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Design Study of Trimaran Frigate DFT

Mohamed SAID
FANB Bin
Department of Engineering, Naval University of Engineering,
Wuhan, Hubei, 430033, China.

Abstract:- This research describes the Study of a basic ship design and stealthy performance of a Defense Frigate Trimaran ship for the Comorian Coast Guard (CCG) as part of the Comoros government military asset. The Comoros island is located between Madagascar, Mozambique and Tanzania in the Mozambique canal. This research implies the importance of using ship System Integration of the Chinese frigates design. It also recommends expanding the machine gun Systems Integration domain in frigate procurement. The study is looking at current and future propulsion technology based on the mission need statement of the Union of Comoros. The automated process and ways of designing a Defense Frigate Trimaran (DFT) presented in this paper provides a rational and thorough methods to search a design space. The concept of the design represent the best basis for assessing technologies over a range of possibilities considering effectiveness, cost and risk. This automated approach and new tools are evaluated in the context of an Agile Surface Combatant Ship (ASC) and R/V Triton case study as mother ships. The Union of Comoros lacks modern high speed ships for the country's needs, due to the absence of adequate ships such as frigates, destroyers, and so on. This research is an opportunity and open door for not only the Union of Comoros, but for the Indian ocean countries to acquire sufficient vessel for protecting their seas, especially the eastern African countries. To fulfill the DFT designing research, computing software and calculations will be utilized for the ship resistance and hydrostatics calculations, up to the finishing project. The accomplishment of this research will allow the Comoros government to inter in the Naval ship design industry that will lead the CCG to acquire abilities of protecting the Comoros government sovereignty and economy. The selected DFT alternative is a low risk, low cost, knee-in-the-curve displacement multihull (trimaran) design on the cost-risk-effectiveness frontier. This design was chosen because it provides a sharp increase in effectiveness with a minimal increase in cost at a high endurance and at low risk level based on the calculation results. The emphasis of this paper is on the concept exploration design and requirements process [2].

Keywords:- *Ship Design, Trimaran Frigate, Ship Resistance, Hydrostatics Calculations.*

I. INTRODUCTION

The demand for modern Naval ship equipments by the country of Comoros especially the Comorian Coast Guard (CCG), is highly important as their neighbor countries are improving their military in the naval industry sector. Frigate ships are mostly used in the navies for better protection of each and every country. However, the Union of Comoros is a young country which its requirements are based on the country's needs regarding the country's security and well being. The requisite of this paper is to complete a Defense Frigate Trimaran design for CCG for the future of the Union of Comoros Islands and to establish the characteristics of Defense Frigate Trimaran (DFT) design which include ship resistance and hydrostatics calculations. The DFT requirement is based on the Comoros government Mission Need Statement (MNS) and the Chinese Naval Ship Design system integration. However, this leads for this research to put forward the importance of trimaran warship, as mono-hull ship cannot meet the requirements of operation and maintenance when the wind and waves are large. Catamarans have larger deck area than mono-hull ships and their stability have also been greatly improved, but catamarans are more likely to twist shake and anxious shake. Trimarans have better seakeeping performance and are faster than mono hull ships and catamarans[24] . DFT desing is suitable as it can meet the needs and requirements of the Union of Comoros due to fact that the majority of the country's economy is located at sea than on land. This paper is focused on a Trimaran design based on the ship Concept design which comprises Concept Exploration and Concept Development. Ship resistance and hydrostatics calculations are performed by using MAXSURF software including ship stability where graphs of resistance vs peed , and power vs speed, curves of form, and dinamic stability are created, and from a 2D ship model developed from AutoCAD led this research to generate a 3D DFT hull model generated from Rhinoceros and Sketchup software.

II. DESIGN PHILOSOPHY, PROCESS, AND PLAN

In general, Ship design is characterized by a traditional method of an approach of an 'ad hoc' process (i.e a process created or done for a particular purpose as necessary). To assess the selection of design components, design lanes, rules of thumb, experience, and preference were demonstrated. Goal attributes are not adequately synthesized or presented to support efficient and effective decisions. This project research uses a total system approach for the design process, including a structured search of the design space based on the multi-objective consideration of effectiveness, cost and risk.

For most naval ships, to make a ships design becoming reality, the design has to meet five design stages. Firstly, two stages are collectively linked as one stage (Concept Exploration and Concept Development) which form the Concept Design that characterizes the concept exploration. Concept exploration yields one concept baseline design or more than one, which is completed in concept development and preliminary design. The Contract design constitute the finishing stage of the full specifications for the ship, at which point a contract is made by shipbuilders for the construction of the ship. The last stage of design is done by ship builders by collaborating with the constructor of the ship, which characterizes the detail design. To complete these five methods, the ship builders (ship designers) and the constructors of the ship can go through 16 to 20 years to complete it [1].

