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Charpy Impact Energy:
Quantifying Risk in Specifications
for Naval Steels – A Case Study

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Photo by Lt(N) Ryan Howden

The RCN's Naval Engineering Indoctrination course introduces new Naval Technical Officers to life aboard ship, and to the systems they will be working with at sea.

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Charpy testing instrument at the Advanced Materials and Energy section at Defence Research and Development Canada's Atlantic Research Centre.

Photo by Alison Mark, DRDCA

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COMMODORE'S CORNER

Managing Risk in the RCN as a Shared Responsibility

By Commodore Keith Coffen, CD

The sudden, implosive loss of the civilian submersible *Titan* in the North Atlantic on June 18 prompted a fair amount of media coverage around technical risk management processes, and whether these were adequately applied in the design, build and operation of the vessel. Two days later, the tragic crash of a Royal Canadian Air Force CH-147F Chinook helicopter with the loss of both pilots near Petawawa, ON highlighted once again the risks that CAF members are exposed to in the course of their work.

I know from questions that have been raised at recent Town Halls, and from discussions at Naval Board, that the subject of risk in the military is never far from people's minds, so it might be timely now to provide a few thoughts regarding risk management in the Royal Canadian Navy (RCN).

We all understand that risk pervades every aspect of our lives, and I like to believe that whether we are at work or at home we do our best to remain vigilant, while maintaining a healthy sense of perspective. Not surprisingly, naval operations bring with them certain unique risks that most people will never encounter in their lifetime, and sailors — all of us — accept a level of risk associated with our chosen vocation, up to and including being sent in harm's way. Robust safety cultures like that which exists inside the RCN acknowledge that risk is always present, take active measures to ensure that risk is reduced to as low as reasonably practicable (ALARP), and have systems in place to capture lessons learned so as to further refine risk management processes where necessary. From a naval engineering perspective, I would offer that we approach the problem from two fundamental directions — by providing ships that are safe by design, and by ensuring they are operated safely.

Anyone who has ever sailed aboard an RCN vessel will understand that there is an impressive degree of safety "baked into" warship design that is based on structural modelling and engineering calculations informed by decades or even centuries of empirical data, and strengthened by the application of design safety factors that provide a margin for error between the as-designed and as-built conditions — think of the compartmentalization of the ship for flood and smoke control, the presence of redundant systems, surveillance and automatic response systems, emergency systems for life support and incident response, and much more.


Photos by Brian McCullough

Halifax naval dockyard

The Navy has also begun leveraging more directly the professional experience of international marine classification societies to help ensure that RCN vessels are safe, fit for purpose, and compliant with applicable legislation and regulations. Each of the RCN's newest major ship projects — i.e. the Arctic and Offshore Patrol Vessel, Joint Support Ship, and Canadian Surface Combatant — have engaged Classification Society support to provide independent oversight and certification in specific key hazard areas during the design, build, and in-service phases. Classification Society support is also being leveraged to enhance the oversight of RCN legacy vessels, which will provide an added degree of materiel assurance as many of these platforms are operated beyond their originally intended service lives.

The safe operation of our warships speaks to a number of key factors, both on and off the ships. Everything from the organization and establishment of the Naval and Formation staffs, to the Fleet Maintenance Facilities, our shore-based and at-sea training organizations, the life-cycle materiel management and materiel assurance processes conducted through DGMEPM, and the development of

Canadian Forces Technical Orders and Naval Orders — all of these go into shaping the culture of the RCN toward safe operations. Conditions will never be ideal, so risk is always present, but it is managed risk. The naval warfare side of the house also provides strategic and tactical layers of risk management by deciding which missions the RCN will undertake given our force posture and readiness, ensuring that crews are adequately worked-up for solo missions or deployment as part of a larger force, and by keeping the ships navigationally safe at sea.

With today's RCN currently in the midst of the largest peacetime recapitalization in its history, there is a measure of concern around the risk profiles associated with platforms operating at or beyond their originally intended service lives, such as the *Halifax*, *Victoria* and *Kingston* classes. Indeed, there are challenges that we are dealing with, and I think it is safe to say that the *Halifax*-class frigates are receiving the most attention, particularly in the way of additional third-line maintenance.

As part of our response, Chantier Davie Canada Inc., a new third-line shipyard, has been contracted to augment our docking work period capacity. Projects are also in implementation to address system obsolescence and increase capability, and this follows a significant period of major "combat systems refresh" in way of the Halifax Class Modernization effort during the last decade. New innovations are being applied continuously, from augmented reality-assisted training and maintenance, to the use of additive manufacturing techniques for certain repairs, to the potential future use of artificial intelligence to predict where failures might occur next. So, while there are certainly challenges and some risk, the Naval Engineering and Maintenance enterprise is proving itself able to keep up with the aging of the *Halifax* class as we look to maintain core RCN capabilities, and thereby reduce additional risk through the transition period until the arrival of the new surface combatants.

It is worth remembering that military platforms can be a source of risk regardless of age. In 1969, HMCS *Kootenay* had been in service for only 10 years when the ship suffered a devastating gearbox explosion with significant loss of life and injury to personnel. In 1995, I joined an almost-brand new HMCS *Regina* while the ship's company was still mourning the loss of one of their shipmates in a replenishment at sea (RAS) accident, and worked directly with the surviving team members as the safety officer for the ship's very next RAS. In 2004, a new-to-Canada HMCS *Chicoutimi* suffered a fire during its maiden voyage to Canada, during which a fellow submariner and friend lost his life, and several others were injured. And who can forget the April 29, 2020 crash of a still quite new CH-148 Cyclone helicopter in the Ionian Sea that claimed the lives of six CAF members, one of whom was a Naval Technical Officer. While we must be vigilant to the risk profiles of our older platforms, we cannot afford to fixate on one particular set of risks while being blind to others, particularly as new and less-familiar platforms are added to the fleet.

My final point on this subject is that risk management is a shared responsibility, not something that is "done" by senior leadership or someone else — we all play a role. Effective risk management begins, fundamentally, with every one of us learning our craft to the very best of our ability, at both the individual and collective training levels. This means understanding the principles of operation of the machinery and systems we work with, respecting maintenance requirements, staying current with (and following) standard operating procedures, being prepared through training and practice to respond to emergencies, and — perhaps most importantly — ensuring high standards for the sailors we train. Where we observe issues that are not within our capability to resolve, effective risk management requires that we report them for resolution. Where an issue can't be resolved because of time or resource constraints, only then should what we think of as the "risk management process" kick in by communicating the issue and the risks associated with it, considering the actions we can take to mitigate the risk, and ensuring that residual risks are approved at the right level.

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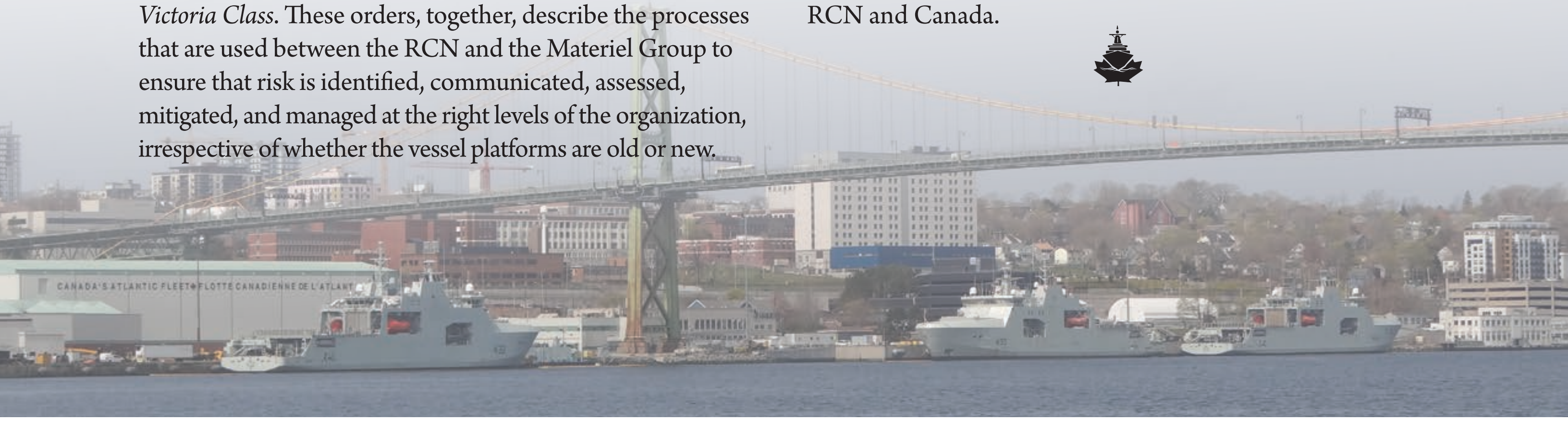
On that note, every sailor should read NAVORDs 3001-0, *In-Service Naval Materiel Risk Management – Policy*, 3001-1, *In-Service Naval Materiel Risk Management – Process*, and C-23-005-001/AG-002, *Naval Materiel Risk Management*. Furthermore, every submariner or aspiring submariner should read NAVORDs 1150-0, *Submarine Safety (SUBSAFE)* Program, 1150-1, *Submarine Safety (SUBSAFE) Process*, and 1150-3, *Submarine Safety (SUBSAFE) Risk Management*, and C-20-VIC-000/AG-001, *Materiel Management and Certification in Submarines – Victoria Class*. These orders, together, describe the processes that are used between the RCN and the Materiel Group to ensure that risk is identified, communicated, assessed, mitigated, and managed at the right levels of the organization, irrespective of whether the vessel platforms are old or new.

