



PROJECT HYDRA

MEDITERRANEAN MULTIROLE COASTGUARD
A PLATFORM BASED SHIP DESIGN

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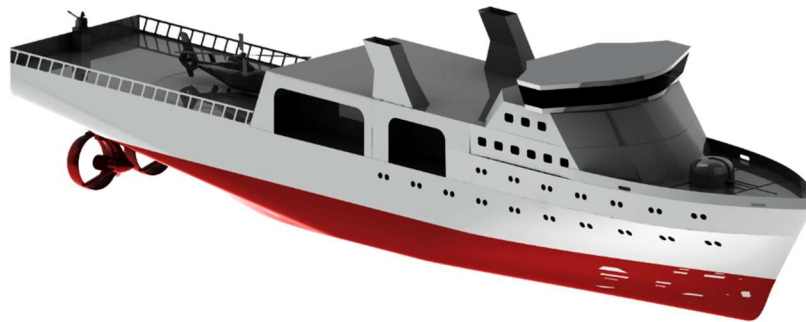




PROJECT HYDRA

A common platform designed for:

- **Research vessel**
- **SUBSAR vessel**
- **Coast Guard vessel**



KEY FEATURES

RESEARCH

Accommodation for
30 scientist
180 [m²] Drylab
120 [m²] Wetlab
80 [m²] equipment bay
Internal L&R system
A-frame

COAST GUARD

4 x Scan Eagles
1 x Helicopter
Large hangar
2 x 11[m] RIBs
2 x 7[m] RIBs
1 x State-of-the-art Ops Room
Accommodation for maintenance and
boarding teams

SUBSAR

Organic Decompression
facilities
NSRS compatible
8 resuscitation wards
20 IC wards
Bloodbank

PLATFORM CHARACTERISTICS

MAIN

DIMENSIONS

Length over all	89.5	[m]
Length on waterline	83.5	[m]
Beam	15.7	[m]
Depth	8.9	[m]
Draught (SLL)	4.42	[m]
Design Displacement	3577	[tons]

SPEED

Cruise speed	14	[knot]
Top speed	20	[knot]

PLATFORM FEATURES

Class 1 Lloyds Fire Fighting		
Towing Bollard Pull	110	[ton]
Towing Winch Force	300	[ton]
Humanitarian Aid	200	Survivors
Platform TEU capacity (NEO)	18	[TEU]

MACHINERY AND PROPULSION

Integrated Fully Electric Propulsion		
Diesel Generator	2x4.2	[MW]
Fuel Systems	2x4.4	[MW]
Steerable Azipull Thrusters	2x3.2	[MW]
Fwd. Tunnel Thruster	1x0.8	[MW]
Fwd. Retractable Thrusters	2x0.8	[MW]

CAPACITY

Total DFO capacity	531	[m ³]
Convertible to Future Fuel tank	370	[m ³]
Total Freshwater	74	[m ³]
Deck Area	400	[m ²]

ACCOMMODATION

Single Standard	24
Single Deluxe	22
Double Standard	6
Officer Suite	2
Captain Suite	1



Abstract

The following report contains a ship design at concept stage. The requirements for the desired vessel have been given by the customer, to which it has been the designer's task to interpret the full extent of the requirements. The project is named project HYDRA, after the Greek mythology multi-headed creature. Project HYDRA is a platform based ship design, designed for three variants, which can be chosen at build. The variants are;

- A research vessel capable of deploying large equipment via various L&R systems, with the additional ability of providing large workshop and laboratory areas for up to 30 scientists.
- A SUBSAR vessel capable of deploying the NSRS or future versions of the system. Furthermore, the SUBSAR variant provides hyperbaric medical treatment up to 35 submariners and conventional medical treatment up to 30 submariners.
- A Coast Guard vessel capable of conducting broad maritime surveillance up to 4000 nm² pr. hour and boarding operations up to 100 nm via. over-the-horizon RIBs or helicopter.

HYDRA has been sized to be compatible for all the three variants. This has inherently resulted in some trade-offs which have been discussed throughout the project. Traditional naval architectural performance analysis has been conducted for one of the variants, as the concept demands similar performance across all three. The analysis has included resistance estimate, structural analysis, stability and trim analysis, seakeeping analysis and manoeuvring analysis.

For enhanced understanding and communication, extensive effort has been put in to the visual representation of the vessel throughout.

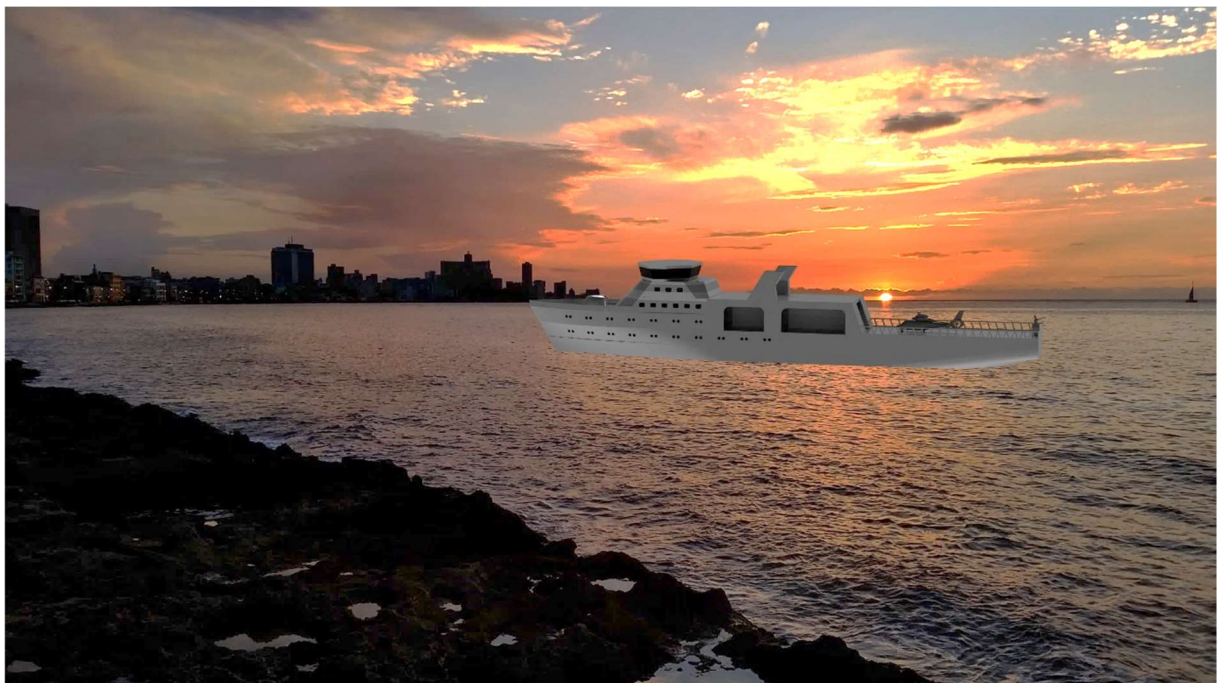




Table of Contents

Official Title page	Error! Bookmark not defined.
1. Abstract	2
Table of Contents	3
2. Navigational Elements	8
2.1. Reference system	8
2.2. Distribution	Error! Bookmark not defined.
2.3. List of figures	9
2.4. List of tables	13
3. Introduction	15
4. Operational Analysis	16
4.1. Prime Tasks	16
4.2. HYDRA Coastguard – Concept of Employment	16
4.2.1. Existing Vessels	16
4.2.2. Maritime Surveillance	17
4.2.3. Boarding and Inspection Operations	17
4.2.4. Hydra Coastguard Target	18
4.3. HYDRA Research - Concept of Employment	19
4.3.1. Existing vessels	19
4.3.2. Laboratory area	20
4.3.3. Targets for Research Vessel	20
4.4. HYDRA SUBSAR - Concept of Employment	21
4.4.1. Existing Vessels	21
4.4.2. Main Equipment	22
4.4.3. Targets for SUBSAR	23
4.5. Secondary Tasks	24
4.5.1. Firefigthing	24
4.5.2. Humaniteration Rescue operation (RBB)	25
4.5.3. Towing (RBB)	27
4.6. Operational Area	29
4.6.1. Enviroment analysis	29
5. Payload selection	31
5.1. HYDRA Platform Payloads	31
5.2. HYDRA Research Payloads	33
5.2.1. Suggested Payloads Summary	35
5.2.2. CCT - Packages	35
5.2.3. CCT - HYDRA Research	36
5.3. HYDRA SUBSAR Payloads	37



5.3.1.	Suggested Payloads Summary	39
5.3.2.	CCT - Packages	39
5.4.	CCT - HYDRA SUBSAR	40
5.5.	Hydra Coastguard Payloads	41
5.5.1.	Suggested Payloads Summary	43
5.5.2.	Packages for Cost Capability Tradeoff	44
5.5.3.	CCT – HYDRA Coastguard	44
5.5.4.	Final Selection	45
6.	Design approach	47
6.1.	Proposed solution to modularity	47
6.2.	Factory floor philosophy	48
7.	Initial Sizing	50
7.1.	Payload volume fraction	50
7.2.	Initial Estimate of weight and volume of the platform	51
7.3.	Visuel Representation	53
7.3.1.	Discussion	53
7.4.	Comparison of Variants	54
8.	Hull form	56
8.1.	Hull form Material	56
8.2.	Hullform Selection	57
8.2.1.	SWOT Analysis for Cat-Swath Concept	57
8.2.2.	SWOT Analysis for Trimaran Concept	58
8.2.3.	SWOT Analysis for Conventional Catamaran	59
8.2.4.	SWOT Analysis for Conventional Monohull	60
8.2.5.	Hullform selection	61
8.3.	Parametric Survey and Hull Characteristics	62
8.3.1.	Operating profile – Work requirement	62
8.3.2.	Constrains	63
8.3.3.	Target	63
8.3.4.	Major Parametric Survey	64
8.3.5.	Minor Parametric Survey	66
8.3.6.	Effect of prismatic coefficient on resistance	66
8.3.7.	Final Main Particulars	67
8.3.8.	Comparison to existing hull forms	68
8.4.	Resistance Estimate	68
8.4.1.	Comparison of Regression Analysis Methods	70
8.4.2.	Results	70
8.4.3.	Resistance Estimation Discussion	71
8.5.	Propulsion Arrangemnet	73
8.5.1.	Main Propulsion	73
8.5.2.	Propulsor Selection	73
8.5.3.	Future fuel conversion	74



8.5.4.	Fuel Cells	74
8.5.5.	Diesel Engines	74
8.5.6.	Energy Storage Devices	74
8.6.	Hullform Design	75
8.6.1.	Approach to hull form design	75
8.6.2.	Generation	75
8.6.3.	Lines plan	76
8.6.4.	Allocation of bulkheads	76
8.6.5.	Tank Distribution	77
8.6.6.	Appendages	78
8.7.	Discussion	79
9.	Complementation	81
9.1.	HYDRA Research – Complementation	81
9.1.1.	Organic Crew	81
9.1.2.	Augmented Personnel – Scientist	81
9.2.	HYDRA SUBSAR– Complementation	82
9.2.1.	Organic Crew	82
9.2.2.	Augmented Personnel - NSRS operators and Medical Personnel	82
9.3.	HYDRA Coastguard Complementation	83
9.3.1.	Organic Crew	83
9.3.2.	Augmented Personnel - Boarding Team and Maintenance Crew	83
9.4.	Accommodation Standards	84
10.	Architecture	85
10.1.	Main layout	85
10.2.	Zones	85
10.3.	Citadel	85
10.4.	Removal Routes	86
10.5.	Passage ways	86
10.6.	Muster station	86
11.	General Arrangement	87
11.1.	03 Deck – Bridge	88
11.2.	02 Deck – High rank accommodation and Offices	89
11.3.	01 DECK – HIGHER RANK CREW ACCOMODATION	90
11.4.	1 Deck and 01 Deck - HYDRA Research	91
11.5.	1 Deck and 01 Deck - HYDRA SUBSAR	93
11.6.	1 Deck and 01 Deck - HYDRA Coastguard	95
11.7.	2 Deck - Accommodation and Auxiliary	97
11.8.	3 Deck - Machinery deck	99



4 Deck - Engine and Tank Deck	100
12. Structural Analysis	102
<u>12.1. Load analysis</u>	<u>103</u>
<u>12.2. Material</u>	<u>104</u>
<u>12.3. Design of Midship section</u>	<u>105</u>
12.3.1. Approach	105
12.3.2. Structural analysis	106
12.3.3. Example Calculations	107
12.3.4. Results	108
<u>12.4. Final Arrangement</u>	<u>116</u>
<u>12.5. FEA analysis</u>	<u>117</u>
12.5.1. Model simplification	117
12.5.2. Mesh Creation	117
12.5.3. Constrains and loading	117
12.5.4. Results	117
<u>12.6. Discussion</u>	<u>118</u>
13. Stability and Trim	120
<u>13.1. Update to Weight Management</u>	<u>120</u>
<u>13.2. Center of Gravity Locations</u>	<u>121</u>
<u>13.3. Comparison of obtained COG</u>	<u>122</u>
<u>13.4. Intact Stability</u>	<u>123</u>
13.4.1. Intact Stability Criteria	123
13.4.2. Condition 1: Start of life – Light Displacement	124
13.4.3. Condition 2: Start of life – Deep Displacement	125
13.4.4. Condition 3: End of life – Light Displacement	126
13.4.5. Condition 4: End of life – Deep Displacement	127
13.4.6. Discussion on Intact Stability	128
<u>13.5. Damage case stability</u>	<u>129</u>
13.5.1. DAMAGE CASE 1 – Compartment A & B	129
13.5.1. DAMAGE CASE 2 - Compartment B & C	130
13.5.1. DAMAGE CASE 3 - Compartment C & D	131
13.5.1. DAMAGE CASE 4 - Compartment D & E	132
13.5.1. DAMAGE CASE 5 - Compartment E & F	133
13.5.1. DAMAGE CASE 6 - Compartment F & G	134
13.5.1. DAMAGE CASE 7 - Compartment G & H	135
13.5.1. DAMAGE CASE 8 - Compartment H & I	136
14. Manoeuvring	137
<u>14.1. Simulation</u>	<u>137</u>
14.1.1. Circle manoeuvre	137
14.1.2. Zig zag manoeuvre	138
<u>Manoeuvring Discussion</u>	<u>139</u>



15.	Seakeeping	140
<u>15.1.</u>	<u>Missions</u>	<u>140</u>
<u>15.2.</u>	<u>Critical Areas</u>	<u>141</u>
<u>15.3.</u>	<u>Environment</u>	<u>141</u>
<u>15.4.</u>	<u>Criteria – Daisy</u>	<u>142</u>
<u>15.5.</u>	<u>Motions</u>	<u>142</u>
<u>15.6.</u>	<u>Summary table and performance</u>	<u>144</u>
<u>15.7.</u>	<u>Seakeeping discussion</u>	<u>145</u>
16.	Costing	146
<u>16.1.</u>	<u>UPC Driver Layout</u>	<u>146</u>
<u>16.2.</u>	<u>Unit Procurement Cost (UPC)</u>	<u>146</u>
<u>16.3.</u>	<u>Market Comparison</u>	<u>147</u>
17.	Compliance with URD	148
18.	Project Discussion	152
19.	Future Work	153
20.	Conclusion	154
21.	References	155
22.	Appendix	158
<u>22.1.</u>	<u>Appendix A – User Requirement Document</u>	<u>158</u>
<u>22.2.</u>	<u>Appendix B - Parametric Survey Graph Read</u>	<u>161</u>
<u>22.3.</u>	<u>Appendix C - Updated Weight Breakdown Structure (Incl. positions)</u>	<u>163</u>
<u>22.4.</u>	<u>Appendix C - Superstructure Effectiveness</u>	<u>172</u>
<u>22.1.</u>	<u>Appendix D – Plating and Stiffener Combinations</u>	<u>173</u>
<u>22.2.</u>	<u>Appendix E – Transverse Stiffener</u>	<u>175</u>
<u>22.3.</u>	<u>Appendix F – Structural Analysis Example – Lower Side</u>	<u>176</u>
<u>22.5.</u>	<u>Appendix G – Seakeeping Results – Global Roll and Pitch</u>	<u>184</u>
<u>22.6.</u>	<u>Appendix H – Sea Keeping Results – Local Area</u>	<u>185</u>
<u>22.7.</u>	<u>Appendix I – Free Surface Correction</u>	<u>188</u>



1. Navigational Elements

The following navigational guidance is provided to ensure easy navigation and understanding of the report.

The internal reference system belongs to the author and have been used in similar projects.

1.1.Reference system

Internal Reference System

- Referencing from one part to another the following 4-position system has been used:

Position 1	Position 2	Position 3	Position 4
M – Main report	# - Number of chapter	T – Table	# - Number of
A – Appendix	or appendix	F – Figure	table, figure,
		E – Equation	equation or
		# - Chapter	subchapter

External Reference System

- All external referring system has been conducted according to the Harvard System



1.2. List of figures

Figure 1 - HYDRA Design spiral	15
Figure 2 - Concept of employment of scan eagles (Produced by HYDRA ME (Hunt, 2017)).....	17
Figure 3 – Operational range for HYDRA Coast guard ((Hunt, 2017)).....	18
Figure 4 - Estimates of laboratory area and open deck area for research vessels (Rosenblatt, 1960)	20
Figure 5 – Haarstad-class coastguard with fully embarked NSRS (www.korabel.ru, 2012)	22
Figure 6 - Amount of survivors arrivals at Greece form Lybia in 2015-16 (The UN Refugee Agency, 2017)	25
Figure 7 - Design approach.....	47
Figure 8 - HYDRA Research workflow.....	48
Figure 9 - HYDRA SUBSAR workflow	48
Figure 10 - HYDRA Coast guard workflow	48
Figure 11 - Seaspeed ASV 6000 (Seaspeed, unknown)	34
Figure 12 - SEAmagine Aurora-4 (Unique Group Diving Equipment, 2016).....	34
Figure 13 - Cost Capability Trade-off output for HYDRA Research	36
Figure 14 - Recompression chamber (Unique Group Diving Equipment, 2016).....	37
Figure 15 - Cost Capability Trade-off for HYDRA SUBSAR	40
Figure 16 - 7m RIB (UCL Zenith Database, 2017)	41
Figure 17 - 11m RIB (UCL Zenith Database, 2017)	41
Figure 18 – CIWS (UCL Zenith Database, 2017)	41
Figure 19 – Lynx Wildcat (UCL Zenith Database, 2017)	41
Figure 20 - Scan Eagle (Unmanned Systems Techology, 2015).....	42
Figure 21 - Cost Capability Trade-off output for HYDRA Coast guard.....	44
Figure 22- Weight and Volume percentage circle representation of HYDRA SUBSAR	53
Figure 23 - Displaced weight comparison of all HYDRA vessels.....	54
Figure 24 - Required volume comparison of all HYDRA vessels.....	54
Figure 25 - CAT-SWATH.....	57
Figure 26 - SWOT Analysis for CAT-SWATH concept.....	57
Figure 27 – RV Triton (Naval Technology).....	58
Figure 28 - SWOT Analysis for Trimaran concept.....	58
Figure 29 -SWOT Analysis for a conventional catamaran	59
Figure 30 - SWOT Analysis for conventional monohull.....	60



Figure 31 - Work required at each speed (based on operational profile average and resistance data)	62
Figure 32 - Optimum block coefficient suggested in DAISY (1996)	64
Figure 33 - Major Parametric Survey	65
Figure 34 - Effect of midships coefficient on resistance	66
Figure 35 - Effect of prismatic coefficient on resistance	67
Figure 36 - Comparison of all investigated existing ships and HYDRAs final main particulars: Beam by displacement	68
Figure 37 - Comparison of all investigated existing ships and HYDRAs final main particulars: L/B ratio by displacement	68
Figure 38 - Resistance prediction for various regression analysis	70
Figure 39 - Location of main propulsion components	73
Figure 40 - Azipull thrusters (Rolls Royce, 2015)	73
Figure 41 - Fuel cell example	74
Figure 42 - Demo-hull shape from Paramarine (Qinetiq, Hampshire)	75
Figure 43- Floodable length and allocation of bulkheads	76
Figure 44 - Tank arrangement	77
Figure 45 - Complementation Ranking for Organic Crew on HYDRA Research	81
Figure 46 - Complementation Ranking for Augmented Personnel on HYDRA Research	81
Figure 47 - Complementation Ranking for Organic Crew on HYDRA SUBSAR	82
Figure 48 - Complementation Ranking for Augmented Personnel on HYDRA SUBSAR	82
Figure 49 - Complementation Ranking for Organic Crew on HYDRA SUBSAR	83
Figure 50 - Complementation Ranking for Augmented Personnel on HYDRA SUBSAR	83
Figure 51 - Modular Single Standard Cabin	84
Figure 52 - Modular Single Deluxe Cabin	84
Figure 53 - Double Standard Cabin	84
Figure 54 - Captains suite (non-modular)	84
<i>Figure 55 - Initial Architectural Considerations</i>	85
Figure 56 - Removal Routes (Credit to HYDRA Marine Engineer (Hunt, 2017)	86
Figure 57 - Bridge layout	88
Figure 58 - 02 Deck layout	89
Figure 59 - 01 Deck layout (Platform part)	90
Figure 60 - 01 Deck and 1 Deck layout for HYDRA Research	91



Figure 61 - 01 Deck and 1 Deck layout for HYDRA SUBSAR	93
Figure 62 - 01 Deck and 1 Deck layout for HYDRA Coast Guard	95
Figure 63 - 2 Deck layout.....	97
Figure 64 - 3 Deck layout.....	99
Figure 65 - 4 Deck layout.....	100
Figure 66 - Paramarine model showing the weight distribtuion.	103
Figure 67 - Shear force distribution	103
Figure 68 - Bending moments	103
Figure 69 - Superstructure and Midship Section.....	105
Figure 70 - Idealised Midships Section.....	106
Figure 71 - FEA Model - Mesh generation - Applied constrains and loading.....	117
Figure 72 - Results of FEA Analysis.....	117
Figure 73 - Comparison of VCG obtained for each variant	122
Figure 74 - Comparison of LCG obtained for each variant.....	122
Figure 75 - GZ-curve SOL-LD.....	124
Figure 76 - GZ-curve SOL-DD.....	125
Figure 77 - GZ-curve EOL-LD.....	126
Figure 78 - GZ-curve EOL-DD.....	127
Figure 79 - Illustration of Damage Case 1	129
Figure 80 - GZ curve in Damage Case 1.....	129
Figure 81 - Illustration of Damage Case 2	130
Figure 82 - GZ curve in Damage Case 1.....	130
Figure 83 - Illustration of Damage Case 3	131
Figure 84 - GZ curve in Damage Case 3.....	131
Figure 85 - Illustration of Damage Case 1	132
Figure 86 - GZ curve in Damage Case 1.....	132
Figure 87 - Illustration of Damage Case 5	133
Figure 88 - GZ curve in Damage Case 5.....	133
Figure 89 - Illustration of Damage Case 6	134
Figure 90 - GZ curve in Damage Case 6.....	134
Figure 91 - Illustration of Damage Case 7	135
Figure 92 - GZ curve in Damage Case 7.....	135
Figure 93 - Illustration of Damage Case 8	136



Figure 94 - GZ curve in Damage Case 8.....	136
Figure 95 - Circle Manoeuvre simulation with skeg.....	137
Figure 96 - Circle Manoeuvre simulation without skeg.....	137
Figure 97 - 10/10 Zig-zag manoeuvre - helm angle by time	138
Figure 98 - 10/10 Zig-zag manoeuvre - helm angle by distance travelled	139
Figure 99 - 20/20 Zig-zag manoeuvre - helm angle by time	139
Figure 100 - Lateral acceleration on bridge in sea state 3	142
Figure 101 - Vertical acceleration at foremost accommodation in sea state 5	143
Figure 102 - Vertical acceleration at foremost operational area in sea state 5.....	143
Figure 103 - Global roll in sea state 5.....	143
Figure 104 - Lateral acceleration at uppermost A-frame position in sea state 5	144
Figure 105 - Seakeeping Summary Table	144
Figure 106 - UPC Driver Layout	146
Figure 107 - Market Comparison	147



1.3. List of tables

Table 1 - Operational ranges for HYDRA Coastguard (Hunt, 2017)	18
Table 2 - Target Values for HYDRA Coast guard.....	18
Table 3 - Analysis of main parameters of existing research vessels	19
Table 4 - Target values for HYDRA Research.....	20
Table 5 - Analysis of main parameters of existing SUBSAR vessels	21
Table 6 - Target values for HYDRA SUBSAR.....	23
Table 7 - Analysis of capacity of mediterranean rescue vessels	25
Table 8 - Estimate of bollard pull ton required for towing the largest container vessels in various sea states.....	27
Table 9 - Estimate of operational time in the Mediterranean Sea	29
Table 10 - Towing winch capacity based on previous AHTS vessels	32
Table 11 - Suggested payloads for HYDRA Research	35
Table 12 - Capability packages for HYDRA Research.....	35
Table 13 - Final payload selection for HYDRA Research	36
Table 14 - Suggested payloads for HYDRA SUBSAR	39
Table 15 - Capability packages for HYDRA SUBSAR.....	39
Table 16 - Final selection of payloads for HYDRA SUBSAR.....	40
Table 17 - Suggested payloads for HYDRA Coast guard.....	43
Table 18 - Capability packages for HYDRA SUBSAR.....	44
Table 19 - Final payload selection for HYDRA Coast guard	45
Table 20 - Initial Sizing and Payload Volume Fraction	50
Table 21 - Final values from initial sizing.....	50
Table 22 - Presentation of all major weight estimates obtained from initial sizing	52
Table 23 - Weighted score analysis of various hull form materials	56
Table 24 - Weighted score analysis of investigated hull forms.....	61
Table 25 - Froude numbers at main operational speeds	62
Table 26 - Vessel constraints for parametric survey	63
Table 27 - Froude number calculations.....	63
Table 28 - Targets for parametric survey	63
Table 29 - Estimation of desired superstructure fraction	64
Table 30 - Final output from parametric survey	67
Table 31 - Comparison of criteria for resistance regression analysis.....	70



Table 32 - Comparson of dimensions and coefficients from hullform generation	75
Table 33 - Load Case and Structural Analysis	106
Table 34 - Obtained Midship Section Modules	108
Table 35 - Selected Transverse Stiffener	108
Table 36 - Output from Transverse stiffener calculation	108
Table 37 - Selected Longitudinal Upper Deck Stiffener	109
Table 38 - Output from Upper Deck Structural Calculation	109
Table 39 - Selected Longitudinal Stiffener for Lower Deck	110
Table 40 - Output from Lower Deck Structural Analysis	110
Table 41 - Selected Longitudinal Stiffener for Upper Side Element	111
Table 42 - Output from Upper Side Structural Analysis	111
Table 43 - Output from Mid Side Structural Analysis	112
Table 44 - Selected Longitudinal Lower Side Stiffener	113
Table 45 - Output from Lower Side Structural Analysis	113
Table 46 - Selected Longitudinal Bottom Shell Stiffener	114
Table 47 - Output from Bottom Shell Structural Analysis	114
Table 48 - Selected Longitudinal Bottom Deck Stiffener	115
Table 49 - Output from Bottom Deck Structural Analysis	115
Table 50 - Final Structural Arrangement of the Midship Section	116
Table 51 - Updated weights after completed machinery and auxiliary selection	120
Table 52 - Hydrostatic values obtained for each variant	121
Table 53 - Condition characteristics - SOL-LD	124
Table 54 - Intact Stability Criteria Check - SOL-LD	124
Table 55 - Condition characteristics - SOL-DD	125
Table 56 - Intact Stability Criteria Check - SOL - DD	125
Table 57 - Condition characteristics - EOL-LD	126
Table 58 - Table 38 - Intact Stability Criteria Check - EOL-LD	126
Table 59 - Condition characteristics - EOL-DD	127
Table 60 - Intact Stability Criteria Check - EOL-DD	127
Table 61 - Manoeuvring criteria	138
Table 62 - Potential motion critical areas	140
Table 63 - Investigated Motion Critical Areas	141
Table 64 - Seakeeping Criteria obtained from DAISY Procedure book (1994)	142

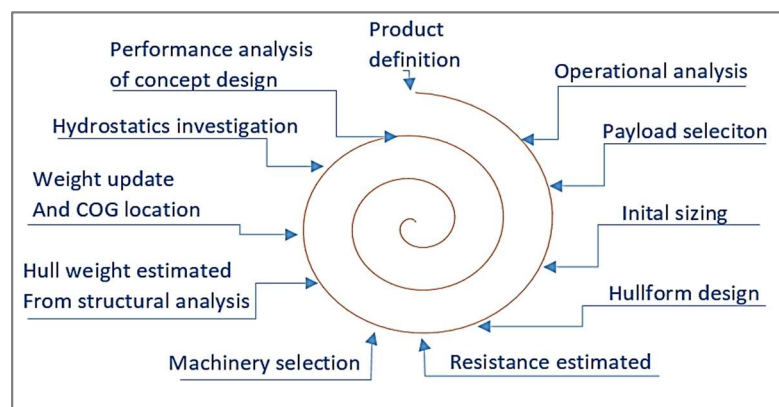


2. Introduction

A platform-based ship design is beneficial, when a customer desires to purchase a several similar vessels rather than individual ship acquirement. By introducing a platform design to which vessels at various roles can be selected at built, brings several benefits for the customer, the shipyard and the designer. The customer receives a lower price, as the platform-based fleet requires less design time, compared to designing individual ships. Once in service the customer will have better knowledge of the fleet performance, as all ships within the fleet will operate similarly. The shipyard will be able to produce platform-based vessels faster and at a lower unit procurement cost, as 1st of class issues is experienced once across the fleet. The shipyards external purchase cost will also be reduced by purchasing larger quantities of each platform machinery. Finally, the designer will need to design only one platform capable of being built for various variants, this reduces design time but constitutes a major challenge in producing an optimum platform for its designated variants. Such a challenge must be met with innovation and skilled engineering;

Project HYDRA is a concept-stage platform-based ship design, built for a 40 year life-span with an in-service date of 2025. To become a serious market competitor, the platform-vessel is required to meet emissions standard and be capable of operating 350 days a year. These requirements must therefore be fulfilled for all variants of HYDRA. The HYDRA Platform is required to of being built as three designated variants: A research vessel, a SUBSAR vessel and a Coastguard vessel

All variants of HYDRA are typically classed as special-purpose vessels. An extensive operational analysis has been carried out for each variant, in order to establish the tasks and equipment required for each variant. Close investigation has been conducted to ensure commonality across the variants in terms of equipment, performance and size. This has led to some inevitable capability trade-offs. The platform has been designed and analysed for the most driving variant in each analysis. The conducted analyses are interdependent and has been linked chronologically, so that one analyses feed into the other. The undertaken design spiral is presented in figure 1. The spiral has been initiated by the operational analysis. This has defined the required equipment, which have been selected through a capability trade-off analysis. At this point commonality have been ensured throughout the variants. An initial sizing and hull form investigation has defined the hull, from which a resistance estimate and propulsion arrangement could be made. The hull definition carried into a layout, from which general arrangements was produced. The propulsion arrangement allowed for a finalised machinery selection. Additional a hull weight estimate from a midship section structural calculation was obtained. This collaborated in a final sizing update. The final sizing and layout produced the exact location of the COG, which carried into an analysis of the overall performance of the vessel.





3. Operational Analysis

An operational analysis for the three variants have been conducted based on the User Requirements Document (URD) presented in Appendix A. The purpose of the operational analysis is to elaborate on the URD and thus define the key design features.

3.1.Prime Tasks

The vessel is specified by the **URD requirement 1.a.** to be designed as a common hull, capable of being built to three different roles; research vessel, SUBSAR vessel, and coastguard vessel.

The following section contains an investigation of the main particulars, payloads and operations of similar vessels, for all the three roles. This provides the foundations of each vessel and an understanding of the individual tasks.

The requirement of designing a platform to three different roles suggest a high level of commonality. The approach to this is therefore closely investigate in section [M.5].

3.2.HYDRA Coastguard – Concept of Employment

An investigation conducted by (Hazell, 2017) of existing coastguard vessels is presented below. This provided an appreciation of similar vessel main particulars, performance and equipment.

3.2.1. Existing Vessels

Name	Nation	D	L	B	V	R	Crew	Equipment
		[te]	[m]	[m]	[m/s]	[NM]		
<i>Roisin & Niamh</i>	Ireland	1500	79		23		44	76mm MCG
<i>Samuel Beckett</i>	Ireland	2256	90		23		44	76mm MCG
<i>Poseidon</i>	Sweden	3773	81	16	18	3000	38	
<i>Nordkapp</i>	Norwegian	3200	105		22		58	57mm MCG, 2 Helos
<i>Harstad</i>	Norwegian	3121	92	16	18		26	40mm MCG, NSRS, Tow
<i>Barentshav</i>	Norwegian	3200	92	16	20		40	40mm MCG, NSRS, Tow
<i>Thor</i>	Iceland	3920	94	16	20	300	48	40mm MCG, Tow
<i>Dattilo</i>	Italy	3600	95		18		38	76mm MCG, Helo
<i>Svalbard</i>	Norway	6375	105	19	18		50	57mm MCG
<i>Average</i>		3438.33	92.5	16.6	20		43	

Table 1- Analysis of main parameters of existing coast guard vessels



3.2.2. Maritime Surveillance

URD requirements 2.a.i. states that the coast guard is required to conduct broad maritime surveillance, specified as visual coverage of 4000 square nm pr. Hour, for EEZ activity control and piracy protection.

The optimal solution is to deploy airborne surveillance equipment, such as drones. Two solutions to conduct this task has been investigated.

1. 2 Fire scouts. 1 in air – 1 in maintenance
2. 4 Scan Eagle. 2 in air – 2 in maintenance

The calculation for the required amount of airborne equipment provided by the HYDRA Marine Engineering team (Hunt, 2017). The calculation is based on the range and maintenance hours. Figure 2 provides the output of such calculations based on the Scan-eagle solution.

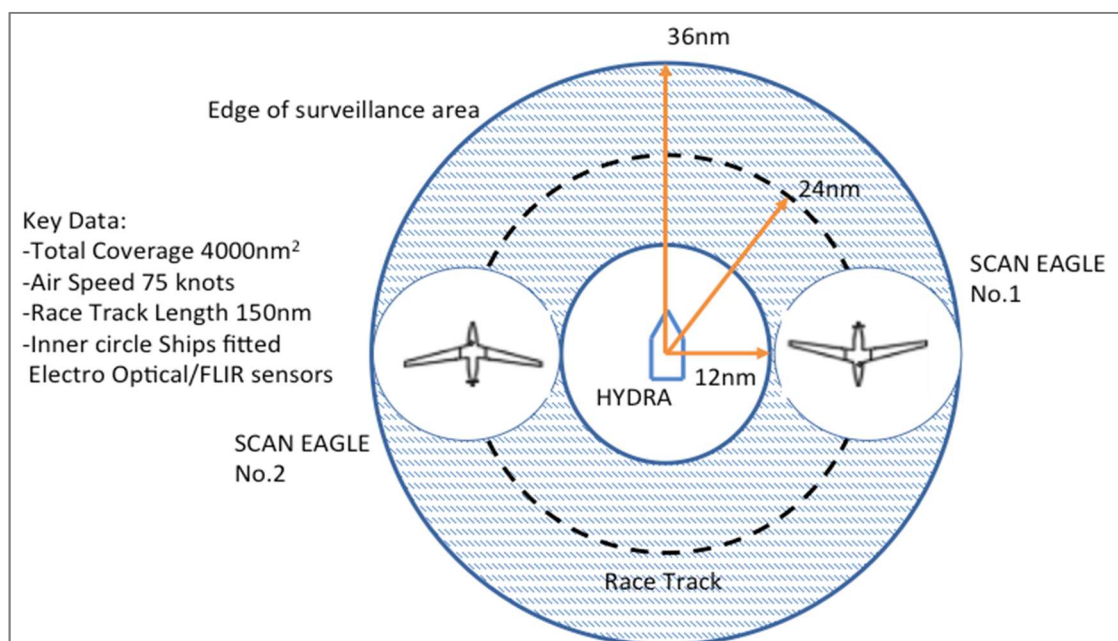


Figure 2 - Concept of employment of scan eagles (Produced by HYDRA ME (Hunt, 2017))

3.2.3. Boarding and Inspection Operations

The **URD requirement 2.a.ii.** requires HYDRA coast guard to undertake boarding, inspection and conduct SAR-operations up to 100[NM]. This task has been further investigated by conducting a range-break down and a systems analysis of typically equipment used for the certain range intervals.

The equipment utilized for this task is dependent on the range of the boarding and/or interdiction operation. It is required by the **URD [10.g]** to operate four 11m RIB. It is suggested that these will be used for close and intermediate range operations. For long range operations, it is suggested to use an organic helicopter.



The ranges are defined as:

- Close Range → 1-12 [NM]
- Intermediate Range → 12-40 [NM]
- Long Range → 40-100 [NM]
-

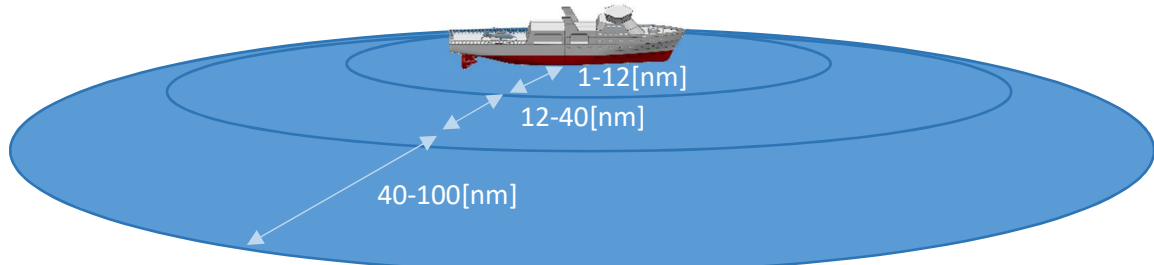


Figure 3 – Operational range for HYDRA Coast guard ((Hunt, 2017))

The following table summarizes the two main tasks in the various range studies.

Range	Key Conditions	Equipment Primary role
Close Range	Interdiction Operations	-11m RHIB -76mm (to provide disabling fire)
	EEZ Surveillance	-electro-optical sensors, FLIR, Hull Mounted Sonar
	Protection	-Helicopter, CWIS, Small Arms (for both interdiction team and vessel protection) -76mm (for vessel protection)
Intermediate Range	Interdiction Operations	-11m RHIB -Helicopter (to provide disabling fire)
	EEZ Surveillance	-Medium Range Radar, Link 22 -2x Scan Eagle UAV (to provide 4000nm ² /hr coverage)
	Protection	-Helicopter (to provide protection to interdiction team)
Close Range	Interdiction Operations	-Helicopter -11m RHIB
	EEZ Surveillance	-Link 22, 4 x Scan Eagle (for limited time on station due to range implications)
	Protection	-Helicopter (to provide support to interdiction team)

Table 1 - Operational ranges for HYDRA Coastguard (Hunt, 2017)

3.2.4. Hydra Coastguard Target

The following table identifies the target values for HYDRA Coast guard based on existing ships analysis.

Target	Value	Justification
Length	92.5 m	Previous ships
Beam	[16-18]m	Previous ships
Top speed	20 knots	Previous ships
Crew	43	
Maritime Surveillance	2D Radar, UAV	Conducted investigation
Boarding and interdiction	11m RIBS, organic helicopter	Conducted investigation
Protection	CWIS, 76mm Deck GUN	Previous ships

Table 2 - Target Values for HYDRA Coast guard



3.3.HYDRA Research - Concept of Employment

The research vessel's main task is to provide adequate facilities for the embarked scientist. Based on general arrangements for Meteor (Reederei F. Laeisz, 1998) and Falkor (Peters Schiffbau, 2009), it was found that typical research facilities include:

- Large operational deck area with winches and cranes for deployment of equipment
- Storage and internal workshop for equipment
- Laboratory space with access of wet objects (wet lab)
- Laboratory space with strictly denied access of wet objects (dry lab).
- Administrative office
- Science Control Room for remote control of deployed unmanned equipment

3.3.1. Existing vessels

An investigation conducted by (Hazell, 2017) presents a collection of existing research vessels. The results are presented in table 4.

Name	Nation	D	L	B	V	R	Crew	Equipment
		[te]	[m]	[m]	[m/s]	[Days]		
RV Alliance	NATO	3180	93	15.2	16.3	30	44	25 SCP
Meteor	Germany	4280	97.5	16.5	11.5		33	30 SCP & 20 Labs
HMS Protector	United Kingdom	5000	89.7	18	15		100	
Ernest Shackleton	United Kingdom	5455	80	17		130	72	
RRS James Cook	United Kingdom	5368	89.5	18.6	16	50	22	32 SCP
James Clark Ross	United Kingdom	5732	99.4	18.9	12	57	26	50 SCP
Italica	Italy	6000	130	17.3	16.5		28	
RRS Discovery IV	United Kingdom	6260	99.7	18	12.5	50	24	28 SCP
Pourquoi Pas	France	6600	107.6	20	14.5	6	18	40 SCP
Akademic Loffe	Russia	6600	117.1	18.2	16.5		53	
Average		5447.5	100.3	17.7	14.5	59	42	34

Table 3 - Analysis of main parameters of existing research vessels



3.3.2. Laboratory area

The URD requirement 2.b.ii. Requires HYDRA Research to provide adequate laboratory space and working deck area. The following section presents the approach to this requirement.

A 1960 SNAME paper “Design of Modern Oceanographic Research Ships” written by L. Rosenblatt, have been used to determine the adequate sizes of laboratory space based on the amount of scientist. Rosenblatt (1960) suggest 100 sq. ft (9.3 m²) pr. scientist, hence for 30 scientists approximately 3000 sq. ft. (280 m²) of internal laboratory space is required.

Furthermore (Rosenblatt, 1960) provides an estimate of cubic number based on internal laboratory space. An initial volumetric displacement to accommodate 280 m² of laboratory space can be obtained by assuming a block coefficient of 0.65. This reveals an initial volumetric displacement of 2944 m³. However, this is likely to be larger for a present vessel, as equipment weight have increased since 1960.

Lastly Rosenblatt (1960) provides an estimate of open deck area based on the cubic number. The cubic number which was previously obtained based on laboratory space is used for this investigation. From this it is seen that approximately 371 m² should be available for open deck area.

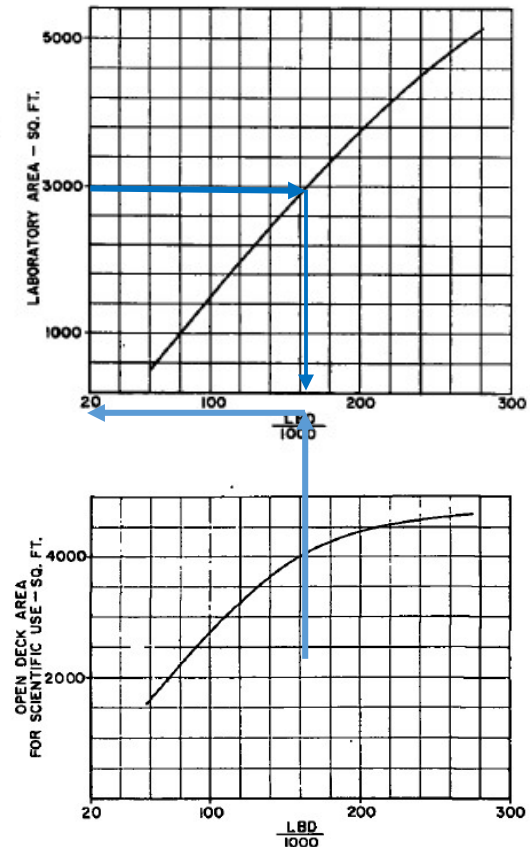


Figure 4 - Estimates of laboratory area and open deck area for research vessels (Rosenblatt, 1960)

3.3.3. Targets for Research Vessel

The following table present the target values for the research vessel, based on the previous investigations.

Target	Value	Justification
Length	[90-100] m	Previous ships
Beam	[16-18]m	Previous ships
Scientist Capacity	30	Previous ships
Laboratory area	280 [m ²]	Rosenblatt (1960)
Open deck area	371 [m ²]	Rosenblatt (1960)
Key features	A-frame	Deployment of Large USV

Table 4 - Target values for HYDRA Research



3.4.HYDRA SUBSAR - Concept of Employment

The **URD requirement 2.c.i** requires the SUBSAR vessel to embark NATO Submarine Rescue System (NSRS) and **URD requirement 2.c.ii requires** adequate medical care to the rescued submariners. The key features of the SUBSAR vessel is:

- Large deck area → Ability to embark NSRS and future version
- Ballast flexibility → Ability to load approximately 200 tons astern
- Extensive medical facilities, including:
 - Recompression chambers incl. compressor units
 - Resuscitation wards
 - Intermediate care wards
 - Operating theatre.
 - Treatment rooms
- Detection ability of distressed submarine

3.4.1. Existing Vessels

An investigation conducted by Hazell(2017) presents a collection of existing SUBSAR vessels. The results are presented in table 5.

Name	Nation	D [te]	L [m]	B [m]	V [m/s]	R [NM]	Crew	Equipment
Harstad	Norwegian	3121	82	16	18		26	NATO NSRS
Anteo	Italy	3874	98.4	15.8	20	10500	100	Cranes, Helo deck and hangar
Moship TR 1	Turkey	4100	90	18	18	4500	89	NATO NSRS, US, SRDRS, PTC, SRC
Cheonghaejin	South Korea	4300	102	16.4	18	4500	140	DSRV
MV Swift Rescue	Singapore	4290	85	16.3	12	3000	27	DSRV 500, TUPC (40)
Igor Belousov	Russia	5037	97.8	17.2	15	3500	96	Bester1 RV(22), Rescue (120)
Chiyoda	Japan	5400	112	17.6	17		120	DDS, DSRV, DPS
MS Belos	Sweden	6150	105	18	13		40	Cranes, URV, UUVs
Average		4735.9	98.6	17.04	16.1	3875	87	

Table 5 - Analysis of main parameters of existing SUBSAR vessels

From this it is observed that the crew size varies extensively. Furthermore, it is seen that the speed is significantly higher than the research vessel.



3.4.2. Main Equipment

Some fundamental equipment is required to conduct SUBSAR operations:

NSRS

The **URD requirement 2.c.i** requires the NATO Submarine Rescue System (NSRS) to be embarked upon request. According to the International Submarine Escape and Rescue Liaison Office (ISMERLO, 2008), the NSRS consists of separate components that can be embarked to several motherships.

The fully embarked NSRS consists of (ISMERLO, 2008):

- IROV – Intervention Remotely Operated Vehicle
- SRV – Submarine Rescue Vehicle (15 pers. Rescue capacity)
- PLARS – Portable Launch and Recovery (A-frame)
- TUP – Transfer Under Pressure (Hyperbaric Chamber TEU)
- PNTCS – Portable Navigation, Tracking and Communication Systems

As a dedicated SUBSAR vessel, it is anticipated that the vessel will require SRV unit, PLARS and PNTCS. It is intended to equip the vessel with stationary hyperbaric chambers, and it is therefore not required to embark the NSRS hyperbaric chamber TUP

The deck area of the NSRS is not specified in any public document. The required deck area has therefore been estimated from ships carrying the NSRS. An example is the Norwegian Haarstad-class.

From figure 5 is seen that the SRV and PLARS is deployed on the aft deck. Furthermore, it is known that the aft deck extends approximately 30% of the length. The Haarstad-class main particulars are mentioned in table 5. It is therefore estimated that an area of 16[m] by 25[m] is required for the full embark of the NSRS system.



Figure 5 – Haarstad-class coastguard with fully embarked NSRS (www.korabel.ru, 2012)

Hyperbaric chamber

According to **URD requirement 2.c.ii** the vessel should be capable of providing hyperbaric treatment. The scope has been estimated as smaller distressed submarines (35-50 crew). It is anticipated that for larger (100+ personnel) distressed submarines with all personnel suffering from compression, additional help from nearby vessels is required.

Equipping the vessel with stationary hyperbaric chambers relieves the requirement of embarking the NSRS Transfer Under Pressure (TUP) system, and allows for a secondary use as a saturation diving platform for commercial purposes.



Medical facilities

The medical treatment should extend to a Tier 2 level, including, but not limited to, an operational theatre, resuscitation wards and intermediate care wards.

It is suggested that the vessel should be capable of providing medical treatment to smaller distressed submarines (35-50 crew). It is anticipated that for larger (100+ personnel) distressed submarines with severely injured personnel, it required to receive additional help from nearby vessels. However, the vessel should be capable of handling large distressed submarines when not all personnel is injured.

3.4.3. Targets for SUBSAR

Target	Value	Justification
Length	[90-100]m	Previous ships
Beam	[16-18]m	Previous ships
Speed	Cruise speed – 12 knots Sprint speed – 18 knots	Previous ships
Medical Facilities /bed	30-50 personnel at Tier 2	
Recompression chambers	30-50 personnel	Useful for other purposes. Releases need to embark NSRS
Deck Area (NSRS)	400 [m ²]	Based on Haarstad-class

Table 6 - Target values for HYDRA SUBSAR



3.5.Secondary Tasks

HYDRA is required to perform several secondary tasks, regardless of the variants chosen, i.e. tasks belonging to HYDRA Platform. The tasks are firefighting, humanitarian rescue and towing. Despite being secondary tasks, they are likely to have a significant impact on the design. Thus, a thorough analysis of each task is provided in the following section.

3.5.1. Firefigthing

The URD requirement [3.a.] states that the ship must be able to provide firefighting to distressed vessels and installations.

The main considerations in providing fire-fighting capability is the supporting machinery systems to conduct this task and the ability to protect the ship itself. Additionally, it is aimed to install remote controlled firefighting equipment to avoid exposure of the crew to the hazardous environment. Furthermore, this is expected to minimize the complement.

Supporting Machinery Systems

The requirements for supporting machinery systems to conduct firefighting is obtained from Lloyds rules. In order to be classed as fire-fighting ship class 1 at Lloyds Register (Lloyds Register, 2015) it is required to have minimum total pump capacity of 2400 m³/h. Furthermore, two monitors (water cannons) must be installed. From the HYDRA ME report it has been estimated that 6 x HPSW pumps fulfils the requirement (Hunt, 2017).

Protection

During firefighting operation, it is important to protect the ship and its crew from the hazardous environment which contains toxic gasses and/or high temperatures. The following protection methods has been investigated for this purpose:

- Remote Controlled Firefighting monitors
Remote control of the firefighting monitors releases the crew from exposure to the potential hazardous environment. The equipment should be controlled from a position inside the superstructure with visual coverage of the distressed vessel.
- Prewet
A Prewet system will protect the hull by activating HPSW sprinklers on the profile of the superstructure and exposed hull, to keep the structure cool and clean from toxic chemicals.
- Citadel
A conventional citadel system provides a safe internal space in environments with hazardous gasses. It includes a cleansing station as a dedicated-entrance in hazardous situation. Furthermore, several airlocks are required to separate the internal environment form engine rooms and crew areas. A citadel furthermore requires self-shutting ventilation.



3.5.2. Humanitarian Rescue operation (RBB)

URD Requirement 3.b. Requires the vessel to be able to provide humanitarian rescue & evacuation on a large scale, including provision of medical aid.

The main consideration in the ability to conduct humanitarian rescue, is the capacity of rescued people and the adequate caretaking once on board. The survivor capacity has been determined from case studies of performing ships, and from recent statistics. The adequate caretaking has been determined from publicized guidance documents.

Case study of rescue capacity

Existing ships performing this ability:

Vessel Name	Owner	Length	Main role	Survivor Capacity	Source
Bourbon Argos	Doctor without Borders	69 m	SAR Ship	700	(MSF (Doctors Without Borders), 2016)
MY Phoenix	Doctor without Borders	40 m	SAR Ship	372	(MSF (Doctors without Borders), 2015)
Dignity I	Doctor without Borders	50 m		300	(MSF (Doctors Without Borders), 2016)
The Vos Hetia	Save the Children	62 m	SAR Ship	300	(Save The Children, 2017)
Maersk Detector	Maersk	90	Anchor handling tug	300	(MAERSK Supply Service, 2011)

Table 7 - Analysis of capacity of mediterranean rescue vessels

This analysis shows that the average ships conducting SAR-operations carry approximately 300 survivors, with exception of the Bourghbon Argos. Furthermore, it is seen that the Maersk detector carries 300 people as a secondary task.

