WHEN IS A MAST A MAST?
THE IMPACT OF INTEGRATED MASTS ON PLATFORM DESIGN AND CLASSIFICATION

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SUMMARY

Recent years have seen the development of integrated masts for warships, with early examples now at sea or under construction. These integrated masts allow the exploitation of modern materials and technology to improve sensor performance and coverage. Further advantages to integrated mast designs include the delivery of the mast, sensors and related equipment as a completed module for installation. This can potentially remove the fit of the mast and the associated sensor system integration from the critical path for build and therefore contribute to de-risking of system testing and acceptance. In addition, when considering retrofit, the integrated mast can be constructed and outfitted prior to vessel arrival for refit.

In general, integrated mast designs do not fit the mould of what a Naval Architect would classically describe as a mast. Differences include the geometry, total weight, centre of gravity, materials used for the structure and the inclusion of equipment spaces within the mast. The question now posed to the Naval Architect, is whether we need to revisit traditional mast design methodologies to take into account these changes of form and function, and how mast structure should be treated by classification societies. Finally, the change from bespoke mast structures built as part of the ship to an integrated mast, designed as a common product and delivered as a complete equipment module, creates challenges when integrating common mast designs into multiple platforms.

NOMENCLATURE

ρ	Density of air (kg m^{-3})
CFD	Computational Fluid Dynamics
DNV	Det Norske Veritas
FRP	Fibre Reinforced Plastic
LR	Lloyd's Register
R_{AA}	Combined Wind and Air Resistance ()
RADHAZ	Radiation Hazard
RCS	Radar Cross-section
V	Ship Speed (m/s^2)
A_T	The transverse projected area of the ship (m^2)
K	Coefficient dependant on shape of the hull and erections

1. INTRODUCTION

1.1 A MAST – DEFINITIONS AND TYPES

The word mast when referring to a ship is commonly used to cover a wide range of differing structures. One definition from a simple web search (Dictionary.com) is:

> "a spar or structure rising above the hull and upper portions of a ship or boat to hold sails, spars, rigging, booms, signals, etc., at some point on the fore-and-aft line, as a foremast or mainmast.

In terms of the modern warship, a mast is essentially a structure used solely to support equipment at a height above that of a superstructure. A typical mast today would be expected to house:

- Radar antenna for navigation and air / surface search;
- Communications antennas;
- Navigation lights;
- Electronic signal detection equipment;
- Electronic jamming equipment.

The structure of a mast may be designed in a variety of ways to support these equipments, and these are typically categorised as (Figure 1):

- Pole / Tripod Mast: A single pole, either free standing or with supporting poles, which can support lower weight items;
- Lattice Mast: Constructed of (open) struts and trusses, typically on a square base, and arranged to provide structural rigidity as a free standing structure and used where the supported equipments are too great for a pole mast;
- Plated mast; Constructed as an enclosed structure, typically on a square base, with a plated skin, with internal diaphragms and stiffening to provide structural rigidity.

The plated mast is used in most cases on warships today due to its advantages of lower radar cross section and improved through life maintenance by enclosing the structure out-weighing the increase in weight over a lattice mast.

Figure 1: Illustrations of Mast Types – Pole (top left), Tripod (top right), Lattice (bottom left), Plated (bottom right)

The mast itself will affect the design of the vessel; its weight will impact the stability performance, air resistance will have an influence (although slight) on ships speed and the arrangement of antennae will affect the top side electromagnetic environment and RADHAZ. Finally, the need to provide access, power and cooling air to the mast has to be considered, as does the affect of the heat plume from the exhausts / funnel impinging on the antennae.

1.2 GENERAL ISSUES IN MAST DESIGN

When designing a mast structure, there are a significant number of factors to be considered. Some of these relate to the performance that will be achieved by the mast or the equipments fitted to it, others relate to how the mast impacts the overall design of the ship. Figure 2 illustrates some of these factors. The mast must be structurally integrated to the ship, the method used depending on the style of the mast. This integration must not only ensure static strength but must be able to withstand whipping loads due to hull slamming, air resistance and wind loads on the mast and, for a warship, shock and whipping load induced by weapons. The structural integration must also take into account how vibrations are transmitted from the ship to the mast, both to avoid resonance occurring in the mast and to prevent interference with antennae.

