



TRA Visions 2016

Final Project Template – This template is to be used for submitting the final version of the project. The final deliverable should be submitted by the 30st of September 2015

Idea Number: **L1-6**

PILLAR / TRANSPORT MODE			
ROAD ☐	RAIL ☐	MARINE ☒	CROSS MODAL ☐
Project Related to:	☐ RA1: Environment – Decarb., Sustainability & Energy Efficiency ☒ RA2: Vehicle & Vessels Technology, Design & Production ☐ RA3: Urban and Long-Distance People Mobility – Systems and Services ☐ RA4: Freight Transport & Logistics ☐ RA5: Safe, Secure and Resilient Transport Systems ☐ RA6: Transport Infrastructures ☐ RA7: Human Factors, Socio-Economics and Foresights ☐ RA8: Automation and Connectivity ☐ RA9: Enabling Environment for Innovation Implementation		

Project Title:

**MODULAR MULTIPURPOSE HYBRID SHIP DESIGN FOR HARBOUR AND WINDFARM
SUPPORT VESSELS TO ACTUALISE ENVIRONMENTAL SUSTAINABILITY**



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1. Introduction

Today, the Maritime Industry faces two major concerns of Safety and Environmental sustainability. In the current market scenario the European Shipbuilding business is being predominantly governed by Windfarm, Harbour, Offshore Support Vessels and Yacht/Cruise/Pleasure Crafts, this idea focuses on design of a safe and eco-friendly common modular vessel that can cater to Windfarm, and Harbour Support Vessels mainly Pilot, Police/Custom Patrol Boats and Wind-farm Crew Transfer vessels for 18-24 m segment.

These vessel types are designed and operated with an intent to carry personnel at fastest possible time while ensuring safety and comfort of personnel on board, quintessentially during embarkation and disembarkation to/ from these crafts.

Conventionally Planing Mono-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. For the intended operation, while planing mono-hulls provide high speed with very poor safety characteristics, the SWATH provides excellent safety/sea-keeping with very high resistance (emissions) and complex/high production cost/time.

To ensure good safety and sea-keeping characteristics the project will use the concept of SWATH and develop a trimaran like Small Water-plane Area Single (Stabilized) Hull popularly termed as SWAS(S)H. Thus decreasing the wetted surface area and in-turn the resistance (emissions). While this solves the problem of safety and emission it raises the issues of practical implementation due to high cost of design and production.

Environmental protection and Sustainability often treated synonymous are similar but not same. Sustainability, unlike protection is a multidimensional thought that focuses not only on technology but also on management factors. The economic slowdown has forced the maritime industry to provide an integrated solution, a design that not only reduces emissions but at the same time provides a practical solution that can be implemented in current volatile market. Hence the need of a design that will ease the complexity and time/cost of production as well, this gave birth to the idea of **CM-SWAS(S)H**, Common Modular - Small Water-plane Area Single (Stabilized) Hull.

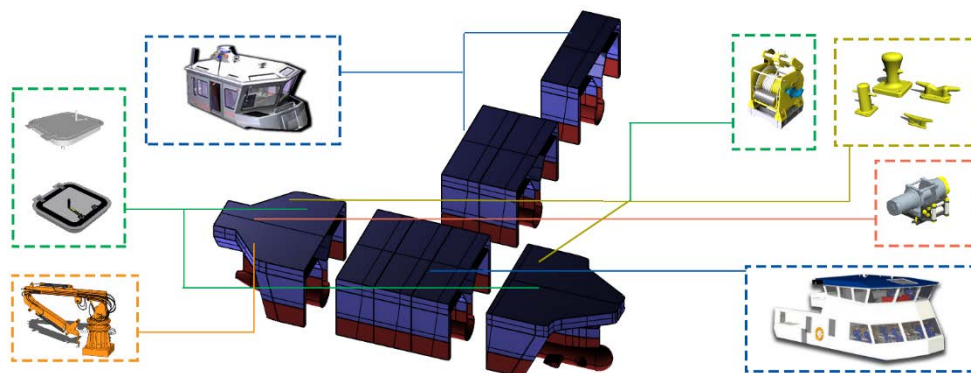


Figure 1.1 Concept of CM-SWAS(S)H

To further enhance the operational profile the Marine power plant is being installed with an Advanced Hybrid Diesel Electric AC-DC System keeping in mind the future compatibility for Battery powered vessel.

While we propose this idea some of the major technological drawbacks that are present in design and production at lack of Classification rules for special trimaran hulls like this, hence the idea will implement the use of conservative approach of using rules for both SWATH and Trimaran Hulls. Another issue is the hull form optimisation for resistance the issue here is which code to be used Potential Flow or RANS. While potential flow is a faster approach, it calls for projection of Total Resistance using form

factor and as of today there is no direct empirical formula to calculate the same. On the other hand RANS can estimate the resistance with much closer accuracy but the issue is that this code requires very high computational time. To resolve this issue we have used a self-developed code to predict total resistance using Potential Flow method, this self-developed code is based on the techniques proposed in scientific works of published author(s). Thus we optimised the hull using potential flow and then validate the data using RANS and Towing Tank test.

NOTE : The towing tank test is scheduled for 2nd Week of October and hence the data could not be presented in this report. If needed it can be made available at later stage.

The successful hull form optimisation for resistance has resulted in 32.56% reduction in total resistance at 25 Knots and 14.55% reduction in total resistance at 20 Knots. The hull form for optimised for these two speeds keeping in mind that current fleet of similar vessels operate predominantly around this operating speed values.

With Advanced Hybrid System this fuel consumption is estimated to decrease further by approximately 10%.

The future scope of work includes use of FEM based Structural optimisation to minimise the effects of conservative design approach used due to lack of Classification rules.

Post structural optimisation the design will introduce fuel oil trim tanks forward and aft of the vessel to maintain the excellent longitudinal stability and to have flexibility for weight movement on-board the vessel.

