

## NAVAL TECHNOLOGY

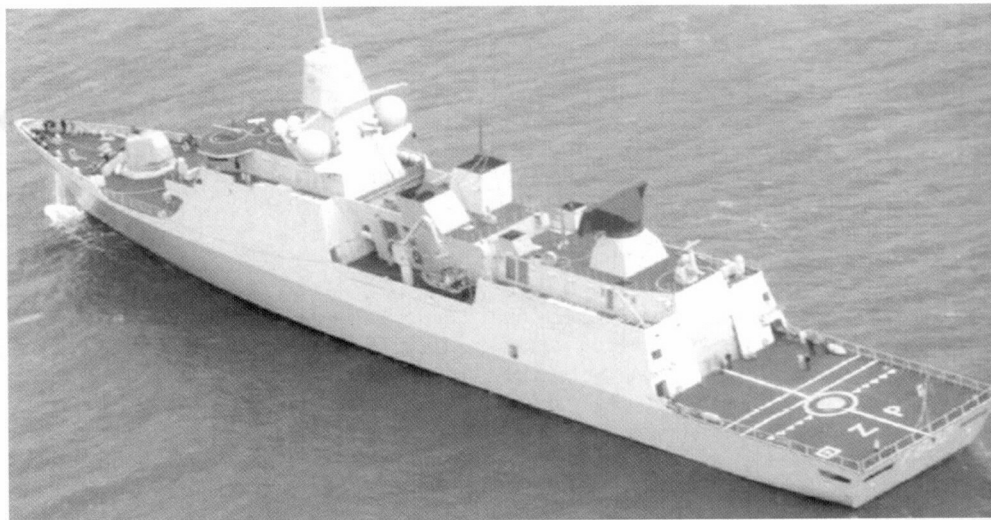
# 'STEALTH' TECHNOLOGY: PROPOSED NEW METHOD OF INTERPRETATION OF INFRARED SHIP SIGNATURE REQUIREMENTS

A new method of deriving and defining requirements for the infrared signature of new ships is presented. The current approach is to specify the maximum allowed temperature or radiance contrast of the ship with respect to its background. At present it is the contractor's (manufacturer's) task to design the ship that meets this requirement or goal.

This approach suffers from a number of drawbacks. Firstly, there is difficulty in assessing the ship's infrared signature at sea, during an acceptance trial due to the vagaries of the effect of the environment. This leads to the risk of an unacceptably high signature during the acceptance trial. The second issue is where the responsibility lies if the ship's signature is unacceptable at the time of the trial. The new method proposes that the IR signature requirements be defined in terms of constructional parameters components e.g. paint type, emissivity and lagging of compartments etc. This avoids specifying the physical or radiological properties of the ship and its response with respect to its environment. Operational analysis sets the limits of the ship's signature that allows it to meet its operational requirements. This uses knowledge of the scenarios in which the ship is likely to be deployed and the threats it may encounter.

The signature requirement can be in the form a weighed optimum deduced from different operational scenarios or for a single mission.

The proposed method is an extension of the analysis that is the current practice and can be undertaken by Government or military scientists, if required. The requirements thus obtained are quantitative, concise and verifiable. The acceptance trials are straightforward and can be completed even before the ship is fully operational.



**INTRODUCTION**

There is a desire by many of the World's Navies to have ships that are less detectable and more stealthy. *Figure 1* shows several new frigates, which were designed to have a high degree of stealth. This provides the military advantages of increased surprise and reduced threat numeracy, leading to increased survivability.<sup>1</sup> This means the ships are able to fulfil their operational tasks with less risk of casualties and damage in the face of increasingly sophisticated surveillance and tracking sensors with the associated more potent threats. In modern ship designs the term 'stealthy' almost always refers to a low Radar Cross Section (RCS), but now additionally to a low infrared (IR) signature contrast (indeed in all the detection bands).

It is the aim of any shipbuilder to reduce as far as possible all signatures, mainly radar cross section, infrared, magnetic, and acoustic. Construction measures to reduce a ship's radar cross section, like superstructure shaping and coatings, are well documented and used for almost all newbuildings. The reduction of magnetic and acoustic signatures has become a matter of routine for shipbuilders and Navies. Reduction of infrared signatures is a relatively new and complex task, which requires significant research. This paper focuses on a framework within which the requirements for the infrared signature can be defined.

There are many threat bands in the electromagnetic spectrum. Goals (the maximum signature a ship may have in a given band) are set so that acceptable detection ranges can be anticipated against given threat sensor systems. The setting of these goals or upper limits is usually determined by Operational Analysis (OA) using knowledge or perception of the potential threat's performance and the defensive capabilities or systems available to the ship.

If the target is illuminated by a known source, as with radar, the characteristics of the returning radiation are usually well known. Using a priori knowledge of the interrogating pulse its presence can be detected even when smaller than the prevailing noise level. A technique that has been successfully exploited by LPI (Low Probability of Intercept) radars.