1.3 INTEGRATED MASTS

In recent years, there has been significant interest in the concept of integrated masts, with a variety of designs being developed. A number of these have now been, or will shortly be, installed such as those in Figures 3 and 4 which demonstrate two different types of integrated mast. Figure 3 is a composite mast which has sensors and antenna fitted within the mast and uses frequency sensitive shielding to allow the sensors to "see" through the mast panel structure. Figure 4 is an example where the sensors are integrated into the structure itself.

The idea of an integrated mast is to create a design in which the various antennae are more integrated within the design of the mast itself, as opposed to current designs where the antennae are fitted on to a structure which is independently designed. It is also likely that more of the electronic equipment will be included within the mast, to allow specific systems to be "integrated" in the mast as a single unit, rather than individual equipments having to be installed remotely and subsequently integrated as the ship nears completion. The result is a mast which may be a complete module, incorporating all the sensors and associated equipment in a structurally self supporting unit.

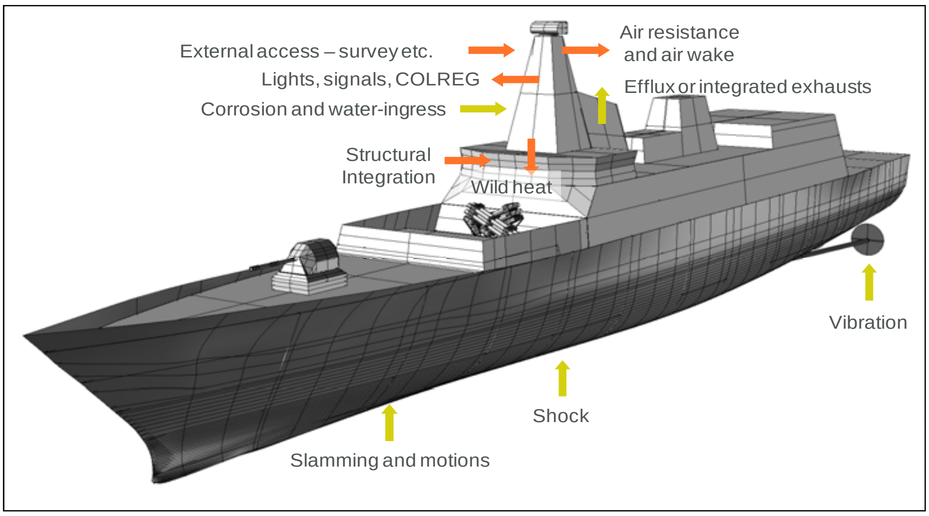

Figure 2: How Mast and Ship Design Impact Each Other

The advantages to this approach are:

- The potential to improve interference between antennae and reduce "Wooding Effects" by fitting antennae in layers around or within a single mast, rather than externally on a number of masts or top side locations than may interfere with each other;
- To reduce integration and setting to work requirements for the shipyard as the module may be delivered as a complete unit with all systems integrated within it;
- The potential to reduce man power by integrating the various systems on the mast and reducing the number of operators required.

However, the approach has some significant disadvantages, particularly for the naval architect. This includes the fact that, with equipment positioned within the mast rather than below decks, the mast is required to be larger. This results in a much larger foot print at its base where it is integrated to the ship and increased weight.

Figure 3: Integrated Mast on USS RADFORD

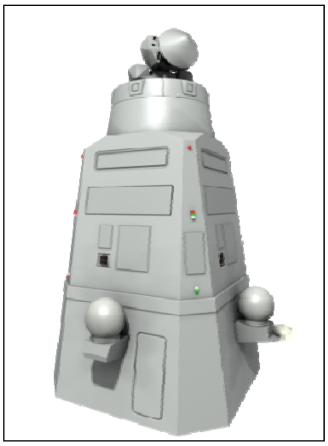

Figure 4: Thales Integrated Mast (I-MAST 100)

2 WHAT DOES THIS MEAN TO CLASS?

2.1 STRUCTURES

Bearing in mind that with sufficient supporting information Classification Societies will consider novel arrangements and materials, the following refers to the standard rule set within LR Naval Rules and Regulations for the Classification of Naval Ships [1]. Some of the main areas captured within the rules are those associated with the following at the design stage:

- Arrangement aspects such as the positioning of partial or main bulkheads underneath masts to transmit the static and dynamic forces into the hull structure;
- Reinforcement of deck scantlings iwo mast structures;
- Ensuring that Mast Natural Frequencies lie outside a +/- 20% band of significant excitation frequencies (e.g. main machinery and ship motions);
- That the structure withstands environmental loads including wind and ice accretion (where applicable);
- That the structure withstands the equipment support loads and maintains equipment alignment within manufacturers tolerances;
- That there is minimum interference of ships sensors;
- That there is internal and external access arrangements for maintenance and survey.