As we close out what I hope has been a restful summer for you and yours, let's reflect together on how best to ensure that risks in our personal and professional domains are maintained as low as is reasonably practicable at all times to ensure the safety and well-being of those who are most important to us — family, friends, and shipmates alike. As always, I am confident in our collective ability to rise to our challenges, and thankful for the resilience, adaptability, fortitude and initiative that the Naval Technical community demonstrates daily as we deliver vital services to the RCN and Canada.



FORUM

The Naval Engineering Indoctrination (NEI) Course Sea Phase

Article and photos by Lt(N) Ryan Howden

Naval Technical Officers (NTOs) understandably have different opportunities and experiences throughout their careers, meaning that no two career paths are the same. However, they almost all begin their technical training with the Naval Engineering Indoctrination (NEI) course at the Naval Fleet Schools. The three-month-long NEI is the first stop on the long road to becoming a qualified NTO, and is designed to introduce students to the numerous engineering systems on board the RCN's *Halifax*-class frigates.

Last year's course, which ran from October through December 2022, saw 20 NTO students come from a vast array of academic backgrounds to take this first major step of their technical careers. During the month of November, the class was able to go aboard HMCS *Montréal* (FFH-336), and spend a couple of weeks at sea. During their time aboard ship, they got to see first-hand the actual equipment they'd been studying, and speak with the ship's engineers and technicians. For many, this was their first time being at sea, so it also became a learning experience about what life is like in a seagoing unit.

The NEI uses theory and practical demonstration to teach students how the various shipboard systems operate in conjunction to "create" a warship. The course offers a rare opportunity for students who will be following either a Marine Systems or a Combat Systems engineering path to learn more about their counterparts' role.

The Naval Engineering Indoctrination course begins in the classroom, where experienced NTO instructors introduce students to 12 different ship systems:

Marine systems:

- Main propulsion and shaft line
- Main lube oil system
- Fuel oil services
- Steering system
- Electrical power generation and distribution
- Integrated Platform Management System

Combat systems:

- Radar suite
- Communications suite
- Navigation suite
- Combat management system
- Fire-control system
- Weapons and sensors envelope

Afterward, students have an opportunity to get a walk-through tour of these systems on a ship tied up alongside in the dockyard. The course is designed to have a sea phase, but for several years this segment had to be cancelled for various reasons. Our thanks really went out to the captain and crew of HMCS *Montréal*, who graciously hosted our students on board for the month of November. Due to limited bunk space, the class was split into two, which allowed everyone to spend roughly two weeks aboard ship. For most of the students, life at sea took some getting used to, especially when the seas got the ship rolling and pitching, and the Gravol was flowing freely. However, most everyone adjusted well after a few days on the open ocean.

An average day for the students began by standing watches in the machinery control room, operations room, and bridge, which allowed them to gain knowledge from both operators and technicians, gain an understanding of the capabilities of all the systems on board, and see what the day-to-day roles of the personnel in their departments were like. In the afternoons, senior engineering officers and technicians guided the students on walk-throughs of the various engineering systems, and in the evenings the students would conduct practice boards for their classmates, and field questions from the other engineering officers on board.

While this was the planned schedule for the sail, there had to be flexibility to allow students to observe and participate in major ship evolutions such as replenishments at sea, aiding the operations team during exercises, and weapon firings, including getting a closer look at the maintenance required both prior to and after firing a weapon. This allowed the students to gain knowledge on systems with a hands-on approach, and have the experience of being part of the team aboard ship.

The first group of students departed Halifax on the first of November, and had the opportunity to sail as part of a NATO task group that included ships from France, Spain, Denmark, Germany, and the U.S., the most noteworthy ship being the newest American aircraft carrier, the USS *Gerald R. Ford* (CVN-78). It was a fantastic opportunity to witness how our navy interacts with our allies, and to gain real operational experience. During the first half of the sail, the ship held a Remembrance Day ceremony on the flight deck, a reminder of why we do this job in the first place.

After two weeks of sailing, HMCS *Montréal* made landfall at Cardiff, Wales. For many, this was their first ever port visit, and it was much enjoyed by all of us. We took the opportunity to decompress after the sail, and took in the many sights that

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Cardiff has to offer. Most notable was Cardiff Castle, located right in the heart of the city. It was in Cardiff that the first group of students travelled back to Halifax via aircraft, and the second group flew in to join the ship.

This second group was the more experienced of the two, and included two students who had previous time in the ranks. Departing Cardiff on the eighteenth, this group went right into the same schedule of watches, walk-throughs, and practice boards. When the ship went alongside in the Azores to refuel, all of the students took part in the fuelling evolution. The rest of the sail back to Halifax consisted of more operational serials such as weapon firings, and morale events such as the "Mar Tech Open" golf tournament that was played on mini-courses throughout the ship, and a banyan (BBQ) on the flight deck. This second group of students may not have had the opportunity to sail with a task group, but they were able to see that being at sea isn't all just hard work; there is plenty of opportunity to have fun and build camaraderie with your shipmates.

Upon arriving home in Halifax, the students were glad to set foot on solid ground again, although they quite enjoyed their experience, and look forward to their next sea posting as Phase VI trainees.

The sea phase would not have been as successful as it was had it not been for the generous assistance given to us by *Montréal*'s crew, especially those in the engineering departments. Of special note were: **Lt(N) Connor Hoekstra, Lt(N) Chris Quigley, Lt(N) Chris Chang and SLt Nathan Sherwood.**

As the Course Training Officer, I had the privilege of seeing all the hard work these students put in pay off, as their knowledge and presentations consistently improved as the sail went on. The students' final boards occurred in December of 2022, and the depth and breadth of knowledge they displayed was impressive. There is no doubt in my mind that the sea phase benefitted the students immensely, and will serve them well in their future careers as NTOs in the Navy.

I personally believe that having a sea phase on courses such as NEI is invaluable as it not only provides hands-on experience with engineering systems, but also provides the practical knowledge of how a ship operates at sea, which is incredibly useful for future seafaring positions such as Phase VI, Assistant Head of Department (AHOD), and ultimately Head of Department (HOD).

Lt(N) Ryan Howden is an NTO Course Officer, and instructor for the Naval Engineering Indoctrination course at Naval Fleet School Atlantic in Halifax, NS.

FEATURE ARTICLE

Defence Research and Development Canada (Atlantic): Charpy Impact Energy in Specifications for Naval Steels – A Case Study

By Dr. Alison Mark, Ph.D.

Probabilistic or reliability methods of analyzing platform structures and materials are becoming more attractive to vessel owners and operators as vessels age and margins thin. The demand for more sophisticated cost-benefit analyses imposed by aging ships, tightening budgets and environmental considerations, coupled with the now relatively low cost of computing power, makes risk quantification a highly worthwhile investment.

Traditional methods in structural engineering usually use safety factors to ensure a structure's strength is more than sufficient to meet its loads; uncertainty in either side of the balance is dealt with in the size of the safety factor. Probabilistic methods incorporate the uncertainty on each value required to calculate strength and load in the analysis. Probabilistic analyses take more work, but provide risk-based metrics to the designer and the decision-maker [1, 2].

In this article, a case study is discussed in which basic probabilistic analysis was applied to toughness specifications for ship steel.

Background

Material specifications provide assurance that a material will meet the requirements of a design. Ships are designed to operate and safely carry a crew in a range of conditions (e.g., types and magnitudes of loads, temperatures) and a design is based on the assumption that the materials used will have certain properties (strength, toughness, etc.). Toughness is required to prevent failure of the ship by cracking, particularly rapid, brittle cracking.

Material toughness can be measured in a number of ways. Charpy impact energy tests are quick and relatively easy to conduct. Fracture toughness tests, which are fairly common in research laboratories, are more complex to set up and analyze. Drop tower dynamic tear tests are in between in complexity, but require a large instrument, of which there are only a few in Canada. The DRDC (Atlantic) Advanced Materials and Energy (AME) lab at CFB Halifax can perform all three types of tests to support the RCN.

Figure 1 shows a Charpy impact tester and the corresponding material sample, which is a 10-mm-square bar, 50 mm long, with a relatively blunt notch in the middle of one edge. The Charpy impact test measures the energy required to fracture this relatively small specimen with its pre-existing notch (crack starter) under a high-loading-rate (impact) load. All of these factors — specimen size, crack sharpness and loading rate — affect the fracture behaviour of a material. A larger specimen with a sharper notch under a higher loading rate tends to encourage brittle behaviour.

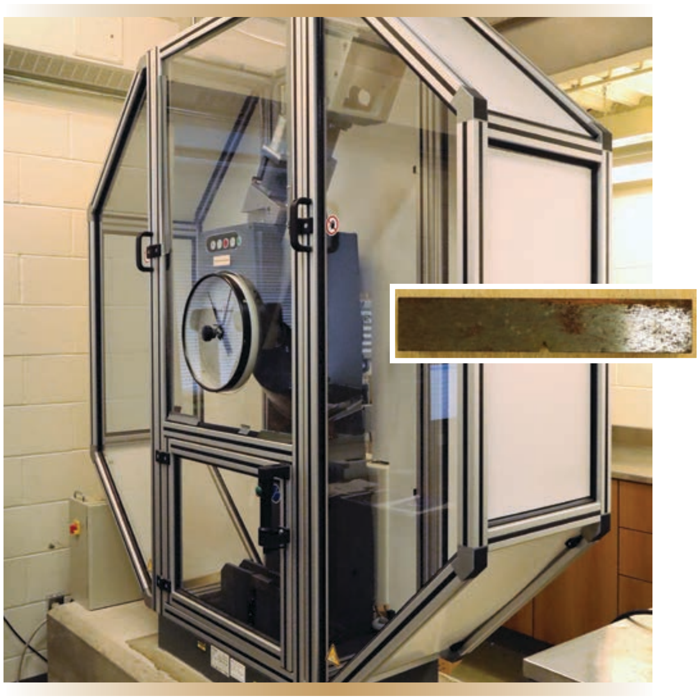

Figure 1. Charpy testing instrument at the Advanced Materials and Energy lab at Defence Research and Development Canada's Atlantic Research Centre. Inset: Charpy test specimen.

