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Balancing Survivability, Operability and Cost for a Corvette Design

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SUMMARY

With reducing fleet sizes and budgets, navies are looking to achieve more from less. They are driven to designing for cost rather than capability and this drives greater integration of commercial practice and systems into warship design. The move to more flexible and multi role platforms to improve the function of a class of ships also impacts the operability and the survivability of a design potentially affecting its war fighting capability. For a corvette design which is weight, power and deck area constrained, finding the correct balance whilst fulfilling the customer requirements is increasingly difficult. This paper looks to investigate how the right balance can be achieved.

NOMENCLATURE

AAW	Anti Air Warfare
ASM	Anti Ship Missile
ASW	Anti Submarine Warfare
ASuW	Anti Surface Warfare
CPP	Controllable Pitch Propeller
EOD	Electro/Optic Director
MCG	Medium Calibre Gun
NF	Naval Fires
RMS	Root Mean Square
SCG	Small Calibre Gun
SME	Subject Matter Expert
TLS	Torpedo Launch System
UPC	Unit Purchase Cost
UXV	Unmanned Vehicle

1. INTRODUCTION

At the concept stage for a vessel designed to cost, with a defined capability and combat system, the principal dimensions become an attractive method for controlling costs. If the hull size and principal dimensions are constrained or reduced to minimise costs, this has an impact on the operability and survivability of a vessel.

The decreasing hull numbers of naval fleets and the increasing diversity of operations require greater capability within each vessel. With the longer service life for modern vessels, relative to the technology and equipment embarked within them, flexibility is gaining a greater importance within a design. A method of achieving this without increasing crew and limiting the hull principal dimensions is through role reconfiguration and modularity. Whilst this has a large impact on rank structures and training, it is a model more and more navies are turning towards. This investigation builds upon the work carried out by BMT on the VENATOR [1, 2] and SECURITOR [3] concepts to ensure that the impact of modularity and flexibility on the design is included as part of the baseline design.

With fewer hulls available, the survivability of a design becomes increasingly important, as the lead time for designing and building a naval ship means it cannot be replaced quickly. It is also true that as the ships are only allowed to fire when fired upon they require a level of resilience, and this is reinforced by emerging roles such as counter piracy where a presence is required to be maintained.

A method of assessing the operability of a design is required to allow comparison with cost and survivability. In this paper tools developed by BMT are used to assess the operability, survivability and cost differences of two designs fulfilling the same requirement.

2. CORVETTE DESIGN

Two conventional monohull baseline designs were created and a summary of the principal dimensions are shown in Table 1. The first design represents a compact design where the ship principal dimensions were reduced to achieve the minimum acceptable top side length and deck area. For the second design, the principal dimensions were increased to allow a greater level of separation between high value compartments.

	Compact Corvette	Stretched Corvette
Overall Length, metres	95	114
Waterline Length, metres	90	107
Waterline Breadth, metres	14.5	15.4
Hull Depth, metres	7.6	10.5
Design Draught, metres	4.2	4.5
Design Displacement, tonnes	2870	3850

Table 1: Principal Dimensions of Baseline Designs

2.1 FLEXIBILITY/ MODULARITY

From previous research work carried out by BMT a number of missions that could be achieved through the use of modules were envisaged, for the baseline designs with the required payload both deadweight items and military fit equipments defined. The roles considered were Mine Countermeasures, Mine Countermeasures Support, Hydrographic Survey and Rapid Environmental

Assessment, Maritime Security Operations, Offshore Patrol and Training.

The mission specific equipment would be embarked in modules based on twenty foot equivalent ISO containers and requiring a total complement between 60 and 80 personnel. A modular mission station is included in each of the baseline designs.

2.2 OUTLINE REQUIREMENTS

An indicative set of user requirements was created based on the typical set of missions for a corvette of the size investigated. In addition to those missions described by the flexibility/modularity missions, a number of missions considered to be a permanent requirement for the vessels were defined. The permanent missions are Anti Submarine Warfare (ASW), Anti Surface Warfare (ASuW), Naval Fires (NF) and Anti Air Warfare (AAW).

2.3 DESIGN DESCRIPTION

To undertake an ASW role the baseline designs have a towed array sonar and an embarked helicopter. To allow a layered defence for the platform, a torpedo launch system and decoy system are included.