Structure considered as masts within the rules fall into the categories of pole masts, lattice masts and plated masts as previously presented. Integrated masts are closest in arrangement to the latter.

Proposed amendments to Lloyd's Naval Rules (expected to be incorporated in 2011) are more specific in their requirements. These new regulations now advise that plated mast structure is to be treated as superstructure and is thus subject to the rules for superstructure scantling determination and the associated minimum rules.

As a comparison DNV regulations specify that for Naval and Naval Support Vessels, for the structural arrangement of Masts "Static strength calculations shall be performed for mast supporting sensors and sensor systems" [2]. DNV have advised for a specific case that the integrated mast is "to be considered as a crane or other part of superstructure that is not subject to the full set of rules. The safety and structural load cases need to be taken into account". This approach suggests the mast could be treated either as an item of equipment or as a superstructure block.

3 MATERIAL CHOICES

3.1 GENERAL

The materials usually considered for mast structures can be subdivided into Steel, Aluminium and FRP. These have been considered for, or used on, integrated mast designs both independently and in combination (e.g. Steel frame with FRP panels). The paragraphs below provide a high level view of the advantages and disadvantages of each approach.

3.2 STEEL

Steel is often the preferred material in UK naval applications and although other materials or combinations thereof can result in benefits such as improved performance through life, lower weight etc. these are often rejected for reasons such as initial cost and confidence in material design and performance. When considering the benefits of steel in this particular application it can be seen that the advantages include it being low cost and low risk against the disadvantages of high maintenance requirements through life, the risk of distortion for low thicknesses during build and high weight. The increased weight of a steel mast over other material choices becomes more critical for the larger integrated masts than for traditional mast designs.

3.3 ALUMINIUM

Aluminium can be a lighter alternative to steel but also comes with its own challenges. It has better corrosive properties than steel but needs good design at the steel / aluminium interface if the vessel hull is of steel construction. In general it is a higher cost material than steel and is less resistant to fire due to its lower melting point; thus requiring additional structural fire insulation. Aluminium structures can provide significant difficulties for fire fighting with deck structure at risk of melting under fire conditions.

3.4 FRP

It is usually considered that the use of FRP opens up the potential for significant benefits. This is however, offset by the lack of in-service experience for this application and usually higher initial cost. The benefits include lower through life maintenance requirements, the opportunity to integrate sensors inside the mast structural envelope and the potential for it to be a lower weight option. Consideration needs to be given to the interface with steel or aluminium hulls. The use of FRP superstructures on steel ships to resolve fatigue issues has been considered in the past and composite superstructures have been used on the French, La Fayette frigate with the USS RADFORD integrated mast being of composite construction. RCS must be considered for FRP masts with the integration of a mesh to provide reflective properties. Where the antennas are contained within the mast, the mesh must be tailored to allow antenna signals out whilst reflecting external signals.

The fire performance of FRP is heavily dependant on material selection. Consideration needs to be given to smoke generation, toxic by-products and maintaining structural strength under fire conditions.

3.5 STEEL FRAME/FRP PANELS

One further option is to combine steel and FRP through the use of a load bearing steel frame and FRP panels. There may be the potential to reduce weight in comparison to a fully steel structure whilst reducing through life costs due to corrosion.

Differing expansion rates between the panels and the steel frame require consideration to maintain structural integrity under fire conditions. This means that the connection method between the frame and the panels needs careful design. Furthermore, novel insulation solutions may be required to prevent conduction of heat through the steel frame work.

4 INTEGRATION ISSUES

4.1 STRUCTURAL INTEGRATION

If an integrated mast has been chosen at the design stage then the integration and alignment of the mast into the ship structure can be fully considered. Good Naval Architecture practice is to position at least one fwd or aft mast face over a major transverse bulkhead and to extend the structure at least two decks into the vessel. For a new ship design the frame and bulkhead positioning can be defined to accommodate the footprint of the chosen mast. If however, other drivers are constraining the ship design or the mast is being retrofitted onto an existing vessel then some mechanism for providing that interface needs to be realised. Once again the trade off becomes weight and centre of gravity against the other benefits of having an integrated mast. One option is the design of an interface piece that allows structure to be aligned. An interface piece may also offer a good opportunity for providing separation between an aluminium mast and a steel deck. The design of the interface piece will be entirely dependant on the underdeck structure which will influence both the footprint size and the height to allow good transition from the mast to the deck. The height of an interface piece will also have to consider access arrangements for the purposes of survey and running systems. An example of how the mast might be integrated is shown in Figure 5.