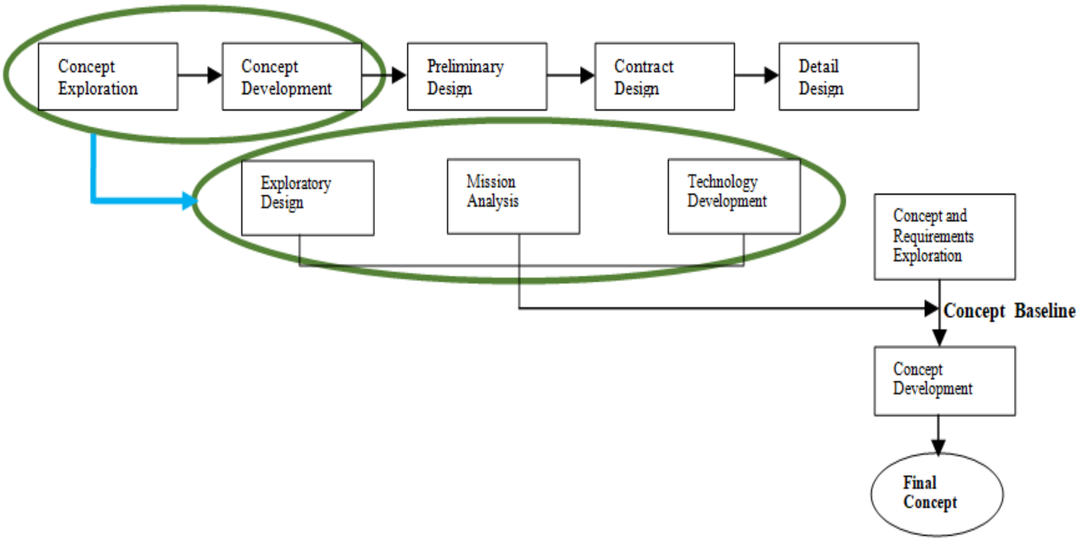

Figure 1 - Design Process [1]

Concept exploration and concept development are a major points for this project. The concept exploration is a process that is used as to provide the appropriate ship design feasibility that will respond to the need of the preliminary design as shown in Figure 2. Concept Exploration and concept development will respond to the stated mission need with an early high-level assessment of a broad range of the ship design options and technology. The process involves constructing DFT design space of several variables and then searching that design space for the "best designs" in terms of cost, effectiveness and risk regarding resistance and hydrostatics, stability and stealthy performance. The results are the selection of a baseline design, and a selection of technology.

III. MISSION DEFINITION

Capabilities and design parameters are considered by the Concept Exploration that puts a necessity to perform the ship's mission, and to have a significant impact on ship balance, military effectiveness, cost and risk. The first process in this concept, is to develop a clear and precise mission definition that will help to develop functional capabilities and a list of required operations. To commence with design characteristics or specific requirements will not be taken as the first priority. The process described in this paper is initiated to illustrate the required mission of DFT in the context of a trimaran frigate program for integrating ship's capabilities. In this paper, Mission definition usually consists of a Concept of Operations, Projected Operational Environment (POE) and threats, specific missions operation (SMO), mission scenarios, and Required Operational Capabilities (ROCs).

The primary DFT mission serviceable areas and capabilities include [2]:

- Port and Coastal Security (PCS)
- Search And Rescue (SAR)
- Drug Interdiction (DRUG)
- Migrant Interdiction (AMIO)
- Protect Living Marine Resources (LMR)
- Other Law Enforcement (OLE)
- Secondary: Defense Readiness (DR)

Life circle or service life for the ship design is projected to be 30 to 40 years. This life circle is an extended timeframe which providing flexibility in improving, maintaining and promoting the ship's capability over time is demanded. Table 1 lists the specific capability gaps and requirements of DFT.

Table 1 -DFT Capability Gaps including Goals and threshold [2]

Priority	**Capability Description**	**Threshold Systems or metric**	**Goal Systems or metric**
1	Mobility	Sustained speed = 25 knots Range = 2160+ nm @15 knots Endurance = 7 to 30 days	Sustained speed = 30 knots Range = 5000nm @15 knots Endurance = 40+ days
2	Aviation Support	Hangar and a support for 1x (Seahawk) SH-60, and (medium-range helicopter) MH-60T or MH-65C	Hangar and a support for 1xSH-60, 1xUAV and MH-60T or MH-65C
3	Small Boat Support	A distinct ramp launch for 1x Short Range Patrol boat (SRP) or 1x Long Range Interceptor ship (LRI)	A distinct ramp launch for 1 x Short Range Patrol boat (SRP) and 1 x Long Range Interceptor ship (LRI)
4	Combat Systems	C4i system 3 x SPY-1D radar MK 110 57 mm gun 2 x 50cal machine guns MK15 CIWS/32cell VLS MK53 SRBOC/ SLQ32(v2)	Type 752 radar/Type 354 radar or Type 341,344,346 radar MK 45 5in/54 gun 2 x 50cal machine guns Type 730 CIWS/ ZKJ-4B or ZKJ-4B II, ZKJ-5 CDS, MK 53, SRBOC

DFT must be able to fully operate through high seas and on shallow water, to be able to support limited operations through high risky areas. The ship must be able to tow up to its equivalent weight, and rescue multiple individual operations straightly from the sea. DFT's Command, Control, Communication, Computers, Intelligence, Surveillance and Reconnaissance equipment collection must be compliant with law enforcement information security standards and be interoperable with the C4ISR systems of the department responsible for the national security and other institutions. Reliability is a parameter that should be kept in consideration as it is a key performance for the ship design. Two propulsion water-jets are required, and DFT will be carried out as an example of the type of Navy Vessels regarding to the characteristics of ASC vessel and R/V Triton as a mother ships. DFT follow-ship acquisition cost must not be higher than $150M at the same time, the ship must acquire performance capabilities such as speed, endurance, weapons payload, ability to operate and survive in hostile environments and reliability under combat conditions [4,5].

