SIGNATURE MANAGEMENT - THE PURSUIT OF STEALTH

LOWERING WARSHIP SIGNATURES: ELECTROMAGNETIC AND INFRARED†

J. Thompson
D. Vaitekunas
B. Brooking

W.R. Davis Engineering Limited
Ottawa, Ontario, Canada
www.davis-eng.on.ca

ABSTRACT

This paper discusses the major sources of IR and EM signature aboard a ship, and the latest technologies available to suppress these sources. The state of computer signature modelling is also discussed. Throughout the paper, computer signature modelling has been employed as a means of quantifying the relative merits of the different signature suppression methods.

INTRODUCTION

It has been long established that a ship's susceptibility will ultimately depend on its detectibility. With the advent of modern electromagnetic (EM) and electro-optical (EO) sensors, the issue of detectibility extends well beyond that visible by the human eye.

All ships emit electric and magnetic fields, which propagate through the water. These emissions have been measured using passive underwater sensors, and can be used to distinguish between different classes of ship or even individual ships. Such information can in turn be used to trigger remote detection systems, or even trigger "smart" mines. This capability poses a threat to modern naval ships.

The infrared (IR) guided anti-ship missile has been in use for over 40 years. It has proven itself an effective weapon, and continues to develop in complexity and capability. The newest generation of missiles will be capable of identifying targets based on their shape and size, and will be able to select an aim point to maximize damage.

Most modern naval ships include some form of signature suppression[1,2] to reduce the ship susceptibility to the threats mentioned above. In some cases the suppression may be very basic while, in other ships great care has been taken in the ship design process to achieve a very low signature. The trend in recent years with new ship programs is towards a more systematic and comprehensive approach to signature suppression.

With the improvements modern technology have brought to a threat's capabilities, the simple signature specifications of the past are no longer good enough. New ship design programs include detailed signature management studies that include suppression tradeoff studies, detailed susceptibility analysis and cost benefit analysis. These studies consider the operating environment, the ship layout, and the anticipated threats. To achieve this level of detail, it is necessary to make use of computer modelling. The use of computer models permit the study of important but otherwise difficult to measure effects such as solar heating/reflection, sea surface clutter, or flare decoy deployment (IR); and water salinity, shaft speed, or cathodic protection system (EM). This computer modelling capability means that new ships can be designed with lower signatures and improved survivability.

ELECTROMAGNETIC SHIP SIGNATURES

One of the most effective weapons against ships in littoral waters is the naval mine. With the increasing stealth of modern vessels and the increased sophistication of modern mine warfare, naval mines are capable of detecting and exploiting other ship signature components such as electromagnetic (EM) emissions.

The electromagnetic signature of a vessel arises from the presence of a strong electric field that surrounds it (see Figure 1). Periodic fluctuations in the field give rise to both a Static Electric (SE) component to the signature and an Alternating Electric

† presented at the SMi "Signature Management - The Pursuit of Stealth" Conference, 21 & 22 February, 2000.

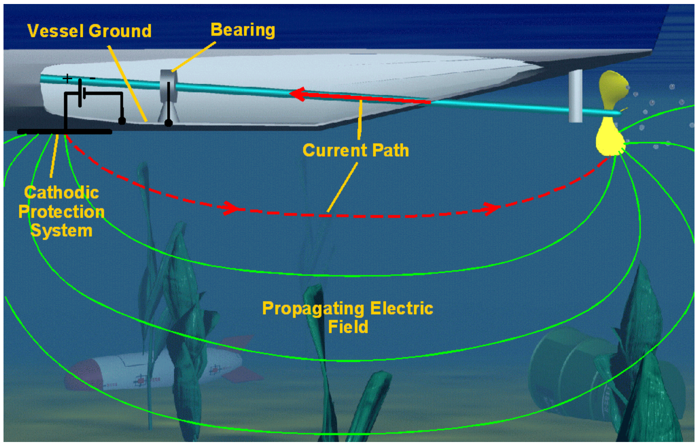

Figure 1: **Origin of the SE/AE Signature**

(AE) component (also known as Extremely Low Frequency Electric or ELFE). The fluctuations in the field also induce a corresponding Alternating Magnetic (AM) field around the vessel.

The electric field surrounding the vessel is produced by the presence of large electric currents passed through the water by Active Cathodic Protection (ACP) systems (also known as Impressed Current Cathodic Protection or ICCP) to provide enhanced corrosion protection for the ship. Electric current is passed from anodes on the hull through the propellor or hull locations that lack adequate coating protection. A resulting SE signature is produced that is proportional to the current path lengths.

Because most military vessels use uncoated propellers, the large majority of the ACP current is passed through the propellers and the shafts (refer to Figure 1). This current returns to ground via the ship's bearings or, if a Passive Shaft Grounding (PSG) system is in place, through the PSG brush connections. Because electrical connections through bearings can be highly variable and PSG systems break down over time, the resistance of the current path, and therefore the current level, through the shaft varies as the shaft turns. A modulation of the current occurs at the frequency of the shaft rotation resulting in a large AE signature that broadcasts the shaft frequency.

EM Signature Modelling

Algorithms have been developed for the purposes of computer modelling of the electromagnetic signature of vessels[3]. By predicting the ACP current levels from the ACP system design, the resulting SE and AE signatures can be predicted in a varying range of marine environments. The effectiveness of design changes and countermeasures for reducing the EM signature of a ship can then be evaluated relative to the baseline design. DAVIS has utilized state-of-the-art computer modelling developed by the Canadian Defence Research Establishment Atlantic (DREA) to model the SE/AE/AM signatures of proposed ship designs. The software was used to evaluate the effectiveness of design changes and countermeasures to meet predetermined design goals for the EM signatures.