For the IR, it is the inherent black body radiation that is emanated by all warm bodies, i.e. above absolute zero (-273 °C), that is detected. The precise nature of this radiation is determined by the body's temperature (on the absolute scale) to the power 4 and the surface characteristics (emissivity). This inherent black body radiation or self emission will be present without any illumination unlike radar system. It is this that makes IR detection passive, again unlike radar. Unfortunately the target surface is also subject to the vagaries of the prevailing environment conditions. This makes predicting the nature of the IR radiation (signature) very difficult as these conditions are all outside the control of the interrogating (passive) sensor system.

If the emitted radiance from the target is different to that of the background then a detection can be declared provided there is sufficient contrast in the collected radiation. The target may be more or less bright than the background, so called positive or negative contrast respectively. However the temperature of the target surface can be influenced by the weather i.e. rain, wind in addition to convectional heat transfer, and solar loading. The reflectivity (emissivity) of the surface determines the proportion of inherent black body radiation, compared to the reflected component from an unknown background. The atmospheric transmission from the target or background to the sensor can also vary significantly depending upon the nature of the former e.g. its humidity, CO<sub>2</sub> concentration, the air path temperature, etc.

Specifying the signature level for a given radar band is relatively simple as many parameters are known. The environment has little effect on the radar return apart from perhaps rain; significant

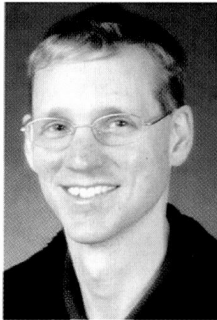
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(TNO Defense, Security and Safety, Den Haag, The Netherlands) graduated in geophysics from Utrecht University, where he was assistant professor in seismology for several years. At TNO he became involved in electro-optical signature research and developed infrared signature prediction codes and signature measurement methods. His current interests include infrared signature modelling and signature reduction.



**Marcus Wilson**

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**Keith Youern**

(Dstl, Portsmouth West, Fareham, Hampshire, United Kingdom) graduated from Durham University after studying Physics and Reading after specialising in Optics. He has worked for many years for Dstl and its predecessor organisations (in the United Kingdom) in many capacities where his interests have been in lasers, sensors, tracking Kalman filters, signal processing and more latterly signature control.



effects can also arise from multipath and ducting. The same is not true for the IR signature as the environment can be significant if not dominant. So far it has proved extremely difficult to specify the signature goal of a ship because the environmental conditions need to be known (or specified) at the time of measurement or observation.

This paper aims to pave the way for a new way of specifying IR signature requirements that are concise and verifiable, that does not necessarily require specialist modelling on the part of the ship designer or constructor and that does not require the disclosure of restricted information on expected threats or operational areas to the shipbuilder. The new method of specifying an IR signature goal also gives the respective Navy the degree of IR signature control required or demanded.

**REQUIREMENT FOR STEALTH**

From an operational point of view a stealthy ship is one that remains undetected and therefore can be deployed closer to the threat, which

Fig. 1: Modern ship designs, showing the effects of stealth design on the ship's appearance: the Air Defence and Command Frigate of the Royal Netherlands Navy (top), the new Type 45 destroyer of the Royal Navy (centre) and the MEKO<sup>®</sup> A200 corvette of the South African Navy. All ships were designed for radar stealth; only the SAN corvette has measures to provide IR stealth.

## THALES NEDERLAND: STEALTH IN INTEGRATED TOPSIDE DESIGN

Today's ships are more and more stealthy by hull design, shielding of equipment with walls or by applying radar-absorbing materials. However, distributed over the topside, these same ships carry a lot of sensor and antenna systems. Each antenna requires its own pedestal or mounting construction, causing numerous reflections that contribute highly to the Radar Cross Section of the ship (see figure 1). These issues are often underestimated and not taken into account for during the design phases of a ship. A lot of peripheral equipment is added in the final stage of the ship's design, in the end significantly reducing the stealth characteristics of the platform. This effect is in most cases irreversible.

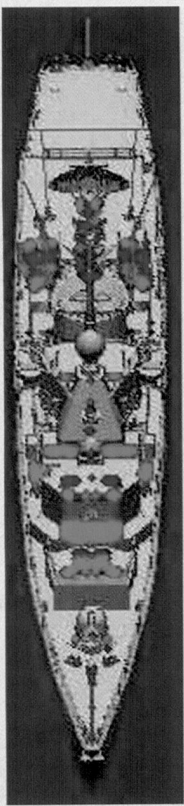


Figure 1: Multiple reflections caused by distributed topside arrangement.

