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# Damage Control and Crew Optimization

*John A. Hiltz*

**Defence R&D Canada – Atlantic**

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Author

John A. Hiltz

Approved by

Richard M. Morchat

Head Emerging Materials Section

Approved for release by

Kirk Foster

DRP Chair

## Abstract

The costs associated with personnel and maintenance account for approximately 70% of the total operating costs of a ship. Of these costs more than 50% are associated with personnel. As the Canadian Forces have made the reduction of the total operating costs of ships a priority, approaches to the reduction in crewing levels without jeopardizing operational capabilities and safety are being investigated. Of particular concern is how labour intensive tasks, such as damage and fire control, can be carried out on ships with reduced crewing levels.

To aid in addressing the challenges arising from attempts to reduce crewing levels and maintain or enhance damage control, DRDC Atlantic has initiated a project entitled Damage Control and Crew Optimization. In this memorandum, the approaches to reducing crewing levels, including the use of functional analysis in conjunction with modeling and simulation to evaluate the effectiveness of several crewing level-automation for damage control technology configurations, reviews of damage and fire control technologies, the evaluation of the impact of remote condition monitoring systems on maintenance requirements and situational awareness, and the introduction/development of materials with enhanced fire and damage tolerance are discussed.

## Résumé

Les frais touchant le personnel et l’entretien représentent environ 70 % des coûts d’exploitation d’un navire. De ces derniers, plus de 50 % sont associés au personnel. Les Forces canadiennes ayant fait de la réduction des frais d’exploitation totaux des navires une priorité, on étudie la façon de réduire l’effectif minimal requis sans porter atteinte à la sécurité et aux capacités opérationnelles. Ce qui nous préoccupe particulièrement c’est comment s’acquitter à bord de navires de tâches qui exigent une main-d’œuvre considérable, comme le contrôle des avaries et des incendies, lorsqu’il y a réduction de l’effectif minimal requis.

Pour qu’il soit plus facile de faire face aux défis issus des tentatives de réduire l’effectif minimal requis tout en assurant ou en améliorant le contrôle des avaries, RDDC Atlantique a lancé un projet baptisé Contrôle des avaries et optimisation des équipages. Dans ce document, il sera question des diverses façons de s’y prendre pour réduire l’effectif minimal requis, y compris l’utilisation de l’analyse fonctionnelle parallèlement à la modélisation et à la simulation afin d’évaluer l’efficacité de plusieurs procédés automatisés au niveau de l’équipage, appliqués aux configurations des techniques de contrôle des avaries, les examens des techniques de contrôle des avaries et des incendies, l’évaluation de l’impact des systèmes de commandement et de contrôle à distance sur les besoins en maintenance et la connaissance de la situation, ainsi que l’introduction/la mise au point de matériels munis d’une meilleure tolérance au feu et aux avaries.

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# Executive summary


Introduction

The Canadian Navy has identified the reduction of through life costs of ships as a priority. As crewing levels are the major contributor to through-life (total operating) costs, this has led to an increased interest in how crewing levels can be reduced without jeopardizing the ship's ability to complete its mission. Labour intensive operations, such as fire and damage control, become a major concern when ships are being designed to operate with reduced crewing levels.

To aid in addressing the challenges arising from attempts to reduce crewing levels and maintain or enhance damage control, DRDC Atlantic has initiated a project entitled Damage Control and Crew Optimization. In this memorandum, the elements of the proposed program are discussed.

Results

The proposed work plan for this project has four elements. These are the use of functional analysis in conjunction with modeling and simulation to evaluate the effectiveness of several crewing level/automation for damage control technology configurations, reviews of damage and fire control technologies, the identification of materials with enhanced damage and fire tolerance, and the evaluation and demonstration of remote condition monitoring systems.

Significance

Functional analysis in conjunction with modeling and simulation will be used to determine how automation will affect crewing level requirements. Conversely, if crew levels are mandated this type of analysis can be used to determine the level of automation required to ensure that damage control can be carried out effectively.

The reviews of damage and fire control technologies will indicate the current state-of-the-art and indicate gaps in these technologies. These reviews will be used to provide input of automation levels in the modeling and simulation studies.