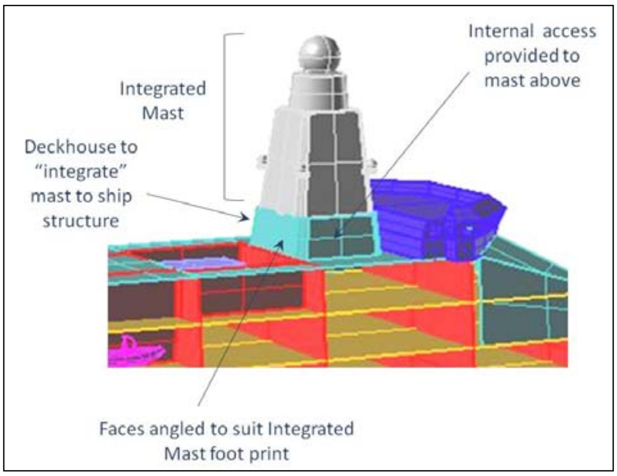

Figure 5: Example of Thales Integrated Mast/Superstructure Integration

4.2 STRUCTURAL MISALIGNEMENT

The importance of structural continuity and alignment with supporting structure is well documented. The problems caused by discontinuities at the end of superstructure blocks are not confined to the Naval Industry. The combination of the structural discontinuity and misalignment is commonly fatigue cracking.

The issue of fatigue for integrated masts due to longitudinal bending of the ship is perhaps more pertinent than for classic plated mast designs since the increased footprint size makes it more susceptible to failure in this way. This will be affected by the design of the superstructure on which the mast sits, and the structural continuity of the mast. In addition the proximity of the mast to midships and thus higher stresses due to longitudinal bending aggravates this problem. The use of an interface piece could be considered as beneficial in this aspect since, particularly for retrofit, the geometry of the interface piece could be tailored to the built geometry of the ship rather than design drawings.

Misalignment seen on vessels at the superstructure/mast and deck interface has included the following:

- Port-starboard;
- Fwd-aft;
- A combination of the above;
- Vertical.

The first three of these has occurred when a built superstructure block is lowered onto the deck. The last when a mast has been lowered into the structure with internal decks in place resulting in misalignment with the external deck (Figure 6). All cases have resulted in fatigue cracking due to the misalignment increasing stress levels at a discontinuity where there will already be a stress concentration. Good attention to detail during design and build can significantly reduce these problems occurring through life.

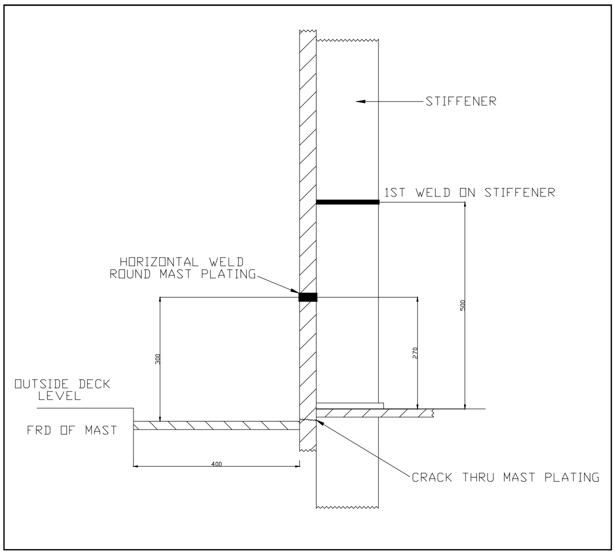

Figure 6: Fatigue Crack Survey Findings

4.3 STABILITY IMPACTS

Masts have a disproportionate effect on stability due to their high centre of gravity. Increasing the weight of a mast and its equipment increases the overall ship vertical centre of gravity and thus reduces ship stability performance.

An integrated mast will have a higher weight than a conventional mast design, because:

- It needs to be larger in size to accommodate flat panel arrays or internally mounted sensors;
- It may include the processing equipment for the antennae within the mast itself;
- The equipment included will have increased weight, thus requiring additional structural weight to support the mast;
- An additional interface piece may be required to allow structural continuity.