Rescue operation statistics

A statistical analysis conducted by The UN Refugee Agency, which shows the daily estimate of sea arrivals to Greece from Lybia (The UN Refugee Agency, 2017). A potential rescue area for HYDRA.

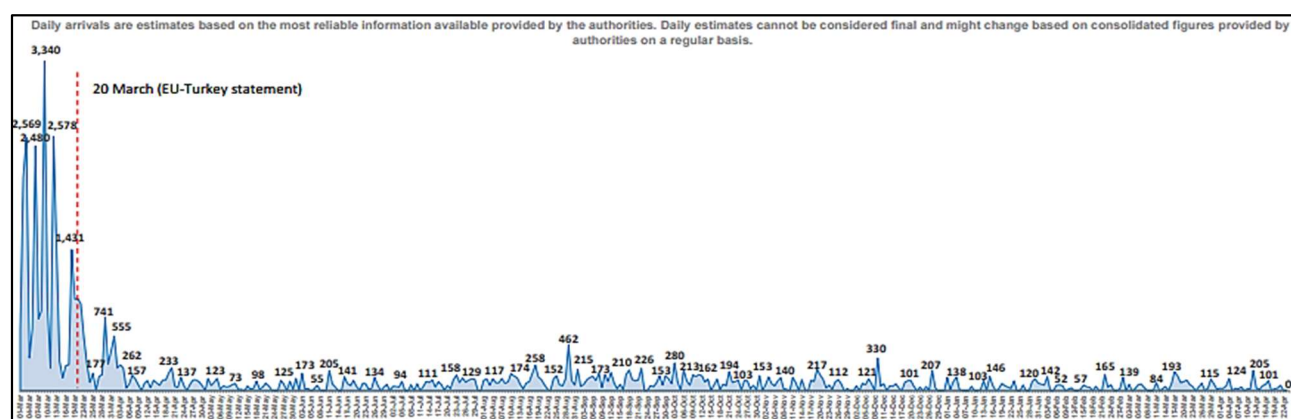


Figure 6 - Amount of survivors arrivals at Greece form Lybia in 2015-16 (The UN Refugee Agency, 2017)

From Figure 6 it is seen that past 20th of March 2016 (EU-turkey statement), the average daily arrival is approximately 200 people. Furthermore, it is noticed that the sea arrivals have significantly decreased since 2016.



Caretaking of rescued survivors

Once the survivors have been taken on board, a caretaking plan must be initiated. The full scope of the plan is evidently to be defined by the operator. However, it is intended to prepare the design for a typical rescue plan. A publication by International Chamber of Shipping (International Chamber of Shipping, 2015) presents an approach to large scale rescue operation at sea:

Storage areas should be reserved for:

- Food and drinking water
- Survival bags
- Plastic sheeting
- First aid and medical supplies
- Additional PPE (Personal Protective Equipment)

Accommodation for rescued survivors:

Accommodation should be divided into men, women and children, and sick/injured personnel. Sick and injured survivors should be placed near medical facilities. (International Chamber of Shipping, 2015)

Sanitation for rescued survivors:

It is advised that sanitary facilities should at least be 1:50. (International Chamber of Shipping, 2015).

Target

From the survivor capacity study, it has been determined that a capacity of 200 survivors is a sufficient capacity, particularly as a secondary task. From the rescue operation statistics is suggested that a capacity of 200 is equally sufficient to handle the current situation. Therefore, it has been decided to design for a survivor capacity of 200 personnel.

Furthermore, dedicated storage areas will be reserved for food, equipment and medical storage.

It is intended to place survivors onto 3 divisions on the main deck. All survivors should be located internally, with an approximated designated area of 1.5[m²] pr. survivor. In the event of good weather conditions, the survivors will remain on the open deck as it reduces the impact on the vessel.

Additional sanitary facilities will be implemented on the main deck, to accommodate for sanitary requirements in the event of humanitarian rescuing.



3.5.3. Towing (RBB)

In the **URD requirement 3.c.** it is required to perform towing operations of the largest container ships passing through the Mediterranean Sea.

Considerations:

Towing operations is conducted by attaching a connection from a strong point on the towing vessel to a strong point on the distressed vessel. By inspection of various ships, it has been determined that a winch is typically installed to provide flexibility in the connecting line, and avoid critical tension. Furthermore, it has been found that towing ships typically uses azimuth thrusters to ensure a high-level of manoeuvrability.

The largest container ship in-build today is the Madrid Maersk with a capacity of 20,568 TEU, hence this is the target.

Bollard pull estimate

The required bollard pull is estimated from a scientific paper from ASME produced by (Shigunov & Schellin, 2015)

This paper investigates five conventional containerships based on TEU capacities. The investigation is based on manoeuvring theory, where wind impact and sea state is incorporated into the force derivatives. Calm water force coefficients have been determined from a finite-volume RANS CFD simulation. (Shigunov & Schellin, 2015) provides an approximate formula for estimation of towing force (bollard pull) of an 18000 TEU containership, based on significant wave height and LPP.

(Shigunov & Schellin, 2015) furthermore, provides a graph of towing forces of various containerships, as a function of significant wave height, in all wave directions. As none of the investigated ships complies with the defined target value, a scaling factor has been determined. This is based on linear interpolation of the 18000 TEU and 14000 TEU at sea state 5 and 6.

Sea State	SS5(hs=4m) Bollard pull	SS6(hs=6m) Bollard pull
14000 TEU	75 ton	109 ton
18000 TEU	85 ton	131 ton
20568 TEU	91.09 ton	144.67 ton

Table 8 - Estimate of bollard pull ton required for towing the largest container vessels in various sea states



Towing equipment Arrangement

Typical towing equipment arrangement has been investigated from a publicized guidance document. The typical propulsions arrangement are shown in table (European Tugowners Association, 2015):

Propulsion Arrangement	Configurations	Limitations	Benefit	Application
Conventional propulsion system (European Tugowners Association, 2015)	2 x shaft line 2 x rudders	- Requires great experience from towing master - Is considered the most dangerous method	Conventional configuration	Likely to be compliant with other HYDRA requirements
Azimuth Stern Drive (ASD) (European Tugowners Association, 2015)	2 x Azimuth thrusters located aft Propeller either FPP or CPP	- Large flat surface at stern - Can produce reduce bollard pull in direction-thrust combination	360[deg] rotation - High manoeuvrability	Very compliant with DP-requirement for HYDRA Research and SUBSAR
Azimuth Tractor tug with Rudder Propellers (European Tugowners Association, 2015)	1-2 x Azimuth Thrusters located at bow 2 x Rudders located aft	- Produce poor hydrodynamic performance - Makes Docking extremely difficult	360[deg] rotation - High manoeuvrability - Beneficial for push operations	Likely to be a poor solution for top speed requirement
Voith Schnieder Water Tractor (European Tugowners Association, 2015)	2 x Cycloid propellers located at the bow	- Produce poor hydrodynamic performance - Makes Docking extremely difficult	Provide thrust in any direction by controlling blades	Likely to be a poor solution for top speed requirement

Table 9 - Typical Propulsion Arrangements for Towing vessels

Target

Evidently it is most sensible to select an ASD arrangement which can provide a 145 [ton] bollard pull for this requirement. However this may reduce the hydrodynamic performance and introduce docking problems.

It is furthermore advised to install a towing winch, to obtain control of the tension in the towing line. (European Tugowners Association, 2015)



3.6.Operational Area

HYDRA is designed for operation in the Mediterranean Sea per **URD requirement [4.a]**.

3.6.1. Enviroment analysis

Each variant of HYDRA has requirements to its operability within certain sea states; the coastguard must be at station all time during normal operation, the research vessel must be able to deploy UXV's at high sea state but is unlikely to perform common operation at large sea states and the submarine rescue ship must be deployed the NSRS is designed to be operated up to sea state 6. The fulfilment of these requirements will be investigated in the seakeeping analysis [M.14]



Table 10 - Estimate of operational time in the Mediterranean Sea

An investigation of published sea state data has shown the ship can operate approximately 97% of the time in Sea state 6 (Hogben & Lumb, 1967). This has therefore been accepted as a design sea state for the baseline ship.



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4. Payload selection

The payload selection has been arranged into four subdivisions for this project. This is done for simplicity and an enhanced overview. The subdivisions are:

1. Platform payloads
2. Research module payloads
3. SUBSAR module payloads
4. Coastguard module payloads

Evidently the individual ships total payload is a addition of the platform payloads and one of the modular payloads. The objective of this section is to provide the justification and considerations for the selection of each suggested payload, based on the previous operational analysis. Furthermore, it is intended to present the cost, weight and volume of each component. The final selection and quantity of each item is decided upon via cost-capability trade-off analysis.

A major naval architectural challenge of this concept design, is to ensure that the three modules is equally voluminous and heavy. In that way, the modules become directly interchangeable and the performance analyses can be conducted for one variant solely.

4.1. HYDRA Platform Payloads

There are several payloads that are connected directly to the primary function of a ship and therefore becomes universal to all three variants. Furthermore, the vessel is required to perform several secondary tasks, regardless of the selected variant, hence these are performed by the HYDRA platform.

The following list summarises the payloads suggested for the platform.

1. Medium External Communication Package

It is suggested that the platform contains a medium external communication package. According to the Zenith database (UCL Zenith Database, 2017) this communication package is adequate for ship operating alone in international waters without support. The package includes:

- Main Communications Office
- Medium Frequency (MF) Antenna
- Medium Frequency (MF) Equipment Room
- 2 x High Frequency (HF) Transmitter Antennas
- 2 x High Frequency (HF) Receiver Antennas
- 4 x Very High Frequency (VHF) Antennas
- 8 x Ultra High Frequency (UHF) Antennas
- Datalink Mast



2. Surveillance radars

Two conventional navigation radars are to be installed on the ship, in order to navigate in poor visibility. (UCL Zenith Database, 2017)

3. Visual signalling equipment

A selection of search- and navigational lights are suggested to be installed. All relevant data is obtained from the UCL Zenith Database (UCL Zenith Database, 2017)

4. Audible signalling equipment

A selection of ships whistles- and loud speakers for notifying other vessels are suggested to be installed. All relevant data is obtained from the UCL Zenith Database (UCL Zenith Database, 2017)

5. Deck cranes

Two conventional 3-ton deck cranes are to be installed on either side, near amidships. The cranes will assist in loading and unloading of minor provision and cargo. Furthermore, the cranes can be used for deployment of smaller equipment, for all three variants.

6. Monitor (Water cannons for firefighting)

The water cannons are specifically included to accommodate for the secondary task of firefighting. From market research it has been found competitors typically have two placed above the bridge, with internal control. The sizing of the required pumps are conducted in the HPSW-calculation by the HYDRA Marine Engineer (Hunt, 2017). The HPSW furthermore provides water to the ship internal firefighting and Prewet system. In order to obtain Lloyds Register Fire Fighting Ship Class 1 It is required to place two remote-controlled watercannons on the bridge. (Lloyds Register, 2015)

7. Winch

An aft deck towing winch will be included to provide flexibility in the towing operation. An investigation into equipment of existing towing winch have been made. This has shown that there is a general relationship between bollard pull and installed towing force.

Ship	Reference	Length	Bollard pull	Towing force
Wärtsila WSD 4628 AHTS	(Wartsila, 2017)	83 m	180 T	300-400 T
Wärtsila VS 4612 AHTS	(Wartsila, 2017)	69.6 m	150 T	350 T
Wärtsila VS 482 AHTS	(Wartsila, 2017)	80.2 m	180 T	400 t
Maersk Detector	(MAERSK Supply Service, 2011)	89.3 m	218 T	400 T

Table 11 - Towing winch capacity based on previous AHTS vessels

From the above table it is seen that towing force is typically twice the bollard pull. Previously it has been presented that the vessel requires approximately 145 [Ton] bollard pull, thus a 300 [Ton] towing force is required. Relevant data for a 300 [ton] towing winch is obtained from Fukusei type 2 (Fukusei, Unknown)

8. Rescued personnel

From the secondary task humanitarian rescue it has been decided that the ship shall be capable of carrying 200 survivors. It is estimated that the average survivor weighs 90 [kg] including belongings, thus it becomes a total non-volumes payload of 18 tons.



4.2. HYDRA Research Payloads

The following list summarises the payloads suggested for HYDRA Research.

1. 7 m RIBs

Two 7m RIBs are suggested for the research vessel to conduct rescue operations. The ships are to be installed on either side, for flexibility. The ships are considered part of the modular payload due to the RIB requirements for the coastguard. All relevant data is obtained from the UCL Zenith Database (UCL Zenith Database, 2017)

2. Laboratory facilities

Laboratory facilities are required to conduct on-board experimentation and processing of collected samples. Two types of laboratories are typically installed: dry lab and wet lab. It is intended to place the wet labs near the open deck in order to enhance the workflow. Furthermore it is intended to place some motion-sensitive wet labs near amidships.

From the operational analysis [M.4.3] it is suggested that for a 30 scientist ship it is sufficient to provide 9.2m² (100 sq.ft) of laboratory space pr. scientist is sufficient. This therefore suggest a total of 280 m² of laboratory space. This has been increased to 300 m². It is assumed that 30% is wet lab and 70% is dry lab.

3. Additional Research related facilities

Science control room

A science control room is suggested to operate remote-controlled equipment related to the research operations. Based on the Falkor GA (Peters Schiffbau, 2009) it is suggested to reserve at least 16 m² and to be placed near the operational areas.

Meeting room

A meeting/conference room is suggested for briefing scientist.

4. CTD System

Conductivity, Temperature & Depth measurement device assembled in a rosette form is suggested standard equipment for the research vessel. The system requires an on-board winch.



5. Remote Operated Vehicle (ROV)

A number of Inspection ROVs is suggested, with a dedicated maintenance and storage area within the equipment storage. All relevant data on the ROV is obtained from the UCL Zenith Database,

6. ASV 6000

Following a UCL SDE lecture by Dr. Bradbeer (Bradbeer, 2017) on Autonomous Vehicles it was suggested to include four autonomous semi-submersible vessels, that will mainly be used for hydrographic survey. The relevant information is obtained from **sea speed** (Seaspeed, unknown). The storage envelope of 1 unit is 6mx1m [6m²]. Furthermore a 10m² area within the equipment storage space is reserved for maintenance and spare parts.

L&R will be conducted by an organic a-frame.

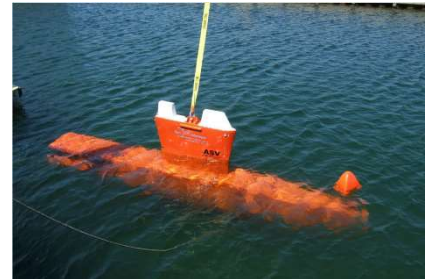


Figure 7 - Seaspeed ASV 6000 (Seaspeed, unknown)

7. Manned submarines

As an optional capability it has been suggested to reserve area for a 4-person manned submarine (SEAmagine, 2016) (See Figure 8). This extends the capability of ROVs. This requires 5mx3x[15m²]. One unit weighs 6.7 ton. (SEAmagine, 2016)
L&R will be conducted by an organic a-frame.



Figure 8 - SEAmagine Aurora-4 (Unique Group Diving Equipment, 2016)

8. Equipment storage and workshops

Large internal area for storing all equipment. All larger equipment will have a rail-deployment system to the open deck, from which it will be launched by the a-frame. Small equipment will be deployed and launched by a rail system open from a port. The required size of the equipment storage is driven by the amount of equipment that will be included. It is acknowledged that more equipment may be installed through vessel life. This will be accommodated for by a growth margin.

9. Hull mounted sonar

A hull mounted sonar is suggested for the research vessel to conduct bathymetric mapping, sub-bottom profiling, biomass estimation etc. All relevant data is obtained from the UCL Zenith Database (UCL Zenith Database, 2017)

10. Towed array

All relevant data is obtained from the UCL Zenith Database. (UCL Zenith Database, 2017)

11. A-frame

An A-frame is to be fitted for deployment of all large and heavy equipment; this is expected to be the CTD and USVs L&R system.

For consistency between designs it is estimated that the A-frame weighs approximately 100 tons. And can lift 30 tons. This is acknowledged to be too large for this purpose.



4.2.1. Suggested Payloads Summary

The following table provides an initial estimate of the modular payloads suggested for the research ship, in terms of cost, required volume and weight. Furthermore, a ranking system is applied in order to perform cost capability trade-off analysis, where A is the baseline.

Item	Ranking	Quantity	Cost [£mil.]	Volume [m ³]	Weight[ton]
A-Frame	A	1		NIL	100
Wetlab	A/B/C	S/M/L	0.5/0.75/0.825	330/495/577.5	10
Drylab	A/B/C	S/M/L	0.5/0.8/0.95	412.5/687.5/825	10
Control Room	A/B	1	0.1	27.5	2.5
Meeting Room	C	1	0.1	41.25	2.5
7m RIB	A	2	0.25	430	10
In. ROV	A/B	2/4	0.05/0.1	20.625/41.25	0.8
ASV 6000	A/B	2/4	0.25/0.5	66/132	3.6/7.2
AUV Bluefin	B	2	0.25	41.25	2.5
Maned sub	C	1	2	63	7
CTD + Winch	A	1	0.5	41.25	10
Storage and Workshops	A/B/C	S/M/L		128.7/255.7/318.7	5
Hull mounted sonar	B	1	5	48.5	18
Towed Array	C	1	5	13.75	6.3

Table 12 - Suggested payloads for HYDRA Research

4.2.2. CCT - Packages

For cost capability trade-off the items are categorized in package based on the applied ranking system.

Package	Minimum- baseline	Medium	Maximum
Equipment	- 2 x 7m RIB - 2 x ROV - 2 X ASV - CTD winch - Equipment storage - A frame	- 2 x 7m RIB - 4 x ROV - 4 X ASV - 2 X AUV - CTD winch - Equipment storage - A frame	- 2 x 7m RIB - 4 x ROV - 4 X ASV - 2 X AUV - Maned submarine - CTD winch - Equipment storage - A frame
Sensor	- CTD System	- CTD System - Hull mounted Sonar - Towed Array	- CTD System - Hull mounted Sonar - Towed Array - Multibeam
Laboratories	- Small Wetlab - Small Drylab - Science Control room	- Medium Wetlab - Medium Drylab - Science Control room	- Large Wetlab - Large Drylab - Science Control room - Meeting room

Table 13 - Capability packages for HYDRA Research



4.2.3. CCT - HYDRA Research

A CCT analysis has been conducted for the suggested packages of HYDRA Research. The equity is based on optimising the cost and ensuring reasonable volume requirement. From the table below it seen that the cost is optimised, with a suggestion of large laboratory facilities. However, it is seen from a volume perspective that large laboratories will increase that to be much greater than other HYDRA variants.

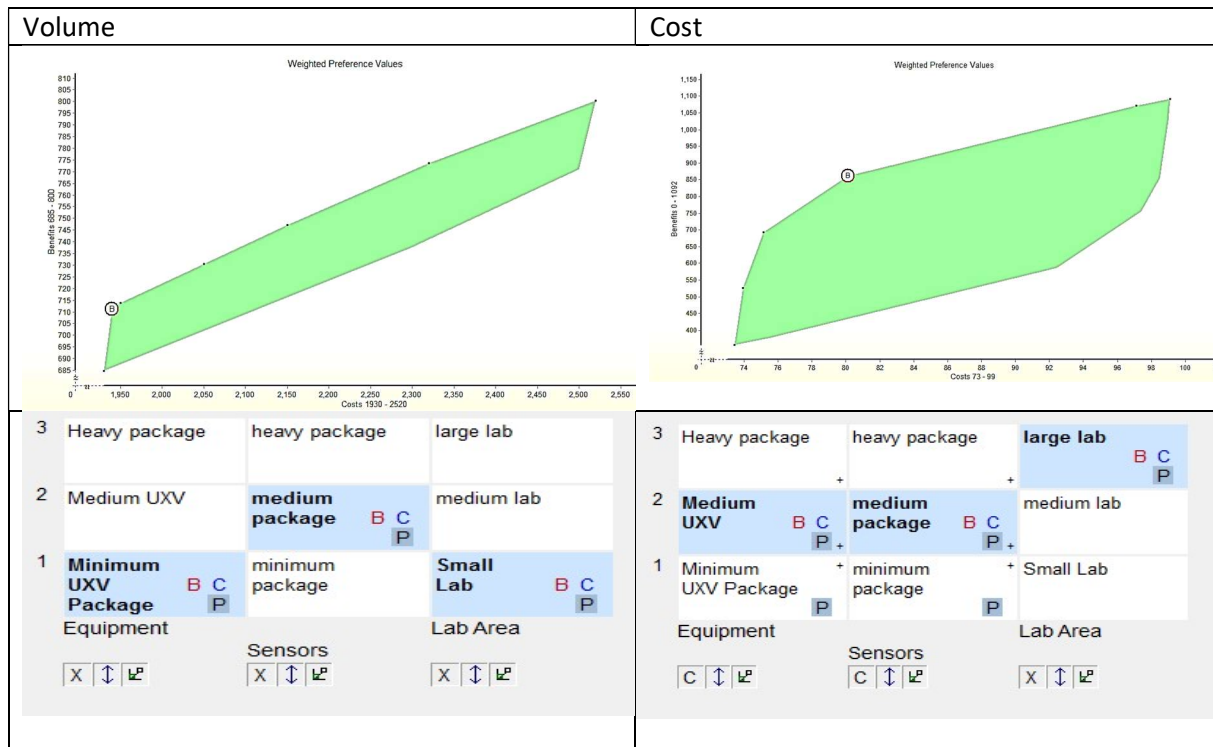


Figure 9 - Cost Capability Trade-off output for HYDRA Research

It is therefore suggested to used the presented minimum equipment package, with a medium sensor package and small laboratory facilities. Recalling that small laboratory is the size recommend from the operational analysis.

Item	Ranking	Quantity	Cost [£mil.]	Volume	Wieght
A-Frame	A	1		NIL	100
Wet lab	A	S	0.5	330	10
Dry lab	A	S	0.5	412.5	10
Control Room	A	1	0.1	27.5	2.5
7m RIB	A	2	0.25	430	10
In. ROV	A	4	0.05	20.625	0.8
ASV 6000	A	4	0.25	66	3.6
AUV Bluefin	B	2	0.25	41.25	2.5
CTD System	A	1	0.5	41.25	10
Storage and Workshops	A	S		128.7	5
Hull mounted sonar	B	1	5	48.5	18
Towed Array	B	1	5	13.75	6.3
Total			12.4	1560.075	178.7

Table 14 - Final payload selection for HYDRA Research



4.3. HYDRA SUBSAR Payloads

1. 7 m RIBs

Two 7m RIBs are suggested for the HYDRA SUBSAR to conduct rescue operations. The ships are to be installed on either side, for flexibility. The ships are considered part of the modular payload due to the RIB requirements for the coastguard. All relevant data is obtained from the UCL Zenith Database, (UCL Zenith Database, 2017).

2. NATO Submarine Rescue System and A-frame (NSRS)

A NSRS is required by the costumer in order to rescue distressed submarines. The NSRS weighs 30 ton and requires a 9m open deck storage space. The associated A-frame (PLARS) is portable and weights a 100 ton. A typical layout is shown by NSRS (ISMERLO, 2008)

3. Recompression chambers and compressors

Recompression chambers is required for slow rise of depressurized submariners. The chamber system should be located near the a-frame, in order to lock with the NSRS. The amount of hyperbaric treatment places is related to the average crew-size of a conventional submarine. Therefore, in event of a larger nuclear submarine SAR operation, assistance is required. The relevant data is obtained from (Unique Group Diving Equipment, 2016)

The feasibility of enlarging these facilities will be investigated, in terms of cost and volume.



Figure 10 - Recompression chamber (Unique Group Diving Equipment, 2016)

4. Resuscitation and Intermediate Care Wards

Large medical facilities are required to treat injured submariners. All relevant data is obtained from the UCL Zenith Database. The medical facilities are based on the ability to treat a conventional 30 crew submarine. The feasibility of enlarging these facilities will be investigated, in terms of cost and volume.

5. Operating Theatre

For intensive medical treatment, an operational area is suggested as an optional capability. All relevant data is obtained from the UCL Zenith Database. The feasibility of enlarging these facilities will be investigated, in terms of cost and volume.

6.

Additional medical areas

A 20m² medical meeting/office space is suggested. This is optional and the feasibility of this will be investigated, in terms of cost and area, (UCL Zenith Database, 2017)

7. Hull mounted sonar

A hull mounted sonar is suggested in order to detect distressed submarines accurate position. All relevant data is obtained from the UCL Zenith Database. (UCL Zenith Database, 2017)



8. Towed array

A towed array is suggested to extend the capability of detecting distressed submarines that have not released a distress signal. This is, however, considered an optional capability. All relevant data is obtained from the UCL Zenith Database, (UCL Zenith Database, 2017)

Surface supply diving and additional compressors

As an optional capability it is suggested to provide surface supply divers to assist shallow water distressed submarines. This is an optional capability. All relevant data is obtained from the UCL Zenith Database, (UCL Zenith Database, 2017)



4.3.1. Suggested Payloads Summary

The following table provides an initial estimate of the modular payloads on board the research ship, in terms of cost, required volume and weight. Furthermore, a ranking system is applied, to conduct cost capability trade off, where A is the baseline.

Item	Ranking	Quantity	Cost [£mil.]	Volume	Weight
A-Frame	A	1	Free	NIL	100
NSRS	A	1	Free	NIL	30
Resuscitation ward	A/B/C	5/10/40	0.5/1/4	137.5/275/1100	20
Intermediate care ward	A/B/C	10/20/50	1/2/5	165/330/825	10
Operation Theatre	B/C	1/3	1.7/8.5	165/495	N/A
Hyperbaric chambers	A/B/C	6/30/90	0.3/1.5/4.5	66/550/1650	26.5
Treatment offices	B	1	0.2	55	3.2
Surface supply diving	B	1 (6 divers)	0.25	55	5
7m RIB	A	2	0.25	430	5
In. ROV	C	4	0.1	41.25	0.8
Work ROV	C	1			N/A
AUV Bluefin	B	2	0.25	41.25	2.5
Hull mounted sonar	B	1	5	48.5	18
Towed Array	C	1	5	13.75	6
Total					227.3

Table 15 - Suggested payloads for HYDRA SUBSAR

4.3.2. CCT - Packages

For cost capability trade off the items are categorized in packages based on the above ranking:

	Minimum - Baseline	Medium	Maximum
Detection	Hull mounted sonar	Hull mounted sonar Small Towed Array AUV Bluefin	Hull mounted sonar Towed Array AUV Bluefin Inspection ROV
Assistance	- NSRS - A-frame	- 2x 7m RIB - NSRS - A-frame	- 2x 7m RIB - NSRS - A-frame - Surface Supply Diving
Treatment	- 5 resuscitation wards - 10 intermediate wards - 6 Hyperbaric chamber beds	- 10 resuscitation wards - 20 intermediate wards - 30 Hyperbaric chamber beds	- 40 resuscitation wards - 50 intermediate wards - 90 Hyperbaric chamber beds

Table 16 - Capability packages for HYDRA SUBSAR



4.4.CCT - HYDRA SUBSAR

The CCT analysis shows that the selected packages are optimised (on the knee) from a cost perspective. From a volume perspective, it is seen that this requires a sensible volume in comparison to other HYDRA variants. Furthermore, it is seen that large treatment facilities (maximum packages) drives the volume significantly but does not contribute to the capability, as it is estimated that it will rarely be required to have such facilities.

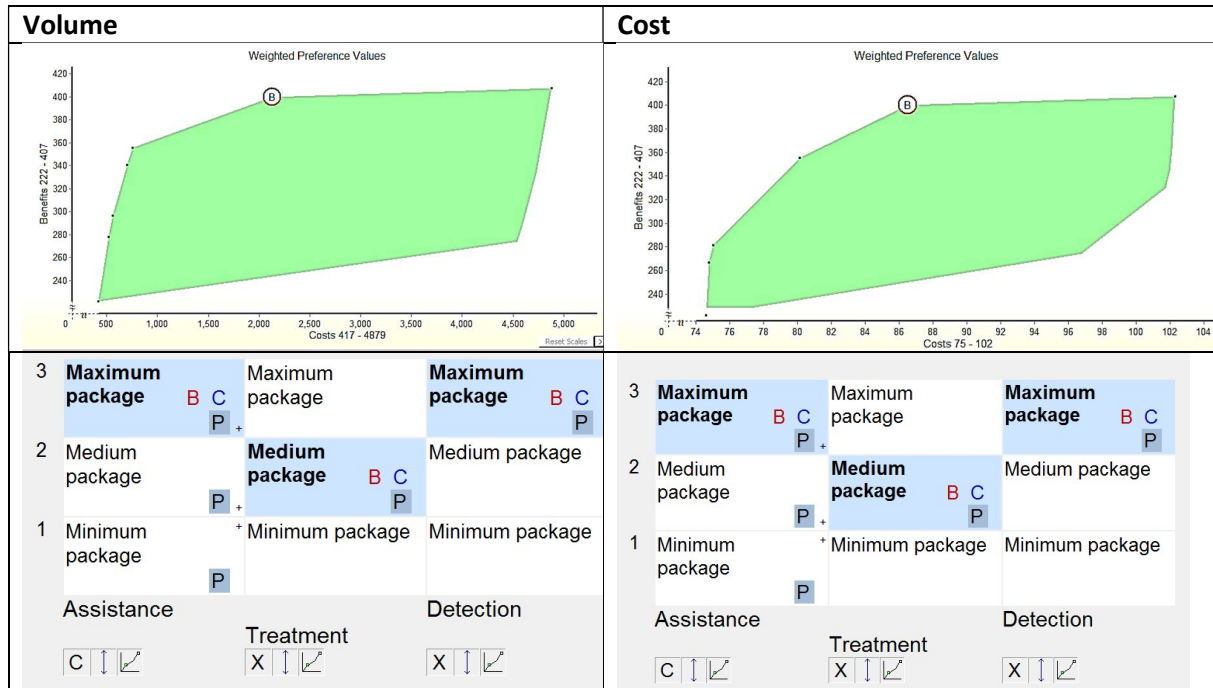


Figure 11 - Cost Capability Trade-off for HYDRA SUBSAR

Item	Ranking	Quantity	Cost [£mil.]	Volume	Weight
A-Frame	A	1	Free	NIL	100
NSRS	A	1	Free	NIL	30
Resuscitation ward	B	10	1	275	20
Intermediate care ward	B	20	2	330	10
Hyperbaric chambers	B	35	1.5	550	26.5
Treatment offices	B	1	0.2	55	3.2
Surface supply diving	B	1 (6 divers)	0.25	55	5
7m RIB	A	2	0.25	430	5
In. ROV	C	4	0.1	41.25	0.8
AUV Bluefin	B	2	0.25	41.25	2.8
Hull mounted sonar	B	1	5	48.5	18
Towed Array	C	1	5	13.75	6
Total			15.55	1839.75	227.3

Table 17 - Final selection of payloads for HYDRA SUBSAR



4.5. Hydra Coastguard Payloads

1. 7 m RIBs

Two 7m RIBs are organic for all other variants. It is therefore sensible to investigate their feasibility for HYDRA Coastguard. The ships are to be installed on either side, for flexibility. All relevant data is obtained from the UCL Zenith Database, (Unique Group Diving Equipment, 2016).



Figure 12 - 7m RIB (UCL Zenith Database, 2017)

1. 11 m RIBs

Four 11m RIBs is required for the coastguard vessel to conduct boarding operations up to 100 nm. The ships are to be installed on either side, for flexibility. All relevant data is obtained from the UCL Zenith Database.



Figure 13 - 11m RIB (UCL Zenith Database, 2017)

2. 76mm OTA-Melara Deck gun

A deck gun is to be installed in order to provide distant warning-shooting capability to interact with other vessels. It is suggested to fit a 76mm OTA-melara, based on a survey of similar coastguard ships. However the feasibility of the total artillery package will be further investigated. All relevant data is obtained from the UCL Zenith Database.

3. Close-In-Weapon-System (CIWS)

A CIWS is suggested to be fitted in order to provide nearby warning shooting capability, and if necessary direct fire at smaller approaching vessels. This is considered an optional capability and the feasibility of the artillery package will be further investigated. All relevant data is obtained from the UCL Zenith Database.



Figure 14 – CIWS (UCL Zenith Database, 2017)

4. 5-ton Organic Helicopter

A helicopter is suggested as the main equipment to conduct interdiction and boarding of vessels up to 100 nm. It is suggested to install a 5-ton organic helicopter, with a capacity of 4 personnel. Furthermore, a hangar will be provided. All relevant data is obtained from the UCL Zenith Database.



Figure 15 – Lynx Wildcat (UCL Zenith Database, 2017)



5. Firescout UAV

Two fire scouts are proposed to perform a 4000nm^2 visual coverage in an hour. The advantages of utilizing Firescouts are; simple L&R and flexibility in adding more equipment. The disadvantages are; high cost, demanding maintenance and required personnel. An investigation on the feasibility will be provided. All relevant data is obtained from the UCL Zenith Database.

6. Scan Eagle UAV

Four Scan Eagles are proposed to perform a 4000nm^2 visual coverage in an hour. The advantages of using Scan Eagles are; low cost and required personnel. The disadvantages are; complicated L&R system, poor equipment flexibility, large storage for UAVs and L&R. An investigation on feasibility will be provided. All relevant data is obtained from the UCL Zenith Database.



Figure 16 - Scan Eagle (Unmanned Systems Technology, 2015)

NOTE: It is either Firescout solution or Scan Eagle solution.

7. Medium range radar

A medium range radar to support EEZ Surveillance and helicopter operations. The radar is to have a vertical position capable of tracking larger vessel at a 12-40nm radius, i.e. the limit of intermediate range.

8. Infrared radar and/or electro optical sensor

Additional sensors are suggested for HYDRA Coastguard to extend the surveying capability at night and other poor visibility conditions.

9. Hull mounted sonar

A hull mounted sonar is suggested to detect submarine activity in the patrol region. It is considered an optional capability and will be further investigated. All relevant data is obtained from the UCL Zenith Database.



4.5.1. Suggested Payloads Summary

The following table provides an initial estimate of the suggested modular payloads on board the HYDRA Coast Guard ship, in terms of cost, required volume and weight. Furthermore, a ranking system is applied to perform cost capability trade-off:

Item	Ranking	Quantity	Cost [£mil.]	Volume	Weight
7m RIBS	B	2	0.25	430	10
11 m Ribs	A/B/C	4/2/2	1/0.5/0.5	1120/560/560	40
Deck gun	A	1	3	65.3	11.9
CWIS	A/B	1	10/5	77/38.5	13.9
5 ton Helicopter	B	1	4*	519.3	45.5
Firescout UAV	A	2	21	137.8	8
Scan Eagle UAV	B	4	2.5	55	4.8
Medium range radar	A	1	1.5	11	N/A
Infrared radar	B	1	2	0	N/A
Electro optical radar	A	1	2	8.3	1
Hull mounted sonar	B	1	5	40	18
Ops Room	B	1	0.2	110	2
Boarding party Ready room	B	1	0.05	55	2
Detention	C	1	0.05	55	0.5

Table 18 - Suggested payloads for HYDRA Coast guard



4.5.2. Packages for Cost Capability Tradeoff

For a cost capability tradeoff, the items are categorized in package

	A - baseline	B	C
Boarding	- 2 X 11m RIB - Boarding party Ready room	- 2 x 7m RIB - 2 x 11m RIB - 1 x 5ton helicopter - Ops Room - Boarding party Ready room	- 4 x 11m RIB - 1 x 5ton helicopter - Ops Room - Boarding party Ready room
Surveillance	- 4 x Scan Eagle UAV - Medium range radar - Electro optical radar	- 4 x Scan Eagle - Medium range radar - Infrared radar - Electro optical radar - Hull mounted sonar	- 2 x Firescout - Medium range radar - Electro optical radar - Infrared radar - Hull mounted sonar
Protection	- 76mm Deck gun	- 76mm Deckgun - 1 x CWIS	- 76mm Deckgun - 2 x CWIS

Table 19 - Capability packages for HYDRA SUBSAR

4.5.3. CCT – HYDRA Coastguard

The CCT-analysis for HYDRA Coastguard shows that the payload selection is optimised from a cost perspective. It is seen that the required volume is increased significantly by installing 4 x 11 m ribs. However, it is seen that 2 x 11m RIBs and 2 x 7m RIBs provides a volume that is significantly close to the other variants of HYDRA. This was therefore discussed with the costumer.

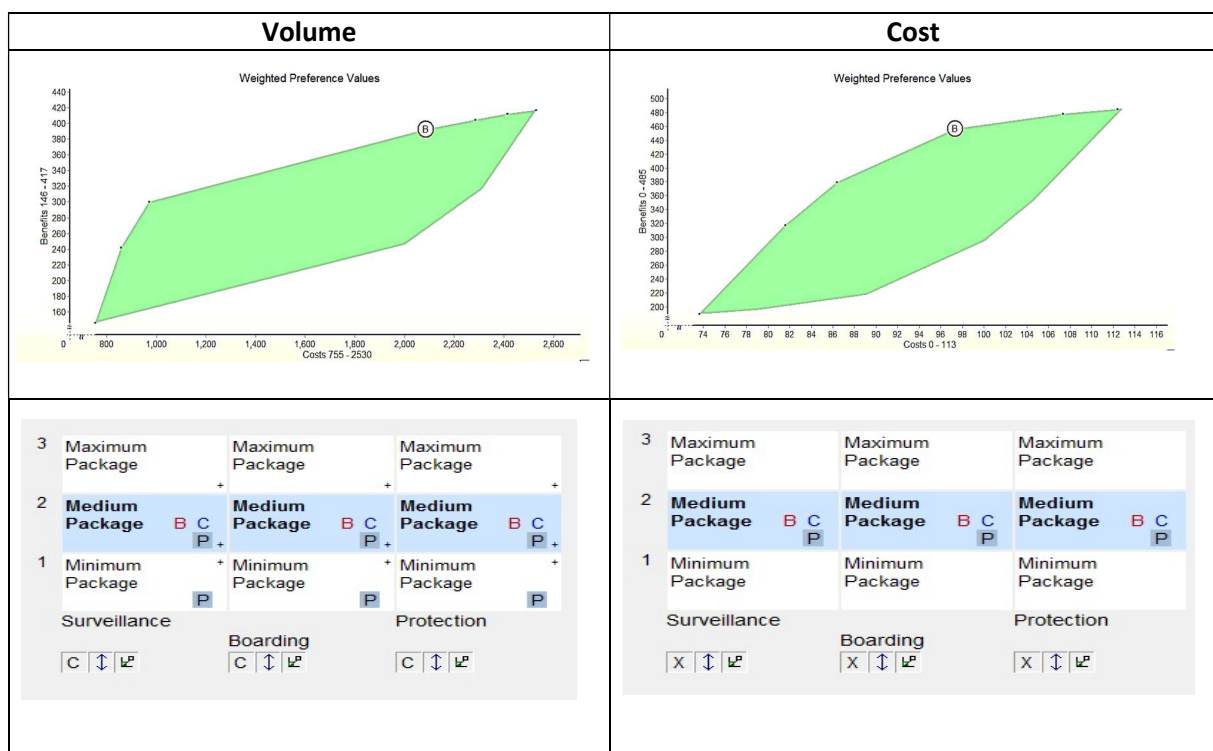


Figure 17 - Cost Capability Trade-off output for HYDRA Coast guard



4.5.4. Final Selection

The customer accepted a reduction of **URD requirement 10.g** from 4 x 11m RIBs to 2 x 11m RIBs and 2 x 7m RIBs. This also brought stronger commonality across all variants of HYDRA.

The following table shows the final payloads selected for HYDRA Coast Guard.

Item	Ranking	Quantity	Cost [£mil.]	Volume	Weight
7m RIBS	B	2	0.25	430	10
11 m Ribs	B	2	0.5	560	40
Deck gun	A	1	3	65.3	11.9
CWIS	A	1	5	38.5	13.9
5 ton Helicopter le.	B	1	4*	519.3	45.5
Scan Eagle UAV	B	4	2.5	55	4.8
Medium range radar	A	1	1.5	11	N/A
Infrared radar	B	1	2	0	N/A
Electro optical sensor	A	1	2	8.3	1
Hull mounted sonar	B	1	5	40	18
Ops Room	B	1	0.2	110	2
Boarding party Ready room	B	1	0.05	55	2
Detension	C	1	0.05	55	0.5
Total			22.05	1947.4	164.6

Table 20 - Final payload selection for HYDRA Coast guard



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5. Design approach

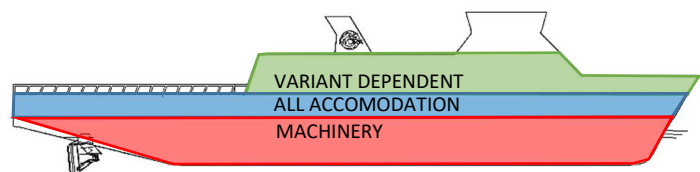
The general concept of the vessels design is to be adaptable to three different tasks. Hence considerations have been made into a preparation philosophy of the platform. The concept suggests a high level of modularity. The approach to this is to design three modules that can interchangeably be inserted to the design, without affecting displacement, stability or resistance, radically. This is done by dedicating a VARIANT DEPENDENT area. This is possible as it was previously shown that the payloads for each variant were similar in weight and volume.

5.1. Proposed solution to modularity

The following solution-generation suggests 4 general approaches to the interchangeability of modules (Figure 18). The “variant dependent” area defines the variant. All other aspects are common for all variants.

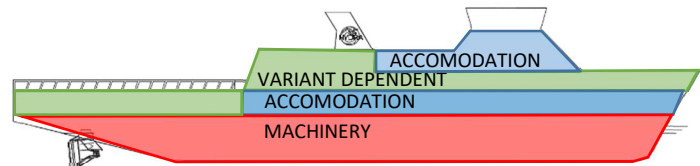
Solution 1: 1 deck and 01 deck

1 deck and 01 deck constitutes the variant. Below deck is all accommodation. This requires a low superstructure



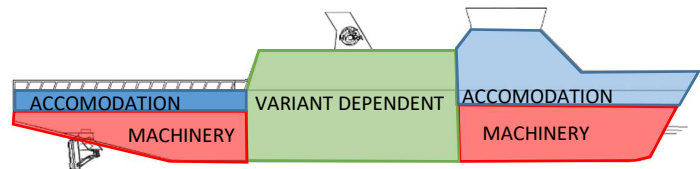
Solution 2: Superstructure excl. bridge

The variant dependent area is the main deck which becomes a factory floor, where offices and higher rank accommodation are placed above and all lower rank personnel is placed within the hull.



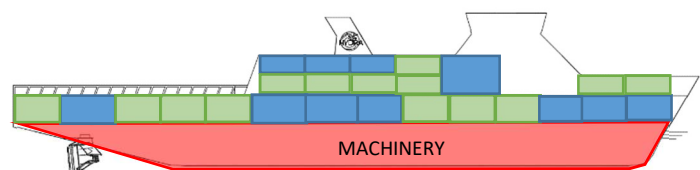
Solution 3: Parallel midbody

Variant dependent section is part of the parallel midbody. Allows for length extension if needed.



Solution 4: Modular blocks within ship

Various blocks within the ship are reserved for the variants. Provides flexibility in allocation of spaces.



Solution 2 is selected as it offers the ability to extend the volume to two decks. Furthermore, it achieves the possibility of a factory floor philosophy at 1 deck.

Figure 18 - Design approach



5.2. Factory floor philosophy

It has been decided to carry solution 2 forwards. The philosophy is that the main deck is a factory floor producing a product, where operations are managed in offices above and workers are accommodated elsewhere. A preliminary workflow is presented for each variant, in order to show the main product philosophy behind the layout.

Research Vessel Workflow

The research vessels product is scientific data. Samples are gathered by deployed equipment → The equipment is recovered at the open deck → Equipment goes into storage → Samples are taken out of equipment and transferred to laboratories → Samples are processed and data is gathered.

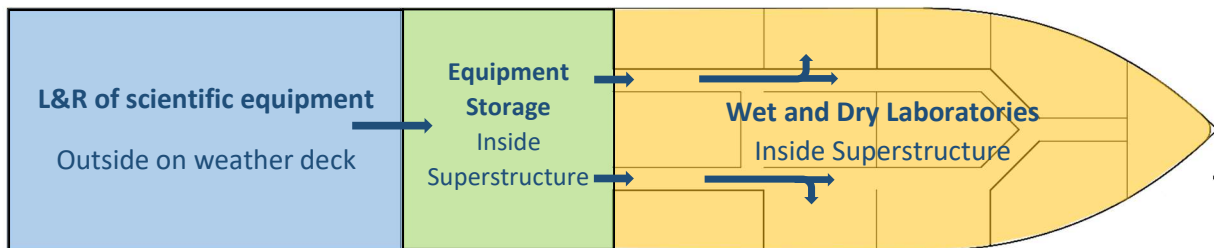


Figure 19 - HYDRA Research workflow

SUBSAR Vessel Workflow

NSRS is deployed and recovered via A-frame at open deck → NSRS interlocks with hyperbaric chambers → Intoxicated submariners are transferred at correct pressure into hyperbaric chambers → Hyperbaric chambers are slowly depressurized → Submariners are transferred to medical facilities. Non-intoxicated submariners are transferred directly to medical facilities.

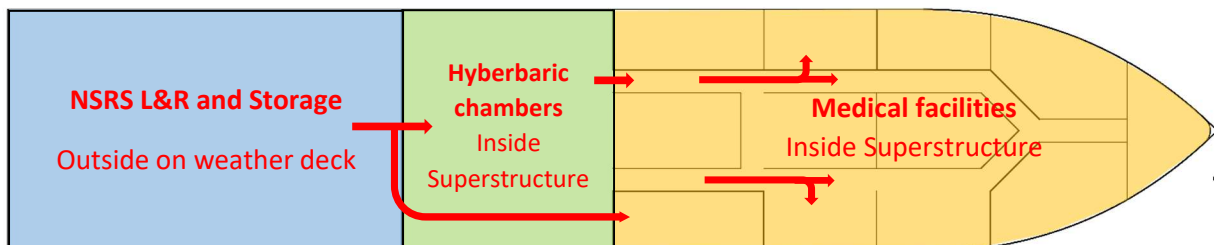


Figure 20 - HYDRA SUBSAR workflow

Coastguard Vessel Workflow

Boarding operations: Boarding team is prepared on ready rooms → Boarding team board transport vehicle → Transport vehicle is deployed.

Surveillance: Surveillance gear is launched and recovered at open deck → Surveillance gear is transferred to storage area.

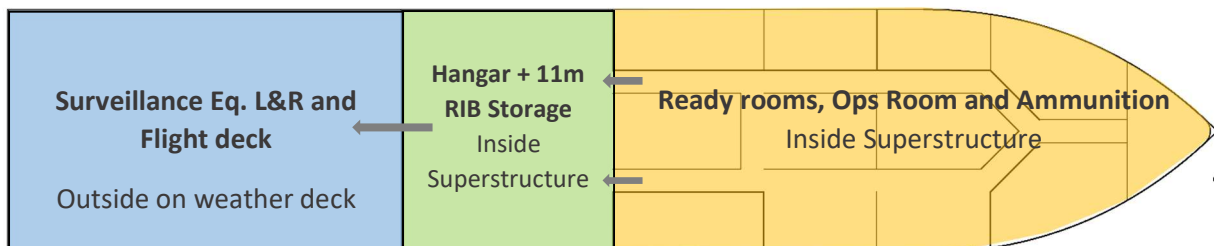


Figure 21 - HYDRA Coast guard workflow



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6. Initial Sizing

In order to initiate the iterative process of the design circle, it is necessary to obtain an estimated displacement. The following section describes the undertaken approach to obtain this value. The weights of the ship are subdivided by the UCL Weight Break Down Structure. The required volumes and weights of the majority of the components are obtained from the UCL Zenith database (UCL Zenith Database, 2017). The UCL Zenith database contains primarily estimates based on previous ships, expressed in algebraic form as function of the total enclosed volume. It is therefore necessary to obtain a proper initial estimate of this. The Payload Volume Fraction (PVF) method has been used of this estimation.

6.1. Payload volume fraction

The proposal of PVF method is to estimate the total enclosed volume as a multiplication of the constant payload volume. The largest payload volume of the three variants has been used for this.

The individual payloads have been listed in the previous section. This is summarized in the table below:

Description	Symbol	Volume
Payload Volume Research	V_{PR}	1677.06
Payload Volume SUBSAR	V_{PS}	1907.06
Payload Volume Coastguard	V_{PC}	1947.4
Payload Volume Platform	V_{PP}	205.7
Max Total Payload Volume	V_{PTOT}	2112.76

Table 21 - Initial Sizing and Payload Volume Fraction

Evidently the coastguard requires the largest volume. The selected PVF is 0.22 and the selected total density, ρ_{tot} is 0.33, based on the value of a typical frigate. It is acknowledged that this might be higher for this vessel, however it is sufficient as an initial approximation. The initial total enclosed volume, ∇_G becomes.

$$\nabla_G = \frac{V_{PTOT}}{PVF} = 9603.453m^3$$

And the estimated displacement, Δ , becomes

$$\Delta = \nabla_G \cdot \rho_{tot} = 3169.14 \text{ ton}$$

These values feed into the initial sizing spreadsheet, and are compared to the actual obtained volume and displacement. This iteration is continued until the following is satisfied:

$$\Delta_{Obtained} = \Delta_{Required} \mp 1\%$$

And

$$\nabla_{G_Obtained} \geq \nabla_{G_Required} \mp 1\%$$

The final values from the initial sizing

Description	Symbol	Volume
Displacement	$\Delta_{Obtained}$	3666.42 [te]
Volumetric Displacement	$\nabla_{Obtained}$	3577 [m ³]
Total Enclosed Volume	$\nabla_{G_Obtained}$	9561.36 [m ³]
Total Density	ρ_{tot}	0.38

Table 22 - Final values from initial sizing



6.2.Initial Estimate of weight and volume of the platform

The following section present the results of initial weight estimation. It is presented according to the WBS and clarifies the main weight drivers. Solely the primary weights, over 10 tonnes, are shown in the table below.

Component	Weights [te]	Source / Comment
GROUP 1: HULL		
Misc. Fittings	22.37	Dependent on ∇_G
Gyro	21	3 gyros required for DP 2
Anchor and Chain	30	
Hull Structure	860.52	Dependent on ∇_G
Misc. Stores	32.84	
Access (Passage Ways)	28.45	Dependent on ∇_G
Paint	21.04	Dependent on ∇_G
GROUP 2: PERSONNEL		
Provisions Stores	11.2	Depend on number of crew and endurance
Personnel	9.15	Dependent on crew
GROUP 3: SHIP SYSTEMS		
HVAC	32	Dependent on ∇_G
Chiller and Distribution	20.88	Dependent on ∇_G
Desalination Plant And distribution	15.38	Dependent on ∇_G
Seawater Pumps and distribution	21.91	Dependent on ∇_G
Fuel processing	22.95	Dependent on ∇_G
Air compressors And distribution	10.98	Dependent on ∇_G
Sewage Treatment	22	Dependent on ∇_G
Stabiliser	19.6	Rolls Royce Catalogue
GROUP 4: MAIN PROPULSION		
Fuels Cells	80.9	ME estimate
2 X 3.3 MW Diesel Generator	147.2	From Daisy
Motor Conversion	40	
Machinery Ventilation	20	Dependent on ∇_G
Machinery Firefigting	10	Dependent on ∇_G
Retractable Azipod	16.5	Rolls Royce Catalogue



Tunnel Thruster	11.73	
Main propulsion cables	90	Dependent on ∇_G
2 X Azipull Thruster	90	
Seats and supports	94.466	
GROUP 5: ELECTRICAL POWER		
Switchboards	10	
Electrical Distribution Center	12	Dependent on ∇_G
Electrical Distribution	49.78	Dependent on ∇_G
GROUP 6.1 : PLATFORM PAYLOADS		
Winch	100	
2 X Firefighting Monitors	10	Estimate
200 X Rescued Survivors	20	Assuming 100 kg pr. survivor
GROUP 6.2 : RESEARCH VESSEL PAYLOADS INCL. VARIABLES		
Dry laboratory	10	Estimate
Wet laboratory	10	Estimate
Equipment storage and workshop	10	Estimate
A-frame	100	Based on NSRS
GROUP 6.3 : SUBSAR VESSEL PAYLOADS INCL. VARIABLES		
Hull mounted Sonar	18	
Tier 2 Medical Facilities	38	
NSRS Submarine	30	NSRS Catalogue
NSRS A-frame	100	NSRS Catalogue
Recompression Chambers	26.25	
GROUP 6.4 : COAST GUARD VESSEL PAYLOADS INCL. VARIABLES		
76mm Deck Gun and CIWS	25.8	
5-ton Helicopter	45.5	
2 X 11m RHIBS	45	
Hull mounted Sonar	18	
GROUP 7: VARIABLES		
DFO	600	ME estimate
Freshwater	71	ME estimate
Bilge Water	26	ME estimate
Ballast Water	250	From preliminary stability check
Misc. Stores	42	

Table 23 - Presentation of all major weight estimates obtained from initial sizing



6.3. Visual Representation

The above tables have presented the main estimated weights for the vessel, based on the UCL Zenith Database. This has allowed for a comparative study of the individual weight groups, in order to identify the key drives in terms of weight and volume.