Figure 2 shows a compact tension specimen in a load frame, a set-up that can be used for fracture toughness tests, e.g. crack growth tests. Fracture toughness tests have thickness-controlled specimens, and use sharp crack

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starters and low loading rates, which are more representative of conditions aboard ship. Fracture toughness tests are designed to give material parameters that can be used to predict crack growth behaviour in real situations.

Figure 2. Compact tension specimen with specialized clevis grips and strain gauge, and the hydraulic loading instrument required for fracture toughness testing. Inset: Compact tension specimen.

The drop tower at the AME lab (Figure 3) is an impact tester that uses a similarly-shaped sample to the Charpy bar, but larger (approx. 16 x 40 x 180 mm). It can be used for simple fracture appearance tests, which rely on analyzing the fracture surfaces of tested bars to distinguish between brittle behaviour and ductile behaviour. It can also be instrumented and used to measure the dynamic tear energy, which represents a material's resistance to rapid crack growth [3].

All of the tests provide values of energy or toughness, but what is often more useful is how these values change with temperature.

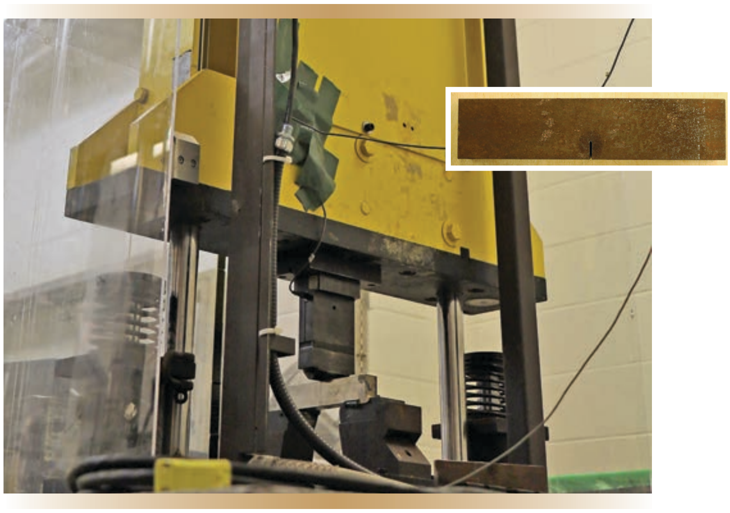

Figure 3. Instrumented drop tower at the Advanced Materials and Energy lab at the DRDC Atlantic Research Centre. Inset: Dynamic tear specimen.

Toughness of steels is strongly affected by temperature. Ductile behaviour dominates at higher temperatures while brittle behaviour dominates at low temperatures. The impact energy-temperature relationship, for example, is best described by an "S" curve, as shown in Figure 4. For many steels, at higher temperatures the behaviour is fully ductile, and the impact energy plateaus at what is called the upper shelf energy; as the temperature decreases, the behaviour becomes more brittle, and the impact energy decreases until it reaches a lower plateau of fully brittle behaviour. A transition temperature is a useful concept, generally defined as the temperature when the behaviour of the material transitions from primarily ductile to primarily brittle as the temperature decreases. What must be remembered, however, is that the value of the transition temperature depends on the test used to determine it. Because of the differences in how a steel behaves under the different test conditions, the Charpy energy transition temperature from Charpy tests is not the same as the fracture toughness transition temperature from crack growth tests. Much research has been devoted to investigating and trying to predict the relationship between different transition temperatures for steels.

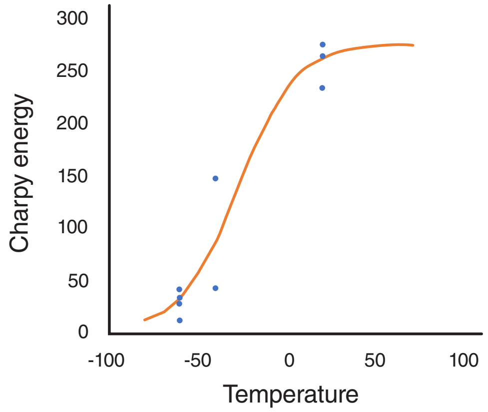

Figure 4. Charpy impact energy versus temperature 'S' curve for C-Mn steels. Figure redrawn from [4].

Because of the ease of performing Charpy impact energy tests, Charpy energy values (CVN, which stands for Charpy V-Notch energy) are often used to define the toughness specifications for steels. The origin of CVN limits for naval steels is usually traced to an extensive study of ship failures (such as shown in Figure 5) that was done during the Second World War [5]. The study examined many samples of ship steels in use at the time; Charpy impact energy tests were done over a range of temperatures and the data was combined with in-service failure data for those same steels. The data set was used to find CVN energies and temperatures that correlated with "safe" behaviour in-service. The research showed that initiation of fractures in-service was not likely if the operating temperature was above the temperature at which CVN = 20 J for the steel, and cracks would most likely arrest above the temperature at which CVN = 27 J [5]. This led to the idea of using CVN-temperature combinations in steel specifications. A steel should have a CVN of certain value (often 27 J) at a temperature chosen to be below the lowest operating temperature of the ship. The aim was to ensure the material would be operating in its ductile region — i.e., its operating temperature would stay above the ductile-to-brittle transition temperature.

The correlation between Charpy energy and cracking behaviour that was determined from the study of the wartime steels served as the basis for the idea of using Charpy energies in steel specifications, but the specific values used depend on the steel and the application. The RCN, for example, has long specified three CVN-temperature combinations in its specifications for steels where high-toughness is required. The relationship between Charpy energy and fracture toughness is not simple or predictable from theory, and, as steels have improved, much effort has continued to be devoted to collecting data and developing empirical relationships between various toughness values.

The Question

As mentioned, the RCN specifies three CVN-temperature combinations for high toughness steels; it is also moving to use Class rules for some vessels, and Class rules, Lloyd's Register (LR) for example, only specify one CVN-temperature combination. So, the question was asked: With the current knowledge of modern steel toughness relationships, what is the impact of knowing one Charpy energy value, versus three, on the prediction and understanding of the fracture toughness behaviour of a naval steel?

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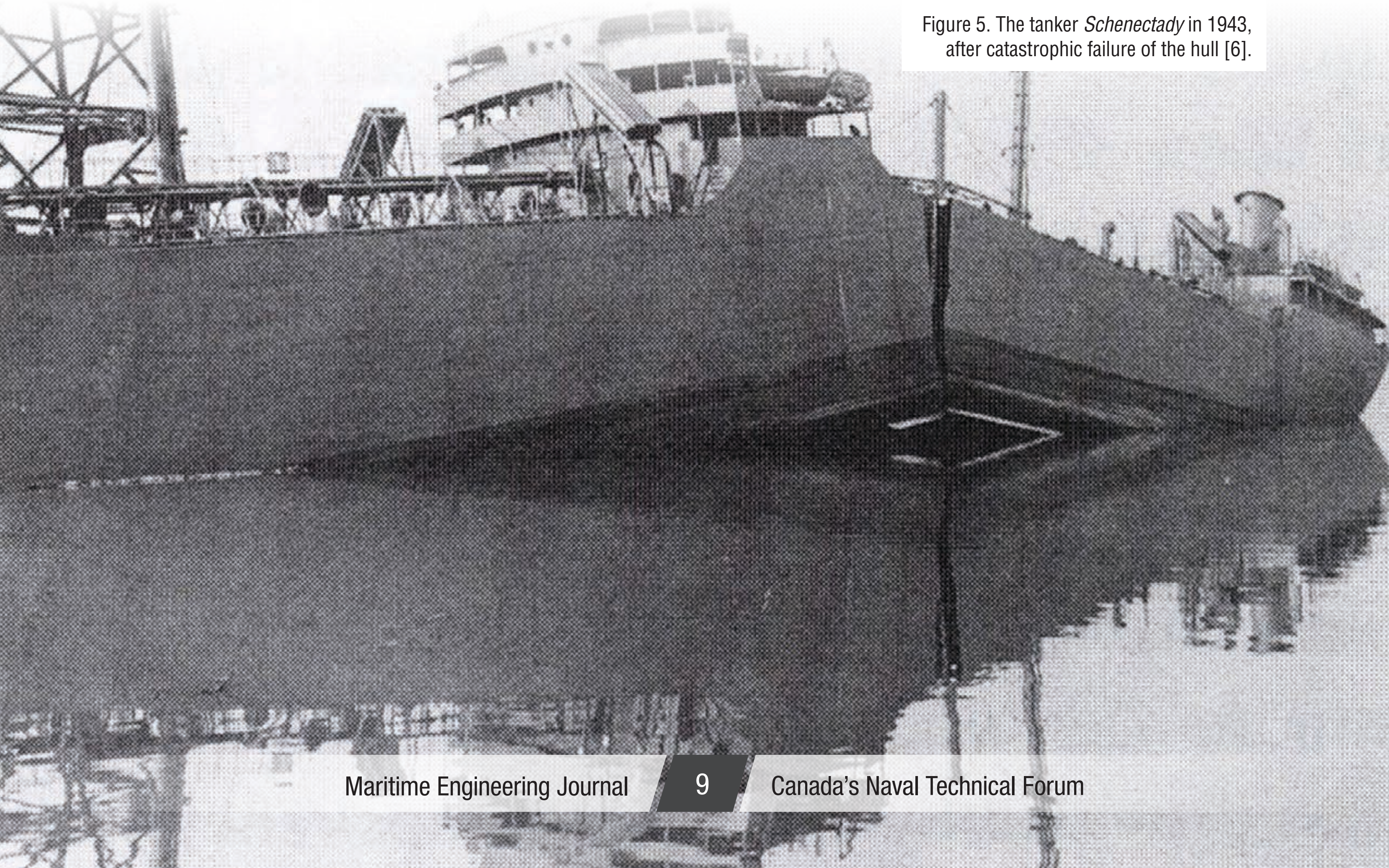

Figure 5. The tanker *Schenectady* in 1943, after catastrophic failure of the hull [6].