### Optimal solution for minimal reflection

The solution for decreasing the reflections of single antennas is to combine and enclose them into one Integrated Mast Module (IMM). In an IMM the antennas are placed in radomes of Frequency Selective Surfaces (see figure 2). This FSS is transparent in the bandwidth of operation and reflects all other frequencies. The radomes are placed at an optimised tilt angle, between 10 and 15 degrees, so the RF energy is not reflected and therefore not received by the source of (enemy) transmission. An IMM consists of composite materials. Radar Absorbing Structures may be applied in the ship's superstructure or Radar Absorbing Material could be placed inside the mast, both options reducing the effect of reflection.

### Enhanced survivability

Another stealth aspect is the optical signature of the ship and its topside equipment. Within the enclosed mast, the temperature is regulated which reduces the infrared emission and characteristics of the equipment inside. The walls are isolated so personnel moving in

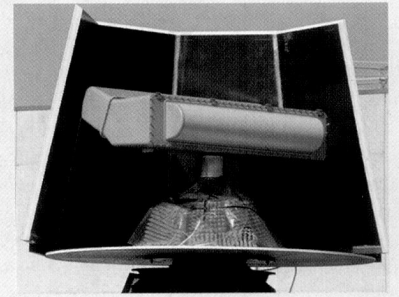
the integrated mast cannot be easily detected. Within the visual spectrum the integrated mast is also beneficial since solar flashes are avoided due to the enclosure of rotating radars. By using composite enclosed Integrated Mast Modules, the detection and classification of the equipment placed inside the structure is difficult and the overall signature of the ship will be reduced, making it stealthier and enhancing the survivability of the platform.

### IMM summary

Summarising, integrating several systems in one configuration offers several benefits:

- Reduction of acquisition costs through combined cost items
- Less maintenance, increased safety level and Lower Life Cycle costs

Figure 2: Radar placed in FSS radome.



- Optimization of performance; EMI, EMC and Blocking
- Reduction of ship's signatures
- Reduction of ship's topside weight

### THALES' IMM: MASC

Thanks to its experience in design and integration aspects of sensor and antenna configurations, THALES is capable of designing, manufacturing, assembling and testing an IMM before installing it on top of a platform. This ensures high quality and reduced costs.

THALES recently introduced a Multiple Antenna & Sensor Configuration (MASC), which is an excellent representation of THALES' capacities in the ITD services area (see figure 3). In fact, MASC is the physical representation of the sensor and antenna configuration solution for future warships combining flat arrays with other (more conventional) antennas.

Different operational functionalities e.g. air and surface search radar, communication, electronic warfare, and optical systems are brought together in this configuration in the most optimum and cost-effective way. Because of its modular design a MASC solution can also be used for upgrade or overhaul of platforms. The building block structure makes a scalable and "customer specific" design possible.

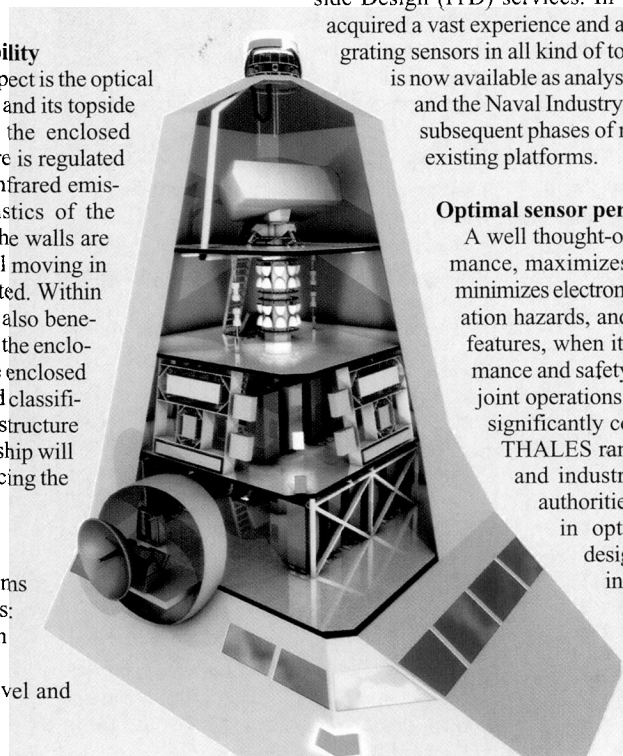
### Track record in integrating sensors

THALES recently launched a number of innovative Integrated Topside Design (ITD) services. In the past decades, THALES has acquired a vast experience and an impressive track record in integrating sensors in all kind of topside structures. This knowledge is now available as analysis and advisory services to Navies and the Naval Industry during the conceptual design and subsequent phases of new ships or the modernization of existing platforms.

### Optimal sensor performance and safety

A well thought-out ITD concept optimises performance, maximizes electromagnetic compatibility, minimizes electromagnetic interference, reduces radiation hazards, and minimizes ship signatures. Key features, when it comes to optimal sensor performance and safety, and an effective participation in joint operations. Successfully integrated topsides significantly contribute to mission success. The THALES range of ITD services assist navies and industries (e.g. shipyards, ship design authorities and combat system integrators) in optimizing the integrated topside design of naval platforms. By performing such analysis and advise in early stages, expensive modifications later in a program are avoided.