The computer modelling techniques have been validated using the underwater electric ranges of DREA to compare actual ship signature measurements with computer model predicted signatures.

EM Countermeasures

In order to counter the modulation of the ACP current flowing through the shaft of the vessel, a system that actively detects fluctuations in the resistance between the shaft and the hull and adjusts a low resistance shunt to maintain a constant current level through the shaft has been developed. In this manner the Active Shaft Grounding (ASG) unit removes the periodic modulation of the current due to the shaft frequency and virtually eliminates the AE signature arising from this source. The effectiveness of the ASG unit is illustrated in Figure 2. The figure shows the measured ELFE signature of a warship, with and without its ASG unit engaged.

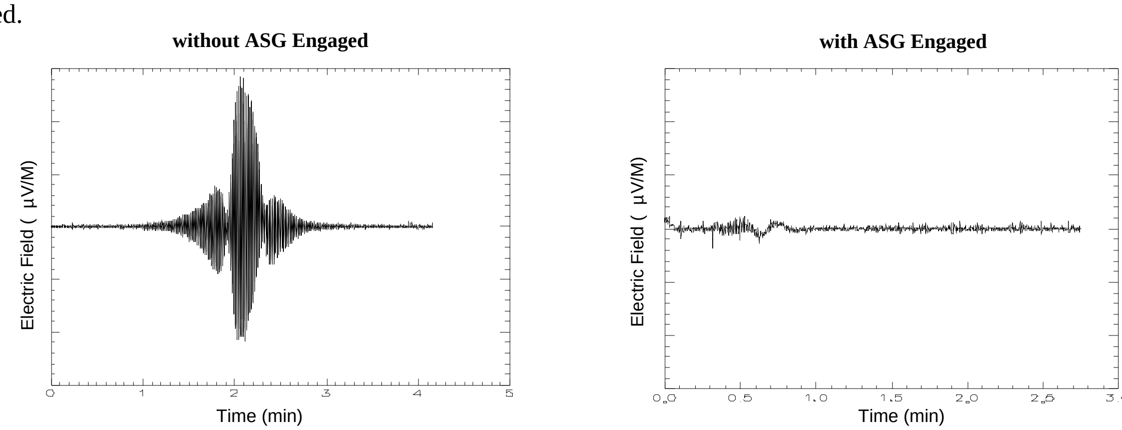

Figure 2: **Measured ELFE Signature of a Typical Warship**

Benefits of EM Signature Reduction

Reducing the AE signature of a vessel through the use of countermeasures reduces the range within which a naval mine can exploit this aspect of the ship's signature. The ability to reduce the range within which the vessel may be detected improves the survivability of the ship.

INFRARED SHIP SIGNATURES

IR Signature Overview

A ship's IR signature is made up from two main components: internally generated sources, and externally generated sources. Internally generated signature sources include rejected heat from engines and other equipment, exhaust products from engines, waste air from ventilation systems and heat losses from heated internal spaces. Externally generated sources result from the surfaces of a ship absorbing and/or reflecting radiation received from its surroundings (ie. radiation from the sun, sky and sea).

The primary internal IR source results from the main machinery onboard any vessel, in particular drive engines and electrical generators. The magnitude of signatures produced by other sources such as heated windows, weapon systems, and deck mounted machinery is insignificant in comparison if main machinery is not suppressed. Figure 3 illustrates the ways in which the heat from a ship's machinery can manifest itself in the form of IR emissions.

Figure 3: **IR Image of a Typical Unsuppressed Ship**

Five types of internal IR sources, or "hot-spots" can be identified in Figure 3. First are the warm sections of hull, indicating the location of engine compartments on the other side of the un-insulated hull plate. Next are the funnel spaces, heated by engine room ventilation air and hot exhaust uptakes running through them. With no insulation installed on funnel walls, the funnel exterior has been heated much like the sections of ship's hull. At the top of the two funnels can be seen the extremely hot (300-400°C typically) exhaust uptake metal; the single largest contributor to internally generated signatures. Adding to the uptake metal hot-spot are the emissions from hot exhaust gases. The final hot-spot shown in Figure 4 is the communications mast that has been heated by exhaust plume impingement.

Typically ship surface temperatures are much lower than that of exhaust uptakes and other internal hot-spots. However, because of the large surface area of the ship, even very small contrast temperatures can result in a large signature. This is especially true under solar heating conditions. Sun elevations larger than 10° can result in surface contrast temperatures in excess of +10°C.

To provide an idea as to the relative magnitude of the various IR sources, Figure 4 shows a breakdown of a typical frigate class ship's 3-5 μm band signature as predicted by ShipIR/NTCS (details about the IR signature prediction code NTCS will be presented later in this paper). The ship is traveling at 30 knots in a mid-latitude summer environment, on two LM2500 engines, with no engine suppression. The sun is positioned directly off the starboard beam, at an elevation of 30°. The plot is made for an observer 500 m away, looking down on the ship at a 15° angle.