Materials with enhanced damage and fire tolerance improve ship survivability. A critical review of the availability of these materials will also indicate opportunities and requirements for further research and development.

Condition monitoring systems are critical to reduced crewing levels and damage control systems.



Hiltz, J. A. 2005. Damage Control and Crew Optimization. DRDC Atlantic TM 2005-010. Defence R&D Canada – Atlantic.

# Sommaire


Introduction
La Marine canadienne a indiqué que la réduction des coûts du cycle de vie des navires constituait une priorité. Comme les équipages (coûts relatifs au personnel) occasionnent les frais les plus élevés dans le coût du cycle de vie des navires (frais d'exploitation), on s'intéresse de plus en plus à la façon de réduire l'effectif minimal requis sans nuire à la capacité des navires de mener leur mission à terme. Les opérations exigeantes en main-d'œuvre, telles que le contrôle des incendies et des avaries, sont une préoccupation majeure lorsque les navires doivent fonctionner avec des équipages réduits.

Pour qu'il soit plus facile de faire face aux défis issus des tentatives de réduire l'effectif minimal requis tout en assurant ou en améliorant le contrôle des avaries, RDDC Atlantique a lancé un projet baptisé Contrôle des avaries et optimisation des équipages. Dans ce document, les éléments du programme proposé sont passés en revue.

Résultats
Le plan de travail proposé pour ce projet est doté de quatre éléments. Ce sont l'analyse fonctionnelle utilisée de concert avec la modélisation et la simulation afin d'évaluer l'efficacité de plusieurs procédés automatisés au niveau de l'équipage, appliqués aux configurations des techniques de contrôle des avaries, les examens des techniques de contrôle des avaries et des incendies, l'utilisation de matériels munis d'une meilleure tolérance au feu et aux avaries, ainsi que l'évaluation et la démonstration de systèmes de commande et de contrôle à distance.

Portée
L'analyse fonctionnelle utilisée parallèlement à la modélisation et à la simulation servira à déterminer les conséquences que pourrait avoir l'automatisation pour les besoins minimums en membres d'équipage. Par contre, si l'effectif minimal requis est dicté, ce type d'analyse peut servir à déterminer le niveau d'automatisation requis pour que le contrôle des avaries puisse s'effectuer efficacement.

Les examens des techniques de contrôle des avaries et des incendies indiqueront l'état de la plus récente technologie de même que les lacunes de cette technologie. En outre, les examens serviront à intégrer les données sur les niveaux d'automatisation aux études de modélisation et aux études en simulation.

Les matériaux dont la tolérance au feu et aux avaries est accrue améliorent la survivabilité des navires. Un examen critique de la disponibilité de ces matériaux recensera également les occasions de recherche et de développement et les besoins y afférents.

Les techniques de surveillance d'état revêtent une importance capitale pour un effectif minimal réduit et les systèmes de contrôle des avaries.



Hiltz, J. A.. 2005. Contrôle des avaries et optimisation des équipages. RDDC Atlantique TM 2005-010. R & D pour la défense Canada – Atlantique.

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# 1. Introduction

The two major contributors to through life costs of naval vessels are crewing and maintenance. These account for approximately 70% of the through life (total ownership) costs associated with a ship. Of these costs more than 50% are associated with personnel[1,2] A breakdown of the through life costs of a ship is shown in Figure 1.

