A family of underway replenishment ships

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SYNOPSIS

An analysis has been undertaken to determine the operational, functional and system requirements for the next generation of Underway Replenishment ships. Rolls-Royce undertook detailed customer analysis around the world during 2003/04. These requirements have been used to produce several ship designs of varying size and speed that are all incrementally upgradeable.

Commercially developed and proven ferry hullforms have been used to provide efficiency, good seakeeping and station keeping performance, essential to cost effective fuel and solids transfer up to high sea-states.

The design has been developed to allow flexible use of the ship for the transportation of various cargoes, allowing for VERTREP and aviation support to the fleet. The ships have been designed in 14,000dwt and 25,000dwt capacity versions with many different propulsion system options to suit the operating profile of the customer Navy. A full economic analysis of the propulsion options has been carried out to determine the most cost effective solution through life.

Full structural design and hydromechanic analysis has been completed to ensure confidence in the design weight, speed and stability of the ships.

The design has been developed with incremental acquisition in mind with many systems capable of being added later in the ship’s life if required. These system options ensure an affordable solution from the outset.

The paper discusses the requirement analysis, hullform selection, design development and overall analysis that has provided an adaptable and upgradeable design with high confidence, and low risk.

Author’s Biography

David Bricknell started his career at HM Dockyard Devonport. After graduating from Southampton University, he joined UK Shipbuilder Vosper Thornycroft and was involved in the build of a number of Naval Ships before moving to British Aerospace as Chief Engineer-Systems. In the nineties, David joined the Naval Architecture and Marine Engineering Consultancy British Maritime and finally joined Rolls-Royce in 1999. He is now a Vice President in the Naval business responsible for integrated ship and propulsion systems.

Robert Skarda graduated from The University of Southampton in 1996 with a degree in Ship Science. He then joined the Ministry of Defence and completed the Defence Science and Engineering Graduate training scheme. Robert then completed his Masters Degree in Naval Architecture at University College London followed by the Submarine Design Course. He then joined the Defence Procurement Agency where he worked on the Future Surface Combatant and Astute Class Projects. In November 2004 he joined Rolls-Royce as the Manager Systems, Naval where he is responsible for the development of Naval ship designs.

Per-Egil Vedlog is the Design Manager at Rolls-Royce Marine AS based in Ålesund, Norway. He was educated at Ålesund Technical University in Naval Architecture, Ship and Offshore Technology and started working as a naval architect in 1985. He has 17 years experience as a Senior Designer. For the last three years he has worked as the Design Manager and is responsible for new design developments of many different types of vessels, including high-speed vessels, cruise ships, RO-RO & RO-PAX vessels, container ships, car carriers, general cargo ships, tankers and fishing vessels.

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INTRODUCTION

The authors have recently completed a number of designs of varying deadweight capacity for Underway Replenishment vessels capable of 20 to 27 knots. The designs utilise commercially developed, fully proven and efficient hullforms from successful Rolls-Royce Ro-Ro designs. The ship design provides for an identified incremental upgrade path of capability from build through the service life of the vessel. These upgrade paths allow for tailoring of the solution to any customer’s specific requirements. As the starting point for the family of designs is a commercial standard vessel it is anticipated that the ship’s acquisition costs will be low. The addition of military capability such as aviation facilities, self-protection systems, additional dual capacity replenishment rigs and the potential for future upgrade has been designed into the ship to reduce the risk of future platform obsolescence.

A detailed structural definition, seakeeping analysis, systems selection and general arrangement drawings have all been completed, as has an economic analysis on a range of propulsion systems.

REQUIREMENTS ANALYSIS

The changing geo-politics of defence have seen an upsurge in warships being deployed worldwide in multinational operations. Nations involved in these often fast-developing crises are seeking to put early-entry forces into theatre to rapidly stabilise the situation through their presence, or to take action. This presence demands long-term support to those forces, and that in turn requires re-supply. Getting into theatre rapidly also demands either pre-positioning or support along the route for fuel, to allow a rapid transit. For all these reasons many nations are looking to acquire or to improve their Underway Replenishment (UnRep) capability. Examples include Norway, to support the Fridtjof Nansen class of frigates, and Romania to support Regele Ferdinand and Regina Maria (formerly Type 22 frigates HMS Coventry and HMS London). Other established bluewater nations such as the United Kingdom, Australia and India are looking to replace their ageing, non-MARPOL compliant ships with more cost effective solutions.

