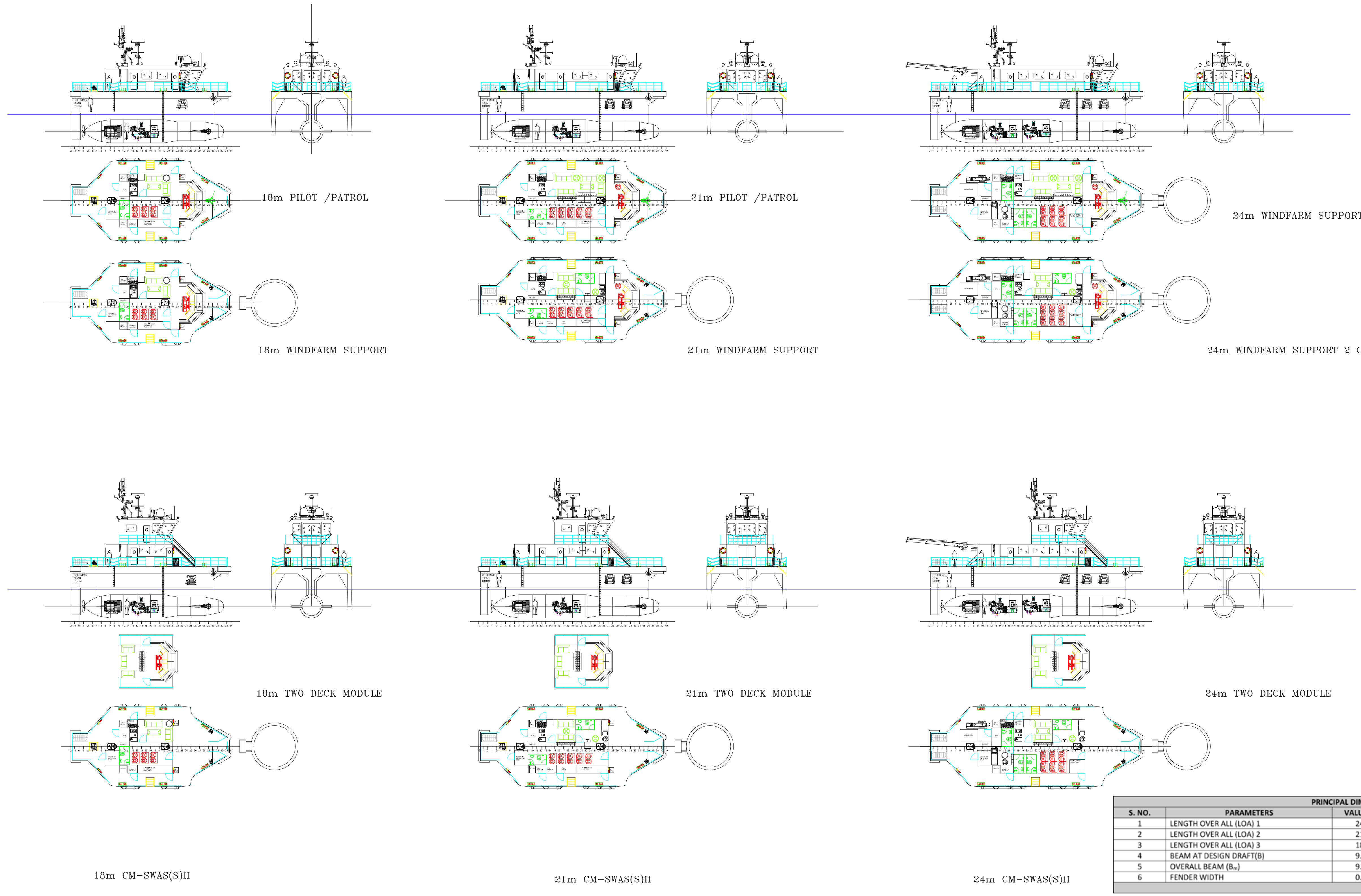
GENERAL SPECIFICATION – 18 m WINDFARM SUPPORT VESSEL			
GENERAL		**DECK LAYOUT**	
HULL MATERIAL	Aluminium 5083, H116	ANCHOR EQUIPMENT	2 x 60 kg HHP with chain and line
SUPERSTRUCTURE	Aluminium 5083, H116	FENDERING	Rubber "D" type and heavy duty foam filled
BASIC FUNCION	Crew, Personnel And Cargo Duties	DECK CRANE / WINCH	Aft Winch 0.5 T @ 2 m
CLASSIFICATION RULES	DNV - GL 100 A5 HSDE RAS (200), Transfer Vessel + MC AUT	MOB RECOVERY SYSTEM	Electrically operated elevation platform
DIMENSIONS		**LIFE SAVING EQUIPMENT**	
LENGTH O.A.	18.0 m	LIFE BUOY	4
LENGTH W.L.	13.0 m	LIFE JACKETS	8
BEAM O.A.	9.50 m	LIFE RAFT	1 x 16
DEPTH	5.75 m	FIRE EXTINGUISHER	Hand fire extinguishers Fixed Fi-Fi system
DRAUGHT	3.20 m	EPIRB + SART	2
CAPACITIES		**AUXILLIARY EQUIPMENT**	
FUEL OIL	7 tonne	ENGINE ROOM VENTILATION	6380 m3/hr in engine room
FUEL OIL TRIM TANK	5 tonne	GENERAL SERVICE PUMP	Electrically driven, 400V, Azcue CA 50
LUBE OIL	1 tonne		
FRESH WATER	1.2 tonne	**ACCOMMODATION**	
WASTE WATER	0.8 tonne	LOUNGE / GALLEY	6 People
CREW	2	TOILETS	2
INDUSTRIAL PERSONNEL	6	SEATING AREA	6
		CABINS	-
PERFORMANCE		AIR CONDITIONING	49000 BTU
SERVICE SPEED	20 Knots		
MAX. RANGE	700 nm at Max Speed	**NAUTICAL AND COMMUNICATION**	
		SEARCH LIGHT	1x 1000W 230V
DIESEL ELECTRIC SYSTEM		COMPASS	Magnetic
PROPULSION	1 x MTU 1490 kW	ECHO SOUNDER	
TOTAL POWER	1790 kW	VHF + VHF HAND HELD	
PROPELLER	Fixed Pitch XX Blade XX D	RADAR + GPS + NAVTEX	
BOW THRUSTER	1 x 48 kW	AIS + MF/HF	
ELECTRICAL NETWORK	24V d.c. 230V/400V 50 Hz a.c.	IMMERSAT / V-SAT WIFI SYSTEM + CCTV	
EMERGENCY BATTERY	68 kVA		

GENERAL SPECIFICATION – 21 m PILOT / PATROL/CUSTOM BOAT			
GENERAL		**DECK LAYOUT**	
HULL MATERIAL	Aluminium 5083, H116	ANCHOR EQUIPMENT	1 x 67 kg HHP with chain and line
SUPERSTRUCTURE	Aluminium 5083, H116	FENDERING	Rubber "D" type and heavy duty foam filled
BASIC FUNCION	Crew and Pilot/Custom/Patrol Duties	DECK CRANE / WINCH	Aft Winch 0.5 T @ 2 m
CLASSIFICATION RULES	DNV - GL 100 A5 HSDE RAS (200), Transfer Vessel + MC AUT	MOB RECOVERY SYSTEM	Electrically operated elevation platform
DIMENSIONS		**LIFE SAVING EQUIPMENT**	
LENGTH O.A.	21.0 m	LIFE BUOY	4
LENGTH W.L.	16.0 m	LIFE JACKETS	15
BEAM O.A.	9.50 m	LIFE RAFT	1 x 16
DEPTH	5.75 m	FIRE EXTINGUISHER	Hand fire extinguishers Fixed Fi-Fi system
DRAUGHT	3.20 m	EPIRB + SART	-
CAPACITIES		**AUXILLIARY EQUIPMENT**	
FUEL OIL	9 tonne	ENGINE ROOM VENTILATION	9560 m3/hr in engine room
FUEL OIL TRIM TANK	5 tonne	GENERAL SERVICE PUMP	Electrically driven, 400V, Azcue CA 50
LUBE OIL	1.5 tonne		
FRESH WATER	1.2 tonne	**ACCOMMODATION**	
WASTE WATER	0.8 tonne	LOUNGE / GALLEY	10 People
CREW	2	TOILETS	1
INDUSTRIAL PERSONNEL	6	SEATING AREA	10
		CABINS	-
PERFORMANCE		AIR CONDITIONING	55000 BTU
SERVICE SPEED	20 Knots		
MAX. RANGE	700 nm at Max Speed	**NAUTICAL AND COMMUNICATION**	
		SEARCH LIGHT	1x 1000W 230V
DIESEL ELECTRIC SYSTEM		COMPASS	Magnetic
PROPULSION	1 x MTU 1839 kW	ECHO SOUNDER	
TOTAL POWER	1960 kW	VHF + VHF HAND HELD	
PROPELLER	Fixed Pitch 5 Blade 2.0 D	RADAR + GPS + NAVTEX	
BOW THRUSTER	1 x 48 kW	AIS + MF/HF	
ELECTRICAL NETWORK	24V d.c. 230V/400V 50 Hz a.c.	IMMERSAT / V-SAT WIFI SYSTEM + CCTV	
EMERGENCY BATTERY	68 kVA		

GENERAL SPECIFICATION – 21 m WINDFARM SUPPORT VESSEL			
GENERAL		**DECK LAYOUT**	
HULL MATERIAL	Aluminium 5083, H116	ANCHOR EQUIPMENT	2 x 67 kg HHP with chain and line
SUPERSTRUCTURE	Aluminium 5083, H116	FENDERING	Rubber "D" type and heavy duty foam filled
BASIC FUNCION	Crew, Personnel And Cargo Duties	DECK CRANE / WINCH	Aft Winch 0.5 T @ 2 m
CLASSIFICATION RULES	DNV - GL 100 A5 HSDE RAS (200), Transfer Vessel + MC AUT	MOB RECOVERY SYSTEM	Electrically operated elevation platform
DIMENSIONS		**LIFE SAVING EQUIPMENT**	
LENGTH O.A.	21.0 m	LIFE BUOY	4
LENGTH W.L.	16.0 m	LIFE JACKETS	15
BEAM O.A.	9.50 m	LIFE RAFT	1 x 16
DEPTH	5.75 m	FIRE EXTINGUISHER	Hand fire extinguishers Fixed Fi-Fi system
DRAUGHT	3.20 m	EPIRB + SART	2
CAPACITIES		**AUXILLIARY EQUIPMENT**	
FUEL OIL	10 tonne	ENGINE ROOM VENTILATION	9560 m3/hr in engine room
FUEL OIL TRIM TANK	5 tonne	GENERAL SERVICE PUMP	Electrically driven, 400V, Azcue CA 50
LUBE OIL	1.5 tonne		
FRESH WATER	1.2 tonne	**ACCOMMODATION**	
WASTE WATER	0.8 tonne	LOUNGE / GALLEY	10 People
CREW	3	TOILETS	1
INDUSTRIAL PERSONNEL	10	SEATING AREA	10
		CABINS	-
PERFORMANCE		AIR CONDITIONING	55000 BTU
SERVICE SPEED	20 Knots		
MAX. RANGE	700 nm at Max Speed	**NAUTICAL AND COMMUNICATION**	
		SEARCH LIGHT	1x 1000W 230V
DIESEL ELECTRIC SYSTEM		COMPASS	Magnetic
PROPULSION	1 x MTU 1839 kW	ECHO SOUNDER	
TOTAL POWER	1960 kW	VHF + VHF HAND HELD	
PROPELLER	Fixed Pitch 5 Blade 2.0 D	RADAR + GPS + NAVTEX	
BOW THRUSTER	1 x 48 kW	AIS + MF/HF	
ELECTRICAL NETWORK	24V d.c. 230V/400V 50 Hz a.c.	IMMERSAT / V-SAT WIFI SYSTEM + CCTV	
EMERGENCY BATTERY	68 kVA		

GENERAL SPECIFICATION – 24 m WINDFARM SUPPORT VESSEL			
GENERAL		**DECK LAYOUT**	
HULL MATERIAL	Aluminium 5083, H116	ANCHOR EQUIPMENT	2 x 67 kg HHP with chain and line
SUPERSTRUCTURE	Aluminium 5083, H116	FENDERING	Rubber "D" type and heavy duty foam filled
BASIC FUNCION	Crew, Personnel And Cargo Duties	DECK CRANE / WINCH	Deck Crane Heila HLM 20-2S
CLASSIFICATION RULES	DNV - GL 100 A5 HSDE RAS (200), Transfer Vessel + MC AUT	MOB RECOVERY SYSTEM	Electrically operated elevation platform
DIMENSIONS		**LIFE SAVING EQUIPMENT**	
LENGTH O.A.	24.0 m	LIFE BUOY	4
LENGTH W.L.	19.0 m	LIFE JACKETS	16
BEAM O.A.	9.50 m	LIFE RAFT	2 x 16
DEPTH	5.75 m	FIRE EXTINGUISHER	Hand fire extinguishers Fixed Fi-Fi system
DRAUGHT	3.20 m	EPIRB + SART	2
CAPACITIES		**AUXILLIARY EQUIPMENT**	
FUEL OIL	12 tonne	ENGINE ROOM VENTILATION	12000 m3/hr in engine room
FUEL OIL TRIM TANK	5 tonne	GENERAL SERVICE PUMP	Electrically driven, 400V, Azcue CA 50
LUBE OIL	2 tonne		
FRESH WATER	1.2 tonne	**ACCOMMODATION**	
WASTE WATER	0.8 tonne	LOUNGE / GALLEY	12 People
CREW	3	TOILETS	2
INDUSTRIAL PERSONNEL	12	SEATING AREA	12
		CABINS	1
PERFORMANCE		AIR CONDITIONING	60000 BTU
SERVICE SPEED	20 Knots		
MAX. RANGE	700 nm at Max Speed	**NAUTICAL AND COMMUNICATION**	
		SEARCH LIGHT	2x 1000W 230V
DIESEL ELECTRIC SYSTEM		COMPASS	Magnetic
PROPULSION	2 x MTU 1020 kW	ECHO SOUNDER	
TOTAL POWER	2200 kW	VHF + VHF HAND HELD	
PROPELLER	Fixed Pitch 5 Blade 2.0 D	RADAR + GPS + NAVTEX	
BOW THRUSTER	1 x 48 kW	AIS + MF/HF	
ELECTRICAL NETWORK	24V d.c. 230V/400V 50 Hz a.c.	IMMERSAT / V-SAT WIFI SYSTEM + CCTV	
EMERGENCY BATTERY	68 kVA		

GENERAL SPECIFICATION – 24 m WINDFARM SUPPORT VESSEL (With Capt. Cabin)			
GENERAL		**DECK LAYOUT**	
HULL MATERIAL	Aluminium 5083, H116	ANCHOR EQUIPMENT	2 x 67 kg HHP with chain and line
SUPERSTRUCTURE	Aluminium 5083, H116	FENDERING	Rubber "D" type and heavy duty foam filled
BASIC FUNCION	Crew, Personnel And Cargo Duties	DECK CRANE / WINCH	Deck Crane Heila HLM 20-2S
CLASSIFICATION RULES	DNV - GL 100 A5 HSDE RAS (200), Transfer Vessel + MC AUT	MOB RECOVERY SYSTEM	Electrically operated elevation platform
DIMENSIONS		**LIFE SAVING EQUIPMENT**	
LENGTH O.A.	24.0 m	LIFE BUOY	4
LENGTH W.L.	19.0 m	LIFE JACKETS	16
BEAM O.A.	9.50 m	LIFE RAFT	2 x 16
DEPTH	5.75 m	FIRE EXTINGUISHER	Hand fire extinguishers Fixed Fi-Fi system
DRAUGHT	3.20 m	EPIRB + SART	2
CAPACITIES		**AUXILLIARY EQUIPMENT**	
FUEL OIL	12 tonne	ENGINE ROOM VENTILATION	12000 m3/hr in engine room
FUEL OIL TRIM TANK	5 tonne	GENERAL SERVICE PUMP	Electrically driven, 400V, Azcue CA 50
LUBE OIL	2 tonne		
FRESH WATER	1.2 tonne	**ACCOMMODATION**	
WASTE WATER	0.8 tonne	LOUNGE / GALLEY	12 People
CREW	3	TOILETS	2
INDUSTRIAL PERSONNEL	12	SEATING AREA	12
		CABINS	2
PERFORMANCE		AIR CONDITIONING	60000 BTU
SERVICE SPEED	20 Knots		
MAX. RANGE	700 nm at Max Speed	**NAUTICAL AND COMMUNICATION**	
		SEARCH LIGHT	2x 1000W 230V
DIESEL ELECTRIC SYSTEM		COMPASS	Magnetic
PROPULSION	2 x MTU 1020 kW	ECHO SOUNDER	
TOTAL POWER	2200 kW	VHF + VHF HAND HELD	
PROPELLER	Fixed Pitch 5 Blade 2.0 D	RADAR + GPS + NAVTEX	
BOW THRUSTER	1 x 48 kW	AIS + MF/HF	
ELECTRICAL NETWORK	24V d.c. 230V/400V 50 Hz a.c.	IMMERSAT / V-SAT WIFI SYSTEM + CCTV	
EMERGENCY BATTERY	68 kVA		



PRINCIPAL DIMENSIONS OF PROPOSED HULLS

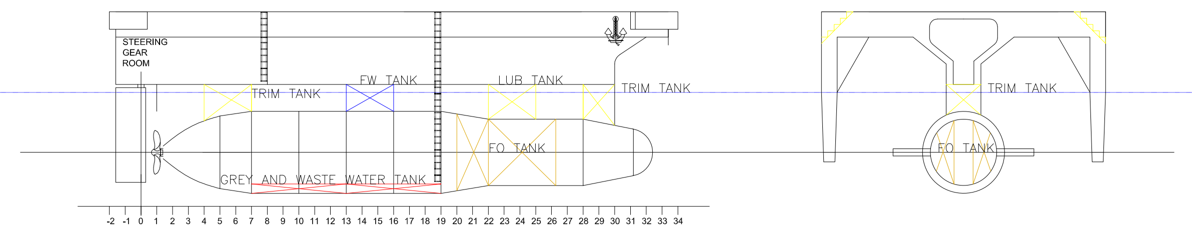
S. NO.	PARAMETERS	VALUE (m)	S. NO.	PARAMETER	VALUE (m)
1	LENGTH OVER ALL (LOA) 1	24.0	7	MAX. OUTRIGGER WIDTH	0.50
2	LENGTH OVER ALL (LOA) 2	21.0	8	MIN. OUTRIGGER WIDTH	0.35
3	LENGTH OVER ALL (LOA) 3	18.0	9	DESIGN DRAFT (T)	3.2
4	BEAM AT DESIGN DRAFT(B)	9.00	10	LIGHT SHIP DRAFT (T')	2.1
5	OVERALL BEAM (B_m)	9.50	11	DEPTH (D)	5.75
6	FENDER WIDTH	0.25	12	MAX TUBE DIAMETER	2.6

NOTE – To view the technical specifications of each of the vessels please refer the General Specification Sheets

Tel. : +32– 497677494 (BELGIUM)
Tel. : +91– 9716025852 (INDIA)
akula@greenexponent.com
www.greenexponent.com

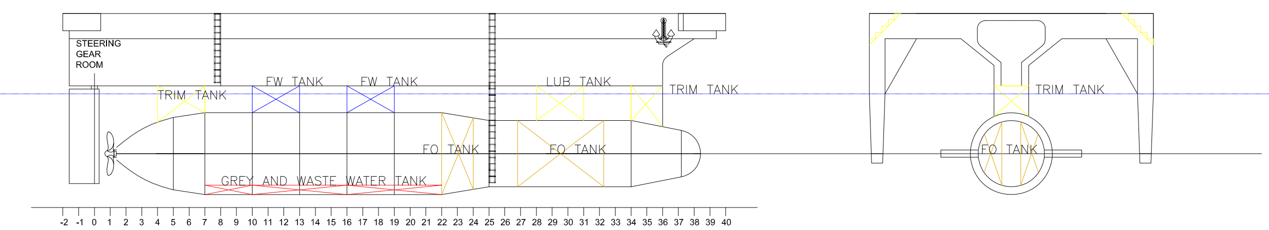
AKULA NIDARSHAN
MARINE ENGINEER AND NAVAL ARCHITECT

VESSEL NAME	AKULATOR	VESSEL TYPE	CM – SWAS(S)H PILOT / WSV		
TITLE	GENERAL ARRANGEMENT				
SCALE	DRAWN: AKULA N.	APPROVALS	YARD NUMBER	DRAWING NUMBER: CMS – 1	NIL
	TRACED: AKULA N.	OWNER			
	CHECKED	MMD			
	SEC. HEAD	CLASS	DATE :	SHEET:–	REV



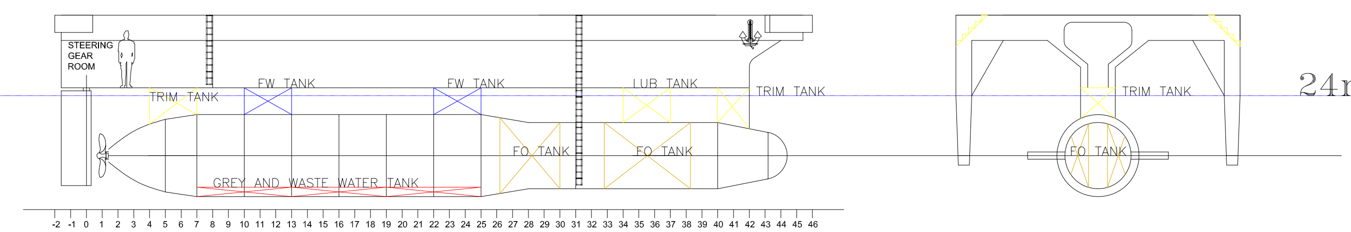
18m CM–SWAS(S)H

18 m – TANK VOLUMES			
FO TANK		FW TANK	
TRIM TANK		LO TANK	
GW TANK		WW TANK	



21m CM–SWAS(S)H

21 m – TANK VOLUMES			
FO TANK		FW TANK	
TRIM TANK		LO TANK	
GW TANK		WW TANK	



24m CM–SWAS(S)H

24 m – TANK VOLUMES			
FO TANK		FW TANK	
TRIM TANK		LO TANK	
GW TANK		WW TANK	

NOTE - To view the Tank Capacities of each of the vessels please refer the General Specification Sheets

Tel. : +32– 497677494 (BELGIUM)
Tel. : +91– 9716025852 (INDIA)
akula@greenexponent.com
www.greenexponent.com

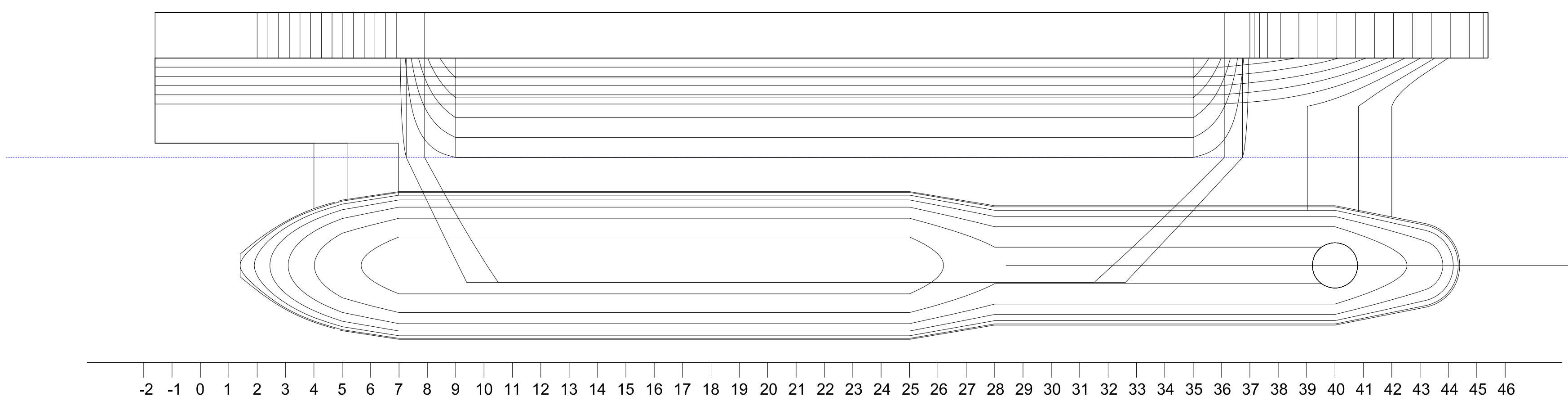
AKULA NIDARSHAN
MARINE ENGINEER AND NAVAL ARCHITECT

VESSEL NAME: AKULATOR

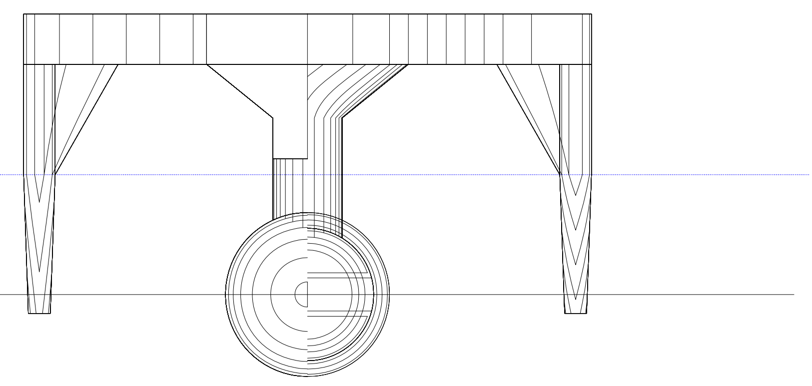
VESSEL TYPE: CM – SWAS(S)H PILOT / WSV

TITLE: TANK PLAN

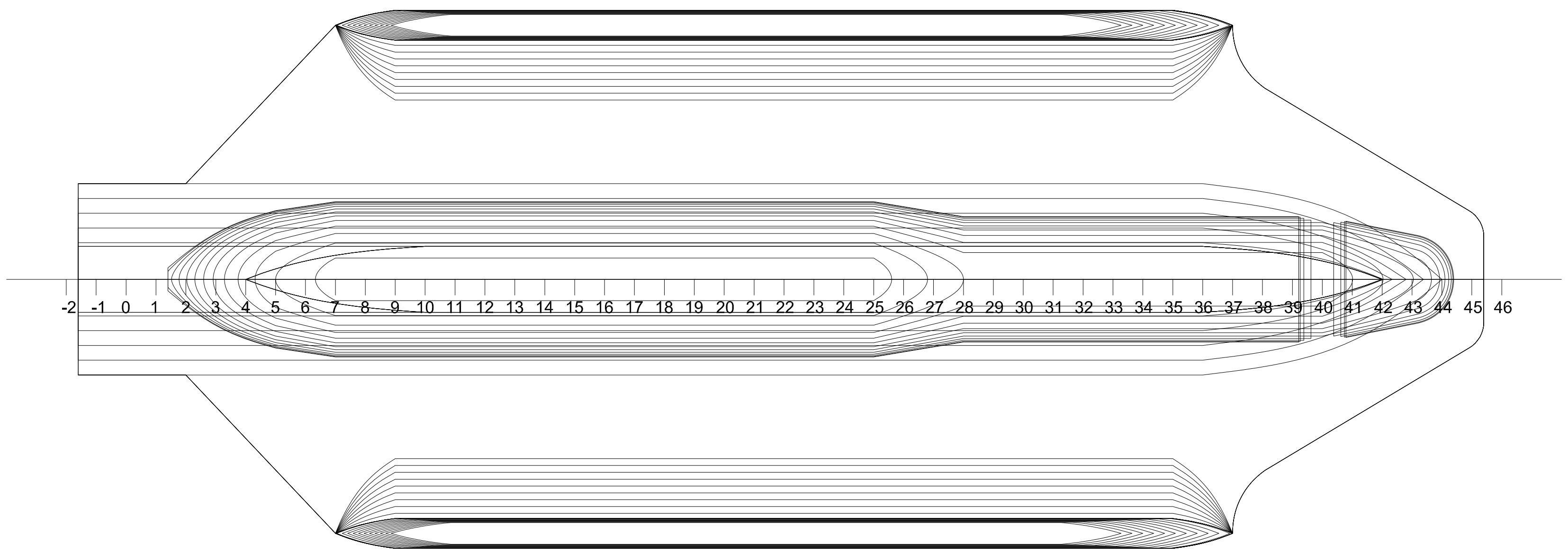
SCALE			APPROVALS		YARD NUMBER	DRAWING NUMBER	
	DRAWN	AKULA N.				CMS – 2	NIL
	TRACED	AKULA N.	OWNER				
	CHECKED		MMD				
	SEC. HEAD		CLASS		DATE :	SHEET:–	REV



SECTIONS



BUTTOCK LINES



WATER LINES

Tel. : +32- 497677494 (BELGIUM)
Tel. : +91- 9716025852 (INDIA)
akula@greenexponent.com
www.greenexponent.com

AKULA NIDARSHAN
MARINE ENGINEER AND NAVAL ARCHITECT

VESSEL NAME: AKULATOR	VESSEL TYPE: CM – SWAS(S)H PILOT / WSV		
TITLE: LINES PLAN 24m CM-SWAS(S)H			
SCALE	DRAWN: AKULA N. / TRACED: AKULA N. / CHECKED / SEC. HEAD	APPROVALS: OWNER / MMD / CLASS	YARD NUMBER / DATE :
DRAWING NUMBER: CMS – 3	SHEET:–	REV: NIL	

ANNEX – 2
STRUCTURES

CLASSIFICATION RULES - DNV-GL HSC 2012

CLASS NOTATION

✠ 100 A5 HSDE RSA (200) "Transfer Vessel"

✠ MC AUT

In GL rules the notation above is divided into following representations:	
✠	The Maltese Cross means Hull, machinery and/or special equipment (e.g. refrigerating installation) have been constructed :under the supervision of and in accordance with the Rules of DNV-GL at the shipyard and/or at subcontractors supplying construction components/hull sections – with certification by DNV-GL of components and materials requiring inspection, subject to the DNV-GL Construction Rules As for example, hull, which has been constructed under supervision as stated in 2.3, and for which proof of subdivision and damage stability has been furnished, one of the two markings, shown on the left are assigned.
100 A5	The ship's hull fully complies with the requirements of the Construction Rules of DNV-GL or other rules considered to be equivalent.
HSDE	Notation for craft which have been constructed by using elements of Part 3 – Special Craft, Chapter 1 – High Speed Craft and which are not subject to the IMO HSC Code. Details regarding rule application are specified in the Class Certificate.
RSA (200)	this area of service is restricted, in general, to trade along the coast, provided that the distance to the nearest port of refuge as well as the offshore distance do not exceed 200 nautical miles. This applies also to trade in the North Sea and within enclosed seas, such as the Mediterranean, the Black Sea and waters with similar seaway conditions. Trade to Iceland, Spitsbergen and the Azores is exempted.
MC	MC means that the machinery including electrical installations complies with the requirements of the Construction Rules of DNV-GL or other rules considered to be equivalent.
AUT	The machinery installation is fitted with equipment for unattended machinery spaces, so that it does not require to be operated and/ or maintained for periods of at least 24 hours.