Figure 3: THALES' Integrated Mast Module.



can increase the efficacy of the ship in performing its tasks. For a low-observable ship, this will benefit from enhanced survivability, as for example, decoys will be more effective.

To take advantage of this philosophy modern warships are increasingly adopting low-observable strategies in their designs. For example, plume cooling of emissions or even re-positioning of the diesel and gas turbine outputs to be close to the water line, increased use of lagging particularly in engine rooms, etc. Equivalent strategies are being used to reduce radar signatures. Improved communications systems, guidelines, procedures and tactics further decrease the RF emissions leading to the integrated operation of a more stealthy ship.

The first step in developing low-observable platforms is to define the desired level of the platform's contrast between itself and its environment or background. This desired level (or levels) is derived from the expected tasks of the new platform, its area of deployment and the threats that it may encounter. These aspects collectively can be expressed as survivability, from which a maximum signature of the platform can be deduced. The signature level needs to be derived for each operational scenario and location. These are often combined into a single signature requirement that can be used in the design and construction process.

**PRESENT SITUATION TO SPECIFYING A SIGNATURE GOAL**

In spite of the obvious advantages of acquiring and deploying low-observable ships, it has proven to be difficult to obtain a quantitative specification or requirement for the IR signature levels of new ships in a framework that is acceptable to the main parties. These latter being the navy, the sponsors who specify the performance and capabilities of the ship they wish to acquire,

Fig. 2: Schematic diagram showing the route to acquiring a low-observable or stealth ship.

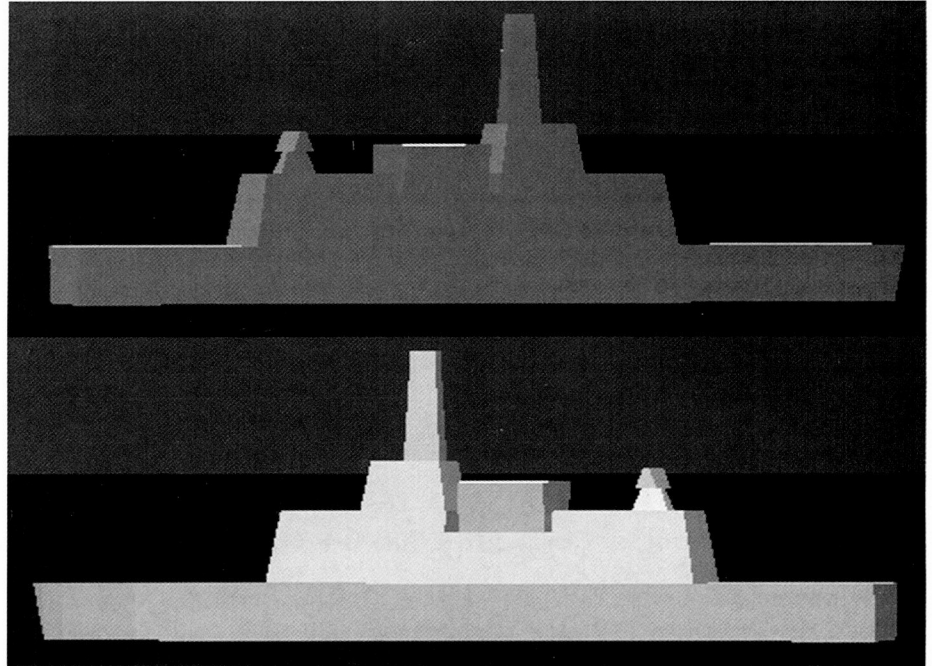
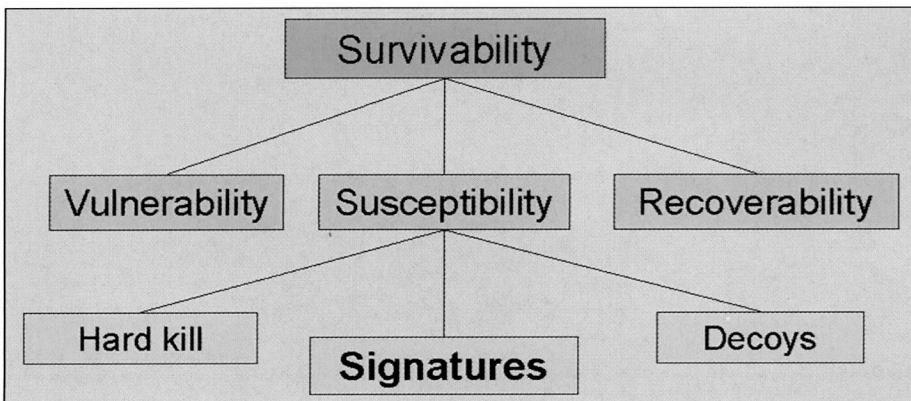


Fig. 3: Computed IR image of a frigate-size ship. Top: shadow side, bottom: sunlit side. The images show apparent temperature in the 3-5  $\mu\text{m}$  band, in the range 15-35  $^{\circ}\text{C}$ . Whereas the shadow side may be at an acceptable temperature contrast with the background, the IR signature of the ship on sunlit side may well be at an unacceptable level.

and the ship builders, who construct the ship to meet the specified acceptance criteria.