For new vessels this can be readily mitigated by increasing beam to compensate (as increases in beam have a greater effect on stability than resistance; for example, if fitting a 40 tonne integrated mast with additional interface structure then a 0.25m beam increase in beam might be sufficient). Figure 7 illustrates the relative impact of increasing the mast weight on the ship overall vertical centre of gravity and how an integrated mast will affect this compared to a conventional plated mast (this example is for a larger patrol ship circa. 3,500 tonnes displacement).

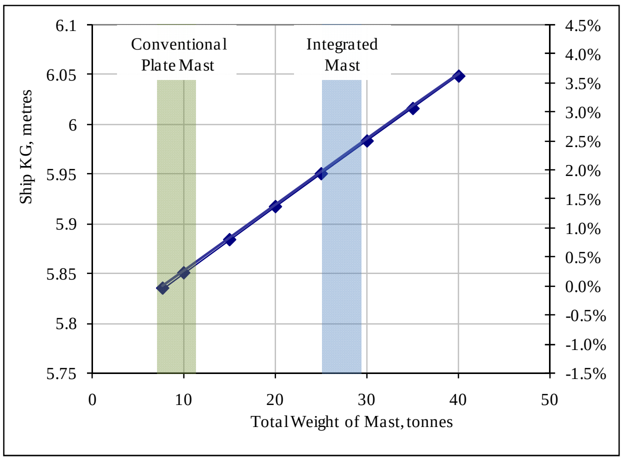

Figure 7: Impact of Mast Weight on Ship Vertical Centre of Gravity (KG)

When retro-fitting an integrated mast on to an existing vessel not designed for one, the beam is already fixed so a higher weight mast will be a significant issue as it will reduce ship stability. Typical in-service growth margins for vertical centre of gravity may be 5% or less over a 10 year period [3] and as Figure 7 illustrates, the adoption of an integrated mast would require a sizable proportion of this margin.

Also not to be forgotten is the impact of the larger windage area; heeling due to wind is proportional to the above water area. As the mast is high, its contribution to the wind lever is greater and this could be particularly significant for smaller craft when fitting an integrated mast (for example fast attack craft).

4.4 ARRANGEMENT IMPACTS

A traditional mast will typically have access arranged externally, through a weather door at its base accessing an internal ladder. An external ladder will also be provided. These are required for:

- Access to survey the mast structure, internally and externally, to monitor structural strength and corrosion effects;
- Access to maintain the structure including painting;
- Access to maintain antenna, navigation lights and other equipment fitted, including mast head radar and items on yard arms.

Integrated masts will also require such access, but with some notable differences:

- As more equipment is included within the mast structure itself, more regular access will be required into compartments within the mast structure;
- External access will still be required, however use of FRP or novel coatings may require more thought when designing access arrangements to prevent damage to the mast skin;
- As more of the equipments are either within the mast or are built into the structure as flat panels, then the need to maintain external antenna will reduce, similarly reducing the requirement for external access.

The above suggests that integrated masts will focus more on internal access from within the superstructure rather than externally from the weather deck. The access will need to be designed ergonomically to facilitate more regular access into the lower parts of the mast where equipment is expected to be housed. One aspect to be considered is escape and evacuation from the equipment “compartments” within the mast. Although not a manned compartment, it may be necessary to enter the space to maintain, repair or monitor equipment whilst at sea. If there is only one reasonable access route from below, this should be designed to facilitate casually evacuation and ensure that the space complies with confined access regulations. Additionally, the ventilation of the equipment space will need consideration due to the wild heat generated and whether, for a warship, this compartment will be treated within or without the citadel. Finally there is benefit from having support equipment close to the sensors potentially reducing the cabling requirements.

One important role for the mast is to support navigation safety and communications items, including navigation lights, flags / shapes and horns. These items, as well as having a military communications role, are also necessary to meet the requirements of international conventions for safety at sea. The navigation lights may be readily incorporated within the design of an integrated mast, noting that their location will need to be considered against the IMO Collision Regulations. Horns may also be fitted in the mast, but there remains an issue with how flags and shapes will be flown. The simplest option will be to incorporate a yardarm into the integrated mast specifically for the purpose of attaching wires from which flags and shapes may be flown. However, this seems contradictory to the aim of an integrated mast, although such yardarms could be designed to minimise RCS and appropriate material selection should reduce the maintenance requirements. Alternatively, lines may be attached directly to the mast from another suitable point on the topside, e.g. the funnel.