When considering the different roles and operations that navies conduct, the authors have concluded that these can be captured in two different sizes and types of Underway Replenishment ship. The first type is for those nations with strike carrier capability whose requirements are for a large capacity of fuel for the ships, in addition to a significant AVCAT capacity. These carrier support tankers may also require high-speed to keep up with the potentially nuclear powered carriers they are servicing. The second type of ship is optimised for worldwide support of surface combatants. This ship type has also been designed to carry dry stores and ammunition to provide a complete capability.

The two variants of the 14,000dwt surface combatant support ships and the 25,000dwt strike carrier support ship have the characteristics described in Table 1.
Conventional tanker hullforms and designs do not provide the capability required, such as economical transit speeds up to twenty knots, a significant aviation support capability, good manoeuvring and

Table 1 - UnRep Ship Family Characteristics

<table>
<thead>
<tr>
<th>Main Dimensions</th>
<th>14,000 dwt - 20 knot</th>
<th>14,000 dwt - 27 knot</th>
<th>25,000 dwt - 20 knot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Over All</td>
<td>173.20 m</td>
<td>188.20 m</td>
<td>223.40 m</td>
</tr>
<tr>
<td>Length Between P.P.</td>
<td>161.70 m</td>
<td>176.70 m</td>
<td>210.00 m</td>
</tr>
<tr>
<td>Breadth mld.</td>
<td>26.60 m</td>
<td>26.60 m</td>
<td>28.80 m</td>
</tr>
<tr>
<td>Depth 3rd deck</td>
<td>13.30 m</td>
<td>13.30 m</td>
<td>13.30 m</td>
</tr>
<tr>
<td>Draught Summer</td>
<td>9.00 m</td>
<td>9.00 m</td>
<td>9.00 m</td>
</tr>
<tr>
<td>Scantling Draught</td>
<td>9.30 m</td>
<td>9.30 m</td>
<td>9.50 m</td>
</tr>
</tbody>
</table>

| Performance         |                      |                      |                      |
| Service Speed       | 20 knots             | 27 knots             | 20 knots             |
| Deadweight          | 14000 tonnes         | 14000 tonnes         | 25,000 tonnes        |

| Ship Capacity       |                      |                      |                      |
| Marine Diesel Oil   | 2300 m³              | 3900 cu.m            | 3800 cu.m            |
| Fresh water         | 1000 m³              | 1000 cu.m            | 1000 cu.m            |
| Water ballast       | 7000 m³              | 7000 cu.m            | 11400 cu.m           |

| Cargo Capacity      |                      |                      |                      |
| Marine Diesel Oil   | 8000 m³              | 8000 m³              | 15000 m³             |
| Fresh water         | 1000 m³              | 1000 m³              | 1000 m³              |
| Avcat               | 2000 m³              | 2000 m³              | 7000 m³              |
| Lub oil             | 1000 m³              | 1000 m³              | 1000 m³              |
| Dry Cargo           | 4100 m³              | 4100 m³              | 4100 m³              |
| Provisions          | 1000 m³              | 1000 m³              | 1000 m³              |
| Containers          | 17 FEU or 34 TEU     | 17 FEU or 34 TEU     | 21 FEU or 42 TEU     |

| Class. Notation     | +1A1, DG-P, DEICE, OPP-F, HELDK-SHF, F-AMC, LCS-DC, E0, RP, Clean Design |                      |                      |

HULLFORM DEVELOPMENT

Fig. 1 - MV Olympic Champion, NVC designed 27.5 knot Ro-Ro

Conventional tanker hullforms and designs do not provide the capability required, such as economical transit speeds up to twenty knots, a significant aviation support capability, good manoeuvring and
station keeping performance, large volumes of dry stores and sufficient complement to manage the running of the ship as well as the stores management and replenishment operations.

