THE ADVANCED TECHNOLOGY MAST FOR HMS ARK ROYAL

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SUMMARY

The Royal Navy has adopted composites technology for use in its advanced technology mast. The mast has been designed, installed and is currently in-service on one of the UK's aircraft carriers, HMS Ark Royal. The multi-functionality of the materials has enabled the varied and complex design drivers to be met.

Keywords: Mast, ARK ROYAL, Naval, Structure, Design

BACKGROUND

Since the early 1990s, QinetiQ has been developing advanced mast designs for the Royal Navy. The concept aims to house sensors within the protection of the structure whilst ensuring that they are still able to function efficiently, offering an improved signature and arc of coverage. Several full-scale structures have been built and tested. Initial work focussed on electromagnetic interference (EMI) and stealth. More recent work aimed to improve upgradeability whilst minimising initial and through-life costs.

Following on from the technology demonstration programmes, the Major Warships Integrated Project Team (MW IPT) of the UK MOD identified the need for a third mast for HMS Ark Royal. Aiming to provide them with enhanced performance over traditional designs, work began to develop the Advanced Technology Mast (ATM) in 2002. The ATM concept for Ark Royal is intended to provide a solution to the sensor fit requirement, as specified at design, but also to allow future adaptation to accept upcoming sensor technologies during the platform lifetime. The benefits of this in-built flexibility are primarily functional but may also be significant in terms of through-life cost. After a two phase programme, the ATM was finally completed in late 2006.

PHASE 1 – CONCEPTUAL DESIGN

Context

Concept development for the ATM began in 2002. This initial study considered the implementation of an ATM design as the 3rd mast for HMS Ark Royal, located towards the aft of the superstructure. The need had been identified to enhance the current sensor fit capability and the implementation of a third mast was selected as the preferred route. In parallel with this project, HMS Illustrious was also undergoing such a capability enhancement, however a 'conventional' steel mast design was being implemented. The two construction methods lead to widely differing implementations of the sensor fit and the advantages of adopting an advanced composite design with integrated technologies prompted the move towards an ATM for HMS Ark Royal.

QinetiQ had developed the concepts behind the Advanced Technology Mast over a number of years. Technology demonstrators and test rigs have been produced to prove the concepts, particularly in relation to the operation of sensors from behind ‘transparent’ walls – opening up the opportunity to provide novel mast solutions with distinct advantages.

Prior to the installation of the ATM on HMS Ark Royal, there were no such masts in operation within the RN fleet. Other Navies, particularly the Americans, began to exploit similar technologies most notably with their Advanced Enclosed Mast/Sensors (AEM/S) mast onboard USS Arthur W. Radford [1]. Interestingly the twin mast AEM/S design implemented on the US LPD-17 class vessel [2] utilises an octagonal modular design (as used by QinetiQ since the early 90’s) as opposed to the hexagonal design of USS Radford which was assembled from very large sub-assemblies.

The Phase 1 conceptual design focussed on the requirements of the equipment fit. This didn’t allow for full exploitation of the previously developed technologies but did provide the UK with a means of demonstrating some important features including the design and manufacture of the composite panels. Perhaps the most notable aspect of the design is the shape, which, similarly to the AEM/S structure, reduces in section towards the superstructure – in both cases reflecting the constraints of a retrofit design.

The ATM concept for Ark Royal was intended to provide a solution to the sensor fit requirement, as then specified, but also allowed for future adaptation to readily accept upcoming sensor technologies during the platform lifetime. The benefits of this in-built flexibility are primarily functional but may also be significant in terms of through-life cost, particularly where reconfiguration is encountered.

Design

The drive for an Advanced Technology Mast was partly borne of the need to mitigate the electromagnetic interference issues resulting from overcrowded masts of the type shown in Figure 1. In addition to the long-term cost-saving opportunities there was a desire to provide a benign environment to maintain the enclosed sensors.