CLASSIFICATION RULES - DNV-GL HSC 2012

CLASS NOTATION
✠ 100 A5 HSDE RSA (200) "Transfer Vessel"
✠ MC AUT

BASIC PARTICULARS				
S. No.	**PARTICULARS**	**SYMBOL**	**VALUE**	**UNITS**
1	Length Over All	Loa	24	m
2	Length b/w Perpendiculars	Lbp	21	m
3	Length at Waterline	Lwl	19	m
4	Depth	D	5.75	m
5	Draft Amidships	T	3.2	m
6	Immersed depth	d	3.2	m
7	Beam Overall	Boa	9.5	m
8	Beam max extents on WL	Bwl	9	m
9	Block coeff. (Cb)	Cb	0.848	
10	Speed	Vs	20	Knots
11	Speed	Vs	10.28	m/s
12	Displacement (Volume)	∇	118.5	m3
13	Displacement (Mass)	Δ	121.4625	Tonne
14	Applicability of GL-HSC Rule		**TRUE**	
15	Longitudinal CG	LCG	11.1	m
16	Vertical CG	VCG	2.1	m
17	Waterplane Area	Awp	27.7	m2
18	Operational H1/3	Hs	2	m

NOTES	
I Part 3	
Chapter 1	
C 1.4.63	“Small waterplane area twin hull” (SWATH) is a craft for which the weight is substantially supported by a submerged twin hull connected to the emerging part of the craft by struts with a small waterplane area.
Section 2	Buoyancy, Stability and Subdivision
C 2.1.6	Model or full-scale tests and/or calculations (as appropriate) shall also include consideration of the following known stability hazards to which highspeed craft are known to be liable, according to craft type:
C 2.1.6.1	directional instability, which is often coupled to roll and pitch instabilities;
C 2.1.6.2	broaching and bow diving in following seas at speeds near to wave speed, applicable to most types;
C 2.1.6.8	pitch instability of SWATH (small waterplane area twin hull) craft due to the hydrodynamic moment developed as a result of the water flow over the submerged lower hulls;

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 2
BUOYANCY, STABILITY AND SUBDIVISION

FRAME SPACING & COLLISION BULKHEAD (CB)

24 m - CM-SWAS(S)H				
S. No.	**PARTICULAR**	**FORMULA**	**VALUE**	**UNITS**
1	Frame Spacing	1.2*(0.35+0.005L)	0.534	m
2	CB Min Dist. From FP	0.05 L	0.95	m
3	CB Max Dist. From FP	0.05 L +3	3.95	m

21 m - CM-SWAS(S)H				
S. No.	**PARTICULAR**	**FORMULA**	**VALUE**	**UNITS**
1	Frame Spacing	1.2*(0.35+0.005L)	0.516	m
2	CB Min Dist. From FP	0.05 L	0.8	m
3	CB Max Dist. From FP	0.05 L +3	3.8	m

18 m - CM-SWAS(S)H				
S. No.	**PARTICULAR**	**FORMULA**	**VALUE**	**UNITS**
1	Frame Spacing	1.2*(0.35+0.005L)	0.498	m
2	CB Min Dist. From FP	0.05 L	0.65	m
3	CB Max Dist. From FP	0.05 L +3	3.65	m

APPROXIMATE FRAME SPACING

To initiate the design a conservative approach is followed to fix the frame spacing. This rule to approximate the frame spacing is taken from DNV-GL Rules High Speed Crafts: Yacht and Boats less than 24 m, Part 3, Section 1, Chapter 3, Hull Structure B. Glass Fibre Reinforced Plastic Hulls, 5.8. In practical scenario also, for aluminium hulls the frame spacing is not more than 500 mm. We could have taken any other value (let's say 380-450mm) also, all it will do is change the structural calculation with plate thickness and scantlings to match the required Section modulus based on the calculated bending moment and shear force. As we intended to do structural optimisation we took this as a starting reference.

NOTES	
C 2.1.8	At least the following watertight bulkheads are to be fitted in all craft: − one collision bulkhead, − one afterpeak bulkhead, − one bulkhead at each end of the machinery space.
C 2.6.2	For the purpose of making damage stability calculations, the volume and surface permeabilities shall be, in general, as follows:

SPACE	PERMEABILITY	REMARKS
Appropriate to cargo or stores	60	
Occupied by Accomodation	95	
Occupied by Machinery	85	
Intended for Liquids	0 or 95	
Appropriate to cargo vehicles	90	
Void Spaces	95	

C 2.6.4	The Administration may permit the use of low-density foam or other media to provide buoyancy in void spaces, provided that satisfactory evidence is provided that any such proposed medium is the most suitable alternative and is:
C 2.6.4.1	of closed-cell form if foam, or otherwise impervious to water absorption;
C 2.6.4.2	structurally stable under service conditions;
C 2.6.4.3	chemically inert in relation to structural materials with which it is in contact or other substances with which the medium is likely to be in contact (reference is made to 7.4.3.7); and
C 2.6.4.4	properly secured in place and easily removable for inspection of the void spaces.
C 2.6.5	The Administration may permit void bottom spaces to be fitted within the watertight envelope of the hull without the provision of a bilge system or air pipes provided that:
C 2.6.5.1	the structure is capable of withstanding the pressure head after any of the damages required by this section;
C 2.6.5.2	when carrying out a damage stability calculation in accordance with the requirements of this section, any void space adjacent to the damaged zone shall be included in the calculation and the criteria in 2.6, 2.13 and 2.15 complied with;
C 2.6.5.3	the means by which water which has leaked into the void space is to be removed shall be included in the craft operating manual required by Section 18; and
C 2.6.5.4	adequate ventilation is provided for inspection of the space under consideration as required by 2.2.1.2.
C 2.6.5.5	void spaces filled with foam or modular buoyancy elements or any space without a venting system are considered to be void spaces for the purposes of this paragraph, provided such foam or elements fully comply with 2.6.4.

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

Applicability of DNV-GL-HSC Rule

If V ≥ 7,16*Δ^1/6	15.93	Knots
Applicability of DNV-GL-HSC Rule	**TRUE**	

C 3.1.3 **Units**

C 3.1.3.1 Unless otherwise specified, the following units are used in the Rules:
- thickness of plating [mm]
- section modulus of stiffeners [cm3]
- shear area of stiffeners [cm2]
- span and spacing of stiffeners [m]
- stresses [MPa]
- concentrated loads [kN]
- distributed loads [kN/m] or [kPa]

Table C 3.2.1 **Aluminium alloys for welded construction**

Guaranteed Mechanical Characteristics							
Aluminium Alloy				**Unwelded Condition**		**Welded Condition**	
ALLOY	**Products**	**Temper**	**Thickness**	**Rp0.2**	**Rm**	**Rp0.2'**	**Rm'**
			mm	**MPa**	**MPa**	**MPa**	**MPa**
5083	Rolled	0/H111/H112	t ≤ 50	125	275	125	275
		H116/H32/H321	t ≤ 50	215	305	125	275
Rp0.2 and Rp0.2' are the minimum guaranteed yield stresses							
Rm and Rm' are the minimum guaranteed tensile strengths							

The heat-affected zone may be taken to extend 25 mm on each side of the weld axis.

C 3.2.3.2	Influence of welding on mechanical characteristics
C 3.2.3.2.5	Aluminium alloys of series 5000 other than condition 0 or H111 are subjected to a drop in mechanical strength in the welded areas. The mechanical characteristics to consider in welded condition are, normally, those of condition 0 or H111, except otherwise indicated in Table C3.2.1. Higher mechanical characteristics may be taken into account, provided they are duly justified.

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.2.3.3.1 **Material factor "k" for scantlings of structural members made of aluminium alloy**

k **0.8**

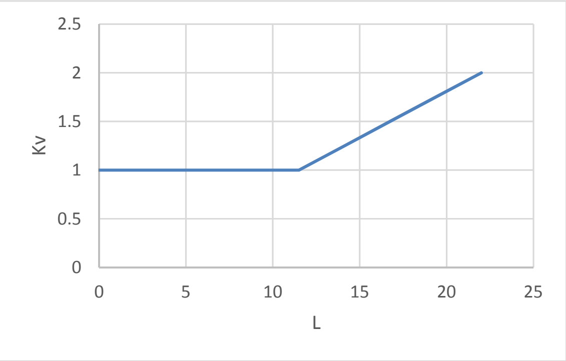
C 3.3.1 **Vertical acceleration at LCG**

S. No.	Parameter	Value	Units	REMARKS
1	aCG	2.294	m/sec2	
2	cHSC	0.5		Table C 3.3.1 Pilot Boat Conservative Approach
3	cRW	1		

The longitudinal distribution of vertical acceleration along the hull is given by:

LCG	11.5	m

S. No.	Position X	Kv	aV
1	0	1	2.294
2	11.5	1	2.294
3	14.125	1.25	2.868
4	16.75	1.5	3.441
5	19.375	1.75	4.015
6	22	2	4.588



C 3.3.2 **Transverse acceleration**

S. No.	Parameter	Value	Units
1	at	1.605	m/s2
2	r	19	m

C 3.3.3 **Assessment of limit operating conditions**

S. No.	Parameter	Value	Units	REMARKS
1	Hsm	5.485	m	Max Hs
2	Hs	2	m	NOTE : Selected from the General Data Available

C 3.3.3.2 **Limitation imposed by vertical acceleration at LCG**

S. No.	Parameter	Value	Units
1	Kt	0.879	
2	Kf	5.201	
3	K	5.918	
4	Kh	1.869	
5	Xcg	10.300	m
6	Hs	1.728	m

C 3.3.3.4 **Limitation imposed by global loads**
C 3.3.3.4.3 For SWATH craft, the global loads as given in C3.4.3 are not depending on ship motions.

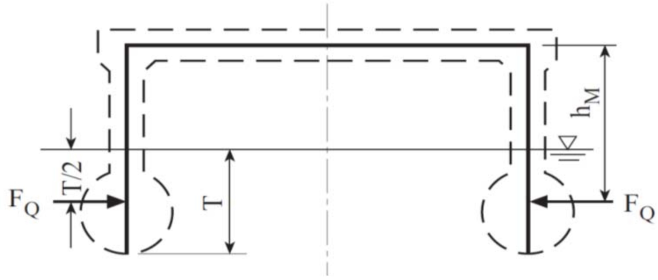
CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.4 **Overall Loads**
C 3.4.3 **Small waterplane area twin-hull (SWATH) craft - Forces and moments acting on twin-hull connections**

C 3.4.3.1 **Side beam force**

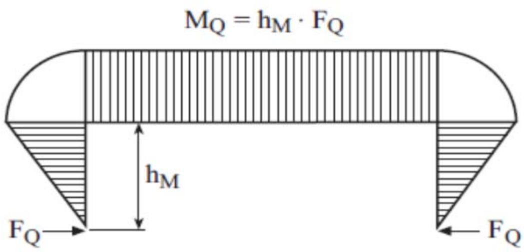
The design beam side force



S. No.	Parameter	Value	Units
1	Fq	3228.606	kN
2	T	3.2	m
3	Δ	121.4625	tonne
4	d	1.541719	m
5	Ls	2.134626	m
6	λ	1.901863	
7	Alat	220	m2

S. No.	Parameter	Value	Units
1	The lateral pressure		
	Pq	14.67548346	kN/m2
2	Effective length		
	Le	68.75	m
3	The constant lateral force per unit length		
	qQ	46.96154706	kN/m

C 3.4.3.2 **Bending moment**



S. No.	Parameter	Value	Units
1	Mq	6941.504	kN.m
2	hM	2.15	m
3	Height of Deck	0.8	m
4	Depth of Vessel	5.75	m

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.5 **Local Loads and Design Criteria**
C 3.5.2 **Load centre**

C 3.5.2.1 **For plates:**

vertical stiffening system:		
stiffener spacing	0.5	m

horizontal stiffening system		
Midpoint of plate field	0.25	m

C 3.5.2.2 **For stiffeners and girders:**

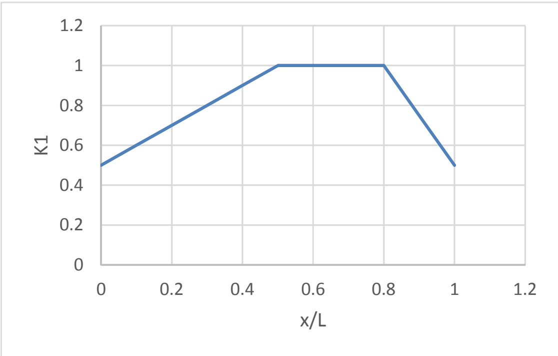
centre of span		0.5	m

C 3.5.3 **Impact pressure on the bottom of hull**

S. No.	Parameter	Value	Units
1	Vfr	2.358	m/s
2	Lwl	19	m
The impact pressure			
3	Psl	NA	kPa

Longitudinal bottom impact pressure distribution factor

S. No.	Position X	x/L	K1
1	0	0	0.5
2	1.9	0.1	0.6
3	3.8	0.2	0.7
4	5.7	0.3	0.8
5	7.6	0.4	0.9
6	9.5	0.5	1
7	11.4	0.6	1
8	13.3	0.7	1
9	15.2	0.8	1
10	17.1	0.9	0.75
11	19	1	0.5



Factor accounting for impact area

S. No.	Parameter	Value	REMARKS
1	K2 ≥	0.5	Plating
2	K2 ≥	0.45	Stiffener
3	K2 ≥	0.35	Girder and Floors

PLATING				
S. No.	Parameter	Value	UNITS	REMARKS
1	K2	0.412		
2	u	2.823		
3	s	0.750		
4	Sr	26.570	m2	Reference Area
5	Stiffener Spacing	0.5	m	
6	Stiffener Span	1.5	m	
7	**Selected K2**	0.5		

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

STIFFNER				
S. No.	**Parameter**	**Value**	**UNITS**	**REMARKS**
1	K2	0.412		
2	u	2.823		
3	s	0.750		
4	Sr	26.570	m2	Reference Area
5	Stiffener Spacing	0.5	m	
6	Stiffener Span	1.5	m	
7	**Selected K2**	0.45		

GIRDERS AND FLOORS				
S. No.	**Parameter**	**Value**	**UNITS**	**REMARKS**
1	K2	0.412		
2	u	2.823		
3	s	0.750		
4	Sr	26.570	m2	Reference Area
5	Stiffener Spacing	0.5	m	
6	Stiffener Span	1.5	m	
7	**Selected K2**	0.412		

Factor accounting for shape and deadrise of the hull

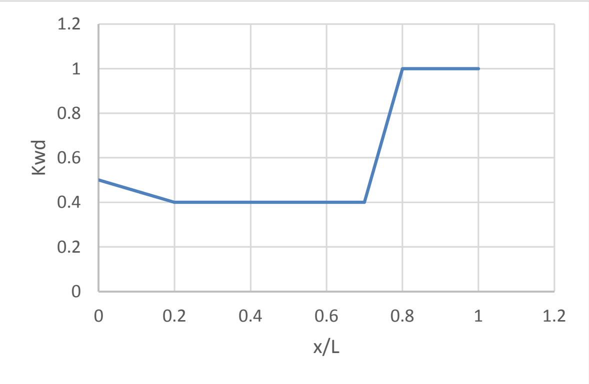
S. No.	Parameter	Value	Units
1	K3	1.1	
2	αd	15	deg
3	αdCG	20	deg

C 3.5.4 Impact pressure on wet deck (including tunnel radius)

S. No.	Parameter	Value	Units	REMARKS
1	psl		kPa	
2	Vsl	2.835	m/s	relative impact velocity

Longitudinal wet deck impact pressure distribution factor

S. No.	Position X	x/L	KWD	psl
1	0	0	0.5	-3.918
2	1.9	0.1	0.45	-3.526
3	3.8	0.2	0.4	-3.134
4	5.7	0.3	0.4	-3.134
5	7.6	0.4	0.4	-3.134
6	9.5	0.5	0.4	-3.134
7	11.4	0.6	0.4	-3.134
8	13.3	0.7	0.4	-3.134
9	15.2	0.8	1	-7.836
10	17.1	0.9	1	-7.836
11	19	1	1	-7.836



Vx	20	knots	
Ha	2.55	m	air gap equal to the distance between the waterline at draught T and the wet deck

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.5.5 Sea pressures
C 3.5.5.1 Sea pressure on bottom and side shell

For Under Water Hull Central Tube				
S. No.	Position X	x/L	Ps min	Ps (kPa)
1	0	0	7.52	33.17
2	1.9	0.1	7.52	33.17
3	3.8	0.2	7.52	33.17
4	5.7	0.3	7.52	33.17
5	7.6	0.4	7.52	33.17
6	9.5	0.5	7.52	33.17
7	11.4	0.6		33.17
8	13.3	0.7		33.17
9	15.2	0.8		33.17
10	17.1	0.9	15.04	33.17
11	19	1	15.04	33.17

For Over Water Hull Central Tube				
S. No.	Position X	x/L	Ps min	Ps (kPa)
1	0	0	7.52	7.67
2	1.9	0.1	7.52	7.67
3	3.8	0.2	7.52	7.67
4	5.7	0.3	7.52	7.67
5	7.6	0.4	7.52	7.67
6	9.5	0.5	7.52	7.67
7	11.4	0.6		7.67
8	13.3	0.7		7.67
9	15.2	0.8		7.67
10	17.1	0.9	15.04	7.67
11	19	1	15.04	7.67

For Under Water Hull Outrigger				
S. No.	Position X	x/L	Ps min	Ps (kPa)
1	0	0	7.52	36.05
2	1.9	0.1	7.52	36.05
3	3.8	0.2	7.52	36.05
4	5.7	0.3	7.52	36.05
5	7.6	0.4	7.52	36.05
6	9.5	0.5	7.52	36.05
7	11.4	0.6		36.05
8	13.3	0.7		36.05
9	15.2	0.8		36.05
10	17.1	0.9	15.04	36.05
11	19	1	15.04	36.05

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

For Over Water Hull Outrigger				
S. No.	**Position X**	**x/L**	**Ps min**	**Ps (kPa)**
1	0	0	7.52	10.55
2	1.9	0.1	7.52	10.55
3	3.8	0.2	7.52	10.55
4	5.7	0.3	7.52	10.55
5	7.6	0.4	7.52	10.55
6	9.5	0.5	7.52	10.55
7	11.4	0.6		10.55
8	13.3	0.7		10.55
9	15.2	0.8		10.55
10	17.1	0.9	15.04	10.55
11	19	1	15.04	10.55

C 3.5.5.5 **Sea pressures on deckhouses**

S. No.	Parameter	Value	Units
1	Front Wall		
	pSU	17.9	kPa
2	Side and Aft Wall		
	pSU	4	kPa
3	Other Walls and Side		
	pSU	3	kPa
4	Unprotected front walls located at the fore end		
	pSU	NA	kPa

C 3.5.6.2 **Pressures on watertight bulkheads**

S. No.	Parameter	Value	Units
1	pSB	31.883	kPa
2	h3	3.25	m

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.5.8 Deck loads
C 3.5.8.1 General

S. No.	Parameter	Value	Units	REMARKS
1	Pd	12.334	kPa	
2	p	4.350	kPa	uniform pressure due to the load carried [kPa]
3	av	4.588	m/s2	design vertical acceleration, defined in C3.3

C 3.5.8.2 Weather decks and exposed areas

S. No.	Parameter	Value	Units	REMARKS
1	p	4.35	kPa	if 2 < zd < 3
2	zd	2.55	m	vertical distance from deck to waterline at draught T

C 3.5.8.4 Enclosed accommodation decks

p	**3**	**kPa**

C 3.5.8.6 Platforms of machinery spaces and mooring decks

The minimum value to be considered for platforms of machinery spaces

p	**8**	**kPa**

The minimum value to be considered for platforms of mooring decks

p	**6**	**kPa**

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.7 **Steel and Aluminium Alloy Craft**
C 3.7.1 **Structural Details**

$$\mu = \sqrt{1.1 - 0.5 * \left(\frac{s}{l}\right)^2}$$

S. No.	Parameter	Value	Units	REMARKS
1	μ	1.022		which needs not be taken greater than 1.0
2	s	0.5	m	
3	l	1.5	m	
4	μ	1		Selected

C 3.7.3 **Overall strength (Global)**
C 3.7.3.1 **Longitudinal strength**

$$\sigma_{bl} = \left| \frac{M_{bl}}{I_y} * (z - z_0) * 10^{-3} \right|$$

S. No.	Parameter	Value	Units	REMARKS
1	σam	87.5	MPa	**Refer Allowabale Stress Annex**
2	Mbl	6941.504	kNm	
3	σbl	58.34	MPa	
4	Structure	**TRUE**		if σbl < σam

C 3.7.4 **Effective width of plating**
C 3.7.4.1 **Stiffeners**

Plating Width	0.5	m	spacing of stiffeners (secondary members)

C 3.7.4.2 **Girders**

Table C 3.7.1 **Effective width "em" of frames and girders**

S. No.	Parameter	Value	Units	REMARKS
1	l	1.5	m	
2	e	0.5	m	
3	l by e	3		
4	em1/e	0.82		Selected for Our Case
5	em2/e	0.52		

C 3.7.7 **Plating**
C 3.7.7.1 **Formula**

$$t = 22.4 * \mu * s * \sqrt{\frac{p}{\sigma_{am}}}$$

C 3.7.7.2 **Keel**

The thickness of keel plating is to be not less than that required for adjacent bottom plating.
This requirement may be waived in the case of special arrangements for dry-docking of craft of unusual hull design in the opinion of GL.

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.7.7.3 **Bottom shell and bilge plating**

S. No.	Parameter	Value	Units
1	p	33.17	kPa
2	σam	106.25	MPa
3	μ	1	
4	s	0.5	m
5	t	6.258	mm

C 3.7.7.4 **Plating of front walls**

S. No.	Parameter	Value	Units
1	p	17.9	kPa
2	σam	106.25	MPa
3	μ	1	
4	s	0.5	m
5	t	4.597	mm

C 3.7.7.4 **Plating of side shell**

S. No.	Parameter	Value	Units
1	p	4	kPa
2	σam	106.25	MPa
3	μ	1	
4	s	0.5	m
5	t	2.173	mm

C 3.7.7.6 **Deck plating**

S. No.	Parameter	Value	Units
1	p	12.33367	kPa
2	σam	106.25	MPa
3	μ	1	
4	s	0.5	m
5	t	3.816	mm

C 3.7.7.8 **Plating of deckhouse walls**

S. No.	Parameter	Value	Units
1	p	3	kPa
2	σam	106.25	MPa
3	μ	1	
4	s	1.5	m
5	t	5.646	mm

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.7.8 **Ordinary stiffeners**
C 3.7.8.1 **General**

$$Z = 1000 * \frac{l^2 * s * p}{m * \sigma_{am}}$$

$$A_t = 5 * \frac{l * s * p}{\tau_{am}}$$

Z	cm3	section modulus
At	cm2	shear area

C 3.7.4

Coefficient "m"	Value
Continuous stiffeners	12
Non-continuous stiffeners and without brackets at the end of span	**8**

The web thickness is to be not less than	
S. No.	**REMARKS**
1	1/15 of the depth, for flat bars
2	1/35 of the depth, for other sections
3	The thickness of the face plate is to be not less than 1/20 of its width.

C 3.7.8.2 **Bottom and bilge stiffeners**

S. No.	Parameter	Value	Units
1	l	1.5	m
2	s	0.5	m
3	p	33.17	kPa
4	m	8	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	53.309	cm3
8	At	2.211	cm2

C 3.7.8.3 **Side wall stiffeners**

S. No.	Parameter	Value	Units
1	l	1.5	m
2	s	0.5	m
3	p	4	kPa
4	m	8	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	6.429	cm3
8	At	0.267	cm2

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.7.8.3 **Front wall stiffeners**

S. No.	Parameter	Value	Units
1	l	1.5	m
2	s	0.5	m
3	p	17.9	kPa
4	m	8	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	28.768	cm3
8	At	1.193	cm2

C 3.7.8.5 **Deck stiffeners**

S. No.	Parameter	Value	Units
1	l	1.5	m
2	s	0.5	m
3	p	12.33367	kPa
4	m	8	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	19.822	cm3
8	At	0.822	cm2

C 3.7.8.6 **Stiffeners of boundary walls of deckhouses**

S. No.	Parameter	Value	Units
1	l	1.5	m
2	s	0.5	m
3	p	3	kPa
4	m	8	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	4.821	cm3
8	At	0.200	cm2

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.7.9 **Primary supporting members**
C 3.7.9.1 **General**

$$Z = 1000 * \frac{S^2 * b * p}{m * \sigma_{am}}$$

$$A_t = 5 * \frac{S * b * p}{\tau_{am}}$$

m	10

The web thickness is to be not less than	
S. No.	**REMARKS**
1	The web thickness is to be not less than 1/35 of web depth.
2	1/35 of the depth, for other sections
3	The face plate thickness is to be not less than 1/20 of face plate breadth (1/10 for face plates which are not symmetrical with respect to the web).

C 3.7.9.2 **Floors and girders of single bottom**

S. No.	Parameter	Value	Units
1	S	0.5	m
2	b	1.5	m
3	p	33.17	kPa
4	m	10	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	14.216	cm3
8	At	2.211	cm2
9	t	3.426	mm

C 3.7.9.3 **Primary supporting members of sides walls**

S. No.	Parameter	Value	Units
1	S	0.5	m
2	b	1.5	m
3	p	4	kPa
4	m	10	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	1.714	cm3
8	At	0.267	cm2

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.7.9.3 **Primary supporting members of front walls**

S. No.	Parameter	Value	Units
1	S	0.5	m
2	b	1.5	m
3	p	17.9	kPa
4	m	10	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	7.671	cm3
8	At	1.193	cm2

C 3.7.9.5 **Primary supporting members of decks**

S. No.	Parameter	Value	Units
1	S	0.5	m
2	b	1.5	m
3	p	12.33367	kPa
4	m	10	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	5.286	cm3
8	At	0.822	cm2

C 3.7.9.6 **Primary supporting members of deckhouse boundary walls**

S. No.	Parameter	Value	Units
1	S	0.5	m
2	b	1.5	m
3	p	3	kPa
4	m	10	
5	σam	87.5	MPa
6	τam	56.25	MPa
7	Z	1.286	cm3
8	At	0.200	cm2

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

C 3.7.11 **Bulkhead Structures**
C 3.7.11.1 **Plating**

$$t = 22.4 * f_m \mu * s * \sqrt{\frac{p_S}{\sigma_{am}}}$$

S. No.	Parameter	Value	Units	REMARKS
1	fm	0.7		for aluminium alloy structures
2	µ	1		
3	s	0.5	m	
4	Psb	31.883	kPa	
5	σam	118.750	MPa	
6	t	4.062	mm	

C 3.7.11.2 **Stiffeners and girders**

The required scantlings of stiffeners and girders are determined according to strength calculations, by applying the following permissible stress Values
Refer Table Allowable Stress

C 3.7.13 **Bow, Shell Side and Stern Doors**
C 3.7.13.1 **Plating**

$$t = 22.4 * \mu * s * \sqrt{\frac{p_S}{\sigma_{am}}}$$

S. No.	Parameter	Value	Units
1	µ	1	
2	s	0.5	m
3	Psb	36.05	kPa
4	σam	106.25	MPa
5	t	6.524	mm

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3.7
ALLOWABLE STRESS

BASIC PROPERTIES		
Young's Modulus of aluminium (N/mm2)	E	70000
Poisson's ratio of aluminium	v	0.33
material factor k	k	0.8
	Aluminium Alloy	5083 H116
In welded condition_table 1 (N/mm2)	R'p0,2	125
In welded condition_table 1 (N/mm2)	R'm	275
Proof stress (yield strength) in N/mm2 as indicated by the supplier	Rp0,2	215
Tensile strength, in N/mm2 as indicated by the supplier	Rm	305

Type of Stress considered	Structural component considered	Design admissible stress (N/mm2)
Global stress induced by longitudinal hull girder loads	plating	87.5
		87.5
	stiffeners	87.5
		87.5
PLATING		
C3.7.7.3 Bottom shell and bilge plating	Impact Pressure	
	σam	118.75
	Sea Pressure	
	σam	106.25
C3.7.7.4 Plating of side shell and front walls	σam	106.25
C3.7.7.6 Deck plating	σam	106.25
C3.7.7.8 Plating of deckhouse walls	σam	106.25
ORDINARY STIFFENERS		
C3.7.8.2 Bottom and bilge stiffeners	σam	87.5
	τam	56.25
b. stiffeners contributing to the longitudinal strength c. stiffeners not contributing to the longi. strength	σam	87.5
	τam	56.25
C3.7.8.3 Side and front wall stiffeners	σam	87.5
	τam	56.25
b. stiffeners contributing to the longitudinal strength c. stiffeners not contributing to the longi. strength	σam	87.5
	τam	56.25
C3.7.8.5 Deck stiffeners	σam	87.5
	τam	56.25
b. stiffeners contributing to the longitudinal strength c. stiffeners not contributing to the longi. strength	σam	87.5
	τam	56.25
C3.7.8.6 Stiffeners of boundary walls of deckhouses	σam	87.5
	τam	56.25

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3.7
ALLOWABLE STRESS

PRIMARY STIFFENERS		
C3.7.9.2 Floors and girders of single bottom	σam	87.5
	τam	56.25
b. Floor	σam	87.5
c. Girder	τam	56.25
C3.7.9.3 Primary supporting members of sides and front walls	σam	87.5
	τam	56.25
C3.7.9.5 Primary supporting members of decks	σam	87.5
	τam	56.25
C3.7.9.6 Primary supporting members of deckhouse boundary walls	σam	87.5
	τam	56.25
BULKHEAD STRUCTURE		
C3.7.11.1 Plating	σam	118.75
C3.7.11.2 Stiffeners and girders	σam	112.5
	τam	68.75
	σvM	118.75
BOW AND SIDE SHELL		
C3.7.13.1 Plating	σam	106.25
C3.7.13.2 Ordinary stiffeners	σam	87.5
	τam	56.25
C3.7.13.3 Primary members, securing and supporting devices	σam	68.75
	τam	43.75
	σvM	87.5

CLASSIFICATION RULES - DNV-GL HSC 2012

CHAPTER 1, SECTION 3
STRUCTURAL DETAILS

DIRECT CALCULATION	
C 3.1.2	**Direct calculations**
C 3.1.2.1	DNV-GL may require direct calculations to be carried out, if deemed necessary. Such calculations are to be carried out based on structural modelling, loading and checking criteria described below. Calculations based on other criteria may be accepted if deemed equivalent to those laid down by DNV-GL.
C 3.1.2.2	In order to increase the flexibility in the structural design of ships DNV-GL also accepts direct calculations with computer programs. The aim of such analyses should be the proof of equivalence of a design with the rule requirements.
C 3.1.2.3	Direct calculations may also be used in order to optimise a design; in this case only the final results are to be submitted for review.
C 3.1.2.2	**General programs**
C 3.1.2.2.1	The choice of computer programs according to "State of the Art" is free. The programs may be checked by DNV-GL through comparative calculations with predefined test examples. A generally valid approval for a computer program is, however, not given by DNV-GL.
C 3.1.2.2.2	Direct calculations may be used in the following fields – global strength – longitudinal strength – beams and grillages – detailed strength
C 3.1.2.2.3	For such calculation the computer model, the boundary condition and load cases are to be agreed upon with DNV-GL. The calculation documents are to be submitted including input and output. During the examination it may prove necessary that GL perform independent comparative calculations.
C 3.1.2.2.4	DNV-GL is prepared to carry out the following calculations of this kind within the marine advisory services :
C 3.1.2.2.4.1	**STRENGTH**
	Linear and/or non-linear strength calculations with the FE-method: For an automated performance of these calculations, a number of effective pre- and post processing programmes is at disposal: – calculation of seaway loads as per modified strip method or by 3 D-panel method – calculation of resultant accelerations to ensure quasi-static equilibrium – calculation of composite structures – evaluation of deformations, stresses, buckling behaviour, ultimate strength and local stresses, assessment of fatigue strength

T-PROFILES SECTION MODULUS (Z) CALCULATIONS

CENTRAL TUBE SCANTLINGS												
S. No.	ELEMENT	Plate Thickness	Web Thickness	Web Height	Flange Thickness	Flange Width	B	H	b	h	Z	CLASS (Z)
		mm	mm	mm	mm	mm	mm	mm	mm	mm	cm3	cm3
1	Outer Plate Thickness	8	-	-	-	-	-	-	-	-	-	-
2	DB Plate Thickness	8	-	-	-	-	-	-	-	-	-	-
3	Bow Plate Thickness	8	-	-	-	-	-	-	-	-	-	-
4	Central Girder	8	10	300	10	40	40	318	30	300	249.6317	53.309
5	Side Girder	8	10	300	10	40	40	318	30	300	249.6317	53.309
CENTRAL STRUT SCANTLINGS												
S. No.		Plate Thickness	Web Thickness	Web Height	Flange Thickness	Flange Width	B	H	b	h	Z	
		mm	mm	mm	mm	mm	mm	mm	mm	mm	cm3	
1	Plate Thickness	4	-	-	-	-	-	-	-	-	-	-
2	Longitudinal Member	4	10	40	10	40	40	54	30	40	13.51407	6.429
3	Transverse Frame	10	10	200	10	40	40	220	30	200	140.8485	130.4
OUTRIGGER SCANTLINGS												
S. No.		Plate Thickness	Web Thickness	Web Height	Flange Thickness	Flange Width	B	H	b	h	Z	CLASS (Z)
		mm	mm	mm	mm	mm	mm	mm	mm	mm	cm3	cm3
1	Plate Thickness	4	-	-	-	-	-	-	-	-	-	-
2	Longitudinal Member	4	10	40	10	40	40	54	30	40	13.51407	6.429
3	Transverse Frame	10	10	200	10	40	40	220	30	200	140.8485	130.4
DECK SCANTLINGS												
S. No.		Plate Thickness	Web Thickness	Web Height	Flange Thickness	Flange Width	B	H	b	h	Z	CLASS (Z)
		mm	mm	mm	mm	mm	mm	mm	mm	mm	cm3	cm3
1	Upper Deck Plate	8	-	-	-	-	-	-	-	-	-	-
2	Lower Deck Plate	8	-	-	-	-	-	-	-	-	-	-
3	Longitudinal Member	8	10	80	10	40	40	98	30	80	37.90422	19.822
4	Transverse Member	8	10	200	10	80	80	218	70	200	205.5188	158.9
SUPERSTRUCTURE SCANTLINGS												
S. No.		Plate Thickness	Web Thickness	Web Height	Flange Thickness	Flange Width	B	H	b	h	Z	CLASS (Z)
		mm	mm	mm	mm	mm	mm	mm	mm	mm	cm3	cm3
1	Plate Thickness	6	-	-	-	-	-	-	-	-	-	-
2	Longitudinal Member	6	10	40	10	40	40	56	30	40	15.19238	4.821
3	Transverse Frame	6	10	200	10	80	80	216	70	200	189.9812	142.4