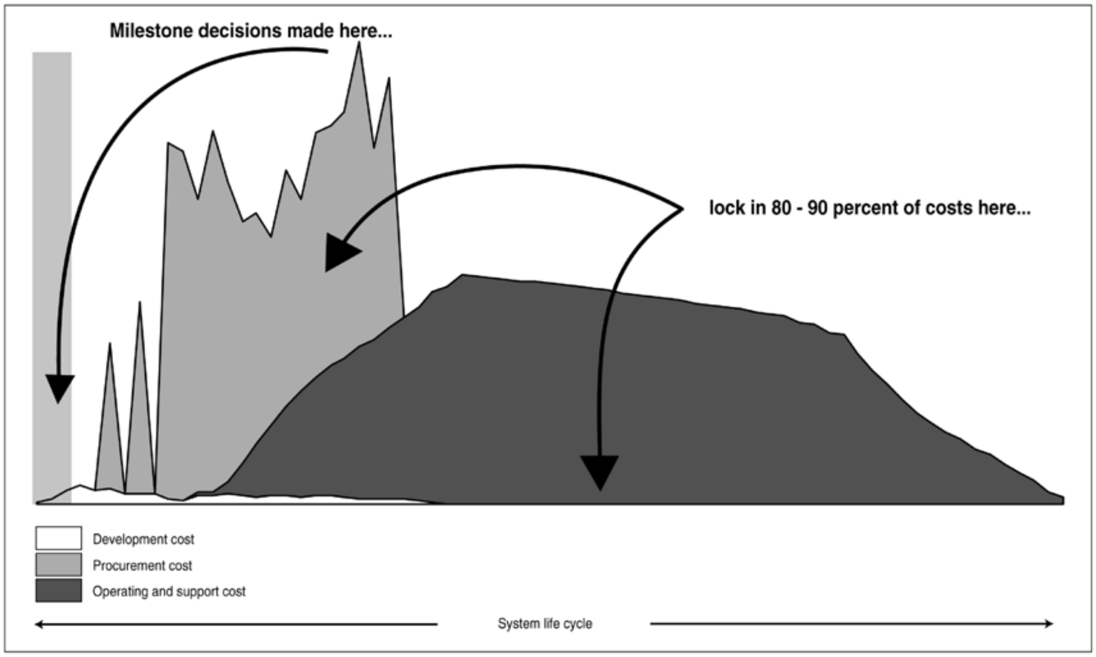


***Figure 1. Contribution of development costs, procurement costs, and operation and maintenance costs to the through life (total ownership) costs of a naval ship. (taken from reference 1)***

The Canadian Navy has identified the reduction of through life costs of ships as a priority. This has led to an increased interest in how crewing levels can be reduced without jeopardizing the ship's ability to complete its mission. Labour intensive operations, such as fire and damage control, become a major concern when ships are being designed to operate with reduced crewing levels. A 1996 report[3] indicated that damage control requirements were not the controlling factor in determining ship manning at the time this report was written. However, the damage control requirements for fighting the ship while damaged will be the limiting factor in determining crew size of in-service and new ships with more automation and less maintenance requirements. To achieve the reduced manning goals on future ships will require that the crew receive superior training, be supported by capability enhanced damage control equipment, and have improved communications and situational awareness capabilities. Discussions with DGMFD/MRCC[4] indicate that fire/damage control in large spaces, such as vehicle storage areas on the proposed Joint Support Ship, present a challenge. Specifically, any reduction in crew available for damage control will adversely affect the capability of the ship to survive damage.

To aid in addressing the challenges arising from attempts to reduce crewing levels and maintain or enhance damage control, DRDC Atlantic has initiated a project entitled Damage Control and Crew Optimization. In this memorandum, the approaches to reducing crewing levels, including the use of modeling and simulation in conjunction with functional analysis, human factors research, automation, and improved control systems, sensors and materials, will be reviewed and discussed with respect to maintaining and/or enhancing damage control on CF ships.

## 2. Optimized Manning

It is important that the term optimized manning or crewing is defined. The definition proposed by Malone et al.[5] has been used throughout. They define optimized manning as "the minimum number of personnel consistent with human performance, workload, safety requirements, and affordability, risk and reliability constraints". Optimized manning can also be defined in terms of three variables; total ownweship cost (TOC), manning level, and ship capability. A plot of TOC, manning level and capability taken from reference 2 is shown in Figure 2. The optimized manning level is taken as the position of minimum TOC for a particular capability level.