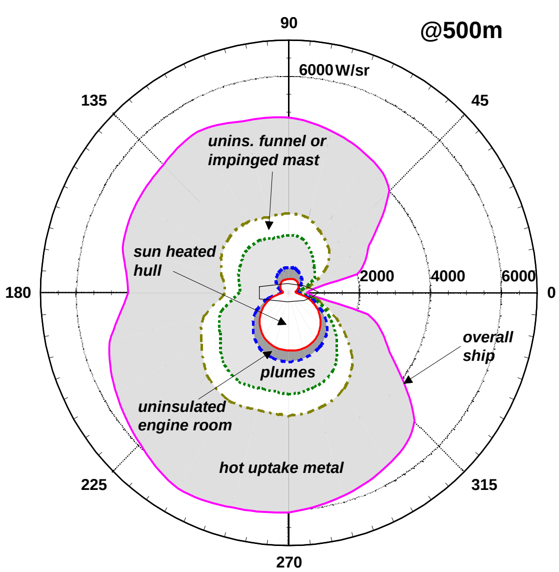

Figure 4: **Plot of 3-5μm Signature Components**

Effective IR suppression of a ship must consider both internal and external sources. It must also consider the range of operating conditions and threats the ship is to be exposed to, both present and future. Some argue that there is no point to suppressing the internally generated sources (plumes, uptakes, hot spots) because it is not possible to suppress the external sources. This ignores the fact that there is no solar heating at night or when the sky is overcast. It also ignores the fact that the sun also generates clutter. Finally, as with all things, technology eventually provides a solution to all problems including solar heating, as will be discussed later.

Suppressing a ship's IR signature will reduce its detectibility to IR guided threats. Avoiding or delaying detection is a key component of the "soft kill" side of ship survivability and is complimentary to the use of decoys. A smaller signature results in a smaller detection (lock-on) range, and thus more time to deploy decoys after a threat is identified. It is important to have incoming threats lock-on to decoys before the ship since many modern missiles are capable of protecting themselves against false lock-ons after the initial lock is achieved and tracking has begun. These missile counter-countermeasures make it very difficult to break a missile's lock on a ship once it is achieved.

IR Signature Modelling

Simulation and modelling has become a widespread tool in assessing new and emerging technologies, and infrared stealth technology is no exception. It permits the evaluation of "soft" prototypes, where general input parameters are studied before any detailed design or construction phase is even pursued. It also permits the scientific investigation of simulation parameters that are not even available through experiment. In the case of infrared threats, the experimental evaluation of live threats against the actual ship platform is neither a physical or economically viable option. As a result, more and more emphasis is placed on the simulation, and the fidelity and systematic validation of the underlying models is imperative.

SHIPIR/NTCS[4] is an integrated ship, threat and countermeasure model, capable of predicting the infrared signature of naval warships in their maritime background (see Figure 5). Developed in the early 90's for the Canadian Department of National Defence, it has now been adopted by the U.S. Navy and NATO as the standard ship IR signature model.

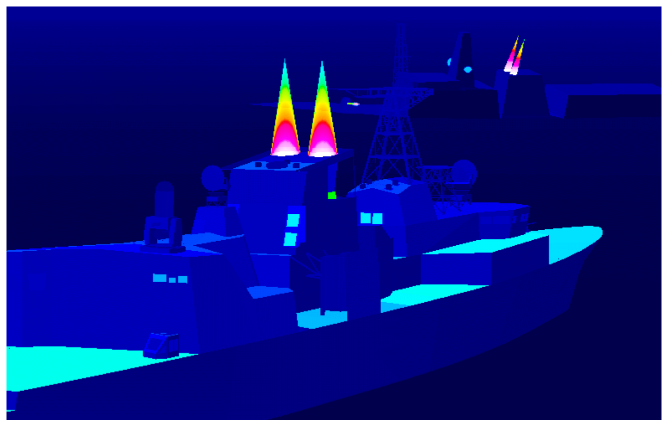

Figure 5: Typical Output From SHIPIR/NTCS

The SHIPIR component of the model consists of several sub-models. The background model predicts the thermal and in-band radiance of the sun, sky, sea, as well as atmospheric propagation effects. The target model is based on generalized 3D CAD geometry, a heat transfer model, and a complex surface reflectance model to predict the in-band target skin signature. A plume model based on empirical stack flow correlations and a spectral gas-band model is used to predict the IR emission of each exhaust plume on the ship. The observer and scenario models are used to view the IR scene interactively, based on observer range, altitude, heading, and selected IR band, and are used to perform both signature analysis and threat engagement analysis. The naval threat and countermeasure (NTCS) component of the model uses the observer and scene models to produce fly-in engagements between a seeker and any number of naval targets.

Both SHIPIR and NTCS are fully-deterministic and physical models which require the input of real physical data. Various meteorological data, geography, and date/time are required to simulate the maritime background, in addition to the IR band and spectral response characteristics of the observer. A bulk of the work in preparing the IR simulation involves the input and specification of a target model. Complex 3D geometry, optical surface properties, trajectory, speed, and onboard power-plant usage are key elements used to determine the ship signature. To perform an IR analysis of the threat, various target aspect (relative location, range, heading) and seeker performance data are required.

With recent improvements to the background and target models[5], a large number of full-ship trial comparisons have been made. Such countries as Canada, USA, Netherlands, Germany, and Italy have taken a lead role in the full-ship validation of SHIPIR/NTCS. More than 8 existing ships have been modelled and validated using IR trial data. One benefit of such studies is the standardization of methods and procedures used to measure, simulate, and quantify the infrared signature of naval vessels.

An example of such a full-ship trial comparison is shown in Figure 6, which shows a pair of IR images obtained for the same condition in the 3–5μm band, one from a trial measurement and the other from SHIPIR. In this example, solar heated decks and rear aft-mast, as well as hot metal and plume show similar peak radiance profiles in both measured and simulated images.