WEIGHT ESTIMATION OF 18m CM-SWAS(S)H

Construction Material Data	Material	Aluminium Alloy 5083	
	Density	2700	kg/m^3
Measurement references	Horizontal	From frame 0 + Forward	
	Vertical	Keel (Hull Baseline) + Up	
	Transverse	From CL Starboard positive	

Number	Item	Quantity	Unit Weight (kg)	Total Weight (kg)	V.C.G. (m)	L.C.G. (m)	T.C.G. (m)
STRUCTURES	**Hull Structure**	1.00		39670.00	3.45	15.42	0.00
	Margin (5%)			1983.50	3.45	15.42	0.00
	Allowance for weld & mill tolerance (3.5%)			1388.45	3.45	15.42	0.00
	Allowance for paint (2%)			793.40	3.45	15.42	0.00
	Subtotal			**43835.35**	**2.03**	**8.23**	**0.00**
SYSTEMS	**Systems and Mechanical**	1.00		21447.50	1.52	16.26	0.02
	Allowance (5%)			1072.38	1.52	16.26	0.02
	Subtotal (Excl. Fluids in pipes and equipment)			**22519.88**	**1.28**	**9.32**	**0.02**
EXT. OUTFIT	**External Fit out**	1.00		3027.99	5.29	15.08	-0.09
	Allowance (5%)			151.40	5.29	15.08	-0.09
	Subtotal			**3179.39**	**4.14**	**8.68**	**-0.11**
INT. OUTFIT	**Internal Fit out**	1.00		2717.03	5.22	6.72	0.15
	Allowance (5%)			135.85	5.22	6.72	0.15
	Subtotal			**2852.88**	**5.82**	**8.45**	**0.16**
ELECTRICAL	**Electrical Fit out**	1.00		2482.43	5.23	4.12	-0.18
	Allowance (5%)			124.12	5.23	4.12	-0.18
	Subtotal			**2606.55**	**2.64**	**4.82**	**-0.21**
PROPOLSION	**Propulsion**	1.00		3643.56	1.59	4.62	0.09
	Allowance (5%)			182.18	1.59	6.13	0.09
	Subtotal			**3825.74**	**1.59**	**4.69**	**0.09**
	PERSON ON BOARD	6	86.00	516.00			
	TOTAL ESTIMATION			**79335.78**	**2.10**	**8.10**	**0.00**

WEIGHT ESTIMATION OF 21m CM-SWAS(S)H

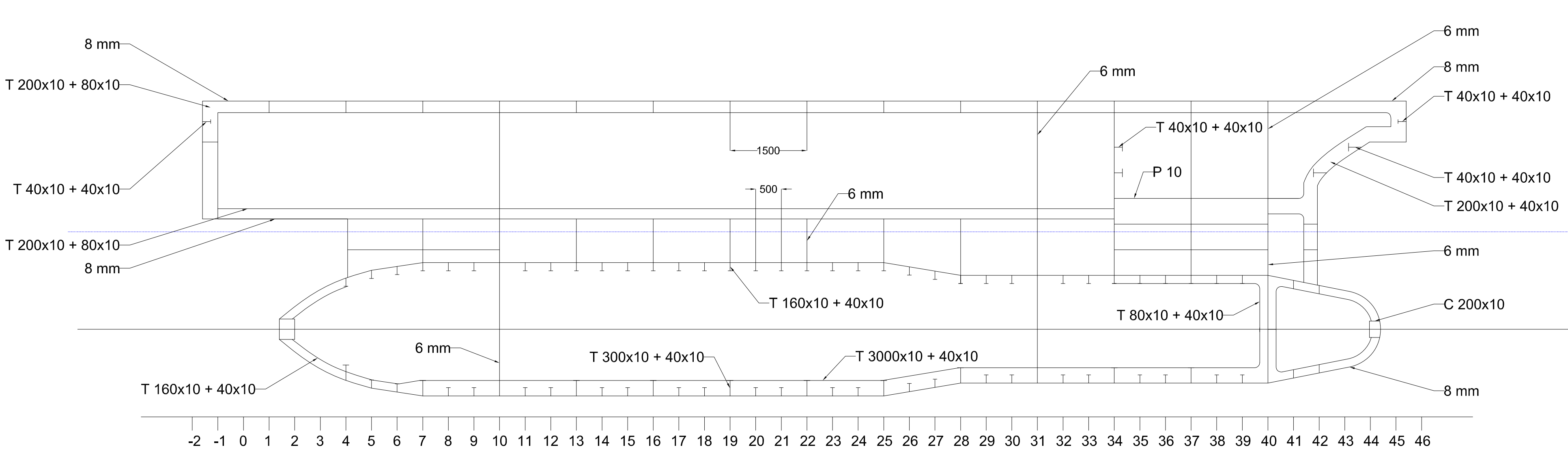
Construction Material Data	Material	Aluminium Alloy 5083	
	Density	2700	kg/m^3
Measurement references	Horizontal	From frame 0 + Forward	
	Vertical	Keel (Hull Baseline) + Up	
	Transverse	From CL Starboard positive	

Number	Item	Quantity	Unit Weight	Total Weight	V.C.G.	L.C.G.	T.C.G.
			(kg)	(kg)	(m)	(m)	(m)
STRUCTURES	**Hull Structure**	1.00		49720.00	4.26	18.46	0.00
	Margin (5%)			2486.00	4.26	18.46	0.00
	Allowance for weld & mill tolerance (3.5%)			1740.20	4.26	18.46	0.00
	Allowance for paint (2%)			994.40	4.26	18.46	0.00
	Subtotal			**54940.60**	**1.76**	**8.66**	**0.00**
SYSTEMS	**Systems and Mechanical**	1.00		29553.30	1.67	17.34	0.02
	Allowance (5%)			1477.67	1.67	17.34	0.02
	Subtotal (Excl. Fluids in pipes and equipment)			**31030.97**	**0.95**	**10.90**	**0.01**
EXT. OUTFIT	**External Fit out**	1.00		3169.72	5.38	17.87	-0.09
	Allowance (5%)			158.49	5.38	17.87	-0.09
	Subtotal			**3328.20**	**3.97**	**8.68**	**-0.10**
INT. OUTFIT	**Internal Fit out**	1.00		2808.41	5.84	8.90	0.15
	Allowance (5%)			140.42	5.84	8.90	0.15
	Subtotal			**2948.83**	**5.67**	**9.80**	**0.16**
ELECTRICAL	**Electrical Fit out**	1.00		2686.86	5.23	4.12	-0.18
	Allowance (5%)			134.34	5.23	4.12	-0.18
	Subtotal			**2821.20**	**2.45**	**4.46**	**-0.19**
PROPOLSION	**Propulsion**	1.00		3643.56	1.59	4.62	0.09
	Allowance (5%)			182.18	1.59	6.13	0.09
	Subtotal			**3825.74**	**1.59**	**4.69**	**0.09**
	PERSON ON BOARD	10	86.00	860.00			
	TOTAL ESTIMATION			**99755.54**	**2.00**	**9.50**	**0.00**

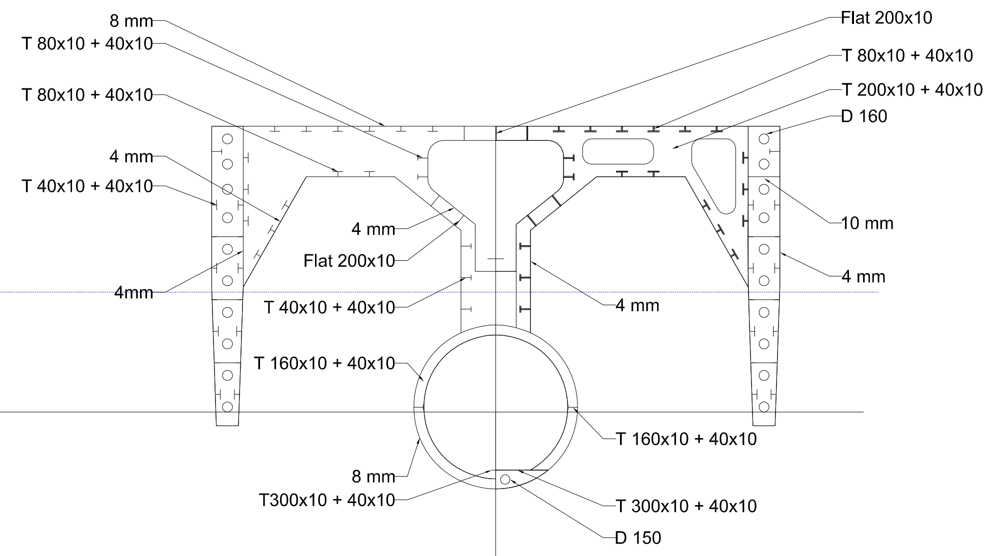
WEIGHT ESTIMATION OF 24m CM-SWAS(S)H

Construction Material Data	Material	Aluminium Alloy 5083	
	Density	2700	kg/m^3
Measurement references	Horizontal	From frame 0 + Forward	
	Vertical	Keel (Hull Baseline) + Up	
	Transverse	From CL Starboard positive	

Number	Item	Quantity	Unit Weight (kg)	Total Weight (kg)	V.C.G. (m)	L.C.G. (m)	T.C.G. (m)
STRUCTURES	**Hull Structure**	1.00		59770.00	1.68	12.28	0.00
	Margin (5%)			2988.50	1.68	12.28	0.00
	Allowance for weld & mill tolerance (3.5%)			2091.95	1.68	12.28	0.00
	Allowance for paint (2%)			1195.40	1.68	12.28	0.00
	Subtotal			**66045.85**	**1.29**	**11.63**	**0.00**
SYSTEMS	**Systems and Mechanical**	1.00		35697.90	1.38	19.34	0.02
	Allowance (5%)			1784.90	1.38	19.34	0.02
	Subtotal (Excl. Fluids in pipes and equipment)			**37482.80**	**0.79**	**12.83**	**0.01**
EXT. OUTFIT	**External Fit out**	1.00		3761.48	5.64	19.71	-0.09
	Allowance (5%)			188.07	5.64	19.71	-0.09
	Subtotal			**3949.55**	**3.40**	**10.28**	**-0.09**
INT. OUTFIT	**Internal Fit out**	1.00		3046.00	5.59	12.60	0.15
	Allowance (5%)			152.30	5.59	12.60	0.15
	Subtotal			**3198.30**	**5.23**	**11.60**	**0.15**
ELECTRICAL	**Electrical Fit out**	1.00		2920.50	6.23	4.12	-0.18
	Allowance (5%)			146.03	6.23	4.12	-0.18
	Subtotal			**3066.53**	**2.33**	**4.12**	**-0.18**
PROPOLSION	**Propulsion**	1.00		3643.56	1.59	4.62	0.09
	Allowance (5%)			182.18	1.59	6.13	0.09
	Subtotal			**3825.74**	**1.59**	**4.69**	**0.09**
	PERSON ON BOARD	12	86.00	1032.00			
	TOTAL ESTIMATION			**118600.76**	**1.85**	**11.50**	**0.00**



PROFILE VIEW



ORDINARY FRAME | STRONG FRAME

18 m			
LOADED SHIP		LIGHT SHIP	
DISPL. (t)	79.34 (t)	DISPL. (t)	63.97 (t)
LCG (m)	8.10 (m)	LCG (m)	7.50 (m)
VCG (m)	2.10 (m)	VCG (m)	2.60 (m)
TCG (m)	0.00 (m)	TCG (m)	0.00 (m)

21 m			
LOADED SHIP		LIGHT SHIP	
DISPL. (t)	99.76 (t)	DISPL. (t)	77.56 (t)
LCG (m)	9.50 (m)	LCG (m)	8.90 (m)
VCG (m)	2.00 (m)	VCG (m)	2.75 (m)
TCG (m)	0.00 (m)	TCG (m)	0.00 (m)

24 m			
LOADED SHIP		LIGHT SHIP	
DISPL. (t)	118.6 (t)	DISPL. (t)	93.39 (t)
LCG (m)	11.50 (m)	LCG (m)	11.0 (m)
VCG (m)	1.85 (m)	VCG (m)	2.95 (m)
TCG (m)	0.00 (m)	TCG (m)	0.00 (m)

MIXED FRAMING SYSTEM

FRAME SPACING : 500 mm

STRONG FRAME : 1500 mm

Tel. : +32– 497677494 (BELGIUM)
Tel. : +91– 9716025852 (INDIA)
akula@greenexponent.com
www.greenexponent.com

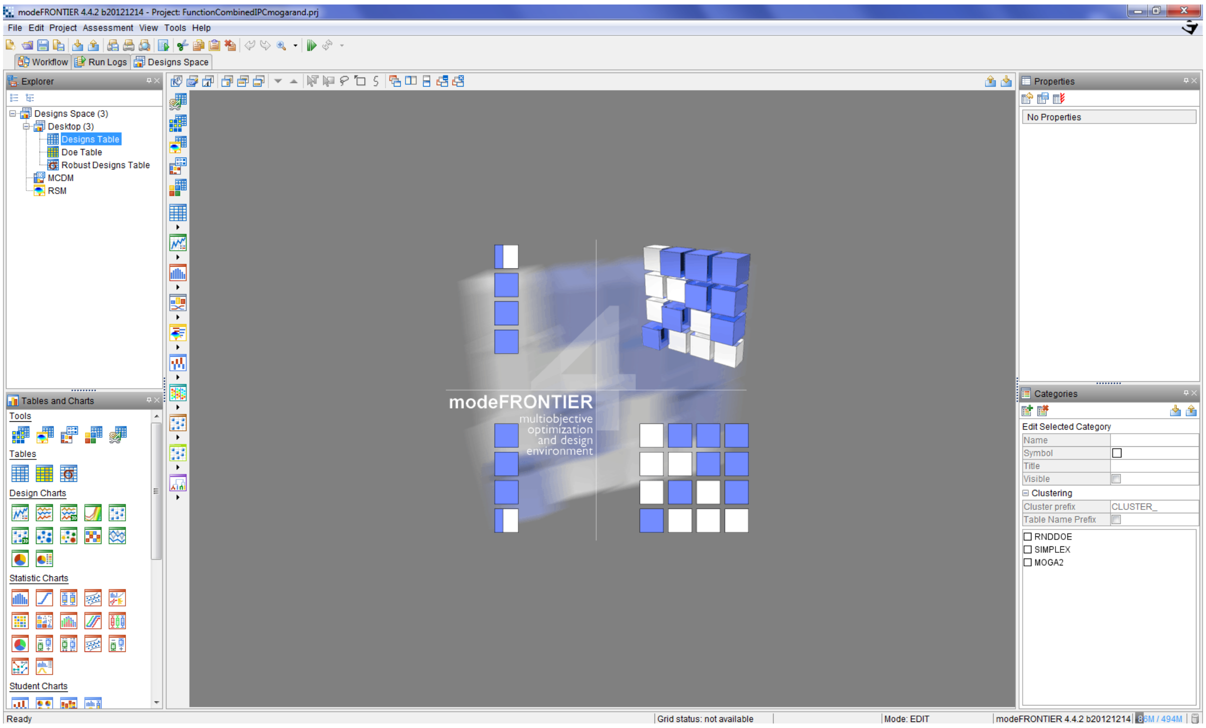
AKULA NIDARSHAN
MARINE ENGINEER AND NAVAL ARCHITECT

VESSEL NAME	AKULATOR
VESSEL TYPE	CM – SWAS(S)H PILOT / WSV
TITLE	COMMON MODULAR STRUCTURE
SCALE	
DRAWN	AKULA N.
TRACED	AKULA N.
CHECKED	
SEC. HEAD	
APPROVALS	OWNER / MMD / CLASS
YARD NUMBER	
DATE :	
DRAWING NUMBER	CMS – 4
SHEET:–	
REV	NIL

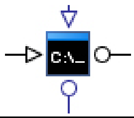
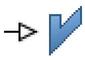
ANNEX – 3
RESISTANCE

STEPS AND PROCEDURE TO CARRY OUT OPTIMISATION IN modeFRONTIER

modeFrontier uses a classic tab based GUI, which enables the used to shift between the Optimisation Window to Design Space with single click. The window is the Tab used for creating the Optimisation layout while the design space is for viewing and plotting optimisation results.



1) ICON DEFINITIONS

ICON	ICON NAME	ICON	ICON NAME
	**INPUT VARIABLE**		**DOS OPERATOR**
	**INPUT FILE**	DOE SIMPLEX 	**EDULER**
	**CONSTRAINT**		**OUTPUT FILE**
	**SUPPORT FILE**		**OUTPUT VARIABLE**
	**EXIT FUNCTION**		**MINIMISER/MAXIMISER**

2) THE OPTIMISATION CIRCUIT LAYOUT

Though, this master thesis was carried out to test with only multi-objective function here different types of objective functions are explained to understand the process, with different variables and constraints. The first step to initialise the optimisation problem is to define the layout and then provide operating data to each element of the layout.

2.1) SINGLE OBJECTIVE

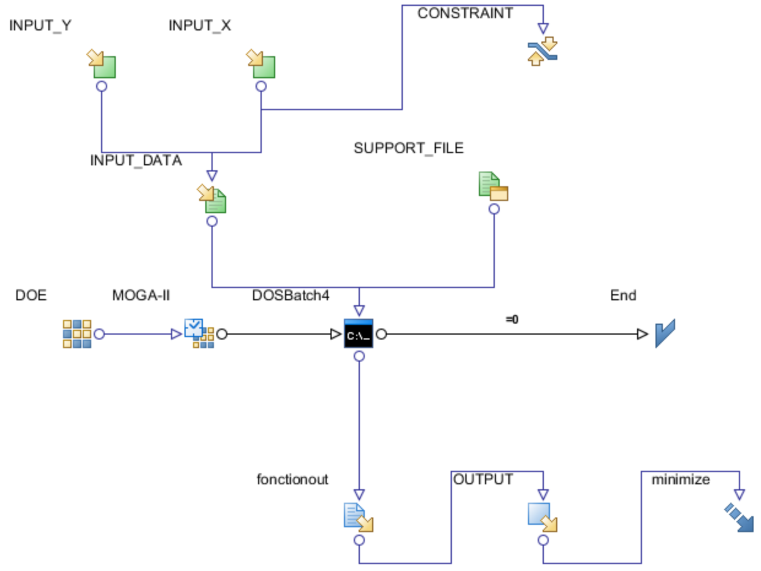


Figure 1 SINGLE OBJECTIVE LAYOUT

The above layout shows the optimisation circuit for minimising a single objective function with two input variables and a constraint on input X (please note that we can remove the constraint and use the same layout, for constrain free optimisation), the optimisation is for MOGA, but can be used for SIMPLEX buy changing the variables in the scheduler.

2.2) MULTI-OBJECTIVE

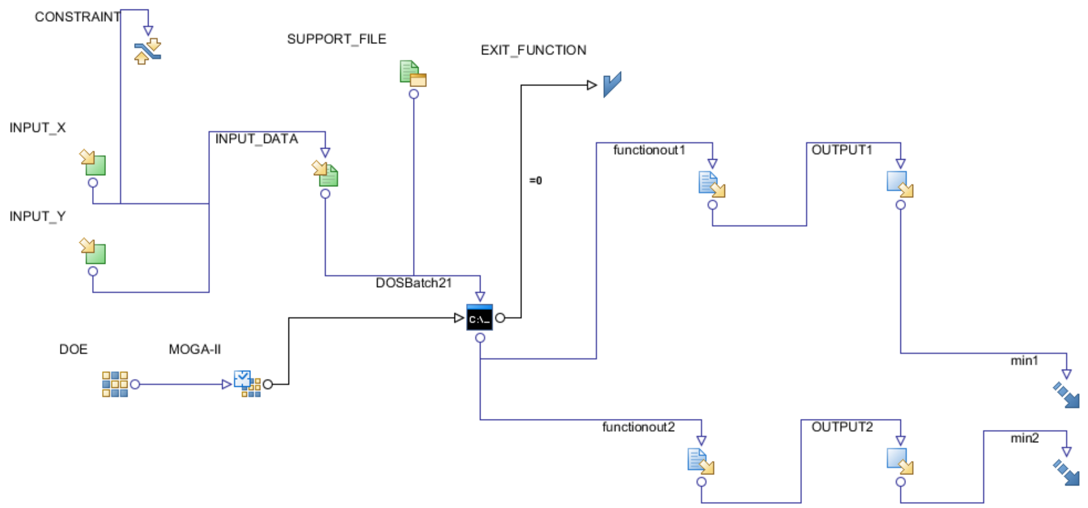


Figure 2 MULTI-OBJECTIVE LAYOUT

The above layout shows the optimisation circuit for minimising a two multi objective functions with two input variables and a constraint on input X (please note that we can remove the constraint and use the same layout, for constrain free optimisation), the optimisation is for MOGA, but can be used for SIMPLEX buy changing the variables in the scheduler.

2.3) MULTI-OBJECTIVE WEIGHTED FUNCTION

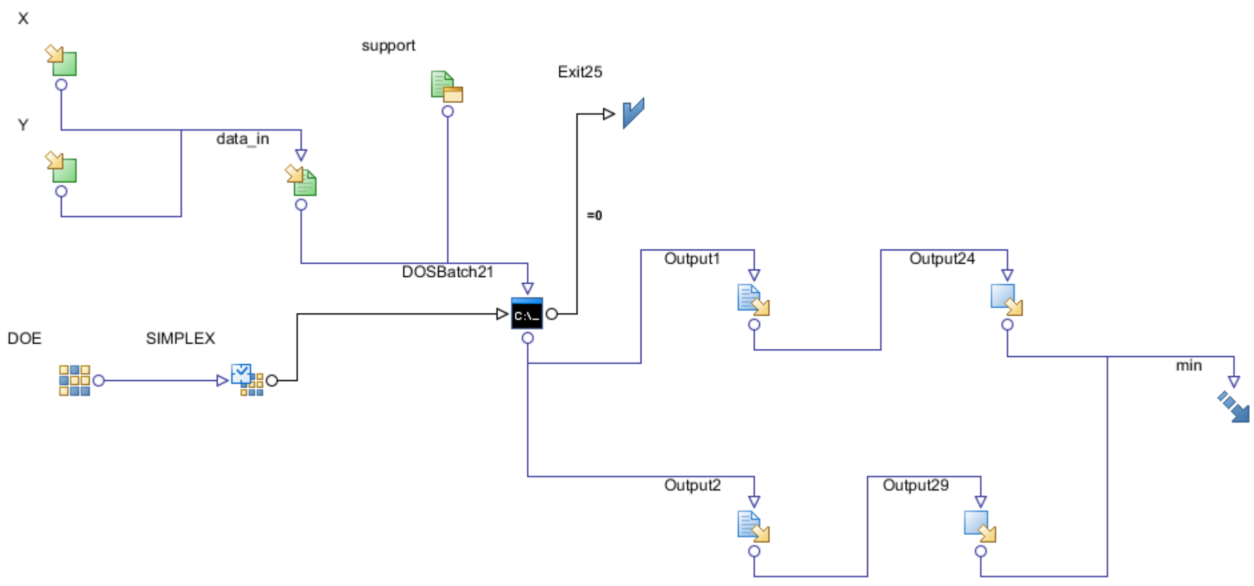


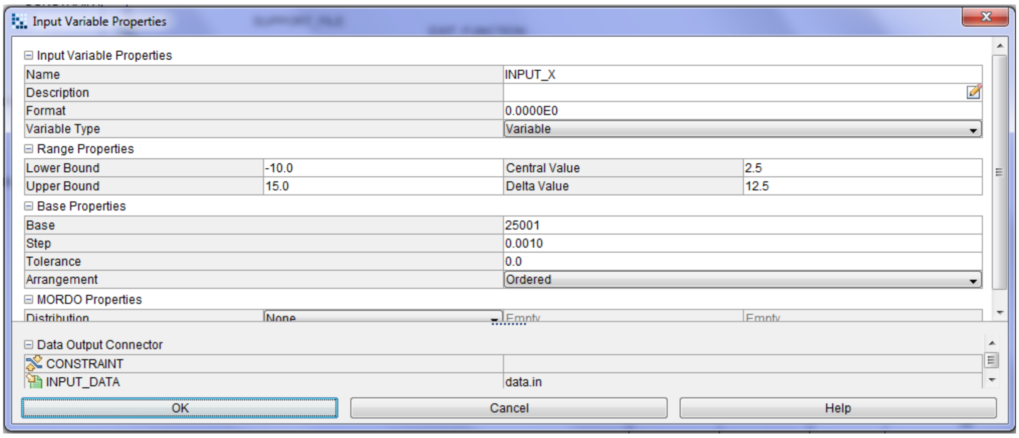
Figure 3 WEIGHTED FUNCTION LAYOUT

The above layout shows the optimisation circuit for minimising a two multi objective functions with two input variables the optimisation is for SIMPLEX. The weighted function is used to convert the Multi-Objective problem to Simplex to achieve the results faster. As discussed earlier in the report this has its own limitations in certain aspects.

3) INPUTTING VARIABLES INTO DIFFERENT FILES AND FUNCTION

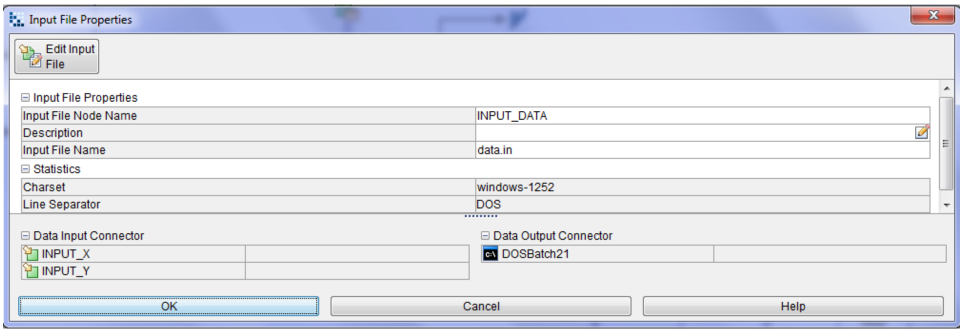
3.1) INPUT VARIABLE

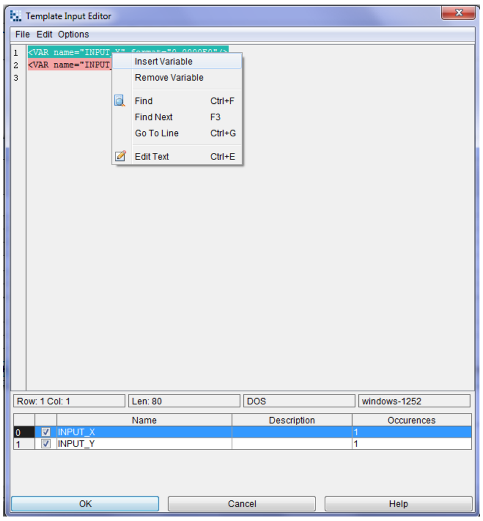
Double Click input variable, to enter properties like Name, Lower Bound Upper Bound etc. The lower bound and Upper bound values limit the variation for the particular variable.



3.2) INPUT FILE

Double Click input file, to select Input data file by clicking Edit Input File. Load a new File or assign new values using already existing file.

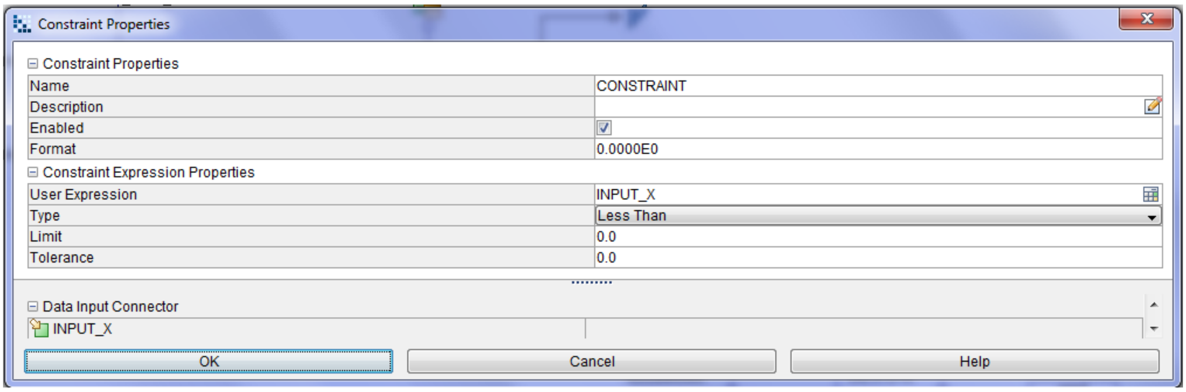




Inside Input Editor, select the Input Variable, then select the value, right click on the value to be assigned and select insert variable.

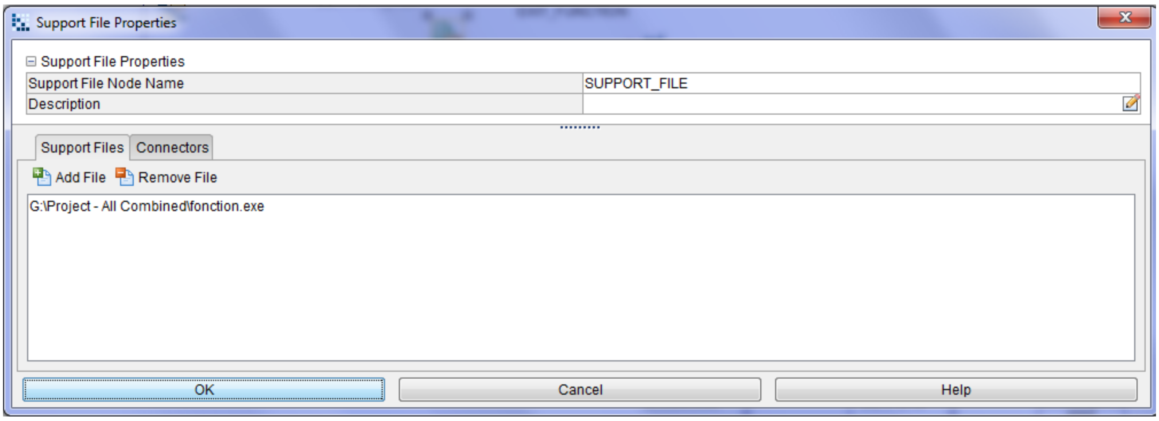
3.3) CONSTRAINT

In the constraint file, select the user expression, select the type of constraint (Less than or Greater than) and enter the limiting value of the constraint.



3.4) SUPPORT FUNCTION

In support function, click Add File to add all *.exe and other supporting algorithm files necessary to run the optimisation.



3.5) EXIT FUNCTION

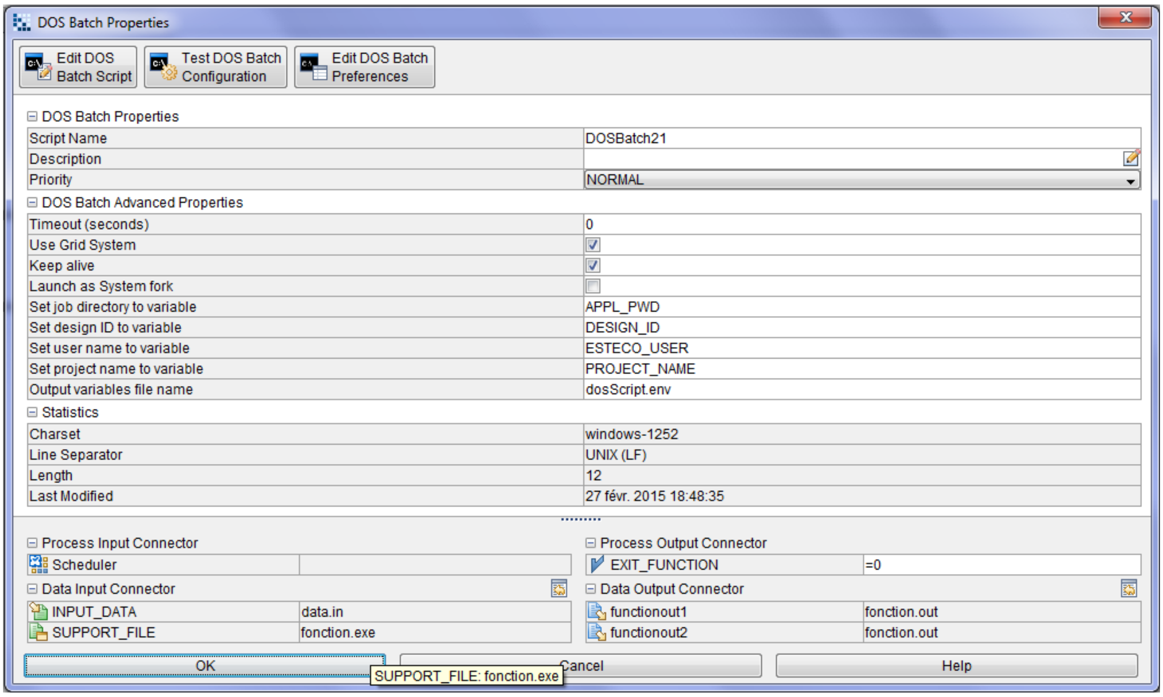
The role of exit function is to exit the optimisation operator in case the desired objective has been achieved. We did not alter any values or variables in the exit function.

