A GENERIC WARSHIP MODEL FOR SURVIVABILITY ANALYSIS

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ABSTRACT

A generic warship model is proposed to provide a standardised capability for collaboration on naval platform survivability analysis within the scientific community. The generic warship model is based on a decommissioned Royal Australian Navy *River* Class destroyer escort, ex-HMAS *Derwent*. The model is free from security sensitivities, allowing for it to be easily distributed. This generic warship model will allow collaborators to test and compare output from sensitive vulnerability and recoverability computer algorithms without needing to share those algorithms. Data collected from blast, and fire and smoke experiments performed onboard ex-HMAS *Derwent* can also be utilised to verify vulnerability and recoverability algorithms using the *Derwent* model. Survivability experiments, using decommissioned naval platforms, are rare and expensive occurrences. These experiments are important for providing valuable data to generate, and verify and validate survivability algorithms; however, such experiments are limited in the scope of scenarios that can be examined. Conversely, modelling and simulation enables exploration of complex survivability scenarios that would be difficult to perform during experiments. A computer model based on ex-HMAS *Derwent* will provide a standardised, realistic warship simulation environment to analyse complex survivability scenarios, to promote collaboration, and to enhance warship survivability. Development of the three-dimensional generic warship model is discussed, highlighting problems encountered and overcome. Examples in vulnerability, fire, and crew movement studies are also presented.

1. INTRODUCTION

Survivability of a naval platform is dependent on the platform's capability to avoid a threat, resist threat effect and recover from resultant damage, referred to, respectively, as susceptibility, vulnerability and recoverability. Each of these three domains can be assessed individually or as an integrated combination of each domain. The combination of all three domains is known as Integrated Survivability [1]. It is believed that the ability to assess platform Integrated Survivability will enhance platform survivability; contribute to capability trade-off decision-making across the three survivability domains during all phases of the platform capability life-cycle; and assist with mission planning. An ongoing research program is examining requirements for naval platform Integrated Survivability analysis, with the aim of developing an Integrated Ship Survivability Assessment Capability (ISSAC) [1, 2].

A risk associated with naval platform survivability collaborations relates to security sensitivities. A failure to properly manage the risk may compromise the operational effectiveness of the platform and associated missions. Consequently, in managing the risk, the collaborations may be limited in their usefulness. Therefore, to alleviate security sensitivity concerns, and to maximise the scope and usefulness of the collaborations, a generic three-dimensional warship (platform) computer model was developed. This model will be available to those involved in the collaborations, to facilitate development of naval platform survivability models, and perform Modeling and Simulation (M&S) analysis in a standardised environment. That is, the warship model will be a common factor amongst the collaborators, thereby minimising (or, even, eliminating) the need to share intellectual property and security sensitive information. The collaborators can perform M&S using the warship model and share the output with other collaborators for analysis and comparative purposes, or for ongoing development and refinement of survivability algorithms and software tools.

The proposed warship model is derived from ex-HMAS *Derwent* (hereafter referred to as *Derwent*), a decommissioned Royal Australian Navy (RAN) *River* Class destroyer escort [3]. After decommissioning, *Derwent* was used in the Ship Survivability Enhancement Program (SSEP), where it was subjected to a series of live explosive and fire experiments [4]. Data collected from the SSEP was utilised to verify various survivability algorithms. The data may also be utilised by collaborators to verify survivability algorithms in conjunction with using the warship model.

This paper presents an overview of M&S for survivability analysis, including experiments such as the SSEP (Section 2); and then briefly describes *Derwent* (Section 3). Developing the warship model based on *Derwent*, identifying and overcoming challenges, and adapting it for use in the different M&S software tools is described (Section 4). An overview of applications in which the *Derwent* model has been used is also presented (Section 5).