SHIPIR/NTCS is a powerful tool for analysing, predicting, and confirming ship signatures. In fact, it would not be feasible to

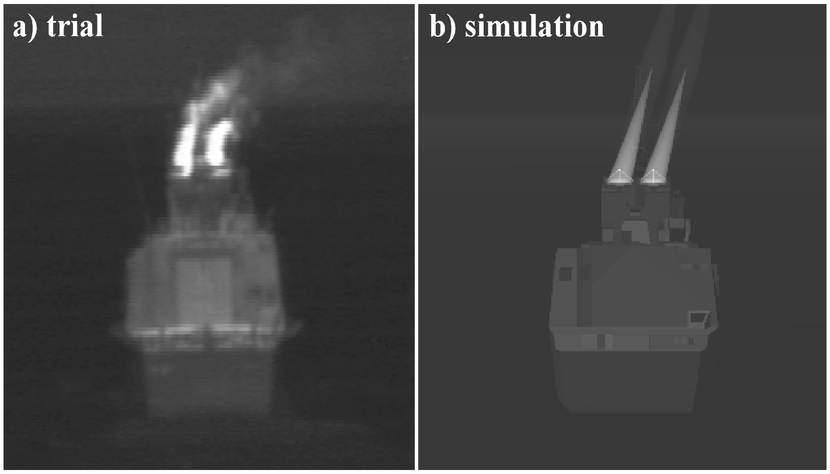

Figure 6: Trial 3-5μm Measurement vs. SHIPIR Simulation

confidently control the ship's IR signature without such a code.

IR Signature Suppression (IRSS)

The potential to improve a ship's survivability should be sufficient incentive to invest in one of the many methods of IRSS. Warm hull sections and funnel sides are normally eliminated as sources of IR through the application of good thermal design. Application of proper ventilation, and application of insulation to exterior bulkheads usually reduce outer skin temperatures to an acceptable contrast temperature.

Exhaust Cooling

The remaining internal hot-spots (ie. hot uptake metal, plume, plume impinged mast) are most effectively treated by suppressing their source, the hot exhaust gases from the main machinery. Simple suppression devices provide an optical block, or film cooling of hot uptake metal, ignoring the importance of hot plume emissions. Plume cooling is also required, to reduce direct IR emissions from the plume, and reduce mast temperatures under impingement situations. Figure 7 illustrates two IRSS devices in use today.

Each of these devices use a film of cool ambient air to suppress the visible metal. Resultant metal temperatures are similar for both devices, approximately 20-30°C above ambient. This is considered to be a sufficient level of suppression to protect against today's threats.

The ability of each device to cool the average plume temperature can be controlled at the design stage. The Eductor/Diffuser and DRES-ball both naturally entrain cooling air for metal and plume cooling. The efficient diffuser section in the Eductor/Diffuser and DRES-Ball aids each device in achieving plume cooling superior to other types of suppressors. Devices of this type in service today have been shown to achieve average plume temperatures of 200-250°C. The DRES-ball has the added advantage of full optical blockage, providing overhead protection as well as sea-skimming.

The IR suppression performance of an IRSS device differs primarily in the manner and extent to which cooling air is drawn in and mixed with the exhaust stream. Passive devices depend only on the static pressure distribution along the length of the device to draw in ambient air. These devices are favored for their simplicity and ease of maintenance. The Eductor/Diffuser and DRES-ball can both operate as passive devices. Active engine exhaust IR suppressors make use of large capacity fans to force cool ambient air through the device. A hybrid of the completely active system is the fan-assisted suppressor, which is a device capable of passive operation (eg. DRES-ball) and can operate with additional fan air to achieve improved plume suppression performance and/or reduced static back pressure.

All IRSS devices will impose some level of back pressure on an engine, dependant upon the level of plume cooling desired. Devices can be designed to give cooling with no back pressure, but average plume temperatures will be considerably higher. An example of this relationship is given in Figure 8 for a number of different suppressor designs, installed on a typical LM2500 engine exhaust.

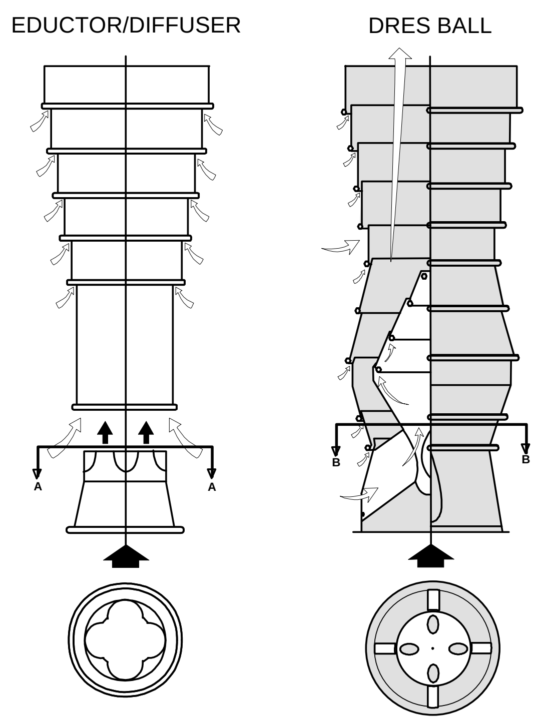

Figure 7: Engine Exhaust IRSS Devices

As shown in the plot, a lower plume temperature can be achieved in a number of ways, including making the device larger (150%), and adding fan assistance. Alternatives to these two methods exist for use in cases where available space or system cost prohibit the use of large and/or fan assisted devices to achieve very low plume temperatures (~150°C). One solution is to use sea water injection to achieve a portion of the desired plume cooling. Thus, a smaller passive device that would normally deliver a 250°C plume can be assisted by water injection to achieve a 150°C plume.