A medium calibre gun (MCG) capable of engaging surface targets for ASuW and NF together with a degree of air engagement capability is assumed. To complete the ASuW role an anti ship missile (ASM) system is incorporated and two small calibre guns (SCG) are fitted for defence.

For the AAW role an anti- air missile system and decoy launchers are included.

An air / surface search radar is provided to support the weapons systems with an electro-optical surveillance and tracking system added for the MCG and SCG systems.

To support the day to day operation of the vessel, a minimum of two ship boats are fitted.

To ensure that the modular mission area can fulfil the functions required, direct access is provided to the operations centre and weather deck spaces. This allows greater flexibility through life for unmanned vehicles and emerging roles.

Figures 1 and 2 show the arrangements achieved for the two baseline designs. With the operations centre and bridge shown in light grey, the main and auxiliary machinery spaces shown in dark grey and mission modular spaces provided shown in black.

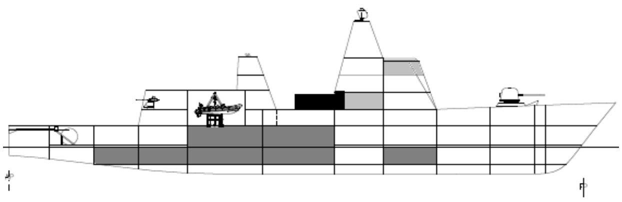


Figure 1: 90m LWL Compact Corvette Profile

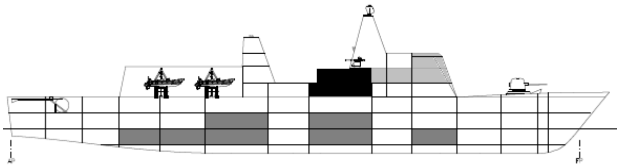


Figure 2: 107m LWL Stretched Corvette Profile

The requirement for a long endurance and an emphasis on affordability led to the selection of a straight forward mechanical / diesel drive propulsion system. Building on the research carried out by BMT and RENK into multi engine diesel propulsion systems [4] four high speed diesel engines were selected, with two per shaft driving into a reduction gearbox with a 3.6 metre CPP propeller. The propulsion engines are located within two main machinery compartments.

The additional length available in the stretched design allows separation to be achieved between the main machinery spaces. The additional length also allows the provision of additional positions for ship's boats.

With the increased length, the hull depth of the 107m design has also been increased, allowing improved fore and aft access within the ship and increased internal area. This internal area is utilised for greater mission module spaces, larger operational spaces and additional accommodation.

3. SURVIVABILITY

The ability of a design to withstand damage can be considered in three parts; the susceptibility of a design to damage; the survivability of the design as damage occurs; and the recoverability of a design after initial damage. Only the survivability of the baseline designs was assessed. The susceptibility was assumed to be comparable over the range of ship sizes considered and the level of design information produced did not support a recoverability assessment. Damage from flooding was not assessed as it was assumed to be covered by the damage stability regulations used.

Models of the baseline ship options were developed in PREVENT; a BMT tool for rapid survivability modelling. A two dimensional profile of the centreline of the ship was assessed with typical deck and bulkhead material, thickness and stiffening regimes assumed. Armour protection from small arms was assumed around the operations complex for both baseline designs.

The assessment focused on a simple range of threats and indicative systems for each of the ship roles, with only above water threats considered.

3.1 SYSTEMS

Five indicative systems were assessed within the model, each system was defined within PREVENT as a set of equipment and functions. The equipment and functions defined are shown in Figure 3 for the centreline profile. Each number represents an individual item of equipment or function that can be referenced by more than one system.