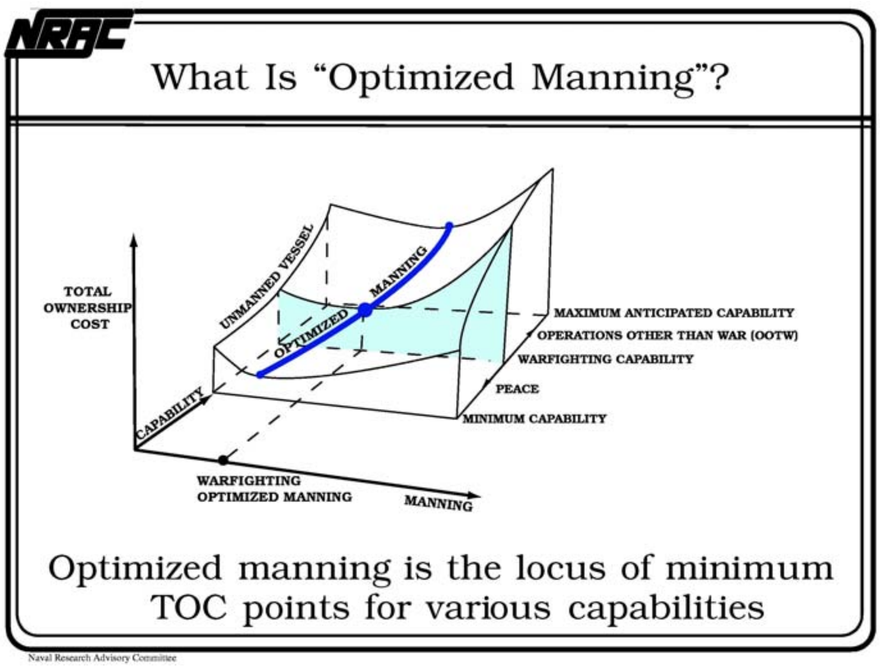


*Figure 2. Plot of total ownweship costs, manning level and capability (taken from reference 2).*

### 2.1 Research and Development Opportunities

From a research and development perspective the question that must be answered is: what can be done to optimize crewing levels and still accomplish the assigned mission? Beevis[6] has noted there are a number of areas where research and development can support efforts directed at optimized manning. These include the development of: modeling capabilities to estimate ships complements as part of the design stage of new vessel construction, advanced power systems, materials with improved corrosion and wear resistance, improved lubricants, advanced machinery control, monitoring and diagnosis systems, robotics, micro electrical mechanical systems, automated systems for fire and damage control, and human factors based research aimed at maximizing task performance under abnormal conditions.

Lockheed Martin Canada Inc. prepared a manning study for the Afloat Logistics and Sealift Capability (ALSC) project in 2001[7]. Although this project is no longer active, the findings of the study provide insight on where research and development are required and will have maximum impact on optimized crewing and damage control in new ships.

The report concludes that the application of current technology to the damage control environment will deliver its greatest savings in the area of damage control incidence monitoring, compartment and boundary assessment, and communications. Some improvement in capability in damage control systems with respect to re-configuration or isolation of fire mains or chilled water (HVAC) systems is predicted. Current technology does not eliminate any manning levels associated with fire or flood control and only limited ability to automatically extinguish fires through automated suppression devices. The report notes that manning levels associated with damage control have traditionally taken advantage of manning levels established by other requirements- predominantly machinery watch keeping and associated maintenance. If manning levels for these requirements are reduced, then the ship's damage control capability will be adversely affected unless automation of damage control tasks can be accomplished.

Plans for the ALSC (and at present the Joint Support Ship) call for the launch and recovery of two aircraft simultaneously. This is a new scenario for CF ships. Currently six firefighters are required (mandated) for launch and recovery of a single aircraft. Six firefighters may not be sufficient for the increased size of the flight deck required for launch and recovery of two aircraft.

The report also comments on the requirements for condition assessment and damage control systems. For condition assessment systems future directions will include expansion of the scope of equipment monitored under the condition based maintenance (CBM) program, the incorporation of knowledge gained from CBM into smart systems, the implementation of smarter sensors into data collection systems as they become available, and the development and incorporation of new data evaluation techniques. For damage control systems future directions will include increased decision making capabilities to automatically perform sequences, automatic reconfiguration of systems according to operational status and damage control needs, adoption of new hardware such as remote control fire nozzles, infrared video cameras, and personnel monitors, and the introduction of portable human machine interfaces to enable users instant access to ship-wide damage control activity.

In the following sections a number of areas where research and development efforts can support an optimized crewing and damage control project are discussed. Modeling and simulation tools provide a means of evaluating the effectiveness of different configurations of crew and technologies (automation) in the performance of tasks. These tools aid in the selection of the best approach to maintaining operational capabilities with fewer crew. Human factors research considers how to best design systems that provide operators with the information/decision making capabilities they need to perform their tasks efficiently. Critical assessment and installation of the most effective damage and fire sensing, suppression and control systems will lessen the effect of fire and battle damage. The development of materials, such as blast resistant coatings and porous materials, that harden ship structures will result in ships that are inherently less vulnerable to damage.