The route to procuring a low-observable or stealthy ship typically starts with the naval requirements. These are typically specified in high-level documents and reflect the prevailing national procurement policy for the respective country's Navy. Some of these documents specify desires, others aspirations but some contractual (hard) performance requirements. The precise nature of documents used depends on the country's procurement policy. For example, the

present UK policy is SMART procurement which is described in [1].

The survivability of the ship is the driving requirement. This is made up of three integrated areas namely susceptibility, vulnerability and recoverability [2], as depicted in *Figure 2*. These are respectively the likelihood of detection, the probability of being hit and the capability to repair the ship while maintaining its functionality. There are of course interactions between these three topics. For example, under smart procurement, there will be trade offs between signature (the likelihood the ship will be detected) and the ability for self-defence using hard kill systems or decoys. However the details of these trade-offs is not necessarily specified in the above requirement documents. *Figure 2* is a schematic diagram to represent the process. To some extent this is the philosophy of smart procurement, namely that the details of the trade offs are left to the ship builder, who may or may not seek advice from government scientists.

Inherent in the naval requirements documents is the assumption that 'stealth' is a performance characteristic supporting many capability areas. A minimum performance may be specified by the Navy for operational reasons and if so this is still equivalent to a (signature) goal or target, but it limits the smart procurement trade-off space. One example of operation reasoning may be the expected number of missiles required during a mission. This may impact on signature limits.

Signatures may also have another role to play in vulnerability. If signatures or signature control methodologies are applied this may affect

the vulnerability of certain areas of the ship by these being preferentially targeted by the inbound threat. This idea will not be developed further here in this document but this is why the diagram of the procedure in Figure 2 is termed a schematic and greatly simplified.

After much negotiation and trading between the competing platform performance requirements a signature goal or level is established. Interpreting the requirements at each level is the role of scientists performing Operational Analysis (OA). This process attempts to exploit all known knowledge sources. For example, given the performance of an opposing sensor system, susceptibility is interpreted as a probability of detection against range of the ship for a given signature level or the inverse by setting the

abstracted format and need to be interpreted so that meaningful performance and signatures levels can be specified. Perhaps more importantly these abstracted values need to be interpreted by the ship builders when designing the ship, in terms of constructional parameters.

**THE PROBLEM FOR IR SIGNATURE SPECIFICATION**

For the thermal contrast of the ship to be specified, both the signature of the ship and that of the background need to be known. While this can be done relatively easily during simulation, the same cannot be said during a ranging (measurement) trial. The prevailing environmental conditions are highly interactive with the ship,

of acceptance trial, which would make the ship's signature contractually unacceptable. Since the interactions of the environment with the ship are complex, it is very difficult to predict the ship's signature in one environment given observations in another [3 – 5]. *Figure 3* illustrates the problem with synthetic IR images of a ship in sunny conditions.

It is this uncertainty of the environment, its dynamic nature and the lack of resolution in its measurement that is the essence of the difficulty. The crux of the acceptance issue is who is contractually responsible for this risk. A new approach, as discussed below, which de-couples the weather from the specification of ship's IR signature at the time of acceptance. This is thought to have significant advantages over previous methods of specifying the IR signature of a ship.

**A NEW METHOD OF IR SIGNATURE SPECIFICATION**

The solution to the above difficulty would seem to be to de-couple the signature specification from the environment. Ideally the IR signature should be specified in a way that is easily verified. The proposed method does just this. It advocates specifying the IR signature as constructional parameters such as

- degree of lagging,
- spectral emissivity,
- temperature of internal compartments.

These constructional parameters are easily verified at the time of acceptance. Thus the acceptance of the ship is much simpler and easier. It avoids the risk and vagaries of the environment. This also reduces the requirement by the ship builder to interpret the IR signature specified in radiance terms.

It is proposed that the 'missing' link of converting the radiological IR signature specification into constructional parameters is achieved by further OA and other predictive modelling. This is summarised schematically in *Figure 4*. The modelling is to be performed for a range of atmospheric conditions that covers the expected operation locations of the new ship. The constructional parameters can be computed from a weighed averaged over the atmospheric conditions considered. *Figures 5 and 6* give an illustration of the process, showing the interpretation of signature minimisation in terms of paint spectral emissivity.