2. NAVAL PLATFORM SURVIVABILITY MODELLING AND SIMULATION

A M&S environment makes use of algorithms to approximate the 'real world'. These algorithms can be generated from observations collected during experiments, either using full scale environments or scaled approximations of the real environments. Experiments provide opportunities for data collection to understand material response to various stimuli and facilitate development, and verification and validation, of algorithms. In the domain of naval platform survivability analysis, experiments to understand platform response to different threat scenarios using decommissioned naval platforms have occurred. For example, the SSEP consisted of a series of live explosive, fire and smoke events to measure the response of the platform [4]. The explosive events were designed to simulate missile detonations, with different explosive yields being tested. The fire trials were designed to analyse heat transfer and fire progression; and the smoke trials were designed to understand the progression of smoke through the platform, as well as smoke clearance rates. The data collected from the SSEP was used to verify vulnerability algorithms; and will be used to assist development of algorithms for a naval platform recoverability capability.

Naval Research Laboratory (NRL) also utilised a decommissioned naval platform for research, and test and evaluation purposes [5]. Ex-USS *Shadwell* (hereafter referred to as *Shadwell*) was a World War 2 era dock landing ship. After de-commissioning in 1970, *Shadwell* was later converted for use in damage control experiments, primarily fire and fire fighting analysis. For example, *Shadwell* was utilised to test halon replacement systems for fire suppression [6, 7]; to investigate fire spread and examine submarine ventilation doctrine for *Los Angeles* Class attack submarines [8]; and to verify output from the *Fire and Smoke Simulator* (*FSSIM*) [9]. NRL also developed a virtual environment based on *Shadwell* to examine the use of the virtual environments in training naval fire fighters [10].

Experimentation using scaled approximations of naval platform structures also occurs. For example, experiments involving explosive charges detonated inside 1m^3 steel containers were performed to understand structural deformations, and strain profiles, and to evaluate numerical modelling used in naval platform vulnerability analysis [11]. Scaled response experiments allows for an increased number of experiments and can be used to verify vulnerability algorithms to model platform compartments subjected to air explosion events.

Analysis of human movement transit time is another example of live experiments. For example, crew movement transit time relating to damage control activities was measured on board an active naval platform [12], and in structures analogous to naval platforms [13]. Measurements performed when *Derwent* was in active service were recorded for transiting a corridor, ladders, and door and hatch entry. These measurements contributed to the development of models for a fire management training software tool [12]. Later, a limited study, using a land-based facility, measured people movement transit times to examine the suitability of a commercially available human movement software tool [13].

Experiments, such as the afore-mentioned examples, provide data for specific situations and scenarios. If variations to those scenarios were required, more experiments would be necessary, requiring extra resources (time, funding, platforms on which to perform the trials, and specialist personnel). Alternatively, M&S tools can be utilised to duplicate those experiments and study new scenarios.

M&S is often utilised to understand complex, real world scenarios. In particular, M&S can facilitate analysis of situations that may be deemed high-risk, ethically prohibitive and/or financially prohibitive to perform in the real world. M&S software tools have been developed to analyse elements of naval platform susceptibility, vulnerability and recoverability [14, 15, 16, 17]. These tools can be used to examine aspects of survivability, and can be used to analysis variability within those scenarios. Analysis capability afforded by these tools can facilitate examination of configuration changes and trade-off studies; inform training and policy and enable analysis of actual naval damage incidents [18, 19]. The challenge associated with modelling survivability scenarios, though, is the need to accurately represent the real world within the M&S environment. In particular, one model that will be required is that of the naval platform. In some instances, this model will represent the actual platform being examined; however, there will be situations requiring the use of a generic warship model. A generic warship model can be used as a baseline within the M&S environment to enable analysis and comparison of new technologies or procedures. A generic warship model also has the advantage of enabling collaboration with national and international design authorities, research and development institutions, academia, and defence agencies. It will permit the sharing of results between collaborators without needing to share M&S capabilities, or the underlying algorithms. The *Derwent* model is proposed to be that generic warship model; to be a shared asset during collaborations; and to be utilised to further develop M&S capability for naval platform survivability analysis. Data collected during the SSEP means that *Derwent* model can also be used for the verification and validation of vulnerability and recoverability M&S software.