# 3. Proposed Elements of the Damage Control and Optimized Crewing Project

## 3.1 Modeling and Simulation

### 3.1.1 Tools for Crewing Level Determination

There are a number of modeling and simulation tools available to aid in determining the required crewing (manning) levels for a ship or a particular mission scenario. For instance, reference 8 reviews tools used by the United States, United Kingdom, Australia, Netherlands and Canada. These tools can be separated into two types; resource scheduling or “top-down” models and task network simulation or “bottom-up” models.

The resource scheduling tools generate ships complements through use of top-down functional (requirement) analysis. Functional or requirement analysis involves determining what a human must do and what a machine can do. Tools based on top-down models do not need detailed mission timelines or scenarios as input. Crewing estimates are based on snapshots of average or typical missions.

Bottom-up tools focus on complement validation by answering the question “can the proposed complement operate, maintain, and support the platform successfully for a pre-determined mission or missions?” These models are applied to existing platforms and have limited usefulness in reductions in crewing levels.

### 3.1.2 Human Systems Integration (HSI) Top Down Requirement Analysis (TDRA)

It was noted in previous section that top down functional or requirement analysis is integral to the use of modeling tools to determine crewing levels for ships. Functional analysis is part of the HSI process.

HSI is defined as the technical process of integrating human engineering, personnel, training, systems safety and health hazards with a material system to ensure safe, effective operability and supportability[9]. Malone et al.[5] state that “The goal of HSI in the early stages of system acquisition is to define requirements for reduced workload and optimized manning, determine requirements for human performance and safety, specify technology requirements to achieve optimized manning, and integrate these requirements into system performance specifications”. The major objective of HSI in system development is to ensure that the needs and consideration of the human element of the system will influence design in the acquisition process.

Malone notes that simply automating systems does not provide the crew with what is needed to accomplish their mission. The development of a system must consider how the crew will be affected by the introduction of technology. Automated systems must support the crew with decision aiding capabilities including predictive simulation and information integration, data fusion and knowledge generation. To be effective the HSI approach must be aware of the complementary and collaborative roles of the human and technology in system functions and how those roles are affected by changes in workload, crew availability and changes to the mission. For instance, although increased automation of tasks will reduce the need for humans to carry them out, the introduction of automation may require increased training of the crew to operate, maintain and/or interpret data coming from the automated system.

Top down requirement analysis (TDRA) provides the means of achieving this goal. TDRA considers the roles and the requirements of people and machines to perform functions associated with a particular mission. This, in turn, defines the information, decision and performance requirements of the associated acquisition. These requirements lead to the development of design requirements for the interface between crew and machine, crewing levels, training, safety and health, and quality of life. TDRA is the basis for the development of innovative and non-traditional design concepts that will lead to optimized manning.

Function allocation is critical in TDRA[10]. When the development objective is to downsize systems with respect to an existing system to optimize or reduce crewing, the objective of allocation of functions must change from optimizing human performance to minimizing human involvement. The strategy is to automate functions to the level where the required reduction in workload and crewing can be achieved without jeopardizing human performance and safety. A NATO Workshop[11] concluded that function allocation was not a stand-alone process but must be included in the analysis-design-evaluation cycle of the acquisition process.

Two US reports emphasize the importance of HSI in realizing reduced crewing levels. The US Government Accounting Office report[1] evaluated the application of HSI to the US Navy's development and acquisition of four ships, the DD(X) destroyer, the T-AKE cargo ship, the JCC(X) command ship, and LHA(R) amphibious assault ship. They found that only the DD(X) acquisition had the potential to realize significant crewing level reductions and that this was a direct result of the application of HSI. They made several recommendations concerning the use of HSI in the ship acquisition process. These were: that a HSI assessment be preformed as concepts for a system are developed and alternative concepts are evaluated, that HSI analyses, including trade off studies of alternatives, be used to establish an optimized crew size goal that will be become a key performance parameter in an acquisition program's requirements document, and that HSI assessments be updated prior to all subsequent milestones in the acquisition process.