There are no conventional tanker designs today designed for speeds above 16 knots. Generally the hullforms on product tankers are designed for high deadweight and relative low speed (14-16 knots). Conventional tankers with a capacity of 10-20,000 dwt normally have a Block Coefficient (Cb) of 0.78-0.80. Depending on the propulsion system, these high block coefficient hullforms are normally course unstable, and hence are not optimal for replenishment ships, as they need to maintain a stable course during the replenishment operation.

A service speed of 20 knots requires a totally different hull type such as those designed for Ro-Ro or Ro-Pax passenger vessels and reefer. A typical Cb on passenger and cargo vessels with service speed of 20 knots is around 0.60 – 0.64.

A fast-ferry hullform has been used by Rolls-Royce to provide the efficient and dynamically stable basis on which to design the Underway Replenishment ship, as it does not suffer the same hydrodynamic problems as a products tanker. Shown in Fig. 1 is the Ro-Ro MV Olympic Champion designed by Rolls-Royce NVC. This is a 204m long, 27.5-knot (sustained) ferry, two of which have been built and are operating in the Mediterranean. This hullform is the base for the family of Underway Replenishment ships described here.

The base hullform has been well proven in service and has been extensively tank tested. Designed with twin-screw propulsion the hullform was also varied for different propulsion options such as a single screw with Azipull tractor mechanical pods and Mermaid electric pods. The hullform resistance for these options was estimated using MARINTEK EmPower, which uses a database of similar geometries and resistance tests to provide a derived resistance curve with high confidence.

Fig. 2 - Comparative Hullform Efficiency

In terms of overall efficiency the hullform can be compared to other amphibious and auxiliary ships either planned or in existence by using the installed propulsion power with a speed and displacement factor derived from the Admiralty Coefficient. The graph above, Fig. 2 shows Installed Power (Ps) vs \( D^{2/3}V^{1} \). As can be seen, the hullform used is efficient in comparison with other vessels of the same type, even those that are as yet still at the planning stage. The continuous development that is necessary in the commercial market place aids the naval designer in being able to select a state-of-the-art, efficient hullform.
STRUCTURAL DESIGN

The structural design of the ship follows commercial practices and includes a double-hull to meet the latest MARPOL requirements. The structure has been designed to comply with IACS rules, in this case Det Norske Veritas.

A NAPA steel model was constructed (Fig.3) and analysed to provide confidence that the steel weight was correct, which is important to ensure the stability and powering calculations are also accurate. The bulkheads are designed using standard corrugated steel and are placed to ensure that the ship meets Naval rules (DEFSTAN 02-109, the UK Ministry of Defence, ‘Stability Standard for Surface Ships’).

Fig. 3 - NVC 20 knot Underway Replenishment Ship NAPA Steel Model

The tank deck is enclosed to reduce the effects of corrosion on the pipe systems and hence reduce the maintenance burden. Atmospheric ventilation of this space will be controlled and monitored. The flightdeck is designed to withstand the crash-on-deck loads and normal wheel loads of the Merlin helicopter.

ARRANGEMENT

The whole arrangement of the ship aims to provide the most effective reception, movement, treatment, storage and delivery of fuels, liquids and dry stores. The ship also includes a substantial aviation facility to enable operation and maintenance of the ship’s helicopter, as well as the capability to undertake maintenance of fleet aviation assets for ships who do not have the necessary space to do this maintenance themselves. A General Arrangement drawing is shown in Fig. 12 at the end of this paper.

The upper deck is dominated by the Replenishment-at-Sea and Fuelling-at-Sea (RAS/FAS) rigs. The clearway enables rapid access of dry stores to the dual-purpose rigs as well as the between deck storerooms. Additionally, a fully automated material handling system capable of stores inventory management and movement of pallets – from the controlled atmosphere store rooms and onto the rigs - will be included to improve safety, stores management and optimise crew numbers to reduce through-life costs.