While it is a known fact that the Small Waterplane Area Hull exhibit excellent Sea-keeping characteristics, it is proposed to carry out RANS based sea-keeping analysis of the final hull in future.

The modular design of hull is proposed to encourage the adaptability to different kinds of vessel types and to reduce design and production man-hours. To efficiently achieve this it is recommended that moulded/extruded stiffened panels be used as they further enhance the productivity and reduce the financial burden that is introduced due to complex structure both in terms of welding and quantity of raw material used.

2. Selection of research area

The idea selected pertaining to Vehicle & Vessels Technology, Design & Production, also amalgamates the philosophy of crew safety and environmental sustainability in the design process to provide a comprehensive solution that can be practically implemented. It is our belief that sometimes to solve a complex problem we have to start from scratch at a design table. While many efforts have been made in order to reduce the environmental pollution, the practical feasibility of many good solutions is very limited at this time. Hence it was decided to redesign a vessel that represents highest order of safety and then optimise it for lower emissions and in addition design the marine power plan that can be easily adapted to future technology with battery power may it be solar or wind.

The operational profile of the vessels selected requires them to operate majorly in near coast region. In accordance to UNFCCC Copenhagen 2009, all EU nations have pledged to reduce the CO₂ 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 CO₂ 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 on both sides. 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 we will increase, in an optimised manner the size of the central tube and the strut. And the stability will be balanced out by optimising the outriggers, attached passive fin stabilizers and introduction of trim tanks.

3. Literature Survey

The concept of SWASH and Modular Hulls as of today exist in two separate class of vessels. There are only two documented cases of SWASH design that have been practically implemented one by A&R Shipyard Germany for a Pilot tender vessel for one 21m vessel that was built as an in-house research project and the other is Windserver 25 and Windserver 30 project by Fjellstrand AS. The Windserver project has seen a lot of success with delivery of 3 vessels of 24 m and 3 vessels of 29 m. This success provided the idea that if we can design a SWAS(S)H vessel with multi-utility, the success can be implemented to A&R design also.

This brought in idea of implementing the modularity concept which is a common design practice in larger vessels with large parallel middle body like trailer suction hopper dredger and bulk carriers.

In first quarter of 2015 Offshore Marine Technology published the paper an article on Thailand based Albatross Marine Design (AMD), which proposes the use of modular structure with composite materials for windfarm support vessels from length 18-24 m catamaran hull. The concept of modularity is selected in this length range due to the fact that right now industry is focused on 18, 21, 24 and 29m vessels but the class rules for vessels is different for less than 24m and greater than 24m vessel, hence the lengths are limited to 24m.

Two issues with AMD's solution are, firstly as of today the classification rules for composite material built ships are not available for intended operations of windfarm support vessels and secondly catamaran exhibit very high torsional load thus requiring stronger and complex transverse structure. This causes the lightship weight to be higher.

4. Proposed Solution and Potential Technology Gaps

Pilot Boats, Police/Custom Patrol Boats and Wind-farm Support Vessels are designed and operated with an intent to carry personnel at fastest possible time while ensuring safety and comfort of personnel on board, in addition one of the most quintessential requirement is of 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 below.

TABLE OF COMPARISON			
S. NO.	ELEMENT	PLANING MONO-HULL	CATAMARAN/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
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 4.1 Comparison table of Planing Mono-hull and Catamaran/ SWATH

Now we compare the vessels in terms of the values in numbers as per practical application, please note that the data below represents vessels of different sizes but intended for same operation and similar of Deck Area.

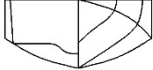
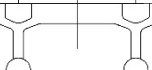
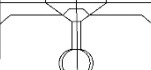
COMPARISON OF DIFFERENT HULL FORMS					
No.	ELEMENT				
1	Vessel Type	PLANING	SEMI-PLANING	SWATH	SWAS(S)H
2	Main Dimensions	26 m x 5.8 m	23 m x 8 m	25 m x 13 m	20 m x 12 m
3	Displacement	75 t	80 t	125 t	70 t
4	Propulsion Power	2300 kW	1600 kW	1800 kW	1300 kW
5	Max Speed	20 Knots	20 Knots	14 Knots	15 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 4.2 Comparison table of Planing Mono-hull, SWATH, SWAS(S)H

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

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 student will try to combine all the solutions in the best/most optimised manner to propose the new concept hull form.

4.1 RESISTANCE AND STABILITY

High resistance means high installed operating power thus higher emissions. The operational profile of the vessels selected requires them to operate majorly in near coast region. In accordance to UNFCCC Copenhagen 2009, all EU nations have pledged to reduce the CO₂ 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 CO₂ 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's proposed to use a trimaran like multihull design with single submerged hull stabilised by two outriggers on both sides. 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 we will increase, in an optimised manner

the size of the central tube and the strut. And the stability will be balanced out by optimising the outriggers, attached passive fin stabilizers and introduction of trim tanks.

The constraint here is to select the right optimisation technique, as explained earlier we will predict the resistance using potential flow method (Maxsurf-Slenderbody Method), with ITTC formulation and validate the data with RANS solver (FineMarine[®]) and the Towing Tank test for the final hull form

Note:

- 1) In addition the vessel will switch to Trimaran mode operation during light ship condition, this way during return travel the vessel will have the ability to travel at higher speeds as the resistance will decrease further.
- 2) The towing tank test is scheduled for 2nd Week of October and hence the data could not be presented in this report. If needed it can be made available at a later stage.

4.2 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.

4.3 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, to allow for movement of cargo, as the movement of weight in and out of these vessels is supercritical for the stability. Thus the student proposes use Aluminium 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.

4.4 FINANCIAL ASPECTS

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

4.4.1 PRODUCTION COST

The construction of multi-hulls in general calls for high cost of production due to the complex structure, in addition the introduction of Aluminium increases the raw material and welding cost of the project as well. To reduce this, the student 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.

4.4.2 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 in design and operation of the propeller at 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 and 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 System which is a modification of ELFA system used on European Bus Transport System to reduce emission.