3. HMAS *DERWENT*

Derived from the Royal Navy (RN) Type 12M *Rothesay* Class frigate and commissioned in April 1964, *Derwent* was a *River Class* Destroyer Escort of the RAN [3]. Historically, the RN Type 12 frigate commenced with the *Whitby* Class frigate, and underwent several design class changes that included *Rothesay*, *Leander* and *River* Classes. *Derwent* was constructed at the Williamstown Dockyard in Victoria, Australia, with the hull being an all-welded design of light metals and alloys. Armament varied during *Derwent*'s operational life. Primary weapons consisted of two 4.5" guns in a twin turret; a *Seacat* anti-aircraft missile system (*Derwent* was the first RAN platform to launch a guided missile); the Australian designed *Ikara* anti-submarine missile system; and two triple mounted anti-submarine torpedo tubes. A triple barrel limbo anti-submarine mortar was removed during a modernisation program between 1981 and 1985. Crew complement consisted of 240 officers and enlisted personnel. *Derwent* was recognised with battle honours for operations during the Indonesian-Malaysian Confrontation (1964 to 1966). *Derwent* also served as escort for the troopship HMAS *Sydney* during the Vietnam War. *Derwent* was decommissioned in August 1994, and subsequently utilised as the trials platform in the SSEP. After the SSEP, on 21 December 1994, *Derwent* was scuttled in deep water off the coast of Western Australia.

4. A GENERIC WARSHIP COMPUTER MODEL

Development of any computer model needs to take into consideration the intended use of the model; resources available to assist with building the model; time constraints; and the required digital file format. These considerations can dictate, for instance, the software package used for the build; and whether to start with small details, or to build a broad shape and work down to the smaller details. The form of the 'building blocks' to construct the model is also governed by those considerations. The building blocks are the mathematical representations for the three-dimensional geometry, such as the use of polygons or Non-Uniform Rational B-Splines (NURBS). The building blocks affect, for example, computer memory space and translating the model to other formats for use in relevant M&S software. In the case of *Derwent*, the finished model had to be flexible because it would be used in different software tools, with each having different model requirements.

4.1 Polygons versus NURBS

The decision to use polygons or NURBS is generally governed by the end-use of the model and, to some extent, by the shape of the object being modelled. For the *Derwent* model, the hull was a large, simple and smooth shape. This suited NURBS modelling, which uses fewer control points and results in a smoother curve than a curve generated using polygons. However, some of the end use survivability analysis software required a polygon format. This meant the hull could be modelled using NURBS, but it would need to be converted to polygons when the final shape was achieved. Conversely, the decks primarily consisted of sharply defined shapes, which is better suited to polygon modelling. Consequently, even though it was valid to build the hull using NURBS and the decks in polygons, the decision was made to use polygons for the entire model.

4.2 Constructing the *Derwent* Computer Model

One method to construct the outer shape of an object is the use of photogrammetery [20], and this was the original method of choice to construct a model of *Derwent*'s outer hull. Photogrammetery is the process of obtaining measurement and details for an object using photographs showing the object in its entirety at varying angles, including aspects that would not normally be seen (such as, below the waterline). Unfortunately, there were not enough suitably consistent photographs of *Derwent* to enable the use of photogrammetry. Instead the printed design drawings of *Derwent* were available for scanning and these were used to construct the deck and infer the hull shape.

4.2.1 Constructing the Decks

The *Derwent* design drawings consisted of deck plans and a side profile. These were scanned, and the process of constructing computer models of the decks commenced. Due to the large physical size of the design drawings, the digitised images were distorted during the scanning process. Advanced image processing software, such as Autodesk *Maya* [21], has capability to make corrections to the images whereby warped lines can be straightened and compressed areas can be stretched. Correcting the distortions was made easier using a linear measurement scale, with evenly spaced distance markings, along the centerline of the ship in the original design drawings.

The next step was to create each digitised deck as a separate image layer superimposed over the other decks. A 'transparency' function within *Maya* allowed each deck to be aligned and scaled. Figure 1 shows the digitised scan of each deck aligned and in scale. The digital scans resulted in flat, non-interactive images that would be used to construct wireframes of the decks. To do this, the scans were imported, separately, into *Maya* and a method known as 'digital tracing' was utilised to manually trace, point-by-point, the outline of each deck.