To comply with maritime legislation all accommodation is aft of the bulkhead at the front end of the superstructure. In front of this bulkhead are all the cargo areas, especially those for the fuel. This arrangement brings many safety benefits minimising any through bulkhead penetrations that may lead to the spread of fumes or fire.

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The fuel tanks have nitrogen inert gas systems to minimise fire risks as well as comprehensive fuel treatment systems to enable fuel to be cleaned prior to delivery to the combatants and other naval vessels. The tanks are also split athwartships into three sections with the centre tanks receiving the cleaned fuel before it is discharged to the receiving ship; this ensures that the stability is retained. A full damaged stability analysis has been conducted including asymmetric damage cases to ensure that IMO and UK MOD stability standards have been met.

The cargo will be delivered from the tanks using commercial high-reliability deepwell pumps, running at a rate of up to 600m³ per hour per tank. This will enable fuel to be pumped via twin hoses on two rigs at up to 2400m³ per hour, enabling rapid fuelling of large units such as Carriers and Assault ships. Alternatively, one rig per side can be used for fuel and the other for dry stores. At least one stern reel can be fitted to enable over the stern fuelling-at-sea operations to other ships, including those without RAS receiving moveable highpoints, such as patrol boats and corvettes.

The propulsion machinery is arranged dependent on the system selected as the best match for the operating profile and requirements of the customer. All the options assessed provide additional redundancy compared to a commercial products tanker. The systems that use the Mermaid™ Pod and Azipull fully azimuthing mechanical pod with a centreline boost, have different hullforms to optimise the inflow into the propellers and hence gain the most performance advantages. This not only reduces the hullform resistance, due to reduced surface area from other appendages, but the improvement in inflow conditions to the propeller also improves the efficiency of the propeller. Both these factors were taken account of in the analysis.

The large skeg fitted to the design ensures the ship can be docked with minimal adjustment to the dock structure and blocks, and to ensure acceptable dock block pressures. The hullform is also slab-sided for as much of its length as possible to simplify berthing arrangements as well as reducing build costs.

The accommodation illustrated in Fig. 11 is designed to support a combined Royal Navy and Royal Fleet Auxiliary (RFA) complement. The naval cabins are located around the inside of the aft accommodation area and the RFA cabins are to merchant accommodation standards, with natural light around the outside of the area. All cabins are en-suite in this example. Within the aft area are the frozen, cold and dry provisions storerooms with access to the stores deck and flightdeck via a lift. The lift will be cleared for carriage of munitions from the below waterline magazine forward, to either the stores deck or for loading onto the helicopter.

The citadel for the ship covers the volume aft of the forward bulkhead of the superstructure. There are two cleansing stations, one servicing the foredeck and the other the quarterdeck and flightdeck. Both are however accessible from all parts of the upperdeck to ensure there is no wasted decontamination effort. The ship is designed For-But-Not-With (FBNW) a pre-wet system for full Chemical Biological Radiological and Nuclear (CBRN) capability.

The aviation facilities for the ship include a flightdeck that provides space for large helicopters such as a Chinook or EH101/Merlin. The hanger has been designed to accommodate two folded Merlin helicopters and to facilitate maintenance, including main rotorhead and gearbox removal and replacement. There is space around the hanger to embark a modularised support system for the helicopters as well as workshop, stores, office and planning space for the ship’s embarked flight. The flightdeck is fitted for a fixed fire-fighting foam installation as well as the necessary systems for Night Vision Goggle and reduced visibility operations.

Underway Replenishment ships have not traditionally had very comprehensive Combat Systems. Requirements are dominated by close range self-protection systems. As this ship is based predominantly on a commercial ship, a minimal baseline Command System has been incorporated, utilising modern COTS electronics modules and an open system architecture to provide the ability to upgrade throughout the life of the ship. The particular ship shown has adopted an Ultra Electronics OSIRIS Mission Management System, integrating sensors, countermeasures and weapons systems to provide Command with enhanced situational awareness, and a more effective response capability. The ship can be fitted with a range of self-defence systems as well as sensors, all of which are integrated into the OSIRIS system. An operations and planning room is provided aft of the bridge, where the
Command System and Operational communications are accessed and operated via OSIRIS multi-function consoles.