4.5 EXHAUST PLUME AND UPTAKES

The topside needs to account for the impact of temperature and corrosive particulates on equipments and structure due to the exhaust plume.

The effect depends on the proximity of the mast and exhausts and the temperature at the exhaust (which is dependent on the type and number of prime movers and also if a cooling device is fitted). However, if placed too close then even a reduced temperature plume may have an adverse affect on antennae performance. It also needs to be noted that a cooler plume will not rise as high and therefore the risk of impingement on the upper works of the ship is actually increased.

The effects of the plume can be modelled through CFD or other similar techniques to assess how the plume will dissipate under different environmental conditions. Figure 8 indicates a typical example of such modelling and this illustrates how the plume expands and can be swept over the top side, engulfing any masts or sensors. These affects would be common to any mast, although the integrated mast approach can be advantageous as it could reduce the need for an aft mast which is more likely to suffer plume effects.

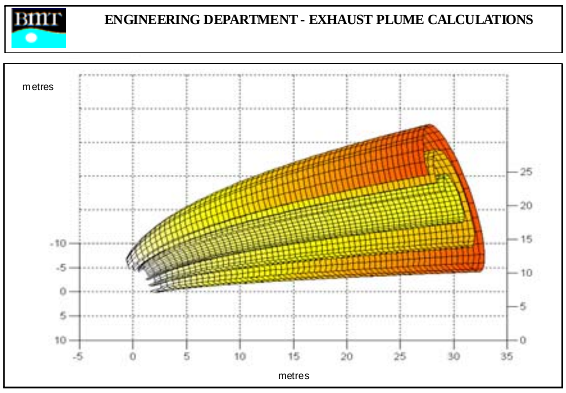

Figure 8: Typical Plume Modelling

Many warships use the mast as an exhaust (typically for diesel generators), as the power generation equipment is usually distributed and therefore remote from the primary exhausts (e.g. funnels). The impact here is not only external proximity of plume to mast structure and sensors, but also:

- High temperatures inside the mast, close to the ducting;
- Risk of fire inside structure;
- Access around the ducts within the confines of the mast and corrosion due to inaccessibility and high temperatures.

This is much more problematic for an integrated mast, where the internal volume is utilised for equipment thus reducing space available to include ducting and the heat generated by the exhausts which would be a significant issue for electronic systems fitted in close proximity. Further, the use of flat panel arrays for integrated masts would make it difficult to design a mast which could include an exhaust which would not impinge directly on to one of the panels.

On this basis the designer will need to reconsider exhaust routings where an integrated mast is specified and seek to combine all uptakes into the funnels rather than utilising the mast as a potential exhaust route.

4.6 AIR WAKE

Specifically for aviation capable ships, consideration needs to be given to the effect that the top side design has on air wake. Velocity differentials and shear forces created by the effect of laminar flow detaching from the superstructure can create significant increases in pilot workload as the helicopter is brought behind the superstructure to landing on the flight deck. Masts and other top side items also create turbulence that can affect the operation of helicopters.

Wider masts will create stronger shear and greater velocity differentials and where the mast becomes so large as to become faired into the side of the superstructure, then the air flow effects can become very pronounced over the flight deck behind. Hence, a large integrated mast structure would need to be positioned to minimise this effect and care should also be taken in the design of the mast itself, to ensure that it does not generate air flow which would cause a significant increase in pilot workload.

In addition, siting of anemometers needs to be considered; these require “clean air” and can often be placed on yard arms off the mast. For an integrated mast, these might need to be sited on dedicated “arms” out of the mast laminar flow layer or located elsewhere all together.

Both aspects can be considered through CFD modelling of the arrangement early in the design process, as shown in Figure 9.

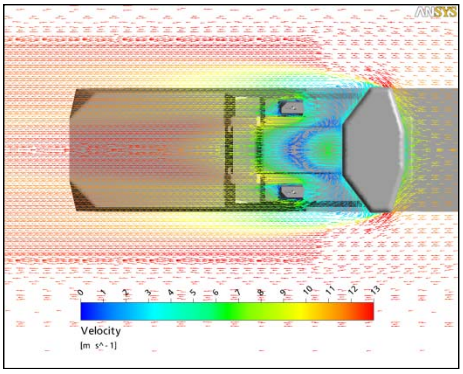

Figure 9: CFD Analysis Showing Air Flow Effects Due to Superstructure on Flight Deck Operations

4.7 AIR AND WIND RESISTANCE

The air and wind resistance is that part of the ships overall resistance (i.e. force to be overcome to propel the ship) which is contributed due to the resistance of the above water parts of the ship moving through the air / wind.