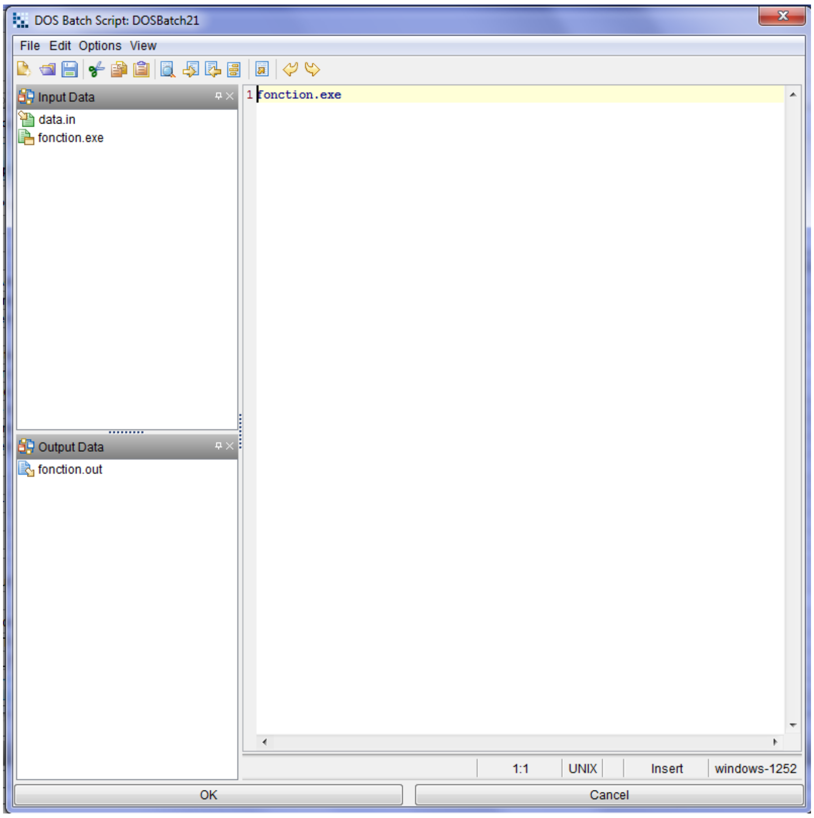
3.6) DOS OPERATOR

The dos operator is the main operating variable that receives input from Scheduler, Input Function, provides output to output function and exit function.

The main objective of DOS Operator is to integrate the input function and the support files. Take input of variables from scheduler for a certain optimisation type and process the information.

Click Edit Dos Batch Script to select the supporting functions from both input and output files.



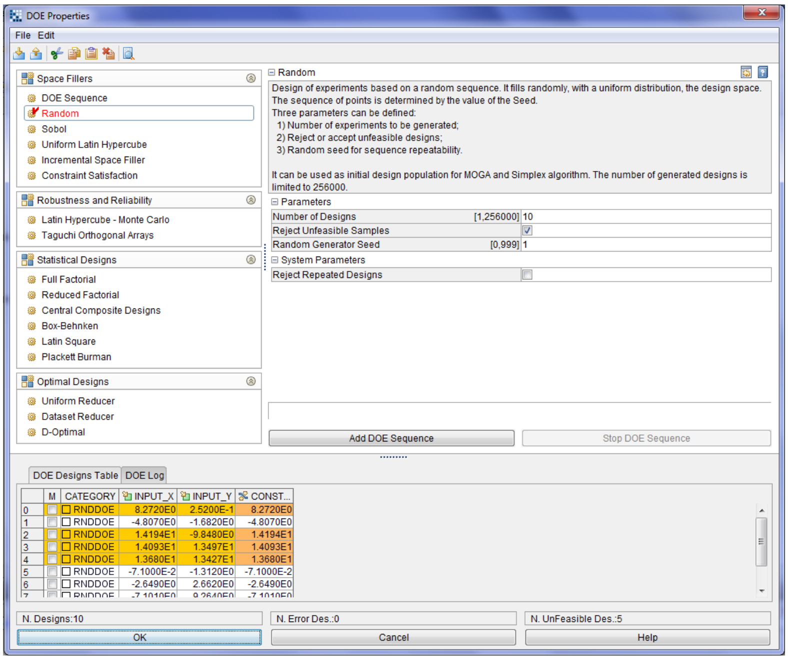


In Dos batch, either we can select the files from the listed ones or we can enter any specific file directory.

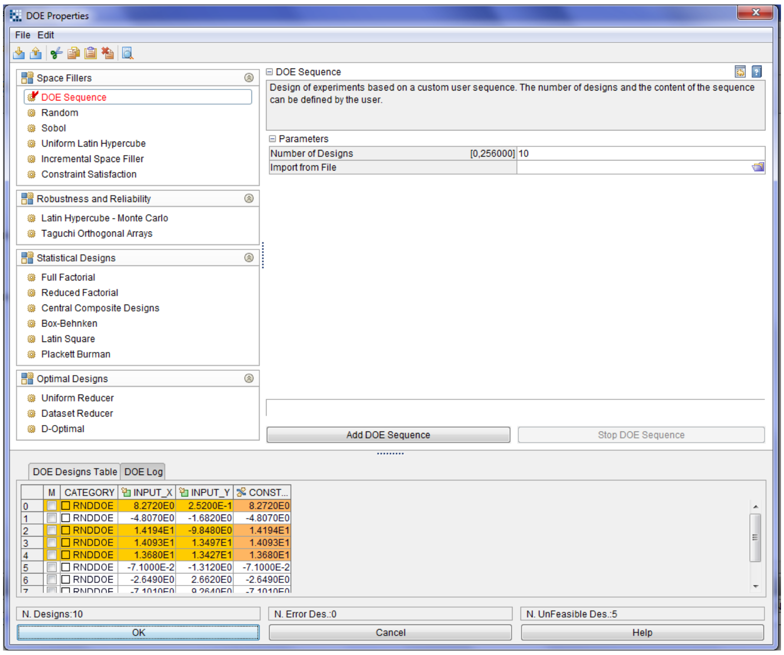
3.7) SCHEDULER – DESIGN OF EXPERIMENT (DOE) & OPERATOR SELCTION

There are two parts of selection in a Scheduler one for selecting DOE and Other to select Type of optimisation operator. In DOE selection we have used two options one for RANDOM variables and other USER DEFINED.

3.7 A) SCHEDULER – DESIGN OF EXPERIMENT (DOE)



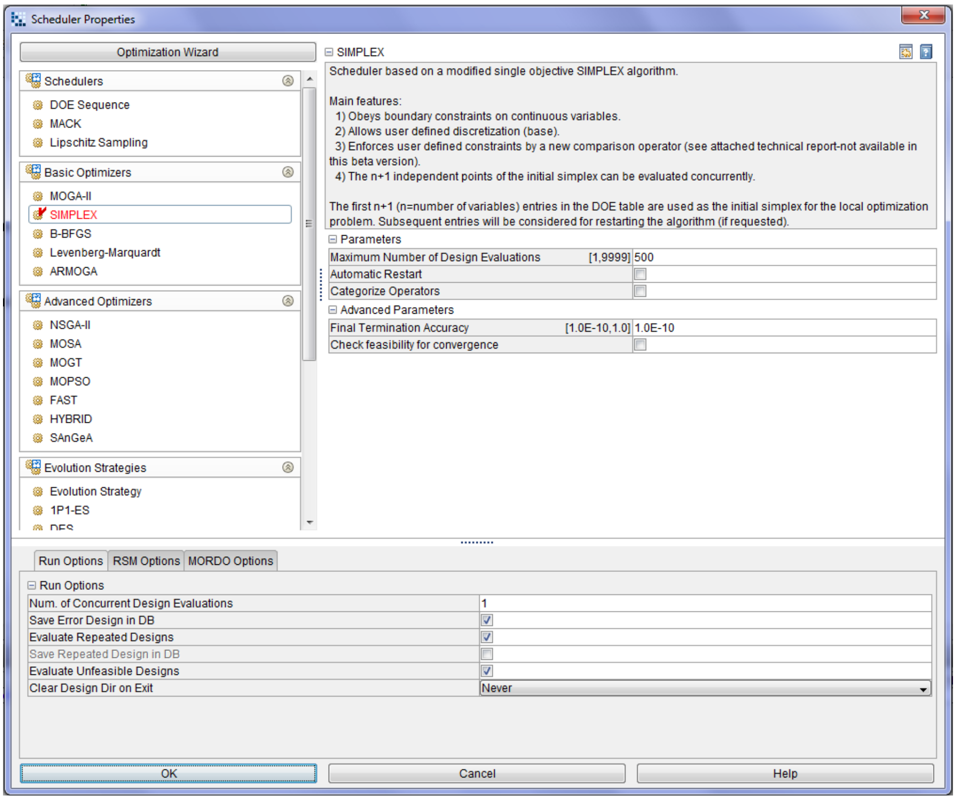
For random variable select random in space filters and number of design and click add DOE sequence.

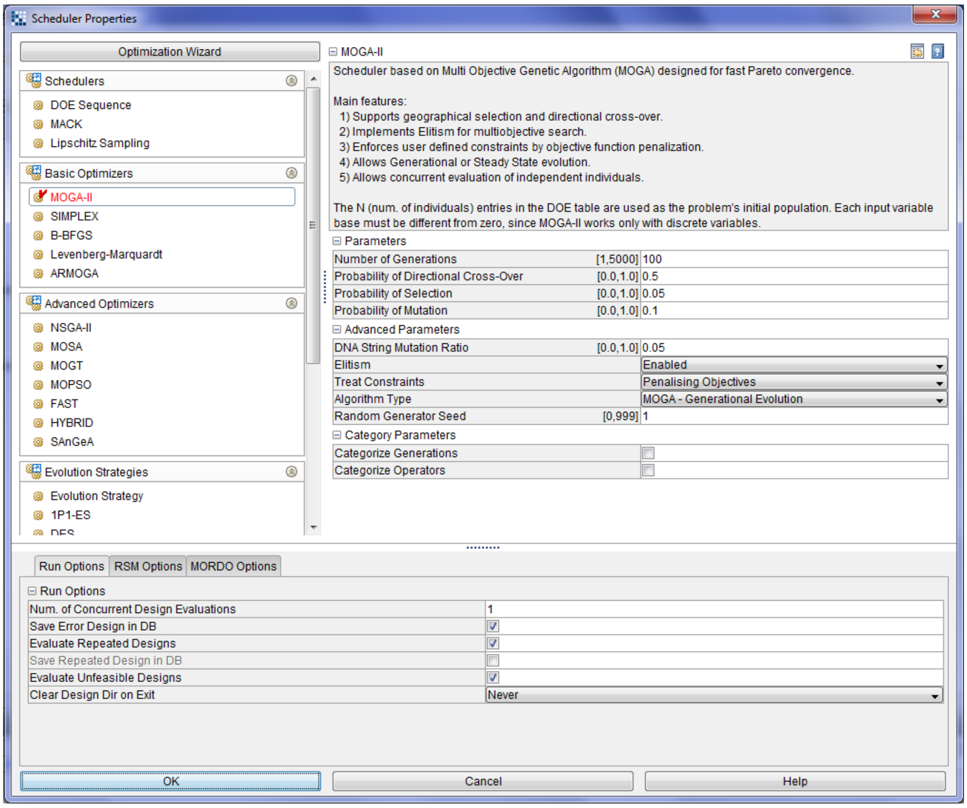


For User Defined Variables select DOE Sequence in space filters and number of design and click DOE sequence. After that we need to enter the user defined values in the DOE Design Table.

3.7 B) SCHEDULER – OPERATOR SELECTION

While selecting the optimisation in Scheduler, when we select SIMPLEX we have the option to select the maximum number of design evaluation.

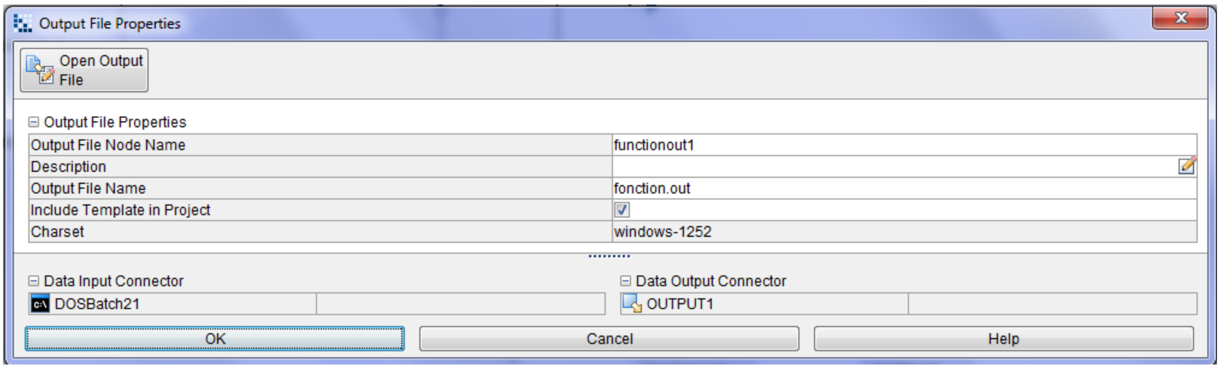


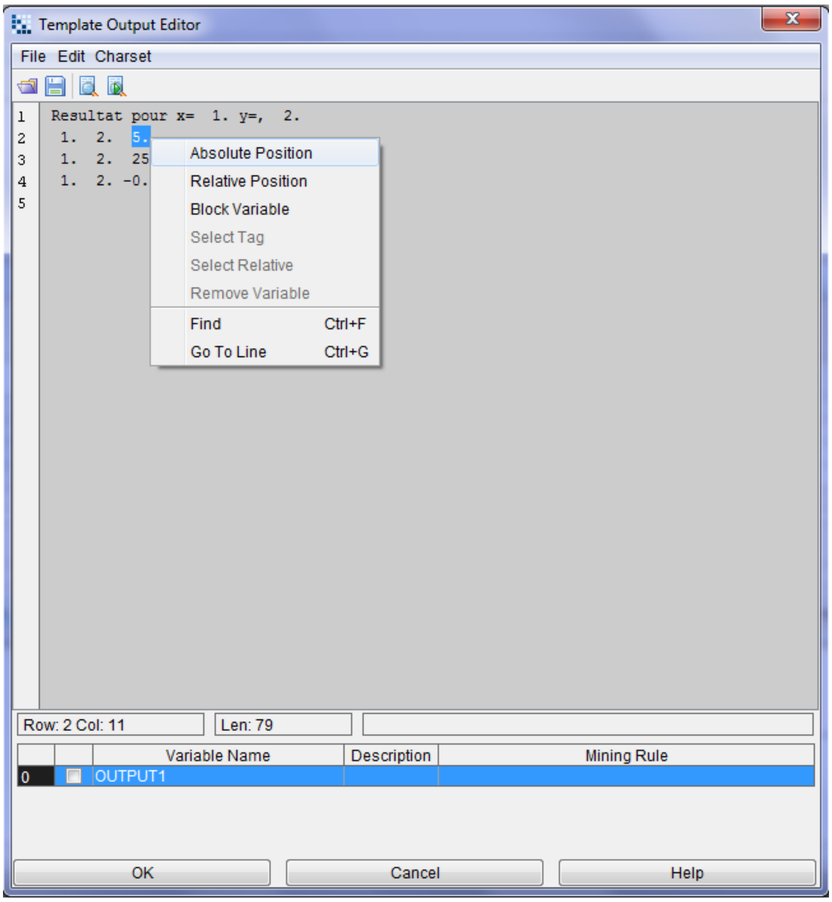


When we select MOGA in scheduler we have the option to select the number of generation and the probability, this effects the no. of iteration MOGA will run before it stops automatically irrespective of whether the desire results are achieved or not.

3.8) OUTPUT FILE

To assign output variables open output file properties and click Open Output file to assign values





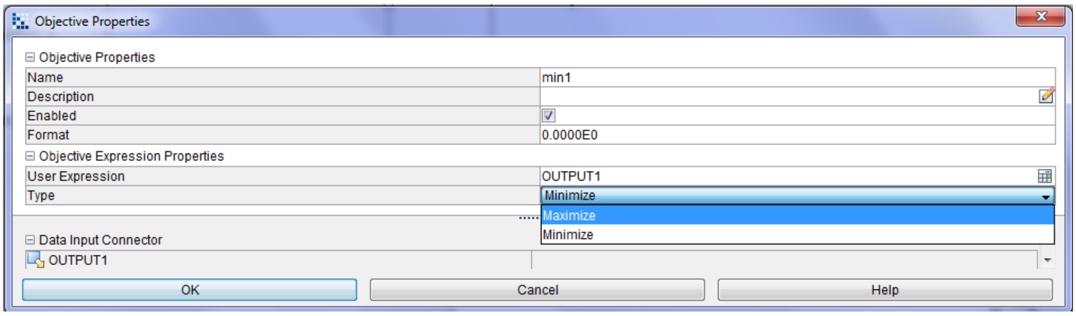
In Output editor select the output variable, right click on the value to be assigned and select absolute position.

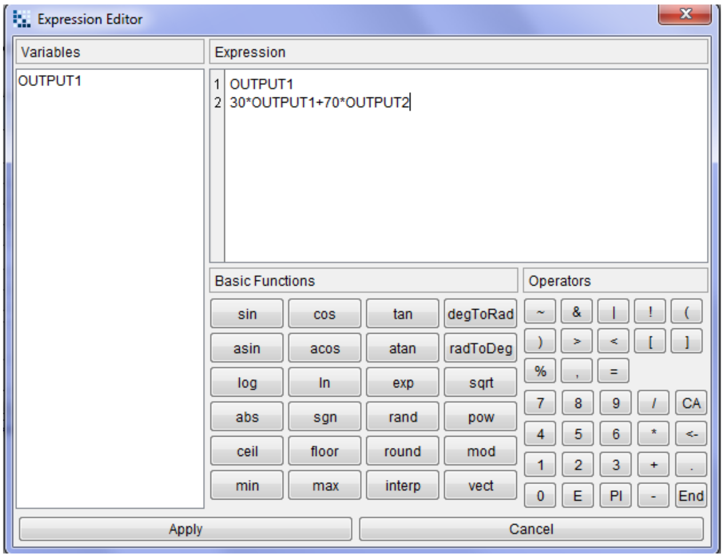
3.9) OUTPUT VARIABLE

In output variable we assign the input variable to be optimised.

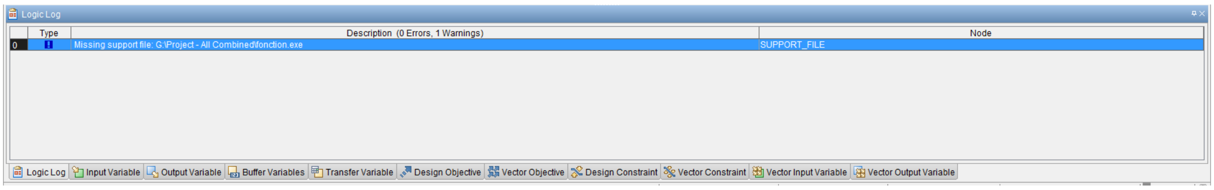
3.10) MINIMISER / MAXIMISER

This tool is used to select the output to be minimised or maximised. In addition we also have the ability to select a user defined weighted function in case we convert the Multi-Objective problem to be solved using Simplex Method.

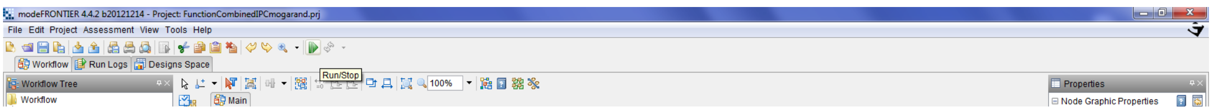




The above figure shows the second option where output1 is given 30% weightage and output2 is given 70%. We can test the optimisation for different weightage as long as the total weightage of all function is 1 (or 100%)



Check the Logic Log for error, rectify if any (as shown above).



Click RUN at top tool bar to start the optimisation process.

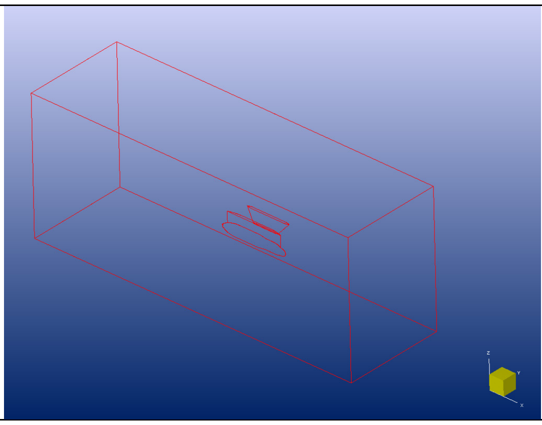
We can then check the Design Space to track the optimisation and then generate Graphs and Plots to analyse the result, in this case we have exported the values of iteration to MS Excel and MATlab to carry out the analysis.

SETUP DETAILS AND REULSTS FOR FINE MARINE ANALYSIS

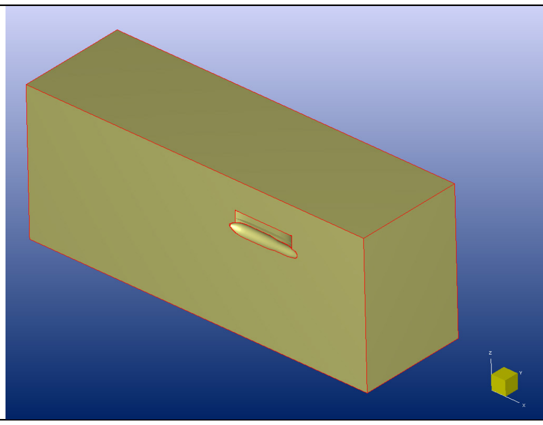
FineMarine© is a solver based on Reynolds Averaged Navier Stokes Equation (RANSE), FineMarine© was chosen due to licence availability at DN&T, Liege. The modelling was done in Rhino3dM and a parasolid export was carried out in order to import the model into FineMarine©. Once the model is imported we need to check continuity of surfaces in HEXPRESS and then prepare the project setup which involves following basic steps

BASIC STEPS TO SETUP			
S. No.	**ELEMENT NAME**	**S. No.**	**ELEMENT NAME**
1	Defining Domain	7	Surface Refinement
2	Manipulating Domain	8	Mesh Snapping
3	Grid/Boundary Condition Definition	9	Mesh Optimisation
4	Initial Meshing	10	Viscous Layer Generation
5	Free Surface Mesh	11	Defining Motion Parameters
6	Global Refinement	12	Setting-up Computational Controls

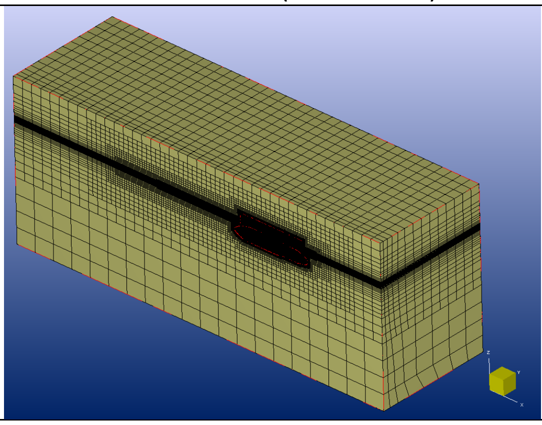
4) MODELING MESH WIZARD



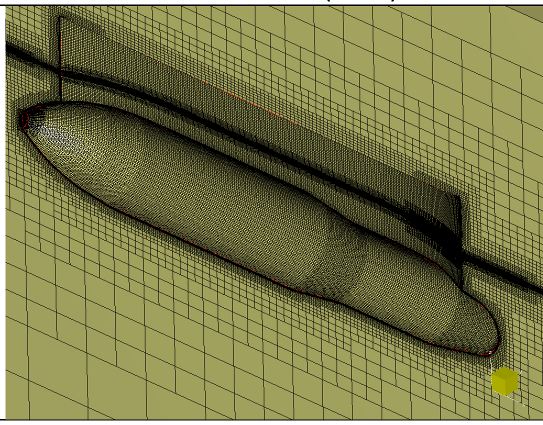
Initial Domain (Wire Frame)



Initial Domain (Solid)



Initial Mesh



Final Optimised Mesh

1.1) INITIAL MESH DEFINIATION

The initial mesh involved subdividing the domain bounding box along Cartesian coordinates as be details below

MESH DEFINITION					
S. No.	**ELEMENT**	**VALUE**	**S. No.**	**ELEMENT**	**VALUE**
1	X – Axis	20	4	Z – Axis	10
2	Y – Axis	06	5	No. of Cells	1200
3	N_b Cells	4,397,433	6	N_b Vertices	5,167,773

1.2) MESH REFINMENT AND TRIMING

This involves optimising and snapping the auto generated mesh to adapt to geometry.

GLOBAL REFINEMENT PARAMETERS		
S. No.	**ELEMENT DESCRIPTION**	**VALUE**
1	Max. No. of Refinement	10
2	Refinement Diffusion	02
3	No. of Cells in Gap	07
4	Max. Cell Size	1e+20

SURFACE REFINEMENT PARAMETERS					
DECK CENTRAL AND OUTRIGGER			**HULL CENTRAL AND OUTRIGGER**		
S. No.	**ELEMENT**	**VALUE**	**S. No.**	**ELEMENT**	**VALUE**
1	Max. No. of Refinement	04	1	Max. No. of Refinement	06
2	Curvature	NO	2	Curvature	YES
3	Target Cell Sizes	X: 0; Y: 0; Z: 0;	3	Target Cell Sizes	X: 0.35; Y: 0.35; Z: 0.35;
TRANSOM			**INTERNAL SURFACES**		
S. No.	**ELEMENT**	**VALUE**	**S. No.**	**ELEMENT**	**VALUE**
1	Max. No. of Refinement	07	1	Max. No. of Refinement	08
2	Curvature	NO	2	Curvature	NO
3	Target Cell Sizes	X: 0; Y: 0; Z: 0;	3	Target Cell Sizes	X: 3.1744; Y: 3.1744; Z: 3.1744;

1.3) VISCOUS LAYER INSERTION

VISCOUS LAYER PARAMETERS					
GLOBAL			**SURFACE**		
S. No.	**ELEMENT**	**VALUE**	**S. No.**	**ELEMENT**	**VALUE**
1	First Layer Thickness	1e-005	1	First Layer Thickness	3.08e-004
2	Stretching Ratio	1.2	2	Stretching Ratio	1.2
3	Inflate Viscous Layer	Fixed No.	3	No. of Layers	20

5) COMPUTATION WIZARD

The computation wizard can be divided into mainly three different elements

- Physical Configuration
- Numerical Model
- Computational Control

The description below will provide the details of each element and their specific sub-elements

2.1) PHYSICAL CONFIGURATION

GENERAL PARAMETERS		
S. No.	**ELEMENT DESCRIPTION**	**VALUE**
1	Time Configuration	Steady
2	Mono-Fluid	Steady Approach
3	Multi-Fluid	Time-marching Method

FLUID MODEL					
S. No.	**ELEMENT**	**VALUE**	**S. No.**	**ELEMENT**	**VALUE**
1	Name	WATER	1	Name	AIR
2	Dynamic Viscosity	0.001103 Pa-s	2	Dynamic Viscosity	1.85e-005 Pa-s
3	Density	1025.07 kg/m^3	3	Density	1.2 kg/m^3

FLOW MODEL		
S. No.	**ELEMENT DESCRIPTION**	**VALUE**
1	Turbulence Model	k-omega-SST
2	Reference Length	15.5 m
3	Reference Velocity	10.28 m/s
4	Reynolds Water	1.4808E+008
5	Froude	0.83367

BOUNDRY CONDITION					
SOLID			**EXTERNAL**		
S. No.	**ELEMENT**	**VALUE**	**S. No.**	**ELEMENT**	**VALUE**
1	Deck Central and Outrigger	Slip	1	Z-max	Prescribed Pressure (Updated Hydrostatic Pressure)
2	Hull Central and Outrigger	Wall Function	2	X-min	Far Field
			3	Far Field Velocity	Constant: 0 m/s (VX, VY and VZ)
			4	Mass Fraction	Default Value

BODY MOTION (GEOMETRY : HALF BODY)					
DOF MOTION DEFINITION					
S. No.	ELEMENT	VALUE	S. No.	ELEMENT	VALUE
1	TX	Imposed, ½ Sinusoidal Ramp	1	RX (Roll)	FIXED
2	TY	FIXED	2	RY (Pitch)	FIXED
3	TZ	SOLVED	3	RZ (Yaw)	FIXED

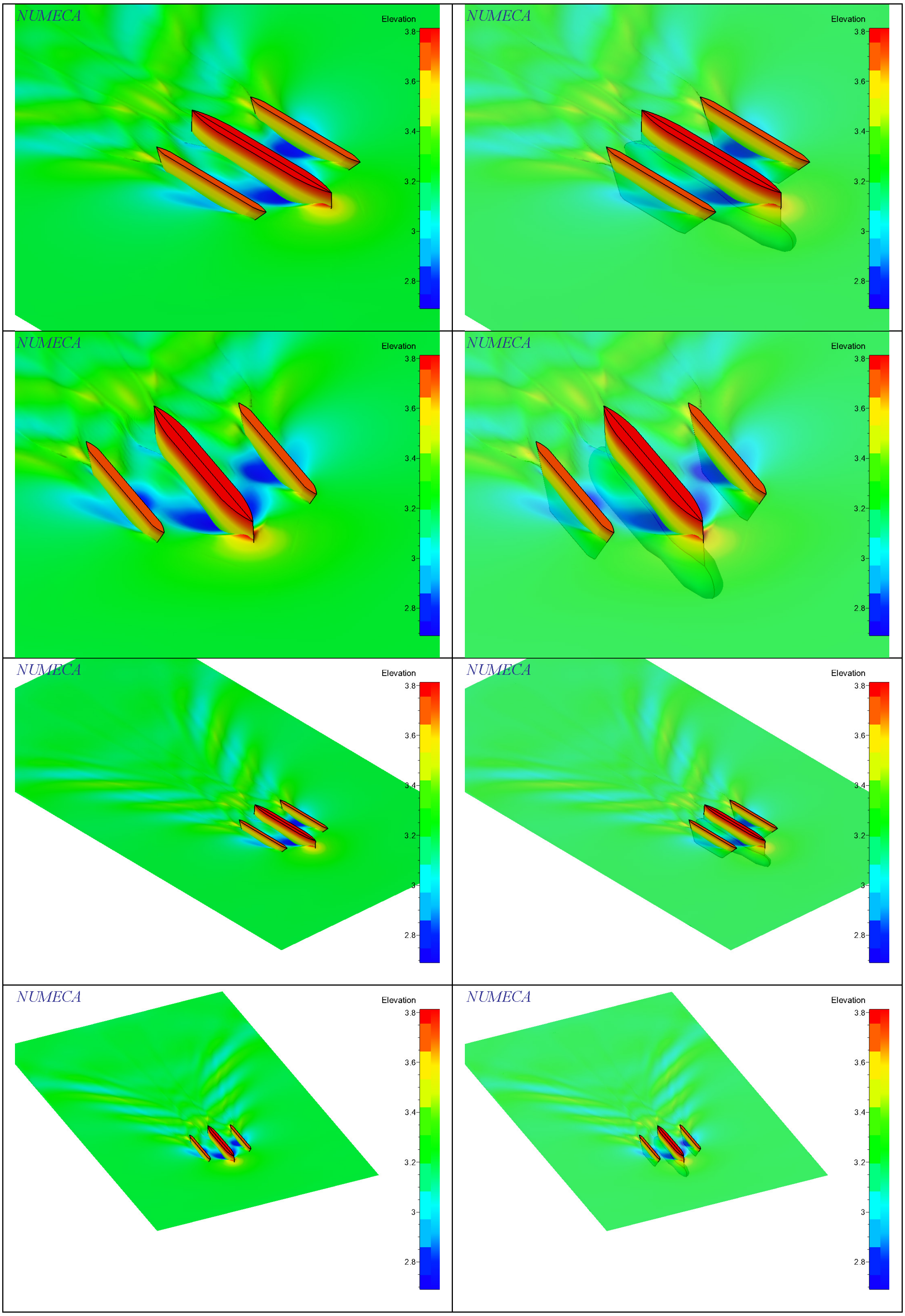
2.2) NUMERICAL MODEL

NUMERICAL SCHEME					
DISCRETISATION SCHEME			UNDER-RELAXATION PARAMETERS		
S. No.	ELEMENT	VALUE	S. No.	ELEMENT	VALUE
1	Turbulence	AVLSMART	1	VX, VY, VZ	0.5
2	Momentum	AVLSMART	2	Pressure	0.3
3	Multi-Fluid	BRICS	3	Velocity Flux	1.0
4	Cavitation	None	4	Correction	0.5
			5	Turbulent KE	0.2
			6	Turbulent (Hz)	0.2
			7	Mass-Fraction	0.5