Analysis

Part of the complexity in predicting fracture toughness from Charpy energy values arises from the difficulty in measuring fracture toughness itself; laboratory measurements are sensitive to sample size and temperature, and there is significant scatter in results. Intensive research probing large data sets for patterns was carried out, and it was found that there is a common shape to the relationship between temperature and a reference fracture toughness (at a certain thickness) for a wide range of steels [5]. The Master Curve was developed, which is a plot of reference toughness against relative temperature, T-T0, where T0 corresponds to the temperature just above the fully brittle lower shelf temperature. T0 is commonly used as a fracture toughness transition temperature. If T0 can be determined for a given steel, the Master Curve can be anchored on the temperature axis, and the reference fracture toughness can then be determined over a range of temperatures. Knowing the thickness of the actual part, the part fracture toughness can be predicted from the reference toughness. The scatter in the data is captured in uncertainty values that are included in the prediction relationships.

Investigations into the relationship between Charpy transition temperature and T0 for the same range of steels also produced results [5]. The TC27J temperature was chosen to represent the Charpy transition temperature because it corresponds to a similar point on the Charpy transition curve as the T0 temperature on the Master Curve. TC27J is the temperature at which the Charpy energy is 27 J. An equation was developed that enables the prediction of T0 from TC27J when the yield stress and the upper shelf Charpy energy of the steel are also known. Again, the scatter in the data is captured in uncertainty values.

To answer the question posed on the impact of specifying three CVN-T combinations versus one, these relationships were used in a probabilistic analysis to estimate mean fracture toughness transition temperature and its uncertainty from Charpy energy data. The results were compared for three input CVN datasets: a) measured Charpy energy data at three temperatures, b) three specified Charpy energy-temperature combinations (as in the RCN specifications), and, c) one specified Charpy energy-temperature combination (as in Class rules specifications). A fuller description of the calculations can be found in a DRDC report, “On the use of Charpy impact energy in specifications for naval steels” [7].

To do a probabilistic analysis, the uncertainties of the input values need to be known, or estimated. In this study, all of the values were considered to be normally distributed and represented by a mean value, plus or minus a standard deviation (which represented the uncertainty.) This reflects the scatter in the data whenever a material property is measured. For example, a steel’s yield stress might be reported as 350 MPa, but if 100 measurements were done the values would actually vary around that number and yield stress would be reported as, e.g. 350 ± 18 MPa. Standard deviations for the input values were determined from literature, or by calculation using the relevant data sets.

Step One was to determine the Charpy transition temperature (TC27J) from the Charpy energy data, which was done two ways:

For cases with multiple data points, this was done by fitting a curve to the Charpy energy-temperature data and then calculating TC27J using the equation of the curve. The uncertainty in the value of TC27J from curve-fitting was determined using equations relating it to the uncertainty of the fitting procedure.

Where only one CVN data point was available, TC27J was estimated using a general relation that gives a conservative estimate of the transition temperature based on one Charpy energy value and the temperature at which it was measured, the yield stress of the steel, and the upper-shelf Charpy energy of the steel. When the upper-shelf Charpy energy was not known, it was estimated to be twice the highest measured Charpy energy for the steel. The uncertainty of TC27J in this case was determined by the Monte Carlo method [9]. Knowing the distributions (means and standard deviations) of the values of the input parameters, TC27J was calculated ~100,000 times with different input values randomly selected from their respective distributions. This gave a set of TC27J values, which was fitted to a normal distribution, which gave a mean and a standard deviation (used as the uncertainty) for TC27J.

Step Two was to calculate the fracture toughness transition temperature (T0) from TC27J:

This was done using the previously mentioned relationship between T0 and TC27J that depends on yield stress and upper-shelf Charpy energy. The standard deviation for T0 determined with this equation is given in the literature as 18°C [5]; this was determined during development of the equation.

The input Charpy datasets are described in Tables 1 to 3.

	Temperature [°C]	Mean Value [J]	Standard Deviation [J]
CVN	20	259	21.2
	-40	69	74.1
	-60	29	12.7

Table 1. Input data for case a) measured Charpy energy at three temperatures [4].

	Temperature [°C]	Mean Value [J]	Standard Deviation [J]
CVN	20	60	18
	-40	40	12
	-60	20	6

Table 2. Input data for case b) three specified Charpy energy-temperature combinations.

	Mean Value	Standard Deviation
CVN [J]	40	12
Temperature [°C]	-40	2

Table 3. Input data for case c) one specified Charpy energy-temperature combination.

Results

The Charpy energy and fracture toughness transition temperature distributions calculated in the three cases are given in Table 4.

	TC27J [°C]	T0 [°C]
Case a)	-64.7 ± 10	-108.9 ± 18
Case b)	-57.3 ± 10	-96.8 ± 18
Case c)	-42.3 ± 10	-86.5 ± 18

Table 4. Calculated transition temperatures.

Since the aim of toughness specifications is to ensure that the steel remains in its ductile behaviour range at all operating temperatures, the transition temperature should be below the lowest operating temperature of the steel. Here, for each case, the distribution of possible transition temperatures, represented by the mean plus or minus the standard deviation, was compared to a lowest operating temperature set at -40°C [10]. The probability that the transition temperature was actually above the lowest operating temperature was determined. A visual depiction of the comparison is shown in Figure 6. The transition temperature distribution is shown as the curve, and the probability that the transition temperature is higher than the set lowest operating temperature is represented by the area under the curve in red. The value can be found in standard tables [9]. The results are shown in Table 5.

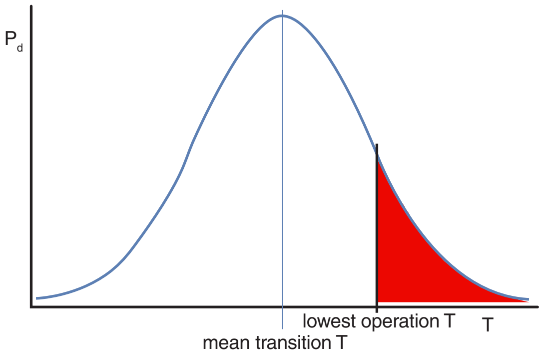

Figure 6. Schematic showing mean and distribution of the transition temperature compared to the lowest operating temperature. The probability that the transition temperature is above the operating temperature is represented by the red area.

	TC27J [°C]	Probability	T0 [°C]	Probability
Case a)	-64.7 ± 10	0.7%	-108.9 ± 18	~0
Case b)	-57.3 ± 10	4.2%	-96.8 ± 18	0.1%
Case c)	-42.3 ± 10	40.9%	-86.5 ± 18	0.5%

Table 5. Results of probabilistic calculations of TC27J and T0, and the probabilities that each transition temperature is higher than an operating temperature of -40°C.

Summary

The aim of steel toughness specifications is to ensure that the steel in a ship is tough enough to safely withstand the loads and conditions it will experience. The common practice for achieving this is by ensuring that the fracture toughness transition temperature of the steel is below the lowest operating temperature of the ship. In this analysis, the fracture toughness transition temperature, T0, was used as the transition temperature, calculated from Charpy energy data.

The results show that, for representative data for naval steel (including the limiting values from specifications), whether T0 is estimated from three values at different temperatures or one value at -40°C, the calculated mean

(Continues next page...)

fracture toughness transition temperature is well below the lowest operating temperature. The calculations also show that using only one Charpy energy value is more conservative; a higher transition temperature is estimated. This is built into the calculation method; the relationships are designed to give more conservative results for “worse” input data.

The benefit of specifying three Charpy energy values, rather than just one, is seen in the calculated values of TC27J. Despite fracture toughness tests being more representative of most real cracking situations, ideally the Charpy transition temperature would also be below the operating temperature. For case c), with one specified Charpy energy-temperature combination, the results show a significant probability that it is not.

The advantage of using probabilistic analysis is that a quantitative value is assigned to the uncertainty of the result. The advantage of having more and better material data can also be quantified. Sensitivity analyses can easily be done to determine where materials property characterization efforts will provide the most value in reducing risk. The same probabilistic methods can be applied to load limit analyses, crack growth calculations, and more.

Future work in this area at AME at DRDC will focus on fracture mechanics analyses, including defect assessments and crack growth calculations. The aim is to provide quantified risk data to better support RCN decision-makers.

◆

Dr. Alison Mark, PhD, is a Defence Scientist with Defence Research and Development Canada (Atlantic), working in the Advanced Materials and Energy (AME) section located at CFB Halifax, NS.

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FEATURE ARTICLE

The Bathtub Curve: Did we get this right?

By LCdr Eric Bertrand

Illustrations by the author except where noted.

The Bathtub curve is a cornerstone diagram that is used to illustrate reliability and maintenance demands of a system over time. As seen in Figure 1, the bathtub curve is simplified into three distinct phases: Start-up/Commissioning; Normal In-service Operation; and End of Life. This is, unfortunately, where most reliability models and education about reliability over time of systems ends. This is taught in Naval Engineering Indoctrination (NEI), as well as in several other technical courses as background theory, without any analysis or further study into the curve itself. This theory is, however, applied throughout the ship maintenance cycles of our naval platforms without considering that we might have missed the mark due to underlying assumptions.

As identified in Figure 2, the bathtub curve is defined more precisely as having three root causes: infant mortality failures that decrease over time, random failures that occur with steady rates over time, and wear-out failures that increase over time. When all three distributions are added together, we end-up with something that looks like a basic bathtub curve.