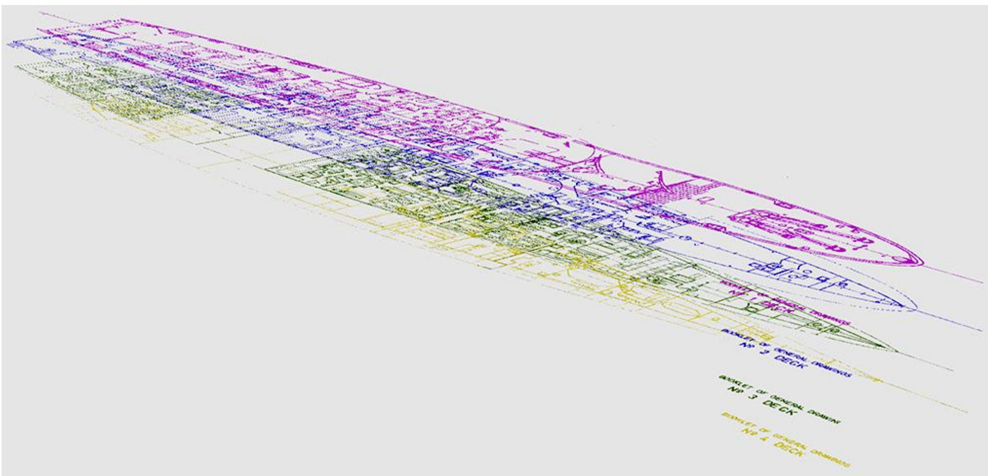

Figure 1: Pictorial layers of Derwent deck plans, aligned and scaled, ready for digital tracing

Examination of a profile view of *Derwent*'s design drawings revealed that the decks were not horizontal – there was a slight upward curve in Decks 2 and 3 on approach to the bow, as seen in Figure 2. To replicate this curvature, the wireframe decks were aligned with *Derwent's* profile view, and the digital tracing process was repeated. Figure 2 includes the wireframe overlay on the design drawings. The profile view was also used to measure the spacing between decks to enable the construction of bulkheads (walls) giving the model three dimensions and deck connectivity. Most of the M&S software, in which the *Derwent* model will be used, does not require the bulkheads and decks to have thickness; they could remain as two-dimensional planes (in three-dimensional space). Future development of the *Derwent* model, for use in training, will include that dimensionality and added texturing to give a semblance of visual realism.

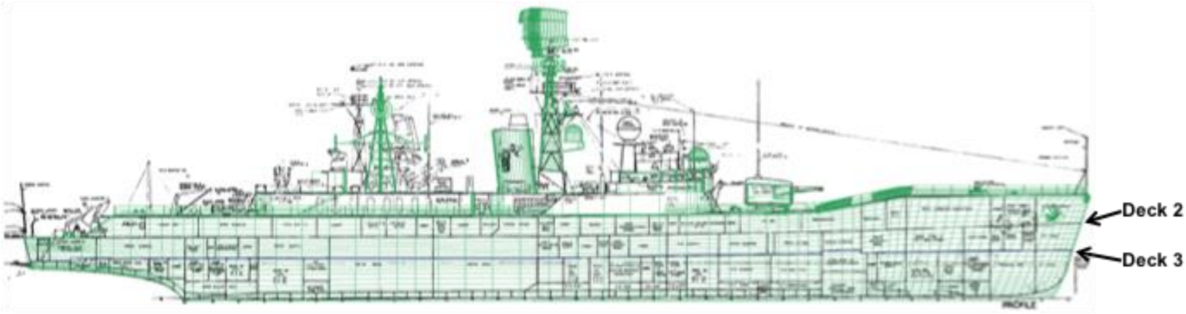

Figure 2: Derwent profile showing curves in Decks 2 and 3, with wireframe model overlay for digital tracing