2.3) COMPUTATION

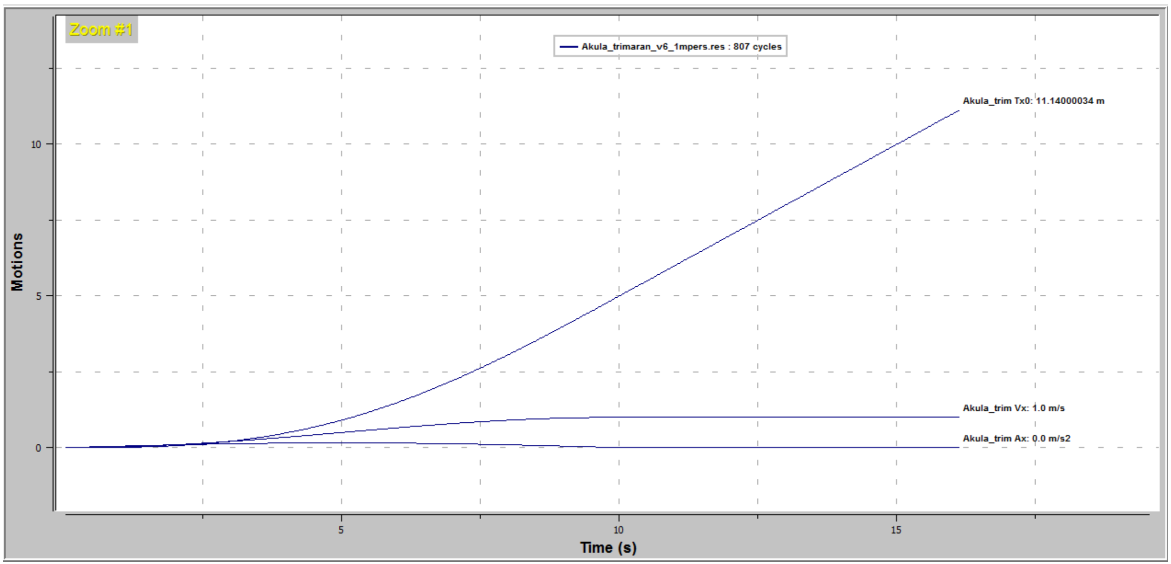
CONTROL VARIABLES					
GENERAL PARAMETERS			TIME STEP PARAMETERS		
S. No.	ELEMENT	VALUE	S. No.	ELEMENT	VALUE
1	Max. No. of Non-linear Iteration	6	1	No. of Time Steps	1000
2	Convergence Criteria	2 orders	2	Time Step Law	UNIFORM

6) WAVE PROFILE AT 20 knots for FineMarine©

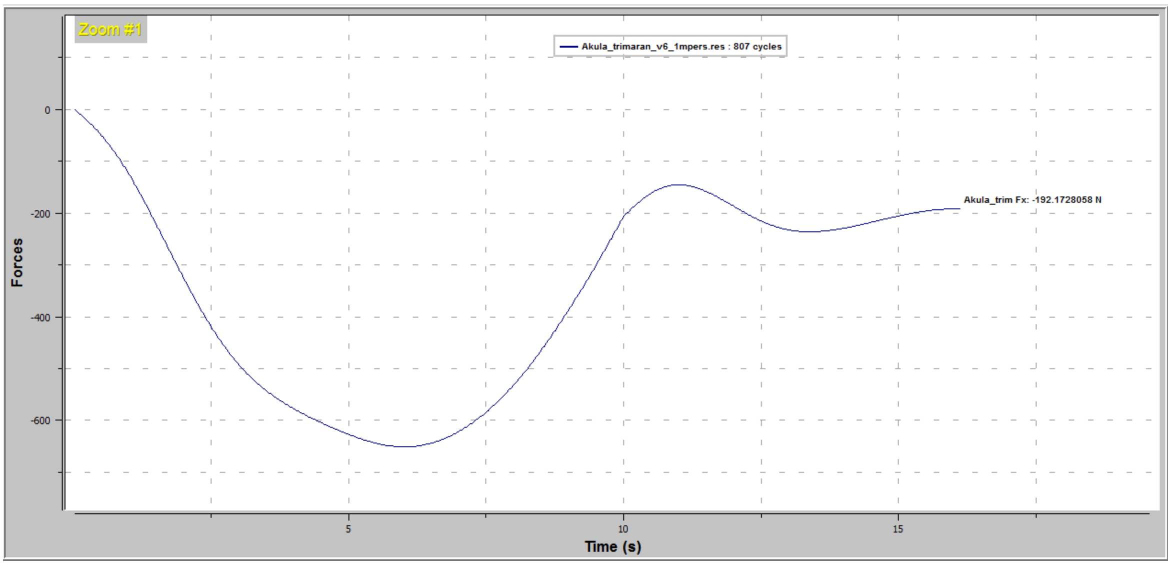


7) RESISTANCE RESULTS AT 1 m/s

MOTION VS TIME

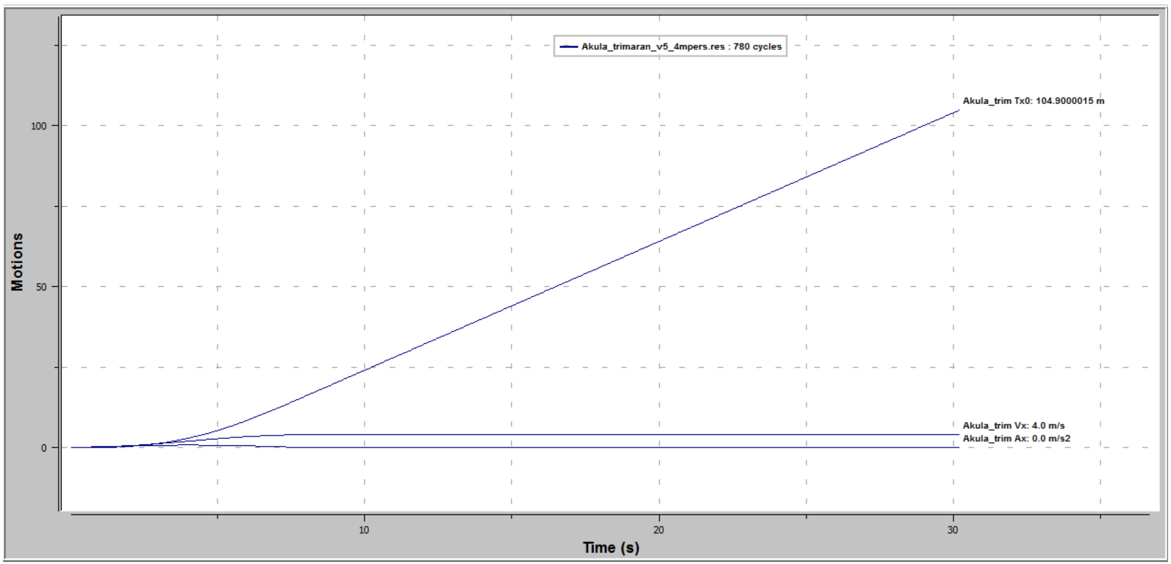


FORCE (HALF RESISTANCE) VS TIME

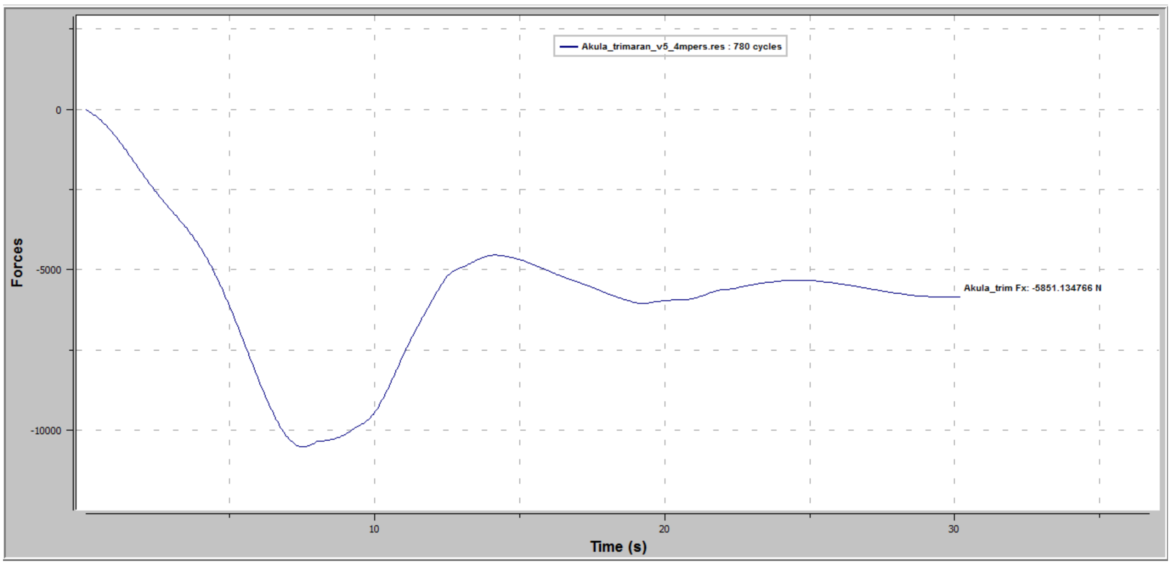


8) RESISTANCE RESULTS AT 4 m/s

MOTION VS TIME

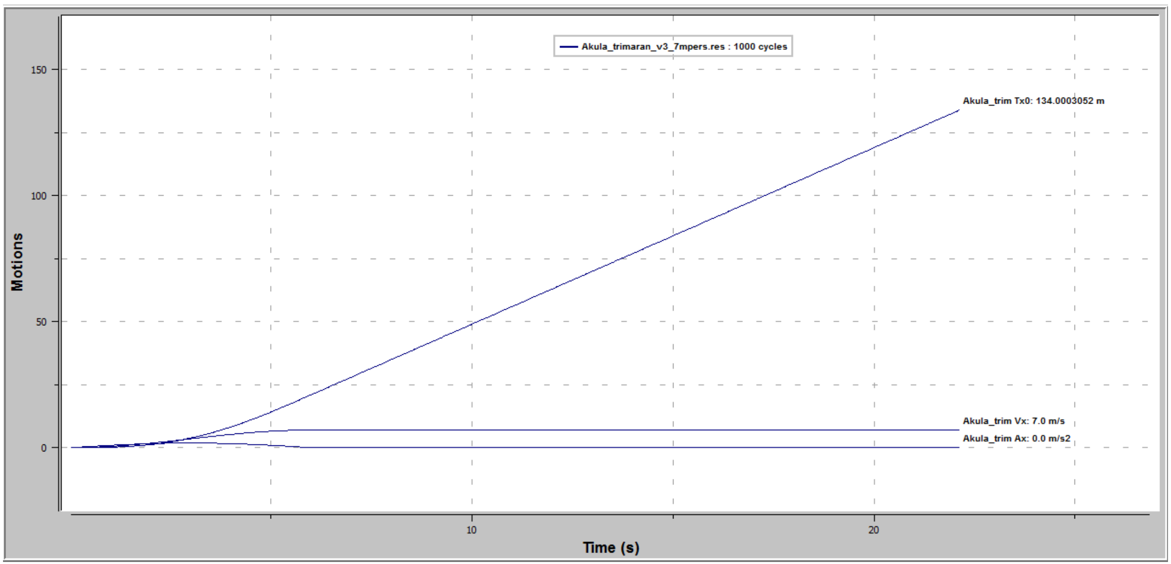


FORCE (HALF RESISTANCE) VS TIME

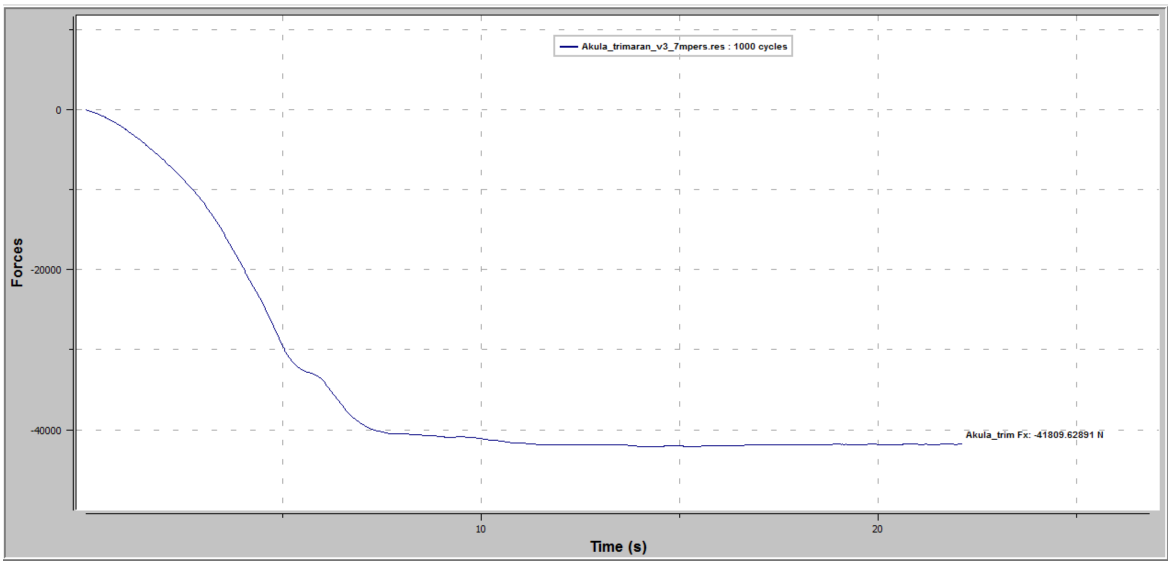


9) RESISTANCE RESULTS AT 7 m/s

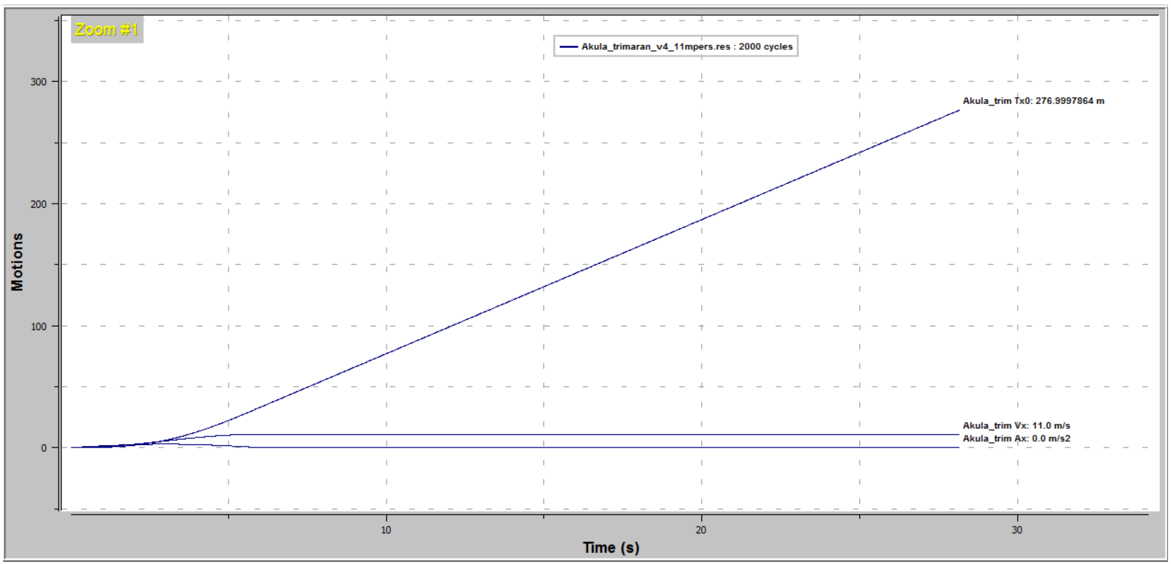
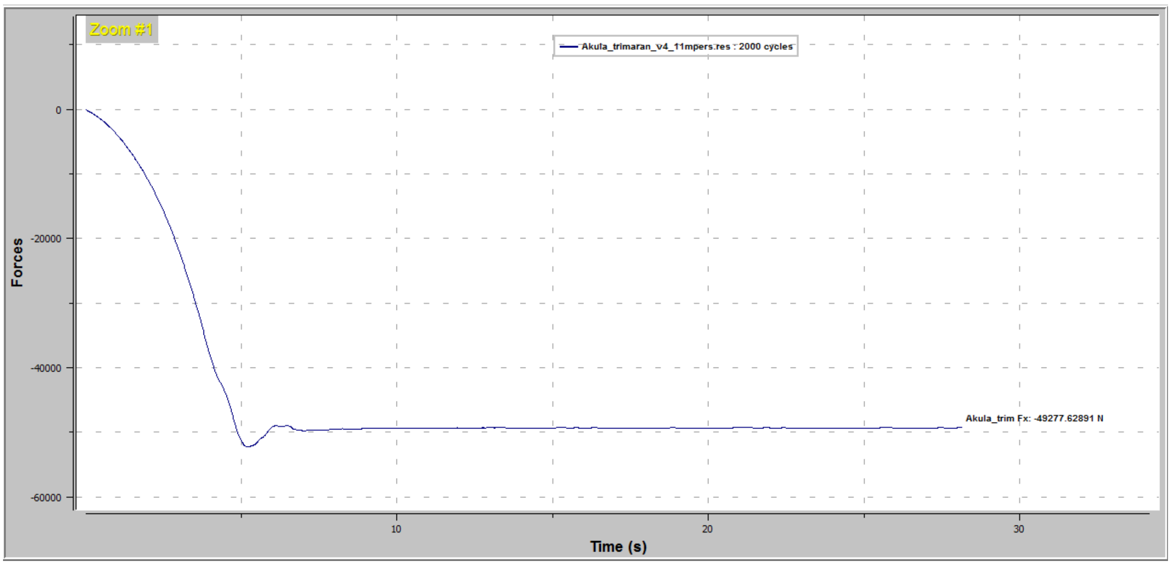
MOTION VS TIME



FORCE (HALF RESISTANCE) VS TIME

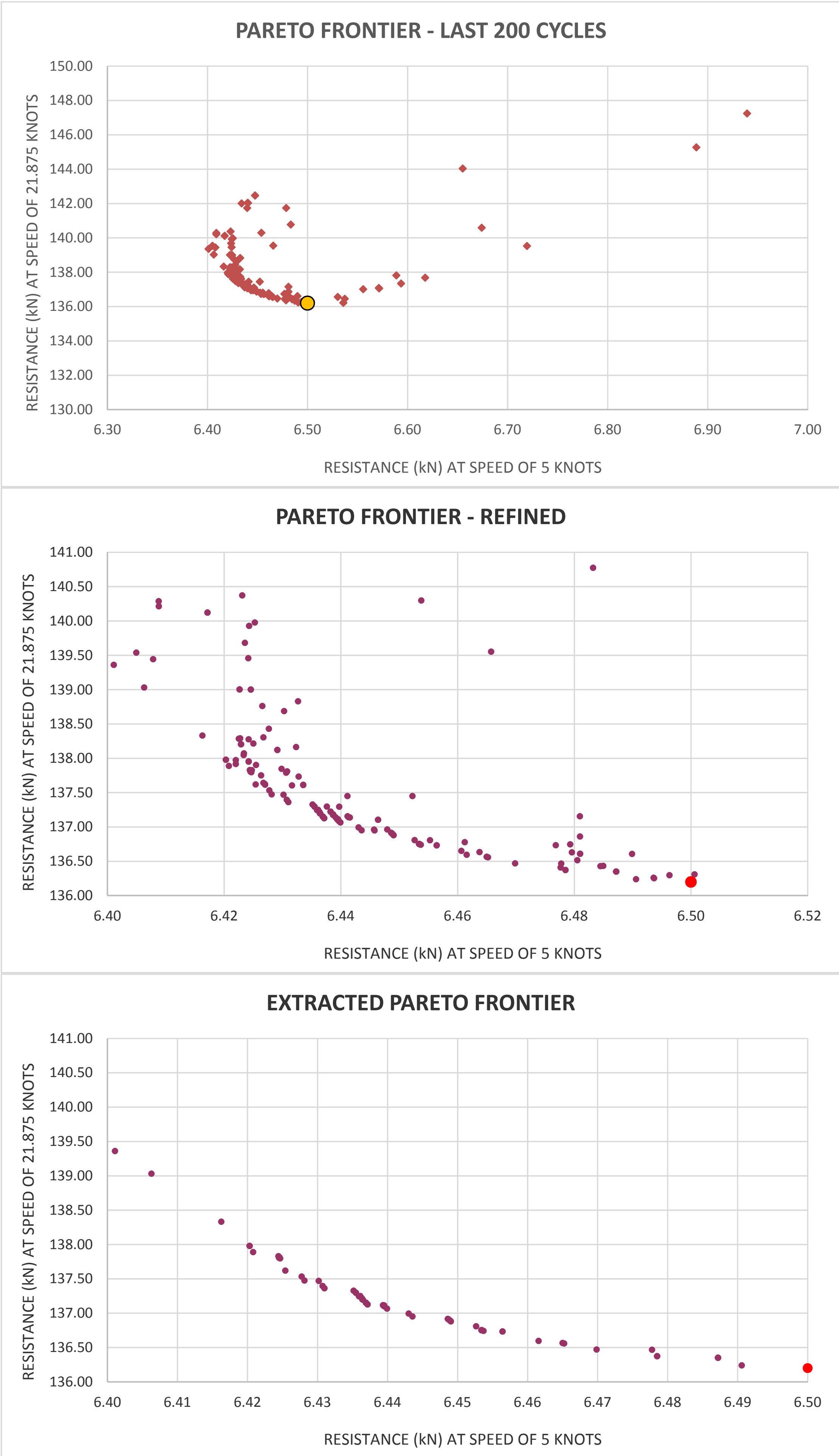


10) RESISTANCE RESULTS AT 11 m/s

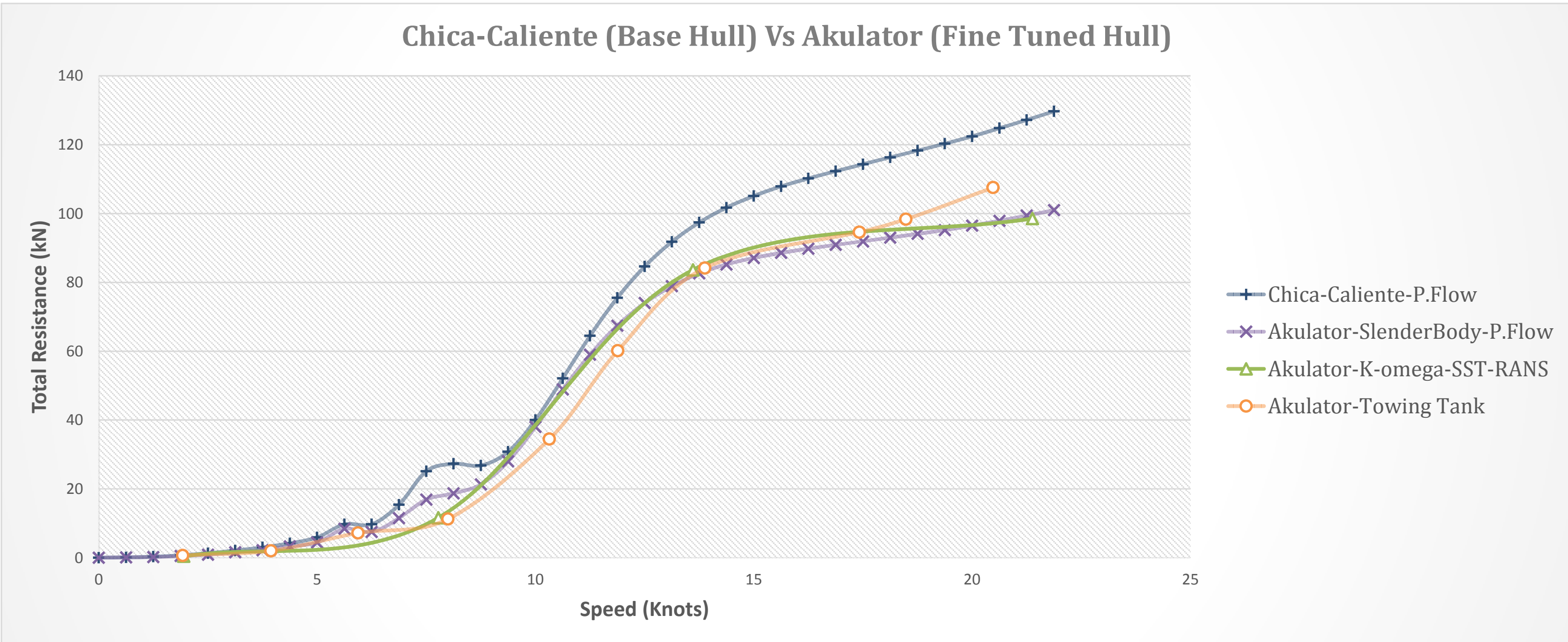
MOTION VS TIME

FORCE (HALF RESISTANCE) VS TIME


REULSTS – LAST 200 CYCLES PARETO FRONTIER VALUES

Extacted Pareto Frontier Iterations		Extacted Pareto Frontier Iterations		Extacted Pareto Frontier Iterations		Extacted Pareto Frontier Iterations	
21.875 knots	5 knots	21.875 knots	5 knots	21.875 knots	5 knots	21.875 knots	5 knots
160.642	6.852	137.605	6.432	136.753	6.453	137.952	6.424
179.546	7.361	142.011	6.434	136.962	6.446	138.286	6.423
156.070	7.214	140.373	6.423	136.748	6.479	138.072	6.423
150.047	6.848	137.470	6.430	137.152	6.437	138.277	6.424
179.621	7.361	136.743	6.454	137.752	6.426	137.249	6.436
166.217	7.625	136.516	6.481	223.772	7.574	137.974	6.422
150.047	6.848	136.410	6.478	137.734	6.433	137.185	6.439
147.370	7.144	136.994	6.443	144.035	6.655	137.890	6.421
153.833	6.639	136.566	6.465	137.152	6.437	136.952	6.444
147.452	7.151	136.779	6.461	137.298	6.435	137.814	6.425
154.072	6.640	138.121	6.429	138.830	6.433	137.102	6.440
147.316	7.148	136.917	6.449	140.774	6.483	137.827	6.425
139.527	6.719	138.762	6.427	139.004	6.423	137.138	6.442
137.818	6.589	138.430	6.428	141.739	6.479	138.049	6.423
137.680	6.618	136.635	6.464	139.683	6.424	137.157	6.441
136.261	6.494	136.433	6.485	139.929	6.424	147.247	6.939
137.347	6.593	138.165	6.432	137.642	6.427	239.386	9.275
136.199	**6.500**	139.001	6.425	139.004	6.423	137.066	6.440
137.157	6.481	136.595	6.462	137.298	6.435	137.115	6.440
137.013	6.556	136.310	6.501	137.617	6.427	137.980	6.420
136.222	6.536	136.566	6.465	137.810	6.431	142.467	6.448
137.065	6.572	139.001	6.425	137.152	6.437	137.115	6.439
136.881	6.449	136.809	6.453	137.223	6.438	137.102	6.440
136.222	6.536	136.453	6.537	137.327	6.435	137.295	6.440
137.082	6.571	136.753	6.453	137.223	6.438	142.467	6.448
137.129	6.437	137.451	6.452	137.807	6.425	137.247	6.436
136.240	6.491	145.272	6.889	188.139	7.115	137.980	6.420
136.254	6.494	136.908	6.449	137.363	6.431	162.009	6.772
137.615	6.434	136.753	6.453	137.534	6.428	137.917	6.422
136.861	6.481	136.807	6.455	137.830	6.424	137.085	6.440
136.430	6.484	136.609	6.490	137.396	6.431	137.298	6.438
180.792	7.026	136.470	6.470	140.122	6.417	137.178	6.439
136.881	6.449	136.632	6.480	137.904	6.425	137.145	6.441
140.298	6.454	136.652	6.461	140.122	6.417	137.217	6.436
137.104	6.446	136.298	6.496	165.981	6.832	137.178	6.439
137.129	6.437	136.734	6.456	139.540	6.405	137.116	6.439
136.374	6.478	136.735	6.477	137.195	6.436	140.215	6.409
137.104	6.446	136.559	6.465	139.361	6.401	139.031	6.406
137.201	6.436	136.350	6.487	139.458	6.424	137.847	6.430
136.374	6.478	136.745	6.454	137.620	6.425	140.289	6.409
136.609	6.481	138.205	6.423	137.956	6.424	138.291	6.423
138.215	6.425	139.553	6.466	141.743	6.440	138.332	6.416
136.963	6.448	138.205	6.423	137.243	6.436	139.445	6.408
136.467	6.478	136.734	6.456	137.799	6.425	137.115	6.439
136.609	6.481	137.626	6.427	142.033	6.441	137.791	6.431
138.121	6.429	136.899	6.449	138.688	6.430	139.977	6.425
137.611	6.434	136.350	6.487	137.143	6.439	136.350	6.487
140.591	6.674	137.475	6.428	142.041	6.440	137.451	6.441
136.564	6.530	136.951	6.446	138.305	6.427		


PARETO FRONTIER - LAST 200 CYCLES
RESISTANCE (kN) AT SPEED OF 21.875 KNOTS
RESISTANCE (kN) AT SPEED OF 5 KNOTS
150.00
148.00
146.00
144.00
142.00
140.00
138.00
136.00
134.00
132.00
130.00
6.30
6.40
6.50
6.60
6.70
6.80
6.90
7.00
PARETO FRONTIER - REFINED
RESISTANCE (kN) AT SPEED OF 21.875 KNOTS
RESISTANCE (kN) AT SPEED OF 5 KNOTS
141.00
140.50
140.00
139.50
139.00
138.50
138.00
137.50
137.00
136.50
136.00
6.40
6.42
6.44
6.46
6.48
6.50
6.52
EXTRACTED PARETO FRONTIER
RESISTANCE (kN) AT SPEED OF 21.875 KNOTS
RESISTANCE (kN) AT SPEED OF 5 KNOTS
141.00
140.50
140.00
139.50
139.00
138.50
138.00
137.50
137.00
136.50
136.00
6.40
6.41
6.42
6.43
6.44
6.45
6.46
6.47
6.48
6.49
6.50

18 m - Base Hull (Chica-Caliente) Vs Optimised Hull (Akulator)



Chica-Caliente	
Potential Flow	
Speed (Knots)	Resistance (kN)
0	0
0.625	0.1
1.25	0.3
1.875	0.7
2.5	1.3
3.125	2.1
3.75	3
4.375	4.2
5	5.9
5.625	9.7
6.25	9.7
6.875	15.4
7.5	25.1
8.125	27.3
8.75	26.8
9.375	30.8
10	40
10.625	52.1
11.25	64.5
11.875	75.5
12.5	84.6
13.125	91.8
13.75	97.4
14.375	101.7
15	105.1
15.625	107.9
16.25	110.2
16.875	112.3
17.5	114.3
18.125	116.3
18.75	118.3
19.375	120.3
20	122.4
20.625	124.8
21.25	127.2
21.875	129.7