A US Navy Research Advisory Committee report[2] recommended that the ship design process be modified to include Human Engineering (HSI) so that optimal performance is achieved with as few sailors as possible, and that Research and Development efforts be aligned so that components and subsystems for ships incorporate the same types of processes and specifications used for the platform.

### 3.1.3 Planned Approach

A functional analysis will be conducted to identify and to break down the functions that need to be performed during damage assessment and control, and to specify the resources (i.e., humans, automation, or both) needed to perform these functions. Multiple system configurations and their capabilities will be modeled in the Integrated Performance Modeling Environment (IPME). The configurations might include present damage control crew with limited automation, reduced crew with limited automation, and reduced crew with advanced automation. A number of damage control scenarios representing different levels of complexity will be simulated. The effectiveness, relative strengths and weaknesses of each system configuration will be revealed as performance data are captured during computer simulations of the scenarios.

The results of the functional analysis will be used to aid in the design of an integrated human-computer interface for damage control systems. Instead of a separate interface for each piece of technology, an interface that incorporates the input from the different technologies will be designed. This will inform the operator how the different technologies are working together to perform the damage assessment and control functions.

## 3.2 Damage/Fire Control

### 3.2.1 Automation

The ability to control damage is critical to the survival of the ship and safety of its crew. On most ships in service today, fire fighting and damage control are labour intensive functions and major contributors to crewing level requirements. It is not surprising then that a major concern about initiatives to reduce crewing levels is how effective fire fighting and damage control will be realized.

There has been a major effort in the US to address this requirement. The "Damage Control - Automation for Reduced Manning" (DC-ARM) program is directed at the development of a control system and technologies for automated and effective damage control that reduce manpower requirements[12-17]. As part of the DC-ARM program, a distributed, integrated, supervisory system for controlling firemains at the device, system and ship level was developed. This system can also be used to control other types of damage. The control system enables the damage control assistant to direct crew actions, control ships systems remotely and integrate ship systems functions with crew function. Capabilities include video monitoring of spaces, remote actuation of water mist systems, and remote isolation of ruptured firemains. Crewmembers are required to establish fire boundaries only when the automated water mist system is not available to contain a fire.

The DC-ARM program also resulted in the development and testing of a number of new fire detection and fire fighting technologies. These include heat, smoke and pressure sensors to monitor both occupied and unoccupied shipboard spaces, remotely actuated valves to control water mist fire suppression/extinguishing systems or to stop flow to ruptured piping, and ventilation control to limit oxygen availability and/or control smoke spread in shipboard spaces.

Tests of the DC-ARM system (September 2000) demonstrated the effectiveness of the system. Damage control on a simulated missile strike was realized with 60% fewer personnel.

Human systems integration (HSI) was a significant contributor to the success achieved with the DC-ARM system. During system development, system displays were periodically evaluated and functional analysis was used to define tasks and allocate them to either crewmembers or automated systems. The analysis was also used to determine what information had to be displayed to support decisions and actions taken by the operator.

### 3.2.2 Fire Fighting/Control - Halon Replacements

Ozone depleting substances, including Halon 1301 and Halon 1211, will not be used on the Joint Support Ship (JSS)[18]. This requires that alternatives to ozone depleting gaseous fire extinguishing agents be identified and their efficacy determined. Alternatives include other gaseous agents such as heptafluoropropane (HFC-227ea or FM200), trifluoromethane (FE-13)[19], HCFC BlendA (a mixture of chlorodifluoromethane (HCFC-22) and 1-chloro-1,1-difluoroethane (HCFC-142b)[20], and dodecafluoro-2-methylpentan-3-one (Novec 1230)[21].

In addition to the requirement for zero ozone depleting potential, replacement agents have been mandated to have the global warming potential (GWP) less than 3450. The GWP of a gas is the ratio of the radiative forcing that would result from the emission of one kilogram of that gas to the radiative forcing from the emission of one kilogram of carbon dioxide over a period of time (usually 100 years). Radiative forcing is defined as the change in the balance between radiation coming into the atmosphere and radiation going out.