It is calculated as:

$$R_{AA} = K\tfrac{1}{2}\,\rho A_T V^2 \quad [4]$$

In general terms A_T is approximately contributed as:

$$0.3A_1 + A_2 \text{ (Figure 10)}$$

so increasing mast size will have an impact on A_2.
Normally for larger vessels, at conventional speeds R_{AA} is not significant; however this could become more important when retrofitting to smaller fast craft, where both the speed is higher and the relative impact of an integrated mast on topside area is greater.

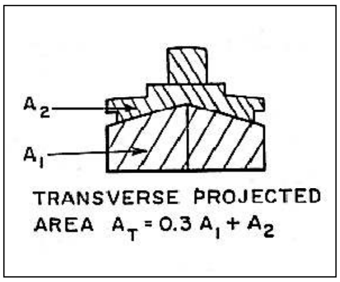

Figure 10: Transverse Area Estimate for Air Resistance Calculation [4]

5 IMPACTS ON MAST PERFORMANCE

5.1 SHIP MOTIONS AND SLAMMING

The mast structure and sensors of a vessel with a conventional plated mast are subject to accelerations due to ship motions and slamming and this will also be the case for integrated masts. One clear difference between the conventional mast and integrated mast designs is where there is siting of sensor supporting equipment within the mast envelope. By virtue of being placed higher in the vessel, these equipments will be subjected to higher accelerations. This requires that the supporting structure and connections are designed taking this into account and that the equipment has been designed to withstand these accelerations.

5.2 VIBRATION

Vibrations, induced principally by ship motions, main engines and the propeller, will affect the operation of equipments and may cause resonance within the structure of the ship. Whilst the frequency of excitation due to propulsion machinery will encompass a range according to vessel speed, an objective of the designer is to avoid structural resonance at key speeds that the vessel may spend significant periods of time, for example its maximum speed or cruise speed. At the design stage masts are assessed to identify their natural frequencies and to ensure that they are clear of the main excitation frequencies. If the mast frequencies lie in a band that is considered to be too close to any of these then steps are taken to modify one the contributing factors (e.g. weight, CoG, stiffness).

For mast design, the natural frequency of the structure will, in simple approximate terms, relate to not only the height of the mast but also its connectivity to the hull / superstructure and its stiffness and mass [4]. Here, an integrated mast will vary from the conventional; a tradition plate mast may have a foot print measured as 2 or 3 metres on each side whilst an integrated mast will have a greater supporting base, possibly in the region 5 to 8 metres along each side. This will have a significant impact on the natural frequency of the mast and may bring it within the range of excitation from the propulsion machinery at critical speeds. This will also be true in general for masts with a significantly larger base foot print, even if not of the integrated type. However, with an integrated mast which may be to a common design, it is less easy to adjust the structural design of the mast to increase damping and change its natural frequency to one more suitable for an individual vessel.

5.3 SHOCK

The inclusion of shock capability in a vessel is driven by customer requirements. On this basis it is difficult to design a ‘one size fits all’ mast incorporating design features for shock. This certainly presents a challenge to the mast designer since the incorporation of shock capability will invariably result in greater space requirements and increased weight.
Sighting equipment within the mast from the perspective of underwater shock however reduces the accelerations seen by the equipment in comparison to sighting it within the hull envelope. However, shock due to air blasts for superstructure may be worse than those experienced from an underwater threat.
The decision for shock mounting is then between mounting items of equipment individually or in groups. Certainly mounting equipment on rafts retains much better space availability but tends to result in greater complexity and a reduction in ease of survey and maintenance. Mounting of equipments individually results in a need to maintain displacement distances between equipments and thus comes with the potential need to have a larger mast with the resulting impact on weight and stability.
Avoidance of misalignment, insufficient clearances, stress concentrations and materials with high fatigue resistance will result in a structure that is more damage tolerant in a shock environment.