The problem, as we have discovered, is that the parts of this curve are not as neatly balanced in the naval ship maintenance industry as it is represented in Figures 1 or 2. For per-ship curves, we have a curve that looks very different than that of a bathtub, with practically no steady-state. Open-source research, along with Maritime Equipment Program Management (MEPM) and Royal Canadian Navy (RCN) measurements, show that the infant mortality failure distribution is objectively small and tends to only significantly affect the first few ships in a class. Fortunately, steady-state failures are well understood and are serviced by steady-state preventive maintenance plans based on industry experience and material studies. However, the wear-out failure distribution is the dominant feature that affects maintenance rates early in a ship's life and increases exponentially until the very end of life. Figure 3 shows United States Navy (USN) modelling graphs that illustrate the Navy budget office using exponential figures to trend and plan service life requirements for ships with fixed-fiscal year (FY) dollars to remove the effects of inflation.

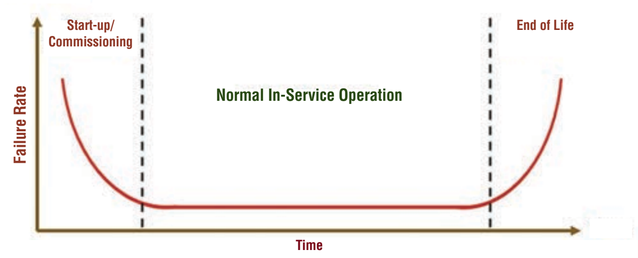
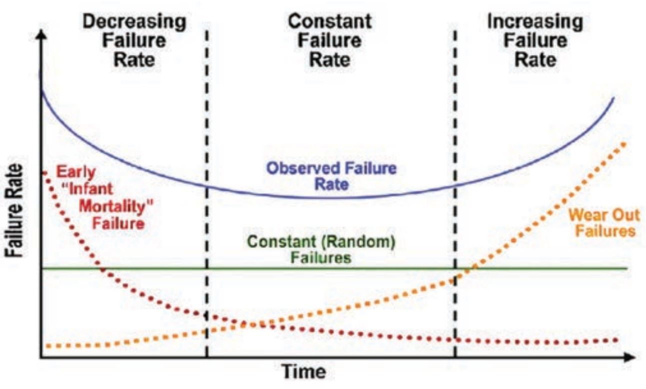
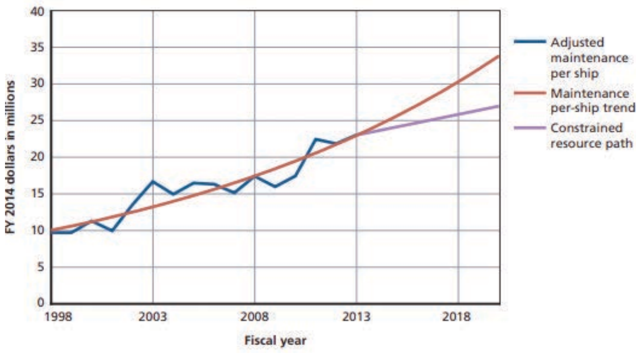


Figure 1. The standard balanced bathtub curve.



Courtesy, Maisonnier, D., Fusion Engineering and Design (2018), https://doi.org/10.1016/j.fusengdes.2018.04.10

Figure 2. The bathtub curve is a combination of three separate and unequal failure distributions.



Source: RAND_RR1155

Figure 3. USN uses exponential distribution to plan naval surface ship strategies.

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Figure 4 shows MEPM measurements of direct labour hours used for docking work periods (DWPs) for the *Halifax*-class frigates, which indicates an exponential increase of labour, therefore cost, over time. This all-ship trend can be roughly translated to per-ship trends as all 12 platforms were commissioned within a three-year time frame, and are of a similar age.

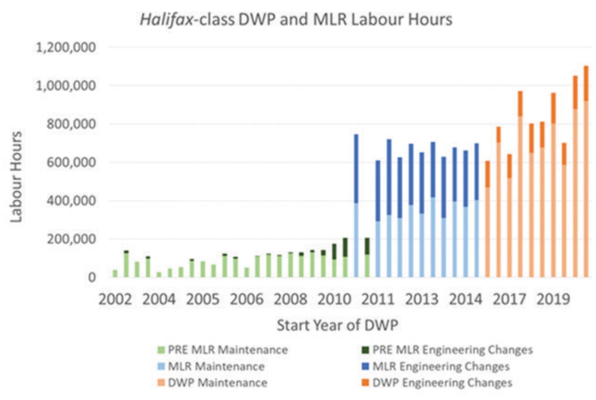

Figure 4. Docking work period labour hours increase at a roughly exponential rate for the *Halifax* class.

Now, if we add all three failure root cause areas to the same per-ship distribution at the true scales observed in our navy (Figure 5), we will see something similar to Figure 3, with a resultant distribution that trends exponentially and appears in-line with the USN model.

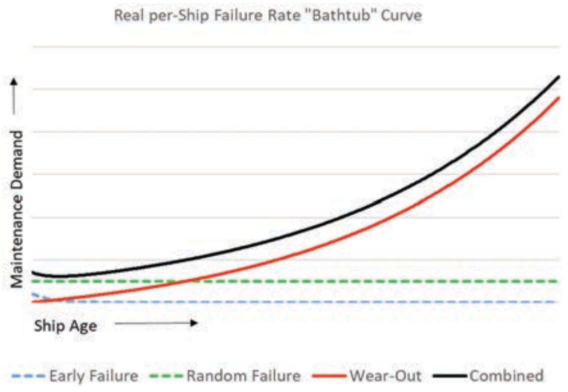

Figure 5. Properly sizing root cause distributions adjust the Navy per-ship bathtub curve to an almost purely exponential distribution.

Assuming a steady state in planning and strategy, but observing an exponentially increasing state causes multiple problems: we do not adequately forecast ever-increasing maintenance demands in our program management plans; we do not forecast growing durations in our docking work periods and we do not plan Force Posture & Readiness (FP&R) around the assumption that ships will need more maintenance as they become older. The long-term material readiness plans still call for DWP lengths that are fixed over time, extended work periods that are fixed, and short work period volumes that are fixed. For example, the ship's maintenance profile for *Halifax* class still calls for 12 weeks of short work periods per year throughout the entire lifecycle.

Poor forecasting also means that industry cannot adjust to our demands without going through a violent boom and bust cycle. For example, let's assume that we had a major class of destroyers and assume that maintenance demands would be steady state. If we are only concerned with balancing the maintenance industry according to this class of ship, then it is perfectly fine to purchase all ships within a 10-year time frame and then replace these ships one-for-one 30 years later with a new batch of ships over another 10-year time frame. Figure 6 illustrates this exchange with a resultant steady-state number of ships over time, using the steady-state assumptions that ignore the fact that older ships need significantly more maintenance than the newer ones.

Figure 7 illustrates modelling results of what the exponentially increasing maintenance demands will do to the maintenance industry with all ships purchased near the same time, highlighting a major boom and bust cycle. This is one of the most significant problems with ignoring exponential growth in per-ship maintenance demands.

If we, however, considered exponentially increasing maintenance demands, we might stagger the production of these destroyers such that the last destroyer in a batch is produced as the new batch is ready to begin production, as shown in Figure 8.

This balanced approach produces a steady average age per ship and stabilizes overall fleet maintenance demands. These steady-state impacts on the maintenance industry are modelled and shown in Figure 9. FP&R would be easier to commit to and to predict because it uses realistic underlying assumptions while using tailored, per-ship, readiness expectations.

I propose expanding the bathtub curve education in our service with more tailored curves that match the RCN experience. As well, exponentially increasing maintenance demands should be incorporated at all levels of planning

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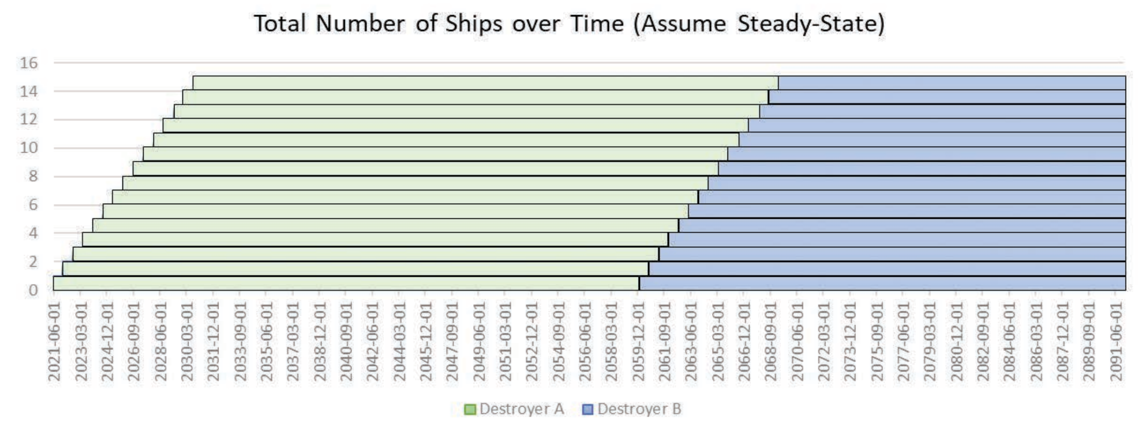

Figure 6. Destroyer example: steady-state planning shows same number of ships over time. Maintenance demands should be stable right?