Close-In Weapon Systems can be fitted on the hanger and RASCO roofs and there are additional weapons stations on the ship for heavy Machine Guns and Miniguns where required to provide all round defence against small craft and helicopters.

**PROPULSION SYSTEMS**

An economic analysis has been conducted of four different propulsion systems for the 20 knot 14,000 dwt ship. All use diesel propulsion and/or generators with various system architectures.

The aim of the system designs is to minimise the initial and through-life cost of the system whilst still providing for the key requirements of; speed, efficiency, redundancy, reduced maintenance burden, overall power balance, heat balance and ship fit impact.

The power balance investigated was between propulsion at full power with hotel load and propulsion at 16 knots, (the maximum RAS speed), together with hotel load, load from the all-electric RAS/FAS winches and from the fuel transfer pumps. An additional load was added to the all-electric propulsion systems to account for the heat losses within those systems that would have to be removed from the air-conditioned sections of the ship.

The four options analysed were:

1. Twin CPP hybrid electric-mechanical system with low voltage shaft/motor generators on each shaft.
2. Twin FPP shafts with all-electric propulsion.
3. Twin mechanical Azipull azimuthing propulsors with electric drive and a single CPP centreline boost shaft powered by a hybrid-electric solution.
4. Twin Mermaid podded propulsors with all-electric propulsion.

These options were chosen to provide efficiency, reliability, redundancy and modern technology. It is imperative that the customer’s operating profile, or estimate of the profile is used to determine the best option for the through life costs of the system, including elements such as maintenance. The affect on build cost of the propulsion options was also taken into account.

Fig. 4 - Twin CPP hybrid electric-mechanical system with low voltage shaft/motor generators on each shaft
This system is designed to operate in the following modes:

- **Low Speed <12 knot** - using the electric motors powered from the ship’s generators.
- **RAS operations 12-16 knots** - providing redundancy using both main propulsion diesels and generating power for the ship’s hotel load. The ship’s generators provide power for the fuel transfer pumps and the RAS rigs.
- **High Speed 16-20 knots** - the propulsion engines are linked with the motors powered from the diesel alternator sets. One diesel alternator is redundant allowing for maintenance.

Propulsive power required is 16.3 MW with margins and total installed power is 24MW.

The system provides many of the advantages of a full-electric system. Flexible use of prime movers and the ability to run both shafts with only one main engine operating is seen as an advantage. A Low Voltage electrical system can be adopted thereby reducing initial and through-life costs. Transmission efficiency is high.

**Fig. 5 – All-Electric System**

The All-Electric system is very flexible with the ability to load the generators to their most efficient. There are, however, greater losses associated with this option due to the generation, distribution and conversion of the power through the electric system, drives, motors and into the water. Most of these losses will be turned to heat, some in the engine room but some will be within the air-conditioned boundary of the ship, namely the drives. This heat loss will have to be removed by the air conditioning system, which will drive up the power requirements especially in hot and humid conditions.

**Fig. 6 - Twin Azipull with Boost Shaft**
The Azipull with Boost system is designed to operate in the following modes:

- **Low Speed <12 knot** - using the Azipull units powered from the ship’s generators or the Power Take Off (PTO) generator on the main shaft. The centreline shaft will remain feathered up to 16 knots. The Azipull units are extremely efficient due to the uniform flow into the tractor propeller face, they also provide excellent manoeuvring characteristics and course stability.

- **RAS operations 12-16 knots** – redundancy is provided by using the man shaft and generating power for the ship’s hotel load through the PTO generator. The ship’s generators provide power for the fuel transfer pumps and the RAS rigs. The Azipull units provide good course stability during the RAS operation.