IV. CONCEPT EXPLORATION

The process uses a multiple-objective genetic optimization (Brown and Salcedo 2002) from Matlab software to find the design space and carry out the trade-offs. A simple ship synthesis model is used to balance the design, to assess feasibility and calculate cost, risk and effectiveness. Alternative designs are classed by cost, risk, and effectiveness, and presented as a series of non-dominated frontiers. on [2] a non-dominated frontier (NDF) represents ship designs in the design space that have the highest effectiveness for a given cost and risk.

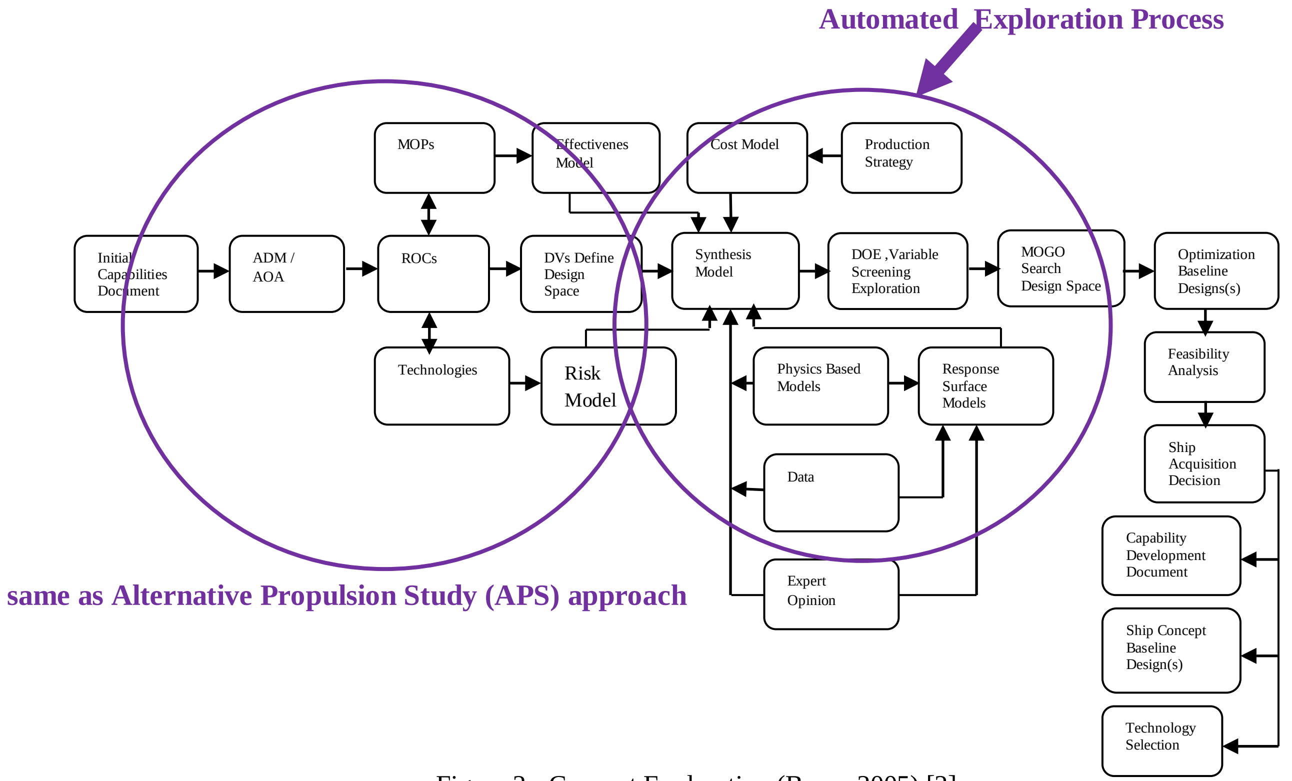

Figure 2 - Concept Exploration (Brozn 2005) [2]

As shown in Figure 3, the methods applied is compared to the APS approach, and Figure 1, in developing reference missions, required operational capabilities, identifying applicable technologies and developing an effectiveness model. In addition, a technology risk model and large design space are defined so that a broad range of technologies with different risk may be considered. The mission scenarios developed are unique to the design reference missions scenarios that DFT is requested. Required operational capabilities will be demanded once these scenarios are developed. These capabilities are a collection of abilities that are required for the ship to perform its mission's procedures of performance. To define the design variables the required operational capabilities are carried out to build an overall measure of effectiveness metric for the designs. Technology selection is also considered in the process.