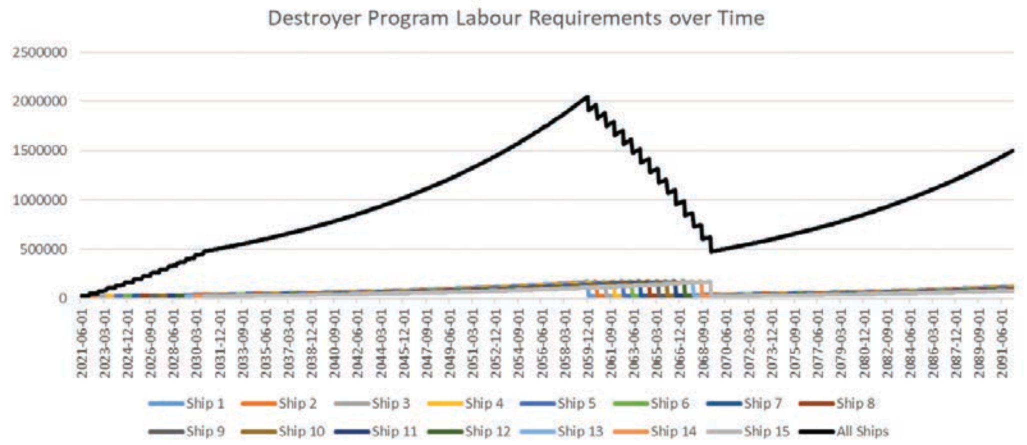

Figure 7. Destroyer example: ignoring per-ship maintenance demand growths over time can lead to a major boom and bust cycle.

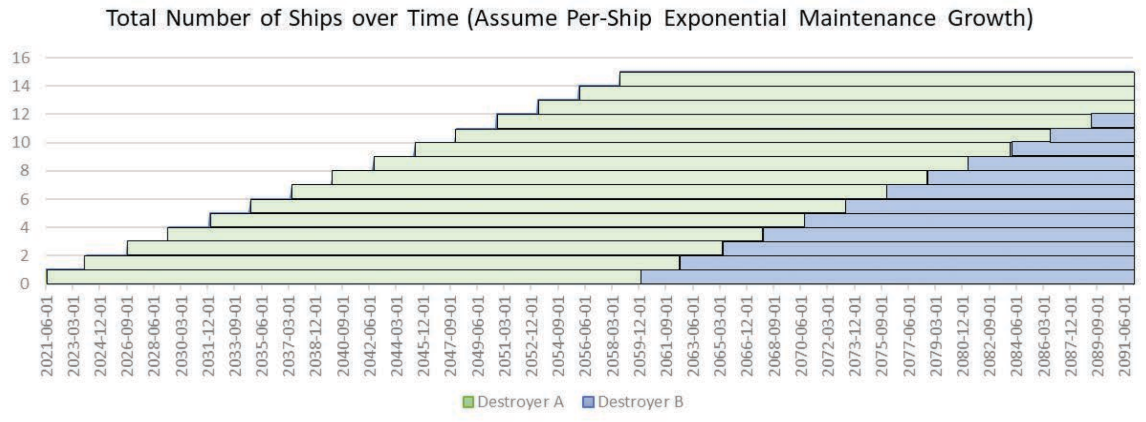

Figure 8. Staggered ship building ensures stability in the supporting industries.

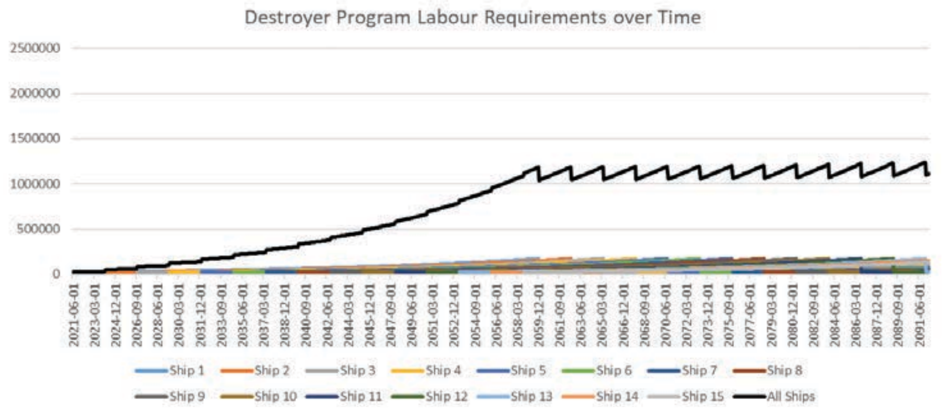

Figure 9. Total maintenance demands can achieve a steady state despite per-ship exponential growth in maintenance demands.

throughout the entire ship lifecycle, from the FP&R commitments, the maintenance plans for all lines of maintenance, and for the acquisition and decommissioning of ships.

LCdr Eric Bertrand was the Performance Measurement and Management Support Officer for Fleet Maintenance Facilities Cape Scott and Cape Breton, and is now Executive Assistant to the Chief of Staff Operations, Military Personnel Command in Ottawa.

FEATURE ARTICLE

A Proposal to Replace the Halon 1301 Fire Suppression System on board *Halifax*-class ships with a more Environmentally Friendly System*

By MS A.G. Cleghorn
(Technical Advisor: PO1 Phillipe Kelley)

[*Adapted from a July 2022 Naval Fleet School (Atlantic) Mar Tech RQ-PO2 course student Technical Service Paper.]

The Halon 1301 fire-suppression system fitted on board the Royal Canadian Navy's (RCN) *Halifax*-class frigates, as the name suggests, utilizes Halon 1301 (i.e. bromotrifluoromethane) as an extinguishing agent to smother fires.

The inherent problem with Halon gas is that it is an ozone depleting substance that can remain present in the Earth's atmosphere for about 65 years, [1] has an extremely high ozone depleting potential (ODP) of 10.0 or higher, and a high global warming potential (GWP) of approximately 6290 [2]. (Contrary to popular misconception, limited exposure to the release of Halon 1301 in occupied spaces poses minimal risk to personnel.)

Although Canada banned the import/export and production of Halon and its supporting products in the 1990s, it is still legal for use in military ships and certain other exempted vehicles under the Ozone-depleting Substances and Halocarbon Alternatives Regulations. However, since the frigates are expected to be in service until they are replaced by the new Canadian surface combatants beginning sometime in the 2030s, the purpose of this technical service paper, completed in fulfillment of course requirements, is to propose two environmentally friendly replacement options for the current Halon 1301 system on board *Halifax*-class ships, and to present viable options for their implementation.

Current Halon configuration

The Halon 1301 fire suppression system on board the *Halifax* class is comprised of approximately 60 bottles, along with sensors, nozzles, and piping to direct Halon into each individually protected space. The system can be activated in a number of ways including manually from the bottles, locally from a pull station outside the protected space, remotely from an integrated platform management system (IPMS) terminal, or automatically in protected machinery spaces.

Replacement Option A – 3M Novec 1230 fire suppression system

Option A investigated the 3M Novec 1230 fire protection fluid, which is currently employed by the RCN on board the *Harry DeWolf*-class Arctic and offshore patrol ships as a primary fire suppression system, and on board the *Halifax*-class ships as fire protection on the CAT® diesel generators. The Novec 1230 system offers an excellent environmental profile, with an ODP of 0, a GWP of less than 1, a mere five-day atmospheric presence, as well as a large margin of safety for occupied spaces with respect to environmental properties and toxicity to personnel [3].

The Novec 1230 system extinguishes fire primarily by removing heat. Stored as a liquid when at room temperature, it is released as a gas when applied. Both the liquid and gaseous forms of Novec 1230 are electrically non-conductive, making it ideal for use in spaces containing electrical cabinets and components. It has a very low heat vaporization, approximately 25 times less than water, as well as a vapour pressure 12 times that of water, meaning it will evaporate approximately 50 times faster than water. This allows the Novec 1230 fluid to be applied evenly and very quickly throughout the space it is meant to protect.

When it is discharged, Novec 1230 creates a gaseous mixture with air that has a high heat capacity that is able to absorb more and more heat energy for every degree of temperature change it experiences. This allows the system design to be tailored based on the size and layout of each individual protected space, such that it will discharge a sufficient amount of agent to absorb the necessary amount of heat energy to cool the space to the point at which combustion can no longer occur. Novec 1230 claims to have the highest heat capacity of all commercially available Halon replacements, which also makes it one of the most efficient fire suppression systems. [3]

As the Novec 1230 system is already employed within the RCN, it is expected that replacement bottles, parts, and Novec 1230 fluid would be readily available, thereby ensuring a quick turnaround when maintenance or replacement is required, and that subject matter experts (SMEs) would be available as required. The system is currently delivered to the RCN by Kidde Fire Protection Systems, and its maintenance program is currently handled by Don Brenton's Fire Protection, both of whom the RCN has conducted business with for many years.

Work to install the Novec 1230 system on board the *Halifax* class in its optimal configuration, as it is on the *Harry DeWolf*-class ships (Figure 1), would be substantial. The existing Halon 1301 bottles would first need to be disconnected and removed by qualified personnel following strict environmental guidelines. Next, the Novec 1230 holding tank size for each space would have to be determined, and the deck mounts modified to accommodate the new tanks and the nitrogen bottle(s) used to pressurize the system. Since the hose connections from the Halon 1301 bottles to the piping manifold would no longer be required, these would have to be capped or welded. The discharge hose or pipe from the Novec 1230 tank would then be

(Continues next page...)

Source: DND photo

Figure 1. Novec 1230 arrangement on board HMCS *Harry DeWolf* for the port/starboard LV (low-voltage) spaces.

plumbed through a pressure regulator into the end of the former Halon 1301 manifold to make use of the existing piping arrangements. All required electronic control devices that activate the system could be installed using the existing wiring arrangements, while heat sensors, smoke sensors, and pull stations would be replaced using existing wiring where possible. Finally, the spray nozzles inside the protected spaces would have to be replaced with those required by the Novec 1230 system. The ship's IPMS would then be updated to ensure that full integration of the Novec 1230 system was achieved.