4.2.2 Constructing the Hull

Imagery accurately portraying *Derwent*'s hull form was difficult to locate, and the design drawings only presented the cross sectional profile shown in Figure 2. To overcome the lack of information regarding the *Derwent* hull form, an existing computer model of a generalised hull form was acquired and fitted to the modelled decks. Each deck was used as a cut plane through *Derwent*'s hull and aligned in virtual space, along with a profile view of the ship, as shown in Figure 3. Vertices in the generalised hull form were then manually moved to the desired position fitting the shape inferred by the decks. A requirement of the generalised hull form was that it be very simple, since the technique of manually moving the vertices was a laborious task. Furthermore, moving too many vertices into position by hand increased the risk of error and could have resulted in diminished accuracy for the level effort involved. Conversely, polygon modelling algorithms have sophisticated methods to smooth surfaces created from very few vertices. Therefore, it was advantageous to manually move a few vertices to their exact positions, and use polygon algorithms to smooth the shape between the vertices. The result is shown in Figure 4. Since *Derwent*'s hull form was symmetrical, only half the hull was constructed via this method. Once completed, that half was copied and mirrored to create a three-dimensional hull form. The final step was to refer back to photos, and re-work the model, using digital tracing, until the new hull form fitted the evidence presented in photos that were available, while also accommodating the shapes of the decks. Figure 5 shows the completed hull form, along with completed superstructure details. Figure 6 presents a shaded exterior view of the finished *Derwent* hull form.

5. EXAMPLES USING THE DERWENT MODEL

The *Derwent* model is being utilised in several research programs to develop M&S capability contributing towards vulnerability and recoverability assessments for the fleet-in-being and to ensure future naval platform capability achieves, or exceeds, RAN survivability requirements. Currently, no susceptibility research programs are utilising the *Derwent* model; however, others have utilised a model of a *Leander* Class platform to test coupling between a radar cross-section simulation with *SURVIVE* [22]. The following sections provide examples of *Derwent*'s use in vulnerability and recoverability modelling.

5.1 Vulnerability Modelling

Simulation of warhead blast and fragmentation is achieved using the *CVAM* vulnerability modelling tool [23]. Figure 7 presents the *Derwent* model in the vulnerability modelling capability; and Figure 8 shows a simulated warhead detonation [24]. Ray tracing (white lines) represent the weapon's fragmentation distribution, while red shading identifies areas on the platform affected by the blast. In this example, the weapon detonation occurred in the operations room.