4.5 SUMMARY OF PROBLEMS AND SOLUTION

In the table below shows 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

4.6 THE CONCEPT

CM - SWAS(S)H ©



5. Design Philosophy

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 below

- 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) FEM base Structural Optimisation,
- 5) Validation of Resistance results by way of towing tank test.

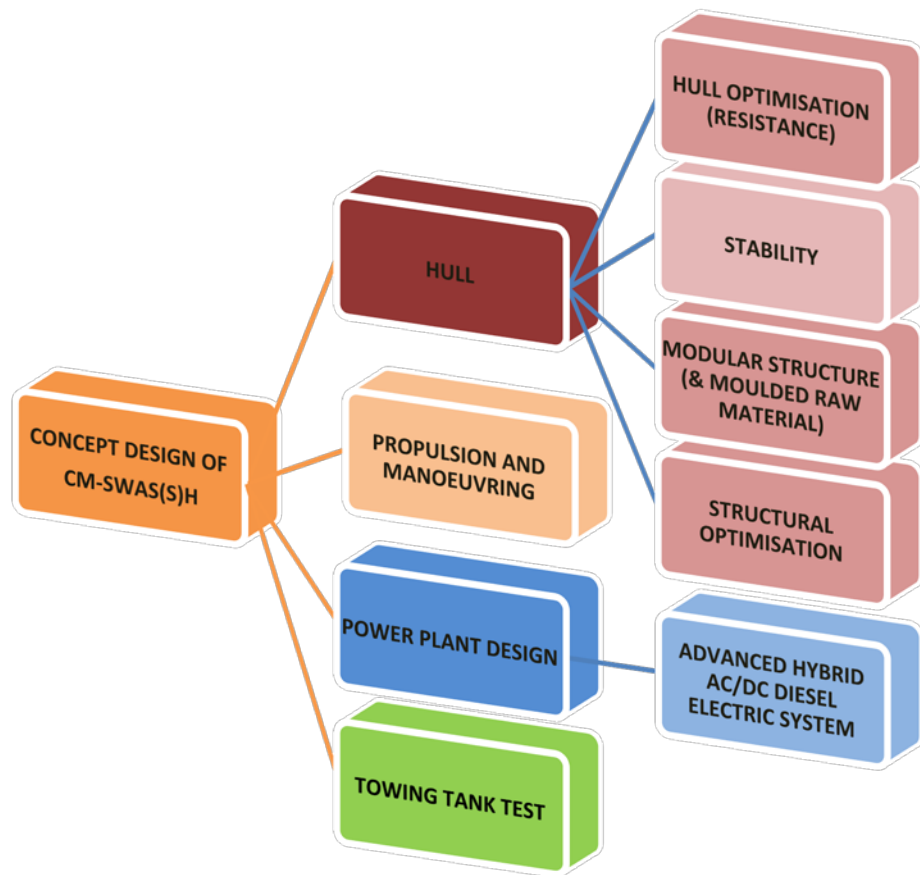


Figure 5.1 Project Structure for the proposed concept design

5.1 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.

5.2 HULL FORM

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

5.3 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.

5.4 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.

5.5 STABILITY

The design of outriggers, passive fin stabilisers 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.

5.6 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.

5.7 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.

5.8 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.

5.9 FEM BASED STRUCTURAL OPTIMISATION

Most Classification Societies allow for direct calculation for certain categories of vessels when there are no specific rules/guidelines provided by Classification Societies, the numerical model proving the integrity of structure can be submitted to Class Authorities for review and after careful analysis if found satisfactory, the same design can receive class approval as special case. A mixed framing system type of structural design is designed and optimised using FEM Analysis with Class Rules as foundation. Ansys Structural is used for this optimisation.