Replacement Option B – IG-55 argon fire suppression system

Option B investigated the IG (inert gas)-55 argon fire suppression system, which is offered by several different companies including Kidde Fire Protection Services, who currently supply the RCN with Novec 1230 systems, as well as the galley fire suppression systems.

The IG-55 system is currently used in several marine platforms, including but not limited to cruise ships, merchant marine vessels, and military vessels. It employs a 50-50 mixture of argon and nitrogen, and has an ODP and a GWP of zero, as both gases are always present in the atmosphere. It is safe for spaces designed for human occupancy. This system could be installed on board *Halifax*-class ships using the same configuration as the Halon 1301 system, with minor differences that would not require significant changes to the existing infrastructure (Figure 2).

The IG-55 suppression system extinguishes fire by completely flooding the protected space with the argon-nitrogen mixture, forcing the oxygen content down to a level at which fire can no longer burn. The system is both stored and released as a gas mixture, resulting in little to no reliance on vaporization either through atmospheric reaction or mechanical means (such as a nozzle), which removes a small potential for an ineffective release. The IG-55 can be stored at pressures of 200 bar or 300 bar, making it possible to adapt the amount of extinguishing gas required based on the size of the individual space requiring protection, or the storage space available for the bottles. This suppression system employs a proprietary regulating valve from the bottles, which ensures ideal discharge and flow rates, and can provide a total discharge time of as little as one minute [4].

Source: https://www.inertgasfiresystems.com

Figure 2. A typical IG-55 installation arrangement, similar to Halon 1301.

Each worldwide company offering this system uses the same catalogue of bottles, valves, controllers, and other miscellaneous parts available on their web site, along with part numbers. Ordering replacement parts or getting access to SMEs could be as easy as making a phone call or sending an email, especially since Kidde is already the RCN's current supplier of the IG-55 suppression system. Additionally, the argon and nitrogen gases used within the system are readily available in most countries, including Canada, and at an individual consumer level, meaning that they are very easily acquired in a cost-effective manner.

Installing the IG-55 system on board the *Halifax*-class would not be difficult. The Halon 1301 bottles would need to be disconnected and removed, and the new IG-55 cylinders could be placed in the same racks, though potentially with rubber bushings to accommodate their slightly smaller diameter. The discharge hoses could use the same connections as the Halon 1301 bottles, and the electronic control devices could be installed using existing wiring connections. As with the Option A installation, the heat sensors, smoke sensors, and pull stations would be replaced using existing wiring where possible. The spray nozzles fitted within the protected spaces would be replaced with those required by the IG-55 system. Lastly, the IPMS system would require an update to ensure the full integration of the IG-55 system.

Option Analysis

Options A and B are both workable, as they are able to be integrated into the *Halifax*-class ship's current configuration, and meet the desired improvement in environmental and safety concerns. Specifically:

1. they use a similar setup as the Halon 1301 system in that the large, pressurized cylinders can be controlled by solenoids, pressure-regulating valves, and manual activation;
2. both can be monitored and controlled by the IPMS in the same way as the Halon system, facilitating a more seamless integration;
3. both provide fire suppression and protection equal to, or greater than the Halon 1301 system;
4. both have a very high margin of safety for the occupants of the spaces, as neither uses an extinguishing medium that is directly harmful to humans; nor do they reduce the level of oxygen in the space to a level at which brain and physical functions are severely impaired, ensuring personnel have more than enough time to evacuate themselves to safety; and
5. both meet the environmental impact goals. The extinguishing agent used in the Novec 1230 system has an ODP of 0 and a GWP of <1, and the gases used in IG-55 have an ODP of 0 and a GWP of 0. These numbers represent a near zero-percent chance that either system could be detrimental to the environment or atmosphere in any possible way, meaning that they fall within all current environmental regulations, and would likely not be banned any time in the foreseeable future.

Conclusion and Recommendation

This technical service paper identified an issue with the current Halon 1301 fire suppression system aboard the *Halifax*-class ships, in that the extinguishing medium is extremely harmful to the environment. While both of the proposed replacement options meet all the required criteria for implementation, and their integration would be virtually seamless, the IG-55 system (Option B) is the preferred choice. It would require significantly less work to install, and cost roughly $37,000 less than the $200,000 cost estimated to fit the Novec 1230 system (Option A).

It is therefore recommended that this proposal be reviewed as deemed appropriate by the chain of command, and if successfully validated, be presented before a panel of *Halifax*-class lifecycle managers to determine if the options presented are viable for implementation, based on time lines and budgetary constraints.

* * *

Master Sailor Alexander Cleghorn is the Senior Fire Fighter aboard HMCS St. John's (FFH-340).

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Although Canada banned the import/export and production of Halon and its supporting products in the 1990s, it is still legal for use in military ships and certain other exempted vehicles under the Ozone-depleting Substances and Halocarbon Alternatives Regulations.

Photo by Brian McCullough

NEWS BRIEFS

Mar Tech occupation structure to undergo transformation after consultations

(Our Navy Today, July 6, 2023)

Announced in NAVGEN 25/23, the RCN will transform the Mar Tech occupation into two feeder occupations, Electrical and Mechanical, at the ranks of Sailor 3rd Class (S3) to Petty Officer 1st Class (PO1), and a receptor occupation at the rank of Chief Petty Officer 2nd Class (CPO2).

The new Occupation Structure will consist of three separate occupations inside a Marine Technician functional grouping:

1. Two feeder occupations:
    a. Marine Systems Mechanical Technician (MSMT) from S3 to PO1. Within the MSMT occupation is a Marine Systems Structures Technician (MSST) sub-occupation from Sailor 1st Class to PO1.
    b. Marine Systems Electrical Technician (MSET) from S3 to PO1.
2. One receptor occupation: Marine Systems Chief (MSC) at the CPO2 rank.

The decision was made as part of the ongoing Mar Tech occupation analysis (OA). It is important to note that this decision does not conclude the OA, but signals the beginning of implementation planning, policy updates, and detailed refinement. These will be communicated once put in place.

NETE Change of Command

A Change of Command ceremony for the Naval Engineering Test Establishment (NETE) in Montréal, Québec was held on July 17, 2023. Outgoing commanding officer **Cdr Frédéric Bard** (at left), and incoming CO, **Cdr Christian Nadeau** (seated at right), signed the transfer documents under the supervision of **Cmdre Keith Coffen**, Director General Maritime Equipment Program Management (DGMEPM). NETE is a field unit of DGMEPM. The ceremony was hosted by NETE site manager **Joël Parent** (at podium), and streamed live on MS Teams for NETE and DGMEPM personnel to view.

NEWS BRIEFS

FMFCB apprentices demonstrate innovation, creativity with new system

By Gabrielle Brunette

The Sonic Analysis, Detection and Ranging (SADAR) system, a device with the capability to simulate the functionality and design of a ship's navigational radar system, was designed and produced by a group of four apprentices as part of their training at Fleet Maintenance Facility Cape Breton (FMFCB) in Esquimalt, BC.

"Each apprentice in our Electronics program must complete a project that showcases their knowledge from school, and experience gained through their rotations in the different shops," said Group 5 General Manager **Ryan Solomon.**

Apprentices **Jordan Baird, Luke Vinden, Walter Parsons,** and **Jaden Prigione** — graduates of the Electrical Engineering Technology program at Camosun College in Victoria, BC — were given a set of requirements to follow by Solomon, who emphasized the need for the product to be both interactive and portable. As the OPI for recruitment, Solomon wanted a product that could easily be transported to various outreach events — showcasing FMF's capabilities, while also generating employment interest for the facility.

SADAR works similarly to traditional radar systems, but uses high-frequency sound to detect and display targets, as opposed to measuring the time it takes for an electromagnetic wave to bounce off a target and return to the receiver.

"We sought to imitate an existing system on the Canadian patrol frigates, the navigation radar, using simple, hobbyist components that would demystify the complexity of the actual system," Parsons said.

The system is made up of two main parts: The blue box is essentially the brain component of the SADAR, and is responsible for generating and analyzing signals. The position and distance of surrounding targets are then displayed onto the plan position indicator (PPI). The small grey box with interchangeable sensor heads, allowing for future expansion on system capabilities, is the sound transducer and receiver, which rotates 360 degrees.

The team invested hundreds of hours into the hardware, software, and system infrastructure, while simultaneously balancing their regular apprenticeship duties, and coordinating with other shops across FMFCB. The team was pleased to see other trades that supported the project take pride in the individual work they contributed towards SADAR.

Photo by Andrew Yancoff

The apprentice team's SADAR project works similarly to traditional radar systems, but uses high-frequency sound to detect and display targets.

"Beyond seeing the final completed project, the camaraderie we developed not just between our cohort of Electronics apprentices, but also with members of the supporting trades was really rewarding," Parsons said.

Throughout the project development, the team met various challenges, from troubleshooting to navigating limited programming experience — all of which they surmounted together.

"The SADAR project not only challenged and subsequently grew the apprentice team's electronics knowledge, it also enhanced their abilities on technical design, and helped them better understand how the various shops within the FMF work together to complete work," Solomon said.

"We feel our abilities and strengths wouldn't be at the level they are without our robust education," Parsons added.

Gabrielle Brunette is the Communications Coordinator Student at Fleet Maintenance Facility Cape Scott in Halifax, NS.

PRESERVING CANADA'S NAVAL TECHNICAL HERITAGE

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Looking Back: Canadian Government-Industry Marine Technology Success Stories

By Dr. Chris Madsen

In May 2009, the Marine Industries Working Group of the Canadian Association of Defence and Security Industries (CADSI) issued a position paper on shipbuilding in Canada, focusing on issues surrounding Government of Canada (GoC) ships designed, built, and supported by Canadian Industry. The report included an interesting historical appendix titled, "Export Sales Generated by Participation in Canadian Ship Acquisition Projects," that highlighted a number of marine technology success stories that had good potential for domestic and export sales.