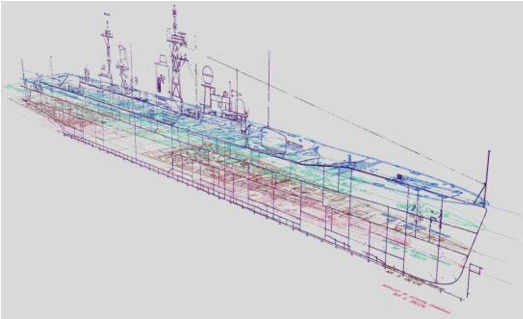

Figure 3: Decks and profile aligned

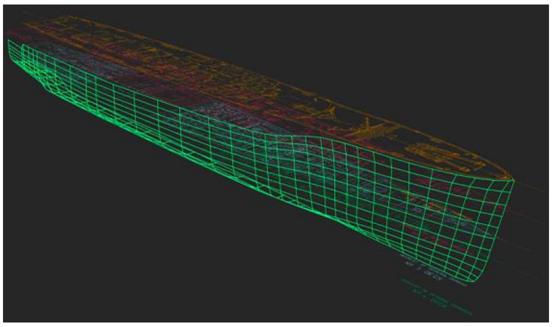

Figure 4: Half hull wireframe inferred from aligned decks

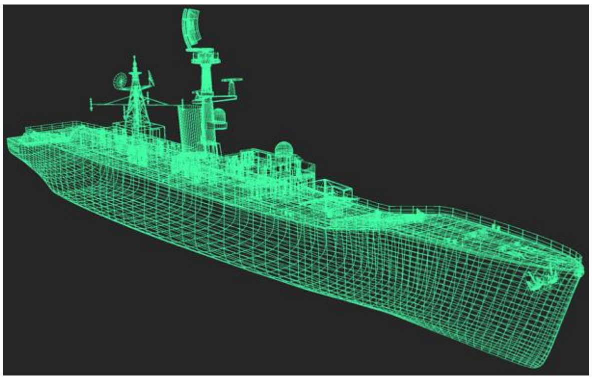

Figure 5: Completed wireframe hull form

Figure 6: Three-dimensional shaded representation

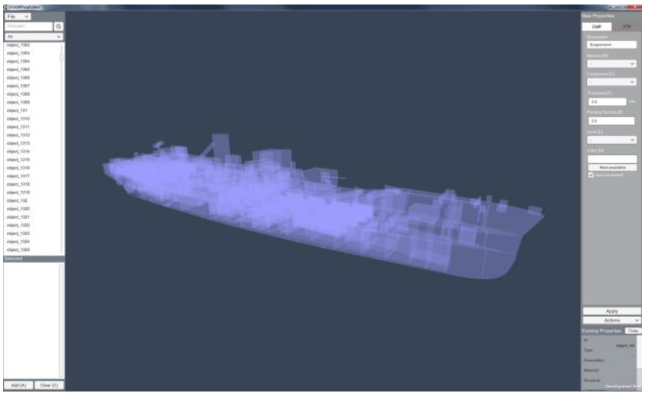

Figure 7: Vulnerability modeling editor interface

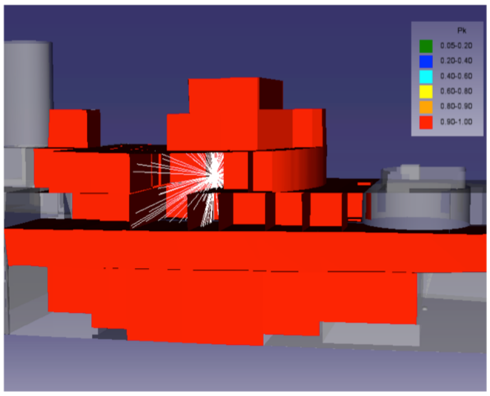

Figure 8: Simulated missile detonation [24]

5.2 Recoverability – Fire Progression and Heat Transfer

A research program involving DST Group and Fire Safety Engineering Group (FSEG), University of Greenwich, United Kingdom, has an aim of developing a recoverability capability linking the fire modeling software, *SMARTFIRE* (*SMF*), with the crew movement software, *maritimeEXODUS* (*mEX*) [2]. This capability is referred to as the *Naval Damage Incident Recoverability Toolset* (*NavDIRecT*). The *Derwent* model is ideal for this research program; it enables the developers of *SMF* to utilise a warship-like environment without needing access to sensitive fleet-in-being platform models and data. For example, Figure 10 presents part of *Derwent*'s forward section for Decks 2 and 3. A hatch connects Decks 2 and 3; and holes in the hull of Deck 3 represent damage from a non-detonating missile that impacted the starboard hull and caused damage in the port hull. The open hatch, the weapon entry hole, and port hull damage act as vents for a fire that initiated from unspent missile fuel. Labels T1, T2, and T3 in Figure 10 represent three approximate locations where temperature recordings occurred during the SSEP. Figure 11 presents the temperature recorded at T1, T2 and T3 up to 500 seconds after fire initiation.

During development of *NavDIRecT*, a simplified version of the aforementioned fire scenario is being utilised. The simplified fire scenario commences at the location indicated in Figure 12 (similarly located to that in Figure 10 for the actual fire scenario); however, the fuel load and distribution (that is, items that will burn) is less than that used during the SSEP. Figure 12 presents a heat map output from the *SMF* simulation at 200 seconds after fire initiation [2]. During the SMF simulation, temperatures open hatch and at V1 and V2 along the weapon entry hole (shown in Figure 12) were measured. Figure 13 presents the temperatures for these locations up to 500 seconds after fire initiation.