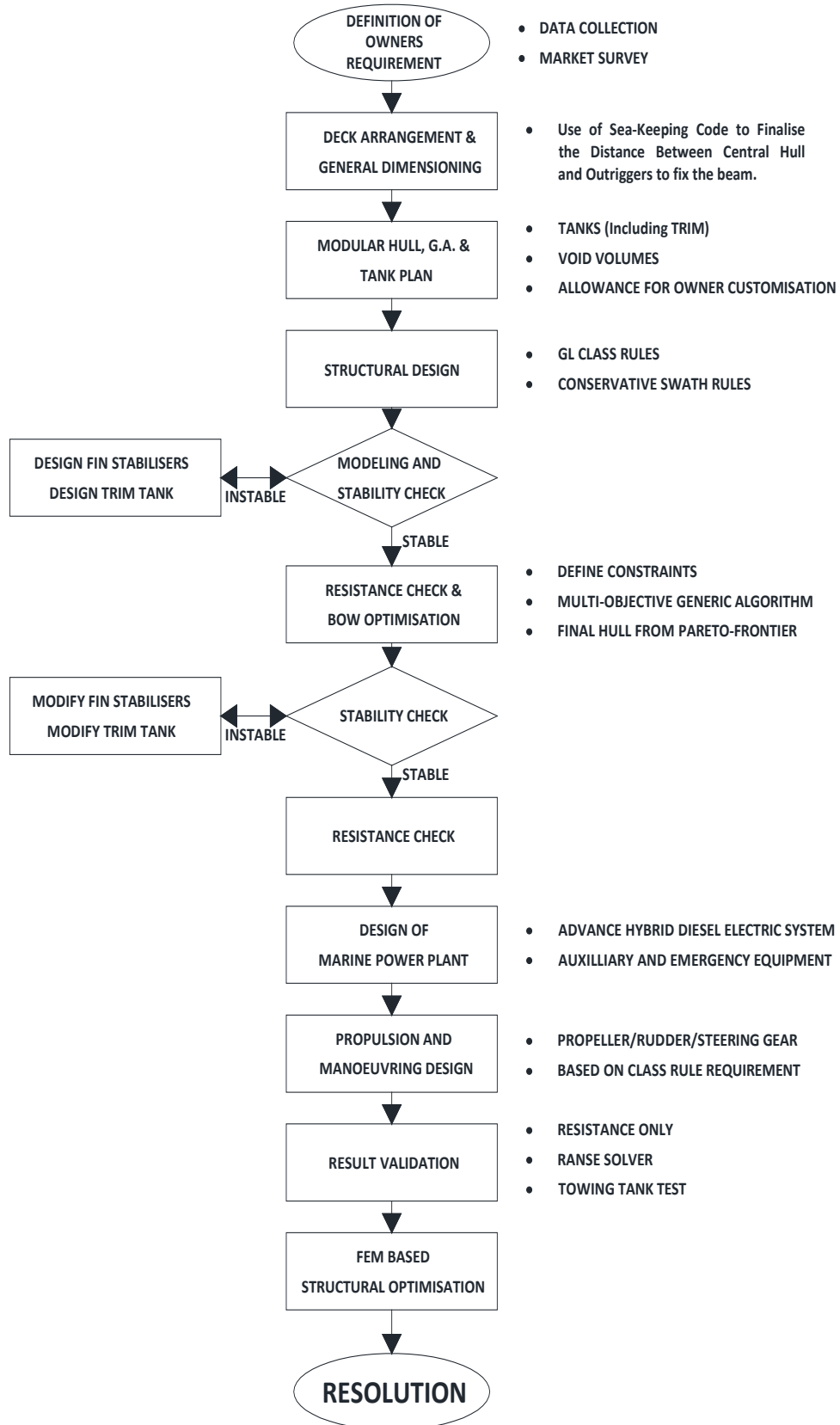


Figure 5.2 Project Work Flow Chart

6. Design and Technical Data

6.1 OWNERS REQUIREMENT

The owner's requirement is defined based on the market survey of most common vessel size and requirement. 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 the Classification Rules for vessels less than equal 24 m length are different from those with length greater than 24 m. Since the concept proposes the use of common modular hull, it was finalised that the vessels will be designed for length ranging from 18 to 24 m. It total seven (7) vessels of three different types and sizes will be designed in common modular hull form, the details of the same are given below

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	Operating Speed		25 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 @ 2m		All Vessel
6	Cabins		1 - 2 Personnel Cabin 1 - Captain's Cabin		24 m WS Vessel

Table 6.1 Table for Vessel Type and Length Configuration including basic Owners Requirements

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. The same in comparison with mono-hull are mentioned below:

NO.	PARAMETERS	NOTATION	MULTI-HULL	MONO-HULL
1	Overall Breadth/Length Ratio	B _m /L	0.3 - 1.0	0.1 - 0.2
2	Hull Depth/Overall Length	D/L	0.10 - 0.25	0.07 - 0.2
3	Depth/Length Ratio	H/L	0.10 - 0.30	0.07 - 0.10
4	One Hull Breadth/Draft Ratio	B ₁ /T	0.5 - 2.5	2 - 4
5	One Hull Length/Breadth Ratio	L/B ₁	3.0 - 30	3.0 - 10

Based on the Multi-Hull dimensioning principle listed above and the owners requirement the final dimension of all the vessels were defined as

PRINCIPAL DIMENSIONS OF PROPOSED HULLS			
PARAMETERS	VALUE (m)	PARAMETER	VALUE (m)
LENGTH OVER ALL (LOA) 1	24.0	MAX. OUTRIGGER WIDTH	0.50
LENGTH OVER ALL (LOA) 2	21.0	MIN. OUTRIGGER WIDTH	0.35
LENGTH OVER ALL (LOA) 3	18.0	DESIGN DRAFT (T)	3.2
BEAM AT DESIGN DRAFT(B)	9.00	LIGHT SHIP DRAFT (T')	2.1
OVERALL BEAM (B _m)	9.50	DEPTH (D)	5.75
FENDER WIDTH	0.25	MAX TUBE DIAMETER	2.6

Table 6.2 Principal Dimensions of Proposed Hulls

6.2 CLASSIFICATION NOTATION

The Vessel will be designed as per the class rules under DNV-GL, as

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

6.3 FRAME SPACING

The Vessel will be designed as per the class rules under DNV-GL, as

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 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.

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

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.

$$\begin{aligned} \text{Minimum Distance from FP} &= 0.05 * L_{wl} \\ \text{Maximum Distance from FP} &= (0.05 * L_{wl}) + 3 \end{aligned}$$

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 length needed to be carried out to arrive final values. Based on the calculation shown above 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.

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 6.3 Selected Values for Frame Spacing and Position of Collision Bulkhead for Modular Hull

6.4 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 below

6.4.1 EMBARCATION / 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.

6.4.2 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.

6.4.3 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

6.4.4 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.

6.5 TANK CAPACITIES

Post Engine, Generator and Stability Calculations, the tank capacities were computed based on an endurance of 24 Hours of operation and fully loaded condition of cargo and crew.

TANK CAPACITIES						
TANK TYPE	18 m		21 m		24 m	
	P.P.C.	WSV	P.P.C.	WSV	P.P.C.	WSV
FUEL OIL	5 t	7 t	9 t	10 t	-	14.2 t
FO TRIM TANK	3 t	4 t	4 t	5 t	-	8 t
LUBE OIL	1 t	1 t	1.5 t	1.5 t	-	2 t
FRESH WATER	1.2 t	1.2 t	1.2 t	1.2 t	-	1.2 t
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 6.4 Tank Capacities for all vessel configurations

6.6 STRUCTURAL DESIGN

As mentioned 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 it was decided to use a conservative approach and use the class rules for SWATH and Trimaran Hulls as applicable.

To limit the structural weight of the vessel to 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 5083, H116**, this is due to the fact that as per DNV-GL Class rules for Special Ships-High Speed Crafts, 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 details properties of welded/un-welded yield and tensile strength refer to **annexure**. 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.

NOTE : Refer to annexures for Detailed Strcutural Model images and Calculations.