The graph below shows a percentage chart of the weight and volume based on the WBS for the HYDRA SUBSAR.

HYDRA SUBSAR example:

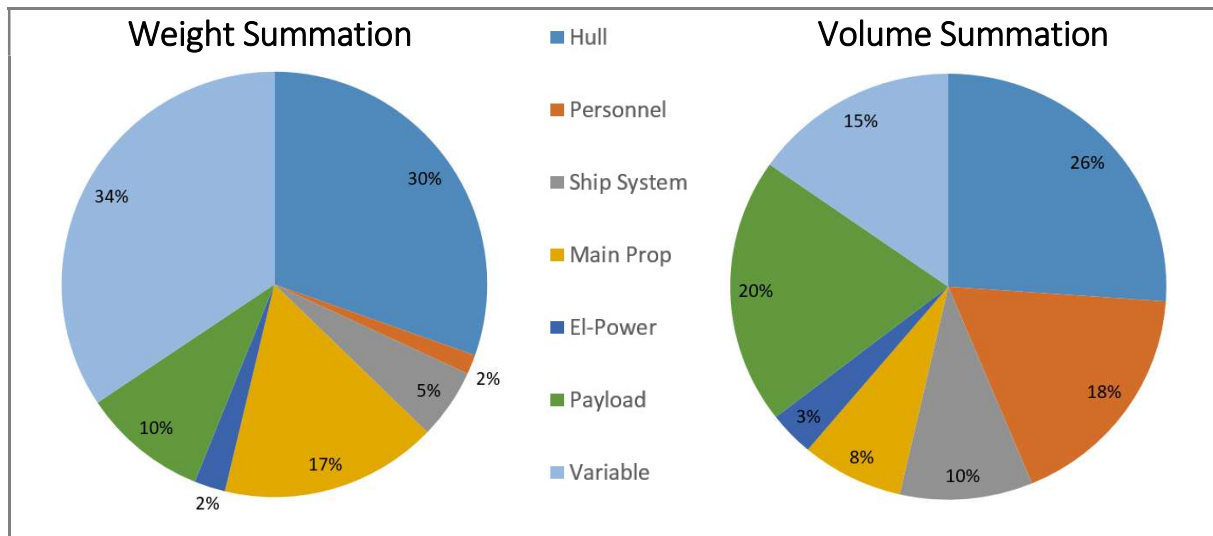


Figure 22- Weight and Volume percentage circle representation of HYDRA SUBSAR

6.3.1. Discussion

From figure 22 it seen that the hull group is the main driver in terms of both weight and volume. The driving volume is due to the passage ways and storages for 30 days mission [URD 5.a.] being a significant part of the vessel. The weight is due to the structure, hence a accurate structural weight is desired.

Furthermore, it is seen that the variable group, i.e. fuel and freshwater is significant in terms of weight and takes up a large amount of volume. It is seen that the personnel group is an insignificant weight driver but requires large volumes, due to the light but spacious cabins required for the crew and augmented personnel.

The main propulsion group is seen to be significantly heavy, but requires less volume. This is an expected relationship.

Lastly it is seen that the payload group takes up 20% of the vessel volume, because of the initial PVF method. However, the installed payloads weights are not driving the vessel.

The estimated displacement is have shown to be significantly lower than the displacement cap. It is possible that the estimated payloads have been seized to small, however it is more likely that the cap has been set to high.



6.4. Comparison of Variants

The main naval architectural challenge in project HYDRA is to design a platform that can be built as three different ships, without making radical changes to the platform. It is therefore paramount that the selected payloads, that constitutes each variant, is similar in volume and weight.

A comparative study of the initial sizing for all three vessels has been made.

It is evident that HYDRA SUBSAR is driving the volume. This is due to the large requirement of medical facilities and the hyperbaric chamber area. However, it is seen that all three vessels required payload volume is similar. From figure 23 it is seen that HYDRA SUBSAR is approximately 90 tons heavier than HYDRA Coast Guard, this will result in different draughts and performance, which will be investigated further. Furthermore, it is noticed that all HYDRA variants does not exceed the displacement cap [URD 10.c].

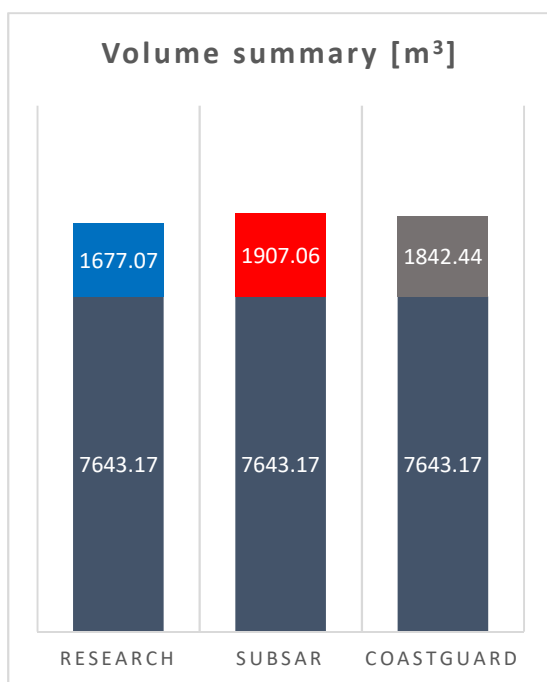


Figure 24 - Required volume comparison of all HYDRA vessels

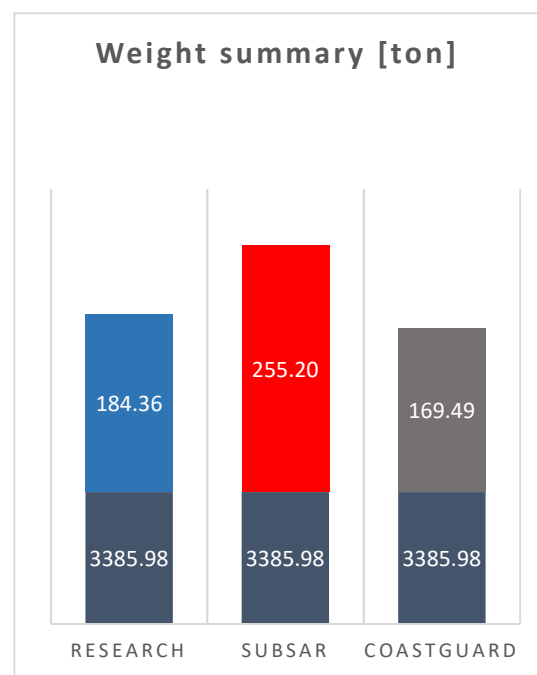


Figure 23 - Displaced weight comparison of all HYDRA vessels



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7. Hull form

The following section presents the selection process regarding the governing parameters of the hull form. This regards hull form type, material and final shape. The final shape is refined by a parametric survey, to obtain the final dimensions and shape parameters.

7.1.Hull form Material

Table 24 presents Weight-Score Method selection of hull form materials. The knowledge of the materials applications and limitations are based of the authors several years of material studies. The scale is from 1 to 5(good).

Criteria	Weight [1-5]	Material [1-5]					
		Steel		Aluminium		Carbonfiber composite	
		Assigned score	Weighted score	Assigned score	Weighted score	Assigned score	Weighted score
Structural Weight	3	2	6	4	12	5	15
Tensile strength	3	4	12	3	9	5	15
Compressive strength	3	4	12	3	9	2	6
Production	4	4	16	3	12	1	4
Corrosion	2	2	4	2	4	5	10
Maintenance Ability	3	4	12	4	12	1	3
Mid-life refit	4	4	16	3	12	2	8
Fire protection	4	5	20	2	8	2	8
Vibration	1	2	2	3	3	3	3
Innovation	3	1	3	1	3	3	9
Total			103		76		81

Table 24 - Weighted score analysis of various hull form materials

From this it is seen that primarily due to fire-fighting requirement [URD 3.a.], mid-life update [URD 10.h] and commercial production, it is sensible to select conventional steel. It is acknowledge that this does not bring innovation to the design.



7.2. Hullform Selection

The following section presents SWOT analysis for the considered hull form types, which is used in a weight-score method to select the final hull form type.

7.2.1. SWOT Analysis for Cat-Swath Concept

A Cat-Swath combines the features of a catamaran and SWATH via an unconventional ballast system. It is intended to operate in catamaran condition, i.e. with empty ballast tanks during transit, when alongside it will fill its ballast and sink to SWATH mode (see figure 24), thus providing a stable platform for motion sensitive operations.

An example of its application is Danish Yachts, whom produced four crew-transfer vessels for the offshore windmill industry (A2SEA, 2015). The ships were fully constructed of a carbonfiber-polystyren-sandwich construction. All sister ships proved to be beneficial in SWATH condition, but suffered several structural failures, due to low ductility and crack propagation.

A SWOT analysis has been made on the Cat-Swath concept. It is based on information from (Dubrovsky & A, 2001)

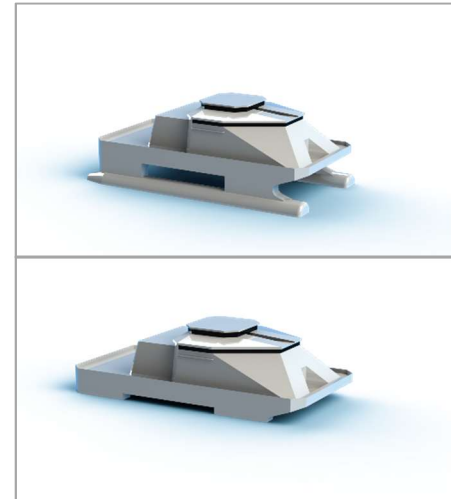


Figure 25 - CAT-SWATH
(Original Concept Illustration)

Strength - Large righting moment - Significant roll damping due to wide beam (in SWATH mode) - Beneficial for high speed vessel - Shallow draught (in catamaran mode) - Operational flexibility in conversion between being a highspeed catamaran or stable SWATH	Weaknesses - Very difficult tank layout - Difficult to implement podded propulsion - High freeboard (in catamaran mode) - Wave interference resistance between hulls - Constrained layout options - RIBs deployment must be at sides → suggest narrow hull
Opportunities - Large deck area - Possibly better work flow at main deck due to a more square shape - Innovative solution - Requires two shaftlines/azipods	Threats - Roll damping results in large relative motions in beam seas - Structural issues in beam seas - Sensitive to load changes in SWATH mode - Requires high level of structural investigation - Higher UPC due to complex design

Figure 26 - SWOT Analysis for CAT-SWATH concept



7.2.2. SWOT Analysis for Trimaran Concept

A trimaran is typically composed of a mainhull and two side floats. The buoyancy is distributed so that the side floats provides roll stability and the main hull remains long and slender. The extension of the side-pontoons, results in a significantly low transverse GM. The hull is therefore stiff in roll. Furthermore, the extension provides a large deck area.



Figure 27 – RV Triton (Naval Technology)

An inspirational example of its application is the UK-built RV Triton (Naval Technology, unknown). She was built to prove the feasibility of trimaran hull in warships application. Beam is 22m and LPP is 90m. She has briefly served as a research vessel, and is currently operating as an OPV in Australia.

A SWOT analysis has been made on the trimaran concept. It is based on the following literature:

Strength - Large righting moment - Significant pitch damping due to long slender mainhull - Significant roll damping due to side floats - Beneficial for high speed vessel	Weaknesses - Preferably one centred shaft line which results in low DP ability - Less proven designs than other hull forms - Interference resistance between hulls - Constrained layout options - RIBs deployment must be at sides → suggest narrow hull
Opportunities - Large deck area - Innovative solution	Threats - Structural issues in beam seas - Requires high level of structural investigation - Higher UPC due to complex design - Deployment difficulties

Figure 28 - SWOT Analysis for Trimaran concept



7.2.3. SWOT Analysis for Conventional Catamaran

Catamaran hull forms consist of two parallel hulls connected by a main platform. It utilizes the concept of distributing the buoyancy into two hulls, and thus obtains a shallower draught for the same displacement as a monohull. The wide beam provides a tall transverse metacentric height. This significantly increases roll damping, thus provides a safe ship. However, it is prone to large relative roll motions in beam seas at high sea states. The wide beam furthermore provides an opportunity for a large deck area. However, it also typically results in low L/B ratio, which can potential results in similar transverse and longitudinal metacentric height causing poor seakeeping.

Catamaran are typically applied as high-speed vessel. The Tasmanian company INCAT have produced several designs, (Incat, 2017).

Strength - Large righting moment - Significant roll damping due to wide beam - Beneficial for high speed vessel - Shallow draught	Weaknesses - Difficult tank layout - Difficult to implement azipod propulsion - Shallow draught gives higher freeboard - Wave interference resistance between hulls - Constrained layout options - RIBs deployment must be at sides → suggest narrow hull
Opportunities - Large deck area - Possibly better work flow at main deck due to a more square shape - Innovative solution - Requires two shaftlines/azipods	Threats - Roll damping results in large relative motions in beam seas - Structural issues in beam seas - Requires high level of structural investigation - Higher UPC due to complex design

Figure 29 -SWOT Analysis for a conventional catamaran



7.2.4. SWOT Analysis for Conventional Monohull

Monohulls are the dominant hull form choice in large-scale naval architecture. It is a well proven design with substantial understanding of its typical issues. A monohull provides large continuous volume in the hull, which allows for large machinery. Furthermore, a slender monohull can achieve better resistance and large pitch damping. However, a slender i.e. large L/B ratio, also provides a roll sensitive ship with a low transverse metacentric height.

Strength - Long slender hull provides pitch damping - Large internal volume gives flexibility in machinery configuration - Cost effective - Well understood design - Easy comparison to existing ship	Weaknesses - Deep draught potentially results in too low freeboard - Sensitive to roll - Poor stability due to low transverse GM
Opportunities - Easy 3-division concept implementation - Possible podded propulsion gives ability for high-level DP - Ribs can be installed at each side, with shared boarding room - A-frame can be installed astern.	Threats - Structural bending in large L/D - Undistinctive design - Poor seakeeping

Figure 30 - SWOT Analysis for conventional monohull



7.2.5. Hullform selection

The hull form selection is based upon the SWOT-analyses conducted for each considered hull form. The abilities of each hull form are transferred to a weighted score model (WSM). The criteria in the WSM is based on the operational analysis [M.4]. Furthermore, each criterion is weighted based on its importance for the designs integrity and operational performance.

Criteria	Weight	Hull form [1-5]							
	[1-5]	Cat-Swath		Trimaran		Conventional Catamaran		Conventional monohull	
Longitudinal strength	3	2	6	3	9	3	9	4	12
Transverse Strength	4	2	8	3	12	1	4	4	16
Resistance at high speeds	1	3	3	3	3	5	5	3	3
Resistance at low speeds	4	2	8	3	12	3	12	4	16
Deck area	2	4	8	4	8	4	8	2	4
Roll damping	4	4	16	3	12	2	8	2	8
Pitch damping	4	5	20	2	8	2	8	4	16
Propulsion arrangement	4	1	4	2	8	3	12	5	20
Sensitivity to load changes	3	1	3	3	9	3	9	4	12
Design security	3	2	6	4	12	3	9	4	12
Project risk	3	4	12	3	9	3	9	5	15
Innovation	3	4	12	4	12	3	9	2	6
Total			106		114		102		140

Table 25 - Weighted score analysis of investigated hull forms

From this it is seen that is sensible to design a monohull for this application. Hence this will be carried on in the forthcoming design.



7.3. Parametric Survey and Hull Characteristics

Previous studies have produced an estimate for displacement, total enclosed volume and required power of the heaviest variant. A parametric survey can be undertaken, to determine the main and form parameters. The main particulars are coupled by empirical formulas and plots obtained from (UCL Naval Architecture Department, 2016). The surveys will be subdivided into a major and minor parametric survey. The major parametric survey will determine the minimum depth of the hull and the superstructure fraction. The minor parametric survey will determine the prismatic coefficient and midship coefficient, hence providing the block coefficient.

7.3.1. Operating profile – Work requirement

A paramount design criteria is the ability to reach the design speed. The operational profiles of each variant have been defined by the HYDRA marine engineer (Hunt, 2017). Together with a preliminary power-speed curve, it is possible to determine the percentages work required at each speed. This is shown in the graph below. It is clear that the ship will require most work at 14 knots, followed by a sprint speed of 20 knots.

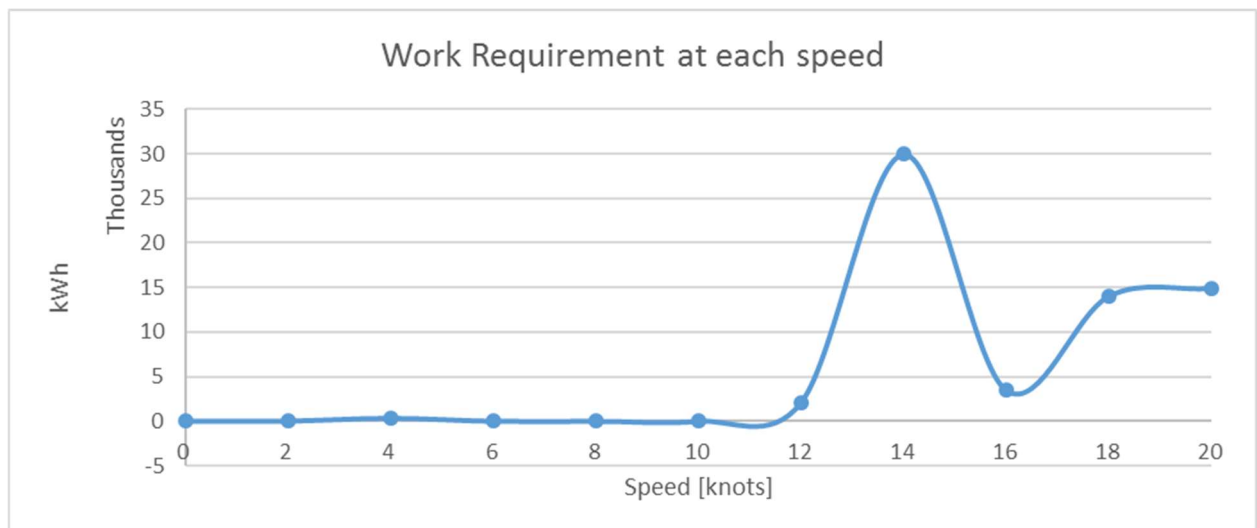


Figure 31 - Work required at each speed (based on operational profile average and resistance data)

In addition to this the Froude displacement number and a preliminary Froude number has been estimated based on the minimum main particulars from the constrain section.

	Variable	14 [kts]	20 [kts]
Preliminary Froude number	Length=80 [m]	0.25	0.36
Froude displacement number	Volumetric Displacement=3489[m ³]	0.59	0.84

Table 26 - Froude numbers at main operational speeds

(Molland, 2011) recommends that Froude numbers near 0.3 should be avoided as it is on the prismatic hump and will cause increased hull resistance. Due to the fixed operational profile, it has been found that in order to avoid this Froude number region the ships length should be less than 60m or more than 100m. This is evidently not feasible, and it has therefore been decided to accept this Froude number region and optimise the prismatic coefficients.



7.3.2. Constrains

The ship is constrained by several geometrical, structural and hydrodynamic boundaries. This means that there are certain values from the output of the parametric survey that is not reasonable for the ship. The constrain are presented in the following table:

Constrain	Value	Reason
Minimum Superstructure fraction	0.2	Calculation provided on next page
Minimum beam	12 [m]	2 parallel main engines
Minimum length	75[m]	Modular Factory Deck
Max speed	20 [knot]	Coastguard sprint
Cruise speed	14 [knot]	All variants cruise speed
Freeboard	4.5 [m]	Flight deck for coastguard variant
Length and depth ratio	14, preferably 12	Structural issues
Maximum Beam and draught ratio	4	Stability Issues
Minimum circular M	5	
Maximum circular M	9	

Table 27 - Vessel constrains for parametric survey

7.3.3. Target

An amount of targets is applied for the parametric survey in order to achieve the optimum output. The targets are distinguished from the constrain, as they are not required to be fulfilled. The targets are mainly based on the design lines and charts provided by (UCL Naval Architecture Department, 2016), hence all relevant chart reading is provided in the appendix B.

Table 28 - Froude number calculations

Definition of targets

Target	Value	Chart read
Optimum Cb – 14 knots	0.8	Appendix B.1
Optimum Cb – 20 knots	0.62	Appendix B.1
Desing lane Cp – 14 knots	0.665	Appendix B.2
Design lane Cp – 20 knots	0.58	Appendix B.2
Design lane CircM – 14 knots	5.8	Appendix B.3
Design lane CircM - 20 knots	7.8	Appendix B.3
Minimise Pitch	>6	(UCL Naval Architecture Department, 2016)
Minimise Heave	>6	(UCL Naval Architecture Department, 2016)

Table 29 - Targets for parametric survey



7.3.4. Major Parametric Survey

The major parametric survey investigates the minimum amount of decks within the hull that satisfies the constraints presented above. Hence it determines the minimum height of the hull. This is therefore directly linked to the amount of volume that is allocated above the hull, i.e. within the superstructure.

An alternative approach has been taken to develop the adequate superstructure volume fraction. The coastguard variant requires 2 X 11m RIBs. These must be located above the DC deck as they require 2-decks height, hence they must be located within the superstructure. Furthermore, components such as hangar, bridge, captain suite, officer suites and deck artillery should be located within the superstructure.

From Table 30 it is seen that the desired total superstructure volume is 2061 [m³]. This yields a superstructure fraction of approximately 0.2. However it is acknowledge that this could be reduced, thus various superstructure fraction in the range of [0.16; 0.22] have been investigated. A graphical representation of optimum C_b with varying Froude displacement number is provided by the Daisy Procedure Book (UCL Naval Architecture Department, 2016). The chart has been modified to ensure accurate reading. Based on the previously estimated initial displacement a Froude displacement number of 0.68 is obtained at 14knots.

As the ship is required to achieve at 20 knots sprint speed, it is decided to design for the lower bound curve. This will result in a less effective ship at operational speed, for the trade-off of being more effective at sprint speed. From the graph it is seen that the optimum block coefficient is 0.65. A initial waterplane area coefficient of 0.78 have been selected based on the table provided in the DAISY book, (UCL Naval Architecture Department, 2016)

Selection

The graphical representation of the major parametric survey is presented in Figure 33. It is seen that a 2 internal deck configuration conflicts with the $L/D < 14$ constrain, thus 3 decks is require. From the various superstructure fraction values, it is seen that 0.2 yields a circular M value larger than 5, however it also yields a low L/D ratio.

Component	Volume [m ³]
02 Deck	
Bridge	89.50
01 Deck	
Ships offices	104.81
Captain suite	108.00
2nd command ac.	137.70
Other accomodation	108.00
1 Deck	
Davits	145.8
2 x 11m RIBS	560
Hangar	579.1
Artillery	101.95
Messes	61.00
Galley	65.00
Total superstructure volume	2060.85
Desired superstructure fraction	0.20767

Table 30 - Estimation of desired superstructure fraction

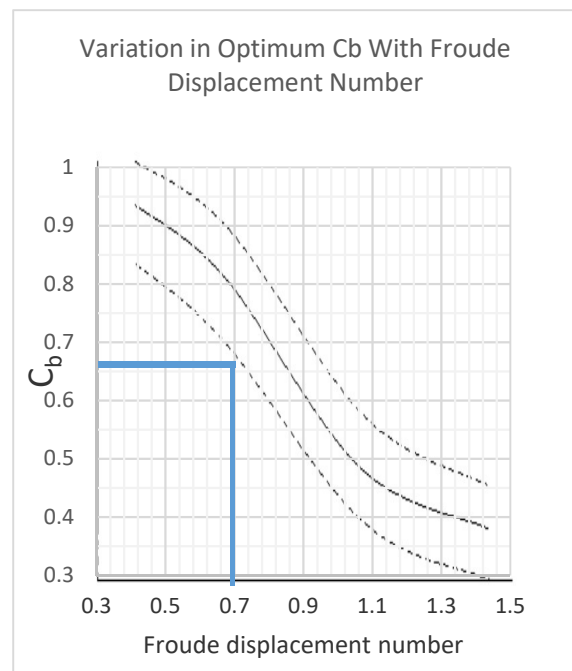


Figure 32 - Optimum block coefficient suggested in DAISY (1996)

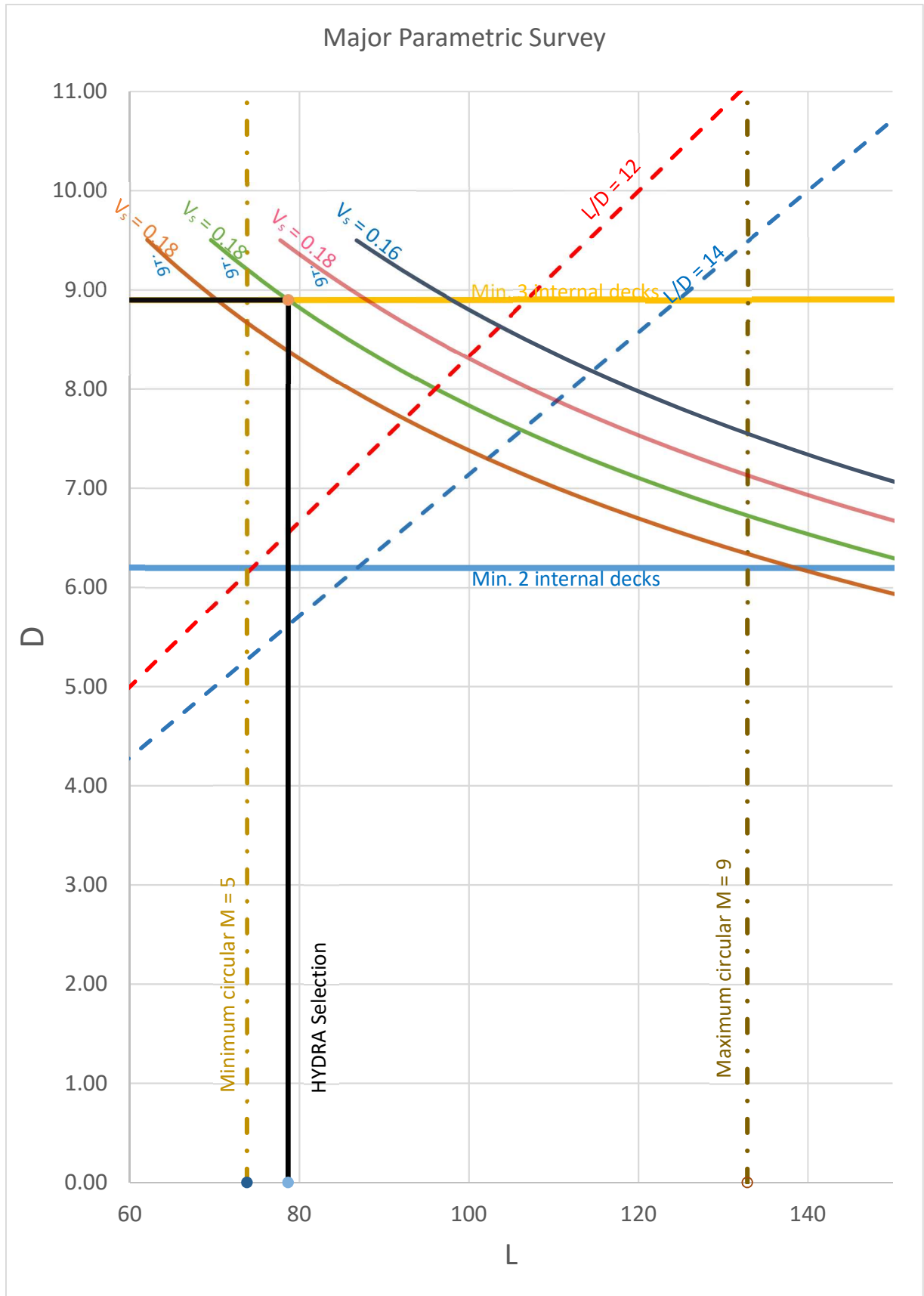


Figure 33 - Major Parametric Survey



7.3.5. Minor Parametric Survey

The minor parametric survey investigates the shape of the hull based on small variants in depth above the minimum value. Previously a superstructure fraction has been selected, that satisfies the required volume and list of constraints.

Hence it is now possible to investigate the shape of the hull further. The shape of the hull is, for initial purposes, defined by the prismatic coefficient and midship coefficient. The prismatic coefficient is linked to the waterplane coefficient. Two parametric investigations within the minor parametric surveys have been conducted with the aim of refining the hull to achieve the targets; A strict constrain is to obtain a freeboard of 4.5 [m], due to flight deck restrictions. Therefore, small increments of depth are investigated with variants of prismatic coefficient. The midship coefficient is constrain at 0.92. This investigation is presented in Figure 36. It shows that a prismatic coefficient of 0.70 provides an increase in circular M, complies well with the free board constrain and obtains the desired block coefficient.

The final parametric investigation is the small-incremental variation of the midship coefficient at the selected prismatic coefficient, 0.70. This investigation is presented in Figure 37. The main concern is ensuring sufficient beam at the machinery deck.

7.3.6. Effect of prismatic coefficient on resistance

The minor parametric survey was expanded from its traditional scope, as it was noticed that the ship operates near the prismatic maximum value, which is heavily influenced by the prismatic coefficient. Therefore an initial resistance investigation was performed. The investigation was conducted in Paramarine, and used the Oortmensen regression analysis is based on data from tugs and trawlers (Paramarine, Qineteq, Hampshire). It is acknowledged that this investigation may present faulty values, however it is useful for qualitative comparison.

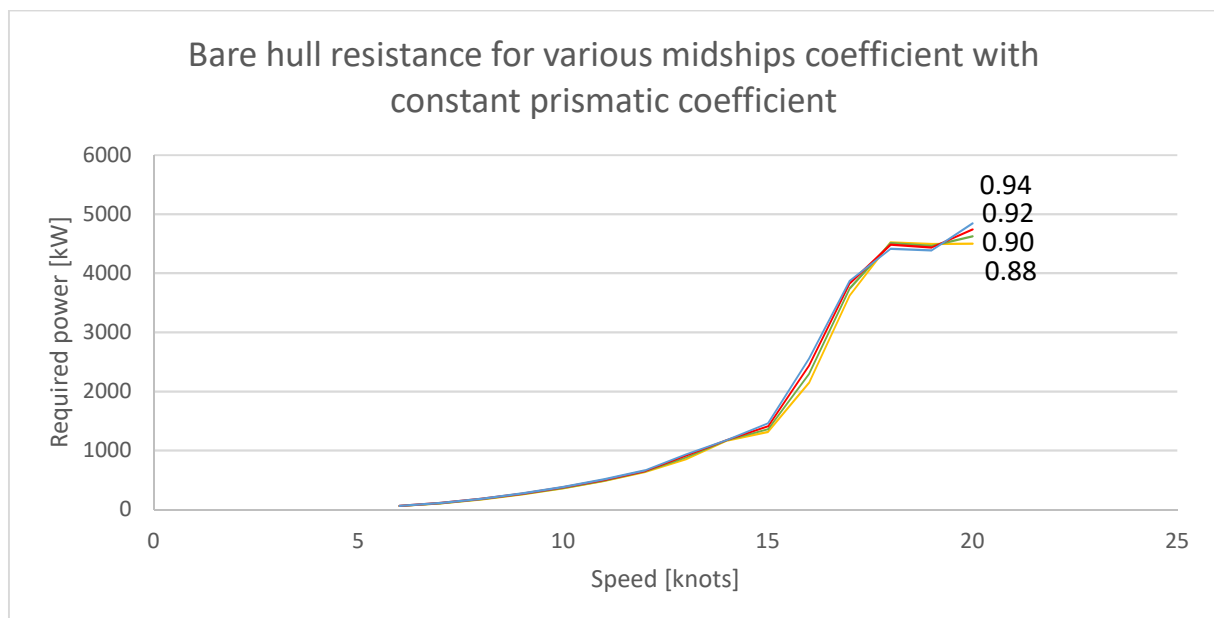


Figure 34 - Effect of midships coefficient on resistance

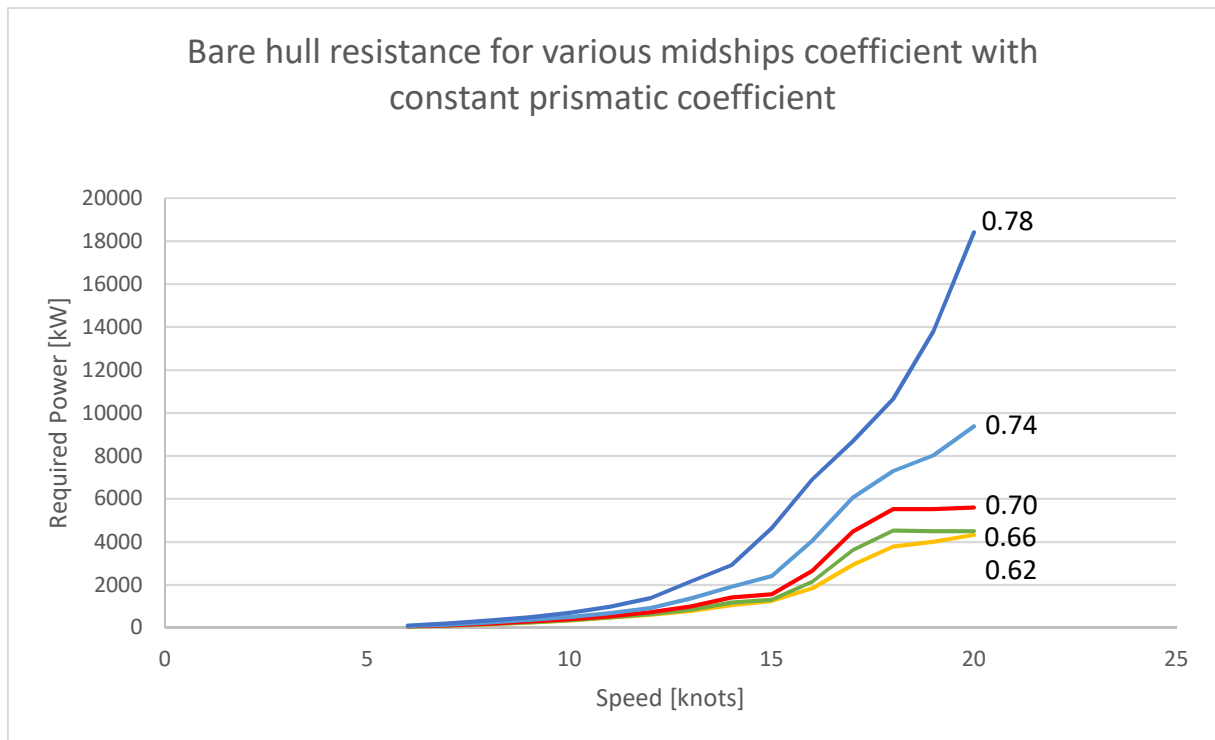


Figure 35 - Effect of prismatic coefficient on resistance

From this investigation, it was found that lowering the prismatic coefficient from its previous value significantly lowered the bare hull resistance, however for the trade-off of a lower block-coefficient, ie. moving further away from the optimum value.

The final main particulars are presented in Table 31 - Final output from parametric survey

7.3.7. Final Main Particulars

Particulars		Coefficient	
Deep displacement	3577[ton]	Block coefficient	0.61
LPP	83.5 [m]	Waterplane coefficient	0.8
Beam	15.7[m]	Prismatic coefficient	0.66
Draught	4.38[m]	Midships coefficient	0.92
Depth	8.9[m]	L/D ratio	9.38
Freeboard	4.57[m]	Circular M	5.52

Table 31 - Final output from parametric survey



7.3.8. Comparison to existing hull forms

A check has been made upon the selection of the final parameters. The final monohull dimensions and shape parameters are compared to all the investigated existing vessels, presented in the operational analysis [M.4]

Length and displacement relation

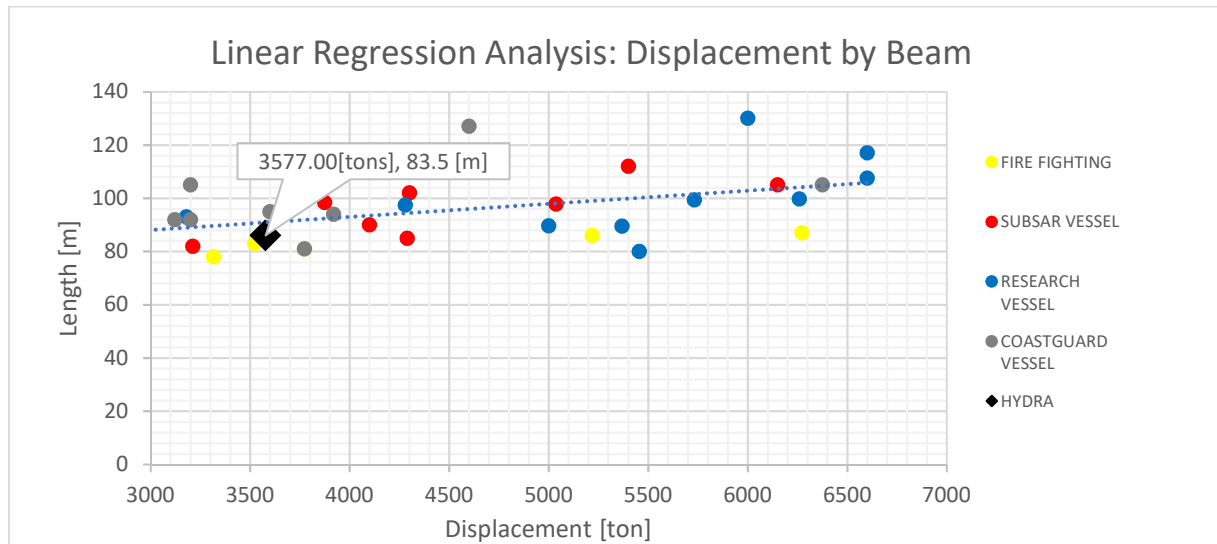


Figure 36 - Comparison of all investigated existing ships and HYDRAs final main particulars: Beam by displacement

From Figure 36 it is seen that the vessel is situated in the light end of the displacement span. However, the length appears to be sensible.

L/B ratio and displacement relation

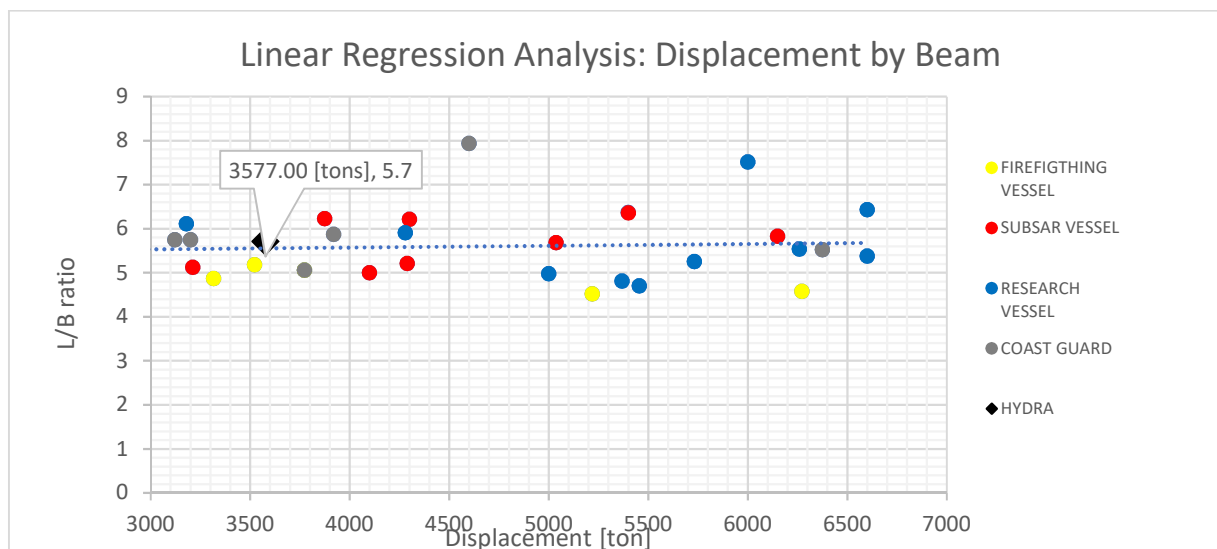


Figure 37 - Comparison of all investigated existing ships and HYDRAs final main particulars: L/B ratio by displacement

The ship is significantly beamy. Figure 37 supports that the selected beam is sensible as it is situated directly on the trendline of the L/B ratio of existing ships.



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7.4. Resistance Estimate

The resistance of the hull is paramount for the selection of the main propulsion systems, hence the ship's ability to obtain its design speed. Ship resistance regression analysis has been used to obtain a resistance estimate. Several regression analysis methods have been considered, from which only the applicable have been selected based on compliance with certain criteria.

The selected models are presented in Table 32. It is noted that none of the selected methods complies with all criteria.

7.4.1. Comparison of Regression Analysis Methods

Method	L	L/B	B/T	Fn	C _M	C _P	C _B	Type
SHIP VALUES	83.5	5.31	3.58	<0.359	0.92	0.66	0.61	Research
Taylor	N/A	N/A	2.2<L/B<3.75		=0.925	N/A	N/A	N/A
Holtrop Mennen	N/A	5.3<L/B<8.0	N/A	0.30<Fn	N/A	0.56<C _p <0.75	N/A	Cargo Liners
Oortmersen	N/A	3.0<L/B<6.0	1.9<L/B<4.0	0.1<Fn<0.5	N/A	0.5<C _p <0.72	N/A	Small ships

Table 32 - Comparison of criteria for resistance regression analysis

7.4.2. Results

Figure 38 shows the results of the three different methods. It is noted that the Oortmersen-method is the only one able to predict higher speeds, however it is seen that there is good coherence between all methods.

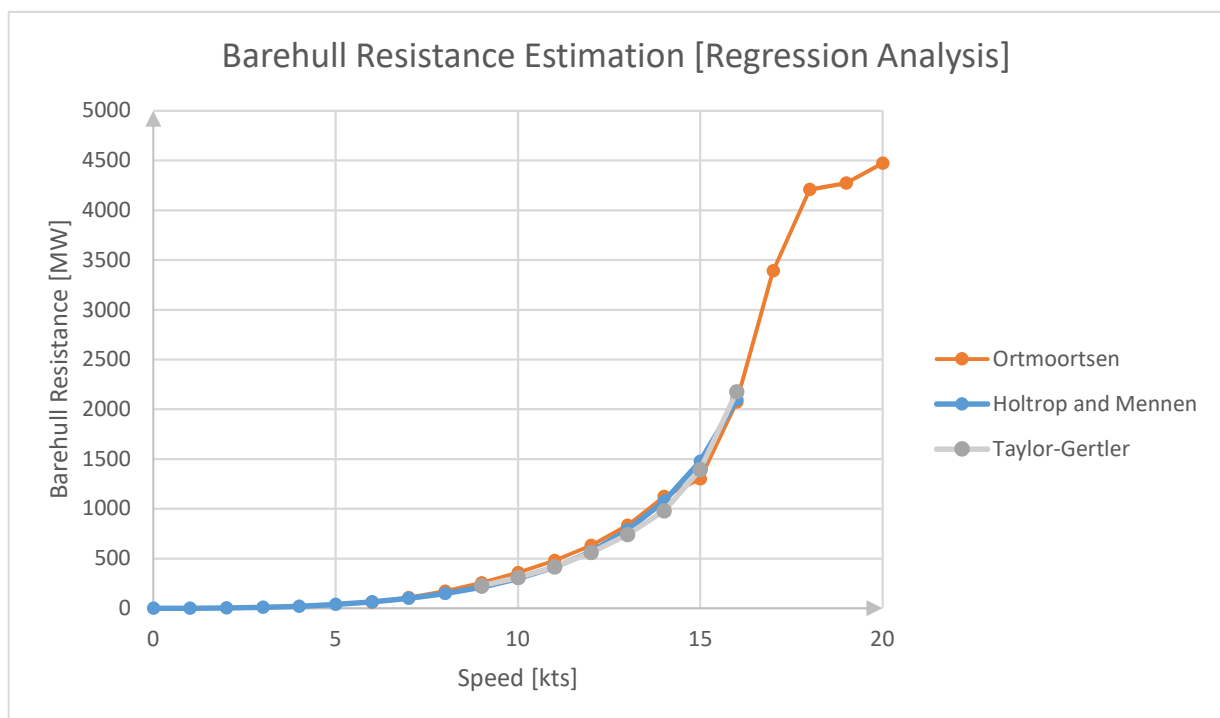


Figure 38 - Resistance prediction for various regression analysis



The general trend shows that the curve increase exponentially up to the 16 knots, where after an incoherent growth becomes apparent. This is expected as the speed region from 16-20 knots is on the prismatic hump. It is therefore expected that if the ship has been longer the resistance would have been less at this speed

7.4.3. Resistance Estimation Discussion

The predicted resistance does not include appendage resistance. It is expected that the ships fin-stabiliser, sea chests, tunnel thruster and retractable azimuth thruster will have a significant impact on appendage resistance. This therefore requires further analysis. Furthermore, it is assumed that the ship is at even keel, therefore further analysis into predicting the optimum trim-condition should be conducted. The ship is, however, equipped with for- and aft ballast tanks, with the purpose of adjusting to optimum trim.

The regression analysis methods used for the resistance prediction is not ideal. It is shown in Table 32 that none of the methods are fully compliant with this type of vessel. Holtrop and Mennen is considered a good estimate as it is built upon a vast database of various ships, and has been claimed to be able to predict for any type, however it is limited to 16 knots, i.e. Before the prismatic hump.

Taylor-Gertler is only applicable for a specific midships coefficient of 0.925. It has been previously been presented that this vessel has a midships coefficient of 0.92, and it was therefore accepted to change this slightly in order to apply the Taylor Gertler Method.

The Oortmersen-Method can predict beyond the prismatic hump. It is seen that there is good coherency between all three methods before the prismatic hump, and it is therefore expected that the further prediction is reliable. However, the Oortmersen-method is derived for smaller ships, i.e. tugs and trawler. Both vessel types are short and beamy ships, with a deep draught. It is recognized that the Hydra-hull form is far from an oceangoing tug, due to its length. However, it might be resembling to a larger trawler. The Oortmersen-method is therefore considered best-suited for this investigation.



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7.5.Propulsion Arrangement

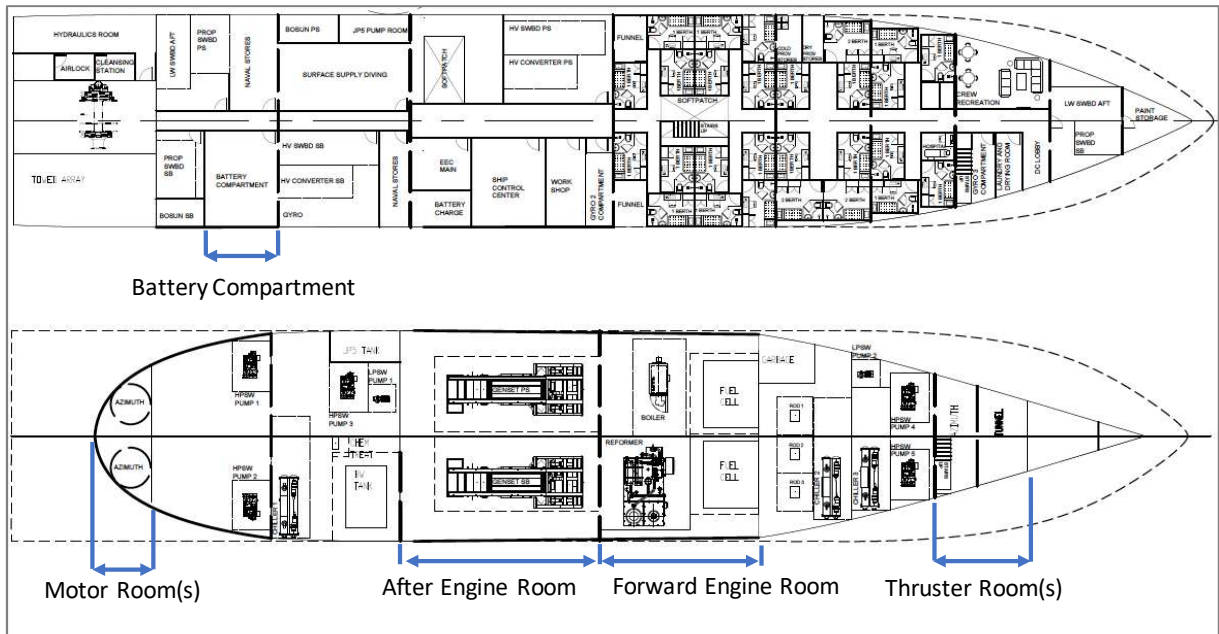


Figure 39 - Location of main propulsion components

7.5.1. Main Propulsion

The propulsion arrangement has been developed by the HYDRA marine engineer in close cooperation with the Naval Architect. An initial power-speed curve was produced in the previous section. This enable a completion of the main propulsion arrangement. An investigation into propulsion architecture was carried out by the marine engineer, from which it was selected to implement Integrated Fully Electric Propulsion (IFEP). This was justified on the ability to reduce fuel consumption, reduce emissions and allowing for variable engine speed as required by **URD [10.d]**. IFEP furthermore introduced more flexibility into the layout of the propulsion arrangement.

7.5.2. Propulsor Selection

It was selected to install podded propulsion, based on the requirement for high level of dynamic positioning and the ability to produce a large bollard pull. This form of propulsion is often selected for an IFEP-system.

Based on a presentation from Rolls-Royce it was selected to use the Azipull podded propulsor (Rolls Royce, 2015). The Azipull propeller operates as a screw that pull the vessels forward.

The Azipull decreases drag, in comparison to a conventional azimuth thruster. It is assumed that the bollard pull is similar to the ducted azimuth thruster. The obtained bollard pull is 110 tons. In relation to the **URD 3.c** this allows for towing of the largest container ship limited to sea state 5. Two HYDRA vessels are required for SS6 towing operations.

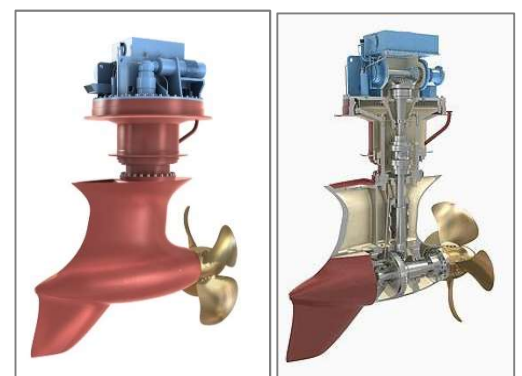


Figure 40 - Azipull thrusters (Rolls Royce, 2015).