DFT Machinery Alternatives is characterized by DFT power system which is connected to two sources of power responsible of the ship performance and functioning. First, DFT power system is supplied by a Mechanical Drive with Epicyclical Gears (MDEG), this is characterized by two options, and secondly DFT power system is linked to an Integrated power system (IPS) from which three options are possible, as shown in Figure 3.

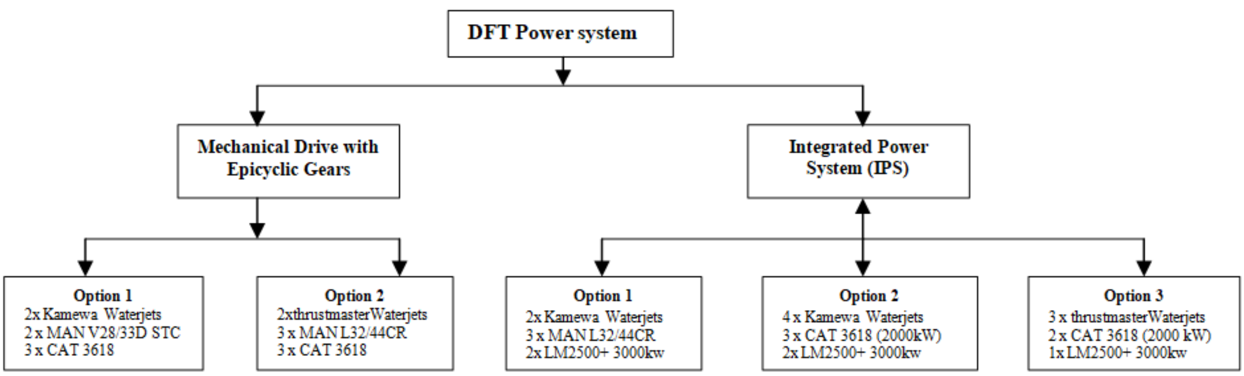

Figure 3 - DFT Machinery Alternatives [19, 20]

The ship synthesis model (carried out from RHINO) is used to balance, check feasibility and analyze the ship design. It is composed of modules used to calculate hull form characteristics, powering, space, weights, and stability. Using the ship synthesis model, design experiments for DFT research may be possible to be completed. The design experiment investigates the defined design space that in return is used for the data gathering and variable broadcasting.

V. TRADE STUDES, CONCEPTS , TECHNOLOGIES AND DESIGN VARIABLES

Existing technologies and concepts necessary to provide mandatory functional capabilities are identified and defined in terms of performance, cost, risk, and ship impact (weight, area, volume, power). On [5] Trade-off studies are performed using technology and other design variables to select trade-off options in a multi-objective genetic optimization for the total ship design. Form Rhino software, Figure 4 is displaying the hull form of DFT as the primarily parent hullform.

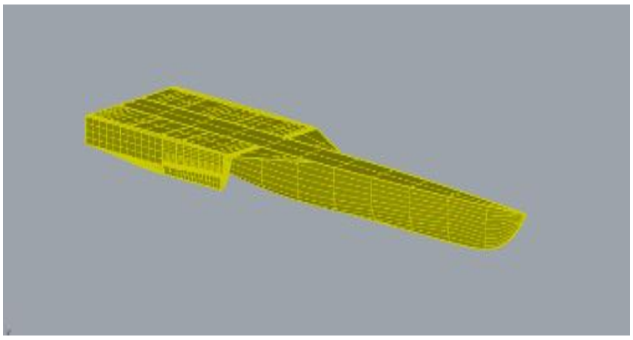

Figure 4 - DFT parent Hullform (RHINO)

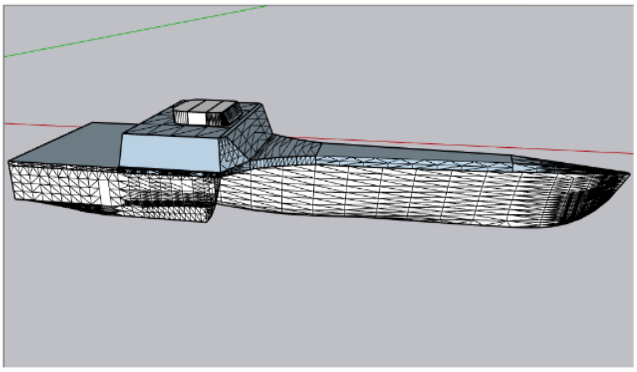

Figure 4 - DFT Hullform design (SKETCHUP)

DFT hullform was generated using Rhino hull Assistant and Sketchup software. Design variables and parameters in MAXSURF provide a flexible and consistent framework for specifying and modifying the hull form. The hull form design space for DFT is based on design lanes for similar designs consistent with the DFT mission with LOA equal to 97-100 meters, Length to Beam ratio of 3.6-7.6, Beam to Draft ratio of 2.7-6.2, Depth of 7.5-9.5 meters, Longitudinal Prismatic Control ratio of 0.25-0.56, and Transom Deck Width ratio of 0.8-0.9. A Design of Experiments will be ran using Rhino/AutoCAD software to develop a Response Surface Model involving these design variables to the resulting design characteristics (Figure 5).