The hydrofluorocarbon and chlorofluorocarbon based agents all produce hydrogen fluoride (HF) when exposed to heat and flame. The toxicity of this gas requires that precautions be taken to ensure personnel are not exposed to HF. These precautions include evacuating a space prior to activating the system and ventilating the space after a fire to ensure HF levels are below those that pose a health hazard.

Water mist systems have also been investigated as alternatives to Halon based systems. Several water mist systems are commercially available. Some use high or medium pressure water delivered through nozzles with small orifices to produce a mist while others use twin fluid nozzles (water and air) to produce a mist. Water mist systems have advantages over the hydrofluorocarbon and chlorofluorocarbon gaseous agents. These include no toxicity, no environmental impact and the ability to extinguish fires in a compartment under normal ventilation conditions. That is, the compartment does not have to be 'airtight' to ensure that the agent is effective. Water mist also decreases the temperature in the compartment and allows access to the compartment while the water mist system is activated[22].

There is concern about using water mist systems in spaces where there is electronic equipment. Investigations have shown that water mist can be used to fight fires in spaces with electrical and electronic equipment with minimum water damage[23]. Under certain conditions research has shown that water mist systems are less likely to damage equipment than the thermal decomposition products of the hydrofluorocarbon and chlorofluorocarbon-based gaseous agents[24].

The use of water spray/mist cooling systems in conjunction with heptafluoropropane has also been investigated[19,21]. The results indicate that water spray reduces the hazards associated with the thermal breakdown of heptafluoropropane. For instance, peak HF concentrations were reduced by a factor of 2, and HF concentrations 15 minutes after discharge of the heptafluoropropane were reduced by more than an order of magnitude when a water spray system was started 30 seconds before the heptafluoropropane system was activated[25].

Fluorinated surfactants are used in the production of aqueous film forming foams (AFFF). The extreme stability and chemical inertness of the fluorosurfactants gave these materials an advantage in fire fighting applications. However, this stability and inertness is undesirable from the environmental perspective. Fluorosurfactants based on perfluorooctyl sulfonates have been phased out of production and those based on perfluorooctanoic acid derivatives are under investigation. This has resulted in the requirement for replacement fire fighting foams and testing of replacement foam effectiveness. A recent report[26] indicates that some non-fluorinated foams have fire and vapour suppression capabilities similar to fluorinated foams. However, not all non-fluorinated foams have the same performance and the report indicates that a testing protocol is required to evaluate non-fluorinated foams.

### 3.2.3 Helicopter/Vehicle Deck Fire Fighting

The design plans for the JSS include a two spot flight deck and hanger space for four helicopters. Discussions[18] indicate that the larger flight deck and hanger spaces will require redesign/modifications of the extinguishing systems and fire/damage control doctrine used on the CPF and Tribal Class ships.

Concern was also expressed about fire/damage control on the larger below deck spaces on the JSS[4]. Effective fire/damage control will require investigation of design and fire extinguishing options and development of fire damage control doctrine.

### 3.2.4 Planned Approach

State-of-the art reviews of damage sensing and control systems and fire sensing and control systems will be completed. Improvements in sensor and monitoring technology, automated controls for remote actuation of fire fighting systems (water mist or other extinguishing systems), and rerouting fire main and chilled water flow around ruptures will have an impact on optimized crewing and damage control. The findings of these studies will be incorporated into the crew/automation configuration modeling studies. The reviews will also be used to determine areas where further research and development are necessary to realize damage control with optimized crewing levels.

Effective fire control will require the selection and evaluation of Halon replacement fire extinguishing systems. This may include the use of water mist systems, selection of effective, non-toxic and environmentally compliant gaseous agents and their delivery systems, the selection of non fluorinated fire fighting foam, and the design and engineering of systems and doctrine to control fire in larger shipboard spaces.

## 3.3 Materials and Materials Related Research and Development

The development and introduction of materials that have improved damage or fire tolerance will have an impact on damage control and optimized manning. These materials have the potential to ameliorate the effects of battle damage, damage arising from high sea states, and fires.

Highly porous metals and blast resistant coatings are materials with potential to improve the damage tolerance of naval vessels. The 2005 US Department of Defense appropriations Bill has requested further funding for the development of blast resistant anechoic coatings.