7.5.3. Future fuel conversion

A novelty to the HYDRA design is the ability to be built for DFO and be convertible to low-flash point fuel, such as LNG or methanol, which originated from the **URD [10.d]**. For this it was decided to design the tanks in compliance with the existing rules on low-flash point fuels. The tank arrangement will be further explained section [M.10.5]. This furthermore required energy production systems that are compatible with both diesel oil and low-flash point fuel.

A novel solution to this was developed by the HYDRA Marine engineer:

7.5.4. Fuel Cells

The operational profiles for the vessel was developed by the HYDRA Marine engineer. From this it was found that the vessel operates 97% at or below 14 knots, for all three variants.

It was therefore investigated to use an on board energy production system, where energy storage devices would feed the system with its required power for low speeds. Furthermore it was required to obtain a economically and emission friendly system that was compatible with future fuel conversion. Hence it was selected to use fuel cells. It was decided upon two fuel cells for redundancy.

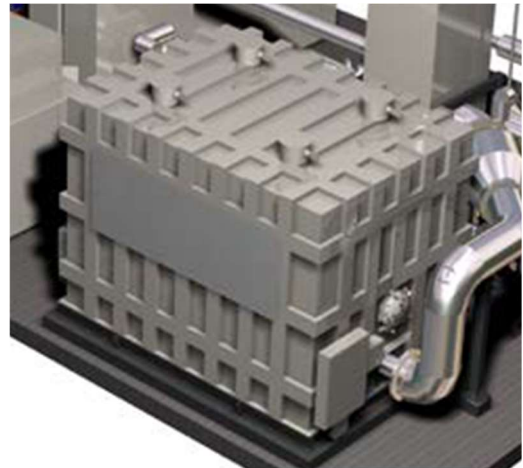


Figure 41 - Fuel cell example

The fuel cells and associated systems are sized in the HYDRA Marine Engineer report (Hunt, 2017). Fuel cells is a novel new technology, that has not yet made its way to the maritime world. It is based of a land-based system, hence it is assumed that this technology will have been developed for maritime purposes before the in-service date of 2025.

7.5.5. Diesel Engines

For high speed capability, it was decided to use diesel generators as an additional boost to the energy storage devices. Diesel generators in an IFEP-system is a conventional, well proven solution. A dual-fuel system was selected for preparation to future fuels. The diesel generators and associated systems have been sized by in the HYDRA Marine Engineer report, (Hunt, 2017).

7.5.6. Energy Storage Devices

In an IFEP system it is required to have energy storage devices to vary the input to the Azipull-motor. The energy storage devices are large batteries, placed above the waterlines.

Furthermore, this system acts as an emergency energy provider, in the event that both main machinery compartments are flooded. It has been estimated by the HYDRA Marine engineer that the vessel can sail 102 [nm] at 7 knots on batteries only, while maintaining adequate hotel-load.



7.6.Hullform Design

In the previous sections, it was justified that a monohull design was most suitable for this project. Furthermore, the main particulars of the monohull was produced from the parametric survey and an azipull propulsion system was selected to ensure high level of dynamic positioning. The following section will present the main consideration in generating the hull form. It will explain the tool that has been used and present the final output in form of a lines plan. It will present the allocation of bulkheads required to pass the floodable length requirement. Furthermore, it will present the tank distribution and obtained volumes. Lastly a discussion upon the hull form design will be provided

7.6.1. Approach to hull form design

One of the key designs features is HYDRA's ability to be built as three different ships without having radical changes to the platform. The hull form must therefore accommodate for the wide beam at the stern required for Hydra SUBSAR's A-frame without interfering with the capability of high-sprint for the coastguard. Furthermore, it has been selected to use Azipull propulsor. This suggest a horizontally flat stern that smoothness into the midbody. Lastly attention was paid towards the azimuth thruster and hull mounted sonar, in ensuring sufficient volume in these locations for the equipment.

7.6.2. Generation

the Paramarine (Qinetiq, Hampshire) Intellihull feature was used to develop the initial hull form. The Intellihull allows the user to select a hull form and demand certain parameters, from which it tweaks the initial hull form. Unfortunately, none of the basis hull forms had the desired stern and it was decided to ignore this in the 3d modelling. The Demo-ship hull form was selected to which the ships parameters was demanded. The final output is presented in Figure 42.

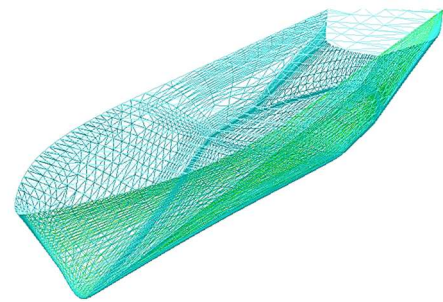


Figure 42 - Demo-hull shape from Paramarine (Qinetiq, Hampshire)

Main Particulars		
Criteria	Demanded Valued	Obtained Value
Deep displacement	3577[ton]	3543 [m ³]
LWL	83.5 [m]	83.5 [m]
Beam	15.7[m]	15.71 [m]
Draught	4.38[m]	4.4 [m]
Depth	8.9[m]	8.9
Freeboard	4.57[m]	4.5 [m]

Coefficients		
Criteria	Demanded Valued	Obtained Value
Block coefficient	0.61	0.59
Waterplane coefficient	0.8	0.79
Prismatic coefficient	0.66	0.617
Midships coefficient	0.92	0.95
L/D ratio	9.38	9.38
Circular M	5.52	5.5

Table 33 - Comparson of dimensions and coefficients from hullform generation



7.6.3. Lines plan

The lines plan is presented in appendix G. It shows the desired stern drawn in red lines.

7.6.4. Allocation of bulkheads

The allocation of bulkheads are paramount to the layout, as they constitute a major constrain. The position of each bulkheads is obtained by calculating the floodable length curve of the hull form. This is obtained using Paramarine (Qinetiq, Hampshire). The positions have been determined from the appropriate factor of subdivision. (Lloyds Register Rules, n.d.) has been applied.

The margin line should, according to Lloyds Register Regulation 2. 6., be located 76mm below the bulkhead deck. 1 Deck is considered the bulkhead deck. All calculations have been made for deep displacement start of life. The floodable length is generated in Paramarine (Qinetiq, Hampshire). 97% permeability have been assumed as a pessimistic approach. The curve is presented in Figure 43

The permissible subdivisions have been determined by applying a factor of subdivision to each floodable length point. The criteria is to withstand two-compartment flooding and the factor of subdivision therefore becomes 0.5. The permissible length is used to ensure that acceptable bulkhead spacing is chosen.

Additional constrains are related to the spacing of the bulkheads in order to ensure space for the large machinery.

- The chosen diesel generators require a service-length of 12.5 [m] in one watertight compartment.
- The fuel-plant requires 12[m] in one watertight compartment. Both compartments should be located low amidships.

Furthermore it is important that the flight deck, for the coastguard variant, end on a bulkhead. This has been taken into account.

The chosen bulkhead-locations are presented in figure 42. It is seen that none of the selected distances violates the permissible length, furthermore it is seen that two-compartment flooding is acceptable for the entire hull. A collision bulkheads is placed 5%LWL from bow.

It is acknowledge that the floodable length curve is design for the deepest start-of-life draught, and thus it may not pass at a deeper end-of-life draught

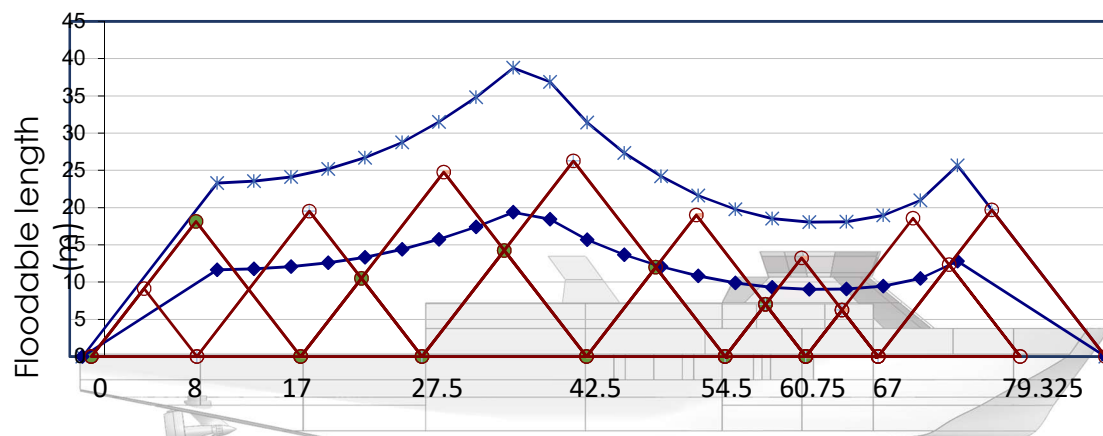


Figure 43- Floodable length and allocation of bulkheads



7.6.5. Tank Distribution

A key asset for project HYDRA is the ability to be convertible to any future fuel. This ability originates from the future fuel URD requirement 10.d. As previously presented HYDRA is equipped with two fuel cells including reformers to convert DFO to its appropriate state, however such fuels can also burn methanol or another low-flash point fuel. In order to prepare the design for a potential methanol conversion, it is necessary to comply with the existing rules at built.

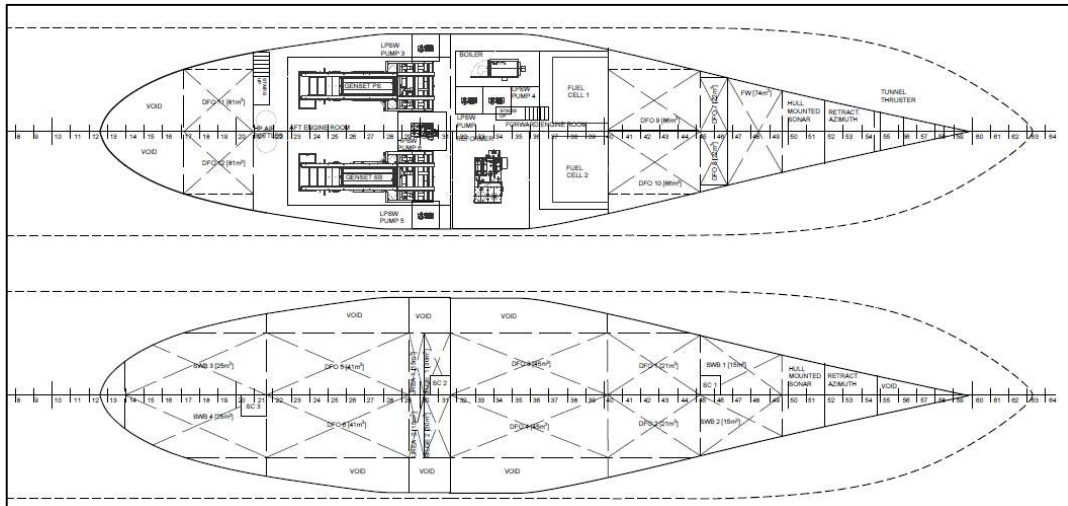


Figure 44 - Tank arrangement

DFO conversion

All DFO tanks on 3 deck has been selected as convertible to future fuel (see Figure 44). Lloyds register provides a collision-distance of B/5 from summer load line beam to the sides of low flash point tanks (Lloyds Register, 2016). This has been incorporated as shown in Figure 44 - Tank arrangement. The tanks space in the keel has not been selected to future fuel conversion, as it is unknown whether future fuel tanks will require cubic volume. These tanks have been selected as through-life DFO.

Urea and black water

Urea and bilge water is placed below the keel. Urea will be used in the scrubbers, during a 30 day mission, and bilge water will be filled up. Both tanks have therefore been split symmetrically along the centreline, in order to not cause a list at end of mission.

Fresh water

HYDRA requires 74[m³] of fresh water. This is placed directly beneath the chiller systems. The fresh water requirement calculation can be found in the HYDRA ME report (Hunt, 2017).

Sea water ballast

HYDRA is a universal vessel, built for three different purposes. Reserving space for sea water ballast is wise, when entering the 2nd design iteration, however the need has not yet been defined. It was found that the vessel trimmed by stern and the for-swb tanks was therefore left full. This should potentially be replaced by led

Tank Description	Capacity
Total DFO tanks	531 [m ³]
- Legacy DFO	(161) [m ³]
- Future fuel convertible	(370) [m ³]
Fresh Water Tank	161 [m ³]
Urea Tanks	45 [m ³]
Bilge Water Tanks	45 [m ³]
SWB Tanks	80 [m ³]
Black Water	30 [m ³]
JP5	60 [m ³]

Table 34 - Tank Capacities



7.6.6. Appendages

The following section will review the selected or potential appendages that the hull may have. The review will be based on the appendages impact on resistance and its ability to be dry docked.

Azipull Main Thruster

Resistance

The azipull thruster is renowned for hydrodynamic benefits, however it is likely to have significant impact on the resistance due to its relative size.

Dry Docking

The overall height is estimated from Wartsila Azimuth Thruster. It is found that the maximum height is 4.5 [m] (Wartsila, 2017). Provide that the desirable changes are made to stern, as explained on the lines plan, it is found that the azimuth thruster will extend approximately 1[m] below the keel as shown in Figure 45

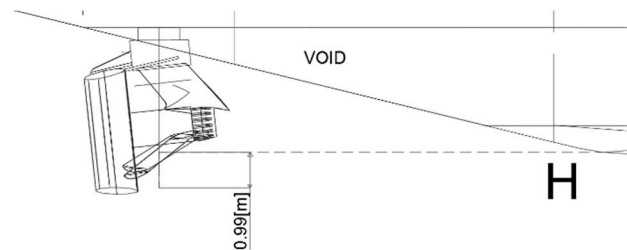


Figure 45 - Azipull thruster arrangement

Retractable Azimuth Bow Thruster

Resistance

The retractable azimuth thruster is extended at low speed loitering or alongside for dynamic positioning. It may not be extended when the hull mounted sonar is extended. It is desired to have a flush surface with the hull when retracted.

Dry Docking

The azimuth thruster should be retracted during all maintenance work.

Retractable Hull Mounted Sonar

The retractable hull mounted sonar is extended when used. It may not be extended when the azimuth thruster is extended. It is desired to have a flush surface with the hull when retracted.

Dry Docking

The retractable hull mounted be retracted during all maintenance work.



7.7.Discussion

In generating the main particulars of the hull form, a number of constraints were determined. The main constraint was the ability to achieve design speed. The design speed was determined by inspection of the operational profiles which proved to be significantly different. This therefore became a challenge in the hull form generation. It was decided upon designing the hull for the speed across the average of all three variants. This has resulted in a vessel designed for a design speed of 14 knots, which is viable for the coast guard and the SUBSAR, but not the research vessel.

It was found that the vessel operated directly on the prismatic hump and that mitigation was impossible. This resulted in an analysis of the prismatic coefficient to which it was found that the prismatic coefficient should be lowered. This lowered the block coefficient, which resulted in a deviation from the suggested optimal range.

The final resistance prediction was obtained from the Oortmertsen Regression Analysis Method, which is based on data from tugs and trawlers. This is not directly related to the special-purpose vessel of HYDRA. However, it was found that other regression methods predicted similar results.

The final hull form design was conducted via the Intellihull feature in Paramarine (Qinetiq, Hampshire). It was found that model main particulars were near the demanded values, however the hydrodynamic coefficients were found to deviate severely. Particularly by the prismatic coefficients. This is expected to have had severe impact on the floodable length curve, which may have resulted in a surplus of bulkheads near the bow. Furthermore, it is expected to carry impact on the following stability analysis. However, it does not affect the resistance, as it is conducted via manually typing the exact parameters.



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8. Complementation

The HYDRA personnel is subdivided into organic crew and augmented personnel, the organic crew divisions are similar for all three variants, and have been optimised by a manning analysis – as required by **URD requirement 6.a**. The augmented personnel are dependent on the variant and tasks conducted. The following crew division has been developed in closed cooperation with the HYDRA Marine Engineering Team. It is based primarily on team-members experience from sea-time.

8.1.HYDRA Research – Complementation

8.1.1. Organic Crew

A traditional ship ranking is presented in Figure 46. The commanding officers is superior to; the executive officer, engineering officer, chief cook and deck officer. The complementation is sized on a minimum of 3 to 1 shift rotation. HYDRA Research contains more Deck Hands than other HYDRA variants due to expected larger equipment handling.

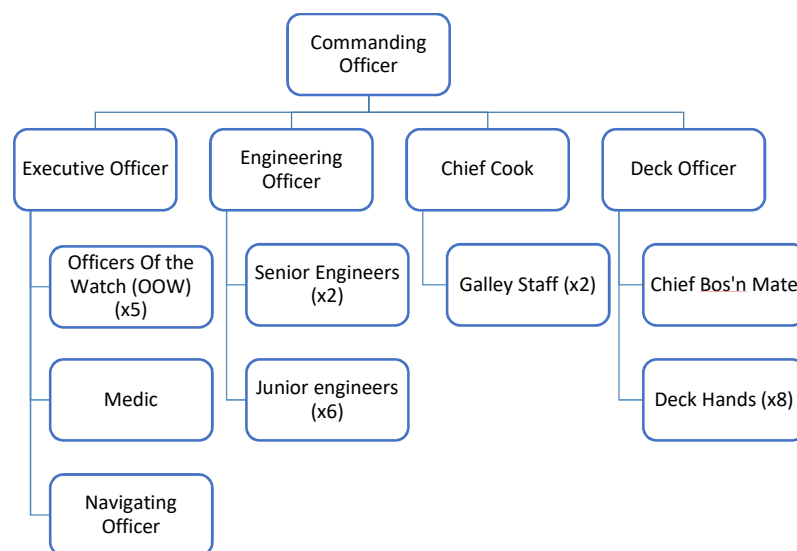


Figure 46 - Complementation Ranking for Organic Crew on HYDRA Research

8.1.2. Augmented Personnel – Scientist

Figure 47 presents a preliminary division of the augmented personnel for HYDRA Research. It includes 1 lead scientist superior to all augmented crew.

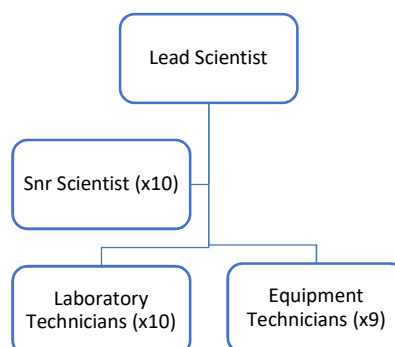


Figure 47 - Complementation Ranking for Augmented Personnel on HYDRA Research



8.2.HYDRA SUBSAR– Complementation

8.2.1. Organic Crew

Figure 48 shows that HYDRA SUBSAR complementation structure is built on similar principle as HYDRA Research. However, it contains less deck hands, as equipment handling personnel for the NSRS will be boarded as augmented personnel. Furthermore, an addition of saturation divers is included.

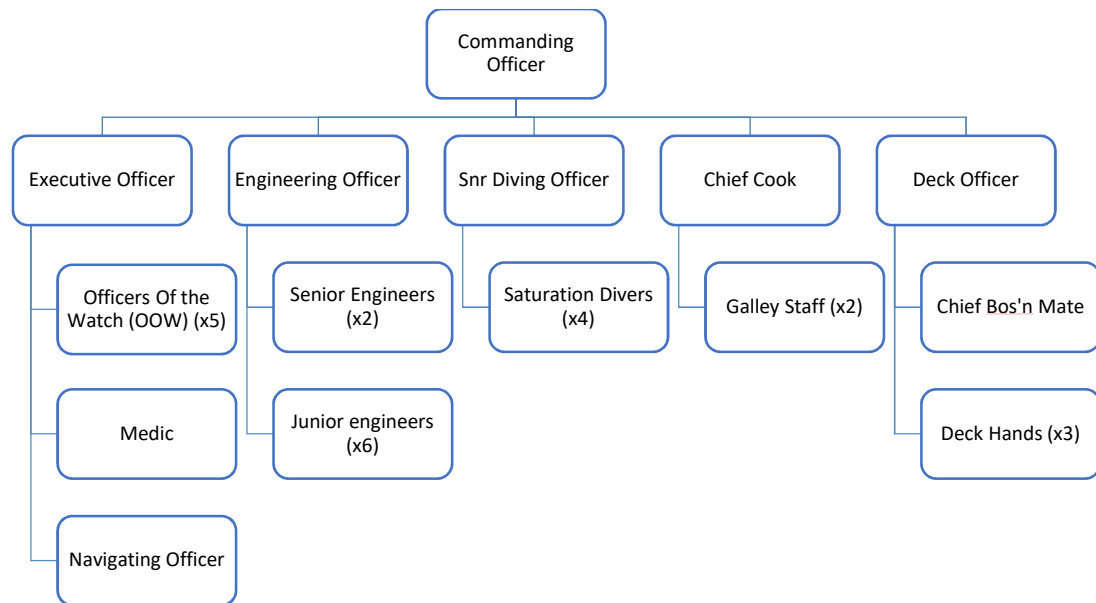


Figure 48 - Complementation Ranking for Organic Crew on HYDRA SUBSAR

8.2.2. Augmented Personnel - NSRS operators and Medical Personnel

Figure 49 displays that the augmented personnel for HYDRA SUBSAR is subdivided into two teams; NSRS and medical staff. A 1:2 basis of doctor to nurses have been assumed.

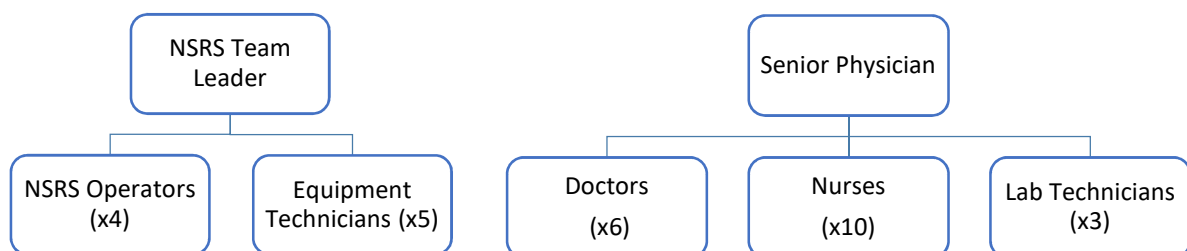


Figure 49 - Complementation Ranking for Augmented Personnel on HYDRA SUBSAR



8.3.HYDRA Coastguard Complementation

8.3.1. Organic Crew

Figure 50 shows the HYDRA Coastguard organic crew complementation structure, which includes a large number of bridge staff functioning as look-outs. It is expected that the organic crew will operate all weapons systems. Furthermore, it is expected that the organic crew will be integrated with the augmented personnel, in contradiction to the other variants.

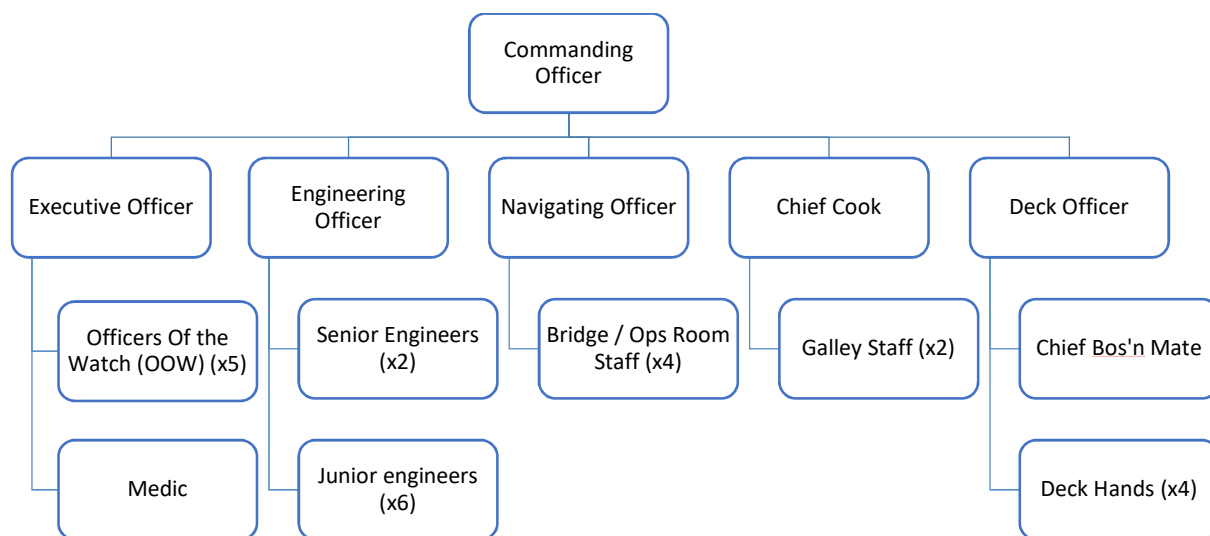


Figure 50 - Complementation Ranking for Organic Crew on HYDRA SUBSAR

8.3.2. Augmented Personnel - Boarding Team and Maintenance Crew

Figure 51 shows the augmented personnel for HYDRA Coast Guard, which is boarded to support the aviation and boarding capabilities. The required personnel for each payload is obtained from the Zenith database. It is assumed that maintenance crew for the helicopter is also trained as maintenance crew for the scan eagles.

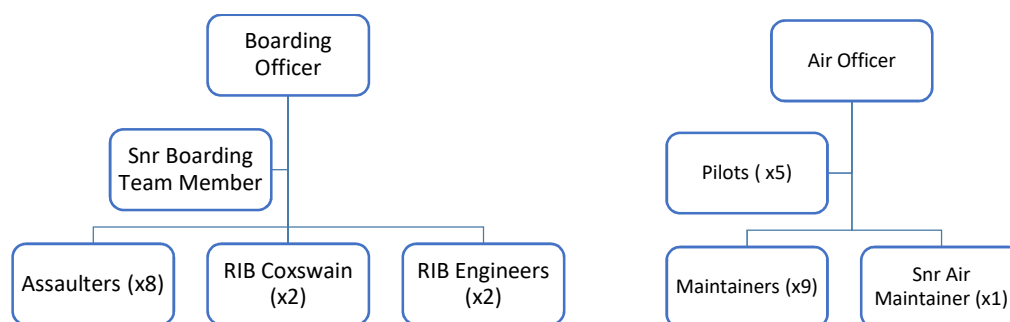


Figure 51 - Complementation Ranking for Augmented Personnel on HYDRA SUBSAR



8.4. Accommodation Standards

The accommodation for HYDRA is a considerable volume driver and hence some key features are presented before introducing the final layout.

HYDRA is built as a commercial ship and is required to meet certain accommodation standards per **URD Requirement 6.a**. The commercial standards used are provided by the Maritime & Coastguard Agency (MCA, 2014). The implementation to HYDRA is conducted to the level of furniture. For ease of production, the cabins have been modularised. Four different standards are produced, which all comply with the applicable guidelines (MCA, 2014)

The HYDRA personnel is subdivided into organic crew and augmented personnel, as specified in the previous sections. The single standard cabins are primarily reserved for organic crew lower rank, and the single deluxe cabins are primarily reserved for the higher rank crew and augmented personnel.

URD Requirement 6.c specifies separation between organic crew and augmented crew. This has been thoroughly implemented and will be presented in the following chapter.

Single Standard Cabin – Lower Rank Organic Crew

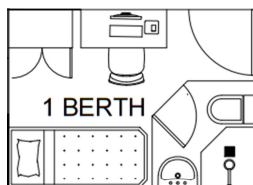


Figure 52 - Modular Single Standard Cabin

- Standard bathroom incl. shower
- Desk incl. comfortable seating
- 1x1.3[m³] Locker
- [1.2mx2.2m] Bed
- Porthole where applicable

Single Deluxe Cabin – Higher Rank Organic Crew and Higher Rank Augmented Personnel

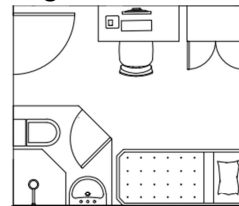


Figure 53 - Modular Single Deluxe Cabin

- Standard bathroom incl. shower
- Desk and comfortable seating
- 1X 1.3[m³] Locker
- [1.5mX2.2m] Bed
- Porthole where applicable

Double Standard Cabin – Lower Rank Augmented Personnel



Figure 54 - Double Standard Cabin

- Standard bathroom incl. shower
- 2x1.3[m³] Locker
- [1.4mX2.2m] Bunk Bed
- Porthole where applicable

Captain and Officers Suite

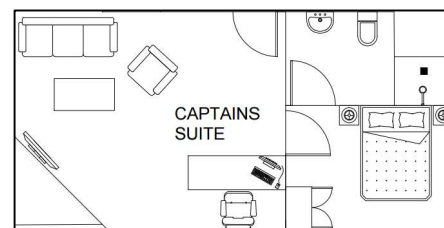


Figure 55 - Captains suite (non-modular)

- Oversized bathroom incl. shower
- Desk and comfortable seating
- Couch and TV area
- 1X 1.3[m³] Locker
- [2mX2.2m] Bed with bed-table
- Porthole where applicable



9. Architecture

The following section present the key design considerations and decision undertaken for the platform vessel. A similar document is constructed for modules and will be presented in the following chapters. The components have been layout in accordance with the WBS, to carry consistency throughout the project. Each component is evaluated based on functionality, economics and compliance with the IMO rules.

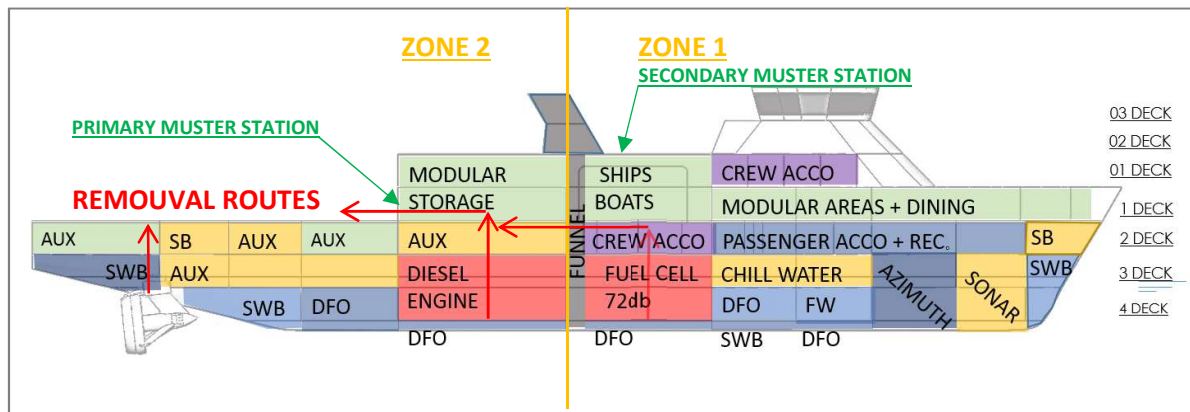


Figure 56 - Initial Architectural Considerations

9.1. Main layout

Some key considerations were conducted for the layout at the initial stages;

It was aimed to place higher rank personnel above the dining areas, and lower rank personnel below the dining areas, to have equal access to the common areas.

- It was strived to separate the organic crew and augmented personnel.
- It was aimed to place the most motion sensitive operations near amidships, such as boat bay, equipment handling, hyperbaric chambers etc.
- It was aimed to carry the funnel up directly at amidships for zoning purposes.
- It was aimed to place the hull mounted sonar, behind the azimuth and tunnel thruster, in order to not interfere with the fluid flow.
- It was aimed to have all stern launched cables, such as the towing cable, below the working deck, so that the working deck was kept clear for dedicated operational tasks.

9.2. Zones

URD Requirement 10.2 requires the ship to be operational post-collision, hence it has been aim to zone the machinery where possible. This has resulted in a 2-zone division; aft and for. The aft engine room has all necessary auxiliary afterwards, and is fully operational in the event of a bow collision, where the forwards engine room is lost.

9.3. Citadel

According to **URD requirement [10.f]**, the vessel must be prepared for CBRN. This has been done by designing for citadel in all three variants. The attached general arrangements show the citadel area in the profile view. A cleansing station is provided aft on 2 deck, with access from 1 deck. Furthermore, an airlock to the internal space is provided on 1 deck for all variants.



9.4. Removal Routes

The removal routes are shown in Figure 57. It is seen that there is a straight vertical route from the aft machinery room. However, the forward machinery room, requires a vertical removal to 2 deck, where it must be longitudinal transferred into the aft machinery room and removed vertical through a shared softpatch. This solution is not ideal, but no other option was found due to location of the above compartments.

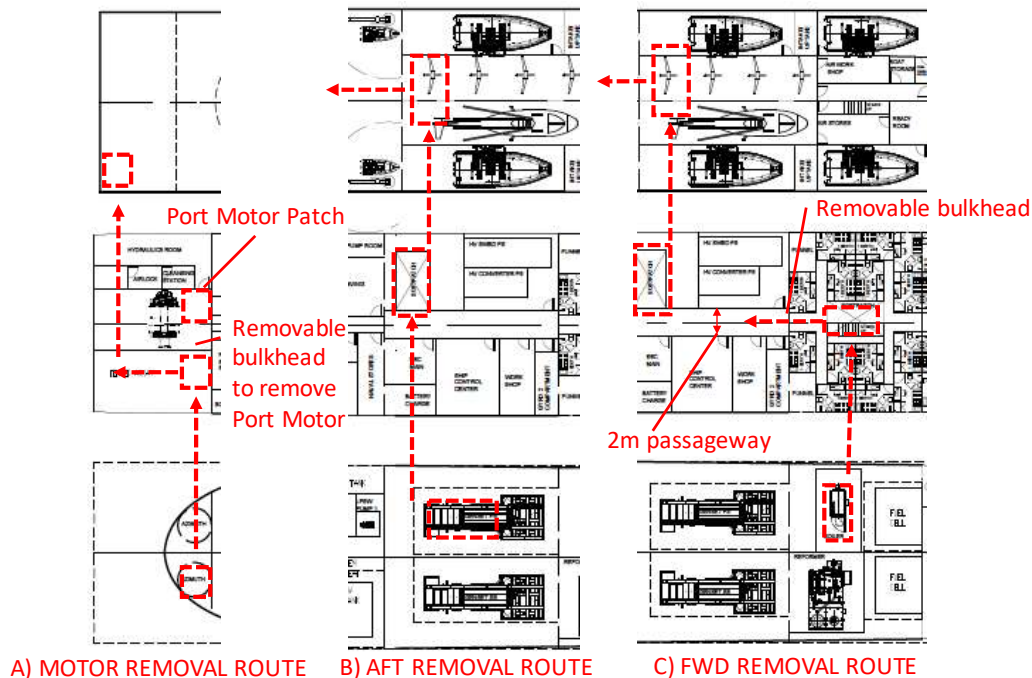


Figure 57 - Removal Routes (Hunt, 2017)

9.5. Passage ways

All HYDRA Variants have a minimum of 1.5 [m] passageways. It is expected that there will be a layer of insulation internally on the passage ways, and is has therefore been deemed, that the minimum allowable passage ways, after construction, is 1.25 [m]. This is based on a two-men shoulder width. There is one exception of a 1[m] passage ways in the crew accommodation area (See GA). This has been accepted as it is not a main passage ways, and will be used rarely.

9.6. Muster station

The muster station has been located in the most central, most accessible and most spacious area for all three variants. This has been selected as the hangar/equipment bay/hyperbaric chamber area across the variants. It is envisioned that in the event of evacuation the personnel will be prepared with life-saving equipment before accessing the open-deck to board the lifeboat rafts.

Lifeboat capacity on 1 deck is 200 personnel in the event of evacuation during humanitarian aid mission. The lifeboats has been placed furthers aft.

An additional number of lifeboats are placed on 02 deck. This is considered a secondary muster station which is used, in the event of incapable access to the primary muster station. The lifeboat capacity as this location is 100 personnel.

The variants organic 7m RIBs are used as marshalling crafts.



10. General Arrangement

The HYDRA general arrangement has been completed to a significantly detailed level. All imported cad-furniture are obtained from an open source library. All imported cad models of military equipment is obtained from shipyard, to which reference can be supplied upon request. A general arrangement for each variant is attached to this report. The drawings numbers are:

- HYDRA Research → HYDRA-01-0100-01-V6
- HYDRA SUBSAR → HYDRA-02-0100-01-V2
- HYDRA Coast guard → HYDRA-03-0100-01-V2

It is advised to open a general arrangement at this point.

In the following sections a review of each deck will be provided. The review is based on the following points, when applicable:

- **Operational Performance**
 - It is intended to critically asses the ability to conduct certain tasks based on the layout of the vessel. The ability to conduct tasks is assessed by location, crew access and deployment area.
- **Crew comfortability**
 - Explains the initiatives and though process behind all aspects of the layout that is related to the crew and augmented personnel comfortability.
- **Infrastructure**
 - Passage ways for crew – marked blue
 - Passage ways for augmented personnel – marked orange
 - Escape Routes – shown by green arrows
 - Vertical Access
- **Removal routes for machinery**
 - Displays the removal routes for main equipment by red hatches and arrows
 - Displays access points
- **Mooring**
 - Displays the implementation of mooring equipment.



10.1. 03 Deck – Bridge

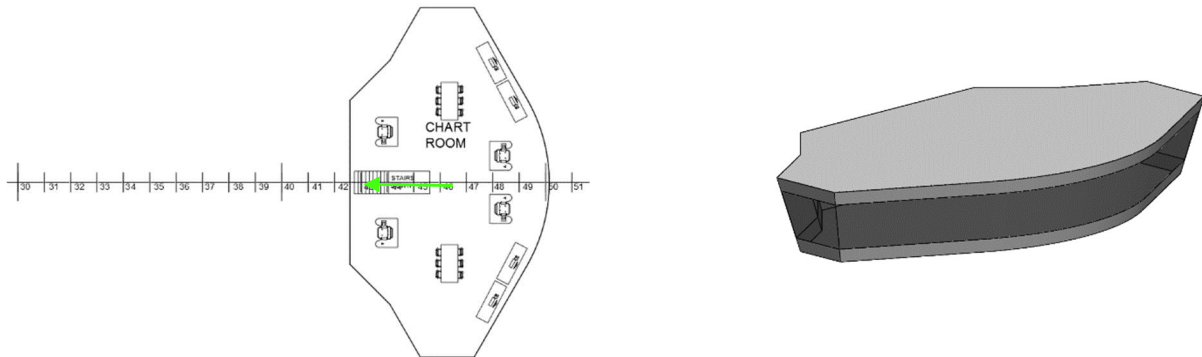


Figure 58 - Bridge layout

Operational Performance

- Windows are slanted 10 degrees outwards as required by Lloyds Rules.
- The bridge deck is placed above all other decks for good visual navigation. It designed with 360 [deg] uninterrupted view. A key asset is the clear view of the open deck, from the afterwards pilotage position. This is done to enable dynamic positioning control during deployment and recovery of various systems, for all variants. Furthermore, this design feature has required the funnel to be located atwardships, which becomes a structural complexity.
- Addition external pilotage positions athwart ships are implemented for manoeuvring through channels and other narrow passages.
- An open chart room is located centrally, towards portside, at the bridge and includes a meeting table and navigation monitors.

Crew comfortability

- A meeting area is located centrally, towards starboard, and can function as a short-break area.
- Sanitary facilities are placed below decks, near the ships office.

Infrastructure & Escape Routes

- The bridge is envisioned as an open space work-environment to achieve highest level of communications.
- Escape is through vertical staircase to 02 deck, where lifeboats are located.

Vertical Access

- Standard 1.2[m] staircase is located centrally at bridge. Direct connection to ships offices and captains suite.



10.2. 02 Deck – High rank accommodation and Offices

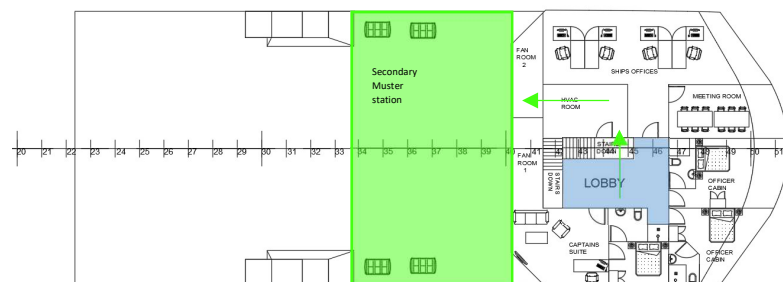


Figure 59 - 02 Deck layout

Operational Capability

- Captains suite is located at portside towards amidships, to reduce pitch motions. It includes a large recreational space, a double-bed sleeping room and a large bathroom.
- Two officer cabins which both includes large bedroom and bathroom facilities, are placed near the bridge in the event on quick-response. Both cabins are not standardised and requires special fitting.
- Ships offices have been sized larger than required by zenith due to commercial application. The ships offices are located near the bridge, for enhanced communication. Furthermore, a meeting area for vessel-specific meeting is located with direct entrance.

Crew comfortability

- Sanitary facilities for the office and bridge personnel are located in the lobby.
- The ships office has large open windows with an uninterrupted view of the horizon.

Infrastructure

- It is deemed that only organic crew is allowed on this deck.
- The lobby will be the busiest area, hence it is left large and open, thus it will provide ease of access to bridge and 02 deck.

Escape Routes

- The main escape route from 02 deck is through the vertical access to 01 deck, towards the muster station on 1 deck.
- In event of blockage a secondary escape route is through the ships offices to the upper open deck, where lifeboats are stowed.

Vertical Access

- There is vertical access to 03 deck from the lobby by standard 1.2[m] staircase.
- There is vertical access to 01 deck from the lobby by standard 1.2[m] staircase.

Removal routes of machinery

- HVAC and Air-conditions Units are to be removed through the upper open deck. No internal alterations are needed.



10.3. 01 DECK – HIGHER RANK CREW ACCOMMODATION

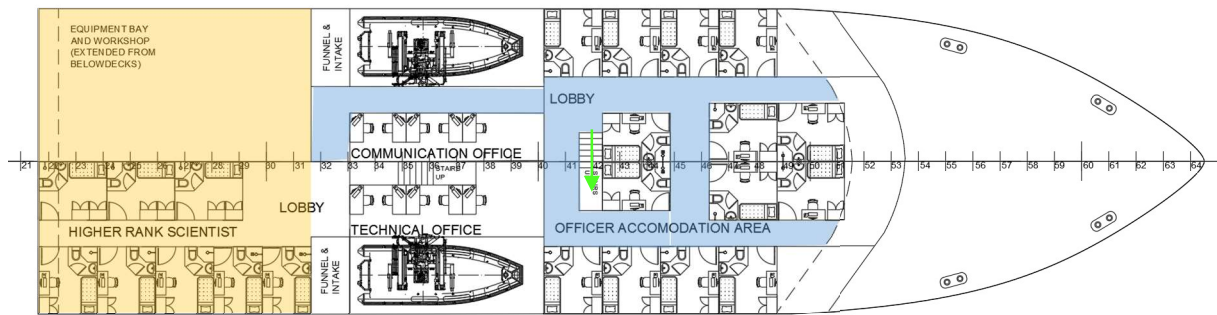


Figure 60 - 01 Deck layout (Platform part)

Operational Capability

Crew accommodation area is located forwards and reserved for organic crew only.

It includes:

- 10 x single deluxe cabins with portholes.
- 2 internal single deluxe cabins
- 2 internal single standard cabins

There is direct access from accommodation area to offices spaces. The highlighted area aft is dependent for all HYDRA variants, and will be presented in the following sections.

Crew comfortability

- Accommodation area is reserved for crew. It is solely a sleeping area and does not have any operational passage ways, apart from the staircase.
- Sanitary facilities for the communication office and technical office are between the offices.

Infrastructure

- It is determined that only organic crew is allowed on this part of 01 deck.
- The lobby provides ease of access to 02 deck and 1 deck.
- The connection to the communication and technical office is through the lobby and does therefore not interfere with the augmented crew passage way.

Escape Routes

- The main escape route from 01 deck is through the vertical access to 1 deck into the muster station.
- In event of blockage a secondary escape route is upwards through the ships offices on 02 deck into the upper open deck, where lifeboats are stowed.

Vertical Access

- There is vertical access near the bow to 02 deck and 1 deck from lobby by standard 1.2[m] staircase. This determined to be solely used by organic crew.
- There is vertical access near amidships from the variant-dependent area to 01 deck from the lobby by standard 1.2[m] staircase. This will mainly be used by the augmented personnel.

Mooring

- Bow-mooring is conducted from four bollards on forwards open deck.



10.4. 1 Deck and 01 Deck - HYDRA Research



Figure 61 - 01 Deck and 1 Deck layout for HYDRA Research

Operational Capability

- 01 Deck on HYDRA Research houses accommodation for higher rank augmented crew
- 1 Deck is the capability deck reserved for scientists only. This deck is for all research related tasks. The main philosophy is that the scientist, when at work, does not have to leave this deck. Furthermore, it is designed so that the scientist does not sleep where they work.
- The deck includes:
 - Open deck with L&R devices and rail-system for heavy equipment.
 - Equipment bay with integrated workshops [80m²]
 - 2 x Wet Laboratories [120m²]
 - 7 x Dry Laboratories, incl. desk space for all scientist [180m²]
 - Recreational space for scientist only
 - Common dining hall for all personnel. Seats for 48 people and assumes two shifts per. Meal.
 - 2 x 7m RIBs
- Humanitarian Aid
 - Humanitarian aid will be restricted to this deck.
 - Men will be placed in equipment storage
 - Women and children will be placed in the dinning hall – The dinning hall furniture will be removed and replaced by collapsible two bunks systems.
 - Injured will be placed in the recreational spaces, nearest the hospital.

Launch and recovery system are envisioned as:

- Heavy L&R uses rail-system and A-frame. Typical objects are USV 6000 for hydrographic survey.
- Medium L&R uses deck cranes or deck winches. Typical objects are CTD.



- Light L&R uses equipment bay internal L&R Davit. Typical objects are inspection class ROVs.

Crew Comfortability

- Recreational space and dining hall are located near the dry lab facilities (internal offices), so that the scientist does not have to walk far, when at work.
- Sanitary facilities are available when working on 1 deck, so that personnel does not have to return to their cabins.

Infrastructure

- Passage ways are mainly used by scientist. Organic crew only uses passage ways when accessing the dining hall.
- There is direct connection between open deck and equipment bay. From the equipment bay there is direct connection to wet lab facilities and science control room.
- When entering the ships main passage ways there is research related facilities to starboard and recreational areas to portside.

Escape Routes

- The main escape route from 1 deck is into the equipment bay where the primary muster station is located.

Vertical Access

- There is vertical access near the bow downwards to 2 deck by standard 1.2[m] staircase. Mainly used by scientists.
- There is double vertical access near amidships downwards to 2 deck and upwards to 01 deck from lobby by standard 1.2[m] staircase. This will be shared by crew and augmented personnel.
- Hatches are flush with floor at several locations, due to 2-ways of access required for watertight sections below.
- 1 x commonly used hatch is placed on the working deck to access the towing winch compartment.

Mooring

- Stern-mooring conducted from four bollards on working-deck. Two at portside and two at starboard.

Removal routes of machinery

- Main machinery removal soft patch is located in the hyperbaric treatment area. The softpatch will include the rails for the railway system. The rails can then be used for transport of removed machinery parts, into the upon deck.



10.5. 1 Deck and 01 Deck - HYDRA SUBSAR

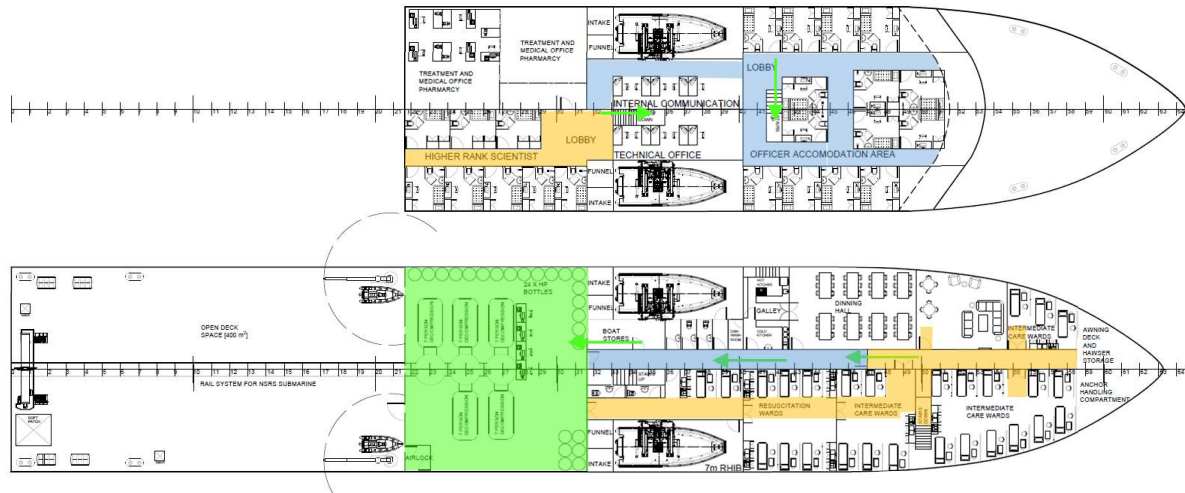


Figure 62 - 01 Deck and 1 Deck layout for HYDRA SUBSAR

Operational Capability

- 01 Deck on HYDRA Research houses accommodation for higher rank augmented crew and medical treatment office.
- 1 Deck is the capability deck reserved for medical personnel only. The main philosophy is that the medical personnel, during operation, does not have to leave this deck. The deck includes:
 - Dedicated open deck area for the NSRS SRV
 - Hyperbaric Treatment area (5 chambers of 7 seats each).
 - HP Air bottles for decompression
 - 2 x Emergency resuscitation. Directly located at entrance to medical area.
 - 6 x Resuscitation wards
 - 19 x intermediate care wards.
 - Common dining hall for all personnel. Seats for 48 people and assumes two shifts per meal.
 - 2 x 7m RIBs
- Humanitarian aid will be restricted to this deck.
 - Men will be placed in hyperbaric chamber compartment
 - Women and children will be placed in the dinning hall – The dinning hall furniture will be removed and replaced by collapsible two bunks systems.
 - Injured will be placed in the recreational spaces, nearest the hospital.
- Launch and recovery system are envisioned as:
 - Heavy L&R uses rail-system and A-frame. The A-frame is dedicated to NSRS
 - Light L&R uses deck cranes or deck winches. Typical objects are Bluefin and inspection ROVs.



Crew Comfortability

- Recreational space and dining hall are located near the medical facilities.
- Sanitary facilities are available when working on 1 deck. This is shared with rescued submariners during operation.

Infrastructure

- Passage ways are strictly divided between organic crew and medical personnel.
- Organic crew passage ways (highlighted in blue) ensures connection between higher rank crew accommodation on 01-deck and dining hall. Stairway also leads to lower rank crew accommodation on 2-deck
- An internal passage way is located within the hospital; this leads to medic recreational space.

Escape Routes

- The main escape route from 1 deck is into the hyperbaric treatment area where the primary muster station is located.

Vertical Access

- There is vertical access near the bow downwards to 2 deck by standard 1.2[m] staircase. Mainly used by medical personnel.
- There is double vertical access near amidships downwards to 2 deck and upwards to 01 deck from lobby by standard 1.2[m] staircase. This will be shared by crew and augmented personnel.
- Hatches are flush with floor at several locations, due to 2-ways of access required for watertight sections below.
- 1 x commonly used hatch is placed on the working deck to access the towing winch compartment.

Mooring

- Stern-mooring conducted from four bollards on working-deck. Two at portside and two at starboard.

Removal routes of machinery

- The main machinery removal soft patch is located within the hyper. 1 hyperbaric chamber must be removed to access the soft patch.