This proposed method relies on sophisticated IR signature prediction codes which are now reaching maturity and are well validated. These include indigenous national software and commercially available codes, such as ShipIR/NTCS (Naval Threat Countermeasures Simulator) or EOSTAR [6].

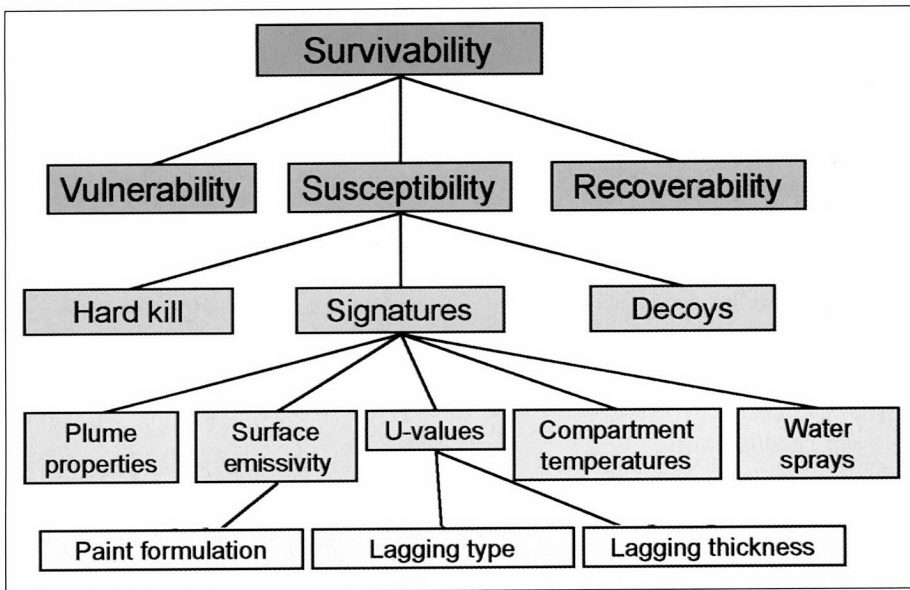


Fig. 4: Schematic diagram showing the extra layer of the proposed interpretation the IR signature of a ship.

required signature level. However if the ship has a 'good' hard-kill self defence system that can counter an inbound threat from a given range, the requirement on signature control may be relaxed. However this requires knowledge of the inbound threat and the hard kill system. The inbound threat may be easily seduced away from the ship by the use of a decoy. Not all the required information may be known, but that which is known is often very sensitive and retained within Government and military control.

The output from the Operation Analysis (OA) is in the form of the lower boxes in Figure 2. The performance of the hard-kill systems and decoys is specified and so are the signature requirements or goals. However these are still in a rather

such as wind, rain, cloud cover, geographical location or solar loading. This list is not exhaustive. Unfortunately the weather or environmental conditions are also non-homogeneous over the observation path, and are prone to be highly volatile. The interactions between the ship and its environment are therefore highly complex. The environmental parameters can only be measured with limited resolution and only a few measurements over the observation path can be taken practically during ranging.

The influence of the environment can have a significant impact on the signature of the ship. This leads to large variations of signature. In some circumstances the signature will be below the signature goal and acceptable from the Navy's point of view but in others, the ship may have a signature above this value. Although the ship builder will strive to offer a design of a ship that offers best thermal signature, there is still a significant risk of unexpected weather at the time

Although survivability has been given as the overall driver in this example in *Figure 4*, other drivers could be used instead. For example, stealth (signature control) may be required for a mission to be achieved covertly. Cost is perhaps another example or factor, which impacts at every level. These drivers or goals and influencing factors can (and should) be addressed in the various studies and OA in moving down the schematic diagram in *Figure 4*, in developing the desired capabilities and characteristics of the platform. The latter are ultimately given to the ship builder as a manufacturing specification (the bottom layer of *Figure 4*).

Other interpretations of the above schematic diagram, particularly for signature control, suggest that plume properties and water sprays could be considered as constructional parameters. For example it may have been identified that for the required signature level, the plume should be cooled or vented at or below the water line. Under these circumstances the plume characteristics become one of the construction parameters as featured in *Figure 7*. Likewise if additional signature control is required that can be offered by water spraying the hull or certain facets this again becomes a constructional parameter directly or an additional system that needs to be fitted to the ship.

In the new procedure, outlined above, all the OA and signature modelling can be performed by Government scientists (or expert contractors), thereby protecting information should this be necessary. The output is a set of constructional parameters which can be given directly to the ship contractor. These constructional parameters now specify the IR signature of the ship. These parameters are easily auditable, which will make acceptance of the ship more easy and unambiguous.

It is only the constructional specifications that need to be released. These do not contain sensitive information on expected operational areas, missions or threats. This therefore greatly simplifies the acceptance process as this is now reduced to checking that the ship has been built to the documented constructional specification. A signature requirement document may be produced by operational analysis scientists, if required, as

is presently the custom, but this does not need to be released to the ship builder.