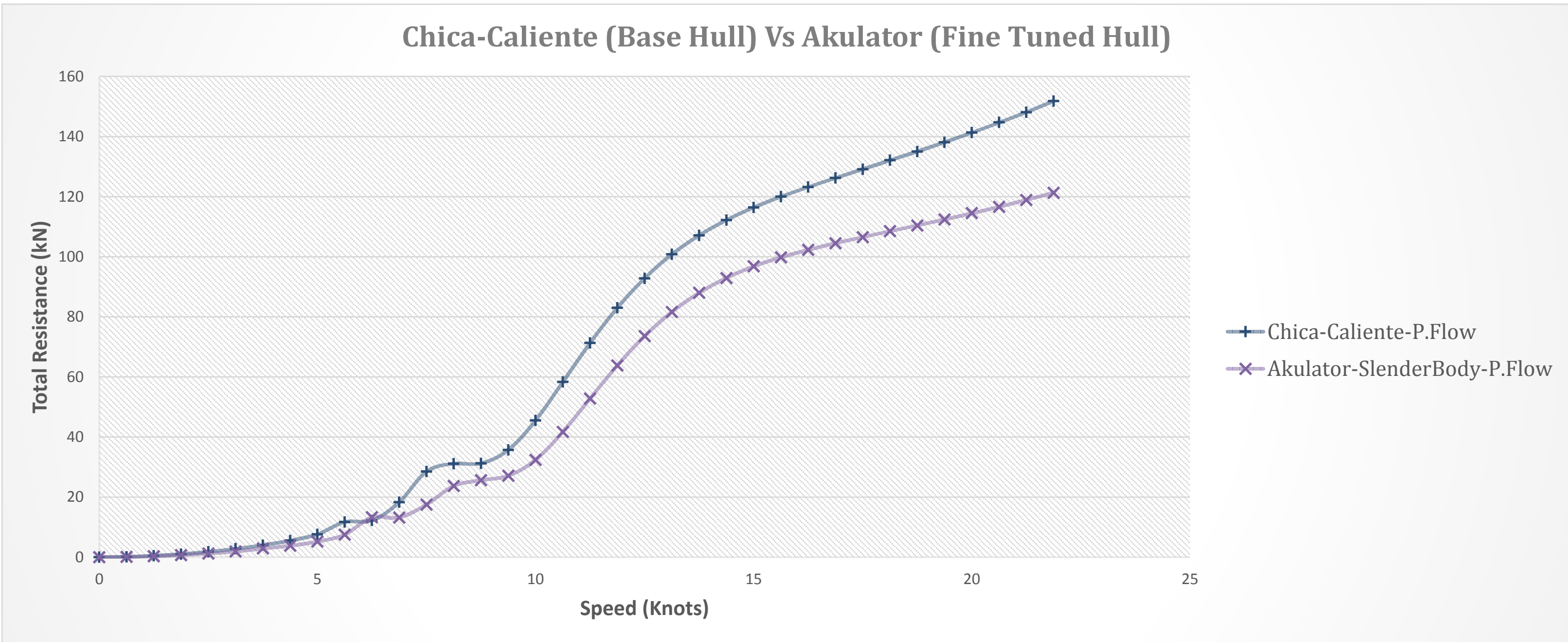
Akulator	
Potential Flow	
Speed (Knots)	Resistance (kN)
0	0
0.625	0.1
1.25	0.2
1.875	0.5
2.5	0.9
3.125	1.6
3.75	2.2
4.375	3.3
5	4.4
5.625	8.4
6.25	7.5
6.875	11.5
7.5	16.9
8.125	18.7
8.75	21.3
9.375	28
10	38
10.625	48.9
11.25	59
11.875	67.4
12.5	74
13.125	78.9
13.75	82.6
14.375	85.2
15	87.1
15.625	88.6
16.25	89.8
16.875	90.9
17.5	91.9
18.125	93
18.75	94.1
19.375	95.2
20	96.5
20.625	97.9
21.25	99.4
21.875	101

Akulator			
RANSE			
Speed (m/sec)	Speed (Knots)	Resistance (kN)	Speed (Knots)
1	1.943845	0.4	1.94384
4	7.775381	11.6	7.77536
7	13.60692	83.618	13.60688
11	21.3823	98.554	21.38224

Akulator	
Towing Tank	
Speed (Knots)	Resistance (kN)
1.924	0.647266708
3.946	2.008649548
5.937	7.185432657
7.998	11.24782018
10.318	34.44892896
11.888	60.16175697
13.878	84.16889488
17.418	94.59014702
18.483	98.34487473
20.481	107.5404989

	P. Flow Vs RANS	RANS Vs Towing Tank	P. Flow Vs Towing Tank
% Error	0.85%	8.36%	8.96%

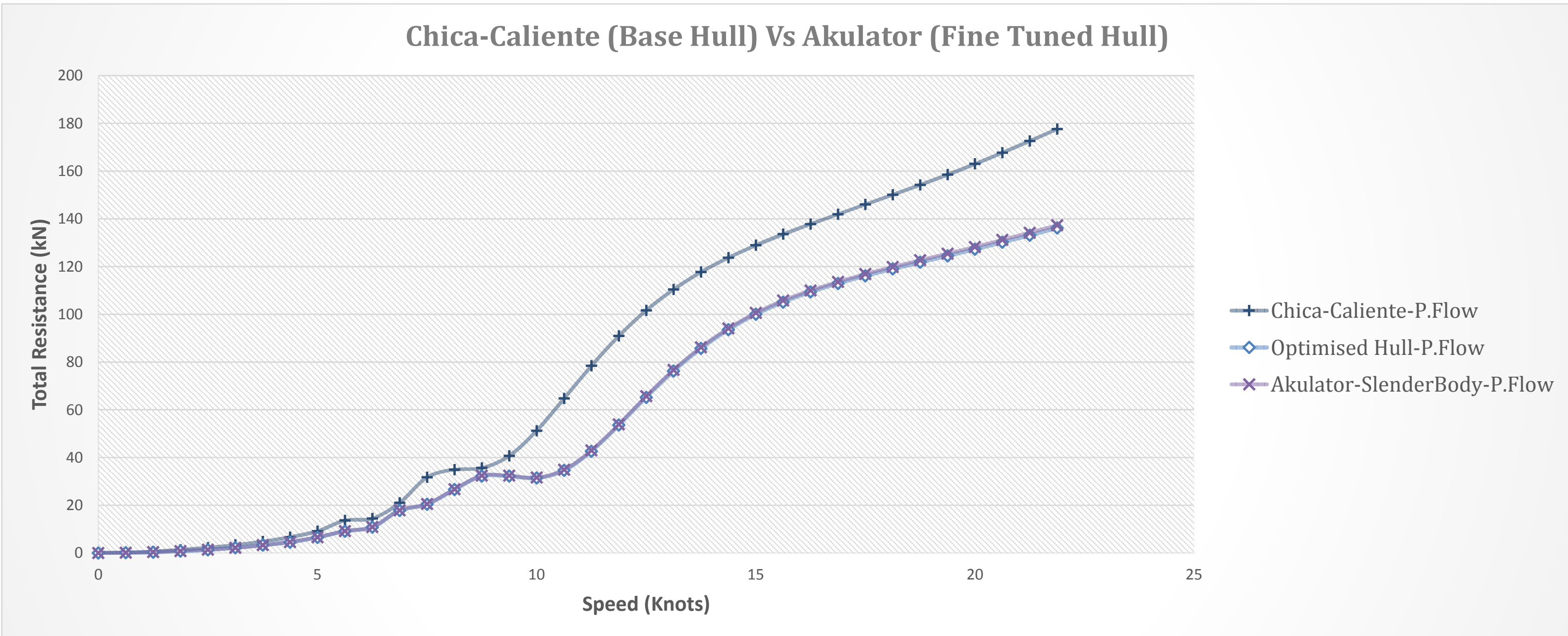
21 m - Base Hull (Chica-Caliente) Vs Optimised Hull (Akulator)



Chica-Caliente	
Potential Flow	
Speed (Knots)	Resistance (kN)
0	--
0.625	0.1
1.25	0.5
1.875	1
2.5	1.8
3.125	2.8
3.75	4
4.375	5.5
5	7.6
5.625	11.7
6.25	12.2
6.875	18.3
7.5	28.5
8.125	31.1
8.75	31.2
9.375	35.7
10	45.5
10.625	58.3
11.25	71.3
11.875	83
12.5	92.8
13.125	100.8
13.75	107.1
14.375	112.2
15	116.4
15.625	120
16.25	123.2
16.875	126.2
17.5	129.1
18.125	132.1
18.75	135
19.375	138.1
20	141.3
20.625	144.7
21.25	148.1
21.875	151.8

Akulator	
Potential Flow	
Speed (Knots)	Resistance (kN)
0	0
0.625	0.1
1.25	0.3
1.875	0.7
2.5	1.2
3.125	1.9
3.75	2.9
4.375	3.8
5	5.2
5.625	7.5
6.25	13.3
6.875	13.2
7.5	17.5
8.125	23.7
8.75	25.6
9.375	27.1
10	32.4
10.625	41.7
11.25	52.8
11.875	63.8
12.5	73.6
13.125	81.6
13.75	88
14.375	92.9
15	96.8
15.625	99.8
16.25	102.3
16.875	104.5
17.5	106.5
18.125	108.5
18.75	110.4
19.375	112.4
20	114.5
20.625	116.6
21.25	118.9
21.875	121.3

24 m - Base Hull (Chica-Caliente) Vs Optimised Hull (Akulator)

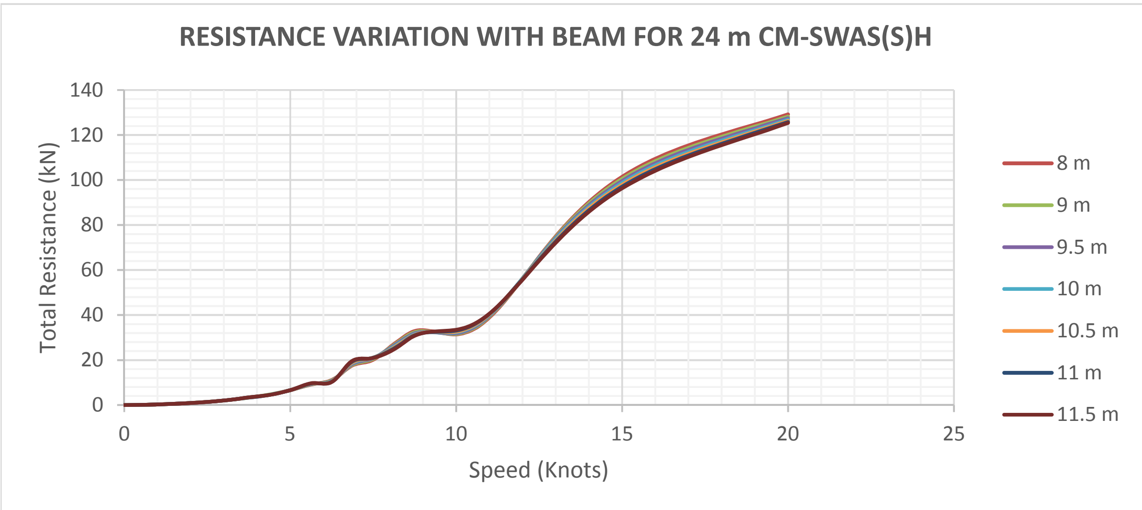


Chica-Caliente	
Potential Flow	
Speed (Knots)	Resistance (kN)
0	0
0.625	0.2
1.25	0.6
1.875	1.3
2.5	2.2
3.125	3.4
3.75	4.8
4.375	6.6
5	9.1
5.625	13.6
6.25	14.4
6.875	21
7.5	31.7
8.125	34.9
8.75	35.6
9.375	40.7
10	51.2
10.625	64.7
11.25	78.4
11.875	90.9
12.5	101.6
13.125	110.4
13.75	117.7
14.375	123.7
15	128.9
15.625	133.6
16.25	137.8
16.875	141.9
17.5	146
18.125	150.1
18.75	154.2
19.375	158.5
20	163
20.625	167.7
21.25	172.6
21.875	177.6

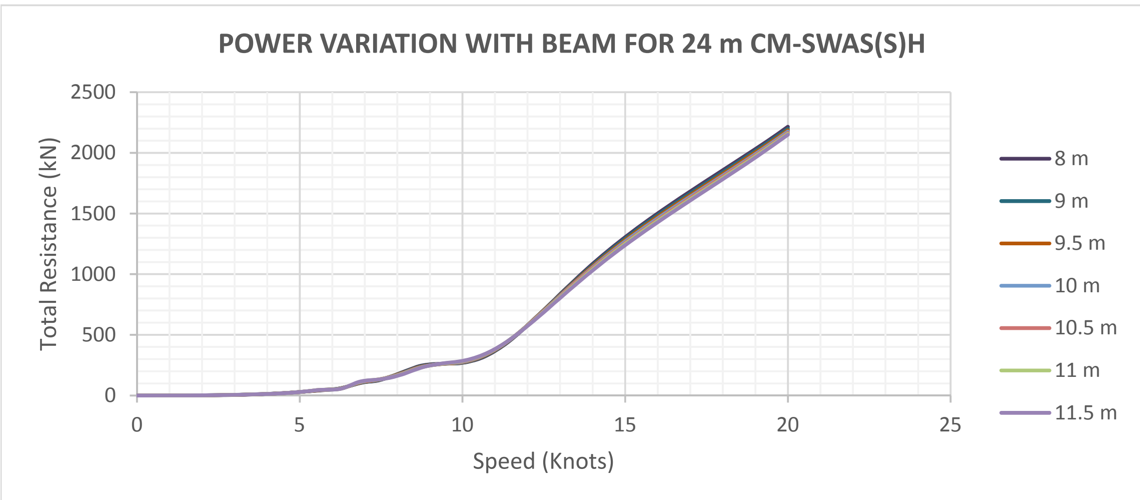
Akulator	
Potential Flow	
Speed (Knots)	Resistance (kN)
0	0
0.625	0.1
1.25	0.4
1.875	0.8
2.5	1.4
3.125	2.2
3.75	3.3
4.375	4.6
5	6.6
5.625	9.2
6.25	10.9
6.875	17.9
7.5	20.5
8.125	26.7
8.75	32.4
9.375	32.4
10	31.6
10.625	34.9
11.25	43
11.875	53.9
12.5	65.7
13.125	76.7
13.75	86.2
14.375	94.1
15	100.6
15.625	105.8
16.25	110
16.875	113.6
17.5	116.9
18.125	119.8
18.75	122.7
19.375	125.4
20	128.2
20.625	131.2
21.25	134.2
21.875	137.3

Optimised Hull	
Potential Flow	
Speed (Knots)	Resistance (kN)
0	0
0.625	0.1
1.25	0.3
1.875	0.8
2.5	1.3
3.125	2.2
3.75	3.3
4.375	4.5
5	6.5
5.625	9.1
6.25	10.8
6.875	17.8
7.5	20.4
8.125	26.6
8.75	32.2
9.375	32.2
10	31.4
10.625	34.6
11.25	42.6
11.875	53.6
12.5	65.2
13.125	76.2
13.75	85.7
14.375	93.6
15	100
15.625	105.1
16.25	109.4
16.875	112.9
17.5	116.1
18.125	119
18.75	121.8
19.375	124.5
20	127.3
20.625	130.2
21.25	133.1
21.875	136.2

RESISTANCE VARIATION WITH BEAM FOR 24m CM-SWAS(S)H								
SPEED (Knots)	BEAM (meters) / RESISTANCE (kW)							
	7 m	8 m	9 m	9.5 m	10 m	10.5 m	11 m	11.5 m
0	0	0	0	0	0	0	0	0
0.625	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1.25	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
1.875	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
3.125	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
3.75	3.3	3.3	3.3	3.3	3.3	3.4	3.4	3.4
4.375	4.6	4.5	4.6	4.5	4.5	4.5	4.5	4.5
5	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
5.625	8.8	9.1	9.2	9.3	9.4	9.5	9.6	9.7
6.25	11.3	11.1	10.9	10.7	10.6	10.4	10.3	10.2
6.875	17.3	17.6	17.9	18.3	18.7	19	19.4	19.7
7.5	19.1	20.1	20.5	20.8	21	21	21	20.9
8.125	27.3	27.1	26.7	26.4	25.9	25.5	25.1	24.7
8.75	34	32.9	32.4	31.9	31.5	31.2	31	30.8
9.375	33.4	32.6	32.4	32.3	32.4	32.5	32.6	32.8
10	31.3	31.4	31.6	31.9	32.3	32.6	33	33.4
10.625	33.8	34.5	34.9	35.3	35.8	36.1	36.5	36.7
11.25	41.8	42.6	43	43.3	43.5	43.7	43.8	43.9
11.875	53.2	53.8	53.9	54	54	53.9	53.8	53.6
12.5	65.8	65.8	65.7	65.5	65.2	64.8	64.5	64.1
13.125	77.6	77.1	76.7	76.2	75.7	75.1	74.6	74
13.75	87.9	86.8	86.2	85.5	84.8	84.2	83.4	82.8
14.375	96.5	94.9	94.1	93.3	92.5	91.7	90.9	90.2
15	103.4	101.5	100.6	99.6	98.8	97.9	97.1	96.3
15.625	108.9	106.8	105.8	104.8	103.9	103	102.2	101.4
16.25	113.3	111.1	110	109.1	108.1	107.3	106.5	105.8
16.875	117	114.7	113.6	112.7	111.8	111	110.3	109.6
17.5	120.2	117.9	116.9	116	115.1	114.3	113.6	112.9
18.125	123.2	120.9	119.8	119	118.1	117.4	116.7	116.2
18.75	125.9	123.6	122.7	121.8	121	120.4	119.8	119.2
19.375	128.5	126.3	125.4	124.7	123.9	123.3	122.8	122.2
20	131.2	129.2	128.2	127.5	126.9	126.3	125.8	125.4



POWER VARIATION WITH BEAM FOR 24m CM-SWAS(S)H								
SPEED (Knots)	BEAM (meters) / POWER (kW)							
	7 m	8 m	9 m	9.5 m	10 m	10.5 m	11 m	11.5 m
0	--	--	--	--	--	--	--	--
0.625	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
1.25	0.378	0.378	0.378	0.378	0.378	0.378	0.378	0.378
1.875	1.232	1.232	1.232	1.232	1.232	1.232	1.232	1.232
2.5	2.92	2.917	2.916	2.917	2.917	2.919	2.92	2.925
3.125	5.795	5.856	5.886	5.919	5.937	5.936	5.892	5.812
3.75	10.64	10.693	10.728	10.67	10.696	10.832	10.934	10.91
4.375	17.14	17.067	17.111	16.987	16.847	16.844	16.949	17.067
5	28.252	28.485	28.348	28.236	28.23	28.251	28.227	28.147
5.625	42.32	43.692	44.236	44.753	45.318	45.885	46.365	46.7
6.25	60.357	59.368	58.557	57.59	56.666	55.832	55.191	54.805
6.875	102.136	103.997	105.623	107.658	109.963	112.219	114.364	116.292
7.5	122.932	129.475	131.971	133.743	134.761	135.075	134.986	134.349
8.125	189.839	188.587	186.306	183.632	180.535	177.518	174.629	171.849
8.75	255.403	246.966	242.859	239.39	236.428	234.193	232.611	231.419
9.375	268.405	262.047	260.563	259.82	260.202	261.086	262.315	263.927
10	268.583	269.29	271.346	273.809	276.769	279.903	283.04	286.095
10.625	307.957	314.387	318.164	321.918	325.685	329.016	332.127	334.227
11.25	402.852	410.721	414.402	417.64	419.741	421.322	422.492	423.255
11.875	541.897	547.811	549.188	549.8	549.748	549.046	547.53	545.546
12.5	704.797	705.264	703.641	701.601	698.366	695.007	690.805	686.534
13.125	873.59	867.461	862.659	857.35	851.568	845.521	839.158	832.713
13.75	1036.648	1023.737	1016.391	1008.56	1000.143	992.084	983.818	975.625
14.375	1188.898	1170.273	1160.202	1150.192	1139.71	1130.081	1120.494	1111.725
15	1329.573	1305.204	1293.366	1281.506	1270.065	1258.849	1248.886	1239.132
15.625	1458.546	1430.568	1416.936	1404.119	1391.723	1380.193	1369.816	1359.109
16.25	1579.148	1548.426	1532.895	1519.716	1506.2	1495.024	1483.97	1473.979
16.875	1693.344	1660.027	1644.37	1630.551	1617.549	1606.487	1595.656	1586.105
17.5	1804.202	1769.11	1753.993	1739.827	1727.48	1715.632	1705.006	1694.699
18.125	1914.164	1878.288	1862.511	1848.961	1835.644	1824.871	1814.131	1805.318
18.75	2023.56	1987.241	1972.086	1958.706	1945.367	1935.385	1925.191	1916.278
19.375	2134.864	2098.47	2083.805	2070.782	2058.904	2047.847	2040.333	2030.729
20	2249.109	2215.081	2199.014	2186.689	2175.947	2165.202	2157.212	2150.422

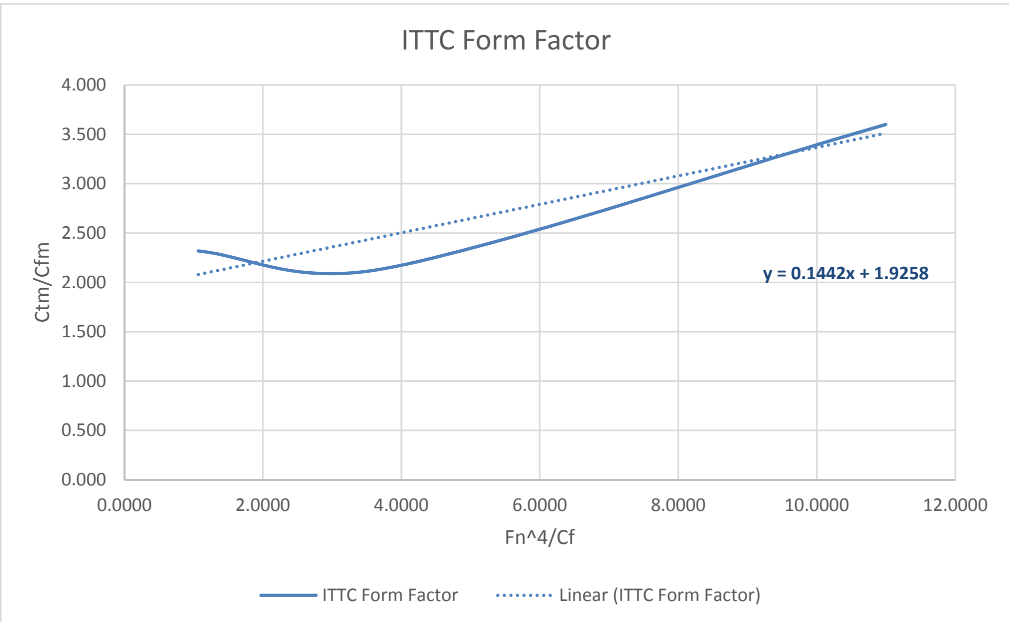


ITTC 1978 Prediction Method

Scale	13

MODEL AND SHIP DETAILS					
MODEL			SHIP		
Disp	36.117	Kg	Disp	79.350	t
LBP	0.962	m	LBP	12.500	m
LWL	1.000	m	LWL	13.000	m
Breadth	0.692		Breadth	9.000	m
Draft	0.246	m	Draft	3.200	m
Surface Area	1.032	m^2	Surface Area	174.481	m^2
Cb	0.880		Cb	0.880	
LCG	0.623	m	LCG	8.100	m (AP)
Density	1.000	t/m^3	Density	1.025	t/m^3
Kinematic Viscocity	1.14E-06	m^2/s	Kinematic Viscocity	1.188E-06	m^2/s
			At	13.51	m^2

INPUT DATA		FORM FACTOR PREDICTION					
Vm (m/s)	Rtm(N)	Fn	Ctm x 10^-3	Rn	Cfm x 10^-3	Ctm/Cfm	Fn^4/Cf
0.2745	0.48069	0.0876	12.358	241000.878	6.557	1.885	0.009
0.563	1.48131	0.1798	9.053	494293.240	5.496	1.647	0.190
0.847	4.29678	0.2704	11.602	743634.767	5.004	2.319	1.069
1.141	6.73947	0.3643	10.028	1001755.926	4.686	2.140	3.759
1.472	17.86401	0.4700	15.971	1292361.721	4.437	3.600	10.995
1.696	29.89107	0.5415	20.131	1489025.461	4.307	4.674	19.961
1.98	41.37858	0.6322	20.446	1738366.989	4.172	4.901	38.284
2.485	47.60793	0.7934	14.935	2181738.367	3.984	3.749	99.459
2.637	49.78575	0.8419	13.869	2315188.762	3.937	3.523	127.623
2.922	54.85752	0.9329	12.446	2565408.253	3.858	3.226	196.351



ITTC 1978 Prediction Method

Scale	13

MODEL AND SHIP DETAILS					
MODEL			SHIP		
Disp	36.117	Kg	Disp	79.350	t
LBP	0.962	m	LBP	12.500	m
LWL	1.000	m	LWL	13.000	m
Breadth	0.692		Breadth	9.000	m
Draft	0.246	m	Draft	3.200	m
Surface Area	1.032	m^2	Surface Area	174.481	m^2
Cb	0.880		Cb	0.880	
LCG	0.623	m	LCG	8.100	m (AP)
Density	1.000	t/m^3	Density	1.025	t/m^3
Kinematic Viscocity	1.14E-06	m^2/s	Kinematic Viscocity	1.188E-06	m^2/s
			At	13.51	m^2

1+K	1.9258
Delta Cf	0.00173268
Caa	7.743E-05

RESISTANCE EXTRAPOLATION						
(1+K)*Cfm	Cwx10^-3	Vs (Knots)	Vs(m/s)	Cfs x 10^-3	Cts x 10^-3	Rts (KN)
12.355	0.003	1.924	0.990	5.575	7.388	0.647
10.356	-1.303	3.946	2.030	4.943	5.450	2.009
9.429	2.173	5.937	3.054	4.631	8.615	7.185
8.829	1.199	7.998	4.114	4.421	7.431	11.248
8.360	7.611	10.318	5.308	4.253	13.674	34.449
8.115	12.015	11.888	6.115	4.164	17.989	60.162
7.860	12.586	13.878	7.140	4.070	18.466	84.169
7.507	7.428	17.418	8.960	3.937	13.175	94.590
7.418	6.451	18.483	9.509	3.903	12.164	98.345
7.269	5.177	20.481	10.536	3.846	10.833	107.540

ANNEX – 4

SEAKEEPING AND STABILITY

SEA-KEEPING ANALYSIS WITH BEAM VARIATION FOR 24 m HULL

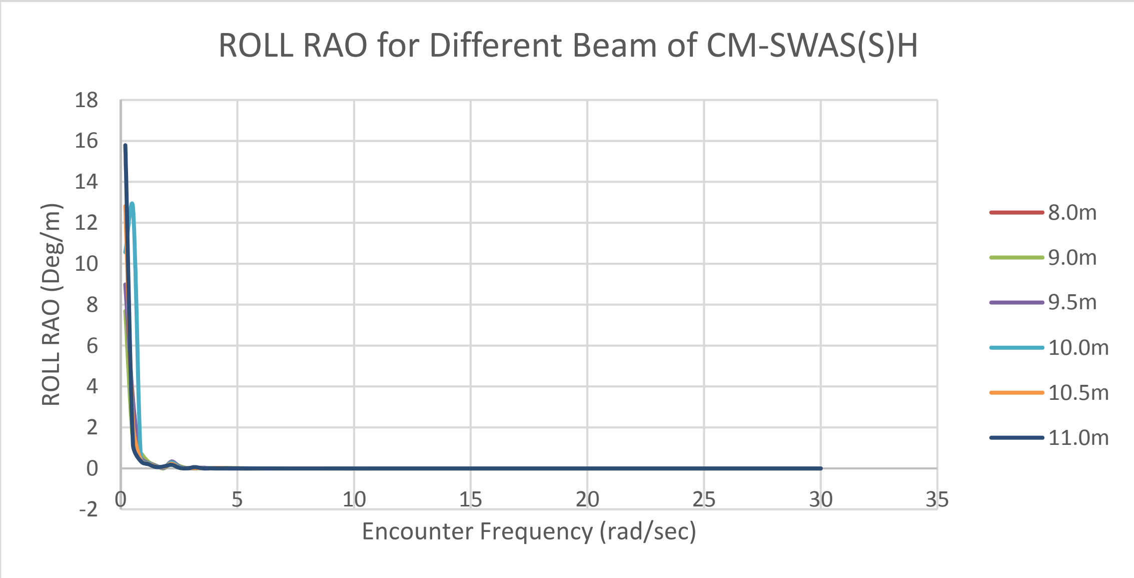
Encounter Frequency	Wave Frequency	8.0 m			9.0 m			9.5 m			10.0 m			10.5 m			11.0 m		
		Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO
rad/s	rad/s																		
0.2	0.2	0.759	5.797	3.923	0.584	7.68	3.906	0.509	8.985	3.92	0.443	10.56	3.834	0.395	12.808	3.849	0.34	15.788	3.787
0.531	0.531	0.729	0.57	0.79	0.772	1.335	0.818	0.786	3.303	0.832	0.802	12.695	0.835	0.823	2.113	0.851	0.831	1.159	0.854
0.862	0.862	0.819	2.293	0.591	0.893	0.748	0.625	0.923	0.553	0.638	0.954	0.472	0.648	0.991	0.396	0.664	1.015	0.354	0.67
1.193	1.193	2.09	0.448	2.728	2.163	0.318	2.764	2.208	0.273	2.771	2.148	0.249	2.738	2.183	0.222	2.748	2.127	0.204	2.704
1.524	1.524	0.918	0.182	2.25	1.048	0.133	2.391	1.113	0.112	2.451	1.168	0.097	2.498	1.239	0.08	2.562	1.289	0.066	2.593
1.856	1.856	0.678	0.041	0.214	0.814	0.005	0.246	0.89	0.025	0.265	0.968	0.05	0.285	1.052	0.075	0.308	1.116	0.101	0.327
2.187	2.187	0.6	0.131	0.085	0.882	0.298	0.137	0.797	0.34	0.133	0.53	0.292	0.093	0.323	0.223	0.058	0.193	0.173	0.036
2.518	2.518	0.755	0.264	0.301	0.095	0.117	0.08	0.011	0.085	0.02	0.03	0.057	0.028	0.047	0.032	0.065	0.055	0.027	0.091
2.849	2.849	0.008	0.028	0.002	0.007	0.018	0.006	0.011	0.013	0.006	0.014	0.009	0.005	0.014	0.005	0.004	0.013	0.001	0.004
3.18	3.18	0.003	0.01	0.008	0.003	0.001	0.012	0.005	0.005	0.013	0.007	0.01	0.012	0.009	0.019	0.012	0.015	0.064	0.014
3.511	3.511	0.012	0.005	0.003	0.02	0.031	0.003	0.016	0.038	0.003	0.004	0.011	0	0.006	0.006	0.001	0.006	0.004	0.001
3.842	3.842	0.023	0.037	0.001	0.007	0.004	0	0.009	0.003	0	0.008	0.002	0	0.005	0	0	0.005	0.002	0
4.173	4.173	0.009	0.002	0	0.006	0	0	0.005	0.001	0	0.005	0.006	0	0.003	0.026	0	0.004	0.001	0
4.504	4.504	0.006	0	0	0.003	0.025	0	0.004	0.002	0	0.004	0.001	0	0.005	0	0	0.005	0	0
4.836	4.836	0.003	0.016	0	0.003	0.001	0	0.004	0	0	0.005	0.001	0	0.004	0.001	0	0.007	0	0
5.167	5.167	0.003	0	0	0.004	0.001	0	0.006	0.001	0	0.006	0	0	0.006	0	0	0.004	0.003	0
5.498	5.498	0.004	0.002	0	0.006	0	0	0.005	0.002	0	0.004	0.002	0	0.003	0.001	0	0.003	0	0
5.829	5.829	0.005	0	0	0.003	0	0	0.003	0	0	0.003	0	0	0.003	0	0	0.004	0	0
6.16	6.16	0.003	0	0	0.002	0	0	0.003	0	0	0.003	0	0	0.004	0	0	0.003	0	0
6.491	6.491	0.001	0	0	0.003	0	0	0.003	0	0	0.003	0	0	0.002	0	0	0.002	0	0
6.822	6.822	0.002	0	0	0.002	0	0	0.001	0	0	0.001	0	0	0.002	0	0	0.002	0	0
7.153	7.153	0.002	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0
7.484	7.484	0	0	0	0.001	0	0	0.001	0	0	0	0	0	0	0	0	0.001	0	0
7.816	7.816	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.147	8.147	0	0	0	0.001	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0
8.478	8.478	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0
8.809	8.809	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0
9.14	9.14	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0
9.471	9.471	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0
9.802	9.802	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0	0.001	0	0
10.133	10.133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