10.6. 1 Deck and 01 Deck - HYDRA Coastguard

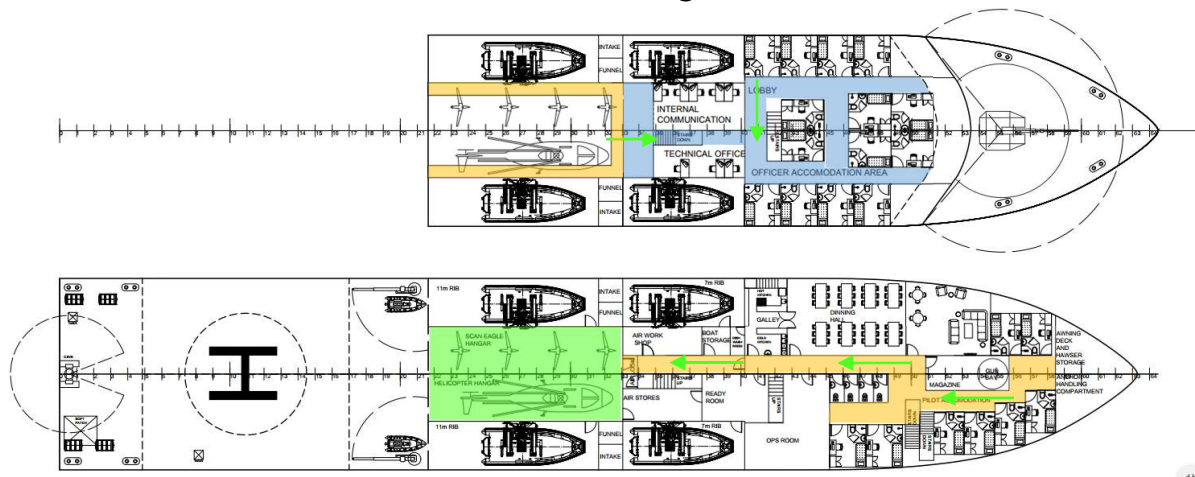


Figure 63 - 01 Deck and 1 Deck layout for HYDRA Coast Guard

Operational Capability

- The variant dependent area of 01 Deck on HYDRA Coastguard is the top of the hangar and boat bays. Maintenance platforms are intended to be implemented to the hangar as shown in figure 60.
- 1 Deck is the capability deck. The main philosophy is that the centre of operation is the ops room. Once briefed, the boarding teams leaves this area to board the transportation equipment to conduct missions. The deck includes:
 - Centralised ops room
 - Ready room
 - Air stores and workshop (direct connection to hangar)
 - 2 x 11m RIB
 - 2 x 7m RIB
 - Pilot accommodation
- Humanitarian aid will be restricted to this deck.
 - Men will be placed in hangar
 - Women and children will be placed in the dinning hall – The dinning hall furniture will be removed and replaced by collapsible two bunks systems.
 - Injured will be placed in the recreational spaces, nearest the hospital.
- Launch and recovery system
 - Scan eagle launch and recovery system has a dedicated area on the open deck for deployment. It will be stowed in the hangar with the scan eagles. It is assumed that the scan eagles can be stacked.

Crew Comfortability

- Sanitary facilities are available when working on 1 deck, near ops room and dining hall.



Infrastructure

- Passage ways are mainly used by scientist. Organic crew only uses passage ways when accessing the dining hall.
- There is direct connection between open deck and equipment bay. From the equipment bay there is direct connection to wet lab facilities and science control room.
- When entering the ship's main passage ways there is research related facilities to starboard and recreational areas to portside.

Escape Routes

- The main escape route from 1 deck is into the hangar where the primary muster station is located.

Vertical Access

- There is vertical access near the bow downwards to 2 deck by standard 1.2[m] staircase. Mainly used by scientists.
- There is double vertical access near amidships downwards to 2 deck and upwards to 01 deck from lobby by standard 1.2[m] staircase. This will be shared by crew and augmented personnel.
- Hatches are flush with floor at several locations, due to 2-ways of access required for watertight sections below.
- 1 x commonly used hatch is placed on the working deck to access the towing winch compartment.

Mooring

- Stern-mooring capable by four bollards on working-deck.

Removal routes of machinery

- The main machinery removal soft patch is located in the hangar. Equipment must be removed to access this soft patch.



10.7. 2 Deck - Accommodation and Auxiliary

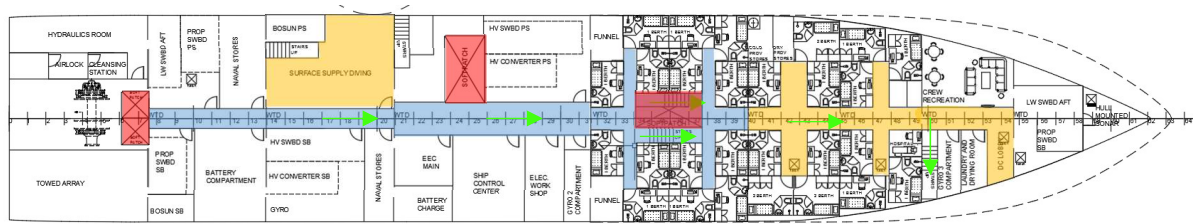


Figure 64 - 2 Deck layout

Operational Capability

Aft-section - Machinery

The aft section from amidships of 2 deck primarily contains auxiliary machinery and electric equipment that is required to be above the waterline. It includes, from aft:

- General stores (includes humanitarian aid stores)
- Cleansing station – For citadel
- Hydraulic rooms
- Towed array compartment
- Towing winch compartment
- Propulsion switchboards
- Battery compartment to support fuel cells and in use in case of total propulsion loss
- High voltage switchboards compartments
- A modular space for either surface supply diving or air compressor.
- Electrical Equipment Workshop
- Ship Control Center
- Light Workshop
- 3 gyros required by the necessary level of dynamic positions, DP 2.

Forward section – Accommodation

The forward section from amidships of 2 deck is reserved for lower rank accommodation of both crew and augmented personnel. A clear division is made between the two types of personnel, as marked with blue and orange.

- The crew accommodation area includes
 - 6 x single standard cabins with portholes
 - 8 x single standard cabins without portholes
 - 1 x recreational area for crew is places near the bow

The augmented personnel accommodation includes

- 6 x internal single standard cabins
- 3 x double standard cabins with portholes
- 4 x single standard cabins with portholes

Furthermore, the forward section of 2-deck includes:

- Galley stores



- Hospital
- Laundry room
-

Crew Comfortability

- There are no cabin doors that open up to main passageways
- The accommodation area is isolated from operational tasks

Infrastructure

- The aft-section passageway is mainly used by ship's crew. Lower rank crew are likely to work near engine space. Hence, placed near this passage way.
- The augmented personnel have access to staircases up to the recreational space.

Escape Routes

- The main escape route from 2 deck is through two vertical staircases up to 1 deck where the primary muster station is located.
- Hatches are in all watertight compartments to ensure two ways of access to each compartment.

Vertical Access

- The aft-most vertical access is downwards to 3 deck by standard 1.2[m] staircase. This is mainly used by organic crew for maintenance tasks.
- Aft of amidships there is vertical access downwards to the diesel generator compartment on 3 deck by standard 1.2[m] staircase. This is solely used by the organic crew. The staircase includes an airlock, in the event of citadel lock-down.
- With the organic lower rank crew accommodation area is a 1[m] stairway downwards to fuel cells, the staircase includes an airlock, in the event of citadel lock-down. Furthermore, a 1.2[m] stairway upwards to 1-deck is included.
- Augmented personnel area includes a 1.2[m] stairway upwards to the dry lab. This stairway may be used by crew as well.

Removal routes of machinery

- A softpatch is included for removal of azipull motors aft.
- A softpatch above the gensets is included
- A softpatch above the fuel cells is included. For this it is necessary to remove staircase, and 1 cabin, to remove the equipment.



10.8. 3 Deck - Machinery deck

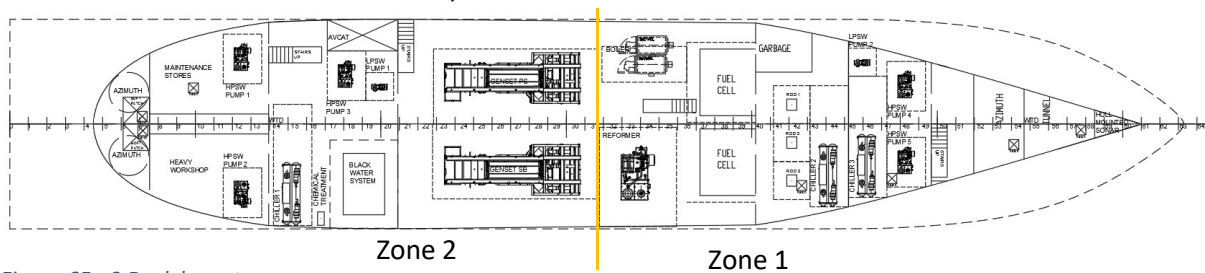


Figure 65 - 3 Deck layout

Operational Capability

Aft-section – Zone 1

Zone 1 is the aft section of 3 deck. It includes, from aft:

- Foundation for two azipull thrusters, subdivided by a longitudinal bulkhead.
- Heavy workshop for maintenance and maintenance stores.
- Chilled water plant for diesel generators
- Black water system
- AVCAT tank – for HYDRA Coastguard. Modular tank for other variants.
- Upper maintenance platform for diesel generators

Forward section – Zone 2

Zone 2 is the aft section of 3 deck. It includes, from aft:

- Upper maintenance platform for fuel cells and reformer
- Chilled water plant for fuel cell compartment and remainder of vessel
- Forward Workshop
- Retractable azimuth thruster
- Tunnel thruster
- Hull mounted sonar equipment storage and access

Escape Routes

- The main escape route from 3 deck is through vertical staircases in each watertight compartment, up two 2 deck.
- Additional hatches are located in each watertight compartment for 2-ways of access.
- There is no watertight doors into the main machinery compartments.

Vertical Access

- The aft-most vertical access is upwards to 2 deck by standard 1.2[m] staircase. Mainly used by organic crew.
- Aft of amidships there is vertical access downwards to the diesel generator seats standard 1.2[m] staircase. Solely used by crew.
- There is vertical access downwards to fuel cells foundation on 4 deck by a 1[m] stairway downwards. Solely used by crew.
- Fore-most vertical access is upwards to 2 deck a 1.2[m] stairway upwards. Solely used by crew.
- Hatches to access azimuth thruster and tunnel thruster.



4 Deck - Engine and Tank Deck

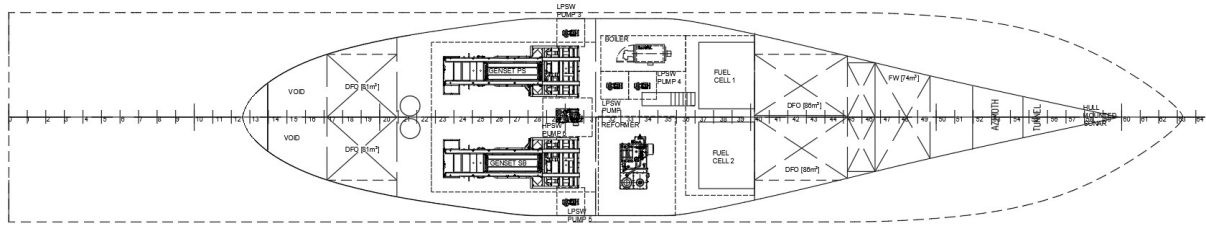


Figure 66 - 4 Deck layout

Operational Capability

Aft-section – Zone 1

The aft section of 4 deck is part of zone 1. It includes, from aft:

- DFO day tank for Diesel generators
- HP-bottles for diesel generators start-up
- Diesel generators foundation

Forward section – Zone 2

Zone 2 is the aft section of 3 deck. It includes, from aft:

- DFO day tank for fuel cells
- Fuel cell foundation
- Azimuth thruster
- Tunnel thruster
- Hull mounted sonar

Escape Routes

- The main escape route from 4 deck is through vertical staircases in each watertight compartment, up two 3 deck.
- Additional hatches located in each watertight compartment for 2-ways of access.
- There are no watertight doors between any bulkheads.

Vertical Access

- Vertical access upwards to 3 deck by standard 1.2[m] staircase from diesel generator compartments. Solely used by organic crew.
- Vertical access upwards to 3 deck by a 1[m] stairway downwards. Solely used by crew.
- Hatches to access azimuth thruster, tunnel thruster and hull mounted sonar.



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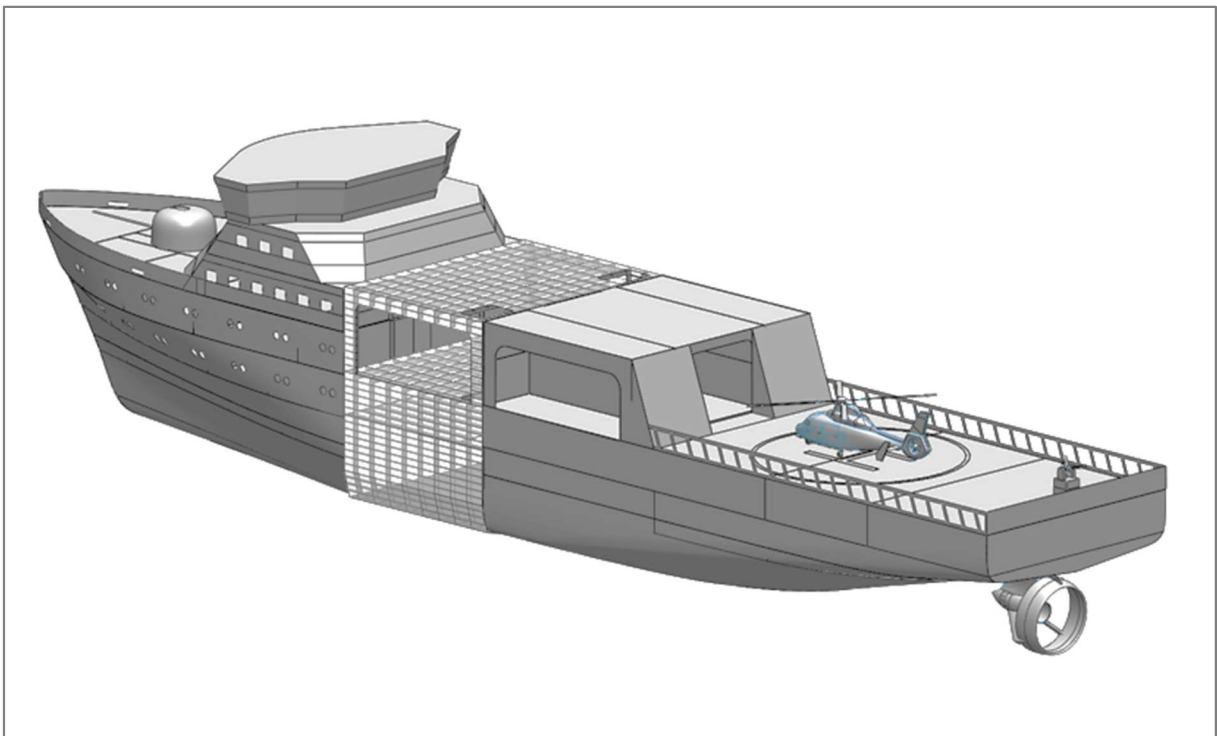


11. Structural Analysis

A preliminary structural analysis has been conducted for the concept design. The primary object is to obtain an estimate of the structural weight to refine the weight estimate and costing of the ship. The overall estimate will be based on a structural analysis of the midship section.

The following sections will present the structural consideration of the load cases and appropriate structural checks. A load analysis will be provided to estimate the key loadings on the ship, based on its internal distributed weights. It has previously been justified to use conventional steel, therefore a presentation of the actual selected material and its properties will be presented.

This will carry into a structural analysis of the midship section. The analysis is subdivided into two parts; a conventional sizing of the plating and stiffeners and a FEA analysis of potential stress concentration. The conventional sizing is based on the Chalmers approach for warship structures (Chalmers, 1993). This is evidently not applicable for commercial ships and will be discussed further. A Finite Element Analysis has been conducted to locate potential stress concentration, which will be further investigated in the feasibility stage.





11.1. Load analysis

The ship is exposed to two primary load cases; wave induced bending and hydrostatic pressure. It is commonly accepted that ships less than 100m will experience larger hydrostatic loading than bending, however it is intended to analyse for a combination of both conditions.

Wave Induced Bending

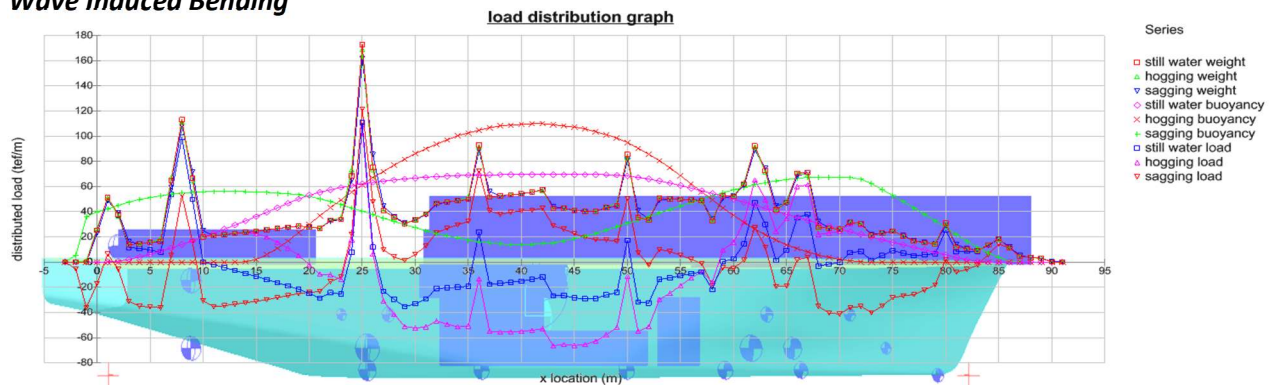


Figure 67 - Paramarine model showing the weight distribuion.

The wave induced bending is obtained from a Paramarine macro provided by the university department. The shear force distribution is obtained by defining the major internal weights distributed along the vessels. An illustration of the Paramarine model is provided in Figure 67.

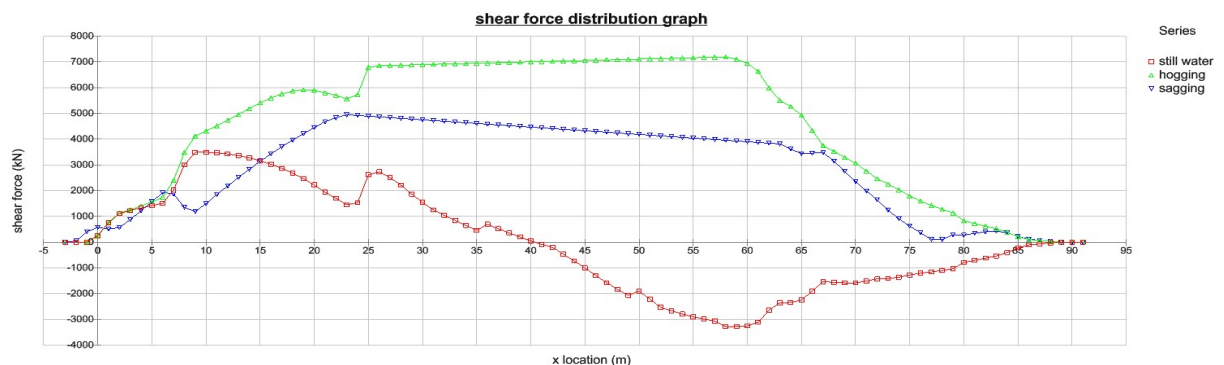


Figure 68 - Shear force distribution

The still water shear force distribution, in Figure 68. shows large peaks and the main discrete weights, such as the aft DFO at 25[m] from aft. The largest shear force occurs at hog.

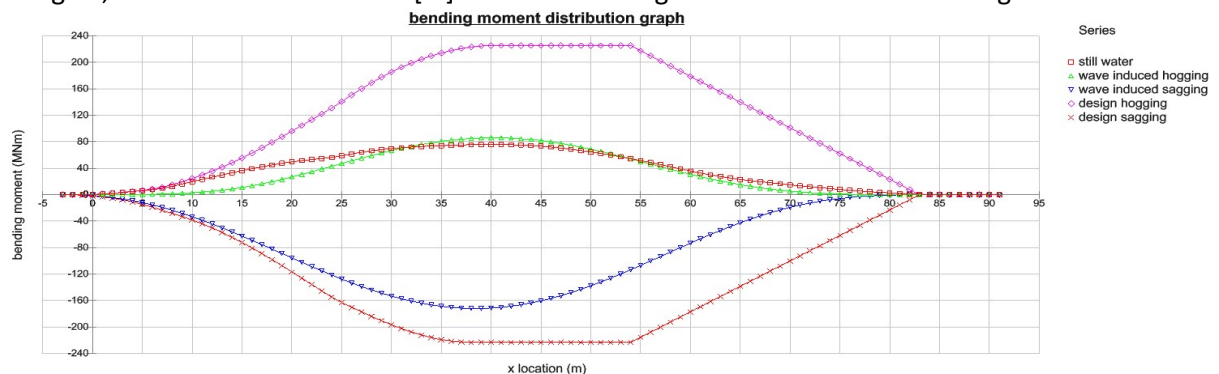


Figure 69 - Bending moments



The shear force distribution is converted into bending moments, as shown in Figure 69. The following values are obtained for:

Maximum Still water: 75.83 [MNm] in Hogging condition

Maximum shear stress amidships: 7.81 [MN]

	Hog	Sag
Wave induced	86.045	171.84
Design	225.39 [MNm]	223.16 [MNm]

Table 35 - Midship Bending Moments

Hydrostatic Pressure

The hydrostatic pressure is present on all immersed elements of the structure. Chalmers (1993) provides a method of estimating this load based on experience from previous ships. (Chalmers, 1993) proposes an addition of 5m head for the dynamic pressure at the midship section. This has been interpreted as an addition to the hydrostatic pressure.

Chalmers (1993) furthermore suggest to apply 25 [KPa] loading on the weather deck to accommodate for green sea loading. Additionally, Chalmers (1993) suggest to apply 50 [KPa] to be applied to sides girders above the waterline, to accommodate for a beam sea loadings.

11.2. Material

In section [M.8.1] it was justified to use steel for the structure. In order to conduct structural calculation is necessary to define the steel type. It is proposed to apply B quality (crack arrest) due to the vessels long life span defined by **URD requirement 9.a**. However, this may result in a more expensive structure.

The steel properties are obtained from Chalmers (1993)

Material Property	Symbol	Value
Yield Strength	σ_{yield}	280 [MPa]
Elastic Modulus	E	207 [GPa]
Shear Modules	G	80 [GPa]
Poissons Ratio	ν	0.3

Table 36 - Material properties of B quality steel (Chalmers, 1993)



11.3. Design of Midship section

The midship section is the heaviest loaded structure in terms of bending. The applied calculation method is obtained from Chalmers (1993). It is acknowledged that is a naval-procedure and will therefore likely produce a midship section that exceeds the requirements of commercial standards. The approach is used due to sufficient support from the university department.

11.3.1. Approach

The section forward of amidships contains large side penetration for the ships 7m RIBs. Furthermore, vertical penetrations for the funnels are located athwart ships near the midship bulkhead, see Figure 70. Evidently this is most critical section. An investigation of superstructure efficiency has been conducted

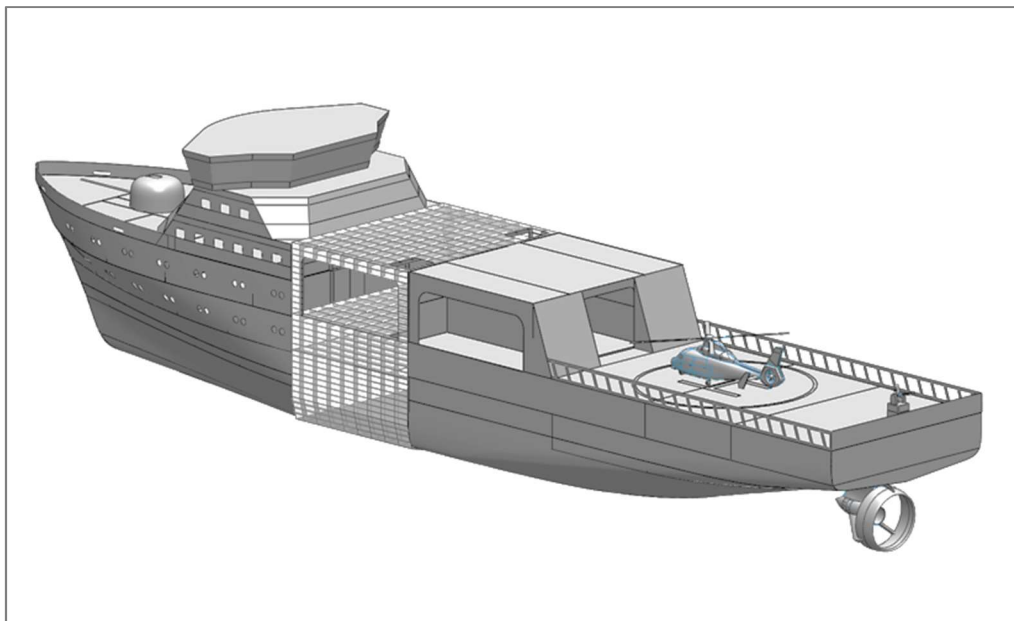


Figure 70 - Superstructure and Midship Section

The superstructure efficiency, η_s is estimated from Lloyds Register Naval rules (Lloyds Register, 2015). The calculation is presented in appendix D. From the structural lectures (Selfridge, 2016) it was presented that the superstructure effectiveness could be determined by the following criteria.

If

1. $P > \eta_s \rightarrow$ Superstructure contribution is efficient and should be implemented to structural analysis
2. $P > \eta_s > P^2 \rightarrow$ Superstructure contribution is significant but does not need to be implemented to structural analysis if it is desired to obtain a low KG.
3. $P < \eta_s \rightarrow$ Superstructure contribution is not efficient and does should not be implemented to structural analysis.

In appendix D it is seen that this design meets the second criteria. It is expected that the ship will suffer from a high KG, and the ability to not include the superstructure has been seized as an opportunity to lower KG.



11.3.2. Structural analysis

The idealised midship section is presented in Figure 71. It decomposed into straight elements and the critical point of each element is circled and numbered. The load case and appropriate structural analysis to each the critical area of each is presented in Table 37 - Load Case and Structural Analysis .

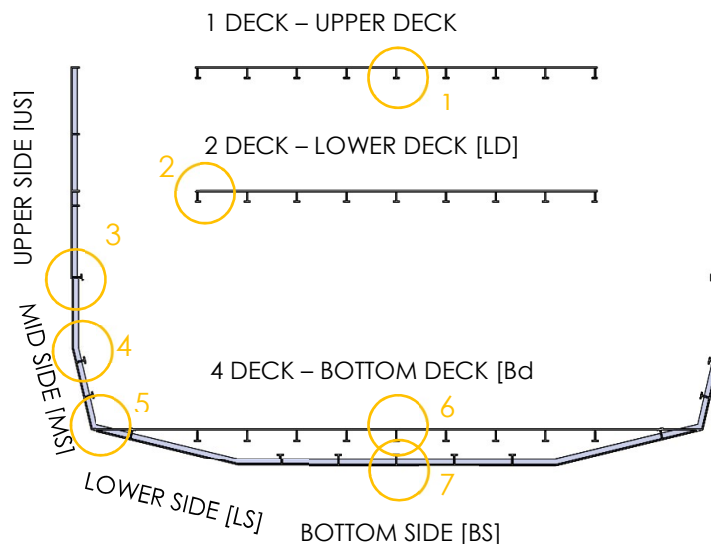


Figure 71 - Idealised Midships Section

Point of Investigation	Element Designation	Load case	Structural Analysis
1	UPPER DECK	- Pure longitudinal bending stress - Green sea loading in boat bay	- Plate buckling - Interframe flexural buckling - Localised green sea
2	LOWER DECK	- Longitudinal bending - Shear stress - Machinery weight loading	- Plate buckling - Interframe flexural buckling - Plate shear buckling - Panel shear buckling - Combination of above
3	UPPER SIDE	- Hydrostatic bending stress - Longitudinal bending stress - Significant shear stress	- Plate shear buckling - Panel shear buckling - Hydrostatic bending
4	MID SIDE	- Hydrostatic bending stress - Longitudinal bending stress - Some shear stress	- Plate buckling - Interframe flexural buckling - Hydrostatic bending - Plate shear buckling - Panel shear buckling - Combination of above
5	LOWER SIDE	- Hydrostatic bending stress - Longitudinal bending stress - Shear stress	- Plate buckling - Interframe flexural buckling - Hydrostatic bending - Plate shear buckling - Panel shear buckling - Combination of above
6	BOTTOM DECK	- Longitudinal bending stress - Shear stress	- Plate buckling - Interframe flexural buckling - Hydrostatic bending
7	BOTTOM SIDE	- Hydrostatic bending stress - Longitudinal bending stress	- Plate buckling - Interframe flexural buckling - Hydrostatic bending

Table 37 - Load Case and Structural Analysis



11.3.3. Example Calculations

The calculations is conducted in Mathcad. The template is adopted from the authors previous work, (Bilde, 2017)

Transverse frames sizing from hydrostatic pressure

The transverse frames are seized from the lowest and longest element. The calculation is a simple clamped beam calculation where it is assumed that the longitudinal does does contribute. An example can be found in Appendix F

Hydrostatic bending

The hydrostatic bending is an added load case for the immersed longitudinal stiffener. This bending moment is obtained from a assuming simply supported constrains between to transverse frames. The hydrostatic bending is added to the overall bending. An example can be found in Appendix G

Plate buckling

The plate buckling calculations investigates the strength of the plate itself. It is common that this failure occurs due to selected of too large stiffeners. This is shown in Appendix G

Interframe Flexural buckling

IFB analyses the strength of the selected plate-stiffener combination under compressive loading. It assumed that buckling occurs before yield. An example is shown in Appendix G, where the allowable combination is obtained from appendix E

Longitudinal and Transverse Stiffener Tripping

The stiffener may lose strength due to a sudden tripping. This can be caused by the longitudinal compressive bending or transverse pressure of the hull. An example is shown in Appendix G

Shear Failure

The elements are analysed for shear failure. The shear force distribution may cause plate failure or panel failure. An example is shown in appendix G

Combined bending and shear stress

An MOD Standard approach to combined stress has been applied where possible. An example of this is shown in appendix G.



11.3.4. Results

The following results are obtained by applying the appropriate calculations at each element, as presented in Table 37.

Section modulus based on equivalent thicknesses

	Obtained Section Modules	Required Section Modulus	Deviation
Sagging condition	1.4122 [m ³]	1.412 [m ³]	17%
Hogging condition	2 [m ³]	1.872 [m ³]	13%

Table 38 - Obtained Midship Section Modules

It is seen from Table 38 that there is an excessive strength of 17% in the upper deck under sagging compression and 13% in the keel under hogging compression. Chalmers (1993) advises a 10% flexibility, these conservative values have therefore been used throughout the analyses, but does leave possibility for improvement.

Distribution of equivalent thickness based on the example in Chalmers (1993)

Equivalent thickness	Value
Upper deck	14 [mm]
Lower deck	10 [mm]
Bottom deck	12 [mm]
Upper side	10 [mm]
Mid side	10 [mm]
Lower side	10 [mm]
Bottom shell	14 [mm]

Transverse Stiffener

	Equivalent thickness	Stiffener type	Plating thickness	Element length	Frame spacing	Number of stiffeners	Weight pr. Span
Upper deck	Various	(177.8x355.6) Large stiffener	Various	50.689	1.4 [m]	1 pr. 1.4 m	3.003 [ton]

Table 39 - Selected Transverse Stiffener

Description	Value	Unit	Requirement	Comment
Bending moment	244.811	[kNm]		
Required section modulus	1533.9	[cm ³]		
Obtained section modules from proposed frame	1579.544	[cm ³]		
Safety factor	1.03	[-]	1	Achieved

Table 40 - Output from Transverse stiffener calculation

Upper deck



Longitudinal Stiffener

	Equivalent thickness	Stiffener type	Plating thickness	Element length	Frame spacing	b/t	Number of stiffeners	Total Area
Upper deck	14 [mm]	Type 5	15[mm]	4.85 [m]	0.606[m]	58.33	16	0.156 [m ²]

Table 41 - Selected Longitudinal Upper Deck Stiffener

	Value	Unit	Requirement	Comment
Parameters				
Aspect ratio (a/b)				
Plate ratio (b/t)	62.179		60<b/t<90	Passed
Applied bending stress	128.021	[MPa]	56	
Plate thickness including corrosion	9.75	[mm]		
Plate Buckling				
Critical Buckling stress	182.378	[MPa]	>Applied stress in deck	1.42 larger than applied stress
Residual Stress	29,904	[MPa]		Assuming tension block is 3
Plate buckling stress	155.214	[MPa]	>Applied stress in deck	1.21 larger than applied stress
Interframe Flexural Buckling				
Slenderness ratio	2.287	[-]	<2.5	Achieved
Column collapse stress	275.515	[MPa]	>Applied stress in deck	2.95 larger than applied stress
Compression factor	0.767	[-]	>0.57	Achieved
Average collapse stress	214.733	[MPa]	>Applied stress in deck	1.67 larger than applied stress
Longitudinal Tripping				
Stiffener stress	787.771	[MPa]		
Plate stress	368.905	[MPa]		
Total instability stress	493.559	[MPa]	>1.3X applied stress in deck	3.85 larger than requirement

Table 42 - Output from Upper Deck Structural Calculation

From the results in Table 42 it is seen that the upper deck longitudinal stiffeners are most likely to fail in plate buckling



Lower deck

Longitudinal stiffener

	Equivalent thickness	Stiffener type	Plating thickness	Element length	Frame spacing	b/t	Number of stiffeners	Total Area
Lower deck	10 [mm]	Type 2	8[mm]	9.7 [m]	0.485[m]	58.33	10	0.156 [m ²]

Table 43 - Selected Longitudinal Stiffener for Lower Deck

Compressive stress

Description	Value	Unit	Requirement	Comment
Parameters				
Plate ratio (b/t)	62.179	[-]	60<b/t<90	Achieved
Applied stress	60.707	[MPa]		Pure bending
Plate thickness including corrosion	7.8	[MPa]		
Plate Buckling				
Critical Buckling stress	157.85	[MPa]	>Applied stress in deck	2.6 X larger than applied stress
Residual Stress	26.629	[MPa]		Low tension block
Plate buckling stress	131.654	[MPa]	>Applied stress in deck	2.15 X larger than applied stress
Safety factor	2.169	[-]		
Interframe Flexural Buckling				
Slenderness ratio	2.541	[-]	<2.5	Failed
Column collapse stress	258.218	[MPa]	>Applied stress in deck	4.24 X larger than applied stress
Compression factor	0.645	[-]	>0.57	
Average collapse stress	180.727	[MPa]	>Applied stress in deck	2.97 X larger than applied stress
Tripping				
Stiffener in-plane tripping stress	334.315	[MPa]		Achieved
Plate in-plane tripping stress	348.741	[MPa]		Achieved
Total instability stress	346.087	[MPa]	> 1.3 X Applied stress in deck	5.76 X larger than applied stress
Lateral load tripping stress	1080	[MPa]	> 4 X Applied stress in deck	17.09 X larger than applied stress

Shear stress

Description	Value	Unit	Requirement	Comment
Design shear stress	50.227	[MPa]		
Plate shear buckling stress	88.989	[MPa]	> Design shear stress	1.7 X larger than applied stress
Panel shear buckling stress	321.238	[MPa]	> 2 X Design shear stress	6.39 X larger than applied stress

Combined stress

Description	Value	Unit	Requirement	Deviation
Compressive Ratio	3.183	[-]		
Shear Ratio	1.025	[-]		Achieved

Table 44 - Output from Lower Deck Structural Analysis



Upper side

Longitudinal stiffener

	Equivalent thickness	Stiffener type	Plating thickness	Element length	Frame spacing	b/t	Number of stiffeners	Total Area
Upper deck	10 [mm]	Type 2	8[mm]	6.3 [m]	0.45[m]	58.33	14	[m ²]

Table 45 - Selected Longitudinal Stiffener for Upper Side Element

Hydrostatic Wave Induced pressure

Description	Value	Unit	Requirement	Comment
Hydrodynamic wave load	50	[kPa]		(Chalmers, 1993)
Bending moment	13.5	[kN/m]		Due to localised hydrostatic pressure
Maximum bending stress	116.814	[cm ³]	<yield stress	
Safety factor	2.41	[cm ³]		

Shear stress

Description	Value	Unit	Requirement	Comment
Design shear stress	64.949	[MPa]		
Plate shear buckling stress	111.013	[MPa]	> Design shear stress	1.70 X larger than applied stress
Panel shear buckling stress	310.96	[MPa]	>2 X Design shear stress	4.76 X larger than applied stress

Table 46 - Output from Upper Side Structural Analysis



Mid side

Longitudinal stiffener

	Equivalent thickness	Stiffener type	Plating thickness	Element length	Frame spacing	b/t	Number of stiffeners	Total Area
Mid side	10 [mm]	Type 2	8[mm]	1.9 [m]	0.464[m]	59.468	4	0.018 [m ²]

Longitudinal stiffener - Compressive stress

Description	Value	Unit	Requirement	Comment
Parameters				
Applied stress due to bending	31.394	[MPa]		
Applied hydrostatic bending stress	44.403	[MPa]		
Total applied bending stress	75.798	[MPa]		
Plate Buckling				
Critical Buckling stress	189.5	[MPa]	>Applied stress in deck	2.5 X larger than applied stress
Residual Stress	31.421	[MPa]		Low tension block
Plate buckling stress	162	[MPa]	>Applied stress in deck	2.13 X larger than applied stress
Safety factor	2.137			
Interframe Flexural Buckling				
Slenderness ratio	2.147	[-]	<2.5	Achieved
Column collapse stress	252.622	[MPa]	>Applied stress in deck	3.33 X larger than applied stress
Compression factor	0.692	[-]	>0.57	
Average collapse stress	193.649	[MPa]	>Applied stress in deck	2.55 X larger than applied stress
Tripping				
Stiffener in-plane tripping stress	334.315	[MPa]	>Applied stress in deck	
Plate in-plane tripping stress	593.545	[MPa]	>Applied stress in deck	
Total instability stress	539.723	[MPa]	>1.3 X Applied stress in deck	7.12 X larger than applied stress
Lateral load tripping stress	1861.07	[MPa]	>4 X Applied stress in deck	24.5 X larger than applied stress

Shear stress

Description	Value	Unit	Requirement	Comment
Design shear stress	66.696	[MPa]		
Plate shear buckling stress	130.881	[MPa]	> Design shear stress	1.9 X larger than applied stress
Panel shear buckling stress	339.495	[MPa]	> 2 X Design shear stress	5.09 X larger than applied stress

Combined stress

Description	Value		Requirement	Deviation
Compressive Ratio	2.55			
Shear Ratio	1.045		Compressive ratio > Shear Ratio	Achieved

Table 47 - Output from Mid Side Structural Analysis



Lower side

Longitudinal stiffener

	Equivalent thickness	Stiffener type	Plating thickness	Element length	Frame spacing	b/t	Number of stiffeners	Total Area
Lower side	10 [mm]	Type 2	8[mm]	[m]	3.65[m]	59.46	8	0.036 [m ²]

Table 48 - Selected Longitudinal Lower Side Stiffener

Compressive stress

Description	Value	Unit	Requirement	Comment
Parameters				
Applied stress due to bending	70.95	[MPa]		
Applied hydrostatic bending stress	64.214	[MPa]		
Total applied bending stress	135.164	[MPa]		
Plate Buckling				
Critical Buckling stress	192.967	[MPa]	>Applied stress in deck	1.42 X larger than applied stress
Residual Stress	32.112	[MPa]		Low tension block
Plate buckling stress	165.452	[MPa]	>Applied stress in deck	1.22 X larger than applied stress
Safety factor	1.224			
Interframe Flexural Buckling				
Slenderness ratio	2.145	[-]	<2.5	Achieved
Column collapse stress	259.04	[MPa]	>Applied stress in deck	4.23 X larger than applied stress
Compression factor	0.717	[-]	>0.57	
Average collapse stress	200.8	[MPa]	>Applied stress in deck	1.48 X larger than applied stress
Tripping				
Stiffener in-plane tripping stress	334.315	[MPa]	>Applied stress in deck	
Plate in-plane tripping stress	636.919	[MPa]	>Applied stress in deck	
Total instability stress	573.114	[MPa]	>1.3 X Applied stress in deck	4.23 X larger than applied stress
Lateral load tripping stress	1876.699	[MPa]	>4 X Applied stress in deck	13.88 X larger than applied stress

Shear stress

Description	Value	Unit	Requirement	Comment
Design shear stress	62.682	[MPa]		
Plate shear buckling stress	136.095	[MPa]	> Design shear stress	2.17 X larger than applied stress
Panel shear buckling stress	353.019	[MPa]	> 2 X Design shear stress	5.63 X larger than applied stress

Combined stress

Description	Value		Requirement	Deviation
Compressive Ratio	1.489			
Shear Ratio	1.033		Compressive ratio > Shear Ratio	Achieved

Table 49 - Output from Lower Side Structural Analysis



Bottom shell

	Equivalent thickness	Stiffener type	Plating thickness	Element length	Frame spacing	b/t	Number of stiffeners	Total Area
Bottom shell	14 [mm]	Type 5	10[mm]	3.85[m]	0.428[m]	65.812	6	[m ²]

Table 50 - Selected Longitudinal Bottom Shell Stiffener

Longitudinal Stiffener

Description	Value	Unit	Requirement	Comment
Parameters				
Applied stress due to bending	90.728	[MPa]		
Applied hydrostatic bending stress	37.076	[MPa]		
Total applied bending stress	127.803	[MPa]		
Plate thickness including corrosion	9.75	[MPa]		
Plate Buckling				
Critical Buckling stress	170.639	[MPa]	>Applied stress in deck	1.33 X larger than applied stress
Residual Stress	28.088	[MPa]		Low tension block
Plate buckling stress	143.896	[MPa]	>Applied stress in deck	1.125 X larger than applied stress
Safety factor	1.126			
Interframe Flexural Buckling				
Slenderness ratio	2.42	[-]	<2.5	Achieved
Column collapse stress	275.649	[MPa]	>Applied stress in deck	2.15 X larger than applied stress
Compression factor	0.739	[-]	>0.57	
Average collapse stress	208.632	[MPa]	>Applied stress in deck	1.63 X larger than applied stress
Tripping				
Stiffener in-plane tripping stress	1081.215	[MPa]	>Applied stress in deck	
Plate in-plane tripping stress	198.661	[MPa]	>Applied stress in deck	
Total instability stress	386.78	[MPa]	>1.3 X Applied stress in deck	3.02 X larger than applied stress
Lateral load tripping stress	1559.466	[MPa]	>4 X Applied stress in deck	12.19 X larger than applied stress

Table 51 - Output from Bottom Shell Structural Analysis



Bottom deck / Inner bottom

Longitudinal stiffener

	Equivalent thickness	Stiffener type	Plating thickness	Element length	Frame spacing	b/t	Number of stiffeners	Total Area
Upper deck	12 [mm]	Type 2	10[mm]	7.4 [m]	0.46[m]	47.436	16	0.156 [m ²]

Table 52 - Selected Longitudinal Bottom Deck Stiffener

Compressive stress

Description	Value	Unit	Requirement	Comment
Parameters				
Applied stress	70.95	[MPa]		Pure bending
Plate thickness including corrosion	9.75	[MPa]		
Plate Buckling				
Critical Buckling stress	222.416	[MPa]	>Applied stress in deck	2.2 X larger than applied stress
Residual Stress	40.545	[MPa]		Low tension block
Plate buckling stress	195.923	[MPa]	>Applied stress in deck	1.85 X larger than applied stress
Safety factor	2.761			
Interframe Flexural Buckling				
Slenderness ratio	1.745	[-]	<2.5	Achieved
Column collapse stress	258.82	[MPa]	>Applied stress in deck	3.43 X larger than applied stress
Compression factor	0.785	[-]	>0.57	
Average collapse stress	219.864	[MPa]	>Applied stress in deck	2.44 X larger than applied stress
Tripping				
Stiffener in-plane tripping stress	334.315	[MPa]	>Applied stress in deck	
Plate in-plane tripping stress	937.206	[MPa]	>Applied stress in deck	
Total instability stress	832.748	[MPa]	>1.3 X Applied stress in deck	3.88 X larger than applied stress
Lateral load tripping stress	1327	[MPa]	>4 X Applied stress in deck	14.61 X larger than applied stress

Shear stress

Description	Value	Unit	Requirement	Comment
Design shear stress	27.801	[MPa]		
Plate shear buckling stress	281.499	[MPa]	> Design shear stress	6.36 X larger than applied stress
Panel shear buckling stress	459.996	[MPa]	> 2X Design shear stress	14.052 X larger than applied stress

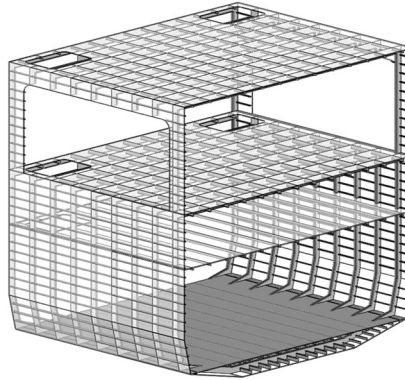
Combined stress

Description	Value	Unit	Requirement	Deviation
Compressive Ratio	2.441	[-]		
Shear Ratio	1.009	[-]	Compressive ratio > Shear Ratio	Achieved

Table 53 - Output from Bottem Deck Structural Analysis



11.4. Final Arrangement Longitudinal stiffener



	Equivalent thickness	Stiffener type	Plating thickness	Element length	Frame spacing	b/t	Number of stiffeners	Total Area
Upper deck	14 [mm]	Type 5	10[mm]	4.85 [m]	0.606[m]	58.33	8	0.0693[m ²]
Lower deck	10 [mm]	Type 2	8[mm]	4.85 [m]	0.485[m]	58.33	10	0.0482 [m ²]
Upper deck	10 [mm]	Type 2	8[mm]	6.3 [m]	0.45[m]	58.33	14	0.0639 [m ²]
Mid side	10 [mm]	Type 2	8[mm]	1.9 [m]	0.464[m]	59.468	4	0.0189[m ²]
Lower side	10 [mm]	Type 2	8[mm]	3.65[m]	0.455[m]	59.46	8	0.0364 [m ²]
Bottom deck	12 [mm]	Type 2	10[mm]	3.7 [m]	0.464[m]	47.436	8	0.0445 [m ²]
Bottom shell	14 [mm]	Type 5	10[mm]	3.85[m]	0.642[m]	65.812	6	0.0541[m ²]

Table 54 - Final Structural Arrangement of the Midship Section

Weight estimate of longitudinal elements. Multiplied by 2 as calculation is conducted for half of the structure due to symmetry.

$$W_{long} = (Total\ Area[m^2] * 2) * 1.4[m] * \rho_{steel} \left[\frac{ton}{m^3} \right] = 7.55 \frac{ton}{1.4m}$$

Addition of weight of 1 transverse stiffener

$$W_{1.4[m]} = W_{long} + W_{trans} = 10.55 \frac{ton}{1.4m}$$

The hull has approximately 1/3 parallel midbody. The total weight of the hull is calculated by assuming the structure refines with the prismatic coefficient, beyond the parallel midbody.

$$W_{long} = 10.55 * \frac{LOA}{1.4[m]} + 10.55 * \frac{2 * LOA}{1.4[m]} * 0.66 = 517.25\ ton$$



11.5. FEA analysis

It is noticed that the midship section structure has large penetration both vertically, due to uptakes, and horizontally, due to the boat bays. As previously explained, the superstructure was found ineffective in contribution to the hull strength, however it is candidate for large stress concentrations due to the penetration.

An preliminary FEA analysis has been conducted to identify the critical stress areas, hence the output will be approached purely qualitative. The identification of critical stress concentration can be used a preparation for a refining structural design in further design iteration.

11.5.1. Model simplification

The model has been simplified due to time-constrain and lack of computational power. All longitudinal and transverse stiffeners has been removed. The equivalent plate thickness, presented in the previous section, has been used as it is considered the best representation of the strength available.

11.5.2. Mesh Creation

A global mesh was generated for the structure, where an adaptive local mesh refinement was used to ensure accuracy in critical areas. The output is seen in Figure 72, noticed local mesh refinement at funnel. Adaptive local mesh refinement often cures any inconvergence, hence a mesh convergence analysis has not been done. Additionally the results will be discussed on a qualitative bases.

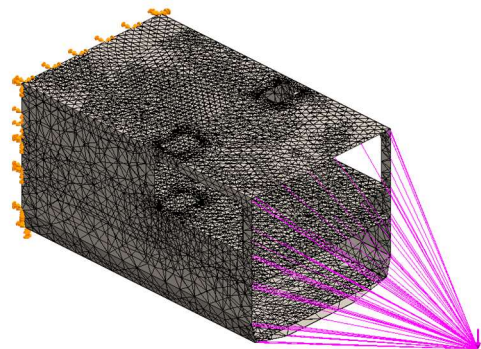


Figure 72 - FEA Model - Mesh generation - Applied constraints and loading

11.5.3. Constrains and loading

In order to ensure full development of stress, the model has been extended by another section. This section is fully constrained. The load is applied as remote load at a distance, which creates the maximum bending moment in sag condition, (compression in upper deck).

11.5.4. Results

The results shows, as expected that there are high stress concentrations near the uppermost funnel penetrations. Furthermore the lower corners of the boat bay are subject to large stresses. Reinforcement and mitigation should be applied at these areas in further design iterations.

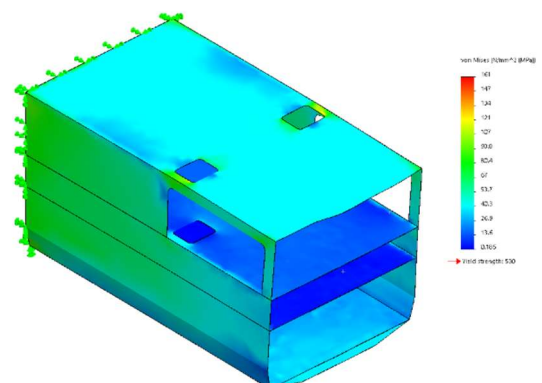


Figure 73 - Results of FEA Analysis



11.6. Discussion

The hydrostatic load provided by Chalmers (1993) is based on previous ships. It is the driving load for this vessel and does therefore require further analysis.

The Chalmers (1993) approach is based on an estimate of equivalent thickness. The equivalent thicknesses are arbitrary chosen to produce a section module that satisfies the required section modules. The distribution of the equivalent thickness was based on an example calculation from a frigate. It is likely that that this has produced a undesirable distribution for investigated midships section. To support this, it was found that the upper deck and bottom shell was the most critical areas.

The FE analysis showed critical areas near the funnel and boat bays, however it did not incorporate the stiffeners and bulkheads. The stiffeners may provide additional reinforcement near the critical stress concentration areas. Where the bulkhead may produce other stress concentration, and must therefore be included.

The structural analysis showed a final arrangement which produces a structural weight of 517.25 ton. This was found to be significantly close to the Naval estimate of 570 [ton] provide by the (UCL Zenith Database, 2017). However, it was found deviating from the commercial estimate of 675.89 [ton], used in the weight estimation. This is deemed to be due to the naval approach undertaken for this structural analyses. The previous estimated has therefore been carried on to the following analysis.



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12. Stability and Trim

The previous sections have presented a finalised machinery selection which has led to an updated in hull weight. Furthermore, the structural weight estimation has been refined from the midship section structural analysis. This allows for estimation of the exact centre of gravity for each variant which provides a solid foundation for the intact and damage case stability calculations.

12.1. Update to Weight Management

A further equipment investigation by the HYDRA Marine Engineer has enabled an update to the weight management of the vessel. Only updated weights are shown below.