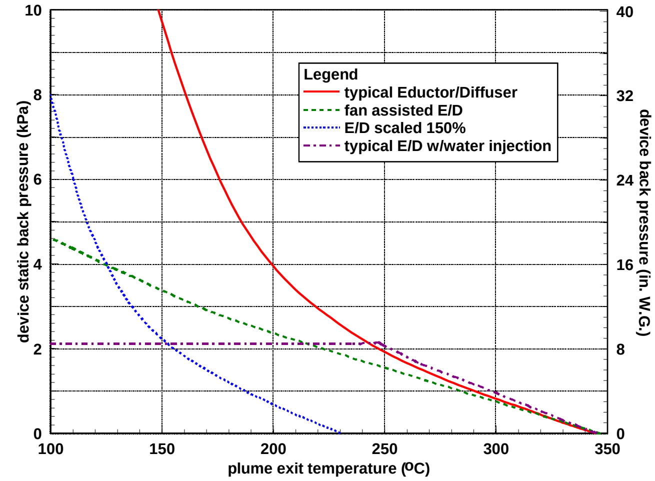

Figure 8: Back Pressure Imposed By IRSS Devices

Extensive 1/5th scale LM2500 hot flow tests of both vertical and horizontal exhaust configurations with water injection have been performed. Figure 9 summarizes some of the results. During the tests, fresh and sea water was injected at varying flow rates, and the corresponding 3.4-5 μm and 7-14 μm signatures measured. Signature values in the figure have been normalized by the unsuppressed 500°C exhaust in each band, and water flow rate as a fraction of the hot gas flow rate.

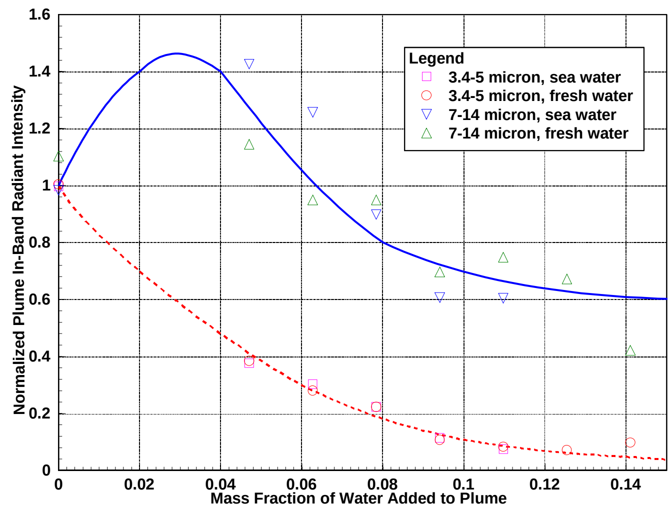

Figure 9: Plume Signature vs. Water Injection Rate

The results in Figure 9 show that the effect of injected water on the appearance of the plume depends on which IR band is being considered. In the mid-wave band (3-5 μm), the addition of water to the plume quickly cools the hot gases, reducing its in-band signature. In the long-wave band (8-12 μm) however, the addition of water to the plume initially increases its signature. This is due to water vapour tending to emit more in the long-wave band. At some point (in this case about 6.5% mass fraction water), enough water will have been added to sufficiently cool the exhaust gas so that the effect of the additional water concentration is overcome by the cooler gas temperature. Note that there was no significant signature differences measured between fresh and sea water.

Water spray does have some disadvantages including an increase in the visual band signature of the plume due to condensed water vapor. Also, spraying salt water into the stack has some practical concerns that need to be addressed using careful material selection and proper maintenance.

Another solution is to use a variable geometry device. When the ship is operating in a low risk environment, the device would be opened up to provide a small amount of plume cooling (~300-350°C) with no back pressure. When the ship enters into a high risk environment the device would close down, providing a much reduced plume signature at a cost of a higher back pressure. With this type of system, the power loss penalty associated with a low plume temperature would only be incurred over a short period of the ship's operational life. Variable geometry versions of the DRES-ball and Eductor/Diffuser have been shown to be very effective.

Surface IRSS Technology

Suppression of an excessive hull temperature is regarded as a difficult, if not impossible task. The large surface areas involved, and wide range of environmental factors influencing ship skin temperatures pose an interesting challenge. Three solutions have been proposed at present:

- use of special surface treatments (paints) to reduce IR emission;
- blanket entire ship in a cloud of heavy water mist; and
- cool solar heated surfaces with sea water.

Special Paints - A surface's appearance depends on its reflectivity (or the compliment, its absorptivity/emissivity). The spectral reflectivity of a surface can be manipulated by varying surface roughness and surface layer materials. The selection of an optimal paint spectral reflectivity distribution is a very complex issue and there is no single correct answer. There will always be a tradeoff between the best solution for sunny conditions versus the best solution for night time or cloudy day conditions.

For example, a very high reflectivity paint would make surfaces appear like the background and would tend to suppress emissions from warm areas. At night or in cloudy conditions, this would be beneficial. However, when the sun is visible it will strongly reflect from the surface, making it appear much warmer than it really is (see Figure 10).