Material developments also have potential applications in the fire hardening of ships. Materials that are less susceptible to fire will affect the level of effort required to bring a fire under control. For instance, materials that prevent the spread of smoke and flame from one compartment to the next, such as bulkhead penetration sealants, intumescent coatings[27,28], and fire resistant cable sheathing would control the spread of fire and smoke. In large below deck spaces the development of materials such as deployable curtains could be used to control the spread of smoke and flame.

### 3.3.1 Planned Approach

A review of materials technology related to damage and/or fire control will be completed. The findings of the review will be the basis for recommendations of materials with enhanced damage/fire control potential. In addition, the review will highlight areas where research and development will result in or is required to realize damage/fire tolerant materials.

## 3.4 Remote Condition Monitoring Systems

Maintenance of naval vessels is both costly and labour intensive. As such it is a major contributor to the total operating costs of a ship. The introduction of automation will add to the requirement for routine periodic maintenance. If maintenance could be done on an 'as needed' basis this would reduce labour (crewing ) requirements. Condition based maintenance (CBM) provides a way to accomplish this. Rather than have crew perform routine periodical maintenance on critical systems, a CBM system monitors the health of these systems and indicates and/or aids the crew in determining when maintenance is required.

Continuous monitoring and quantification of platform performance is another area critical to damage control and reduced crewing levels. Sensors make crew aware of a problem, its extent, and the effectiveness of control measures. Parameters such as temperature, smoke, flooding, firemain pressure, hull integrity can all be monitored. For instance, a system could be used to monitor structural damage and the effectiveness of damage control measures in real time.

### 3.4.1 Planned Approach

Research in CBM has been initiated. The objectives of this research are the evaluation and characterization of novel CBM sensor technologies, the demonstration of the advantages of wireless data transfer for shipboard CBM, and the demonstration of the use of novel sensors and wireless data transfer on an operational vessel. The construction of a prototype system has begun and a proof of concept will be completed in 2005. A full-scale demonstration system will be designed and tested in 2006, and a full-scale system will be evaluated on an operational vessel in 2007.

The objectives of research in the area of condition monitoring of structural damage and damage control effectiveness are the evaluation of emerging condition monitoring and assessment technologies, the configuration and assembly of generic monitoring systems for Naval platforms, and the demonstration of monitoring systems on an operational platform.

# 4. Summary

The proposed DRDC Atlantic approach to damage control and crew optimization has been described. The project will include the use of functional analysis in conjunction with modeling and simulation to evaluate the effectiveness of several crewing level-automation for damage control technology configurations, reviews of damage and fire control technologies, the impact of remote condition monitoring systems on maintenance requirements and situational awareness, and the introduction/development of materials with enhanced fire and damage tolerance.

Functional analysis in conjunction with modeling and simulation will be used to determine how automation will affect crewing level requirements. Conversely, if crew levels are mandated this type of analysis can be used to determine the level of automation required to ensure that damage control can be carried out effectively.

The reviews of damage and fire control technologies will indicate the current state-of-the-art and indicate gaps in these technologies. These reviews will be used to provide input of automation levels in the modeling and simulation studies.

Materials with enhanced damage and fire tolerance improve ship survivability. A critical review of the availability of these materials will also indicate opportunities and requirements for further research and development.

Condition monitoring systems are critical to reduced crewing levels and damage control systems.

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The costs associated with personnel and maintenance account for approximately 70% of the total operating costs of a ship. Of these costs more than 50% are associated with personnel. As the Canadian Forces have made the reduction of the total operating costs of ships a priority, approaches to the reduction in crewing levels without jeopardizing operational capabilities and safety are being investigated. Of particular concern is how labour intensive tasks, such as damage and fire control, can be carried out on ships with reduced crewing levels.

To aid in addressing the challenges arising from attempts to reduce crewing levels and maintain or enhance damage control, DRDC Atlantic has initiated a project entitled Damage Control and Crew Optimization. In this memorandum, the approaches to reducing crewing levels, including the use of functional analysis in conjunction with modeling and simulation to evaluate the effectiveness of several crewing level-automation for damage control technology configurations, reviews of damage and fire control technologies, the evaluation of the impact of remote condition monitoring systems on maintenance requirements and situational awareness, and the introduction/development of materials with enhanced fire and damage tolerance are discussed.

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