6.6. 1MOULDED 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 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 below. It should be noted that these specimen images are from the samples available at ULg Laboratory provided courtesy of **Abeking & Rasmussen Schiffs- und Yachtwerft Aktiengesellschaft (A&R)** for academic research purposes.

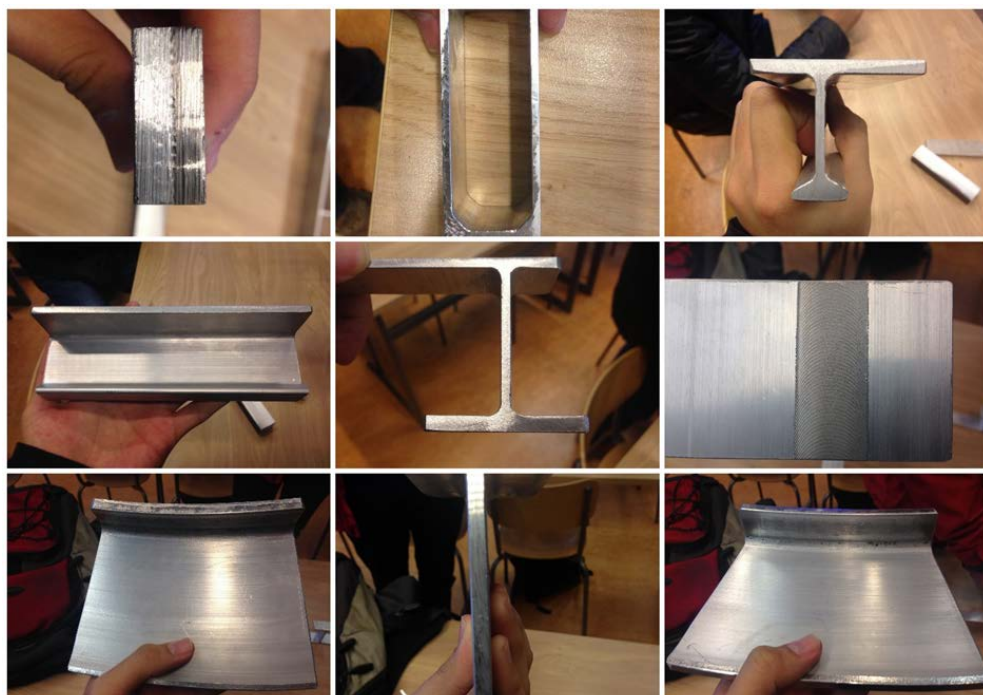


Figure 6.5 Sample images of Moulded Stiffened Panels

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

6.7 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 discusses in earlier sections high resistance offered by this design leads to high fuel consumption and higher emission.

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

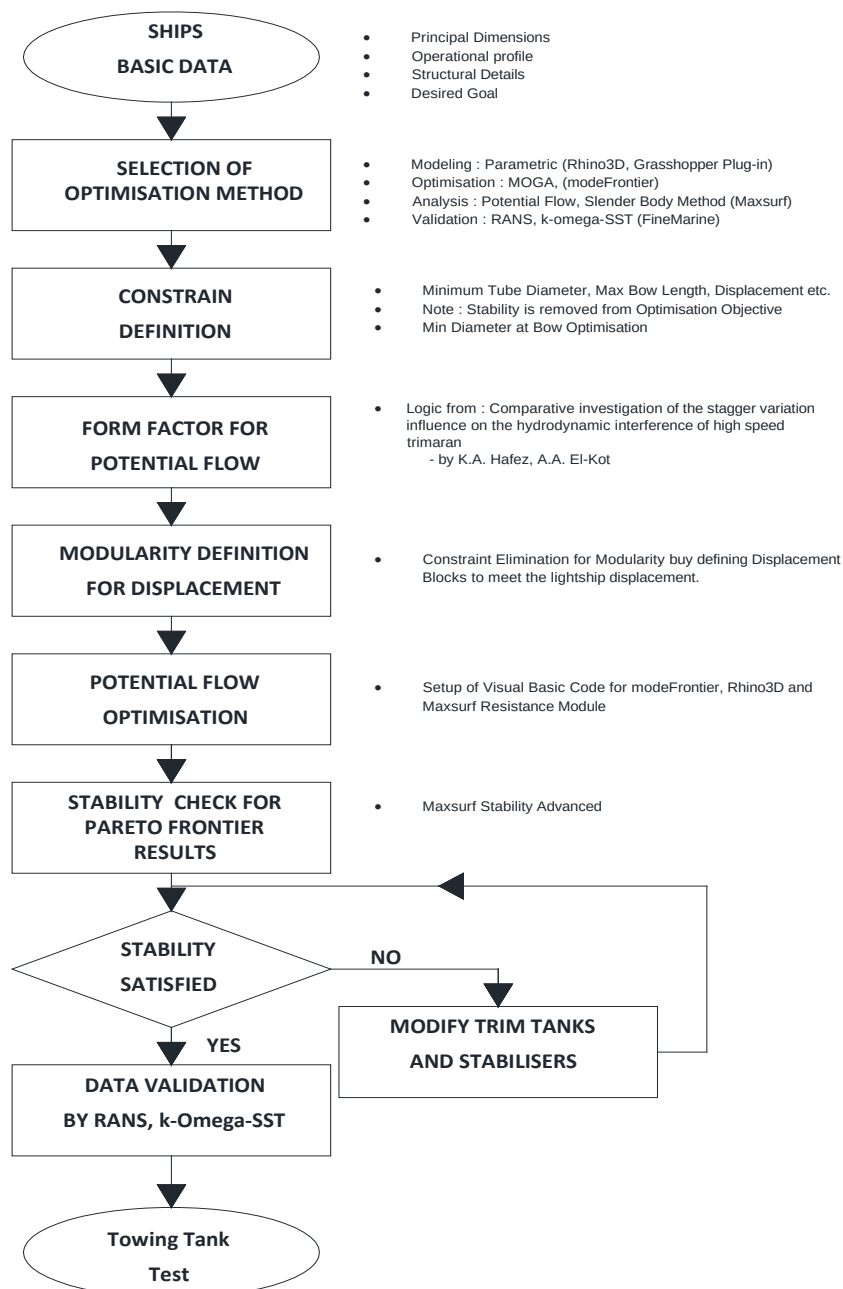


Figure 6.6 Flow chart for Hull Form Optimisation for Calm Water Resistance

As the first step of optimisation, the model setup plays a critical role as it not only depends of 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.