- **High Speed 16-20 knots** - the propulsion engines drive the main shaft mechanically and also provide power from the PTO generator to the Azipull units, which are also powered from the diesel alternator sets. One diesel alternator is redundant allowing for maintenance.

Propulsive power is 16.3MW. Total installed power is 23.4MW. The Azipull units do not have variable speed drives but starter units, the motor maintaining constant RPM and the thrust is varied by changing the pitch on the CPP. This arrangement greatly simplifies the system, reducing cost and complexity.

Only having one shaft also reduces build costs due to shaft alignment, with the Azipull units fitting into manufacturer provided welded-in housings.

**Fig. 7 – All-Electric System with Azimuthing Electric Pods**

Podded propulsion provides excellent propulsive efficiency as well as excellent manoeuvrability. The initial costs are however, high, even after accounting for a reduced ship build cost. As the manoeuvring requirements for this type of ship are not as demanding as for a cruise ship or an amphibious ship, the capability does not benefit from the increased initial cost.

Of the four options assessed the indications were that the most cost effective through life is the hybrid electro-mechanical system, as it provides the most flexibility and redundancy with the lowest installed power. Figure 8 below shows a comparative Through Life Costing using a 6% discount rate and assuming a thirty-year life. The comparisons are against the same operating profile and hotel/RAS loads.

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RAS SYSTEMS

The ship is designed to include up to four Rolls-Royce all-electric dual-purpose replenishment rigs, with at least one stern reel for FAS operations and a reception point for over the bow fuel reception from another ship.

Fig. 9 - RASCO, RIG and Winch Arrangement

The all-electric system has been adopted by the Royal Fleet Auxiliary and others due to its reliability, safety and comparatively low maintenance load. The system can operate automatically when transferring stores to ensure that the load moves quickly and smoothly. Knowledge of the position of both ships is maintained through the winches to ensure that the load is brought to a smooth stop to minimise any dangerous swinging. The electric RAS system has been thoroughly de-risked in-service.
with the Royal Navy with significant work completed to negate the impact of transients and regeneration on the ships electrical system.

The propulsion and electrical generation plant has been sized to enable the RAS operations to be conducted at speeds less than 16 knots, the electrical power provided by the main propulsion engines as well as the ships generators, which will also power the deep well pumps, RAS winches and auxiliary systems to maintain the optimum speed of stores and liquid transfer.

**SEAKEEPING ANALYSIS**

A very important aspect of the design is the seakeeping performance of the hull and its effect on replenishment operations and on the flightdeck. A full seakeeping evaluation of the design was conducted using MARINTEK’s ShipX Hydrodynamic Workbench software package to determine both the inherent ability of the hull and the effects of both stabiliser fins and roll stabilisation tanks.

The Vessel Responses (‘VERES’) plug-in provided both pre- and post processing for the seakeeping analyses. Operability limiting requirements for RAS-operation used in the study were taken from NATO STANAG 4154 [1]. Operability for the North Sea (annual) and North Atlantic (in winter) are calculated based on these limiting requirements. Short-term statistics for a significant wave height of 6 meters (top of SS6) and a wave period range representative for the sea areas mentioned above are also calculated. Only short crested seas were evaluated.

The effects of two roll-damping systems were assessed. These were a passive stabilizer tank on the forecastle deck and one pair of fin stabilizers. The influence of the effects of forward speed on operability was determined so that the effectiveness for various operations could be analysed.

Against the design sea state and wave period range chosen, the vessel meets most criteria for replenishment modes given in NATO STANAG 4154 [1] as illustrated in Fig 10. The hardest criteria to fulfil are those related to vertical displacements and accelerations. Vertical displacement at the helicopter deck exceeds the given criterion, the most limiting helicopter takeoff and landing roll displacement in replenishment mode is not a problem in sea areas dominated by short wave lengths (below 12 seconds). In sea areas dominated by long wave periods, roll damping is necessary to meet the roll displacement criterion. The roll damping system that proved to be most effective in replenishment mode was the passive tank stabiliser as it is not speed dependent as the fins stabilisers are hence for the relatively low speed RAS operations it is more effective.
Operability in short wave period sea areas such as the North Sea is good and no roll stabilization is needed from an operability point of view.