Component	Initial Weights [ton]	Updated Weights [ton]	Comment
GROUP 1: HULL			
Hull Structure	860.52	675.89 (hull)+168.97 (superstructure)	
GROUP 2: PERSONNEL - REMAINS UNCHANGED			
GROUP 3: SHIP SYSTEMS			
HVAC	32		
Chiller Water Plant And distribution	20.88	34.2+(11.92)	11.4 ton pr. unit + (distribution)
Desalination Plant And distribution	15.38	4.2+(11.92)	1.4 ton pr unit + (distribution)
Seawater Pumps and distribution	21.91	3(HPSW) + 1.37(LPWS) + (14.25)	0.5 ton pr. HPSW unit + 0.27 te pr. LPSW unit + (distribution)
Air compressors And distribution	10.98	3	0.75 ton pr. compressor
GROUP 4: MAIN PROPULSION			
Fuels Cells	80.9	153.5	2 X 48.5 ton Fuel Cells + 1 X 48.5 ton Reformer + 1 X 8 ton Boiler
2 X 3.3 MW Diesel Generator	147.2	147.2	
Motor Conversion	40	10	
Seats and supports	94.466	109.386	
GROUP 5: ELECTRICAL POWER			
Switchboards	10	6.8	
Electrical Distribution Center	12	13	
Electrical Distribution	49.78	52.13	
GROUP 6.1 : PLATFORM PAYLOADS - REMAINS UNCHANGED			
GROUP 7: VARIABLES			
DFO	510	466	
Freshwater	71	128	
Bilge Water	26	15	
Ballast Water	250	30.75	

Table 55 - Updated weights after completed machinery and auxiliary selection



12.2. Center of Gravity Locations

The following table presents the locations of centre of gravity for each variant, based on the updated weights presented in the previous section.

The conditions are light and deep for start and end of life. End of Life is obtained by assuming a 0.5% Growth to each WBS section, over a 40 year life-span. This results in a 21.6 % growth. The additional growth weight has been added longitudinally to LCB and vertically at mid-span of 2 deck. It is acknowledged that this margin is obtained from warship data, and may be an overestimate for the HYDRA-vessels. The critical COG positions have been highlighted in the below table.

The light-ship conditions are obtained by assuming empty fresh water and DFO, as recommended by (UCL Naval Architecture Department, 2016). It is acknowledged that this is not entirely correct, but it brings a conservative approach.

Condition	Displacement	LCG	Trim	Deviation From SUBSAR	VCG	Deviation From SUBSAR	TCG
HYDRA SUBSAR							
START LIGHT	2535.8	40.417	N/A	0%	5.83	0%	-0.01
START DEEP	3244	40.173	N/A	0%	4.85	0%	0.00
END LIGHT	3050.4	40.519	N/A	0%	6.12	0%	-0.01
END DEEP	3758.6	40.41	N/A	0%	5.22	0%	0.00
HYDRA Research							
START LIGHT	2472.8	40.73	0.45 m by stern	0.64%	5.86	0.51%	-0.01
START DEEP	3181	40.56	0.28 m by stern	0.59%	4.85	0%	0.00
END LIGHT	3000.9	40.468	0.337 m by stern	0.59%	6.16	0.65%	-0.01
END DEEP	3709.1	40.62	0.084 m by stern	0.51%	5.24	0.38%	0.00
HYDRA Coast Guard							
START LIGHT	2445.8	42.062	N/A	0.77%	5.75	-1.39%	-0.02
START DEEP	3154	41.42	N/A	0.95%	4.76	-1.89%	-0.01
END LIGHT	2964.1	41.737	N/A	-0.13%	6.0634	-0.93%	-0.02
END DEEP	3672	41.383	N/A	0.52%	5.15	-1.36%	-0.01

Table 56 - Hydrostatic values obtained for each variant



12.3. Comparison of obtained COG

The final layouts has yielded the exact centre of gravity positions for all three variants in four different conditions. It is paramount for a feasible design, that there is similarity between the positions. Furthermore this study reveals the worst-case variant in terms of intact stability.

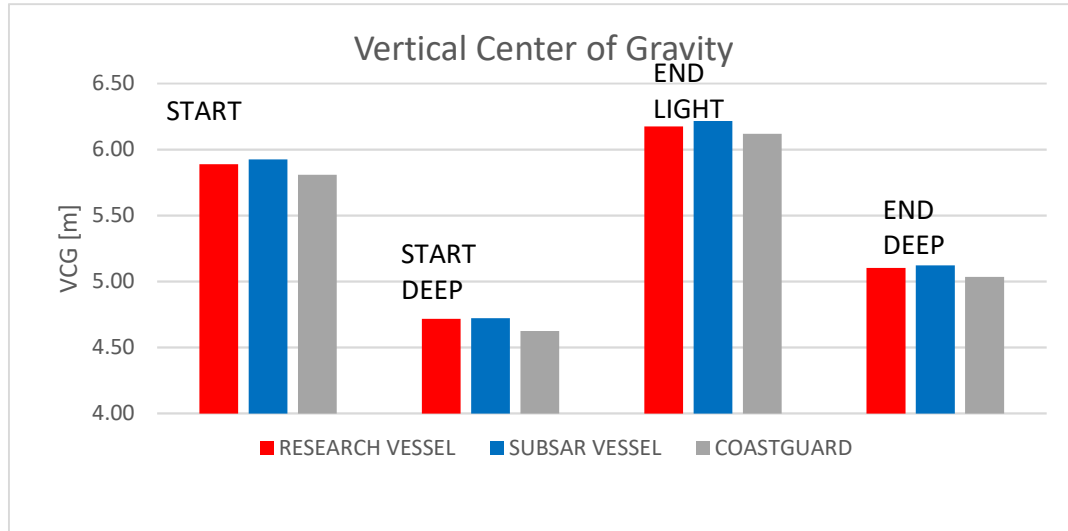


Figure 74 - Comparison of VCG obtained for each variant

From the above graph Figure 74 it is seen that the vessels have obtained significantly similar VCG. This is due to the philosophy of making decks variant dependent, compared to various compartments. It is furthermore seen that the research vessel has the highest VCG position, across all four condition. This variant has been carried through to intact stability check.

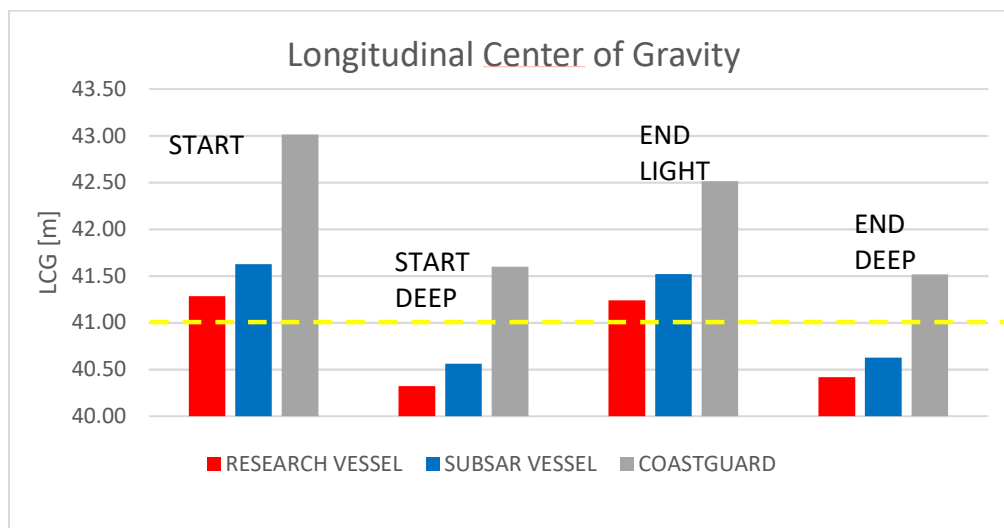


Figure 75 - Comparison of LCG obtained for each variant

The dashed yellow line represents the LCB position. Any deviation from this line causes trim. It is seen that the coastguard will likely trim significantly by the bow. Furthermore It is seen that the Research and SUBSAR vessel will trim by stern in deep condition. This therefore requires further investigation to mitigate the trim. The options are either a revisit of the layout or implementation of SWB or led.



12.4. Intact Stability

The following stability calculations are conducted for the research vessels various condition. In the previous, this variant was proven to have the highest vertical COG. It is acknowledged that all conditions for all variants should be checked in further design development. The stability calculations are conducted in Paramarine (Qinetiq, Hampshire), hence it utilizes the shape of the initial hull form.

Free-surface correction has been made for the tanks at the largest surface area. An example calculation is provided in appendix J. This shows the free-surface correction for light-start condition. Smaller tanks have not been included, due to insignificance.

12.4.1. Intact Stability Criteria

The following criteria is directly cited, in its original words, from Daisy Design Procedure Book (1996)

Minimum Merchant Ship Intact Stability Rules (Merchant Shipping Load Line Rules 1968)

1. *The area under the GZ curve shall not be less than:*
 - a. *0.055 metre-radians (mrad) up to angle of 30 deg;*
 - b. *0.09 mrad up to an angle of 40 deg or the angle at which the lower edges of any openings in the hull, superstructure or deckhouses, being openings which cannot be closed weathertight, become immersed if the angle is less.*
 - c. *0.03 mrad between an angle of heel of 30 deg and one of 40 deg or such lesser angle as referred to in (b)*
2. *The righting lever (GZ) shall be at least 0.20m at an angle of heel equal to or greater than 30 deg.*
3. *The maximum righting lever (GZ) shall occur at an angle of heel of not less than 30 deg.*
4. *The initial transverse metacentric height (GM) shall not be less than 0.15m. In the case of a ship carrying a timber deck cargo which complies with sub- paragraph (1) by taking into account the volume of the timber deck cargo the initial transverse metacentric height shall not be less than 0.05m*



12.4.2. Condition 1: Start of life – Light Displacement
GZ –CURVE:

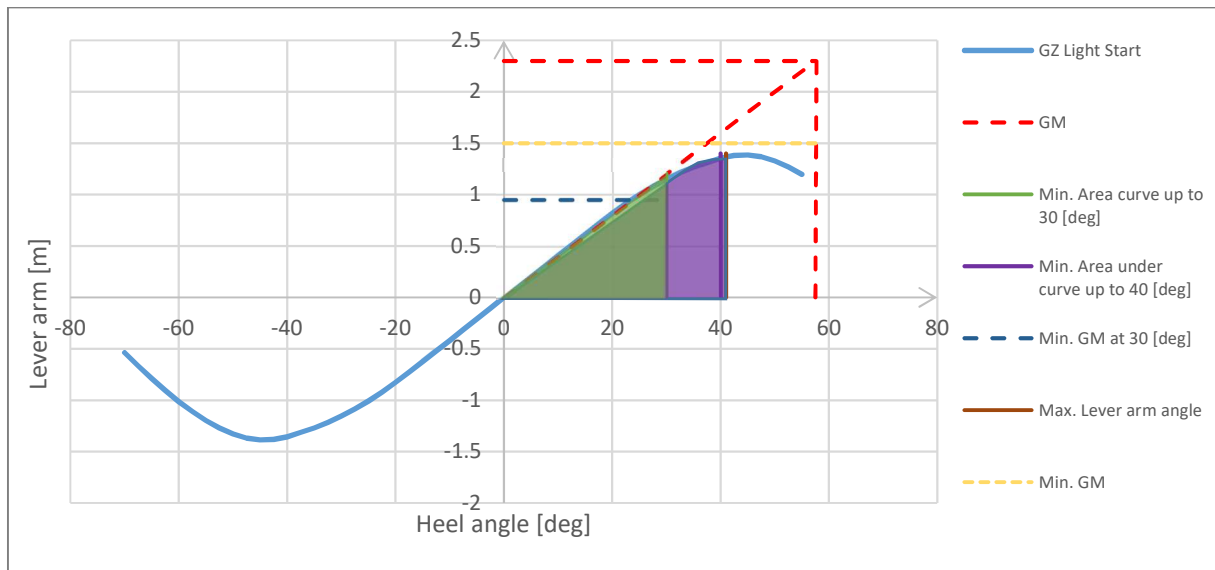


Figure 76 - GZ-curve SOL-LD

Condition characteristics

Characteristics	Value (tons)
Displacement	2472.8
KG	5.86 m
LCG	40.73 m
Trim	0.45 m by stern
GMts	2.23 m
Free surface correction	0.138 m
GMtf	2.092 m

Table 57 - Condition characteristics - SOL-LD

Incact Stability Criteria Check

Criteria	Criteria Description	Obtained Value
1a	0.055 mrad to 30 [deg]	0.314 (pass)
1b	0.09 mrad to 40 [deg]	0.488 (pass)
1c	0.003 mrad between 30 and 40 [deg]	0.174 (pass)
2	GM 0.2m at 30[deg] or greater	Pass
3	Max GZ occur after 30[deg]	Pass
4	Min. initial GM greater than 1.5m	Pass

Table 58 - Incact Stability Criteria Check - SOL-LD



12.4.3. Condition 2: Start of life – Deep Displacement
GZ –CURVE:

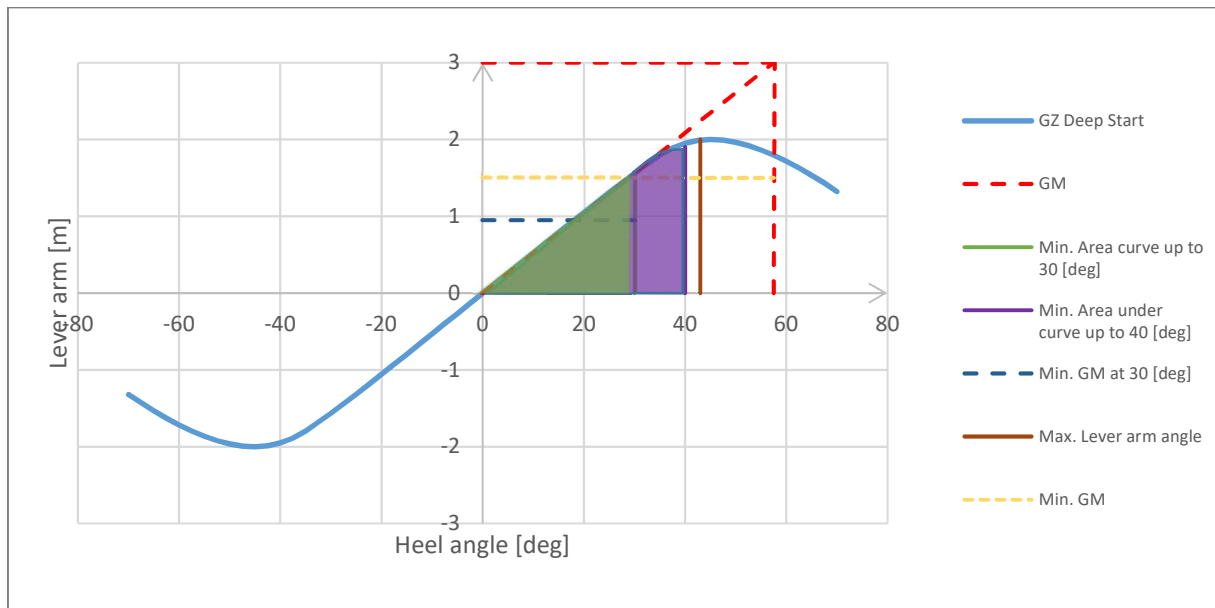


Figure 77 - GZ-curve SOL-DD

Condition characteristics

Criteria Description	Obtained Value
Displacement	3181 tons
KG	4.85
LCG	40.56
Trim	0.28 m by stern
GMts	2.98 m
Free surface correction	0.107 m
GMtf	2.87 m

Table 59 - Condition characteristics - SOL-DD

Incact Stability Criteria Check

Criteria	Criteria Description	Obtained Value
1a	0.055 mrad to 30 [deg]	0.405 (pass)
1b	0.09 mrad to 40 [deg]	0.663 (pass)
1c	0.003 mrad between 30 and 40 [deg]	0.257 (pass)
2	GM 0.2m at 30[deg] or greater	Pass
3	Max GZ occur after 30[deg]	Pass
4	Min. initial GM greater than 1.5m	Pass

Table 60 - Incact Stability Criteria Check - SOL - DD



12.4.4. Condition 3: End of life – Light Displacement
GZ –CURVE:

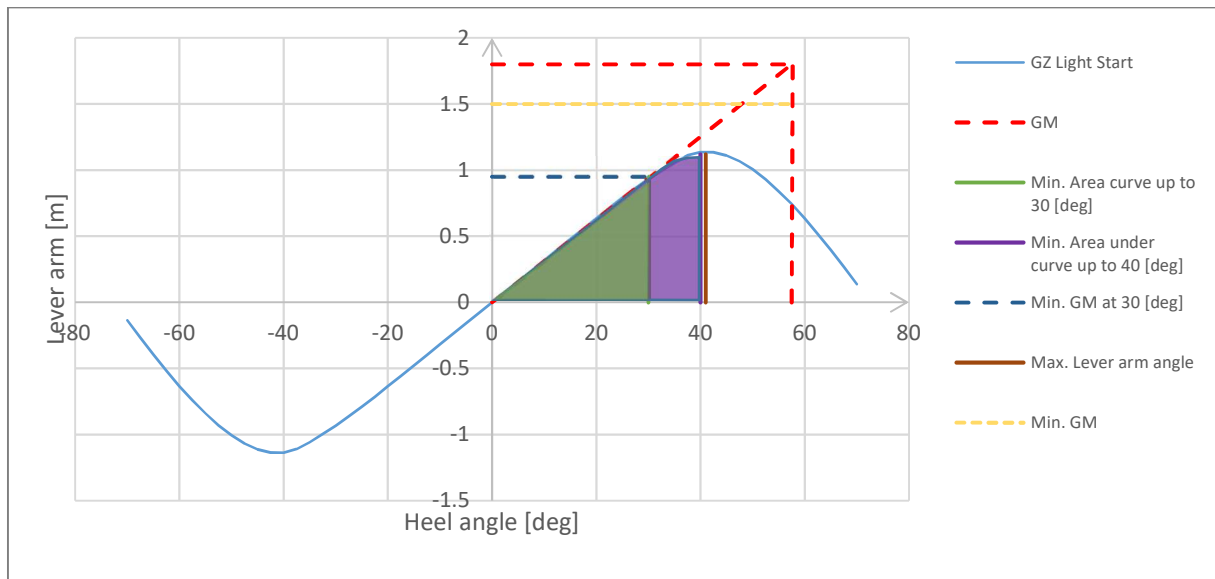


Figure 78 - GZ-curve EOL-LD

Condition characteristics

Criteria Description	Obtained Value
Displacement	3000.9 tons
KG	6.16 m
LCG	40.468 m
Trim	0.337 m by stern
GMts	1.78 m
Free surface correction	0.11 m
GMtf	1.67 m

Table 61 - Condition characteristics - EOL-LD

Stability Criteria

Criteria	Criteria Description	Obtained Value
1a	0.055 mrad to 30 [deg]	0.248 (pass)
1b	0.09 mrad to 40 [deg]	0.390 (pass)
1c	0.003 mrad between 30 and 40 [deg]	0.142 (pass)
2	GM 0.2m at 30[deg] or greater	Pass
3	Max GZ occur after 30[deg]	Pass
4	Min. initial GM greater than 1.5m	Pass

Table 62 - Table 38 - Intact Stability Criteria Check - EOL-LD



12.4.5. Condition 4: End of life – Deep Displacement
GZ –CURVE:

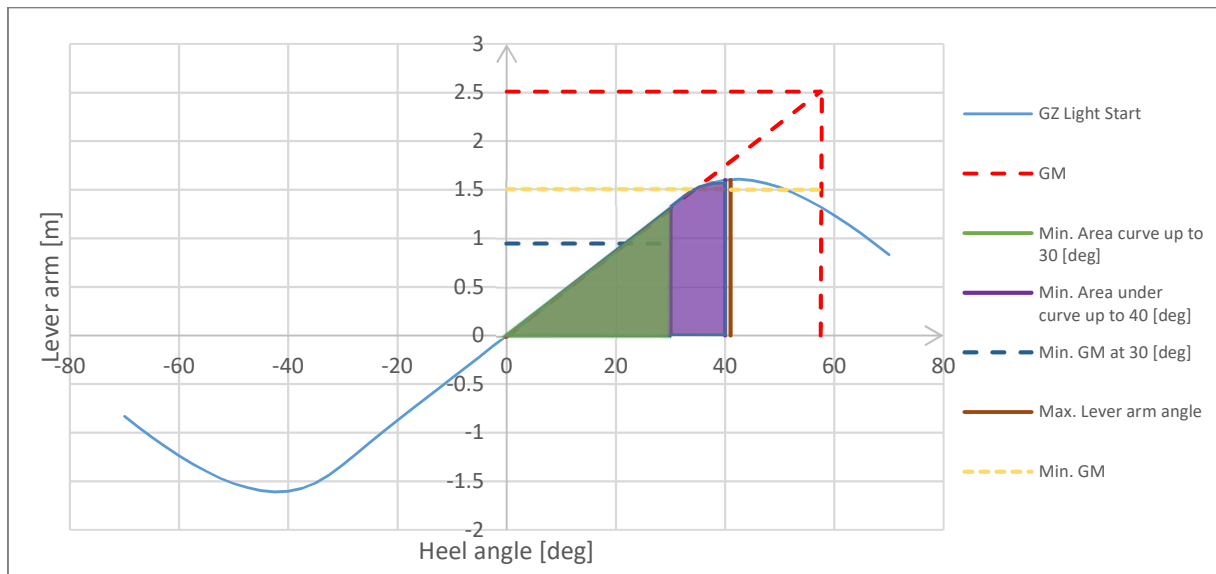


Figure 79 - GZ-curve EOL-DD

Condition characteristics

Criteria Description	Obtained Value
Displacement	3709.1 tons
KG	5.24 m
LCG	40.62 m
Trim	0.084 m by stern
GMts	2.51 m
Free surface correction	0.09242251
GMtf	2.42

Table 63 - Condition characteristics - EOL-DD

Stability Criteria

Criteria	Criteria Description	Obtained Value
1a	0.055 mrad to 30 [deg]	0.340 (pass)
1b	0.09 mrad to 40 [deg]	0.558 (pass)
1c	0.003 mrad between 30 and 40 [deg]	0.218 (pass)
2	GM 0.2m at 30[deg] or greater	Pass
3	Max GZ occur after 30[deg]	Pass
4	Min. initial GM greater than 1.5m	Pass

Table 64 - Intact Stability Criteria Check - EOL-DD



12.4.6. Discussion on Intact Stability

The obtained GM for all condition are considered large compared to the estimation from the parametric survey (1.5m). However, it is expected that the GM will be large due to the wide beam, and the heavy weights placed down low.

Some suspicion can be made to an error in estimation of VCG, however this has been checked several times to ensure correctness.

The intact stability investigation conducted for this vessel suffers from some limitations. The intact stability does not take wind-arm into account. This will evidently lower the GM for all conditions, but is not suspected to be critical due to the large values obtained. Furthermore the investigation does not take potential deck-ice into account. HYDRA is built to operate within the Mediterranean and this is therefore not a problem. However, in the event of the concept being sold to other operational areas, it is necessary to perform such analysis.

The free surface effect is calculated for the largest area possible, within the tanks. This is evidently provides a conservative reduction for all condition. It is particularly expected that the free surface effect will be significantly less for light condition, due to the shape of the hull, hence decrease in surface area.

The analysis above is solely conducted for the research vessel, based on the COG investigation. Furthermore it is conducted for light- and deep condition, in start- and end of life. For future analysis this should be conducted for all HYDRA variants, and the condition should be expanded to loaded-operational and light-operational.

Damage Case Stability



12.5. Damage case stability

The vessel is required by URD requirement to operate post collision. It is therefore important to ensure safety in each damage case. The following presents the worst case scenario, however in order to fully provide information of the vessel survivability, it is required to be conducted for all possible damage cases.

12.5.1. DAMAGE CASE 1 – Compartment A & B

trim_BP (m)	mean_draught (m)	draught_AP (m)	draught_FP (m)	list_or_oll_angle (deg)	GMtf (m)
-2.790	5.067	3.672	6.461	-0.000	2.651
MARPOL CRITERIA	PASS				

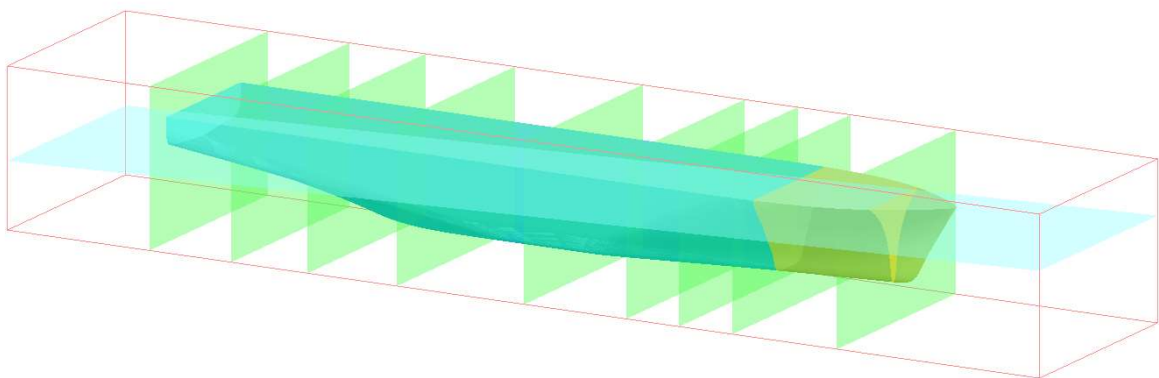


Figure 80 - Illustration of Damage Case 1

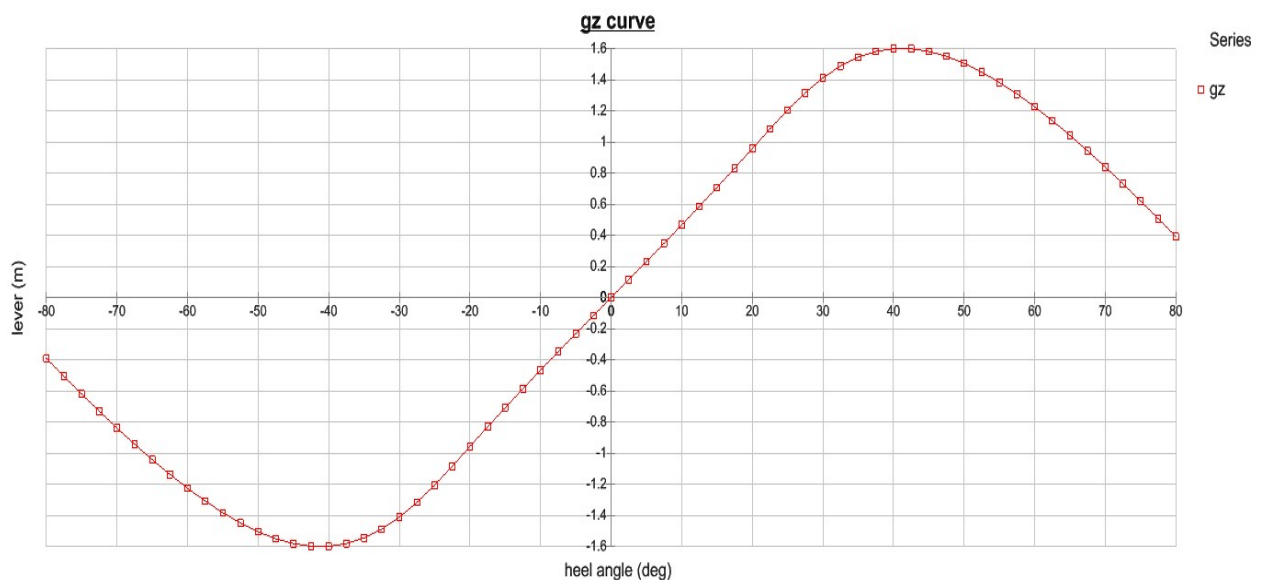


Figure 81 - GZ curve in Damage Case 1



12.5.1. DAMAGE CASE 2 - Compartment B & C

trim_BP (m)	mean_draught (m)	draught_AP (m)	draught_FP (m)	list_or_oll_angle (deg)	GMtf (m)
-5.749	5.651	2.777	8.526	-0.000	2.485
MARPOL CRITERIA	PASS				

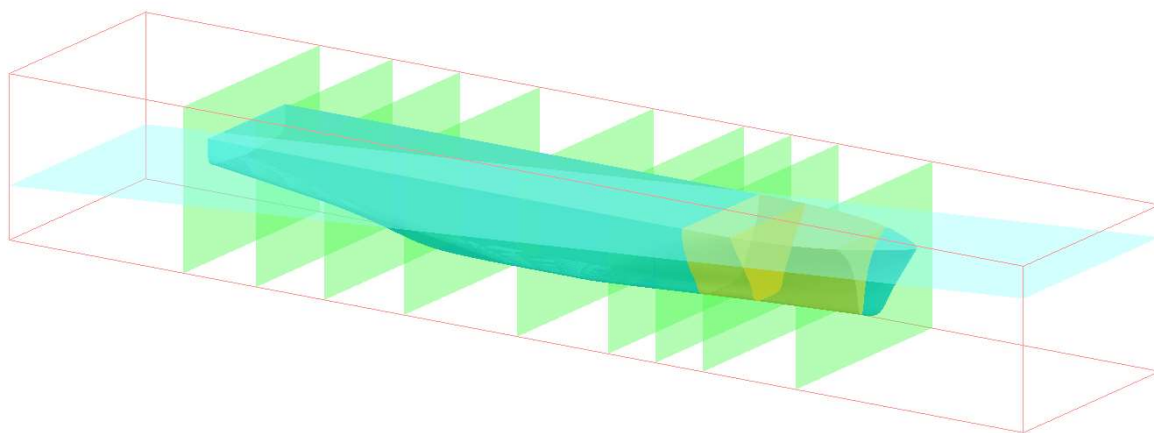


Figure 82 - Illustration of Damage Case 2

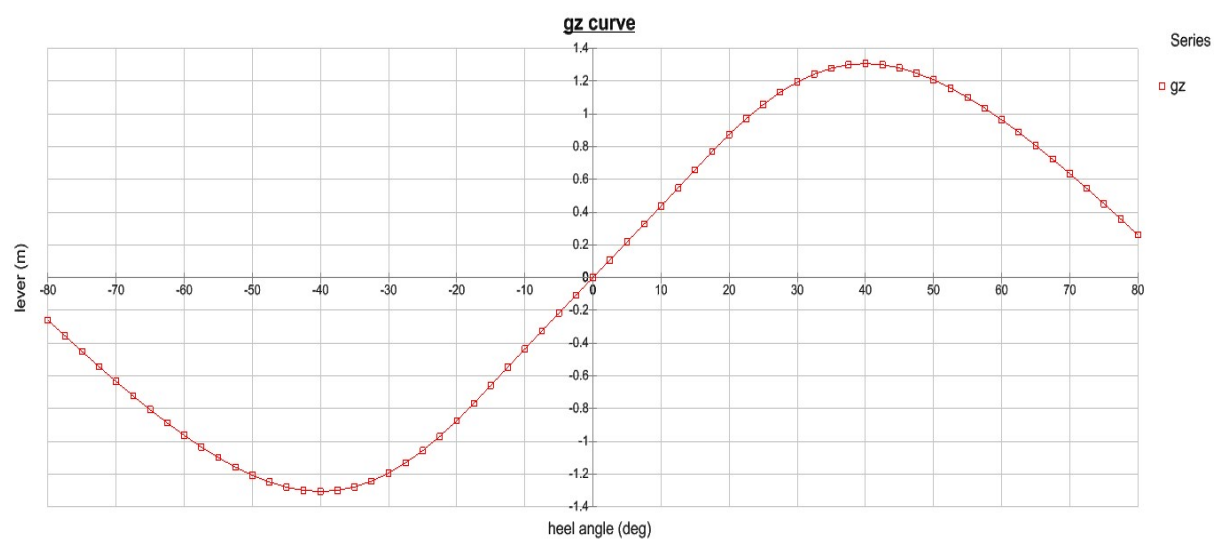


Figure 83 - GZ curve in Damage Case 1



12.5.1. DAMAGE CASE 3 - Compartment C & D

trim_BP (m)	mean_draught (m)	draught_AP (m)	draught_FP (m)	list_or_loll_angle (deg)	GMtf (m)
-3.728	5.556	3.692	7.420	-0.001	2.483
MARPOL CRITERIA	PASS				

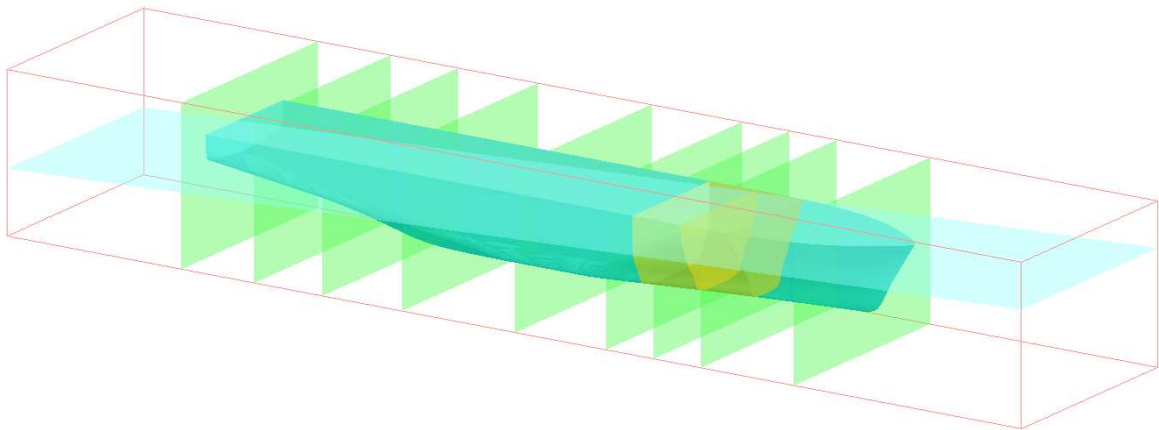


Figure 84 - Illustration of Damage Case 3

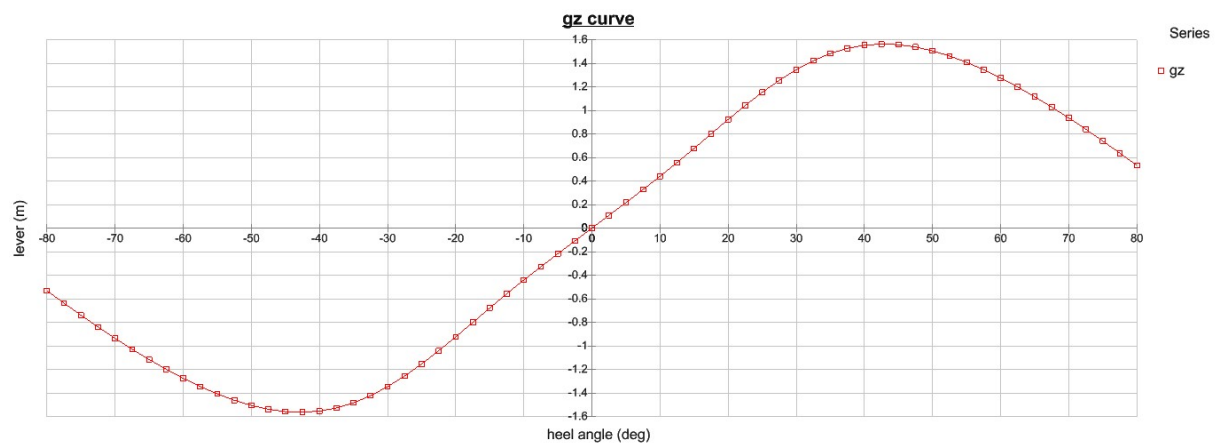


Figure 85 - GZ curve in Damage Case 3



12.5.1. DAMAGE CASE 4 - Compartment D & E

trim_BP (m)	mean_draught (m)	draught_AP (m)	draught_FP (m)	list_or_loll_angle (deg)	GMtf (m)
-3.881	6.337	4.397	8.278	-0.001	2.944
MARPOL CRITERIA					

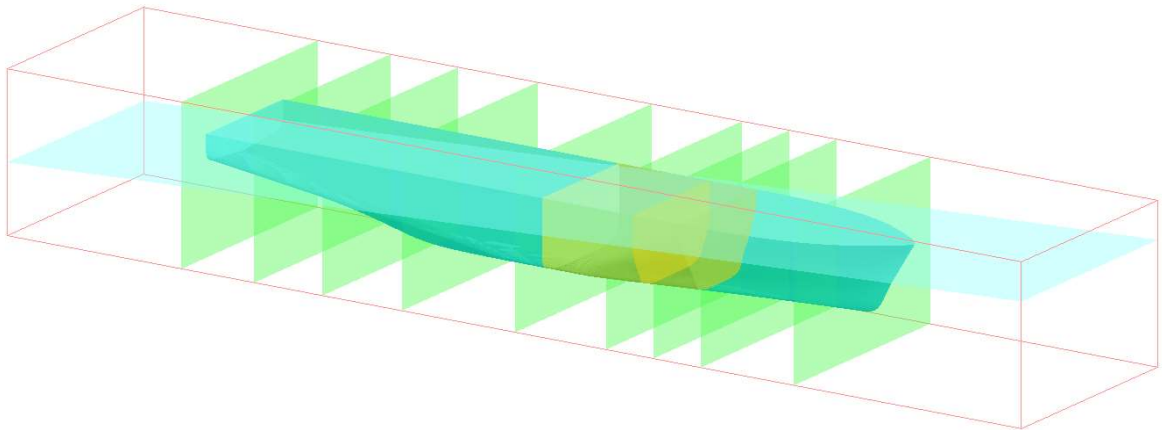


Figure 86 - Illustration of Damage Case 1

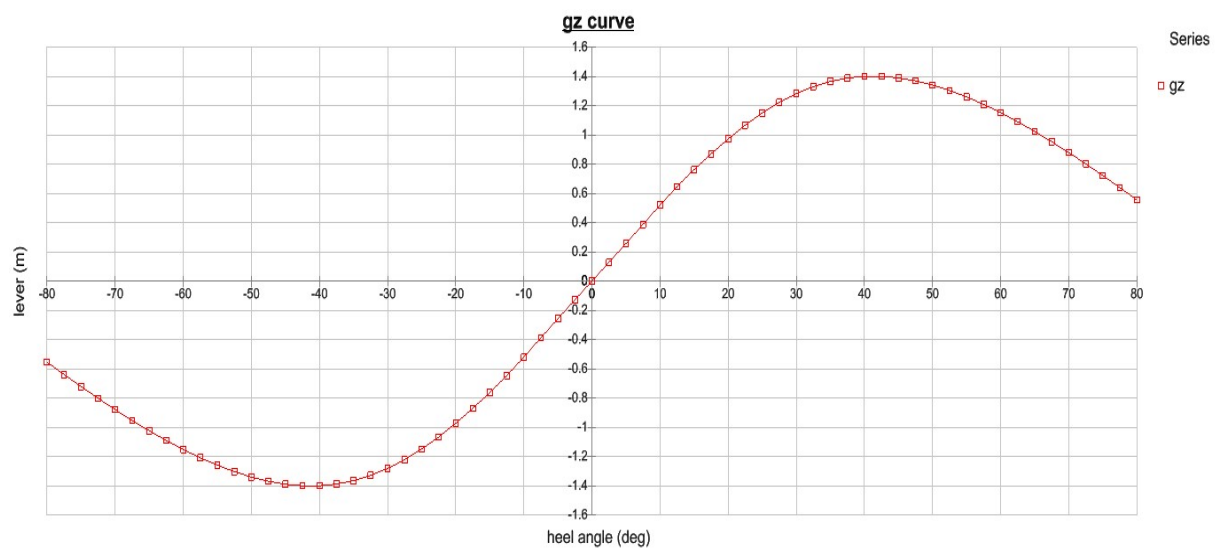


Figure 87 - GZ curve in Damage Case 1



12.5.1. DAMAGE CASE 5 - Compartment E & F

trim_BP (m)	mean_draught (m)	draught_AP (m)	draught_FP (m)	list_or_loll_angle (deg)	GMtf (m)
-1.819	7.223	6.313	8.133	-0.000	3.610
MARPOL CRITERIA					

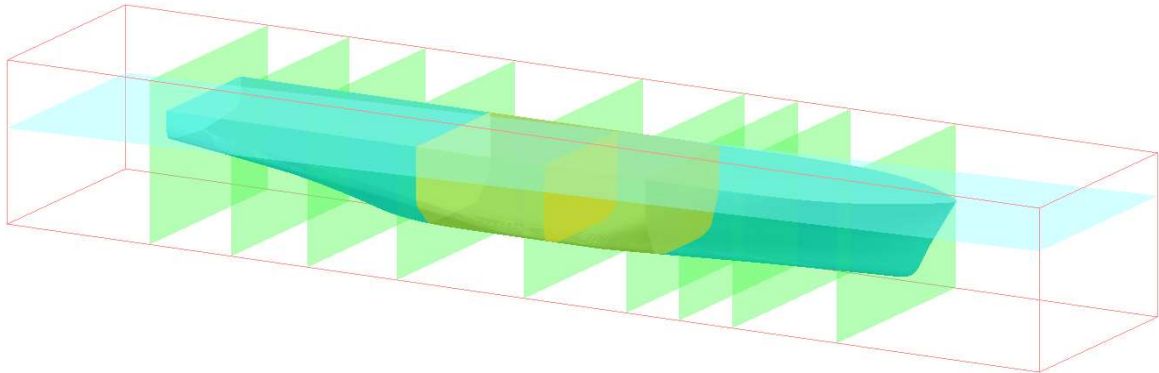


Figure 88 - Illustration of Damage Case 5

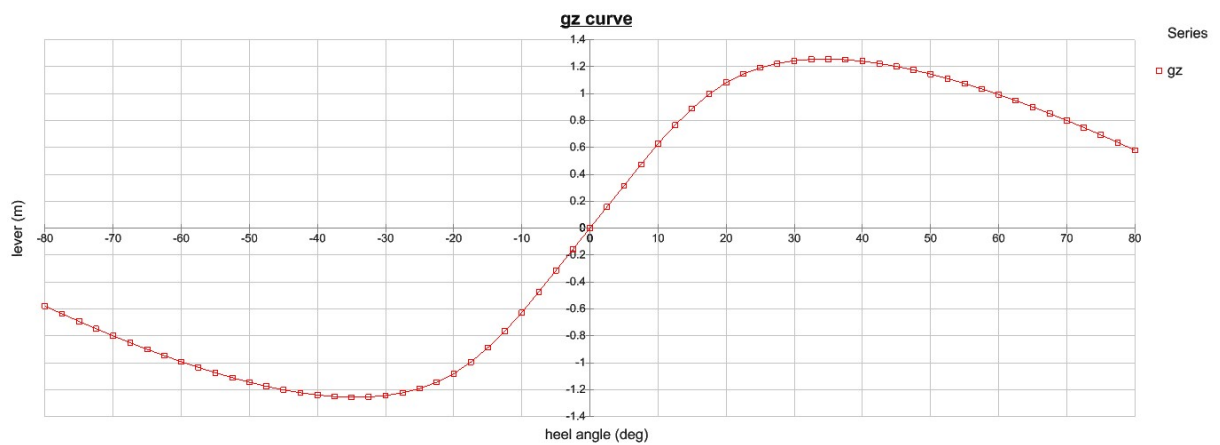


Figure 89 - GZ curve in Damage Case 5



12.5.1. DAMAGE CASE 6 - Compartment F & G

trim_BP (m)	mean_draught (m)	draught_AP (m)	draught_FP (m)	list_or_loll_angle (deg)	GMtf (m)
2.277	6.691	7.830	5.553	-0.000	2.965
MARPOL CRITERIA	PASS				

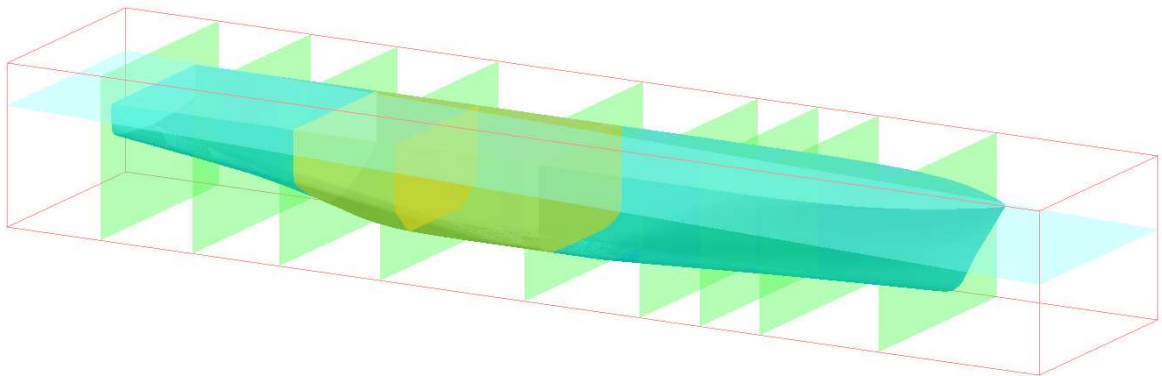


Figure 90 - Illustration of Damage Case 6

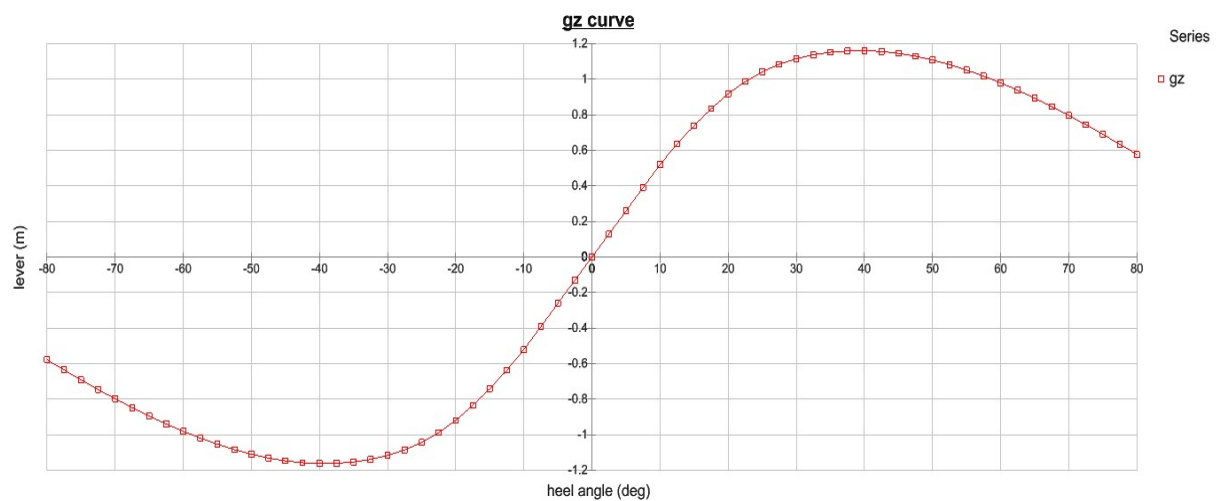


Figure 91 - GZ curve in Damage Case 6



12.5.1. DAMAGE CASE 7 - Compartment G & H

trim_BP (m)	mean_draught (m)	draught_AP (m)	draught_FP (m)	list_or_loll_angle (deg)	GMtf (m)
4.199	5.619	7.719	3.520	0.000	2.396
MARPOL CRITERIA					

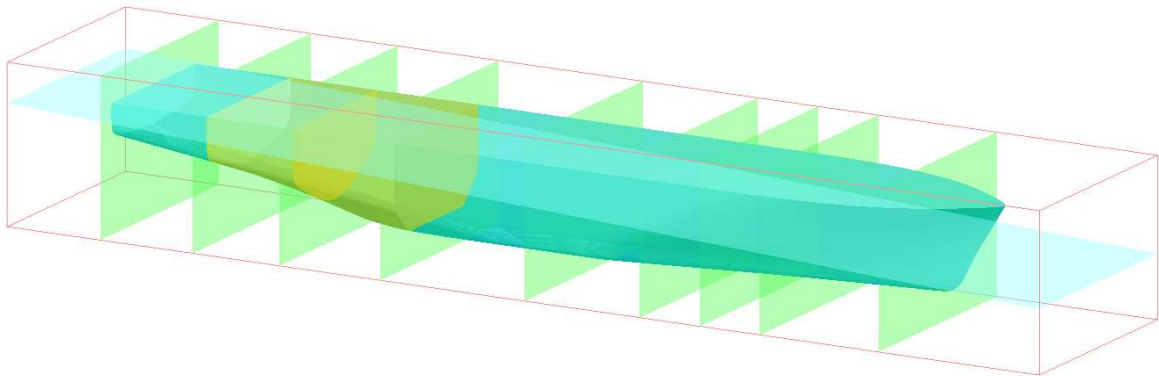


Figure 92 - Illustration of Damage Case 7

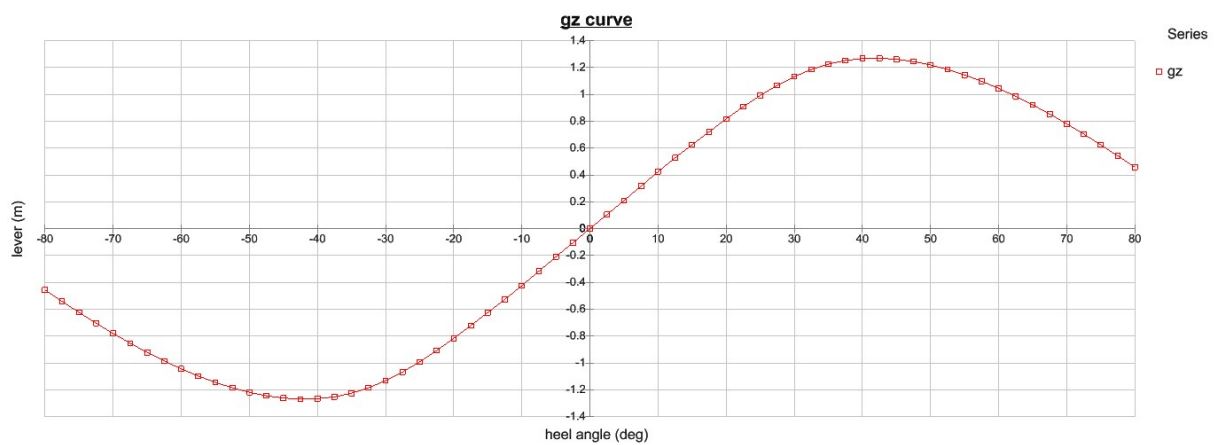


Figure 93 - GZ curve in Damage Case 7



12.5.1. DAMAGE CASE 8 - Compartment H & I

trim_BP (m)	mean_draught (m)	draught_AP (m)	draught_FP (m)	list_or_oll_angle (deg)	GMtf (m)
3.844	5.051	6.973	3.129	0.001	1.859
MARPOL CRITERIA	PASS				

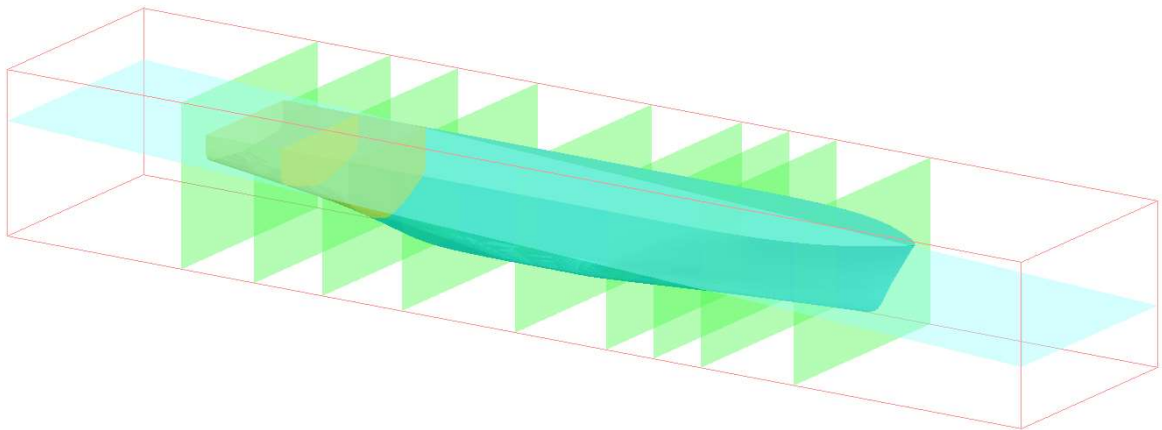


Figure 94 - Illustration of Damage Case 8

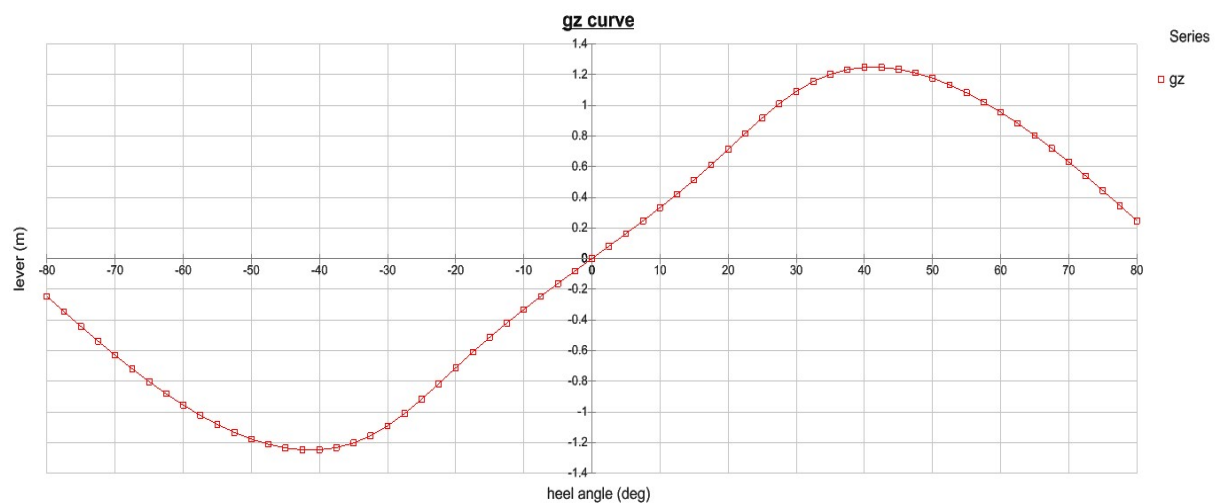


Figure 95 - GZ curve in Damage Case 8



13. Manoeuvring

A manoeuvring analysis has been conducted for project HYDRA in order to investigate critical performance criteria such as directional stability and response to helm angle.