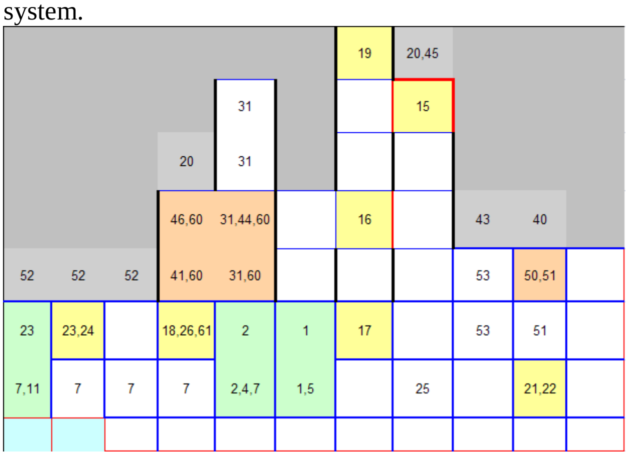


Figure 3: Equipment locations, Compact Corvette

Levels of performance have been defined for each system that describe the residual capability of the system as items of equipment or functions are damaged. Table 2 shows the levels of performance defined for each system and the primary equipment required. In addition, for all systems, at all performance levels a power, chilled water and a command and control function are required.

System	Performance (%)	Description
AAW	100	AAM, MCG, Decoy
	50	MCG, Decoy
	20	MCG
ASuW	100	ASM, MCG, SCG, Radar, EOD
	50	MCG, SCG, Radar
	50	MCG, SCG, EOD
	20	SCG
ASW	100	Helicopter, TLS, Sonar
	50	TLS, Sonar
NF	100	MCG, Radar
	50	MCG, EOD
Move	100	Maximum Speed
	50	Cruise Speed

Table 2: System Description

3.2 THREATS

A range of three generic blast weapons were assumed they represent a realistic range of threats that a corvette may be expected to survive [5]. Table 3 provides a summary.

Charge Weight (kg)	Indicative Weapon Type
1	RPG
30	Light ASM
165	ASM

Table 3: Threat Descriptions

A non weighted hit gird was assumed for the analysis for all threat types, with hits modelled for every ship compartment above the waterline.

3.3 RESULTS

For the threats assessed, each system is assessed for all the possible hits and the level of system performance calculated. A graphical display of the results for one system and one threat are shown in Figure 4. The hit locations that do not affect system performance are indicated with 100%, dependent on the system performance levels defined for the system, lower percentages indicate the level of residual capability after a hit at that location.

Figure 4: Compact Corvette, Move, 1kg

From Figure 4 it can be seen that the combined uptakes and down takes of the forward and aft main machinery spaces and the steering gear space are single points of failure within the system design with no residual capability when hit. The reduction in system performance to 50% when each of the main machinery spaces is damaged can also be seen.

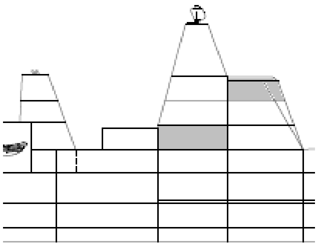
The ship performance for each system against each threat can then be calculated and a combined result across all the weapons systems calculated. A total ship functional performance of 64% was achieved for the compact baseline design and a performance of 76% achieved by the stretched baseline design. The 12% improvement in ship functional performance achieved by the stretched design is achieved through the greater separation of main machinery spaces and associated equipment.

3.4 OPTIMISATION OF DESIGNS

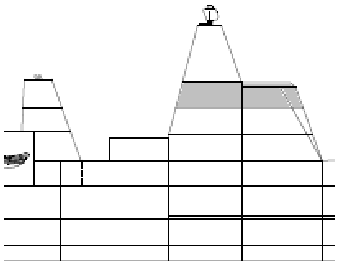
By the addition of minimal armour to key compartments the total ship functional performances increased to 67%

and 78% respectively, with the main machinery spaces demonstrating the largest improvement.

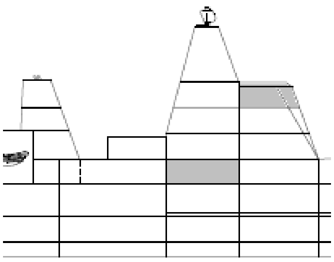
Two alternative arrangements were assessed to understand the impact on survivability of the proximity of the operations centre to the bridge and the separation achievable within the corvette design. The three options for the compact design are shown in Figure 5.



Baseline Configuration



Adjacent Configuration



Separated Configuration

Figure 5: Operations Room Locations Assessed

The total ship functional performances are shown in Table 4. The results show a small improvement to performance by moving the operations room adjacent to the bridge. Analysis of the results shows this is due to the reduction in hit footprint and that the most improvement is gained for the light ASM. For the RPG threat there is no difference achieved between the options due to the small arms armour assumed around the operations room. The separation achieved in the separated configuration is insufficient to improve the functional performance against the ASM threat.