VI. TECHNOLOGY SELECTION AND DESIGN VARIABLES

Design Variables used to specify the bounds of the theoretical design space of DFT is listed on the following table.

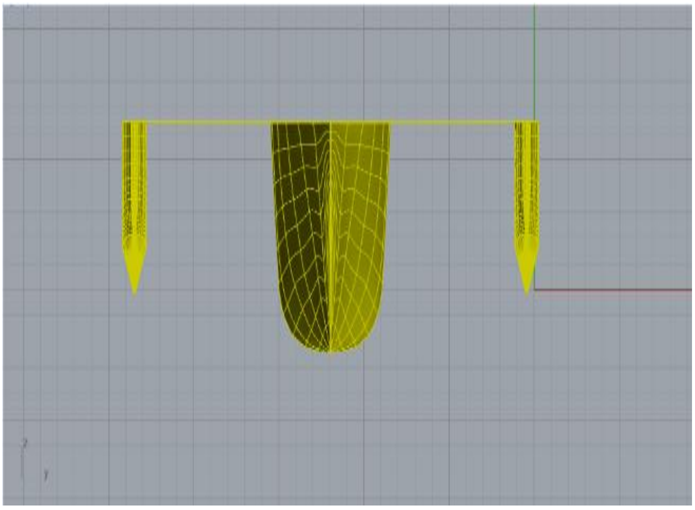

Figure 5 - Ship hull Design Characteristics

Table 2-DFT engine variables [18, 12]

DFT #	DFT Name	Description	Metric	
1	LOA	Length Overall	m	90-100
2	LtoB	Length to Beam ratio		3.6-7.6
3	LtoD	Length to Depth ratio		7.5-9.5
4	BtoT	Beam to Draft ratio		2.7-6.2
5	Cp	Prismatic coefficient		0.45 – 0.64
6	Cx	Maximum section coefficient		0.35 – 0.75
7	Crd	Raised deck coefficient		0.7 – 0.8
8	VDH	Deckhouse volume	m3	500-2000
9	MTD	Deckhouse Material Type	Alternative	Option 1) aluminum Option 2) steel
10	EBGT	Gas Turbine Boost Engine	Alternative	LM2500+
	EDP	Diesel Propulsion Engine	Alternative	Option 1) MAN V28/33D STC 3000 kW Option 2) CAT 3618 (2000 kW) Option 3) MAN L32/44CR
9	HULL type	Offshore Patrol Vessel or ASC		Trimaran
10	PGM	Power Generation Module		Option 1) 2x CAT 3618, AC synchronous, 4160(V) AC

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				Option 2) 2x MAN V28/33D STC, generator, 4160 (V) AC Option 3) 3xLM2500+, AC synchronous, 4160 (V) AC Option 4) 3xLM2500+, SCH generator, 4160 (V) AC Option 5) 2x MAN L32/44CR , AC synchronous, 13800 (V) AC Option 6) CAT 3618, generator, 13800 (V) AC Option 7) 3x MAN V28/33D STC , AC synchronous, 4160 (V) AC
11	SPGM	Secondary Power Generation Module		Option 1) none Option 2) 2x MAN L32, geared, w/AC sync Option 3) CAT 3608 (1830kW) Option 4) 2x MAN V28 3.0kw Fuel Cells Option 5) 2x MAN V28 5.0kw Fuel Cells Option 6) 2x MAN L32
12	PROP type	Propulsor type		Option 1) 2xFPP Option 2) 2xPods Option 3) 1XFPP + SPU (7.5MW)
13	PDIST type	Power distribution type		Option 1) AC ZEDS Option 2) DC ZEDS *(OPV)
14	PMM	Propulsion Motor Module		Option 1) AIM (Advanced Induction Motor) Option 2) PMM (Permanent Magnet Motor) Option 3) SCH (Superconducting Homopolar Motor)
15	Ts	Provisions duration		60-75 days
16	Ncps	Collective Protection System		0 = none, 1 = partial, 2 = full
17	Ndegaus	Degaussing system		0 = none, 1 = degaussing system
18	Cman	Manning reduction and automation factor		0.5 – 0.1
19		Anti-Air Warfare options		Option 1) SPY-3/VSR+++ DBR, IRST, AEGIS BMD 2014 Combat System, CIFF-SD, SLQ/32(R) improved, MK36 SRBOC with NULKA Option 2) SPY-3/VSR++ DBR, IRST, AEGIS BMD 2014 Combat System, CIFF-SD, SLQ/32(R) improved, MK36 SRBOC with NULKA Option 3) SPY-3/VSR+ DBR, IRST, AEGIS BMD 2014 Combat System, CIFF-SD, SLQ/32(R) improved, MK36 SRBOC with NULKA
20	ASUW	Anti-Surface Warfare alternatives		Option 1) 1x155m AGS, SPS-73, Small Arms, TISS, FLIR, GFCS, 2x7m, RHIB, MK46 Mod1 3x CIGS Option 2) 1xMK45 5"/62 gun, SPS-73, Small Arms, TISS, FLIR, GFCS, 2x7m RHIB, MK46 Mod1 3x CIGS
21	BT	BOAT	alternative	Option 2) 2 x SRP, 1 x LRI Option 1) 1 x SRP, 1 x LRI
22	C4ISR	Command Control Communication alternatives	alternative	Option 1) Enhanced C4ISR Option 2) Basic C4ISR
23	LAMPS	LAMPS alternatives		Option 1) none Option 2) LAMPS haven (flight deck), 2xVTUAV Option 3) 2 x Embarked LAMPS w/Hangar, 2xVTUAV
24	GMLS	Guided Missile Launching System alternatives		Option 1) 160 cells MK57 + 8 cells KEI Option 2) 160 cells MK57 Option 3) 128 cells MK 57 Option 4) 96 cells MK 57