Figure 10: Solar Glint from Typical Navy Paint

In addition to diffuse reflection, surfaces also tend to reflect specularly over a narrow range of incidence angles. This behaviour is quantified as the bidirectional reflectance distribution (BRDF). Figure 10 presents two IR images of a ship turning with the sun across its beam. Within a narrow angle (~2-4°), the normally diffuse low reflectance ship surface appears highly reflective. Computer modelling advances in recent years now permit the study of how a surface's BRDF affects the ship's survivability. NTCS is currently the only IR signature analysis software capable of properly modelling BRDF.

Ideally, a paint is required that: is highly reflective in the short wave IR band (0.2-3.0 μm) to minimize solar heating, is non to moderately reflective in the mid-wave band (3.0-5.0 μm) to eliminate solar glint, and is highly reflective in the long-wave band (8-12 μm) to reflect the background and minimize emissions from warm ship surfaces. Paints or other surface treatments with these special properties can (in theory) exist, but are very expensive to produce and maintain. A high reflectivity surface will quickly degrade due to unavoidable factors such as salt build-up, engine exhaust, soot and dirt.

Little unclassified data on the in-service experience of ships that use special paints has been available. Without extensive field trials, signature measurements, and computer modelling it is not possible to recommend an alternate surface finish with confidence. Considering the high cost of these coatings, they do not yet present a viable solution to the problem of a large sun heated surface.

Water Mist - As a second solution to the hull IR signature problem, it has been proposed that a thick cloud of water mist be sprayed about the ship, in effect hiding the ship from the view of IR seekers. No data has been found on the effectiveness of this type of system as an IR countermeasure. Preliminary analysis suggests that: a water cloud may only partially obscure the hull from incoming threats; the cloud will obscure onboard optical sensors such as IRST; there will be a constant build up of salt all over the surface of the ship; and finally to engage such a system would require the ship to come to a complete stop, or else the water cloud would be blown away.

Surface Cooling - The third and currently the most effective suppression technique consists of actively cooling the hot parts of the ship's surface with sea water. During the Gulf War, ships successfully used existing NBC (Nuclear Biological Chemical) water wash systems or hastily retrofitted wash systems to cool their surfaces. With some careful planning, new ship programs can have active hull cooling systems capable of effectively cooling the ship's surface to ambient temperatures without significant additional cost.

To be most effective, a water wash system must be carefully designed to cool the entire surface of the ship to ±5°C contrast from +10 to +30°C. The wetting system should be designed to distribute water uniformly over the subject area so that no hot spots remain. The variation in the surface temperature after cooling should be less than 5°C.

Extensive experiments on active hull cooling system components have been performed such as: nozzle type, nozzle placement, and water flow rate. Figure 11 shows the measured effect of water wash on the temperature of a painted (Canadian navy grey) 20' square plate oriented towards a sunny sky. In this case a typical navy deck sprinkler was used to wash a horizontal panel (5° incline), with a water flow rate ranging from 2 to 8 gal/ft^2-hr. As can be seen from the figure, the water wash reduces the plate temperature to below +5°C contrast in approximately 7 minutes.

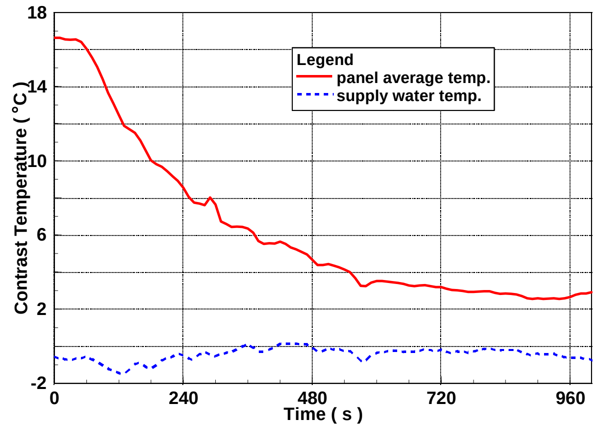

Figure 11: Cooling Time of a Water Washed Panel

The water wash system should be divided into separate zones so that water wash can be applied on only those zones that need cooling. As a minimum the water wash systems should be separately controlled for the port and starboard sides of the ship. Care must also be taken not to over-cool the surfaces of the ship. A large negative contrast imposes as effective a target to modern seekers as a positive one. By using a feedback control system, water could be turned on and off as needed, maintaining the surface of the ship at a relatively constant low contrast temperature.

The use of sea water wash to cool ship surfaces has a number of other concerns associated with it. One is that a wet surface will reflect solar radiation in a specular manner and therefore solar glint effects will be increased with water wash. However, this glint effect is usually limited to a narrow range of view angles and therefore is considered acceptable when considering the large potential benefits from hull cooling. Advanced computer BRDF models such as SHIPIR/NTCS will be used to analyze this issue in more detail.

Active hull cooling systems can introduce other problems including corrosion and salt buildup. A feedback controlled system would only need to be cycled on for ~15 minutes every hour to maintain the desired surface temperature. Also, by suppressing the hull in high threat situations, the water wash system would only need to be used for a fraction of the ship's operational life. These factors minimize problems arising from spraying sea water on the ship's surface.

Variable IRSS

Many of the IRSS methods described above can be applied only when required. Thus, the active hull cooling system can be designed to engage only when the ship's surface temperature is too high. Also, variable signature engine exhaust suppressors that have fan assistance, water injection or variable geometry can be engaged when in a high risk situation.