Figure 1: Typical mast sensor fit

A great number of aspects were considered within the early design, including platform-integration issues, incorporation of upgradeability, equipment selection/location constraints, overall-shape (aesthetics), electromagnetic transmission, stealth aspects, weight reduction, space maximisation, stiffness, material selection, cost reduction/efficiency and blind-arc reduction. As is the case when many drivers are identified, which are often competing, a prioritised compromise was ultimately reached.

Following consideration of the various aspects described above, and through a consultative process involving the MOD customer, the concept was steadily refined. A period of consultation was necessary in the preliminary stages to ensure that this novel solution would be acceptable to the Royal Navy (RN) fleet. Some conceptual views can be seen in Figure 2.

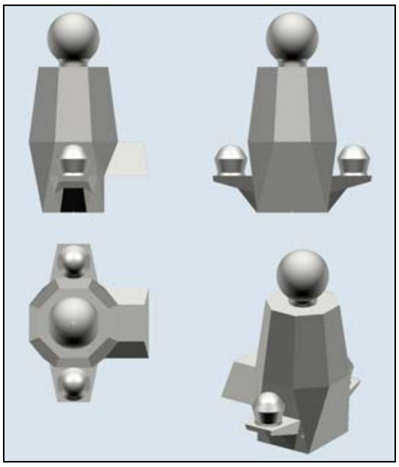

Figure 2: Conceptual views of the ATM

The design of the mast was severely constrained by non-structural considerations. In particular, the width of structural columns was restricted by the need to minimise blockage of signals from internal equipment and the configuration of the composite panels was driven by their transparency to those same signals. In regions outwith the radome compartments, composite panel design was driven by the need to minimise radar cross section (RCS) and therefore stealth materials were employed.

The concept of the mast is simple; it is essentially a steel framework, which carries most of the loading, braced by composite sandwich panels. The composite panels stiffen the structure considerably whilst carrying low level shear forces and out of plane buckling is precluded by the high bending stiffness. It was found that substantial changes in the configuration of the panels had a small effect on the overall response and so the scope for changing internal equipment would not be compromised. Whilst the concept may be simple, of course the devil is in the detail.

A hybrid steel/composite structure was therefore developed capable of accommodating and housing the proposed mast equipment fit. A margin for expansion within the mast design was included for potential equipment upgrades, insertions and special fits. The steelwork was initially sized using relatively conservative assumptions extracted from MOD design rules [3] and Lloyd's Rules for Naval Ships [4]. Panel thicknesses were effectively pre-determined by electromagnetic requirements. A number of Finite Element (FE) models were then developed to optimise and test the designs under a variety of static, quasi-static and dynamic loadcases. The static and quasi-static loads included: self-weight, equipment weight, acceleration loads due ship motions, ice loads, wind loads, pressure loads for panels and live loads. Appropriate load combinations were also considered. Finally the mast structure was subjected to severe shock loading.

In order to achieve useable structural stiffness using GRP (glass reinforced plastic) it would be necessary to use either thick monolithic laminates, which would be detrimental in terms of weight and transmission performance, or preferably sandwich panels which can offer stiffness and weight benefits over standard steel plating. However, as the sandwich would primarily be a radome wall, further considerations had to take into account the transmission of energy through the material, which is related to the material thickness and permittivity, and the wavelength of the signal passing through it. Further, different base materials exhibit different properties and in the case of composites, the manufacturing method can also significantly affect the overall material properties.

Many of the materials were selected due to availability and adherence to relevant standards and to address issues such as environmental performance (resistance to fire and weathering). An iterative process of modelling and subsequent testing was conducted to develop and verify an electromagnetic design that took account of each of these factors.

Materials

One of the primary reasons for proposing the use of polymer composites in the manufacture of the mast was their relative transparency to electro-magnetic (EM) radiation, giving the ability to house sensors within compartments. This not only bestows the benefits of protecting the sensors from military and environmental threats, but it allows sensors to be stacked on top of each other giving the potential for greater isolation and thus reduced interference between them. It is also likely that such a structure will have reduced necessity for maintenance.