The technologies represented significant advancements for the Royal Canadian Navy (RCN) and other government agencies in partnership with Canadian private companies. The full listing (https://www.defenceandsecurity.ca/UserFiles/File/pubs/cadsi-mir.pdf) includes familiar kit such as the highly successful "SHIN" series of digitally integrated shipboard systems, and "Beartrap" Helicopter Hauldown and Rapid Securing Device. However, there were other commercially successful technologies that are today less well-known, and in danger of being forgotten by the RCN's naval technical community.

Even though the technology narratives in the appendix were written 15 years ago, and the development and operational deployment of some of these systems have progressed, these important summaries represent an important historical artifact that deserve to be preserved in a wider forum. What follows is an abridged and edited précis of just a few of these fascinating GoC-Industry success stories, as they were described in 2009:

Sonar Systems

As a predominantly anti-submarine warfare (ASW) specialized navy, in the 1960s Canada began to develop sonars that could be towed behind a ship and streamed to depths better suited to detecting submarines. The Naval Research Establishment, now Defence Research and Development Canada (Atlantic), developed the concept of the variable-depth sonar (VDS), and worked with Canadian industry to produce streaming and handling systems that would permit use in the rough conditions of the North Atlantic. The next-generation AN/SQS 505 sonar was conceived by the RCN, and developed by Westinghouse (receiver and processing), and Edo, subsequently C-Tech (transducer and transmitter). This sonar was installed in both hull-mounted and variable-depth configurations on board the Improved Restigouche-class IREs and DDH-280 Tribal-class destroyers in the early 1970s.

Follow-on development focused mainly on improvements to signal processing, led by DRDC(A), and engineered by Computing Devices Canada (CDC, becoming General Dynamics Canada). All the sonar systems on the Canadian patrol frigates (*Halifax* class): the AN/SQS-510 medium frequency hull-mounted sonar, the AN/SQR-501 Canadian Towed Array System (CANTASS) processor, and the AN/UYS-503 sonobuoy processing system, were designed and produced by CDC. In each case, a research concept was converted into a ruggedized military system through a successful collaboration between DRDC(A) and the contractor. These sonars enjoyed significant foreign sales, and played a prominent role in the RCN by keeping Canada at the forefront of ASW on the world stage.

Stealth Technology

Naval ships conceal their presence by reducing signatures, such as infrared (IR) emissions from engine exhaust gases, and extremely low-frequency electromagnetic (ELFE) underwater signals generated by the alternating current flow between a ship's cathodic protection system and its propellers. The former can be detected by IR sensors in the guidance systems of in-coming missiles, and the latter by underwater influence mines that can trigger their detonation.

In the early 1980s, the Defence Research Establishment in Suffield, Alberta began working on devices to dilute exhaust gas emissions, and developed a configuration that became known as the DRES ball (image at right), due to its shape. W.R. Davis Engineering won the contract to develop the DRES ball, and would eventually install this system in the two main gas-turbine exhausts of the Canadian patrol frigates. A different configuration was fitted to the modernized TRUMP tribal-class destroyers. Davis became the world leader with this technology, to such an extent that it has no competitor in the western world, and its products have been installed on all programs that use IR suppression.

Similarly, early developments led to the production of an active shaft-grounding system that virtually eliminates the ELFE signature by grounding the propeller shaft to the ship's hull, so that a constant anode-to-hull current is achieved through the shaft rotation. This product is unique and has no competitors. It has a more limited market, but is being fitted to all new naval construction in the United States. In addition, it has been supplied to naval ships in Canada, Norway, the United Kingdom, Australia, and South Korea.

To complement its IR work, Davis developed the Naval Threat Countermeasures Systems software to model the infrared signature of a ship and its IR threats. This unique software has been adopted by both the USN and NATO. There are over 20 users as well as ongoing development contracts with some of those users.

Modelling and Simulation of Naval Propulsion Systems and Machinery Control

One of the key components of the Integrated Machinery Control System (IMCS) implementation for the Canadian patrol frigate was the development of an LM 2500 (GE gas turbine) engine controller. GasTOPS, a Canadian private company with expertise in marine gas turbines controls and dynamic simulation, developed a high-fidelity simulation model of the LM 2500 that accurately depicted gas-turbine rotor dynamics, fuel control and combustion processes, as well as a digitized version of the hydromechanical control algorithms for the engine.

GasTOPS would expand its dynamic modeling and simulation capabilities, and go on to develop world-class simulation-based processes to assess and design control solutions for naval propulsion systems for the RCN and international navies, ship propulsion system integrators, and marine control system equipment vendors. Keeping pace with the emergence of integrated electric propulsion as a viable solution to naval and marine propulsion, GasTOPS went on to include simulation solutions for the assessment of both mechanical and electrical propulsion dynamics in its suite of simulation tools.

Reconfigurable Synthetic Training Systems

The arrival of the Canadian patrol frigate and its complex systems underlined the need for more effective and less costly training methods for both operator and maintenance procedures. Past practice had used a complete set of ship's equipment in a shore-based training facility, but in the early 1990s it was recognized that the evolution of personal computers and synthetic training environments had reached a level of maturity that could be practically exploited.

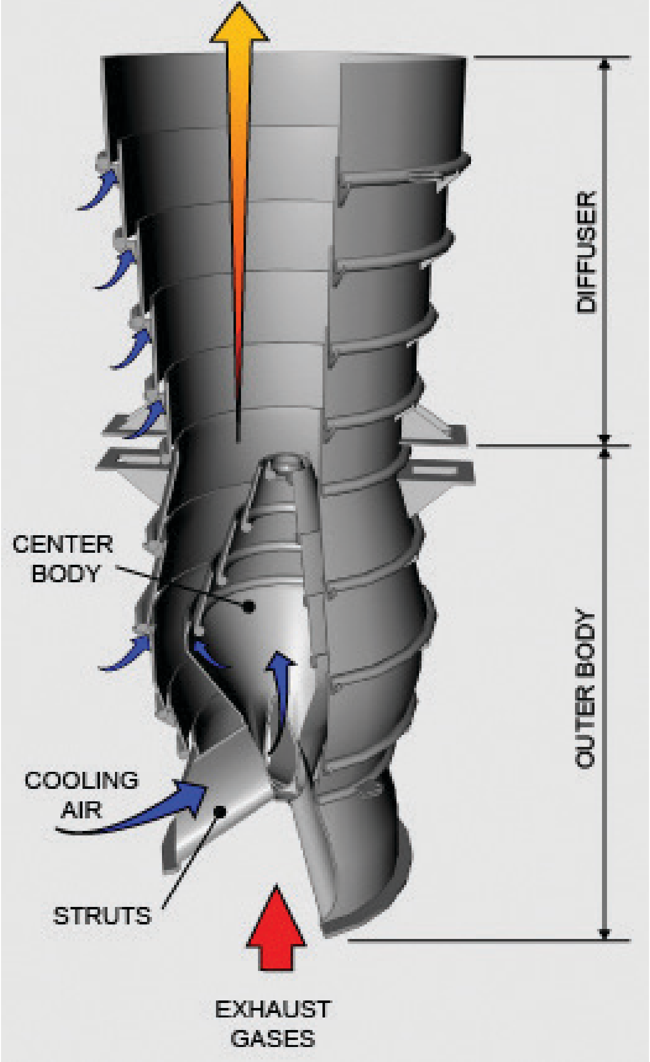

Image courtesy W.R. Davis Engineering Ltd

Stealth technology: DRES ball IR suppressor

The RCN contracted with Canadian industry to develop synthetic trainer solutions that would allow personnel to be trained in a more efficient and cost-effective manner. One of these was the MacDonald, Dettwiler and Associates (MDA) reconfigurable, PC-based, Naval Combat Operator Trainer (NCOT) that emulated the shipboard systems and equipment.

NCOT, in turn, led MDA to develop the Reconfigurable Maritime Training System (RMTS), an exportable, modular training solution that could be readily adapted to suit specific requirements for naval training systems around the world, including those of NATO navies. This resulted in an export contract with the Royal Navy to train combat personnel on Type 42 and Type 45 destroyers, with potential to expand the system to other ship classes, and into much broader training schemes that would generate additional sales.

(Continues next page...)

Active Phased Array Radar

In the early 1990s, Canada was a significant participant in the NATO Anti-Air Warfare System (NAAWS) study. The study generated a recommended combat system configuration to counter the threats navies would face entering the 21st century. A significant component of this was the development of a Multi-Function Radar (MFR) and a long-range Infra Red Search and Track system (IRST).

At the time, the RCN was developing the replacement ship for the *Iroquois* class, known as the Command Air Defence Replacement (CADRE) Project. In pursuing technologies that embraced the NAAWS concept, Canada entered into a memorandum of agreement with the Royal Netherlands Navy and the Federal German Navy for the development of a multi-function radar, which became known as APAR. The prime contractor for this activity was Thales Nederland, with several Canadian companies involved in critical product development of this revolutionary radar system. These companies included Brecon Ridge (Nortel at that time), Lockheed Martin Canada, Stork Canada, Thales Canada, and CMC Electronics.

Although the CADRE Project did not proceed to contract, APAR became a major success story in the international market, allowing Canadian companies to reap a significant 4:1 return on the RCN's investment.

As the 2009 CADSI Annex concludes: "These notable developments by Canadian industry resulted directly from their involvement in Canadian government ship projects, and supporting R&D programs. Without the ship projects, these developments, resulting export sales, and ongoing employment would not have occurred."

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Honorary "Maritime Engineer"

On June 21, CNTHA Executive Director **Tony Thatcher** (left) and former NDHQ engineering division Director General Cmdre (Ret'd) **Bill Broughton** presented longtime MEJ Production Editor **Brian McCullough** with a certificate, recognizing him as an Honorary Maritime Engineer for his more than four decades of service to the RCN's technical community.