The concept of "variable IRSS" has numerous benefits. Since the IRSS systems are only engaged when needed, the penalties associated with the IRSS are not imposed over the majority of the ship's life. For example, the back pressure penalty imposed by a low plume temperature IRSS system results in increased fuel consumption. Since a variable system would only be engaged when the low signature is required, the IRSS system results in a negligible increase in fuel consumption over the operational life of the ship. Similarly, the use of active hull cooling systems only when in high risk environments will essentially eliminate problems such as salt build-up.

Having a variable IR signature can also be used to deceive potential threats. If a modern seeker identifies a target by its typical IR signature, then when operating in regions where such a seeker is known to be used, the ship can simply change its IR signature to something else. Figure 12 illustrates visually the effect of employing different levels of IRSS. The top image is a simulated IR image of a generic frigate sailing at full-power with solar heating and no IRSS. The middle image represents the appearance of a modern ship employing standard IRSS;

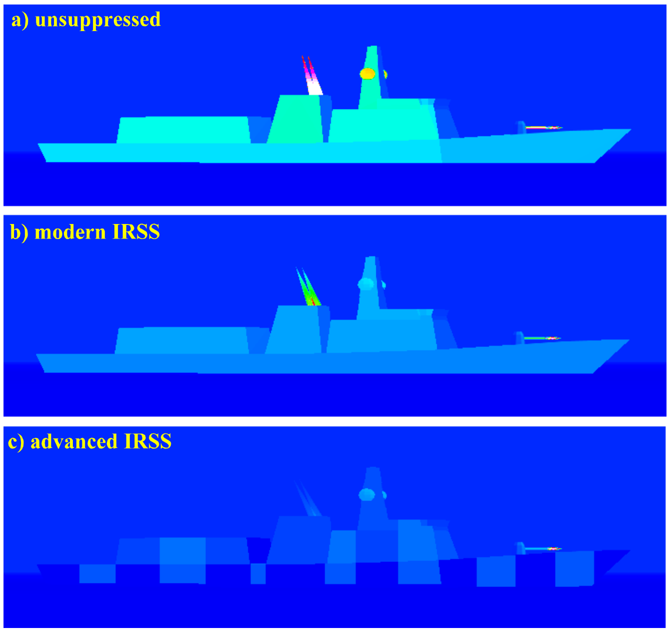

Figure 12: Simulated IR Images of IRSS Levels

plume suppression to 250°C, and simple active hull cooling. The final image is meant to show what can be achieved using advanced engine IRSS (plume <150°) and feedback zone-controlled active hull cooling. The plume emission of the ship has been essentially eliminated, and the surface of the ship has been intermittently cooled to make it difficult to identify.

An effective way to maintain a variable IR signature is through the use of an integrated ship IR signature monitoring and control system. The DAVIS Onboard Signature Manager (OSM) is a prime example. The system measures temperatures and system status from all over the ship. This information is used to calculate ship IR signature and lock-on ranges for display to the operator in real-time. By displaying the real-time ship IR signature to the operator, decisions regarding IRSS can be more quickly and effectively applied. In fact, OSM can be configured to automatically control ship IRSS and countermeasure systems. In this way, the operator can simply indicate the level of signature desired and let OSM implement the required actions.

Benefits of IRSS

A number of IRSS methods have been described above. To further illustrate the effectiveness of these techniques, NTCS has been used to simulate some of the IRSS methods.

NTCS can be used to predict the IR signature of a ship with and without an IRSS method employed. These signature predictions can be produced for any observer location relative to the ship, and allow for the fair comparison between IRSS methods. Of perhaps more use for comparison of effectiveness is the use of predicted IR seeker lock-on range. Figure 13 shows the predicted polar lock-on ranges of a Type IV seeker (Penguin-like 3-5μm imaging seeker) on a generic frigate class vessel with varying levels of active hull cooling. The frigate is cruising on suppressed diesel engines at 20 knots, with the sun at 30° elevation, directly off the starboard beam. Ship surface contrast temperatures in the unwashed case range from +10 to +17°C. Washed surfaces were assumed to be at ±2°C contrast with the ambient air temperature, in this case 15°C.

Figure 13 shows the dramatic reduction in ship susceptibility that may be realized by cooling the surface of the ship with sea water. The figure also suggests that to achieve the largest reduction, the hull must be suppressed in addition to the superstructure.

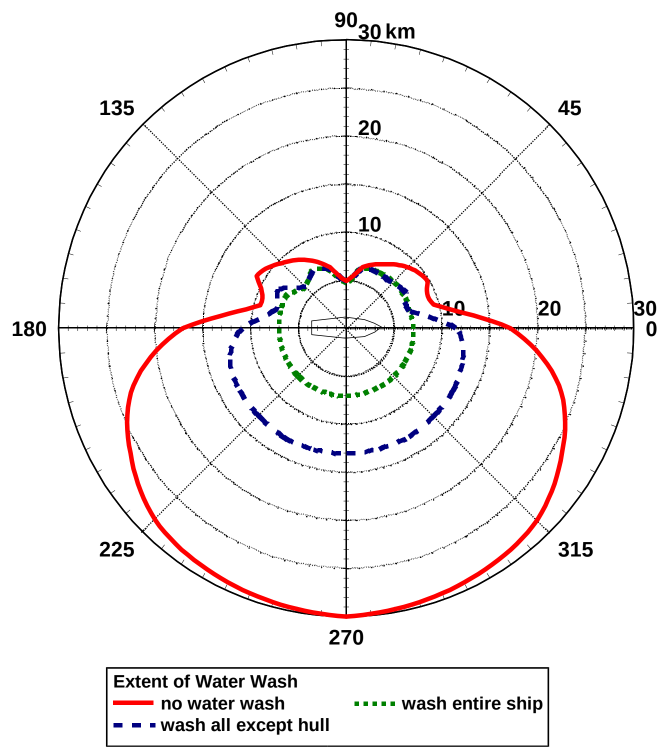

Figure 13: Effect of Different Levels of Active Cooling On Lock-On Range

The relative impact of different exhaust plume temperatures has been simulated in NTCS, the results are shown in Figure 14. Each of the three plume temperatures shown are of a frigate traveling at night under full-power on its two LM2500 engines. The ship is assumed to be sailing level, so no uptake metal is visible. Again, the Type IV seeker (Penguin-like) model was used for the lock-on range predictions.