The investigation is conducted as a simulation on the initial hullform in Paramarine. The Paramarine simulation uses linearized theory and does therefore not model non-linearity. A circle-manoeuvre simulation has been used to assess the directional stability of the ship. A zig-zag manoeuvre has been used to assess the response to a helm angle. The results are compared to the public available ABS criteria (American Bureau of Shipping, 2006)

13.1. Simulation

The simulation is conducted on the vessel in full loaded condition at start of life for the SUBSAR variant. The COG position and displacement is presented in section [M.13.1]. The GZ-curve is linked to the Paramarine model in order to determine permissible heel.

13.1.1. Circle manoeuvre

The circle manoeuvre is assessing the ships ability to turn. It uses a hard-over helm to its maximum permissible helm angle. This is assumed to be 20 [deg] due to the arrangement of the azimuth thrusters. Furthermore it is to be conducted at design speed; this has been selected as 14 knots based on the operational profile.

Criteria

The criteria is obtained from ABS (American Bureau of Shipping, 2006). ABS presents that IMO requires a tactical diameter to be less than five times the ship length, i.e. $D/LWL < 5$

Results

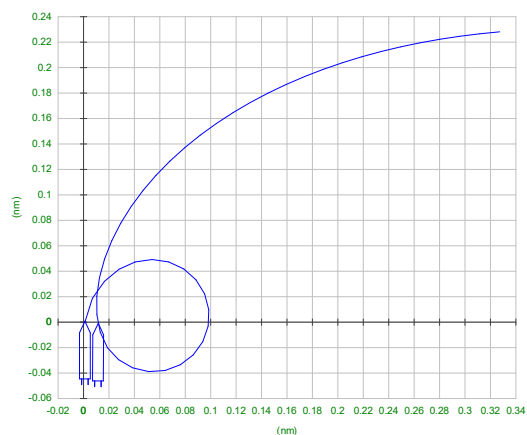


Figure 97 - Circle Manoeuvre simulation without skeg

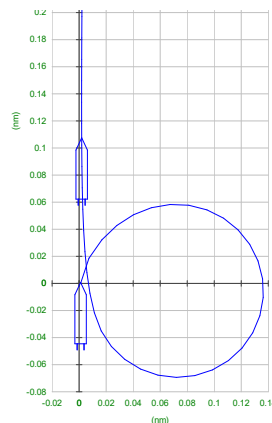


Figure 96 - Circle Manoeuvre simulation with skeg



The design was initially investigated without a skeg. The results of this, is shown in figure 97. This shows the ship to be inherently directionally unstable and portrayed the need for a skeg. The skeg was selected based on available space between the two rudders.

The design with the skeg was investigated and the results are presented in Figure 97. This shows the ship to be directionally stable. Furthermore, it is seen that the tactical diameter is approximately 0.13 [nm]. This results in $D/LWL = 2.88$, which passes the criteria.

13.1.2. Zig zag manoeuvre

The zig-zag manoeuvre assesses the ships response to an ordered helm angle. The principal is that a helm angle is ordered to portside, to which the ship initiate and follows the turn until its direction has reached the helm angle, there after the ship execute the same helm angle to starboard and hence produces a zig-zag trail.

The manoeuvre produce response and enables an assessment of the allowable overshoot. The ABS criteria has been used for this assessment. The assessment will be carried out for a 10/10 and a 20/20 manoeuvre as recommended by ABS (American Bureau of Shipping, 2006).

Criteria

ABS present the following rating based on the following ship parameters, C_b , LWL and speed (American Bureau of Shipping, 2006). The actual values have been inserted in the table:

Rating	10/10 Manoeuvre	20/20 Manoeuvre	Turning ability
Greater is better	First overshoot	Second Overshoot	First overshoot
1	Cannot be assigned due to initial criteria	$\alpha < 26.2$	$22.79 < \alpha < 25$
2		$\alpha < 26.2$	$17.54 < \alpha < 22.79$
3		$\alpha < 26.2$	$10.54 < \alpha < 17.54$
4		$\alpha < 26.2$	$5.29 < \alpha < 10.54$
5		$\alpha < 5.29$	$L_{10/10} < 136.105$

Table 65 - Manoeuvring criteria

Results

10/10 Zig-zag Manoeuvre – Helm angle by time

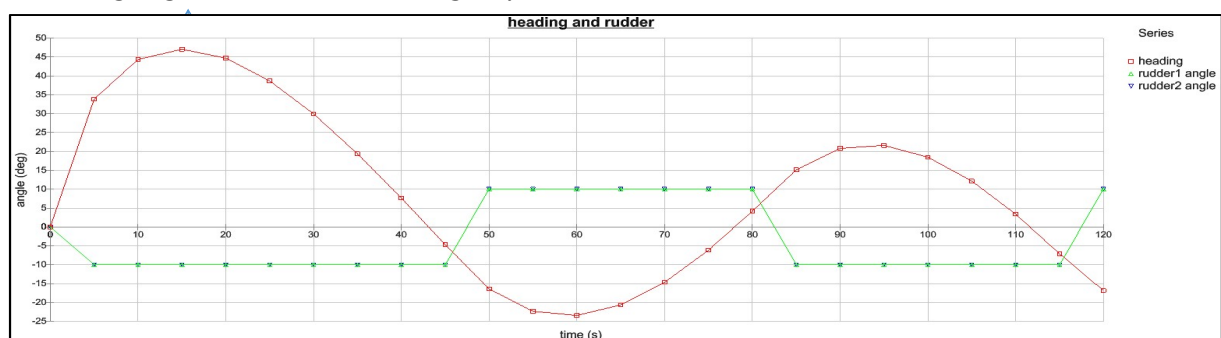


Figure 98 -10/10 Zig-zag manoeuvre - helm angle by time

From this it is seen that the ship complies with the second overshoot criteria for the 10/10 manoeuvre.



10/10 Zig-zag Manoeuvre – Helm by distance travelled

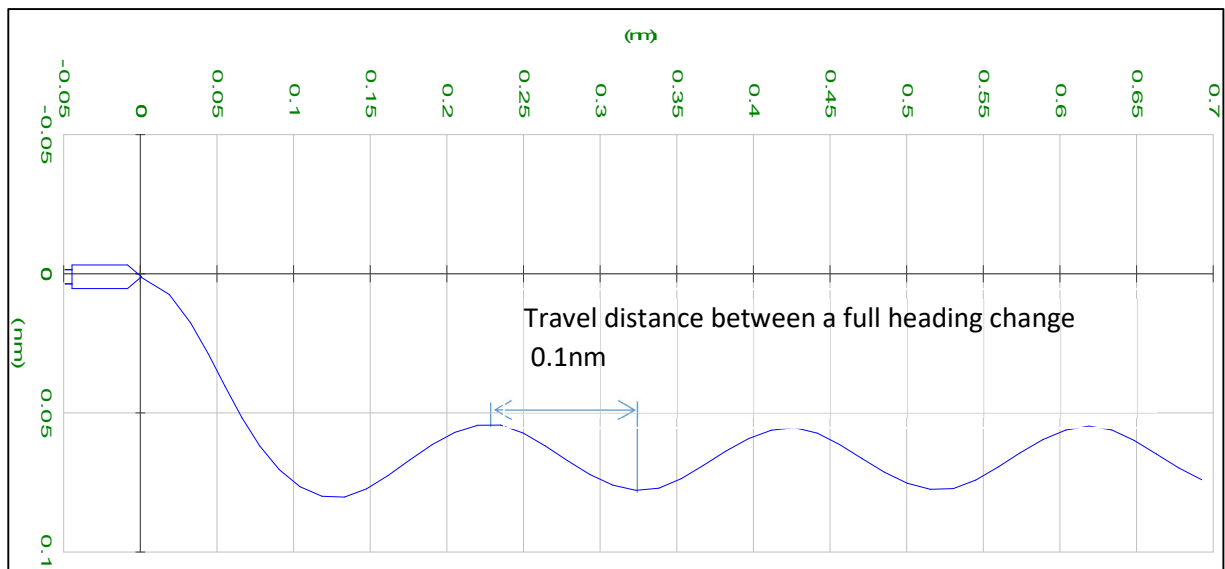


Figure 99 - 10/10 Zig-zag manoeuvre - helm angle by distance travelled

Thus, the vessel travel 185.2[m] to change course 10[deg], which is the second lowest rating, Rtd 2. However, it passes the minimum criteria.

20/20 Zig-zag Manoeuvre – Helm angle by time

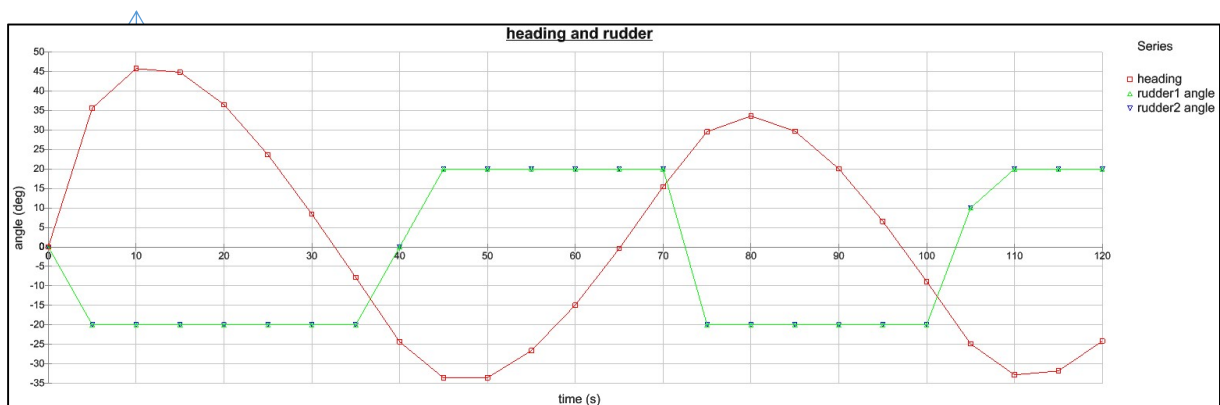


Figure 100 - 20/20 Zig-zag manoeuvre - helm angle by time

From this it is seen that the ship complies with the second overshoot criteria for the 10/10 manoeuvre.

Manoeuvring Discussion

The main issues with the above simulations is the construction of the simulation model. It has not been possible to do a final propeller selection, therefore the propeller-model used is not entirely representative of the actual configuration. In addition it is unknown whether 20 [deg] is the maximum helm angle. Furthermore the insertion of the selected skeg may not be geometrically possible, hence it requires further investigation.



14. Seakeeping

The following analysis is conducted to assess the seakeeping performance of the vessel. It includes an outlay of the intended missions and corresponding environments, the seakeeping criteria for each mission and an investigation of the performance in the corresponding environments.

14.1. Missions

The ship is expected to perform various tasks at each role. The following table is an outlay of all critical missions that requires seakeeping analysis. The most critical areas have been selected from this table and will be carried through to motion-analysis. This is done due to restrain on the scope of the project.

Platform	• Launch Towing Connection from Stern compartment • Ensure acceptable motions for embarked survivors during humanitarian aid
Research Vessel	• Launch and recover large scientific equipment (i.e. USV) using stern A-frame • Launch and recover small scientific equipment (i.e Bluefin UAV) • Deploy Towed Array from stern compartment • Deploy CTD from deck winch • Ensure safe work environment for scientist • Launch and recover 7m RHIB
SUBSAR Vessel	• Launch and recover NSRS • Deploy towed array for stern compartment • Ensure acceptable motions for rescued survivors • Ensure safe work environment for medical staff • Launch and recover 7m RHIB
Coastguard Vessel	• Launch and recover 11 m RHIB" • Provide stable land platform for helicopter • Launch and Recover Scan Eagle • Launch and Recover Towed array

Table 66 - Potential motion critical areas



14.2. Critical Areas

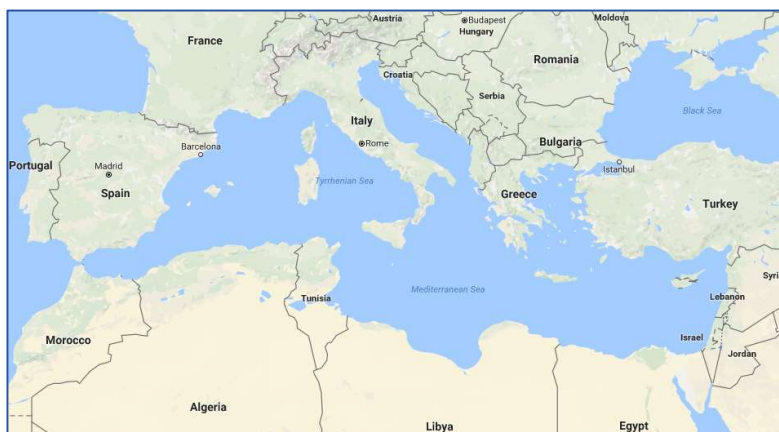
The table below presents the areas that will be investigated for seakeeping performance. The bridge and foremost accommodation is related to the platform. The foremost laboratory/medical/accommodation is a common critical area for all three variants, due to motion-sensitive human operations. The flight deck constitutes the most critical area for the Coast Guard and the A-frame operability is critical for the SUBSAR and Research variant.

Location	Longitudinal	Vertical	Issue	Performance
Bridge	66 m	03 Deck [18.25m]	Human operation	Criteria Determines sea states
Foremost Accommodation	Aft of Collision Bulkhead [60m]	2 Deck [7.55m]	Human comfort	Criteria Determines sea states
Foremost Laboratory/Medical facility /Accommodation	Aft of Collision Bulkhead [60m]	1 Deck [10.25m]	Human operation	Criteria Determines sea states
Flight Deck	Aft of Supers	1 Deck	Landing	Criteria Determines sea states
RIB deployment	Amidships		Deployment	Must deploy in sea state 3
A-frame Operation	Astern	01 Deck	Deployment	Must deploy in sea state 5

Table 67 - Investigated Motion Critical Areas

14.3. Environment

The ship is built to operate in the Mediterranean Sea at 350 days pr. year. A collection of all seasons wave statistics is obtained from (Hogben & Lumb, 1967). This is presented below. From this it is seen that Sea State 5 operability allows for 94% of time.



SEA STATE	OCCURRENCE	OPERATIONAL TIME
0	12136	14%
01	16693	32%
02	26040	61%
03	17312	80%
04	8482	89%
05	4658	94%
06	2344	97%



14.4. Criteria – Daisy

The following criteria are obtained from Daisy (UCL Naval Architecture Department, 2016)

	Lateral Acceleration	Vertical Acceleration	Roll	Pitch
Bridge	0.12 [g]	0.163 [g]	6	N/A
Foremost Accommodation	0.15 [g]	0.2 [g]	6	N/A
Foremost Laboratory/Medical facility /Accommodation	0.15 [g]	0.1 [g]	6	N/A
Flight Deck	0.08 [g]	0.2 [g]	3.2 [deg]	1.5
A-frame Operation	0.05 [g]	0.15 [g]	3	N/A

Table 68 - Seakeeping Criteria obtained from DAISY Procedure book (1994)

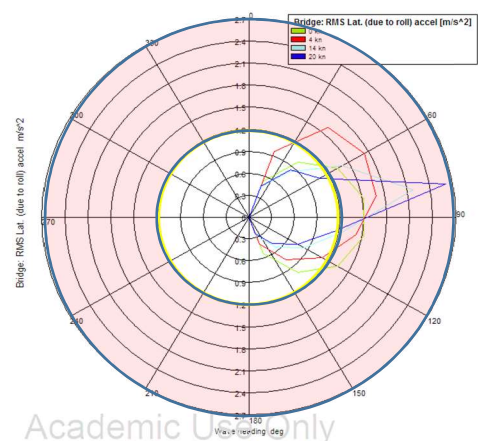
14.5. Motions

The motions of each area, which exceeds the criteria, has been shown below.

Bridge

The limiting motions at the bridge is the lateral acceleration at sea state 3. The limit is represented by a yellow ring in Figure 101. It is seen that most headings exceeds the limit at a certain speed, and it is clear that the ship is inoperable in beam seas.

It is expected that this criteria is too restrictive. In order to mitigate this issue, it is possible to install active-stabilisers or bilge keels, however this requires further investigation.





Foremost Accommodation

The foremost accommodation is limited by vertical acceleration in sea state 5 up to 4 knots. Due to the foremost location it is expected this is expected to be an issue.

It is clear that the vessel experiences large pitch motions in head seas due to the increase in wave encounter frequency.

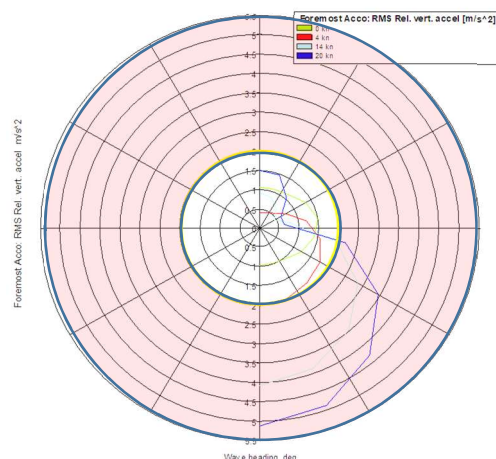


Figure 102 - Vertical acceleration at foremost accommodation in sea state 5

Foremost Operational Area

The foremost operational area is common for all three ships. It is limited by vertical acceleration in sea state 5 up to 4 knots. This evidently limits the ships ability to perform tasks during transit, which is an issue for the SUBSAR.

Similar to the foremost accommodation it is mainly an issue in head seas due to the increase in encounter frequency.

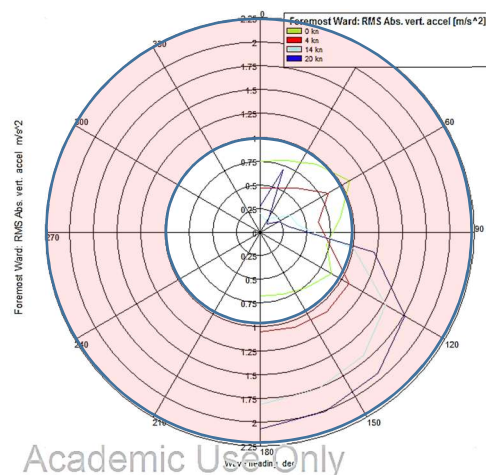


Figure 103 - Vertical acceleration at foremost operational area in sea state 5

Flight deck

The flight deck is solely installed on the HYDRA Coast Guard, however all variants must be able to conduct VERTREP. The flight deck is limited by the restrictive roll criteria of 3.5[deg]. It is seen that the ship will pass this criteria in with a 10[deg] span of head or following seas. It is therefore advised only to operate helicopter in this condition.

Non-related to the flight deck; it is seen that the roll motions exceeds the global ship criteria. The vessel itself is beamy and have a full midships section, thus the next mitigation action is to install active fin-stabilisers or bilge keels.

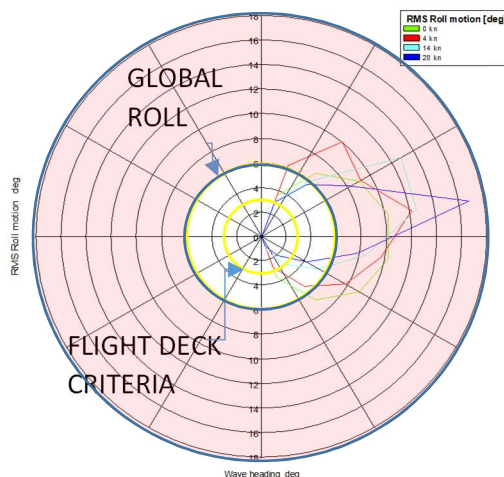


Figure 104 - Global roll in sea state 5



A-frame

A-frame investigation is only relevant for HYDRA Research and HYDRA SUBSAR. It is considered as a sensitive deck task and the criteria is therefore relatively restrictive. From Figure 105, it is seen to pass the criteria in sea state 5 in a 20[deg] heading span from head or following seas.

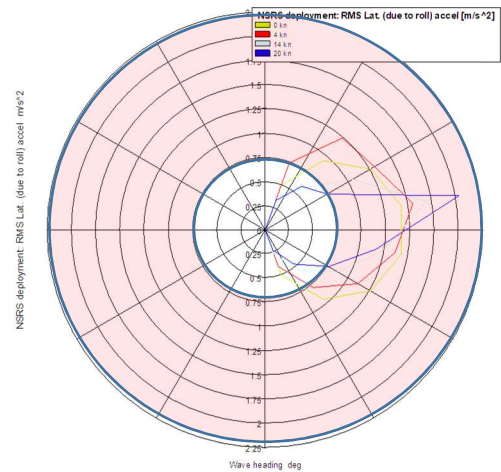


Figure 105 - Lateral acceleration at uppermost A-frame position in sea state 5

14.6. Summary table and performance

Exceedance of criteria is marked in by bold text.

	Lateral Acc.	Max. pass	Vertical Acc.	Max. pass	Roll	Max. pass	Operability
Bridge	0.12 [g]	Sea state 3 up to 14 knots	0.163 [g]	Sea state 5 - all speeds	6	*Sea state 5 in heads seas	80%
Foremost Accommodation	0.15 [g]	Up to sea state 6 – all speeds	0.2 [g]	Sea state 5 up to 4 knots	6	*Sea state 5 in heads seas	94%
Foremost Operational Area	0.15 [g]	Sea state 6 – all speeds	0.1 [g]	Sea state 5 up to 4 knots	6	*Sea state 5 in heads seas	94%
Flight Deck	0.08 [g]	Sea state 6 – all speeds	0.2 [g]	Sea state 6 – all speeds	3.2 [deg]	Sea state 5 in heads seas	94%
A-frame Operation	0.05 [g]	Sea state 5 in 0-20 deg head seas	0.15 [g]	Sea state 6 - alongside	3	Sea state 5 in heads seas	94%

Figure 106 - Seakeeping Summary Table

* Limiting for all cases. However should be mitigated by installing bilge keels or fin stabilisers.



14.7. Seakeeping discussion

The seakeeping analysis has shown that the vessel exceeds most criteria in sea state 5, thus becomes highly operable in the dedicated area. However it should be acknowledge that this is merely a preliminary investigation.

It is of utmost important that the NSRS for HYDRA SUBSAR is operable in sea state 5. The criteria chosen for this operation is based of manual work at working deck. In further investigations, this should be defined as the actual value for the NSRS.

It is seen that the vessel experience extremely large roll at 20 knots beam seas. This suggest that stabilisers will be beneficial, particularly for HYDRA Coast Guard that is likely to sail under these conditions. The full extent of the helicopter land-&-take off should be refined, to determine the full capability of the helicopter.

In relation to HYDRA Coast Guard, it is important to analyse the vessels seakeeping for bow emergence and potential green seas as it has sensitive equipment on the forwards open deck. Additionally this will reveal the slamming period for the vessel which could be a potential structural issue.

An extensive investigation should be conducted for motion sickness incidence in rough sea states. The ship will at most carry 260 people incl. crew, during a humanitarian rescue mission, at which motion sickness is highly undesirable.



15. Costing

The following report outlays the economic considerations related to the construction and service of the vessel. The report presents a detailed cost outlay of all items and associated labour in accordance with the WBS. This information is used for two detailed studies; the unit procurement cost (UPC) of the vessel and the vessel cost through life (TLC). This evidently sums as the overall cost of the vessel from laying the keel to scrap.

The UPC is equipped with a detailed Economic Risk Analysis to portray the additional cost margins of building the ship.

15.1. UPC Driver Layout

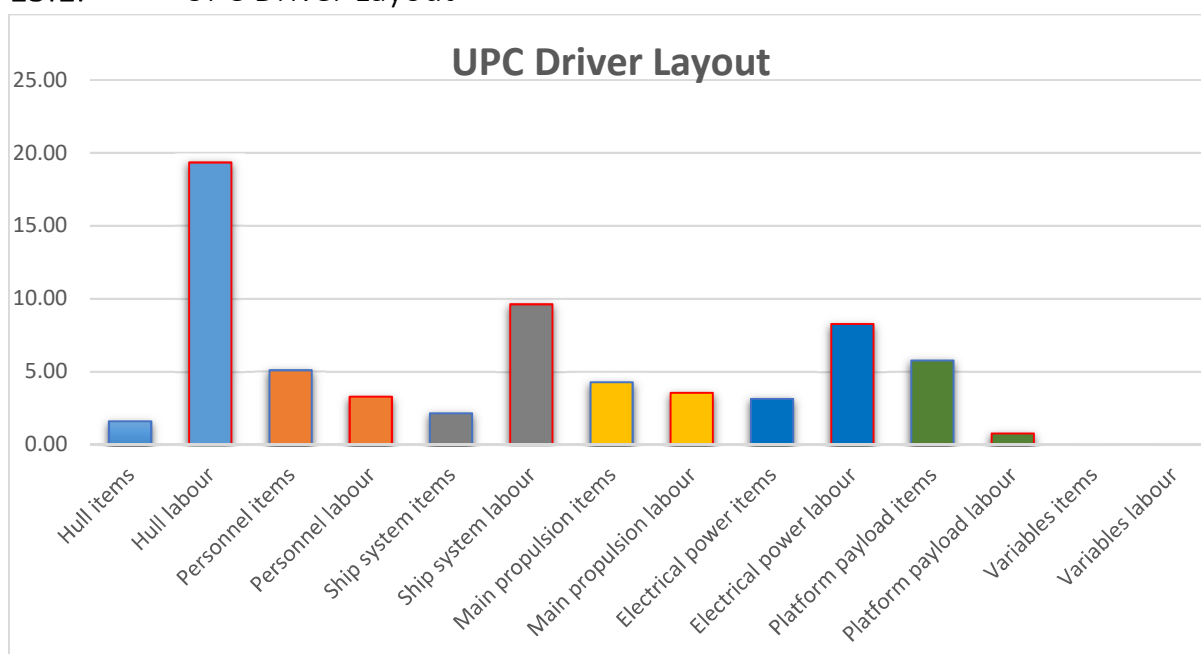


Figure 107 - UPC Driver Layout

The cost groups from 1 (Hull) to 5(Electrical power) is based of estimates from Daisy Data book. The estimates are presented as data from 2008, therefore 9 years of inflation has been added. The cost estimates for each payload, are based of Zenith data and commercial catalogues.

The above graph shows that labour hours is significantly driving the cost. Particularly in hull construction and instillation of ship systems and electric power equipment.

15.2. Unit Procurement Cost (UPC)

A unit procurement cost has been estimated for each vessel. The platform cost is dependent on the first 6 catagiores of the WBS, and the oayload

Driver	HYDRA Research	HYDRA SUBSAR	HYDRA Coastguard
Platform	£66.93 mil.		
Payloads	£20.68 mil.	£20.02 mil.	£28.56 mil.
Total	£87.61 mil.	£86.95 mil.	£95.49 mil.



15.3. Market Comparision

A market investigation has been conducted by the HYDRA Marine Engineer (Hunt, 2017). A comparison tho the unit procurement cost is presented in f

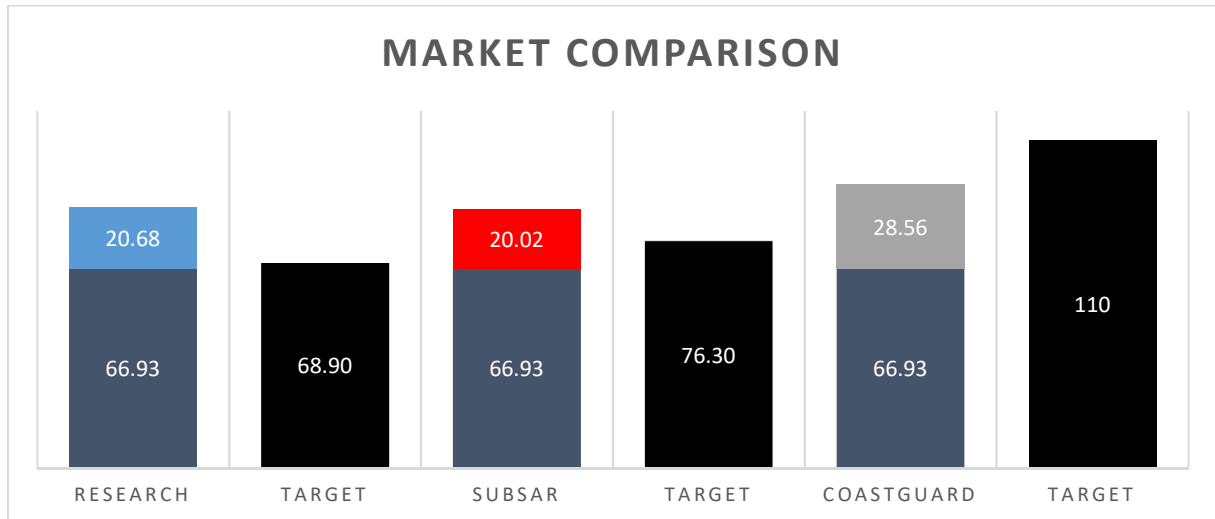


Figure 108 - Market Comparison

The above comparison in figure 108 shows that HYDRA Research and HYDRA SUBSAR is slightly above the target value. This is expected to be due to the high labour hour cost selected. HYDRA Coast Guard is the most expensive but slightly below the target value. This is supposedly due to a poor market analysis where some ships are extensively more armed than HYDRA Coast Guard.



16. Compliance with URD

	Description from appendix A	Solution	Mitigation
1.a	A common hull which can be completed as a coastguard vessel, research vessel or submarine rescue vessel. Once completed, there is no requirement to change role during the ship's life.	HYDRA is designed as a common platform adaptable at built to three variants: Research, SUBSAR and Coastguard Vessel.	
2.a.i	<i>HYDRA Coast Guard</i> Very broad area maritime surveillance (visual coverage of 4,000 square nm per hour) for EEZ activity control and piracy protection.	HYDRA Coast Guard provides 4 scan eagles to conduct 4000 nm ² pr. Hr. surveillance for 22 hours pr. day.	
2.a.ii	<i>HYDRA Coast Guard</i> Undertake Boarding, Inspection, Search and Seizure operations at as long a range as practicable (up to 100nm.)	2 x 7m RIBs in close range 2 x 11m RIBS in intermediate range 1 x 5 ton Helo for long range	
2.b.i	<i>HYDRA Research</i> Deploy large USV / semi-submersibles for hydrographic survey.	Light L&R in internal equipment davits system Medium L&R via deck cranes Heavy L&R via rail system and A-frame	
2.b.ii	<i>HYDRA Research</i> Support ocean science research work with laboratory spaces and a working deck to deploy ocean buoys.	HYDRA Research provides 180 m ² dry lab facilities, 120 m ² wet lab facilities 400 m ² working deck And 80 m ² equipment storage bay	
2.c.i	Embark and deploy the NATO Submarine Rescue System to recover the crew of a distressed submarine.	HYDRA SUBSAR provides organic a-frame, recompression chambers, and 400 m ² open deck to support remaining NSRS equipment required.	



2.c.ii	Provide medical care to the rescued submarine crew, at hyperbaric conditions if required	HYDRA SUBSAR provides a Tier 2 medical facilities including 19 IC wards, 8 resuscitation wards, laboratory facilities, and 35 seat hyperbaric chamber for medical treatment	It was decided not to incorporate a permanent operating theatre, due to the interruption with the workflow. SSK not SSN
3.a	Provide firefighting capability to other vessels and installations.	HYDRA Platform HPSW System is classed to Lloyd's Fire Firefighting Ship Class 1. Additionally the vessel has citadel and Prewet for self-protection	
3.b	Provide humanitarian rescue & evacuation on a large scale, including provision of medical aid.	All variants of HYDRA are capable of accommodating up to 200 personnel, in compliance with international guidance.	
3.c.	Tow disabled ships, up to the largest container ships and bulk carriers.	All variants of HYDRA are capable of towing the largest containership (20568 TEU) up to sea state 5.	Two hydra vessels are required in towing operations above sea state 5.
4.a.	The Mediterranean Sea	HYDRA is operable for the 97% of the time for the majority of task in area of operations.	
5.a.	30 days mission durations	HYDRA consumption stores are prepared for 30 day mission. HYDRAs endurance on DFO is 32 days at sea	For future fuel conversion the endurance reduces to 20-29 days at sea depending on fuel selection.
6.a.	Complement – Minimise complement	HYDRAs optimised minimum core crew is 31 personnel, based on a manning level analysis.	
6.b.	<u>Accommodation</u> - Crew accommodation commensurate with high commercial standards.	All HYDRA accommodation is made for high-level crew commercial standard. This includes ensuite single-cabins.	A number of crew cabins do not contain access to a porthole, due to layout constraints.
6.c.	Scientific / Medical Accommodation – Should be self-contained and physically separated from the crew accommodation.	All augmented crew are located in areas with designated passage way.	



7.a	Maximise availability on station per annum; availability to exceed 350 days per year available for tasking	Equipment sizing and systems design have been generated to provide 100% functionality with 50% of the system inoperable. Maintenance workshops and stores have been included for onboard maintenance((Hunt, 2017)	
8.a	Accept resupply of urgent stores/personnel by VERTREP	All have vessels have 400m ² open deck to conduct vertrep	
9.a.	40 years	The end-of-life displacement accounted for 21.6% growth margin. All systems have been sized for 20% in-service growth margin.	
9.b.	An in-service date of 2025 is required.	All technology are available as of 2017.	The fuel cells and diesel reformer are both emerging technologies, which may not be ready in time, therefore full diesel engine system has been sized for redundancy.
10.a.	No cost cap	Market research has been conducted and HYDRA initial costing has been competitively priced with market analysis.	
10.b.	Extended low speed loitering, capable of high speed dash for emergency response or to reach DISSUB site.	HYDRA propulsion system has been optimized to provide maximum fuel efficiency during low speed loitering operations. The hull form has been designed for 14 knots, with a propulsion system top speed of 20 knots.	
10.c.	Deep displacement at start of life (in any Role configuration) may not exceed 5,000 tonnes. If the required roles cannot be met on this displacement cap, a strong justification should be provided to resolve the conflict.	None of the HYDRA variants exceed the displacement cap/	
10.d.	Should design assuming that carbon-containing fuels will increase by an unknown amount between 200% and	HYDRA's tank and engines configuration have been designed to easily convert to any potential future fuel,	



	500% by 2085, assuming linear increase per year. Strict future emissions regulations should be considered likely during the life of the ship; design to minimise the risk of having to scrap ships early.	regardless of flash point, in accordance with Lloyd's Regulations.	
10.e.	Assume that collision is likely during the ship's life and design to continue operations post collision damage.	HYDRA is designed for 2 zones division. Damage case stability has shown operational for any two compartment damage.	In the event of midship collision, loss of both engine room, the vessel we be limited to battery operations to a maximum of 145 nm at 7 knots.
10.f.	Must have sufficient gas protection to provide rescue/firefighting services to gas carrier vessels.	HYDRA is designed with Prewet system and Citadel, including cleansing stations and airlocks.	
10.g.	Consider unoccupied vehicles for contributing to surveillance task. Should be able to operate four 11m RIB/semi-submersible USVs in the survey task.	1. 4 UAV for HYDRA Coast Guard 2. 2 x 11m RIBS 3. 4 x USV 6000 for HYDRA Research	Discussion with clients reduced requirement from 4 x 11m RIBs to 2 x 11m RIBS and 2 x 7m RIBs
10.h.	Scientific facilities should be designed for ease of modification through life. Submarine rescue vessel should be designed to easily accept NSRS successor rescue vehicle, as yet not designed.	HYDRA Research design incorporates ease of accessibility for equipment change. HYDRA SUBSAR provides 400m ² working deck for future NSRS replacement.	
10.i.	Multihulls should be considered, and the choice of hullform justified.	Four hull form types have been considered. Through SWOT analysis and Weight-Score analysis, justification has been to design monohull.	



17. Project Discussion

The HYDRA project has proven a design that is capable of being built as three distinguished variants. The operational analysis showed significant commonality across the three special-purpose variants; HYDRAs general layout was selected as a factory floor. HYDRA SUBSAR and HYDRA Research required a large open-deck, hence it was sensible to utilize this as flight deck for the HYDRA Coast Guard. The large open internal space also showed commonality, by the coast guard and research ship requiring large open hangars or equipment bay, which was utilized as a hyperbaric chamber / saturation diving compartment for the SUBSAR ship. It is deemed that the capability deck was a sensible decision based upon these two arguments, however it also introduced some significant limitations;

The remaining forward part of the capability deck was utilized as a dry-lab area for the research vessel. The size of the laboratory facilities was based on a SNAME document. The SUBSAR vessels was determined to provide medical facilities for 30 submariners. The required area for a tier 2 hospital of 30 people showed to be similar, to that of the dry lab. However, this also included a operating theatre. The operating theatre was deemed to destroy the visualised work flow of the SUBSAR, and was therefore neglected, which constituted a significant loss for the SUBSAR. At the point of discarding the operating theatre, the vessel had been sized to accommodate for the space. This space was converted into a diving equipment maintenance room.

The SUBSAR and research vessel both included 7m RIBs as marshalling crafts, it was therefore considered sensible to transfer this to the coast guard. This resulted in a removal of the requirement of 4 x 11m RIBs to 2 x 11m RIBS and 2 x 7m RIBs. This decision significantly improved the commonality of the capability deck.

Returning to the operational analysis it was found that despite finding large commonality in required volume between the vessels, the individual ship type's operational profile varied extensively. It was determined to design the hull form for the most average work speed across the variants, 14 knots. This however meant that the research vessels hull was designed to go faster than necessary.

The obtained resistance, for a hull form designed for 14 knots, allowed for an innovative main propulsion arrangement as a combination of fuel cells and diesel engine. However it was acknowledge that fuel cells has not yet been commercialised, hence the solution is a risk to the 2025 in-service date. In relation to this it was shown that the selected propulsor was estimated to achieve 110 [ton] bollard pull, based on other similar propulsors. Despite serious effort, it was not possible to have this confirmed by the supplier. The selected propulsion arrangement may therefore require a revisit.

The project has suffered to the author's inexperience with the university recommended Paramarine software. The majority of the future work that is suggested, is primarily due to this incapability.



18. Future Work

Due to a small design team, compared to previous UCL SDE teams, there was a number of analysis that could easily have been done to improve the project. These analysis was deemed of lower priority due to their significance on the overall project. It is acknowledge that the design is currently as concept stage. Hence the following will solely present future work that will complete the concept stage.

1. The humanitarian aid capability have been implemented throughout the design. However a final improvement can be made by producing a **plan for a maximum humanitarian aid** scenario, i.e. 200 survivors.
2. The vessel have been proven to be capable of achieving the towing requirement, however it could be **improved by structural reinforcement analysis** in this area.
3. The hull form was proven not to be entirely accurate due to limitations of the rapid hull form generation method in Paramarine (Qinetiq, Hampshire). All **hull form related analysis** should be updated for the correct shaped hull form.
4. **The stern shape** was not able to refined, due to incapability in Paramarine (Qinetiq, Hampshire).
5. From the uncertainty of the propulsor selection, due to limited information from the supplier it was deemed of lower priority to **select a propeller** for the vessel. However this will not interfere with the docking arrangements, as the maximum allowable propeller diameter for the selected is 4.2 [m].
6. The layout have proven sufficiently capable of conducting the designated tasks, however for all variants can be radically improved by having the capability deck layouts **revised by personnel for the industry** of each variant. It is acknowledge that the pilot accommodation for HYDRA Coast Guard is not ideal.
7. The intact stability was carried out from a first-principle basis due to constrain in Paramarine (Qinetiq, Hampshire). It is acknowledge that this requires improvements by **inserting the tanks** and obtaining the actual free surface correct.
8. Similarly **the damage case stability** was solely conducted for the worst-case scenario, however in order to understand the vessel extended survivability at post-collision it is necessary to significantly extend this analysis.
9. The structural weight estimate proved to be similar to a warship structure, and differentiate far from a commercial vessel. **The structural analysis** should therefore be conducted on a commercial basis.
10. **The cost analysis** was conducted on a top-level basis. For concept stage this should be extended to more effort in market analysis, unit procurement cost of each selected machinery and a final through life cost.



19. Conclusion

Project HYDRA has presented the feasibility of a platform design for three variants. It has proven that this design approach is only possible when large commonality exist between the general ship types. Furthermore, it is seen that for the difference between the ship types it is necessary to conduct trade-offs. The trade-offs undertaken for project HYDRA has not produced poor designs, due to the philosophy of increasing capability across the variants, instead of limiting. As an example, the research vessel is capable of sailing 20 knots.

HYDRA Research was designed capable of accommodating 30 scientists, with an individual drylab for each scientist. Furthermore 2 large wet laboratories were incorporated. The equipment bay L&R system extended from a light-deployment system internally to a heavy A-frame and rail system on the open deck. The factory floor visualisation proved particularly well for this variant.

HYDRA SUBSAR was designed capable of rescuing SSK submarines (up to 35 crew). The variant offered hyperbaric treatment for all personnel, or traditional medical treatment facilities. The factory floor visualisation proved to be functional for this vessel, however it was deemed necessary to discard the operational theatre due layout complications. It was suggested to conduct further analysis in implementing this.

HYDRA Coast Guard was designed capable of providing surveillance up 4000nm² pr. hour and boarding operations up to 100 nm. Scan Eagles was found to be the optimal solution for surveillance, due to its low cost and long endurance. The boarding operations was divided into ranges, from which ships boats was suggested for close range boarding operations and helicopter flight for long range boarding operations. A URD requirement for the 11m RIBs was found to be driving the overall platform design and was therefore discarded, on acceptance of the costumer.



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21. Appendix

21.1. Appendix A – User Requirement Document

(The following document is written by the costumer)

MSc NAVAL ARCHITECTURE and MSc MARINE ENGINEERING

2016-17 SHIP DESIGN EXERCISE

OUTLINE REQUIREMENTS

USER REQUIREMENT DOCUMENT (URD)

GROUP 3: MEDITERRANEAN MULTIROLE COASTGUARD SHIP

1. ROLE

- a. A common hull which can be completed as a coastguard vessel, research vessel or submarine rescue vessel. Once completed, there is no requirement to change role during the ship's life.

2. PRIMARY TASKS

Conduct ONE of the following sets of tasks, chosen at build:

- a. Coastguard
 - i. Very broad area maritime surveillance (visual coverage of 4,000 square nm per hour) for EEZ activity control and piracy protection.
 - ii. Undertake Boarding, Inspection, Search and Seizure operations at as long a range as practicable (up to 100nm.)
- b. Oceanographic & Scientific Research
 - i. Deploy large USV / semi-submersibles for hydrographic survey.
 - ii. Support ocean science research work with laboratory spaces and a working deck to deploy ocean buoys.
- c. Submarine Rescue
 - i. Embark and deploy the NATO Submarine Rescue System to recover the crew of a distressed submarine.
 - ii. Provide medical care to the rescued submarine crew, at hyperbaric conditions if required.

3. SECONDARY TASKS

- a. Provide firefighting capability to other vessels and installations.
- b. Provide humanitarian rescue & evacuation on a large scale, including provision of medical aid.
- c. Tow disabled ships, up to the largest container ships and bulk carriers.
- d.



4. AREA OF OPERATIONS

- a. The Mediterranean Sea

5. DURATION OF MISSION

- a. 30 days

6. COMPLEMENT AND ACCOMMODATION

- a. Complement – Minimise complement
- b. Accommodation - Crew accommodation commensurate with high commercial standards.
- c. Scientific / Medical Accommodation – Should be self-contained and physically separated from the crew accommodation.

7. ARM

- a. Availability Reliability & Maintainability (ARM) – Maximise availability on station per annum; availability to exceed 350 days per year available for tasking.

8. RESUPPLY POLICY

- a. Replenishment At Sea –Accept resupply of urgent stores/personnel by VERTREP

9. SHIP LIFE AND IN SERVICE DATE (ISD)

- a. Ship Life – 40 years
- b. ISD – An in-service date of 2025 is required.

10. CONSTRAINTS / SPECIAL STUDIES

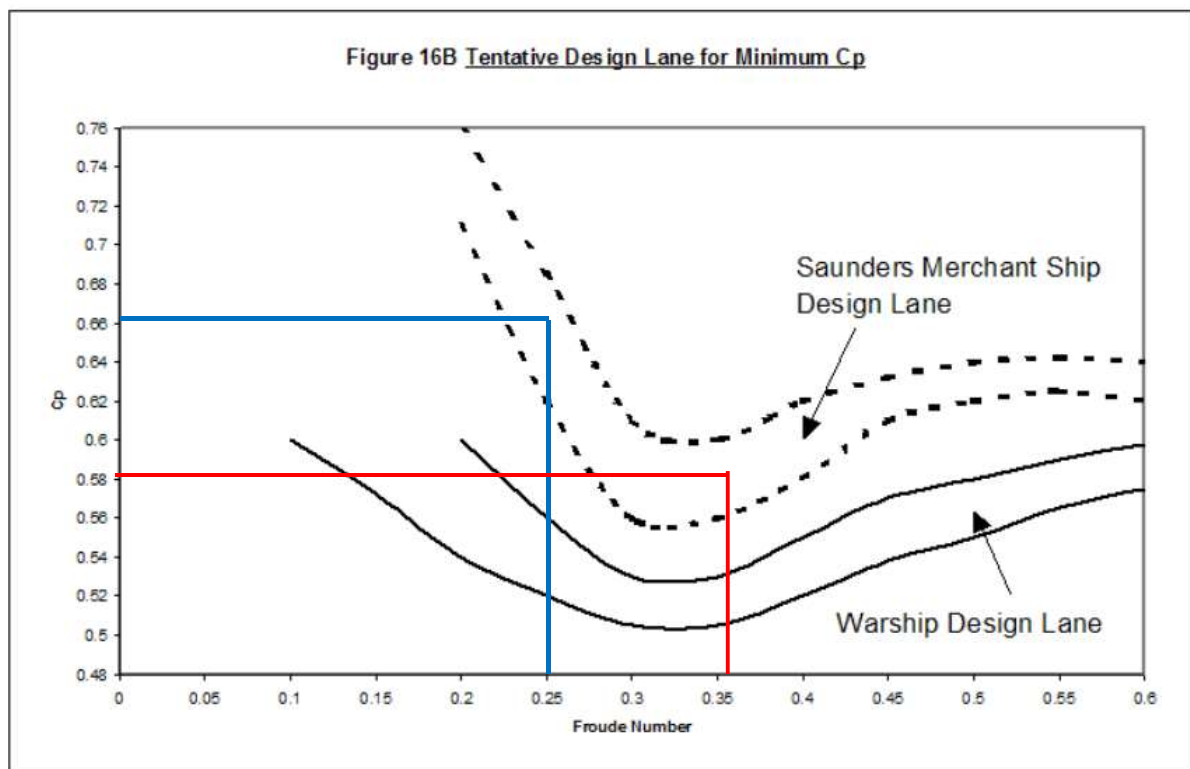
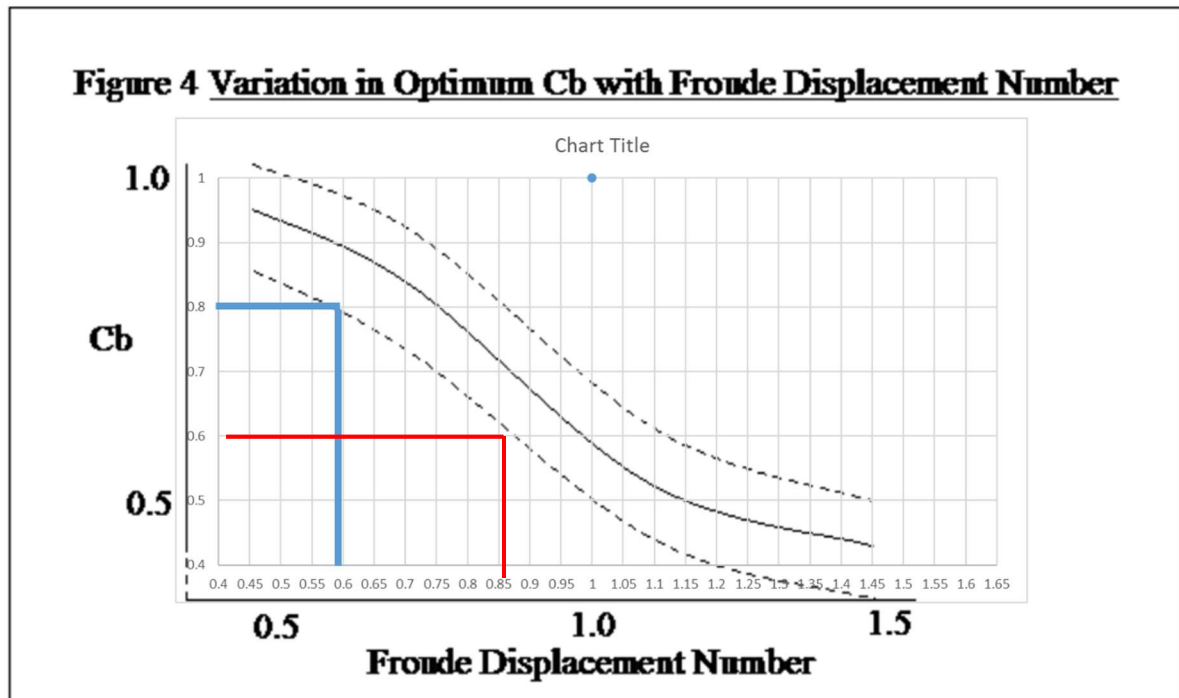
- a. Cost – No cost cap
- b. Speed – Extended low speed loitering, capable of high speed dash for emergency response or to reach DISSUB site.
- c. Displacement – Deep displacement at start of life (in any Role configuration) may not exceed 5,000 tonnes. If the required roles cannot be met on this displacement cap, a strong justification should be provided to resolve the conflict.