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A range of mission and combat system alternatives will be identified, and ship impact will be assessed for each configuration. In [22, 23] The Analytical Hierarchy Process (AHP, R. W. Saaty 1996) and Multi-Attribute Value Theory (MAVT, Belton 1986) where used to estimate the Value of Performance for each system alternative. Table 2 is the resulting design space for DFT. The optimizer chooses the design variable values from the range provided and inputs the values into the ship synthesis model. Once the design variable values are inputted into the ship synthesis model, the ship will be balanced, checked for feasibility, and assessed based on risk, cost, and effectiveness regarding to resistance and hydrostatics calculations that will be carried out.

VII. RESISTANCE AND HYDROSTATICS CALCULATION

1. Resistance

Resistance, speed and power calculations are performed using MAXSURF software. MAXSURF requires the input of hull characteristics, speed, heeling angle characteristics, and ship geometry. The Holtrop, Compton, and Slander body method is used for a preliminary estimate of DFT's resistance. Speeds between 1 and 30 knots are considered. MAXSURF does have the direct capability of performing these calculations for a trimaran, so both the center hull and side hulls are modeled as multi-hulls. The following Figure 6 is displaying the resistance vs. speed curve, and Figure 7 is displaying the speed vs. power curve [5].

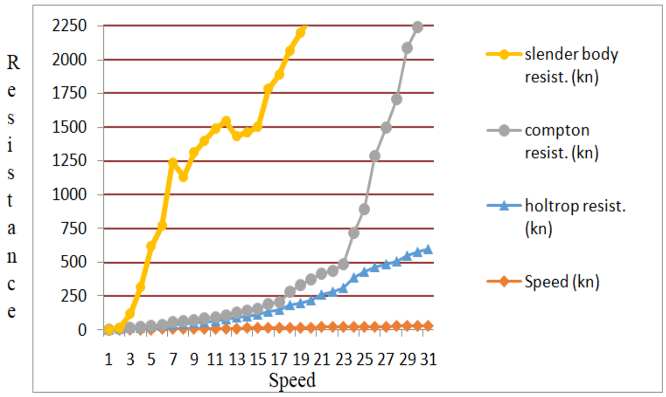

Figure 6 - Resistance vs. Speed Curve

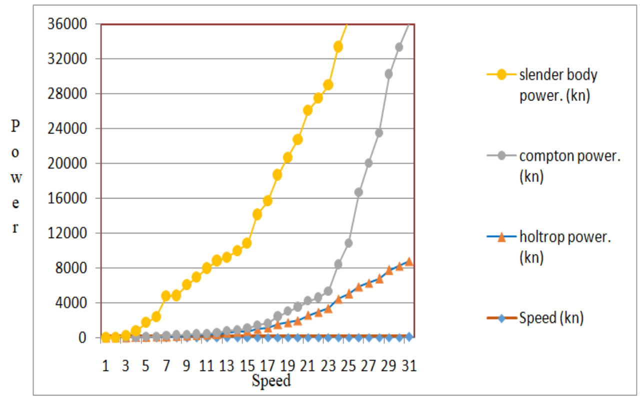

Figure 7 - Power vs. Speed Curve

DFT characteristics where imported to Maxsurf software for resistance calculations, three elements are used as a method utilized to give an understanding result for DFT resistance and power at a designed speed that is Holtrop, Compton, and Slender body method. Table 3 illustrates the results assessment summary of DFT resistance calculations.