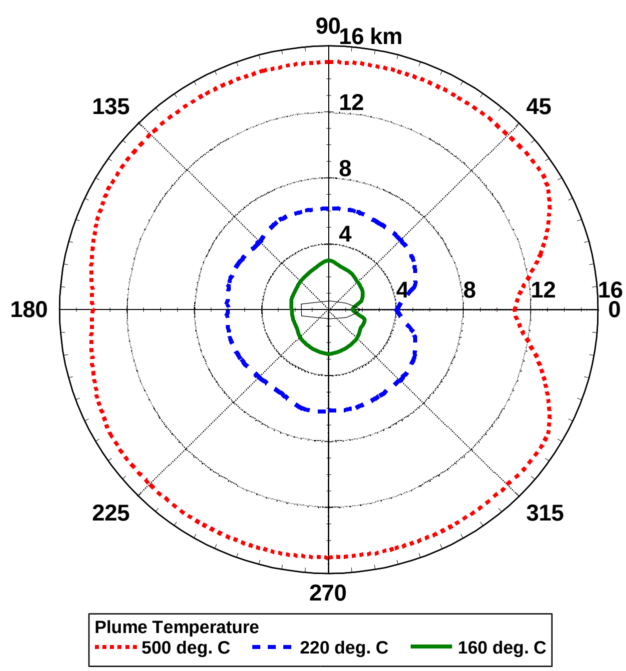

Figure 14: Effect of Plume Temp. on Lock Range

The 500°C curve is representative of a typical unsuppressed LM2500 exhaust plume. 220°C is indicative of a modern level of plume suppression, achieved by the IRSS devices (specifically DRES-Balls and Eductor/Diffusers) currently in service. The 160°C curve represents the level of susceptibility achievable using advanced plume cooling techniques such as variable geometry and/or water injection.

NTCS has also been used to examine the effect of variable and complex ship IRSS methods. Simulated IR images of three IRSS levels (unsuppressed, modern, advanced) have already been presented in Figure 12. Figure 15 summarizes the effect of these three IRSS levels on the ship's overall susceptibility to a Type IV seeker. The NTCS ship models used are as in Figure 12: an unsuppressed, sun heated frigate at full power on two LM2500's; the frigate with modern exhaust IRSS (250°C plume) and simple active hull cooling; and the same frigate with advanced IRSS (150°C plume) and feedback zone-controlled active hull cooling.

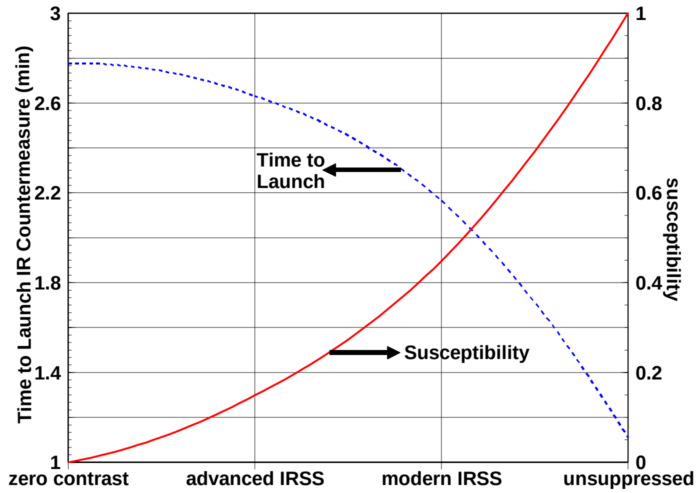

Figure 15: Effect of IRSS Level on Ship Susceptibility and Time to Launch Countermeasures

Ship susceptibility in Figure 15 has been calculated based on the azimuth averaged Type IV seeker lock-on ranges predicted by SHIPIR/NTCS. The countermeasure launch times assume that the seeker is first detected at a 50 km range, and that it flies at a speed of Mach 1.0. The figure shows that the use of IRSS dramatically reduces the seeker's lock-on range, and thus has increased the time span over which seeker distraction is effective.

SUMMARY

In today's environment of increasingly sophisticated EM and IR threats, the importance of knowing a ship's signature over a range of operating conditions is very important. Through EM/IR signature suppression, a ship's detectibility can be dramatically reduced, improving its chance of survival.

Identifying potential signature problems, and selecting the most cost effective suppression solution can be difficult. Computer modelling techniques have now advanced to a level of complexity and accuracy that permits most aspects of a ship's EM/IR signature to be studied. When used properly, these new analysis capabilities allow for optimization of a ship's signature.

Signature suppression methods available today have been presented throughout this paper. As well, the use of advanced computer modelling has been discussed. If ship's are to maintain their survivability in the future, signature management techniques must evolve with that of the threats.

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