The use of composites in the design of naval vessels is not a new concept; Royal Naval MCMVs (Mine Countermeasures Vessel), SRMHs (Single Role Mine Hunter) and the gun housings on RN destroyers and frigates have been manufactured from GRP for many years. They have, however, rarely been considered for the manufacture of other structures on any specific vessel. The result of this is that there are few standards that can be specifically related to structures made from these materials. During the course of this programme, close co-operation between the designers and Class Society was necessary to ensure Class Approval would be ultimately gained.

Selection of the most appropriate materials was based upon their electromagnetic, mechanical and environmental performance and applicability with appropriate manufacturing techniques.

The mast was split into a number of areas where different configurations of materials were proposed. There were two designs of composite side panel used, related to the sensor within the compartment, and also two designs of composite decks. Where possible, Class Society approved materials were selected, most notably those certified by Lloyd's Register.

Manufacturing method

Because of the need to use a manufacturing route that was compatible with typical shipyard methods, the manufacturing methods for advanced masts have taken into account the capabilities of such teams. Early demonstrator structures were based around pre-preg materials because the inclusion of a FSS (Frequency Selective Surface) within the laminate meant that thickness tolerances needed to be high. In later programmes, it was shown that the thickness tolerance, close to that achievable with pre-preg, and at least suitable for the radome structure being proposed for Ark Royal, could be obtained using a resin infusion technique. Resin infusion tends to be a much more cost-effective process and has been used by UK shipbuilders. This technique was therefore adopted for HMS Ark Royal's ATM.

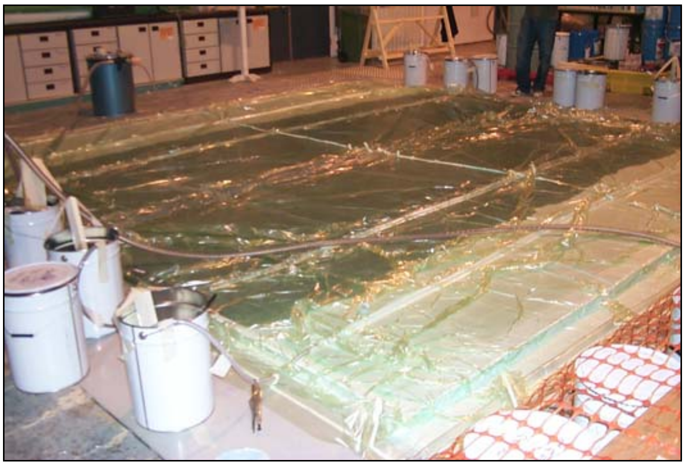

Figure 3: A deck panel being infused with resin

The visual appearance of UK Naval Vessels is an important consideration and so it was necessary to obtain as smooth a surface finish as possible on the outside of the panels, while completing the infusion process in one shot for cost effectiveness. Typically, this is achieved for sandwich structures by perforating the core material to allow greater flow of resin to the lower glass reinforcement plies. However, in the case of the walls for the navigation enclosure, this was not deemed to be possible, as the resin would affect the overall electrical permittivity of the core material in a detrimental manner.

The solution in the past has been to use distribution media on both sides of the whole sandwich structure. A ‘damping’ layer of cloth would be used between the distribution media and the release layer of material to produce a better surface finish. However, the use of a gel coat meant that such a method could not be used because the gel coat needs to be in contact with the tool face to enable the best surface finish.

A Vacuum Infusion Process (VIP), a development of a typical resin infusion technique, was agreed on to manufacture the sandwich panels. To get round the problem of drilled cores or the use of damping layers, grooving was incorporated in the core surfaces. These grooves act as the distribution media. Consequently, a tool face finish incorporating a gel coat was achieved in a one-shot process without any loss of EM performance.

However, grooving also had the potential to affect the transmission performance, by acting as a diffractive structure. The spacing of the grooves was therefore deliberately large compared to the wavelength of interest to ensure no interference at the relevant frequency ranges.