Ranging the ship is still recommended, even using the new approach, as it is important to know by measurement the actual signature profile of the platform. There may be some features that were inadequately modelled in the signature prediction software. These may manifest themselves when the ship is built, such as unexpected hot spots. The military significance of these needs to be accessed. Additionally, signature measurement trials are important for further model validation purposes.

## OTHER ASPECTS

In this section, a number of aspects of a ship's IR signature are addressed, that are not considered above, but that may have to be taken into account prior to performing the signature requirement analysis:

- Camouflage used to change a ship's appearance, by locally changing or reducing its signature. Whether or not that camouflage is applicable in the above procedure depends on the operational requirement.
- Decoy efficacy may be an operational requirement that relates the ship's signature to decoy deployment.
- New technologies or philosophies that may be developed for signature control need to be accommodated in the proposed procedure.
- Active signature control systems. This could result in an additional requirement to that for a passive treatment alone.

The following sections treat each of these aspects in more detail.

## CAMOUFLAGE

Camouflage has an effect on the ship survivability (via susceptibility) but does not necessarily reduce the contrast of the ship as a whole. It works at a different level, redistributing the IR radiation in an unexpected way, creating confusion and / or soothing edges of the ship silhouette, leading to reduced detection (and recognition) ranges. Applied to certain parts of the ship, camouflage can disrupt the outline of the ship, making the ship appear like a different type or even like two ships. The selection of effective camouflage schemes (i.e. which parts of the ship are painted with a given paint) will require image assessment capability, either human or computer-based, in order to optimise the design. Once this (modelling) capability is available, it could be added to the above procedure, expressing requirements on camouflage in terms of physical characteristics, such as the material, patterns or colour.

## DECOYS

A possible requirement could state that the IR signature of the ship should be such that, the IR decoys have a certain effectiveness. However, this raises the question of what constitutes an effective decoy. It can be argued that if the radiant intensity of the decoy is larger than that of the ship, the decoy can be considered effective, since a hot spot seeker will probably 'lock on' to the decoy. The signature of many modern frigates and modern decoys is such that, a single decoy sub-munitions is brighter than the ship in most environments. In the case of a large ship, the simultaneous deployment of two decoy rounds suffices to obtain a decoy that has sufficient radiant intensity. However, such reasoning ignores both the nature of the threat (imaging as well as hot spot seekers) and the role of the decoys (seduction vs. distraction). These effects can be assessed with 'fly-in' models. Seeker behaviour, such as the search pattern and the search area, are also important parameters in determining the effect of ship signature reduction on decoy effectiveness [7]. Once metrics for assessment of performance of decoys become available these could be added into the procedure.

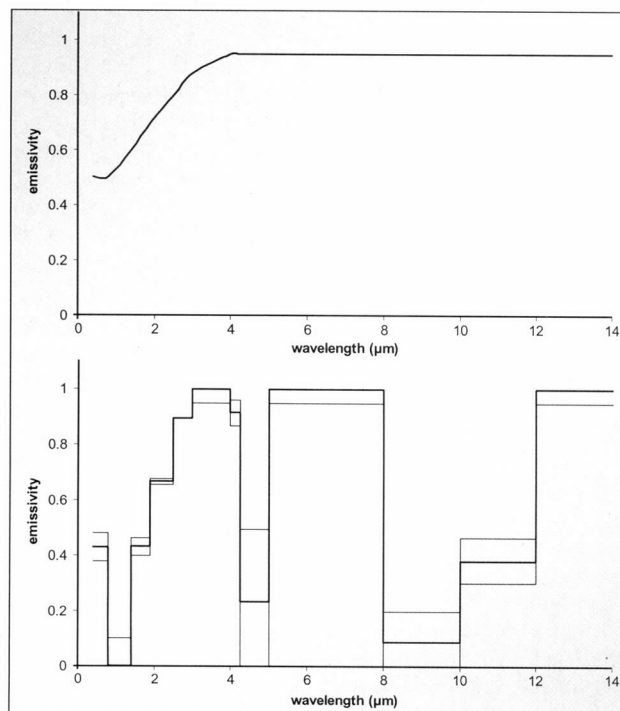
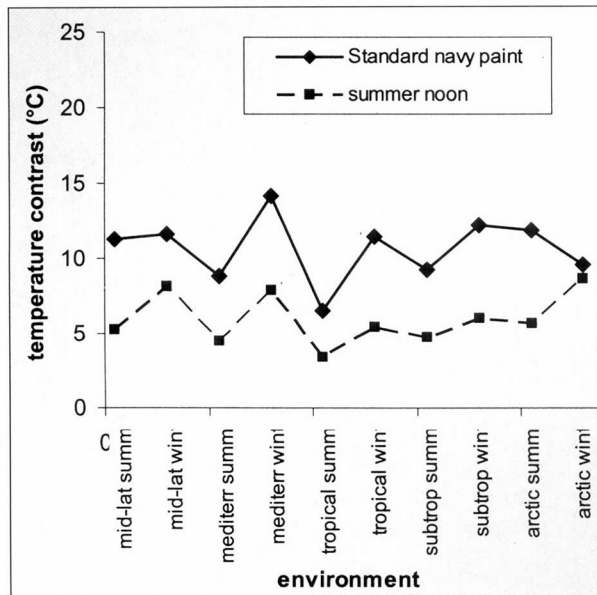