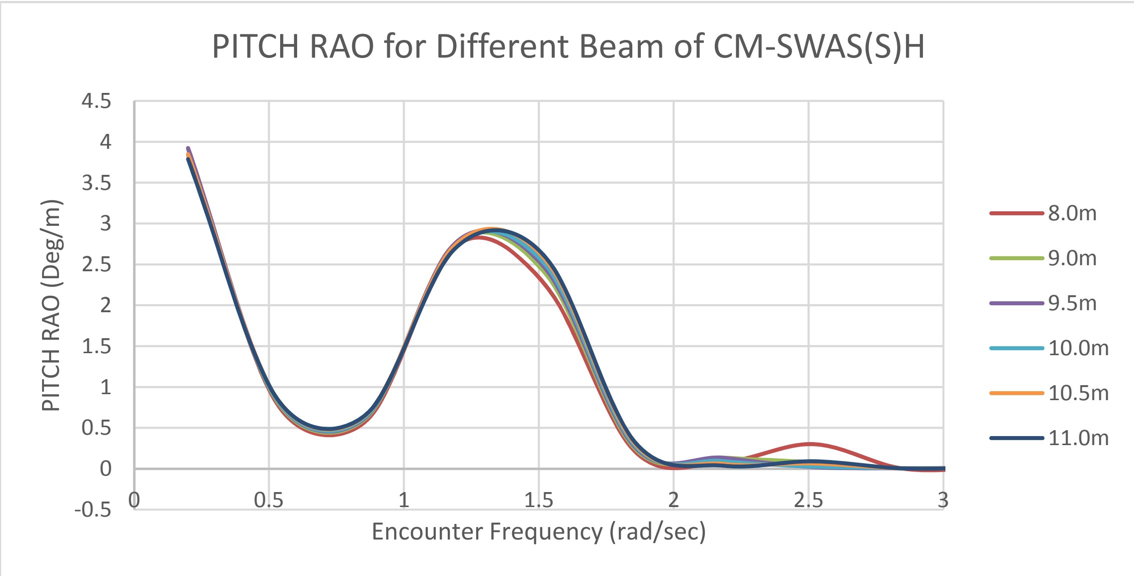
SEA-KEEPING ANALYSIS WITH BEAM VARIATION FOR 24 m HULL

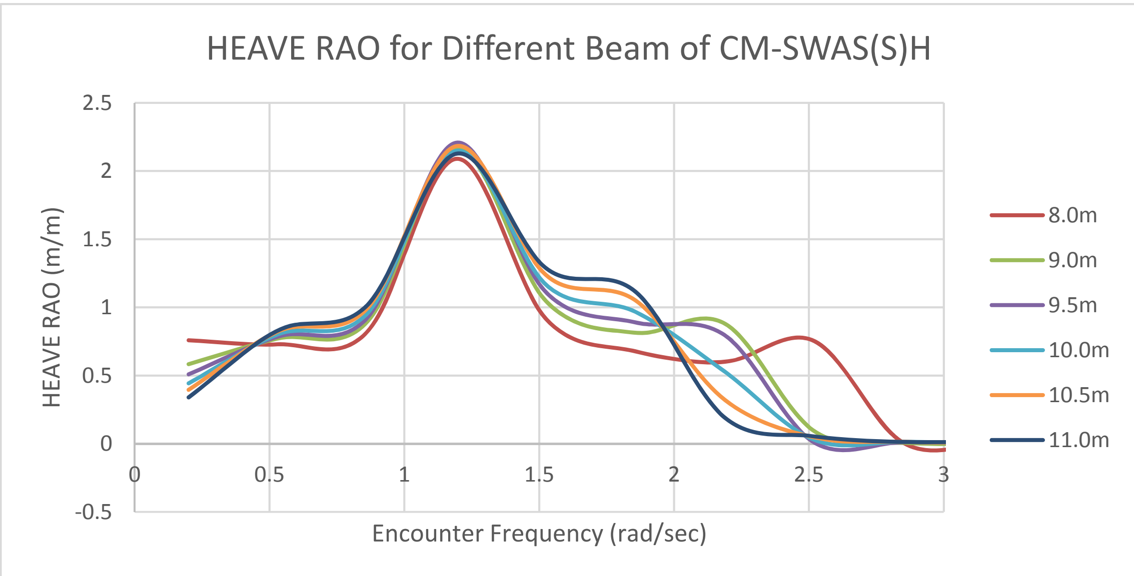
Encounter Frequency	Wave Frequency	8.0 m			9.0 m			9.5 m			10.0 m			10.5 m			11.0 m		
		Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO
10.464	10.464	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.796	10.796	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.127	11.127	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.458	11.458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.789	11.789	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.12	12.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.451	12.451	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.782	12.782	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.113	13.113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.444	13.444	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.776	13.776	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.107	14.107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.438	14.438	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.769	14.769	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.1	15.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.431	15.431	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.762	15.762	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.093	16.093	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.424	16.424	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.756	16.756	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.087	17.087	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.418	17.418	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.749	17.749	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.08	18.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.411	18.411	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.742	18.742	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.073	19.073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.404	19.404	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.736	19.736	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.067	20.067	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.398	20.398	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.729	20.729	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.06	21.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.391	21.391	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.722	21.722	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.053	22.053	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SEA-KEEPING ANALYSIS WITH BEAM VARIATION FOR 24 m HULL

Encounter Frequency	Wave Frequency	8.0 m			9.0 m			9.5 m			10.0 m			10.5 m			11.0 m		
		Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO	Heave RAO	Roll RAO	Pitch RAO
22.384	22.384	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.716	22.716	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23.047	23.047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23.378	23.378	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23.709	23.709	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24.04	24.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24.371	24.371	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24.702	24.702	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25.033	25.033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25.364	25.364	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25.696	25.696	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.027	26.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.358	26.358	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.689	26.689	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.02	27.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.351	27.351	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27.682	27.682	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.013	28.013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.344	28.344	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28.676	28.676	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.007	29.007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.338	29.338	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.669	29.669	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0


ROLL RAO for Different Beam of CM-SWAS(S)H
ROLL RAO (Deg/m)
Encounter Frequency (rad/sec)
8.0m
9.0m
9.5m
10.0m
10.5m
11.0m

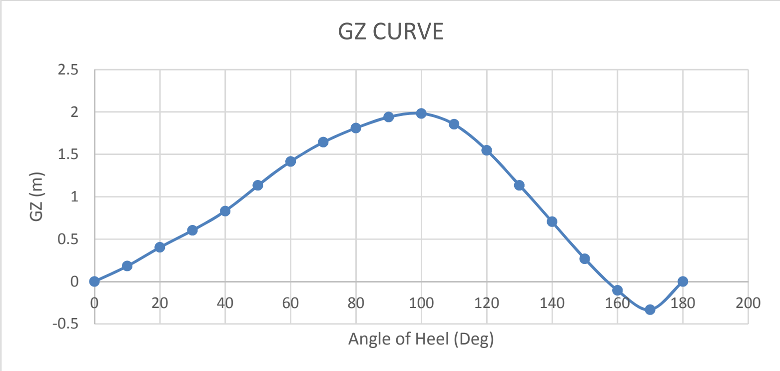

PITCH RAO for Different Beam of CM-SWAS(S)H
PITCH RAO (Deg/m)
Encounter Frequency (rad/sec)
8.0m
9.0m
9.5m
10.0m
10.5m
11.0m


HEAVE RAO for Different Beam of CM-SWAS(S)H
HEAVE RAO (m/m)
Encounter Frequency (rad/sec)
8.0m
9.0m
9.5m
10.0m
10.5m
11.0m

INTACT STABILITY
IMO / DNV / HSC CRITERIA

18 m - CM-SWAS(S)H
LIGHTSHIP CONDITION

ELEMENT	VALUE	UNIT
DRAFT	2.3	m
DISPLACEMENT	63.97	tonne
LCG	7.5	m
VCG	2.6	m
TCG	0	m



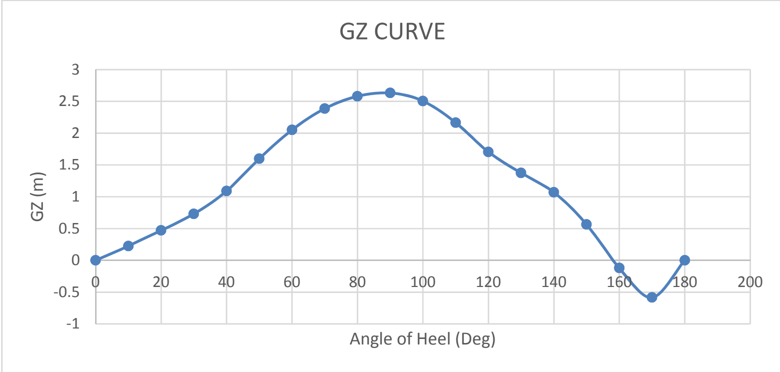
DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0	0.182	0.403	0.604	0.831	1.134	1.416	1.643	1.81	1.94	1.982	1.855	1.548	1.134	0.706	0.267	-0.104	-0.332	0

Code	Criteria	Value	Units	Actual	Status	Margin %
C400. Intact stability with wind heeling.	C402.(a). Ratio of GZ(intersection) / GZ (Max)	60.00	%	0.00	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(b). Angle of Heel at Equilibrium	15.0	deg	0.0	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(c). Range of GZ curve.	70.0	deg	157.1	Pass	+124.41
Intact Stability	C304/404. Intact stability criteria for vessels equipped with cranes.				Pass	
	Angle of steady heel shall not be greater than (<=)	15.0	deg	0.0	Pass	+100.00
	GZ(intersection) / GZ(max) shall not be greater than (<=)	60.00	%	0.00	Pass	+100.00
Intact Stability	C305/404: Intact stability criteria for turning.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	11.7	Pass	+21.70
	Area1 / Area2 shall be greater than (>)	40.00	%	93.46	Pass	+133.65
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	11.01	Pass	+81.65
Intact Stability	C306/404: Intact stability criteria with Passengers.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	5.7	Pass	+61.72
	Area1 / Area2 shall be greater than (>)	40.00	%	96.89	Pass	+142.22
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	5.01	Pass	+91.65
HSC 2000 Annex 7 Multihull. Intact	1.1 Area 0 to 30	3.1510	m.deg	8.8452	Pass	+180.71
HSC 2000 Annex 7 Multihull. Intact	1.2 Angle of max. GZ	10.0	deg	98.2	Pass	+881.82
HSC 2000 Annex 7 Multihull. Intact	1.5 Area between GZ and HTL				Pass	
	Hpc + Hw	1.6040	m.deg	2.0999	Pass	+30.91
	Ht + Hw	1.6040	m.deg	2.0999	Pass	+30.91
HSC 2000 Annex 7 Multihull. Intact	3.2.1 Angle of equilibrium with gust wind HL2				Pass	
	Wind heeling (Hw)	10.0	deg	0.7	Pass	+92.94
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	1.940	Pass	+4750.00
	8.2.3.3: Launching heeling moment	0.040	m	1.940	Pass	+4750.00
	8.2.3.3: Wind heeling arm	0.040	m	1.913	Pass	+4682.50
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	1.985	Pass	+3870.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	157.1	Pass	+2144.14
HSC multi. Intact	1.1: Area from 0 to 30	3.1513	m.deg	8.8452	Pass	+180.69
HSC multi. Intact	1.2: Angle of maximum GZ	10.0	deg	98.2	Pass	+881.82
HSC multi. Intact	1.5: HTL: Area between GZ and HA				Pass	
	Hpc + Hw	1.6043	m.deg	2.4792	Pass	+54.53
	Ht + Hw	1.6043	m.deg	2.4793	Pass	+54.54
HSC multi. Intact	3.2.1: HL1: Angle of equilibrium				Pass	
	Wind heeling (Hw)	16.0	deg	4.6	Pass	+71.08

INTACT STABILITY
IMO / DNV / HSC CRITERIA

18 m - CM-SWAS(S)H
LOADED SHIP CONDITION

ELEMENT	VALUE	UNIT
DRAFT	3.2	m
DISPLACEMENT	79.34	tonne
LCG	8.1	m
VCG	2.1	m
TCG	0	m



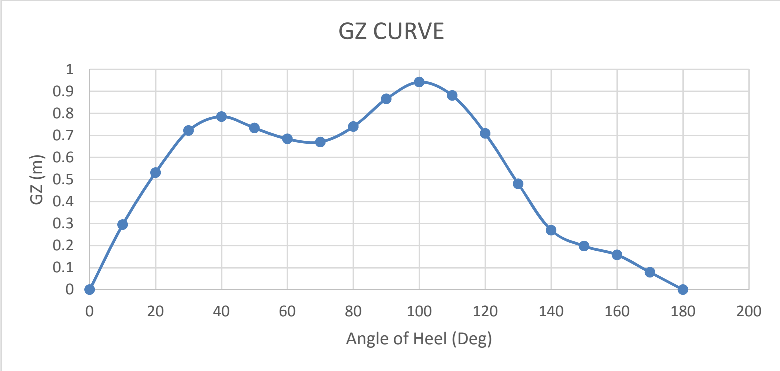
DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0	0.226	0.472	0.73	1.091	1.599	2.052	2.387	2.58	2.632	2.505	2.165	1.705	1.374	1.071	0.564	-0.12	-0.584	0

Code	Criteria	Value	Units	Actual	Status	Margin %
C400. Intact stability with wind heeling.	C402.(a). Ratio of GZ(intersection) / GZ (Max)	60.00	%	0.00	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(b). Angle of Heel at Equilibrium	15.0	deg	0.0	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(c). Range of GZ curve.	70.0	deg	158.7	Pass	+126.70
Intact Stability	C304/404. Intact stability criteria for vessels equipped with cranes.				Pass	
	Angle of steady heel shall not be greater than (<=)	15.0	deg	0.0	Pass	+100.00
	GZ(intersection) / GZ(max) shall not be greater than (<=)	60.00	%	0.00	Pass	+100.00
Intact Stability	C305/404: Intact stability criteria for turning.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	4.8	Pass	+67.89
	Area1 / Area2 shall be greater than (>)	40.00	%	97.49	Pass	+143.72
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	4.05	Pass	+93.25
Intact Stability	C306/404: Intact stability criteria with Passengers.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	5.6	Pass	+62.65
	Area1 / Area2 shall be greater than (>)	40.00	%	97.09	Pass	+142.72
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	4.72	Pass	+92.13
HSC 2000 Annex 7 Multihull. Intact	1.1 Area 0 to 30	3.1510	m.deg	10.5747	Pass	+235.60
HSC 2000 Annex 7 Multihull. Intact	1.2 Angle of max. GZ	10.0	deg	88.2	Pass	+781.82
HSC 2000 Annex 7 Multihull. Intact	1.5 Area between GZ and HTL				Pass	
	Hpc + Hw	1.6040	m.deg	2.5710	Pass	+60.29
	Ht + Hw	1.6040	m.deg	2.5710	Pass	+60.29
HSC 2000 Annex 7 Multihull. Intact	3.2.1 Angle of equilibrium with gust wind HL2				Pass	
	Wind heeling (Hw)	10.0	deg	0.8	Pass	+91.64
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	2.634	Pass	+6485.00
	8.2.3.3: Launching heeling moment	0.040	m	2.634	Pass	+6485.00
	8.2.3.3: Wind heeling arm	0.040	m	2.595	Pass	+6387.50
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	2.634	Pass	+5168.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	158.7	Pass	+2167.00
HSC multi. Intact	1.1: Area from 0 to 30	3.1513	m.deg	10.5747	Pass	+235.57
HSC multi. Intact	1.2: Angle of maximum GZ	10.0	deg	88.2	Pass	+781.82
HSC multi. Intact	1.5: HTL: Area between GZ and HA				Pass	
	Hpc + Hw	1.6043	m.deg	2.7930	Pass	+74.10
	Ht + Hw	1.6043	m.deg	2.7613	Pass	+72.12
HSC multi. Intact	3.2.1: HL1: Angle of equilibrium				Pass	
	Wind heeling (Hw)	16.0	deg	5.5	Pass	+65.55

INTACT STABILITY
IMO / DNV / HSC CRITERIA

21 m - CM-SWAS(S)H
LIGHTSHIP CONDITION

ELEMENT	VALUE	UNIT
DRAFT	2.3	m
DISPLACEMENT	77.56	tonne
LCG	8.9	m
VCG	2.75	m
TCG	0	m



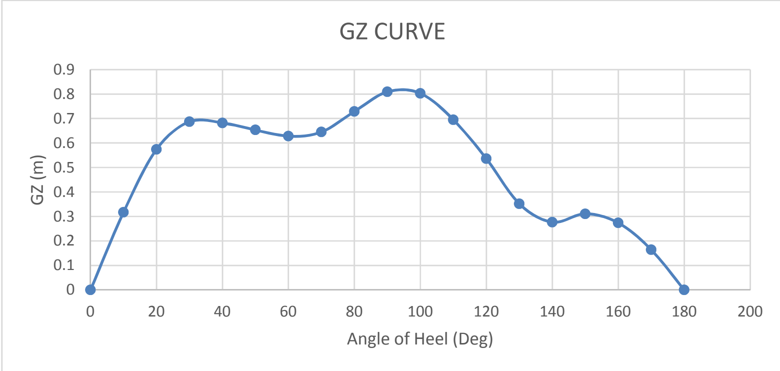
DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0	0.295	0.531	0.722	0.785	0.734	0.684	0.67	0.74	0.866	0.942	0.881	0.709	0.48	0.27	0.198	0.158	0.079	0

Code	Criteria	Value	Units	Actual	Status	Margin %
C400. Intact stability with wind heeling.	C402.(a). Ratio of GZ(intersection) / GZ (Max)	60.00	%	0.00	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(b). Angle of Heel at Equilibrium	15.0	deg	0.0	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(c). Range of GZ curve.	70.0	deg	180.0	Pass	+157.14
Intact Stability	C304/404. Intact stability criteria for vessels equipped with cranes.				Pass	
	Angle of steady heel shall not be greater than (<=)	15.0	deg	0.0	Pass	+100.00
	GZ(intersection) / GZ(max) shall not be greater than (<=)	60.00	%	0.00	Pass	+100.00
Intact Stability	C305/404: Intact stability criteria for turning.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	4.0	Pass	+73.26
	Area1 / Area2 shall be greater than (>)	40.00	%	93.04	Pass	+132.60
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	13.02	Pass	+78.30
Intact Stability	C306/404: Intact stability criteria with Passengers.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	3.4	Pass	+77.61
	Area1 / Area2 shall be greater than (>)	40.00	%	94.13	Pass	+135.32
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	10.93	Pass	+81.78
HSC 2000 Annex 7 Multihull. Intact	1.1 Area 0 to 30	3.1510	m.deg	12.0072	Pass	+281.06
HSC 2000 Annex 7 Multihull. Intact	1.2 Angle of max. GZ	10.0	deg	100.9	Pass	+909.09
HSC 2000 Annex 7 Multihull. Intact	1.5 Area between GZ and HTL				Pass	
	Hpc + Hw	1.6040	m.deg	3.2738	Pass	+104.10
	Ht + Hw	1.6040	m.deg	3.2738	Pass	+104.10
HSC 2000 Annex 7 Multihull. Intact	3.2.1 Angle of equilibrium with gust wind HL2				Pass	
	Wind heeling (Hw)	10.0	deg	0.3	Pass	+96.60
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	0.866	Pass	+2065.00
	8.2.3.3: Launching heeling moment	0.040	m	0.866	Pass	+2065.00
	8.2.3.3: Wind heeling arm	0.040	m	0.843	Pass	+2007.50
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	0.942	Pass	+1784.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	180.0	Pass	+2471.43
HSC multi. Intact	1.1: Area from 0 to 30	3.1513	m.deg	12.0072	Pass	+281.02
HSC multi. Intact	1.2: Angle of maximum GZ	10.0	deg	100.9	Pass	+909.09
HSC multi. Intact	1.5: HTL: Area between GZ and HA				Pass	
	Hpc + Hw	1.6043	m.deg	2.8770	Pass	+79.33
	Ht + Hw	1.6043	m.deg	2.9934	Pass	+86.59
HSC multi. Intact	3.2.1: HL1: Angle of equilibrium				Pass	
	Wind heeling (Hw)	16.0	deg	2.4	Pass	+85.03

INTACT STABILITY
IMO / DNV / HSC CRITERIA

21 m - CM-SWAS(S)H
LOADED SHIP CONDITION

ELEMENT	VALUE	UNIT
DRAFT	3.2	m
DISPLACEMENT	99.76	tonne
LCG	9.5	m
VCG	2	m
TCG	0	m



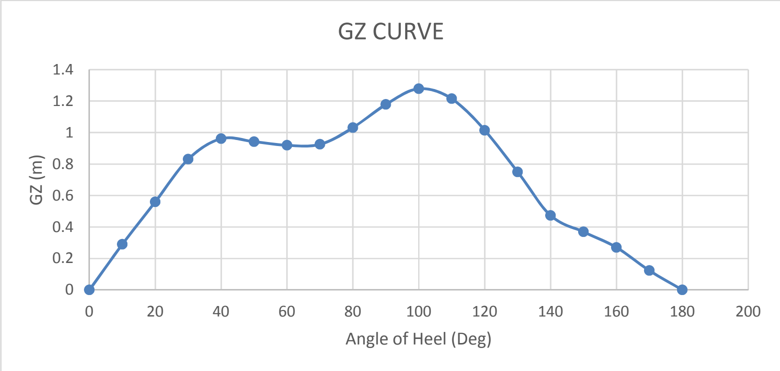
DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0	0.317	0.574	0.687	0.682	0.654	0.628	0.645	0.729	0.809	0.803	0.695	0.536	0.352	0.277	0.311	0.274	0.164	0

Code	Criteria	Value	Units	Actual	Status	Margin %
C400. Intact stability with wind heeling.	C402.(a). Ratio of GZ(intersection) / GZ (Max)	60.00	%	0.00	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(b). Angle of Heel at Equilibrium	15.0	deg	0.0	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(d). Range of GZ curve.	70.0	deg	180.0	Pass	+157.14
Intact Stability	C304/404. Intact stability criteria for vessels equipped with cranes.				Pass	
	Angle of steady heel shall not be greater than (<=)	15.0	deg	0.0	Pass	+100.00
	GZ(intersection) / GZ(max) shall not be greater than (<=)	60.00	%	0.00	Pass	+100.00
Intact Stability	C305/404: Intact stability criteria for turning.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	0.0	Pass	+100.00
	Area1 / Area2 shall be greater than (>)	40.00	%	100.00	Pass	+150.00
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	0.00	Pass	+100.00
Intact Stability	C306/404: Intact stability criteria with Passengers.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	2.5	Pass	+83.58
	Area1 / Area2 shall be greater than (>)	40.00	%	95.11	Pass	+137.77
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	9.75	Pass	+83.75
HSC 2000 Annex 7 Multihull. Intact	1.1 Area 0 to 30	3.1510	m.deg	12.5814	Pass	+299.28
HSC 2000 Annex 7 Multihull. Intact	1.2 Angle of max. GZ	10.0	deg	94.5	Pass	+845.45
HSC 2000 Annex 7 Multihull. Intact	1.5 Area between GZ and HTL				Pass	
	Hpc + Hw	1.6040	m.deg	3.5466	Pass	+121.11
	Ht + Hw	1.6040	m.deg	3.5466	Pass	+121.11
HSC 2000 Annex 7 Multihull. Intact	3.2.1 Angle of equilibrium with gust wind HL2				Pass	
	Wind heeling (Hw)	10.0	deg	0.2	Pass	+98.30
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	0.809	Pass	+1922.50
	8.2.3.3: Launching heeling moment	0.040	m	0.809	Pass	+1922.50
	8.2.3.3: Wind heeling arm	0.040	m	0.796	Pass	+1890.00
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	0.820	Pass	+1540.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	180.0	Pass	+2471.43
HSC multi. Intact	1.1: Area from 0 to 30	3.1513	m.deg	12.5814	Pass	+299.24
HSC multi. Intact	1.2: Angle of maximum GZ	10.0	deg	94.5	Pass	+845.45
HSC multi. Intact	1.5: HTL: Area between GZ and HA				Pass	
	Hpc + Hw	1.6043	m.deg	3.3756	Pass	+110.41
	Ht + Hw	1.6043	m.deg	3.4917	Pass	+117.65
HSC multi. Intact	3.2.1: HL1: Angle of equilibrium				Pass	
	Wind heeling (Hw)	16.0	deg	1.2	Pass	+92.35

INTACT STABILITY
IMO / DNV / HSC CRITERIA

24 m - CM-SWAS(S)H
LIGHTSHIP CONDITION

ELEMENT	VALUE	UNIT
DRAFT	2.3	m
DISPLACEMENT	93.39	tonne
LCG	11	m
VCG	2.95	m
TCG	0	m



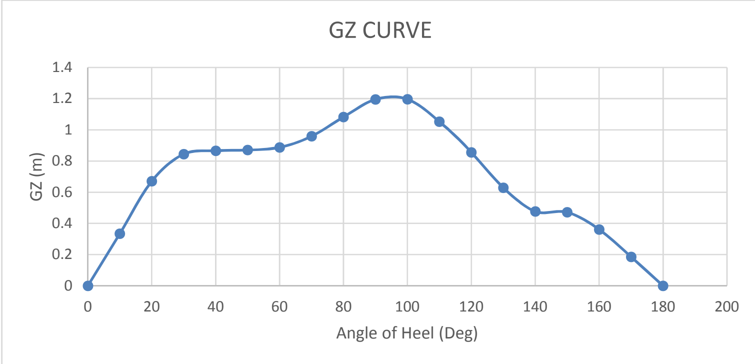
DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0	0.29	0.56	0.831	0.961	0.942	0.919	0.925	1.031	1.179	1.278	1.215	1.014	0.75	0.473	0.369	0.27	0.123	0

Code	Criteria	Value	Units	Actual	Status	Margin %
C400. Intact stability with wind heeling.	C402.(a). Ratio of GZ(intersection) / GZ (Max)	60.00	%	0.00	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(b). Angle of Heel at Equilibrium	15.0	deg	0.0	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(c). Range of GZ curve.	70.0	deg	180.0	Pass	+157.14
Intact Stability	C304/404. Intact stability criteria for vessels equipped with cranes.				Pass	
	Angle of steady heel shall not be greater than (<=)	15.0	deg	0.0	Pass	+100.00
	GZ(intersection) / GZ(max) shall not be greater than (<=)	60.00	%	0.00	Pass	+100.00
Intact Stability	C305/404: Intact stability criteria for turning.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	0.0	Pass	+100.00
	Area1 / Area2 shall be greater than (>)	40.00	%	100.00	Pass	+150.00
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	0.00	Pass	+100.00
Intact Stability	C306/404: Intact stability criteria with Passengers.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	2.9	Pass	+80.71
	Area1 / Area2 shall be greater than (>)	40.00	%	96.37	Pass	+140.92
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	6.68	Pass	+88.87
HSC 2000 Annex 7 Multihull. Intact	1.1 Area 0 to 30	3.1510	m.deg	12.7179	Pass	+303.61
HSC 2000 Annex 7 Multihull. Intact	1.2 Angle of max. GZ	10.0	deg	101.8	Pass	+918.18
HSC 2000 Annex 7 Multihull. Intact	1.5 Area between GZ and HTL				Pass	
	Hpc + Hw	1.6040	m.deg	3.2405	Pass	+102.03
	Ht + Hw	1.6040	m.deg	3.2405	Pass	+102.03
HSC 2000 Annex 7 Multihull. Intact	3.2.1 Angle of equilibrium with gust wind HL2				Pass	
	Wind heeling (Hw)	10.0	deg	0.4	Pass	+96.32
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	1.179	Pass	+2847.50
	8.2.3.3: Launching heeling moment	0.040	m	1.179	Pass	+2847.50
	8.2.3.3: Wind heeling arm	0.040	m	1.156	Pass	+2790.00
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	1.280	Pass	+2460.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	180.0	Pass	+2471.43
HSC multi. Intact	1.1: Area from 0 to 30	3.1513	m.deg	12.7179	Pass	+303.58
HSC multi. Intact	1.2: Angle of maximum GZ	10.0	deg	101.8	Pass	+918.18
HSC multi. Intact	1.5: HTL: Area between GZ and HA				Pass	
	Hpc + Hw	1.6043	m.deg	3.0966	Pass	+93.02
	Ht + Hw	1.6043	m.deg	3.1616	Pass	+97.07
HSC multi. Intact	3.2.1: HL1: Angle of equilibrium				Pass	
	Wind heeling (Hw)	16.0	deg	2.5	Pass	+84.23

INTACT STABILITY
IMO / DNV / HSC CRITERIA

24 m - CM-SWAS(S)H
LOADED SHIP CONDITION

ELEMENT	VALUE	UNIT
DRAFT	3.2	m
DISPLACEMENT	118.6	tonne
LCG	11.5	m
VCG	1.85	m
TCG	0	m



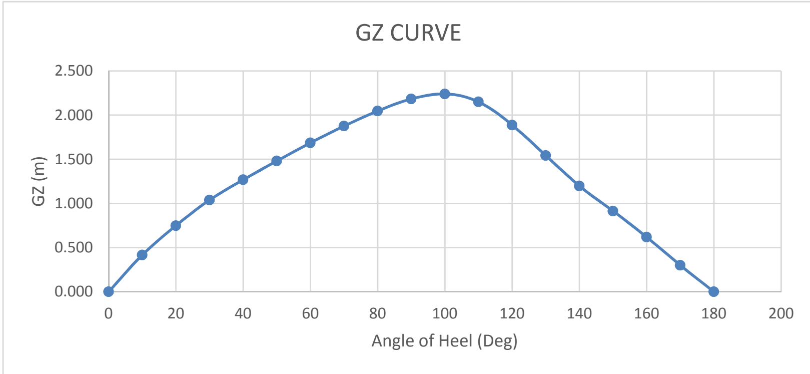
DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0	0.334	0.671	0.844	0.866	0.871	0.887	0.959	1.082	1.195	1.196	1.053	0.856	0.629	0.477	0.472	0.361	0.185	0

Code	Criteria	Value	Units	Actual	Status	Margin %
C400. Intact stability with wind heeling.	C402.(a). Ratio of GZ(intersection) / GZ (Max)	60.00	%	0.00	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(b). Angle of Heel at Equilibrium	15.0	deg	0.0	Pass	+100.00
C400. Intact stability with wind heeling.	C402.(c). Range of GZ curve.	70.0	deg	180.0	Pass	+157.14
Intact Stability	C304/404. Intact stability criteria for vessels equipped with cranes.				Pass	
	Angle of steady heel shall not be greater than (<=)	15.0	deg	0.0	Pass	+100.00
	GZ(intersection) / GZ(max) shall not be greater than (<=)	60.00	%	0.00	Pass	+100.00
Intact Stability	C305/404: Intact stability criteria for turning.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	0.0	Pass	+100.00
	Area1 / Area2 shall be greater than (>)	40.00	%	100.00	Pass	+150.00
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	0.00	Pass	+100.00
Intact Stability	C306/404: Intact stability criteria with Passengers.				Pass	
	Angle of steady heel shall be less than (<)	15.0	deg	2.1	Pass	+86.10
	Area1 / Area2 shall be greater than (>)	40.00	%	97.08	Pass	+142.70
	GZ(intersection) / GZ(max) shall be less than (<)	60.00	%	5.55	Pass	+90.75
HSC 2000 Annex 7 Multihull. Intact	1.1 Area 0 to 30	3.1510	m.deg	14.4719	Pass	+359.28
HSC 2000 Annex 7 Multihull. Intact	1.2 Angle of max. GZ	10.0	deg	95.5	Pass	+854.55
HSC 2000 Annex 7 Multihull. Intact	1.5 Area between GZ and HTL				Pass	
	Hpc + Hw	1.6040	m.deg	3.7662	Pass	+134.80
	Ht + Hw	1.6040	m.deg	3.7662	Pass	+134.80
HSC 2000 Annex 7 Multihull. Intact	3.2.1 Angle of equilibrium with gust wind HL2				Pass	
	Wind heeling (Hw)	10.0	deg	0.2	Pass	+98.20
SOLAS, II-1/8	8.2.3.3: Maximum residual GZ (method 1)				Pass	
	8.2.3.3: Passenger crowding heeling arm	0.040	m	1.195	Pass	+2887.50
	8.2.3.3: Launching heeling moment	0.040	m	1.195	Pass	+2887.50
	8.2.3.3: Wind heeling arm	0.040	m	1.181	Pass	+2852.50
SOLAS, II-1/8	8.2.4.a Maximum GZ (intermediate stages)	0.050	m	1.214	Pass	+2328.00
SOLAS, II-1/8	8.2.4.b Range of positive stability (intermediate stages)	7.0	deg	180.0	Pass	+2471.43
SOLAS, II-1/8	8.6.3: Margin line immersion - GZ based (EquilAngle ratio)	100.00	%	2874261492.99	Fail	-2874261392.99
HSC multi. Intact	1.1: Area from 0 to 30	3.1513	m.deg	14.4719	Pass	+359.24
HSC multi. Intact	1.2: Angle of maximum GZ	10.0	deg	95.5	Pass	+854.55
HSC multi. Intact	1.5: HTL: Area between GZ and HA				Pass	
	Hpc + Hw	1.6043	m.deg	3.8631	Pass	+140.80
	Ht + Hw	1.6043	m.deg	3.8128	Pass	+137.66
HSC multi. Intact	3.2.1: HL1: Angle of equilibrium				Pass	
	Wind heeling (Hw)	16.0	deg	1.3	Pass	+92.18