PHASE 2 – DETAILED DESIGN, MANUFACTURE, BUILD AND INSTALLATION

Context

Phase 2 encapsulated the detailed design of the ATM and ultimately resulted in the production and installation of the structure on HMS Ark Royal. The conceptual designs were finalised and a sub-contractor was engaged to undertake the manufacture of the mast.

The structural design was finalised through a series of validated finite element (FE) analyses. Two primary FE models were built to assess the performance of the mast. A shell/beam model was used initially to look at the response under a range of operating loads, as defined by Lloyd’s Naval Ship Rules. These include roll, heave, yaw, sway, pitch, surge, gravity, wind and ice loads and combinations thereof. A detailed shell model was produced to assess the performance of the mast under the required shock loads. It was clear that the shock loadcase was by far the most onerous and this has driven much of the detailed design.

QinetiQ placed a sub-contract on Babcock Design and Technology Ltd (BD&T) to carry out the design for manufacture and to build the mast itself. Much effort was expended to ensure that the structural design could be manufactured and installed effectively. Particular attention was given to the mast/ship interface, sensor integration, sponson design and general structural configuration. Throughout the process, potential outfitting problems were assessed, where possible, and the structure evolved sympathetically to those needs. In particular, provision was made for hatches/doors, ladders, walkways and some services.

The final approval of the mast design was achieved through two channels, firstly by gaining class approval through Lloyd's Register for the environmental loads and secondly by gaining approval from the MOD Sea Systems Group for the shock loading.

Detailed design

The main structural members of the mast were sized using the methods previously described. However, appropriate techniques were used to ensure that the final design was suitable for manufacture and took account of the services and other outfitting needs that were required of it. An example of this is shown in Figure 4.

The attachment of the composite panels to the steelwork was clearly a key feature of the design to ensure that load transfer would occur effectively. The panels were attached via a range of bonding and bolting techniques. The number and location of joints had also to be based upon the effect that these would have on the EM performance of the panel. Stronger core materials were required in the areas of the bolts to prevent crushing of the sandwich panel and a number of solid FE analyses were used to determine the effectiveness of the load transfer through the bolts and adhesives. An example FE mesh can be seen in Figure 5.