Table 3 - Resistance results assessment summary

Speed (kn)	holtrop resist. (kn)	compton resist. (kn)	slender body resist. (kn)
1	0,8	0,4	0,4
2,45	4,1	2,2	5,4
3,90	9,8	5,3	101
4,63	13,4	7,3	295,6
5,35	17,5	9,6	584,2
6,08	22,1	12,1	732,8
7,53	32,5	17	1181,8
8,25	38,2	19,3	1069,8
8,98	44,4	21,6	1236,9
9,70	50,9	23,9	1314,4
10,43	57,8	26,4	1395
11,15	65,1	29	1438,4
12,60	80,9	35,2	1304,7
13,33	89,6	38,7	1322,8
14,05	98,9	43,5	1346,2
15,50	119,9	54,2	1593,3
16,23	133,4	59,1	1680,6
17,68	164,4	102,1	1782,9
18,40	181,1	133,8	1866,3

19,13	198,8	155	1954,9
20,58	239,4	153,3	2070,3
21,30	264	152,4	2087,7
22,03	292,5	174	2087,3
23,48	364	328,8	2068,7
24,20	403	465,1	2063,7
25,65	441,7	817,6	2072,4
26,38	461,7	1010,6	2084,1
27,10	482	1199,9	2101,2
28,55	523,9	1533,4	2140,7
29,28	545,5	1667,2	2163,6
30,00	567,4	1775,8	2185,3

2. Hydrostatics and Stability

To assess hydrostatics, intact stability, and damage stability of DFT, ship offsets are imported into AutoCAD, then into Maxsurf software which are software designed for ship design and Maxsurf evaluate various hull forms including damage calculation, stability calculations and so on. In [5] hydrostatics are calculated for a range of drafts. Figure 8 and Figure 9 represent the curves of form, Dynamic stability-GZ curve calculated by using Maxsurf.

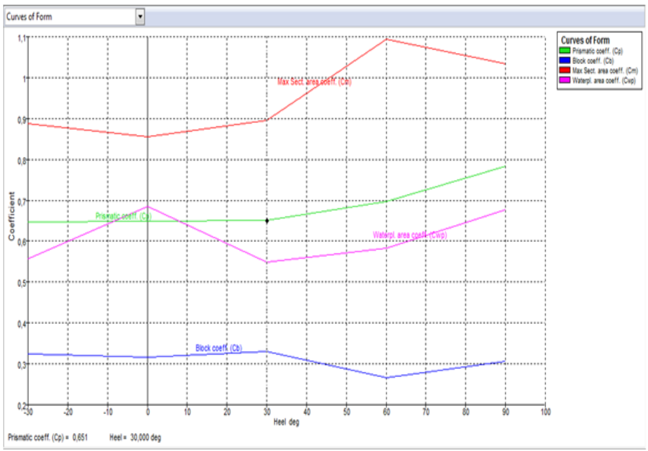

Figure 8 - Curves of form

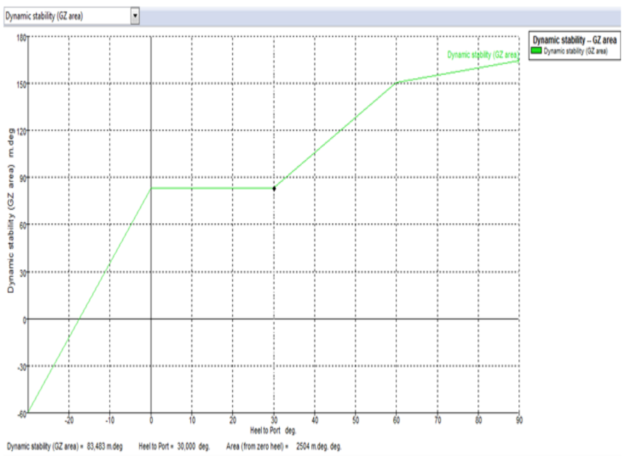

Figure 9 - Dinamic stability- GZ curve

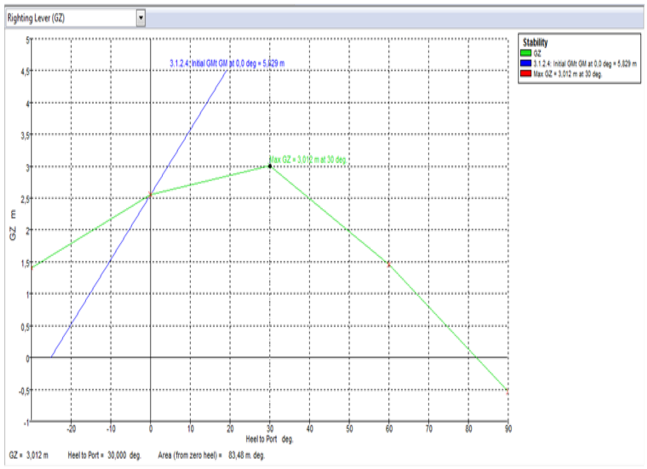

Figure 10 - Stability curve

Considering the information obtained using DFT ship characteristics, Stability curve, Hydrostatics curve, and Large angle stability curve are calculated as well. Using the data obtained from these calculations, an intact stability will be calculated in the loading conditions. Figure 10 to 12 give details of the calculation carried out for Stability, Hydrostatics, and Large angle stability.