DAMAGE STABILITY
IMO / DNV / HSC CRITERIA

18 m - CM-SWAS(S)H
DAMAGE CASE : 2 CENTRAL COMPARTMENT + 50% OUTRIGGER

ELEMENT	VALUE	UNIT
DRAFT	4	m
DISPLACEMENT	93.74	tonne
LCG	7.9	m
VCG	1.9	m
TCG	0.1	m

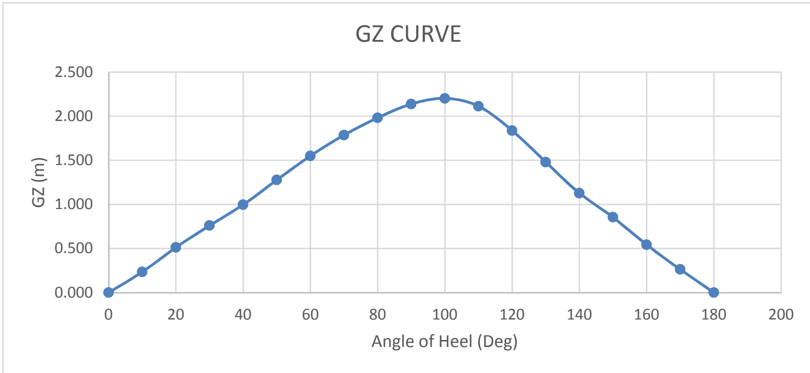


DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0.000	0.417	0.749	1.039	1.268	1.481	1.686	1.876	2.047	2.183	2.239	2.151	1.888	1.543	1.198	0.914	0.620	0.300	0.000

DAMAGE STABILITY
IMO / DNV / HSC CRITERIA

18 m - CM-SWAS(S)H
DAMAGE CASE : 50% OUTRIGGER

ELEMENT	VALUE	UNIT
DRAFT	3.35	m
DISPLACEMENT	84.73	tonne
LCG	7.9	m
VCG	2.05	m
TCG	0.3	m

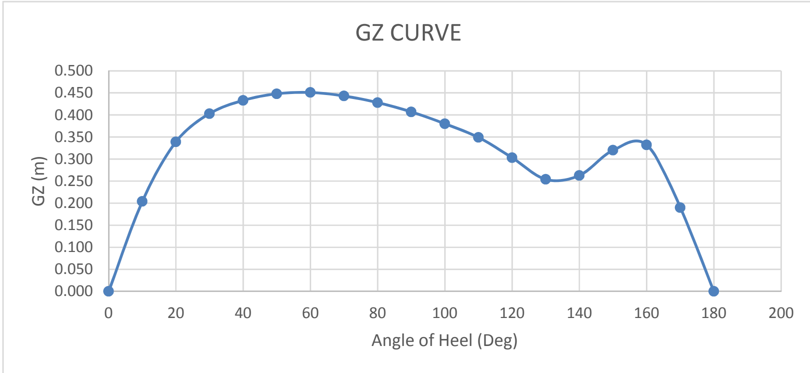


DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0.000	0.235	0.512	0.760	0.997	1.277	1.550	1.786	1.981	2.138	2.202	2.113	1.837	1.480	1.128	0.855	0.543	0.264	0.000

DAMAGE STABILITY
IMO / DNV / HSC CRITERIA

21 m - CM-SWAS(S)H
DAMAGE CASE : 2 CENTRAL COMPARTMENT + 50% OUTRIGGER

ELEMENT	VALUE	UNIT
DRAFT	3.9	m
DISPLACEMENT	112.31	tonne
LCG	9.4	m
VCG	1.9	m
TCG	0.05	m

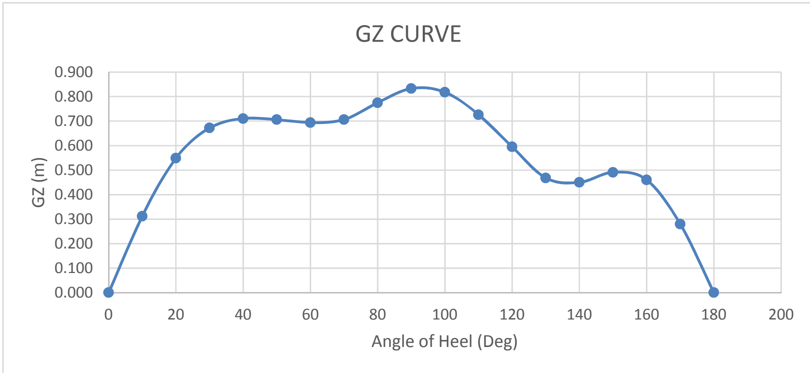


DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0.000	0.204	0.339	0.403	0.433	0.448	0.451	0.443	0.428	0.407	0.380	0.349	0.303	0.254	0.263	0.320	0.332	0.190	0.000

DAMAGE STABILITY
IMO / DNV / HSC CRITERIA

21 m - CM-SWAS(S)H
DAMAGE CASE : 50% OUTRIGGER

ELEMENT	VALUE	UNIT
DRAFT	3.48	m
DISPLACEMENT	107	tonne
LCG	9.3	m
VCG	2.05	m
TCG	0.2	m

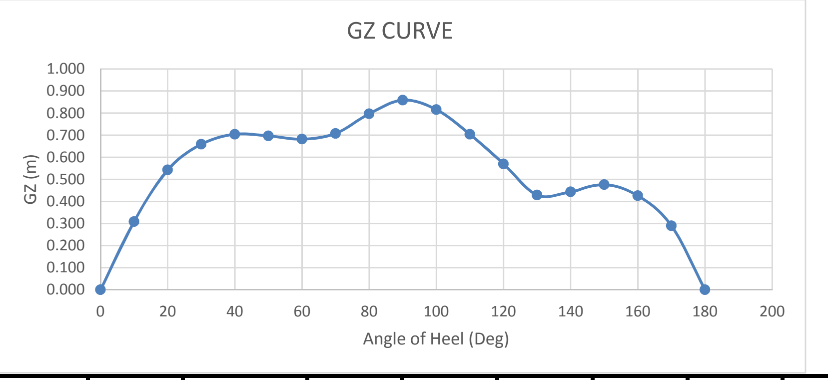


DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0.000	0.312	0.549	0.672	0.710	0.706	0.694	0.706	0.775	0.833	0.818	0.726	0.595	0.468	0.450	0.491	0.460	0.280	0.000

DAMAGE STABILITY
IMO / DNV / HSC CRITERIA

24 m - CM-SWAS(S)H
DAMAGE CASE : 2 CENTRAL COMPARTMENT + 50% OUTRIGGER

ELEMENT	VALUE	UNIT
DRAFT	3.74	m
DISPLACEMENT	134.3	tonne
LCG	11.5	m
VCG	1.85	m
TCG	0.1	m

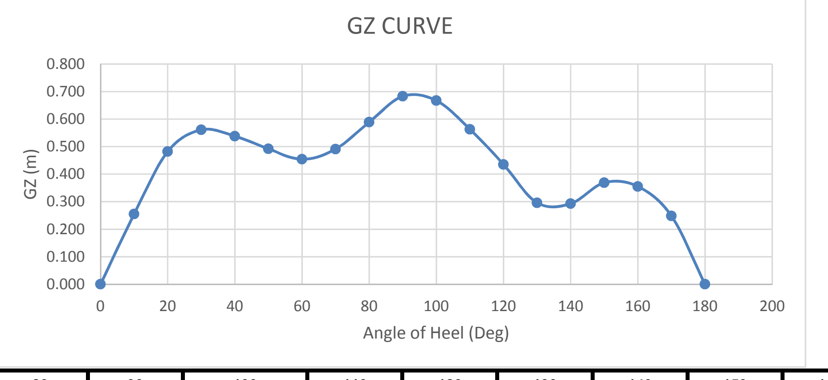


DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0.000	0.309	0.543	0.659	0.704	0.697	0.682	0.708	0.797	0.859	0.816	0.704	0.570	0.429	0.444	0.476	0.426	0.290	0.000

DAMAGE STABILITY
IMO / DNV / HSC CRITERIA

24 m - CM-SWAS(S)H
DAMAGE CASE : 50% OUTRIGGER

ELEMENT	VALUE	UNIT
DRAFT	3.5	m
DISPLACEMENT	127.2	tonne
LCG	11.5	m
VCG	1.8	m
TCG	0.12	m



DEG	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
GZ (m)	0.000	0.255	0.482	0.561	0.538	0.492	0.454	0.491	0.589	0.683	0.667	0.563	0.435	0.296	0.293	0.369	0.355	0.248	0.000

ANNEX – 5

RUDDER, ANCHOR & POWER

RUDDER CALCULATION AND SELECTION				
RUDDER				
Draught	T		3.2	m
Minimum Rudder Blade Span (Height)		0.90 * T	2.88	m
		0.95 * T	3.04	m
Selected Blade Span	Rh		2.6	m
Max Rudder Blade Chord		0.6 * Rh	1.56	m
Min Rudder Blade Chord		0.35 * Rh	0.91	m
Selected Chord	Ch		0.95	m
Rudder Shape			Rectangle	
Rudder Profile			Parabolic Section	
Rudder Area	RA	Rh * Ch	2.47	m2
Stiffener Spacing	S		250	mm
Speed	Vs		20	knots
Speed	Vs		10.28	m/sec
Plate Thickness			10.048	mm
Plate Thickness Selected			12	mm
Max Stiffener Spacing Aluminium	Smax		485.6	mm
Stiffener Thickness (same as plate thickness)			12	mm
Volume of Rudder			0.05928	m3
Weight of Rudder			157.092	kg
Coefficient of Lift	CL		1.2	
Propeller Factor	Pf		1.2	
Force on Rudder			1921.433	kg
Twisting Arm	TA		0.325	m
Bending Arm	BA		2.2	m
Twistin Moment	TM		624.466	Kg.m
Bending Moment	BM		4227.153	Kg.m
Combined Moment	CM		8500.182	Kg.m
Combined Moment	CM		83386.788	N.m
RUDDER STOCK				
Safety Factor	SF		3.34	
Ultimate Tensile Strength (Aluminium 5000 Series)	UTS		245	N/mm2
Rudder Stock Diameter			179.563	mm
Selected Rudder Stock Diameter			200	mm
Length of Rudder Stock			500	mm
Volume of Rudder Stock			15707963	mm3
Volume of Rudder Stock			0.016	m3
Weight of Rudder Stock			41.626	kg
TOTAL WEIGHT OF RUDDER			**198.718**	**Kg**

* The Rudder and Rudder Stock Design and Selection is based on
"Boat Mechanical Systems Handbook - by Dave Gerr" ISBN: 978-0-07-164334-4

ANCHOR CACULATION AND SELECTION

Aa per DNV-GL Class rules for Special Ships-High Speed Ships, Chapter 1, Part 3, Section 6, Sub-section 5.2 Multi-Hull Craft.

LOA - 18 m				
EQUIPMENT NUMBER CALCULATIONS				
Displacement	79.35	Tonnes		
Bo	1.1	m		
To	3.2	m		
Bi	0.5	m		
Ti	2.2	m		
Km	1.655152959			
Displacement	79.35	Tonnes		
a	2.55	m		
B	9	m		
hi	2.5	m		
θi	0	degree		
St	9.4325	m2		
A	15	m2		
EN	59.09847673			
Anchor Cable Dia	8.5	mm		
Proof Loads	42.97312	kN	4380.542	kg
Breaking Loads	85.94623	kN	8761.084	kg
Pull Duty of Windlass	3431.875	N	349.8344	kg
Mass of Anchor	60	kg		
Cable Length	82.5	m		
Diameter K2	10	mm		
Diameter K3	8.5	mm		

LOA - 21 m				
EQUIPMENT NUMBER CALCULATIONS				
Displacement	101.3	Tonnes		
Bo	1.1	m		
To	3.2	m		
Bi	0.5	m		
Ti	2.2	m		
Km	1.655152959			
Displacement	101.3	Tonnes		
a	2.55	m		
B	9	m		
hi	2.5	m		
θi	0	degree		
St	9.4325	m2		
A	15	m2		
EN	64.50257008			
Anchor Cable Dia	9.5	mm		
Proof Loads	53.58009	kN	5461.783	kg
Breaking Loads	107.1602	kN	10923.57	kg
Pull Duty of Windlass	4286.875	N	436.9903	kg
Mass of Anchor	67	kg		
Cable Length	82.5	m		
Diameter K2	11	mm		
Diameter K3	9.5	mm		

LOA - 24 m				
EQUIPMENT NUMBER CALCULATIONS				
Displacement	118.6	Tonnes		
Bo	1.1	m		
To	3.2	m		
Bi	0.5	m		
Ti	2.2	m		
Km	1.655152959			
Displacement	118.6	Tonnes		
a	2.55	m		
B	9	m		
hi	2.5	m		
θi	0	degree		
St	9.4325	m2		
A	15	m2		
EN	68.48909159			
Anchor Cable Dia	9.5	mm		
Proof Loads	53.58009	kN	5461.783	kg
Breaking Loads	107.1602	kN	10923.57	kg
Pull Duty of Windlass	4286.875	N	436.9903	kg
Mass of Anchor	67	kg		
Cable Length	82.5	m		
Diameter K2	11	mm		
Diameter K3	9.5	mm		

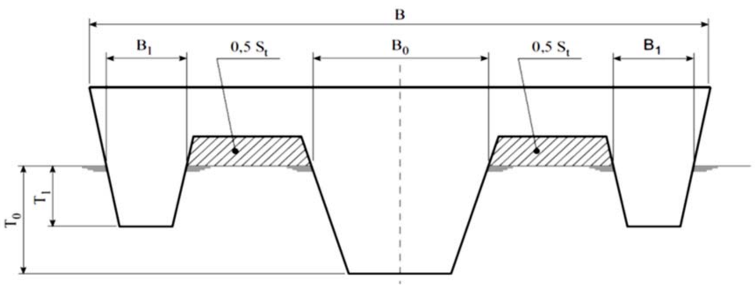
$$EN = K_m * \Delta^{\frac{2}{3}} + 2 * [a * B + \sum_i (b_i * h_i * Sin\,\theta_i) - S_t] + 0.1 * A$$

$$K_m = \frac{(B_0 * T_0)^{\frac{2}{3}} + 2 * \sum_{i=1}^{n} (B_1 * T_1)^{\frac{2}{3}}}{(B_0 * T_0 + 2 * \sum_{i=1}^{n} B_1 * T_1)}$$

$$Proof\ Load\ (PL) = 13.73 * d^2 * (44 - 0.08 * d) * 10^{-3}$$

$$Breaking\ Load\ (BL) = 2 * PL$$

d – diameter of cable selected from Table C6.5.1 Equipment of Class Rules
Anchor Cable and Windlass Calculatiosn are for K3 studless link chain



ELECTRICAL LOAD CHART FOR CM-SWAS(S)H - 18 m

NO.	POWER RECEIVERS	QUANTITY INSTALLED	QTY. IN USE	MAX. POWER EACH IN (KW)	INSTALLED POWER (KW)	SAILING			HARBOUR			MANOUVRING			EMERGENCY		
						LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)	LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)	LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)	LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)
1	PROPULSION MOTOR	1	1	1650	1941	0.8	1	1553	0.8	0	0.00	0.8	1	1553	0.8	0	0.00
2	STEERING GEAR	1	1	4.00	4.71	0.8	1	3.76	0.8	0	0.00	0.8	1	3.76	0.8	0	0.00
4	LO STANDBY PUMP FOR ME	2	2	2.57	3.02	0.8	0.2	0.97	0.8	0.2	0.97	0.8	0.2	0.97	0.8	0.2	0.97
6	SEA WATER COOLING PUMP	2	1	2.00	2.35	0.8	0.5	0.94	0.8	0.4	0.75	0.8	0.5	0.94	0.8	0.5	0.94
7	BILGE/GS/FIRE/BALLAST PUMP	2	2	1.50	1.76	0.8	0.2	0.56	0.8	0.2	0.56	0.8	0.2	0.56	0.8	1	2.82
8	FO TRANSFER PUMP	2	1	0.75	0.88	0.8	0.7	0.49	0.8	0.2	0.14	0.8	0.2	0.14	0.8	0.2	0.14
9	FW HYDROPHORE PUMP	2	1	0.50	0.59	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09
10	SW HYDROPHORE PUMP	2	1	0.50	0.59	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09
11	SEWAGE PUMP	1	1	1.50	1.76	0.8	0.4	0.56	0.8	0	0.00	0.8	0	0.00	0.8	0	0.00
13	HOT WATER CALORIFIER	1	1	5.00	5.88	0.8	0.2	0.94	0.8	0.2	0.94	0.8	0.2	0.94	0.8	0	0.00
14	HOT WATER CIRCULATING PUMP	1	1	0.40	0.47	0.8	0.2	0.08	0.8	0.2	0.08	0.8	0.2	0.08	0.8	0	0.00
15	ER VENTILATION FANS	2	2	2.50	2.94	0.8	1	4.71	0.8	0.2	0.94	0.8	1	4.71	0.8	1	4.71
16	EXHAUST FAN FOR GALLEY	1	1	0.60	0.71	0.8	1	0.56	0.8	1	0.56	0.8	1	0.56	0.8	1	0.56
17	SUPPLY FAN FOR GALLEY	1	1	0.30	0.35	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28
18	A/C PLANT ACCOMODATION	1	1	25.00	29.41	0.8	0.6	14.12	0.8	0.6	14.12	0.8	0.6	14.12	0.8	0	0.00
19	STEERING GEAR ROOM SUPPLY FAN	1	1	0.30	0.35	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28
20	SUPPLY FAN FOR BOW THRUSTER ROOM	1	1	0.30	0.35	0.8	0.8	0.23	0.8	0.2	0.06	0.8	0.8	0.23	0.8	0.8	0.23
21	SUPPLY FAN FOR DECK STORE FWD	1	1	0.25	0.29	0.8	0.8	0.19	0.8	0.2	0.05	0.8	0.8	0.19	0.8	0.8	0.19
22	SUPPLY FAN FOR DECK STORE AFT	1	1	0.30	0.35	0.8	0.8	0.23	0.8	0.2	0.06	0.8	0.8	0.23	0.8	0.8	0.23
24	EXHAUST FAN FOR TOILETS	1	1	0.40	0.47	0.8	0.8	0.30	0.8	0.2	0.08	0.8	0.8	0.30	0.8	0.8	0.30
25	EXHAUST FAN FOR PROV. STORE	1	1	0.25	0.29	0.8	0.8	0.19	0.8	0.2	0.05	0.8	0.8	0.19	0.8	0.8	0.19
28	GALLEY EQUIPMENT	1	1	20.00	23.53	0.8	0.5	9.41	0.8	0.1	1.88	0.8	0.2	3.76	0.8	0	0.00
30	DIRTY OIL TRANSFER PUMP	1	1	0.74	0.87	0.8	0.2	0.14	0.8	0.2	0.14	0.8	0.2	0.14	0.8	0	0.00
32	BOW THRUSTER	1	1	38.00	44.71	0.8	0	0.00	0.8	0	0.00	0.8	0.4	14.31	0.8	0	0.00
33	WINDLASS	1	1	4.30	5.06	0.8	0	0.00	0.8	0.8	3.24	0.8	0	0.00	0.8	0	0.00
34	GENERAL PURPOSE WINCHES	1	1	32.00	37.65	0.8	0.2	6.02	0.8	0	0.00	0.8	0	0.00	0.8	0	0.00
39	BATTERY	1	1	6.00	7.06	0.8	0.2	1.13	0.8	0.2	1.13	0.8	0.2	1.13	0.8	0	0.00
40	EMERGENCY LIGHTING SYSTEM	1	1	4.00	4.71	0.8	0.6	2.26	0.8	0	0.00	0.8	0	0.00	0.8	0	0.00
41	NAVIGATIONAL LIGHTS INCL. SEARCH LIGHTS	2	1	1.50	1.76	1	0.9	1.59	1	0.5	0.88	1	0.9	1.59	1	1	1.76
42	NAV AND COMMUNICATION EQUIPMENT	1	1	2.00	2.35	1	0.8	1.88	1	0.4	0.94	1	0.8	1.88	1	1	2.35
43	LIGHTING AND BATTERY CHARGER	2	1	3.00	3.53	1	1	3.53	0.8	1	2.82	0.8	1	2.82	0.8	1	2.82
	TOTAL POWER							**1608**			**31.14**			**1607**			**18.97**

	SAILING	HARBOUR	MANOUVRING	EMERGENCY
LOAD IN KW	**1608**	**31.14**	**1607**	**18.97**
LOAD IN KVA	**2010.61**	**38.9218**	**2009.05**	**23.7094**
TOTAL LOAD IN KVA WITH 20% RESERVE	**2412.73**	**46.7061**	**2410.86**	**28.4513**

ELECTRICAL LOAD CHART FOR CM-SWAS(S)H - 21 m

NO.	POWER RECEIVERS	QUANTITY INSTALLED	QTY. IN USE	MAX. POWER EACH IN (KW)	INSTALLED POWER (KW)	SAILING			HARBOUR			MANOUVRING			EMERGENCY		
						LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)	LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)	LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)	LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)
1	PROPULSION MOTOR	1	1	1960	2306	0.8	1	1845	0.8	0	0.00	0.8	1	1845	0.8	0	0.00
2	STEERING GEAR	1	1	4.00	4.71	0.8	1	3.76	0.8	0	0.00	0.8	1	3.76	0.8	0	0.00
4	LO STANDBY PUMP FOR ME	2	2	2.57	3.02	0.8	0.2	0.97	0.8	0.2	0.97	0.8	0.2	0.97	0.8	0.2	0.97
6	SEA WATER COOLING PUMP	2	1	2.00	2.35	0.8	0.5	0.94	0.8	0.4	0.75	0.8	0.5	0.94	0.8	0.5	0.94
7	BILGE/GS/FIRE/BALLAST PUMP	2	2	1.50	1.76	0.8	0.2	0.56	0.8	0.2	0.56	0.8	0.2	0.56	0.8	1	2.82
8	FO TRANSFER PUMP	2	1	0.75	0.88	0.8	0.7	0.49	0.8	0.2	0.14	0.8	0.2	0.14	0.8	0.2	0.14
9	FW HYDROPHORE PUMP	2	1	0.50	0.59	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09
10	SW HYDROPHORE PUMP	2	1	0.50	0.59	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09
11	SEWAGE PUMP	1	1	1.50	1.76	0.8	0.4	0.56	0.8	0	0.00	0.8	0	0.00	0.8	0	0.00
13	HOT WATER CALORIFIER	1	1	5.00	5.88	0.8	0.2	0.94	0.8	0.2	0.94	0.8	0.2	0.94	0.8	0	0.00
14	HOT WATER CIRCULATING PUMP	1	1	0.40	0.47	0.8	0.2	0.08	0.8	0.2	0.08	0.8	0.2	0.08	0.8	0	0.00
15	ER VENTILATION FANS	2	2	2.50	2.94	0.8	1	4.71	0.8	0.2	0.94	0.8	1	4.71	0.8	1	4.71
16	EXHAUST FAN FOR GALLEY	1	1	0.60	0.71	0.8	1	0.56	0.8	1	0.56	0.8	1	0.56	0.8	1	0.56
17	SUPPLY FAN FOR GALLEY	1	1	0.30	0.35	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28
18	A/C PLANT ACCOMODATION	1	1	40.00	47.06	0.8	0.6	22.59	0.8	0.6	22.59	0.8	0.6	22.59	0.8	0	0.00
19	STEERING GEAR ROOM SUPPLY FAN	1	1	0.30	0.35	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28
20	SUPPLY FAN FOR BOW THRUSTER ROOM	1	1	0.30	0.35	0.8	0.8	0.23	0.8	0.2	0.06	0.8	0.8	0.23	0.8	0.8	0.23
21	SUPPLY FAN FOR DECK STORE FWD	1	1	0.25	0.29	0.8	0.8	0.19	0.8	0.2	0.05	0.8	0.8	0.19	0.8	0.8	0.19
22	SUPPLY FAN FOR DECK STORE AFT	1	1	0.30	0.35	0.8	0.8	0.23	0.8	0.2	0.06	0.8	0.8	0.23	0.8	0.8	0.23
24	EXHAUST FAN FOR TOILETS	1	1	0.40	0.47	0.8	0.8	0.30	0.8	0.2	0.08	0.8	0.8	0.30	0.8	0.8	0.30
25	EXHAUST FAN FOR PROV. STORE	1	1	0.25	0.29	0.8	0.8	0.19	0.8	0.2	0.05	0.8	0.8	0.19	0.8	0.8	0.19
28	GALLEY EQUIPMENT	1	1	20.00	23.53	0.8	0.5	9.41	0.8	0.1	1.88	0.8	0.2	3.76	0.8	0	0.00
30	DIRTY OIL TRANSFER PUMP	1	1	0.74	0.87	0.8	0.2	0.14	0.8	0.2	0.14	0.8	0.2	0.14	0.8	0	0.00
32	BOW THRUSTER	1	1	42.00	49.41	0.8	0	0.00	0.8	0	0.00	0.8	0.4	15.81	0.8	0	0.00
33	WINDLASS	1	1	4.30	5.06	0.8	0	0.00	0.8	0.8	3.24	0.8	0	0.00	0.8	0	0.00
34	GENERAL PURPOSE WINCHES	1	1	32.00	37.65	0.8	0.2	6.02	0.8	0	0.00	0.8	0	0.00	0.8	0	0.00
39	BATTERY	1	1	6.00	7.06	0.8	0.2	1.13	0.8	0.2	1.13	0.8	0.2	1.13	0.8	0	0.00
40	EMERGENCY LIGHTING SYSTEM	1	1	4.00	4.71	0.8	0.6	2.26	0.8	0	0.00	0.8	0	0.00	0.8	0	0.00
41	NAVIGATIONAL LIGHTS INCL. SEARCH LIGHTS	2	1	1.50	1.76	1	0.9	1.59	1	0.5	0.88	1	0.9	1.59	1	1	1.76
42	NAV AND COMMUNICATION EQUIPMENT	1	1	2.00	2.35	1	0.8	1.88	1	0.4	0.94	1	0.8	1.88	1	1	2.35
43	LIGHTING AND BATTERY CHARGER	2	1	3.00	3.53	1	1	3.53	0.8	1	2.82	0.8	1	2.82	0.8	1	2.82
TOTAL POWER								**1909**			**39.61**			**1909**			**18.97**

LOAD IN KW	**1909**	**39.61**	**1909**	**18.97**
LOAD IN KVA	**2385.9**	**49.51**	**2386.23**	**23.7094**
TOTAL LOAD IN KVA WITH 20% RESERVE	**2863.08**	**59.412**	**2863.47**	**28.4513**

ELECTRICAL LOAD CHART FOR CM-SWAS(S)H - 24 m

NO.	POWER RECEIVERS	QUANTITY INSTALLED	QTY. IN USE	MAX. POWER EACH IN (KW)	INSTALLED POWER (KW)	SAILING			HARBOUR			MANOUVRING			EMERGENCY		
						LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)	LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)	LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)	LOAD FACTOR	UTILITY FACTOR	INPUT POWER (KW)
1	PROPULSION MOTOR	2	2	1050	1235	0.8	1	1976	0.8	0	0.00	0.8	1	1976	0.8	0	0.00
2	STEERING GEAR	1	1	4.00	4.71	0.8	1	3.76	0.8	0	0.00	0.8	1	3.76	0.8	0	0.00
4	LO STANDBY PUMP FOR ME	3	2	2.57	3.02	0.8	0.2	0.97	0.8	0.2	0.97	0.8	0.2	0.97	0.8	0.2	0.97
6	SEA WATER COOLING PUMP	2	1	2.00	2.35	0.8	0.5	0.94	0.8	0.4	0.75	0.8	0.5	0.94	0.8	0.5	0.94
7	BILGE/GS/FIRE/BALLAST PUMP	2	2	1.50	1.76	0.8	0.2	0.56	0.8	0.2	0.56	0.8	0.2	0.56	0.8	1	2.82
8	FO TRANSFER PUMP	3	1	0.75	0.88	0.8	0.7	0.49	0.8	0.2	0.14	0.8	0.2	0.14	0.8	0.2	0.14
9	FW HYDROPHORE PUMP	2	1	0.50	0.59	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09
10	SW HYDROPHORE PUMP	2	1	0.50	0.59	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09	0.8	0.2	0.09
11	SEWAGE PUMP	1	1	1.50	1.76	0.8	0.4	0.56	0.8	0	0.00	0.8	0	0.00	0.8	0	0.00
13	HOT WATER CALORIFIER	1	1	5.00	5.88	0.8	0.2	0.94	0.8	0.2	0.94	0.8	0.2	0.94	0.8	0	0.00
14	HOT WATER CIRCULATING PUMP	1	1	0.40	0.47	0.8	0.2	0.08	0.8	0.2	0.08	0.8	0.2	0.08	0.8	0	0.00
15	ER VENTILATION FANS	2	2	2.50	2.94	0.8	1	4.71	0.8	0.2	0.94	0.8	1	4.71	0.8	1	4.71
16	EXHAUST FAN FOR GALLEY	1	1	0.60	0.71	0.8	1	0.56	0.8	1	0.56	0.8	1	0.56	0.8	1	0.56
17	SUPPLY FAN FOR GALLEY	1	1	0.30	0.35	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28
18	A/C PLANT ACCOMODATION	1	1	55.00	64.71	0.8	0.6	31.06	0.8	0.6	31.06	0.8	0.6	31.06	0.8	0	0.00
19	STEERING GEAR ROOM SUPPLY FAN	1	1	0.30	0.35	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28	0.8	1	0.28
20	SUPPLY FAN FOR BOW THRUSTER ROOM	1	1	0.30	0.35	0.8	0.8	0.23	0.8	0.2	0.06	0.8	0.8	0.23	0.8	0.8	0.23
21	SUPPLY FAN FOR DECK STORE FWD	1	1	0.25	0.29	0.8	0.8	0.19	0.8	0.2	0.05	0.8	0.8	0.19	0.8	0.8	0.19
22	SUPPLY FAN FOR DECK STORE AFT	1	1	0.30	0.35	0.8	0.8	0.23	0.8	0.2	0.06	0.8	0.8	0.23	0.8	0.8	0.23
24	EXHAUST FAN FOR TOILETS	1	1	0.40	0.47	0.8	0.8	0.30	0.8	0.2	0.08	0.8	0.8	0.30	0.8	0.8	0.30
25	EXHAUST FAN FOR PROV. STORE	1	1	0.25	0.29	0.8	0.8	0.19	0.8	0.2	0.05	0.8	0.8	0.19	0.8	0.8	0.19
28	GALLEY EQUIPMENT	1	1	20.00	23.53	0.8	0.5	9.41	0.8	0.1	1.88	0.8	0.2	3.76	0.8	0	0.00
30	DIRTY OIL TRANSFER PUMP	1	1	0.74	0.87	0.8	0.2	0.14	0.8	0.2	0.14	0.8	0.2	0.14	0.8	0	0.00
32	BOW THRUSTER	1	1	48.00	56.47	0.8	0	0.00	0.8	0	0.00	0.8	0.4	18.07	0.8	0	0.00
33	WINDLASS	1	1	4.30	5.06	0.8	0	0.00	0.8	0.8	3.24	0.8	0	0.00	0.8	0	0.00
34	GENERAL PURPOSE WINCHES	1	1	32.00	37.65	0.8	0.2	6.02	0.8	0	0.00	0.8	0	0.00	0.8	0	0.00
39	BATTERY	1	1	6.00	7.06	0.8	0.2	1.13	0.8	0.2	1.13	0.8	0.2	1.13	0.8	0	0.00
40	EMERGENCY LIGHTING SYSTEM	1	1	4.00	4.71	0.8	0.6	2.26	0.8	0	0.00	0.8	0	0.00	0.8	0	0.00
41	NAVIGATIONAL LIGHTS INCL. SEARCH LIGHTS	2	1	1.50	1.76	1	0.9	1.59	1	0.5	0.88	1	0.9	1.59	1	1	1.76
42	NAV AND COMMUNICATION EQUIPMENT	1	1	2.00	2.35	1	0.8	1.88	1	0.4	0.94	1	0.8	1.88	1	1	2.35
43	LIGHTING AND BATTERY CHARGER	2	1	3.00	3.53	1	1	3.53	0.8	1	2.82	0.8	1	2.82	0.8	1	2.82
TOTAL POWER								**2049**			**48.08**			**2051**			**18.97**

	Sailing	Harbour	Manouvring	Emergency
LOAD IN KW	**2049**	**48.08**	**2051**	**18.97**
LOAD IN KVA	**2561.2**	**60.0982**	**2564.35**	**23.7094**
TOTAL LOAD IN KVA WITH 20% RESERVE	**3073.44**	**72.1179**	**3077.21**	**28.4513**