6.7.1 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.

6.7.2 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 mess.

6.7.3 OPTIMISATION ALGORITHM

Considering the multi-dimensional 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.

6.7.4 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.

6.7.5 FORM FACTOR FOR POTENTIAL FLOW

We intend to use Maxsurf Resistance package as essentially a resistance calculation program, which uses a potential flow logic with slender body method which is based on the work of Tuck et al. and Couser et al. we can only estimate the wave making resistance of the vessel. Using this data we need to extrapolate the viscous resistance via ITTC formula with for factor $(1+k)$.

While we have Hultrop and Molland formula for mono-hull and catamaran, 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 is 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*” 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

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

Where

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

And

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

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.

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

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

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

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

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

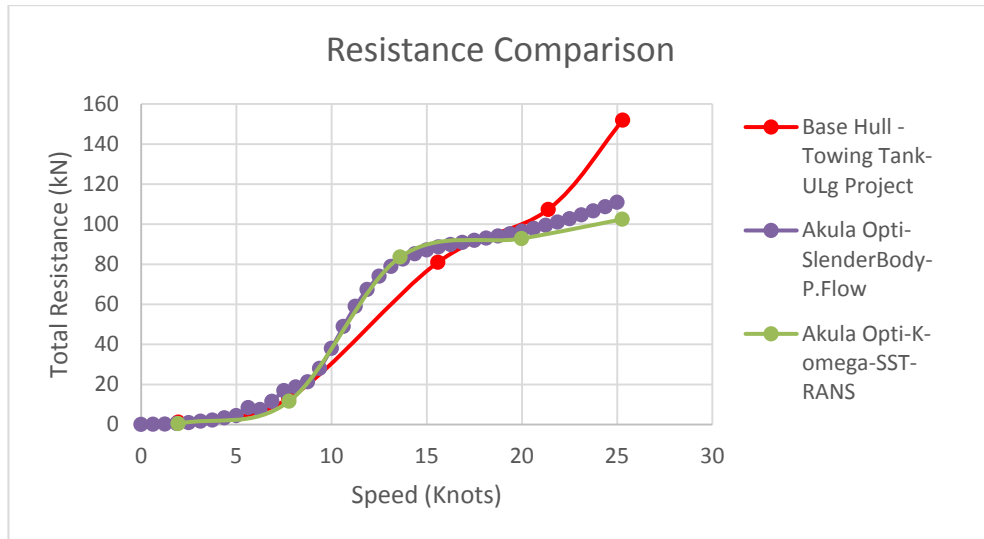
$$C_{T-tri} = \frac{1}{A_{S-tri}} * [A_{S-Tube} * C_{T-tube} + 2 * A_{S-out} * C_{T-out}]$$

Furthermore the resistance can be calculated as

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

6.7.6 RESULTS OF RESISTANCE OPTIMISATION

The successful hull form optimisation for resistance has resulted in 32.56% reduction in total resistance at 25 Knots and 14.55% reduction in total resistance at 20 Knots. The hull form for optimised for these two speeds keeping in mind that current fleet of similar vessels operate predominantly around this operating speed values. And from the figure below it can be seen that the potential flow results are in-line with the RANS results thus validating the potential flow model.



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.

RESISTANCE COMPARISON OF BASE AND OPTIMISED HULLS				
S. NO.	HULL LOA	RESISTANCE OPTIMISATION		
		BASE (kN)	FINAL (kN)	% REDUCTION
1	18 m	151.8	102.5	32.56
2	21 m	172.4	134.1	22.21
3	24 m	198.33	146.2	26.28

Table 6.7 Resistance comparison of base and optimised hull

6.8 ADVANCED HYBRID MARINE POWER PLANT

In earlier sections 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

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.

6.8.1 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 below depicts the the basic principle of operation of an Advanced Hybrid AC-DC Diesel Electric System.

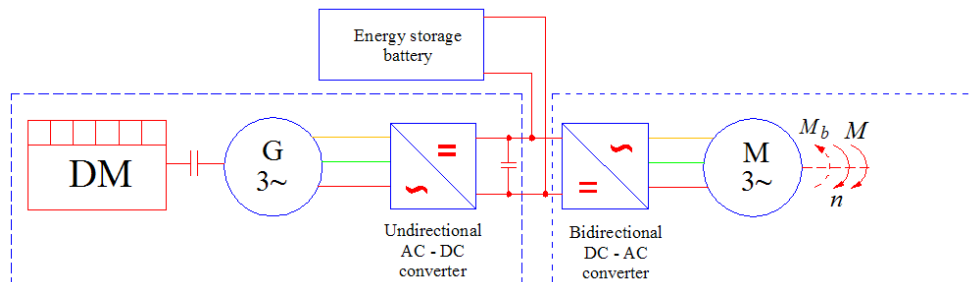


Figure 6.8 Basic layout of Advanced Hybrid AC-DC Diesel Electric System

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.