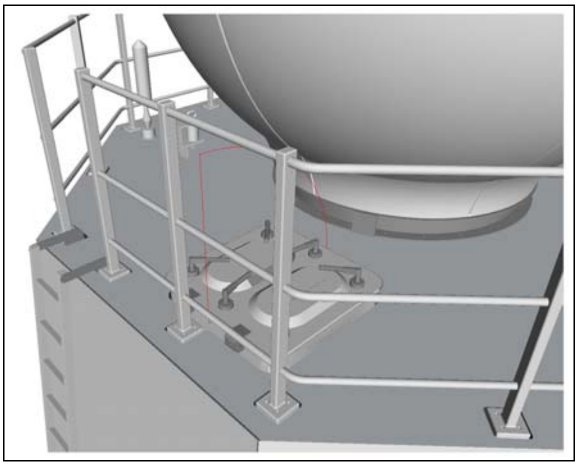

Figure 4: Detailed design features including hand rails and hatches

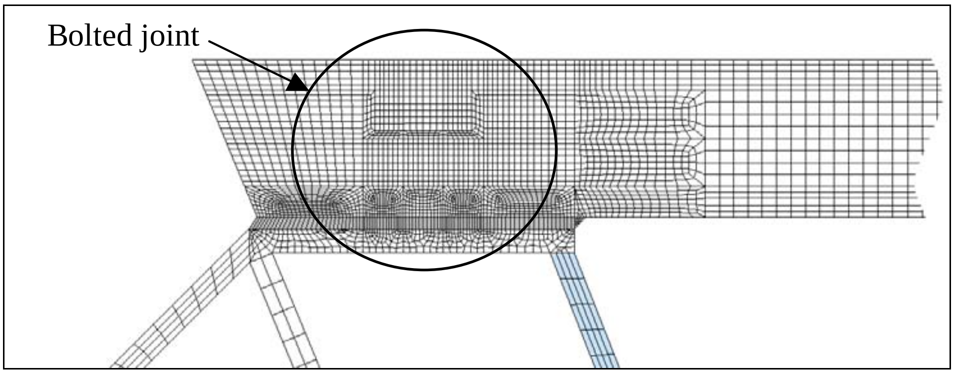

Figure 5: Typical FE mesh for assessing load transfer across joints

Manufacture

The manufacture of the mast was necessarily developed in stages with expertise supplied by both dockyard and composite panel fabrication specialists. Class Society involvement was maintained throughout to ensure that the production matched the design intent as closely as possible.

Since the flat composite panels needed ultimately to be bonded and/or bolted to the steel framework, the tolerances required on out-of-plane flatness for each facet of the mast was high. To meet this high tolerance it was not possible to manufacture much of the steelwork from beam sections. Each facet ultimately had to be machined from plate and welded at the appropriate intersections in order to ensure that flush face. Class society assessors were actively engaged throughout the manufacturing process to ensure that production was carried out in accordance with the design.

Manufacture of the steel framework began in mid-2005. The mast was built in units which would ultimately be brought together to form the ATM. Some early figures of the steel structure can be seen in Figure 6 below.

Figure 6: Initial steel unit production

Babcock Design and Technology worked closely with their composite panel manufacturers to ensure delivery of parts against a short timescale.

Prior to assembly, the composite panels required a final cut to size and edge sealing which was followed by careful preparation of the composite and steel surfaces to ensure that the adhesive had a good bonding area. Nylon spacers were also inserted intermittently between the composite and the steelwork to ensure that the adhesive could not be squeezed out when the bolts were tightened giving a controlled adhesive thickness.

The first composite assembly process to take place was the fitting of the deck panels. This was performed whilst the structure was undergoing final assembly in the synchro-lift building at Rosyth ahead of eventually being moved to the dockside. Most of the wall panels were attached prior to installation of the mast on the ship. Some were temporarily attached to give sufficient rigidity to the structure during transportation but were ultimately only fixed in place once the sensors had been finally sited within the mast. Further, additional lower panels were also attached temporarily to allow for removal prior to completion of hot work during installation. Once all the panels were in place, both sealant and a UV stabilised colour-matched edge capping material was applied over each of the joints between panels. Figure 7 shows the mast in-situ.

Figure 7: (a) Initial mast mounting on HMS Ark Royal (b) Mast with panels in-situ

In-service

HMS Ark Royal returned to service following her refit and installation of the Advanced Technology Mast in Autumn 2006. The ATM has therefore been in-service for over two years. The mast has been shown capable of withstanding the normal operational loads. The original sensor fit is still in place and no requirement for reconfiguration has yet arisen.

CONCLUSIONS

An Advanced Technology Mast design has been produced, its structural performance against both environmental and shock loads has been assessed, and the structure has been built and installed on HMS Ark Royal. Class Society involvement throughout the whole programme ensured that the mast was given Class Approval alongside MOD’s final acceptance. As a demonstrator programme, some lessons have been learnt along the way, most notably in the design for manufacture and the outfitting constraints. However, after over 2 years, the mast is still in-service and operating on the flagship of the Royal Navy, HMS Ark Royal.

Figure 8: HMS Ark Royal reconfigured with the Advanced Technology Mast

ACKNOWLEDGEMENTS

This work was sponsored by the UK MOD's Capital Ships Directorate (formerly Major Warships IPT). In addition to the authors' input, support from the rest of the project team is also recognised, namely Scott Lahiff, Graeme Batchelor and Nigel Duckett. Further support from Derek Graham, Steve Turner and Peter Barnes is also recognised. The input from our manufacturer's Babcock Design and Technology is also gratefully acknowledged.

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