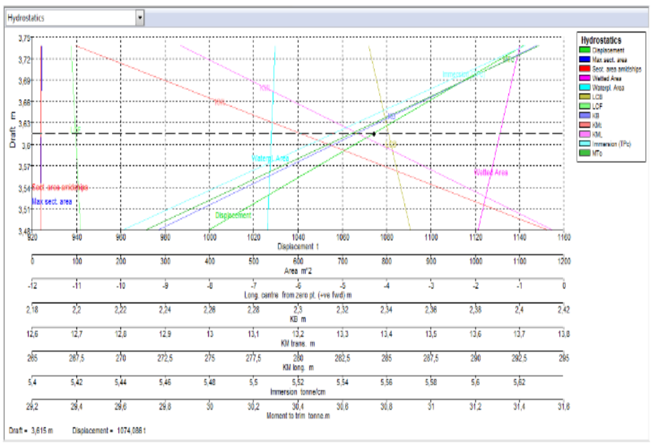

Figure 11 - Hydrostatics curves

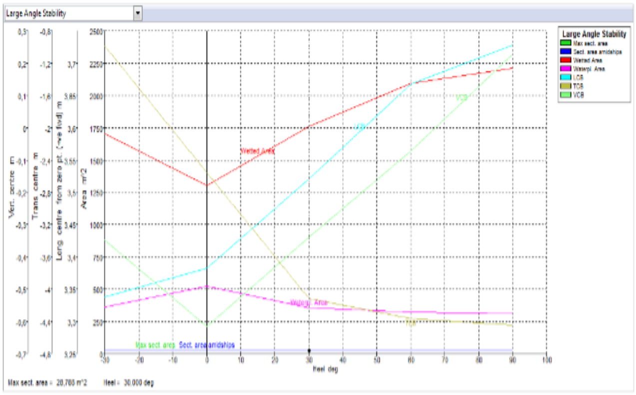

Figure 12 - Large angle stability curve

Hydrostatics of DFT are calculated for a range of drafts utilizing Maxsurf stability, there for, results obtained from these calculations, an intact stability is being calculated in the loading conditions that provided the following table. Table 4 give details of the calculation generated from Maxsurf for DFT Hydrostatics values.

Table 4 - DFT Hydrostatics values

Item	Primary value	Final value
Draft Amidships m	3,481	3,738
Displacement t	1000	1142
Heel deg	0	0
Draft at FP m	4,481	6,738
Draft at AP m	4,481	6,738
Draft at LCF m	4,481	6,738
Trim (+ve by stern) m	0	0
WL Length m	97,365	97,743
Beam max extents on WL m	24,411	24,411
Wetted Area m^2	1007,08	1100,287
Waterpl. Area m^2	530,866	548,545
Prismatic coeff. (Cp)	0,524	0,549
Block coeff. (Cb)	0,324	0,307
Max Sect. area coeff. (Cm)	0,857	0,86
Waterpl. area coeff. (Cwp)	0,613	0,564
LCB from zero pt. (+ve fwd) m	-3,462	-4,405
LCF from zero pt. (+ve fwd) m	-10,903	-11,116
KB m	2,237	2,408
KG m	3,739	3,739
BMt m	11,524	10,289
BML m	292,059	270,926
GMt m	10,022	8,958
GML m	290,557	269,595
KMt m	13,761	12,697
KML m	294,296	273,334
Immersion (TPc) tonne/cm	5,441	5,623
MTc tonne.m	29,717	31,489
RM at 1deg = GMt.Disp.sin(1) tonne.m	174,912	178,535
Max deck inclination deg	0	0
Trim angle (+ve by stern) deg	0	0

VIII. CONCLUSION

Concept Exploration study and the design space optimization is being carried out using different software such as Maxsurf, Rhino, Sketchup, and AutoCAD. Objective attributes for this paper is trimaran frigate design, resistance and hydrostatics calculations, and stability, including cost, risk (e.i technology performance) and mission effectiveness. Therefore, to make this research a reality, the product of resistance and hydrostatics calculations, theoretical ship synthesis methods, stability and stealthy performance, are carried out regarding to cost-risk-effectiveness frontiers which are used to select alternative designs and define operational requirements that will be based on the Union of Comoros government's preference for cost, risk and effectiveness.

A methodical search of the design space by considering all combinations of design variables, and a progression are being demonstrated from the less effective to the more effective design. The good performance of the ship is very important for completing the operation mission during rough sea conditions.

The consideration of a broad range of design, risk and cost provides a clear picture of their relationship to performance, stealth and effectiveness which enables a rational definition of the Union of Comoros requirements at the very beginning of the design process.

The results gathered from several calculations concerning resistance and speed sat from the preliminary design, provide acceptable data for DFT design process. The slender method gives results from a range of 1 to 30 knots at it designed speed that will be able to crouse at a sprint range of 500 nm to 2500 nm. Resistance and Power where compared at the giving speed range, result is being carried out through Holtrop and Comption method that enumerates good outcome for DFT performances and effectiveness.

This design is a perfect asset that will enable the Comoros CCG to, maintain peace in their country including their neighborhoods countries, and to protect their population from any threat ; from sea, Air, and land. Finally, DFT is a perfect choice for the Comoros CCG, as Trimarans are faster with good stability at high endurance (speed), and will provide an opportunity to have a modern high speed ship model with modern technology in it, not only for the Union of Comoros by also for the Indian ocean's countries.

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