Figure 5. Spectral emissivity curve of typical standard navy paint (top) and of an example of a paint that is to minimise the contrast of the sunlit side of a ship at noontime in summer. The thin curves in the bottom panel represent one standard deviation.

Figure 6. Temperature contrasts between the sunlit side of a ship in a variety of operational areas (climate regions) and seasons. The temperature contrasts were computed for the typical Navy paint and the paint optimised for noon-time summer environments ('summer noon') shown in Figure 5. Data taken from [9].



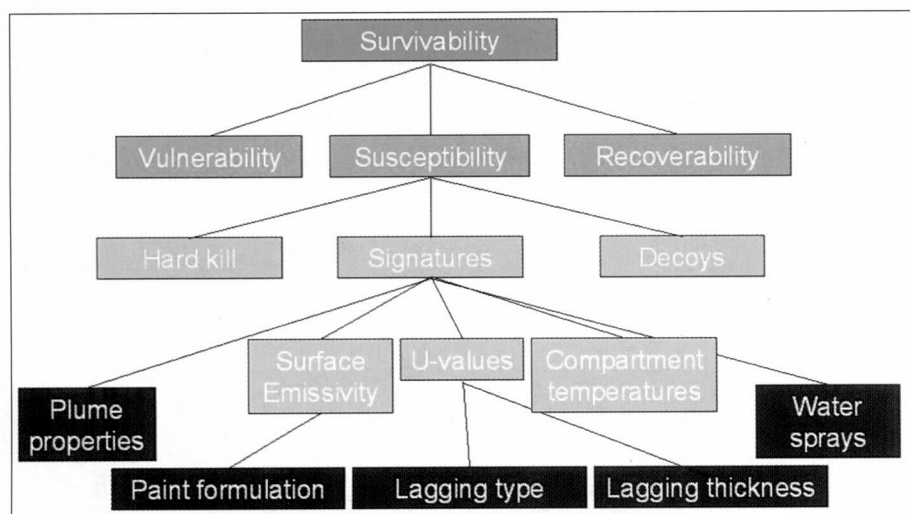
## ACTIVE SIGNATURE CONTROL SYSTEMS

If an active signature reduction scheme is proposed or needed, such as cooling by spraying water (wash down) over the hull and superstructure (e.g., [8]), the procedure of deriving signature requirements from the operational scenarios can still be applied. Rather than concentrating on, for example, deriving emissivity requirements for the coating, maximum (apparent) temperature contrasts must be specified. This then leads to the requirement for the cooling system, which should be capable of reaching the required temperature contrast between ship and background within a certain time frame. The implication of the failure of the active signature control i.e. should the water spray system fail, also needs to be considered, so the definition of emissivity requirements for the coating would still be needed. These requirements would be expected to be less severe than before. Thus, active systems could also be built into the above proposed procedure for IR specification in terms of constructional parameters.

## NEW TECHNOLOGY

Low emissivity is one treatment that is being considered by many nations to reduce the black-body emission to control the signature levels of

Fig. 7: Schematic diagram showing the modified extra layer of constructional parameters.



ships. It can be expected that other techniques, technology or philosophy will arise to control signatures. Each new development will need to be adopted into the analysis, leading to either new constructional parameters or new ways to derive existing parameters.

## CONCLUSION

This paper presents a generic procedure that allows the ships IR signature requirements or goals to be specified in terms of constructional parameters. One of the advantages of the proposal is that it is an extension of existing practises and procedures, which includes the use of high-level military requirement documentation. In the current procedure IR signature requirements are deduced using OA and the various trade-offs during the design process particularly if smart procurement is being used. The extension relies

on the maturity and validity of IR signature prediction codes that are now available, to deduce the constructional parameters, which will give the ship the desired signature level.

The procedure simplifies and de-risks the acceptance trials and can be even completed before the ship is fully operational. The OA can be conducted almost entirely by Government scientists if necessary, thereby controlling the release of sensitive information.

The signature requirement can be deduced from a weighed optimum of different operational scenarios or for a single mission.

As new signature control methods or new deployment philosophies are developed and implemented, new modelling capabilities will be required. This can be added to the proposed procedure above and used to specify the associated constructional parameters. **NAFO**

### Footnote

<sup>1</sup> Survivability can be defined as the ability to complete a mission successfully in the face of a hostile environment [2].

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