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 know the primary elements, the load and their respective efficiency that need to be taken into account. Based on the design shown in figure above 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

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

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

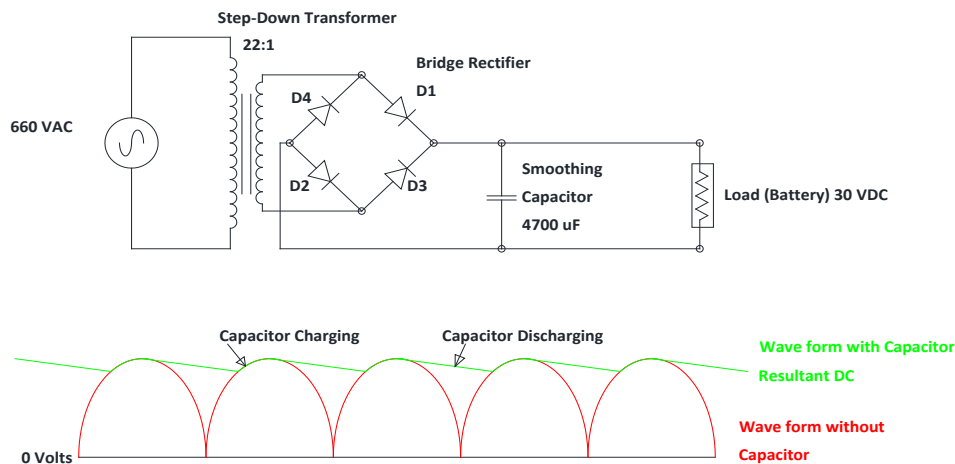


Figure 6.9 Unidirectional Bridge Wave Pulsating AC-DC Rectification Circuit

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 as shown figure below of rectification system.

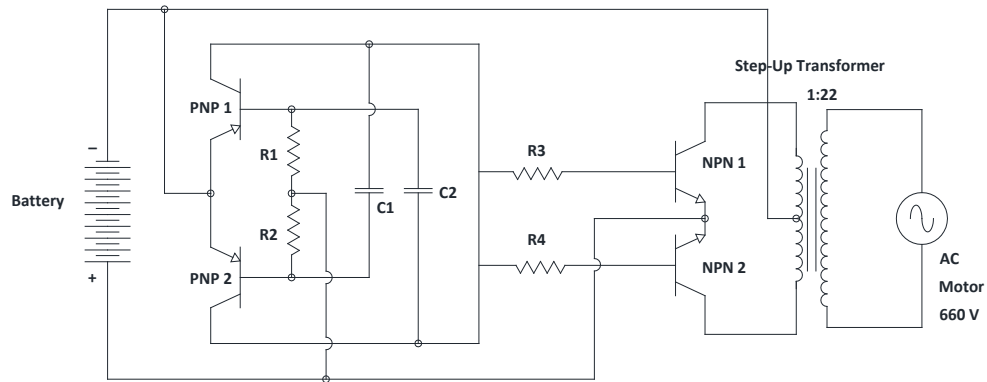


Figure 6.10 Bidirectional DC-AC Converter Circuit

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 below 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 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.

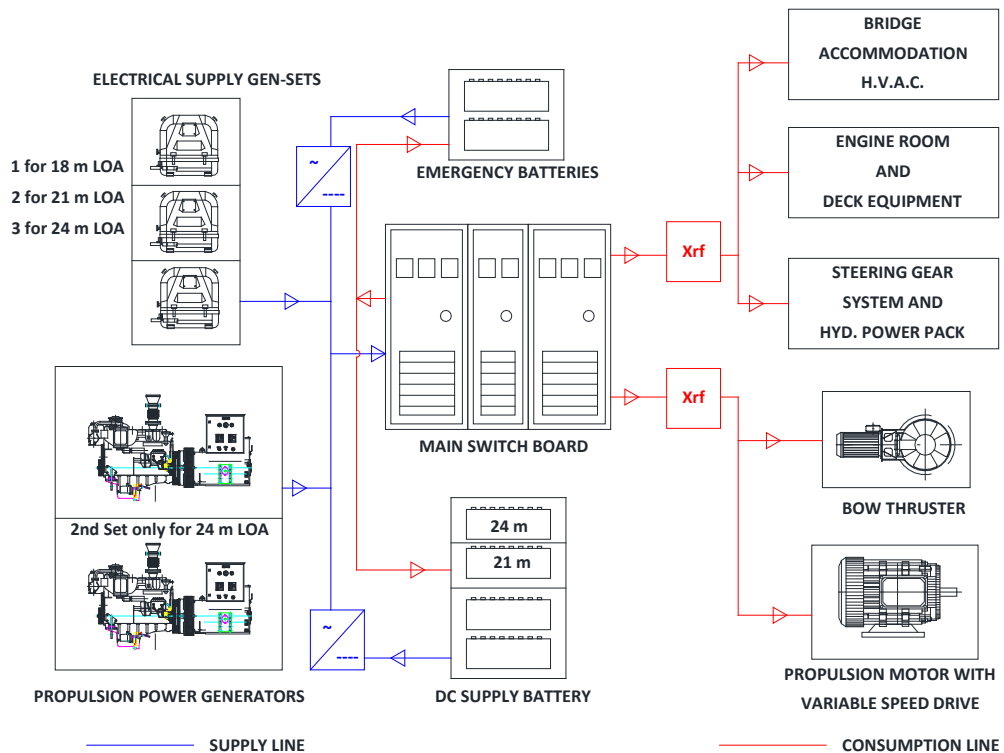


Figure 6.11 Advanced Hybrid AC-DC Main Power Plant Layout

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 above the efficiency of energy storage (battery) system needed to be taken into account.

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

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

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

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

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

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

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

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

Based on the above factors the final calculation of electrical load was carried out for all the three vessel types and the same is available in the annexures. 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.