	Compact Corvette (%)	Stretched Corvette (%)
Baseline	67	78
Adjacent	69	79
Separated	68	78

Table 4: Total ship functional performance comparing bridge/ operations room position.

This simple analysis does not take account of the effect of any protection provided by compartments outboard of the operations centre, which could improve the results for the baseline and separated configurations, where greater hull breadth is available to provide protection. Due to the granularity of the modelling, the system routings between the bridge and operations centre were also not modelled.

Crew casualties were not assessed. With the movement to a lean manned ship the ability of the ship to survive damage and recover may be dependent on the crew rather than the systems.

4. OPERABILITY

BMT has developed a number of operability assessment tools to support the assessment of operability of concept designs. The total operability of the designs was assessed in two areas, the physical integration of ship and the ability of the ship to perform the roles required.

4.1 PHYSICAL INTEGRATION

Detailed general arrangements were created for each of the baseline designs. Location requirements for each compartment were defined using subject matter experts and user feedback. These requirements were divided into two categories, Mandatory and Preferable. Mandatory requirements are linked to the function of the compartment or rules, regulations and standards dependent upon it. Preferable requirements are associated with the optimum performance of a function, the survivability of a compartment and human and system routing.

A scoring system was applied to each of the requirements for each compartment to provide a qualitative comparison between the designs. The mandatory requirements were assessed on a pass/ fail basis and the preferable requirements were given a score between 1 and 10 where 10 represented compliance and 1 represented non-compliance. The scores were used to describe the range of possible methods of partial compliance and were assessed subjectively. Across all the compartments within the designs, there were approximately 130 mandatory and 170 preferable requirements assessed.

The compact design achieved 88% compliance with the mandatory requirements and 82% compliance with the preferable requirements. The stretched design achieved 96% compliance with the mandatory requirements and 82% compliance with the preferable requirements.

100% compliance for a design across the mandatory and preferable requirements is not possible due to conflicting requirements and the available space within a design. The conflicting requirements are retained within the requirement set as they are all valid and represent different areas of whole ship design. Alternative methods of achieving compliance are available other than through physical location but this mitigation will likely introduce additional cost or limitations.

The improvements available within the stretched corvette are due to the additional deck area for arranging dependent compartments and the improved whole ship access.

4.2 PERFORM ROLE

Whilst the physical layout of a vessel is important for achieving an operable design, the ability of the ship and its crew to effectively carry out the roles intended are essential to the performance of a design.

To investigate the ability of the crew to carry out their missions, a list of roles was created and grouped under four headings, perform role, replenish, maintain and respond to threats as described in Table 5. Under each heading a number of supporting roles were identified and a checklist created detailing each of the actions required to complete each supporting role.

Perform Role	Monitor
	Navigate
	Fight
	Briefings
	Boat Operations
	Helicopter operations
	UXV Operations
	Diving Operations
	Engineering systems
	Harbour/ moor/ anchor
	Provide Assistance
	Communications
	Diplomacy
Replenish	Embark Load
	Store
Maintain	Ships Systems
	Environment
	Health
Respond to Threats	Withstand
	Recover
	Preserve Life

Table 5: Functions identified

For the roles identified approximately 160 checks were performed on each layout. Each check was assessed subjectively as either a pass or fail. The compact design passed 88% of the checks and the stretched design passed 94%.

The improvements available within the stretched corvette were due to improved access throughout the ship, the increased area available and the provision of additional or discrete operational spaces.

For the ship to fulfil its role the vessel has to be able to transit to the correct location with sufficient speed, and maintain station with adequate endurance. An indicative top speed, and fuel requirement for a range of 8000nm at a transit speed of 16kts was calculated for the baseline designs, the results are shown in Table 6.

	Compact Corvette	Stretched Corvette
Installed Power (MW)	32.8	32.8
Maximum Speed (Knots)	27	28
Fuel Load for Range (tonnes)	377	400

Table 6: Maximum speed and fuel load

A common propeller and propulsion package were assumed for both baseline designs. The stretched design has a reduced resistance above 21 knots compared to the compact design and an increased maximum speed. Due to the increased resistance of the stretched design below 21 knots the fuel load for the range is increased. As it can be expected for any operating profile that the majority of the vessels time will be spent at speeds below 21knots, this is indicative of the increase in annual fuel required for the stretched design.