6 SURVIVABILITY

6.1 FIRE

In general conventional, plated masts do not cause significant problems with regards to fire protection. This is predominantly due to the there being less electrical equipment within the mast itself. The inclusion of sensor supporting equipment within the mast results in greater challenges from a fire protection perspective. The key considerations include access, containment, subdivision, ventilation and safe egress for personnel. Containment, subdivision and ventilation arrangements are closely linked and will also influence selection of fire fighting solutions. For example gaseous fire fighting systems can offer effective and clean fire fighting solutions, however consideration must be given to ventilation isolations and closure of mast openings both into the hull and to atmosphere; re-entry by personnel (post or during a fire) into the mast also needs to be considered, if gaseous media is heavier than air, to avoid potential contamination of the hull. Containment of any fire within the mast is also important to minimise further loss of equipment through smoke contamination, this may lead to further compartmentalisation of the mast. The inclusion and arrangement of deck / bulkhead closures and subdivision within the mast all require careful consideration if access requirements for maintenance and fire fighting and damage control activities is not to be compromised.

Once again, incorporation of many aspects that will assist in fire protection will result in increased space and/or weight of the overall mast.

6.3 WEAPON THREATS

Encompassing all sensors and associated equipment in a single mast can have its advantages and disadvantages where survivability is concerned. With collocated equipment it potentially makes it more difficult to reduce the capability of the systems through a weapon impact elsewhere on the vessel. However, it also makes the ship vulnerable to the loss of all, or a significant number of, sensors from a single impact. This may require armouring of internal equipment to prevent a ‘cheap kill’ which again will contribute to increased weight. Consideration should be given to the best approach to achieve protection, for example armouring the whole of the compartment or individual equipments.

7 THROUGH LIFE SUPPORT

7.1 MAINTENANCE AND UPKEEP

Further issues to consider are removal routes and routes to access “Fit to Receive / Initial Provision Made in Design” equipments. Traditionally, these have been achieved either through temporary platforms (Figure 11) around the mast during refits or even removal of the mast and its later re-instatement. One concept for the integrated mast technology is to allow upgrades by complete replacement of the mast, either by removal and upgrading the existing unit or replacement with a new unit. Whether this is practical in all cases or whether for limited changes removal routes will be required for the mast in-situ would require consideration, probably on a case by case basis. Again, this is likely to impact the direct access into the mast from the superstructure.

Figure 11: Temporary Staging Erected around Mast for Maintenance

8 CONCLUSIONS

The integrated mast concept has now transitioned from a future technology to one that is successfully being incorporated into naval ships. However, as examples are now offered for future projects, the Naval Architects responsible for the design of these ships must address how the integrated mast will impact on their ship design. Whilst the design and impact on the ship of traditional mast structures is well understood, this paper has set out how many of these aspects are impacted in unfamiliar ways.

Over the coming years, new design and integration procedures will have to be developed to address the potentially more widespread use of integrated masts; this will require renewed focus on material selection for the mast, access arrangements and structural integration and stability as key aspects among many. Not least, the rules from classification societies will have to address how the integrated mast should be considered and design procedures established to confirm both safety and performance are appropriately addressed.

Finally the integrated mast designers themselves will continue to be challenged by how to design a mast or series of masts that offer a solution that is sufficiently flexible for fit to a variety of vessel sizes and satisfy differing customer requirements.

7 ACKNOWLEDGEMENTS

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Pictures,
Figure 1:
USS HARRY W HILL, Scott Akins, Navsource.org

USS GOODRICH, Tony Cowart, Navsource.org
HMS TARTAR, Bob Hanley, navyphotos.co.uk
Figure 3:
USS RADFORD, Ed Zajkowski, Navsource.org

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9 AUTHOR BIOGRAPHY’S

Catriona Savage is a Manager in the Naval Architecture Department at BMT Defence Services, where she is responsible for the Structures Team and the Submarines Team. Catriona has also had periods of secondment to the UK MoD, the Aircraft Carrier Alliance and the Submarine Support Management Group. Although she has gained experience in stability and safety, she has specialist experience in Structural Analysis (including Finite Element Analysis), Ship Structural Assessment to Lloyd's Rules and Regulations for the Classification of Naval Ships and Submarine Structures. She has worked on and led projects involving both through life support of existing vessels and the design of future platforms.

Andy Kimber is a Senior Manager at BMT Defence Services, where he is responsible for a team of Naval Architects engaged in a variety of surface ship design tasks. He has undertaken a variety of auxiliary ship and warship design studies including the joint BMT - Skipskonsulent AEGIR family of replenishment ships and the BMT Venator reconfigurable small warship. Previous to his current role, he held the position of Platform Architecture Manager for the CVF for three years and was a member of the UK MoD’s Sustained Surface Combatant Capability Pathfinder Project. Andy joined BMT Defence Services after completing a degree in Naval Architecture and Ocean Engineering at University College, London.