In sea areas dominated by longer waves, such as the North Atlantic in winter, the vessel needs to be roll stabilized to perform solid RAS operations up to upper sea state six. For vertical replenishment, the vertical displacement and Motion Sickness Indicator (MSI) criteria result in poor operability. Vertical motions and accelerations are the major issues for the vessel in the North Atlantic, the only way of solving these problems for this vessel would be to increase its size or reposition the flightdeck, neither of which is practicable.

MSI is the limiting criterion in transit modes. This problem increases with vessel speed due to frequency of encounter effects. The MSI criteria is however questionable as to its applicability to professional sailors.

The results of this study indicate the difficulty for any vessel of this size to provide solid stores in the North Atlantic winter at upper sea state 6. The larger 25,000dwt vessel has the added advantage of length and mass and passes the criteria. The vessel design has been fitted with a pair of retractable stabilisers to reduce resistance of the vessel at low speed and provide stabilisation for the higher RAS speeds and for flight operations at higher speeds, a critical capability for the ship. A roll-stabilisation tank has been designed in as an option to improve low speed roll motions. Liquid replenishment can be carried out at lower sea state seven for the 14,000dwt design and at sea state seven for the 25,000dwt design.
UPGRADEABLE DESIGN

The key advantage of these ships is that they are purpose-designed for Replenishment-at-Sea with dedicated stores handling areas and equipment, aviation facilities to provide fleet helicopter support and maintenance, and the ability to provide solids or liquid stores quickly and efficiently.

The adoption of commercial standards is not a hindrance for a ship that is designed for robustness with redundancy in power and propulsion to provide a survivable platform. Survivability can be quickly and cost-effectively improved under incremental upgrades planned in at the design stage.

Fig. 11 - View of the 25,000dwt Underway Replenishment Ship

The baseline ship will be fitted as standard with the following mission systems in addition to safety and legislative equipment:

- One Dual Purpose RAS rig port and starboard.
- Hanger and a flight deck but no aviation systems.
- Sufficient propulsion and generator capacity for a top speed of 16 knots.
- Commercial navigation system with IMO compliant equipment.
- Commercial fire-fighting system.
- Operations room not fitted out.
- Hospital fitted out as single bed only.

The following features can be added:

- Two further dual purpose RAS rigs as well as FAS equipment.
- Hanger fitted out with facilities/handling system for helicopters up to Merlin (EH101) size.
- Advanced dual frequency navigation radar for picture compilation.
- Propulsion and generator capacity for a maximum speed of 20 knots.
- Military fire-fighting and damage control system.
- Military communications including Receive Only Link Eleven
- Six bed hospital
- Self-loading ability for containers.
- CBRN protection system, including pre-wet, positive pressure citadel, air-locks, cleansing stations and air filtration spaces.
- Electronic Warfare System comprising ESM-Warner and decoy launchers.
- Security weapons stations.
- Close-in-weapon systems.
CONCLUSIONS

The Rolls-Royce family of Underway Replenishment ships maintains the commercial basis of the ship designs as far as possible including maximising the producability using flat panels and corrugated bulkheads wherever possible. The addition of military features and standards only where necessary supports the design objective of keeping the costs as low as possible whilst maximising the mission capability.

The propulsion options assessed indicated that the most cost effective system through life is a Hybrid Electric-Mechanical system with Low Voltage shaft motor/generators on each of the two shafts. This system gives the most flexibility and redundancy with the lowest installed power due to the ability to share propulsion power during the different operations undertaken by the ship.

The vessel designs achieve good seakeeping performance due to the benefits of the fin stabilisers and a stabilisation tank that are effective throughout the speed range in both long and short crested seas, enabling operability to be maintained and hence replenishment operations to continue in adverse weather conditions.

The result is an optimal balance between commercial and military technology to provide an affordable yet capable solution.

REFERENCES

Fig. 12 - General Arrangement of the 25,000dwt Underway Replenishment Ship