The additional tank volume available within the stretched baseline design is in excess of the additional fuel load required for the transit range.

Under the VENATOR research previously carried out by BMT [1, 2], seakeeping criteria were investigated to ensure global deployability. Based on the seakeeping criteria from STANG 4154 [6], for the vessel sizes considered, the requirement to transit and patrol in up to sea state 6 were found to be the most onerous. The limiting criteria used for assessment are shown in Table 7.

Criteria	Limiting Value
Roll (Deg RMS)	3.8
Pitch (Deg RMS)	1.5
Deck Index, bow (/hr)	30
Vertical Acceleration (g RMS)	0.2

Table 7: Limiting Seakeeping Criteria

Results gained from previous work for similarly sized designs to the compact and stretched baseline designs are shown in Table 8. A summary percentage for all the criteria assessed shows the percentage of all headings over which all criteria are acceptable.

	% of Course Operability for all Headings	
Criteria	Compact Corvette	Stretched Corvette
Pitch	33	64
Roll	100	100
Deck Wetness Index (Bow)	75	81
Vertical Acceleration	69	100
For all Criteria	31	56

Table 8: Course Operability

With active fin stabilisation, at the transit speed of 16kts the roll RMS can be reduced to within the limit defined for all headings for both designs. The stretched design shows a 25% improvement in seakeeping over all headings due to the increased pitch stability but it is still limited in acceptable headings.

The power margin available at 16kts is sufficient to overcome the added resistance from the sea state, however propeller emergence, slamming and motion sickness index have not been assessed. These would typically cause a voluntary reduction in speed due to crew discomfort and potential damage. Due to the increased pitch stability the stretched design can be expected to have a higher transit speed than the compact design in higher sea states.

4.3 OPERATIONS ROOM LOCATION

The two alternative operation room locations investigated in section 3.4, shown in Figure 5 were also assessed for changes to operability. The checklists were assessed for the two alternative locations and a summary is shown in Table 9.

	Baseline (%)	Adjacent (%)	Separated (%)
Mandatory Requirements	88	87	87
Preferable Requirements	82	81	80
Role Checklist	88	88	88

Table 9: Effect of Operations Room Location on Operability

The reduction in the requirements passed for the adjacent option is due to the limited area of the superstructure and the limited number of adjacent compartments possible.

The reduction in the requirements passed for the separated option is due to the reduction in access between the operations room and bridge and the knock on impact of compartments displaced within the hull.

5. COST

The Unit Purchase Cost (UPC) of each of the baseline design options was estimated using the BMT ship costing tool. This is a weight based estimation tool with rates corrected for 2012. The UPC for the compact version was estimated to be 15.5% less than the stretched design.

The cost modelling carried out made no allowance for the decrease in system and outfit density between the two designs. As a common combat system is assumed, the decrease in density of the stretched design should improve access and reduce the work in way, decreasing the man hours per tonne. This would reduce the difference in UPC between the two baseline designs.

6. CONCLUSIONS

Decreasing the waterline length of a corvette design by 16% decreased the estimated UPC by a comparable 15.5%. For the requirements and roles assessed, a reduction in operability of between 6-8% and a decrease in the maximum speed of 1 knot was found. The seakeeping performance was also found to be reduced by approximately 25% and it is expected that the transit speed of the compact corvette will be lower in higher sea states.

Improving the armour of the baseline designs improved the survivability of the design of the order of 2-3%. However, the addition of armour did not recover the 12% reduction in survivability through the reduction of separation from reducing the waterline length.

Moving the operations room adjacent to the bridge provides a small improvement in survivability due to the reduction in hit footprint, but also produces a small reduction in operability due to the limit on the number of adjacent compartments. Increasing the separation of the operations room and bridge without moving the operations room below the damage control deck does not provide either an improvement in survivability or operability. Given the requirement to easily change modular capability, the baseline position is the optimum location for the threats assessed.

7. ACKNOWLEDGEMENTS

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