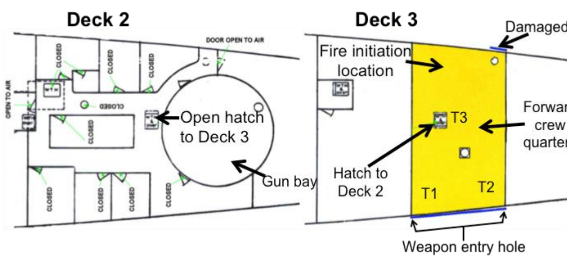

Figure 10: SSEP fire scenario configuration

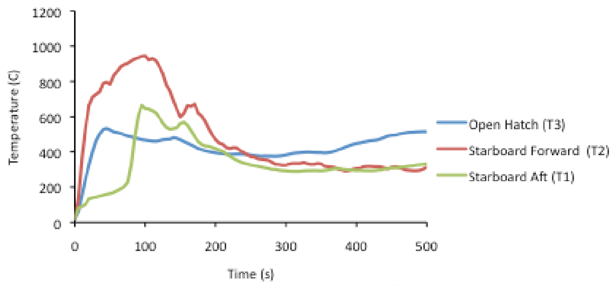

Figure 11: Measured temperatures (^{0}C) during the SSEP

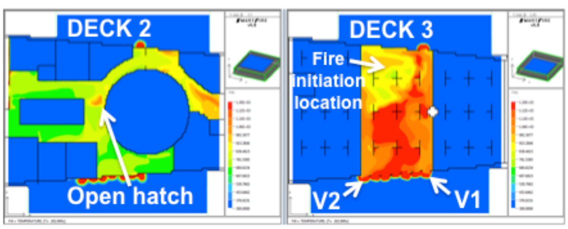

Figure 12: Simulated heat transfer through Deck 2 and Deck 3 at 200 seconds after fire initiation [2]

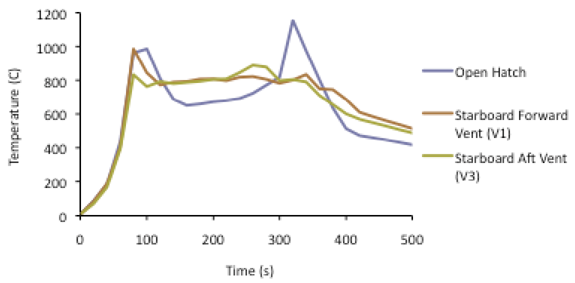

Figure 13: Simulated temperature (^{0}C) curves [2]

The differences between the *SMF* and SSEP experiment design has resulted in the obvious differences between the temperature curves presented Figures 11 and 13. Future refinement of the SMF scenario will align it with the SSEP experimental design, to enable verification of the fire modelling functionality within *NavDIRecT*. When verified, the combined fire modeling and crew movement (Section 5.3) functionality will provide the desired capability to assess naval platform recoverability against fire scenarios.

5.3 Recoverability - Crew Movement

Crew movement modelling for damage control activities is being developed using the *maritimeEXODUS* (*mEX*) software. *mEX* is a ship evacuation modelling tool; however, the research program with FSEG is enhancing *mEX* such that it will facilitate the movement of crew to simulate damage control activities [2]. The current modelling of *Derwent* within *mEX* has shown that artificial agents representing the crew can be assigned a search path to simulate a 'blanket search' to identify casualties and damage [2]. Verification of crew movement modelling on *Derwent* can be achieved using data collected during a crew movement trial while *Derwent* was in operational service [12]. Crew movement and fire modelling (Section 5.2) can then be combined to provide a recoverability capability from fire with verification using experimental data collected from trials performed on *Derwent*. Later work will expand the recoverability modelling capability to include flooding and toxic hazard response.

7. CONCLUSION

M&S provides insight into naval platform response to various threat effects, and enables repeated analysis of complex naval platform survivability scenarios. To perform that M&S, though, algorithms defining the behaviour of the objects being modeled are required. These algorithms can be generated, and verified and validated from experiments using full scale test environments or scaled representations of those environments. Consequently, there will be a continued need to perform experiments; however, M&S can be utilised to perform analysis of complex survivability scenarios not achievable via experimentation.

One model required in the survivability analysis is that of the naval platform. The proposed generic warship computer model, based on *Derwent*, is a valuable asset to enable further development of naval platform survivability M&S capability. Data collected from the experiments performed on *Derwent* during its operational life and during the SSEP will enable verification of naval platform vulnerability and recoverability algorithms. The research being performed to develop *SMF* and *mEX* for M&S of recoverability activities has demonstrated the value of the *Derwent* model as a collaborative tool. The model has facilitated the sharing of information relevant to naval platform survivability analysis without needing to share sensitive information; it has enabled the testing of enhancements to the M&S software using a naval platform environment; and it will be utilised to verify the M&S environment. Future collaborations in the domain of naval platform survivability will similarly benefit from the use of the *Derwent* generic warship model.

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