6.9 ANCHOR, PROPULSION AND MANOEUVRING

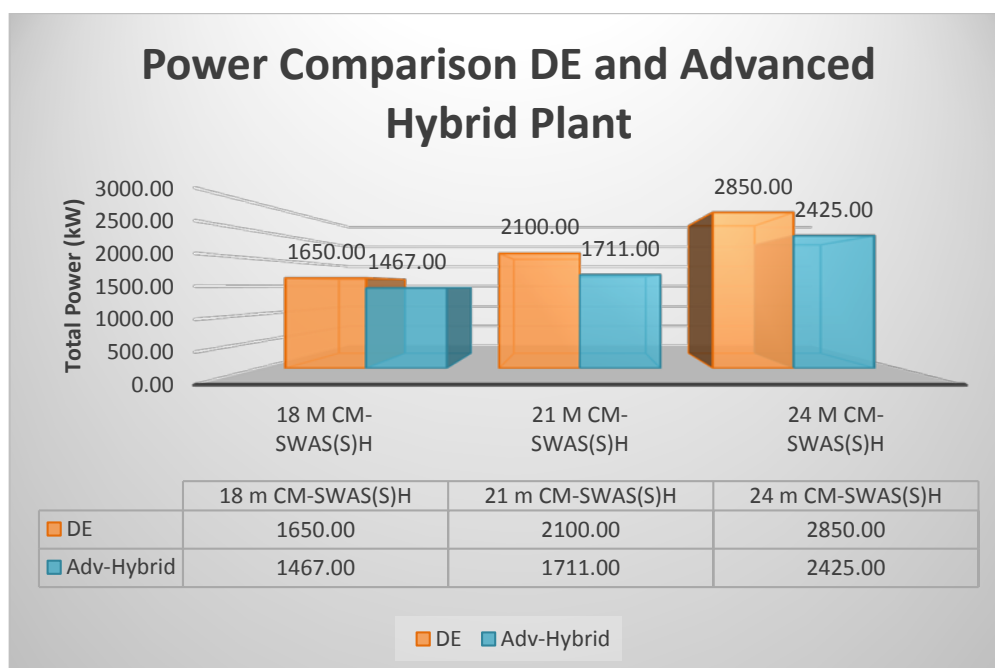
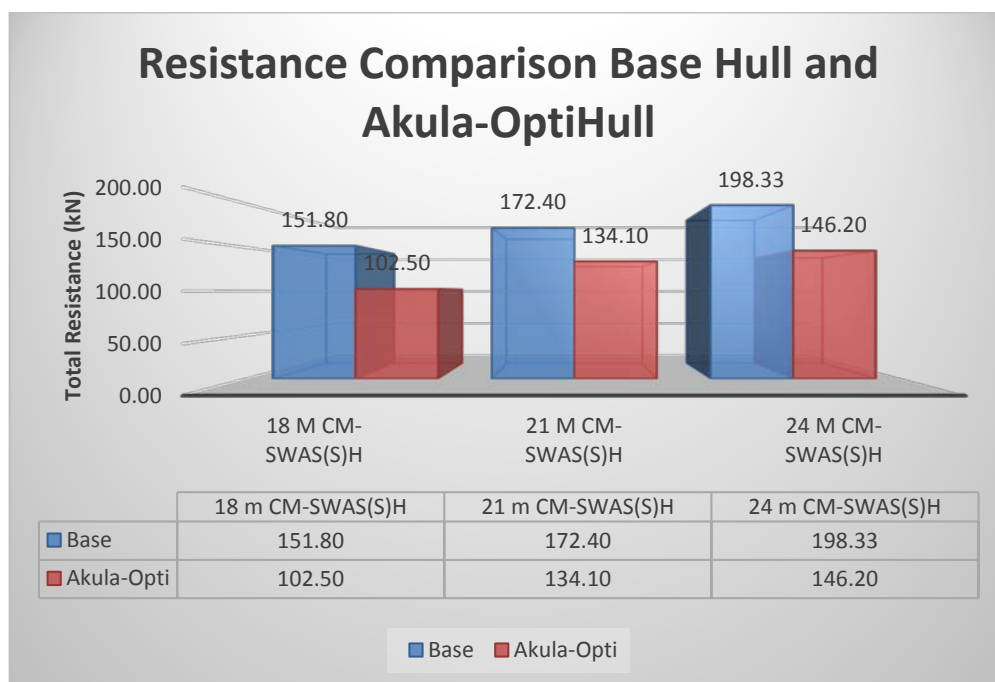
The anchor, propulsion and manoeuvring are selected based on the classification society requirements and the details of the same can be found in the annexures.

6.10 REULST AND COMPARISON

A combined effect of resistance optimisation and Hybrid Power plan shows that the final values of the power consumption of CM-SWAS(S)H are comparable to the values of planing mono-hull (Refer Table 4.2) and with modularity concept the effects of complex structure and the production man hours can be reduced with series production of all the vessels. The table below illustrates the final values of resistance and power reductions

RESULT COMPARISON OF BASE / OPTIMISED HULLS AND MARINE POWER PLANT							
	HULL LOA	RESISTANCE OPTIMISATION			POWER OPTIMISATION (kW)		
		BASE (kN)	FINAL (kN)	% REDUCTION	BASE (kW)	FINAL (kW)	% REDUCTION
1	18 m	151.8	102.5	32.56	1650	1467	11.09
2	21 m	172.4	134.1	22.21	2100	1711	18.52
3	24 m	198.33	146.2	26.28	2850	2425	14.91

Table 6.12 Resistance and Power Optimisation Results of Base and Advanced Hybrid Optimised Hull



7. RESOLUTION

The objective to design a vessel that can operate at current industry requirements of speed and safety and the same time adhere to the guidelines set by environmental organization/ governments is met both in terms of technology and financial aspect. Though it has not been shown exactly how much time can be save using the modularity concept, it is a well-known fact that, sister vessels built at any shipyard around the globe tend to take lesser and lesser time with higher number of production irrespective of infrastructure of that particular shipyard. Thus we can say that though the design has been made keeping in mind the European Market and Industry guidelines, the idea can be implemented globally.

8. Scope of Improvement

Any mathematical finds more validity if the results can be corroborated with experimental results. The author is in process of carrying out the Towing Tank test for resistance result validation, unfortunately the test is schedules for later stage of the month of October 2015 and hence the results could not be provided at this time.

In addition the author also recommends the use of FEM based structural optimization to reduce the lightship weight of the vessel which will provide the designer with flexibility to provide small additional features to the design as per owner's requirement.

9. Bibliography

In addition to the references mentioned in the report some of the other sources that formed the foundation of this concept are mentioned below.

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