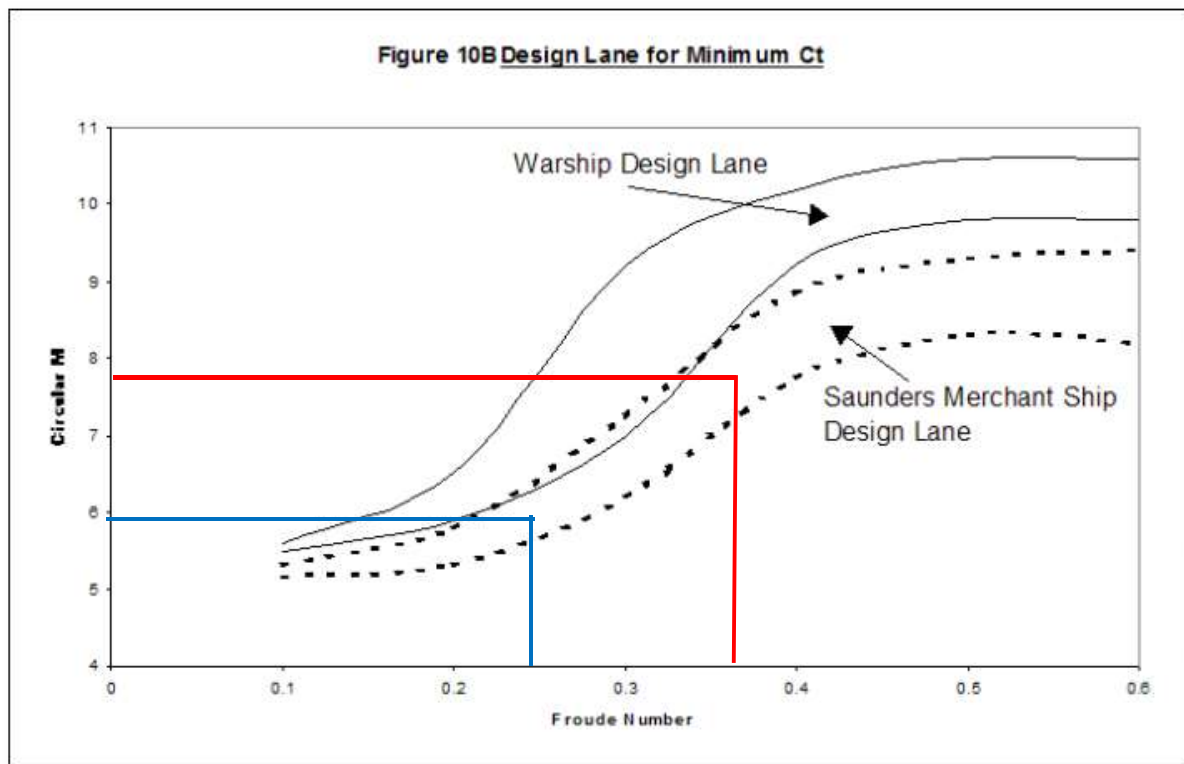


- d. Future Fuels and Emissions – Should design assuming that carbon-containing fuels will increase by an unknown amount between 200% and 500% by 2085, assuming linear increase per year. Strict future emissions regulations should be considered likely during the life of the ship; design to minimise the risk of having to scrap ships early.
- e. Vulnerability Reduction – Assume that collision is likely during the ship's life and design to continue operations post collision damage.
- f. Design for CBRN – Must have sufficient gas protection to provide rescue/firefighting services to gas carrier vessels.
- g. Unoccupied Vehicles (UXVs) – Consider unoccupied vehicles for contributing to surveillance task. Should be able to operate four 11m RIB/semi-submersible USVs in the survey task.
- h. Technology Insertion / Mid-Life Update – Scientific facilities should be designed for ease of modification through life. Submarine rescue vessel should be designed to easily accept NSRS successor rescue vehicle, as yet not designed.
- i. Hullform – Multihulls should be considered, and the choice of hullform justified.
- j. Power Systems – No requirement
- k. Signatures – No requirement



21.2. Appendix B - Parametric Survey Graph Read
Volumetric displacement = 3489 [m³]







21.3. Appendix C - Updated Weigh Breakdown Structure (Incl. positions)

Group		Category		Zenith		Description		Quantity		Cost Factor		Area		Volume		Weight		Weight		LCG		VCG		TCC		Displacement		Displacement		Displacement			
1	Hull																																
11 Fittings	115 Depository	113 Telephone Exchange	1			3.74	$3.25 + (0.02 \times 10^{-4} \times \nabla G)$	10.09		3.32	$1.31 + (2.15 \times 10^{-4} \times \nabla G)$	51	12.85	-2	169.46	43.03	4																
		113 Ty Broadcast	1			7.50	GIVEN	21.33		2.00	$6.40 \times 10^{-3} \times \nabla G$	51	12.85	-2	102.00	25.90	-																
		113 Internal Comms MISC	1			0.00	GIVEN			0.00	$80 \times \left(\frac{H}{15}\right) \times \left(\frac{M}{15}\right)^{\frac{4}{3}}$	51	12.85	-2	0.00	0.00	0																
		114 Masts	1				Depends on area																										
		115 Miscellaneous Fittings	1			0.00	GIVEN	0.00		21.91	$2.34 \times 10^{-3} \times \nabla G$	0.00	0.00	0	0.00	0.00	0																
		121 Navigation Bridge	1			28.14	$14 + (0.738 \times 10^{-3} \times \nabla G)$	75.97		0.66	$0.64 + (3.44 \times 10^{-3} \times \nabla G)$	66	18.35	0	63.50	17.65	0																
		122 External Pilotage Position	2			0.00	GIVEN			0.60	GIVEN																						
		123 Chart Room	1			5.00	GIVEN	13.50		0.60	GIVEN																						
		124 Gyrocompass Room	1			11.00	GIVEN	29.70		7.00	GIVEN																						
		124 Gyrocompass Room	1			11.00	GIVEN	29.70		7.00	GIVEN																						
12 Navigation	125 Miscellaneous Navigation	125 Miscellaneous Navigation	1			0.00	GIVEN	0.00		1.90	$2.7 + (5 \times \frac{G}{G_{WH}})$	0.00	0.00	0	0.00	0.00	0																
		131 Anchors and Cables	1			1.00	$1 \times A$	2.70		24.00	$(24 \times A)$	85	10.425	2	200.00	250.20	48																
		132 Chain Locker	1			12.39		34.00		6.00	$(6 \times A)$	85	10.425	2	510.00	62.55	12																
		141 Routine & Ship's Office	1			18.73	$7.5 + (1.2 \times 10^{-3} \times \nabla G)$	50.88		1.39	$0.5 + (9.5 \times 10^{-3} \times \nabla G)$	62	15.65	3	86.14	21.74	4																
		143 Combined Technical Office	1			18.73	$7.5 + (1.2 \times 10^{-3} \times \nabla G)$	50.88		1.46	$0.6 + (1 \times 10^{-4} \times \nabla G)$	51	12.85	-2	78.55	19.89	-																
		151 Integrated Workshops	1			16.38	$(1.75 \times 10^{-3} \times \nabla G)$	44.24		2.34	$(0.25 \times 10^{-3} \times \nabla G)$	40.9	7.55	-5	95.79	17.67	-11																
		152 Electrical Maintenance	1			6.00	$(6.5 \times 10^{-4} \times \nabla G)$	16.43		0.41	$(6.5 \times 10^{-3} \times \nabla G)$	37.2	7.55	-3	10.59	4.59	-1																
		153 Battery Charging	1			7.00	GIVEN	18.90		0.70	GIVEN																						
		16 Structure	162 Superstructure	161 Hull Structure	1		0.83	0.356	160.89		0.00	GIVEN	0.00		674.46	$0.0025 \times \nabla G$	41.024	5.795	0	270.0256	389.43	0											
		163 Seats and Supports		1			1.65		475							11796.02	2988.69	11796.02	2988.69	0													
171 Naval Store 1	1																																
17 Stores	Naval Store 2	Spare Gear and Bussins Store Portside	1			58.03				156.63		17.9	7.55	5	129.88	54.70	3																
		172 Spare Gear and Bussins Store Starboard	1			21.22	$2.5 + (2 \times 10^{-3} \times \nabla G)$	37.30		3.06	$0.5 + (6 \times 10^{-4} \times \nabla G)$	21.8	7.55	-5	66.88	23.09	-1																
		173 Awaiting Deck and Heavy Store Spaces	1			17.43	$9 + (9 \times 10^{-4} \times \nabla G)$	47.03		3.06	$1.5 + (7 \times 10^{-4} \times \nabla G)$	37.25	7.55	-6	37.25	23.09	-1																
		174 Paint and Inflammables Store Spaces	1			10.68	$6 + (0.5 \times 10^{-3} \times \nabla G)$	28.84		3.78	$0.5 + (3.5 \times 10^{-3} \times \nabla G)$	87	7.55	0	70.64	26.51	0																
		175 Diving Gear Store Spaces	1																														
		18 Miscellaneous Hull	181 Access	181 Access	1			519.33	$(0.07 \times \nabla G)$	140.274		29.69	$(0.001 \times \nabla G)$	60	10.25	0	1781.26	304.90	0														
		182 Paint		1			0.00	GIVEN			20.60	$(2.2 \times 10^{-3} \times \nabla G)$	44.5	5.795	0	516.53	118.15	0															
		183 Ship Control Center		1			32.00	GIVEN	86.40		2.00	GIVEN	36.4	7.55	5	72.80	15.10	1															
		184 Voids and Watertight Compartments		1			86.48		234.05		0.00					0.00	0.00	0															
		185 Solid Ballast and Bioproy		1																													
186 Solid Ballast and Bioproy	186 Solid Ballast and Bioproy	1																															
	187 Solid Ballast and Bioproy	1																															
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	200 Solid Ballast and Bioproy	1					</																										

Page 164 of 189



Wideline		Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7		Group 8		Summary															
Group 3		Ship Systems																		light ship													
		Description		Comment		Rating		Cost		Labour		Area		Volume		Weight		Weight		LCG		VCG		TCG		Moment about Y-axis		Moment about Z-axis		Moment about X-axis			
						Factor		£		Hours		[m²]		[m³]		[tonne]		Formula		[m]		[m]		[m]		[kNm]		[kNm]		[kNm]			
31 HVAC		311 APU's and Fan Rooms		A		0.243						47.11		10 + 25 x 10.3 Vw²		32.39		22 + 0.7 x 10.3 Vw²		37.5		7.625		1214.650656		246.978967		0		0			
		312 Chilled Water Plants 1		A		0.006						150.05		.8079 3.3528y+107.2+2x		405.13		11.40		22.5		4.85		26.5		55.29		0		0			
		312 Chilled Water Plants 2 & 3		A		0.0075												22.80		63.5		4.85		147.8		110.58		0		0			
		313 Chilled Water Distribution		A		0.089												11.88		44.5				528.405089		0		0		0			
		32 Sea and Fresh Water Systems		Desalination - 3 ROD UNITS		A		0.032				23.95				64.66		Jarett		4.20		58.5		4.85		-2		245.7		20.37		-8.4	
				Freshwater Distribution		A		0.089				28722.74		Nil		Nil		Nil		11.88		44.5		528.405089		0		0		0		0	
				Seawater Pumps		A		0.060						5.00		13.50		1.5x1.5x1.5		8.00		41.3		4.85		0		330.4		38.8		0	
				Seawater Pumps Distribution		A		0.0075				0.107		Nil		Nil		Nil		14.22		44.5				632.8753181		0		0		0	
		33 Fuel Systems		331 Fuel Processing Plant		A		0.084				16923.50		Nil		Given		Nil		8.35		58.5		4.85		0		0		0		0	
				332 Fuel Distribution		A		0.0100				0.134		Nil		Given		Nil		13.36						(0.1 x L) (0.16 x L)		0		0		0	
34 Hydraulic Systems		341 Hydraulic Power Packs		A						50.00				135.00		6.00		6.00		5.2		7.55		4		31.2		45.3		24.2			
		342 Hydraulic Distribution		A										Nil		Nil		0.50		5.2		7.55		4		3.775		2.6		3			
35 Compressed Air Systems		351 Air Compressors		Fresh air for machinery systems		A		0.072		7836.74		14.55		29.10		2.3x2.3x2.5		6.00		25		7.55		3		150		45.3		18			
		352 Compressed Air Distribution		A		0.0120		0.062				Nil		Nil		Nil		5.20		75		7.55		3		129.88552		39.248327		15.58602625			
		361 Sewage Treatment		A		0.165		15720.25		34.42		92.93		4.27x2.7x7.5		22.00		Jarett		27		4.85		-5		594		106.7		-31.1			
		362 Garbage Disposal		A		0.0075		0.003		4.03		0.0022 x NS		10.87		0.46		0.00025 x NS		58.5		4.85		-2		26.76375		2.228875		-0.917			
37 Roll Stabilisation		371 Active Roll Stabilisation		Random selected model		B		0		-4818.00		11.73		2.27x1.7x1.5		19.60		5.8 pr Stabiliser		44.5		4.85		0		872.2		95.06		0			
		362 Passive Roll Stabilisation				A																											
		Seals and supports		Total				2.39		160212.83		329.10				907.914		218.544		44.5		7.55		0		441.0519127		74.8301597		581.7890735			
		Board Margin								9.75								265.7491399															
		Grown Margin																															
		Total																															

Page 166 of 189

Page 167 of 189

Page 168 of 189

Page 169 of 189



Welcome		Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7		Group 8		Summary											
Group		Variables																											



Group Research Vessel													
7	Variables		Rating	Area	Area	Volume	Volume	Weight	Weight	Design Margin			
				[m²]	Formula	[m³]	Formula	[tonne]	Formula		[%]		
7	71 Ship Stores	GP 784 Air Sampling Drone	A										
	78 Subcraft and Vehicles	GP 781 7 m RIB Boats		NIL	7x2.5	NIL			5	2.5 pr boat	50	10.25	
		GP 716 Boat gear		NIL		NIL			0.6	0.3 pr boat	50	10.25	
		GP 785 ROV	A	15		40.5			0.8		38	10.25	
		CTD	A	15		40.5			5		38	10.25	
		ASV 6000	B	48		129.6			7.2		38	10.25	
		ALV	B	15		40.5			2.5		38	10.25	
	79 Cargo	791 Solid Cargo											
		792 Liquid Cargo											
		793 Passengers and effects											
TOTAL 276.21 22.577													
Group 7	78 Subcraft and Vehicles	GP 781 7 m RIB Boats		NIL	7x2.5	NIL			5	2.5 pr boat	50	10.25	
		GP 716 Boat gear		NIL		NIL			0.6	0.3 pr boat	50	10.25	
		GP 785 ROV	A	15		40.5			0.8		38	10.25	
	79 Cargo	785 Subcraft and Vehicle Support Equipment											
		NSRS	A			0			30		15	10.425	
		A frame	A			0			100		1	10.425	
	793 Passengers and effects												
	TOTAL 44.55 145.948												
	Group 7	77 Aircraft	771 Fixed wing Aircraft										
			772 Rotating wing Aircraft							0.8		38	10.25
			773 Aircraft Support Equipment							2.75		38	10.25
		78 Subcraft and Vehicles	GP 781 11m RIB Boats		NIL	7x2.5	NIL			20	2.5 pr boat	38	10.25
GP 716 Boat gear				NIL		NIL			2.4	0.3 pr boat	50	10.25	
782 Surface Craft				NIL	7x2.5	NIL			5	2.5 pr boat	50	10.25	
783 Subsurface Craft				NIL		NIL			0.6	0.3 pr boat	50	10.25	
784 Land Vehicles													
785 Subcraft and Vehicle Support Equipment													
79 Cargo		791 Solid Cargo											
		792 Liquid Cargo											
		793 Passengers and effects											
TOTAL 0 33.7585													
1294.9 323.3875 0													



21.4. Appendix D - Superstructure Effectiveness

Based on Lloyds

https://www.cdlive.lr.org/information/documents%5CRules%5CNAVAL%20SHIPS%5C2015%20NAVAL%5CVOLUME%201%5C15%20Naval_v1%20p6.pdf

Length on waterline

$$LWL := 83.5$$

Hull depth

$$D := 8.9$$

Length Rule (Lloyds Def.)

$$L_R := 0.97 \cdot LWL$$

Length of first tier (02 deck)

$$L_1 := 42$$

Length of second tier (03 deck)

$$L_2 := 16$$

Check Criteria

$$L_1 \cdot 0.7 = 29.4$$

$$N := 1$$

Do not include λ

Superstructure tier length relationship

$$L_w := \frac{(2 \cdot L_1 + L_2)}{3}$$

Width of superstructure

$$b_1 := 15.7$$

Height to first effective tier

$$h_1 := 5.4$$

Defined value

$$\varepsilon_1 := 5 = 5$$

Defined relationship

$$\gamma := \frac{L_w}{h_1} = 6.173$$

Empirical formula for estimating superstructure efficiency

$$\eta_s := 7 \cdot \left[(\varepsilon_1 - 5) \gamma^4 + 94 (5 - \varepsilon_1) \gamma^3 + 280 (\varepsilon_1 - 5.8) \gamma^2 + 2766 (9 - \varepsilon_1) \cdot \gamma \right] \cdot 10^{-7} = 0.418$$

Efficiency limit based on
assuming NA to be half of hull depth

$$p := \frac{1}{\left(1 + \frac{2h_1}{D} \right)} = 0.452$$

$$p^2 \rightarrow 0.204$$

$$p > \eta_s > p^2 = 1$$



21.1. Appendix E – Plating and Stiffener Combinations

BOTTOM SIDE / UPPER DECK ELEMENT

Plating and Stiffener Combinations

E	2.07E+11	B Quality Steel	Max Beta	2.5														
Yield	2.8E+08	0.036778	Min b (mm)	430														
te (mm)	14	b/te<0.5	0.0368															
t (mm)		7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
te-t (mm)		7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Type	Area, As (mm2)																	
1	464	Type 1									464.00	#DIV/0!						
2	948	Type 2									474.00	#DIV/0!						
3	1613	Type 3									537.67	806.50	#DIV/0!					
4	2090	Type 4									522.50	696.67	#DIV/0!					
5	2606	Type 5									434.33	521.20	651.50	#DIV/0!				
Spacing - b=As/(te-t)	6	Type 6									456.14	532.17	#DIV/0!					
	7	Type 7									#DIV/0!	#DIV/0!	#DIV/0!					
	Required	Max b	475.82	543.80	611.77	679.75	747.72	815.69	883.67	951.64	1019.62	1087.59	1155.57	1223.54	1291.52	1359.49	1427.46	1495.44

LOWER / BOTTOM DECK ELEMENT

E	2.07E+11	B Quality Steel	Max Beta	2.5	Plating and Stiffener Combinations																	
Yield	2.8E+08	0.036778	Min b (mm)	430																		
te (mm)	12	b/te<0.5	0.0368																			
t (mm)	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22						
te-t (mm)	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10						
Type	Area, As (mm2)																					
1	464	Type 1						464.00	#DIV/0!													
2	948	Type 2						474.00	#DIV/0!													
3	1613	Type 3					537.67															
4	2090	Type 4				522.50																
5	2606	Type 5																				
6	3193	Type 6																				
7	4535	Type 7																				
b=As/te-t	Required	Max b	475.82	543.80	611.77	679.75	747.72	815.69	883.67	951.64	1019.62	1087.59	1155.57	1223.54	1291.52	1359.49	1427.46	1495.44				



UPPER/MID/LOWER SIDE ELEMENT

Plating and Stiffener Combinations

E	2.07E+11	B Quality Steel																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											</
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21.2. Appendix F – Transverse Stiffener

Transverse beam stress due to hydrostatic pressure

Green sea pressure
the spacing

It is assumed that the effective plating is 50% of (Chalmers chapter 3)

$$P_U := (T_{\text{deep}} + 5\text{m}) \cdot g \cdot \rho_{\text{SW}} = 94.378 \text{ kPa}$$

Distributed load over
effective material

$$q_{UD} := P_U \cdot a \cdot 0.4 = 52.852 \frac{\text{kN}}{\text{m}}$$

Bending moment due to
green sea in simply supported
transverse beam

$$M_B := \frac{q_{UD} \cdot L_{BS}^2}{8} = 402.382 \text{ kN} \cdot \text{m}$$

Required section modulus
of stiffener and effective plate

$$Z_{\text{req}} := \frac{M_B}{0.57 \cdot \sigma_{\text{yield}}} = 2521.19 \text{ cm}^3$$

From the above required section modulus it is seen that none of pre-fabricated stiffeners will be sufficient, hence it is necessary to fabricate a larger frame

Generating a custom frame

Depth of web

$$d_w := 457 \text{ mm}$$

Thickness of web

$$t_w := 15.2 \text{ mm}$$

Width of flange

$$d_f := 229 \text{ mm}$$

Height of flange

$$t_f := 30.5 \text{ mm}$$

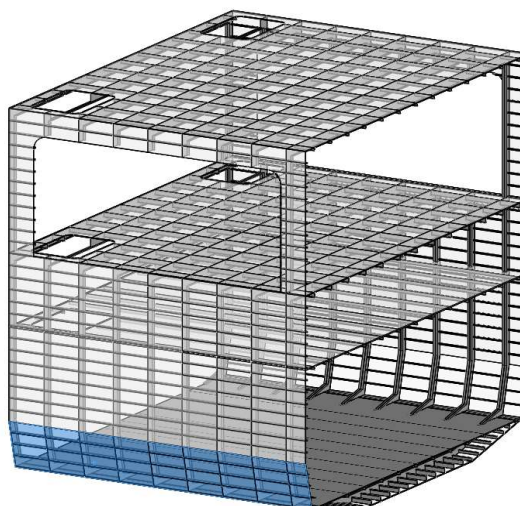
Structural parameters on tabular form

	<u>Area</u>	<u>Centroid</u>	<u>Second moment of area</u>
Flange:	$A_f := t_f \cdot d_f$	$y_{cf} := t_{UD} + d_w + \frac{t_f}{2}$	$I_{cf} := \frac{d_f \cdot t_f^3}{12}$
Web:	$A_w := t_w \cdot d_w$	$y_{cw} := t_{UD} + \frac{d_w}{2}$	$I_{cw} := \frac{t_w \cdot d_w^3}{12}$
Assumed effective: plating	$A_p := 0.5 \cdot a \cdot t_{UD}$	$y_{cp} := \frac{t_{UD}}{2}$	$I_{cp} := \frac{(0.6 \cdot a) \cdot t_{UD}^3}{12}$



21.3. Appendix G – Structural Analysis Example – Lower Side

The following structural analysis is based on a template calculation from a previous analysis conducted by the author (Bilde, 2017)



The lower side is subject to a combination of shear and compressive stress. It has been proven in the "Mid Side" calculation that the shared critical shear point (Nearest NA) is acceptable for type 2 stiffeners. However the lower side is subject a large hydrostatic pressure at the connection with the bottom. The following calculation is therefore aimed to investigate, shear, compressive and hydrostatic combined loads at this point

Generation of stiffener

Upper side thickness $t_{LS} \rightarrow 10\text{ mm}$

Type 2 stiffener at 8mm plate has been selected

Plate properties

Plate thickness $t_{LS} := 8\text{ mm}$

Plate thickness including corrosion $t_{LS} := t_{LS} \cdot 0.975 = 7.8\text{ mm}$

$b_{LS} := 0.474\text{ m}$

Stiffener spacing $b_{LS} := \frac{L_{LS}}{8} = 0.455\text{ m}$

b/t ratio $\frac{b_{MS}}{t_{MS}} = 59.468$



Applied bending moment at critical shear area

Distance from critical shear area to Neutral axis

$$y_{cLS} := y_{NA2K} - (0.8\text{m}) = 3.837\text{m}$$

Maximum compressive stress at the critical area occurs in sagging condition, as it is above the neutral axis

Applied compressive stress

$$\sigma_{cLS} := \frac{M_{hog} \cdot y_{cLS}}{I_{NA}} = 69.085\text{MPa}$$

Applied bending moment due to hydrostatic pressure

Draught

$$h := 5\text{m} + (4.39 - 0.8)\text{m}$$

Hydro static pressure

$$P_{BS} := \rho_{SW} \cdot h \cdot g = 86.429\text{kPa}$$

Distributed load over effective material

$$q_{BS} := P_{BS} \cdot b_{LS} \cdot 0.6 = 23.589 \cdot \frac{\text{kN}}{\text{m}}$$

Bending moment due to green sea in simply supported transverse beam

$$M_{BBS} := \frac{q_{BS} \cdot a^2}{12} = 3.853\text{kN}\cdot\text{m}$$

(Chalmers chapter 3)

Section modules of stiffener type 5

$$Z_{stiffener} := 60\text{cm}^3$$

(Stiffener book)

Applied bending stress to hydro static pressure

$$\sigma_{hLS} := \frac{M_{BBS}}{Z_{stiffener}} = 64.214\text{MPa}$$

From this it is seen that the additional bending stress due to hydrostatic pressure does not result in a total stress larger than the average collapse stress.

$$\sigma_{LS} := \sigma_{hLS} + \sigma_{cLS} = 133.3\text{MPa}$$



Plate buckling

Slenderness ratio for actual arrangement

$$\beta := \frac{b_{LS}}{t_{LS}} \cdot \sqrt{\left(\frac{\sigma_{yield}}{E} \right)} = 2.145$$

Ratio to enter graph G7

$$\frac{a}{b_{LS}} = 3.078$$

K factor from graph reading at worst case scenario i.e. end and sides simply supported

$$K := 3.7$$

Using graph on Data sheet G7

Critical buckling stress on yield stress based on elastic modulus

$$\sigma_{cronymye} := \frac{K}{\beta^2} = 0.804$$

Critical buckling stress on yield stress based on elastic modulus

$$\sigma_{cronymyb} := 1 - \frac{\beta^2}{4 \cdot K} = 0.689$$

Critical stress check

$$\sigma_{cronymyb} < \sigma_{cronymye} = 1$$

Buckling occurs at stress greater than proportional limit

Critical buckling stress

$$\sigma_{crpl} := \sigma_{cronymyb} \cdot \sigma_{yield} = 192.967 \text{ MPa}$$

However residual stress must be included;

Tension block

$$\eta := 3$$

Residual stress on yields stress (based on force balance)

$$\sigma_{ronyv} := \frac{2 \cdot \eta \cdot t_{LS}}{b_{LS} - 2 \cdot \eta \cdot t_{LS}} = 0.115$$

Residual stress

$$\sigma_{rv} := \sigma_{ronyv} \cdot \sigma_{yield} = 32.112 \text{ MPa}$$

Elastic tangent modulus calculation

Tangent modulus

$$E_{tonE} := 4 \cdot \sigma_{cronymyb} \cdot (1 - \sigma_{cronymyb}) = 0.857$$

Residual stress with inelastic effects

$$\Delta \sigma_{crp} := E_{tonE} \cdot \sigma_r = 27.515 \text{ MPa}$$

Actual plate buckling stress

$$\sigma_{platebuckle} := \sigma_{crpl} - \Delta \sigma_{crp} = 165.452 \text{ MPa}$$

$$\gamma_{deckplatebuckling} := \frac{\sigma_{platebuckle}}{\sigma_{LS}} = 1.241$$



Interframe Flexural Collapse

Assuming the slenderness ratio
is within 10% of effective
slenderness ratio

$$\beta_{eff} := \beta_e$$

Assumption!

Effective slenderness ratio

$$\beta_{eff} := \frac{b_{LS}}{t_{LS}} \cdot \sqrt{\frac{\sigma_{yield}}{E}} = 2.145$$

Effective width

$$b_{eff} := \left(\frac{2}{\beta_e} - \frac{1}{\beta_e^2} \right) \cdot b_{LS} = 0.325m$$

Reduced width

$$b_{ered} := \frac{1}{\beta_e} \cdot b_{LS} = 0.212m$$

Reduced effective
width area

$$A_{ep} := b_{ered} \cdot t_{LS} = 1.654 \times 10^{-3} m^2$$

Netrual axis of frame
and reduced effective width

$$y_{oLS} := \frac{A_{S2} \cdot D_{S2} + A_{ep} \cdot \frac{t}{2}}{(A_{S2} + A_{ep})} = 32.756mm$$

Second moment of area of
stiffener and reduced
effective width

$$I_{yy} := \frac{b_{ered} \cdot t_{LS}^3}{12} + A_{ep} \cdot (y_{oLS} - t_{LS})^2 + I_{S2} + A_{S2} [y_{oLS} - (D_{S2} + t_{LS})]^2 = 493.591 cm^4$$

Radius of Gyration

$$k := \sqrt{\frac{I_{yy}}{A_{S2} + t \cdot b_e}} = 29.952mm$$

Column slenderness ratio

$$\lambda := \frac{a}{\pi \cdot k} \cdot \sqrt{\left(\frac{\sigma_{yield}}{E} \right)} = 0.547$$

Check for appropiate calculation
of collumn collapse stress

$$\lambda < \sqrt{2} \rightarrow 1$$

Collumn collapse stress ratio

$$\sigma_{cony} := \left(1 - \frac{\lambda^2}{4} \right) = 0.925$$

No need to iterate as it is within 10%

Compressive strength factor

$$\phi := \sigma_{cony} \cdot \left(\frac{A_{S2} + b_e \cdot t_{LS}}{A_{S2} + b_{LS} \cdot t_{LS}} \right) = 0.717$$

Collumn collapse stress

$$\sigma_{con} := \sigma_{cony} \cdot \sigma_{yield} = 259.04 MPa$$

Applied compressive stress

$$\sigma_{con} := \phi \cdot \sigma_{yield} = 200.8 MPa$$



Longitudinal stiffener tripping

Polar moment needed for calculation

$$I_{\omega\omega} := I_{xx} + I_{yy}$$

Second moment of inertia about the y-axis is known.

Second moment of area about x-axis

Vertical second moment
of inertia of the
about the toe.

$$I_{yy} := I_{S2} + A_{S2} \cdot D_{S2}^2$$

Horizontal second moment
of inertia of the
about the toe.

$$I_{xx} := \frac{d_w \cdot t_w^3}{12} + \frac{t_f \cdot d_f^3}{12} = 7.092 \times 10^{-8} \text{ m}^4$$

There is no need for parallel axis theorem at the horizontal second moment of area as all elements share the same neutral axis. Similarly the toe is connected to the neutral axis, and does not need to be moved.

Polar moment of inertia
about the toe

$$I_{\omega\omega} := I_{xx} + I_{yy} = 7.054 \times 10^{-6} \text{ m}^4$$

Torsion constant

$$J_{\omega\omega} := \frac{(t_w^3 \cdot d_w + t_f^3 \cdot d_f)}{3} = 1.735 \times 10^{-8} \text{ m}^4$$

Warping constant

$$\Gamma_{\omega\omega} := \frac{A_f^3}{144} + \frac{A_w^3}{36} = 4.246 \times 10^{-12} \text{ m}^6$$

Stiffener tripping in-plane compressive load

Tripping stress in stiffener

$$\sigma_{\omega\omega} := \frac{G \cdot J}{I_o} + \frac{\pi^2 \cdot E \cdot [I_{xx} (d_w + t_f)^2 + \Gamma]}{I_o \cdot a^2} = 334.315 \text{ MPa}$$

Tripping stress in plate

$$\sigma_{\omega\omega} := \frac{\pi^2 \cdot E \cdot t_{LS}^2}{12(1 - \nu^2) \cdot b_{LS}^2} \cdot \left(\frac{a}{b_{LS}} + \frac{b_{LS}}{a} \right)^2 = 636.919 \text{ MPa}$$

Tripping stress

$$\sigma_{\omega\omega} := \frac{(\sigma_s \cdot A_{S2} + \sigma_p \cdot b_{LS} \cdot t_{LS})}{(A_{S2} + b_{LS} \cdot t_{LS})} = 573.114 \text{ MPa}$$

Tripping check

$$\sigma_{deck} \cdot 1.3 < \sigma_{tr} = 1$$



Stiffener tripping due to lateral load

ORIGIN:= 1
~~~~~

Various investigated  
modes in order to  
determine minimum stress

$$n := \begin{pmatrix} 0.6 \\ .7 \\ .8 \\ .9 \\ 1 \end{pmatrix}$$

Critical stress at  
which tripping occurs  
due to lateral load

$$\sigma_{tcn} := \frac{GJ}{I_o} + E \cdot \left[ I_{xx} (d_w + t_f)^2 + \Gamma \right] \cdot \frac{\pi^2 \cdot n^2}{I_o \cdot a^2} \dots = \begin{pmatrix} 3076.332 \\ 2343.385 \\ 1876.699 \\ 1565.978 \\ 1353.129 \end{pmatrix} \cdot \text{MPa}$$

$$+ \frac{E \cdot a^2}{I_o \cdot n^2 \cdot \pi^2 \left( 3 \cdot \frac{b_{LS}^3}{t_{LS}^3} + 3.6 \cdot \frac{d_w^3}{t_w^3} \right)}$$

Definition of minimum  
critical stress

$$\sigma_{tc_3} = 1876.699 \text{ MPa}$$

n-value to cause  
minimum stress

$$n_3 = 0.8$$

Safety factor check

$$\sigma_{deck} \cdot 4 < \sigma_{tc_3} = 1$$

**It can be concluded that stiffener tripping due to lateral load does not occur**



## Design Shear Stress

### Initial Explanation

The below formula is used to calculate the shear stress present in the upper side shear stress. It is predicted that the worst shear in this region is nearest the neutral axis of the midship section.

### Calculation

#### **Element cut due to intersection with neutral axis**

The vertical length is calculated as draught subtracted from the neutral axis of the ship

Area above critical shear point in upper side

$$A_{VLS} := (A_{LS} + A_{BD} + A_{BS}) = 0.179 \text{m}^2$$

Distance from NA to NA of above area measured from upper deck

$$z_{LS} := \left( \frac{A_{LS} \cdot y_{LS} + A_{BD} \cdot y_{BD} + \dots + A_{BS} \cdot y_{BS}}{A_{VLS}} \right) - y_{NA2UD} = 4.154 \text{m}$$

Design shear stress

$$\tau_{dLS} := \frac{(V_s \cdot A_{VLS} \cdot 2) \cdot z_{LS}}{I_{NA} \cdot (t_{LS} \cdot 2)} = 59.505 \cdot \text{MPa}$$

## Plate Shear Buckling

Ratio to enter below graph G11-a

$$\frac{b_{LS}}{a} = 0.325$$

Empirical constant from graph reading

$$\chi_{LS} := 5.2$$

Critical elastic shear stress for flat plate

$$\tau_{cr} := \chi_{LS} \cdot E \cdot \left( \frac{t_{LS}}{b_{LS}} \right)^2 = 316.499 \cdot \text{MPa}$$

Ratio for entering plastic reduction factor graph

$$\frac{\tau_c}{\sigma_{yield}} = 1.13$$

Plasticity reduction factor from graph G11-b

$$\eta_{cr} := 0.43$$

Critical shear stress for flat plate

$$\tau_{cLS} := \eta_{cr} \cdot \tau_c = 136.095 \text{MPa}$$

Safety check

$$\tau_{dLS} < \tau_{cLS} = 1$$

**The above shows that the critical stress for a flat plate is larger than the applied shear stress in this area. It can be concluded that the selected stiffener arrangement is acceptable**



## Panel Shear Buckling

Second moment of area of the proposed frame about its connection to the plate

$$I_{st} := I_{S2} + A_{S2} \cdot D_{S2}^2 = 698.335 \text{ cm}^4$$

Stiffness parameter to enter graph G23

$$\mu_{LS} := \sqrt{\left( \frac{I_{st} \cdot b_{LS}}{a^2 \cdot t_{LS}^3} \right)} = 1.848$$

Aspect ratio to enter graph G23

$$\frac{a}{b_{LS}} = 3.078$$

Emperical value from G23

$$K_{LS} := 5.8$$

Critical buckling stress of panel due to sher

$$\tau_{scLS} := K_{LS} \cdot E \cdot \left( \frac{t_{LS}}{b_{LS}} \right)^2 = 353.019 \text{ MPa}$$

Safety check

$$2 \cdot \tau_{dLS} < \tau_{scLS} = 1$$

**The above shows that the critical stress for a flate plate is more than twice as large as the applied shear stress in this area. It can be concluded that the selected stiffener arrangement is acceptable for this criteria.**

## Combined bending and shear stress

Compressive ratio

$$\frac{\sigma_a}{\sigma_{LS}} = 1.506$$

Shear ratio

$$\frac{\tau_{scLS}^2}{\tau_{scLS}^2 - \tau_{dLS}^2} = 1.029$$

Combined bending and shear stress check

$$\frac{\sigma_a}{\sigma_{LS}} > \left( \frac{\tau_{scLS}^2}{\tau_{scLS}^2 - \tau_{dLS}^2} \right) = 1$$

The above binary check shows that the combined stress ratio is not greater than the allowable ratio.

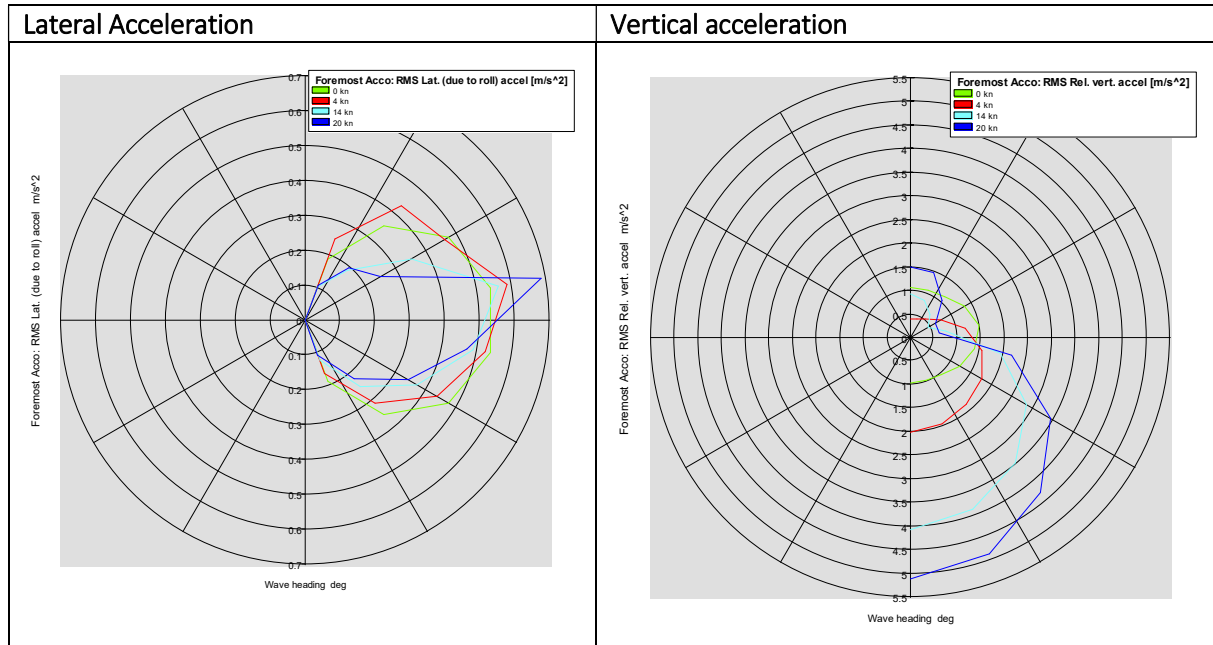
21.5.

|                                         |                                           |
|-----------------------------------------|-------------------------------------------|
| <div>Pitch</div> <div>Sea state 4</div> | <div>Academic Use Only</div> <div> </div> |
| <div>Sea state 5</div>                  | <div> </div>                              |
| <div>Sea state 6</div>                  | <div> </div>                              |

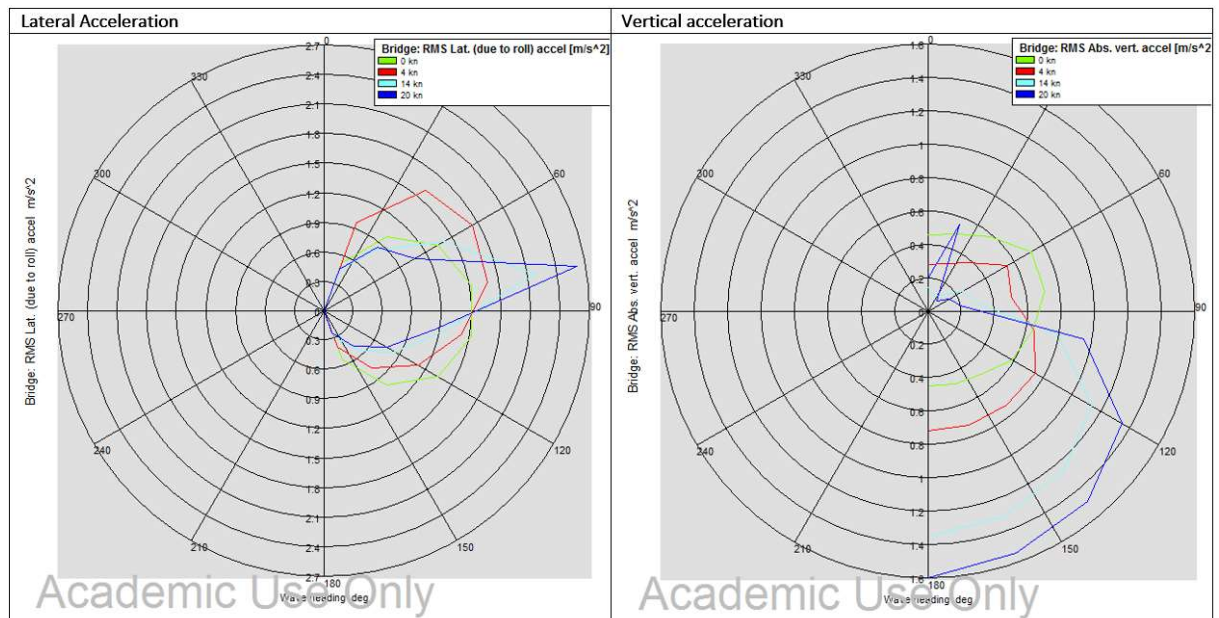


## 21.6. Appendix I – Sea Keeping Results – Local Area

### Bridge

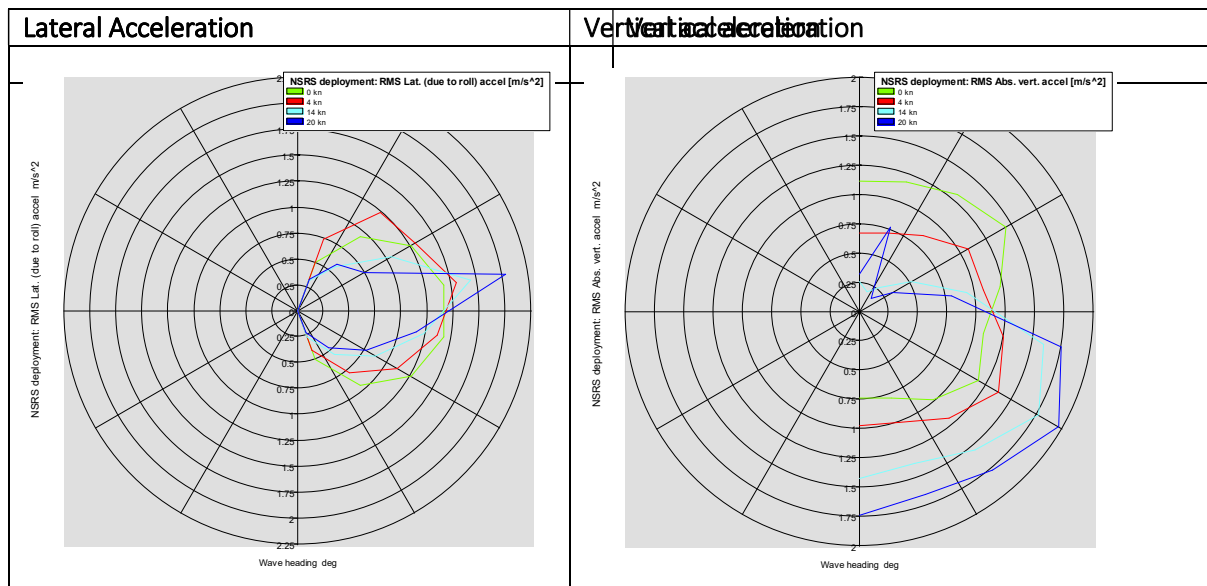


### Foremost Accommodations

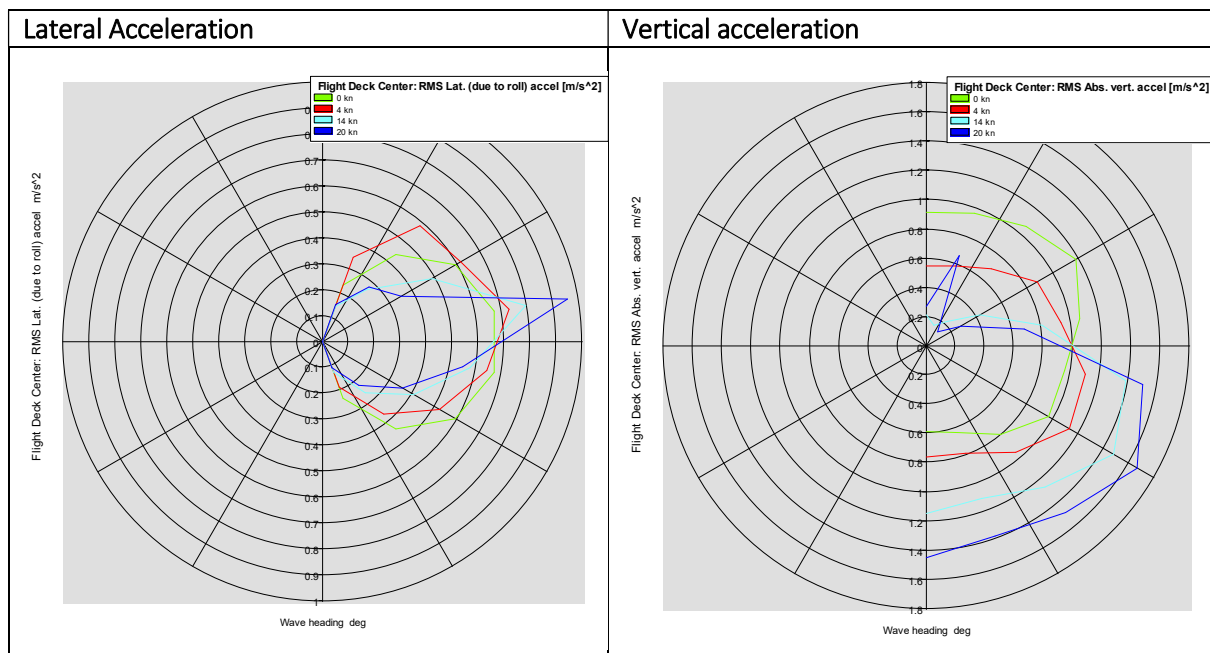




## A-Frame



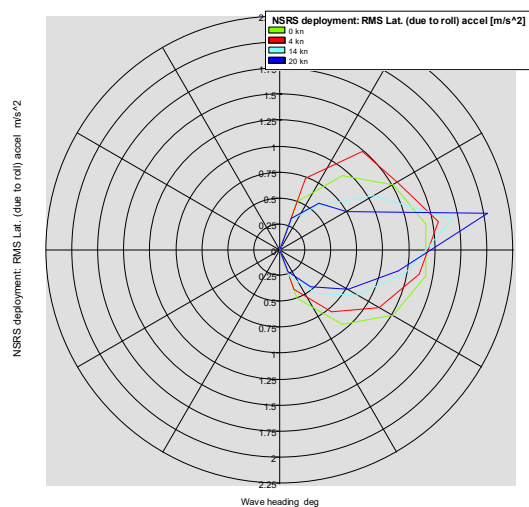
## Flight Deck



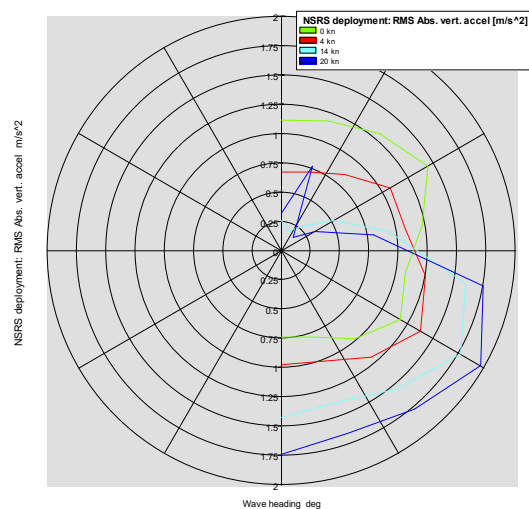


## Foremost Operational Area

### Lateral Acceleration



### Vertical acceleration





21.7. Appendix J – Free Surface Correction

| FREE SURFACE CORRECTION                                              |                         |  |  |                            |  |
|----------------------------------------------------------------------|-------------------------|--|--|----------------------------|--|
| $GM_{correction} = \frac{\rho_t \cdot I_{tank}}{\Delta_{condition}}$ |                         |  |  |                            |  |
| <b>Density of DFO</b>                                                |                         |  |  |                            |  |
|                                                                      |                         |  |  | 850 kg/m <sup>3</sup>      |  |
| <b>Density of fresh water</b>                                        |                         |  |  |                            |  |
|                                                                      |                         |  |  | 1000 kg/m <sup>3</sup>     |  |
| <b>Density of sea water</b>                                          |                         |  |  |                            |  |
|                                                                      |                         |  |  | 1025 kg/m <sup>3</sup>     |  |
| <b>Displacement</b>                                                  |                         |  |  |                            |  |
|                                                                      |                         |  |  | 3709000 kg                 |  |
| <b>DFO 1 &amp; 2</b>                                                 |                         |  |  |                            |  |
|                                                                      | Length                  |  |  | 7 m                        |  |
|                                                                      | Breadth                 |  |  | 4.7 m                      |  |
|                                                                      | Second moment of area   |  |  | 60.56341667 m <sup>4</sup> |  |
|                                                                      | Free surface correction |  |  | 0.013879457                |  |
| <b>DFO 3&amp;4</b>                                                   |                         |  |  |                            |  |
|                                                                      | Length                  |  |  | 12 m                       |  |
|                                                                      | Breadth                 |  |  | 4.7 m                      |  |
|                                                                      | Second moment of area   |  |  | 103.823 m <sup>4</sup>     |  |
|                                                                      | Free surface correction |  |  | 0.023793354 m              |  |
| <b>DFO 5 &amp; 6</b>                                                 |                         |  |  |                            |  |
|                                                                      | Length                  |  |  | 10.8 m                     |  |
|                                                                      | Breadth                 |  |  | 4.7 m                      |  |
|                                                                      | Second moment of area   |  |  | 93.4407 m <sup>4</sup>     |  |
|                                                                      | Free surface correction |  |  | 0.021414019                |  |
| <b>DFO 7 &amp; 8</b>                                                 |                         |  |  |                            |  |
|                                                                      | Length                  |  |  | 7 m                        |  |
|                                                                      | Breadth                 |  |  | 4.7 m                      |  |
|                                                                      | Second moment of area   |  |  | 60.56341667 m <sup>4</sup> |  |
|                                                                      | Free surface correction |  |  | 0.013879457 m              |  |
| <b>DFO 9 &amp; 10</b>                                                |                         |  |  |                            |  |
|                                                                      | Length                  |  |  | 5.28 m                     |  |
|                                                                      | Breadth                 |  |  | 4.7 m                      |  |
|                                                                      | Second moment of area   |  |  | 45.68212 m <sup>4</sup>    |  |
|                                                                      | Free surface correction |  |  | 0.010469076 m              |  |
| <b>Fresh water tank</b>                                              |                         |  |  |                            |  |
|                                                                      | Length                  |  |  | 6.25 m                     |  |
|                                                                      | Breadth                 |  |  | 4 m                        |  |
|                                                                      | Second moment of area   |  |  | 33.33333333 m <sup>4</sup> |  |
|                                                                      | Free surface correction |  |  | 0.008987148 m              |  |
| <b>Total Free surface correction</b>                                 |                         |  |  | <u>0.09242251 m</u>        |  |



## 22. Appendix G

The following appendix contains all plotted drawings submitted with the report.

The drawings are:

HYDRA Research General Arrangement - HYDRA-01-0100-01-V6

HYDRA SUBSAR General Arrangement - HYDRA-02-0100-01-V2

HYDRA Coast Guard General Arrangement - HYDRA-03-0100-01-V2

HYDRA Lines plan – HYDRA-04-0100-01-V1